Foster + Partners

Abu Dhabi Future Energy Company Masdar Development Project

Detailed Masterplan
December 2007

VOLUME 2-2

TRANS SOLAR
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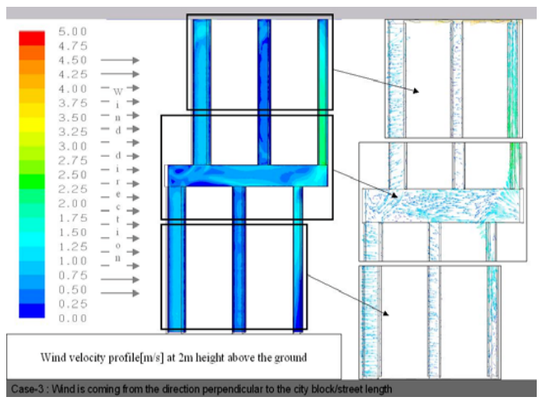

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Executive Summary
Philosophy of the Technical Approach

From UAE Today to Masdar Tomorrow
The United Arabic Emirates are nowadays one of the fastest developing countries of the world and have changed in a period of 40 years from an oil exporting Bedouin country to an important center of the world economy. As a result of this success UAE is ranked with worldwide one of the highest energy consumption in electricity and oil per person, the highest CO2 emission and water consumption per capital, and the highest domestic waste production per capital. Starting from this level it is obvious that an approach for a carbon neutral and zero waste development, following the One Planet Living definition, is quite challenging, not only from a technical but as well from a mental point of view. Therefore aside of the technical approaches and concepts an education of the people living and working at Masdar in this respect is quite essential. And as known from other societies it will take a while to influence peoples behavior.

Most of the technologies proposed for Masdar Development are not yet stand of the art, never before applied in such a scale, and some of them just tested in lab scales or demonstration projects. They need further development in the application, which fits perfect with the Masdar Development approach of a world leading research and development center for renewable energy systems. As for any new development this demands time, which is in total conflict with a so far typical developer schedule or a realization of the whole city in a 7 years period as newly raised.

Solar is the Path to Go
Comparisons of the different renewable energy sources and their potentials available in Abu Dhabi show clearly the highest potential for solar energy with more than 2,000 kWh/m²a horizontal irradiation. A wind potential with an annual mean velocity of ~ 4 m/s at 10 m height can be rated as not efficient, compared to a typical wind power location with minimal 5 m/s mean velocity. Preliminary information of deep geothermal heat sources with up to 200°C at 3.5 km depth are promising, but not proven.
In a global evaluation solar energy is the way to go, using an energy and heat source which keeps the global balance of our atmosphere and is not adding additional heat even from geothermal sources.

The idea of the Masdar Development for a Carbon neutral city as a concept, which can be spread around the globe, demands an applicability for any other location. Even when other locations have annual solar irradiation potentials of only 1,000 kWh/m²a, a solar energy concept and the solutions of the storage and distribution problems in the Masdar Development can be applied with local adjustments.

CO2 Neutral Demands Change in Occupants Behavior
- A sustainable approach cannot be solved only by technical concepts, but demands a rethinking of the way of living.
- We have to learn from local natural adaptations, which minimizes energy and material consumption.
- This means a change in our daily behavior in respect of mobility, comfort expectations, water, energy and material consumption and waste production.
- All energy consumption must come from renewable sources and materials have to flow in a cycle.
- Due to the limited capacities of renewable energies, like sun, wind and geothermal, the first essential step is minimizing the demands and consumption.
- Density is one of the major approaches for a sustainable living.

Three Steps Towards a Sustainable Development:
1. Load reduction
2. System optimization,
3. Renewable substitution

Load Reduction – Passive Design Strategies
40% energy consumption compared to today Abu Dhabi references
Approach:
- solar control for indoor and outdoor spaces
- control of micro climate in the city
- controlled daylight supply replacing artificial lighting
- reduce air infiltration
- thermal mass to buffer temperature swings
- displacement ventilation instead of mixed ventilation
- surface and gravity cooling to reduce air cooling
- change of set point to 26°C instead of 22°C
- buffer spaces and adjusted set point depending on use
- most energy efficient equipment
- reduced water consumption, gray water recycling

Optimizing Supply Systems – Energy Demand Strategies
- 30% energy consumption compared to today Abu Dhabi references
Approach:
- minimizing fresh air rates
- sensible and latent energy recovery
- water based distribution for cooling energy
- shift energy for cooling from electricity to sensible energy
- peak management by thermal short and long term storage
- intelligent metering with saving incentives
- seawater desalination without salt brine rejection into the sea
- bio waste collection and gasification
- sewage treatment and bio gas production

Renewable Energy Sources - Active Renewable Strategies
- 30% energy consumption compared to today Abu Dhabi references
Approach:
- geothermal cooling and recooling
- solar energy plant for electricity and cooling
- wind energy plant
- deep geothermal (option)

Masdar Development – A Solution Development Not Yet a Solution
The concept development and detailed evaluations have shown, that the energy demand of the city including all different types of buildings and programs could not meet the energy production of acceptable sizes of energy plants. This already considered improved microclimate, innovative central systems and nowadays on the local UAE market applicable solutions. To come to an acceptable integration of the energy production facilities a further 30% reduction by adjusted set points, improved envelops and system efficiencies, limited production energy and reduced appliances consumption was necessary. This optimized boundary conditions will not be able to be implemented in the first phase of the Masdar development, but would be a must for the last phases in 2020. Until then the first phases have to be improved on that standard. This correlates with the education efforts for the Masdar citizens, which have to be trained how to live in this development with the CO2 neutral and zero waste target.

In respect of the Carbon neutral balance, the solar systems for the first phases have to be relatively oversized to compensate for the additional consumption. Time delays in delivering the solar systems, which have lead times for example for the CSP systems of 2 to 3 years, will cause CO2 emissions by electricity import or local fossil based production, have to be loaded on a CO2 account. This account then needs to be balanced during the Masdar operation if all systems are installed.

Base System and Innovation Hubs
Due to the fact that most of the cutting edge innovative concept approaches are still in process of development, they cannot be applied in such a large scale of the whole city and with the guaranty of a failure free operation. Therefore the design team propose to go in two systems.

A base system – still very innovative in size and consequent application of energy saving technologies – a central energy supply system, with electrical production based on photovoltaic and CSP, a district cooling network with central electrical and heat driven absorption chillers and a district desiccant based dehumidification network with a central heat driven regeneration. The final areas of the different solar energy system will strongly depend on the Masdar philosophy and agreement with the local electricity supplier about charge and discharge from the electrical grid. In most other countries a daytime grid support would be a welcome input, to limit the daytime peaks, while at nighttime surplus energy in the grid can be given back to Masdar.

Innovation hubs as island solutions for cutting edge technologies, like hydrogen production, storage and fuel cell operation, concentrating tracked photovoltaic systems, deep geothermal power production, down beam solar tower system with zinc power production, algae based bio fuel production and others, will be installed, researched and further developed in one or more city block sized systems. This allows operation under real conditions but in case of system adjustments a backup by the city system is guaranteed. This innovation hub approach perfectly reflects the Masdar Development philosophy to become a world leading edge research and development community.

Next Steps
Based on the detailed load analysis for the city layout and different building typologies the general design guideline should be developed into a design and concept brief for the city and for each building typology. This documents would be a base for the contracts with future developers, giving them clear boundaries in which their building have to be realized in respect of – energy, water, systems, envelope, etc. This typology specific brief can recommend certain systems, or determine the prerequisites for the connection to the local energy network, but would allow for the design teams of the different buildings to develop their own building specific solutions to fit in the Masdar Development design guidelines framework.

Aside from these building guidelines, specific guidelines have to be developed for the central systems and the innovation hubs.

Further work has to be done in respect to the energy consumption of the “light industry” production, this will play an absolute critical role for the overall energy consumption. Guidelines and exemplary solutions have to be setup to show the future industry partners, that they can do a start with energy saving production.

Three Steps Towards a Sustainable Development:
Load reduction, System optimization, Renewable substitution

Load reduction – Passive / Active Design Strategies

approach	design guidelines
solar control for indoor and outdoor spaces	• narrow streets with arcades • external retractable shading of courtyards and piazzas considering sufficient daylight supply for shaded areas and adjacent program • glass facade ratios depending on building level and exposure to supply sufficient daylight • external shading of exposed glass facades • high selective glass quality • adequate insulation for walls and roofs • ventilated roof shading • high reflection of exposed construction surfaces
control of micro climate in the city	• street orientations, street width/height ratio • controlled city ventilation by city grid • wind towers for protection and wind redirection • external thermal mass in shaded areas like walls and street surfaces • night cooling by sky radiation • recooling and regeneration of diluted salt solution outside of the city to exclude local impact like increased air temperature and humidity • combustion car free city and control of all system exhaust of production and services allows to reduce city ventilation • local micro climate support by plantation and - small water features for local evaporative cooling
reduce air infiltration	• air tight facades, doors and building envelops • balanced ventilation systems
thermal mass to buffer temperature swings	• exposed thermal mass towards building inside activate thermal mass by water or air
controlled daylight supply replacing artificial lighting	• courtyard sizes and facade opening to ensure daylight supply • daylight sensors for artificial lighting control
displacement instead of mixed ventilation; hygienic ACR	• pure fresh air systems • no air circulation for space cooling
surface and gravity cooling to reduce air cooling and air flow rate	• radiant chilled ceilings or chilled beams • gravitation driven coolers • system sizing for high cold water temperatures
change of set point to 24°C instead of 22°C	• adjusted set points • buffer zones between outside and inside • occupants training and retraining
buffer spaces and adjusted set point depending on use	• street micro and courtyard climate • tempered entrances and circulation
most energy efficient equipment, appliances and machinery	• only fluorescent light sources • only A or A++ energy label rated equipment • low energy equipment for offices and labs • occupancy controlled light and equipment • fans and pumps only with adaptable flow rates by using frequency converters • limited production energy demands for light industry
reduced water consumption, gray water recycling	• water saving fixtures • gray water collection and reuse • no private laundry • rain water collection • separation toilettes (Hospital, ...)

Optimizing Supply Systems – Energy Demand Strategies

approach	design guidelines
minimizing fresh air rates	• presence and CO2 controlled fresh air supply • return air mode of fresh air system for supplemental dehumidification • operable windows for natural ventilation in winter, fall and spring
sensible and latent energy recovery	• 80% sensible cooling recovery • evaporative cooling of exhaust air with run around heat recovery system in combination with liquid desiccant dehumidification
water based distribution of cooling energy	• district cooling network for high temperature sensible cooling • loss-free salt solution district network for desiccant dehumidification
shift energy from electricity to sensible energy	• sensible and latent cooling by heat driven concepts, to limit electricity on appliances • absorption chiller • liquid desiccant dehumidification • evaporative cooling
intelligent metering with saving incentives	• transparent energy consumption • grid based control for peak shaping • low price for savers, high price for wasters
peak management by thermal short and long term storage	• water based heat storage for medium temperature 90 – 140°C • phase change – latent heat – storage for high temperature solar storage at concentrating solar plants for 24 hour operation
Seawater desalination without salt brine rejection	• salt brine evaporation and salt production by low temperature waste heat
(bio) waste collection and gasification	• fuel cell systems based on bio gas and biogas storages • fermentation rest is humus for soil improvement • sewage treatment and bio gas production • waste to energy; no methane emissions by waste landfilling • waste sorting and recycling

Renewable Energy Sources - Active Renewable Strategies

approach	design guidelines
maximized use of waste heat	• combined heat and power (CHP) • cogeneration of cold in combination with absorption chillers
geothermal cooling and recooling	• borehole system with 100 – 150 m deep closed loop system, COP increase by lower recooling temperatures
solar energy plant for electricity and cooling	• elevated free ventilated PV shading roofs above the city • combined PV and hot water production by hybrid PV-collectors • Concentrating solar energy plant with combined electricity and cooling – by absorption chillers – production with latent heat storage for 24 h or nighttime operation • Evacuated tube collectors and concentrating tube collectors for heat production to drive central regeneration of liquid desiccant dehumidification • Downbeam tower innovation hub • Algae plant for bio fuel production and CO2 consumption
wind energy plant	• visual demonstration and research wind plants for site and city integrated turbines • city wall and wind tower integrated city wind turbines
geothermal deep drilling	• hot dry rock process in conjunction with ORC

General introduction for light, wind and building based Design Guidelines:

For a city sunlight and air are the most important natural resources to feed the city with light to illuminate outdoor and indoor spaces and to provide fresh air for the citizens to breath.

Considering the local climate conditions in Abu Dhabi with high outdoor temperatures in summer and zenithal sun positions demands specific guidelines and recommendations.

Approach using generic models

As a base for an architectural design, which could be evaluated and improved, the short project timeframe demanded to start based on generic models for streets and buildings. Using air flow evaluations by computational fluid dynamic CFD simulations with Fluent and daylight and shading analysis using a backward ray tracing method by Radiance, the generic models had been analyzed and the results had been used to direct the city design.

The same model was used for a first calculation of dynamic building loads, based on certain constructions, external and internal gains and occupancies. Boundary conditions have been discussed and adjusted following team recommendations.

Based on the final proposed exemplary building typologies the load calculations have been actualized, as well to identify the demands for adjustments in the boundary conditions to meet the possible energy production on site.

Fresh air without heat

The primary decision based on the CO2 neutral approach for Masdar development was to ban cars with combustion engines from the inner city. This reduced the demand for the city ventilation to the functions providing fresh air and cold breathes instead to reduce car emissions by a sufficient ventilation to a level people can tolerate. Even without this emissions the outdoor air quality demands a certain city ventilation, which has to consider predominant wind directions, annual temperature swings, heat island effects due to solar absorption and inner city local emissions.

Analysis
Starting with an isothermal air flow analysis to research the impact of air infiltration from the wind flow above the city into the street canyons the model allowed to determine favorite street widths, length and piazza locations. To determine the micro climate above the city due to the high solar absorption of the energy roofs a simplified calculation model of the whole street was defined. It was evaluated without and with wind in respect of the local temperature increases above the city.

Based on the results of the generic models a favorite street and piazza design was identified. With local analysis of the instationary behavior of a street and piazza climate in the arcade area the rules to achieve for even lower temperatures than outside have been identified. A new interpretation of the historical UAE wind tower as a street protection and ventilation device concluded the air flow analysis.

Results
With the proposed orientation and dimensions of the city grid the air quality demands could be ensured and the local climate demands optimized. In the Masdar development streets are mainly used for circulation, fresh air distribution and micro climate protection. Two green park bands through the whole city are oriented towards the sea breath and the cooler night winds create additional fresh air corridors through the large city grid.

Light in the shade

Daylight and sunlight are very important for the human body and soul. Due to the high outside light levels in Abu Dhabi in exposed locations, comfortable indoor and outdoor spaces have to be carefully sunprotected, but not totally darkened.

The design guideline for sizing facade openings have to be adjusted respecting the high level of direct radiation on the project site.

Analysis
Sun path and shading analysis in a first step the solar exposure and illumination of street locations for different street width were analyzed. Using the generic building model the impact of street or courtyard width, building level and glass facade ratios have been calculated and finally extended to a full matrix as a design support for the typology design development. Finally the analysis for extreme conditions for direct sun exposure concluded the evaluations.

Results
Based on the evaluations the project team decided to illuminate the building through the courtyards. Therefore the streets can be as narrow as demanded for a better thermal comfort. The courtyard design differs depending on the type of occupancy. All courtyards need either a shading – to protect this microclimate from high temperatures – or at least an external shading of each facade opening. Facade ratios have been determined for the different floor levels based on the final typology design.

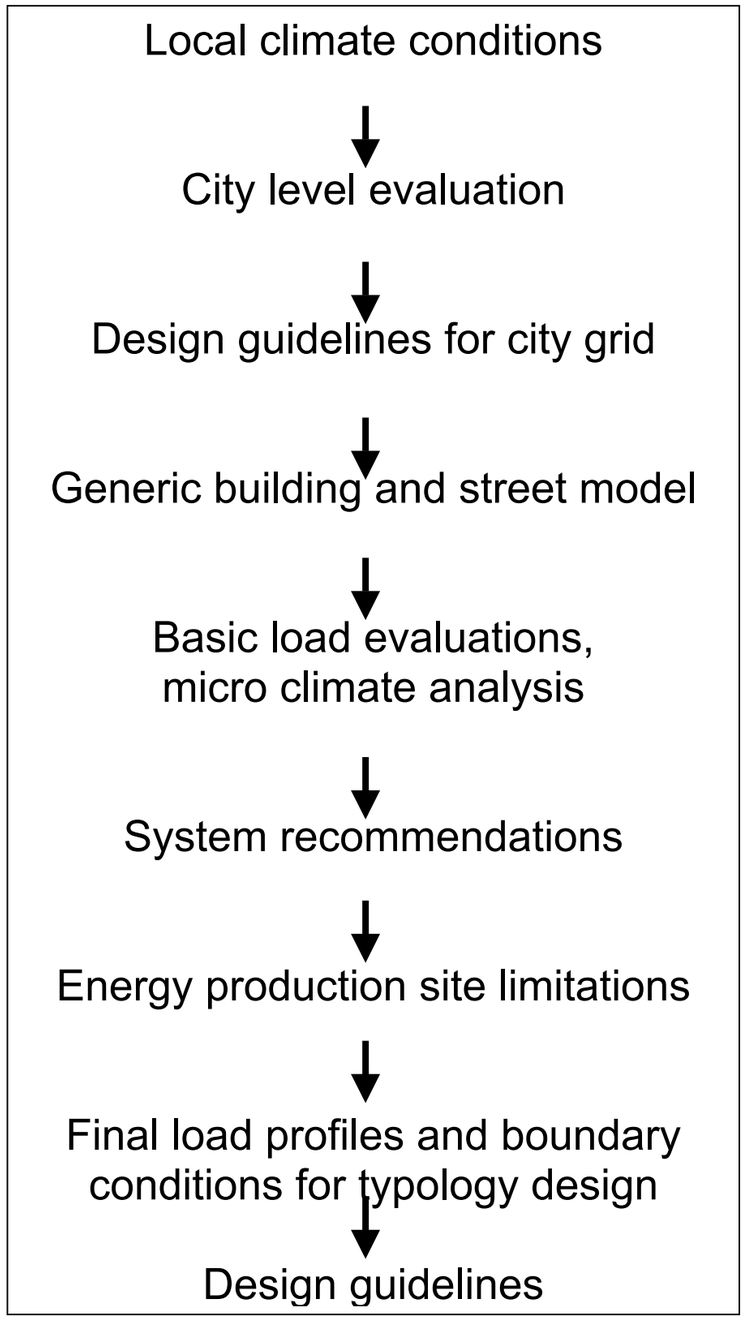
Building loads in the city

The city design determines the city climate and city heat island effect, which are important boundary conditions for the building loads. They are determined by the building design and construction, by external and internal loads, which are depending on the occupancy type.

Analysis
Therefore each building type had to be modeled as a separate model, reflecting internal schedules and the hourly weather data for Abu Dhabi. Using the simulation package TRNSYS and the generic building model annual hourly loads for conditioning about as well for electrical demand could be identified. Adjusted boundary conditions and the final typology design caused three iterations.

Results
The results of the total loads and the differentiation between sensible, latent and electrical loads and their daily profiles have been important inputs for the central system discussions and the sizing of the infrastructure.

Finally the limited energy production on site demanded another iteration to determine the necessary boundary conditions to fulfill a certain further reduction.



Masdar City – Masterplan Building Guidelines

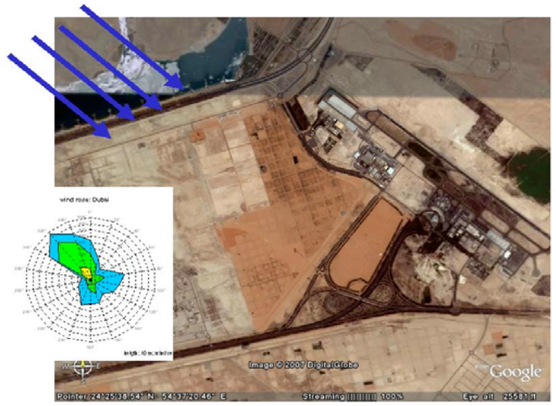
Out of the wind, light and building load analysis the following general guidelines can be concluded.

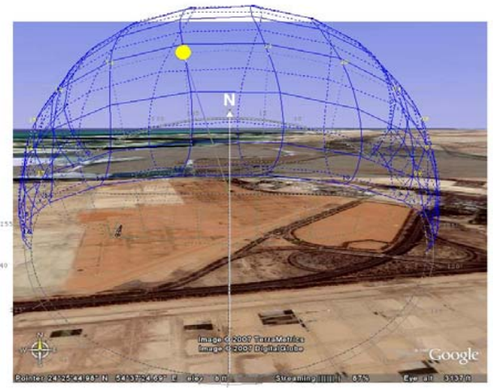
Outdoor:

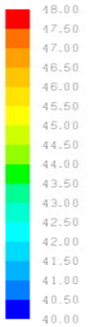
- Street orientations Southeast/Northwest or Southwest/Northeast
- Limited street length of 75 m especially for Northwest /Southeast streets to reduce external wind impact
- Typical street width of 7 / 4 m at 5 level buildings
- Arcades with no direct solar radiation
- Minimized solar absorption, high albedo; 70 % reflectance of wall, roof and floor surfaces (without PV)
- operable shading devices for Piazzas, streets and Courtyards (nighttime no shading for a better radiant city cooling)
- No heat spill from buildings or systems into the streets
- Careful positioning of return air shaft to prevent recirculation in courtyards and streets
- adiabatic cooling and shading by trees
- small shaded water features with water noise for local cooling
- reduced ground and undercraft temperature by good soil connection and limited heat waste
- air towers for reduced or increased street ventilation
- maximize thermal mass in the streets / Piazzas
- prevent redirection of warm air above the city into the streets – careful building height steps

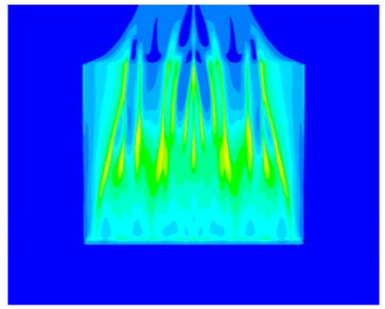
Indoor:

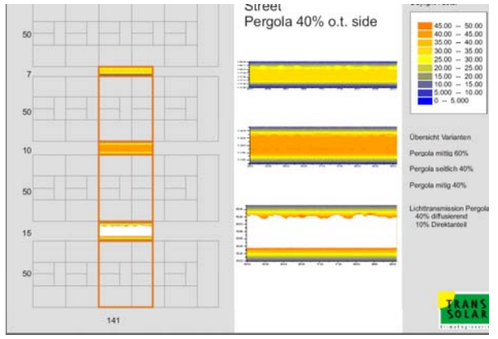
- Window areas depending on floor level and shading opportunity, as well as type of occupancy
- operable windows for natural ventilation during 6 – 8 months of the year
- infiltration rate – air exchange between indoor and outdoor based on leaky building envelop - limited to 0.15 ac/h (adding vestibules, buffer zones, air tight facade)
- natural lighting by courtyards; courtyards with central operable and controlled shading device (fc=0.15) in the top with light diffusing characteristic
- external controlled shading device (fc=0.15) for windows to the streets in particular for upper floors
- solar control glazing; max. energy transmittance of 50 %; U-value of frame and glass = 1.5 W/m²/K, daylight transmission > 65%
- in particular upper floors - facade ratios: max 30 % glazed and 70 % opaque
- roof insulation: 20 cm; 0.04 W/m/K
- opaque facade insulation: 10 cm; 0.04 W/m/K
- thermal mass: 300 kg/m² resp. 50 % of space surfaces should be thermal active
- housing: triple glazing u-value of frame and glass ≤ 1 W/m²K
- radiant and convective cooling (system operation controlled to reduce energy demand and prevent condensate)
- dehumidification of latent loads by L-DCS (liquid desiccant system)
- controlled operation of art. lighting; only illuminants with high efficiency (> 80 lm/W)
- ventilation: evaporative cooling of exhaust air; 80 % efficiency of heat recovery; energy efficient fans, engines (in summary 0.6- 0.6 kWh/1.000 m³ for supply and exhaust; continuous rate control of air flow (frequency converter)
- ventilation: buildings in slight overpressure
- intelligent electric meters; load control systems; adequate electric tarifs
- only central laundries; no private laundering to minimize water and electricity demand
- only high efficient electrical devices in offices and housing

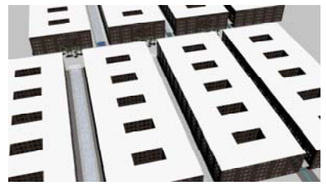


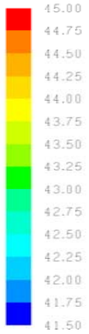


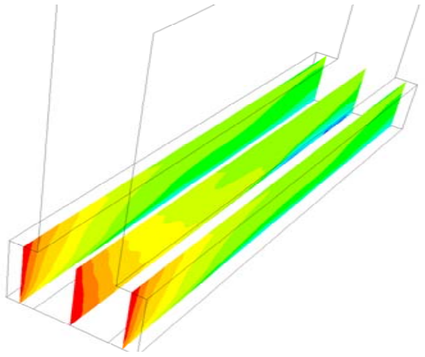


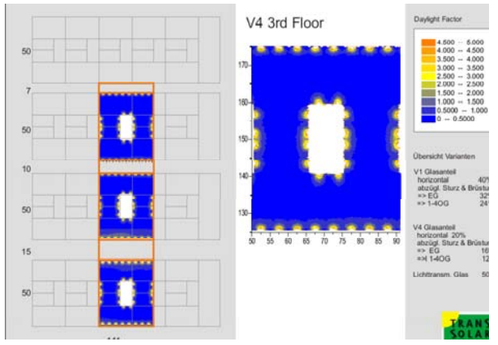












Figures from top to bottom:
Wind and sun exposure on site
Heat island and street illumination
Generic building model
Street climate and building illumination

City and Building Passive Design Guidelines

- Limited street length and width
- NW-SE and NW-SW streets
- Wind towers for protection and redirection
- Protected streets with microclimate below ambient
- Buildings illuminated by courtyards
- Careful height development to prevent hot air redirection
- Building design guidelines
- Target of 80% energy reduction demands strict rules and limitations for equipment consumption
- Waste and solar heat based dehumidification
- Water based building systems with minimal distribution consumption
- Building materials with minimal air load emissions
- Safe base energy system with add-on local innovation hubs

Instruments

City guidelines
- streets spaces
- building block lines
- building heights and distances

Building guidelines
- energy consumption limit
- form and orientation
- component qualities
- technical systems
- roof energy systems

Outfit guidelines
- outfit energy consumption
- lighting and appliances

Design phase reviews and permit for next phase by masterplan team

Occupants training

Risk and opportunities

Risks:

Guidelines are not considered

Masdar ignores the guidelines due to time pressure in their own buildings like university and ADFEC

Building products and construction quality is not available in Abu Dhabi at the time of construction.

No or insufficient review during the design process.

Construction review by educated controller.

Developer is different from final user

Opportunities:

- Masdar Development known for it's micro climate – city cold island – and outdoor facilities
- High quality owrking and living environment
- Low operation costs
- Low noise and high comfort systems
- Identity to live and work is such an environment

Recommendation	Instrument	Risk today	Risk 2015	Risk 2030	Opportunities
City micro climate	city guidelines	M	L	L	attraction city cold island
better building envelope	building guidelines	H	M	L	high quality space high comfort
low energy application	outfit guidelines	M	M	L	low operation cost
high efficient building system	building guidelines	M	L	L	low noise, high comfort
adjusted setpoint human interaction	regular training	H	M	L	identity

Strategy: Phase 1 can accept higher demand, compensated by higher production

Savings

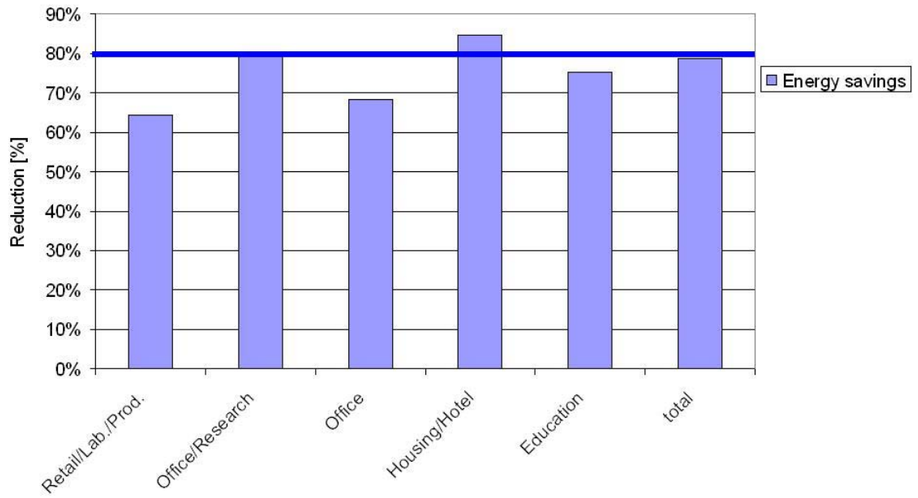
The limitations of the energy production areas on the roofs and the small square pushed the demands for energy consumption reductions to reach in average 80%. This has serious conditions listed in the load calculation chapter for each different typology, as office, laboratories, housing, retail, light industry etc. This boundary conditions are not only related to the building construction but as well a lot to the building equipment and outfit. Without their compliance, the listed numbers cannot and will to be reached.

Aside of the energy consumption numbers – based on Masdar's input – the energy consumption for a design case – 2nd iteration considering today achievable standards following local consultance – and the final report version are listed and compared.

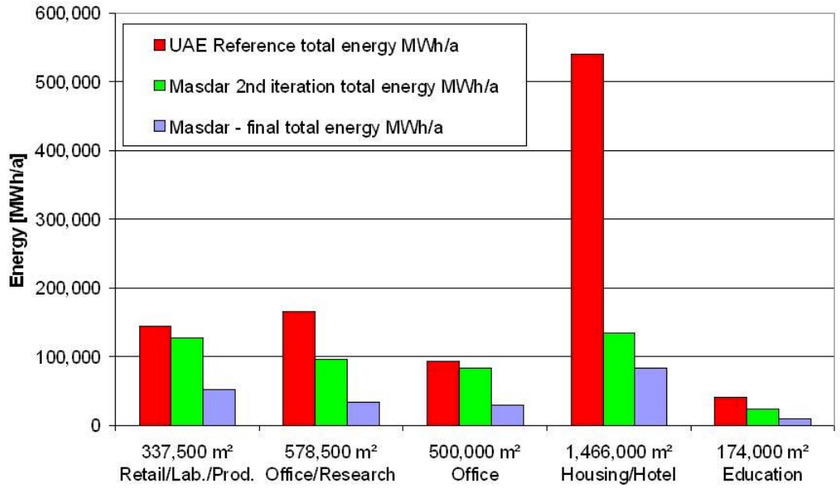
For the office typology the different steps to reach the 80% savings compared to the today standard of 240 kWh/m²a for conditioning, lighting, technical equipment and all appliances, recalculated into pure electricity consumption.

The specific consumption for all typologies shows the different saving demands, which clearly differ in betweer the typologies.

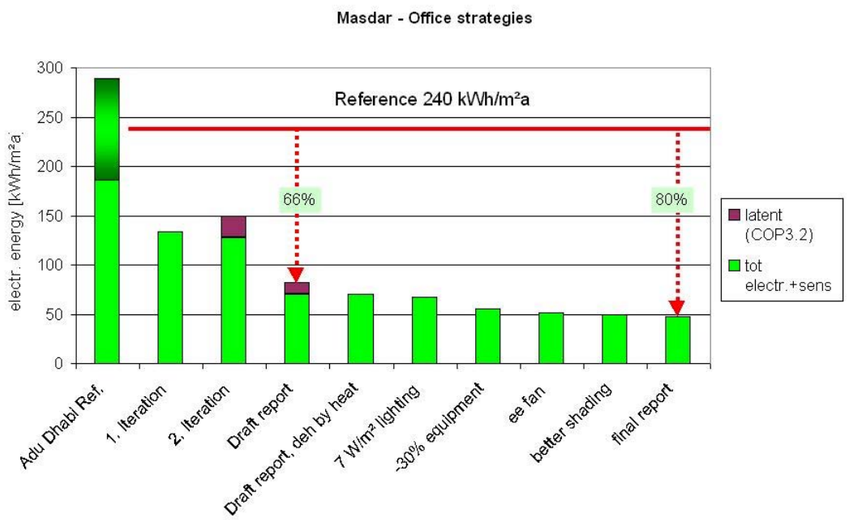
Masdar energy reduction 4th iteration compared to Abu Dhabi today



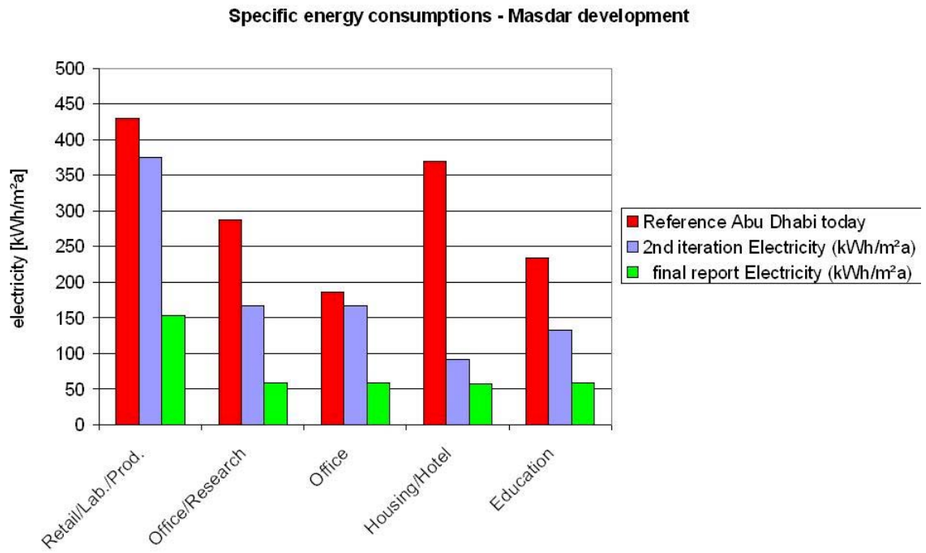
Energy consumption



Final report status of savings compared to today Abu Dhabi status



Program related energy consumption



Go to 80% reduction

Specific electricity consumption per building typology

General Introduction to Air Flow Studies and Evaluation for Design Guidelines

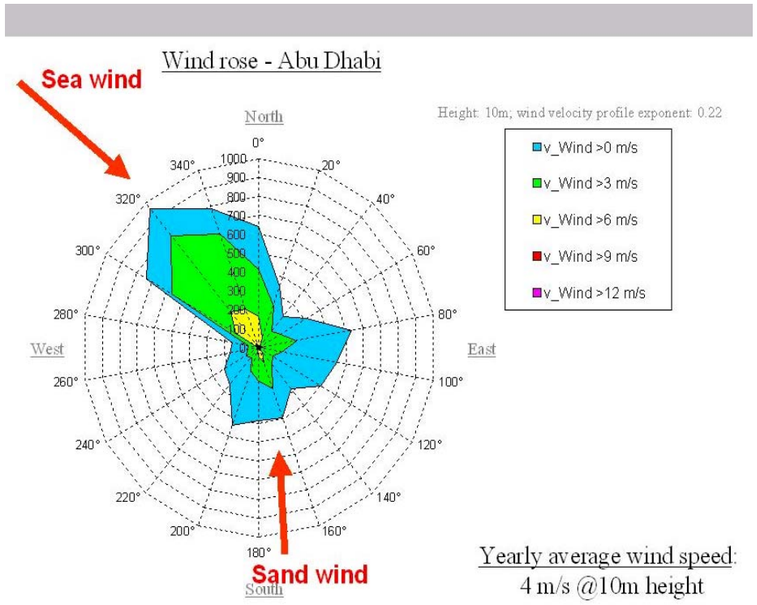
Local conditions
A special local climate phenomena in Abu Dhabi are the typical wind directions form Northwest over the Arabic Gulf and the sand storms out of the desert from Southerly directions.

Nighttime winds are in general with lower velocities and North and Easterly directions.

Even in the extreme hot summer period nigh time temperatures drop to 30°C and below and therefore has to be considered as a cooling source for outdoor spaces. The city design should allow to use the night time air flows to regenerate shaded city thermal mass for the next day to allow a buffer effect against the extreme outside peak temperatures.

Large city opening facing Southerly directions should be avoided as a local protection against the sand storms. The infiltration of the sand and dust into the city by the air flow above the city cannot be prevented, but the design to minimize the air infiltration with limited street length and wind tower protections will as well help to reduce the sand and dust loads. Large height steps facing the Southerly direction should be prevented, while they will cause strong redirections of wind into the city streets and redirect as well sand and dust into the city.

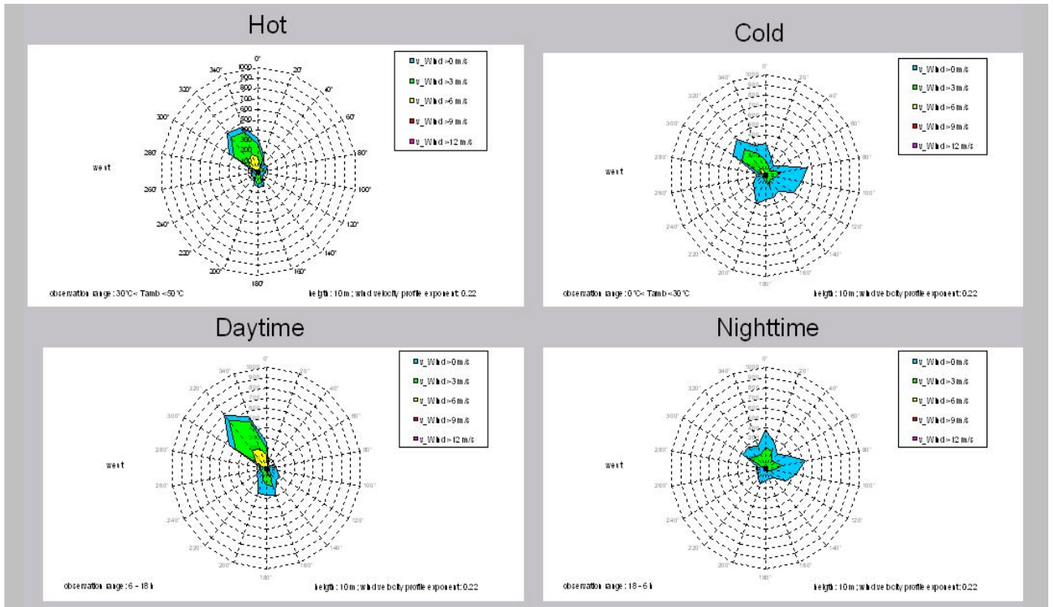
City ventilation demand
Due to the strong variations in outside temperature over the year and the demand for a certain outdoor air quality, the porosity or permeability of the city to outside air should vary. In winter, spring and fall, the wind is strongly welcome as a natural cooling source, while in the hot summer period hot air flows should be prevented.
The edges of the city facing the full wind loads, due to the exposed position of the Masdar Development. At this points a special design had to be developed to ensure a certain protection, without cutting the traffic connection between the city and it's surrounding.



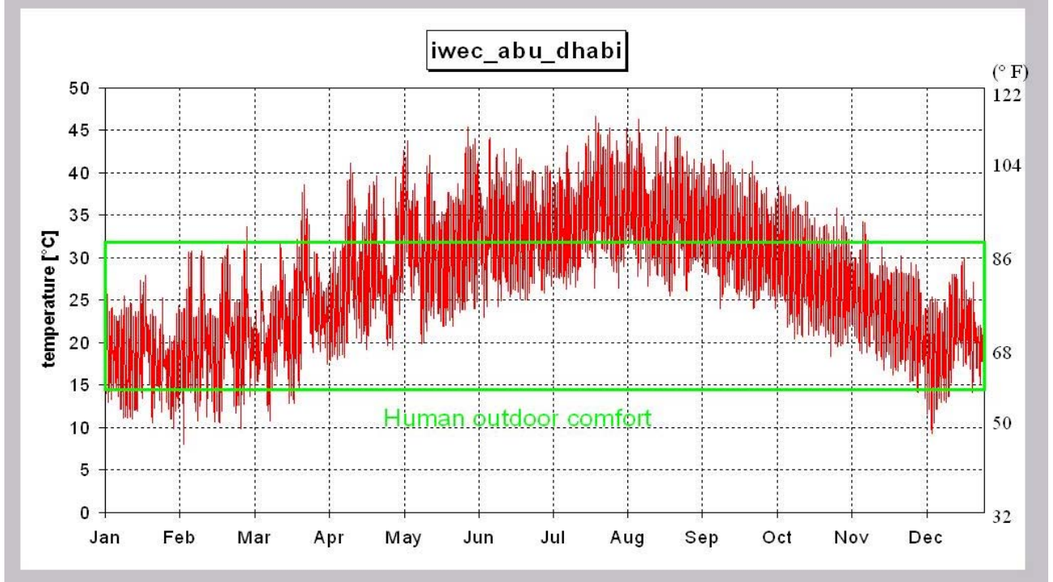
Masdar Development Project

The CO2 neutral approach, which had to activate the roof areas for energy harvesting, is causing a layer of hot air above the city, due to the limited efficiency to convert the absorbed solar radiation into electricity. Therefore nearly 80% of the solar energy are transformed into heat, which causes a air temperature increase above the city. The city street and building design had to respect this point, by minimizing the amount of hot air, which is redirected from the hot air layer above the city into the streets and places.

Even when combustion cars had been banned a city with all it's services and even light industries will still have some emissions into the air. Due to the weight difference of some of this emissions compared to air this air loads may sink into the street network and has to be ventilated before accumulating in certain locations. This demands a certain fresh air ventilation to ensure outdoor air qualities, as a good air source for the indoor spaces.



Wind sorted by temperature (above) and by time (below)



Annual hourly outdoor temperature profile

1 City Grid and Block Design
CFD Modelling for City Grid/ Block Design

1. City Grid/ Block Design

It is known from literature that a certain relation between street width and building height has a strong impact on the air infiltration into the street canyons. While a too narrow street grid is just overflown by the roof top winds, a ratio above 2 – double the width than the building heights – lead to increased infiltration of air into the streets.

Choosing the city grid facing the main wind direction – due to shading and city ventilation considerations – demanded a design recommendation for a typical street length in this direction. Varying the street width in an air flow model between 7 and 15 m and combining it with a piazza intersection allowed to identify a critical length of around 75 m, as a length of limited infiltration. For longer streets –nearly independent form the street width – the air infiltration from the roof top air flow reached critical values. Critical values has to be seen as infiltration rates of this daytime warm air layer – caused by the heat absorption of the energy collection roof systems – which can cause an additional heat source for the street canyons. On the other hand the solar loads into the street canyons – depending strongly on the street width – may cause local temperatures even above the roof top air flow, which then would welcome the infiltration as a cooling source.

For the street grid perpendicular to the main wind direction from Northwest the simulations conformed the literature values of a low impact as long as the street width was below the building height, which even the 15 m wide street case of the 18 m building height fulfilled.

As well a nighttime infiltration should be kept in mind, which can help to recool the street canyons from the daytime accumulated heat.

2. Urban Heat Island Effect

Cities are known for their local microclimate, described as heat island effect. This phenomena is caused by solar absorption in the city, which by it's 3-dimesional structure works like a spatial absorber. Even reflection of solar radiation on vertical facades are redirected into the street canyons and not reflected back to the sky. In addition and heat production by traffic or building systems – like recooling of any air conditioning - relieved into the city causes additional temperature increases.

For the Masdar development with city dimensions of 1.4 by 1.4 km, this problem has to be considered seriously. In addition the roof area energy collecting systems can only transfer a small ratio of the absorbed solar radiation into useful energy, but spill with nearly 70% most of it by radiation and convection back into the surrounding.

This have been evaluated for the two cases without and with wind. Both cases show temperature increases upto 9 Kelvin at local spots and underline the demand for a excluded or reduced infiltration into the street canyons during this times.

3. Wind tower variation

As the previous analysis showed it is critical to protect the street canyons in hot periods against large hot air infiltration. Limited street length and street width – as well recommended by the solar protection approach – can help this approach.

This limited air infiltration is in contradiction to the welcome of an increased infiltration during colder periods of the year and during nighttime. A reversible system with increased protection during daytime and increased infiltration during nighttime or cooler outdoor temperatures would be ideal.

This guided us to a reinterpretation of the classical wind tower in UAE. Due to the increased comfort demand in buildings the original use of this wind towers to increase outside air flows into the building only works for a very short period of the year. Otherwise the outdoor temperatures or humidity levels are above the comfort range and the increased infiltration would be only an additional room load.

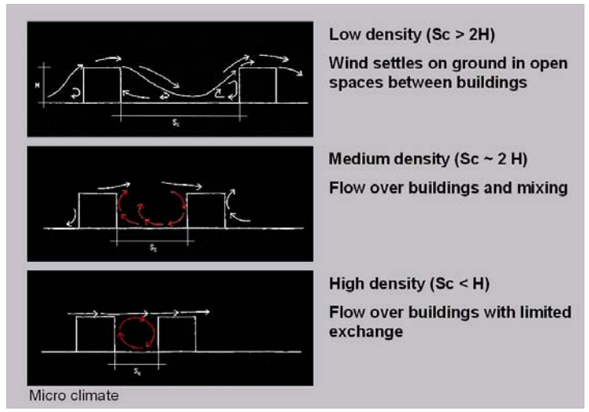
But for the outdoor climate in the street canyons this increased air flow is a welcome source. It supports the city ventilation and by simple flaps in the tower can be controlled depending on daytime and outside conditions. Positioned at the beginning of a street the wind tower create by their wind shadow an additional protection for the street, reducing the infiltration rates from ~ 150 ac/h down to ~ 30 ac/h. By activating the street wind tower the infiltration rate can be increased back to a range of 60 ac/h.

Demands

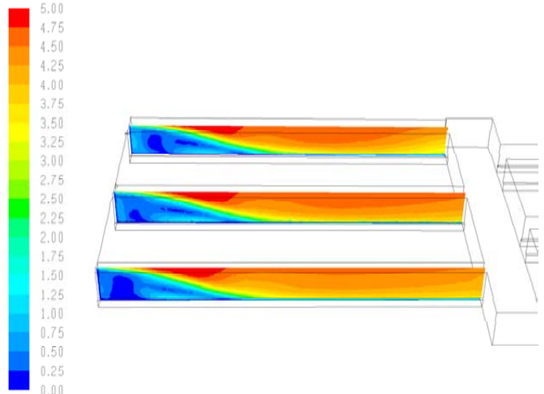
- Ensure basic city ventilation
- sand storm protection
- support of night ventilation
- daytime ventilation during colder periods
- daytime protection during hot periods
- no redirection of hot wind from solar roof areas into the streets

Results:

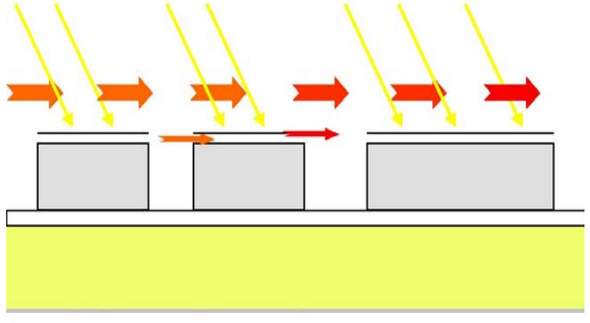
- A limited street length of around 75 m allows to reduce the air infiltration into the street canyons.
- Narrow streets have much smaller wind driven infiltration.
- Pressure distribution in and above the city causes sufficient air change rates even for the narrow street grid.
- Local hot spots due to the solar absorption above the city with temperature increases of 9 Kelvin above ambient conditions has to be considered. As a mean value the city cause a heat island effect of 3.5 K above the ambient conditions.
- Local street wind towers can be a further wind protection for the streets and allow a controlled street ventilation.

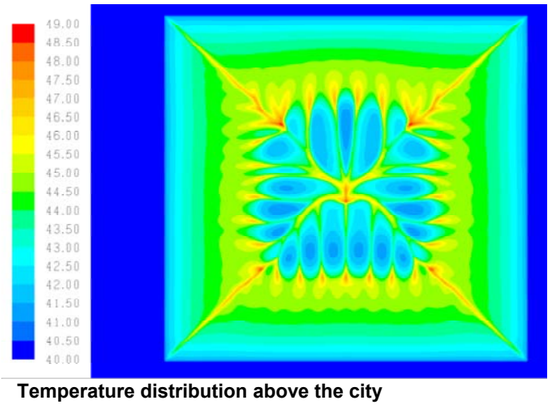


Airflow effects in the street canyons

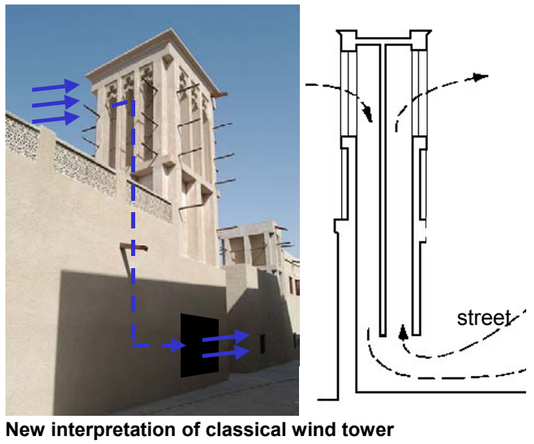


Air velocity profile in a street

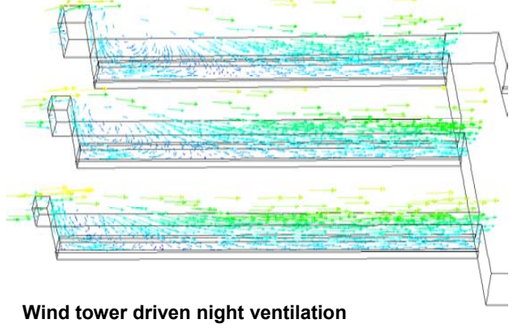

Solar caused city heat island



Temperature distribution above the city



New interpretation of classical wind tower


Wind tower driven night ventilation

1 Air Flow Simulation for City Grid/ Block Design
For a city micro climate to stay below the exposed outside temperature in summer with its temperature peaks , the impact of external wind into the street canyons is a critical point. The following studies make an analysis of this impact possible and allows the development of design recommendation for the city grid in respect of street width an length.

Objective
Generate and analyse the exterior wind pattern due to various “potential” street widths for Masdar Development Project.

Approach
A 3-dimensional Computational Fluid Dynamics(CFD) simulation is carried out for the geometrical model shown on the right half of this page.
Computational Fluid Dynamics(CFD) is a branch of science which uses numerical techniques to solve flow or flow related phenomena(heat, species transport, etc.). In CFD, the region of interest is divided into many(some times millions) of sub-volumes(known as volume cells). Based on provided boundary conditions, a number of equations(known as Navier-Stoke equations) are solved iteratively for each such sub-volumes to reach physically true results.

Geometrical Set-up
Two sets of streets are considered to be connected by a central piazza. First set of streets has one dead(closed) end and the other opening into the piazza, while the second set of streets has both ends open.

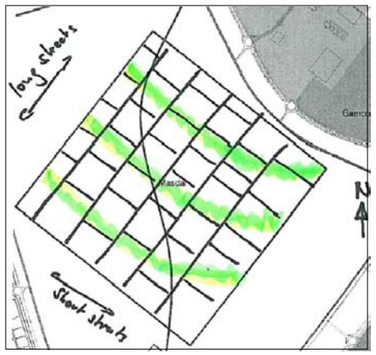
Variants
Following 5 different cases are simulated for the yearly average wind speed for the location
CASE - 1:
Exterior wind direction is parallel to the city block/street length; entering from the streets with dead ends
CASE - 2:
Exterior wind making an angle of 45° to the city block/street length
CASE - 3:
Exterior wind coming from the direction perpendicular to the city block/street length
CASE - 4:
Exterior wind direction is parallel to the city block/street length; entering from the streets with open ends
CASE - 5:
Streets are connected by passage through the blocks - Exterior wind direction is parallel to the city block/street length; entering from the streets with dead ends.

Conclusions
- For the wind direction parallel to the street length, high wind velocity can be observed after 75m to 100 m length of the street, irrespective of street width.(CASE-1)
- When the wind direction is at 45° or 90° to the street length, the width of streets plays a crucial roll. Wider streets allows higher air flow into the streets.(CASE-2 and CASE-3). While street width below 10m are just overflown.
- Exterior wind can attain very high velocity values(>6m/s) at the entrance of the streets near the outer city wall, when the wind direction is parallel to the street length.(CASE-4)
- Position of passage openings into the streets has more impact on air change rate in the passage, than the width of the passage.(CASE-5)

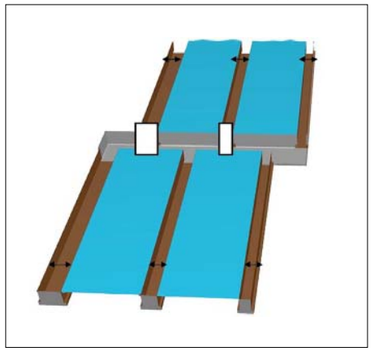
Recommendations
- street width < 15 m
- limited street length < 75 m
- places need wind screens
- open street ends facing the wind need protection
- fairly homogeneous height of the city
- passages with zigzag shape
- passage width = 2.5m

Please note that a wind tunnel study of a city model (scale 1:1000) was done by Wacker Ingenieure showing the wind impact on the designed city grid in this design stage. (see Chapter 4.1.4)

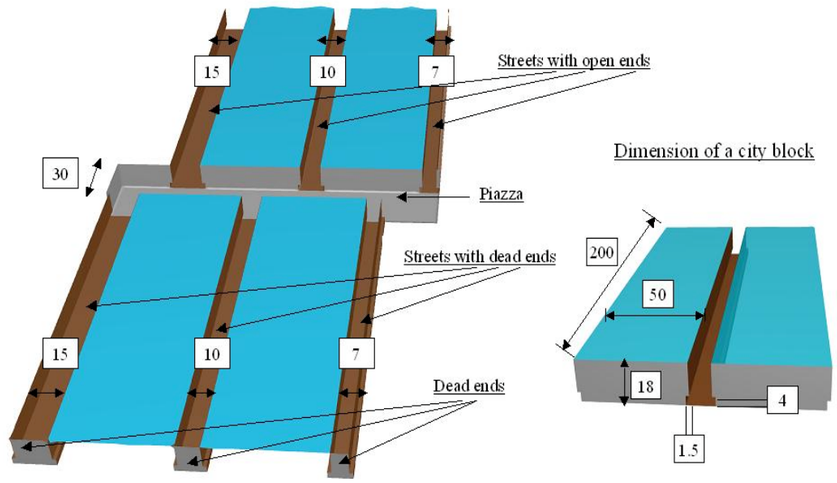
Schematic proposal for the placement of the short/ long streets for the city grid layout.



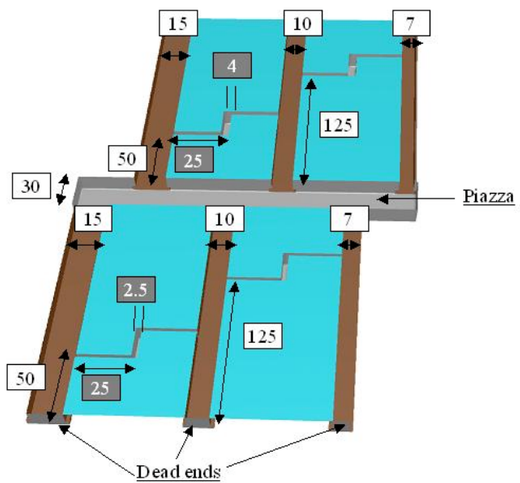
Placing wind towers at the beginning of the streets can be a potential approach.



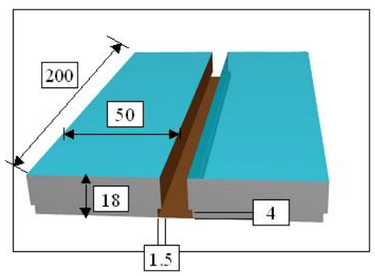
The geometrical model with different street sizes connected by a *piazza*



The geometrical model for case-5 with different street size connected by passage through the blocks



Dimension of a city block



•Streets with dead ends are connected by a “ ⌐ ” shaped passage of **2.5m width** and **25m length** of each leg.

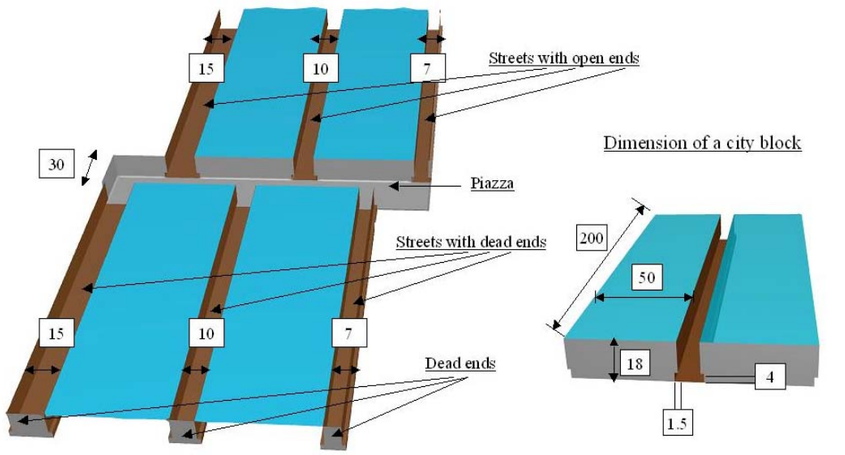
•Streets with open ends are connected by a “ ⌐ ” shaped passage of **4m width** and **25m length** of each leg.

**All dimensions are in m*

CASE - 1
Exterior wind direction is parallel to the city block/street length; entering from the streets with dead ends

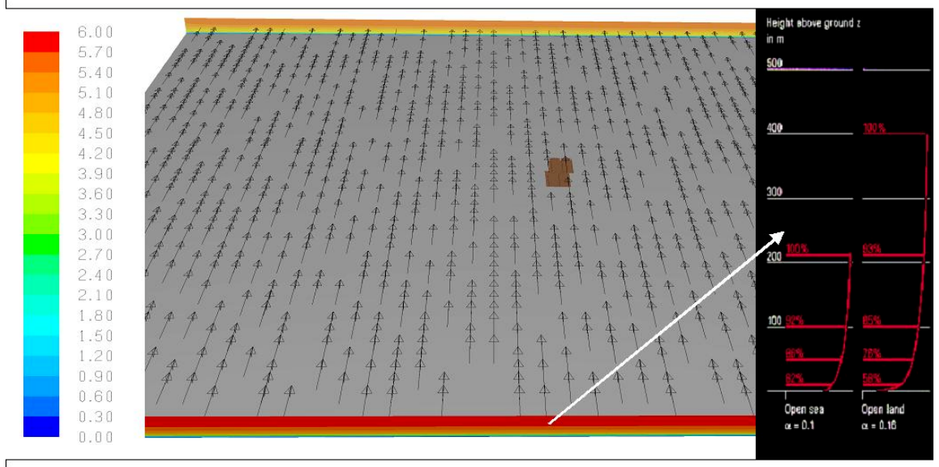
How to interpret the CFD results
Results of the CFD simulation are presented pictorially on the pages to follow.
On the left hand side of each picture is shown a colour bar with the associated values(blue colour represents the minimum and red colour represents the maximum value). The result should be read in the form of colours and the associated value with that colour has to be found from the colour bar on the left. This way the value of various physical quantities(eg. temperature, velocity, etc) can be found at a particular location.

The geometrical model with different street sizes connected by a *piazza - "for case 1-4"*



*All dimensions are in m

The computational domain for the CFD simulation of the Case-1



Undisturbed exterior wind velocity profile[m/s] as a function of height above the ground level

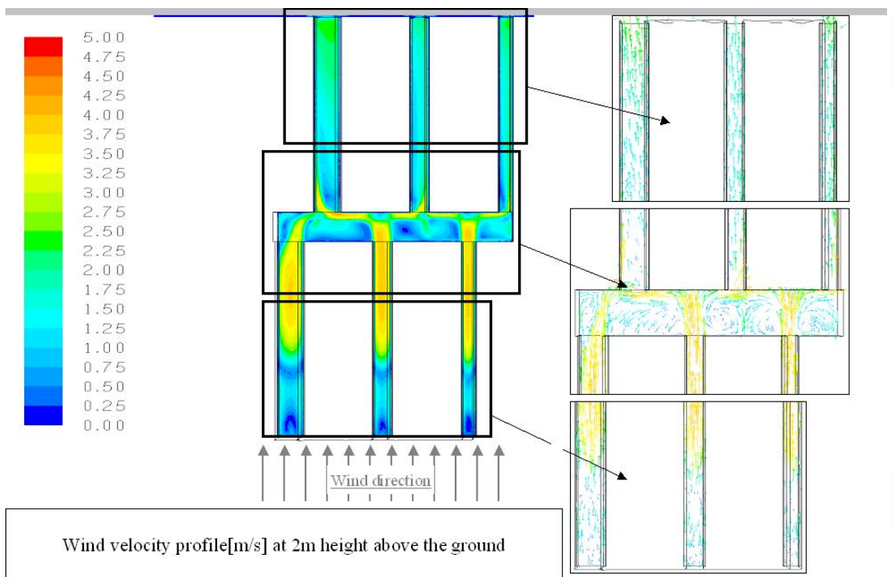
Case-1 : Wind direction is parallel to the city block/street length; *entering from the streets with dead ends*

The top-right picture shows the undisturbed velocity profile as a function of height at the inlet of the CFD model.

The bottom-left picture shows the velocity profile in the streets at pedestrian level(2m above the ground). It can be clearly observed that the velocity reaches up to 4m/s in the second half of the streets with dead end.

The effect is a drop of the roof wind flow into the streets after a certain length. This critical length flows to be independent from the street width at about ~75m.

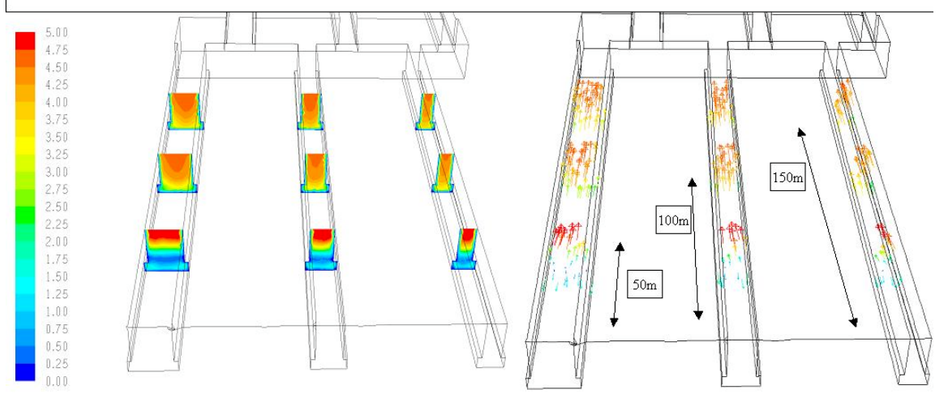
The bottom-right picture shows the velocity profile at the section planes at a distance of 50m, 100m and 150m from the dead end of the streets. It is clear that at the 2nd section plane(at 100m from dead end) the wind velocity is more than 3.5 m/s at the bottom of the streets.



Wind velocity profile[m/s] at 2m height above the ground

Case-1 : Wind direction is parallel to the city block/street length; *entering from the streets with dead ends*

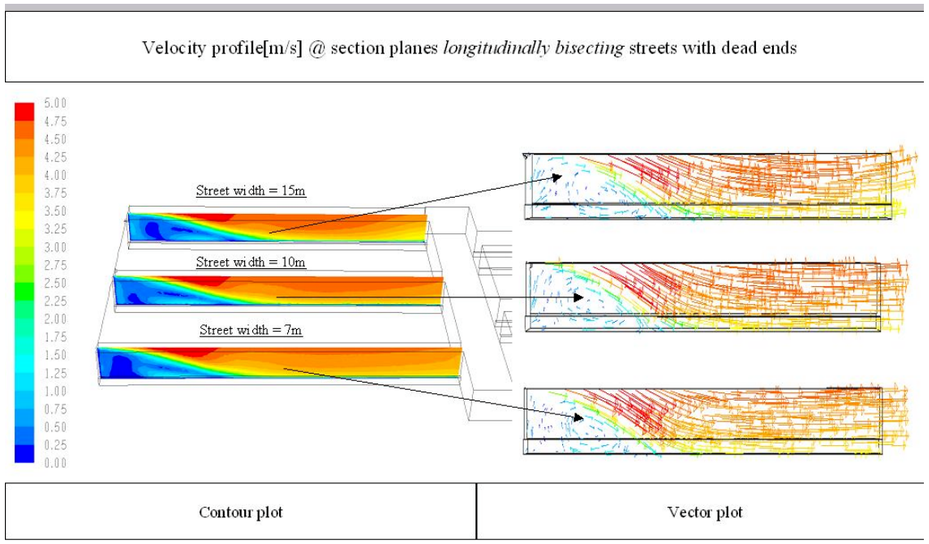
Velocity profile[m/s] @ section planes *radially quadrasecting* streets with dead ends



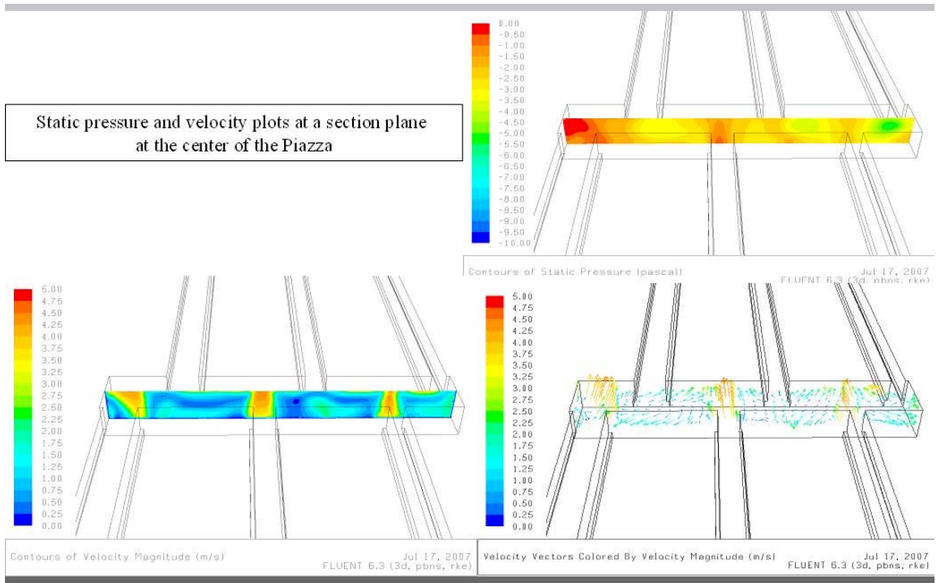
Contour plot | Vector plot

Case-1 : Wind direction is parallel to the city block/street length; *entering from the streets with dead ends*

CASE - 1
Exterior wind direction is parallel to the city block/street length; entering from the streets with dead ends



Case-1 : Wind direction is parallel to the city block/street length; *entering from the streets with dead ends*

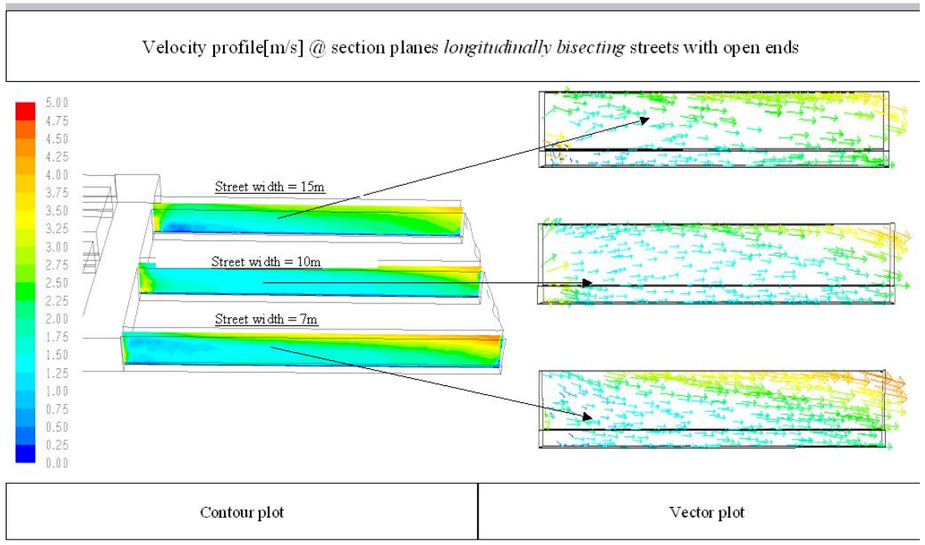


Case-1 : Wind direction is parallel to the city block/street length; *entering from the streets with dead ends*

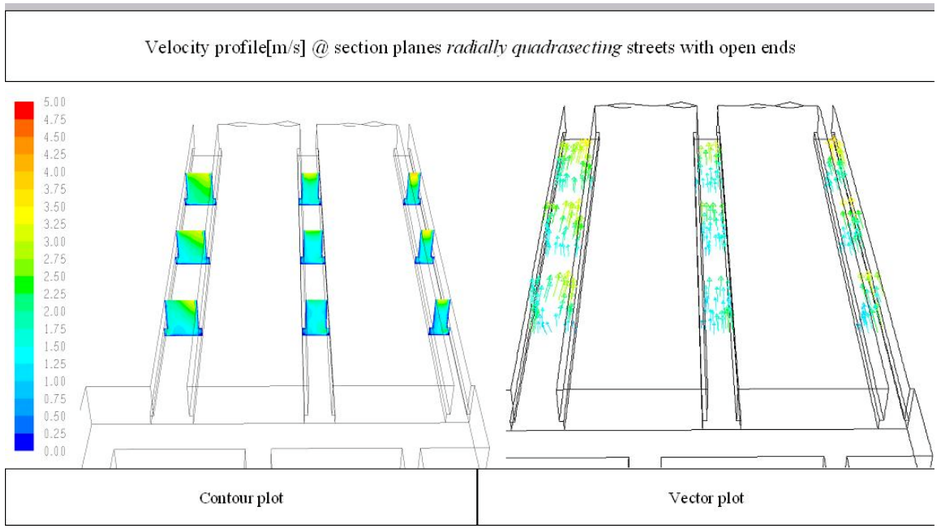
The top-left picture shows the velocity profile at the section planes bisecting the streets with dead ends. The effect of a drop of the exterior wind is clearly visible. Also the impact of shading due to the dead ends and the local turbulence can be observed in the first half of the street.

From the top-right picture, the striking of the wind at the wind facing side of the piazza can be seen with the strongest effect for the 15m street.

The bottom pictures shows the wind velocity profiles in the streets with open ends. Increase in wind velocity near the end of the streets is visible in these pictures as well, but lower than in the dead end streets.



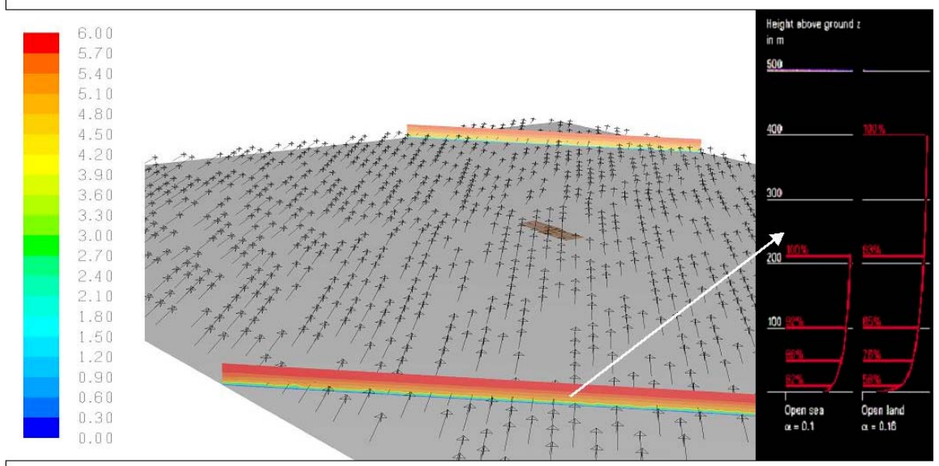
Case-1 : Wind direction is parallel to the city block/street length; *entering from the streets with dead ends*



Case-1 : Wind direction is parallel to the city block/street length; *entering from the streets with dead ends*

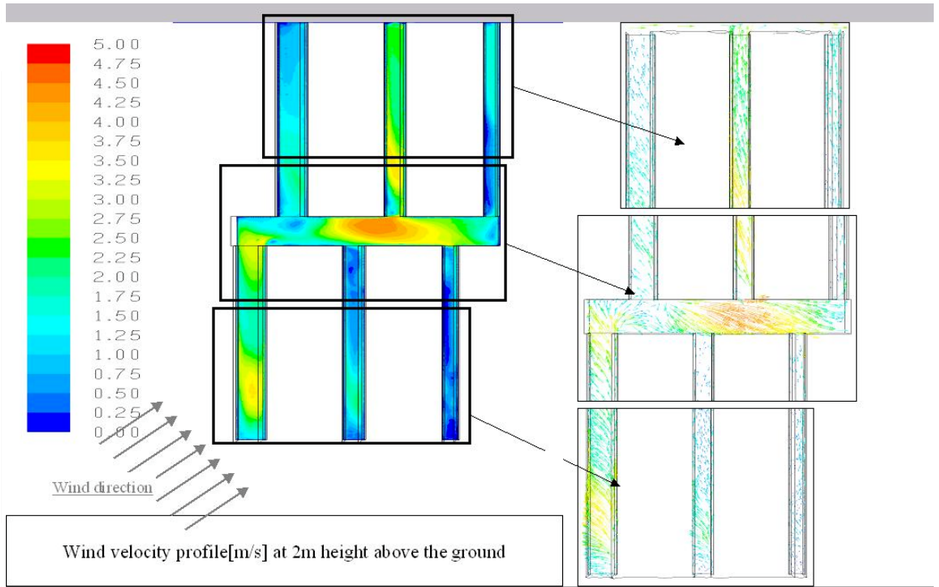
CASE - 2
Exterior wind making an angle of 45° to the city block/street length

The computational domain for the CFD simulation of the Case-2



Undisturbed exterior wind velocity profile[m/s] as a function of height above the ground level

Case-2 : Wind direction is making an angle of 45⁰ to the city block/street length



Wind velocity profile[m/s] at 2m height above the ground

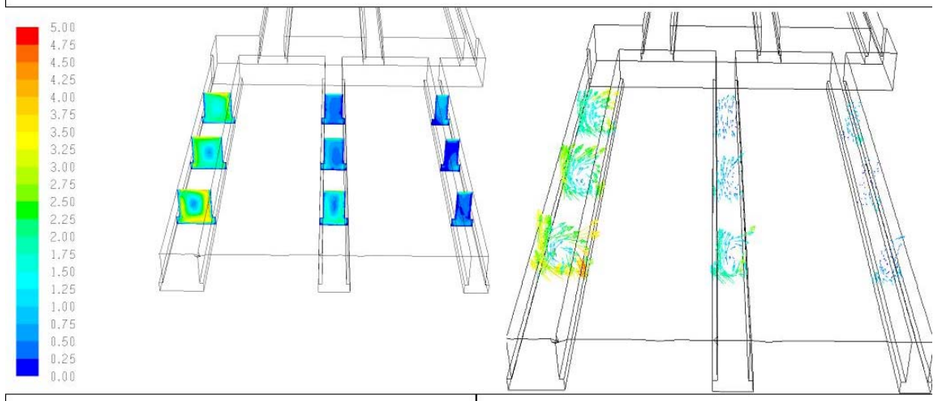
Case-2 : Wind direction is making an angle of 45⁰ to the city block/street length

The top-left picture shows the undisturbed velocity profile as a function of height at the inlet of the CFD model. It is clear that the wind direction is at 45° to the streets now.

The top-right picture shows the velocity profile in the streets at pedestrian level(2m above the ground). Location with higher velocity magnitude can be seen in the piazza and in the wider street facing the wind direction. For the 10 and 7m street the wind "overflows" the street gap and therefore shows only very little impact in the streets.

The bottom pictures shows the wind velocity profiles in the streets with dead ends. Wind velocity decreases gradually for the streets with smaller width.

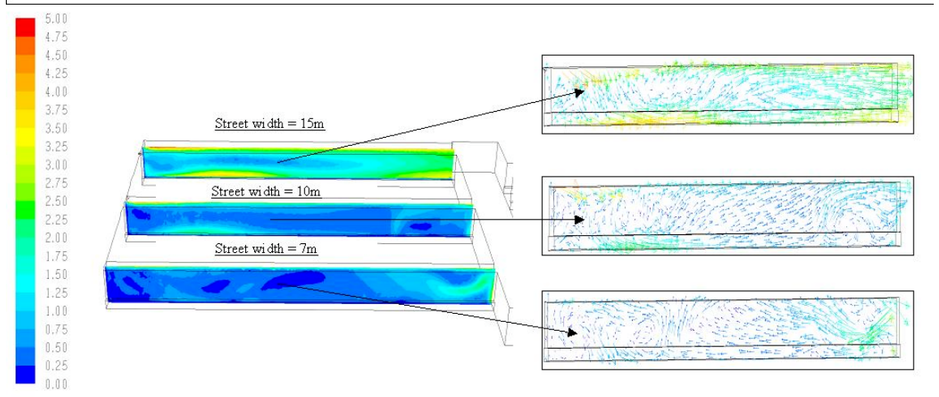
Velocity profile[m/s] @ section planes *radially quadrasecting* streets with dead ends



Contour plot | Vector plot

Case-2 : Wind direction is making an angle of 45⁰ to the city block/street length

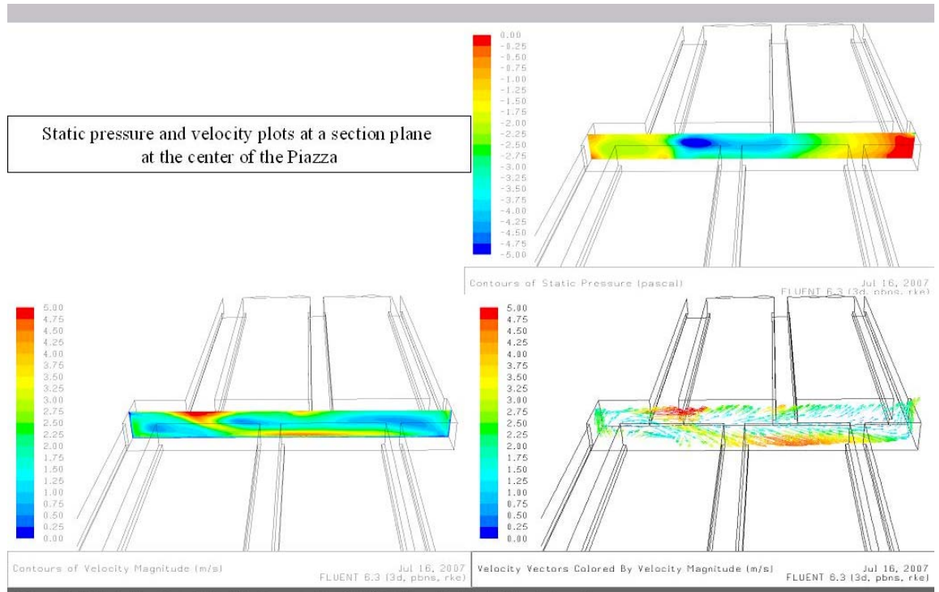
Velocity profile[m/s] @ section planes *longitudinally bisecting* streets with dead ends



Contour plot | Vector plot

Case-2 : Wind direction is making an angle of 45⁰ to the city block/street length

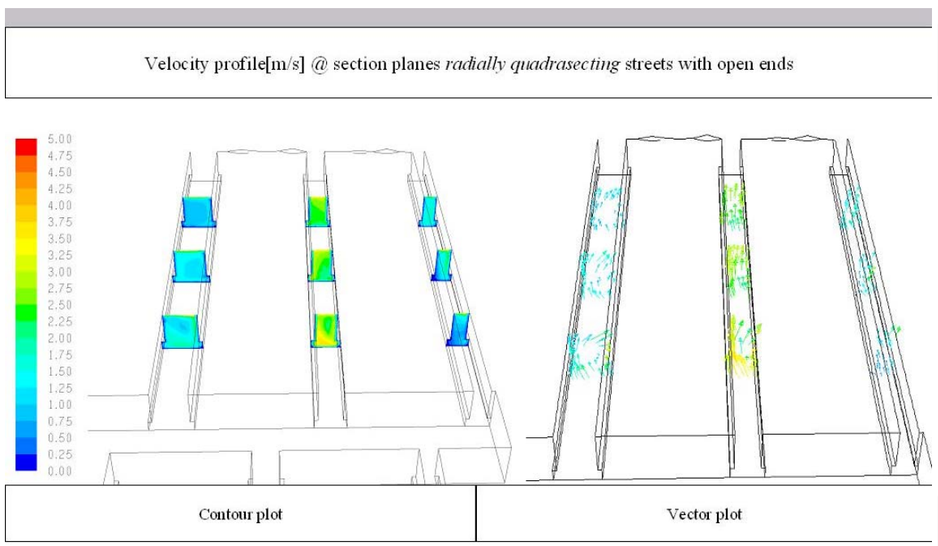
CASE - 2:
Exterior wind making an angle of 45° to the city block/street length



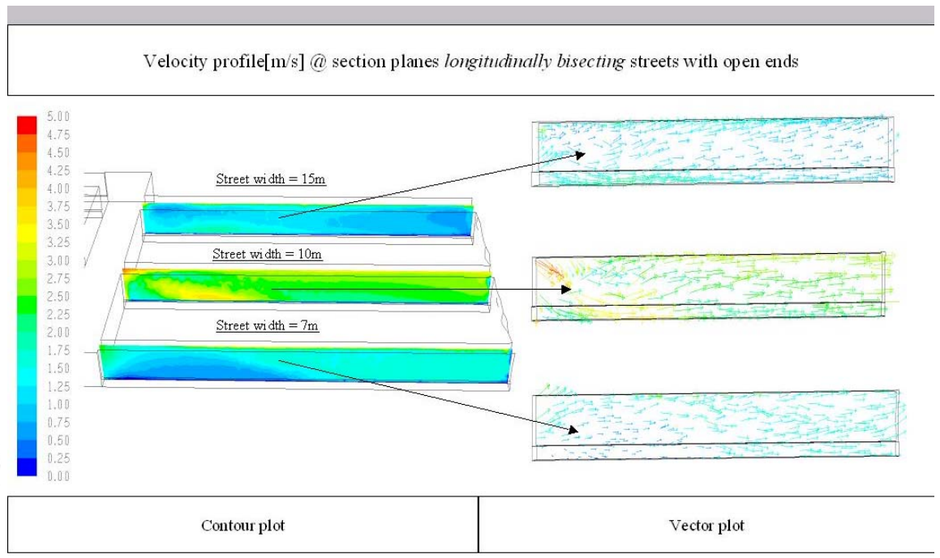
Case-2 : Wind direction is making an angle of 45^0 to the city block/street length

From the top-right picture, the striking of the wind at the wind facing side of the piazza can be seen especially at the extension of the 15m street in wind direction.

The bottom pictures shows the wind velocity profiles in the streets with open ends. Increased wind velocity in the central street can be observed as the opening of this street is close to the location where the wind falls into the piazza.

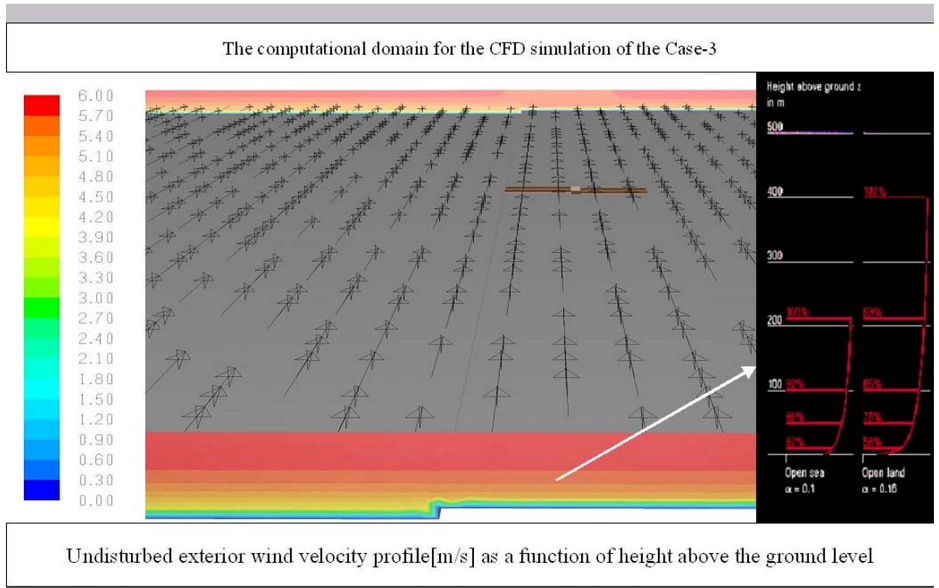


Case-2 : Wind direction is making an angle of 45^0 to the city block/street length

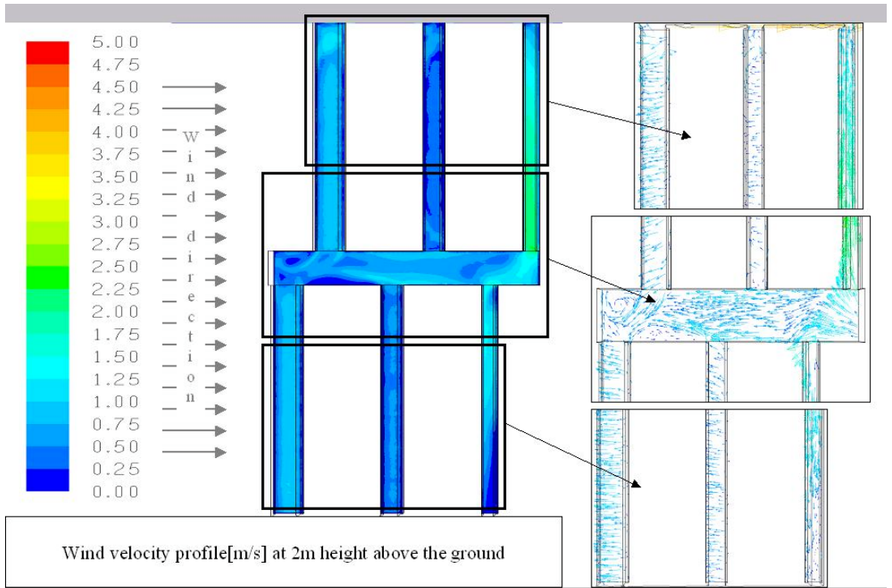


Case-2 : Wind direction is making an angle of 45^0 to the city block/street length

CASE - 3
Exterior wind coming from the direction perpendicular to the city block/street length



Case-3 : Wind is coming from the direction perpendicular to the city block/street length

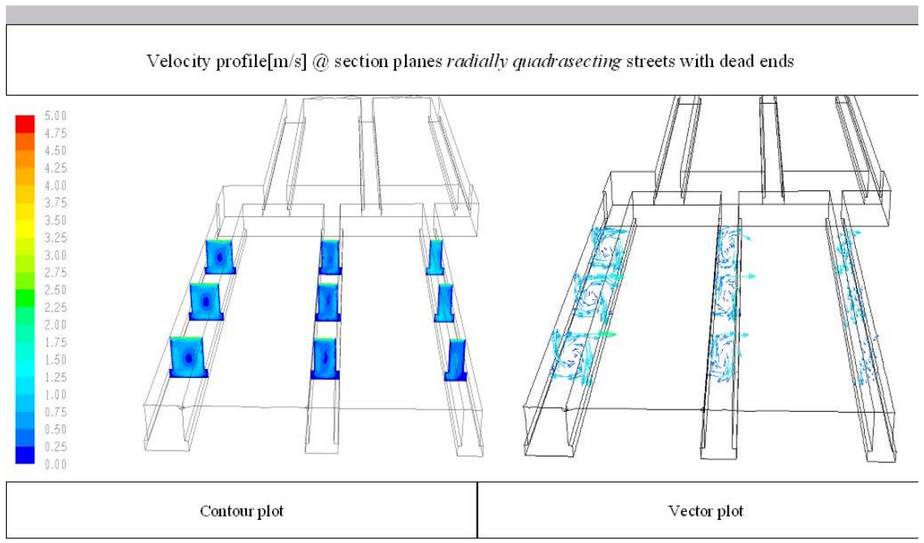


Case-3 : Wind is coming from the direction perpendicular to the city block/street length

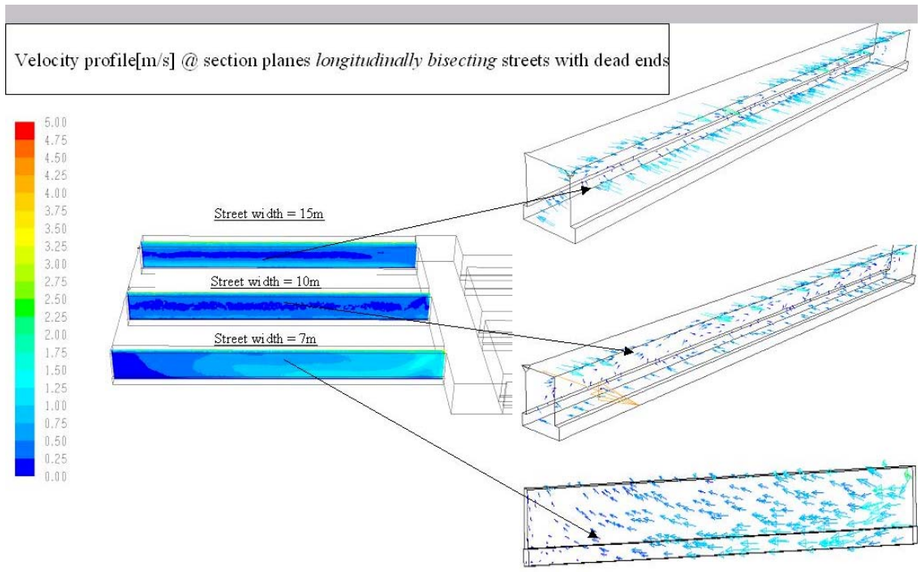
The top-left picture shows the undisturbed velocity profile as a function of height at the inlet of the CFD model. For this case the model is turned to have the exterior wind direction perpendicular to the length of the streets.

The top-right picture shows the velocity profile in the streets at pedestrian level(2m above the ground). Fairly low velocity can be observed in the streets irrespective of their width. All of them are mainly “overflown” by the wind.

The bottom pictures show the wind velocity profiles in the streets with dead ends. Only for the street near the far end of the piazza(7m wide street) gets relatively higher wind diverted from the piazza.

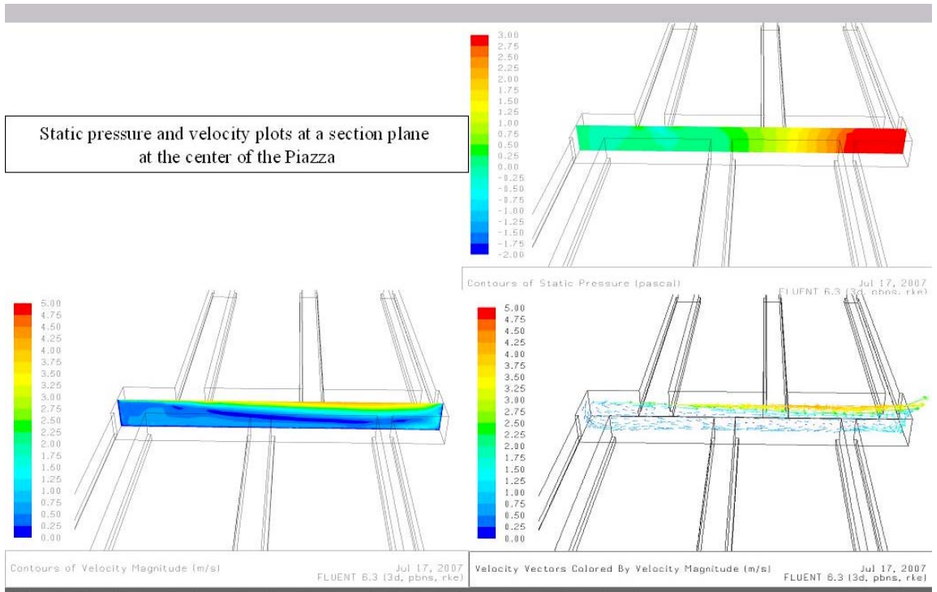


Case-3 : Wind is coming from the direction perpendicular to the city block/street length

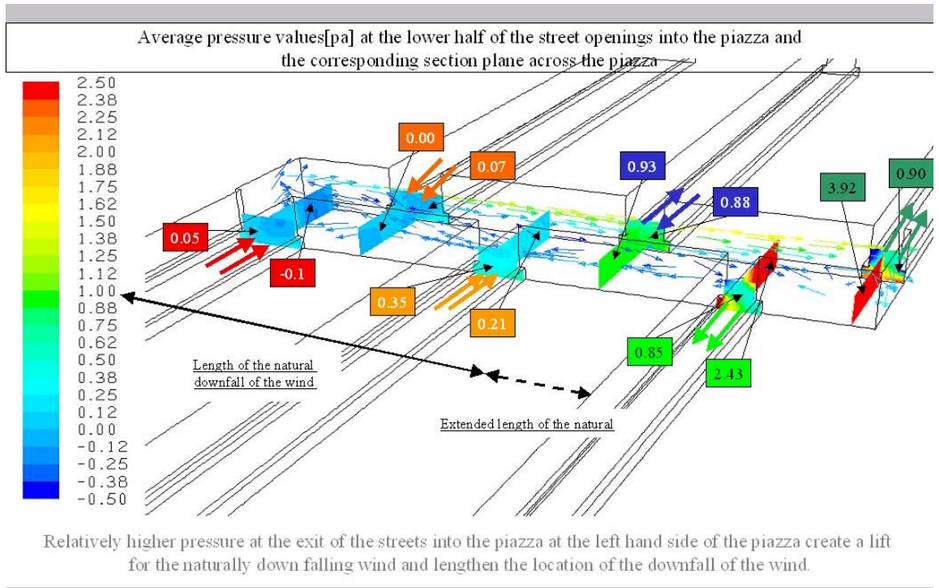


Case-3 : Wind is coming from the direction perpendicular to the city block/street length

CASE - 3:
Exterior wind coming from the direction perpendicular to the city block/street length



Case-3 : Wind is coming from the direction perpendicular to the city block/street length

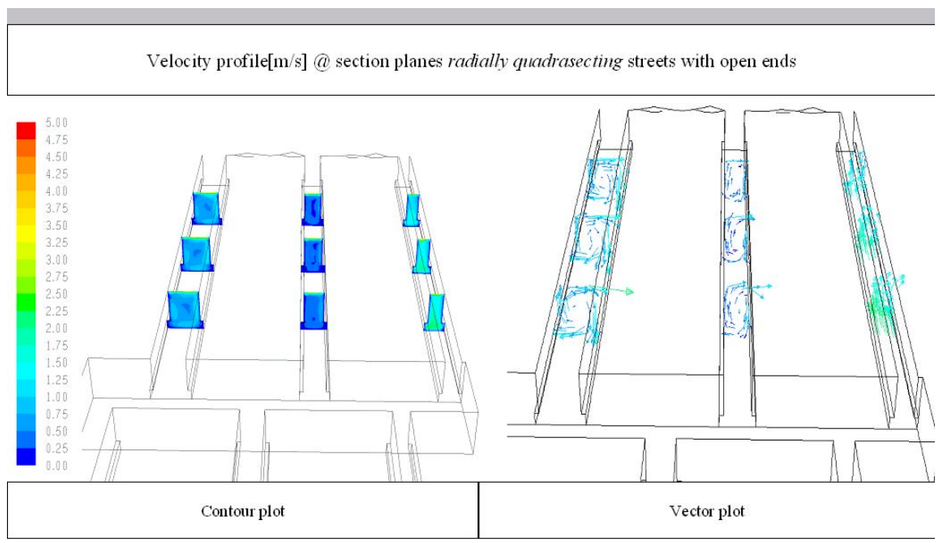


Case-3 : Wind is coming from the direction perpendicular to the city block/street length

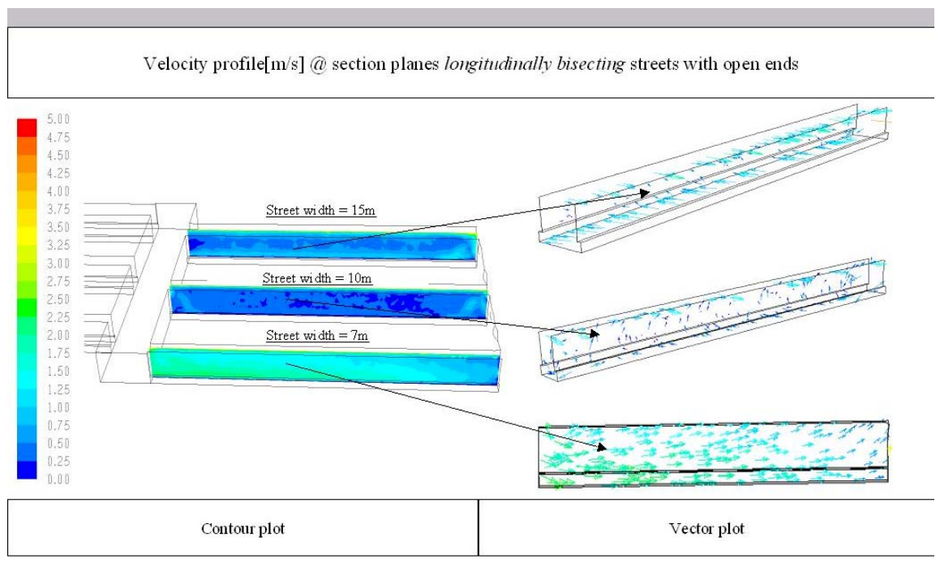
From the top-left picture, the striking of the wind at the far end of the piazza can be seen.

Top-right picture explains by comparing the pressure values at the outlet of the streets into the piazza and at the corresponding section plane in the piazza, the reason why the location of down wall of the wind in this case is longer as compared to case-1. Because of the air flow in the piazza a laminar air layer presents the wind from a direct drop into the piazza. Therefore the critical length is extended to around 100m.

The bottom pictures show the wind velocity profiles in the streets with open ends. Only for the street near the far end of the piazza(7m wide street) gets relatively higher wind diverted from the piazza.



Case-3 : Wind is coming from the direction perpendicular to the city block/street length



Case-3 : Wind is coming from the direction perpendicular to the city block/street length

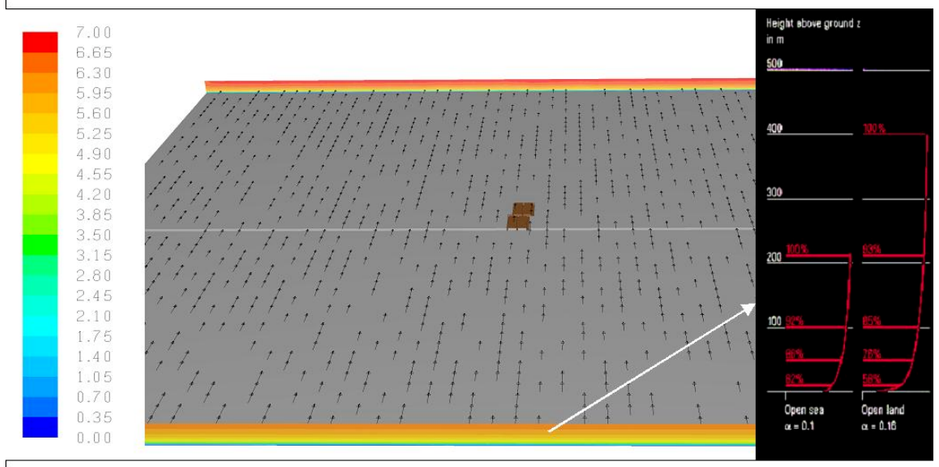
CASE - 4
Exterior wind direction is parallel to the city block/street length; entering from the streets with open ends

The top-left picture shows the undisturbed velocity profile as a function of height at the inlet of the CFD model. This case is simulated to have the wind direction parallel to the streets but the wind entering from the streets with open ends(at 180° compared to case-1).

The top-right picture shows the velocity profile in the streets at pedestrian level(2m above the ground). Extremely high velocity magnitude can be observed near the entrance of the streets with open end which demands a special solution for the city entrances.

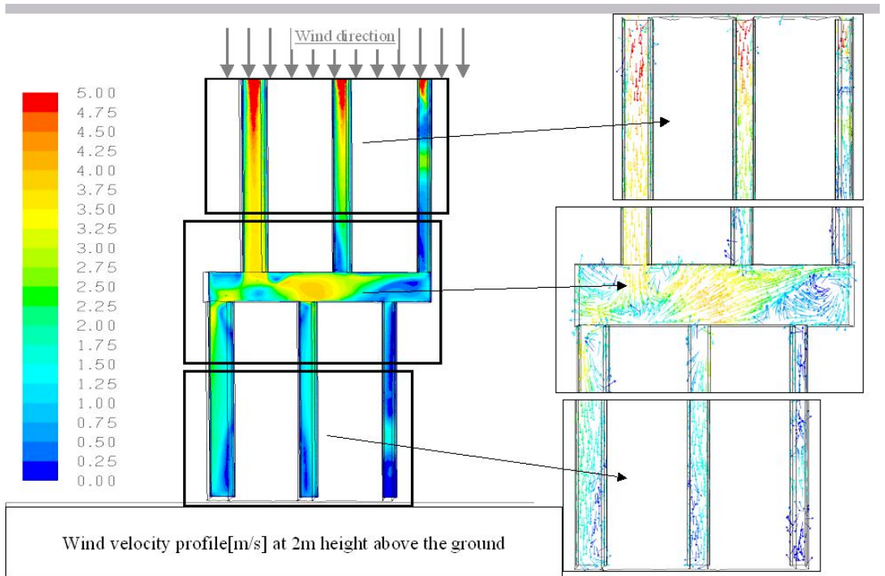
The bottom pictures show the wind velocity profiles in the streets with dead ends. The wind flow can be observed to be obstructed by the dead end and local variations in the velocity can be observed.

The computational domain for the CFD simulation of the Case-4



Undisturbed exterior wind velocity profile[m/s] as a function of height above the ground level

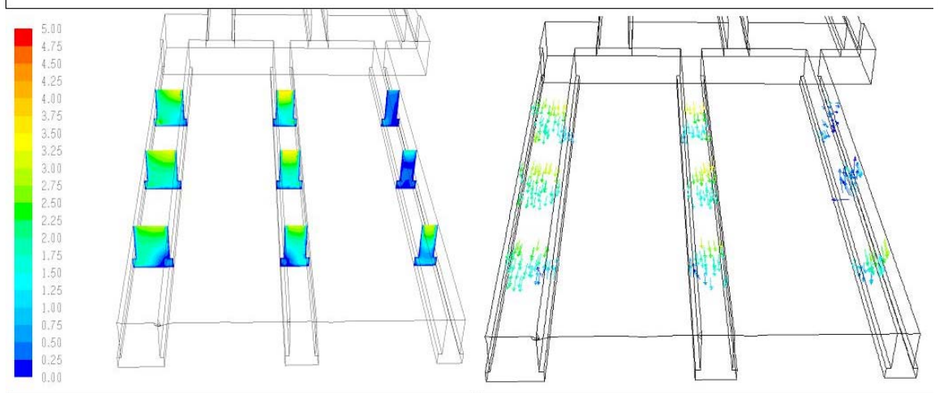
Case-4 : Wind direction is parallel to the city block/street length; *entering from the streets with open ends*



Wind velocity profile[m/s] at 2m height above the ground

Case-4 : Wind direction is parallel to the city block/street length; *entering from the streets with open ends*

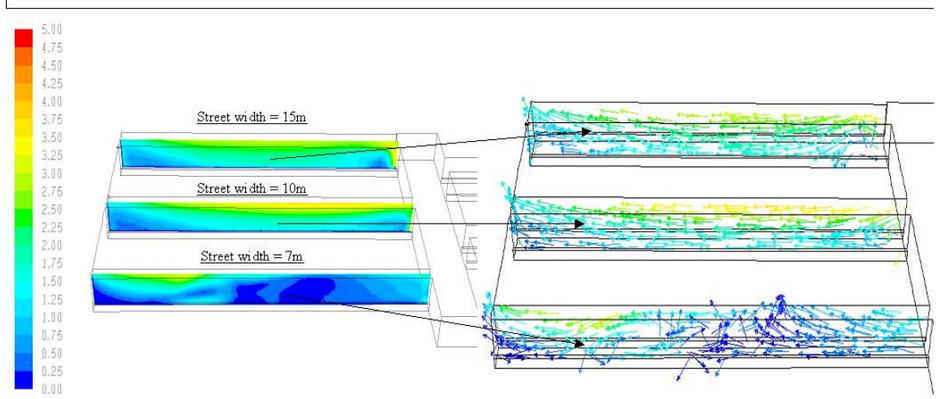
Velocity profile[m/s] @ section planes *radially quadrasecting* streets with dead ends



Contour plot | Vector plot

Case-4 : Wind direction is parallel to the city block/street length; *entering from the streets with open ends*

Velocity profile[m/s] @ section planes *longitudinally bisecting* streets with dead ends



Contour plot | Vector plot

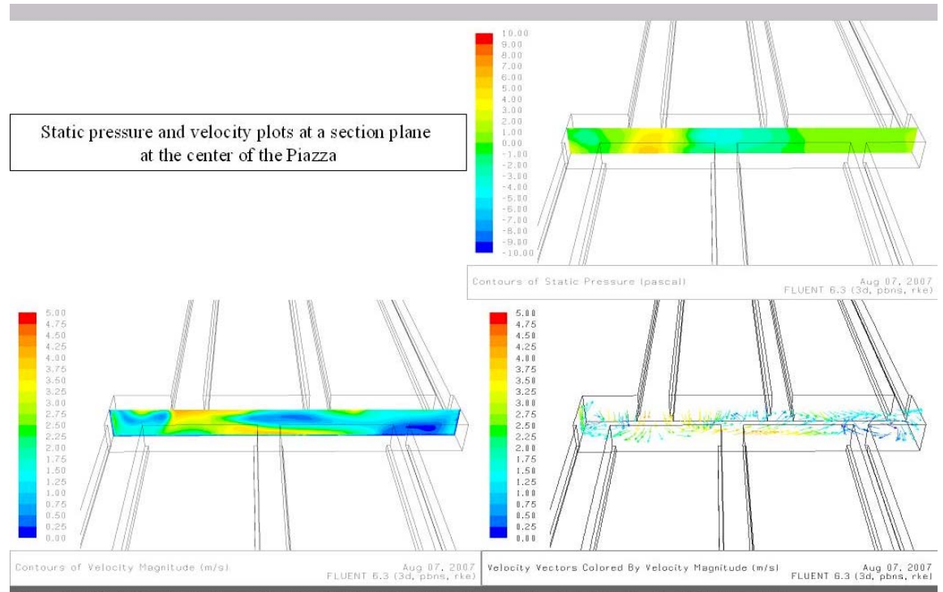
Case-4 : Wind direction is parallel to the city block/street length; *entering from the streets with open ends*

CASE - 4
Exterior wind direction is parallel to the city block/street length; entering from the streets with open ends

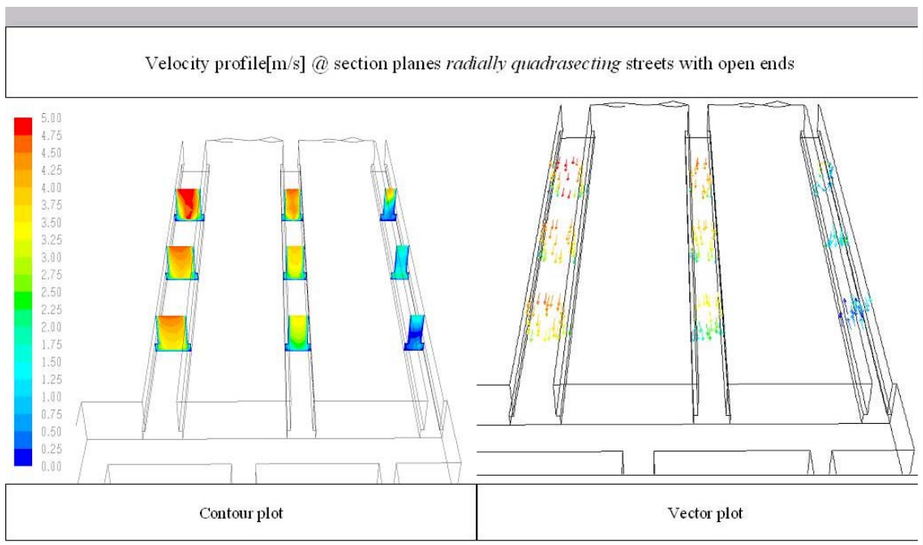
.

From the top-right picture, the striking of the wind at the wind facing side of the piazza can be seen especially for the 15m wide street.

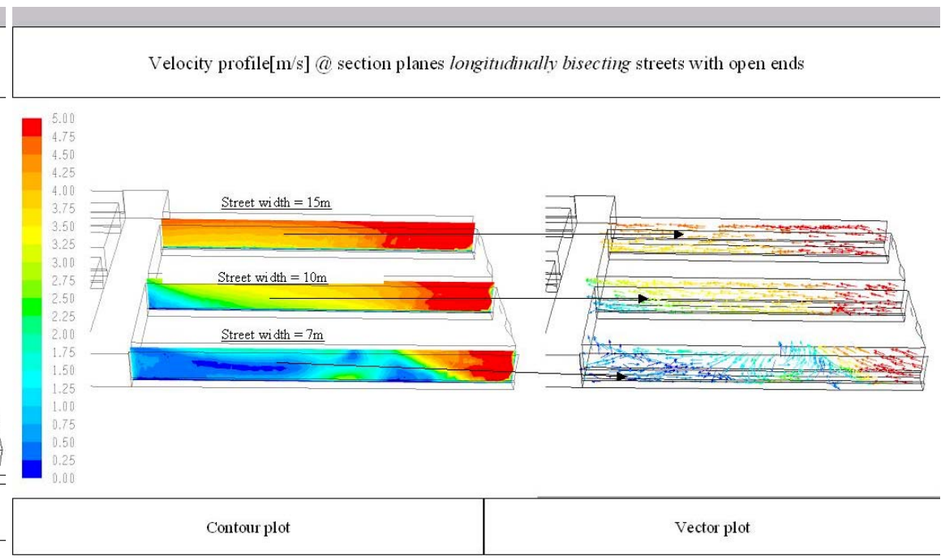
The bottom pictures shows the wind velocity profiles in the streets with open ends. Wind enters the streets with the velocity magnitude value of more than 5m/s into the streets. The wider the street the more critical is this effect.



Case-4 : Wind direction is parallel to the city block/street length; *entering from the streets with open ends*



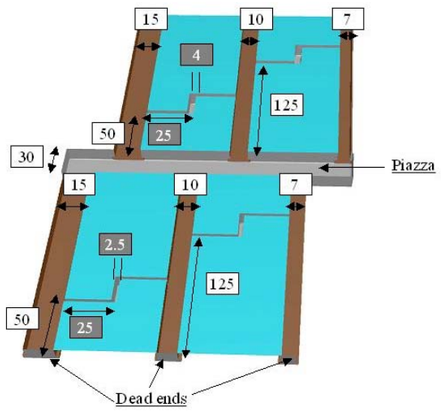
Case-4 : Wind direction is parallel to the city block/street length; *entering from the streets with open ends*



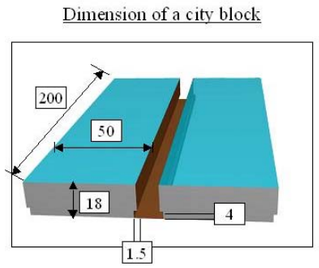
Case-4 : Wind direction is parallel to the city block/street length; *entering from the streets with open ends*

CASE - 5
This case was introduced to determine the air change rates in the small narrow passages between the streets with width of 2.5 and 4m.
Streets are connected by passage through the blocks - Exterior wind direction is parallel to the city block/street length; entering from the streets with dead ends.

The geometrical model for case-5 with different street size connected by passage through the blocks



Dimension of a city block



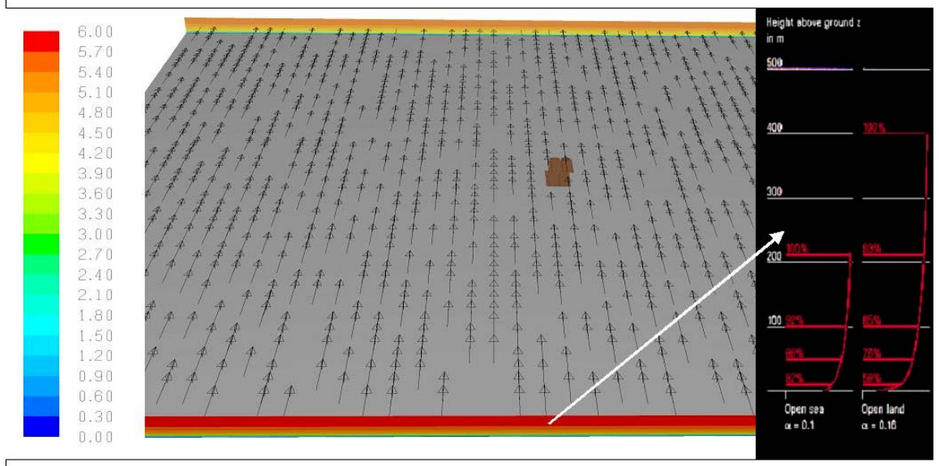
•Streets with dead ends are connected by a "⌐¬" shaped passage of **2.5m width** and **25m length** of each leg.

•Streets with open ends are connected by a "⌐¬" shaped passage of **4m width** and **25m length** of each leg.

**All dimensions are in m*

Case-5 : Wind direction is parallel to the city block/street length; *entering from the streets with dead ends*

The computational domain for the CFD simulation of the Case-5

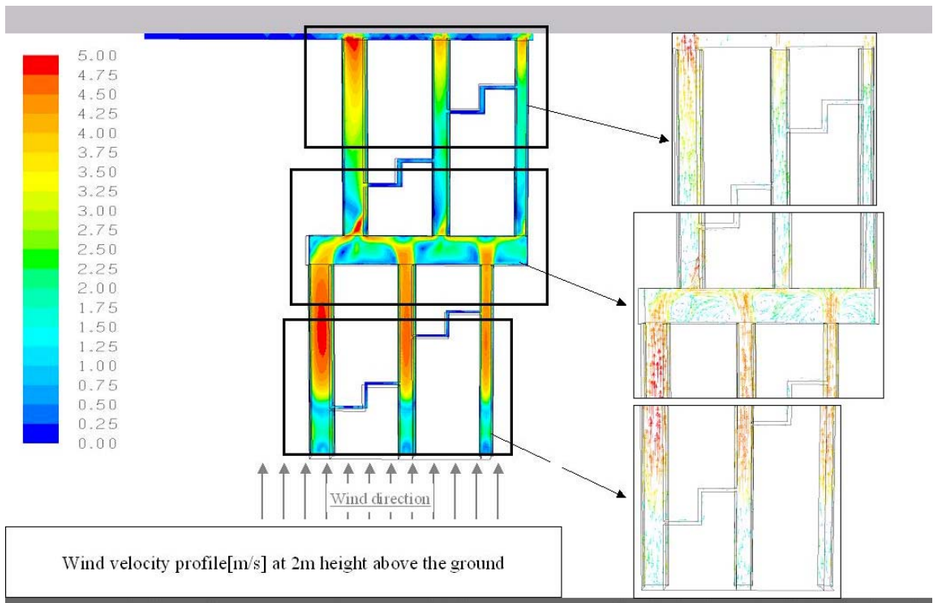


Undisturbed exterior wind velocity profile[m/s] as a function of height above the ground level

Case-5 : Wind direction is parallel to the city block/street length — Streets connected by passage through the blocks

This case is same as case-1 except that now the streets are connected by passages running through the block in a zigzag shape.
Pictures on top shows the model and the undisturbed velocity profile respectively.

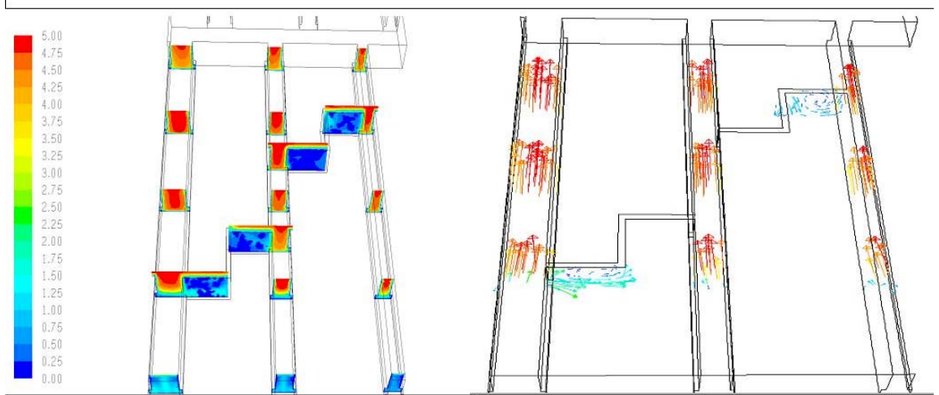
At bottom-left the velocity profile can be seen at pedestrian level. At bottom-right the velocity profile at various section planes through the streets with dead end and inside the first two passages can be seen.



Wind velocity profile[m/s] at 2m height above the ground

Case-5 : Wind direction is parallel to the city block/street length — Streets connected by passage through the blocks

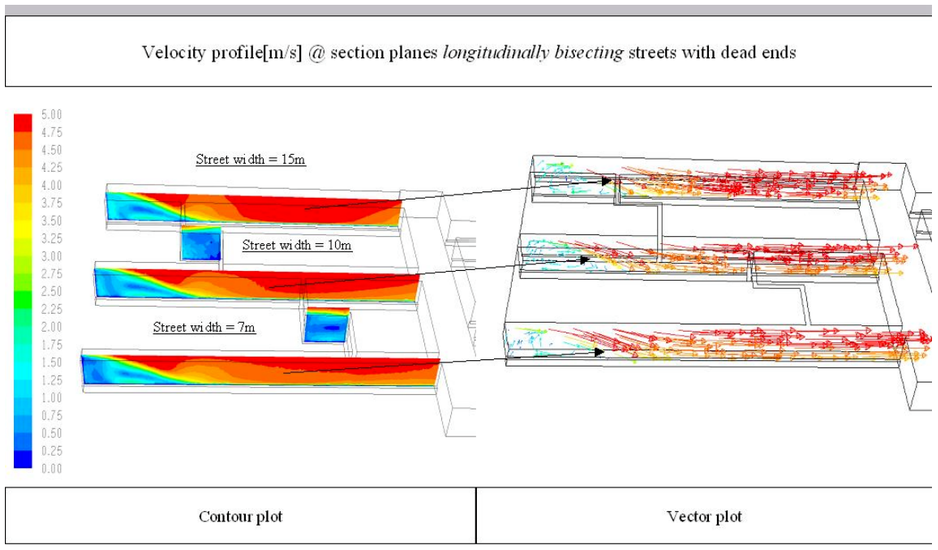
Velocity profile[m/s] @ section planes *radially quadrasecting* streets with dead ends

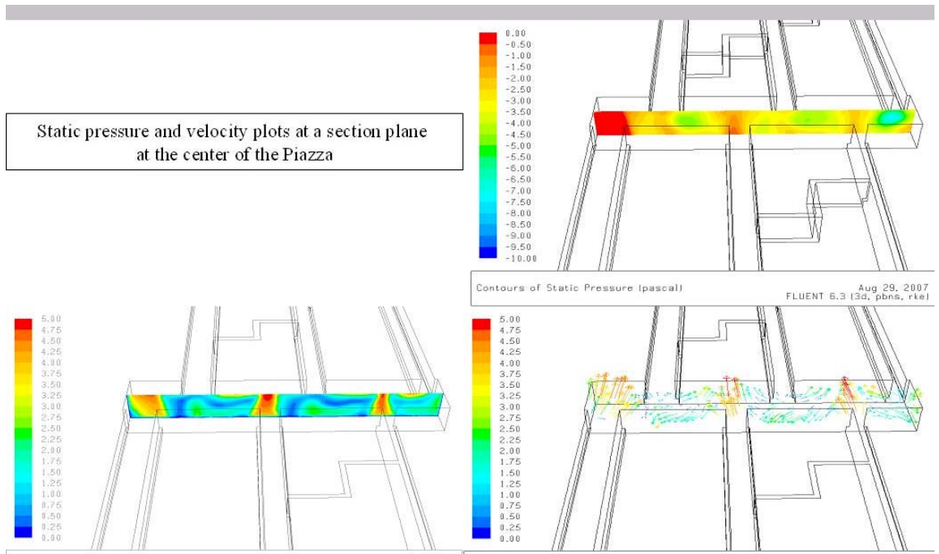


Contour plot | Vector plot

Case-5 : Wind direction is parallel to the city block/street length — Streets connected by passage through the blocks

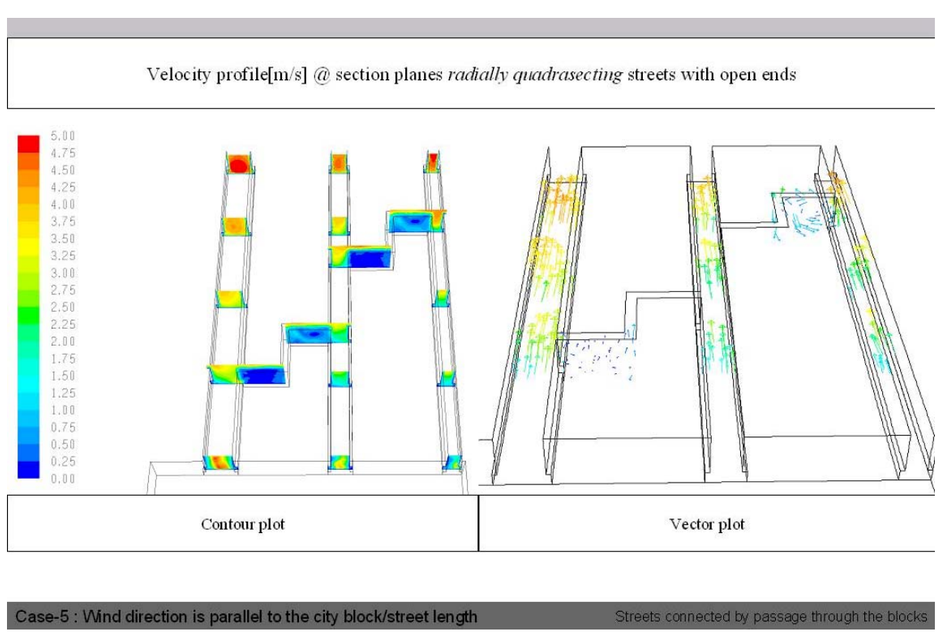
CASE - 5
Streets are connected by passage through the blocks - Exterior wind direction is parallel to the city block/street length; entering from the streets with dead ends.

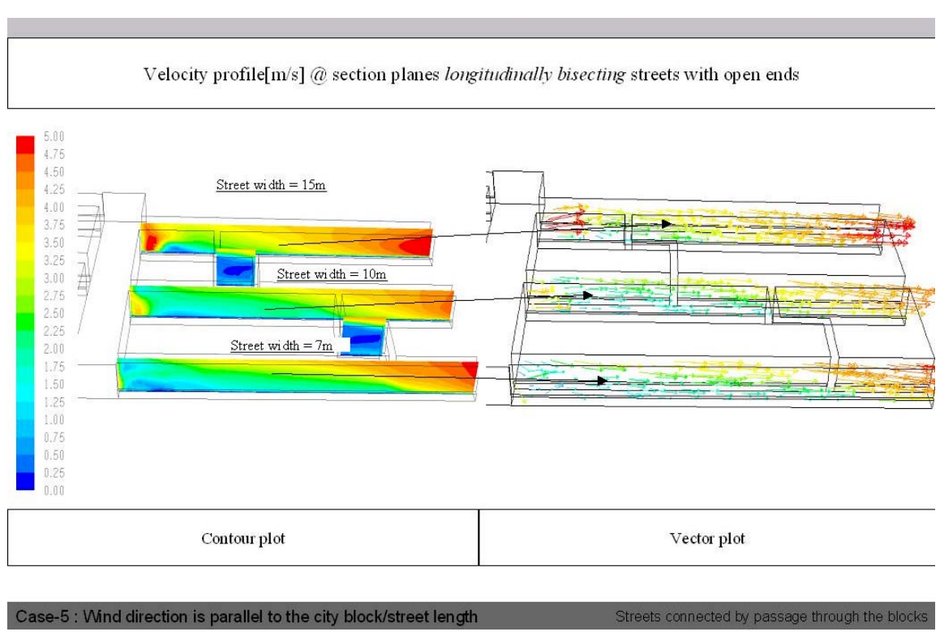




The top-left picture shows the down-fall of the wind into the streets with dead end and local turbulence due to the deal ends.

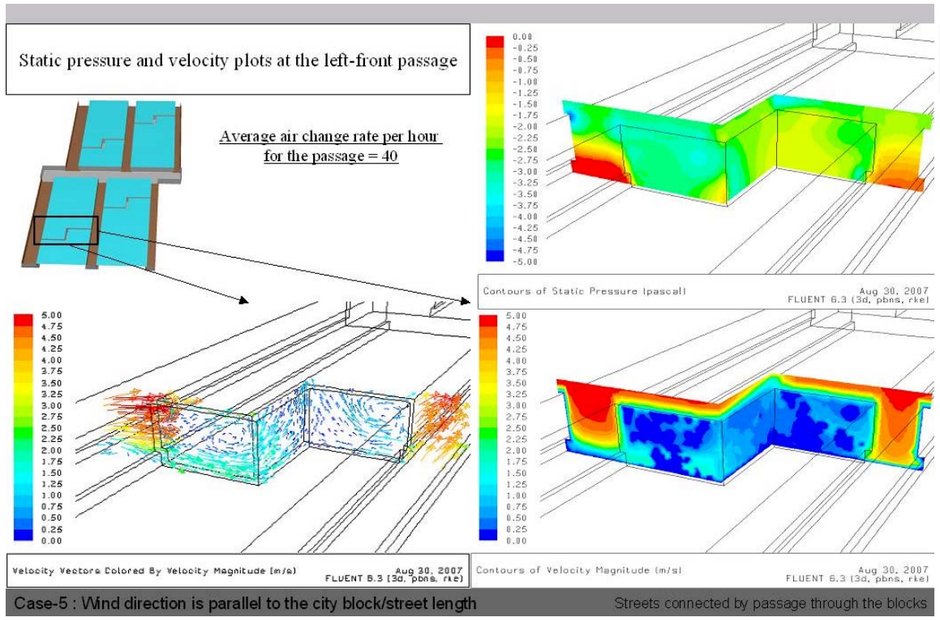
The bottom pictures show the velocity profile inside the streets with open end and in the other two passages. As in case-1, higher wind velocity can be observed at the end of the streets in this case too.

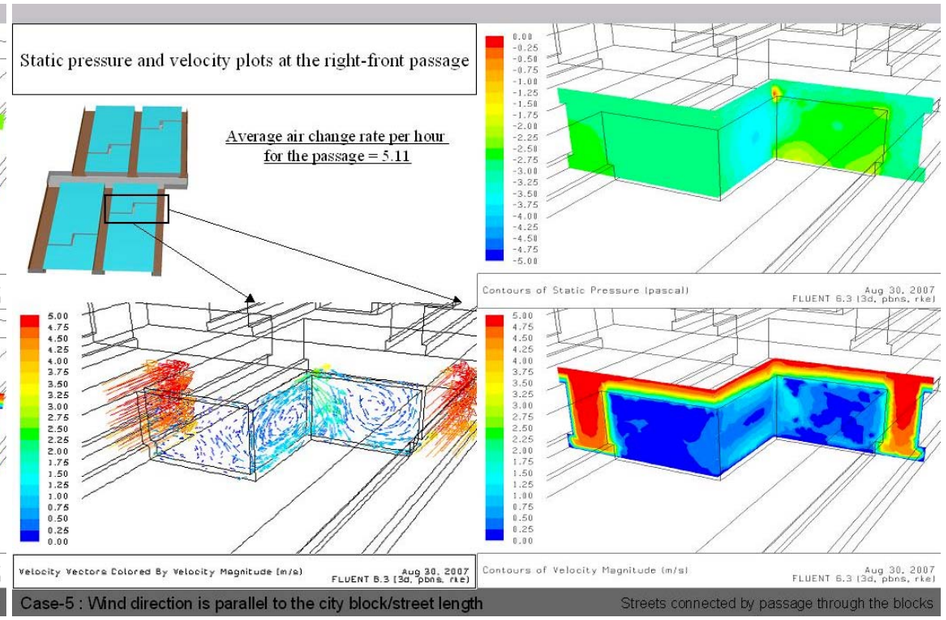




CASE - 5
Streets are connected by passage through the blocks - Exterior wind direction is parallel to the city block/street length; entering from the streets with dead ends.

The air change rate in a passage depends on the pressure difference between the street and the passage at the passage opening into the streets. Bigger the pressure difference higher the air change rate in the passage.



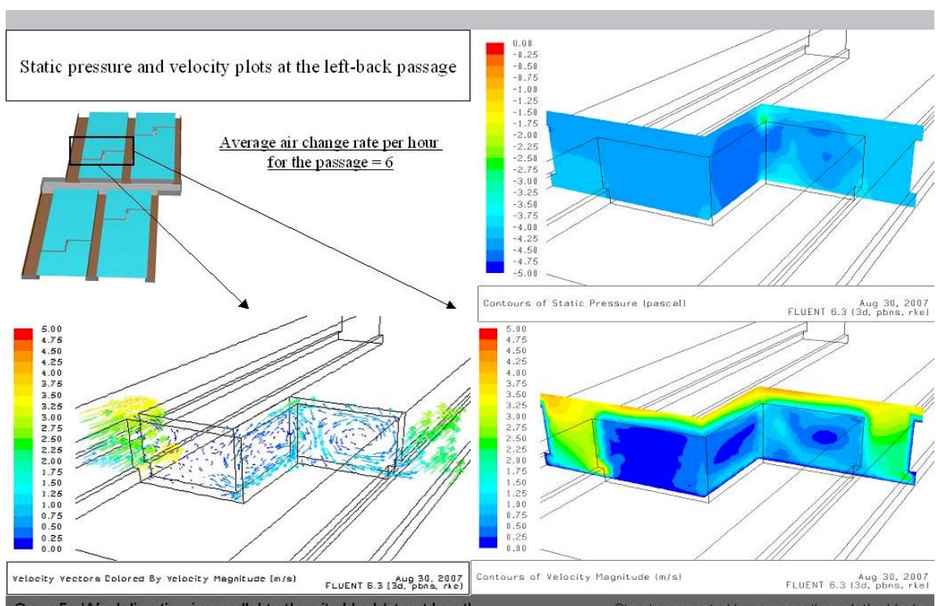


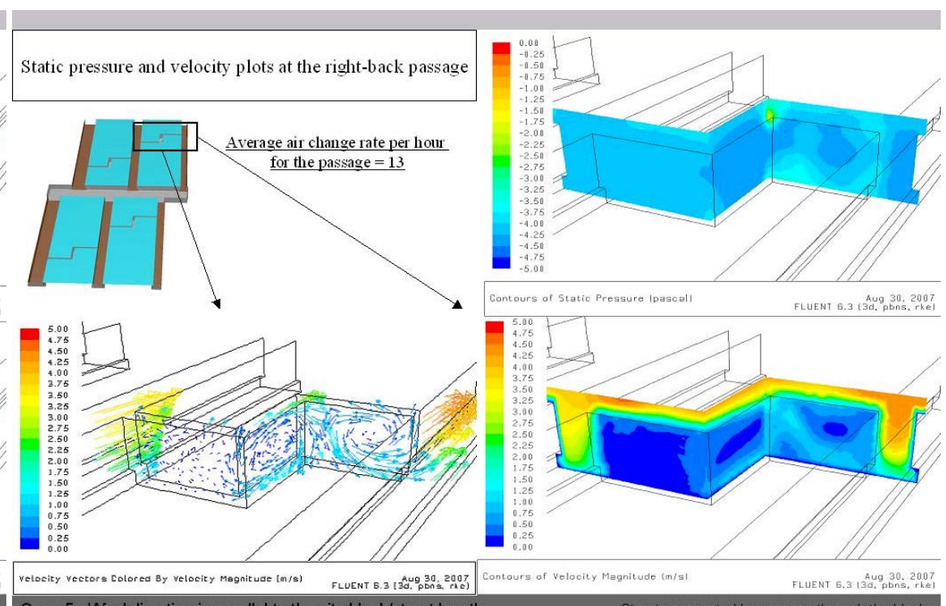
Pictures on this page show the local air behaviour in various passages, which allowed to determine the fresh air rate in air change rate = times of a volume exchange by air from outside per hour.

Starting with the top-left picture, the air change rate in the first passage is relatively big as the opening of this passage is close to the location of down-fall of wind into the streets. This can be explained by the pressure values at the opening of the passage and at the corresponding plane in the streets.

It can be seen in rest of the pictures that the wind direction in the streets is horizontal and tangential to the passage openings, and as a consequence the passage can draw less amount of air from the streets and hence have lower air change rate. This is justified by smaller pressure difference between the passage openings and corresponding location in the streets.

In general the air change rates can be rated as sufficient for a city ventilation.





2 Urban Heat Island Effect
As mentioned before, cities create heat island and in the case of Masdar, this could increased by all the solar systems on the roof. The following analysis should allow a quantitative effect of this effect.

Objective
To generate and analyse the air movement and the heat clouds over the city due to Urban Heat Island Effect.

Approach
A 3-dimensional Computational Fluid Dynamics(CFD) simulation is carried out for the geometrical model shown on the pages to follow.

Assumptions and Simplifications
Due to such a large scale model some simplifications/assumptions are absolutely unavoidable to make computing realisable:
Related to modelling
- The city is considered to be of uniform height.
- No local effects are considered (these effects will be considered as a next step, based on the results of this simulation).

Related to CFD
Heat generated by the region covered with PV-roofs and the remaining city area is averaged over the whole city and provided as a separate volumetric heat source just above the city volume(clarified in the next picture).

The Model Set-up
The city is considered as a cube of 1500m*1500m*20m(l*w*h). All surfaces, including the roofs, are modelled as adiabatic surfaces and as mentioned before, heat generation due to solar absorption by these surfaces is modelled as a separate volumetric heat source above the city.

Caution
This simulation does not consider the effect of local micro-climate of the city zones like garden, green fingers, open spaces, highly dense residential/commercial/industrial areas, etc. Due to this, temperatures can vary from the results of this simulation at some local points.(The micro-climate is reported as a separate chapter).

But the results are good enough to estimate the macro-climate of the whole city considered as a homogenous single unit.

Variants and Applicability:
Following 2 different cases are simulated for the weather conditions at the location:
CASE -1 with external wind (Real world condition):
The wind is coming at yearly average wind speed perpendicular to the city walls. Since the model is geometrically homogenous, the results presented here are true for all four directions, when the wind is coming perpendicular to the city wall(i.e. north-west, north-east, south-west, south-east).
CASE - 2 without external wind (Hypothetical condition):
There is no external wind flow. This variant is simulated to study the air movement merely due to the heat generation by the city in its undisturbed form by the external wind.

Calculation of Heat Generation
Area calculation
Total site area(footprint) of the city = 1500 x 1500 m²
Assumed distribution of the city area:
Built area with PV-roofs = 50% with 70% solar absorption
Built area without PV-roofs + streets + green fingers = 50% with 30% solar absorption

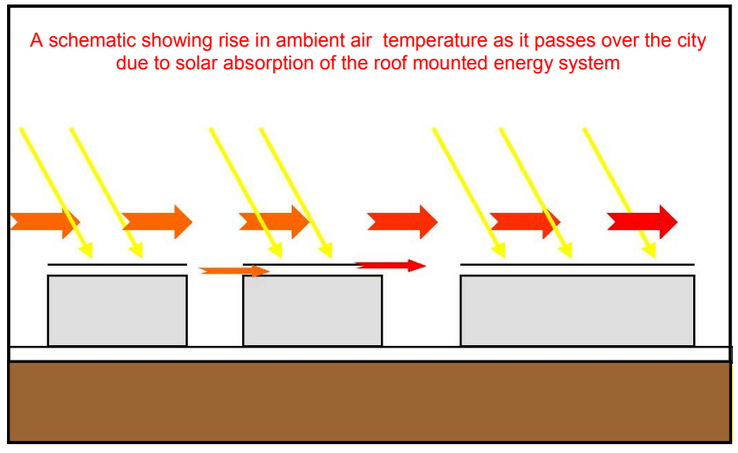
Heat Generation
Average solar radiation = 800 W/m²
Heat generation:
- from PV-roofs = (0.5*2,250,000) * (0.70*800) = 630 MW
- from others = (0.50*2,250,000) * (0.30*800) = 270 MW

Total Heat generation from the city = 900 MW
Average Heat generation from the city area(footprint) = 400 W/m²
This corresponds to a volumetric heat source of 134W/ m^3 assuming a 3m high energy absorbing volume.

Results
Average temperature of the air volume of height 3m above the city
- Case1 (with external wind) = 43.38°C
- Case2(without external wind) = 43.65°C

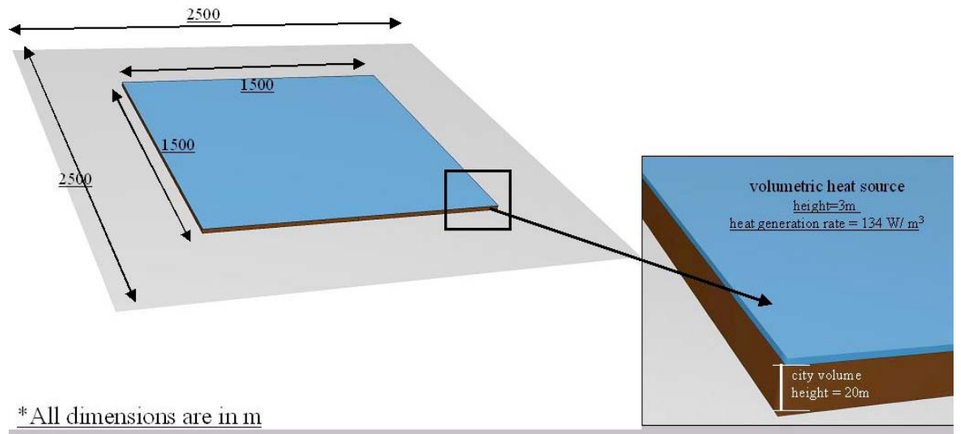
Observation
It is clear from the temperature statistics graph on bottom-right that the local maximum air temperature drops by more than 2 Kelvin at 40m height above the roof level or even 8 Kelvin compared to the mean temperature values.
This supports the idea of having tall wind towers at these locations to divert relatively low temperature wind into the street level.

A schematic showing rise in ambient air temperature as it passes over the city due to solar absorption of the roof mounted energy system



The Geometrical Model Representing the Computational Domain

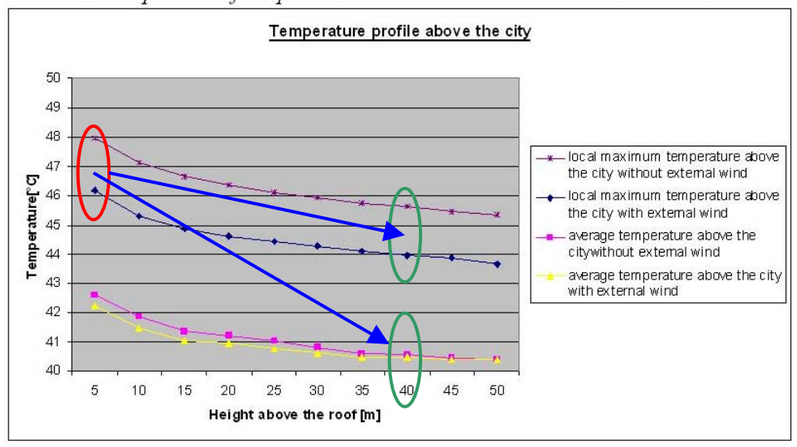
• The ambient temperature is assumed to be 40°C



*All dimensions are in m

Extracts of the results of the CFD simulation

A comparison of temperature increase between the Case1 & Case2



Average temperature of *the air volume of height 3m* above the city
- Case1(with external wind) = 43.38 °C
- Case2(without external wind) = 43.65 °C

* The ambient temperature is assumed to be 40°C

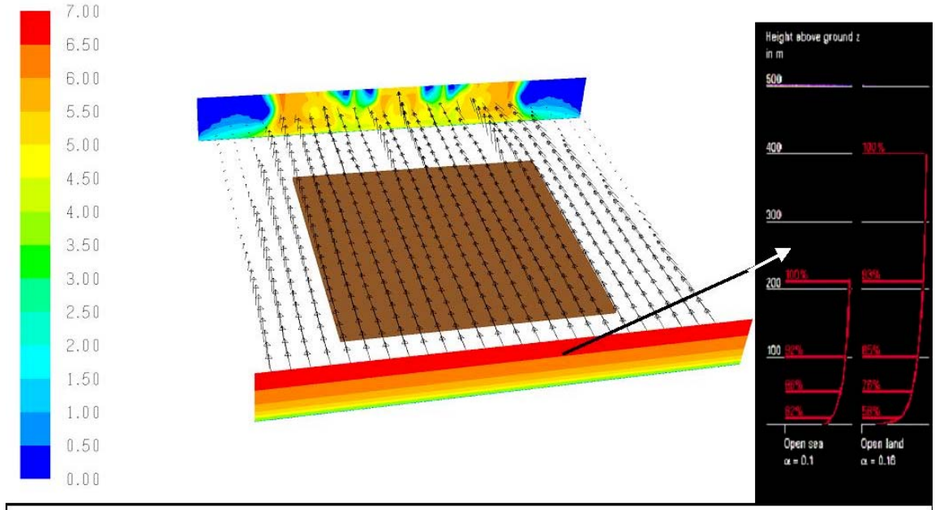
CASE-1 with external wind (Real world condition)
The wind is coming at yearly average wind speed perpendicular to the city walls.
Since the model is geometrically homogenous, the results presented here are true for all four directions, when the wind is coming perpendicular to the city wall(i.e. north-west, north-east, south-west, south-east).

Computational Fluid Dynamics(CFD)
Computational Fluid Dynamics(CFD) is a branch of science which uses numerical techniques to solve flow or flow related phenomena(heat, species transport, etc.). In CFD, the region of interest is divided into many(some times millions) of sub-volumes(known as volume cells). Based on provided boundary conditions, a number of equations(known as Navier-Stoke equations) are solved iteratively for each such sub-volumes to reach physically true results.

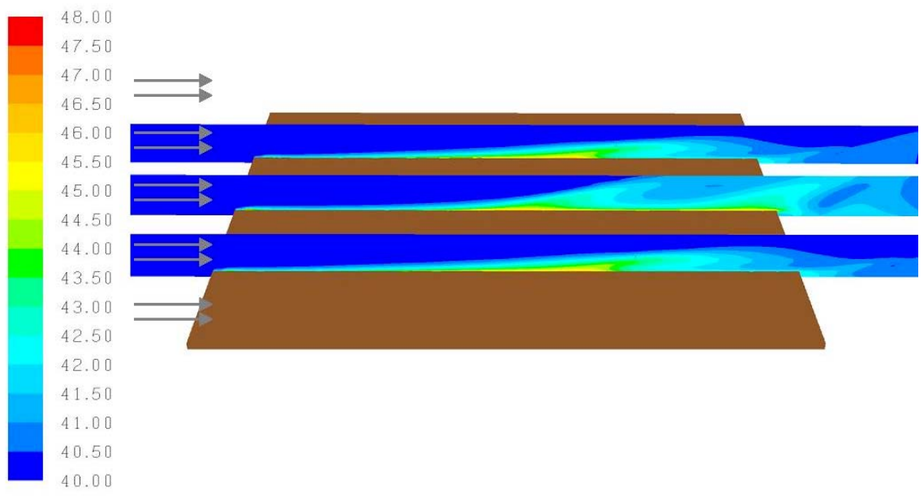
How to interpret the CFD results
Results of the CFD simulation are presented pictorially on the pages to follow.
On the left hand side of each picture is shown a colour bar with the associated values(blue colour represents the minimum and red colour represents the maximum value). The result should be read in the form of colours and the associated value with that colour has to be found from the colour bar on the left. This way the value of various physical quantities(eg. temperature, velocity, etc) can be found at a particular location.

As usual, the top picture shows the CFD model with the boundary conditions and the undisturbed wind velocity profile as a function of height at the inlet of the model.

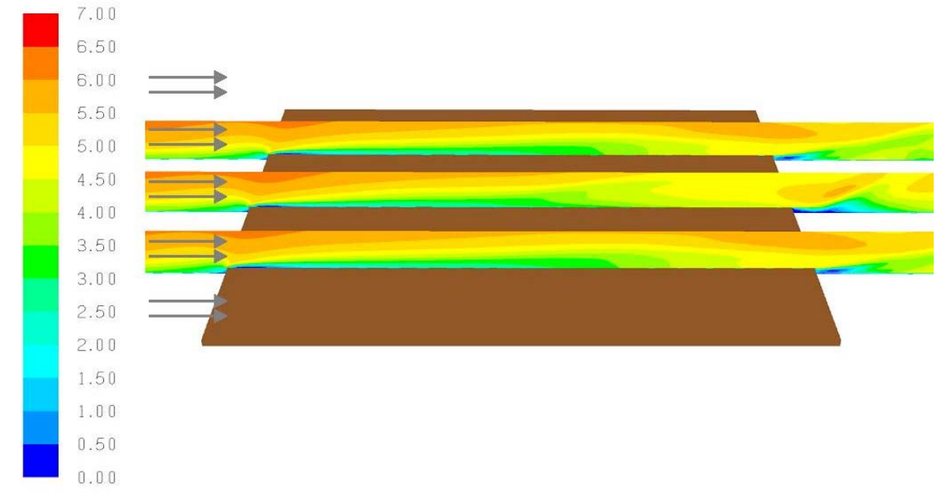
The bottom pictures show the temperature and velocity profile as the exterior wind passes over the city.
The gradual rise in the temperature is clearly visible in the left picture. This make the hot air to rise and being replaced by the cold air from top, which can be seen in the further half of the city.



Contours of velocity magnitude[m/s] at the inlet and the outlet of the CFD model

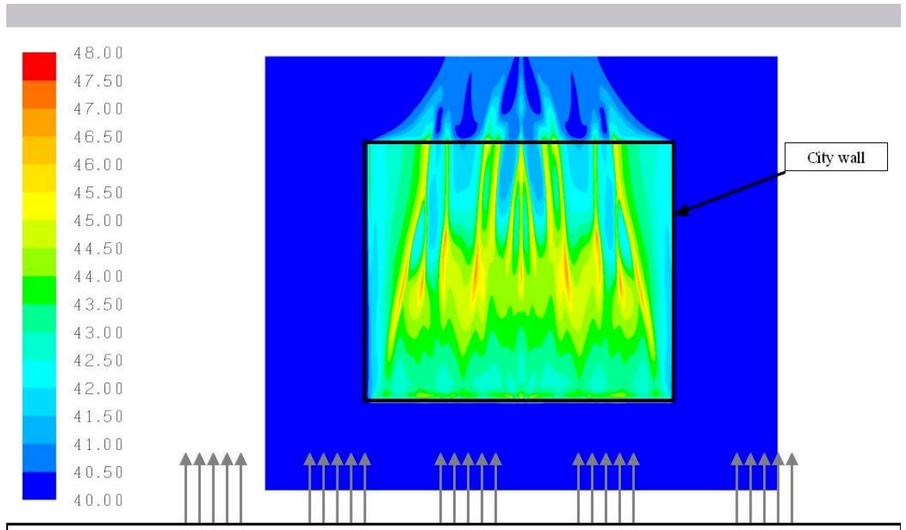


Contours of temperature[°C] at the section planes quadrisecting the city in the direction of external wind

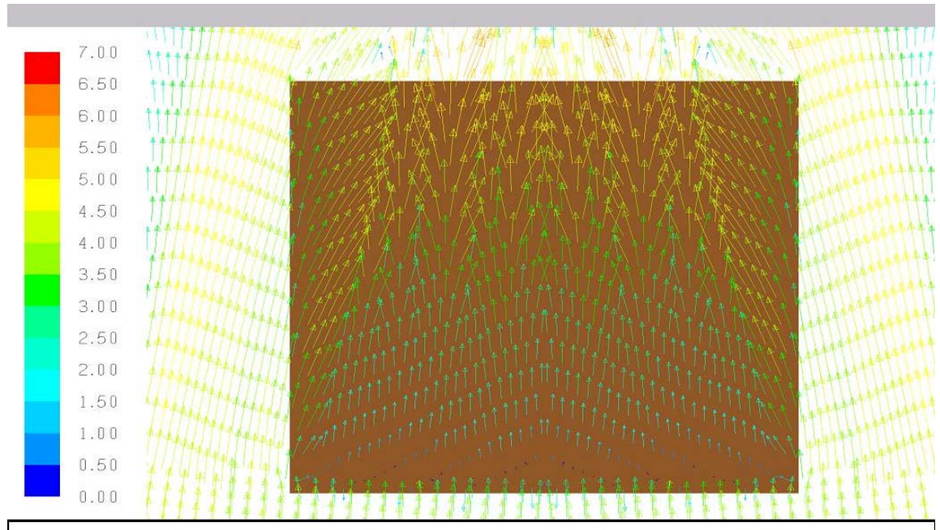


Contours of velocity magnitude[m/s] at the section planes quadrisecting the city in the direction of external wind

CASE -1 with external wind (Real world condition)
The wind is coming at yearly average wind speed perpendicular to the city walls.
Since the model is geometrically homogenous, the results presented here are true for all four directions, when the wind is coming perpendicular to the city wall(i.e. north-west, north-east, south-west, south-east).



Contours of temperature[°C] at the horizontal section plane 1.5m above the roof

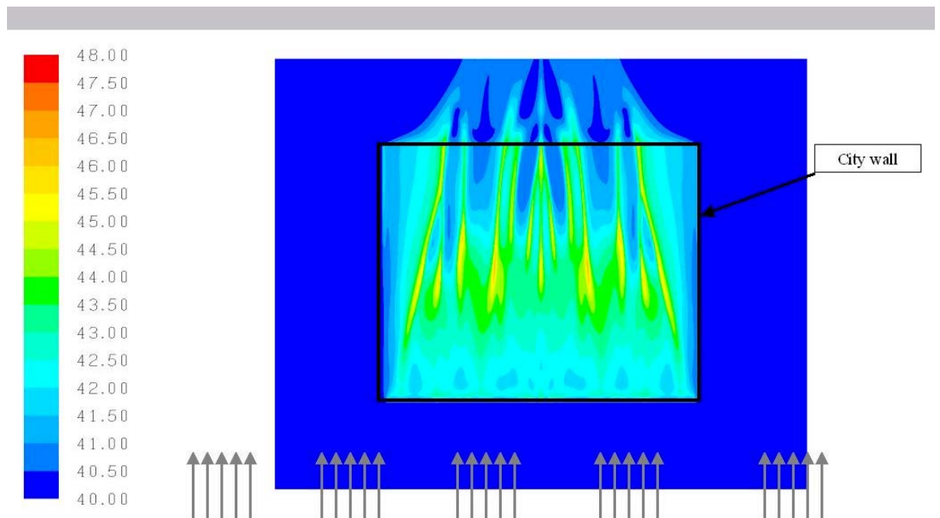


Vectors colored by velocity magnitude[m/s] at the horizontal section plane 1.5m above the roof

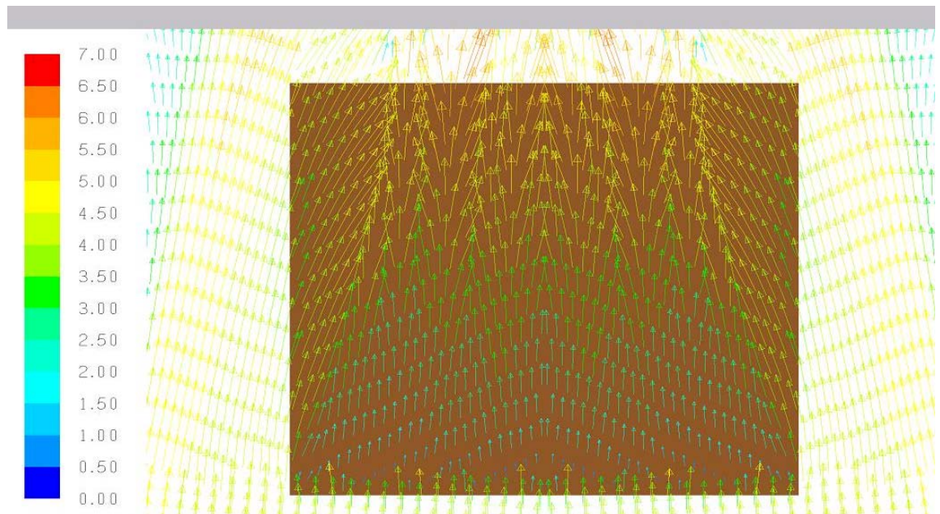
The top and the bottom pictures show the temperature and velocity profiles at a horizontal section plane above the whole city at 1.5 and at 5m height respectively, above the roof.

Locations of local maximum temperatures can be seen from the temperature plots.
As explained in the previous page the temperature rises gradually as the wind passes above the city and the hot air rises up and the cold air from top replaces the hot air near the roof. This explains the maximum temperature locations near the centre of the city and than decrease of air temperature at some locations in the further half of the city.

Other interesting observation can be that the rising hot air above the city is not only replaced by the cold air from top but also by the relatively cold air from the sides of the city. This can be seen in the vector plots, as the arrows are tilted towards the city volume near the sides of the city.

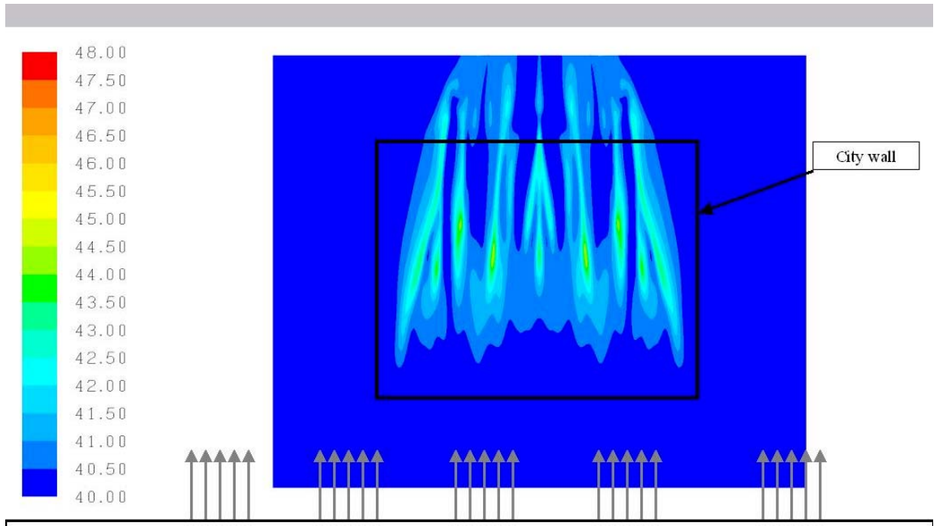


Contours of temperature[°C] at the horizontal section plane 5m above the roof

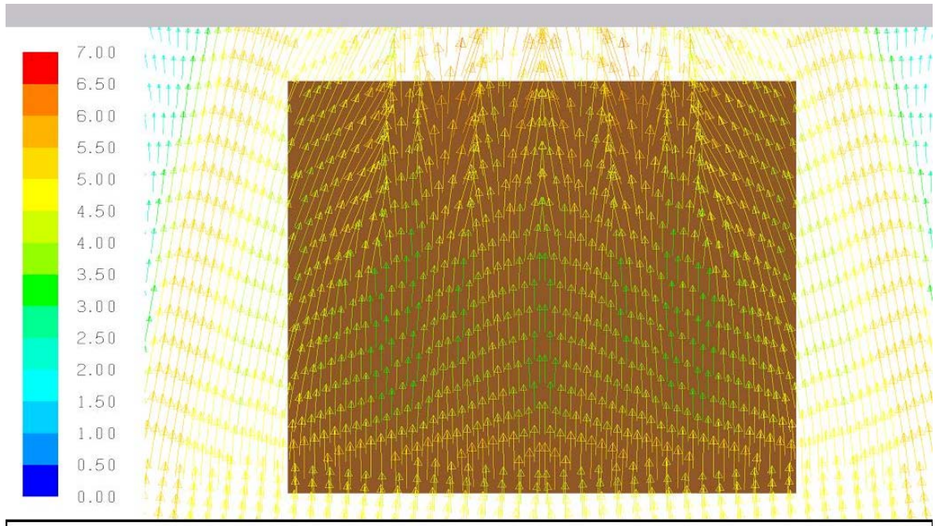


Vectors colored by velocity magnitude[m/s] at the horizontal section plane 5m above the roof

CASE -1 with external wind (Real world condition)
The wind is coming at yearly average wind speed perpendicular to the city walls.
Since the model is geometrically homogenous, the results presented here are true for all four directions, when the wind is coming perpendicular to the city wall(i.e. north-west, north-east, south-west, south-east).



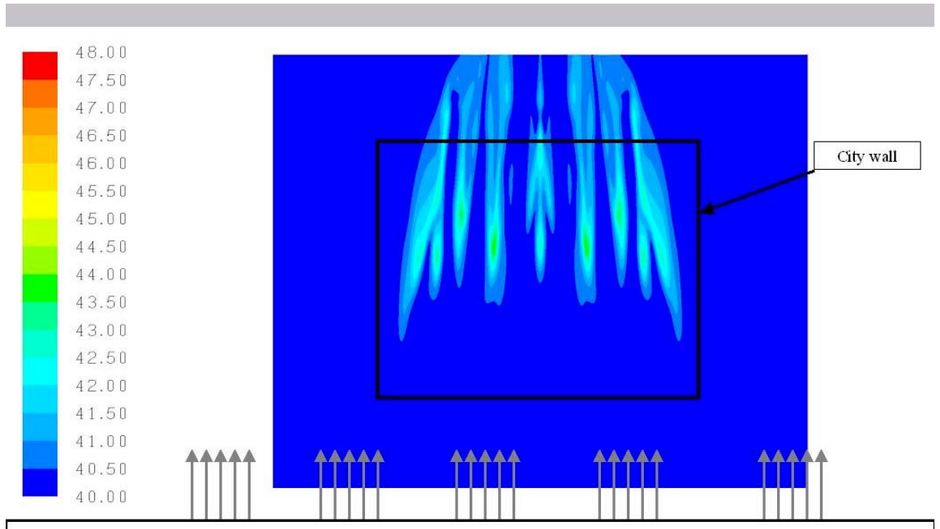
Contours of temperature[°C] at the horizontal section plane 25m above the roof



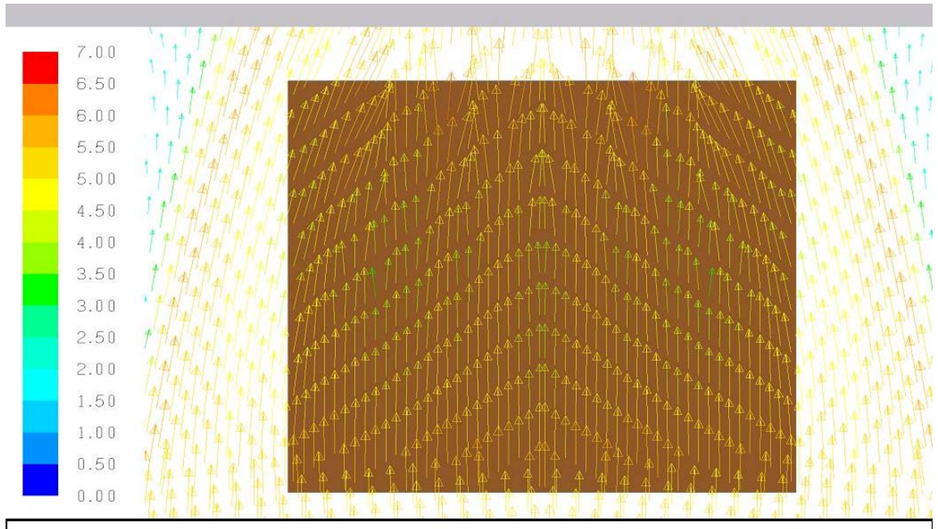
Vectors colored by velocity magnitude[m/s] at the horizontal section plane 25m above the roof

A drop in air temperature can be seen, as the height above the roof increases(25m at top and 40m at bottom).
Temperature can be observed to have dropped down by more than 3°C for the locations with local maximum temperature value, when comparing the temperature plot for the section plane at 1.5m height and at 40m height above the roof.

Also the inclination of the vectors at the sides of the city square can be observed to be decreasing by height in the pictures on right.



Contours of temperature[°C] at the horizontal section plane 40m above the roof



Vectors colored by velocity magnitude[m/s] at the horizontal section plane 40m above the roof

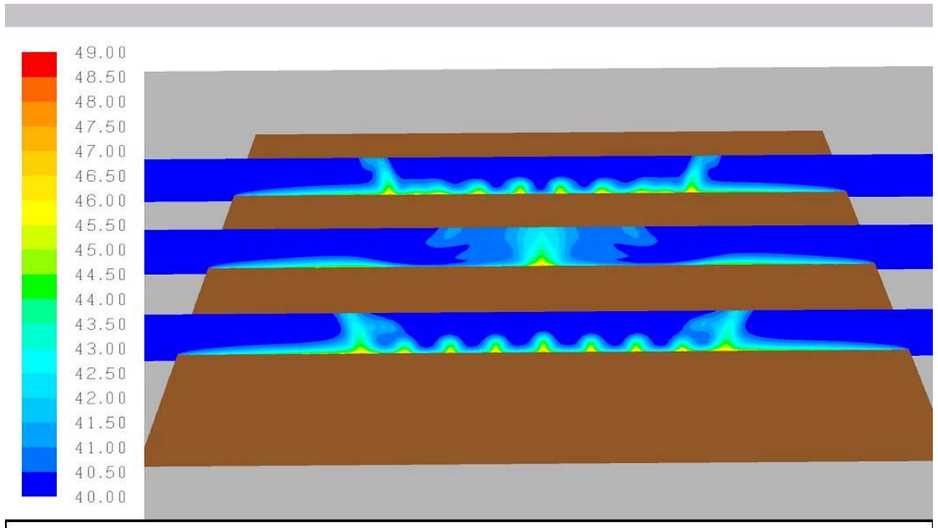
CASE - 2 without external wind (Hypothetical condition):
There is no external wind flow.
This variant is simulated to study the air movement merely due to the heat generation by the city in its undisturbed form by the external wind.

As there is no exterior wind flow in this case, the air movement above and near the city is like the air movement near a flame, caused only by natural convection.

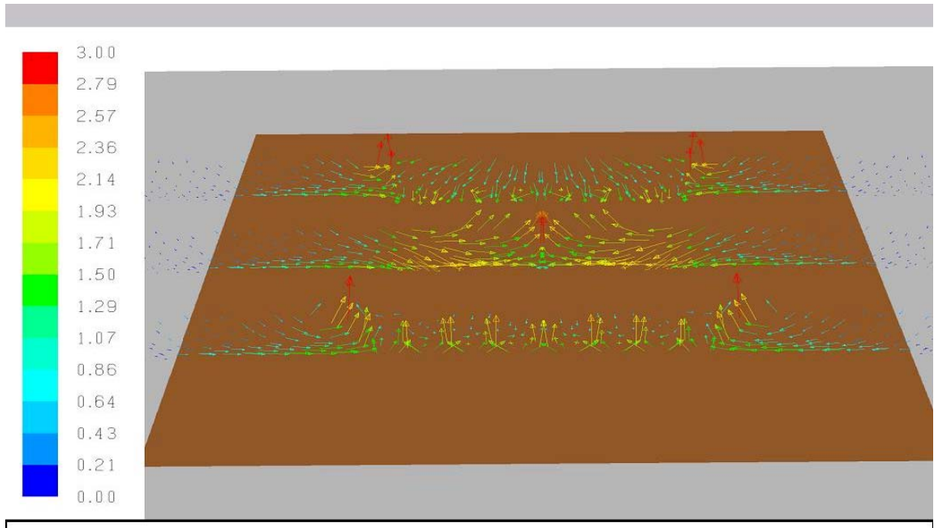
The first expectation should be that the results should be geometrically homogeneous due to geometrically homogenous model, which they are.

The heating of the air above the city, rise of hot air and flow of colder air from surroundings and from top to the void created at these locations happens here as well, but in a different way, which makes the temperature pattern as shown in the pictures on left.

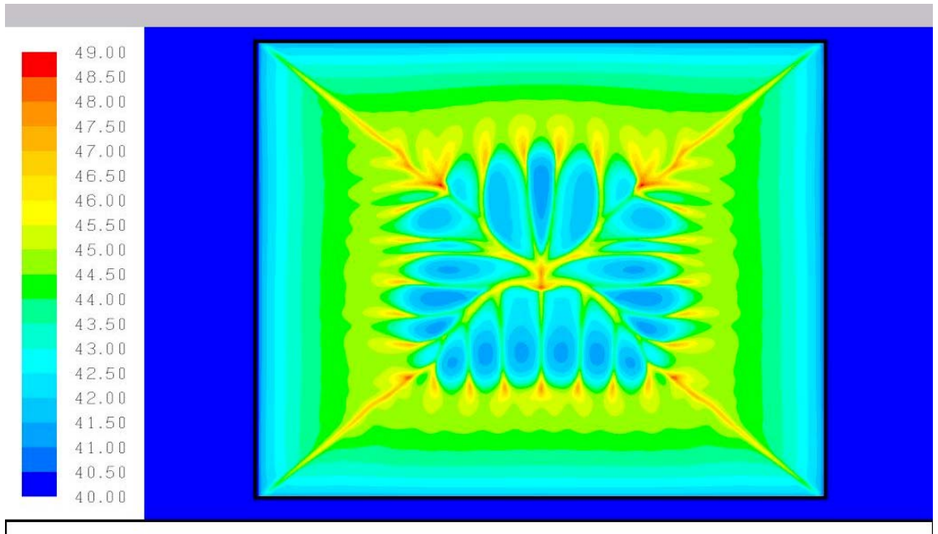
Since the city is square in shape, the shortest path for the air in the vicinity of the city to reach to the location of void created by rising of the hot air would be perpendicular to the city walls. The air flowing in this way meets at the diagonal of the city square and rises up by striking with the air coming from the other direction creating a hot spot. Also, the air coming from the surrounding and flowing above the city gets heated and rises up before it reaches at the centre of the city and hence now the colder air is drawn from the top, which explains the blue(colder) regions after a certain length of the city. Air movement from the surroundings and above the city can be seen in the pictures on right.



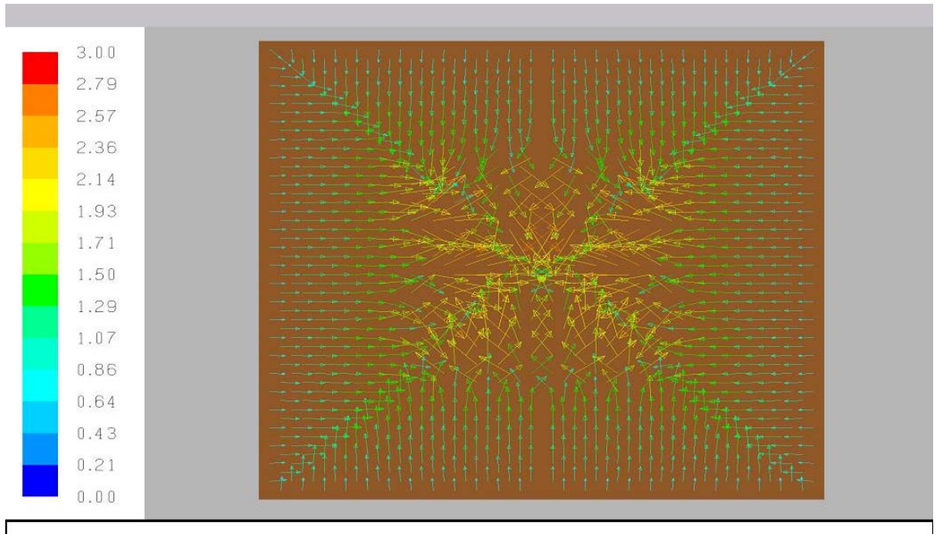
Contours of temperature[°C] at the section planes quadrisecting the city



Vectors colored by velocity magnitude[m/s] at the section planes quadrisecting the city

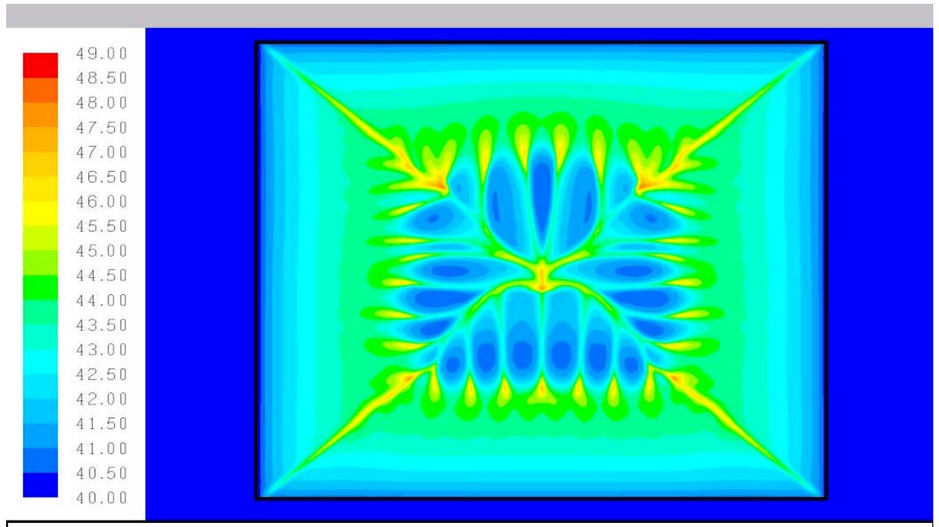


Contours of temperature[°C] at the horizontal section plane 1.5m above the roof

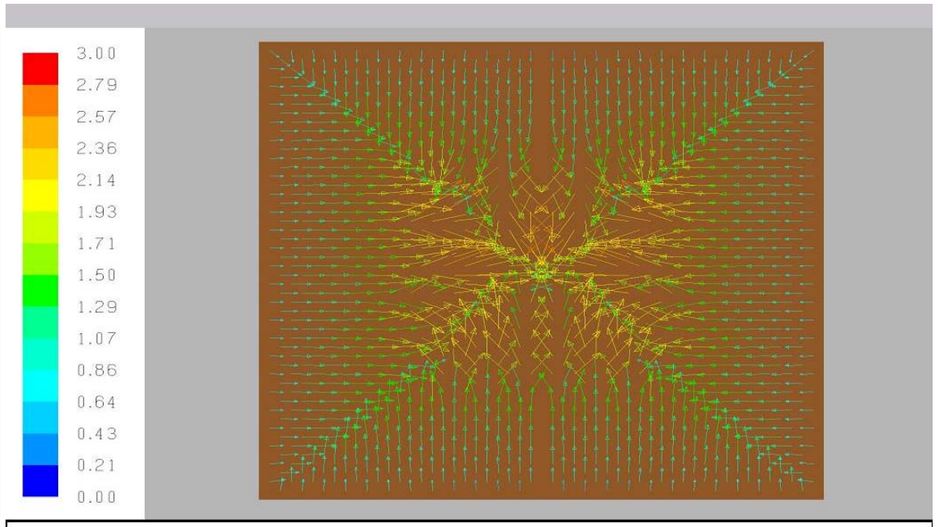


Vectors colored by velocity magnitude[m/s] at the horizontal section plane 1.5m above the roof

CASE - 2 without external wind (Hypothetical condition):
There is no external wind flow.
This variant is simulated to study the air movement merely due to the heat generation by the city in its undisturbed form by the external wind.



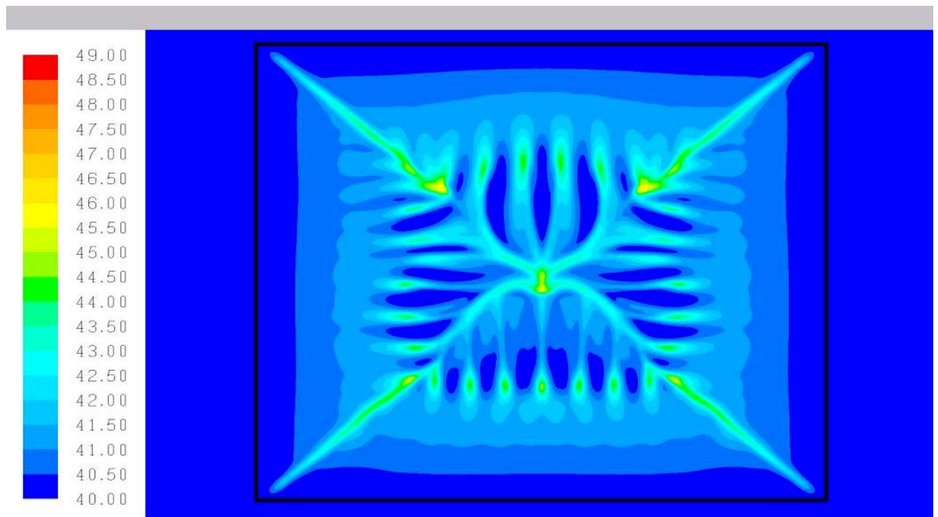
Contours of temperature[°C] at the horizontal section plane 5m above the roof



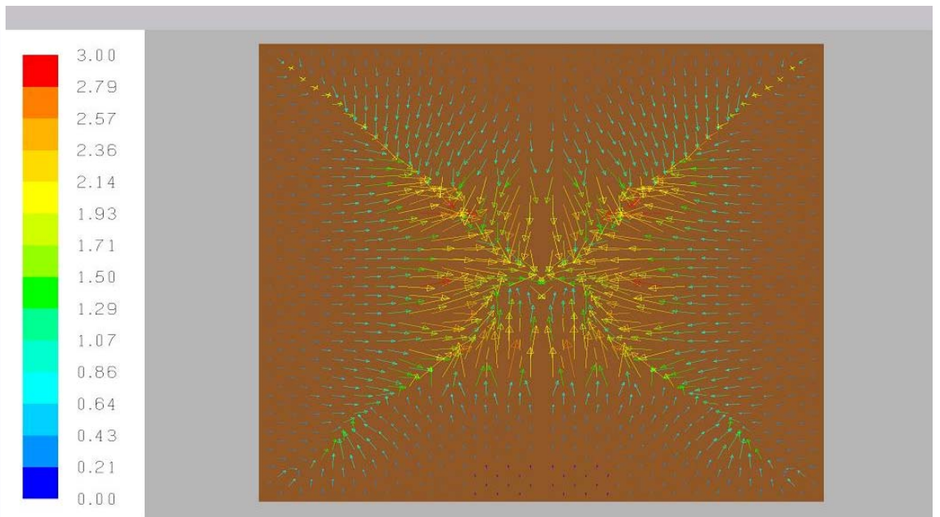
Vectors colored by velocity magnitude[m/s] at the horizontal section plane 5m above the roof

In principle the same physical phenomena can be seen to occur at 5m and 25m above the city as explained in the previous page.

Relative drop in the air temperature can be seen for higher elevation, which makes sense too.



Contours of temperature[°C] at the horizontal section plane 25m above the roof

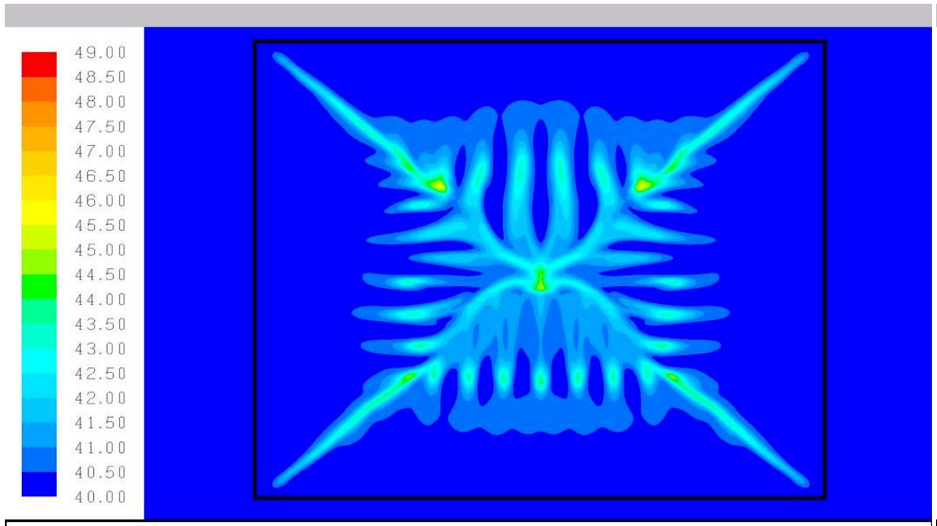


Vectors colored by velocity magnitude[m/s] at the horizontal section plane 25m above the roof

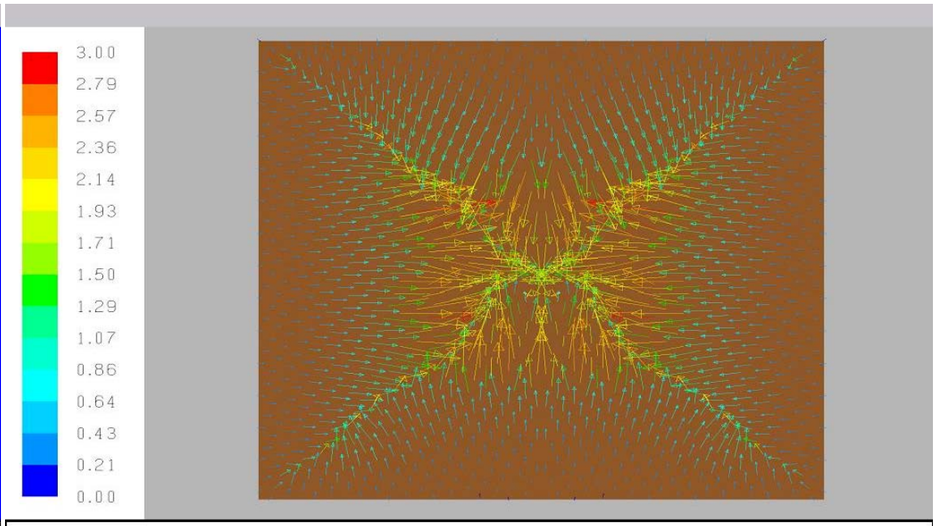
CASE - 2 without external wind (Hypothetical condition):
There is no external wind flow. This variant is simulated to study the air movement merely due to the heat generation by the city in its undisturbed form by the external wind.

Further drop in the air temperature can be seen for the horizontal section plane at 40m height above the city.

Also, the colder air in the vicinity of the centre of the square can be observed to be dropping down now.
The results show that at a certain height above the city colder air can be found, which would be a help for the city if deviated into the city.



Contours of temperature[°C] at the horizontal section plane 40m above the roof



Vectors colored by velocity magnitude[m/s] at the horizontal section plane 40m above the roof

Wind Towers

Strategy

Introducing wind towers at the entrance of a street as additional wind screens and by a controlled ventilation to increase street ventilation depending on outside conditions.

Objective

Generate and analyse the exterior wind pattern inside the streets due to wind towers – without and with openings and different sizes - facing the incoming wind direction for *Masdar Development Project*.

Approach

A 3-dimensional Computational Fluid Dynamics(CFD) simulation is carried out for the geometrical model shown on the pages to follow.

Geometrical Set-up

Two sets of streets are considered to be connected by a central *piazza*. First set of streets begins with wind-tower in the incoming wind direction and ends into the piazza, while the second set of streets starts at the piazza and has the other end open.

Variants

Following 2 different cases are simulated for the yearly average wind speed for the location

CASE-1: the wind towers are closed

CASE-2: the wind towers are open

Variant-1: wind towers with short openings

Variant-2: big wind towers with wide openings.

In all cases the exterior wind direction is parallel to the city block/street length and in the direction of the typical local wind.

Benefits the wind towers can bring

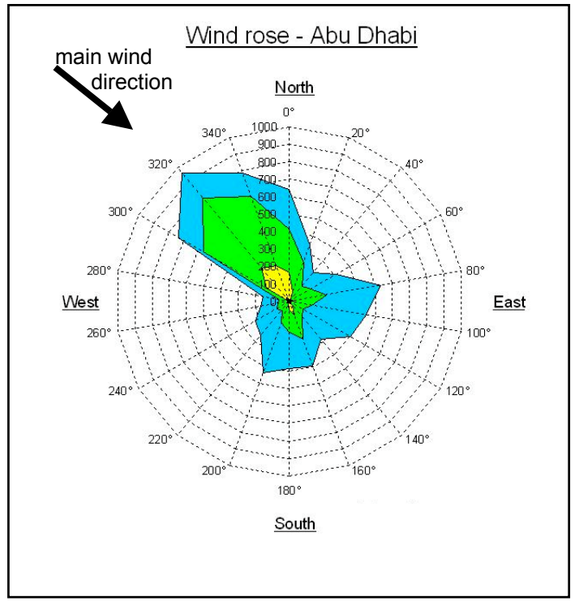
Properly designed and strategically placed wind tower can

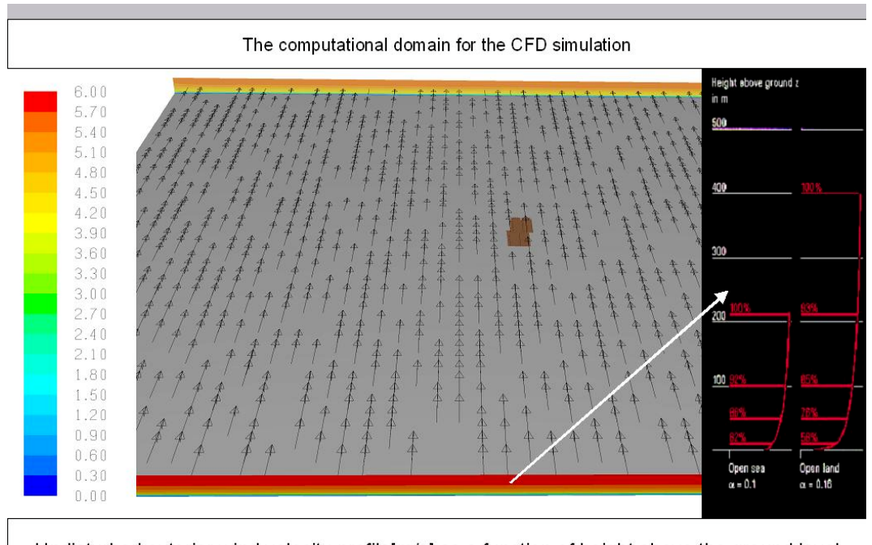
- Reduce/block the exterior wind entering the streets
- Control the amount of wind that should be supplied into the streets by operating properly
- Reduce the wind velocity entering the streets(especially useful for the street openings near the outer city wall)
- Bring in relatively cold air at higher elevation into the streets(it was shown in the chapter “Air Flow Simulation-2 Urban Heat Island effect” that the exterior wind temperature drops by more than2- 8 Kelvin at 40m height above the city)
- Supply the air in a laminar form (like as it flows in parallel layers which is preferred) than the turbulent form (in a chaotic way which is generated due to down fall of the exterior wind into the streets)
- Depending on the typical wind shadow profile over the city the towers height grows with the depth of the city.

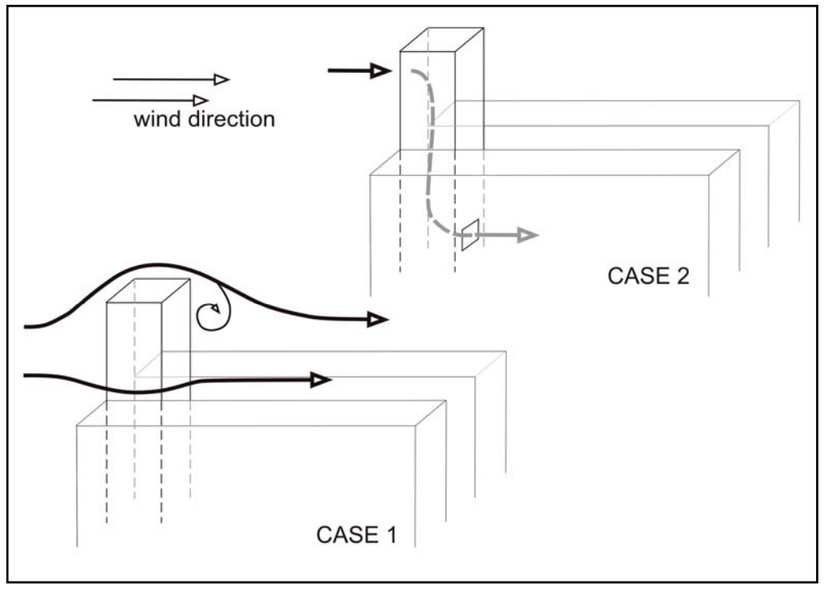
Conclusion/Proposal

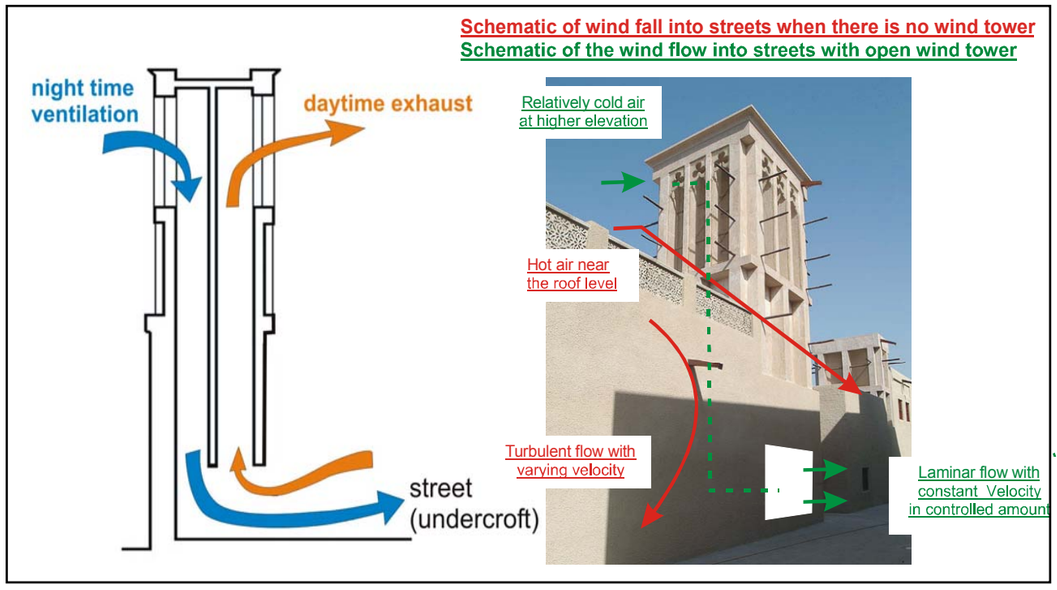
The wind towers can be effectively utilised to block the ambient hot and humid air entering the streets when closed to direct the ambient air into the street in controlled amount when opened accordingly to facilitate climate conditioning inside the street, night ventilation/flushing, etc.

Utmost care has to be taken in wind tower design(height of the tower; area & positioning of in/outlet) to make the wind tower function as required. A detailed design process for the wind towers is recommended to be carried out in the development phases to follow.



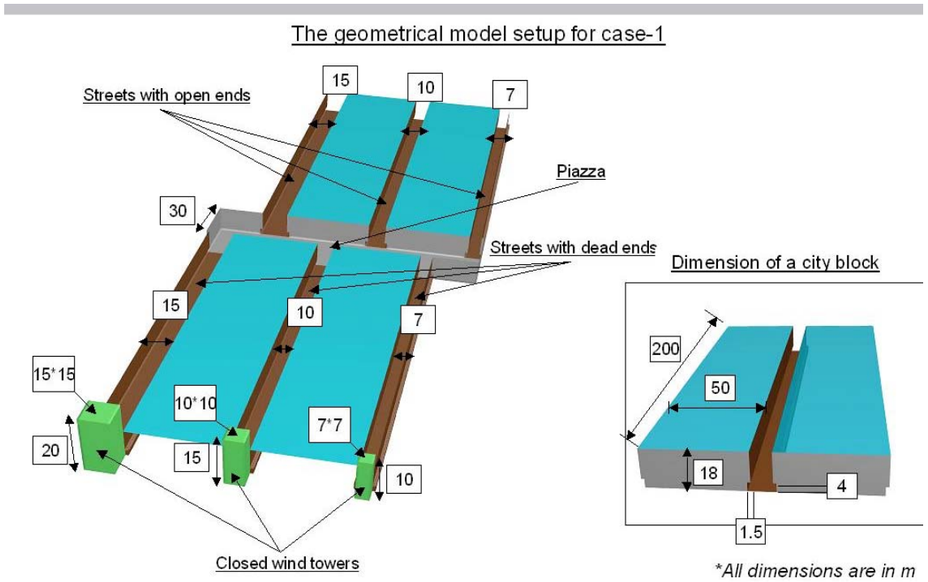




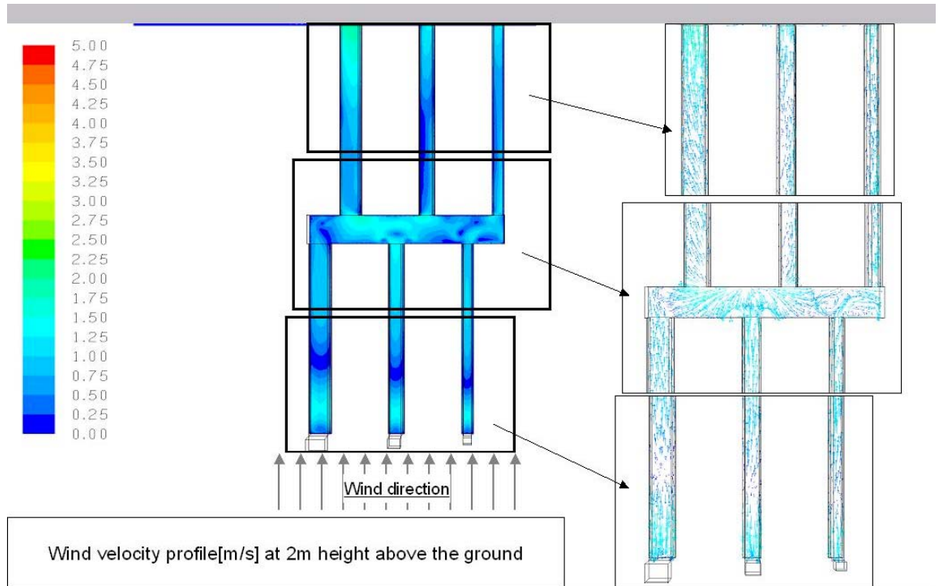


CASE-1 Closed Wind Towers
The wind towers are closed.

How to interpret the CFD results
Results of the CFD simulation are presented pictorially on the pages to follow.
On the left hand side of each picture is shown a colour bar with the associated values(blue colour represents the minimum and red colour represents the maximum value). The result should be read in the form of colours and the associated value with that colour has to be found from the colour bar on the left. This way the value of various physical quantities(e.g. temperature, velocity, etc) can be found at a particular location.



Case-1 : *The wind towers are closed*



Case-1 : *The wind towers are closed*

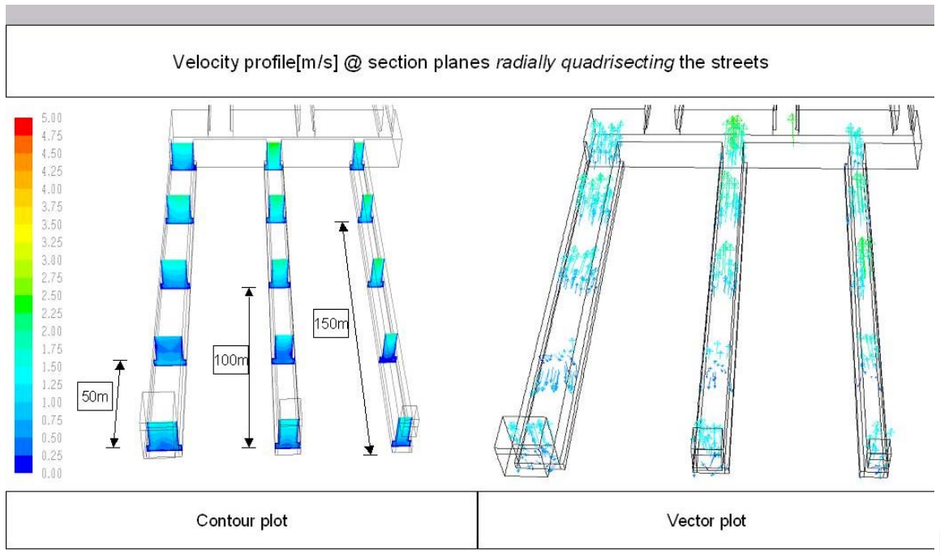
Comparison

The picture on top-left shows the geometrical model with the closed wind towers of varying height in front of the streets facing the wind direction.

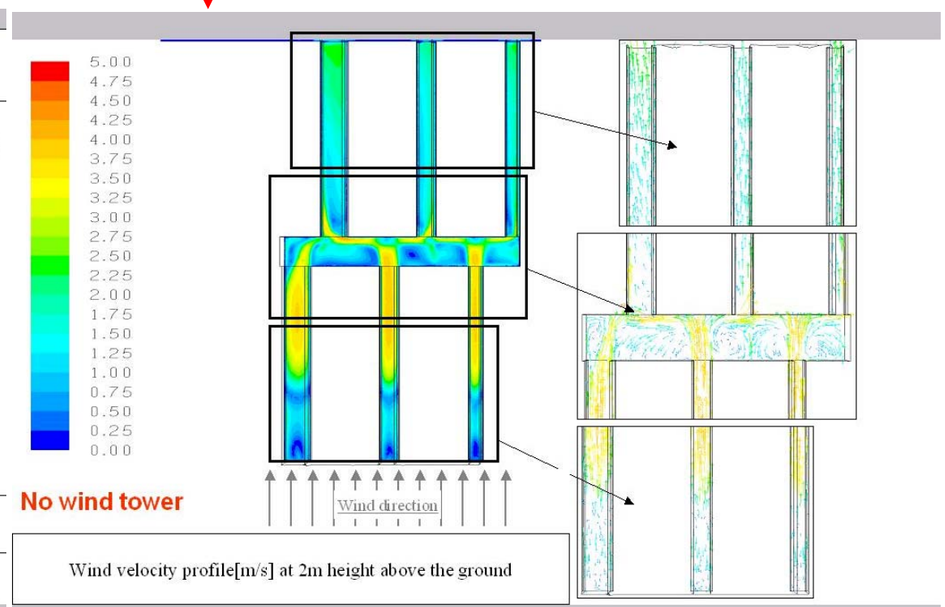
The pictures on right side shows a comparison of velocity profile at pedestrian level(2m above the ground) between this case and the case when there are no wind towers. It can be seen that the velocity magnitude inside the streets are reduced by a factor of ~3 due to the shading effect of the wind towers.

Hence it can be deduced that the wind towers can be effectively utilised to reduce/block the exterior wind entering the streets when closed.

The picture on the bottom-left shows the velocity profile at various vertical section planes in the longitudinal direction of the streets. A reduced velocity can be seen at the bottom of each section plane.

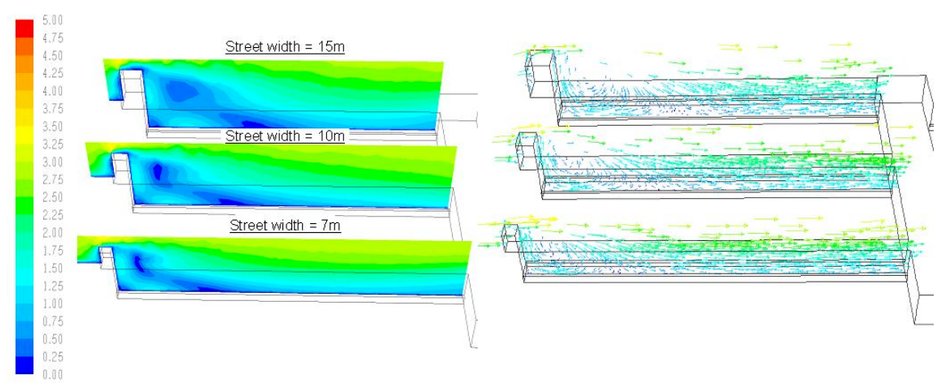


Case-1 : *The wind towers are closed*



CASE-1 Closed Wind Towers
The wind towers are closed.

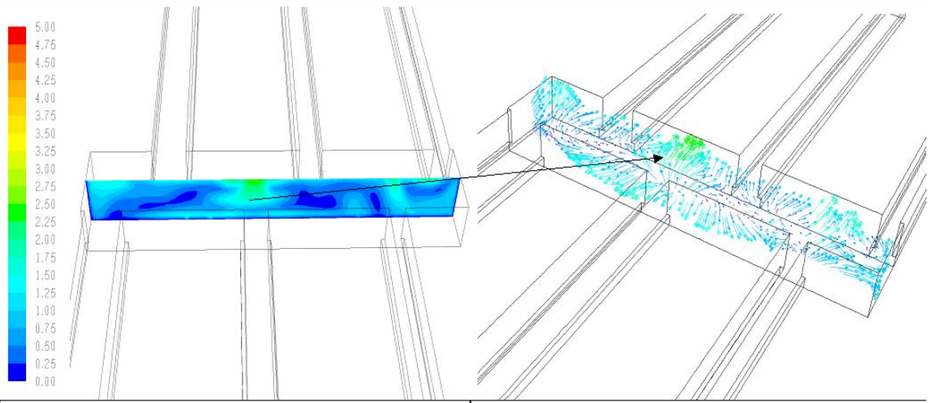
Velocity profile[m/s] @ section planes *longitudinally bisecting* the streets



Contour plot | Vector plot

Case-1 : *The wind towers are closed*

Velocity profile[m/s] @ section plane at the center of the *piazza*



Contour plot | Vector plot

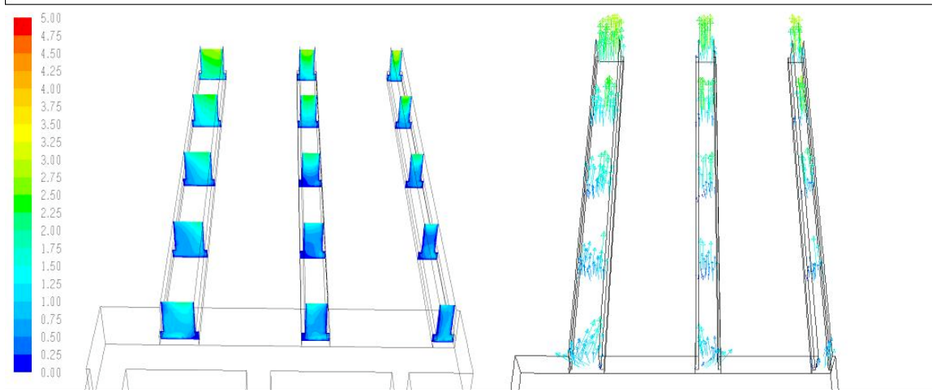
Case-1 : *The wind towers are closed*

The shading effect of the wind towers can be seen in the top-left picture. This shading also creates a local turbulence which is visible in the vector plot. The bigger the tower(i.e. the hindrance to the wind flow) the greater the turbulence.

The picture on top-right shows the local wind behaviour in the piazza.

The bottom pictures show the velocity profiles in the streets with open ends. An increase in velocity magnitude can be observed at the end of the streets. Like in the case of no wind tower.

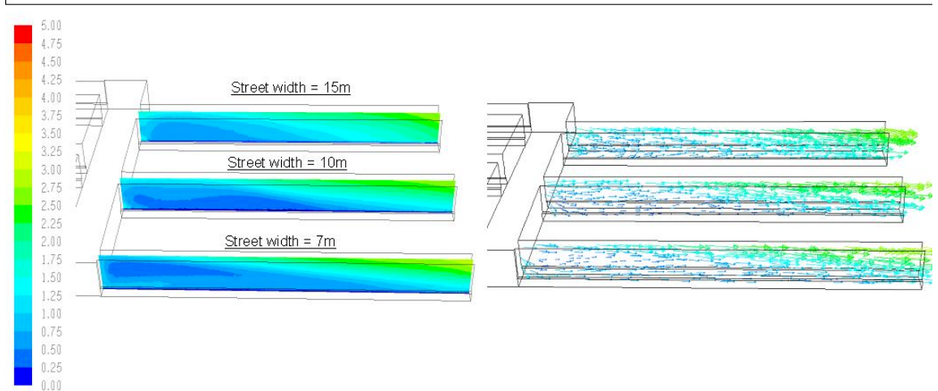
Velocity profile[m/s] @ section planes *radially quadrisecting* the streets with open ends



Contour plot | Vector plot

Case-1 : *The wind towers are closed*

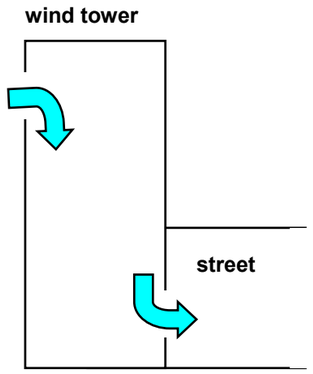
Velocity profile[m/s] @ section planes *longitudinally bisecting* the streets with open ends



Contour plot | Vector plot

Case-1 : *The wind towers are closed*

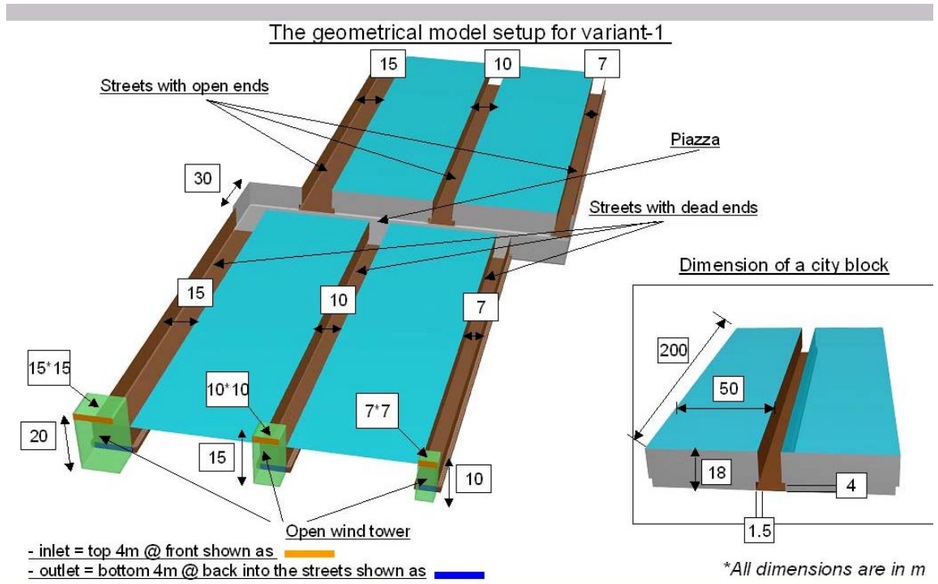
CASE-2 Variant 1 Open Wind Towers
Wind towers with short openings for inlet and outlet.



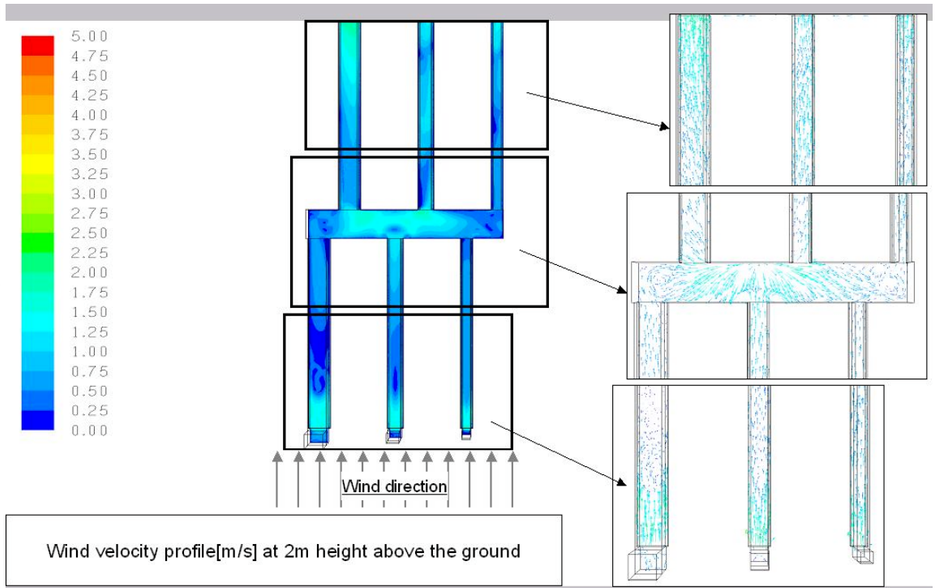
This case deals with the situation when the wind towers are open.
In this variant the wind towers are of the same height as in CASE-1 and all three wind towers have same opening(4m height) for inlet and outlet. The top-left picture shows the model.

The right pictures compares this situation and the case with closed wind towers by comparing the results of velocity magnitude at pedestrian level. A reduced velocity magnitude as compared to that of the CASE-1 can be noticed even though the wind towers are open now.
This is due to the fact that the wind that enters the streets from the wind tower opening gets partially diverted to the region of low pressure behind the wind towers because of the shading effect. Also, the wind coming from the wind towers creates a lift for the exterior wind that enters the streets from the top (as it was in CASE-3 of the chapter “Air Flow Simulation-1 City Grid and Block Design”).

This shows that the wind towers has to be designed in detail to make them function as required.

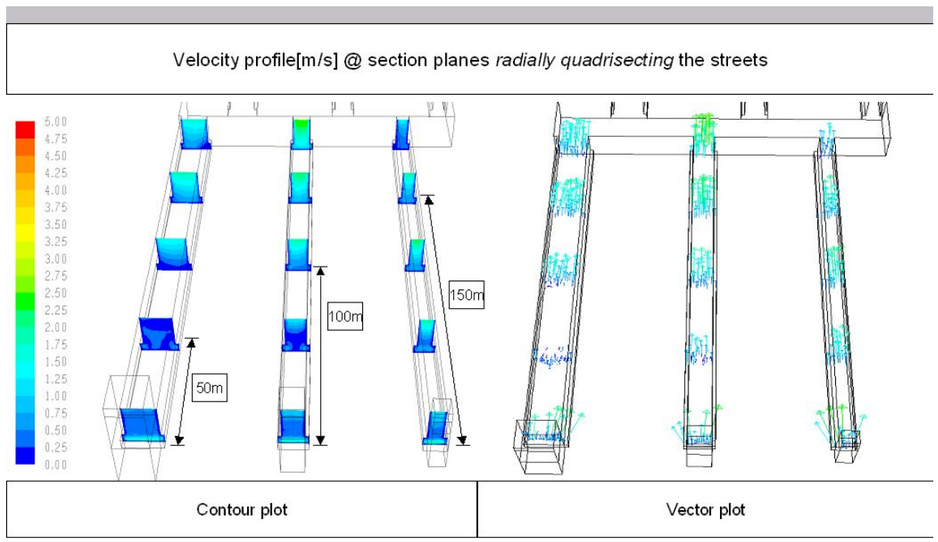


Case-2 : *The wind towers are open* Variant-1: The height and openings are smaller

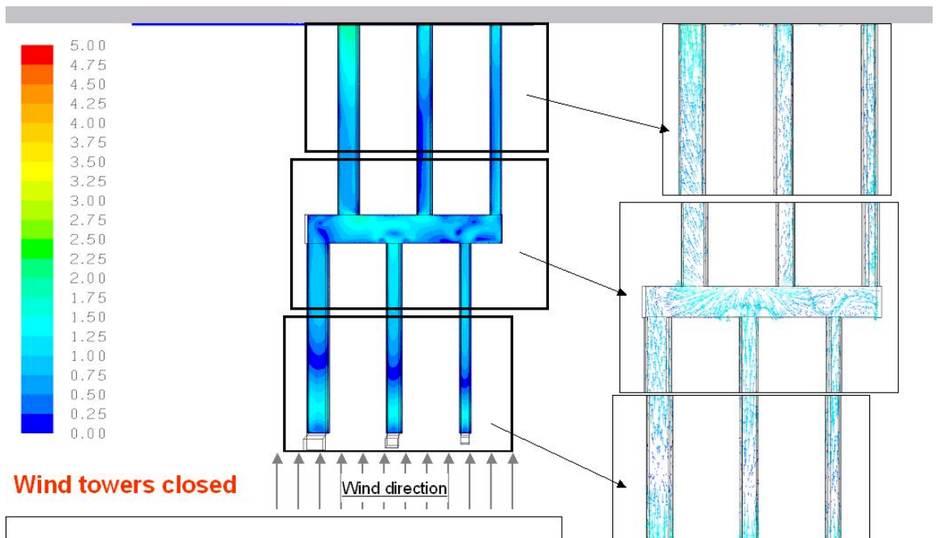


Case-2 : *The wind towers are open* Variant-1: The height and openings are smaller

Comparison



Case-2 : *The wind towers are open* Variant-1: The height and openings are smaller



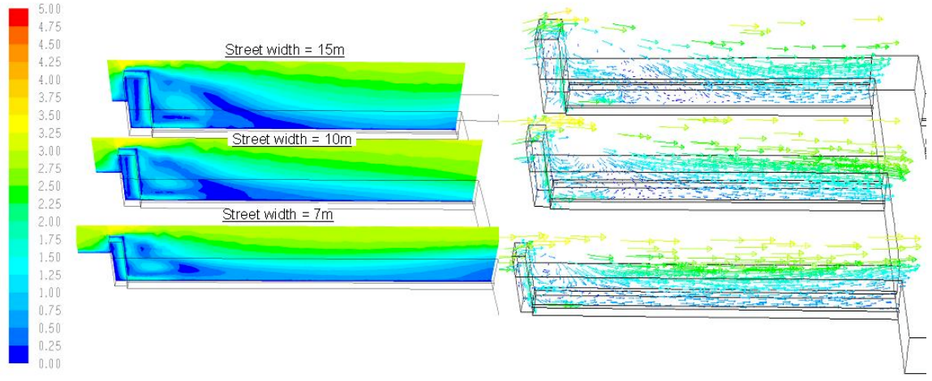
Case-1 : *The wind towers are closed*

CASE-2 Variant 1 Open Wind Towers
Wind towers with short openings for inlet and outlet.

The physical phenomena explained in the previous page can be verified in the pictures here.
The vector plots aid in understanding the local behaviour and the velocity direction.

But at least a qualitative result can be seen with the air supply at the beginning of the street. Assuming this would be cooler air, this airflow will be highly welcome in the street canyons.

Velocity profile[m/s] @ section planes *longitudinally bisecting* the streets

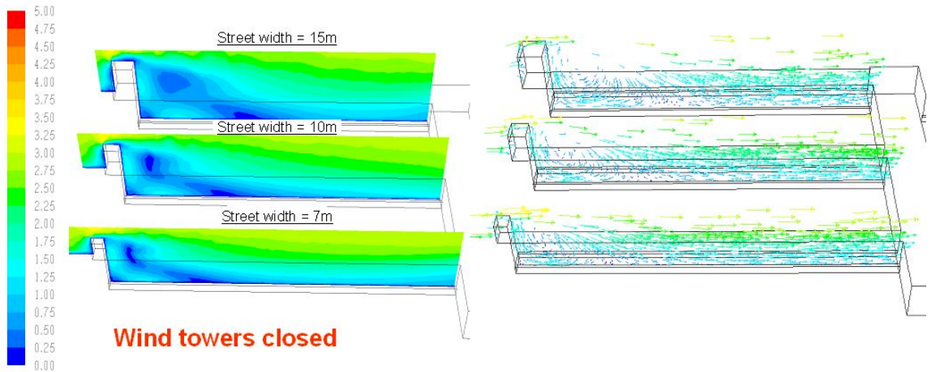


Contour plot	Vector plot

Case-2 : *The wind towers are open* — Variant-1: The height and openings are smaller

Comparison

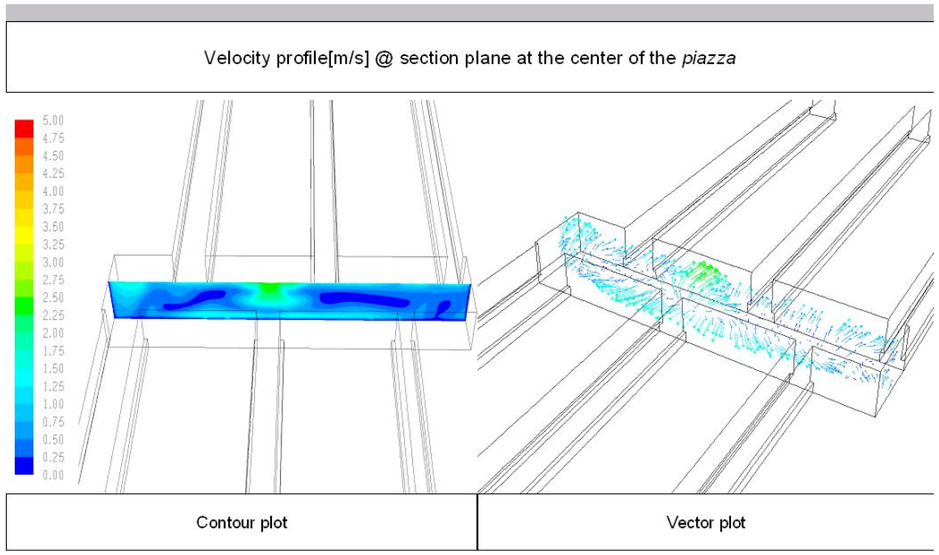
Velocity profile[m/s] @ section planes *longitudinally bisecting* the streets



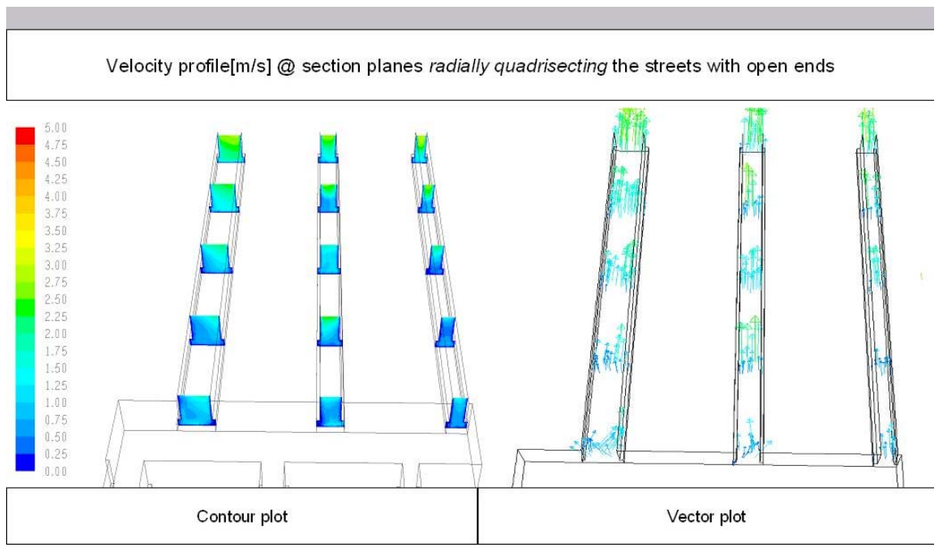
Contour plot	Vector plot

Case-1 : *The wind towers are closed*

CASE-2 Variant 1 Open Wind Towers
Wind towers with short openings for inlet and outlet.

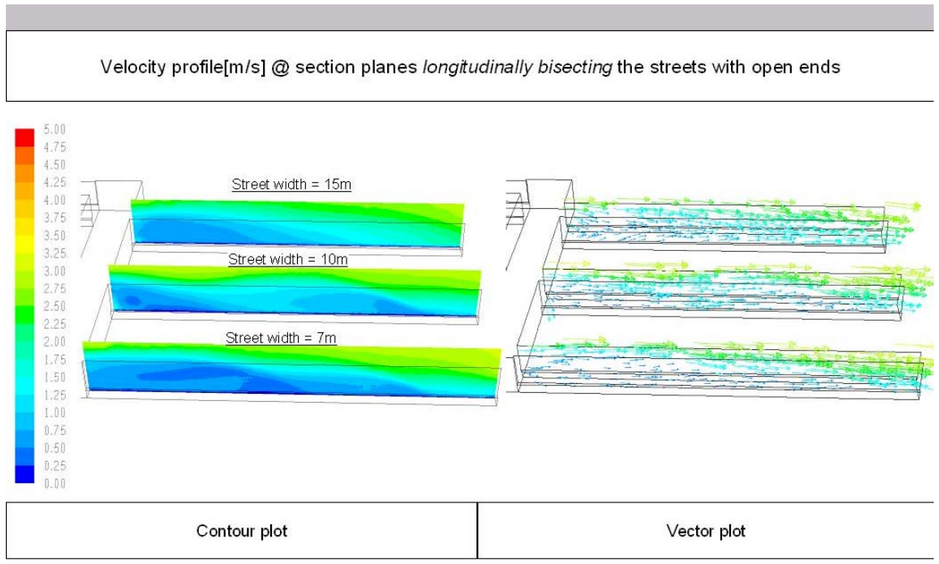


Case-2 : T*he wind towers are open* Variant-1: The height and openings are smaller



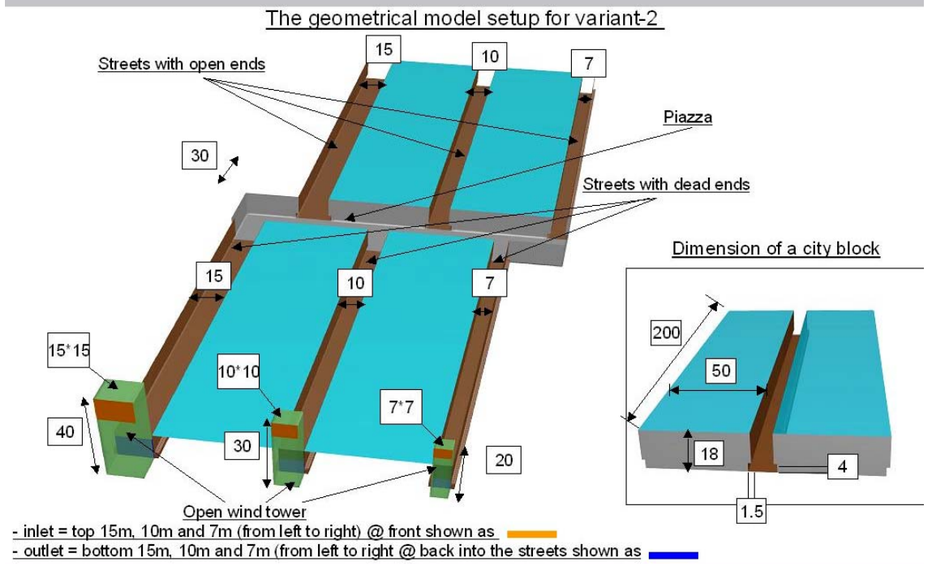
No considerably different behaviour can be monitored for the piazza and for the streets with open ends as compared to previous case.

Case-2 : T*he wind towers are open* Variant-1: The height and openings are smaller

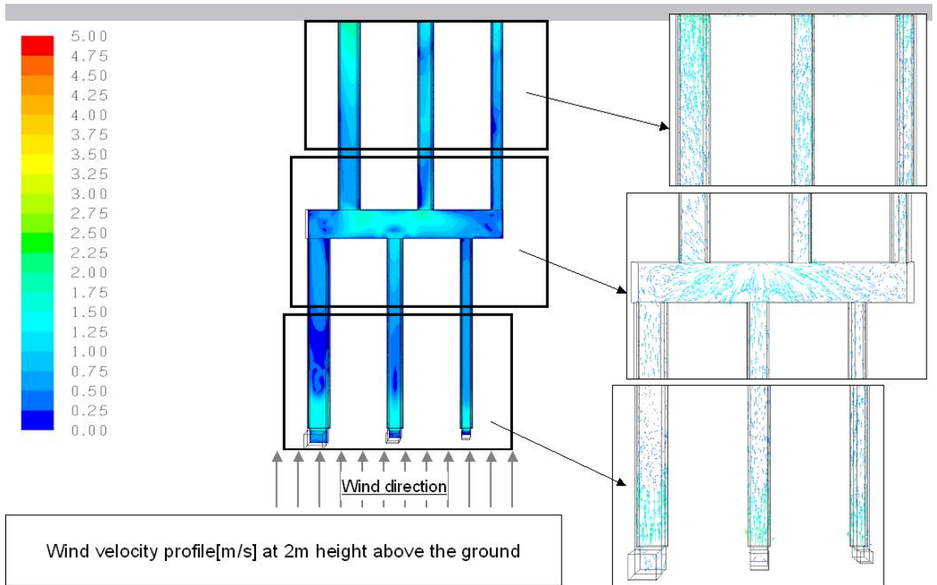


Case-2 : T*he wind towers are open* Variant-1: The height and openings are smaller

CASE-2 Variant 2 Open Wind Towers
Big wind towers with wide openings for inlet and outlet.



Case-2 : *The wind towers are open* Variant-2: The height and openings are bigger



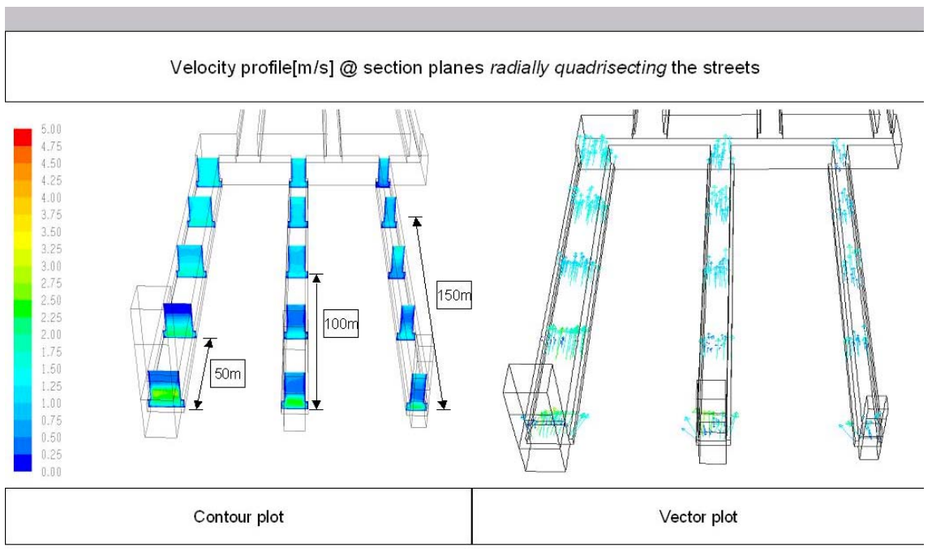
Case-2 : *The wind towers are open* Variant-1: The height and openings are smaller

Comparison

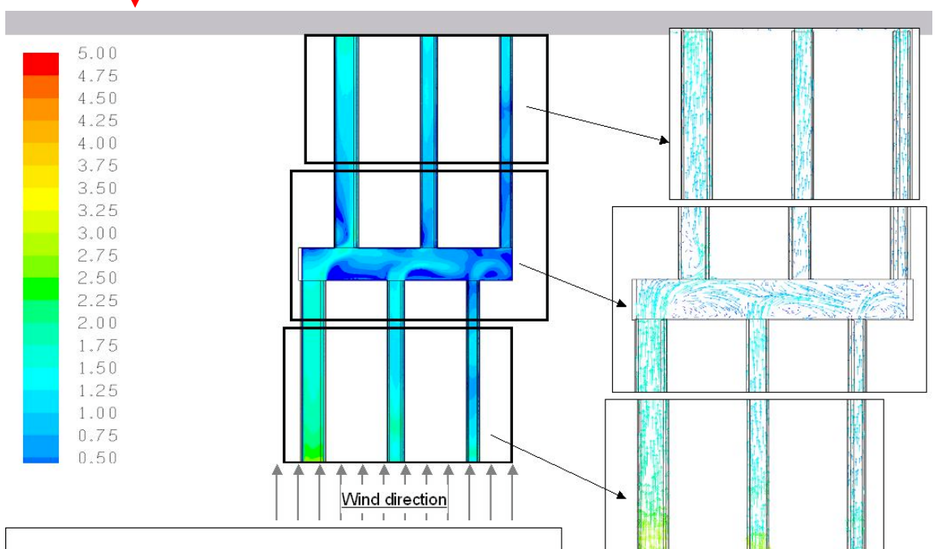
It was observed in variant – 1 that the wind tower openings are not big enough to supply sufficient air into the streets. Hence as a next approach, the wind tower height was doubled as compared to that in the previous models and the openings for inlet and outlet of the wind towers are increased in this variant.

The model can be seen in the top picture.

The result of increase in height and wider openings for the wind towers can be seen in form of higher velocity magnitude inside the streets in the bottom pictures.



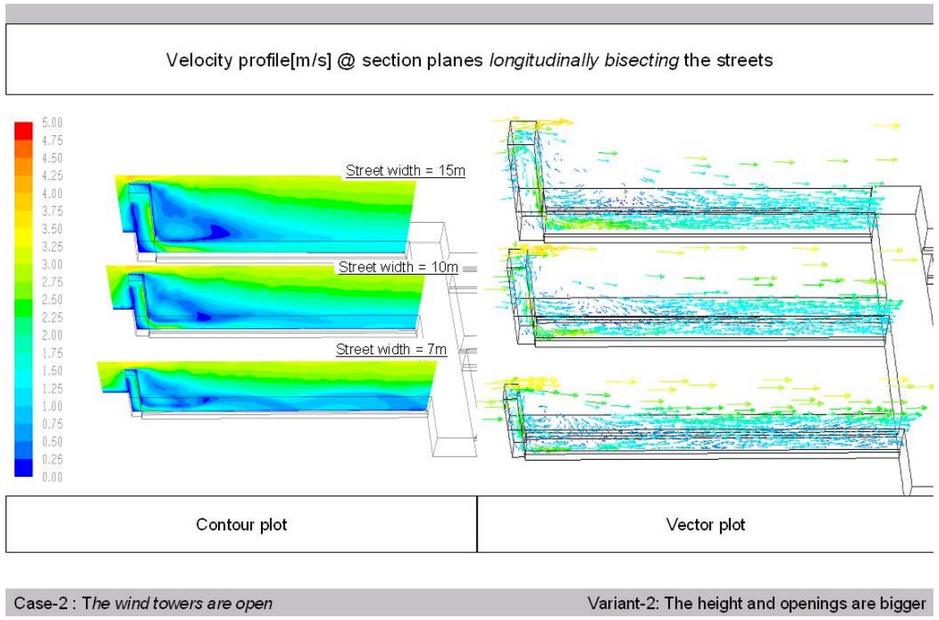
Case-2 : *The wind towers are open* Variant-2: The height and openings are bigger



Case-2 : *The wind towers are open* Variant-2: The height and openings are bigger

CASE-2 Variant 2 Open Wind Towers
Big wind towers with wide openings for inlet and outlet.

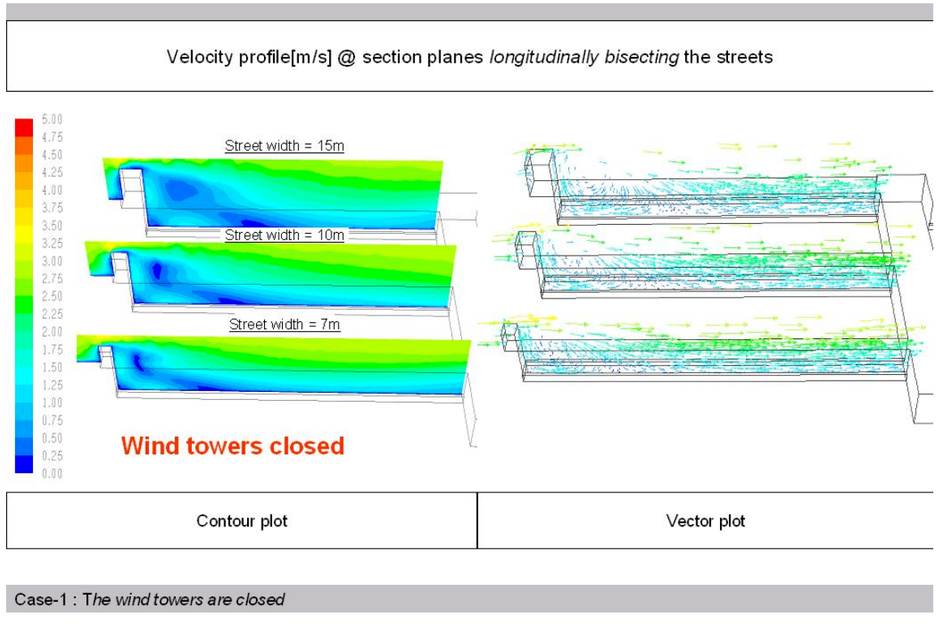
Comparison between
- closed wind towers (bottom-left)
- big wind towers with big openings (top-right)
- wind towers with small openings (bottom-right)



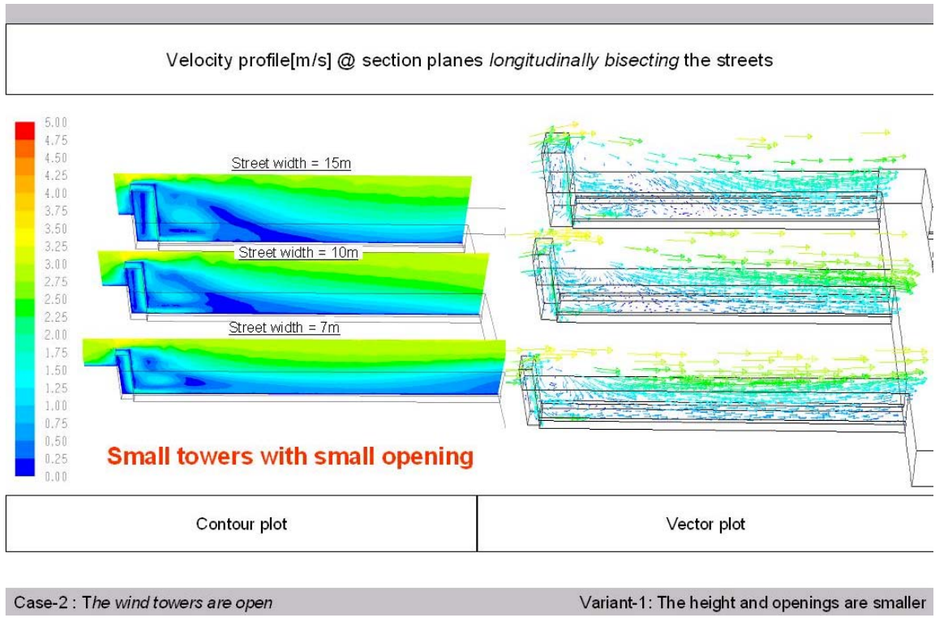
Case-2 : *The wind towers are open* Variant-2: The height and openings are bigger

Comparing all three pictures
- - A laminar flow with approximately constant velocity magnitude can be seen inside the streets for the big wind towers with wide openings.
- - Also, there is maximum air change rate inside the streets for big wind towers with wide openings.

This brings us to the conclusion that by designing the wind towers with proper height and openings, it is possible to supply the streets with better quality exterior wind whenever required by controlling the wind tower openings accordingly .

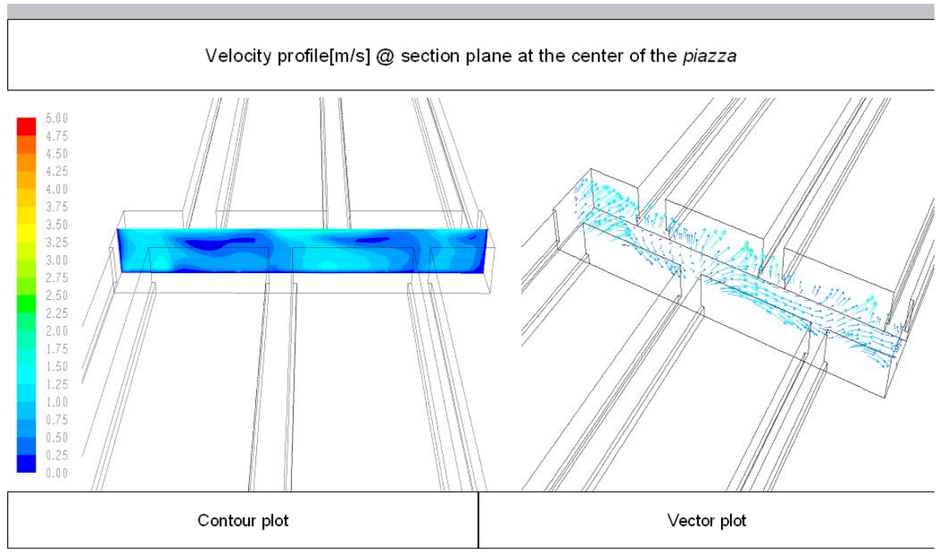


Case-1 : *The wind towers are closed*

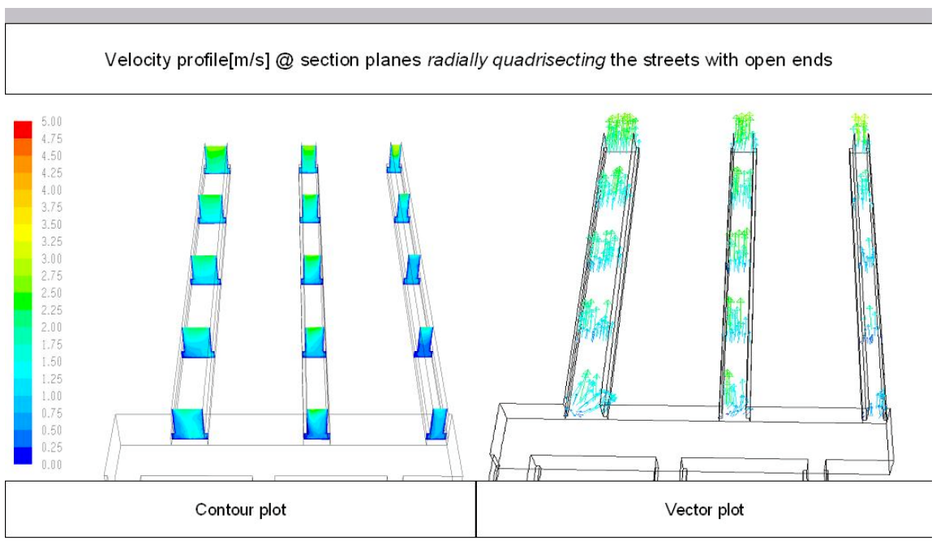


Case-2 : *The wind towers are open* Variant-1: The height and openings are smaller

CASE-2 Variant 2 Open Wind Towers
Big wind towers with wide openings for inlet and outlet.

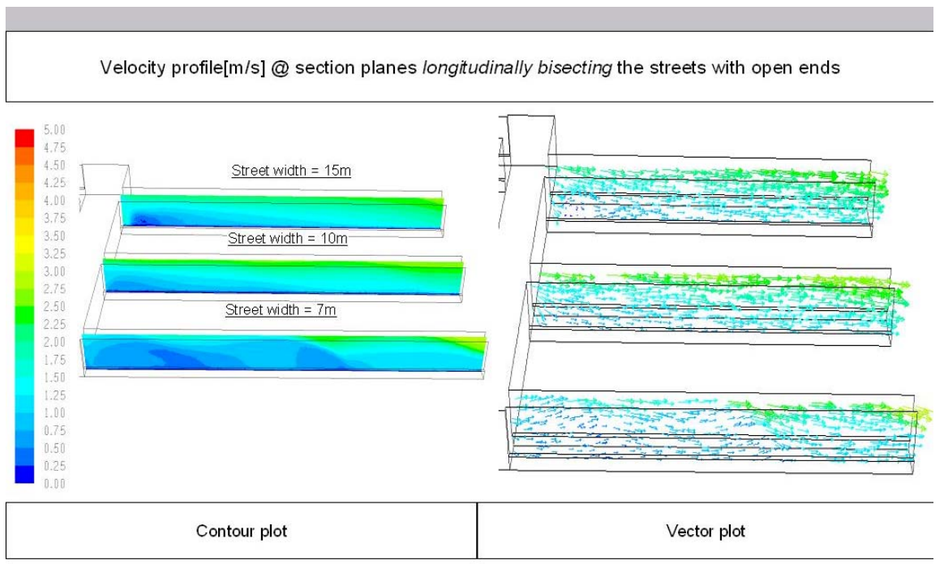


Case-2 : T*he wind towers are open* Variant-2: The height and openings are bigger



Local wind behaviour inside the piazza and in the streets with open ends can be seen in these pictures.
The increased airflow by the tower openings has positive impact even at the open end street.

Case-2 : T*he wind towers are open* **Variant-2: The height and openings are bigger**



Case-2 : T*he wind towers are open* Variant-2: The height and openings are bigger

Wind Tunnel Investigations
by Wacker Ingenieure, Germany

Preferences
In order to investigate the wind impact on the designed Masdar City Wacker Ingenieure, Germany were commissioned to perform wind tunnel tests with a complete city model (scale 1:1000) of the actual design state. The aim of the tests was to analyze the development of the wind field properties at different areas of the planned city at several heights below and above the roof heights in comparison to the undisturbed wind situation at site. The results should give first hints on the intensity of city ventilation for different wind conditions.

Wind tunnel model
In order to obtain realistic wind field properties by means of the wind tunnel tests the most significant modelling laws (geometric similarity, similarity of the approach flow (wind profile and turbulence characteristics), dynamic similarity and so on)) among others were followed in this study as far as possible.

For the tests a 1:1000 scale model of the Masdar City was built in a simplified manner based on the design guidelines of the architects. Photographs of the study model are presented in the figures.
Surroundings beyond the immediate neighbourhood of the Masdar City are simulated by appropriate roughness elements on the tunnel floor in order to provide an accurate simulation of the wind speed profile and turbulence of the approaching wind.

The experiments were carried out in a low speed open circuit boundary layer wind tunnel provided with a test section with dimensions of approximately 10 m length, 2.5 m width and 1.85 m height. Along the floor of the boundary layer wind tunnel a deep turbulent boundary layer flow corresponding to the atmospheric boundary layer flow at the site of the Masdar City was simulated by means of vortex generators at the entrance of the test section, and through roughness elements on the tunnel floor. In this study, the upwind terrain was considered to be nearly open exposure for all winds approaching the study site. To determine the parameters describing the flow, extensive measurements were carried out using pitot-static tubes and constant-temperature hot-wire anemometers. The profiles of the typical mean wind velocity, gust velocity and fluctuations (rms (root mean square)) at site, which were simulated in the wind tunnel, are shown in the figure.

Wind tunnel tests
Different kinds of tests were performed with the wind tunnel model:

1. Sand erosion tests

   Sand erosion tests allow to detect zones of increased wind velocities at ground level in an overview.

2. Hot-wire measurements

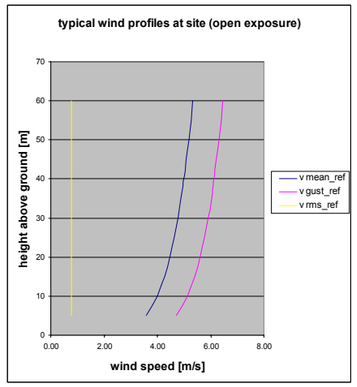
   With hot-wire anemometers the mean and fluctuating wind speeds at different areas within the city complex and in 4 different heights were measured. The measured wind speeds were put into relation to the situation of the undisturbed flow and allow to detect areas of increased or decreased mean wind speeds or turbulence.

3. Tracer gas measurements

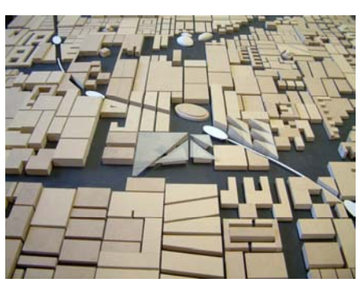
   With tracer gas measurements possible air exchange rates within the narrow street canyons were calculated

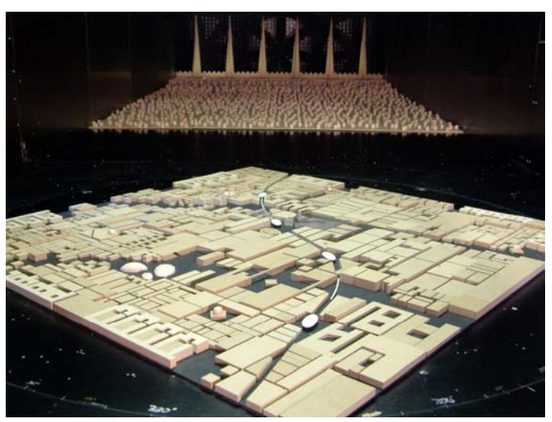
All tests were performed for at least 3 wind directions. The most important wind directions at site with respect to the human comfort are north-westerly winds from the sea side, which transport warm and humid air towards Masdar City , easterly winds, which transport welcome cold air during the nighttimes and southerly winds, which are often correlated with sand storms at site. So the measurements were performed for the wind directions ß = 310°, 90° and 180°.

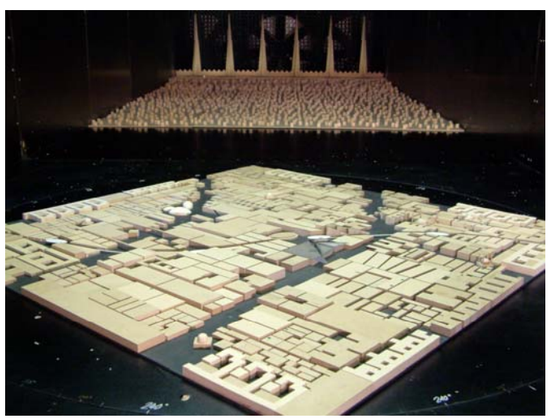
Typical wind profiles at site (open exposure). Annual mean wind speed at site is approx. 4 m/s at 10 m height.



Wind tunnel model of Masdar City (scale 1:1000)







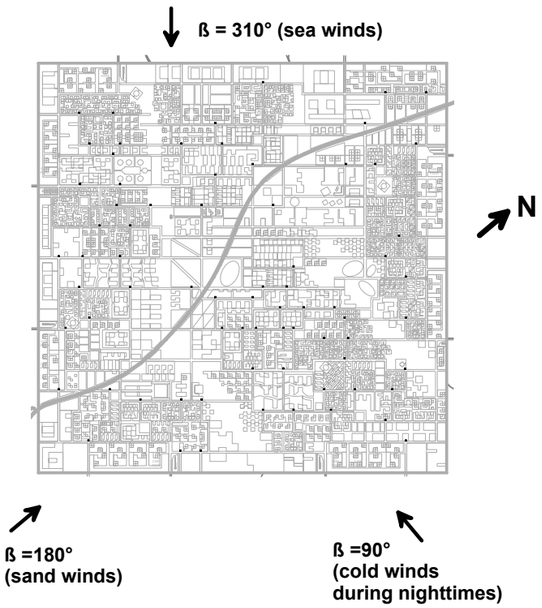
Wind Tunnel Investigations
by Wacker Ingenieure, Germany

Sand erosion investigations
The sand erosion investigations were performed for the 3 most important wind directions (ß = 310°, 90° and 180°). The green finger areas in the model were covered with sand particles. Under wind action the particles will be blown away at those areas were the wind speed near the ground is comparatively increased. These areas appear black in the photographs and are also an indication for zones with air mixing from higher levels.

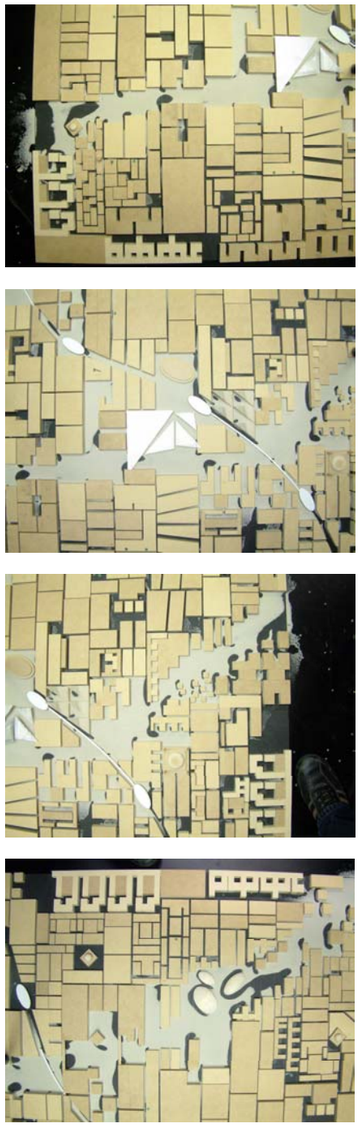
Wind direction ß = 310°
At almost every area along the green fingers wind speed increments occurred caused by the flow around the buildings, which means that winds from higher altitude have been transported downwards towards the ground level. Especially near the exposed higher buildings (mosque at the entrance, pyramid buildings (ADFEC), University and Science Centre) the wind speed is increased. Also some wind shadowing effects behind constrictions of the green fingers are recognizable.

Wind direction ß = 90°
This wind direction is mainly important for the city ventilation during night times with cold air. The sand erosion photos show many zones with increased wind speeds along the green fingers, which indicates effective air mixing from higher levels towards the ground at these areas. Hence, for this wind direction the city ventilation through the green fingers is most effective.

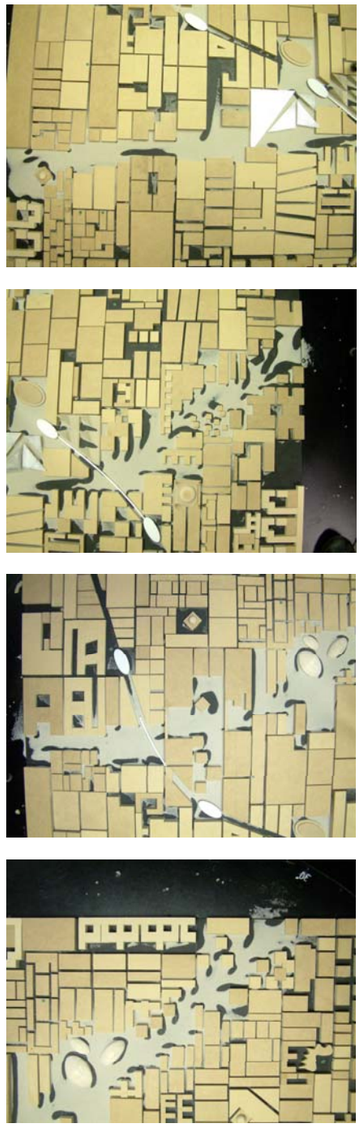
Wind direction ß = 180°
This wind direction is often correlated with sand storms, so infiltration of sandy air towards the green fingers should be minimized. In fact the sand erosion photos show only few areas with increased wind speeds.



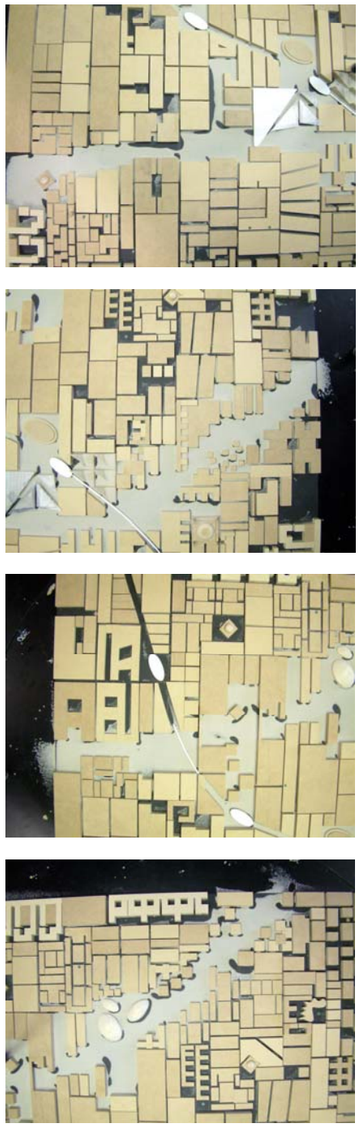
Wind direction ß = 310°:



Wind direction = 90°:



Wind direction ß = 180°



Wind Tunnel Investigations
by Wacker Ingenieure, Germany

Measurements with hot wire anemometers
In order to determine the impact of the building structures of Masdar City on the global wind field wind measurements in the wind tunnel at several locations within the city were performed. These measurements were carried out with hot wire anemometers in four heights above the ground level (5 m, 15 m, 30 m and 50 m (full scale)) at 17 locations and for three wind directions (see figure). Additionally profile measurements at the area of the proposed wind turbines 350 m leeside of Masdar City were performed for the wind direction ß = 310°.

For every measuring point the relation factors between the mean wind speed $X_{i,mean}$, the fluctuations $X_{i,\,rms}$ and the gust wind speed $X_{i,gust}$ at the measuring points in relation to the free and undisturbed flow in the same height level (note: city ground level is 6.5 m above desert level, hence 5 m above ground level corresponds to 11.5 m above the reference base level) were calculated:

$$X_{i,\,mean} = \frac{v_{mean,\,measuring\ \ point}(h)}{v_{mean,\,undisturbed}(h)}$$

$$X_{i,rms} = \frac{v_{rms,\,measuring\ \ point}(h)}{v_{rms,\,undisturbed}(h)}$$

$$X_{i,gust} = \frac{(v_{mean}+\gamma\cdot v_{rms})(h)_{measuring\ point}}{(v_{mean}+\gamma\cdot v_{rms})(h)_{undisturbed}}$$

with γ = 1.5.

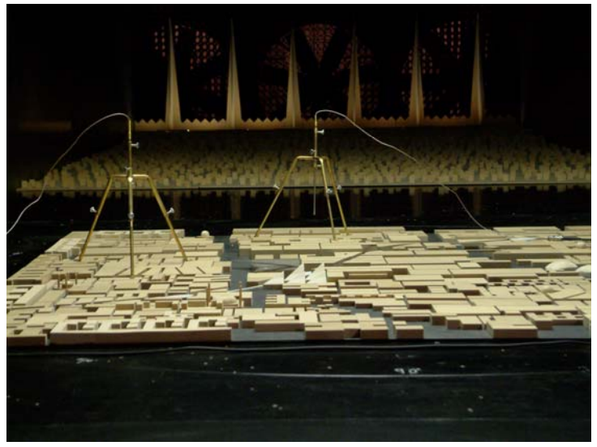
Relation factors Xi > 1 indicate an increase in relation to the undisturbed flow in the same height level and relation factors < 1 indicate a decrease respectively

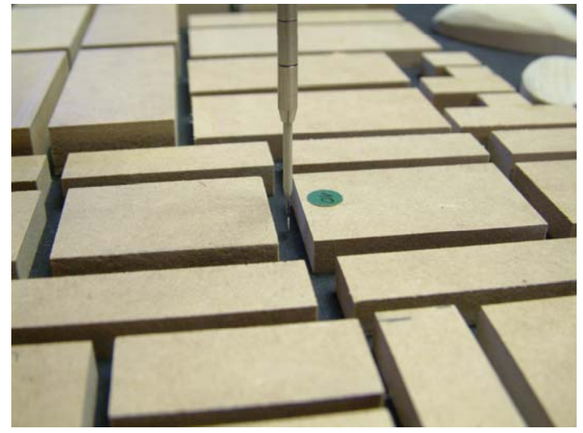
Vertical profiles and horizontal sections
The results of the measurements are shown in two different ways: For the visualizing of the horizontal wind field in same height the measured values of $X_{i,mean}$, $X_{i,rms}$ and $X_{i,gust}$ are presented in horizontal sections. Additionally for some representative locations the vertical profiles of Xi_mean, Xi_rms and Xi_gust are presented in order to investigate the development with height.

As it is to be expected at every location the mean wind speed is reduced near the ground. The influence of the roughness impact of the city decreases with height. In 50 m above city ground level the differences to the undisturbed flow become more or less negligible.

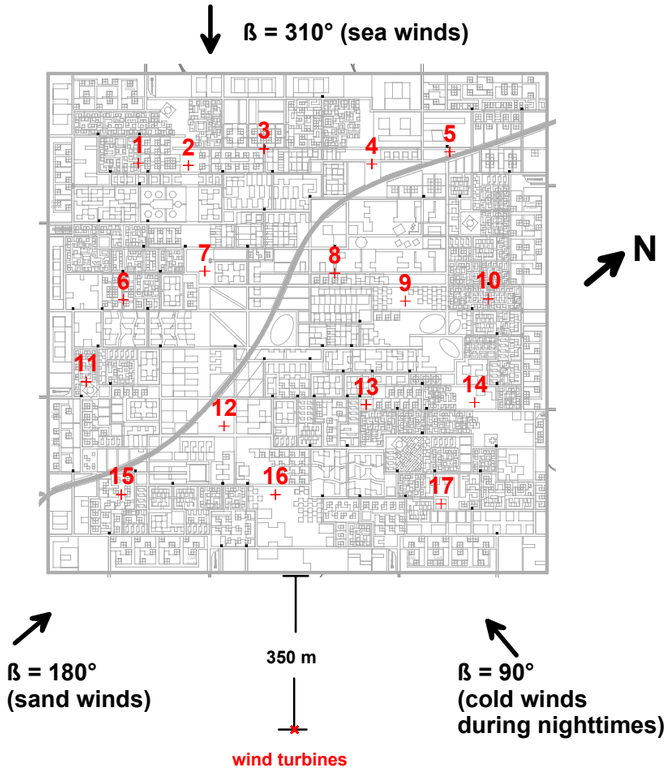
For the wind directions ß = 310° and ß = 90° the reduction of the wind speed along the green fingers is comparatively small, which indicate a comparatively good ventilation capability. The wind direction ß = 180° shows a greater wind speed reduction, hence the entrainment from sandy air from higher levels is reduced in comparison to the other wind directions.

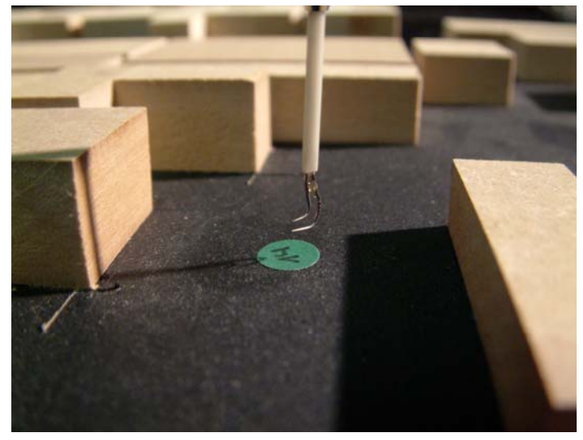
The highest reductions of the wind speeds were measured within the narrow streets in the residential areas. So, the air ventilation is significantly reduced in these areas.





Location of the measuring points (MP) for the hot-wire measurements:





Wind speed relation factors at different locations and heights measured with hot-wire anemometers.

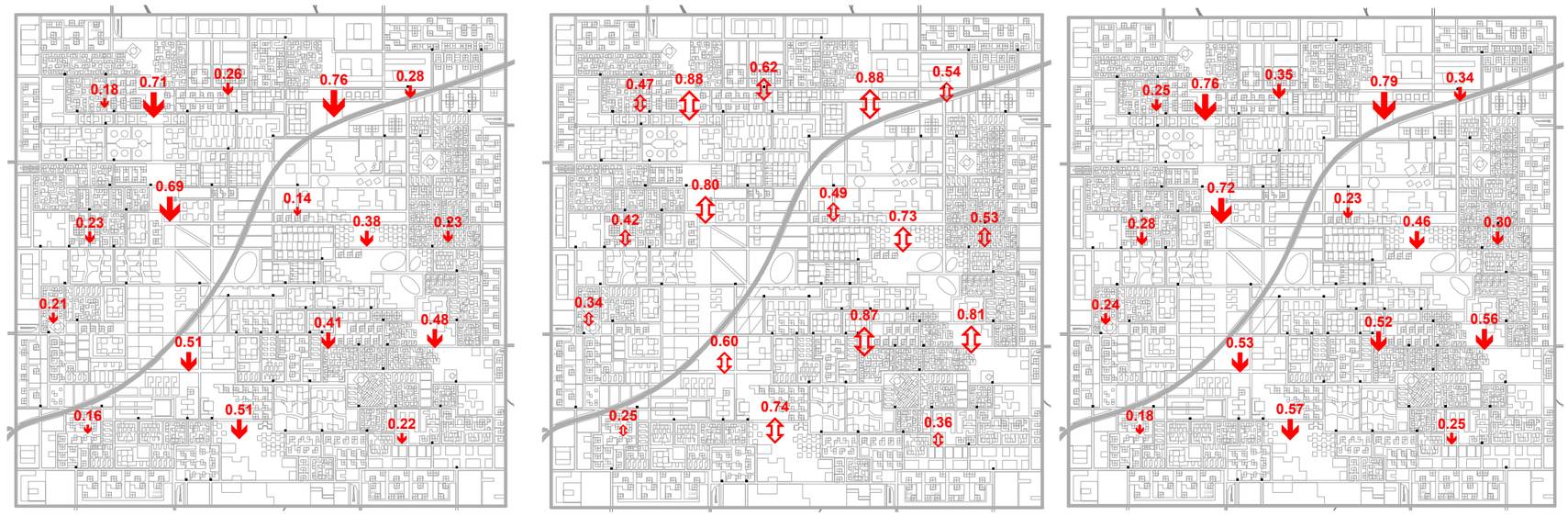
All values are related to the corresponding values for the undisturbed situation at the same height level.

v_mean / v_mean_ref (Xi_mean)

v_rms / v_rms_ref (Xi_rms)

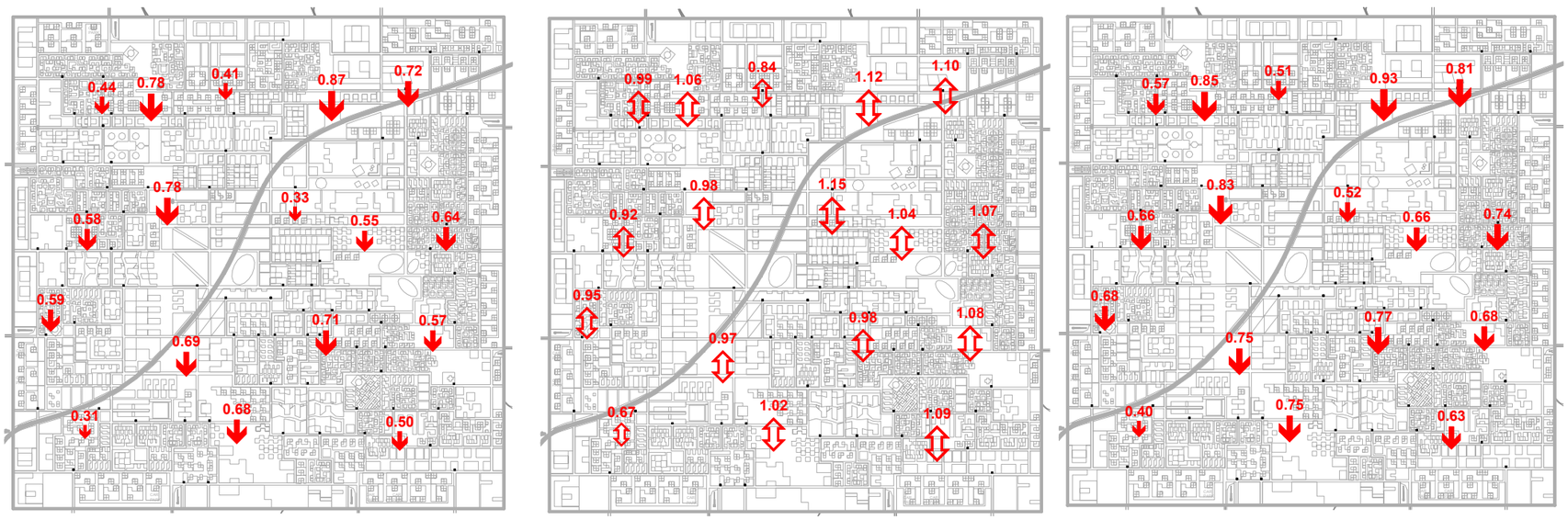
v_gust / v_gust_ref (Xi_gust)

height:
5 m above ground level



ß = 310°

height:
15 m above ground level



Wind speed relation factors at different locations and heights measured with hot-wire anemometers.

All values are related to the corresponding values for the undisturbed situation at the same height level.

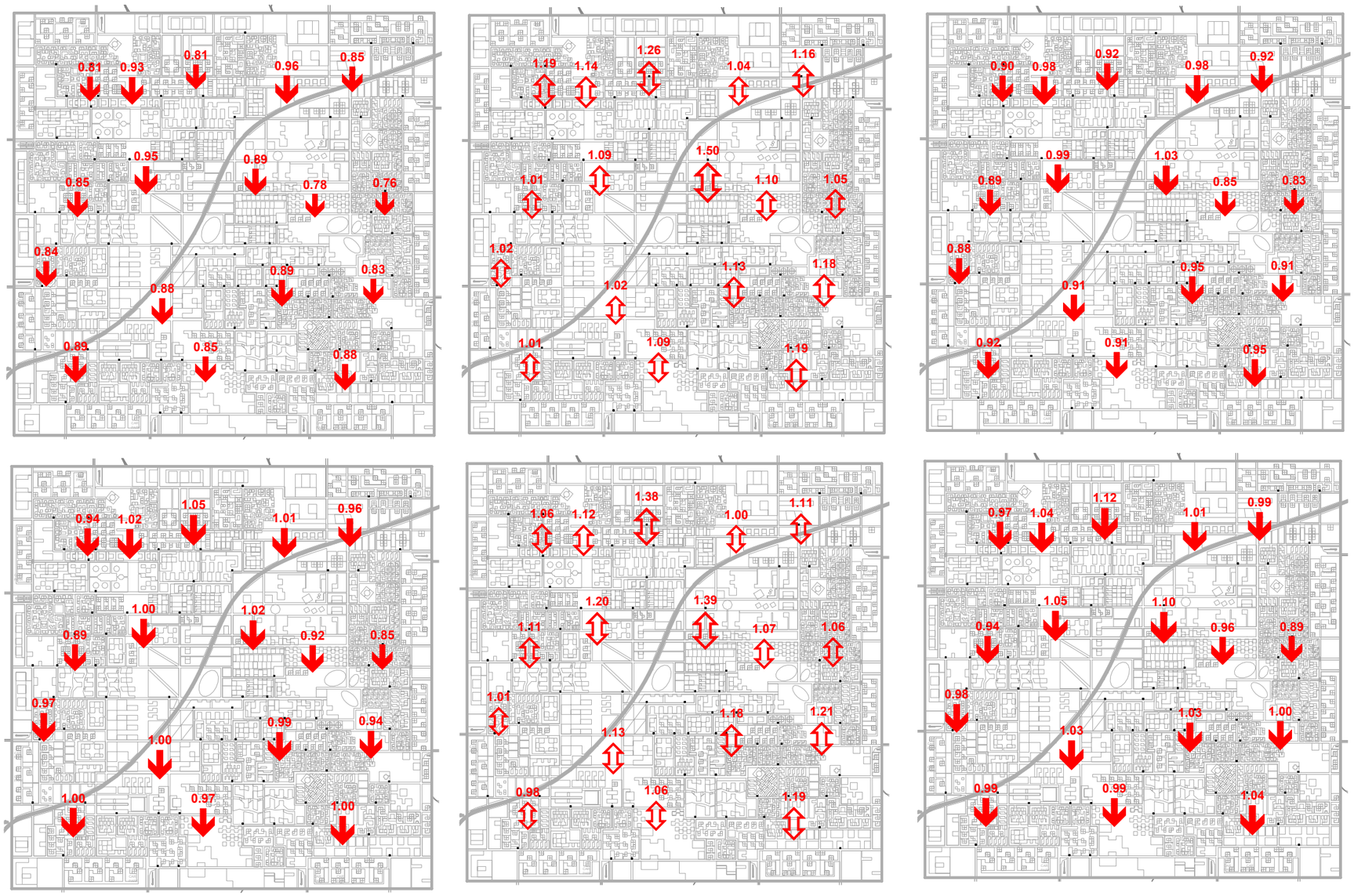
v_mean / v_mean_ref (Xi_mean)

v_rms / v_rms_ref (Xi_rms)

v_gust / v_gust_ref (Xi_gust)

height: 30 m above ground level

ß = 310°



height: 50 m above ground level

Wind speed relation factors at different locations and heights measured with hot-wire anemometers.

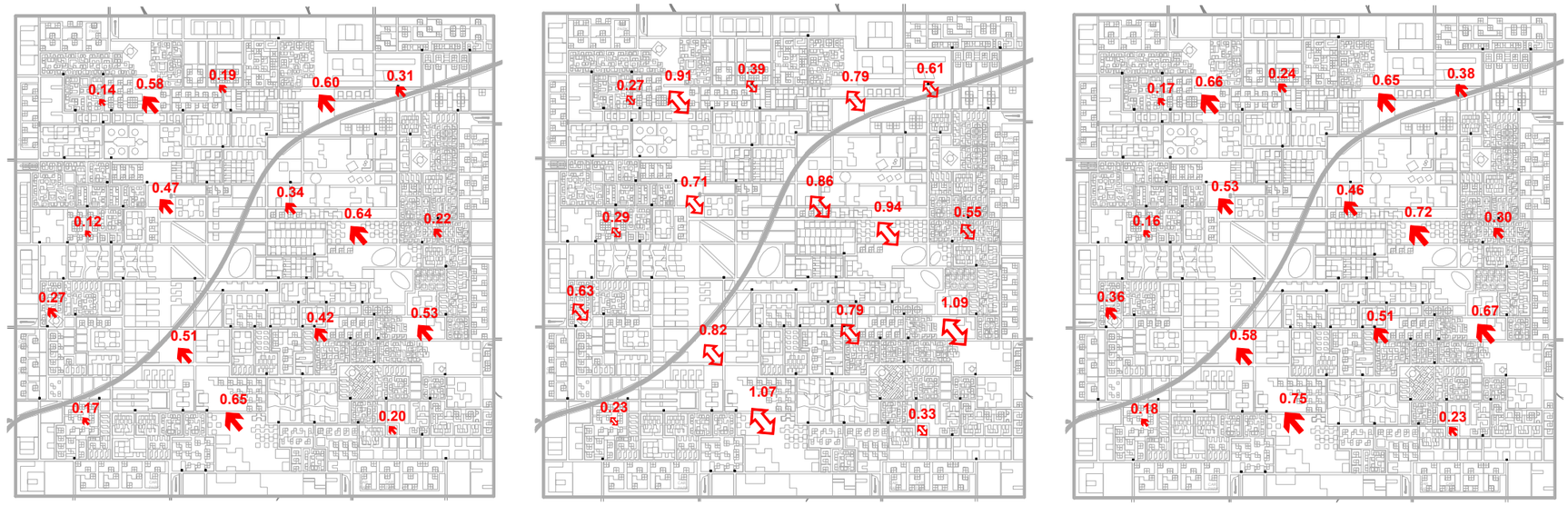
All values are related to the corresponding values for the undisturbed situation at the same height level.

v_mean / v_mean_ref (Xi_mean)

v_rms / v_rms_ref (Xi_rms)

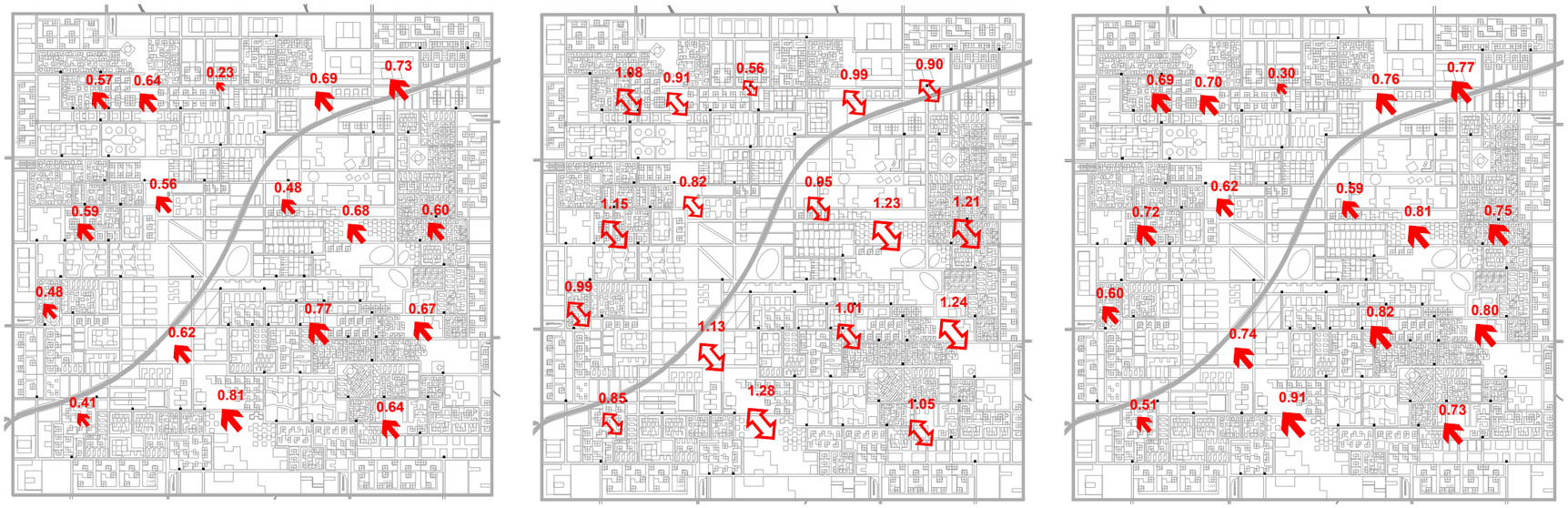
v_gust / v_gust_ref (Xi_gust)

height: 5 m above ground level



ß = 90°

height: 15 m above ground level



Wind speed relation factors at different locations and heights measured with hot-wire anemometers.

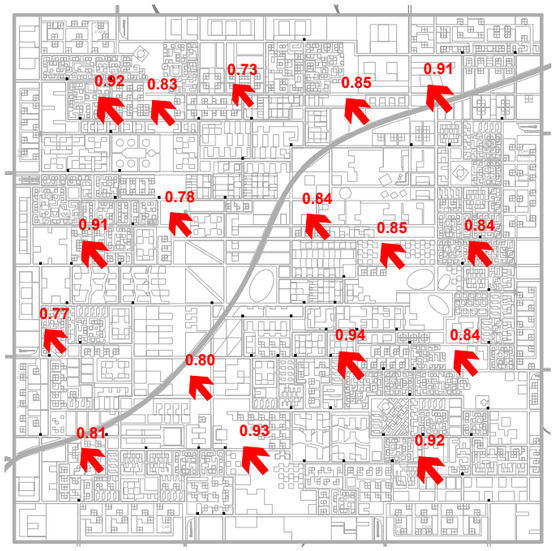
All values are related to the corresponding values for the undisturbed situation at the same height level.

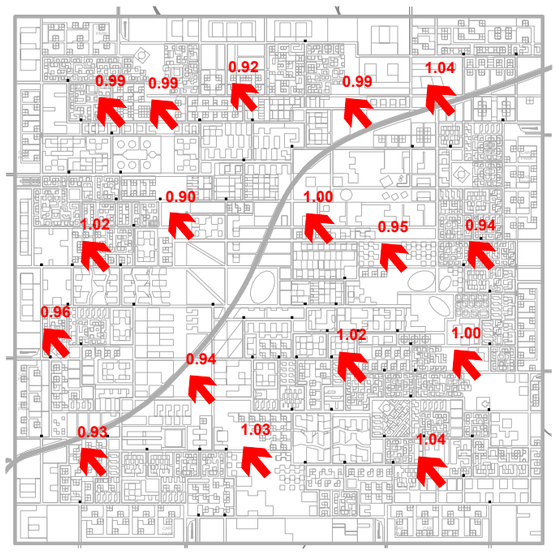
height: 30 m above ground level

ß = 90°

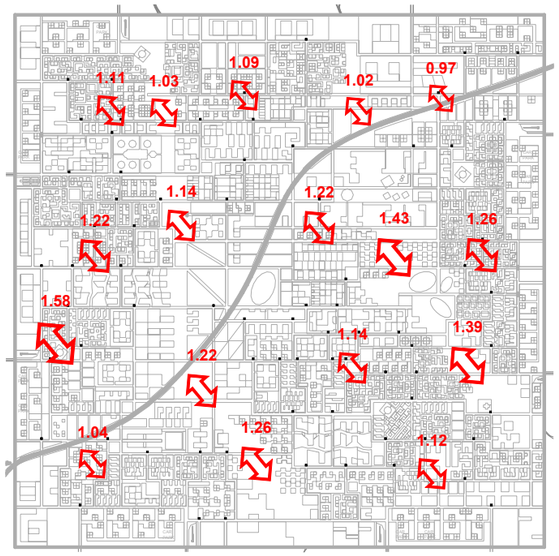
height: 50 m above ground level

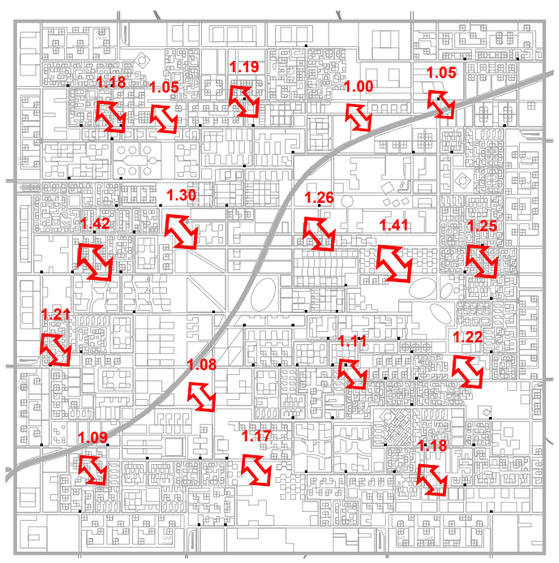
v_mean / v_mean_ref (Xi_mean)



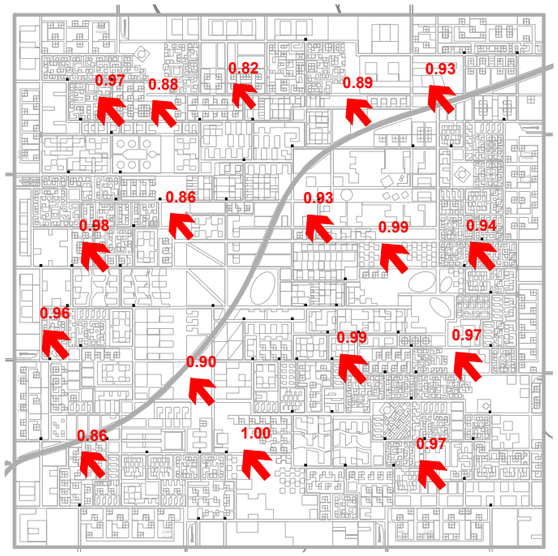


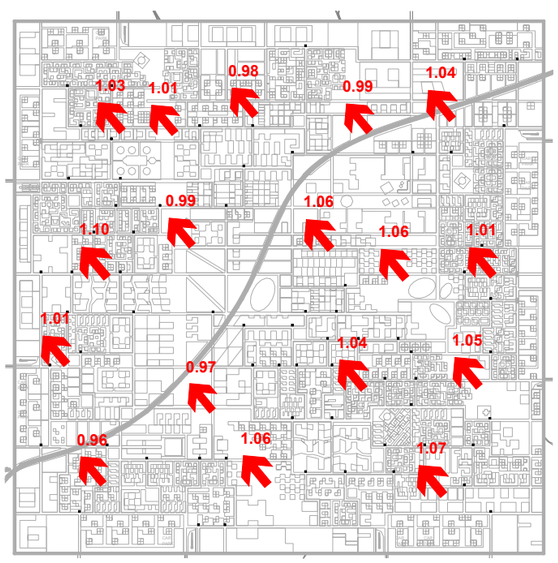
v_rms / v_rms_ref (Xi_rms)





v_gust / v_gust_ref (Xi_gust)





Wind speed relation factors at different locations and heights measured with hot-wire anemometers.

All values are related to the corresponding values for the undisturbed situation at the same height level.

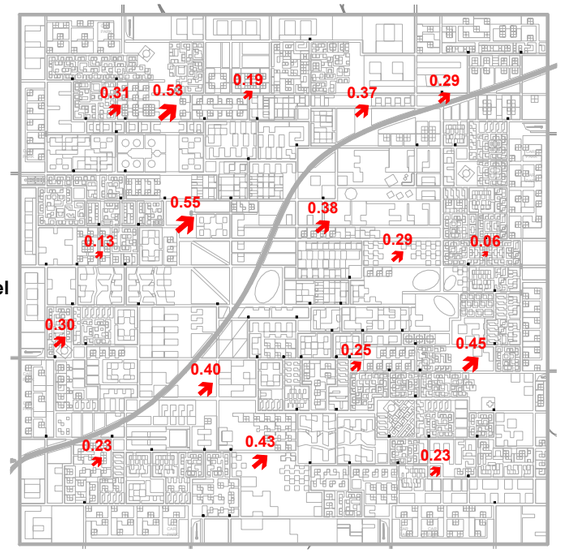
v_mean / v_mean_ref (Xi_mean)

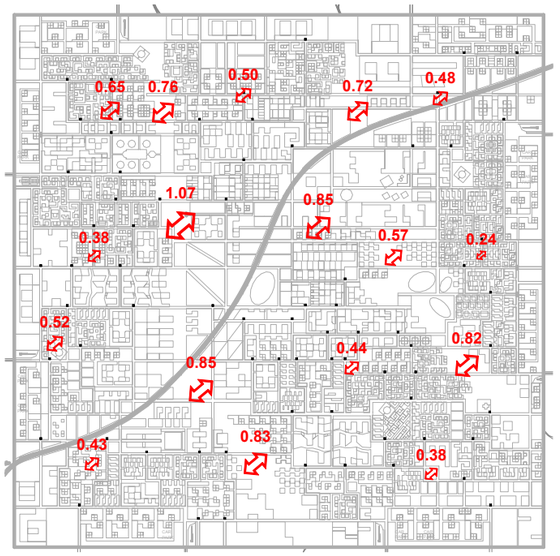
v_rms / v_rms_ref (Xi_rms)

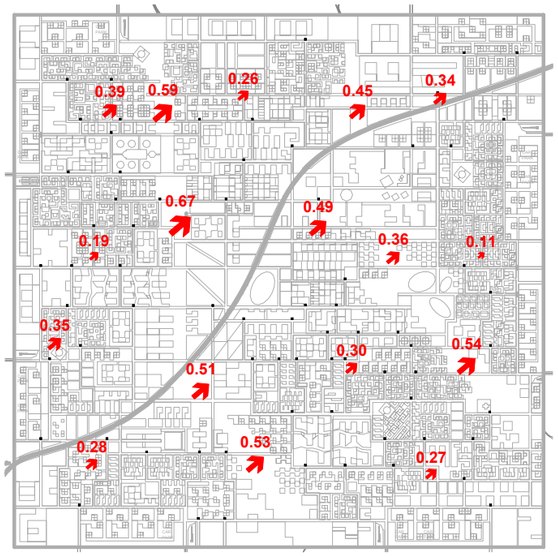
v_gust / v_gust_ref (Xi_gust)

height: 5 m above ground level

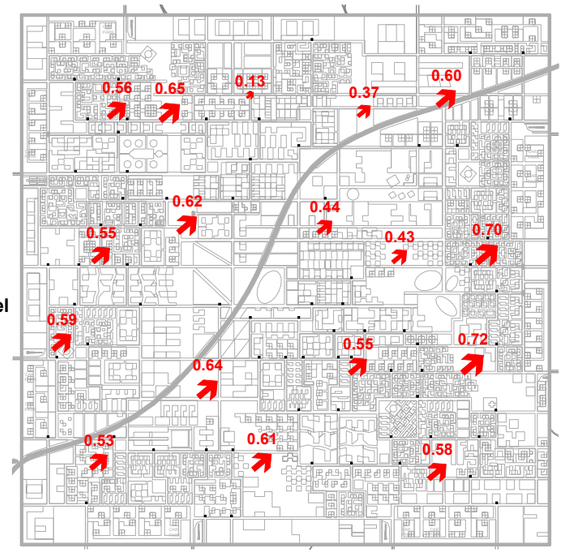
ß = 180°

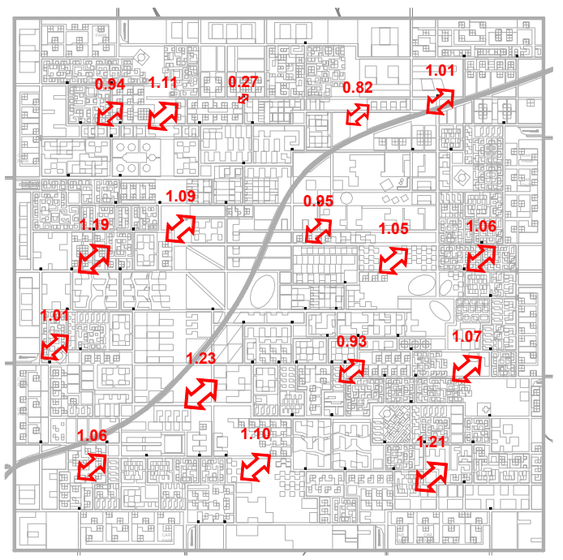


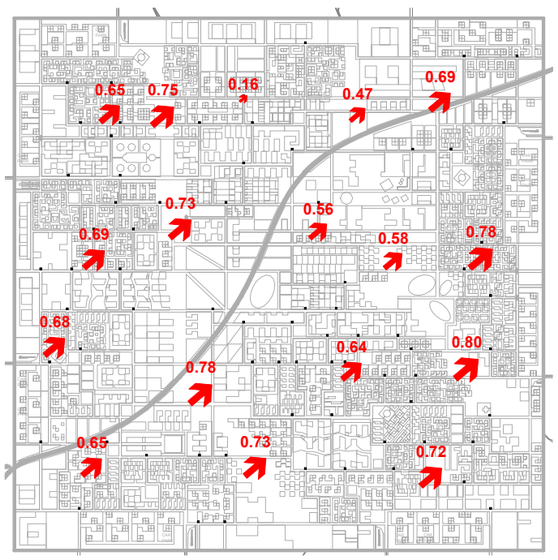




height: 15 m above ground level







Wind speed relation factors at different locations and heights measured with hot-wire anemometers.

All values are related to the corresponding values for the undisturbed situation at the same height level.

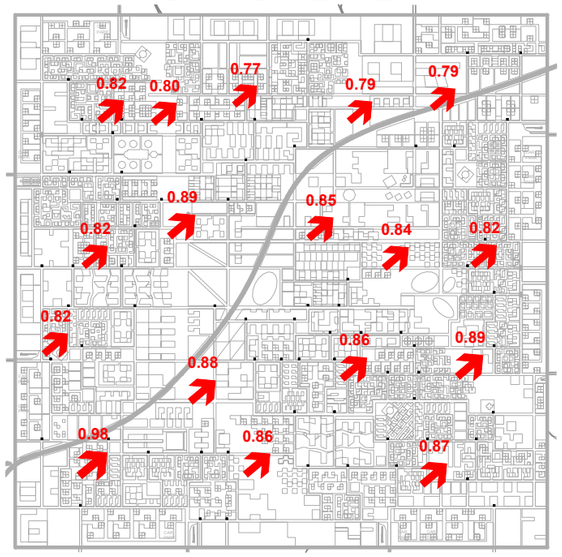
v_mean / v_mean_ref (Xi_mean)

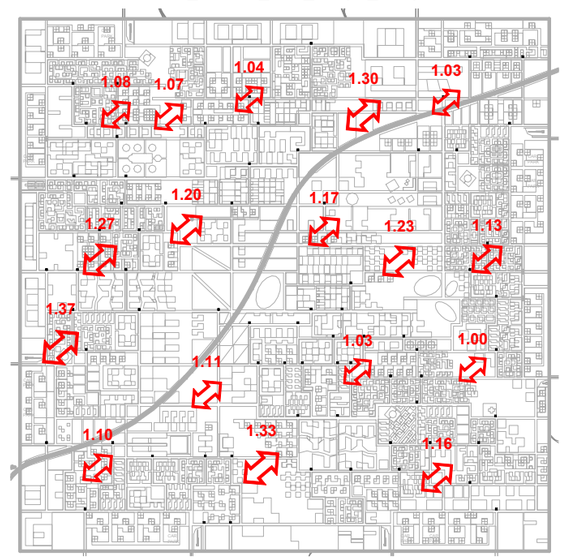
v_rms / v_rms_ref (Xi_rms)

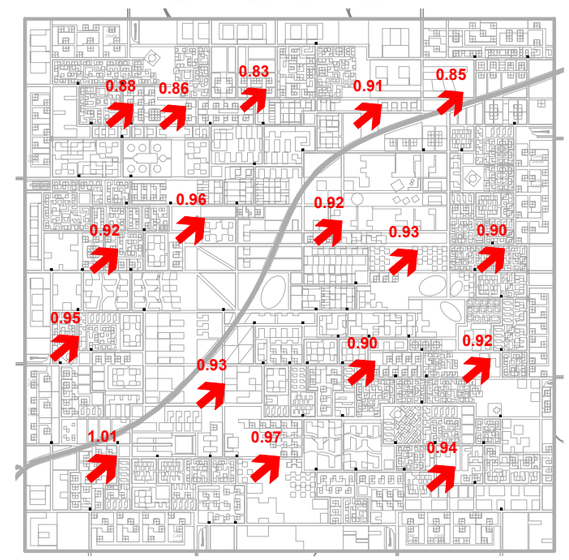
v_gust / v_gust_ref (Xi_gust)

height: 30 m above ground level

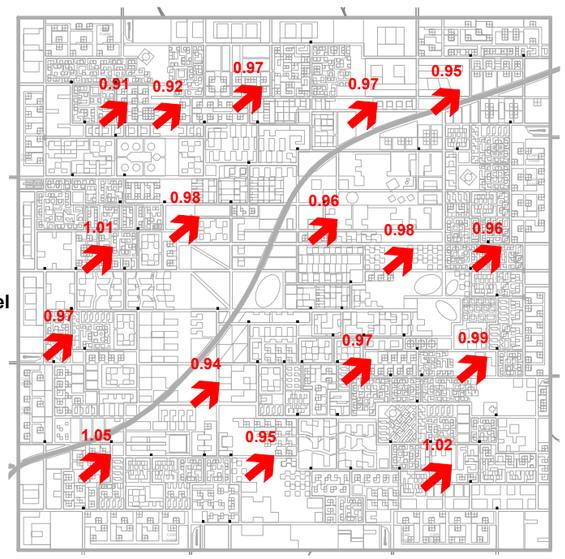
ß = 180°

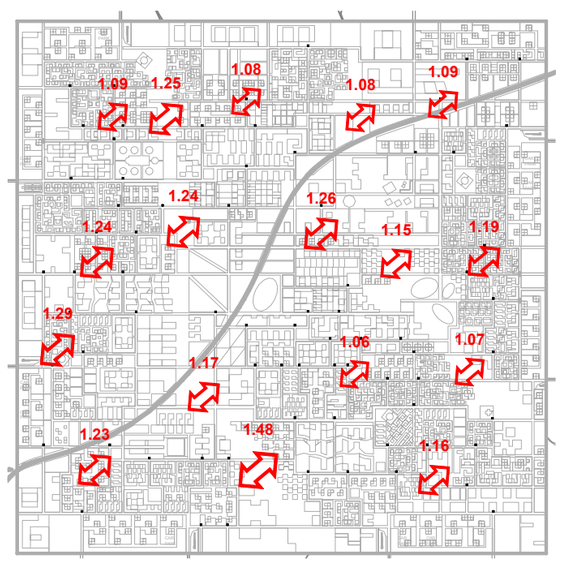


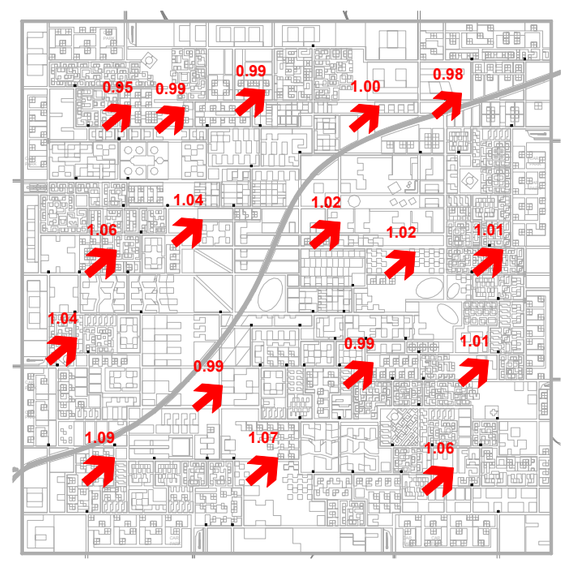




height: 50 m above ground level

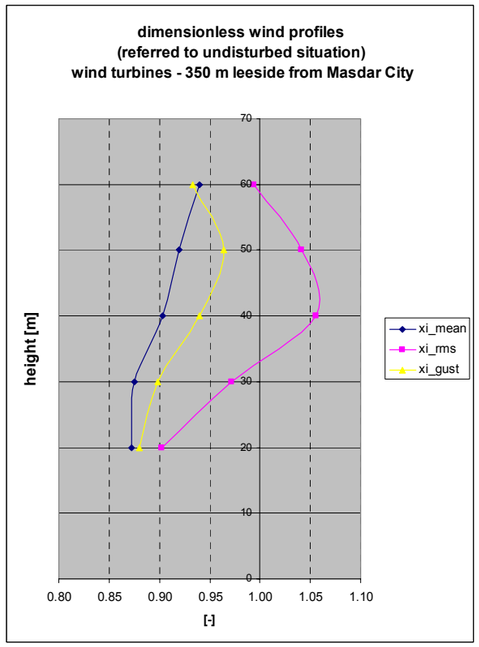


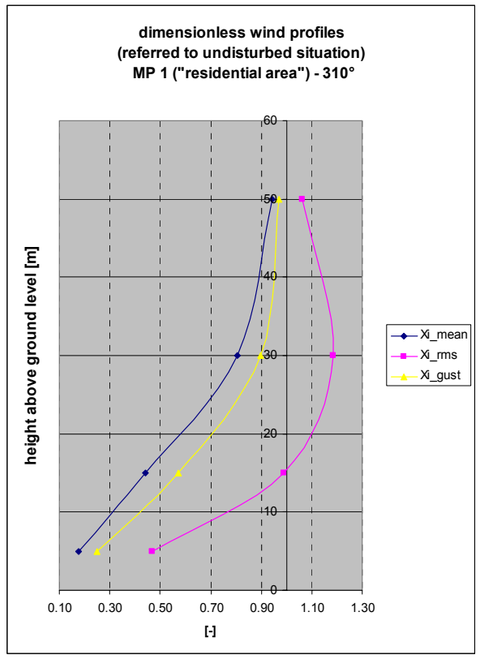


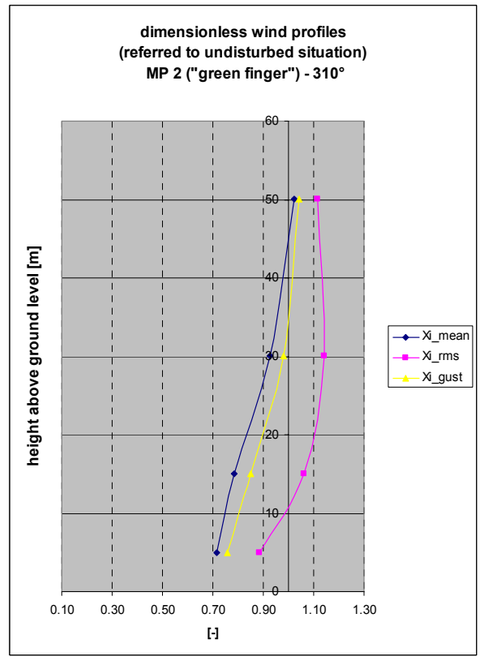


Vertical profiles of the wind speed relation factors at specific locations measured with hot-wire anemometers.

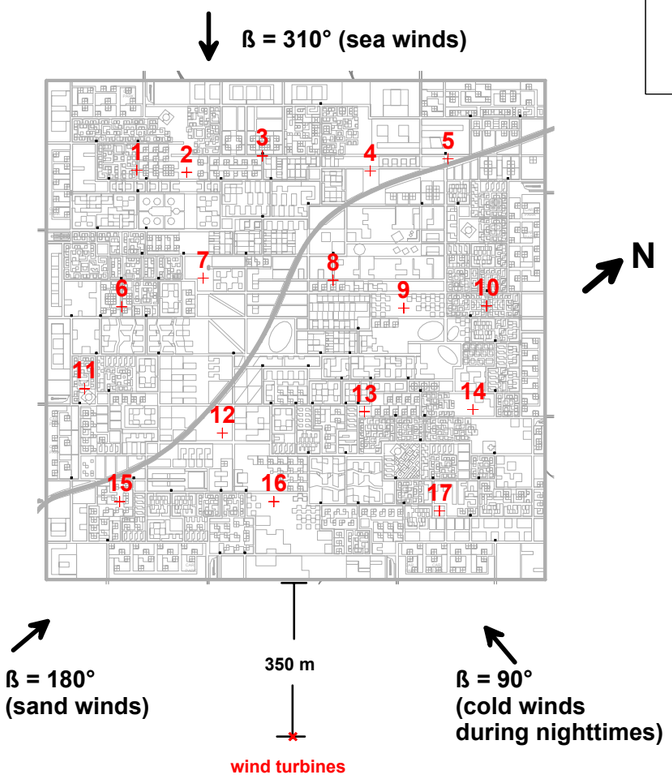
All values are related to the corresponding values for the undisturbed situation at the same height level.

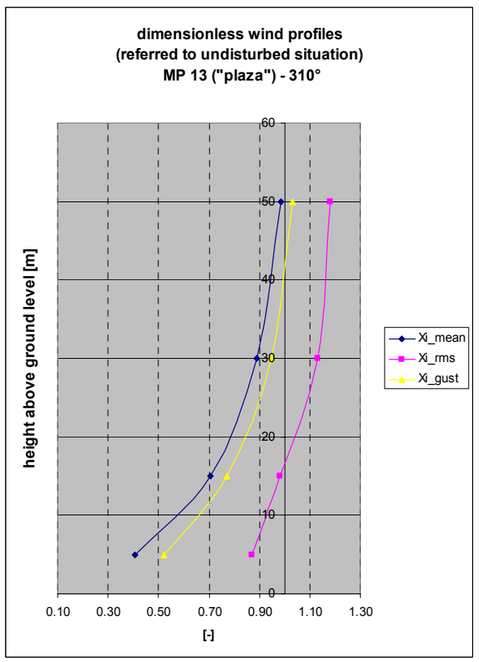


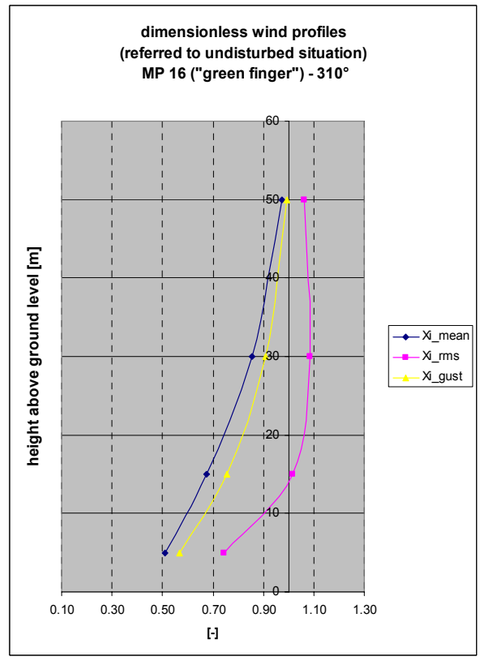




Location of the measuring points (MP) for the hot-wire measurements:



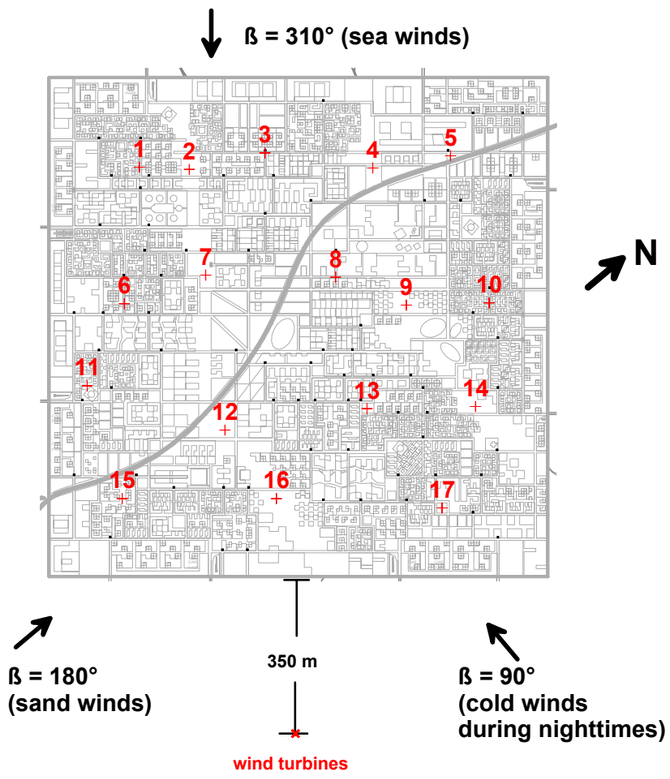


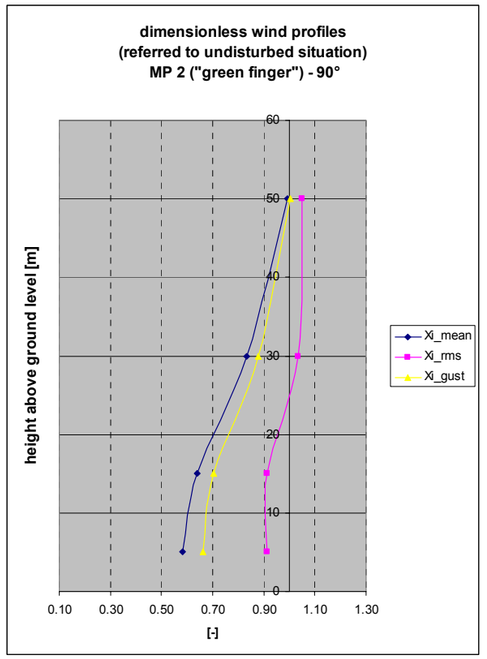


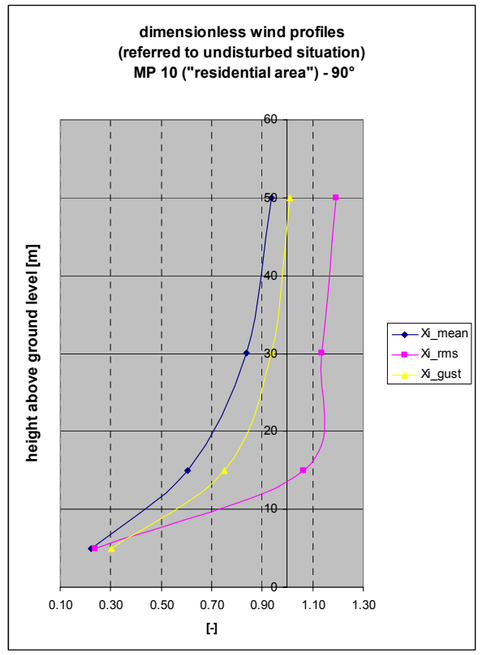
Vertical profiles of the wind speed relation factors at specific locations measured with hot-wire anemometers.

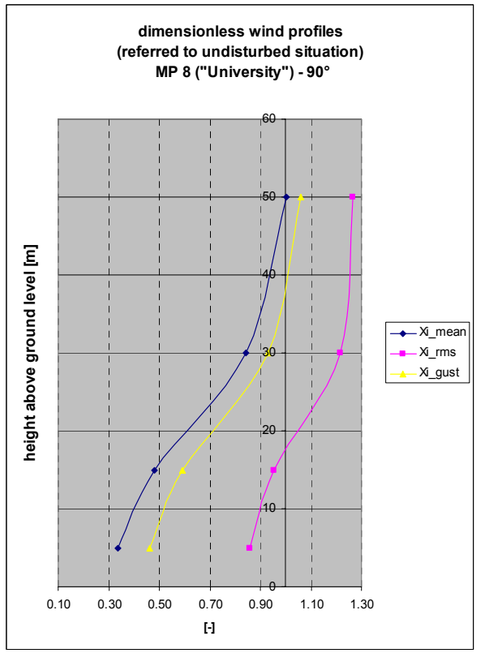
All values are related to the corresponding values for the undisturbed situation at the same height level.

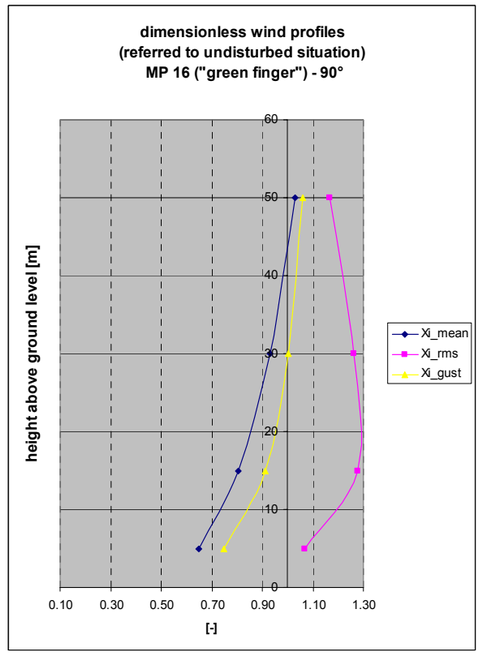
Location of the measuring points (MP) for the hot-wire measurements:







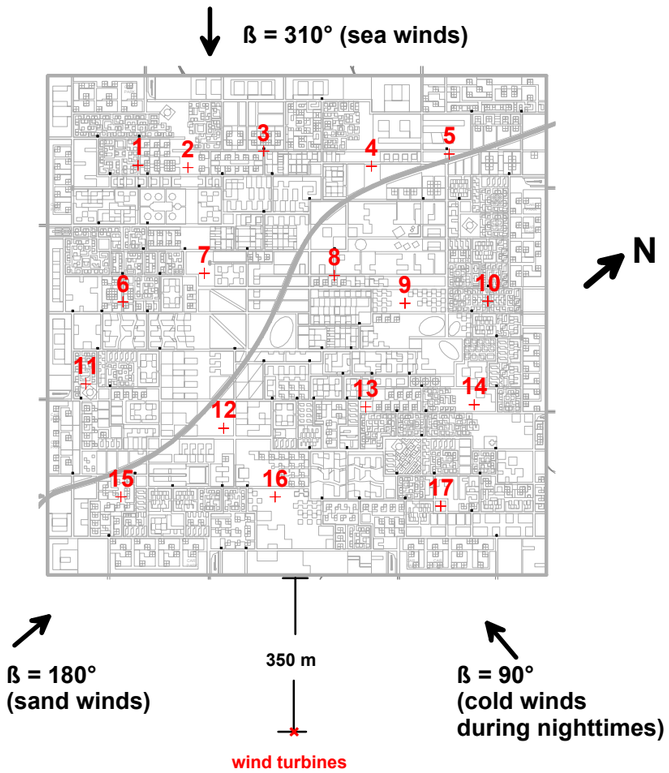


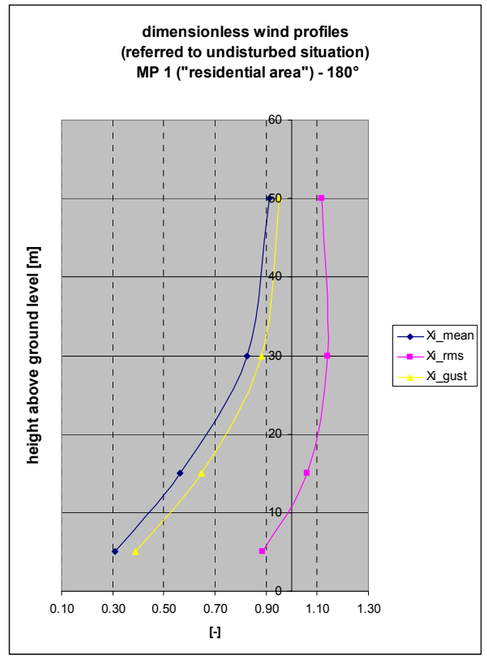


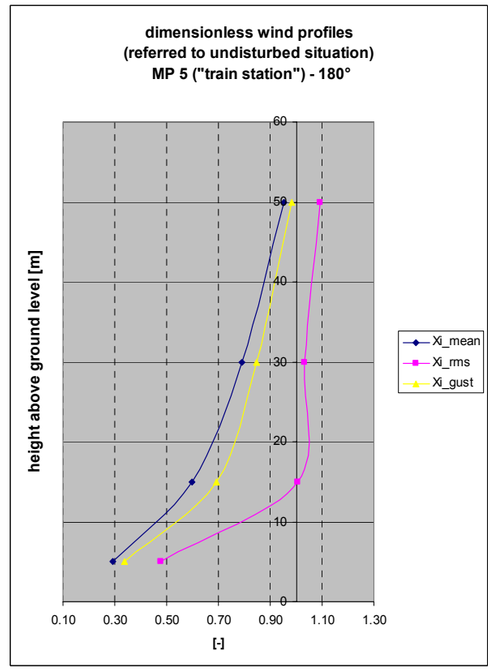
Vertical profiles of the wind speed realation factors at specific locations measured with hot-wire anemometers.

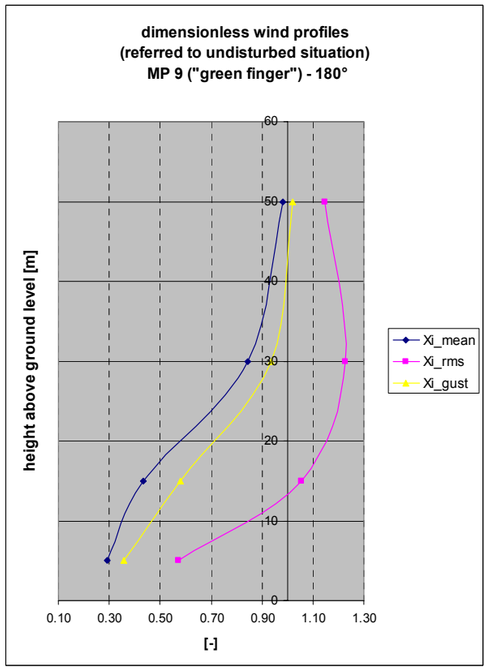
All values are related to the corresponding values for the undisturbed situation at the same height level.

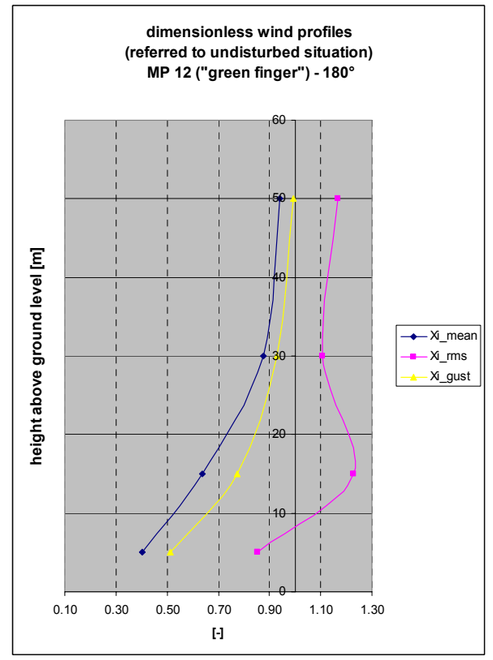
Location of the measuring points (MP) for the hot-wire measurements:











Tracer gas measurements
In order to investigate the fresh air ventilation properties within a narrow street canyon some tracer gas measurements were done at a typical street canyon (width about 7 m, height about 15 m, length about 100 m) within the wind tunnel model (at the location of MP 6 for the hot-wire measurements). Along this street part a line source for a suitable tracer gas (Propane) was built in at ground level. At 3 different positions along the facades in half height of the buildings time series of the tracer gas concentration was recorded with a FID (Flame Ionic Detector) under wind action in the wind tunnel.

The line source was emitting until equilibrium has been reached, then the source has been stopped and the decrease of the tracer gas concentration within the street canyon has been recorded during the wind tunnel operation for different wind direction.

From the recorded time series the air exchange rates AE (fresh air flux divided by the considered volume [1/h]) has been calculated. The air exchange rates indicate how often the air volume in the street canyon will be exchanged within an hour.

Due to the small scale of the city model the calculated values of the air exchange rates have to be considered only as rough estimations.

The measurements were performed at MP 6 for the wind directions 310°, 40°, 90°, 130°, 180° and 220°.

As a result the highest air exchange rates were measured for the wind direction 310° and 130° (longitudinal flow) to

AE (310°) = 5-8 1/h (based on the annual mean wind speed at site)

For easterly wind directions ß = 40° and 90° the air exchange rate is reduced to 30-40% of the corresponding value of the longitudinal flow.

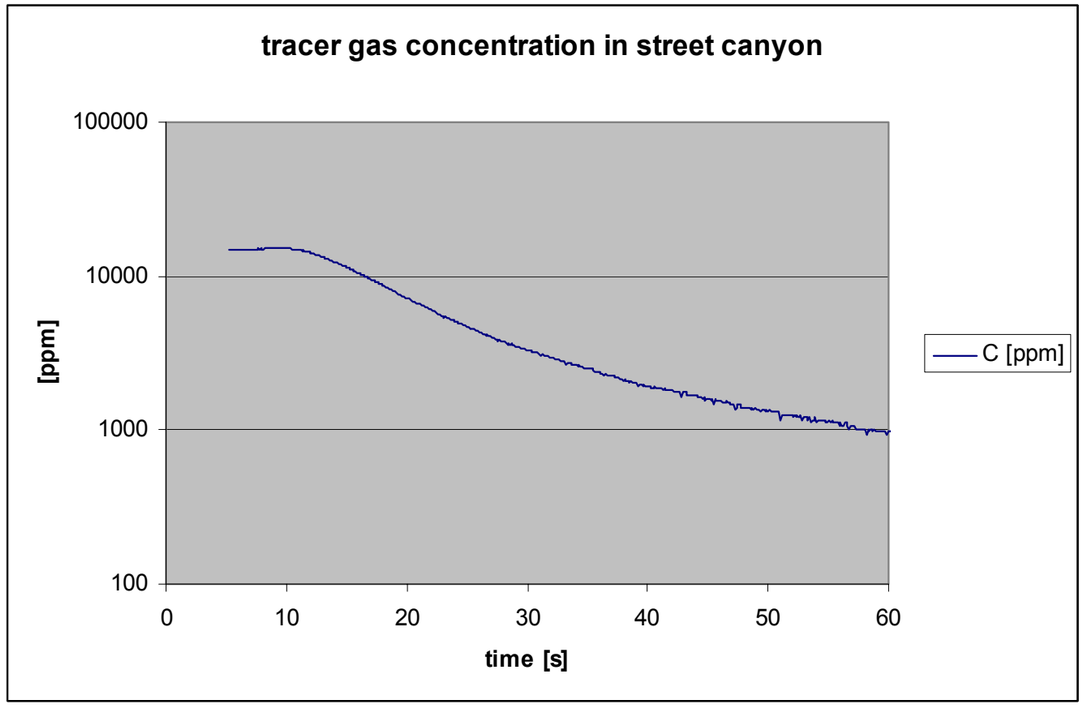
For 180° and 220° air exchange rates in the order of 40-60% of the longitudinal flow has been calculated.

For the wind direction 310° additional measurements with a proposed wind tower (about 20 m high above roof level) at the northern entrance of the street were done. With these small scale measurements no significant differences to the situation without wind tower were determined.

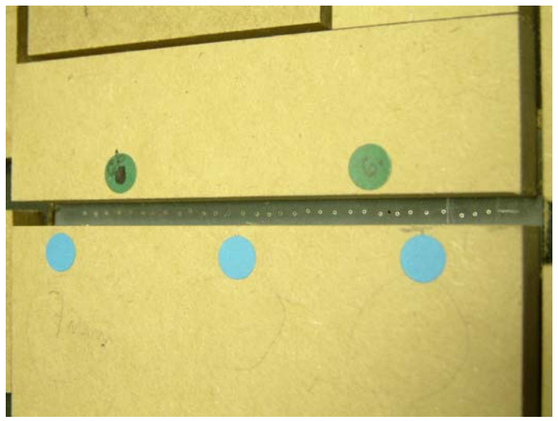
In order to receive more reliable results additional measurements in a larger scale sectional model of the city are recommended.

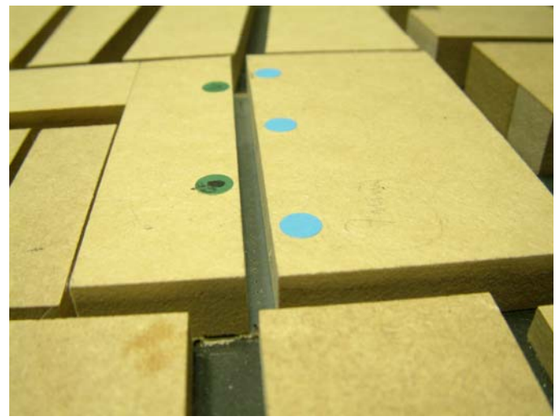
FID (Flame Ionic Detector) used for the concentration measurements

Measured time series of the tracer gas concentration in a narrow street canyon (MP6)



Street canyon at MP6 with built in tracer gas line source





Wind Tunnel Investigations
by Wacker Ingenieure, Germany

Conclusions
The measured wind profiles over mean roof height show no significant alterations along the fetch of the city due to the comparatively smooth building height transitions. The influence of the roughness impact of the city decreases with height. In 50 m height above the city ground level the decelerations of the wind speeds become more or less negligible. The profiles may be used as input parameters for detailed CFD-simulations.

The investigations indicate that the city ventilation at the green finger areas might be intensive. The wind speed reductions along the green fingers are comparatively small. Especially for the wind directions 310° and 90° sufficient air mixing capabilities are to be expected. For the wind direction 180°, which is often correlated with sand storms the air infiltration is reduced in comparison to the longitudinal wind flows.

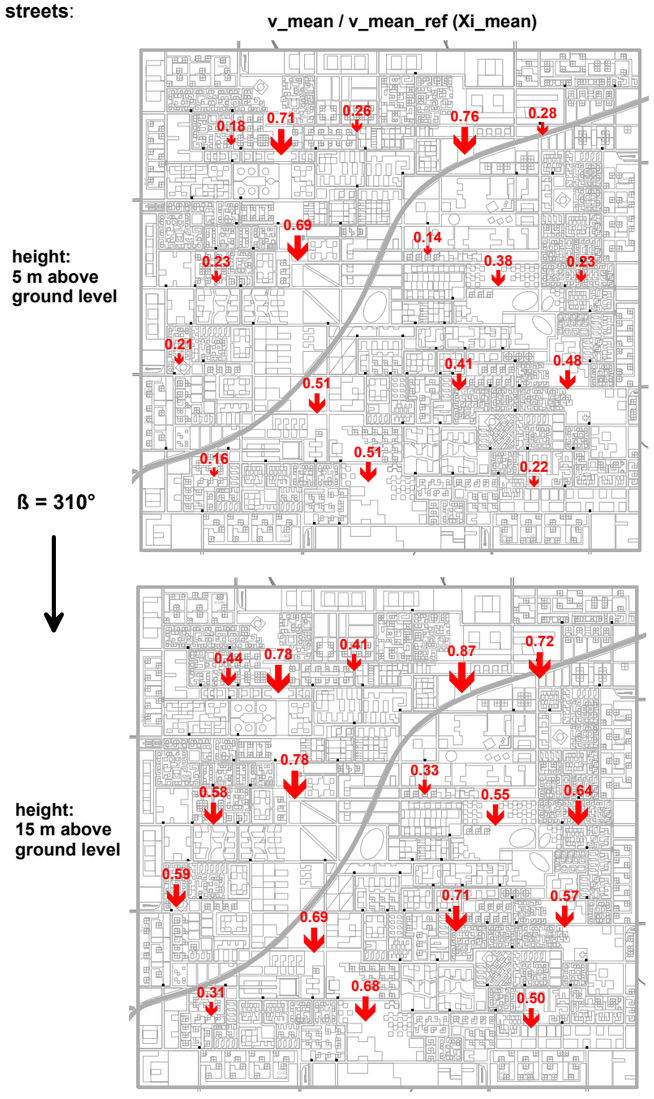
Contractions and obstacles within the green fingers lead to a (limited) area of reduced wind speeds on the leeside of the obstacles (shadowing effect). Hence, the amount of blocking buildings within the green fingers should be minimized with respect to an efficient ventilation capacity of the green fingers.

In the immediate neighborhood of exposed higher buildings within the green finger area increased wind speeds were detected due to acceleration effects. To proof, if local wind shelter measures might be affordable, additional wind comfort tests with a larger scale (section) model are recommended.

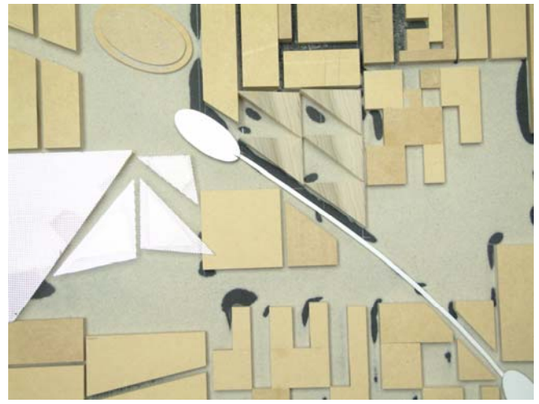
The wind speeds within the narrow streets are significantly reduced. The tracer gas measurements have shown, that air exchange rates less than 5-8 1/h at annual mean wind speeds are to be expected. Due to the significant importance of this aspect and some uncertainties caused by the small scale of the model, it is recommended to perform further tracer gas measurements with a larger scale (section) model.

With this larger scale model also the impact of the proposed wind towers on the ventilation of the street canyons can be analyzed in more detail.

Small wind speed reductions in the green finger area – significant wind speed reduction within the narrow streets:



Zones with increased wind speeds near exposed higher buildings:



Pyramid buildings / train station

Science Center

Effective transport of air from higher altitudes towards the ground for wind direction 90° within the green finger area

Introduction
Daylight planning in architecture is always determined by two basic perspectives that cannot be separated: science and art, or quantity and emotion, including all aspects of traditional and local cultural design principles.

We also have to consider the needs of the local inhabitants as well as of international visitors and employees. The technical aspects are well-defined by the requirements and standards of (day)light, energy and indoor climate planning whereas the emotional aspects are characterized of the individual impressions, experiences and expectations.

It is quite obvious that the emotionally and individually determined experience of a daylight situation can not be as well evaluated and estimated as the design principles and guidelines defined by the technical standards.

Vision is the primary sense through which we experience our environment and the architecture and light is the medium that reveals them. However, light is also energy and will change to heat when it falls on surfaces. This might cause thermal effects like overheating and air movement which have to be considered by the planning of the indoor climate and necessity and quality of shading devices. Planned, manipulated and controlled correctly daylight will minimise the energy consumption of artificial light and the HVAC.

It is a fact that sales are higher in stores with good natural light and worker productivity can increase by 20 percent with high availability or decrease by 20 percent with low or no availability of daylight. The benefit of using daylight in offices and educational buildings - the improvement of the performance - is also well documented. Daylight does not equal sunlight. Daylight is cool in colour and temperature, and by definition, daylighting actually involves keeping the most direct sunlight out of buildings and bringing diffuse light in.

The purpose of our work has to be to fulfil both the personal emotional needs of well-being and health and the practical communal needs of energy savings.

The aspects of sunlight and health have also to be taken into consideration. Daylight belongs to the basic human needs like air, food and drinking water. A lack of daylight might cause physical and mental disease. “Access to the sun is vitally important […] For example, in Arabic countries the traditional open courtyard-type house used to give women a private setting […] Replacement of these […] houses with smaller modern houses, apartment blocks and skyscrapers may have damaged their health considerably. Vitamin D deficiency is now common among Arab women and children even though they live in some of the sunniest countries in the world.” (Richard Hobday: The Light Revolution; 2006 Findhorn Press)

The target of our planning is to give a general guideline of daylight design and to propose architectural design related recommendations. Therefore we evaluate the following tasks:

Light Availability | Local Weather Data
Before the beginning of every kind of architectural, energetic and of course daylight planning an analysis of the local conditions and in our case of the weather especially the illuminance data has to be done.

Outdoor Shading Studies
The first step in planning of the daylight related design is to create an overview of the daylight and solar exposure of the buildings, the city, the landscape, the streets etc. Combined with the local daylight availability this studies set up the base for the further design steps.

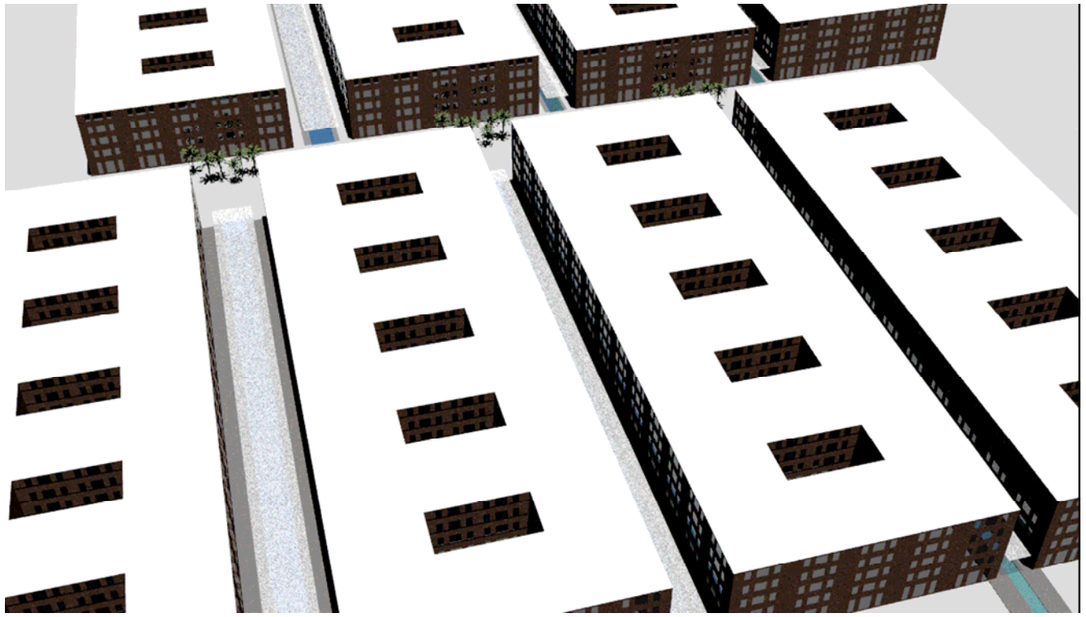
Outdoor Illuminance Studies | CIE-Standard
This studies help to understand the level of daylighting we will get in the streets for different street widths and shading possibilities and give an impression of the outdoor daylight and solar exposure as they can be received by the inhabitants and pedestrians. The daylight level given by the daylight factor is proportional to the opening or the closeness of the public spaces.

Indoor Illuminance Studies | CIE-Standard
The indoor illuminance is one of the main analysis to design the building-, room- and façade- proportions, the glazing measurements and types.

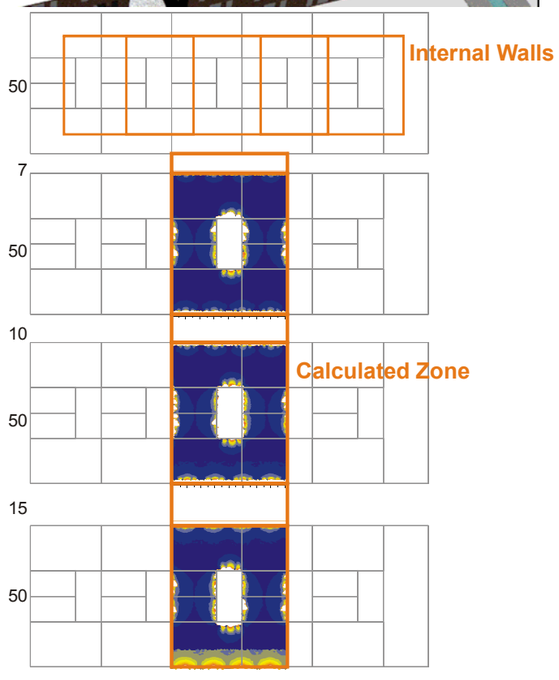
The Matrix
The indoor illuminance studies are developed further to the matrix. The matrix as the result is a tabular worksheet where the availability and quality of the indoor illuminance is shown for different stores and street- and courtyard distances.

Indoor Illuminance Studies | Direct Sunlight and Diffuse Daylight
Equal to the indoor illuminance studies with the CIE-standard (overcast sky) the indoor illuminance is also calculated with the sunny sky. Since the sun is shining more than 90% of the yearly daytime the recommendations and guidelines for the daylight design cannot only base on the CIE-standard – as they do mostly in Europe or north America – but have to take into consideration the influence of the direct sunlight shining or not shining into the room.

Building Typologies | General Guidelines and Design Related Recommendations
The results of the different daylight studies leads us to the general guidelines which have to be observed to achieve the energy saving and daylight quality target and to the design related recommendations for the building typologies of Foster Architects.



the generic daylight simulation model with 15, 10 and 7m wide streets and 9 x 18 m courtyards



Potential of Using Daylight
The greatest benefit in using daylight is its potential in saving energy. Daylight is the most efficient light source for indoor lighting. The “production” of light in proportion to the irradiance is higher than it will be at any artificial light source with neutral white colour. That is: Daylight is the “coolest” possible light source. Using daylight decreases the electric energy consumption both for the artificial light and for the conditioning of the indoor climate. Therefore it is, for example, very important to let in some daylight even with closed shading devices on sunny days. See the histogram down right, showing the lighting efficiency in lumen/watt for some light sources.

Quality of Daylight – Visual Comfort
Visual comfort for the occupants contains uniform and constant indoor lighting with daylight, a high daylight autonomy - that is as much daylight as possible and preferably low necessity of artificial light -, protection against glare and overheating irradiance, an open appearance of the room with a good visual relation to the outside and, where necessary, an ergonomic illuminance of the workplace. Daylight belongs to the basic human needs like air, food and drinking water. A lack of daylight might cause physical and mental disease. Daylight is widely accepted to have a positive psychological effect on the human being, and consequently more cases of mental health problems are registered during the winter months than during the summer months due to the shortened periods of daylight. Cases of depression specifically linked to limited daylight are referred to as seasonal affective disorder. Artificial light cannot entirely substitute daylight. Even though the artificial light can provide a more constant illuminance with fewer disturbances like glare the most people prefer a workplace with daylight near by a window. Windows also provide the visual relation to the outside which is very important for the well being of humans.

Definitions and Targets

Illuminance
Illuminance is the total luminous flux incident on a surface, per unit area measured in lux (lx). The illuminance for workspaces should be 500lx for artificial light and 400lx for daylight.

Luminance
Luminance is a photometric measure of the density of luminous intensity in a given direction. It describes the amount of light that passes through or is emitted from a particular area, and falls within a given solid angle. The SI unit for luminance is candela per square metre (cd/m²). Luminance is often used to characterize emission or reflection from flat, diffuse surfaces. The luminance indicates how much luminous power will be perceived by an eye looking at the surface from a particular angle of view. Luminance is thus an indicator of how bright the surface will appear. In this case, the solid angle of interest is the solid angle subtended by the eye's pupil. A typical computer display emits between 50 and 300 cd/m².

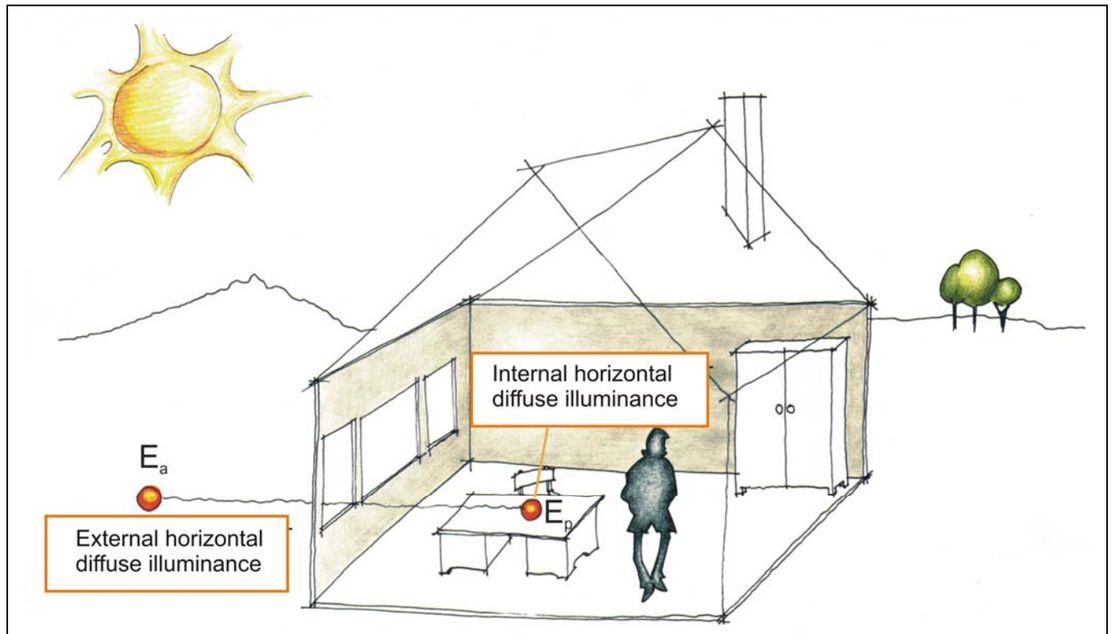
Daylight Factor, Daylight Coefficient
As shown in the picture at the top the daylight factor (DF) describes the subjective daylight quality in a room and is the ratio of external horizontal diffuse illuminance (Ea) over internal horizontal diffuse illuminance at a specific point (Ep), expressed in per cent. The higher the DF, the more natural light is available in the room. It is expressed as such: DF = Ep / Ea x 100%. The daylight factor is always measured or calculated for a standard CIE overcast sky.

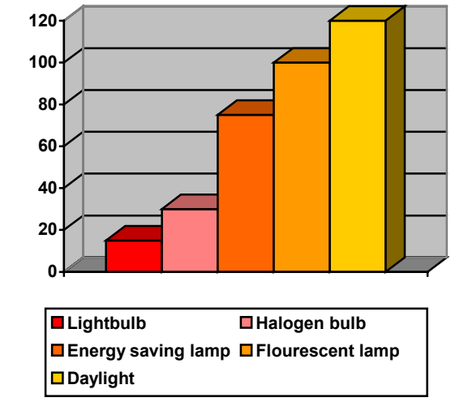
Daylight Autonomy
The daylight autonomy is the time at a specific point (e.g. workspace) when there is enough daylight (more than 400lx for daylight orientated workspaces) and thus no artificial light has to be switched on. For very good indoor daylight quality the daylight autonomy has to be approximately 80% from 08.00 am to 05.00 pm. That is 2900 hours of the year.

Glare and Contrast
Glare is difficulty seeing in the presence of bright light such as direct or reflected sunlight or artificial light. Contrast is the difference in brightness (luminance) of adjacent surfaces. A too high contrast will exceed the possibility of adaptation of the human’s eye. The contrast of very close-by surfaces should not exceed a ratio of approximately 1:3 to 1:5. The contrast of the peripheral field of vision should not exceed 1:10.

Shading Devices
Apart from the function to prevent from overheating radiation a shading device has to protect against glare and too high contrasts. It should also allow the daylight to illuminate the room even when it is closed as described above. The rendering down left shows a situation where the Venetian blinds are closed in the lower part to protect against glare and radiation and are open in the overhead part to let in some daylight without the risk of glare. As far as possible it has to avoid switching on artificial light caused by closed shading during daytime.

Short Guidelines
- Good ergonomic light is important for the quality of work and helps to avoid accidents
- As much direct artificial light as possible as much indirect light as necessary
- The direct light has to be orientated to the work space
- High contrasts have to be avoided
- The reflectance of the surfaces should approximately be: ceiling 70%, walls 50% and floors 30%
- The artificial light should interact with the daylight
- The uniformity ratio should be as low as possible
- But a certain variety of luminaire types and illuminance levels makes the room more agreeable
- A daylight dependent light control decreases the energy consumption
- The zoning of artificial light will also decrease the energy consumption as artificial light near by the windows is switched on later than the light in the depth of the room





Potential of Daylight in Abu Dhabi
The diagrams at the top and down left are showing how many hours per year the illuminance (lux=lx) will exceed a special value in Abu Dhabi (yellow) and in London (green). That is the annual frequency of daylight illuminance. The light yellow and light green arrays are showing the diffuse horizontal illuminance values. That is the daylight emitted by the cloudy sky or the clear sky without sun received by a horizontal surface. The darker yellow and green arrays are indicating the direct horizontal illuminance - the sunlight. The total of both values is called global horizontal illuminance. Daylight is the combination of all direct and indirect sunlight outdoors during the daytime. This includes direct sunlight, diffuse sky radiation, and (often) both of these reflected from the Earth and terrestrial objects. The potential in using daylight in Abu Dhabi is, of course, very high.

Examples (see diagram at the top)

- The external diffuse horizontal illuminance exceeds in London 10'000 lx on 2'900 hours per year and in Abu Dhabi on 3760 hours.
- The external diffuse horizontal illuminance exceeds in Abu Dhabi 15'000 lx on 2'900 hours (ref. London) per year.
- The external global horizontal illuminance exceeds in Abu Dhabi 35'000 lx on 2'900 hours (ref. London) per year.
- For the equal level of daylight autonomy the daylight factor in Abu Dhabi can be much lower than it has to be in London.

For very good indoor daylight quality the daylight autonomy has to be approximately 80% from 08.00 am to 05.00 pm. That is 2900 hours of the year. This requires a daylight factor of 4% in London and, caused by the higher illuminance frequency, 2.7% in Abu Dhabi.
(see also above "Daylight Autonomy")

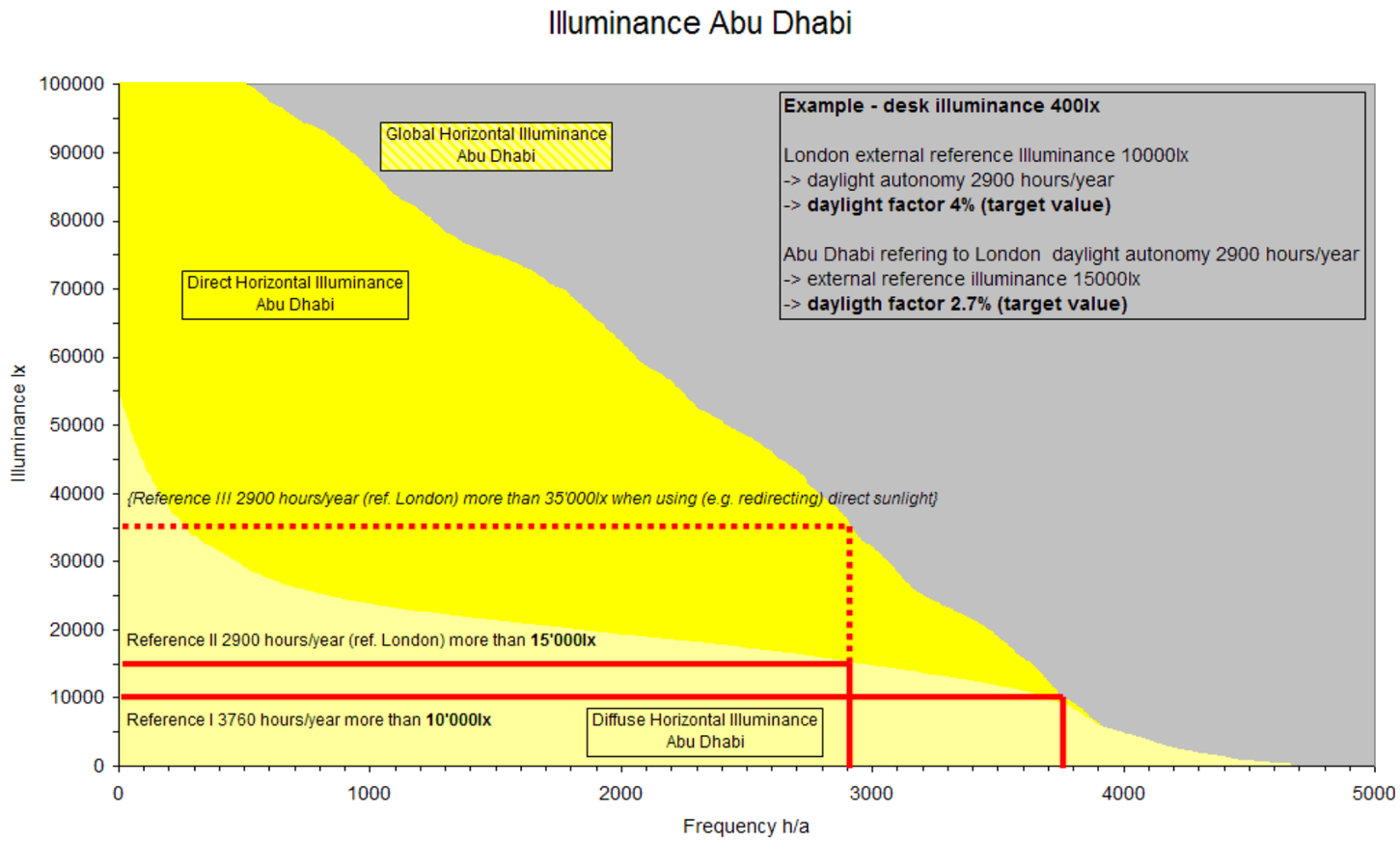
The following examples show the daylight autonomy, or rather, the hours of artificial light needed from 8 a.m. til 18 p.m. for an assumed daylight factor of 2%.

The first spreadsheet gives the hours of artificial light needed if only the diffuse illuminance is taken into consideration. This is the planning standard in North Europe or North America where the part of overcast and cloudy days is about 50%.

hours of artificial light		per day	part
January	233	7,5	42%
February	223	7,7	43%
March	159	5,1	28%
April	137	4,6	25%
May	122	3,9	22%
June	134	4,5	25%
Juli	73	2,4	13%
August	81	2,6	15%
September	118	3,9	22%
Oktober	228	7,4	41%
November	246	8,2	46%
December	233	7,5	42%
Year	1987	5,4	30%

The second spreadsheet gives the hours of artificial light needed if also the direct illuminance is included due to fact that we have 90-95% sunny days in Abu Dhabi. It is quite evident that the potential of saving electricity of artificial light and vice versa the benefit of using daylight is very high in Abu Dahbi.

hours of artificial light		per day	part
January	50	1,6	9%
February	31	1,1	6%
March	39	1,3	7%
April	27	0,9	5%
May	3	0,1	1%
June	0	0,0	0%
Juli	0	0,0	0%
August	16	0,5	3%
September	30	1,0	6%
Oktober	37	1,2	7%
November	63	2,1	12%
December	69	2,2	12%
Year	365	1,0	6%



Daylight | Basics
Sun path

Sun path
Before the beginning of every kind of architectural, energetic and of course daylight planning an analysis of the local conditions and in our case of the weather especially the illuminance data has to be done.

Location
Abu Dhabi is located 24°25’ northern latitude near by the Tropic of cancer which currently lies 23° 26′ north of the Equator.

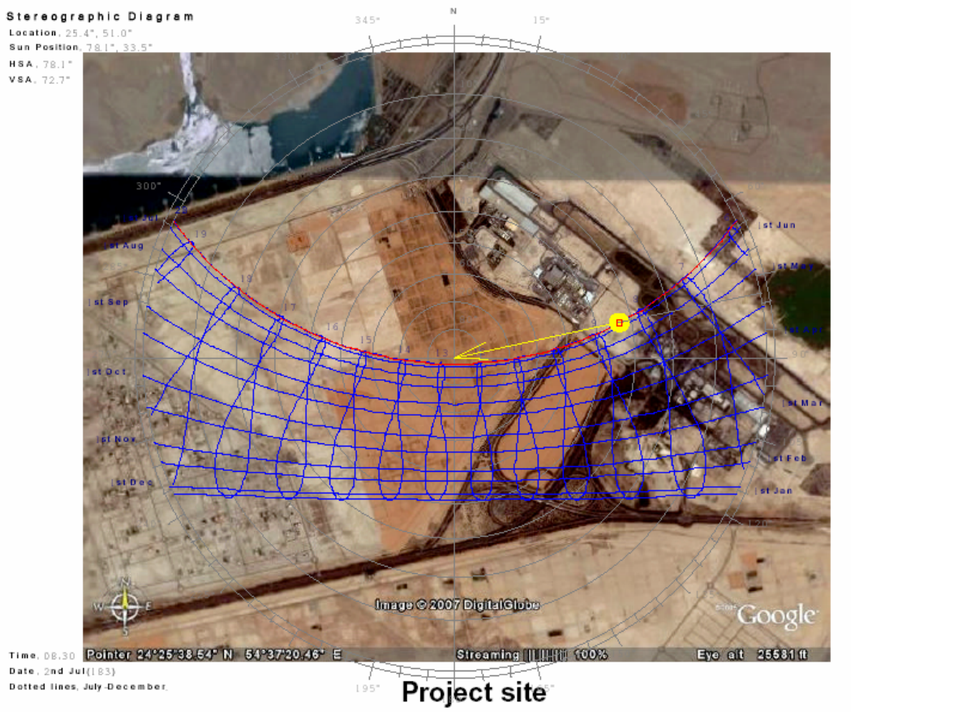
The Tropic of Cancer
The Tropic of Cancer, or Northern tropic, is the most northerly latitude at which the sun can appear directly overhead at noon. This event occurs at the June solstice, when the northern hemisphere is tilted towards the sun to its maximum extent. A solstice occurs twice a year, whenever Earth's axis tilts the most toward or away from the Sun, causing the Sun to be farthest north or south at noon. North of this latitude are the subtropics and Northern Temperate Zone.

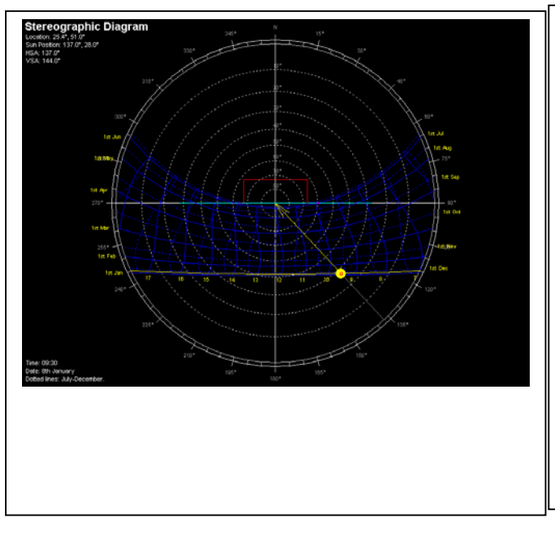
Winter Solstice (December 21)
It begins winter in the Northern Hemisphere and is the shortest day of the year. The sun is low in the sky, at 47 degrees from zenith at noon.

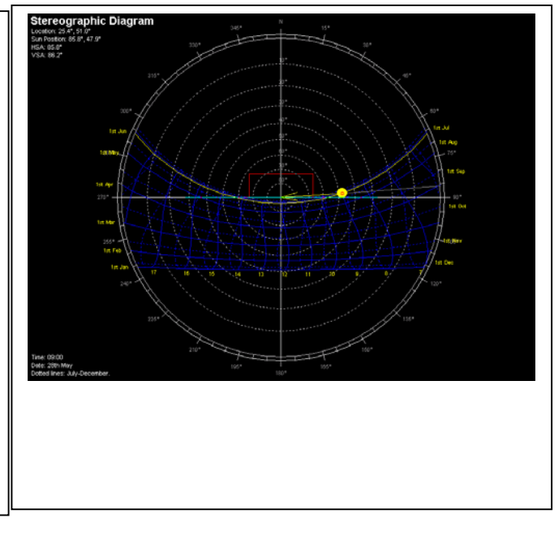
Equinox (March 21, September 22)
This days begins spring or fall respectively in the Northern Hemisphere. There are twelve hours of daylight and twelve hours of darkness at all points on the earth’s surface on the two equinoxes. Sunrise is at 6 a.m. and sunset is at 6 p.m. local (solar) time for most points on the earth’s surface. Abu Dhabi experiences 12 hours of daylight and 12 hours of darkness. The sun is 23.5 degrees off of the zenith.

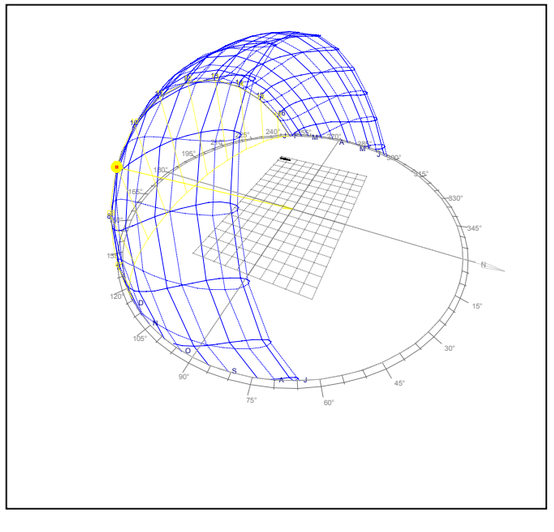
Summer Solstice (June 21)
This day begins summer in the Northern Hemisphere. It is the longest day of the year. The sun is nearly directly overhead at noon.

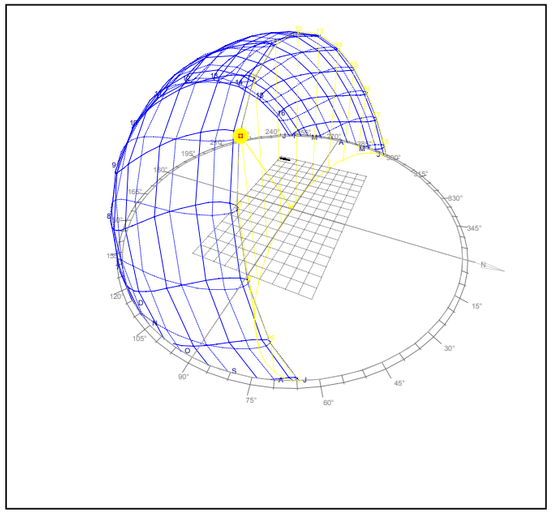
These three days are the “characteristic days” for all kind of daylight studies and simulations.











Overview
The first step in planning of the daylight related design is to create an overview of the daylight and solar exposure of the buildings, the city, the landscape, the streets etc. Combined with the local daylight availability this studies set up the base for the further design steps.

Exposure lines graphics
The exposure lines graphics (see picture on the top) show the sun path over the day for each month in Cartesian coordinates.

The vertical ordinate (y-axis) is the sun height wherein 0° is the sun position at the horizon and 90° at the zenith. The horizontal abscissa (x-axis) is the orientation wherein east is 90°, south is 180°, west is 270° and north is 0° (not shown in the graphics).

The sun exposure is drawn as a coloured hatching pattern overlaying the sun path. It is shown for three positions in the streets: the left side, the right side and the centre.

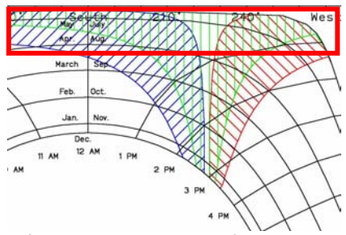
The graphics header gives information about the street orientation and the ratio of building height to street width. So the exposure lines graphics can be used generally for all street widths. For example a building height of 18 meters and a street width of 9 meters is the ratio H : W = 2 : 1. The ratio is independent from the arcades size.

Results
The time of solar exposure in the streets can be taken easily in the following exposure line graphics.

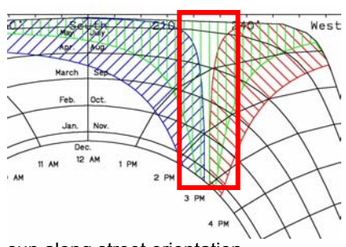
The higher the ratio of building height to street width is the less is the exposure time. At the threshold of a ratio of about 3:1 there is no more great progress in the limitation of exposure time.

There are two cases when it will always be a solar exposure at the street level:
- the sun is at the zenith
- the sun has the same orientation like the street

In both cases the relative sunbeam direction is parallel to the street orientation and the buildings cannot shadow the street (see pictures below).



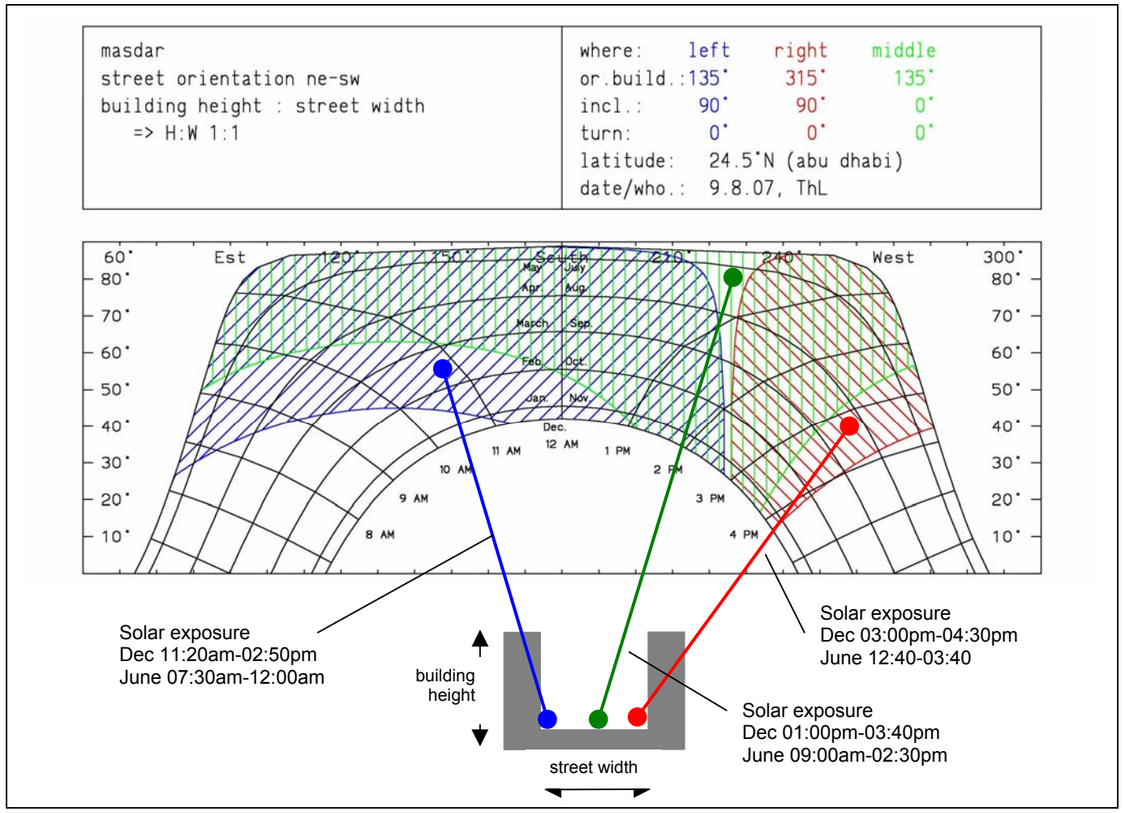
solar exposure t summer time

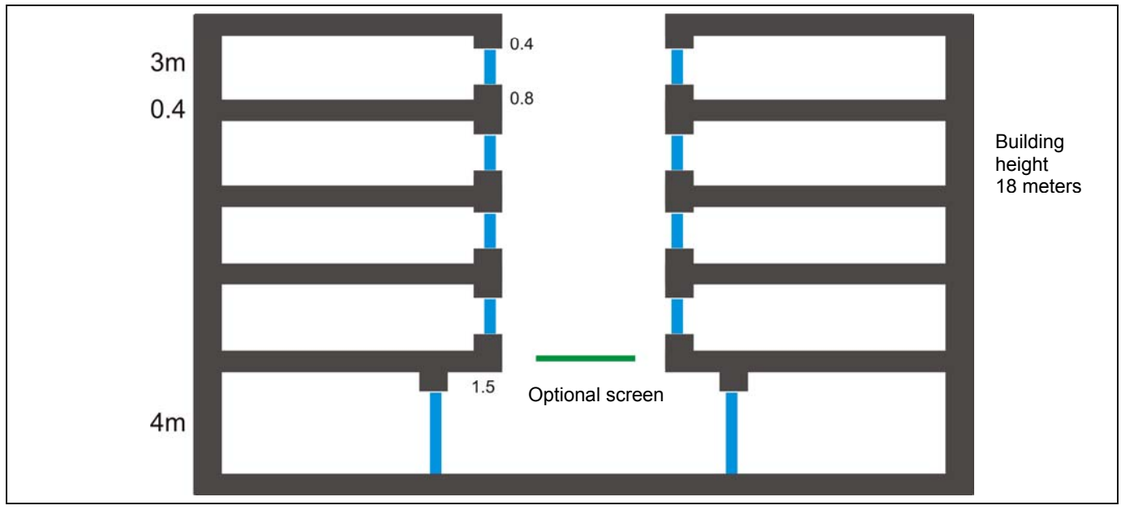


sun along street orientation

The Model
The building heights in the following studies are 18 meters which are made by the ground floor with 4 meters height, 4 levels with 3 meters height above the ground floor and 0.4 meters ceiling thickness per floor.

Further model size information can be seen in the picture at the bottom.



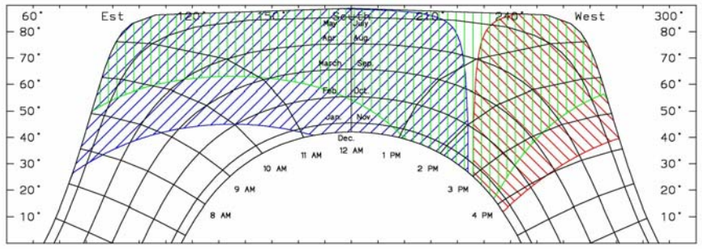


Overview
On this page you will find the Exposure Lines Graphics for streets directed northeast / southwest. It is quite obvious that the buildings cannot shade direct sunlight coming from a sun position near the zenith or the direction southwest.

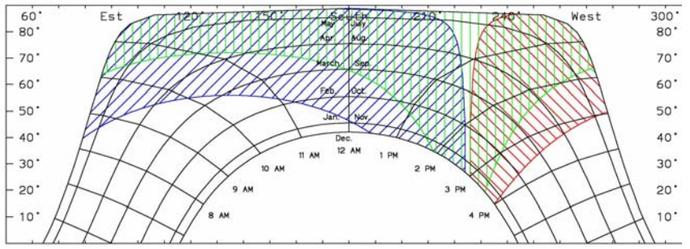
Low ratios of the building height to the street width of approx. 1:1 to 2:1, allows the sun to shine into the streets for the most time of the day. The solar exposure is in December approximately 3 hours and in June approximately 4-5 hours.

Higher ratios cause more shading. Ratios above approx. 3:1 cause only a little more progress on that. The solar exposure is in December approximately 1 hour and in June approximately 2-3 hours.

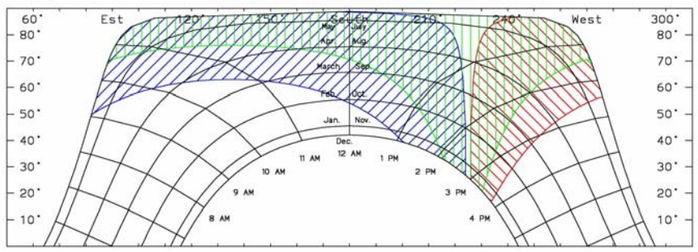
masdar street orientation ne-sw building height : street width => H:W 1:1	where: left right middle or.build.: 135° 315° 135° incl.: 90° 90° 0° turn: 0° 0° 0° latitude: 24.5°N (abu dhabi) date/who.: 9.8.07, ThL



masdar street orientation ne-sw building height : street width => H:W 1.5:1	where: left right middle or.build.: 135° 315° 135° incl.: 90° 90° 0° turn: 0° 0° 0° latitude: 24.5°N (abu dhabi) date/who.: 9.8.07, ThL



masdar street orientation ne-sw building height : street width => H:W 2:1	where: left right middle or.build.: 135° 315° 135° incl.: 90° 90° 0° turn: 0° 0° 0° latitude: 24.5°N (abu dhabi) date/who.: 9.8.07, ThL



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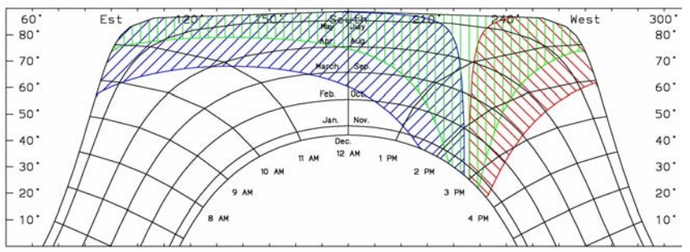

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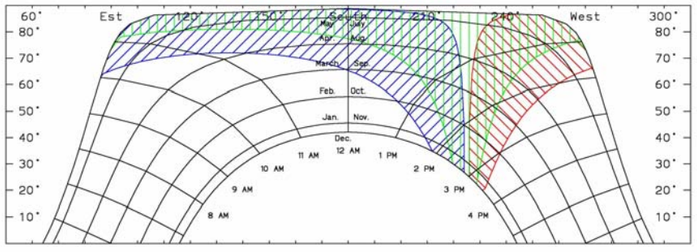

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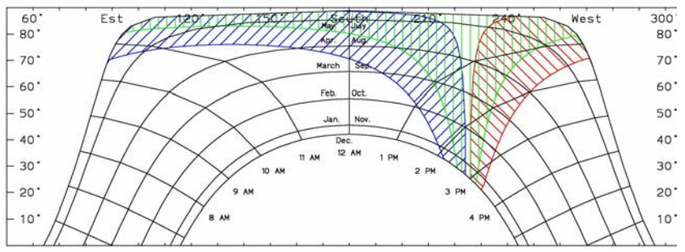
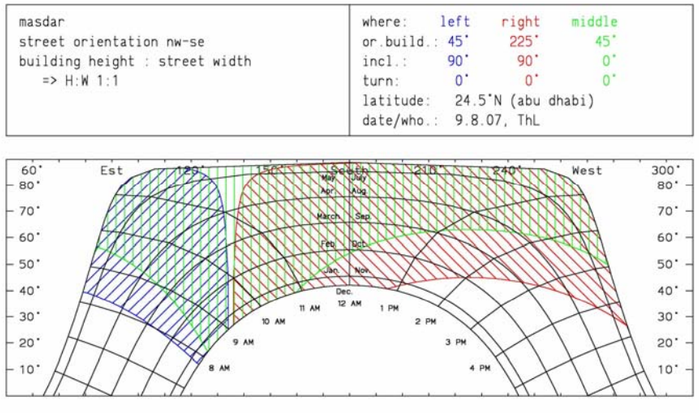
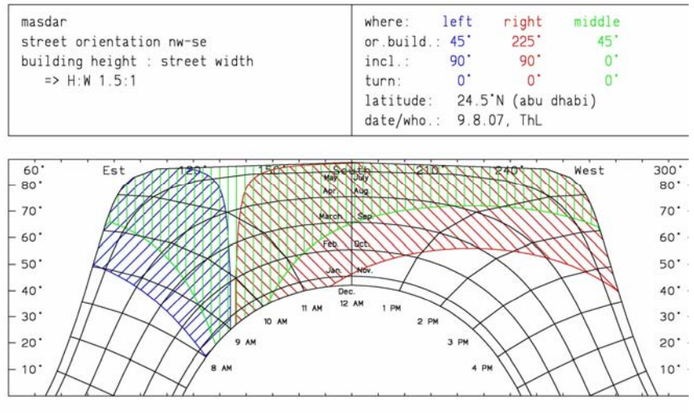


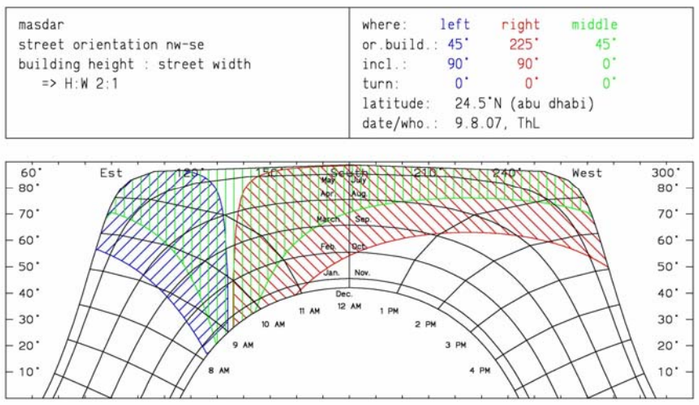
Overview
On this page you will find the Exposure Lines Graphics for streets directed northwest / southeast. It is quite obvious that the buildings cannot shade direct sunlight coming from a sun position near the zenith or the direction southeast.

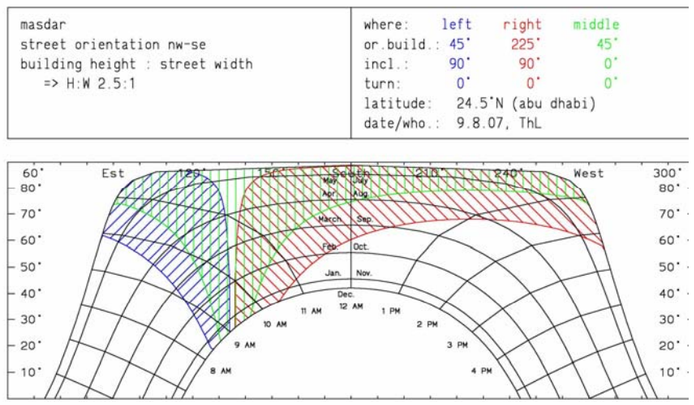
Low ratios of the building height to the street width of approx. 1:1 to 2:1, allows the sun to shine into the streets for the most time of the day. The solar exposure is in December approximately 3 hours and in June approximately 4-5 hours.

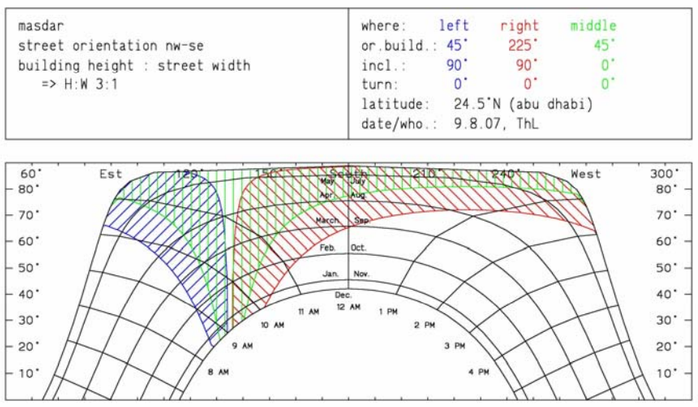
Higher ratios cause more shading. Ratios above approx. 3:1 cause only a little more progress on that. The solar exposure is in December approximately 1 hour and in June approximately 2-3 hours.

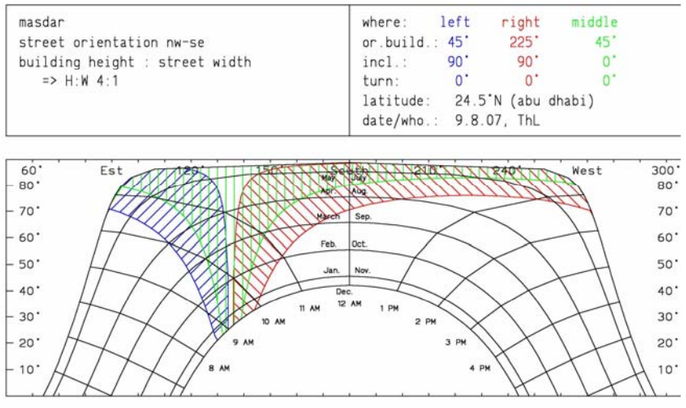












Additionally to the Exposure Lines shown above which are described in very technical ´(and perhaps also a little uninspiring for “non-engineers”) graphics we made some renderings for several street widths and horizontal shading devices over the streets. The renderings are generated from an architectural model with the CAD program Rhinoceros. The model itself is a three dimensional description of the architecture and scene and contains the geometry, the viewpoint, some texture and the daylight, sun and shading information.

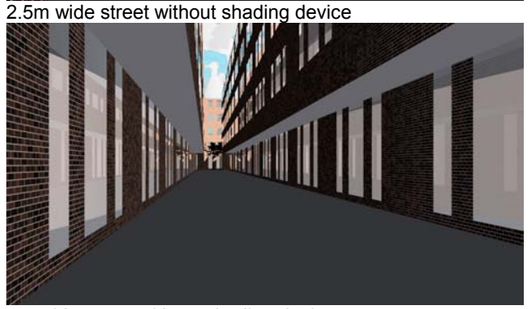
The building heights in this studies are always 18 meters which are made by the ground floor with 4 meters height, 4 levels with 3 meters height above the ground floor and 0.4 meters ceiling thickness per floor.

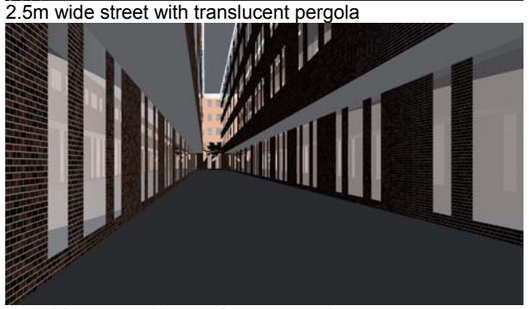
At the beginning of the design studies the street widths which have to be compared are 15 meters, 10 meters and 7 meters. The facades of the ground floor are 1.5 meters shifted backward so that we get an arcade on each side of the street.

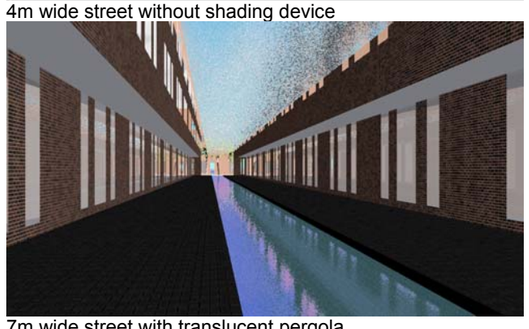
Further in the consecutive planning after some iterative steps of both the daylight and the climate engineering we added renderings of the 4 meters and 2.5 meters street widths which are preferred by the architects. As we will show later in this report this relative narrow street widths will only work in daylight matters with windows towards a wider street or courtyard on the opposite room side.

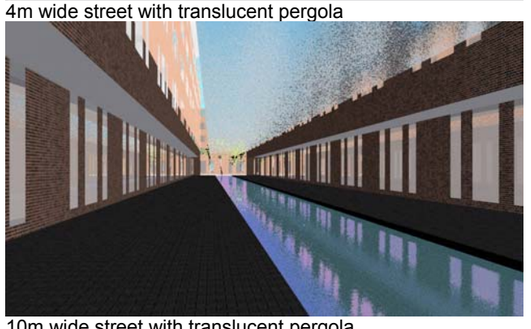
2.5m wide street without shading device

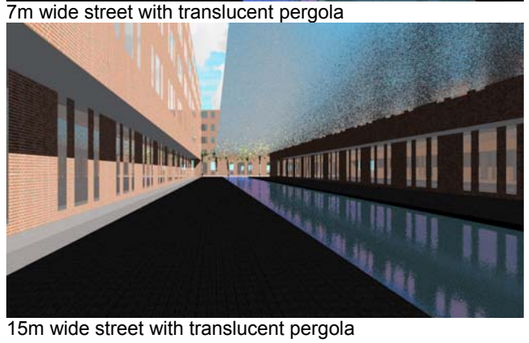
2.5m wide street with translucent pergola

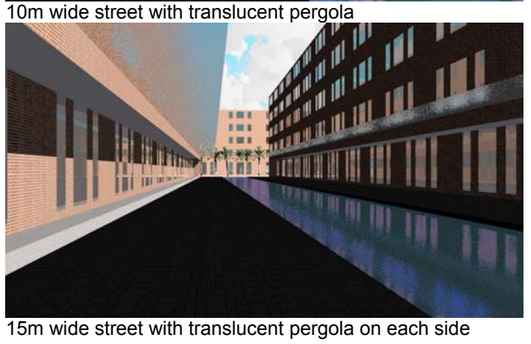

4m wide street without shading device


4m wide street with translucent pergola


7m wide street with translucent pergola


10m wide street with translucent pergola


15m wide street with translucent pergola

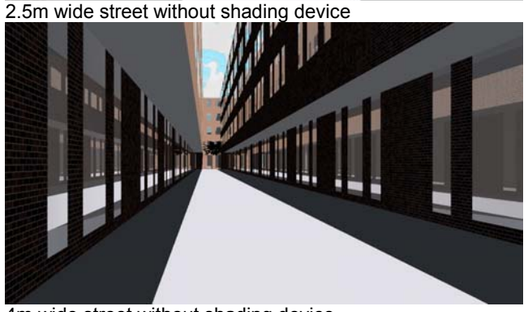

15m wide street with translucent pergola on each side

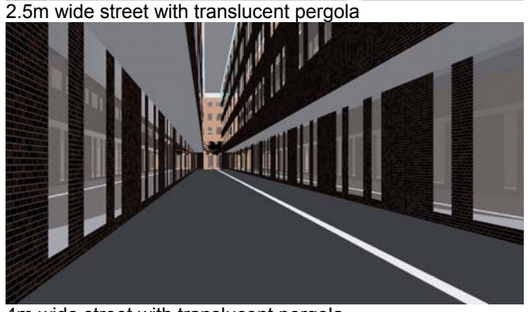
June 9am

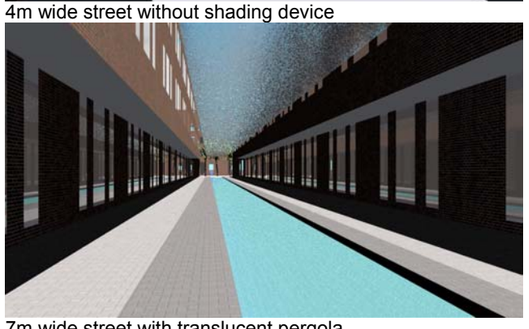
Daylight | Outdoor
Shading Renderings | sunny June 12am and 3pm

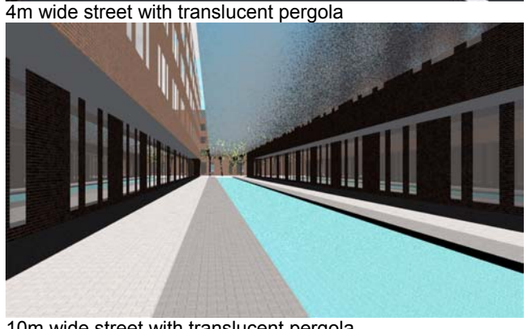
2.5m wide street without shading device

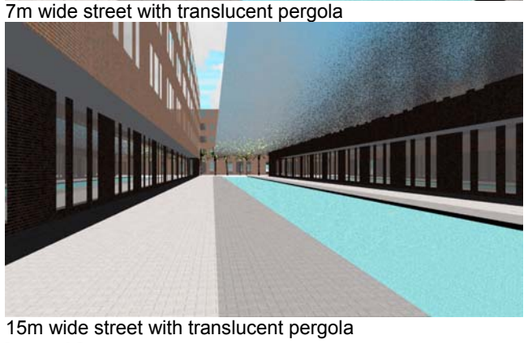
2.5m wide street with translucent pergola

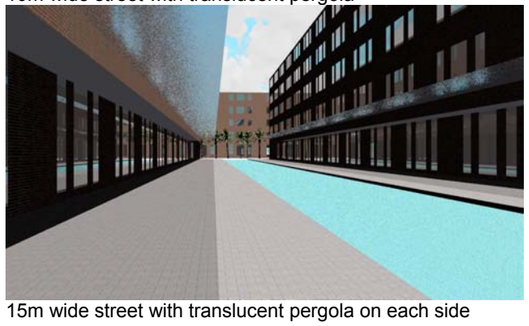

4m wide street without shading device


4m wide street with translucent pergola


7m wide street with translucent pergola


10m wide street with translucent pergola

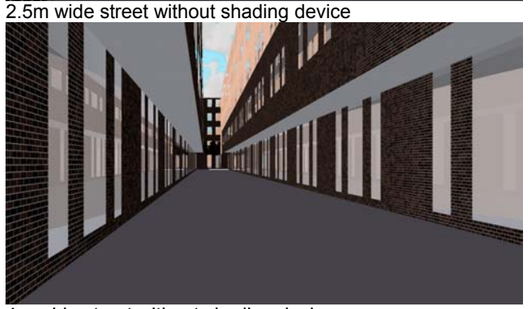

15m wide street with translucent pergola

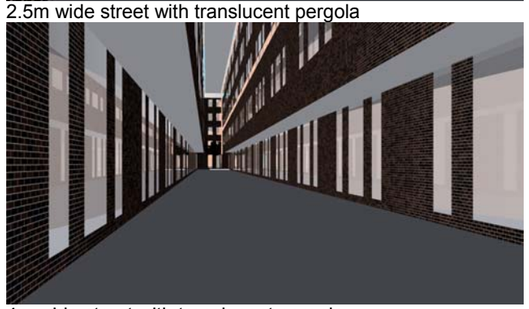

15m wide street with translucent pergola on each side

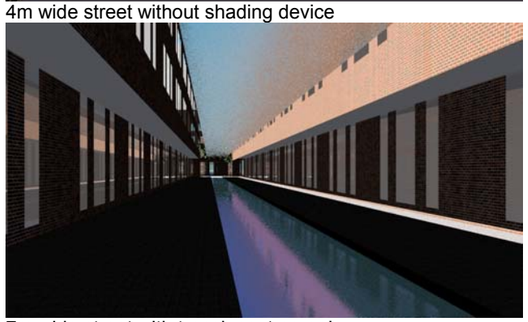
June 12am

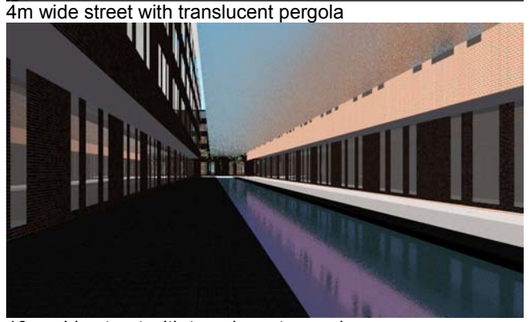
2.5m wide street without shading device

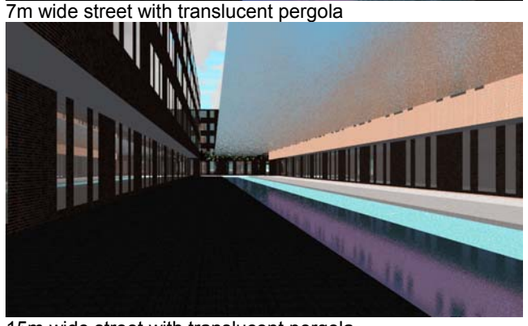
2.5m wide street with translucent pergola


4m wide street without shading device


4m wide street with translucent pergola


7m wide street with translucent pergola


10m wide street with translucent pergola


15m wide street with translucent pergola

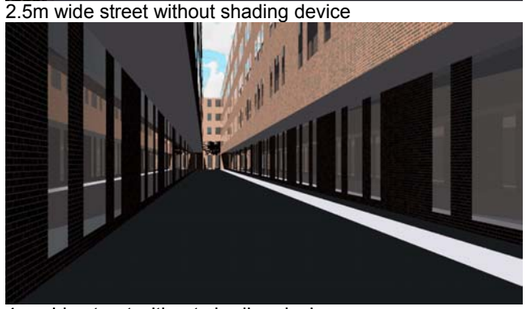
15m wide street with translucent pergola on each side

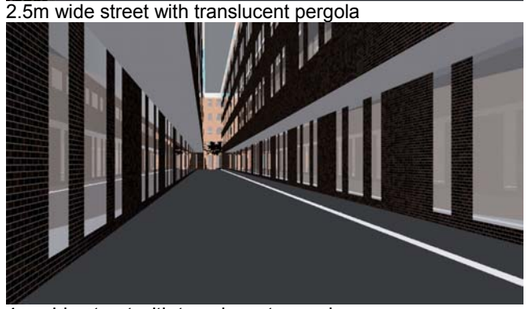
June 3pm

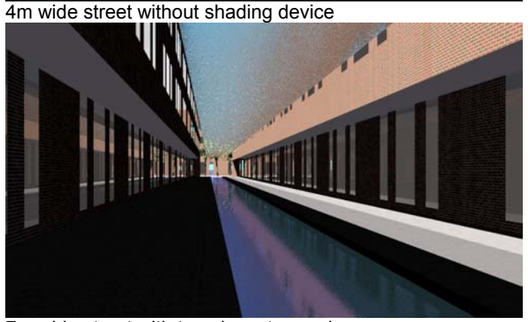
Daylight | Outdoor
Shading Renderings | sunny March 12am and December 12am

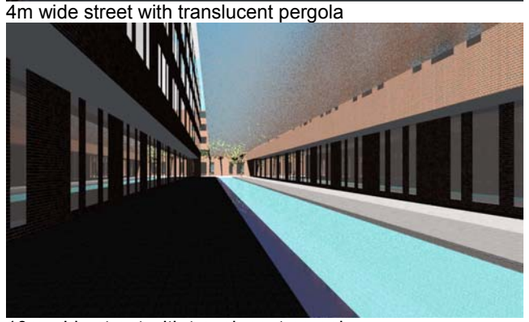
2.5m wide street without shading device

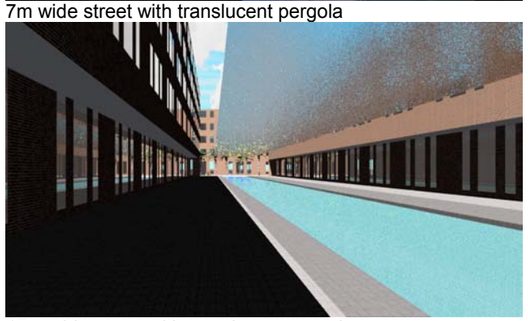
2.5m wide street with translucent pergola


4m wide street without shading device


4m wide street with translucent pergola


7m wide street with translucent pergola


10m wide street with translucent pergola

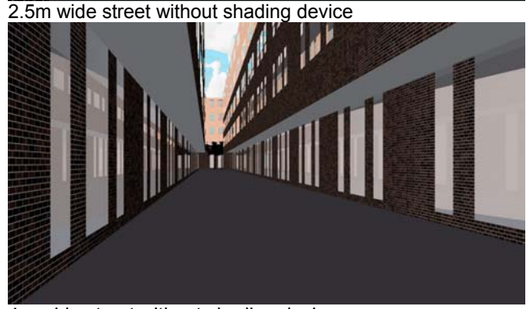

15m wide street with translucent pergola

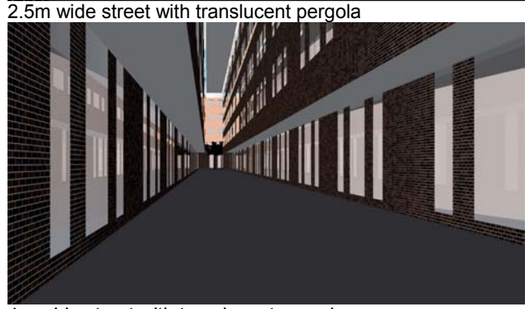
15m wide street with translucent pergola on each side

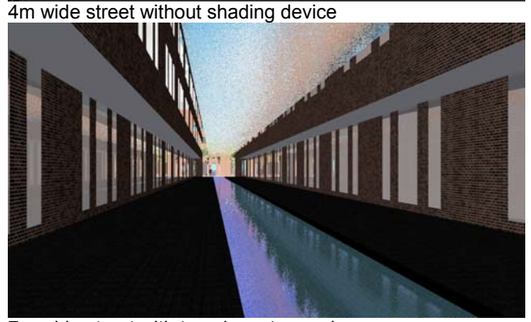
March 12am

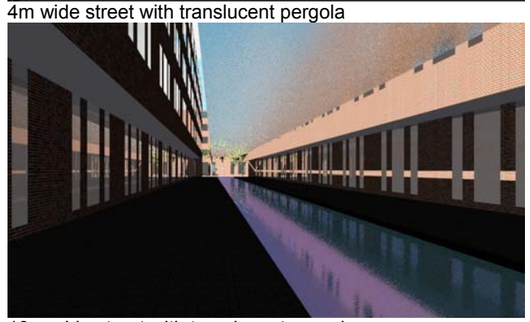
2.5m wide street without shading device

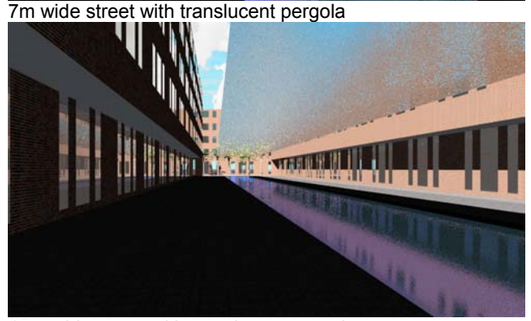
2.5m wide street with translucent pergola


4m wide street without shading device


4m wide street with translucent pergola


7m wide street with translucent pergola


10m wide street with translucent pergola


15m wide street with translucent pergola

15m wide street with translucent pergola on each side

December 12am

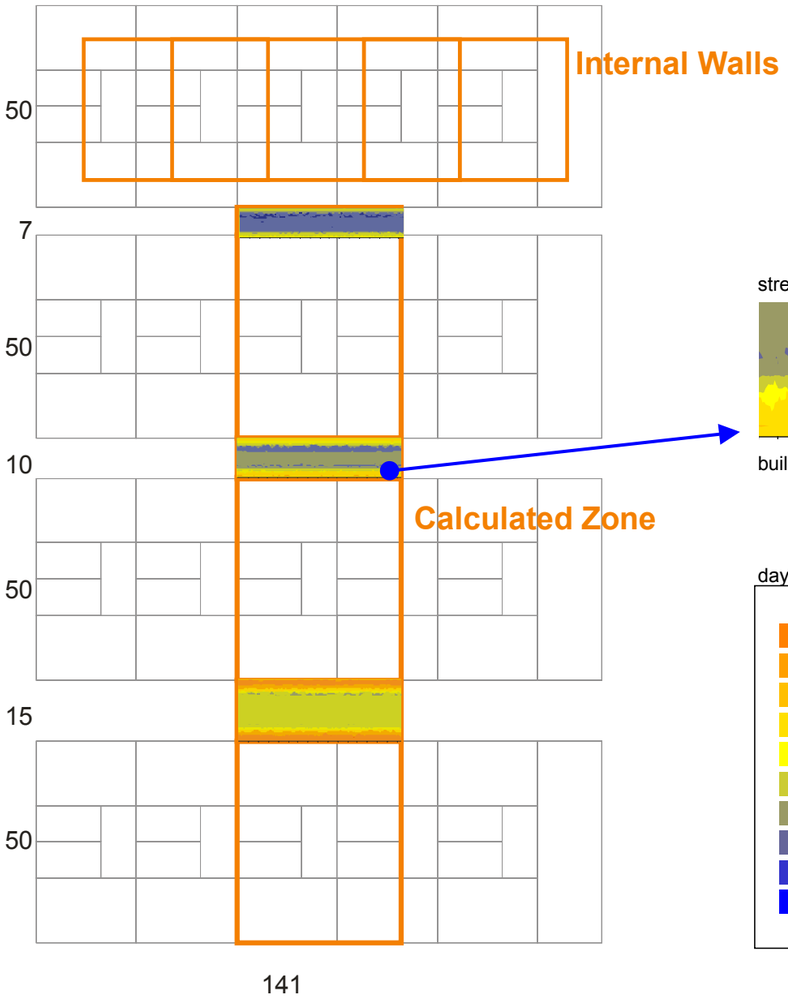
Daylight | Outdoor
Illuminance Daylight Factor

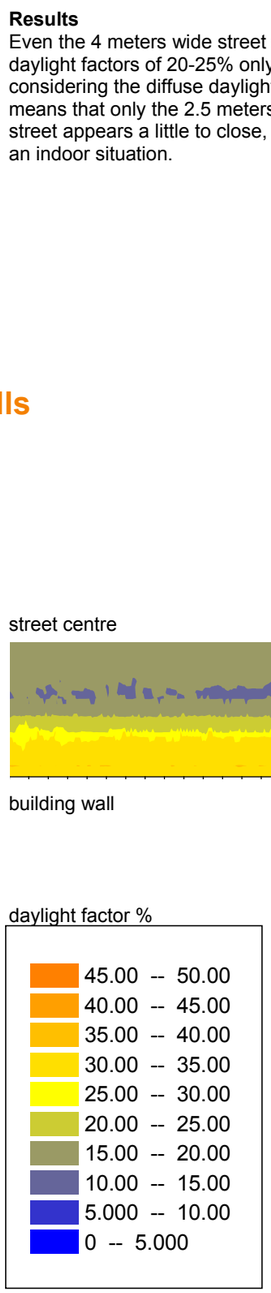
Overview
This studies help to understand the level of daylighting we will get in the streets for different street widths and shading possibilities and give an impression of the outdoor daylight and solar exposure as they can be received by the inhabitants and pedestrians.

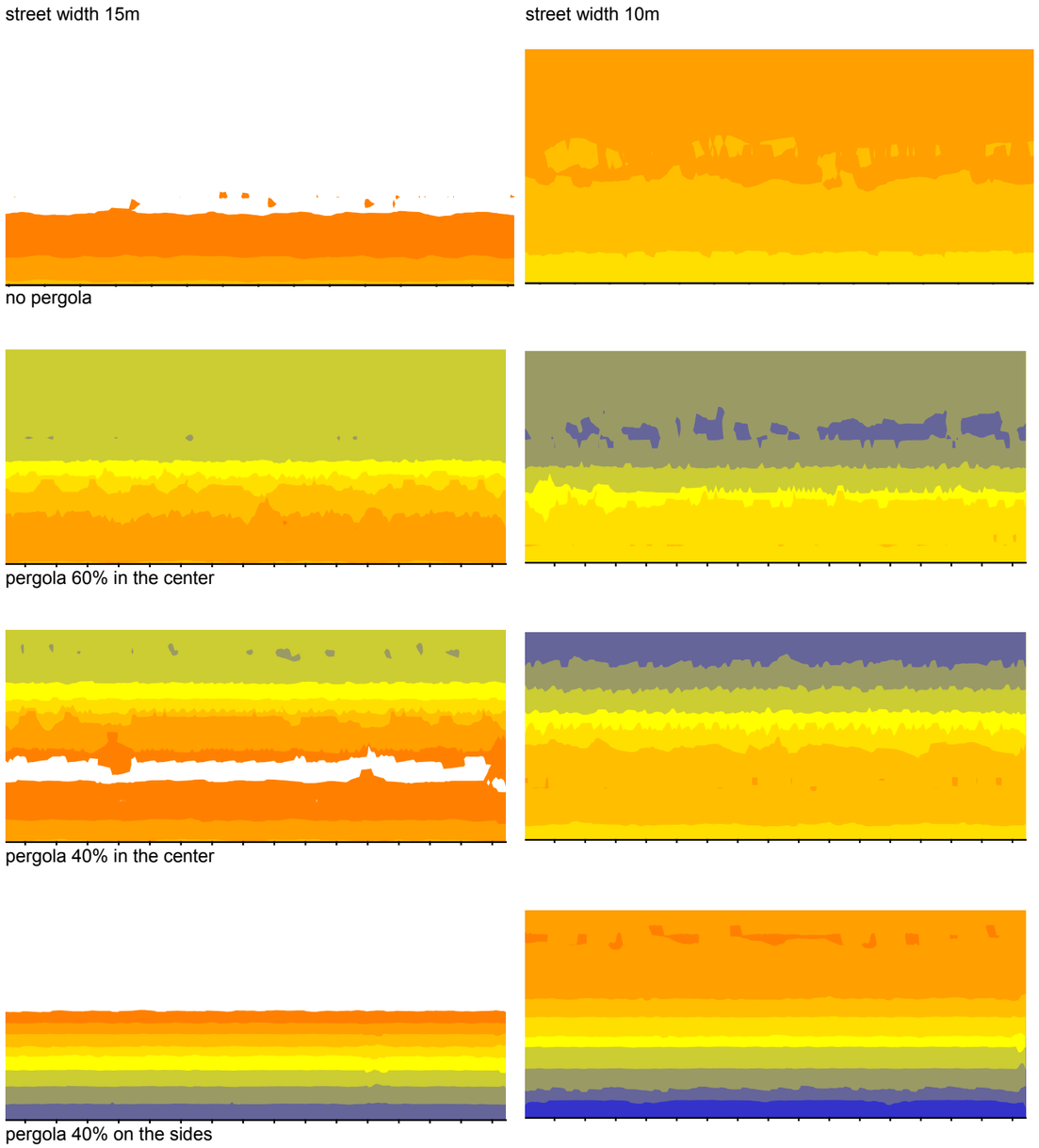
Daylight Level
The daylight level given by the daylight factor is related to the openness or the closeness of a street or space. A level of 50% means that half the sky can be seen.

Daylight factors of approximately 25% and above indicates normal open streets and places. Values lower than 10% let spaces appear relative close nearly like indoor situations.

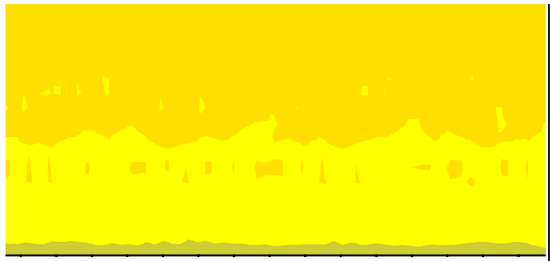
Results
Even the 4 meters wide street shows daylight factors of 20-25% only considering the diffuse daylight. This means that only the 2.5 meters wide street appears a little to close, just like an indoor situation.



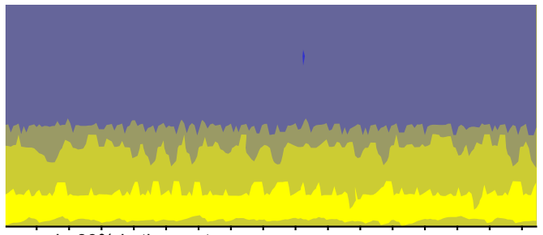




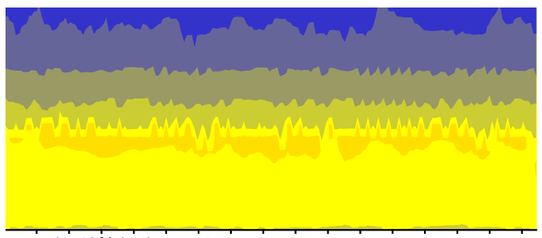
street width 7m



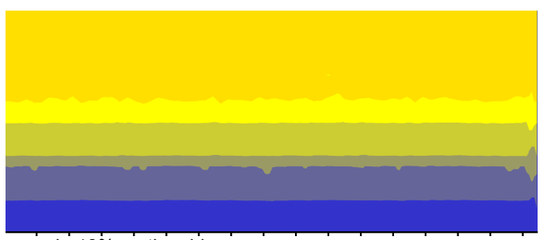
no pergola



pergola 60% in the center

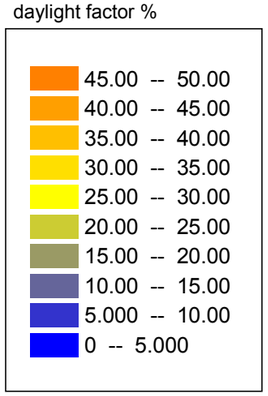


pergola 40% in the center

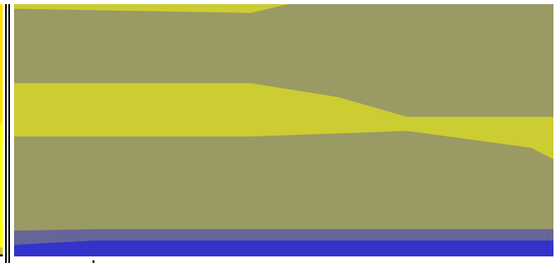


pergola 40% on the sides

daylight factor %



street width 4m



no pergola

pergola in the center, 90% width, 20% light transmittance

street width 2.5m

no pergola

pergola in the center, 90% width, 20% light transmittance

Daylight | Indoor
Illuminance Daylight Factor | Ground Floor

Overview
The indoor illuminance is one of the main analysis to design the building-, room- and façade- proportions, the glazing measurements and types.

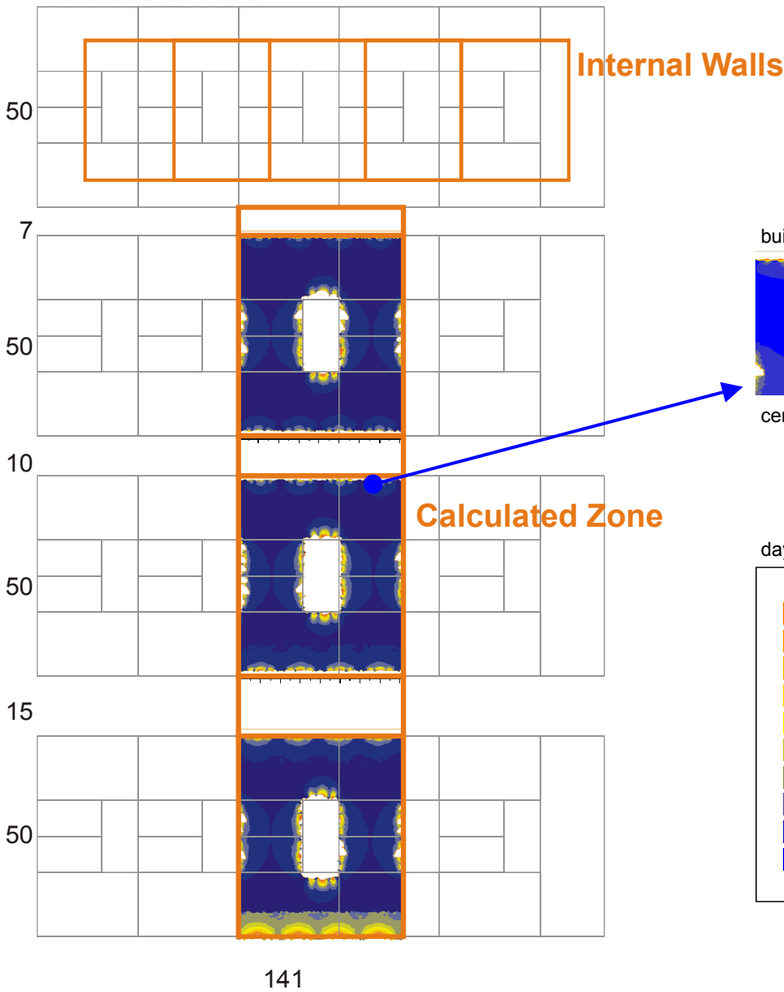
The daylight factor describes the daylight quality in a room and is the ratio of external horizontal diffuse illuminance over internal horizontal diffuse illuminance at a specific point, expressed in per cent. The higher the daylight factor, the more natural light is available in the room. The daylight factor is always measured or calculated for a standard CIE overcast sky, independent from the actual weather data.

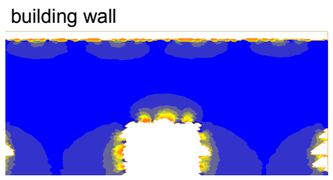
Describing the indoor daylight quality with the daylight factor is the common standard in architectural light planning.

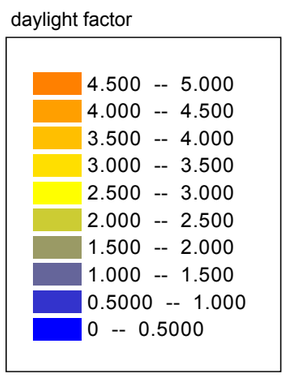
The Graphics
The following graphics shows the daylight factor as coloured areas in the floor plan. The target value, as described before, is 2.7%. The scale shows values above 2.5% in yellow and red colours and values below in grey and blue colours. Values above the scale which is above 5% are white.

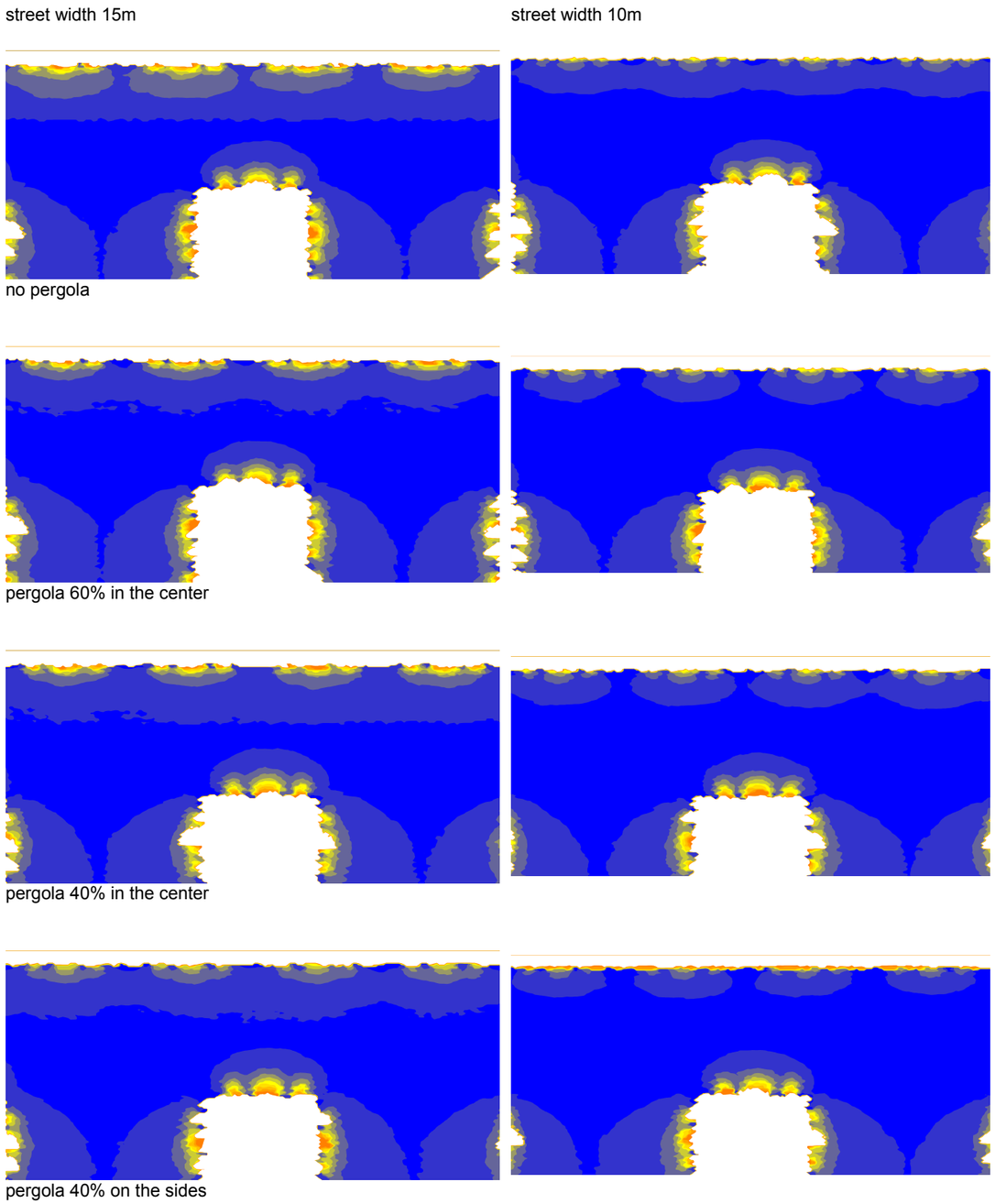
Results
Regarding the graphics one can see that they are nearly all blue. Only near the windows some yellow and red coloured areas can be detected. This means that the daylight cannot shine very deep into the rooms. This is caused by the ratio of building height to street width and courtyard size respectively. This is a quite normal daylight situation for ground floor accommodations with arcades in downtown locations.

(t.b.c.)









(cont.)
They area with a daylight factor above 2.5% reaches about 2.5-3 meters into the room where they are connected to the 9 x 18 meters courtyard or a 15 meters wide street with no shading device on the outside.

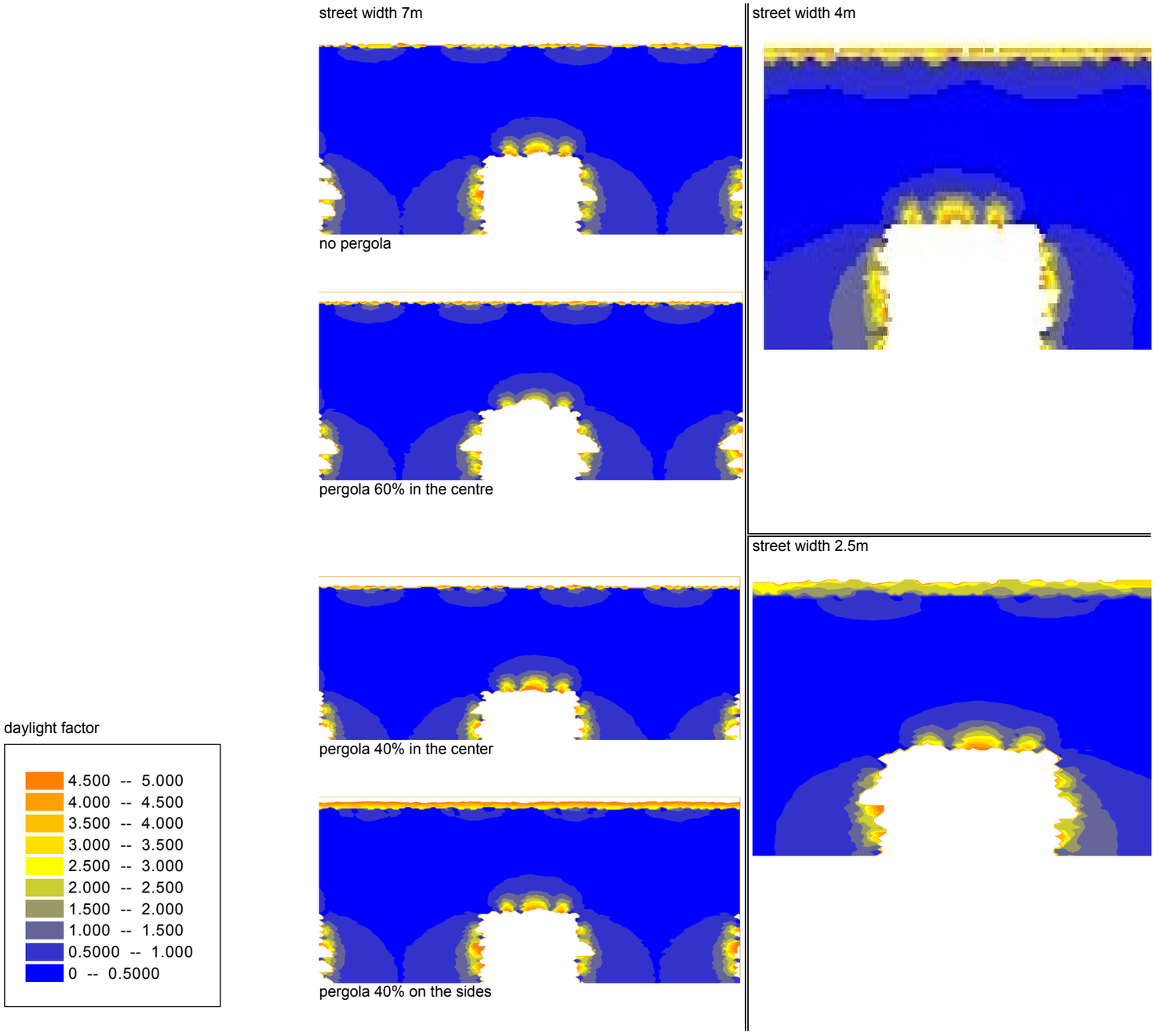
A closed shading device over the middle of the street will reduce the daylight range at the street orientated façade, depending on the light transmittance of that shading device, at approximately 1-1.5 meters.

Comparing the graphics with the 40% pergola in the centre of the street and on the sides shows: A shading device with the equal size but fitted directly at the wall reduces the daylight area much more and, on the other hand, does not produce a sufficient shading in the street.

Therefore, regarding thermal, local-climatic and daylight aspects, it is recommended to fit necessary shading devices over the centre of the streets.

Regarding the graphics for rooms connected to street widths smaller than 10 meters makes clear that the recommended types of utilization for the ground floor have to be artificial lighted ones like shops, restaurants, industry etc. This occupancies are normally lighted with artificial light during the period of use anyway and the need of visual contact to the outside is of no great importance.

It is not recommended to provide offices, living accommodations or similar types of utilization at the ground floor.



Comparison of the street widths
The first row of graphics shows a comparison of the daylight situation in the second floor (the second floor above the ground floor of a five stores high building). The range of daylight above the daylight factor of 2.5% reaches approximately 3 meters at a street width of 15 meters, 2.5 meters at a street width of 10 meters and 1.5-2 meters at a street width of 7 meters.

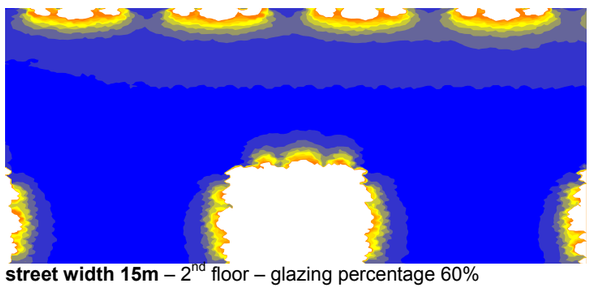
It is quite obvious that the smaller streets result in insufficient indoor daylight situations. In addition the local climate situation are more agreeable in smaller streets. This leads to the idea of the architects to design accommodations with a depth of approximately 8 meters and to assure the supply with daylight with the courtyards.

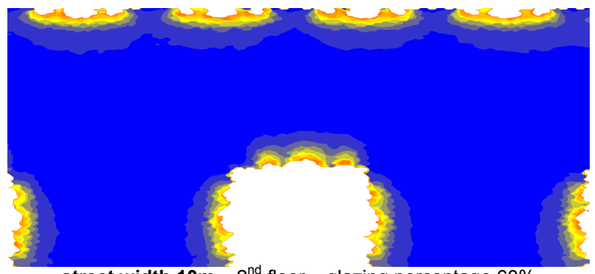
Comparison of the floor levels
The comparison of the floors 2, 3 and 4 pictured at the second row results let us to come to the conclusion that it is recommended to allocate accommodations like living and offices to the upper floors. This types of utilization have a great requirement to daylight and visual contact to the outdoor environment.

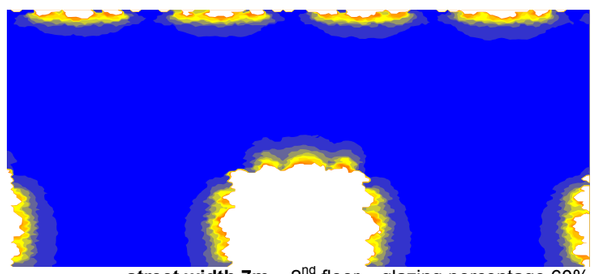
Considering ergonomic and energy saving aspects it would be the best to locate offices in the most upper floors.

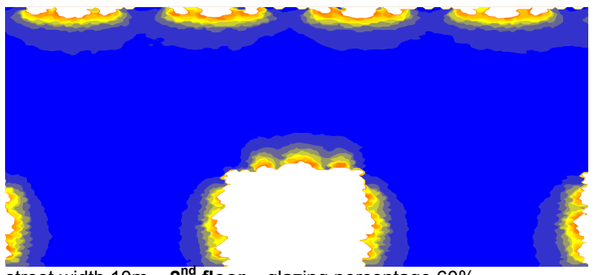
Comparison of the glazing percentage
As shown in the third row a decrease of the glazing percentage does not only reduce the daylight factors but does also cause a greater uniformity ratio of daylight. This means that the contrast of brighter versus darker areas are higher what is unrequested.

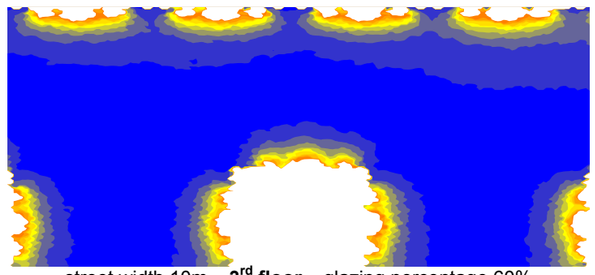
In daylight critical situations like small streets it is recommended to reduce the light transmittance, if necessary, by choosing another glasstype rather than decreasing the glazing percentage.

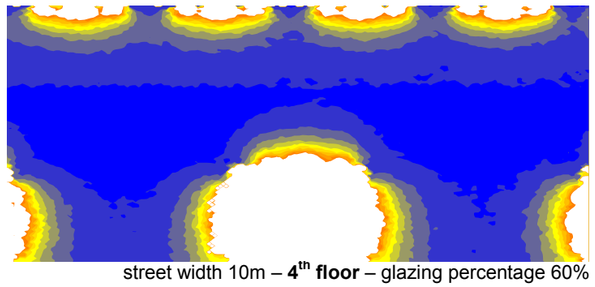

street width 15m – 2nd floor – glazing percentage 60%

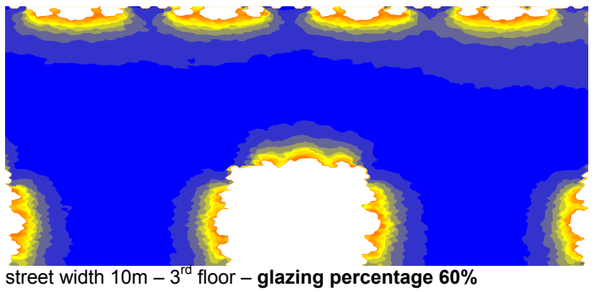

street width 10m – 2nd floor – glazing percentage 60%

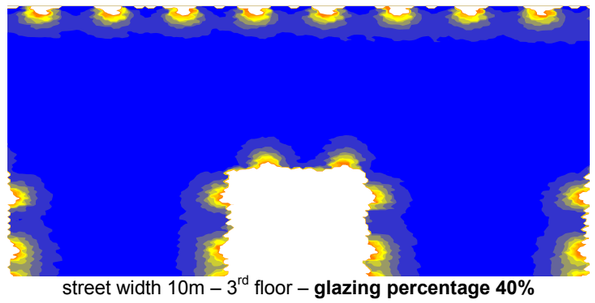

street width 7m – 2nd floor – glazing percentage 60%

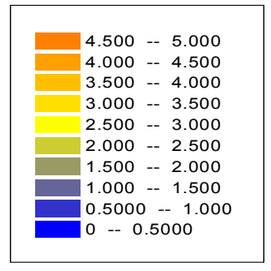

street width 10m – **2nd floor** – glazing percentage 60%


street width 10m – **3rd floor** – glazing percentage 60%


street width 10m – **4th floor** – glazing percentage 60%


street width 10m – 3rd floor – **glazing percentage 60%**


street width 10m – 3rd floor – **glazing percentage 40%**



daylight factor %

Overview
The indoor illuminance studies are developed further to the matrix an tabular worksheet where the availability and quality of the indoor illuminance is shown for different building levels and street- and courtyard sizes.

Conditions
The matrix and its consequential recommendations are based on the following items and preconditions:

- The priority objective is to get a high indoor illumination with daylight to save energy, to feel comfort and to have an good visual relationship to the outdoor environment.
- The daylight autonomy has to be 80% in the time from 8 a.m. to 6 p.m. which requires a daylight factor of 2.7% as previously shown.
- The outdoor daylight conditions are the standard CIE overcastted sky and the clear sky with shaded direct sunlight respectively (see below).
- The (hypothetical) shading device in this studies cuts of the direct sunlight perfectly.

Quality standards (see matrix legend)
The quality standards are graded depending on the target of the daylight autonomy and the depth of the room where this daylight autonomy is provided. The demand for good daylight quality in offices is higher than it is in living buildings. In this regard the depth of the room which can be reached by the daylight factor 2.7% below 0.7 meters is recommended for artificial light use only. The depth from 0.7 to 1.5 meters indicates average Living Quality B and is not recommended for offices. The depth from 1.5 to 2.2 meters indicates good Living Quality A and average Office Quality B. The depth of 2.2 meters and above indicates excellent Living Quality A+ and good Office Quality A.

Results Daylighting
Based on this matrix we recommend the minimum courtyard size of 10 x 10 m or the minimum street width of 10 m for offices and the minimum courtyard size of 7 x 7 m or the minimum street width of 7 m for living buildings.

Roomdepth (meter) of Natural Lighting with the Daylight Factor DF = 2,7%

"minus 4" (3 more floors above)	Width 5,5 m				Width 7,0 m				Width 8,5 m				Width 10 m				Width 11,5 m				Width 13 m				Width 14,5 m				Width 16 m				Width 17,5 m				Width 19 m and more (=Street)			
Transmittance %	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75
Distance 2,5 m	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Distance 4 m	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,3	0,0	0,0	0,0	0,4	0,0	0,0	0,0	0,4	0,0	0,0	0,0	0,5	0,0	0,0	0,0	0,5	0,0	0,0	0,1	0,5	0,0	0,0	0,3	0,5
Distance 5,5 m	0,0	0,0	0,0	0,2	0,0	0,0	0,0	0,5	0,0	0,0	0,2	0,6	0,0	0,0	0,4	0,7	0,0	0,0	0,5	0,8	0,0	0,0	0,6	0,8	0,0	0,0	0,6	0,8	0,0	0,0	0,7	0,9	0,0	0,0	0,7	0,9	0,0	0,0	0,7	0,9
Distance 7 m	0,0	0,0	0,0	0,6	0,0	0,0	0,4	0,8	0,0	0,0	0,6	0,9	0,0	0,0	0,7	1,0	0,0	0,0	0,8	1,1	0,0	0,0	0,9	1,1	0,0	0,0	0,9	1,1	0,0	0,1	1,0	1,2	0,0	0,3	1,0	1,2	0,0	0,4	1,0	1,2
Distance 8,5 m	0,0	0,0	0,4	0,9	0,0	0,0	0,7	1,1	0,0	0,0	0,9	1,2	0,0	0,0	1,0	1,3	0,0	0,2	1,1	1,4	0,0	0,4	1,1	1,4	0,0	0,5	1,2	1,5	0,0	0,6	1,2	1,5	0,0	0,6	1,2	1,5	0,0	0,7	1,3	1,5
Distance 10 m	0,0	0,0	0,6	1,1	0,0	0,0	0,9	1,3	0,0	0,0	1,0	1,4	0,0	0,3	1,2	1,5	0,0	0,5	1,3	1,6	0,0	0,6	1,3	1,7	0,0	0,7	1,4	1,7	0,0	0,8	1,4	1,7	0,0	0,8	1,5	1,7	0,0	0,9	1,5	1,7
Distance 15 m																																					0,7	1,7	2,5	2,9
Courtyard 15x15m Cornerroom																																					0,0	0,9	1,9	2,4

"minus 3" (2 more floors above)	Width 5,5 m				Width 7,0 m				Width 8,5 m				Width 10 m				Width 11,5 m				Width 13 m				Width 14,5 m				Width 16 m				Width 17,5 m				Width 19 m and more (=Street)			
Transmittance %	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75
Distance 2,5 m	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,0	0,0	0,0	0,3	0,0	0,0	0,0	0,4	0,0	0,0	0,0	0,4	0,0	0,0	0,0	0,4	0,0	0,0	0,0	0,4	0,0	0,0	0,0	0,4
Distance 4 m	0,0	0,0	0,0	0,6	0,0	0,0	0,4	0,7	0,0	0,0	0,5	0,8	0,0	0,0	0,6	0,9	0,0	0,0	0,8	0,9	0,0	0,0	0,8	0,9	0,0	0,0	0,8	0,9	0,0	0,0	0,8	1,0	0,0	0,0	0,8	1,0	0,0	0,0	0,9	1,0
Distance 5,5 m	0,0	0,0	0,7	1,1	0,0	0,0	0,8	1,2	0,0	0,0	0,9	1,3	0,0	0,1	1,0	1,3	0,0	0,4	1,1	1,4	0,0	0,5	1,1	1,4	0,0	0,5	1,2	1,4	0,0	0,6	1,2	1,4	0,0	0,6	1,2	1,4	0,0	0,7	1,2	1,4
Distance 7 m	0,0	0,0	0,9	1,3	0,0	0,1	1,1	1,5	0,0	0,4	1,3	1,6	0,0	0,6	1,3	1,7	0,0	0,7	1,4	1,7	0,0	0,8	1,5	1,7	0,0	0,8	1,5	1,7	0,0	0,9	1,5	1,7	0,0	0,9	1,5	1,7	0,0	0,9	1,6	1,7
Distance 8,5 m	0,0	0,0	1,1	1,6	0,0	0,4	1,3	1,7	0,0	0,7	1,4	1,8	0,0	0,8	1,6	2,0	0,0	0,9	1,6	2,0	0,0	1,0	1,7	2,1	0,0	1,0	1,7	2,1	0,0	1,1	1,8	2,1	0,0	1,1	1,8	2,1	0,0	1,2	2,0	2,1
Distance 10 m	0,0	0,2	1,3	1,7	0,0	0,6	1,5	2,0	0,0	0,8	1,6	2,1	0,0	0,9	1,7	2,2	0,0	1,0	1,8	2,3	0,0	1,1	1,9	2,4	0,0	1,2	2,0	2,4	0,0	1,2	2,0	2,5	0,2	1,3	2,1	2,5	0,2	1,3	2,1	2,5
Distance 15 m																																					0,9	2,0	3,0	3,6
Courtyard 15x15m Cornerroom																																					0,0	1,3	2,4	3,1

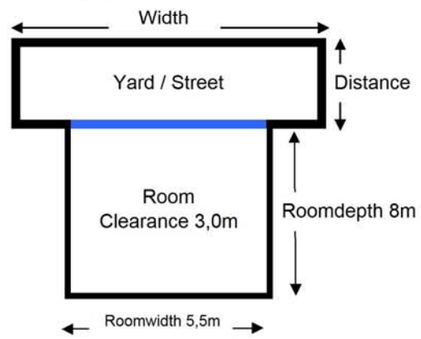
"minus 2" (1 more floor above)	Width 5,5 m				Width 7,0 m				Width 8,5 m				Width 10 m				Width 11,5 m				Width 13 m				Width 14,5 m				Width 16 m				Width 17,5 m				Width 19 m and more (=Street)			
Transmittance %	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75	12	25	50	75
Distance 2,5 m	0,0	0,0	0,7	1,0	0,0	0,0	0,7	1,0	0,0	0,0	0,8	1,1	0,0	0,0	0,9	1,1	0,0	0,0	0,9	1,1	0,0	0,0	0,9	1,1	0,0	0,0	0,9	1,1	0,0	0,0	0,9	1,1	0,0	0,0	0,9	1,1	0,0	0,0	0,9	1,1
Distance 4 m	0,0	0,3	1,2	1,6	0,0	0,6	1,4	1,7	0,0	0,7	1,4	1,8	0,0	0,8	1,5	1,8	0,0	0,9	1,6	1,9	0,0	0,9	1,6	1,9	0,0	0,9	1,6	1,9	0,0	1,0	1,6	1,9	0,0	1,0	1,6	1,9	0,0	1,0	1,6	1,9
Distance 5,5 m	0,0	0,7	1,6	2,1	0,0	0,9	1,7	2,2	0,0	1,0	2,0	2,3	0,0	1,2	2,0	2,4	0,0	1,2	2,0	2,4	0,0	1,3	2,0	2,5	0,0	1,3	2,1	2,5	0,0	1,3	2,1	2,5	0,2	1,3	2,1	2,6	0,3	1,3	2,1	2,6
Distance 7 m	0,0	0,9	1,8	2,4	0,0	2,1	2,0	2,5	0,0	1,2	2,1	2,7	0,1	1,3	2,2	2,7	0,3	1,4	2,3	2,8	0,4	1,5	2,4	2,9	0,5	1,5	2,4	3,0	0,5	1,5	2,4	3,0	0,6	1,6	2,5	3,0	0,6	1,6	2,5	3,0
Distance 8,5 m	0,0	1,0	2,0	2,5	0,0	1,2	2,1	2,7	0,0	1,3	2,2	2,9	0,3	1,4	2,4	3,0	0,4	1,5	2,5	3,1	0,6	1,6	2,6	3,2	0,6	1,6	2,6	3,2	0,7	1,6	2,7	3,3	0,7	1,7	2,7	3,3	0,7	1,7	2,7	3,4
Distance 10 m	0,0	1,1	2,1	2,7	0,0	1,3	2,3	2,9	0,1	1,4	2,4	3,0	0,4	1,5	2,5	3,2	0,5	1,6	2,6	3,3	0,6	1,7	2,7	3,4	0,6	1,7	2,7	3,4	0,7	1,7	2,8	3,5	0,7	1,8	2,8	3,5	0,8	1,8	2,9	3,6
Distance 15 m																																					1,1	2,2	3,5	4,4
Courtyard 15x15m Cornerroom																																					0,7	1,7	3,0	3,8

Legend:

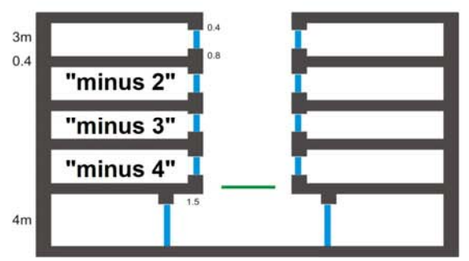
Artificial Light Use (Shops, Restaurant, Manufacturing…)	
Living Quality B	No Office
Living Quality A	Office Quality B
Living Quality A+	Office Quality A

Transmittance = Glass-Ratio x Light Transmittance
DF = Daylight Factor

Calculation Model:



Building levels:



Conclusion
Considering the solar exposure of a 10 or 7 meters wide street the design team concluded to minimize the street width (to optimize the micro climate) and provide all daylight through courtyards. This has strong consequents for the building design in respect of the building depth reflecting a maximum of 8 meters of a single side natural illumination.

Daylight | Indoor

Illuminance on Sunny and Overcast Days | December

Overview
Equal to the indoor illuminance studies with the CIE-standard (overcast sky) the indoor illuminance is also calculated with the sunny sky. Since the sun is shining more than 90% of the yearly daytime the recommendations and guidelines for the daylight design cannot only base on the CIE-standard – as they do mostly in Europe or north America – but have to take into consideration the influence of the direct sunlight shining or not shining into the room.

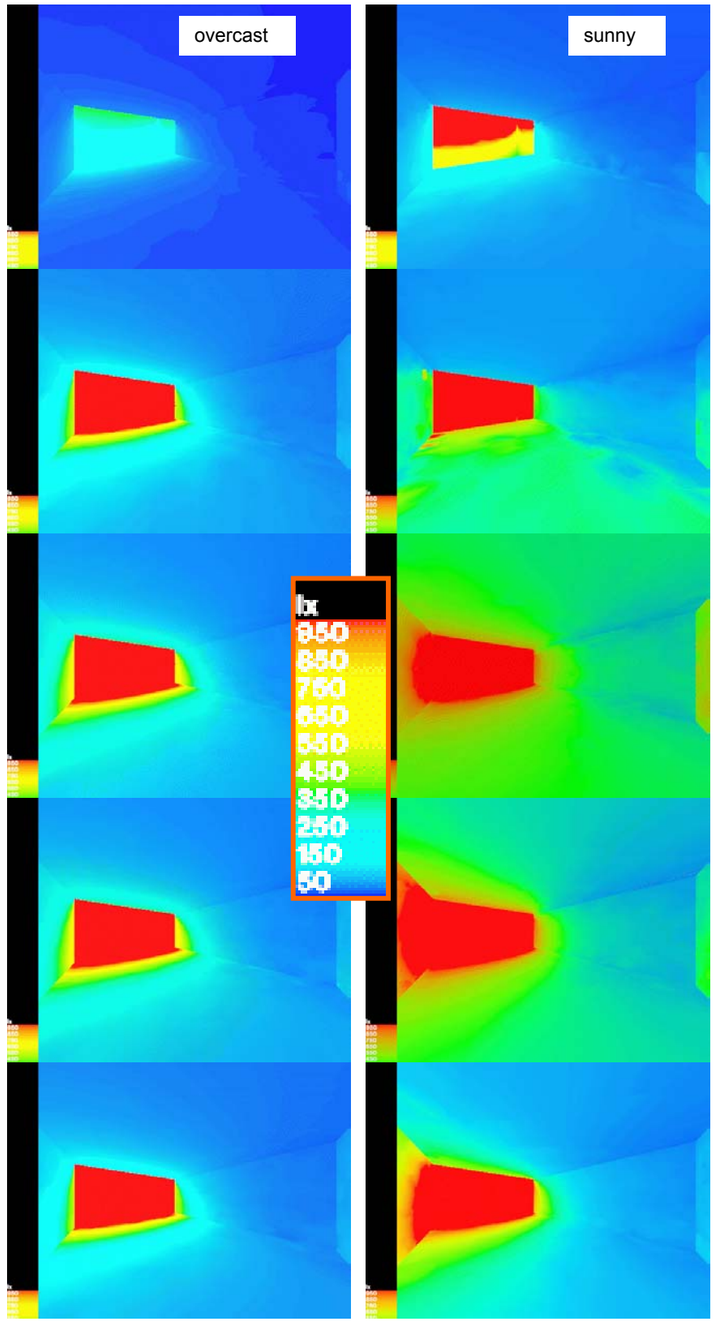
Falsecolour pictures
The falsecolour pictures of a northwest orientated room in the 3rd floor show the illuminance for some hours from the morning to the afternoon at December. The first column shows the daylight situation at an overcast sky and the second column at a sunny sky both at the same time.

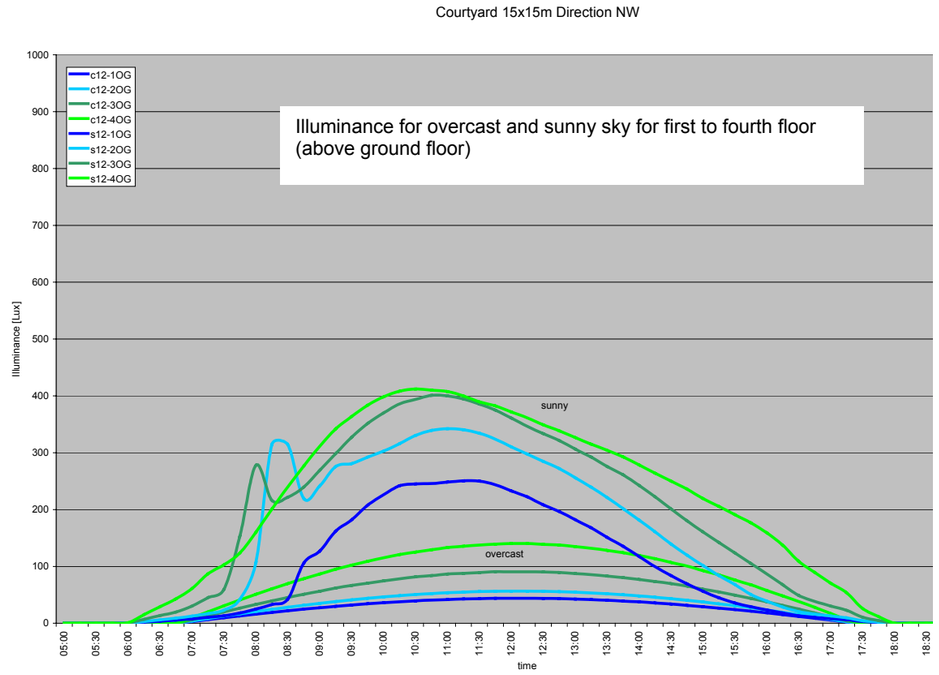
It is quite obvious that on sunny days the indoor illuminance is much brighter than on overcast days. The horizontal values are approximately 200-400% higher – without sun shining directly into the room!

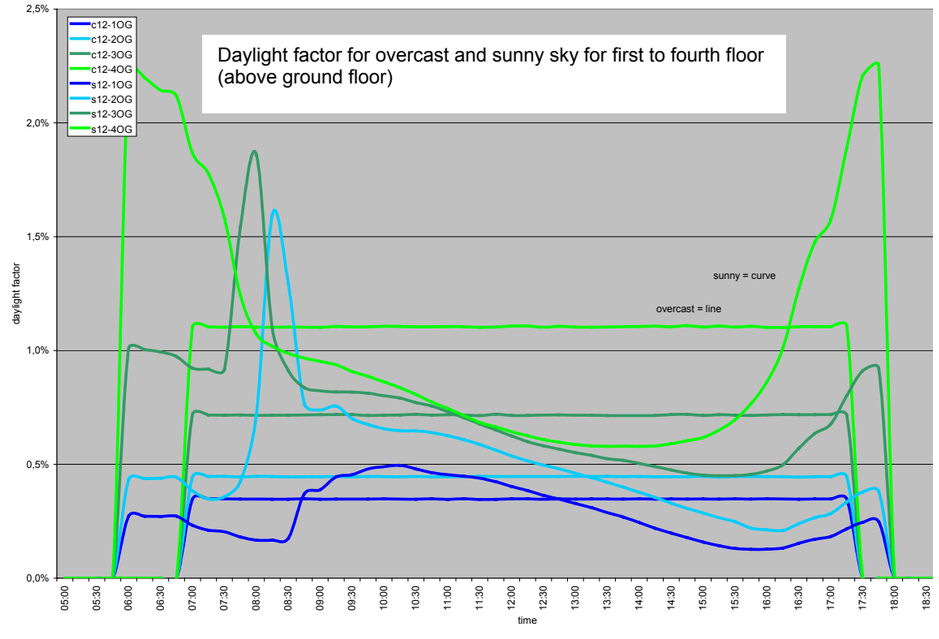
Illuminance Graphs
This fact can also be seen in the illuminance graph on the top right. It describes the horizontal illuminance value over a day in December on the work surface 0.85 meters above floor for the floors 1, 2, 3 and 4 above the ground floor. The curves for the sunny day are always 2 to 4 times higher than the curves for he overcast day.

Daylight factor graphs
The graphs for the daylight factors (right side bottom) shows another aspect when considering the sunny days. The daylight factor for sunny days is sometimes higher and sometimes lower than the daylight factor for overcast days. This fact depends on the direction of the directed light. When the sun is shining in the direction to the room and its window respectively or into the room than the part of the daylight that can be used for the indoor illumination is very high and exceeds the value for overcast days.

(t.b.c.)







Daylight | Indoor

Illuminance on Sunny and Overcast Days | June

(cont.)

Whereas, when the sun is shining relatively steeply from the zenith downwards or in directions away from the room and its window than the usable part of the actual prevailing outdoor daylight and hence the daylight factor also is lower than on overcast times.

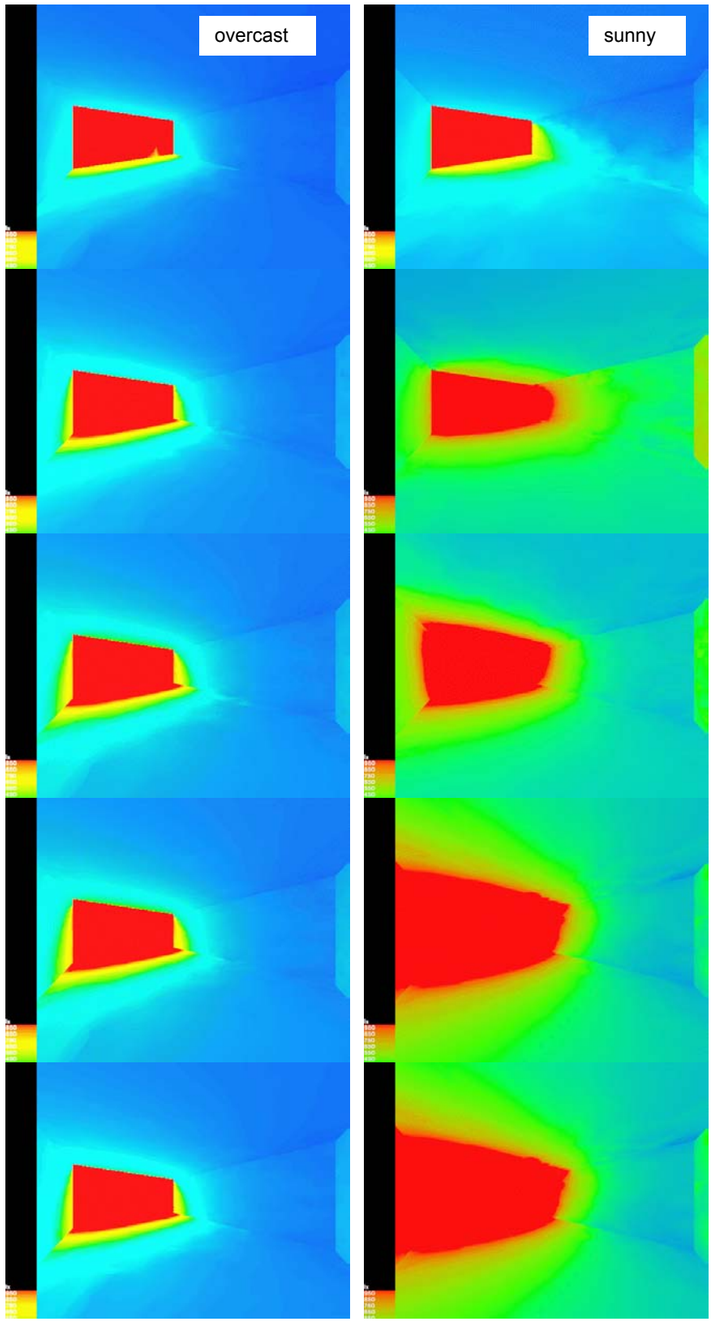
Example June
On this page one can see this situations for a example day in June for an northwest orientated room at the second floor. The described situations of more or less usable daylight are shown very impressively and clearly. Particularly there is an illuminance peak indoors at noon when the sun is standing at the zenith. At the same time the daylight factor has its minimum because the sunlight can hardly be used for the indoor illumination.

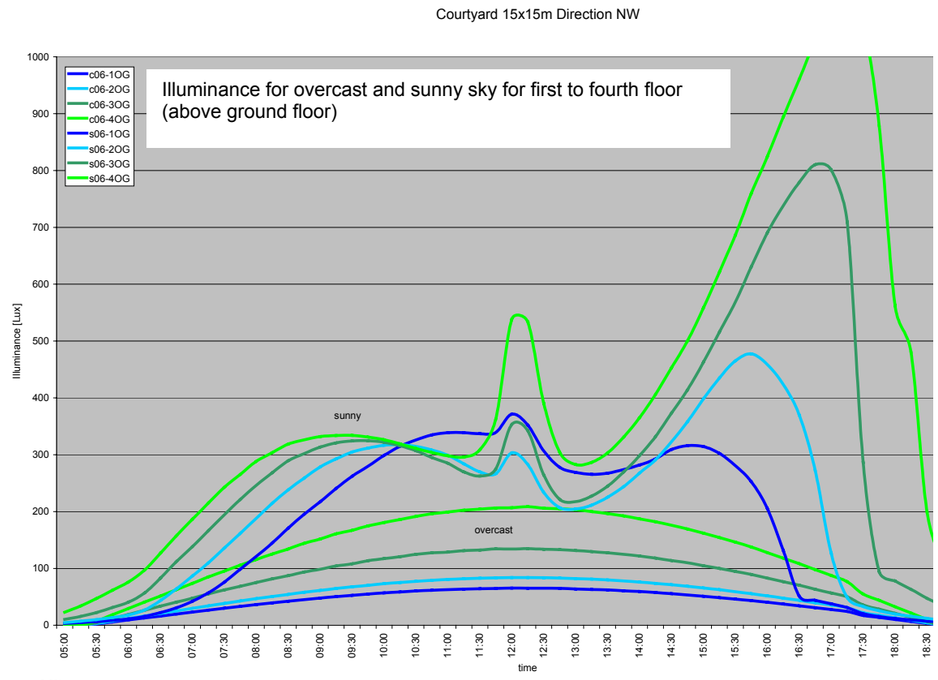
Results and Recommendations
What does it mean for the daylight planning when on sunny days the absolute illuminance indoor value is higher but the corresponding daylight factor – the ratio of indoor to outdoor illuminance – is lower than on overcast days?

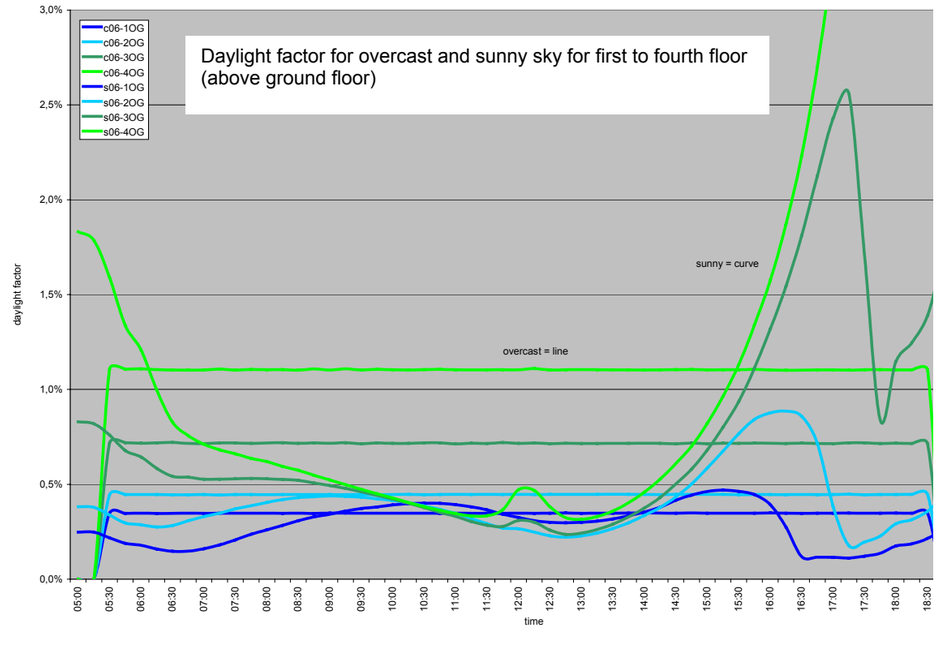
First of all it means that the indoor illuminance is higher anyway and can be used to increase the daylight autonomy.

But it also means that there is a higher risk of uncomfortable glare and contrast. This is caused by higher illuminance on the outside which can be seen by the occupants when looking into the windows direction and is sometimes caused by sunlight shining into the room.

Both situations can decrease the visual user comfort and might cause lower daylight autonomy. To avoid this disadvantages it is strongly recommended to provide smart shading systems which shade overheating solar irradiance as well as uncomfortable glare and allows at the same time that the daylight can illuminate the room. It has to be avoided that a closed shading device causes the necessity of artificial light when there is enough daylight available.

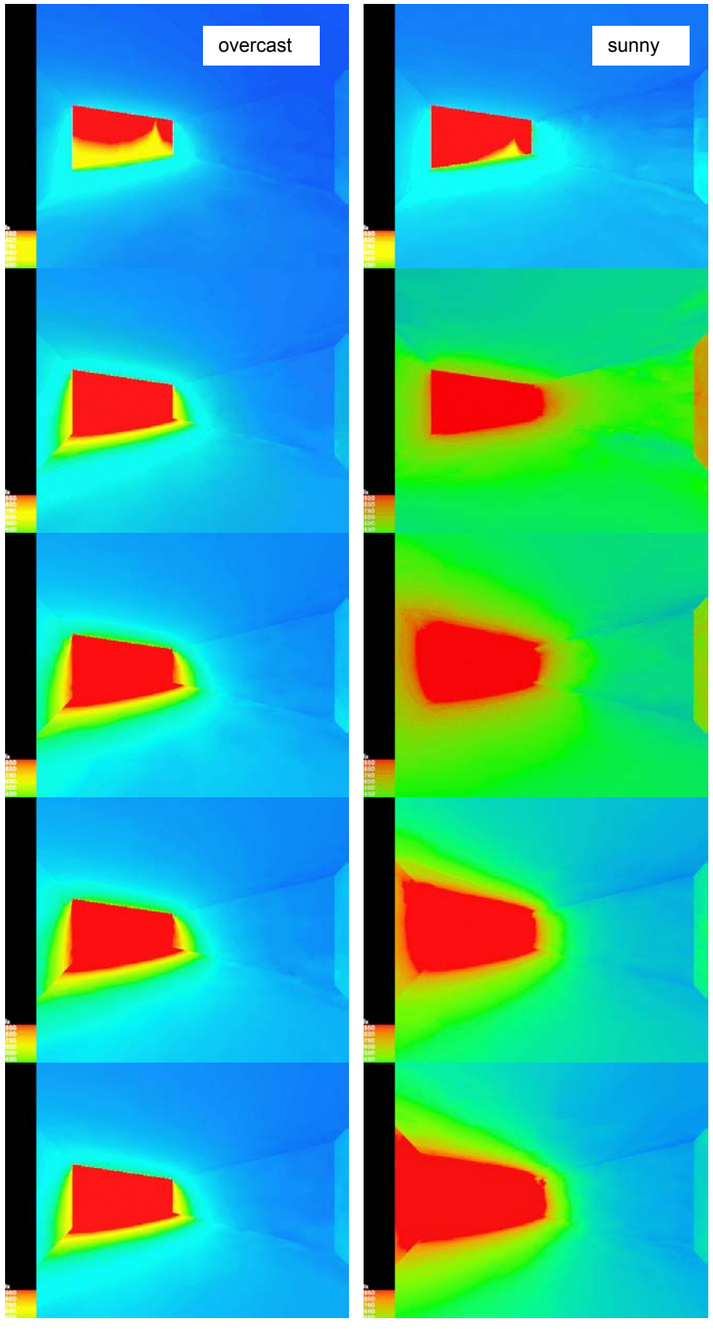


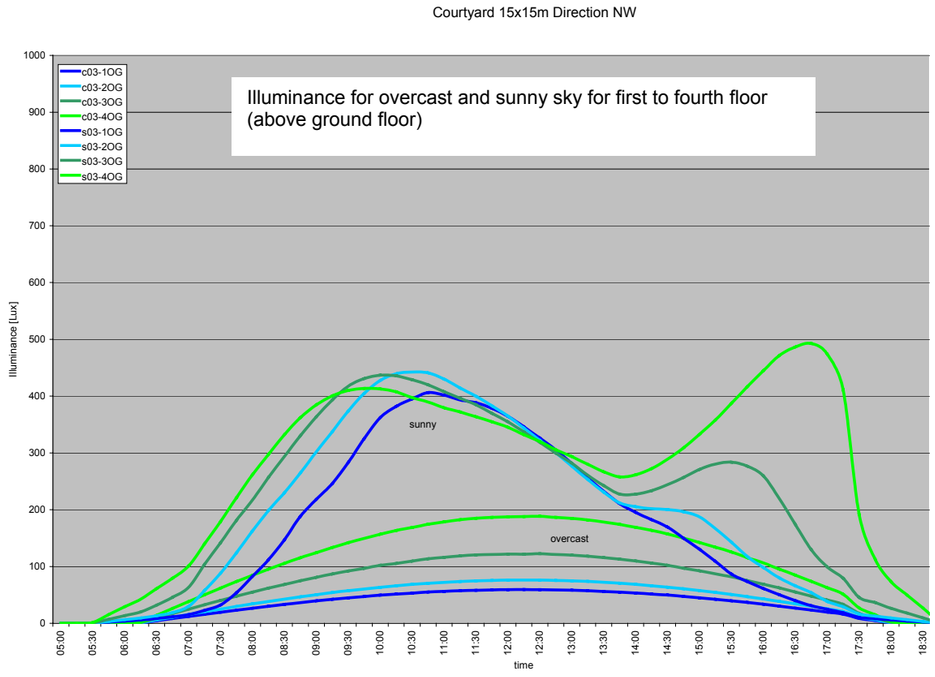


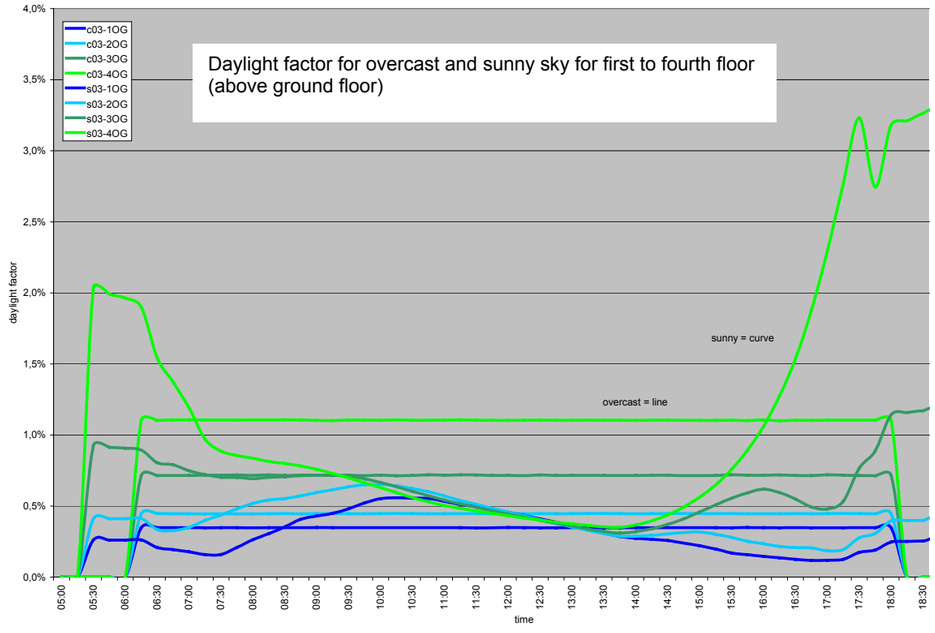


Illuminance on Sunny and Overcast Days | March

Example March
On this page one can see this situations for an example day in March for an northwest orientated room at the third floor. There is no illuminance peak at noon but in the morning and at the afternoon when the sun is shining into the direction of the room. At the same time the daylight factor has also its maximum - remember in June it has its minimum - because in this situation the sunlight can very good be used for the indoor illumination.



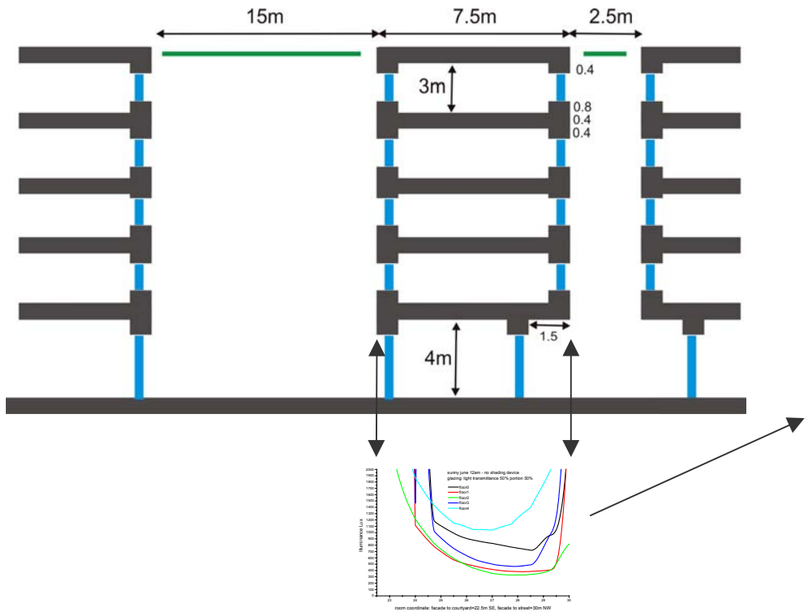


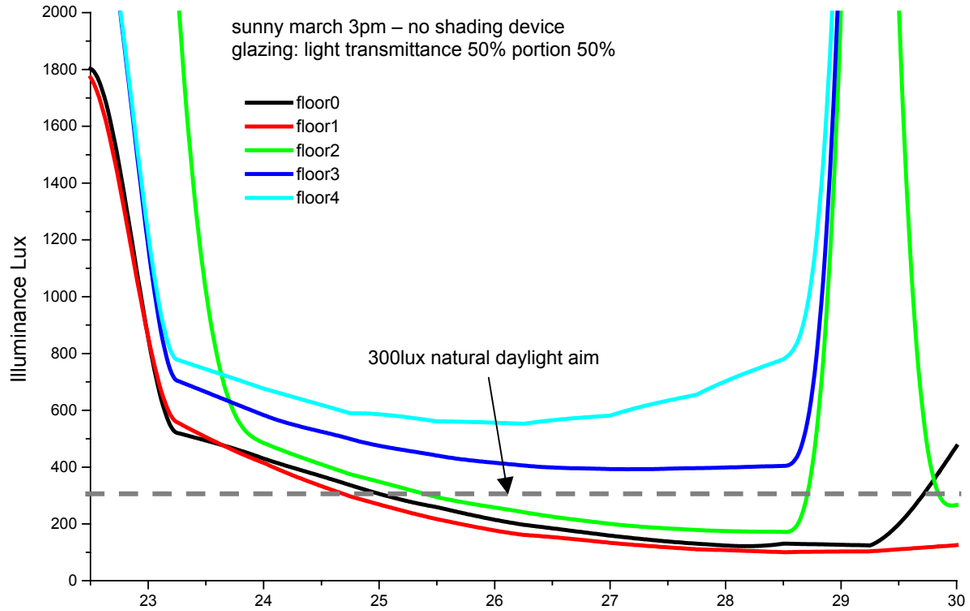


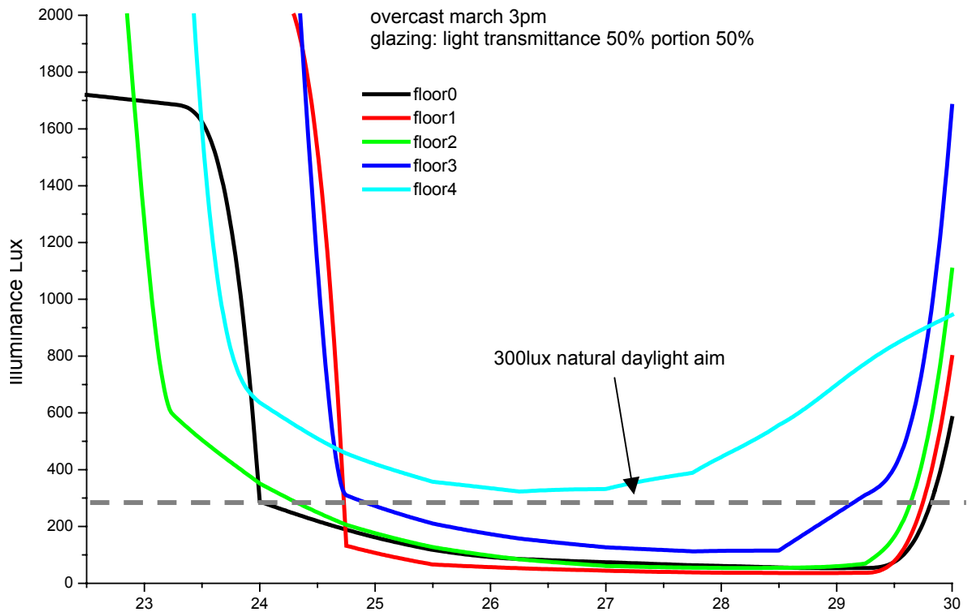
Overview
As a result of the insufficient indoor daylighting at small streets we made some studies with room models with a depth of 7.5 meters which have windows on both sides, one side is orientated to the 2.5 meters wide street and the opposite side to the 15 x 15 meters sized courtyard. The daylight simulations have been done for overcast standard CIE-sky, for clear sky with sun and for clear sky with sun with a shading device in so called “cut-off” adjustment, this means that only the direct sunlight is shaded and the other daylight can pass through the shading device.

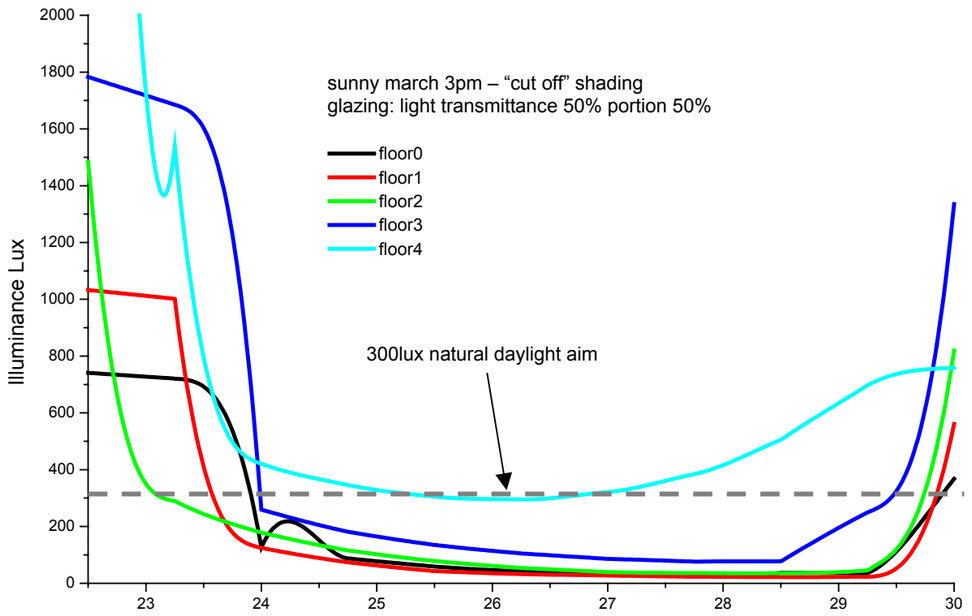
The studies
The graphics show the Illuminance in Lux for a cross section in the middle of the room. The window to the 2.5 meters wide street is on the right side and the window to the courtyard is on the left side. The simulation has been done for a 5 stores high model as described above. On this page you can see the graphs for the example march 21 (equinox).

Model









Dayligth | Indoor

Illuminance with or without shading | Example June

Overview
This graphics show the Illuminance in Lux for a cross section in the middle of the room. The window to the 2.5 meters wide street is on the right side and the window to the courtyard is on the left side. The simulation has been done for a 5 stores high model.

On this page you can see the graphs for the example June 21 (solstice). This day begins summer in the Northern Hemisphere. It is the longest day of the year. The sun is nearly directly overhead at noon.

On the page before you can see the graphs for the example march 21 (equinox).This days begins spring in the Northern Hemisphere. Abu Dhabi experiences 12 hours of daylight and 12 hours of darkness. The sun is 23.5 degrees off of the zenith.

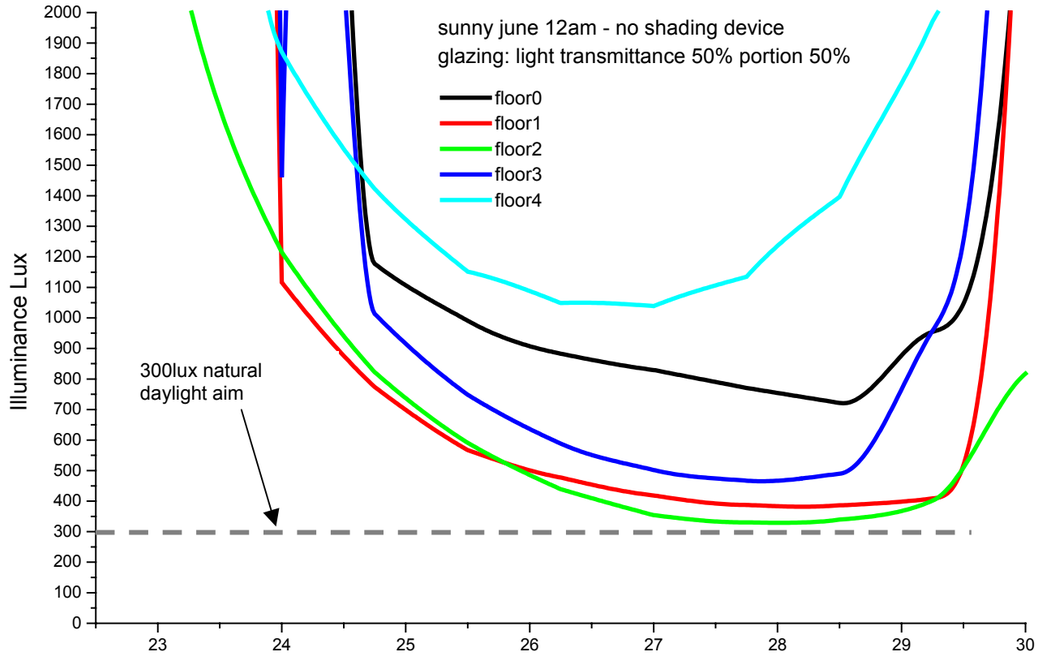
Results
One very obvious result is that the daylight coming from the window at the street cannot shine very deep into the room. The small street makes the main direction of the daylight downwards or in other words: you can only see some sky if you stand very close to the window and look steep upward.

The daylight coming from the courtyard side shines much more gently declined into the room and can so provide the daylight for the indoor illumination.

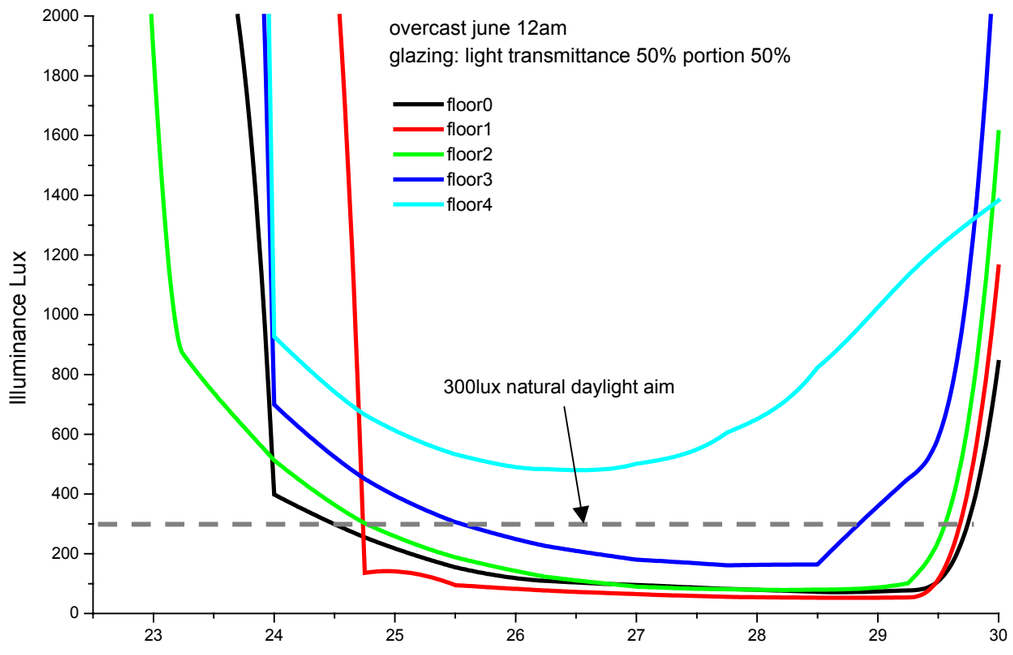
On sunny days without shading device we have, naturally, very high illuminance values in the room – without direct sunlight.

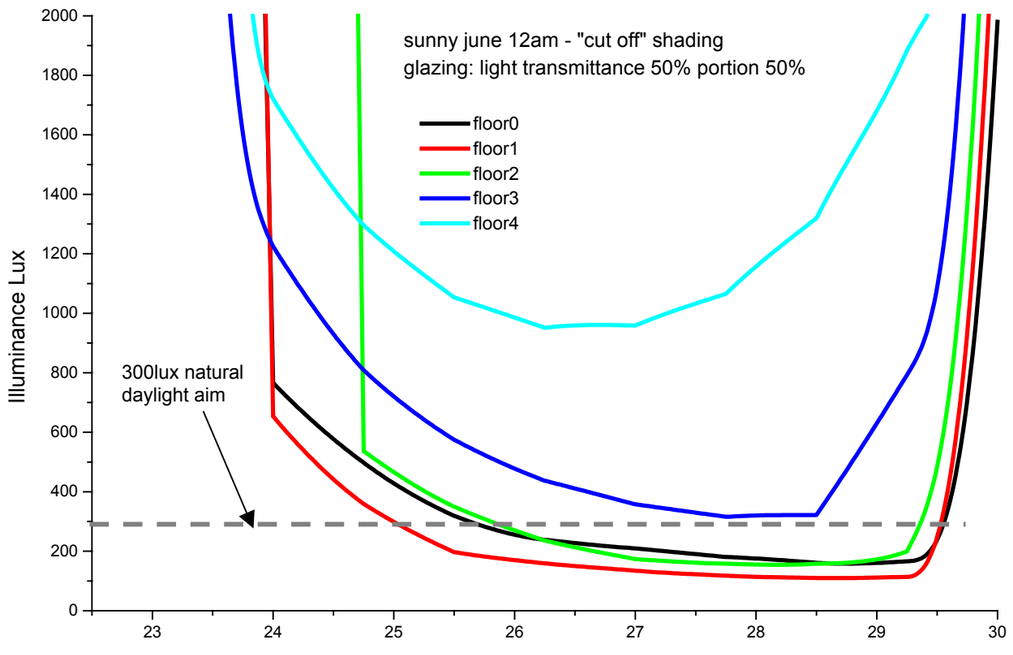
When the shading device over the street and the courtyard is closed to “cut off” the direct sunlight then the illuminance values decreases and are similar to the values of the overcast sky. (see also our comments to the matrix chapter 4.2.3.2).

Recommendations
For the recommendations basing on that simulations and on the matrix please see the chapter 4.2.4 “General Guidelines and Recommendations” on the next page.



room coordinate: facade to courtyard=22.5m SE, facade to street=30m NW





Daylight | Conclusion
General Guidelines and Recommendations

Overview
The results of the different daylight studies lead us to the general guidelines which have to be observed to achieve the energy saving and daylight quality target.

The priority of daylight demands is in descending order:

Class A:
Offices, laboratories, classrooms, hospitals and nursing homes

This type of utilization has the highest demand on a good indoor illumination with daylight on ergonomic and energy saving aspects. The duration of stay with the need of light is the longest of all building and room types. The amount of daylight should be approximately 300-400 lux and the daylight autonomy about 80% from 8am to 5pm. The visual relation to the outdoor environment is very important.

Class B:
Living rooms and buildings

The duration of stay is not as long as it is in class A use. The occupants are more tolerant to partial lacks of illumination. The amount of daylight should be approximately 150-200 lux and the daylight autonomy about 60-60% from 8am to 5pm. The visual relation to the outdoor environment is important.

Class C:
Shops, restaurants, public buildings, etc

The time of use is irregular or at night. This type of utilization is typically illuminated with artificial light anyway. The visual relation to the outdoor environment is not important but preferable.

Class D:
Industry, logistics, supply, etc

The rooms are typically very big and therefore difficult to be illuminated uniform and reliable with daylight. The demands on constant and uniform and therefore artificial light are very high. The visual relation to the outdoor environment is not important.

Location
Depending on the utilization and the type of occupancy (see spreadsheet).

Street and courtyard sizes
For the simulated model size we recommend a minimum street width of 7m and courtyard size of 7 x 7m respectively for living buildings and 10m and 10 x 10m respectively for office and similar utilization (see spreadsheet)

Facades and windows
Solar control glazing with a max. energy transmittance of 50 %, an U-value of frame and glass of max. 1.5 W/m²/K and a daylight transmission > 65%.
Window areas depending on floor level and shading opportunity, as well as type of occupancy (see spreadsheet).

Shading Devices
Apart from the function to prevent from overheating radiation a external shading device has to protect against glare and too high contrasts. It should also allow the daylight to illuminate the room even when it is closed as described above. If possible it has to be avoided switching on artificial light caused by closed shading during daytime.

External controlled shading device for windows to the streets in particular for upper floors.

Courtyards with central operable and controlled shading device in the top with light diffusing characteristic.

Surfaces
The reflectance of the surfaces should approximately be:
ceiling 70%,
walls 50% and
floors 30%

Light control
A daylight dependent light control decreases the energy consumption
The zoning of artificial light will also decrease the energy consumption as artificial light near by the windows is switched on later than the light in the depth of the room. A presence control is recommended.

Artificial light
As much direct artificial light as possible as much indirect light as necessary. High contrasts have to be avoided. The artificial light should interact with the daylight. The uniformity ratio should be as low as possible but a certain variety of luminaire types and illuminance levels makes the room more agreeable.

General lighting to provide an all-over low level illumination of a space of approximately 150 lx.

Task lighting to illuminate an area (desk or bench top) where a higher lighting level is required (400-500 lx)

Less: accent lighting to highlight decorative or dramatic features using spotlights or wall washer lights.

Lamp Types and Ballast
Linear fluorescent lamps which have an efficacy of 80-100 lm/w than incandescent lamps, producing 3 to 5 times as much light for a given input power and thus producing much less heat. They live much longer than incandescent (6 to 8 times) lamps. They require an additional ballast.

Compact fluorescent lamps (CFLs) usually consist of 2 or 4 small fluorescent tubes with a plug-in base or they may be a self contained lamp (i.e. incorporating a ballast) with a screw in base or bayonet cap. They produce light similar to incandescent sources. CFLs are available in low wattage (7 to 26 W) and offer savings of up to 80% when used to replace incandescent. The average life expectancy is over 6 times that of an incandescent lamp.

Ballast provide starting and operating voltages to discharge lamps and limit the amount of current during the operation of the lamp. The introduction of electronic ballast for fluorescent tubes has produced significant improvements in energy efficiency, around 20%. Electronic ballast convert input frequency to a higher frequency, resulting in a more efficient ballast and also allowing for light output modulation.

	Class A	**Class B**	**Class C**	**Class D**
Utilization	Offices, Laboratories, Classrooms, Hospitals, Nursing Homes	Living	Shops, Restaurants, Public Buildings	Industry, Logistics, Supply
Daylight Illuminance (Target Value for Daylight Autonomy)	300-400 lx	150-200 lx	-	300-400 lx in Daylight Orientated Zones
Daylight Autonomy	80% (8am-5pm)	60% (8am-5pm)	-	80% (8am-5pm) in Daylight Orientated Zones
Visual Relation to the Outdoor Environment	Very Important	Important	Preferable	Preferable
Location	Upper Floors	Floors above Ground Floor	Ground Floor and above	Ground Floor and Basement
Minimum Size				Preferable
Courtyard	10 x 10 m	7 x 7 m	-	10 x 10 m
Street Width	10 m	7 m	-	10 m
	Reference Room Size:	Reference Room Size:		
	Depth 8 m	Depth 8 m		
	Clearance 3m (Ground Floor 4m)	Clearance 3m		
Window/Wall Ratio				
Top Floor	30:70	30:70	-	30:70
Beneath	40:60	30:70	-	40:60
Beneath	50:50	30:70	-	50:50
Beneath	70:30	40:60	-	70:30
Beneath	100:0	50:50	-	100:0
Shading	External Controlled Shading Device for Windows to the Streets or the Courtyards, Alternative: Streets and Courtyards with Central Operable and Controlled Shading Device in the Top with Light Diffusing Characteristic			
Glare Protection	Very Important, Individually Adjustable	Not Important, Occupants Matter	Very Important, Individually Adjustable	Very Important, Individually Adjustable
Light Control	Presence Control Zone Dependent Daylight Dependent	Daylight Dependent and Presence Control Preferable	-	Presence Control Zone Dependent Daylight Dependent
Artificial Light	Energy Efficient Fluorescent Lamps with Electronic Ballast General Lighting 150-200 lx, Task Lighting 400-500 lx Less Accent Lighting	Occupants Matter, Ambient Light, Energy Efficient Lamps	Occupants Matter, Ambient Light, Energy Efficient Lamps Preferable	(Like Class A)
Installation Load	10 W/m²	6 w/m²	12 W/m² general 2 W/m² accent	10-15 W/m² depending on work requirement

Microclimate of Streets and Piazza
Air Flow and Thermal Simulation

Concept
Based on the daylight and wind impact simulations the conclusion for the design recommendations is to use narrow streets to reducing the solar exposure and wind impact. This chapter deals now with a local evaluation of the microclimate in a street canyon and on a piazza. To consider dynamic effect of varying outside conditions like temperature and solar radiation on interactive simulation approach was used, with TRNSYS for the dynamic load simulations and Fluent for the air flow impacts.

Objective
To simulate the thermal conditions of a representative street/piazza for the Masdar City.

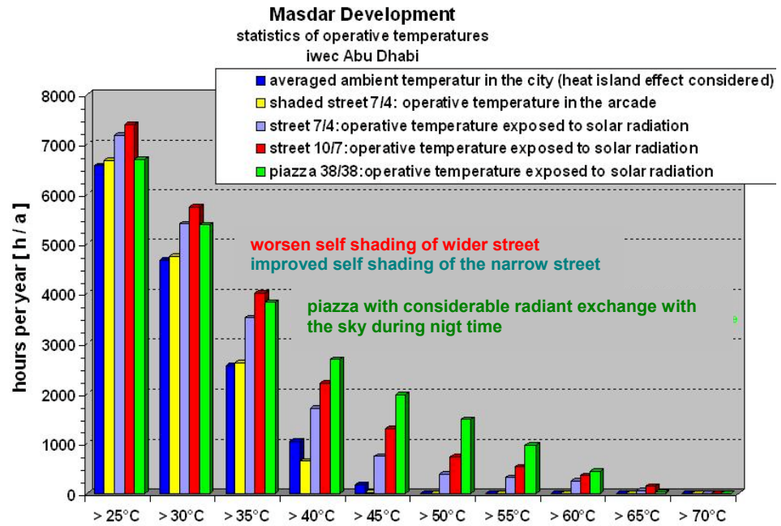
Approach
A 3-step simulation is carried out in order to achieve the desired objective.

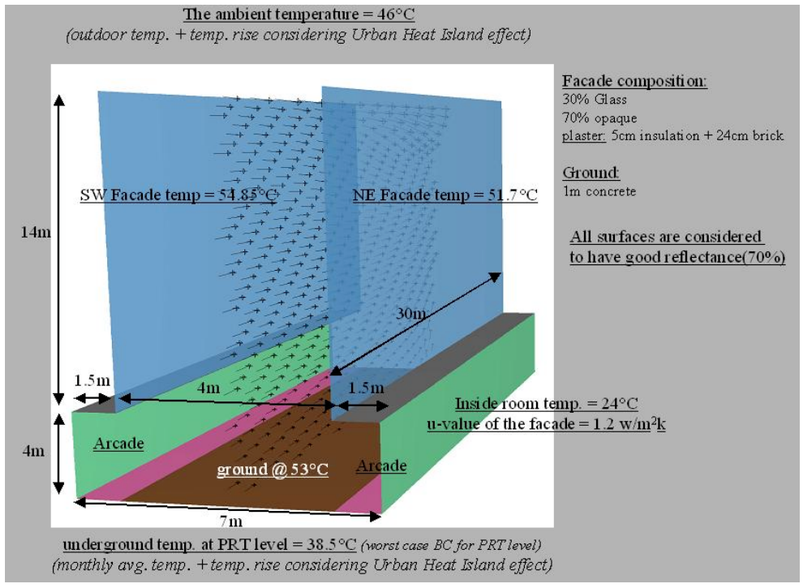
3-Step Procedure
STEP-1 The Outdoor Wind Simulation
The isothermal CFD simulation for the main wind direction is performed for a patch of the street network connected by piazzas. This stage makes it possible to investigate the amount of air entering the streets and the piazzas of various orientation and dimension. The results(in the form of mass flow rate) of this stage are used as input for the next phases. Simulation for this step is carried out with commercial CFD software “FLUENT”.
STEP-2 The Thermal Simulation
Using the inputs from the previous step, thermal simulation is carried out for the selected section of the streets(width = 7/4 and 10/7 m @(bottom/top)) as well as for the piazza(38*38m) for the entire year, based on the yearly weather data for the location(iwec abu-dhabi). With this stage, it is possible to determine the dynamic ground temperature and the surface temperature of various facades. Various temperature data are obtained as a result of this simulation; out of which the condition corresponding to the hottest day in the year is taken as the input for the further step. “Trnsys16”(for dynamic thermal simulation) and “Radiance”(to obtain the shading coefficients based on daily/annual solar curves) are the software for this stage.

STEP-3 The Final CFD Simulation
This final step gathers the data for “mass flow rate” from STEP-1 and the data for “surface temperature” from STEP-2. For the boundary conditions corresponding to each case, individual simulations are performed for the particular point of time representing the worst case scenario. The results of this simulations are shown pictorially. Commercial CFD software “FLUENT” is used again for this step.

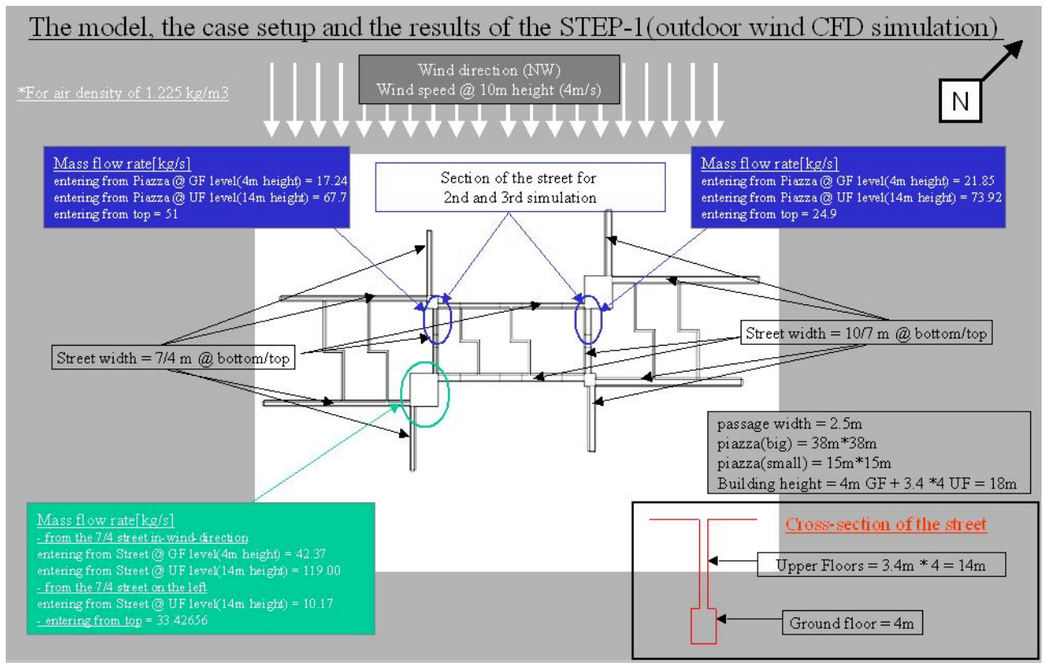
Conclusion
1) Optimal width of streets helps to keep the operative temperature inside the arcade low, by having lower solar gains on facades and ground; as it can be seen in case of the street with the width of 7/4m that the operative temperature inside the arcade is up to 5 K lower than the ambient air temperature.
2) Effective shading device can benefit the micro-climate by reducing the direct solar radiation on the surfaces and hence limiting the rise in surface temperature for the facades and ground.
3) The shading device has to be operable(this is extremely important aspect especially for piazzas) to prevent/reduce the direct radiation from the sky reaching the facades and the ground during day time
- to let the facades and the ground to radiate back to the sky during night time and to facilitate the night time flushing of the city

4) The shading device also prevents the hot ambient air to enter to the street/piazza and inhibits the conditioned pedestrian level air to escape from the street/piazza from the top . This means by further extending the covering, it is possible to approach the already reduced ground/surface temperature (discussed in conclusion 2) as the ground/surface temperature is lower than ambient temperature.
5) Reduced ground and air temperature at street level facilitates obtaining lower temperatures at PRT level, which in turn aids in reducing the operative temperature inside the arcades in the streets.
6) The reflectance of the surfaces has a determining impact on the surface temperatures(albedo effect), and so on the operative temperature. Good reflectance(= 70%) of the surfaces of facades, ground and uncovered roofs helps achieve the desired lower temperature.
7) Finally from the yearly outdoor operative temperature prediction chart(right) it can be observed that the shading of the streets helps in keeping the operative temperature close to the ambient temperature when the ambient temperature is below ~40°C, and for the higher ambient temperatures the shading keeps the operative temperature well below the ambient temperature.
8) An increase of night time ventilation like by active street windows would help the night time cooling and protect at daytime against hot outside air.





Interzonal air chnages at typical wind conditions



Variants
CASE-1
Street width = 7/4m @ (bottom/top) and the street is open from top
CASE-2
Street width = 10/7m @ (bottom/top) and the street is open from top
CASE-1 & CASE-2 are generated to compare the performance of two possible street widths.

CASE-3
Street width = 7/4m @ (bottom/top) and the street is covered from top by an operable shading device + optimistic BCs
Variant-1: The air enters the street at ambient temperature
Variant-2: The air enters the street at the exhaust temperature of variant-1(i.e. the exhaust air of variant-1 enters the street of variant-2 with the same temperature)
CASE-1 & CASE-3 can bring an insight into the change due to the covering of the street from top.

CASE-4
piazza 38*38m(length*width) and the piazza is open from top
CASE-5
piazza 38*38m(length*width) and the piazza is covered from top by an operable shading device
Again, CASE-4 & CASE-5 compares the amendment due to covering from top, but for the piazza.

Results
CASE-1 v/s. CASE-2:
Reduction in *operative temperature inside the arcades can be observed for the street with the width of 7/4m even when it is uncovered, whereas the street with the bigger width(10/7m) adds ~1°C to the ambient air temperature due to higher facade and ground temperature(because of higher solar gains).

CASE-1 v/s. CASE-3:
It can be observed by comparing the results of the street(7/4m) in covered and uncovered conditions that, covering the street is highly effective and can reduce the operative temperature by at least 2.5°C corresponding to 30m covered street length. Additional reduction in temperature can be achieved(up to ground surface temperature) by further covering the street from top.

CASE-4 v/s. CASE-5:
As expected, the operative temperature inside the piazza is found to be reduced by more than 0.6°C when covered from top as against average 2.5°C increase for the open piazza, compared to ambient air temperature .

*Operative temperature is a thermal comfort parameter that describes the felt temperature by a human body when not exposed to direct solar radiation. It takes into consideration the mean radiant temperatures of the surfaces and the mean air temperature. When exposed to direct solar radiation, an additional radiative component has to be taken into account(by Stefan-Boltzmann Equation).

CASE-1
Street width = 7/4m @ (bottom/top) and the street is open from top
CASE-1 & CASE-2 are generated to compare the performance of two possible street widths

Results of the isothermal outdoor wind simulation gives the mass flow rate of the exterior wind entering the street; which is 17 kg/s for the arcade level and 68kg/s the upper floor level. Also there is a drop of exterior wind into the street from top which amounts to 51kg/s.

The picture on top right shows the variations in ambient temperature as well as surface temperature of the ground and various facades, over one of the hottest day for the location. Due to solar gains all surfaces to the sun reach during noon temperatures above the ambient temperature. During night time the external building walls – no inertia – drop down to ambient air temperature, while the ground in the street with a heavy mass remember the hot day and stay above. This graph of temperature values versus time is obtained as a result of dynamic thermal simulation by TRNSYS over a whole year.
To simulate the worst case conditions in detail, the temperature values are taken at 1300hr of the day as the ground temperature is at its peak at that time.

The material composition of various facades and ground is listed below:
Facade at upper floor level:
- 30% Glass
- 70% opaque = 5cm insulation + 24cm brick

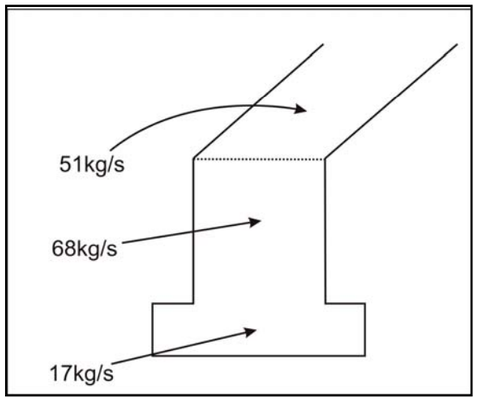
Facade at ground floor level:
- 100% glass
- u value = 1.2W/m^{2}K
- Inside room temperature = 24°C

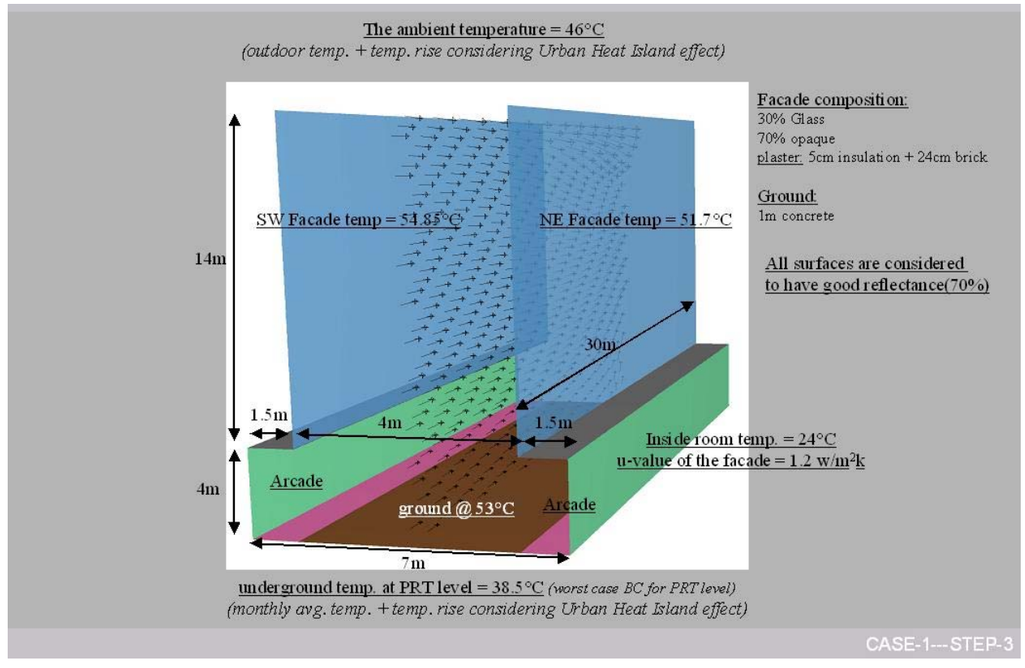
Ground:
- 1m concrete

Underground temperature at PRT level:
- 38.5°C

These values of mass flow rate of the incoming wind into the street and the surface temperature of the facades and ground together with suitable ambient temperature considering the urban heat island effect, makes the required set of boundary conditions for the CFD simulation to evaluate the microclimate of the street.

The geometrical model and the boundary conditions at each component of the CFD model are shown pictorially on bottom right.





Microclimate of Streets and Piazza

Air Flow and Thermal Simulation – CASE 1

Computational Fluid Dynamics(CFD)
Computational Fluid Dynamics(CFD) is a branch of science which uses numerical techniques to solve flow or flow related phenomen. In CFD, the region of interest is divided into many(sometimes millions) of sub-volumes. Based on provided boundary conditions, a number of equations are solved iteratively for each such sub-volumes to reach physically true results.

How to interpret the CFD results
Results of the CFD simulation are presented pictorially on the pages to follow.
On the left hand side of each picture is shown a colour bar with the associated values(blue colour represents the minimum and red colour represents the maximum value). The result should be read in the form of colours and the associated value with that colour has to be found from the colour bar on the left. This way the value of various physical quantities(eg. temperature, velocity, etc) can be found at a particular location.

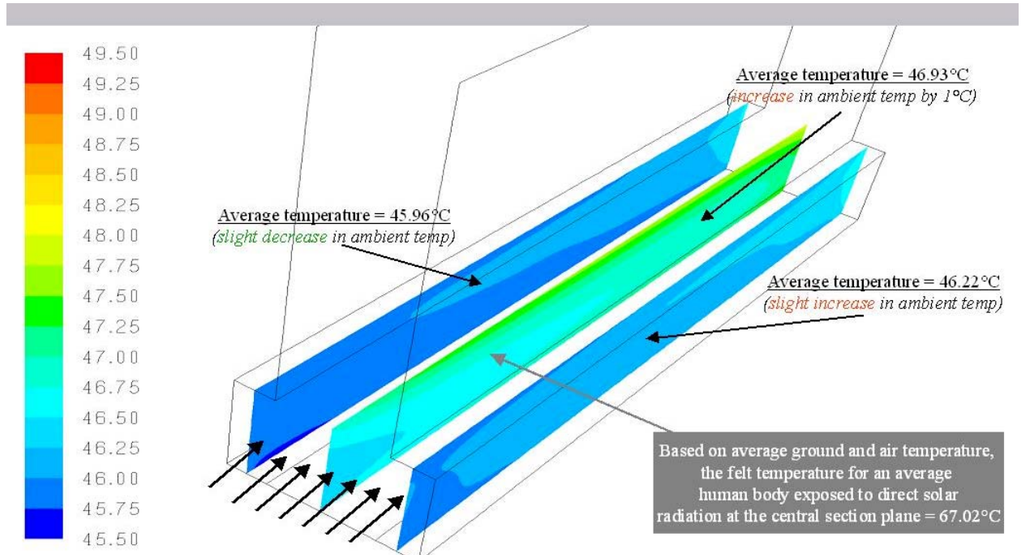
CASE-1
Street width = 7/4m @ (bottom/top) and the street is open from top

CASE-1 & CASE-2 are generated to compare the performance of two possible street widths

The pictures on right side show the operative temperature and the picture on left shows the wind velocity.
The vertical section planes extends from ground level to the arcade level(4m) and the horizontal section plane is at 2m height above the ground level.

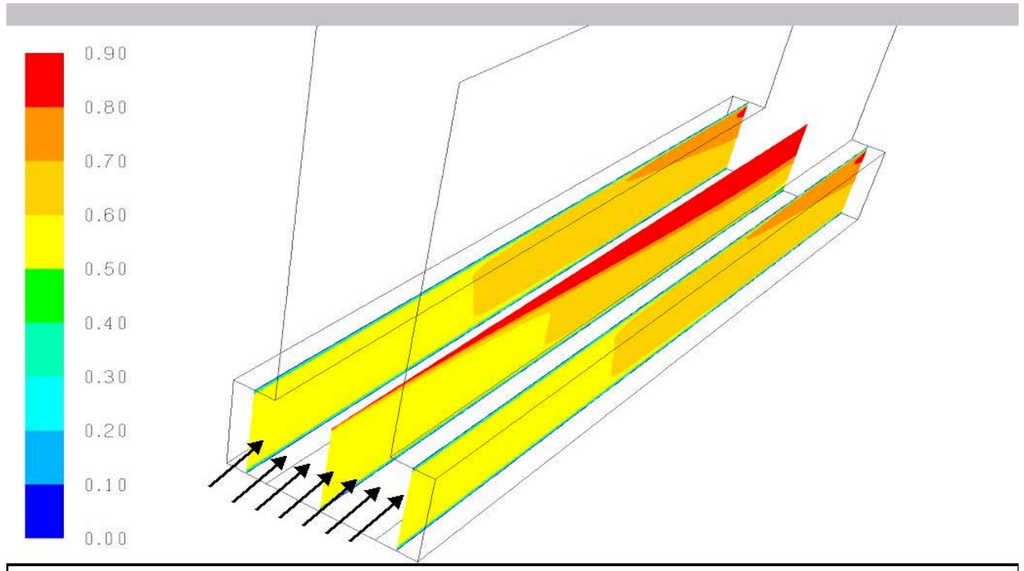
Increase in velocity can be observed, in bottom left picture, as the wind travels along the length of the street..

It can be seen from top right picture that the operative temperature at the central section plane is higher as compared to both section planes below arcade.
Also, when a human body is exposed to direct solar radiation, which is applicable only for the central section plane, the felt temperature could be as high as 67°C. While in contrast to the central section plane, a reduction compared to the outside, even though very little, in operative temperature can be observed for the section planes below arcades



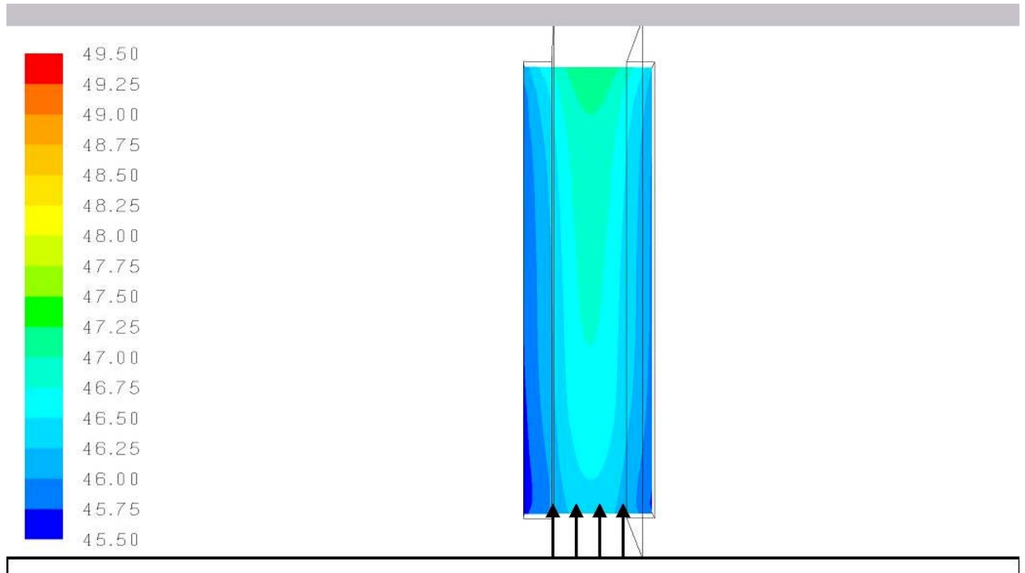
Contours of operative temperature[°C] at the section planes in the wind direction

CASE-1---STEP-3



Contours of velocity magnitude[m/s] at the section planes in the wind direction

CASE-1---STEP-3



Contours of operative temperature[°C] at a horizontal section plane 2m above the ground level

CASE-1---STEP-3

CASE-2
Street width = 10/7m @ (bottom/top) and the street is open from top

CASE-1 & CASE-2 are generated to compare the performance of two possible street widths.

It can be seen in the picture showing the results of the isothermal outdoor wind simulation that the exterior wind enters the street at the rate of 22kg/s from ground floor level; at 74kg/s from upper floor level and at 25kg/s from the top.

The picture on top right shows the variations in ambient temperature as well as surface temperature of the ground and various facades, over one of the hottest day for the location. This graph of temperature values versus time is obtained as a result of dynamic thermal simulation by TRNSYS over a whole year.

Due to higher solar gains in the wider street the surface temperatures are much higher than in the 7/4m street. By the higher solar gains the street ground heats up so much, that it only drops to 39°C Minimum even when the air temperatures reach minimal 33°C.

To simulate the worst case conditions in detail, the temperature values are taken at 1300hr of the day as the ground temperature is at its peak at that time.

Increased surface temperature for all facades as well as for the ground can be observed due to higher solar gains as a result of wider streets.

The material composition of various facades and ground is listed below:
Facade at upper floor level:
- 30% Glass
- 70% opaque = 5cm insulation + 24cm brick

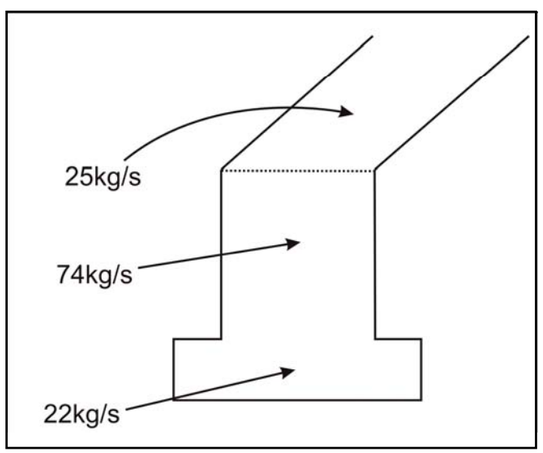
Facade at ground floor level:
- u value = 1.2W/m^{2}K
- Inside room temperature = 24°C

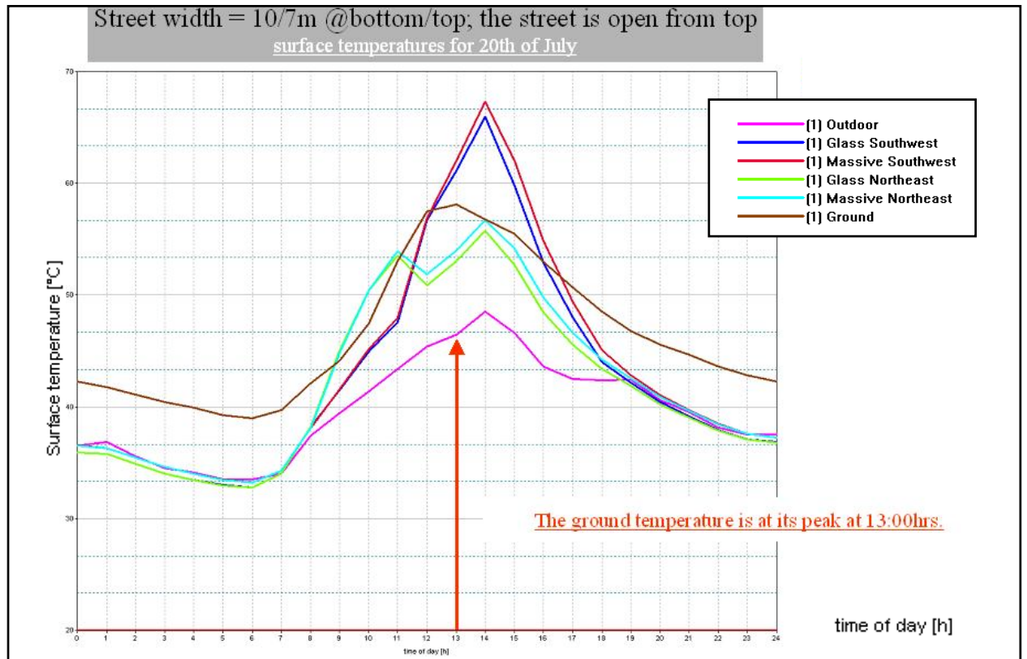
Ground:
- 1m concrete

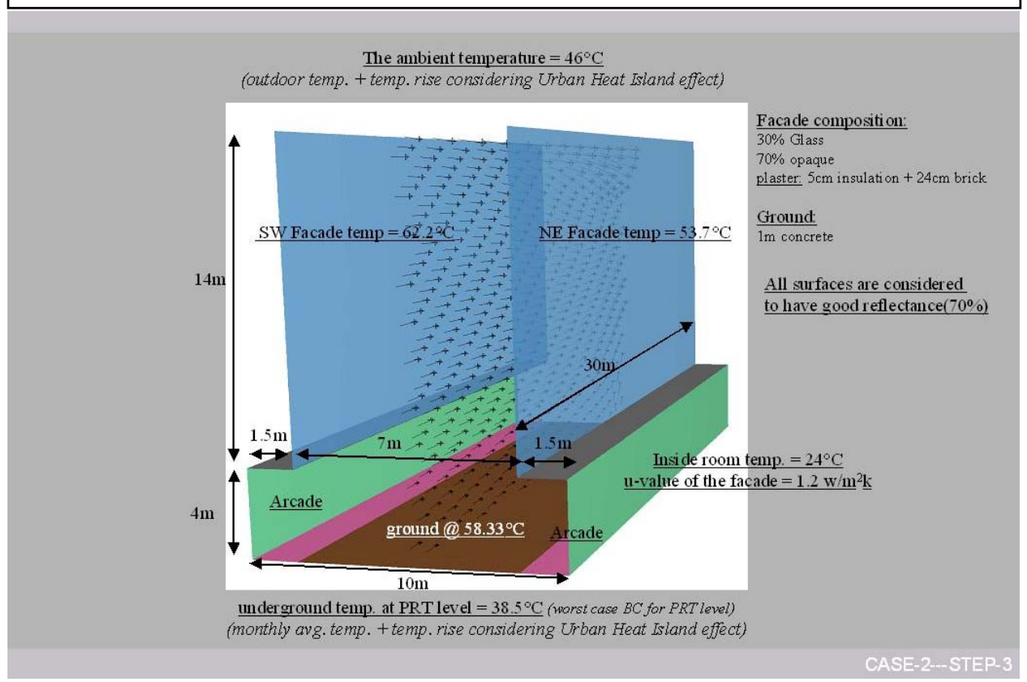
Underground temperature at PRT level:
- 38.5°C

These values of mass flow rate of the incoming wind into the street and the surface temperature of the facades and ground together with suitable ambient temperature considering the urban heat island effect, makes the required set of boundary conditions for the CFD simulation to evaluate the microclimate of the street.

The geometrical model and the boundary conditions at each component of the CFD model are shown pictorially on bottom right.







CASE-2
Street width = 10/7m @ (bottom/top) and the street is open from top

CASE-1 & CASE-2 are generated to compare the performance of two possible street widths.

The pictures on right side show the operative temperature and the picture on left shows the wind velocity.
The vertical section planes extends from ground level to the arcade level(4m) and the horizontal section plane is at 2m height above the ground level.

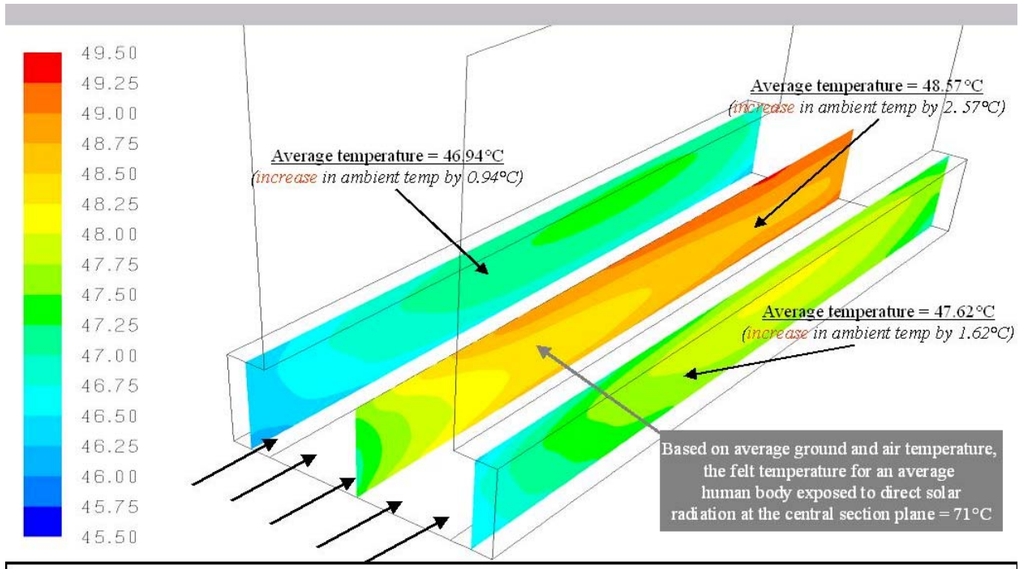
Fairly homogenous velocity city with slight higher velocity at the central section plane can be observed in the bottom left picture.

Due to the higher mass flow in the street the impact from the roof is reduced.

The pictures on right showing the operative temperature values reveal that, the average operative temperature through out the street is higher than the ambient temperature. Also, when a human body is exposed to direct solar radiation, which is applicable only for the region of the street outside the arcade, the felt temperature could be as high as 71°C.

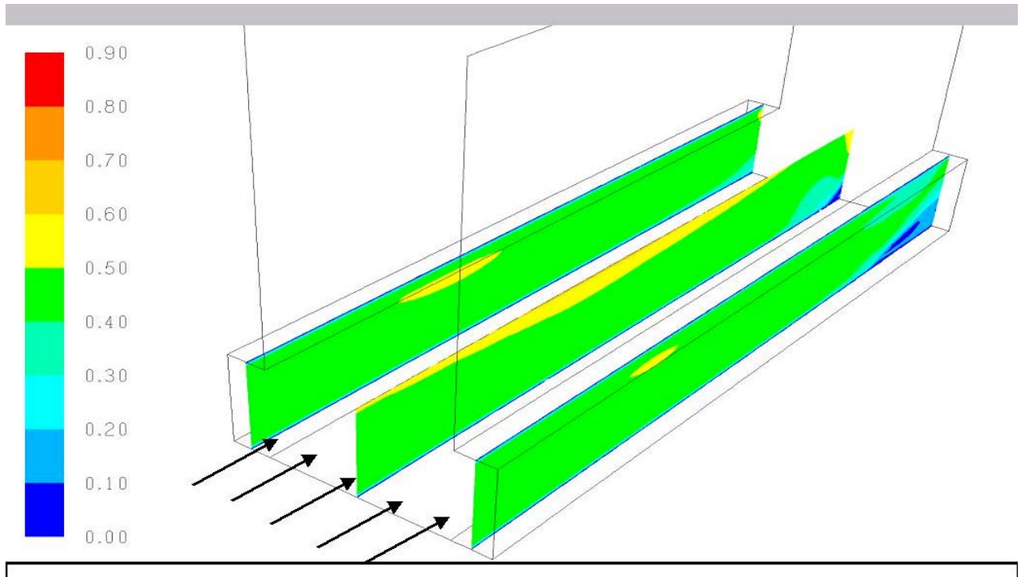
This rise in operative temperature can be attributed to the higher solar gains as a result of wider street.

These results, as compared to those of the previous case, make us believe that the street width has to be restricted to 7/4m at bottom/top.



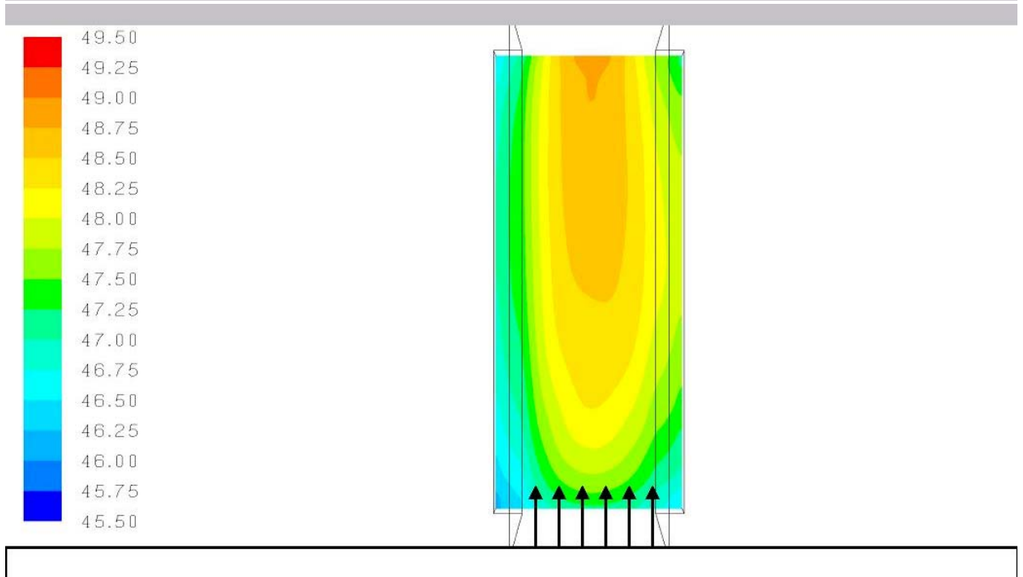
Contours of operative temperature[°C] at the section planes in the wind direction

CASE-2---STEP-3



Contours of velocity magnitude[m/s] at the section planes in the wind direction

CASE-2---STEP-3



Contours of operative temperature[°C] at a horizontal section plane 2m above the ground level

CASE-2---STEP-3

CASE-3
Street width = 7/4m @ (bottom/top) and the street is covered from top by an operable shading device + optimistic BCs

CASE-1 & CASE-3 can bring an insight into the change due to the covering of the street from top.

The pictures on this page show the variations in ambient temperature as well as surface temperature of the ground and various facades, over one of the hottest day for the location. This graph of temperature values versus time is obtained as a result of dynamic thermal simulation by TRNSYS over a whole year.

The top and bottom picture shows the temperature values when the 7/4m wide street is covered from top and the underground temperature at PRT level is estimated to be 30.5°C and 38.2°C respectively.

The first observation is the reduction in surface temperature values as compared to those of the CASE-1; which is common in both graphs. Putting the street in shade can keep all the surfaces far below air temperature to create the microclimate in the street. The surface temperature stay below outside air temperatures and create a microclimate nearly 5 Kelvin below outside-
Also, it is clear by comparing both pictures that variation in the underground temperature at PRT level brings very insignificant change in the ground surface temperature and as a whole in the operative temperature at pedestrian level.

As before, to simulate the worst case conditions in detail, the temperature values are taken at 1300hr of the day as the ground temperature is at its peak at that time.

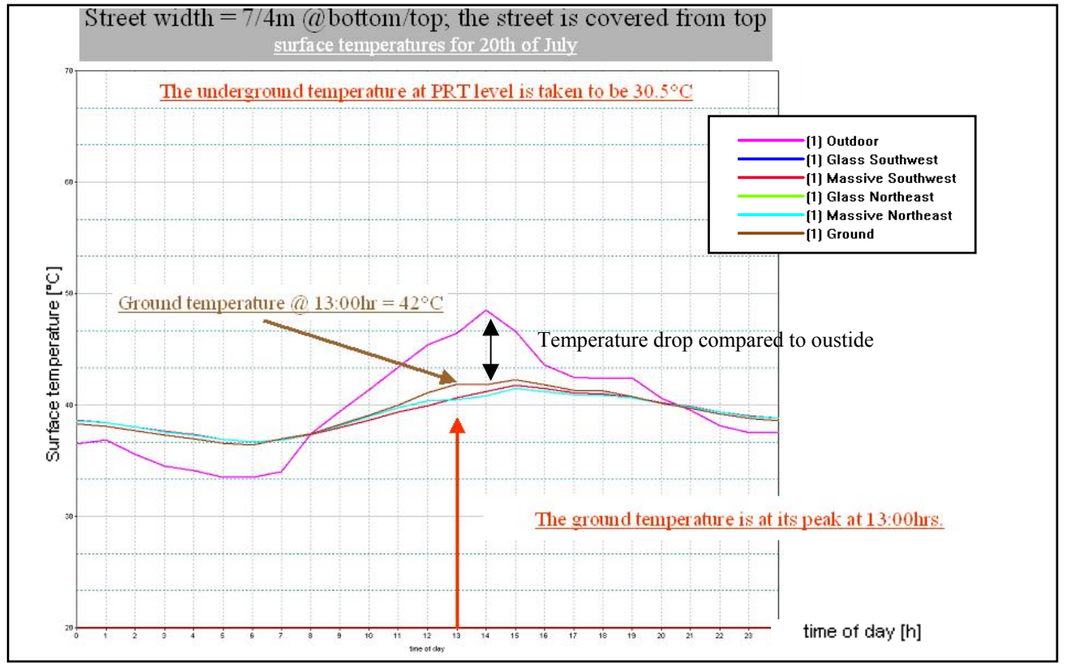
The material composition of various facades and ground is listed below:
Street cover:
- energy transmission = 24.4 %
- solar transmission = 20%
- solar reflection = 68%
- visual transmission = 15.5%

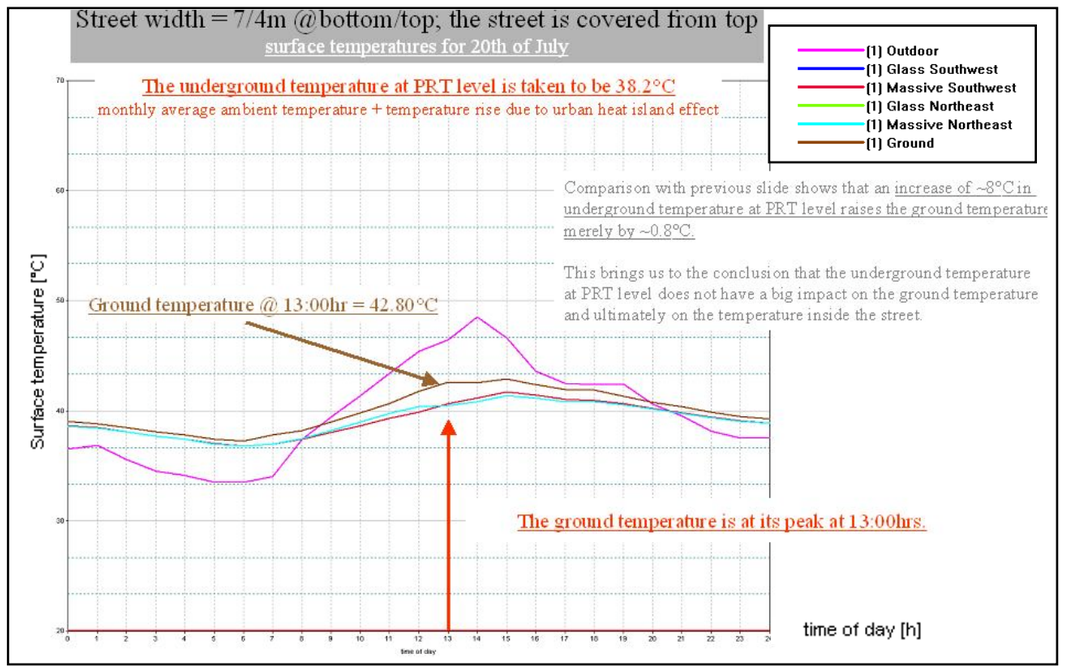
Facade at upper floor level:
- 100% opaque = 5cm insulation + 24cm concrete outside and 5 cm insulation inside

Facade at ground floor level:
- 100% glass
- u value = 1.2W/m^{2}K
- Inside room temperature = 24°C

Ground:
- 1m concrete

Underground temperature at PRT level:
- 30.5°C





CASE-3 Variant-1
Street width = 7/4m @ (bottom/top) and the street is covered from top by an operable shading device + optimistic BCs
Variant-1: The air enters the street at ambient temperature

CASE-1 & CASE-3 can bring an insight into the change due to the covering of the street from top.

The isothermal exterior wind analysis shows the infiltration rate of the exterior wind as below:

- at ground floor level: 17kg/s
- at upper floor level: 68kg/s
- No wind from top as it is covered.

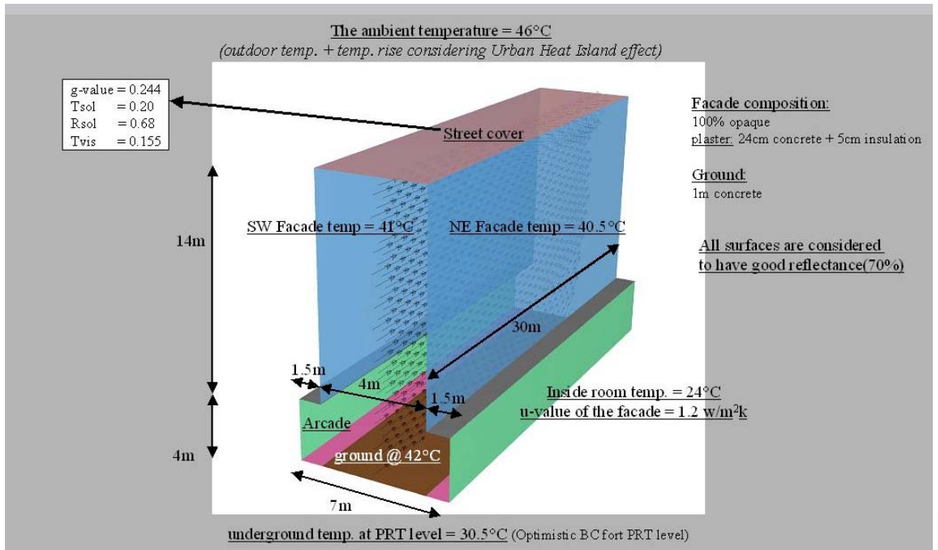
The boundary conditions for the CFD simulation are shown in the picture at top left, the velocity values are shown in the picture at bottom left and the operative temperature values are shown in the pictures on right

The first thing that comes to notice is the drop in operative temperature by 2-3°C for the entire street. Also, as the street is covered from top, now there is no exposure to the direct solar radiation and hence the operative temperature in the central region of the street is well below the ambient temperature.

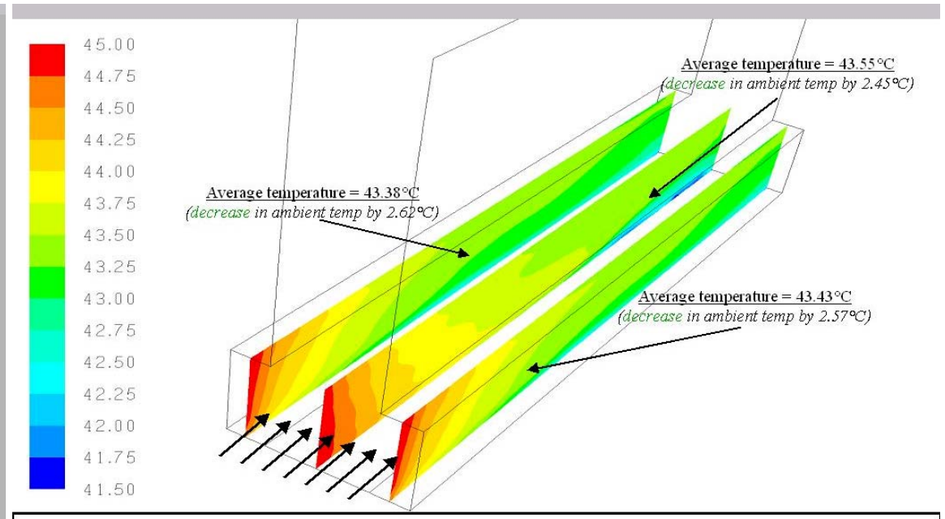
The velocity picture shows fairly homogenous and low velocity values as compared to those for the uncovered street because of nil infiltration from top.

To summarise:
The reduction in operative temperature can be attributed to

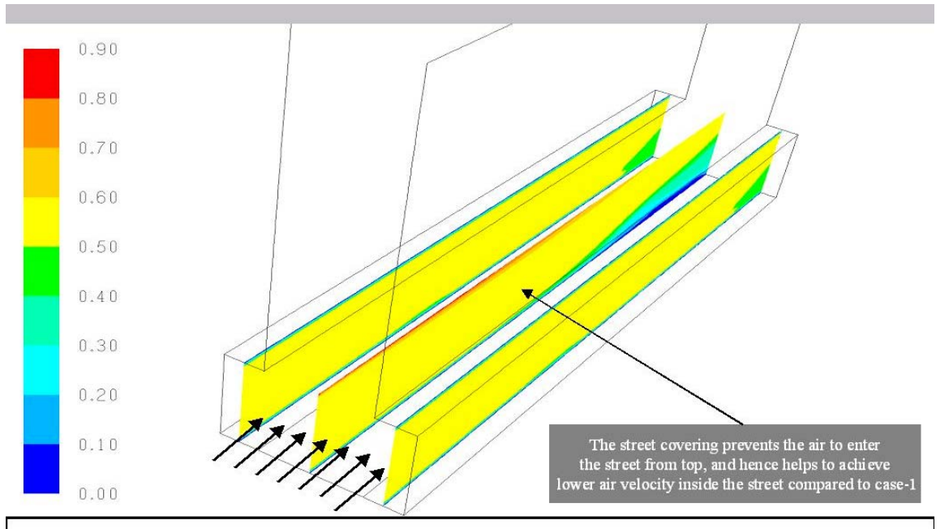
- Effective shading
- Bigger thermal mass of the facade
- Lower radiant temperature
- Lower air flow rate into the street from top reduce air based heat gains



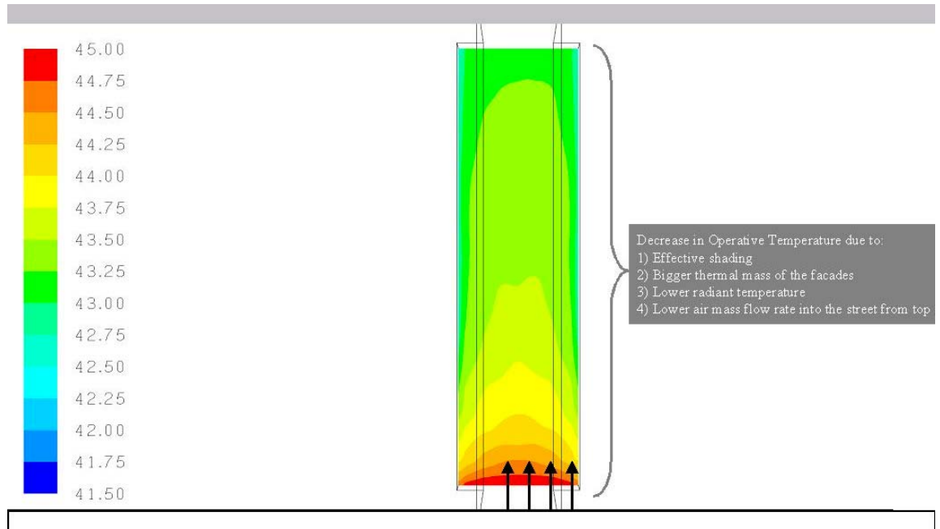
CASE-3/*variant-1*---STEP-3



Contours of operative temperature[°C] at the section planes in the wind direction
CASE-3/*variant-1*---STEP-3



Contours of velocity magnitude[m/s] at the section planes in the wind direction
CASE-3/*variant-1*---STEP-3



Contours of operative temperature[°C] at a horizontal section plane 2m above the ground level
CASE-3/*variant-1*---STEP-3

CASE-3 Variant-2
Street width = 7/4m @ (bottom/top) and the street is covered from top by an operable shading device + optimistic BCs
Variant-2: The air enters the street at the exhaust temperature of variant-1(i.e. the exhaust air of variant-1 enters the street of variant-2 with the same temperature)

CASE-1 & CASE-3 can bring an insight into the change due to the covering of the street from top.

This variant receives the air that comes out from the previous variant and the mass flow rate of the air can be given by

- at ground floor level: 17kg/s
- at upper floor level: 68kg/s
- No wind from top as it is covered.

The air enters the street at 45.25°C.

The boundary conditions for the CFD simulation are shown in the picture at top left, the velocity values are shown in the picture at bottom left and the operative temperature values are shown in the pictures on right.

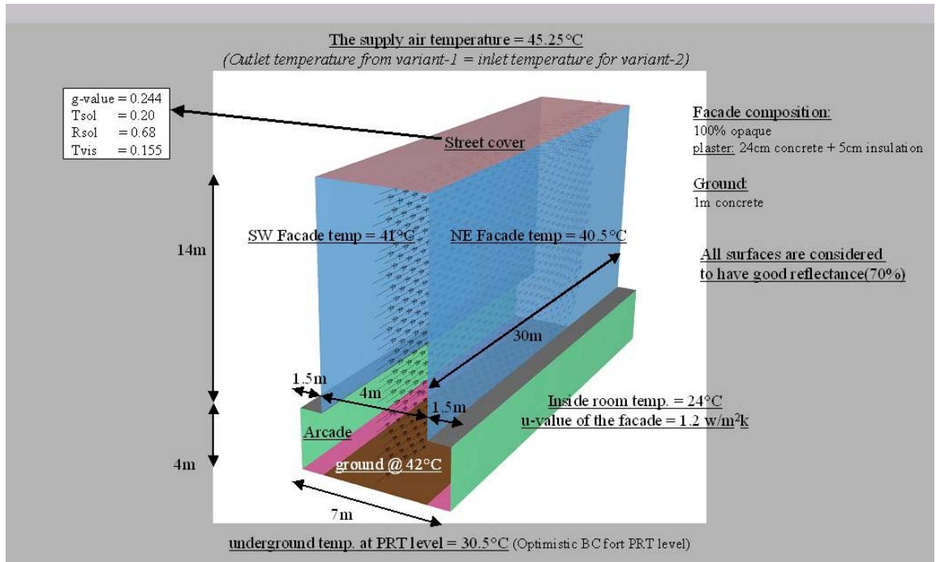
A further drop in operative temperature can be noticed here due to lower inlet air temperature. Reading values of 3-4 Kelvin below outside.

No significant changes in the velocity values can be seen.

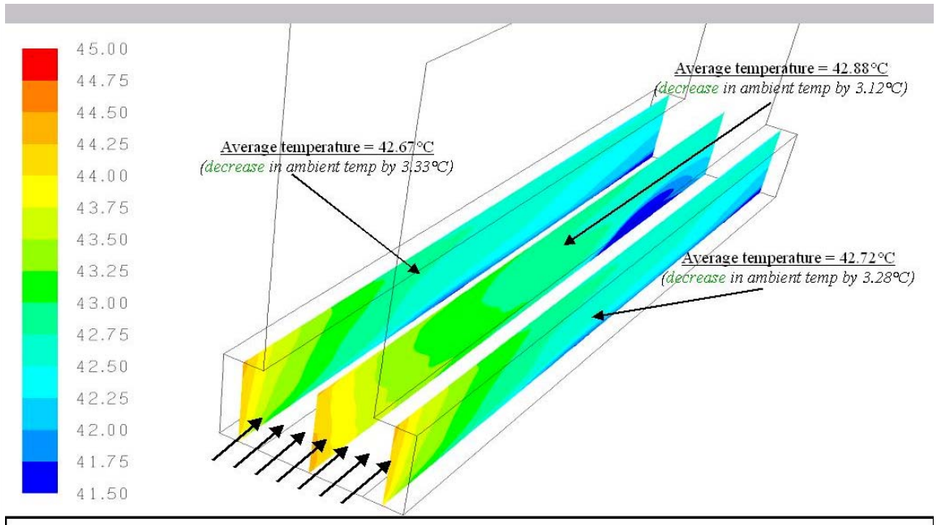
For this variant, the reduction in operative temperature is caused by

- Reduced ground/facade surface temperature by shading
- Bigger thermal mass of the facades
- Preventing the hot ambient air to enter the street
- Preventing the colder air to escape from the street

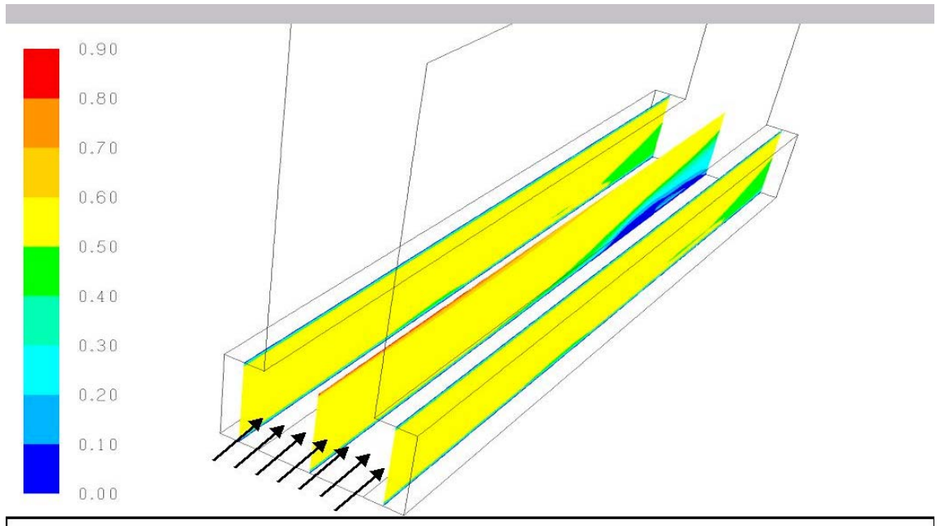
To conclude, the street shading device has a definite and positive impact on the operative temperature and further extending the street covering can help to achieve quite low temperature inside the street.



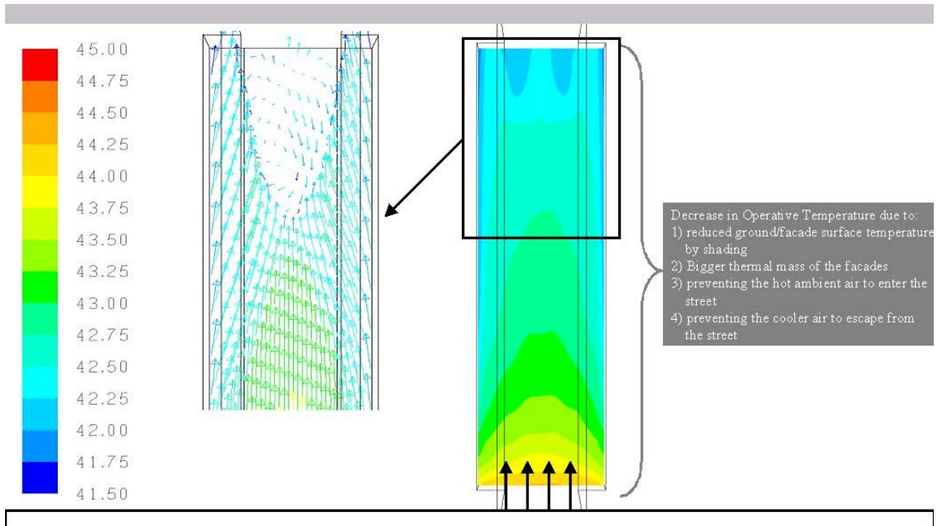
CASE-3/*variant*-2---STEP-3



Contours of operative temperature[°C] at the section planes in the wind direction
CASE-3/*variant*-2---STEP-3



Contours of velocity magnitude[m/s] at the section planes in the wind direction
CASE-3/*variant*-2---STEP-3



Contours of operative temperature[°C] at a horizontal section plane 2m above the ground level
CASE-3/*variant*-2---STEP-3

CASE-4
piazza 38*38m(length*width) and the piazza is open from top

CASE-4 & CASE-5 compares the amendment due to covering from top, but for the piazza.

As before, the results of the isothermal outdoor wind simulation gives the mass flow rate of the exterior wind entering the piazza.

- Inlet NW
  - at ground floor level = 42kg/s
  - at upper floor level = 119kg/s
- Inlet SW
  - At upper floor level = 10kg/s
- Inlet at top = 33kg/s

The picture on top right shows the variations in ambient temperature as well as surface temperature of the ground and various facades, over one of the hottest day for the location. This graph of temperature values versus time is obtained as a result of dynamic thermal simulation by TRNSYS over a whole year.

For the piazza, the ground attains the maximum temperature at 1400hr of the day and hence the surface temperatures are taken corresponding to this time for the further CFD simulation.
Due to the total solar exposure the ground temperature reaches up to 72°C.

The material composition of various facades and ground is listed below:
Facade at upper floor level:

- 30% Glass
- 70% opaque = 5cm insulation + 24cm brick

Facade at ground floor level:

- u value = 1.2W/m^{2}K
- Inside room temperature = 24°C

Ground:

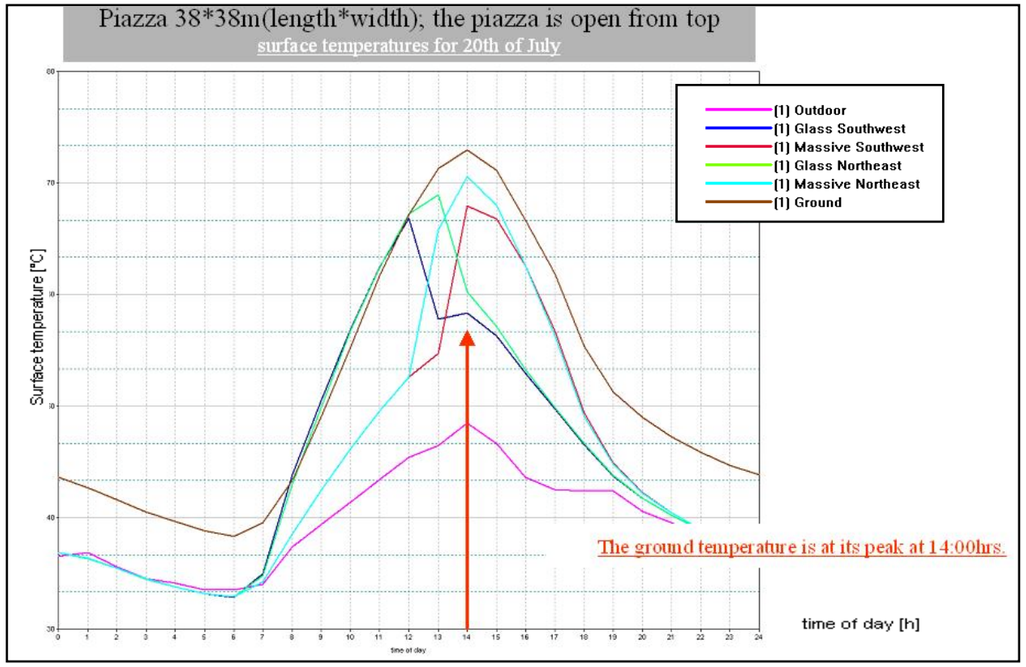
- 1m concrete

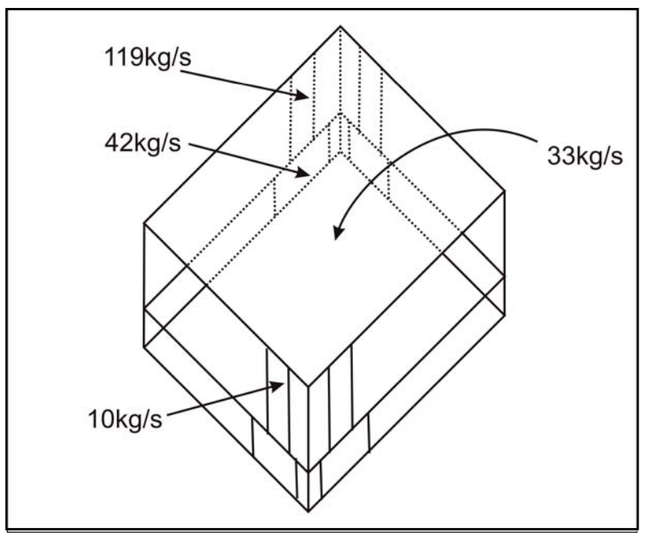
Underground temperature at PRT level:

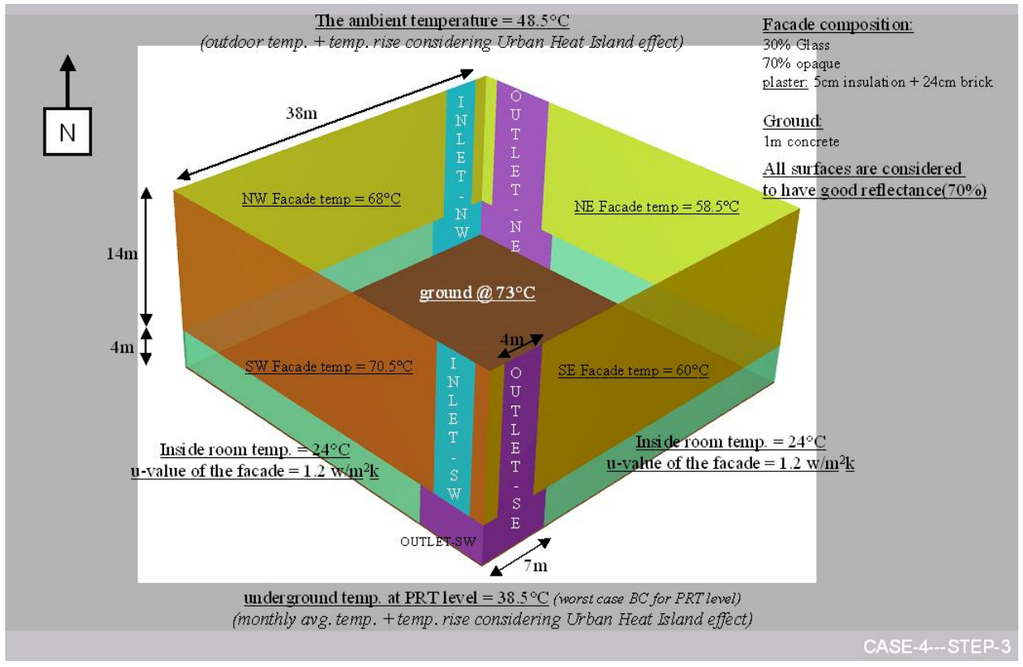
- 38.5°C

These values of mass flow rate of the incoming wind into the piazza and the surface temperature of the facades and ground together with suitable ambient temperature considering the urban heat island effect, makes the required set of boundary conditions for the CFD simulation to evaluate the microclimate of the street.

The geometrical model and the boundary conditions at each component of the CFD model are shown pictorially on bottom right.







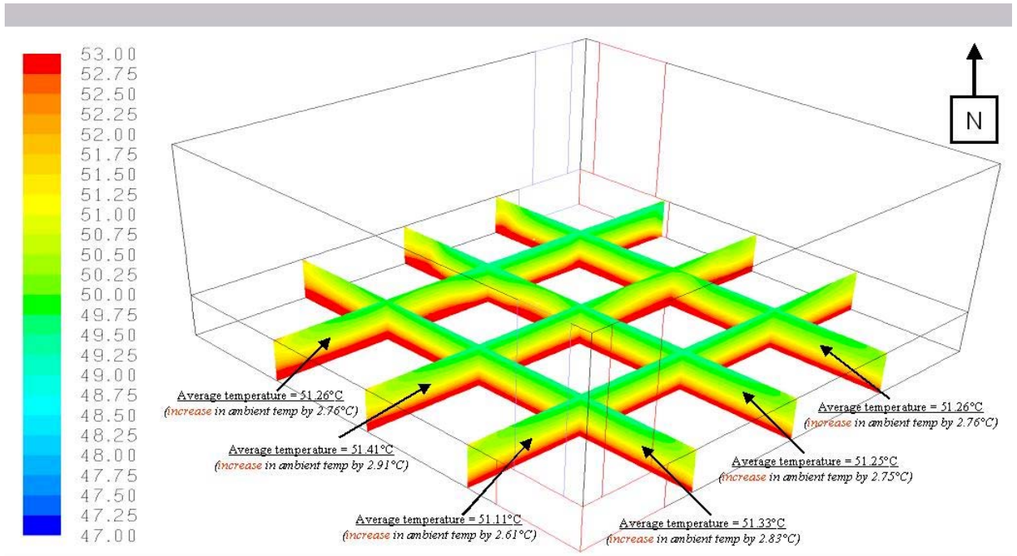
CASE-4
piazza 38*38m(length*width) and the piazza is open from top

CASE-4 & CASE-5 compares the amendment due to covering from top, but for the piazza.

The pictures on top right side show the operative temperature and the picture on bottom left shows the wind velocity. The vertical section planes extends from ground level to the height of 4m and the horizontal section plane is at 2m height above the ground level.

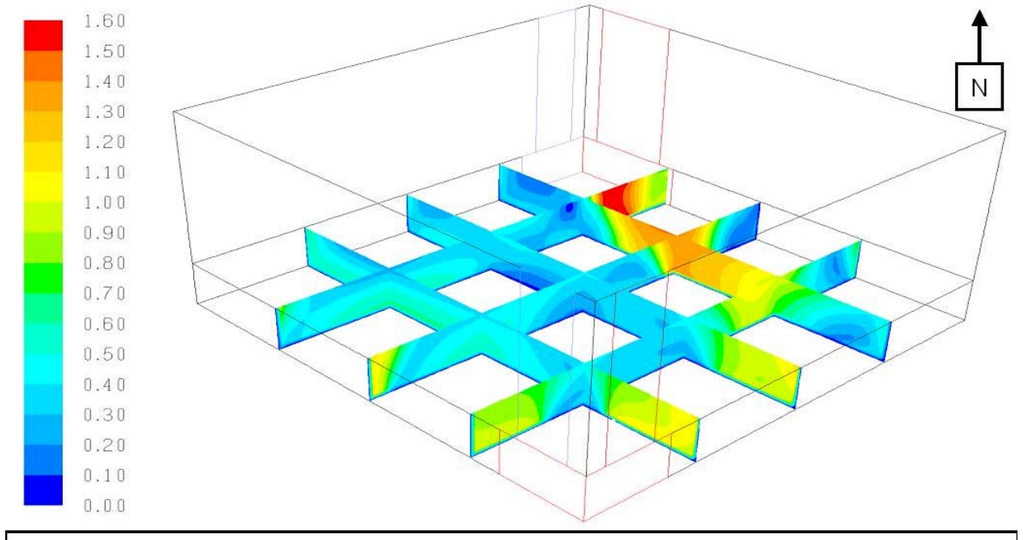
Higher velocity values near the region of inlet, superimposed by the wind entering from the top, can be seen in the velocity picture.

Operative temperature values in the range of 51-53°C can be seen for this case. For the human body exposed to direct solar radiation, this values can climbt up to 71°C, which is true for the entire piazza at pedestrian level.



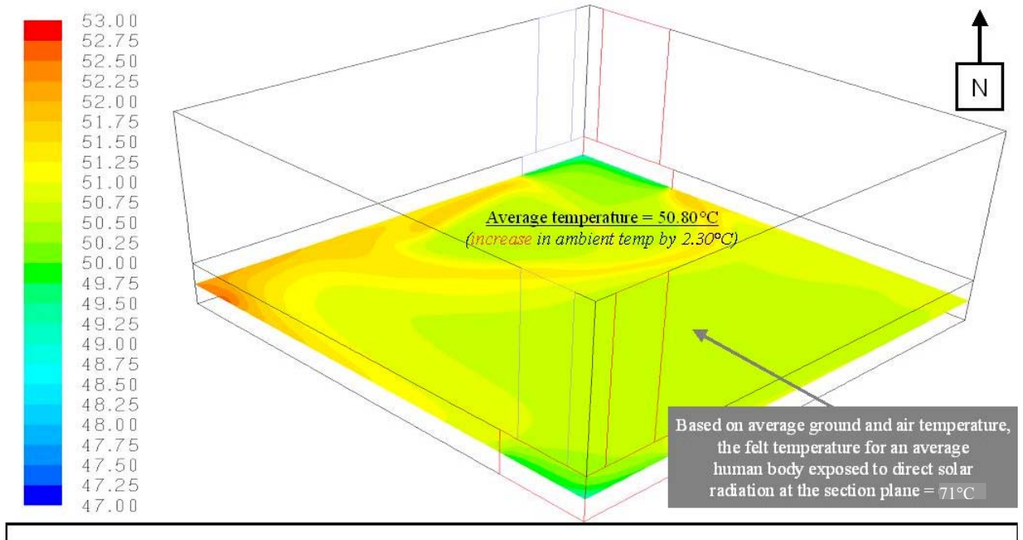
Contours of operative temperature[°C] at the section planes quadrisecting the piazza

CASE-4---STEP-3



Contours of velocity magnitude[m/s] at the section planes quadrisecting the piazza

CASE-4---STEP-3



Contours of operative temperature[°C] at a horizontal section plane 2m above the ground level

CASE-4---STEP-3

CASE-5
piazza 38*38m(length*width) and the piazza is covered from top by an operable shading device

CASE-4 & CASE-5 compares the amendment due to covering from top, but for the piazza.

The air infiltration values from the isothermal outdoor simulation gives

- Inlet NW
  - at ground floor level = 42kg/s
  - at upper floor level = 119kg/s
- Inlet SW
  - At upper floor level = 10kg/s

The picture on top right shows the variations in ambient temperature as well as surface temperature of the ground and various facades, over one of the hottest day for the location. This graph of temperature values versus time is obtained as a result of dynamic thermal simulation by TRNSYS over a whole year.

For the piazza, the ground attains the maximum temperature at 1400hr of the day and hence the surface temperatures are taken corresponding to this time for the further CFD simulation.

Reduction in surface temperature values as compared to those of the previous case is due to the piazza cover. Now the ground temperature stays below the ambient air temperature and reaches at night time with open shading nearly outside temperatures. Due to a better exposure to the cold sky the wall temperatures even drop below ambient air temperature at night, caused by radiant losses.

The material composition of various facades and ground is listed below:
Piazza cover:

- energy transmission = 24.4 %
- solar transmission = 20%
- solar reflection = 68%
- visual transmission = 15.5%

Facade at upper floor level:

- 30% Glass
- 70% opaque = 5cm insulation + 24cm brick

Facade at ground floor level:

- u value = 1.2W/m^{2}K
- Inside room temperature = 24°C

Ground:

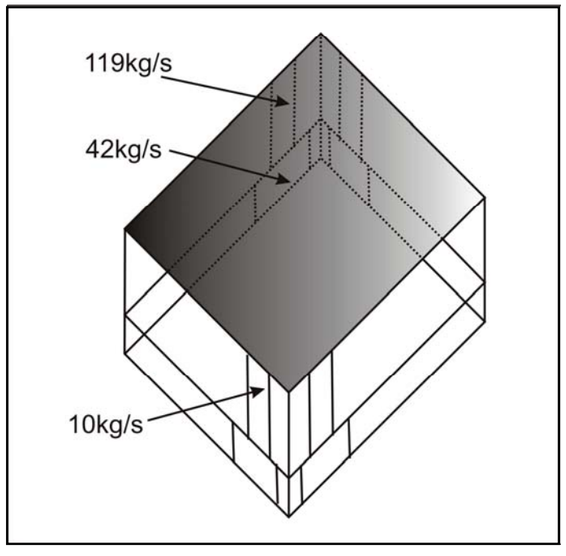
- 1m concrete

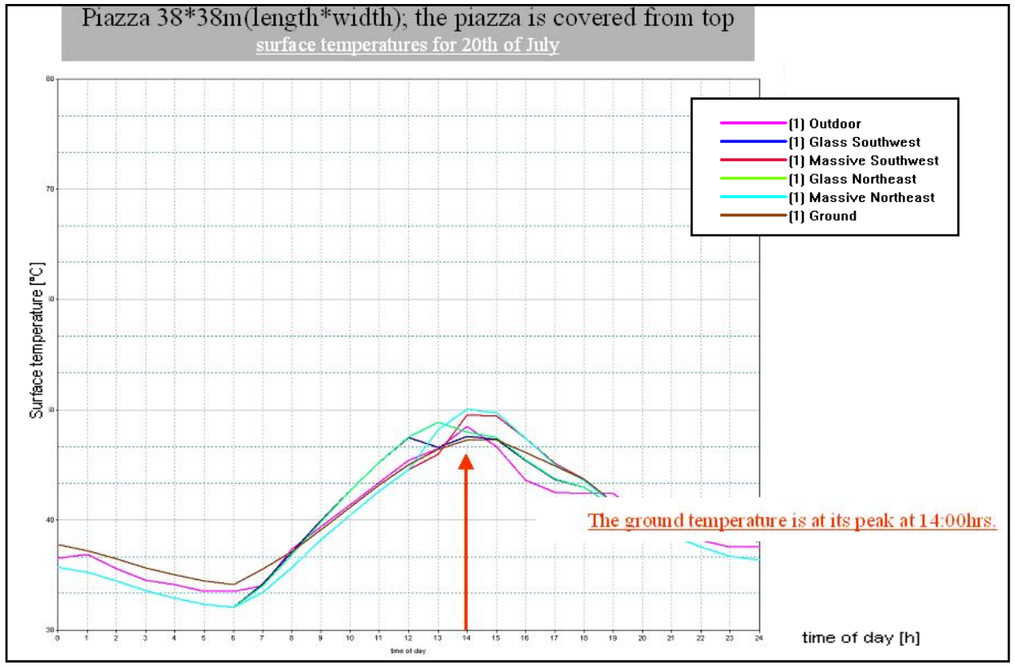
Underground temperature at PRT level:

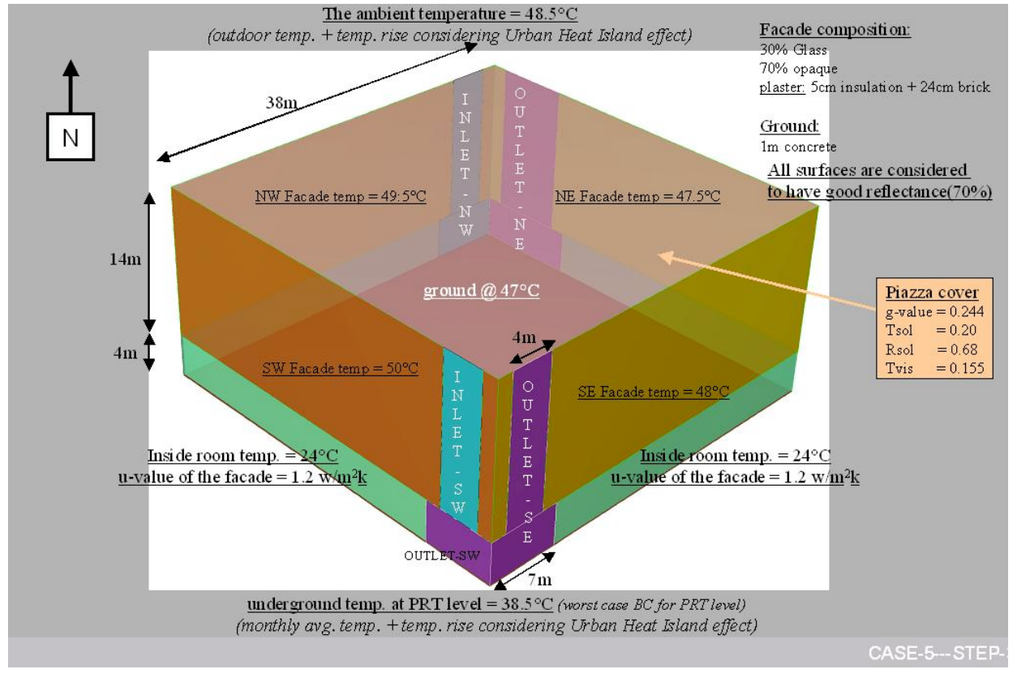
- 38.5°C

These values of mass flow rate of the incoming wind into the street and the surface temperature of the facades and ground together with suitable ambient temperature considering the urban heat island effect, makes the required set of boundary conditions for the CFD simulation to evaluate the microclimate of the street.

The geometrical model and the boundary conditions at each component of the CFD model are shown pictorially on bottom right.







CASE-5
piazza 38*38m(length*width) and the piazza is covered from top by an operable shading device

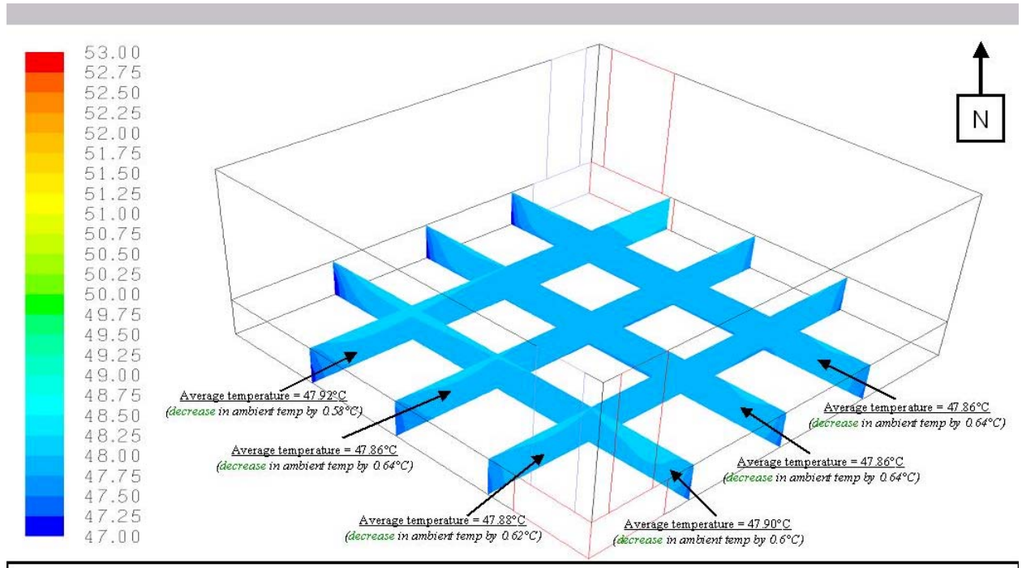
CASE-4 & CASE-5 compares the amendment due to covering from top, but for the piazza.

A little reduction in air velocity at pedestrian level can be noticed in the picture at bottom left, due to no air flow from the top.

What differs greatly from the previous case is the operative temperature values. Here, the operative temperature values are noticed to be below the ambient air temperature.

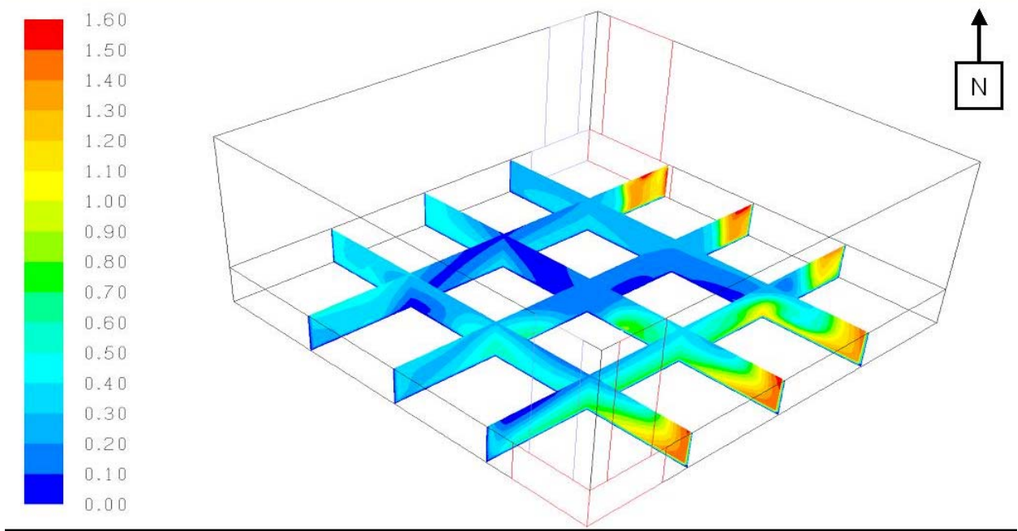
This change is due to
- Effective shading
- Reduced ground/facade surface temperature by shading
- Preventing the hot ambient air to enter the street
- Preventing the colder air to escape from the street

Photographs to the right: Example for shading with umbrellas in Cairo



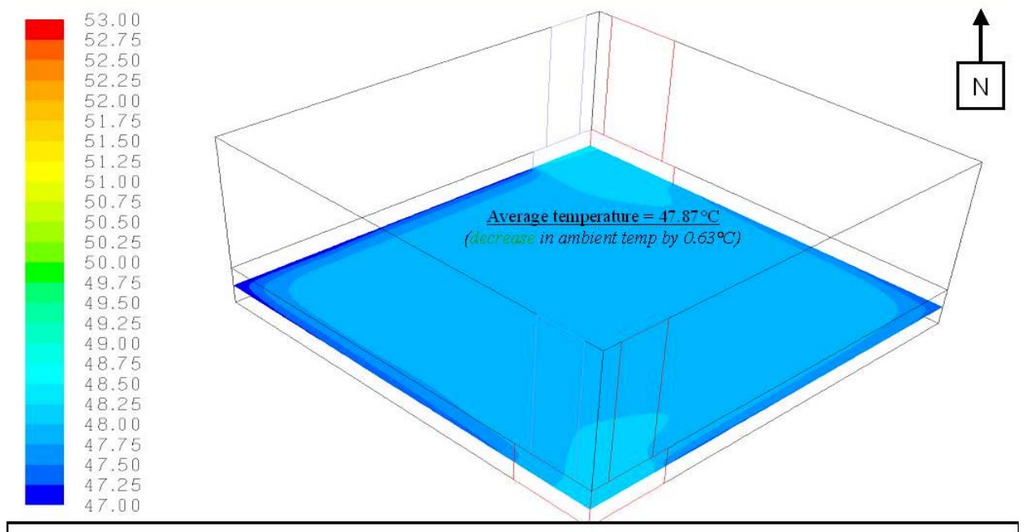
Contours of operative temperature[°C] at the section planes quadrisecting the piazza

CASE-5---STEP-3



Contours of velocity magnitude[m/s] at the section planes quadrisecting the piazza

CASE-5---STEP-3



Contours of operative temperature[°C] at a horizontal section plane 2m above the ground level

CASE-5---STEP-3

Microclimate Measurement
Installation of the Weather Station

Measurement Station for Meteorological Data and Local Environmental Conditions
In order to record the very local meteorological and environmental influences at the location of Masdar, a weather station with a 10 meters high mast was now built up.
For the planning of the new city of Masdar, the goal of an ecologically-oriented energy supply is to minimise effects on the environment. Similarly, the question of to what extent the environment has effects on the future inhabitants of the new city must be considered. Besides the meteorological influences like radiation, temperature, humidity and wind, toxic agents in the air (that originate from the local industries and from the nearby airport) can play a big role.
In order to be able to judge the burden of the region, material lists, as extensive as possible, must be taken into account with the sampling and the subsequent analyses.
Likewise, the most emission relevant materials are from air plane engines and the nearby industry, but also regionally unknown materials should be considered with an emission measurement.

Hydrocarbons Measurement
A simple measurement procedure for the location in Masdar, where there is no infrastructure and no opportunity for using deep analysis technical department, is called the ORSA®-diffusion collector procedure. This procedure is a screening proceeding, which is able to sense non-polar, polar, light and mid- volatile hydrocarbons in the outside air.
Besides benzene, up to 55 other chemicals can be detected semi-quantitatively. In addition, qualitative indications of other air contaminants can be determined. If required, the recognised contaminants can later be examined at the location with a more detailed chemical analysis.
The term of collection for one site depends on the content of materials in the air and the concentration of the materials in the air. Normally, the collectors are deployed at the site for between two and four weeks.

After this measurement period the collector will analysed on content materials in a chemical laboratory in Germany, and a new one will installed in place of the removed one for the next few weeks.

NO2 - Measurement
With a second similar procedure, the concentration of NO2 can be determined at the measurement site. It also applies the method of the passive collector. The analysis of the passive collector also takes place later in a laboratory by means of ion-chromatography in accordance with European standard DIN EN ISO 10304-1. The passive collector will be changed every four weeks as well.

Results
The results are presented in tabular form. The existing limit values from the WHO are compared with the results. This representation should give a first overview of the pollutant situation on the site and will help determine if more intensive measurements should follow. However, a definitive evaluation of the results cannot take place, because the measurement period of the collector does not comply with the measuring-time periods for the WHO limit values

Location of Weather Station
The mast of the weather station was installed on October 10th 2007 on the site of Masdar Development in Abu Dhabi. The originally planned measuring point was found to be badly attainable by car, so a new possibility was found approximately 100 meter nearer to the dirt road and the station was set up there.
The new measuring point has the following coordinates:
24°26'19.06"N
54°37'2.80"E
The new position is marked on the pictures on the right side.

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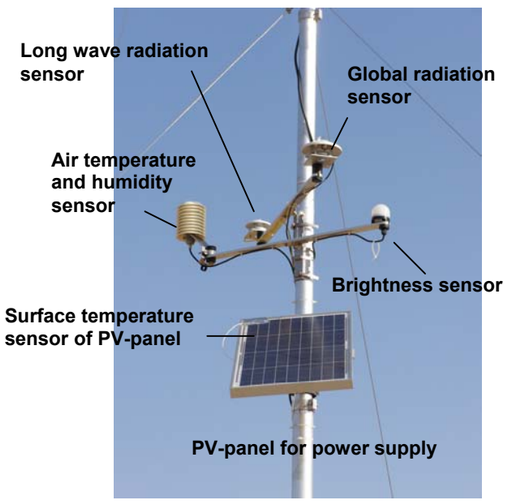
Entrance from the road

Weather Station
The weather station was set up as planned with a 10 m high mast and a small stand beside. Instead of foundations ground anchors were used for fixating the mast in the sandy soil. The following measuring instruments and units were attached to the mast:

- wind speed and direction sensor
- global radiation sensor
- global diffuse sky radiation sensor with shading
- long wave radiation sensor
- air temperature and air humidity sensor
- brightness sensor
- surface temperature sensor of PV-panel
- measurement of air pollution with two small ORSA®-diffusion collectors
- PV-panel for power supply
- indicator and data-logger system
- mobile phone modem and antenna

The measuring instruments are shown in the pictures beside.



indicator and data-logger system with mobile phone modem

Measuring Data
The measuring data is being monitored and then retrieved every two days from Germany via radio communication.
Every three weeks the small ORSA®-diffusion collectors are exchanged. The diffusion collectors are evaluated in a chemical laboratory in Germany.

The figures on the right side show the first results of measured data. The upper four figures show the course of 8 days and the lower figure the course of one day. It`s the 15th of October the first day of the 9 days course.

Course of 8 Days in October
In the figure1 is diagramed the course of wind velocity, wind direction, temperature and relative air humidity from 15th – 23th of 0ctober.
It is remarkable that on every afternoon the wind velocity rose for approximately 5 hours to over 5 m/s. While this time the main wind direction every day changed to around 340 ° which means Northwest. The max wind velocity during this eight days was 8.3 m/s.
In the third diagram of figure 1 the course over several days shows that the temperature always was between 20°C and 37 °C. The highest temperature was in this period 38.1 °C. The deepest temperatures were in the morning hours. Every day in the morning hours the temperature dropped down among 23 °C for around 3 hours.
The course of relative humidity is shown in forth diagram of figure 1. It is remarkable that with the rise of temperature the humidity drops down. On midday on three days the relative humidity was lower than 25 %.

Course of One Day in October
The figure 2 shows the results of the 15th of October 2007.
In the first diagram of figure 2 the wind velocity is noted. The course of on day shows the steady rise in wind and the change of wind direction in detail. It is to be recognized that in the morning hours the wind velocity lies between 0 and 2.5 m/s. After 12:00 noon the wind velocity rises to 5 m/s until 7:00 pm and drops again afterwards. The second diagram in figure 2 shows the wind direction. 360° means North, 270 ° means West, 90°means East and 180° means south.
In the morning the wind blows from a southern direction. When the speed rises around 12:00 noon the wind turns towards Northwest.
The third diagram in figure 2 shows the air temperature. The lowest temperature was 20.5 °C at 6:00 am and it then rose up to around 33.6 °C at 11:30 am. This means there is a temperature change of about 13 Kelvin during the course of the day.
In the same period the relative air humidity changed from nearly 100 % at night to 50 % at daytime.

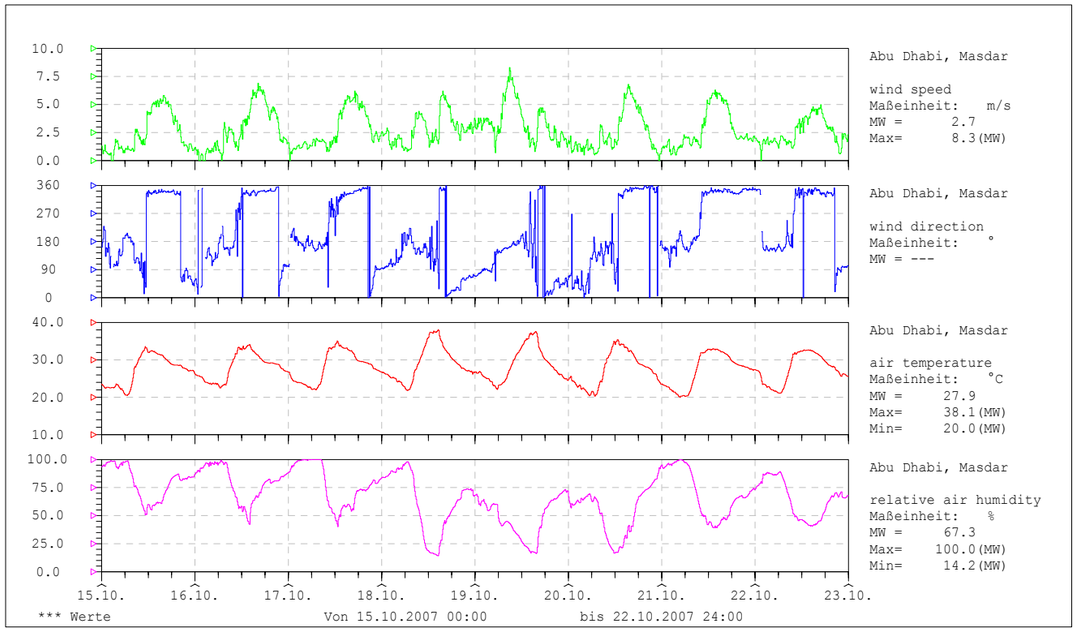


Figure 1; course of 8 days: the figure shows the course of wind speed, wind direction, temperature and air humidity in the course from 15th – 23th of October.

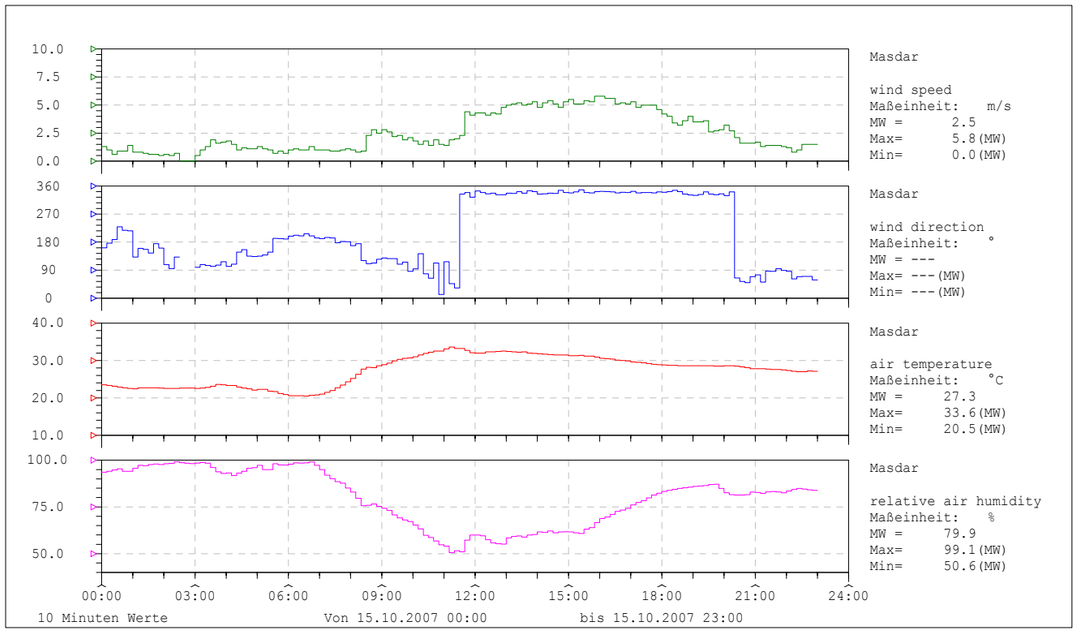


Figure 2; course of 1 day: the figure shows the course of wind speed, wind direction, temperature and air humidity in the course on 15th of October.

Course of 8 Days in November and December
In the figure3 there is diagramed the course of wind velocity, wind direction, temperature and relative air humidity from 26th of November – 4th of December. In the figures it is remarkable the clime change from summer to the transition months (October-Mai). In comparison to the air temperature in the figure 1 the max temperature dropped down from 38.1 °C to 29.3 °C. The middle temperature of the 8 days in figure 1 was 27.9 °C in comparison with 22.5 °C in figure 3. This change shows quite clearly the change of season.

In addition in figure 3 it is quite good visible the high wind speed from 27th to 29 th of November. Probably during this time was a sandstorm. During this two days the wind speed didn't release below 4 m/s even in nighttime. The whole time of this two days the wind direction was Northwest. There was no change in nighttime to South.

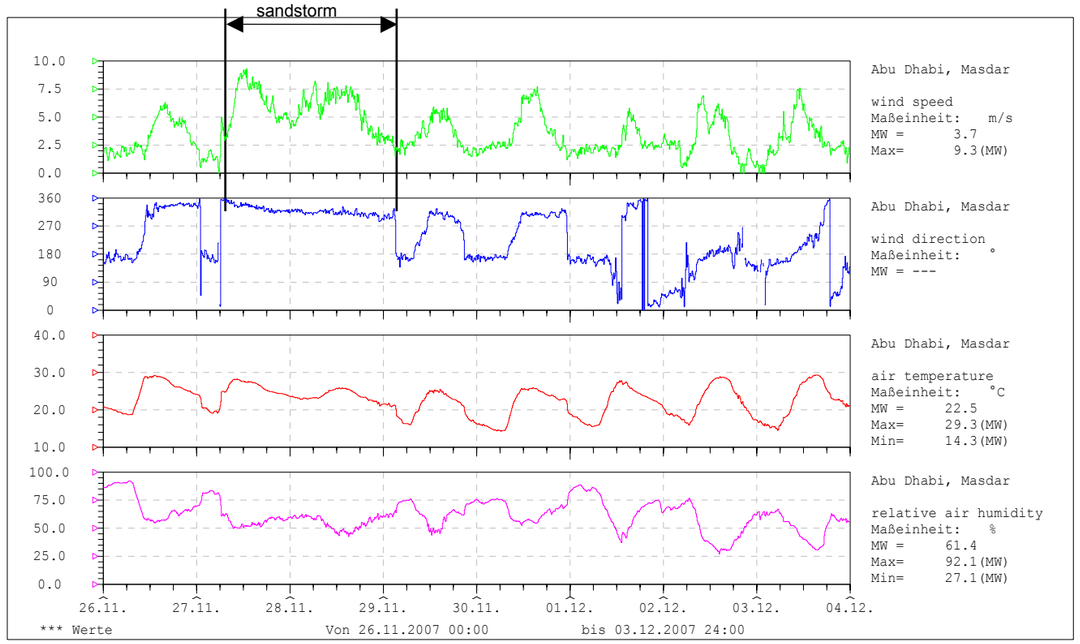


Figure 3; course of 8 days: the figure shows the course of wind speed, wind direction, temperature and air humidity in the course from 26th November– 4th of December.

Course of 8 Days in October
The process of the solar radiation shows that there was only little changes during the 8 days. Every day between sunrise und sundown the global radiation (first diagram of figure 3) rose up to 800 W/m². Global radiation is the sum of global diffuse radiation and beam radiation. Usually the beam radiation was a portion of 80 % of global radiation.
The fourth diagram in figure 4 shows the net long wave radiant, which has radiated from earth to the sky. It is negative because this radiation leads to cooling of the earth. The minimum values of net long wave radiation were at noon with around -130 W/m².
With the net long wave radiation it is possible to calculate the sky temperature. The sky temperature was calculated for two times. It is inscribed in the diagram for noon and midnight.

For the analysis the raditions were added for every day. In Figure 5 the colored bars shows the daily sum of the 8 days in October. The total global radiation was in this periode between 5500 Wh/m² and 6400 Wh/m².

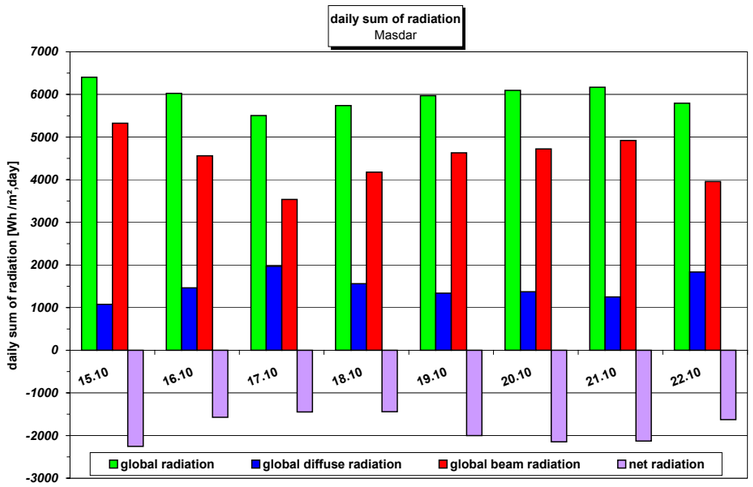


Figure 5; course of 8 days: the figure shows the added daily sum of global radiation, global diffuse radiation, beam radiation and long wave net radiation in the course from 15th – 23th of October.

Course of One Day in October
The first diagram of figure 6 shows the course of the day of the global radiation. It can easily be recognized that after the sunrise around 6:00 am the radiation rises in the morning and drops again in the evening after sunset around 6:00pm. The maximum value of the radiation was 877 W/m². The same behavior arose in the case of the global diffuse radiation (second diagram of figure 4). The global diffuse radiation is part of the global radiation without the beam radiation (third diagram of figure 4). The maximum value of the global diffuse radiation was 182 W/m², which is 20% of the global radiation.
The last diagram of figure 4shows the course of the day of the net long wave radiant, which is radiated from earth to the sky.

It shows that there is change in the process of day of -50 W/m². There is a coherence between increasing of solar radiation and long wave radiation. At daytime, when the solar radiation increases and the sky is clear, the exchange of long wave radiation between earth and sky also increases. This correlates as well with the ambient temperature profile, reaching a maximum around noon, so the highest temperature difference drives as well the high radiation losses.
This correlates as well with the ambient temperature profile, reaching a maximum around noon, so the highest temperature difference arises as well as high radiation losses

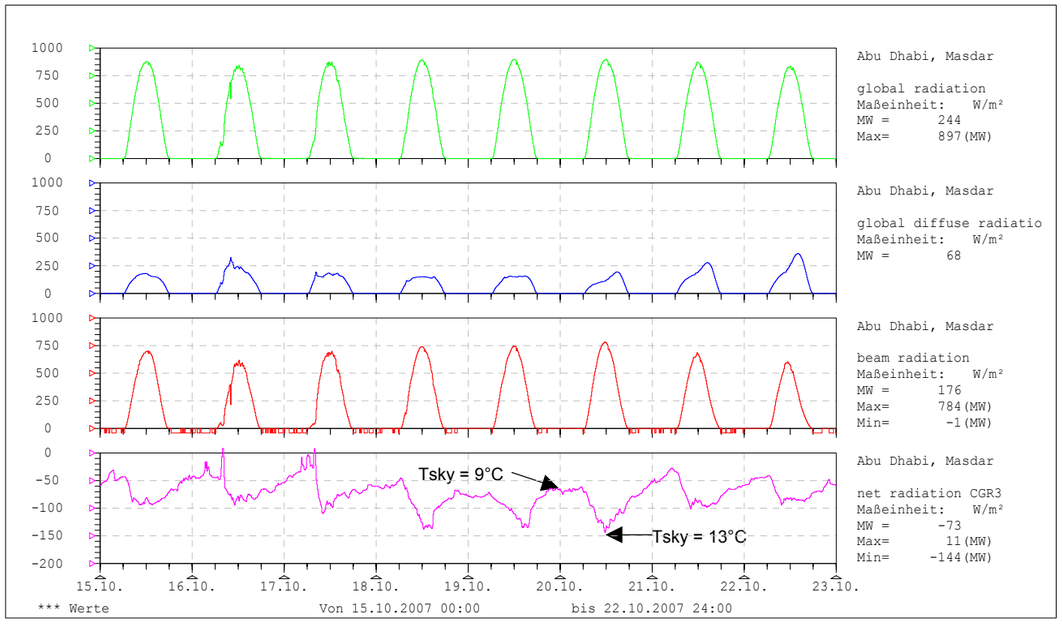


Figure 4; course of 8 days: the figure shows the course of global radiation, global diffuse radiation, beam radiation and long wave net radiation in the course from 15th – 23th of October.

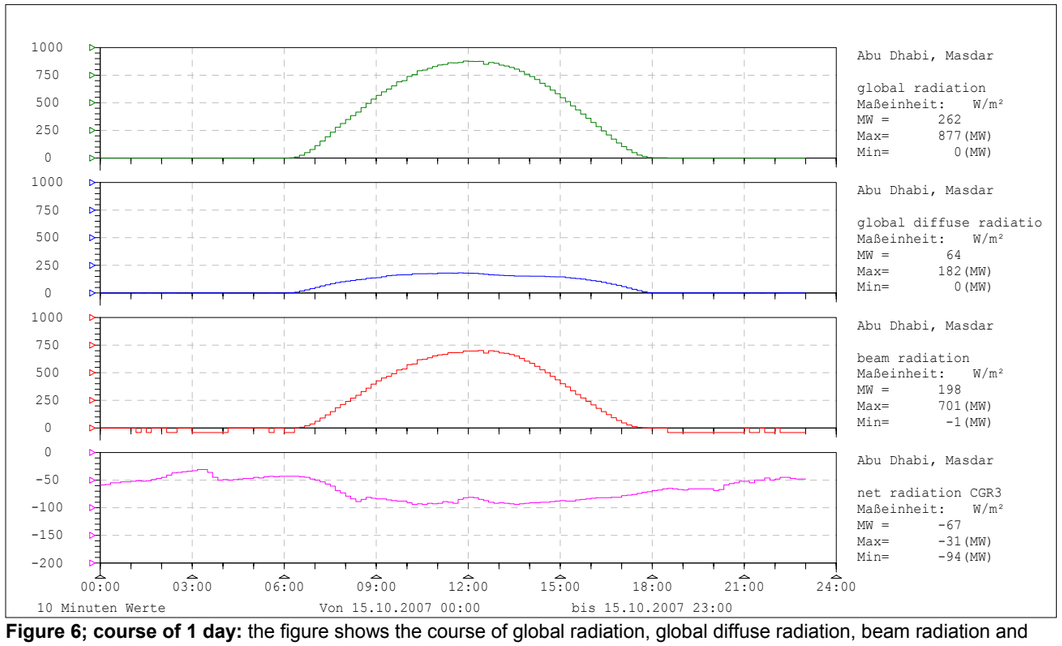
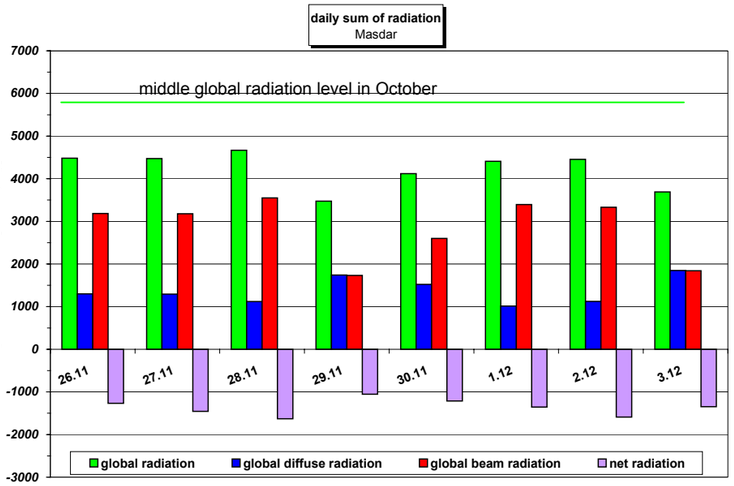


Figure 6; course of 1 day: the figure shows the course of global radiation, global diffuse radiation, beam radiation and long wave net radiation in the course on 15th of October.

Course of 8 Days in November and December
The process of the global solar radiation in figure 7 shows that there was only little changes during the 8 days. In comparison to global solar radiation in October the max. peak in this period was clearly lower. According to this radiation the diffuse radiation and beam radiation was lower as well. Resultant to this findings the daily sums of radiations, which are shown in figure 8 are lower than in October.



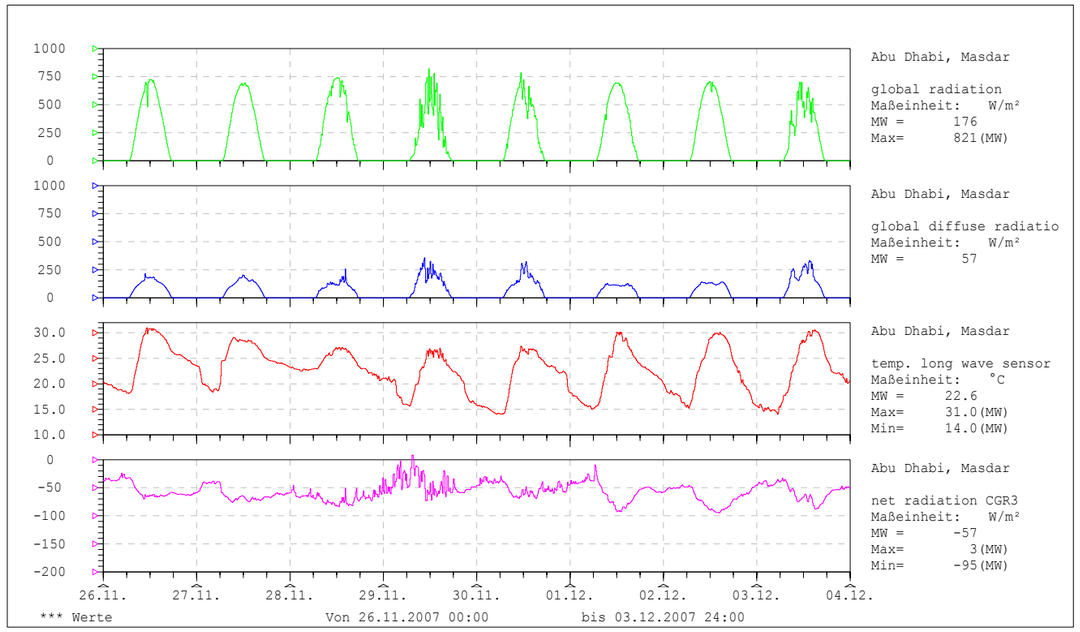


Figure 8; course of 8 days: the figure shows the added daily sum of global radiation, global diffuse radiation, beam radiation and long wave net radiation in the course from 26th of November – 4th of Dezember.

Course of 8 Days in October
Similar to the course of solar radiation the brightness (first diagram of figure 9) every day rose up between sunrise and sundown to around 140.000 kLux.
In the second diagram of figure 5 the course of the surface temperature of solar panel is displayed. The surface of panel has warmed up every day by the beam radiation to 40 °C and 50 °C, which is ~15 Kelvin above ambient air temperature.
The lower two diagrams show again the ambient air temperature and the air velocity.

Course of One Day in October
The two diagrams of figure 10 on the right side show the brightness and the surface temperature of the PV panel during the course of the day. The brightness rose on this day to a maximum of 143000 kLux. The surface temperature reached 44,6 °C which is around 15 Kelvin above ambient temperature.

Course of 8 Days in November an December
In figure 11 the brightness (first diagram of figure 11) is shown. It is noticeable that there was no great change in the maximum of brightness between October (figure 9) and November.

In the second diagram of figure 11 the course of the surface temperature of solar panel should be displayed but there was error in the measurement.

In a further investigation the connection between the air temperatur, panel temperature und the wind speed was examined. No correlation between all three could be determined.

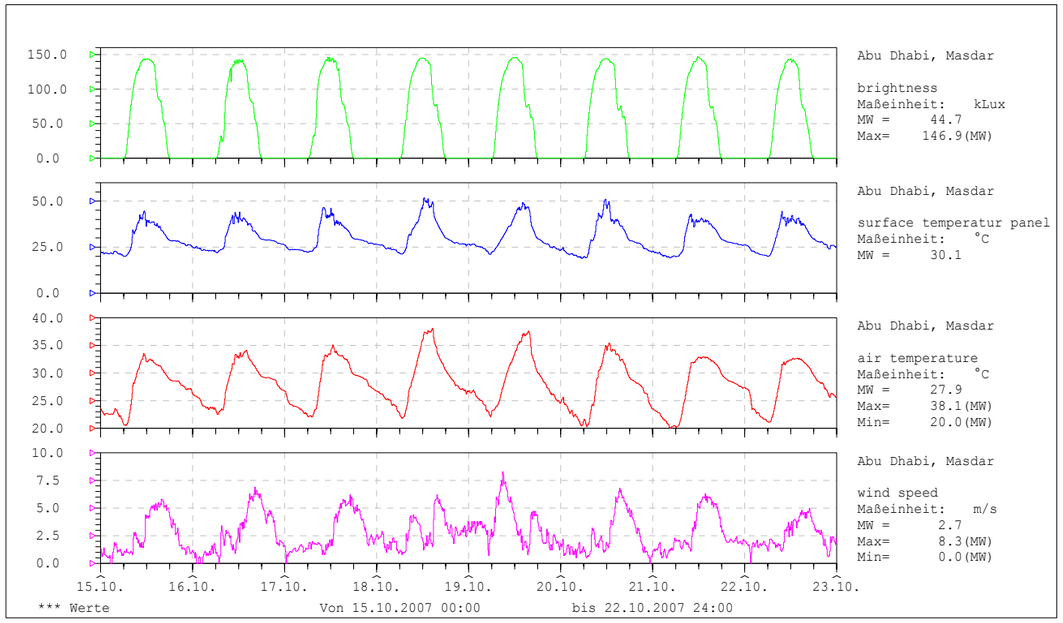


Figure 9; course of 8 days: the figure show the course of brightness, the surface temperature of the solar panel, the ambient air temperature an the wind speed course from 15th – 23th of October.

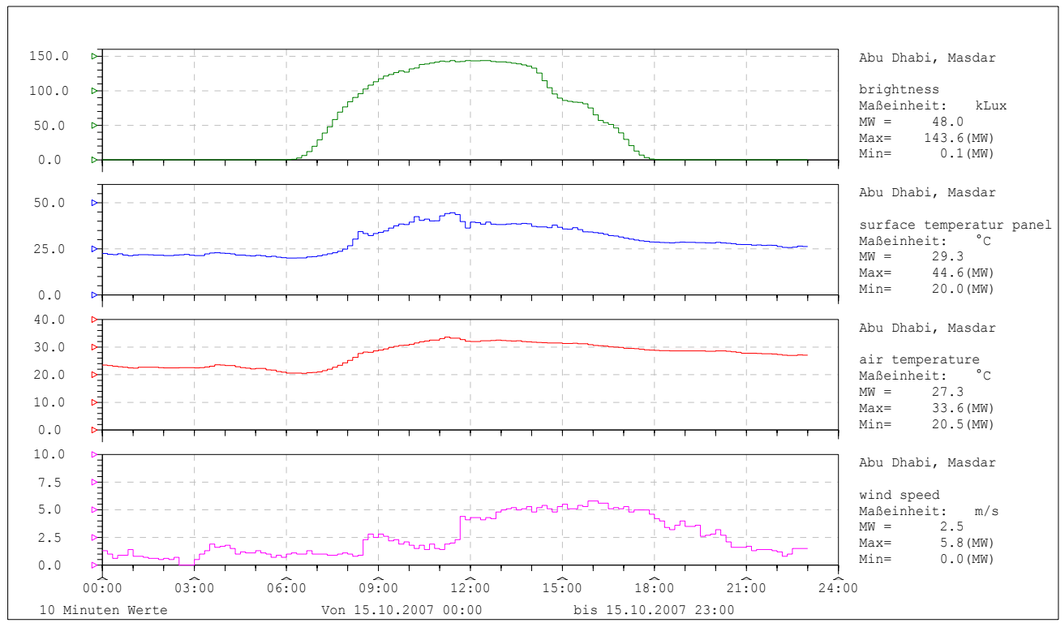


Figure 10; course of 1 day: the figure show the course of, the surface temperature of the solar panel, the ambient air temperature an the wind speed course on 15th of October.

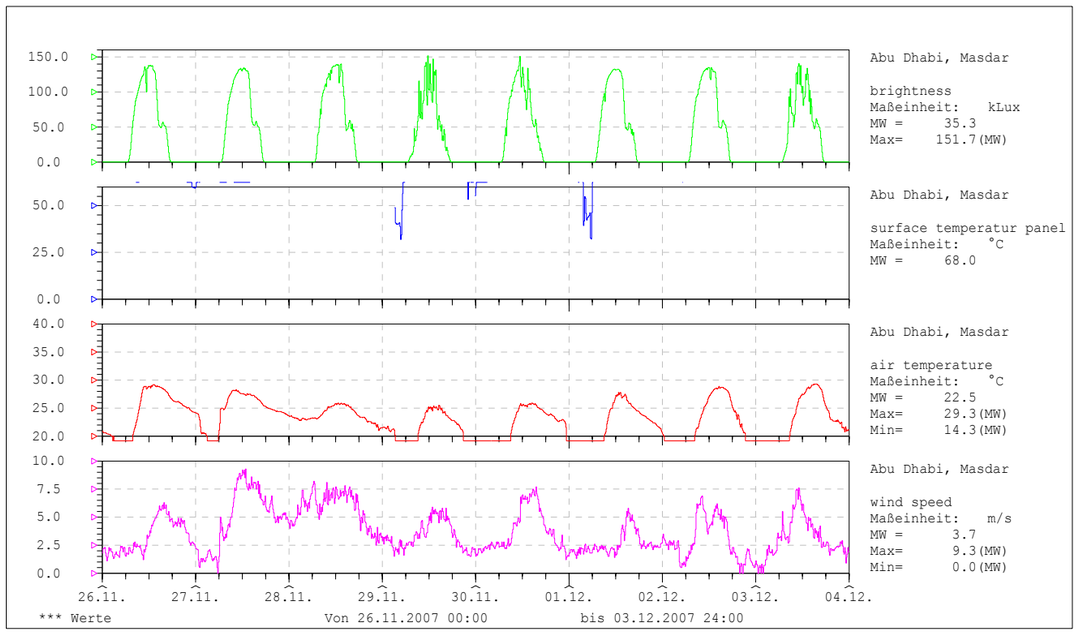


Figure 11 ; course of 8 days: the figure show the course of brightness, the surface temperature of the solar panel, the ambient air temperature an the wind speed course from 26th of November – 4th of December.

Sound measurement
With a sound measurement the admission of the sound to the location should be shown.
The sound measurement was taken throughout Tuesday the 6th of November. The measurement started at 2:00 am and finished at 11:00 pm. The level of sound was measured during this time and stored in a data logger. The precision of sound level meter according to IEC 61672 class 1. It measured all time constants (F, S and I) and the A, C and Flat (or Z) weighting networks simultaneously.

Result of sound measurement
On the following pages the results of the measurement are represented in an 8 page report by the measurement team. On the page 2 of the results the period was evaluated from 5 - 6am, which is represented on page 1. During this time there was no measurable start of airplanes. The basic level of sound is 50 dB (A).
For the further period the correlation between the starts and landings on the airport were made. A clear correlation resulted for the represented times: when an aircraft started the level of sound was 60 -70 dB (A).

On page 8 a middle level for the entire measuring time was computed. The detected rating level L_r is 62 dB (A). The level is high for this location directly in the desert. According to the German standard "TA Laerm" a location with this level would be classified for a mixed trade area and not for a residential area. In figure 4 the classification of TAE Lärm is represented. In Germany the measured noise level would make sound proof windows necessary.

The high value of 62 dB(A) is determined mostly by the high basic noise level of 52 db(A) and the temporary noise peaks by air planes only add around 10 dB(A) to this value. Therefore the question arises where the high background noise level comes from. It is assumed that it was emitted by the building site nearby and on top of this the noise of the motorway E10 was influencing the measurement results.

We recommend to do a longterm noise level measurement, which can allow to eliminate local and temporary effects.

Figure 1: Sensor for sound measurement

Figure 4: Prescriptive limits for noise in Germany for different areas and the result of the sound measurement.

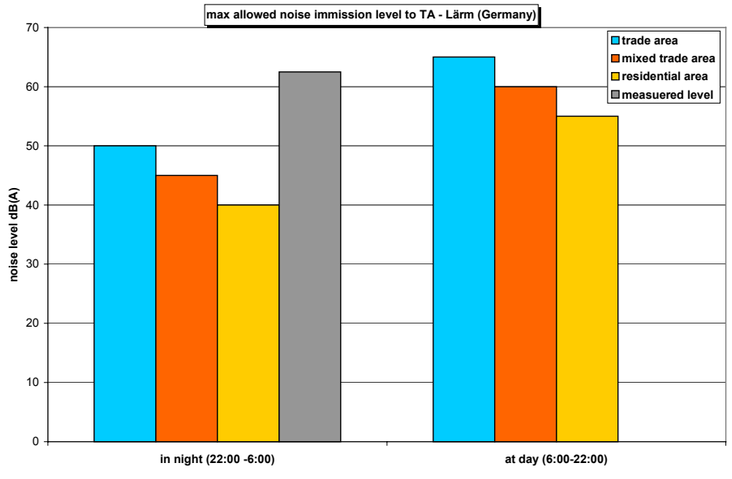
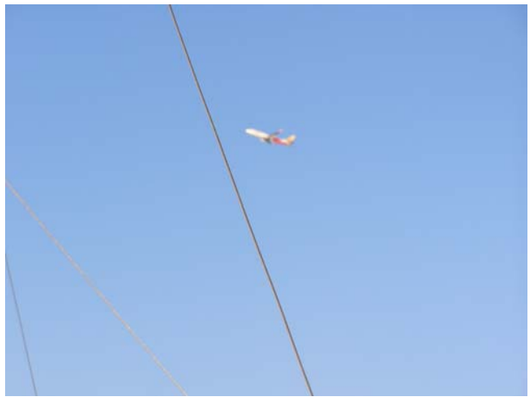


Figure 2: Data logger sound measurement

Figure 3: Start of aircraft during sound measurement



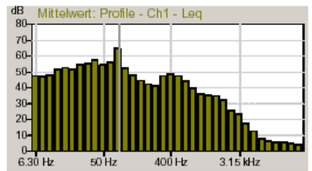
Determination of rating levels from measurement data
to DIN 45645-1 Noise immission in the neighbourhood - part time sound pressure level

Customer : Abu Dhabi Future Energy Company
Projekt : Abu Dhabi Masdar
Specification : **Measurement of noise immission in the neighbourhood**

Testing date : 06.11.2007
Testing area : Weather Station Masdar

Sound pressure level - time diagram

Flat frequency band



Measurement - level averaging
Part-time sound pressure level No. 1
The integrated

equivalent sound pressure level :	$L_{Aeq,m}$ =	**51,0** dB(A)
Takt-maximum sound pressure level :	$L_{AT,5,m}$ =	**53,3** dB(A)
The maximum sound pressure level :	$L_{AF,max}$ =	**62,8** dB(A)

Determination of rating levels from measurement data
to DIN 45645-1 Noise immission in the neighbourhood - part time sound pressure level

Customer : Abu Dhabi Future Energy Company
Projekt : Abu Dhabi Masdar
Specification : **Measurement of noise immission in the neighbourhood**

Testing date : 06.11.2007
Testing area : Weather Station Masdar

Part time sound pressure level i
Reference to

		No. 1 Page 1	
	$L_{Aeq,m,i}$ =	51	dB(A)
Background noise	L_G =	46	dB(A)
$L_{Aeq,i} = 10 \times \lg\left(10^{(0,1 \times L_{Aeq,m,i})} - (0,1 \times L_G)\right)$	$L_{Aeq,i}$ =	49,3	dB(A)
Impuls addition $K_I = L_{AT,5,m} - L_{Aeq,m}$	K_I =	2,3	dB
Tone addition	K_T =	0,0	dB
Addition for rest time	K_R =	0,0	dB
Addition and reduction of special sound	K_S =	0,0	dB
Meteorology adjustment of DIN ISO 9613-2	C_{met} =	0,0	dB
	$L_{r,i}$ =	51,6	dB(A)

Part time i T_i = 3600 s
Specification of part time sound pressure level 05:00...06:00 time of night

Total time T_r = 3600 s

$$L_r = 10 \times \lg\left[\frac{1}{T_r}\sum_{i=1}^{m} T_i \times 10^{0,1 \times \left(L_{Aeq,m,i} + K_{I,i} + K_{T,i} + K_{R,i} + K_{S,i} - C_{met}\right)}\right]$$

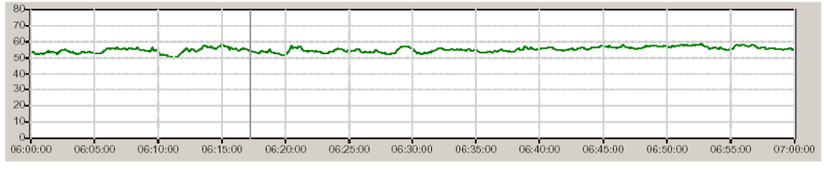
Detection the rating level of measurement L_r = 52 dB(A)

Determination of rating levels from measurement data
to DIN 45645-1 Noise immission in the neighbourhood - part time sound pressure level

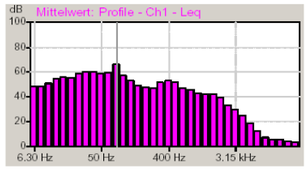
Customer : Abu Dhabi Future Energy Company
Projekt : Abu Dhabi Masdar
Specimen : **Measurement of noise immission in the neighbourhood**

Testing date : 06.11.2007
Testing area : Weather Station Masdar

Sound pressure level - time diagram



Flat frequency band



Measurement - level averaging
Part-time sound pressure level No. 1
The integrated

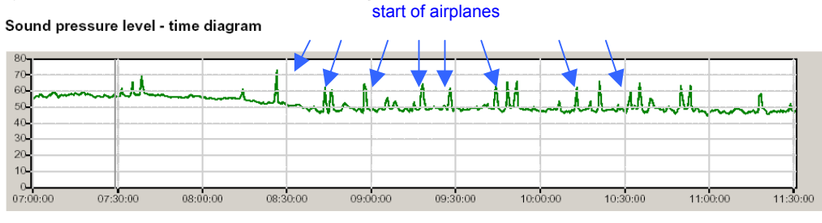
equivalent sound pressure level :	$L_{Aeq,m}$ =	**55,3** dB(A)
Takt-maximum sound pressure level :	$L_{AT,5,m}$ =	**56,9** dB(A)
The maximum sound pressure level :	$L_{AF,max}$ =	**63,7** dB(A)

Determination of rating levels from measurement data
to DIN 45645-1 Noise immission in the neighbourhood - part time sound pressure level

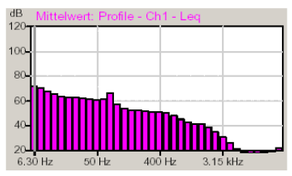
Customer : Abu Dhabi Future Energy Company
Projekt : Abu Dhabi Masdar
Specimen : **Measurement of noise immission in the neighbourhood**

Testing date : 06.11.2007
Testing area : Weather Station Masdar

Sound pressure level - time diagram



Flat frequency band



Measurement - level averaging
Part-time sound pressure level No. 2
The integrated

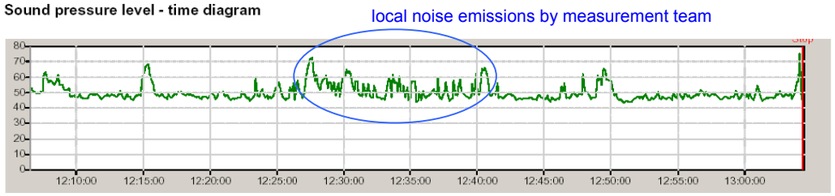
equivalent sound pressure level :	$L_{Aeq,m}$ =	**55,4** dB(A)
Takt-maximum sound pressure level :	$L_{AT,5,m}$ =	**58,8** dB(A)
The maximum sound pressure level :	$L_{AF,max}$ =	**82,4** dB(A)

Determination of rating levels from measurement data
to DIN 45645-1 Noise immission in the neighbourhood - part time sound pressure level

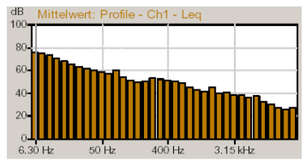
Customer : Abu Dhabi Future Energy Company
Projekt : Abu Dhabi Masdar
Specimen : **Measurement of noise immission in the neighbourhood**

Testing date : 06.11.2007
Testing area : Weather Station Masdar

Sound pressure level - time diagram



Flat frequency band



Measurement - level averaging
Part-time sound pressure level No. 3
The integrated
equivalent sound pressure level : $L_{Aeq,m}$ = **56,2** dB(A)
Takt-maximum sound pressure level : $L_{AT,5,m}$ = **65,4** dB(A)
The maximum sound pressure level : $L_{AF,max}$ = **90,9** dB(A)

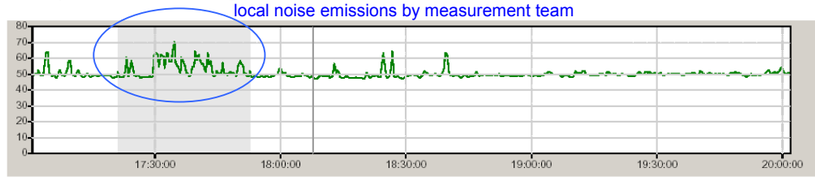
Page 5 of 8
Testing report No. 07/PB.01
Date : 20.11.2007

Determination of rating levels from measurement data
to DIN 45645-1 Noise immission in the neighbourhood - part time sound pressure level

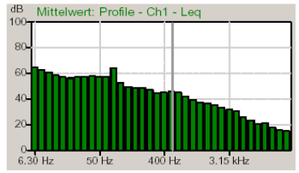
Customer : Abu Dhabi Future Energy Company
Projekt : Abu Dhabi Masdar
Specimen : **Measurement of noise immission in the neighbourhood**

Testing date : 06.11.2007
Testing area : Weather Station Masdar

Sound pressure level - time diagram



Flat frequency band



Measurement - level averaging
Part-time sound pressure level No. 4
The integrated
equivalent sound pressure level : $L_{Aeq,m}$ = **51,3** dB(A)
Takt-maximum sound pressure level : $L_{AT,5,m}$ = **57,6** dB(A)
The maximum sound pressure level : $L_{AF,max}$ = **85,9** dB(A)

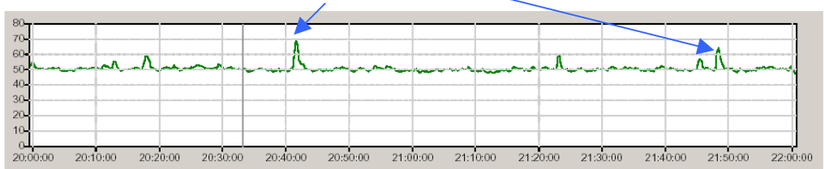
Page 6 of 8
Testing report No. 07/PB.01
Date : 21.11.2007

Determination of rating levels from measurement data
to DIN 45645-1 Noise immission in the neighbourhood - part time sound pressure level

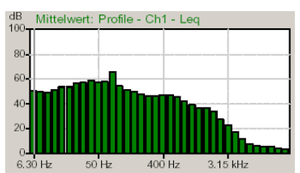
Customer : Abu Dhabi Future Energy Company
Projekt : Abu Dhabi Masdar
Specimen : **Measurement of noise immission in the neighbourhood**

Testing date : 06.11.2007
Testing area : Weather Station Masdar

Sound pressure level - time diagram



Flat frequency band



Measurement - level averaging
Part-time sound pressure level No. 5
The integrated
equivalent sound pressure level : $L_{Aeq,m}$ = **51,9** dB(A)
Takt-maximum sound pressure level : $L_{AT,5,m}$ = **54,0** dB(A)
The maximum sound pressure level : $L_{AF,max}$ = **72,4** dB(A)

Page 7 of 8
Testing report No. 07/PB.01
Date : 21.11.2007

Determination of rating levels from measurement data
to DIN 45645-1 Noise immission in the neighbourhood - part time sound pressure level

Customer : Abu Dhabi Future Energy Company
Projekt : Abu Dhabi Masdar
Specification : **Measurement of noise immission in the neighbourhood**

Testing date : 06.11.2007
Testing area : Weather Station Masdar

Part time sound pressure level i
Reference to

		No. 1 Page 3	No. 2 Page 4	No. 3 Page 5	No. 4 Page 6	No. 5 Page 7	
	$L_{Aeq,m,i}$ =	55,3	55,4	56,2	51,3	51,9	dB(A)
Background noise	L_G =	46,0	46,0	46,0	46,0	46,0	dB(A)
$L_{Aeq,i} = 10 \times \lg\left(10^{(0,1 \times L_{Aeq,m,i})} - 10^{(0,1 \times L_G)}\right)$	$L_{Aeq,i}$ =	54,8	54,9	55,8	49,8	50,6	dB(A)
Impuls addition $K_I = L_{AT,5,m} - L_{Aeq,m}$	K_I =	1,6	3,4	9,2	6,3	2,1	dB
Tone addition	K_T =	0,0	3,0	3,0	3,0	3,0	dB
Addition for rest time	K_R =	6,0	0,0	0,0	0,0	6,0	dB
Addition and reduction of special sound	K_S =	0,0	0,0	0,0	0,0	0,0	dB
Meteorology adjustment of DIN ISO 9613-2	C_{met} =	0,0	0,0	0,0	0,0	0,0	dB
	$L_{r,i}$ =	62,4	61,3	68,0	59,1	61,7	dB(A)
Part time i	T_i =	3600	16200	3480	10800	7200	s
Specification of part time sound pressure level		06:00...07:00	07:00...11:30	12:04...13:02	17:00...20:00	20:00...22:00	Time of day

Total time T_r = 41280 s

$$L_r = 10 \times \lg\left[\frac{1}{T_r}\sum_{i=1}^{m} T_i \times 10^{0,1 \times \left(L_{Aeq,m,i} + K_{I,i} + K_{T,i} + K_{R,i} + K_{S,i} - C_{met}\right)}\right]$$

Detection the rating level of measurement L_r = 62 **dB(A)**

Page 8 off 8
Testing report No. 07/PB.01
Date : 21.11.2007

Air quality measurement

In a further investigation the air quality at the location was examined. The measuring procedure is described in chapter 1. During the measurement collecting tubes are used, which collect during one period of 2-3 week air pollutants. Afterwards the collecting tubes are replaced against new collecting tubes. The evaluation which pollutant was happend effected in a laboratory in Germany. Thus the average pollution impact during the collecting period can be determined very well. This measuring procedure is possible for the contamination guard of air with hydrocarbons and NO2.
So far two measuring periods were accomplished and evaluated. The third period is actually active. From the evaluation of the second period far only the value of NO2 is available.

Results of evaluation

On the figure 1 the results of the NO2 measurement are represented. From the 1st period 39,2 µg/m³ and from the second measurement 46,2 µg/m³ was determined. In the figure also the limit value is represented from 40 µg/m³ to WHO (see appendix). During the first measurement the limit value was a little lower and exceeded during the second measurement far. For the high value of NO2 the cause should be determined in further measurements.
In the figure 2 and 3 is represented the results of the measurements of the hydrocarbons. In this measurement of all types of VOC there was no special remarks. The benzene value is here in Europe limited by 5 µg/m³.

Hydrocarbons (1st period)

chemical bond	Masdar concentration hydrocarbons passive collector
alkane	[µg/m3]
hexane	not traceable
heptane	not traceable
octaene	not traceable
nonane	not traceable
decane	not traceable
undecane	not traceable
dodecane	not traceable
tri decane	not traceable
tetra decane	not traceable
penta decane	not traceable
hexa decane	not traceable
2-methyl heptane	not traceable
2-methyl hexane	2.0
3-methyl hexane	2.5
ethyl cyclo pentane	not traceable
condiments	4
benzene	not traceable
toluene	2.7
ethyl benzene	1.2
m,p-xylene	2.0
styrolene	not traceable
o-xylene	not traceable
3-ethyl toluene/4-ethyl toluene	not traceable
2-ethyltoluene	not traceable
1,3,5-tri methyl benzene	not traceable
1,2,3-tri methyl benzene	not traceable
1,2,4-tri methylbbenzene	not traceable
propyl benzene	not traceable
butyl benzene	not traceable
1-methyl naphthalene	not traceable
other hydrocarbons	6
methyl cyclo hexene	3.4
cyclo hexene	not traceable
4-methyl-2-pentanol	not traceable
2-butoxy ethanol	not traceable
2-phenoxy ethanol	not traceable
4-vinyl cyclo hexen	not traceable
phenyl cylo hexen	not traceable
ethyl hexanol	not traceable
cyclo octane	not traceable
1-octene	not traceable
ester	3
butyl acetate	not traceable
ethyl acetate	1.1
chlorinated hydrocarbon	1
tri chlor ethene	not traceable
1,1,2-tri chlor ethane	not traceable
1,1,1-tri chlor ethane	not traceable
perchlor ethene	not traceable
1,2-di chlor benzene	not traceable
1,3-di chlor benzene	not traceable
Terpene or similar	0
a-Pinen	not traceable
b-pinene	not traceable
d3-carene	not traceable
a-terpinene	not traceable
limonene	not traceable
cineol	not traceable
Longifolene	not traceable
aldehyde	0
hexanal	not traceable
nonanal	not traceable
	0.0
all VOC:	15

Figure 2: Hydrocarbons concentration

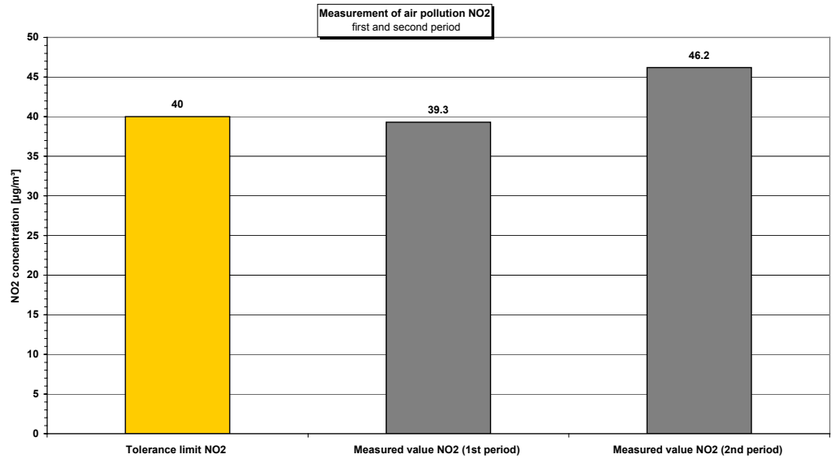


Figure 1: NO2 concentration

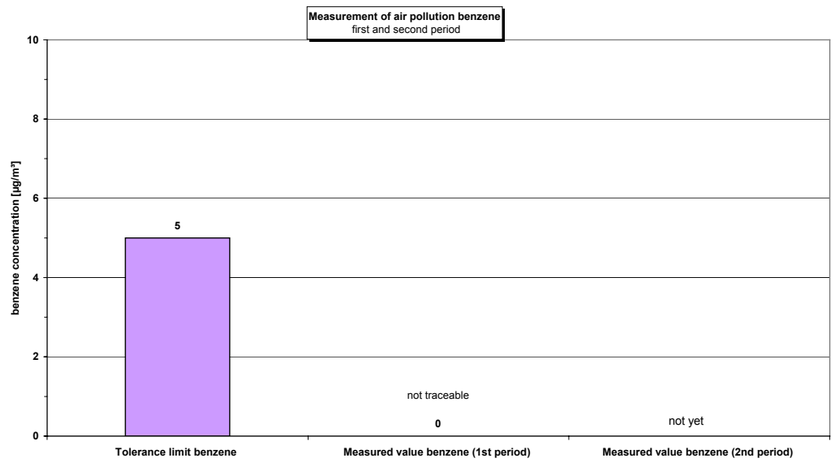


Figure 3: Benzene concentration

Approach
Recent scientific studies [Centre for Energy Policy and Economics – Swiss Federal Institutes of Technology, ETH Zurich – Energie, Umwelt und die 2000-Watt Gesellschaft] show the necessity for developed countries to limit their primary energy demand for heating, cooling, appliances, mobility and material use to a permanent load of 2.000 W/person (17.500 kWh/a/person). Converted to electricity this would mean about 6,250 kWh/a assuming a conversion factor of 2.8. This means for some countries a reduction of the energy demand by a factor > 5.
These studies state the mentioned energy demand as an ecological limit for a sustainable economical global development with guaranteed unaffected economical standards for the first world nations and with the opportunities to the rest of the nations to match the economical standards to those of the first world nations. To reach this goal a guideline is necessary for the following:

1. System Efficiency – total chain of energy conversion from primary energy to secondary energy and usable energy must be considered
2. Efficient energy usage
3. Material Efficiency

In conjunction with the above mentioned aspects the Masdar development has to be a carbon free development. This means, on one hand a drastic reduction of energy demand of the Masdar city as compared to other cities and on the other hand an energy concept completely based on the local available regenerative energy potentials – such as solar, wind, geothermics, waste to energy, power supply from anaerobic digestion of sewage sludge and organic waste.

For this innovative - and first of its kind - approach an accurate and highly realistic beforehand evaluation of the total energy loads for the buildings of the whole development is an absolute prerequisite to adapt the energy system and its detailed components to the city's later real loads and demands. This load calculation has to take into account

- Energy requirement for latent (dehumidification) and sensible cooling
- Energy requirement for domestic water heating (no steam for labs and light industry)
- Electrical demand for equipment, appliances, HVAC devices, machinery, and artificial lighting

In this chapter we evaluate optimal energy demands / loads for various occupant spaces and provide inputs based on which an efficient energy generation system and energy efficient buildings can be developed. The power demand and loads of other energy consuming systems – like

- infrastructure in general (losses for el. power distribution and el. transformation, ventilation and power requirements for active switch gears, thermal losses of district heating / cooling, el. demand of fluid / water pumps, el. demand of processes based on sorption for dehumidification and chilled water production, etc.)
- inner city transportation systems (interior PRT energy requirement)
- water desalination and potable water distribution
- black water treatment and distribution
- grey water treatment and distribution
- power requirements for waste sorting and collecting
- street- , parking- and sport lights
- IT (electrical)
- losses of energy systems using common COP's

must be added to above mentioned energy demands/loads of the buildings.

Methodology
To get the characteristic curves of the building loads three iteration steps with different building typologies and boundary conditions are performed. For the first and second simulation run a standard building typology with a

- footprint of 25 m x 50 m
- total height of 18 m
- central courtyard with the dimension of 9 m x 18 m.

is considered. The generic building was based on climate analysis and low energy standards.

The third simulation run is based on building typologies delivered by the architects. For all simulation runs the IWEC weather data of Abu Dhabi has been used. The validity of these data has already been shown in the inception report comparing them with the local measured weather data.

The total city was subdivided into 8 different occupant spaces in relation to their intended use:

- office ("O")
- labs ("L")
- housing ("H")
- education ("E")
- community support ("CS")
- production / light industry (P)
- catering / retail ("CR")
- divers – like station, science centre, sport zone, entertainment, worship ("D")

First five occupant spaces are located in the upper floors of the standard building. Solar gains corrected by the self shading effect of the building and the shading of the vicinity are considered.

Catering / retail and light industry are assumed to be located at the ground floor level, where reduction of solar gains due to overhang and arcades are taken into account. The last occupant spaces "divers" have no external solar gains; for them only interior heat gains are considered. The remaining boundary conditions like

- air change rate
- operation
- details to the construction, facade, glazing and shading device
- interior heat gains
- design temperature
- ventilation, air change rate and heat recovery

are fixed in the following chapters.

The resulting area specific loads [W/m²] are multiplied by the corresponding footprint area to get the total building loads of the city (electrical, latent and sensible cooling, domestic water). The different BUA-footprint is also fixed for each simulation run in the beginning of the corresponding chapter.

Simulation Tool
For modeling the different building typologies based on their thermal dynamic and total energy characteristics the simulation tool TRNSYSY16 was used. TRNSYS is a complete and extensible simulation environment for the transient simulation of thermal systems including multi-zone buildings. It is used by engineers and researchers around the world to validate new energy concepts, from simple solar domestic hot water systems to the design and simulation of buildings and their equipment, including control strategies, occupant behavior, alternative energy systems (wind, solar, photovoltaics, hydrogen systems), etc.
One of the key factors in TRNSYS' success over the last 25 years is its open, modular structure.
The source code of the kernel as well as the component models is delivered to the users. This simplifies extending existing models to make them fit the user's specific needs.
TRNSYS applications include:
• solar systems (solar thermal and PV)
• low energy buildings and HVAC systems with advanced design features
• renewable energy systems
• cogeneration, fuel cells
• anything that requires dynamic simulation.
For more information see

http://www.transsolar.com/__softwar
ocs/trnsys/trnsys_leistungen_de.htm

Most Important Recommendations Referring to the Boundary Conditions of the Simulations
Indoor:

- infiltration rate limited to 0.15 – 0.2 ac/h (vestibules, buffer zones, air tight facade)
- natural lighting by courtyards; courtyards with central operable and controlled shading device in the top with light diffusing characteristic
- external controlled shading device for windows to the streets in particular for the upper floors; only minimized glazed ratio of the street facades
- solar control glazing; max. energy transmittance of 50 %; U-value of frame and glass =< 1.5 W/m²/K, daylight transmission > 65%
- in particular upper floors - facade ratios of courtyards: max 30 % glazed and 70 % opaque
- roof insulation: 20 cm; 0.04 W/m/K
- opaque facade insulation: 10 cm; 0.04 W/m/K (in particular for housing)
- controlled operation of art. lighting; only illuminants with high efficiency (> 80 lm/W)
- thermal mass: 300 kg/m² resp. 50 % of space surfaces should be thermal active
- dehumidification of latent loads by L-DCS (liquid desiccant system) with an COP of 0.9
- ventilation: 80 % efficiency of heat recovery in conjunction with an indirect evaporative cooling
- energy efficient fans, engines (in summary 0.6 kWh/1.000 m³/h for supply and exhaust; continuous rate control of air flow (frequency converter)
- max. indoor design conditions: 24°C; 12 g/kg; 65 % rel. hum.
- ventilation: buildings in slight overpressure but reduced ACR during non-working hours
- only central laundries; no private laundering
- only high efficient electrical devices in offices and housing

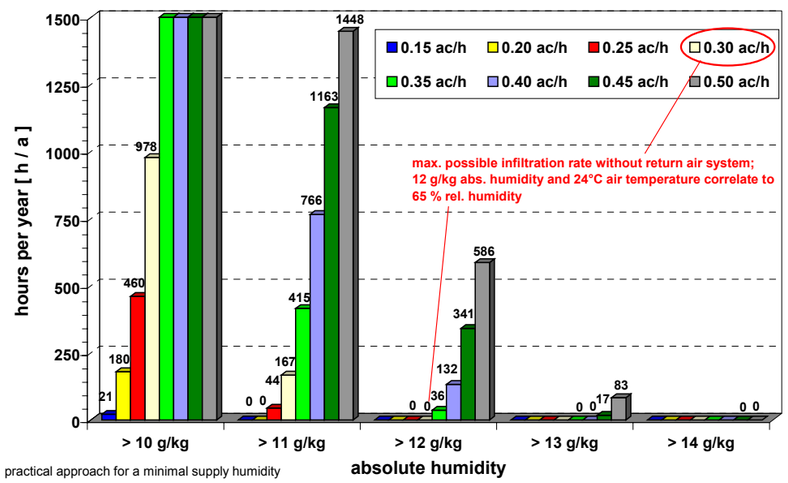
The figure below shows a statistics regarding the indoor humidity of a standard office space. The goal is to have a dehumidification system using only supply air. For this the max. infiltration rate must be limited to 0.3 ac/h.

Outdoor:

- albedo; 70 % reflectance of wall, roof and floor surfaces (without PV)

Figure right:
Sensitivity study for the indoor humidity depending on the infiltration rate

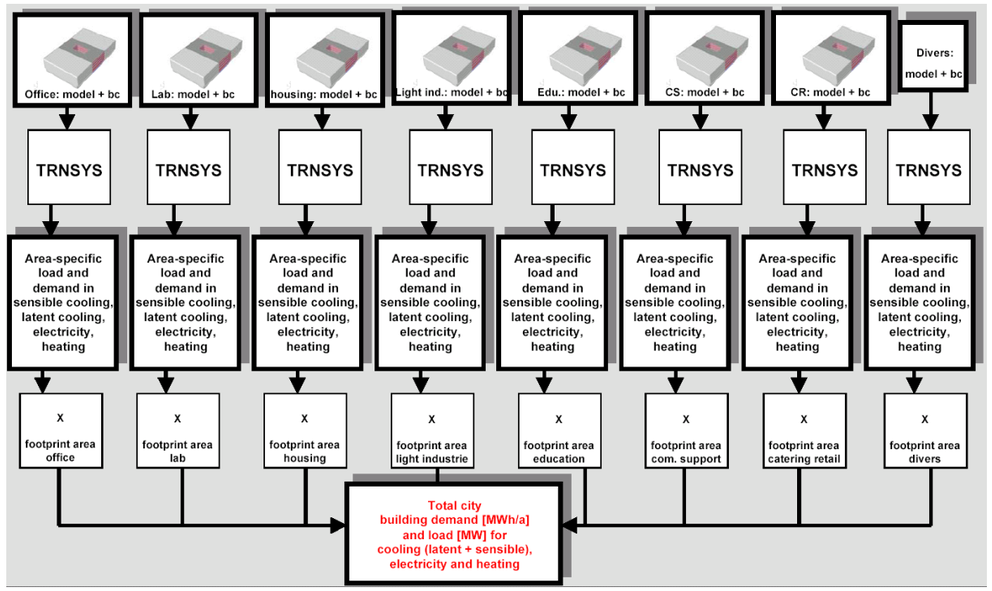
Masdar Development
humidity statistics for an office space depending on the infiltration rate (based on net footprint)
- supply air: 7 g/kg*; acr = 1.5 ac/h (based on working area); operation AHU: 24 / 7 -



*L-DCS: practical approach for a minimal supply humidity

Building Load Simulation for Total Energy Demand Profile of the City

1. Iteration



Top figure: Flow diagram of the simulation proceeding with the simulation tool TRNSYS; physical-numerical simulation models and boundary conditions; the footprint area of each different typology based on its intended use is fixed in the right table.

Boundary Conditions for 1.Simulation Iteration Step

- No city heat island consideration
- External walls: 24 cm brick + 5 cm external insulation
- Internal ceilings: 24 concrete + silencer + carpet
- No special boundaries for top floors

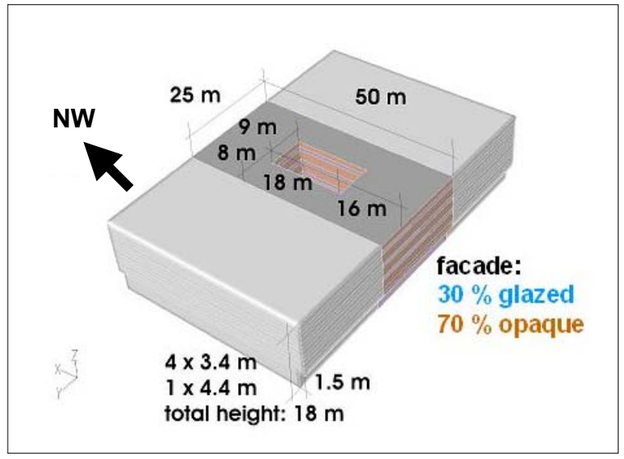
The considered footprint areas and the boundary conditions specific to the using typologies are fixed on the following pages. Most important boundary conditions are:

- time frame of operation
- internal heat gains
- construction of the facade
- infiltration rate
- indoor design conditions

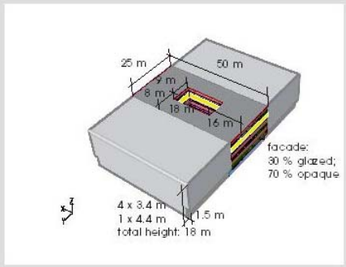
The principle proceeding of the iteration is shown in the top figure.

Right table: Gross footprint area of each different typology based on its intended use.

Bottom figure: Geometry and construction of the generic building.



		BUA [m²]
Office Area		
SEZ-Offices		580,000
Com. / Office centres		294,750
Masdar centre	(without Station)	100,000
Uni -Admin		2,200
Uni-Staff		22,500
Students-Union		413
Community Centre (Community Support)		18,000
Health Centres (Community Support)		9,000
		1,026,863
Labs		
SEZ Research Labs		77,000
Uni Labs		22,550
		99,550
Housing		
Employer Housing / village (inclusive student housing, hotel)	á 50 m² 46,250 m² , 75,000 m²	**1,916,800**
Production SEZ-Techn. Parc	without solar gains clearance 4 m	**450,000**
Catering / Retail	clearance 4 m	
Catering / Retail Plaza	50 % F+B / 50 % Retail	17,578
SEZ - Local Centres		25,000
Uni Shared Amenity		8,113
		50,691
Divers	without solar gains	
Station	50,000 Passengers/day	50,000
Science Centre		48,000
Sport Zone		7,200
Entertainment Complex (Community Support)		10,000
Worship (Community Support)		18,750
Uni Central Admin		2,338
		136,288
Education		
Uni-Hörsäle		1,650
Schulen (Community Support)		50,000
Adult Education (Community Support)		2,000
Lib Uni		5,365
		59,015
Community Support		
Police		3,000
Fire Station		1,500
Hospital		8,500
		13,000
Total		**3,752,207 m²**

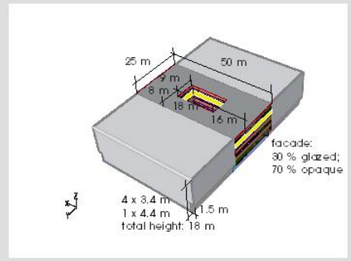


peak loads to gross footprint:
- sensible - 51.9 W/m²
- latent - 32.3 W/m²
- AHU - 1.33 W/m²
- equipment - 10.3 W/m²
- art. lighting - 11.3 W/m²

annual demands
- 123 kWh/m²/a (elect.)
- 29 kWh/m²/a (latent)

Office floors in 2. to 5. story; 3 m clearance

working hours -	8°° to 18°°; 5 days per week
operation of AHU -	6°° to 19°°; 5 days per week; 1.5 acr based on working area
artificial lighting -	operation controlled depending on outdoor illuminance; 13 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.3
facade -	opaque facade ratio of 70 %; 5 cm thermal insulated (outer surface)
exposed ceiling	
infiltration -	0.15 acr during working hours; 0.05 acr in non working hours
design temperature -	24 - 26°C
total area -	1,026,863 m²; 20 m² per occupant ~ 51.340 persons
internal heat gains - (office equipment)	10.3 W/m² during working hours; 5.15 W/m² in non working hours
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery - annual averaged	80 %
chiller-Cop -	3

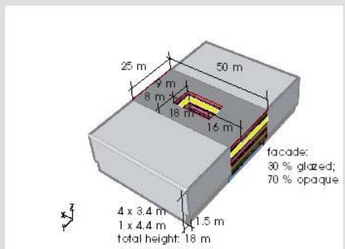


peak loads to gross footprint:
- sensible - 60.7 W/m²
- latent - 87.3 W/m²
- AHU - 3.6 W/m²
- equipment - 19.1 W/m²
- art. lighting - 10.4 W/m²

annual demands
- 202 kWh/m²/a (elect.)
- 180 kWh/m²/a (latent)

Lab floors in 2. to 5. story; 3 m clearance; 50 % office / 50 % laboratory

working hours -	8°° to 18°°; 5 days per week
operation of AHU -	24 h, 7 days per week; 6°° to 19°°: 6 acr in lab area; 3 acr in office area; 19°° to 6°°: 3 acr based on working area
artificial lighting -	operation controlled depending on outdoor illuminance; 13 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.3
facade -	opaque facade ratio of 70 %; 5 cm thermal insulated (outer surface)
exposed ceiling	
infiltration -	0.15 acr during working hours; 0.05 acr in non working hours
design temperature -	24 - 26°C
total area -	99,550 m²; 22 m² per occupant ~ 4.525 Persons
internal heat gains - (office equipment)	19.1 W/m² during working hours; 9.55 W/m² in non working hours
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	80 %
annual averaged chiller-Cop -	3

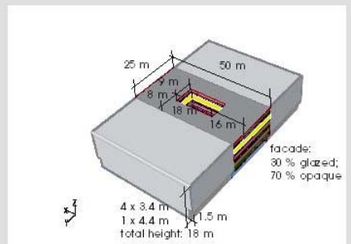


peak loads to gross footprint:
- sensible - 13.4 W/m²
- latent - 37.5 W/m²
- AHU - 1.4 W/m²
- equipment - 2.5 W/m²
- art. lighting - 4 W/m²

annual demands
- 55 kWh/m²/a (elect.)
- 92 kWh/m²/a (latent)
- 17 kWh/m²/a (domestic water)

Housing floors in 2. to 5. story; 3 m clearance

Reduced hours -	8°° to 18°°; 5 days per week
operation of AHU -	24 h, 7 days per week; 1 acr based on used floor area
artificial lighting -	operation controlled depending on outdoor illuminance; 5 W/m² based on used floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.3
facade -	opaque facade ratio of 70 %; 5 cm thermal insulated (outer surface)
exposed ceiling	
infiltration -	0.2 acr during day time; 0.05 acr during night time
design temperature -	24 - 26°C
total area -	1,916,800 m²; 50 m² per resident ~ 38.336 persons
internal heat gains - (household equipment)	465 kWh/resident/a
el. demand of AHU -	0.6 kWh/1,000 m³
domestic water -	35 l/per/d; 65°C
sens. heat recovery - annual averaged	80 %
chiller-Cop -	3

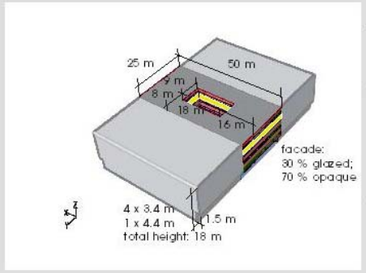


peak loads to gross footprint:
- sensible - 45.3 W/m²
- latent - 71.9 W/m²
- AHU - 3 W/m²
- equipment - 3.5 W/m²
- art. lighting - 10.5 W/m²

annual demands
- 63 kWh/m²/a (elect.)
- 65 kWh/m²/a (latent)

Education floors in 2. to 5. story; 3 m clearance

working hours -	8°° to 18°°; 5 days per week
operation of AHU -	6°° to 19°°; 5 days per week; 35 m³/h per person
artificial lighting -	operation controlled depending on outdoor illuminance; 12 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.3
facade -	opaque facade ratio of 70 %; 5 cm thermal insulated (outer surface)
exposed ceiling	
infiltration -	0.15 acr during working hours; 0.05 acr in non working hours
design temperature -	24 - 26°C
total area -	59,015 m²; 7 m² per student/pupil ~ 8.430 persons
internal heat gains -	3.5 W/m² during working hours
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	80 %
annual averaged chiller-Cop -	3

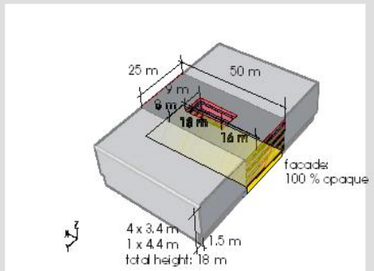


Community Support floors in 2. to 5. story; 3 m clearance

working hours -	24 h; 7 days per week
operation of AHU -	24 h; 7 days per week; 1. acr based on net floor area
artificial lighting -	permanent operation; 8 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.3
facade -	opaque facade ratio of 70 %; 5 cm thermal insulated (outer surface)
exposed ceiling	
infiltration -	0.2 acr
design temperature -	24 - 26°C
total area -	13,000 m²; 109 m² per occupant (hospital) ~ 120 persons
internal heat gains -	2 W/m²; 16.1 kWh/m²/a annual averaged
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	80 %
chiller-Cop -	3

peak loads to gross footprint:
- sensible - 22.7 W/m²
- latent - 41.4 W/m²
- AHU - 1.6 W/m²
- equipment - 1.8 W/m²
- art. lighting - 7 W/m²

annual demands
- 122 kWh/m²/a (elect.)
- 102 kWh/m²/a (latent)
- 7 kWh/m²/a (domestic water)

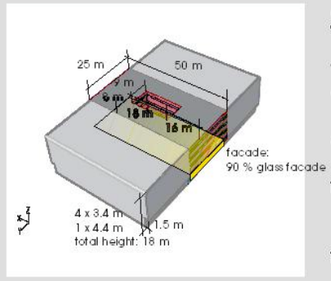


Production floor in 1. story; 4 m clearance

working hours -	24 h; 5 days per week: 6°° to 14°°; 1 day per week
operation of AHU -	24 h; 6 days per week; 1 acr based on net floor area
artificial lighting -	24 h on 6 days per week; 20 W/m² based on net floor area
facade -	no solar gains; 5 cm thermal insulated (outer surface)
exposed ceiling	
infiltration -	0.2 acr during working hours; 0.05 acr in non working hours
design temperature -	24 - 27°C
total area -	450,000 m²; 55 m² per worker ~ 8.180 persons
internal heat gains -	15 W/m² during working hours (production device Solarfabrik in Freiburg, Germany)
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	80 %
annual averaged	
chiller-Cop -	3

peak loads to gross footprint:
- sensible - 47.6 W/m²
- latent - 59.7 W/m²
- AHU - 2.3 W/m²
- equipment - 15 W/m²
- art. lighting - 19 W/m²

annual demands
- 344 kWh/m²/a (elect.)
- 128 kWh/m²/a (latent)



Catering / Retail floors in 1. story; 4 m clearance

working hours -	10°° to 24°°; 7 days per week
operation of AHU -	9°° to 1°°; 7 days per week; 12 m³/h/m² based on net floor area
artificial lighting -	permanent operation during working hours; 20 W/m² based on net floor area
facade -	90% glass; neutral solar control glass 50/25; 20 % frame ratio; exterior shading device as overhang / wingwall
facade -	opaque facade ratio of 10 %; 5 cm thermal insulated (outer surface)
exposed ceiling	
infiltration -	0.15 acr during working hours; 0.05 acr in non working hours
design temperature -	24 - 26°C
total area -	50,691 m² (50 % / 50 %); 13 m² per occupant ~ 3.900 persons
internal heat gains - (only catering)	28 W/m² on 10 h per day
el. demand of AHU -	0.6 kWh/1,000 m³ (retail); 1.0 kWh/1,000 m³ (catering)
sens. heat recovery -	80 %
annual averaged	
chiller-Cop -	3

peak loads to gross footprint:
- sensible - 76.6 W/m²
- latent - 180.8 W/m²
- AHU - 9.1 W/m²
- equipment - 14.2 W/m²
- art. lighting - 19 W/m²

annual demands
- 298 kWh/m²/a (elect.)
- 294 kWh/m²/a (latent)
- 27 kWh/m²/a (domestic water)

On ground floor or basement

peak loads to gross footprint:
- sensible - 40.9 W/m²
- latent - 62.8 W/m²
- AHU - 2.3 W/m²
- equipment - 1 W/m²
- art. lighting - 19 W/m²

annual demands
- 184 kWh/m²/a (elect.)
- 113 kWh/m²/a (latent)
- 4.4 kWh/m²/a (domestic water)

Diverse (Stations, Science Zone, Sports Zone, Entertainment)

working hours -	8°° to 24°°; 7 days per week
operation of AHU -	8°° to 24°°; 7 days per week; 1 acr based on net floor area
artificial lighting -	permanent operation during working hours; 20 W/m² based on net floor area
facade -	no solar gains; 5 cm thermal insulated (outer surface)
infiltration -	0.2 acr during working hours; 0.05 acr in non working hours
design temperature -	24 - 26°C
total area -	136,288 m²; 16 m² per occupant = 8.518 persons
equipment -	pool: 1,000 MWh for 1,000 m² water surface
domestic water -	pool: 438 MWh for 1,000 m² water surface
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	80 %
annual averaged	
chiller-Cop -	3

Building Load Simulation for Total Energy Demand Profile of the City

1. Iteration Results

Results

Legend
Office Area = O
Labs = L
Housing = H
Education = E
Community Support = S
Production = P
Catering/Retail = CR
Diverse = D

Figure 1: The total annual electrical energy demand is shown for each typology based on their intended use; the total demand of 558,383 MWh/a includes
appliances, artificial lighting, sensible cooling and latent cooling for space dehumidification; for this consideration latent and sensible space cooling is delivered by electrical compression chillers assuming a COP of 3.0.
Figure 2: The total electrical demand of figure 1 is split for various consumption types for each typology separately; based on this diagram the biggest consumers are

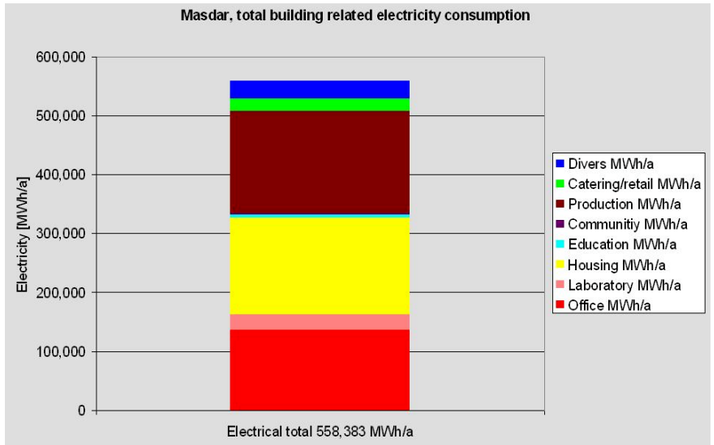
- art. lighting
- appliances
- sensible and latent cooling

for the typologies office, housing and production, which include the largest program areas.
Figure 3: Being more specific energy demand per gross area is shown; labs, light industry and catering / retail are the main consumers now.
Figure 4: Total el. demand of all typologies is shown, which amounts to 452,000 MWh/a with a peak load of 100 MW; the characteristic curve – in descending order - includes

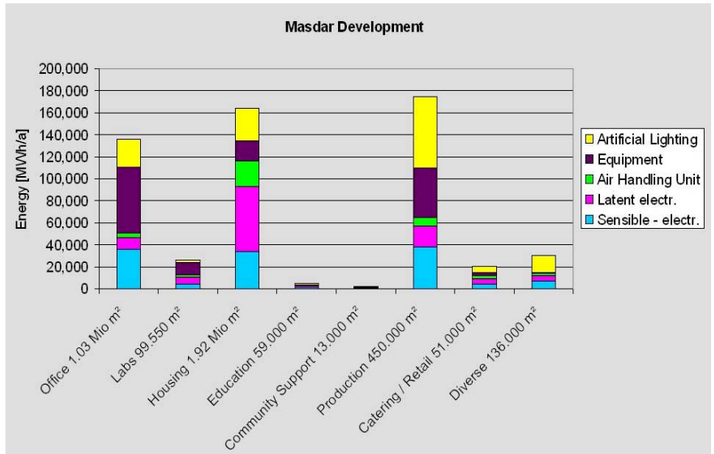
- art. lighting
- appliances
- ventilation
- sensible cooling (COP = 3).

Figure 5: In analogy to figure 4 the total annual buildings' demand of electricity is shown – without latent cooling.
Figure 6: The characteristic curves of the electrical energy requirement for the different typologies are added to the total demand in the month of July – without latent cooling:

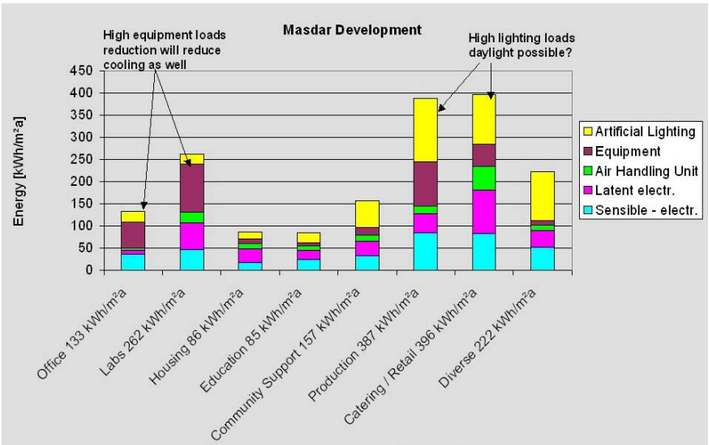
- art. lighting
- appliances
- ventilation
- sensible cooling (COP = 3).



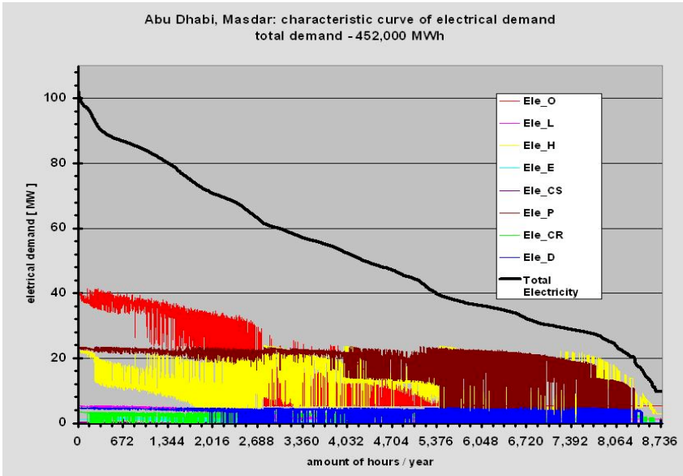
Total electricity consumption - all conditioning by electrical chillers



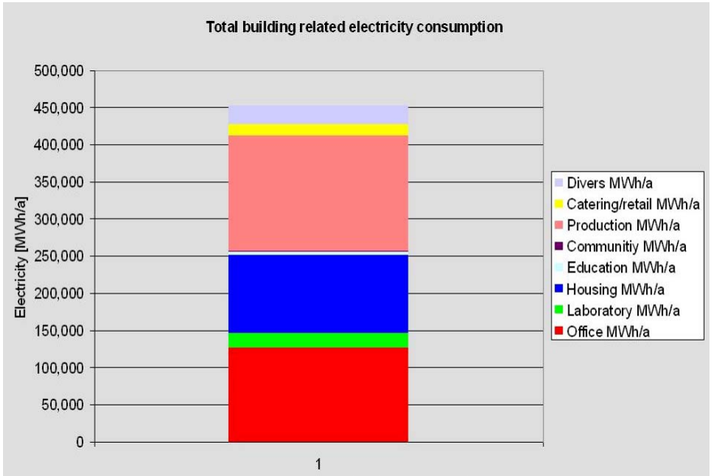
Electricity consumption distribution between the different program



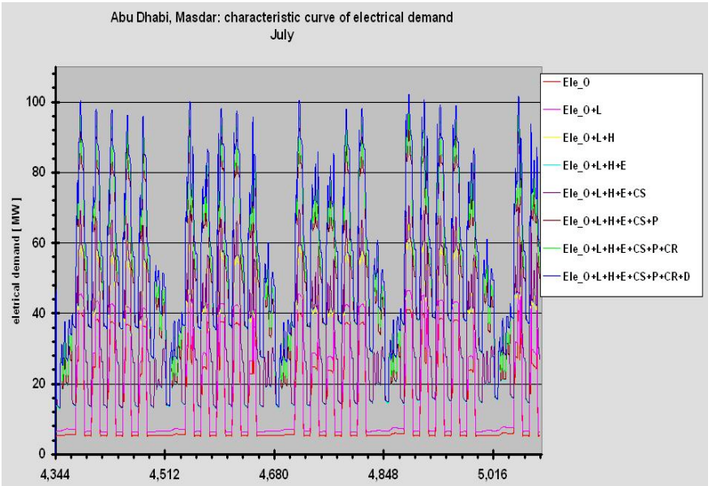
Specific electricity consumption per m² for the different program



Electrical demand without dehumidification (sensible demand included C_{op}=3)



Building related electricity consumption without dehumidification



Building Load Simulation for Total Energy Demand Profile of the City

1. Iteration Results

Legend
Office Area = O
Labs = L
Housing = H
Education = E
Community Support = S
Production = P
Catering/Retail= CR
Diverse = D

Figure 1: The characteristic curves of the electrical energy requirement for the different typologies are added to the total demand; the trend is shown for 23th of July;

- art. lighting
- appliances
- ventilation.
- sensible cooling (COP = 3)

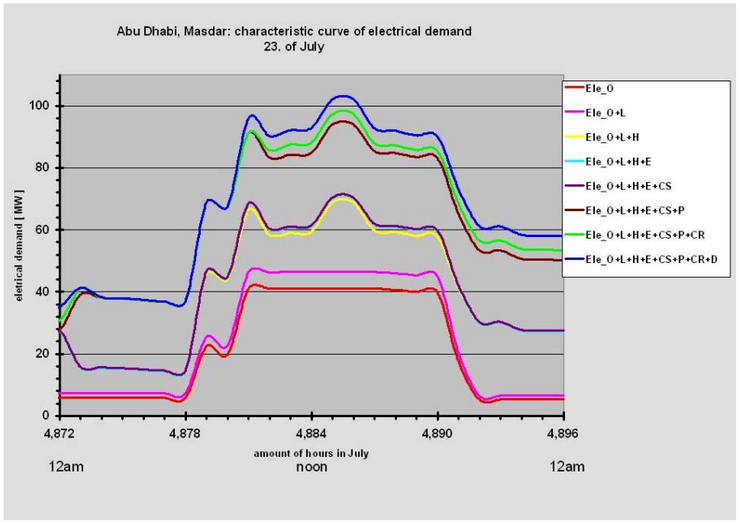
is included – without latent cooling; the trend refers to a Monday, because brown-colored light industry demand at 0 am is 0; the peaks are caused by a switch-on of appliances and art. lighting.

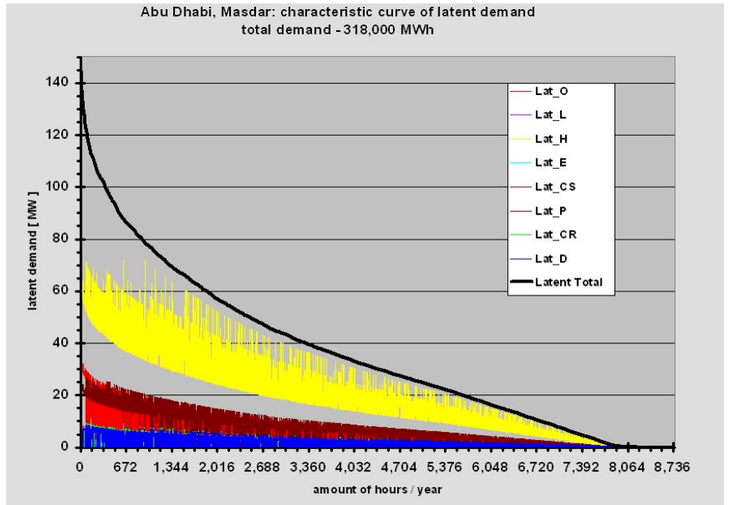
Figure 2: As the sum of the different typologies the total latent demand of all buildings is shown with 318,000 MWh/a and with a peak load of about 140 MW - in descending order.
Figure 3: The characteristic curves of the latent cooling demand for the different typologies are added to the total latent demand in the month of July.
Figure 4: The characteristic curves of the latent cooling demand for the different typologies are added to the total demand; the trend is shown for 3th of July; the dip in the afternoon is caused by a drop of the outdoor humidity.

Figure 5: Buildings' energy demand split for total energy requirements

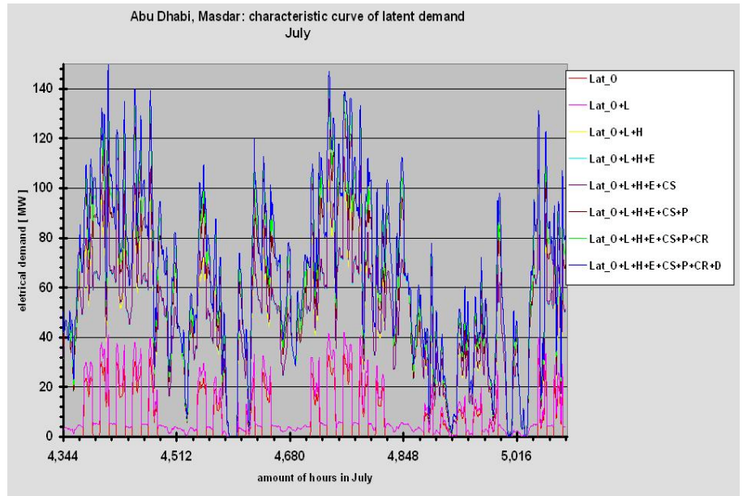
- electricity
- sensible cooling
- latent cooling (dehumidification)

(327 + 376/3 + 318/3)MWh/a=558 MWh/a (COP = 3).
Figure 6: Heating demand for domestic water in housing, catering, pool, hospital; possible steam demand for light industry and labs is **not** considered.

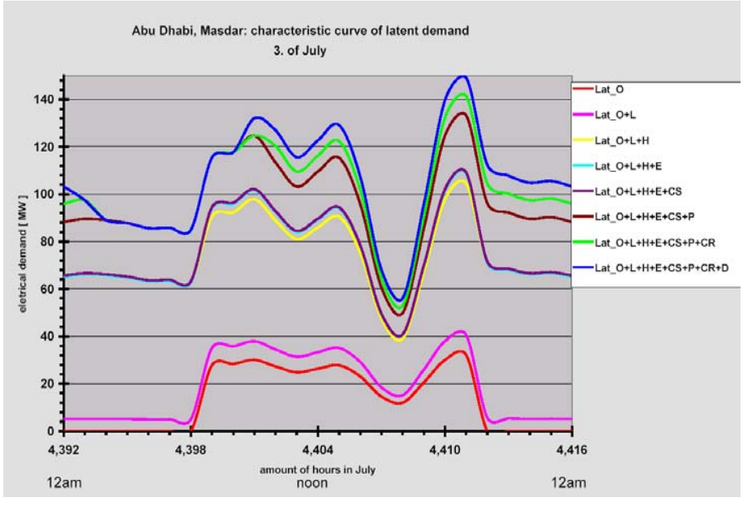


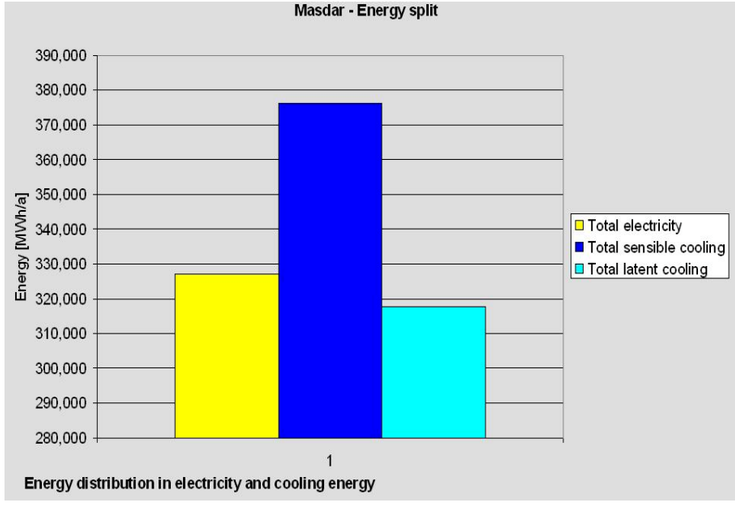


Latent demand for dehumidification

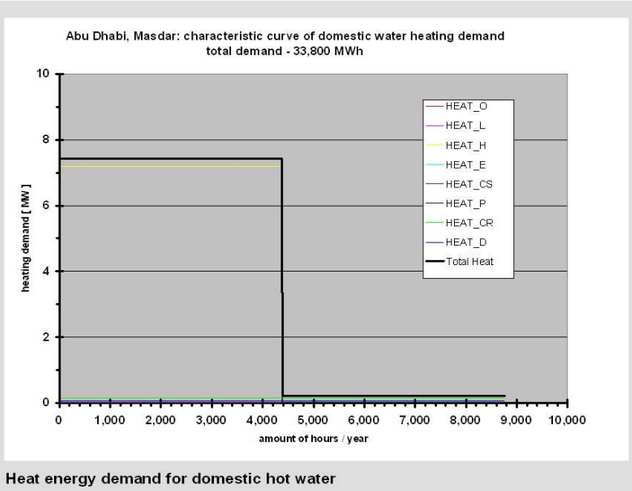


Latent demand for dehumidification





Energy distribution in electricity and cooling energy



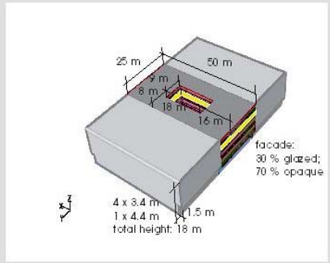
Heat energy demand for domestic hot water

Comparison - Design and Budget Model

To evaluate the load reduction and to prove the simulation model a so called budget model as benchmark was defined. This budget model represents a present standard office space in Abu Dhabi. The changes in the model approaches and in the boundary conditions are highlighted in red:

- higher ventilation rate based on a worsen ventilation efficiency (no displacement ventilation)
- higher internal heat gains by lighting and equipment
- no shading device for glassed facade areas
- no thermal insulation for opaque facade areas
- higher infiltration rates caused by a leaky facade
- standard air handling units without sensible heat recovery for the fresh air system

The annual load calculation results in a total electricity demand of 235 kWh/m²/a assuming a cooling-COP of 3. This value is comparable to energy consumption of typical office buildings provided by the client: from 186 kWh/m²/a to 287 kWh/m²/a.
This comparison can be used to confirm the simulation model. The results of the design model show savings of about 45 % in minimum comparing to the present standard.



Office floors in 2. to 5. story; 3 m clearance

working hours -	8°° to 18°°; 5 days per week
operation of AHU -	6°° to 19°°; 5 days per week;
	2.5 acr based on working area
artificial lighting -	25 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; no shading device;
facade -	opaque facade ratio of 70 %; not thermal insulated
suspended ceiling	
infiltration -	0.5 acr during working hours; 0.4 acr in non working hours
design temperature -	24 - 26°C
total area -	1,026,863 m²; 20 m² per occupant
internal heat gains -	10.3 W/m² during working hours;
(office equipment)	5.15 W/m² in non working hours
el. demand of AHU -	1.2 kWh/1,000 m³
no "heat / cold recovery"	
annual averaged chiller-Cop -	3

Boundary conditions - office budget model

Design Model

	HEAT W/m²	COOL W/m²	LAT W/m²	AHU W/m²	EQUIP W/m²	ALIGHT W/m²
Minimum	0	0	0	0	0	0
Zeitpunkt	1	1	1	1	1	1
Maximum	34.9265	51.8872	32.3008	1.33313	10.2941	11.3272
Zeitpunkt	7	5385	4759	7	9	9
Summe	70.6171	105906	29100.7	4523.29	58516.9	24512.1
Mittelwert	0.00806131	12.0898	3.322	0.516358	6.68001	2.79818

electrical: 35.3 kWh/m²/a + 4.5 kWh/m²/a + 58.5 kWh/m²/a + 24.5 kWh/m²/a = 122.8 kWh/m²/a
latent: 29.1 kWh/m²/a
all electrical total 133 kWh/m²a

Budget Model

	HEAT W/m²	COOL W/m²	LAT W/m²	AHU W/m²	EQUIP W/m²	ALIGHT W/m²
Minimum	0	0	0	0	0	0
Zeitpunkt	1	1	1	1	1	1
Maximum	29.2973	93.6516	62.3094	4.70515	10.2941	21.7831
Zeitpunkt	7	4887	4759	7	9	7
Summe	45.5225	1887.44	70198.9	15964.6	58516.9	73910
Mittelwert	0.00519663	21.5461	8.01358	1.82244	6.68001	8.43722

electrical: 62.9 kWh/m²/a + 16 kWh/m²/a + 58.5 kWh/m²/a + 73.9 kWh/m²/a = 211.3 kWh/m²/a
latent: 70.2 kWh/m²/a
all electrical total 235 kWh/m²a

Comparison - electrical demand - design / budget model

Sector	Building	Yearly Power Consumption KWh 2004	2005	2006	Built Area (sq.m)	Power Consumption (KWh/m2)	Emissions (TCO2/m2)**
Shopping	Madina Zayed Center	**24,645,990**	**27,200,510**	**25,452,020**	60,000	429	0.24
Office	Khalifa Complex (GASCO, ZADCO)	**18,948,520**			66,000	287	0.16
	NBAD Head Quarter	**11,840,290**	**11,886,670**	**12,599,060**	65,000	186	0.10
Hotel	Al Maha Rotan Hotel	**8,203,470**	**8,279,390**	**8,414,200**	22,500	369	0.21
Public	Zayed University	**6,885,310**	**7,493,450**	**6,730,490**	30,000	235	0.13

Abu Dhabi Reference numbers correlate to Budget Model

Proceeding
The principle proceeding of the 2. iteration is the same as for the 1. iteration. The reasons for the 2. iteration step are:

- significant change in the building program and in the footprint areas after a site reduction (PS. table on right)
- review of the 1. step boundary conditions by the team
- comments by local engineers
- impact study on the demands and loads

The changed boundary conditions in iteration step 2 are based on the team notes.

Boundary Conditions for 2.Simulation Iteration Step

- No urban heat island consideration
- External walls: 24 cm brick + 5 cm external insulation
- Internal ceilings: 24 concrete + silencer + carpet
- No special boundaries for top floors

The considered footprint areas and the boundary conditions specific to the typologies based on their intended use are fixed on the following pages. The changes in the model approaches and in the boundary conditions compared to iteration step 1 are highlighted in red. Most important boundary conditions are:

- time frame of operation
- internal heat gains
- construction of the facade
- infiltration rate
- indoor design conditions

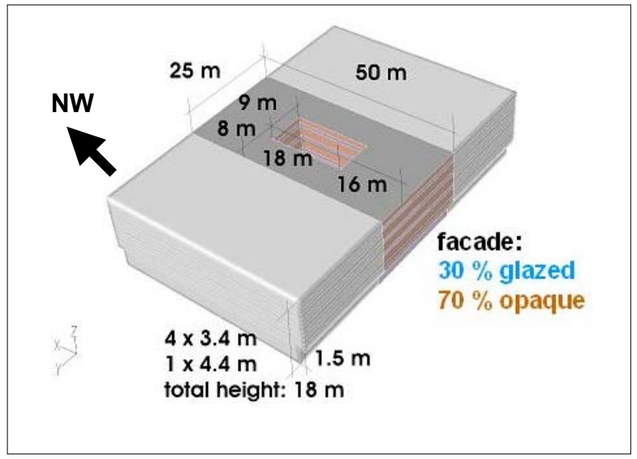


Figure 1: Geometry and construction of the generic building.

Right table: Gross footprint area of each using typology.

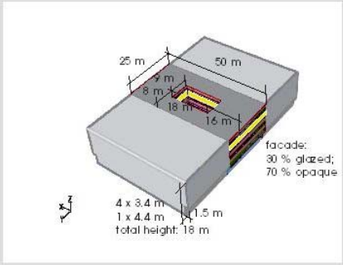
		BUA [m²]
Office Area		
SEZ-Offices		464,000
Com. / Office centres		235,800
Masdar centre	(without station)	80,000
Uni Admin		4,536
Uni Staff		47,568
Community Centre (Community Support)		14,444
Health Centres (Community Support)		7,222
		853,560
Labs		
SEZ Research Labs		61,600
Uni Labs		47,420
		109,020
Housing		
Employee Housing / Village	a 50 m²	1,406,250
Hotel		52,022
Student Dorms		46,300
		1,504,572
Production SEZ-Techn. Parc	clearance 4 m	360,000
Catering / Retail	clearance 4 m	
Catering / Retail Plaza	50 % F+B / 50 % Retail	14,063
SEZ - Local Centres		20,000
Uni Shared Amenity		18,005
Masdar Center (Station Retail)		8,000
		60,068
Divers	with ort solar gains	
Station	50,000 passengers/day	32,000
Science Centre		38,400
Sport Zone		7,200
Entertainment Complex (Community Support)		8,024
Worship (Community Support)		15,045
Uni Central Admin		4,948
Convention Center (Hotel)		7,980
		113,597
Education		
Uni Classroom		3,574
School (Community Support)	9 m²/student	40,121
Adult Education + Lib (Community Support)		1,505
Lib Uni		11,408
		56,708
Community Support		
Police		2,407
Fire Station		1,204
Hospital		6,821
		10,432
Total		**3,067,957 m²**

Changes of the Boundary Conditions

The most important changes in the boundary are:

- reduction of indoor design temperature
- reduction of heat recovery efficiency from 80 % to 60 %
- permanent and constant operation of air handling units – also in non-working hours

All of the above mentioned changes yield to an increase in the energy demand – even after reduction of the footprint areas.
In addition, for some spaces the loads of the artificial lighting are reduced.

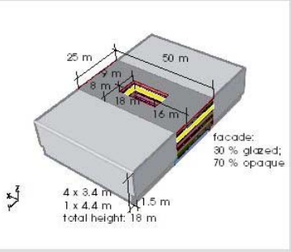


peak loads (to gross footprint):
- sensible - 52 W/m²
- latent - 35 W/m²
- AHU - 1.33 W/m²
- equipment - 10.3 W/m²
- art. lighting - 8.7 W/m²

annual demands (to gross footprint)
- 97 kWh/m²/a (elect.)
- 86 kWh/m²/a (latent)
- 125 kWh/m²/a (sensible)

Office floors in 2. to 5. story; 3 m clearance

working hours -	8°° to 19°°: 6 days per week
operation of AHU -	24 h / 7 d;
	1.5 acr based on working area
artificial lighting -	operation controlled depending on outdoor illuminance;
	10 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.3
facade -	opaque facade ratio of 70 %; 5 cm thermal insulated (outer surface)
exposed ceiling infiltration -	0.15 acr during working hours; 0.05 acr in non working hours
design temperature -	22°C / 55 % r. hum. daytime 24°C nighttime
density -	20 m² per occupant
internal heat gains - (office equipment)	10.3 W/m² during working hours; 5.15 W/m² in non working hours
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	60 %

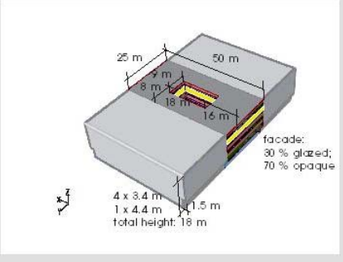


peak loads (to gross footprint):
- sensible - 74 W/m²
- latent - 82.4 W/m²
- AHU - 3.6 W/m²
- equipment - 19.1 W/m²
- art. lighting - 10.4 W/m²

annual demands (to gross footprint):
- 169.3 kWh/m²/a (elect.)
- 155 kWh/m²/a (latent)
- 189 kWh/m²/a (sensible)

Lab floors in 2. to 5. story; 3 m clearance; 50 % office / 50 % laboratory

working hours -	8°° to 19°°; 6 days per week
operation of AHU -	24 h, 7 d; 6°° to 19°°: 6 acr in lab area; 3 acr in office area; 19°° to 6°°: 3 acr based on working area
artificial lighting -	operation controlled depending on outdoor illuminance; 13 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.3
facade -	opaque facade ratio of 70 %; 5 cm thermal insulated (outer surface)
exposed ceiling infiltration -	0.15 acr during working hours; 0.05 acr in non working hours
design temperature -	22°C / 55 % r. hum. daytime 24°C nighttime
density -	20 m² per occupant
internal heat gains - (office equipment)	19.1 W/m² during working hours; 9.55 W/m² in non working hours
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	60 %

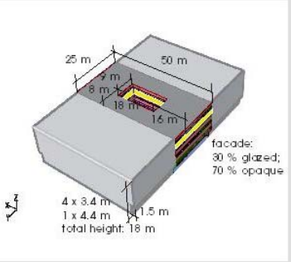


peak loads (to gross footprint):
- sensible - 32.2 W/m²
- latent - 37.5 W/m²
- AHU - 1.4 W/m²
- equipment - 2.5 W/m²
- art. lighting - 4 W/m²

annual demands (to gross footprint):
- 37.5 kWh/m²/a (elect.)
- 92 kWh/m²/a (latent)
- 70 kWh/m²/a (sensible)
- 17 kWh/m²/a (domestic water)

Housing floors in 2. to 5. story; 3 m clearance

Reduced hours -	8°° to 18°°; 5 days per week
operation of AHU -	24 h, 7 days per week; 1 acr based on used floor area
artificial lighting -	operation controlled depending on outdoor illuminance; 5 W/m² based on used floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.3
facade -	opaque facade ratio of 70 %; 5 cm thermal insulated (outer surface)
exposed ceiling infiltration -	0.2 acr during day time; 0.05 acr during night time
design temperature -	22°C / 55 % r. hum. 24°C reduced hours
density -	50 m² per resident
internal heat gains - (household equipment)	465 kWh/resident/a
el. demand of AHU -	0.6 kWh/1,000 m³
domestic water -	35 l/per/d; 65°C
sens. heat recovery -	60 %

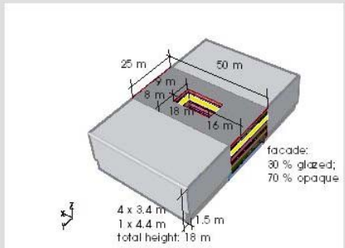


peak loads (to gross footprint):
- sensible - 49 W/m²
- latent - 73.4 W/m²
- AHU - 3 W/m²
- equipment - 3.5 W/m²
- art. lighting - 10.5 W/m²

annual demands (to gross footprint):
- 55.9 kWh/m²/a (elect.)
- 160.6 kWh/m²/a (latent)
- 69.4 kWh/m²/a (sensible)

Education floors in 2. to 5. story; 3 m clearance

working hours -	8°° to 18°°, 5 days per week
operation of AHU -	24 h; 7 days per week; 35 m³/h per person
artificial lighting -	operation controlled depending on outdoor illuminance; 12 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.3
facade -	opaque facade ratio of 70 %; 5 cm thermal insulated (outer surface)
exposed ceiling infiltration -	0.15 acr during working hours; 0.05 acr in non working hours
design temperature -	24°C
density -	9 m² per student/pupil
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	60 %

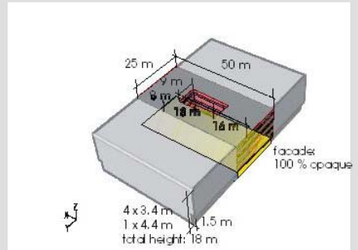


peak loads (to gross footprint):
- sensible - 28 W/m²
- latent - 41.3 W/m²
- AHU - 1.6 W/m²
- equipment - 1.8 W/m²
- art. lighting - 7 W/m²

annual demands (to gross footprint):
- 90.9 kWh/m²/a (elect.)
- 101.6 kWh/m²/a (latent)
- 120 kWh/m²/a (sensible)
- 7 kWh/m²/a (domestic water)

Community Support floors in 2. to 5. story; 3 m clearance

working hours -	24 h; 7 days per week
operation of AHU -	24 h; 7 days per week; 1. acr based on net floor area
artificial lighting -	permanent operation; 8 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.3
facade -	opaque facade ratio of 70 %; 5 cm thermal insulated (outer surface)
exposed ceiling	
infiltration -	0.2 acr
design temperature -	22°C
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	60 %

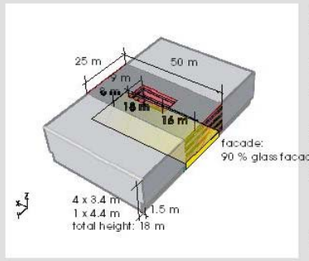


peak loads (to gross footprint):
- sensible - 47.6 W/m²
- latent - 59.7 W/m²
- AHU - 2.3 W/m²
- equipment - 20 W/m²
- art. lighting - 9.5 W/m²

annual demands (to gross footprint):
- 217 kWh/m²/a (elect.)
- 128 kWh/m²/a (latent)
- 220 kWh/m²/a (sensible)

Production floor in 1. story; 4 m clearance

working hours -	24 h; 5 days per week: 6°° to 14°°; 1 day per week
operation of AHU -	24 h; 6 d; 1 acr based on net floor area
artificial lighting -	24 h on 6 days per week; 10 W/m² based on net floor area (daylight controlled)
facade -	5 cm thermal insulated (outer surface)
exposed ceiling	
infiltration -	0.2 acr during working hours; 0.05 acr in non working hours
design temperature -	24 - 27°C
internal heat gains -	20 W/m² during working hours (production device Solarfabrik in Freiburg, Germany)
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	60 %



peak loads:
- sensible - 98 W/m²
- latent - 171 W/m²
- AHU - 9.1 W/m²
- equipment - 14.2 W/m²
- art. lighting - 19 W/m²

annual demands
- 243 kWh/m²/a (elect.)
- 373 kWh/m²/a (latent)
- 302 kWh/m²/a (sensible)
- 27 kWh/m²/a (domestic water)

Catering / Retail floors in 1. story; 4 m clearance

working hours -	10°° to 24°°; 7 days per week
operation of AHU -	9°° to 1°°; 7 days per week; 12 m³/h/m² based on net floor area
artificial lighting -	permanent operation during working hours; 20 W/m² based on net floor area
facade -	90% glass; neutral solar control glass 50/25; 20 % frame ratio; exterior shading device as overhang / wingwall
facade -	opaque facade ratio of 10 %; 5 cm thermal insulated (outer surface)
exposed ceiling	
infiltration -	0.15 acr during working hours; 0.05 acr in non working hours
design temperature -	22°C / 65 % r. hum. 24°C reduced hours
internal heat gains - (only catering)	28 W/m² on 10 h per day
el. demand of AHU -	0.6 kWh/1,000 m³ (retail); 1.0 kWh/1,000 m³ (catering)
sens. heat recovery -	60 %

On ground floor or basement

peak loads:
- sensible - 52 W/m²
- latent - 60 W/m²
- AHU - 2.3 W/m²
- equipment - 1 W/m²
- art. lighting - 19 W/m²

annual demands
- 140 kWh/m²/a (elect.)
- 147.8 kWh/m²/a (latent)
- 174 kWh/m²/a (sensible
- 4.4 kWh/m²/a (domestic water)

Diverse (Stations, Science zone, Sports Zone, Entertainment

working hours -	8°° to 24°°; 7 days per week
operation of AHU -	24 h; 7 d; 1 acr based on net floor area
artificial lighting -	permanent operation during working hours; 20 W/m² based on net floor area
facade -	no solar gains; 5 cm thermal insulated (outer surface)
infiltration -	0.2 acr during working hours; 0.05 acr in non working hours
design temperature -	22 - 26°C
equipment -	pool: 1,000 MWh for 1,000 m² water surface
domestic water -	pool: 438 MWh for 1,000 m² water surface
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	60 %

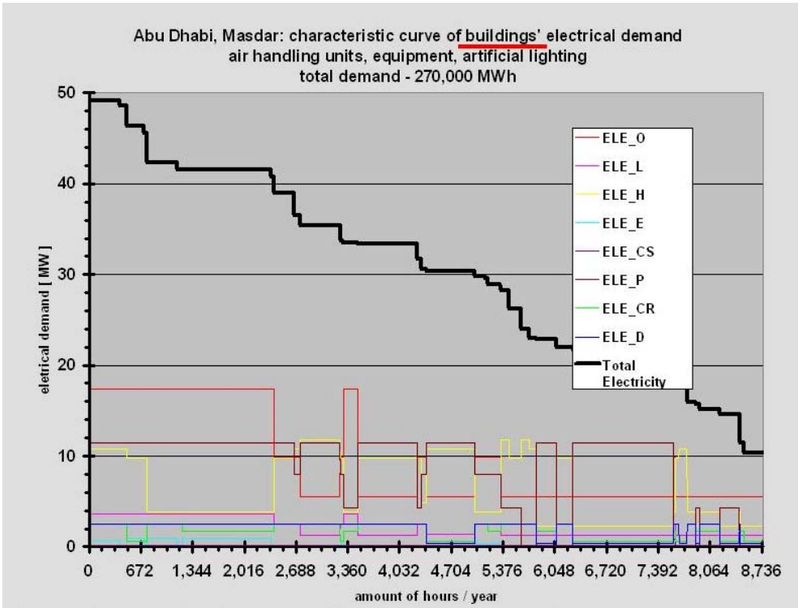
Results

Legend
Office Area = O
Labs = L
Housing = H
Education = E
Community Support = S
Production = P
Catering/Retail= CR
Diverse = D

Figure 1: The total electrical demand of all typologies is shown, which is 270,000 MWh/a with a peak load of about 50 MW; the characteristic curve – in descending order - includes

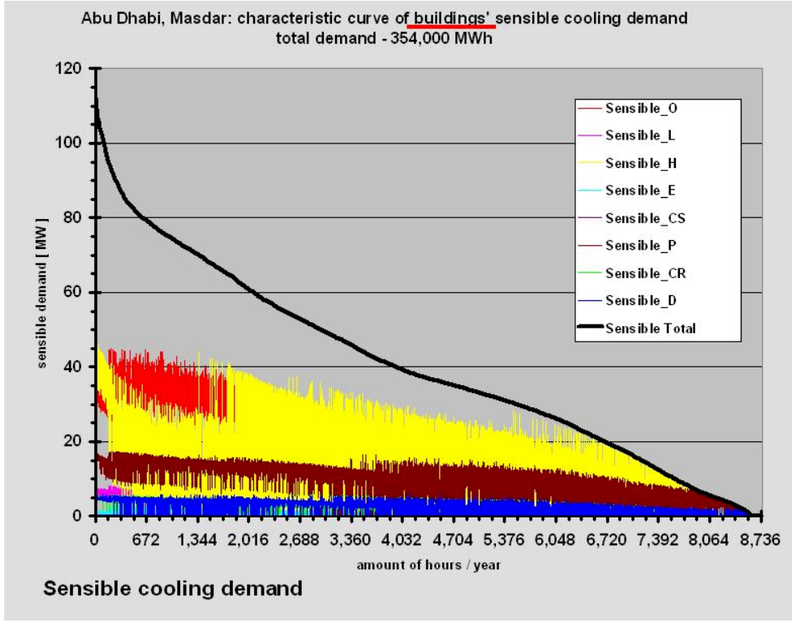
- art. lighting
- appliances
- ventilation;

energy requirements of el. chillers for sensible cooling are excluded in this iteration, which was not the case in the previous simulation iteration.



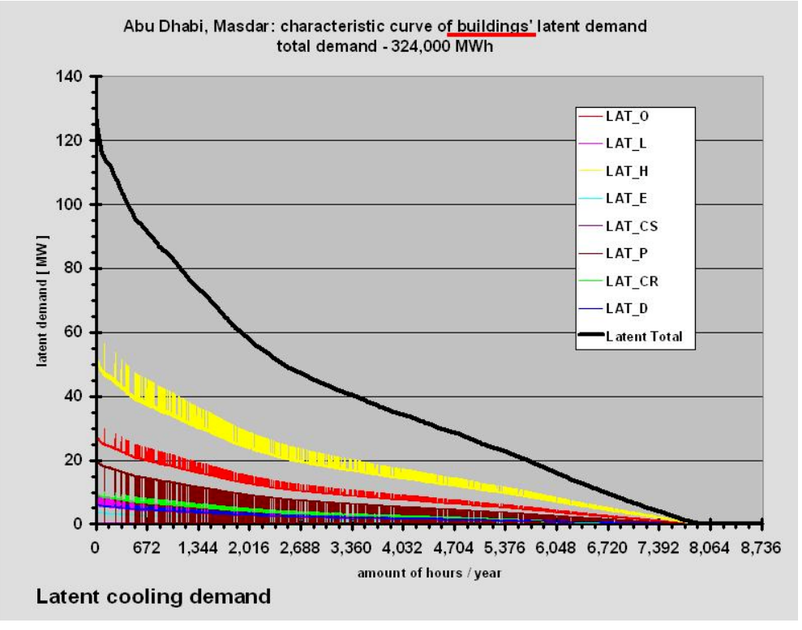
Electrical demand without sensible and latent demand

Figure 2: As the sum of the different typologies the total sensible demand of all buildings is shown with 354,000 MWh/a and with a peak load of about 120 MW - in descending order.



Sensible cooling demand

Figure 3: As the sum of the different using typologies the total latent demand of all buildings is shown with 324,000 MWh/a and with a peak load of about 130 MW - in descending order.



Latent cooling demand

Results

Legend
Office Area = O
Labs = L
Housing = H
Education = E
Community Support = S
Production = P
Catering/Retail= CR
Diverse = D

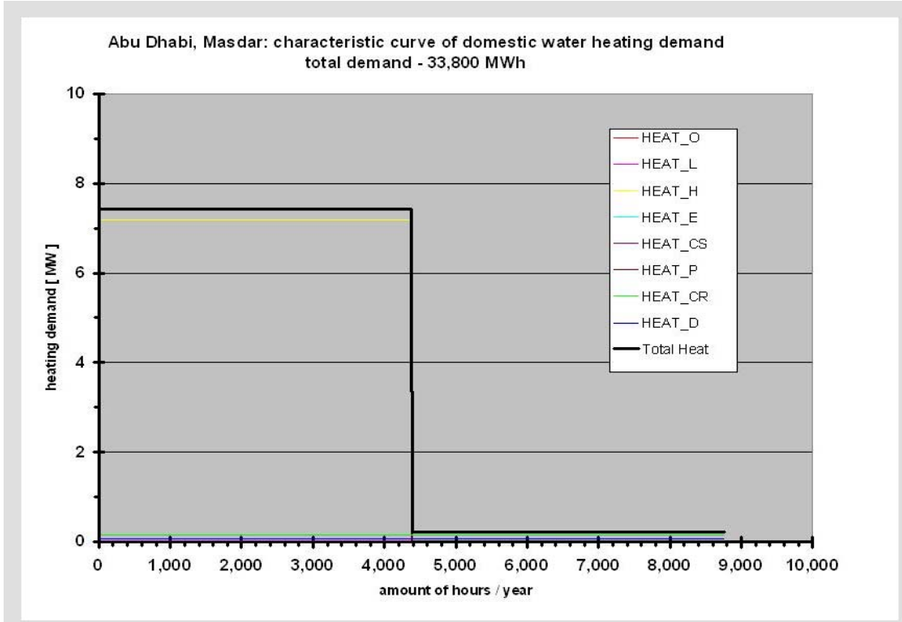
Figure 1: Heating demand for domestic water in housing, catering, pool, hospital; possible steam demand for light industry and labs is **not** considered.

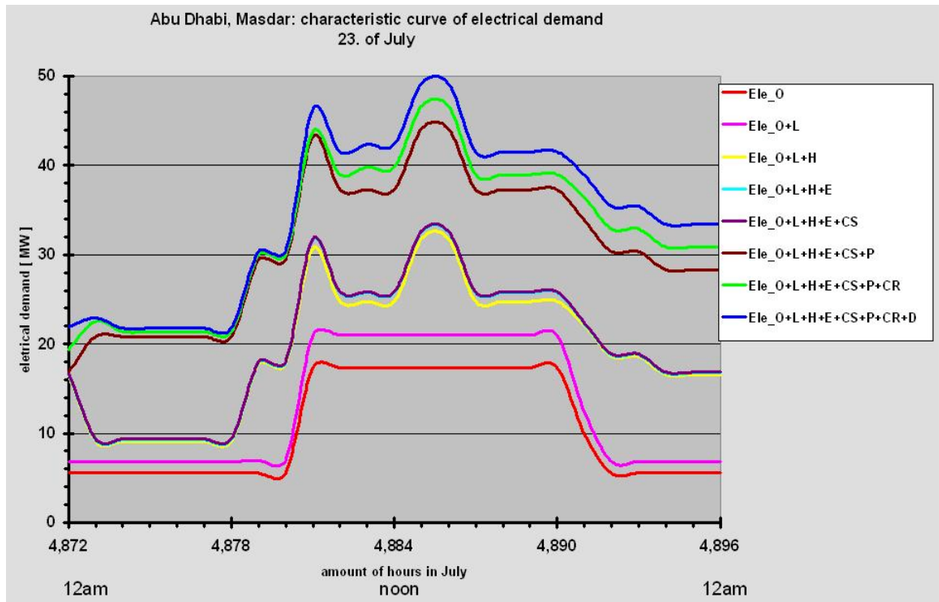
Figure 2: The characteristic curves of the electrical energy requirement for the different typologies are added to the total demand; the trend is shown for 23rd of July;
- art. lighting
- appliances
- ventilation.

is included – sensible and latent cooling is excluded; the trend refers to a Monday, because brown-colored light industry demand at 0 am is 0; the peaks are caused by switch-on of appliances and artificial lighting.

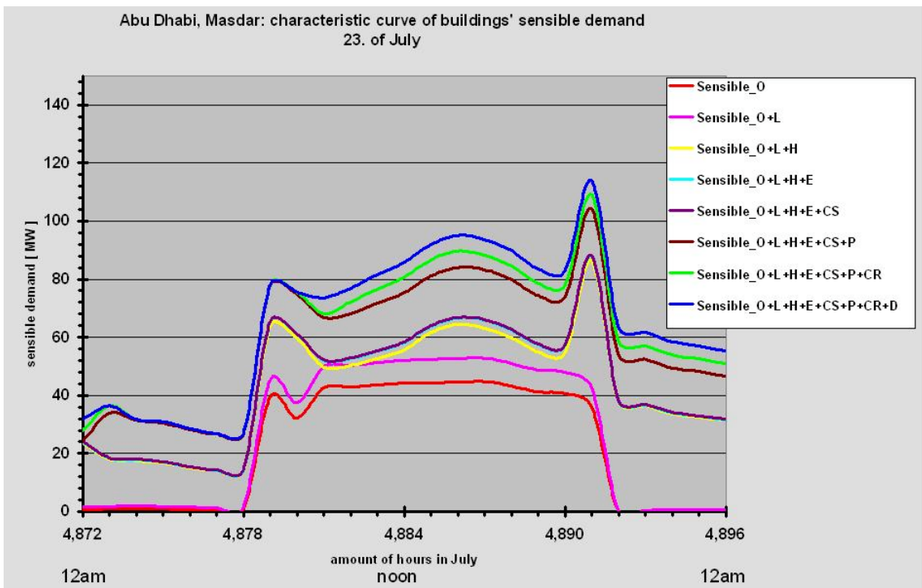
Figure 3: The characteristic curves of the sensible cooling demand for the different using typologies are added to the total demand; the trend is shown for the 23. of July;
the evening peak is caused by internal heat gains and a set-back of the design temperature in housing spaces.

Figure 4: The characteristic curves of the latent cooling demand for the different typologies are added to the total demand; the trend is shown for 3rd of July; the dip in the afternoon is caused by a drop of the outdoor humidity.

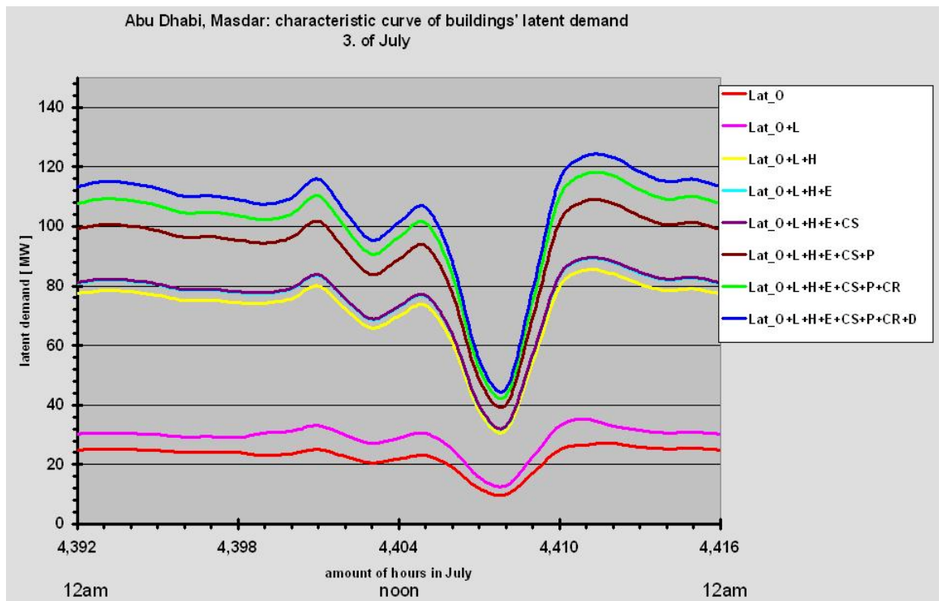




Electrical demand without sensible and latent cooling



Sensible demand for cooling



Latent demand for dehumidification

3. Iteration

Proceeding
The principle proceeding of the 3. iteration is the same as for the previous one. The reasons for the 3. and additional iteration step are:

- little changes in the building program and in the footprint areas (PS. table on right)
- need of a30% load and demand reduction because of limited site area for the energy production
- changed building typologies from generic type to architectural proposal in particular for housing, offices and labs (PS. figure 1 - 5)

The building typology of housing shows a lower density and therefore a lower ratio in cladding area / building space. In difference to the previous iteration steps now special boundary conditions for the top floors are considered.
For a compensation and to avoid additional cooling loads , the simulation results show the need of a proper insulation standard for roofs (20 cm; 0.04 W/m/K), for opaque facades (10 cm; 0.04 W/m²/K) and for windows U_w-value of the windows – including glass and frame - =< 1.5 W/m²/K.

Boundary Conditions
The power demand and loads of other energy consuming systems – like

- infrastructure in general (losses for el. power distribution and el. transformation, ventilation and power requirements for active switch gears, thermal losses of district heating / cooling, el. demand of fluid / water pumps, el. demand of processes based on sorption for dehumidification and chilled water production, etc.)
- transportation systems (interior PRT energy requirement and exterior commuting)
- water desalination and potable water distribution
- black water treatment and distribution
- grey water treatment and distribution
- power requirements for waste sorting and collecting
- street- , parking- and sport lights
- IT (electrical)

must be added to the demands/loads of the buildings

Please consider for designing the energy concept:

- absorption chiller and L-DC systems => COP_elect = 50
- L-DCS => COP_therm = 0.9
- absorption chiller => COP_therm = 0.7 (single effect); COP_therm = 1.1 (double effect)

The heat island effect in the city as calculated in Chapter 4.1.2 is considered by an increased ambient temperature of + 3.5 Kelvin. The max. indoor humidity is limited to 12 g/kg resp. 65 % based on 24°C indoor temperature. It's also important to combine the L-DCS with an indirect evaporative exhaust air cooling and heat recovery (PS inception report) system in each building.
For the latent heat recovery by means of indirect evaporative cooling the same amount of water a year must be taken into account that evaporates via exhaust air as is taken out of the fresh intake air by dehumidification.
For Housing this means approx. 110 kg/m²/a. If more water is vaporized a higher sensible cooling effect can be achieved.

The changes in the model approaches and in the boundary conditions compared to the both first iteration steps are highlighted in red on the next pages.

Table 1: Gross footprint area of each using typology.

Occupant space	Total BUA [m²]
Housing H	1,466,439.38
Offices O	904,488.77
Retail CR	43,562.50
Labs L	115,401.98
Production P	357,027.82
Education E	59,360.65
Community CS	50,045.13
Divers D	65,717.56
	3,062,043.78

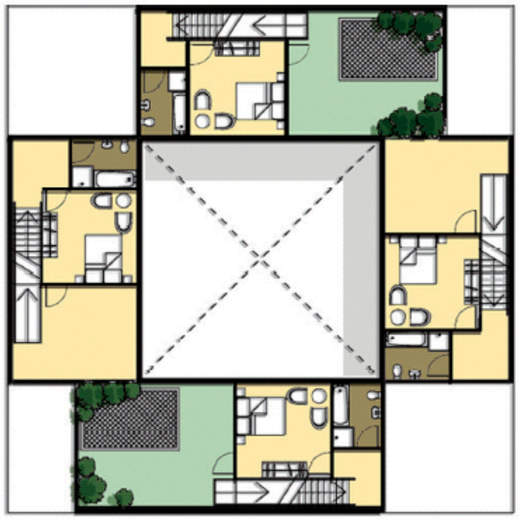


Figure 1: Footprint of new housing typology;3.floor; courtyard 11 x 11 m².

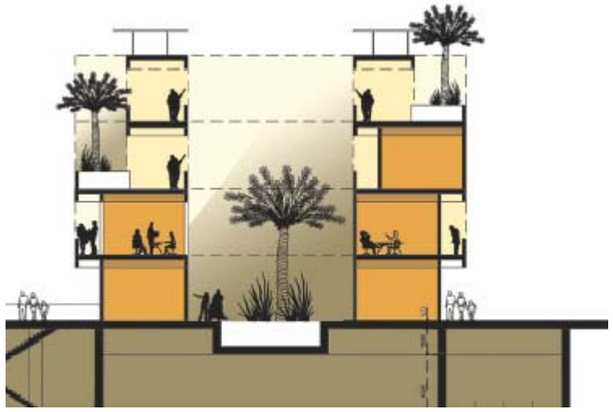


Figure 2: Section of new housing typology;3.floor; courtyard 11 x 11 m².

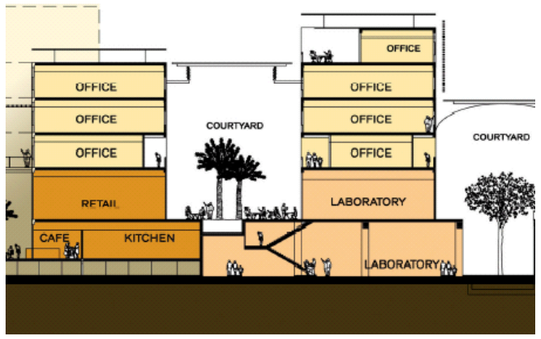


Figure 3 + 4: Section of new commercial typology containing offices, labs retail and catering; courtyard 15 x 30 m².

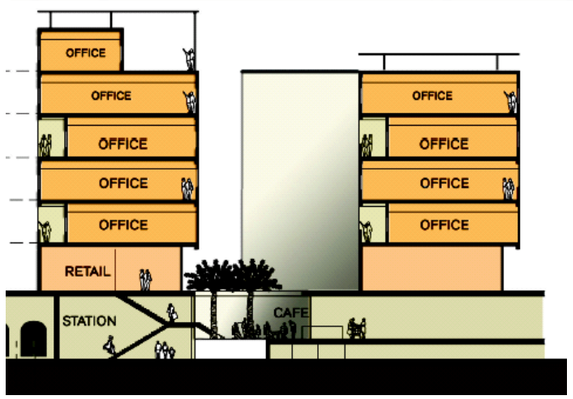
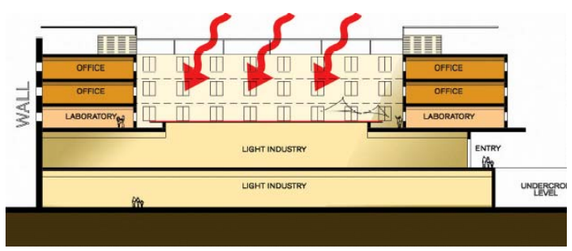


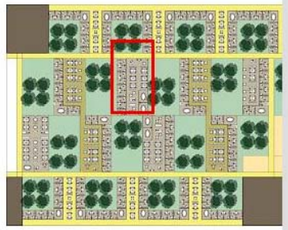
Figure 5: Section of new commercial typology containing light industry / production; about 50 % of light industry area gets natural lighting.



Typologies
For housing, lab and office spaces the newest building typologies are used. For the rest still the generic standard building which was used in the previous iteration steps, is the basis of the simulation model.

Typologies
Commercial SEZ

Courtyard: 15 x 30 m²



peak loads (to gross footprint):

• sensible -	42.3 W/m²
• latent -	31 W/m²
• AHU -	1.3 W/m²
• equipment -	5.3 W/m²
• art. lighting -	9 W/m²

annual demands (to gross footprint)

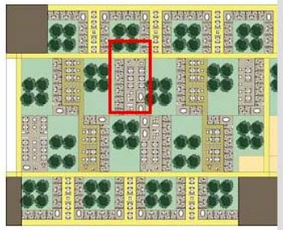
• sensible -	94.8 kWh/m²/a
• latent -	50.5 kWh/m²/a
• electrical -	49.1 kWh/m²/a

Office floors in 2. to 5. story; 3 m clearance;
25 % of total area as top floor area with roof

working hours -	8°° to 19°°; 6 days per week
operation of AHU -	24 h / 7 d; based on working area; working: 1.5 acr; non-working: 0.75 acr
artificial lighting -	operation controlled depending on outdoor illuminance; 10 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.3
facade -	opaque facade ratio of 70 %; 5 cm thermal insulation (outer surface)
roof -	20 cm thermal insulation (outer surface)
exposed ceiling -	as thermal mass
infiltration -	0.15 acr during working hours; 0.05 acr in non working hours
design temperature -	24°C / 65 % r. hum. daytime 28°C in non working hours
density -	20 m² per occupant
internal heat gains - (office equipment)	5.3 W/m² during working hours; 2.65 W/m² in non working hours
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	80 %

Typologies
Commercial SEZ

Courtyard: 15 x 30 m²



peak loads (to gross footprint):

• sensible -	51 W/m²
• latent -	74.2 W/m²
• AHU -	3.7 W/m²
• equipment -	10.6 W/m²
• art. lighting -	8 W/m²

annual demands (to gross footprint)

• sensible -	127.5 kWh/m²/a
• latent -	107.3 kWh/m²/a
• electrical -	99 kWh/m²/a

Lab floors in 2. to 5. story; 3 m clearance;
50 % office / 50 % laboratory

working hours -	8°° to 19°°; 6 days per week
operation of AHU -	24 h, 7 d; working: 6 acr in lab area; 3 acr in office area; non-working: 3 acr;
artificial lighting -	operation controlled depending on outdoor illuminance; 10 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.3
facade -	opaque facade ratio of 70 %; 5 cm thermal insulated (outer surface)
exposed ceiling	
infiltration -	0.15 acr during working hours; 0.05 acr in non working hours
design temperature -	24°C / 65 % r. hum. daytime 28°C in non-working hours
density -	20 m² per occupant
internal heat gains - (office equipment)	10.6 W/m² during working hours; 5.3 W/m² in non working hours
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	80 %

2. floor 3. floor

Courtyard: 11 x 11 m²

peak loads (to gross footprint):

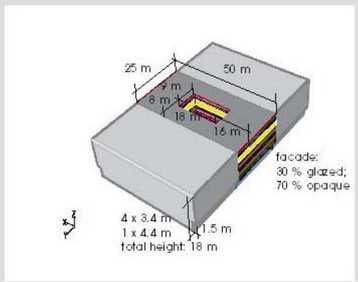
• sensible -	32.3 W/m²
• latent -	35.4 W/m²
• AHU -	1.2 W/m²
• equipment -	2.8 W/m²
• art. lighting -	1 W/m²

annual demands (to gross footprint)

• sensible -	74.3 kWh/m²/a
• latent -	76.9 kWh/m²/a
• electrical -	22 kWh/m²/a
• dom. water heating	15.8 kWh/m²/a

Housing floors in 2. to 5. story; 3 m clearance;
25 % of total area as top floor area with roof

Reduced hours -	8°° to 18°°; 5 days per week
operation of AHU -	24 h, 7 days per week; 1 acr based on used floor area
artificial lighting -	operation controlled depending on outdoor illuminance; 1.25 W/m² based on used floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.2
facade -	opaque facade ratio of 70 %; 10 cm thermal insulated (outer surface)
roof -	20 cm thermal insulation (outer surface)
exposed ceiling	
infiltration -	0.2 acr during day time; 0.05 acr during night time
design temperature -	24°C / 65 % r. hum. 26°C in reduced hours
density -	50 m² per resident
internal heat gains - (household equipment)	430 kWh/resident/a
el. demand of AHU -	0.5 kWh/1,000 m³
domestic water -	35 l/per/d; 65°C
sens. heat recovery -	80 %



peak loads (to gross footprint):

• sensible -	47.2 W/m²
• latent -	63.6 W/m²
• AHU -	3 W/m²
• equipment -	3.5 W/m²
• art. lighting -	10.5 W/m²

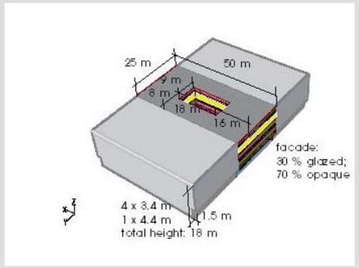
annual demands (to gross footprint)

• sensible -	76 kWh/m²/a
• latent -	67 kWh/m²/a
• electrical -	44.2 kWh/m²/a

Education floors in 2. to 5. story; 3 m clearance

working hours -	8°° to 18°°; 5 days per week
operation of AHU -	24 h; 7 days per week; working: 35 m³/h per person non-working: minimized acr
artificial lighting -	operation controlled depending on outdoor illuminance; 12 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.3
facade -	opaque facade ratio of 70 %; 5 cm thermal insulated (outer surface)
exposed ceiling	
infiltration -	0.15 acr during working hours; 0.05 acr in non working hours
design temperature -	24°C / 65 % r. hum. 28°C in reduced hours
density -	9 m² per student/pupil
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	80 %

* : Please be aware – for light industry a value of 20 W/m² electrical load for machinery is considered. This boundary condition is based on the production of the Solarfabrik Freiburg, Germany. This manufacturer is only an assembler of PV panels; a Si-based wafer production is not included in this load!



peak loads (to gross footprint):

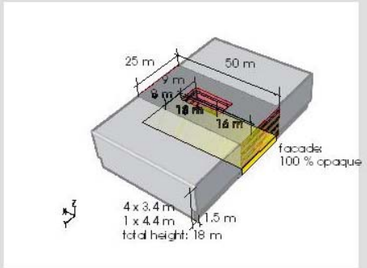
• sensible -	24.6 W/m²
• latent -	39.1 W/m²
• AHU -	1.6 W/m²
• equipment -	1.8 W/m²
• art. lighting -	7 W/m²

annual demands (to gross footprint)

• sensible -	120 kWh/m²/a
• latent -	85.2 kWh/m²/a
• electrical -	90.8 kWh/m²/a
• dom. water heating	7 kWh/m²/a

Community Support floors in 2. to 5. story; 3 m clearance

working hours -	24 h; 7 days per week
operation of AHU -	24 h; 7 days per week; 1. acr based on net floor area
artificial lighting -	permanent operation; 8 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.3
facade -	opaque facade ratio of 70 %; 5 cm thermal insulated (outer surface)
exposed ceiling	
infiltration -	0.2 acr
design temperature -	24°C / 65 % r. hum. 28°C in reduced hours
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	80 %



peak loads (to gross footprint):

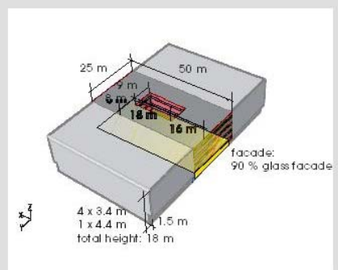
• sensible -	65.6 W/m²
• latent -	55.9 W/m²
• AHU -	3.4 W/m²
• equipment -	20 W/m² *
• art. lighting -	9.5 W/m²

annual demands (to gross footprint)

• sensible -	226.4 kWh/m²/a
• latent -	105.9 kWh/m²/a
• electrical -	232.2 kWh/m²/a

Production floor in 1. story; 4 m clearance (light industry)

working hours -	24 h; 5 days per week: 6°° to 14°°; 1 day per week
operation of AHU -	24 h / 5 d, 8 h / 1 d working: 1 acr based on net floor area non-working: 1/3 acr
artificial lighting -	24 h on 6 days per week; 10 W/m² based on net floor area (daylight controlled in 50 % of the area)
facade -	5 cm thermal insulated (outer surface)
exposed ceiling	
infiltration -	0.2 acr during working hours; 0.05 acr in non working hours
design temperature -	28°C 32°C in non-working hours
internal heat gains -	20 W/m² during working hours (production device Solarfabrik in Freiburg, Germany)
el. demand of AHU -	0.9 kWh/1,000 m³
sens. heat recovery -	80 %



peak loads (to gross footprint):

• sensible -	81.7 W/m²
• latent -	152.3 W/m²
• AHU -	9.1 W/m²
• equipment -	14.2 W/m²
• art. lighting -	19 W/m²

annual demands (to gross footprint)

• sensible -	291.2 kWh/m²/a
• latent -	195.2 kWh/m²/a
• electrical -	225.2 kWh/m²/a
• dom. water heating	27 kWh/m²/a

Catering / Retail floors in 1. story; 4 m clearance

working hours -	10°° to 24°°; 7 days per week
operation of AHU -	9°° to 1°°; 7 days per week; 12 m³/h/m² based on net floor area reduced hours: minimized acr
artificial lighting -	permanent operation during working hours; 20 W/m² based on net floor area
facade -	90% glass; neutral solar control glass 50/25; 20 % frame ratio; exterior shading device (overhang / wingwall)
facade -	opaque facade ratio of 10 %; 5 cm thermal insulated (outer surface)
exposed ceiling	
infiltration -	0.15 acr during working hours; 0.05 acr in non working hours
design temperature -	24°C / 65 % r. hum. 26°C in reduced hours
internal heat gains -	28 W/m² on 10 h per day
(only catering)	
el. demand of AHU -	0.6 kWh/1,000 m³ (retail); 1.0 kWh/1,000 m³ (catering)
sens. heat recovery -	80 %

On ground floor or basement

peak loads (to gross footprint):

• sensible -	43.9 W/m²
• latent -	56.8 W/m²
• AHU -	2.3 W/m²
• equipment -	1 W/m²
• art. lighting -	14.3 W/m²

annual demands (to gross footprint)

• sensible -	145.6 kWh/m²/a
• latent -	124 kWh/m²/a
• electrical -	112.2 kWh/m²/a
• dom. water heating	4.4 kWh/m²/a

Diverse - stations, science zone, sports zone, entertainment

working hours -	8°° to 24°°; 7 days per week
operation of AHU -	24 h; 7 d; 1 acr based on net floor area
artificial lighting -	permanent operation during working hours; 15 W/m² based on net floor area
facade -	no solar gains; 5 cm thermal insulated (outer surface)
infiltration -	0.2 acr during working hours; 0.05 acr in non working hours
design temperature -	24°C / 65 % r. hum.
equipment -	pool: 1,000 MWh for 1,000 m² water surface
domestic water -	pool: 438 MWh for 1,000 m² water surface
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	80 %

Results
Legend
Office Area = O
Labs = L
Housing = H
Education = E
Community Support = S
Production = P
Catering/Retail = CR
Diverse = D

Figure 1: As the sum of the different using typologies the total electrical demand of all buildings is shown with 195,000 MWh/a and with a peak load of about 38 MW; the characteristic curve – in descending order - includes

- art. lighting
- appliances
- ventilation.

In difference to the previous. iteration step the energy requirements of el. chillers for sensible cooling are excluded.
As compared to 2. iteration step the following points lead to the main demand reductions:

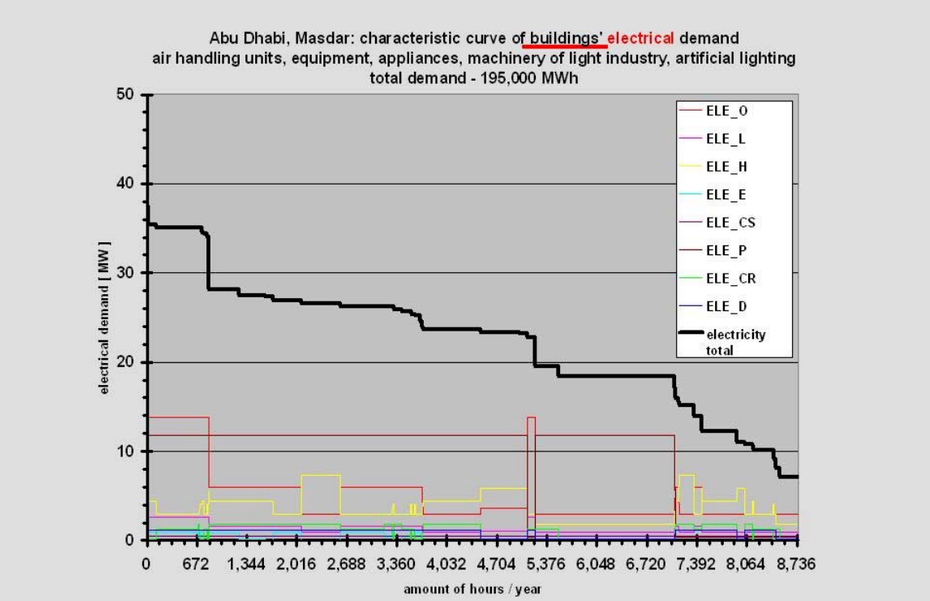
- reduced electrical loads for office- and lab equipment
- reduced electrical loads for housing equipment
- reduced electrical loads for artificial lighting in lab spaces, light industry and divers spaces
- minimized ACR of all spaces in non-working / reduced hours.

Figure 2: The characteristic curves of the electrical energy requirement for the different typologies are added to the total demand; the trend is shown for 23th of July;

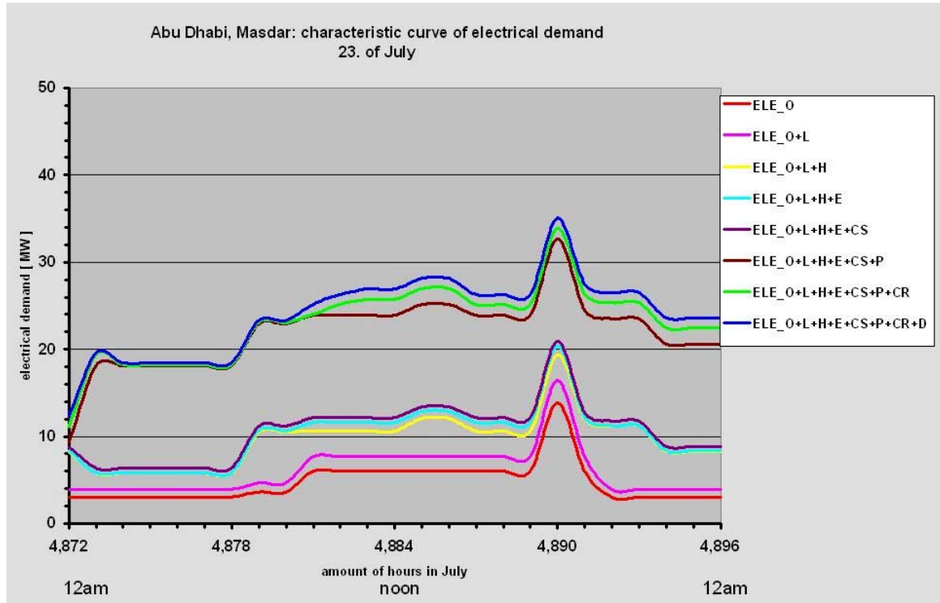
- art. lighting
- appliances
- ventilation.

is included – sensible and latent cooling is excluded; the trend refers to a Monday, because brown-colored light industry demand at 0 am is 0; the evening peak is caused by a switch-on of appliances and artificial lighting.

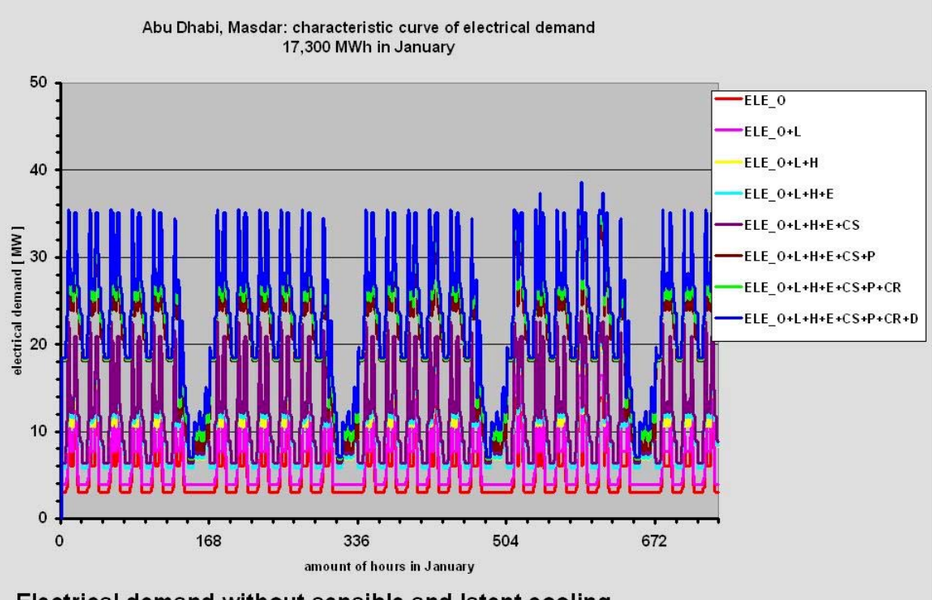
Figure 3 + 4: Characteristic el. demand curves for January and July; regarding the el. demand and the peak loads there is only a slight difference between winter- and summer months;
demand: 17,300 MWh and 16,000 MWh



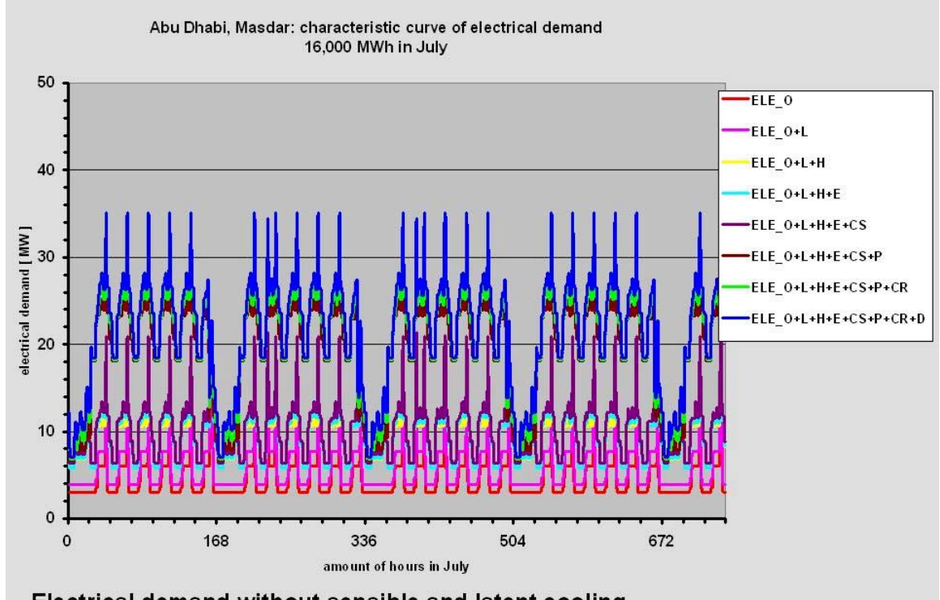
Electrical demand without sensible and latent demand



Electrical demand without sensible and latent cooling



Electrical demand without sensible and latent cooling



Electrical demand without sensible and latent cooling

Results

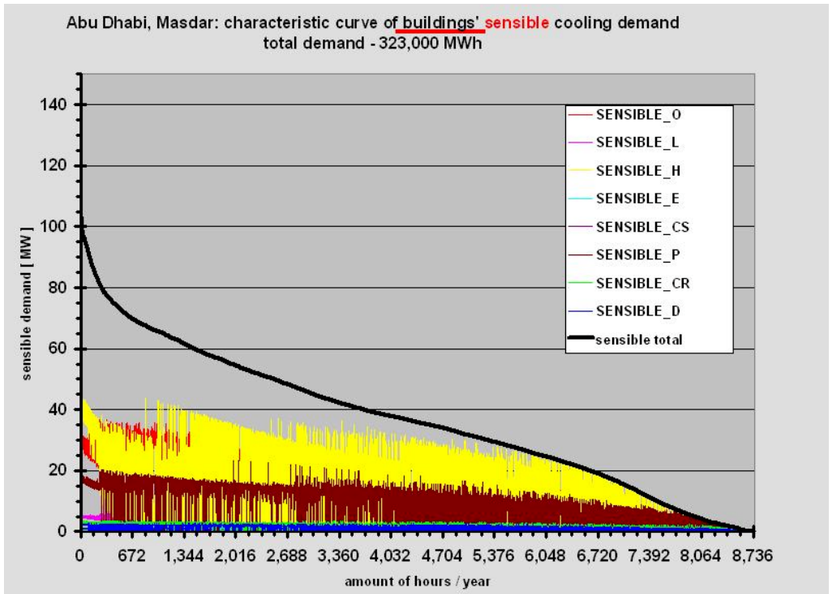
Legend
Office Area = O
Labs = L
Housing = H
Education = E
Community Support = S
Production = P
Catering/Retail = CR
Diverse = D

Figure 1: As the sum of the different using typologies the total sensible demand of all buildings is shown with 323,000 MWh/a and with a peak load of about 110 MW - in descending order. Comparing to 2. iteration step the following points lead to the main demand reductions – even if roof heat loads and the city heat island effect is considered:

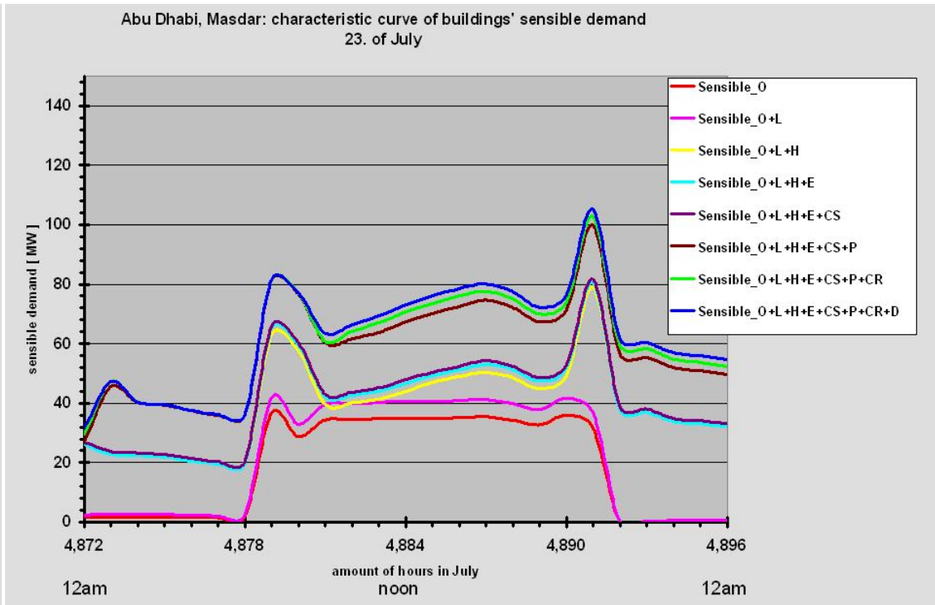
- reduced electrical loads for office- and lab equipment
- reduced electrical loads for housing equipment
- reduced electrical loads for artificial lighting in lab spaces, light industry and divers spaces
- increased design temperature
- increased efficiency of heat recovery to 80 %.

Figure 2: The characteristic curves of the sensible cooling demand for the different using typologies are added to the total demand; the trend is shown for the 23. of July;
the peaks are caused by internal heat gains and a set-back of the design temperature in housing spaces.

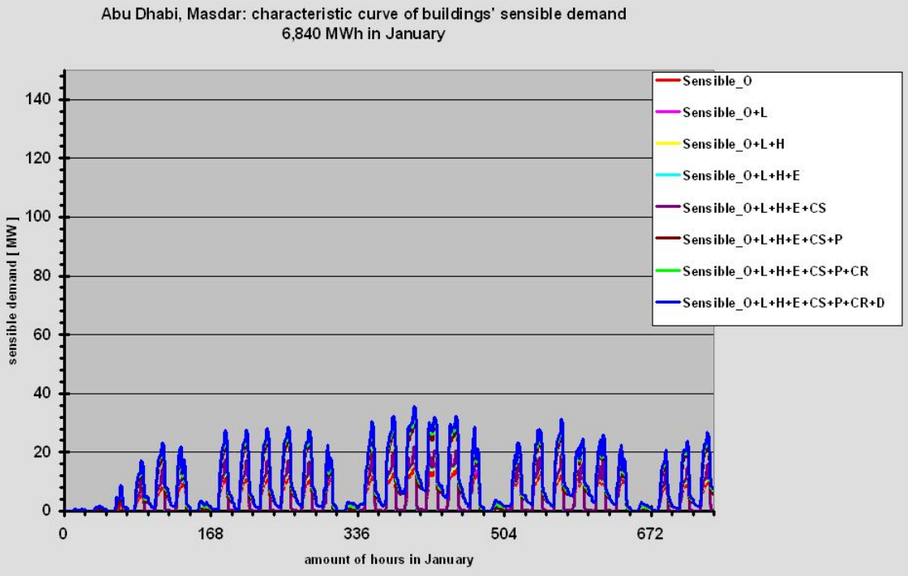
Figure 3 + 4: Characteristic curves of sensible cooling demand for January and July; regarding the sensible demand and the peak loads there is a significant difference between winter- and summer months;
demand: 6,840 MWh and 41,650 MWh
peak load: 36 MW and 110 MW



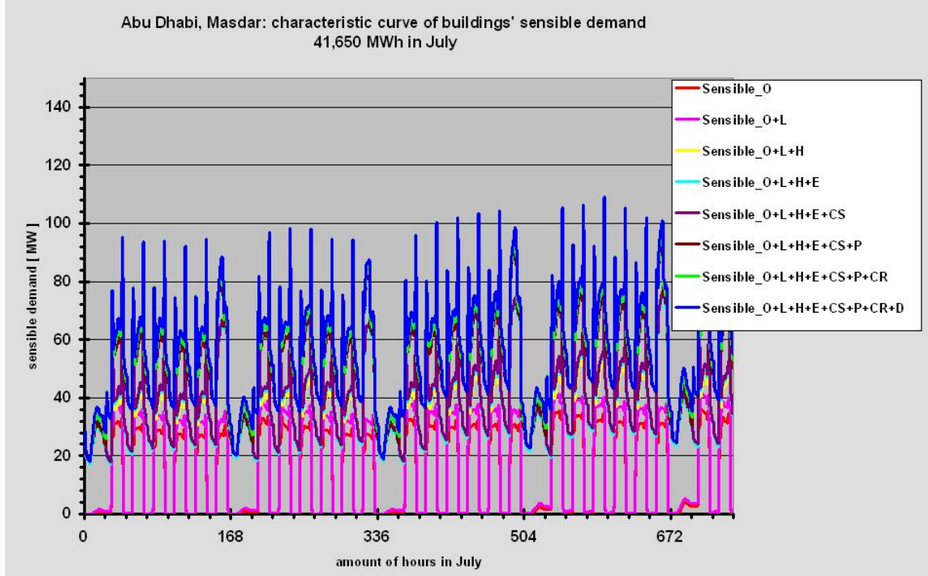
Sensible cooling demand



Sensible demand for cooling



Sensible demand for cooling



Sensible demand for cooling

Results

Legend
Office Area = O
Labs = L
Housing = H
Education = E
Community Support = S
Production = P
Catering/Retail = CR
Diverse = D

Figure 1: As the sum of the different using typologies the total latent demand of all buildings is shown with 234,000 MWh/a and with a peak load of about 116 MW - in descending order. Compared to 2. iteration step the following points lead to the main demand reductions:

- fixed limit of maximal absolute humidity – 12 g/kg – for all spaces; this corresponds to 65 % relative humidity at an indoor temperature of 24°C
- minimized ACR of all spaces in non-working / reduced hours.

Figure 2: The characteristic curves of the latent cooling demand for the different typologies are added to the total demand; the trend is shown for 3th of July; the dip in the afternoon is caused by a drop of the outdoor humidity, what is shown in the small figure.

For designing the solar based components of the city's energy production system it's important to know what the demands during the day and what the demands during the night will be. The switch for the day / night-split is based on the horizontal global radiation => day for Eh_glob > 0; night for Eh_glob = 0:

- **Electrical**

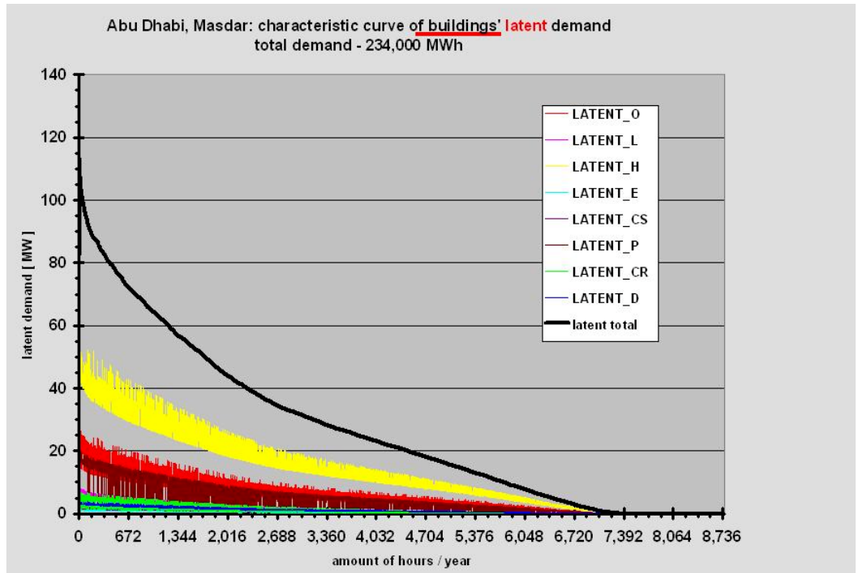
total demand – 195,000 MWh/a
day time demand – 116,000 MWh/a
night time demand - 79,000 MWh/a

- **Sensible**

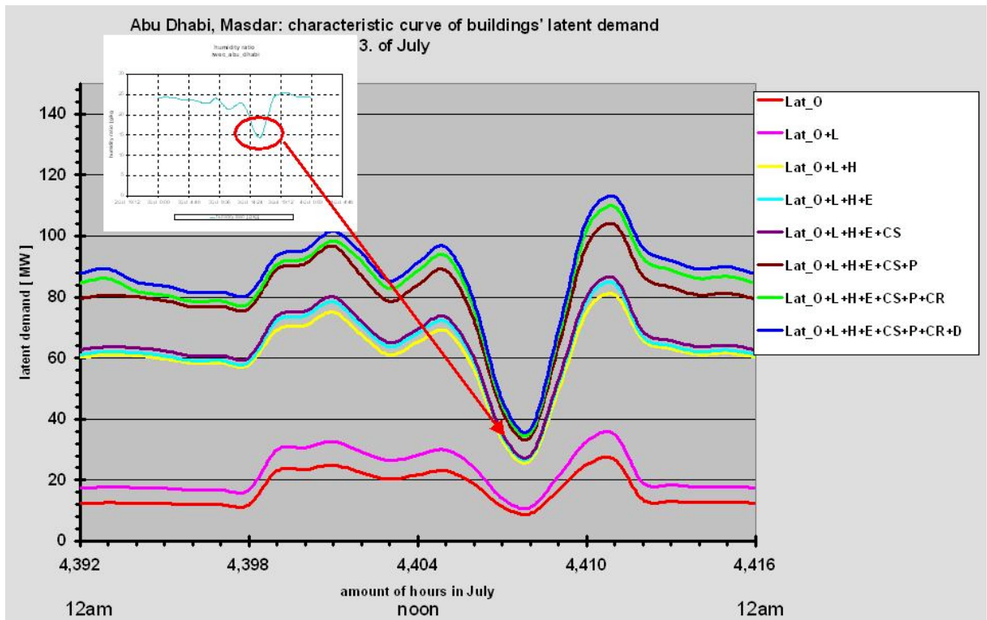
total demand – 323,000 MWh/a
day time demand – 214,000 MWh/a
night time demand – 109,000 MWh/a

- **Latent**

total demand – 234,000 MWh/a
day time demand – 115,000 MWh/a
night time demand – 119,000 MWh/a



Latent cooling demand



Latent demand for dehumidification

Results

Legend
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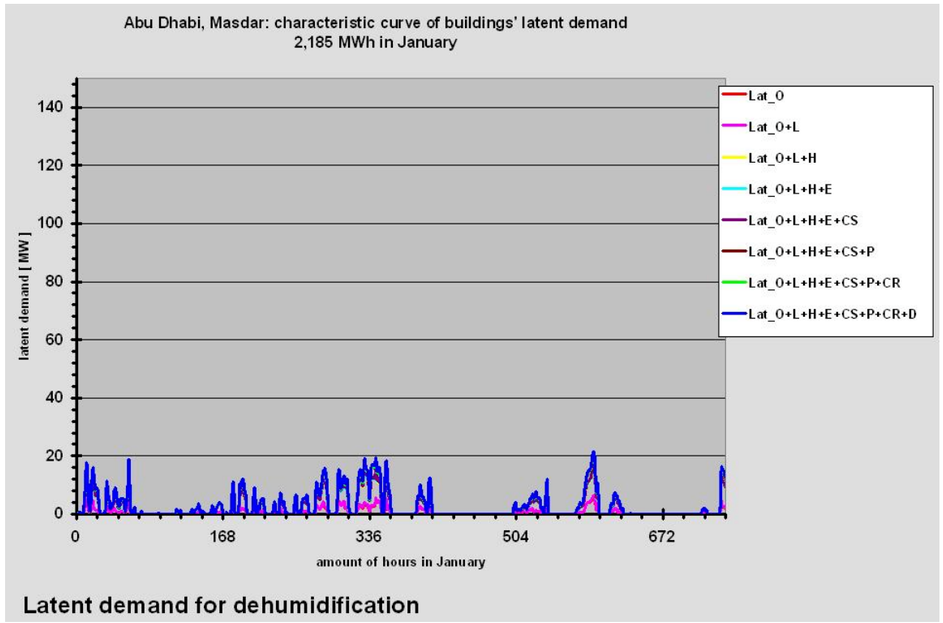
Labs = L
Housing = H
Education = E
Community Support = S
Production = P
Catering/Retail = CR
Diverse = D



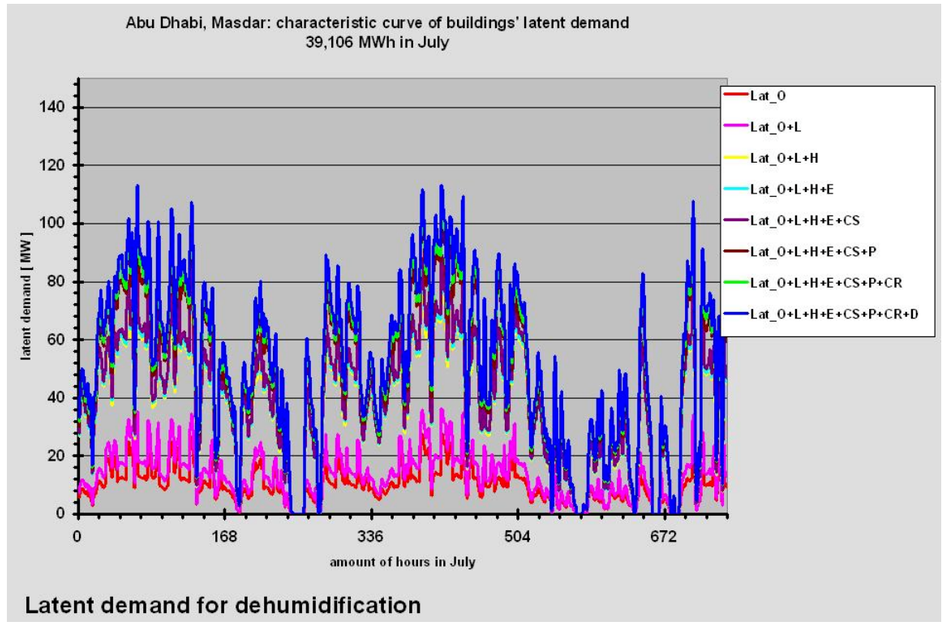


Figure 1: Characteristic curves of latent cooling demand for January.

Figure 2: Characteristic curves of latent cooling demand for July.

Regarding the latent demand and the peak loads there is a significant difference between winter- and summer months;
demand: 2,185 MWh and 39,106 MWh
peak load: 22 MW and 116 MW

Figure 3: Heating demand for domestic water in housing, catering, pool, hospital; possible steam demand for light industry and labs is **not** considered; total annual demand – 25,000 MWh/a

Sensitivities of Prototype "Housing"
Assuming the boundary conditions as fixed for 3. iteration step the result for

- the annual sensible cooling demand is 74.3 kWh/m²/a
- the annual latent cooling demand is 76.9 kWh/m²/a and
- the annual electrical appliances demand is 8.6 kWh/m²/a.

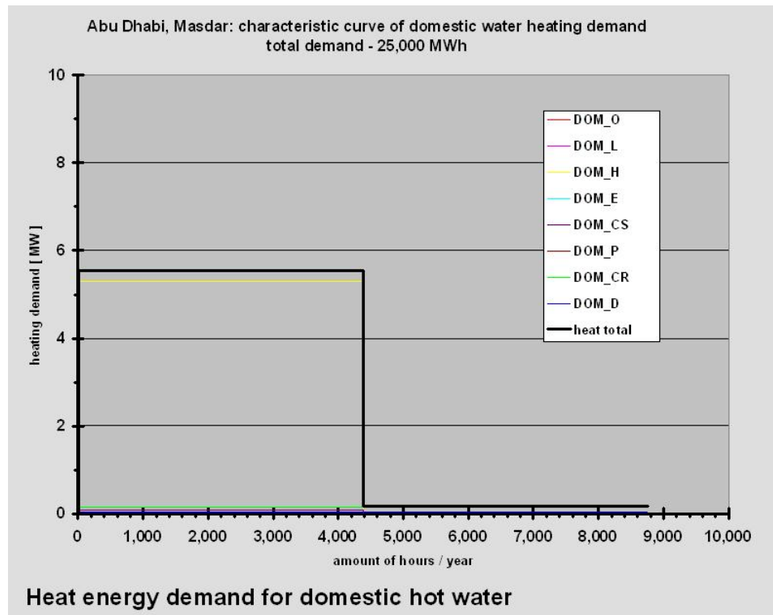
The above numbers refer to the gross footprint and now will correspond to 100 % of the demand (PS. table on right).
Regarding the energy demand the results in table 1 show:

- Particularly for less dense building typology housing a proper insulation standard is important
- the infiltration rate has big impact on latent cooling demand (air dehumidification)
- request: the lower the design temperature, the better the heat recovery
- doubled impact of internal heat gains on the building's energy demand – for sensible cooling and electrical equipment demand

Table 1: Sensitivities of building prototype „housing"; increasing energy demand depending on bc-changes.

	annual sensible demand	annual latent demand	annual el. demand for appliances
prototype "housing"	100%	100%	100%
reduced insulation to 10 % (for facade and roof)	157%	100%	100%
doubled infiltration rate	106%	139%	100%
reduced efficiency of heat recovery (to 60 %)	113%	100%	100%
decrease of design temperature by 2 Kelvin	121%	100%	100%
doubled appliances heat gain	110%	100%	199%
facade: 50 opaque / 50 % glassed; to 0.6 increased shading coefficient	144%	100%	100%

- particularly for upper floors with less self shading, a good shading device and an optimized opaque / glassed-facade-ratio becomes more important.



Proceeding
The principle proceeding of the 4. iteration is the same as for the previous one. The reasons for the 4. and last iteration step is to show the prerequisites for a 80 %-reduction of total annual energy demand comparing to the today's Abu Dhabi building standard.
The building typologies are the same like in iteration step 3.
The most important changes in boundary conditions are:

- for all external walls 10 cm with U-wall = 0.25 W/m²K
- for all roofs 20 cm with U-roof = 0.12 W/m²K
- for all floor against undercroft 8 cm with U-floor = 0.35 W/m²K
- housing windows triple glazing, U-value 0.8 W/m²K with a good frame
- all other glazing double low-e, gas filling, U-value 1.2 W/m²K and a good frame
- best energy efficient light fixtures
- most energy efficient office equipment – including servers
- most energy efficient fresh air system with optimized / reduced fan power
- improved retractable or adjustable external shading for all facade openings or courtyards to reduce rest transmission from 30% to 15%

Boundary Conditions
The power demand and loads of other energy consuming systems – like

- infrastructure in general (losses for el. power distribution and el. transformation, ventilation and power requirements for active switch gears, thermal losses of district heating / cooling, el. demand of fluid / water pumps, el. demand of processes based on sorption for dehumidification and chilled water production, etc.)
- transportation systems (interior PRT energy requirement and exterior commuting)
- water desalination and potable water distribution
- black water treatment and distribution
- grey water treatment and distribution
- power requirements for waste sorting and collecting
- street- , parking- and sport lights
- IT (electrical)

must be added to the demands/loads of the buildings

Please consider for designing the energy concept:

- absorption chiller and L-DC systems => C_{OP_elect} = 50
- L-DCS => C_{OP_therm} = 0.9
- absorption chiller => C_{OP_therm} = 0.7 (single effect); C_{OP_therm} = 1.1 (double effect)

The heat island effect is considered by an increased ambient temperature of + 3.5 Kelvin. The max. indoor humidity is limited to 12 g/kg resp. 65 % based on 24°C indoor temperature. It's also important to combine the L-DCS with an adiabatic cooling and heat recovery (PS inception report and boundary conditions in 3. Iteration step) system in each building.

The detailed changes in the model approaches and in the boundary conditions compared to the 3. iteration step are highlighted in red on the next pages.

Table 1: Gross footprint area of each using typology.

Occupant space	Total BUA [m²]	[m²]
Housing H	1,466,439.38	9.38
Offices O	904,488.77	8.77
Retail CR	43,562.50	2.50
Labs L	115,401.98	1.98
Production P	357,027.82	7.82
Education E	59,360.65	0.65
Community CS	50,045.13	5.13
Divers D	65,717.56	7.56
	3,062,043.78	3.78

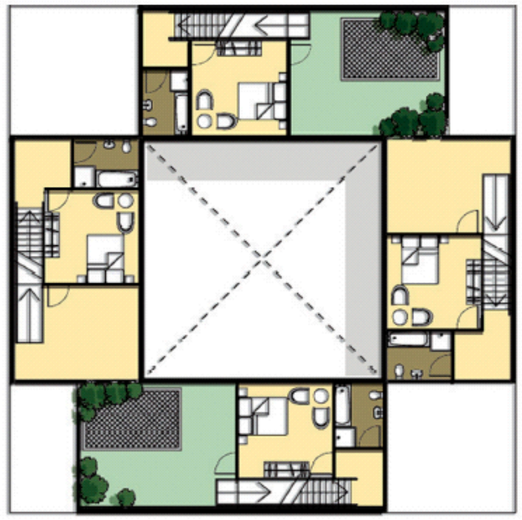


Figure 1: Footprint of housing typology;3.floor; courtyard 11 x 11 m².

Figure 2: Section of new housing typology;3.floor; courtyard 11 x 11 m².

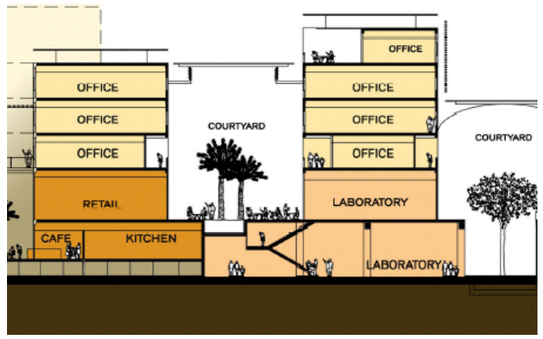


Figure 3 + 4: Section of commercial typology containing offices, labs retail and catering; courtyard 15 x 30 m².

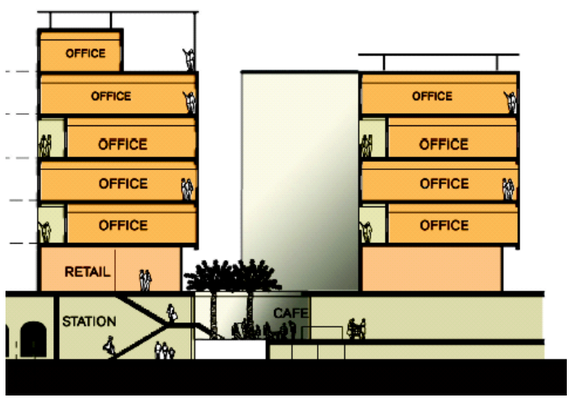
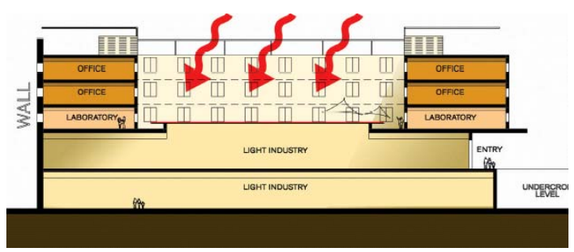
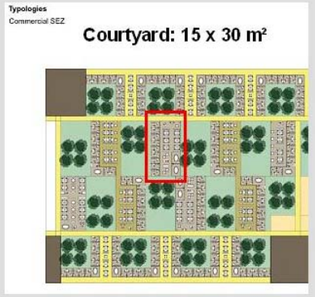


Figure 5: Section of commercial typology containing light industry / production; about 50 % of light industry area gets natural lighting.



Typologies
Similar to the 3. iteration step, for housing, lab and office spaces the newest building typologies are used. For the rest still the generic standard building which was used in the 1. and 2. iteration steps, is the basis of the simulation model.



Office floors in 2. to 5. story; 3 m clearance;
25 % of total area as top floor area with roof

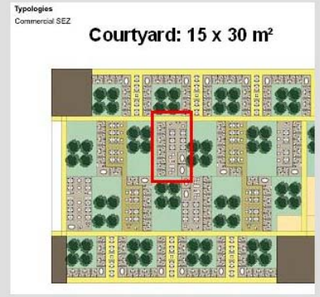
working hours -	8°° to 19°°; 6 days per week
operation of AHU -	24 h / 7 d; based on working area; working: 1.5 acr; non-working: 0.75 acr
artificial lighting -	operation controlled depending on outdoor illuminance; 7 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.15
facade -	opaque facade ratio of 70 %; 10 cm thermal insulation (outer surface)
roof -	20 cm thermal insulation (outer surface)
exposed ceiling -	as thermal mass
infiltration -	0.15 acr during working hours; 0.05 acr in non working hours
design temperature -	24°C / 65 % r. hum. daytime 28°C in non working hours
density -	20 m² per occupant
internal heat gains - (office equipment)	3.1 W/m² during working hours; 1.55 W/m² in non working hours
el. demand of AHU -	0.3 kWh/1,000 m³
sens. heat recovery -	80 %

peak loads (to gross footprint):

• sensible -	37 W/m²
• latent -	31 W/m²
• AHU -	0.7 W/m²
• equipment -	3.1 W/m²
• art. lighting -	6 W/m²

annual demands (to gross footprint)

• sensible -	72.8 kWh/m²/a
• latent -	50.5 kWh/m²/a
• electrical -	29 kWh/m²/a



Lab floors in 2. to 5. story; 3 m clearance;
50 % office / 50 % laboratory

working hours -	8°° to 19°°; 6 days per week
operation of AHU -	24 h, 7 d; working: 6 acr in lab area; 3 acr in office area; non-working: 3 acr;
artificial lighting -	operation controlled depending on outdoor illuminance; 7 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.15
facade -	opaque facade ratio of 70 %; 10 cm thermal insulated (outer surface)
exposed ceiling infiltration -	0.15 acr during working hours; 0.05 acr in non working hours
design temperature -	24°C / 65 % r. hum. daytime 28°C in non-working hours
density -	20 m² per occupant
internal heat gains - (office equipment)	10.6 W/m² during working hours; 5.3 W/m² in non working hours
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	80 %

peak loads (to gross footprint):

• sensible -	48.4 W/m²
• latent -	74.2 W/m²
• AHU -	3.7 W/m²
• equipment -	10.6 W/m²
• art. lighting -	5.6 W/m²

annual demands (to gross footprint)

• sensible -	118.5 kWh/m²/a
• latent -	107.4 kWh/m²/a
• electrical -	96.6 kWh/m²/a

2. floor 3. floor
Courtyard: 11 x 11 m²

Housing floors in 2. to 5. story; 3 m clearance;
25 % of total area as top floor area with roof

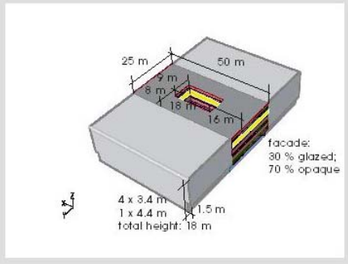
Reduced hours -	8°° to 18°°; 5 days per week
operation of AHU -	24 h, 7 days per week;
artificial lighting -	1 acr based on used floor area operation controlled depending on outdoor illuminance; 1.25 W/m² based on used floor area
facade -	30% glass; 3 pane neutral solar control glass 50/25; Ug < 0.8 W/m²/K; operable, exterior shading device; shading coefficient 0.15
facade -	opaque facade ratio of 70 %; 10 cm thermal insulated (outer surface)
roof -	20 cm thermal insulation (outer surface)
exposed ceiling infiltration -	0.2 acr during day time; 0.05 acr during night time
design temperature -	24°C / 65 % r. hum. 26°C in reduced hours
density -	50 m² per resident
internal heat gains - (household equipment)	375 kWh/resident/a
el. demand of AHU -	0.5 kWh/1,000 m³
domestic water -	35 l/per/d; 65°C
sens. heat recovery -	80 %

peak loads (to gross footprint):

• sensible -	30.9 W/m²
• latent -	35.4 W/m²
• AHU -	1.2 W/m²
• equipment -	2.7 W/m²
• art. lighting -	0.8 W/m²

annual demands (to gross footprint)

• sensible -	68.4 kWh/m²/a
• latent -	76.9 kWh/m²/a
• electrical -	20.7 kWh/m²/a
• dom. water heating -	15.8 kWh/m²/a



Education floors in 2. to 5. story; 3 m clearance

working hours -	8°° to 18°°; 5 days per week
operation of AHU -	24 h; 7 days per week; working: 35 m³/h per person non-working: minimized acr
artificial lighting -	operation controlled depending on outdoor illuminance; 7 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.15
facade -	opaque facade ratio of 70 %; 10 cm thermal insulated (outer surface)
exposed ceiling infiltration -	0.15 acr during working hours; 0.05 acr in non working hours
design temperature -	24°C / 65 % r. hum. 28°C in reduced hours
density -	9 m² per student/pupil
el. demand of AHU -	0.3 kWh/1,000 m³
sens. heat recovery -	80 %

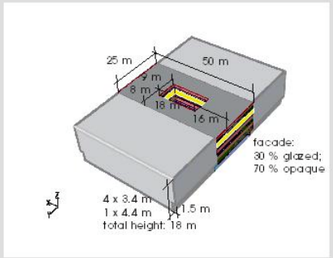
peak loads (to gross footprint):

• sensible -	41.2 W/m²
• latent -	63.6 W/m²
• AHU -	1.5 W/m²
• equipment -	2.4 W/m²
• art. lighting -	6.1 W/m²

annual demands (to gross footprint)

• sensible -	63.3 kWh/m²/a
• latent -	67 kWh/m²/a
• electrical -	25.3 kWh/m²/a

* : Please be aware – for light industry a value of 20 W/m² electrical load for machinery is considered. This boundary condition is based on the production of the Solarfabrik Freiburg, Germany. This manufacturer is only an assembler of PV panels; a Si-based wafer production is not included in this load



peak loads (to gross footprint):

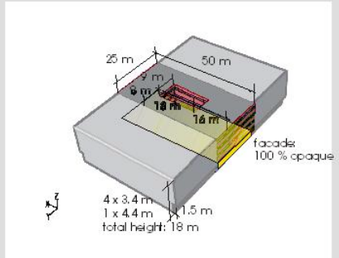
• sensible -	23.7 W/m²
• latent -	39.1 W/m²
• AHU -	0.8 W/m²
• equipment -	1.8 W/m²
• art. lighting -	7 W/m²

annual demands (to gross footprint)

• sensible -	115.5 kWh/m²/a
• latent -	85.2 kWh/m²/a
• electrical -	84.1 kWh/m²/a
• dom. water heating	7 kWh/m²/a

Community Support floors in 2. to 5. story; 3 m clearance

working hours -	24 h; 7 days per week
operation of AHU -	24 h; 7 days per week; 1. acr based on net floor area
artificial lighting -	permanent operation; 8 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.15
facade -	opaque facade ratio of 70 %; 10 cm thermal insulated (outer surface)
exposed ceiling infiltration -	0.2 acr
design temperature -	24°C / 65 % r. hum. 28°C in reduced hours
el. demand of AHU -	0.3 kWh/1,000 m³
sens. heat recovery -	80 %



peak loads (to gross footprint):

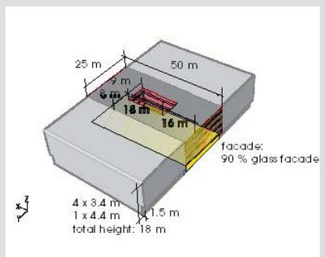
• sensible -	59.4 W/m²
• latent -	55.9 W/m²
• AHU -	2.3 W/m²
• equipment -	20 W/m² *
• art. lighting -	6.7 W/m²

annual demands (to gross footprint)

• sensible -	202.5 kWh/m²/a
• latent -	106. kWh/m²/a
• electrical -	203.8 kWh/m²/a

Production floor in 1. story; 4 m clearance (light industry)

working hours -	24 h; 5 days per week: 6°° to 14°°; 1 day per week
operation of AHU -	24 h / 5 d, 8 h / 1 d working: 1 acr based on net floor area non-working: 1/3 acr
artificial lighting -	24 h on 6 days per week; 7 W/m² based on net floor area (daylight controlled in 50 % of the area)
facade -	10 cm thermal insulated (outer surface) operable, exterior shading device; shading coefficient 0.15 for skylight
exposed ceiling infiltration -	0.2 acr during working hours; 0.05 acr in non working hours
design temperature -	28°C 32°C in non-working hours
internal heat gains -	20 W/m² during working hours (production device Solarfabrik in Freiburg, Germany)
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	80 %



peak loads (to gross footprint):

• sensible -	70. W/m²
• latent -	152.3 W/m²
• AHU -	9.1 W/m²
• equipment -	10.1 W/m²
• art. lighting -	9.5 W/m²

annual demands (to gross footprint)

• sensible -	223.9 kWh/m²/a
• latent -	195.2 kWh/m²/a
• electrical -	154.8 kWh/m²/a
• dom. water heating	27 kWh/m²/a

Catering / Retail floors in 1. story; 4 m clearance

working hours -	10°° to 24°°; 7 days per week
operation of AHU -	9°° to 1°°; 7 days per week; 12 m³/h/m² based on net floor area reduced hours: minimized acr
artificial lighting -	permanent operation during working hours; 10 W/m² based on net floor area
facade -	90% glass; neutral solar control glass 50/25; 20 % frame ratio; exterior shading device (overhang/ wingwall)
facade -	opaque facade ratio of 10 %; 10 cm thermal insulated (outer surface)
exposed ceiling infiltration -	0.15 acr during working hours; 0.05 acr in non working hours
design temperature -	24°C / 65 % r. hum. 26°C in reduced hours
internal heat gains - (only catering)	20 W/m² on 10 h per day
el. demand of AHU -	0.6 kWh/1,000 m³ (retail); 1.0 kWh/1,000 m³ (catering)
sens. heat recovery -	80 %

Diverse: stations, science zone, sports zone, entertainment

On ground floor or basement

working hours -	8°° to 24°°; 7 days per week
operation of AHU -	24 h; 7 d; 1 acr based on net floor area
artificial lighting -	permanent operation during working hours; 7 W/m² based on net floor area
facade -	no solar gains; 10 cm thermal insulated (outer surface)
infiltration -	0.2 acr during working hours; 0.05 acr in non working hours
design temperature -	24°C / 65 % r. hum. 28°C in reduced hours
equipment -	pool: 1,000 MWh for 1,000 m² water surface
domestic water -	pool: 438 MWh for 1,000 m² water surface
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	80 %

peak loads (to gross footprint):

• sensible -	32.6 W/m²
• latent -	56.9 W/m²
• AHU -	2.3 W/m²
• equipment -	1 W/m²
• art. lighting -	6.7 W/m²

annual demands (to gross footprint)

• sensible -	98.3 kWh/m²/a
• latent -	124.1 kWh/m²/a
• electrical -	67.7 kWh/m²/a
• dom. water heating	4.4 kWh/m²/a

Results
Legend
Office Area = O
Labs = L
Housing = H
Education = E
Community Support = S
Production = P
Catering/Retail = CR
Diverse = D

Figure 1: As the sum of the different using typologies the total electrical demand of all buildings is shown with 158,000 MWh/a and with a peak load of about 30 MW; the characteristic curve – in descending order - includes

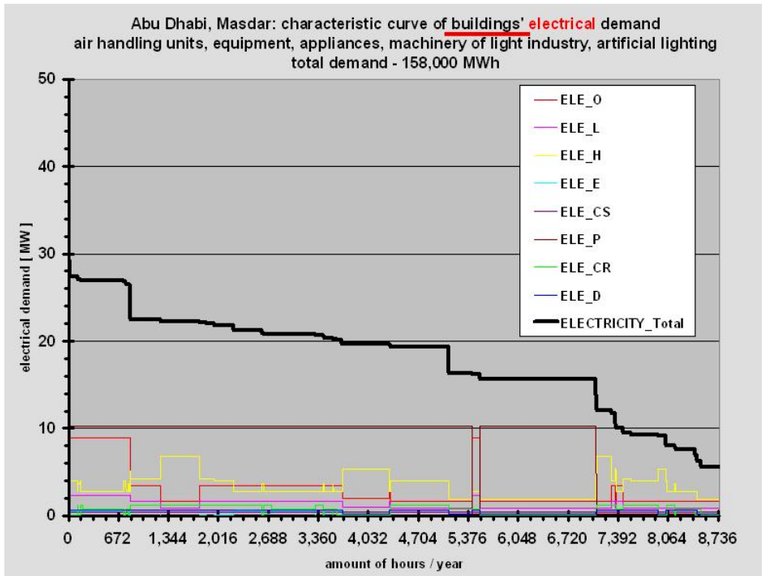
- art. lighting
- appliances
- ventilation.

The energy requirements of electrical chillers for sensible cooling and the energy requirements for latent cooling are excluded.

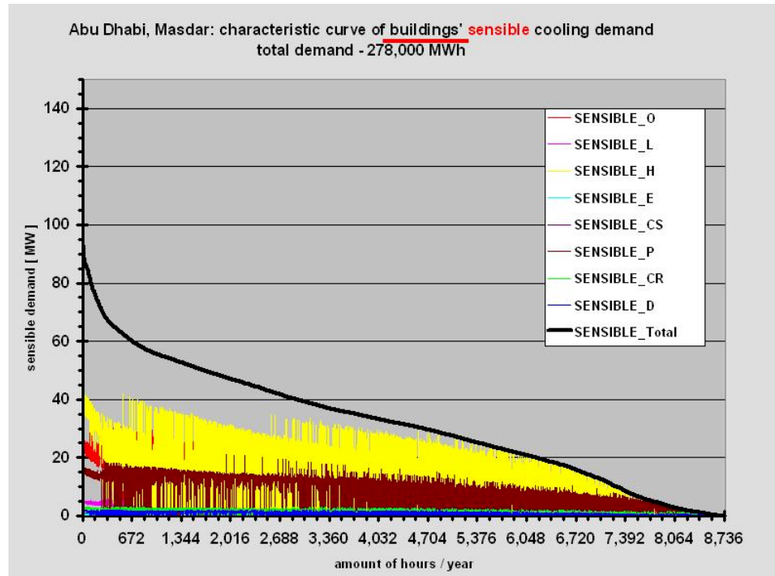
Figure 2: As the sum of the different using typologies the total sensible demand of all buildings is shown with 278,000 MWh/a and with a peak load of about 100 MW - in descending order.

Figure 3: As the sum of the different using typologies the total latent demand of all buildings is shown with 234,000 MWh/a and with a peak load of about 116 MW - in descending order. Compared to the 3. iteration step there is no change of the characteristic curve - regarding dehumidification and latent loads the boundary conditions are unaltered.

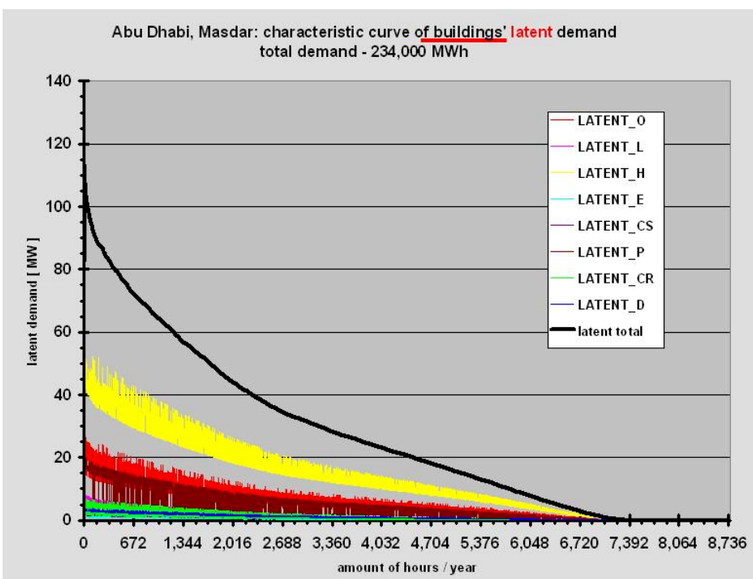
Figure 4: Heating demand for domestic water in housing, catering, pool, hospital; possible steam demand for light industry and labs is **not** considered; total annual demand – 25,000 MWh/a.



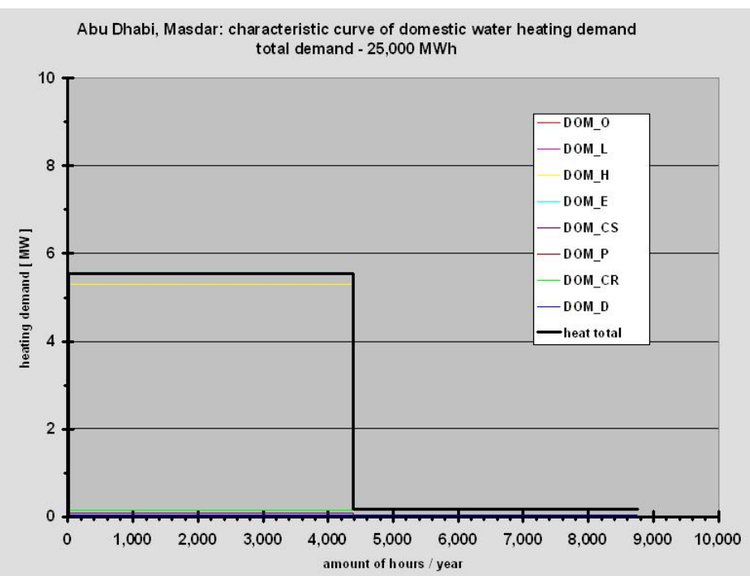
electrical demand without sensible and latent demand



sensible cooling demand



latent cooling demand



Heat energy demand for domestic hot water

From loads to systems
In the load calculations for the different building types no definition had been made in respect how the calculated cooling loads should be supplied into the buildings.

For the building loads, the following load types have to be distinguished:
- electrical load for light and appliances
- electrical loads for fresh air system
- sensible cooling loads
- latent cooling loads
- hot water loads

The general recommendation is to cover the loads with the most efficient systems with a minimal auxiliary energy input for the distribution.

Electrical loads for light and appliances
To minimize the electrical demand the defined boundary conditions require maximum efficient equipment for lighting and appliances and the exclusion of typical energy wasters.

- only high efficient light sources with light efficiencies of 80 – 100 lm/W
- installed light capacities below 10 W/m² with integrated daylight control, shut off above 400 Lux
- only laptop computers with LCD screens
- server equipment with sleep function
- high load equipment with direct water cooling
- only label A or label A++ for refrigerators equipment are allowed
- no private washing machines or dryers, central laundry service
- dish washers had to be connected to the central hot water system
- no production equipment above an annual electricity consumption of 133 kWh/m²a, either by more efficient equipment or lower operation times

Electrical loads for fresh air systems
- low pressure system with max. 0.5 - 0.6 Wh/m³ fan power for supply and exhaust demands increased ducts, high efficient fan with ECE motors
- air quality controlled fresh air rates, no occupancy only minimal fresh air
- sensible heat recovery system with low pressure drop heat exchangers
- return air mode for unoccupied hours and dehumidification demand

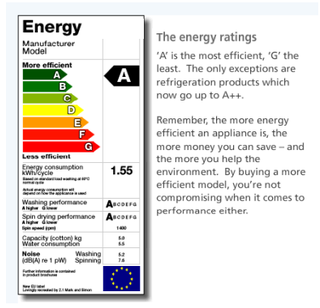
Room sensible cooling
The boundary conditions for the building envelop and equipment had allowed to minimize the sensible cooling loads for the different typologies. To provide the sensible cooling into the spaces typically air is used as the transport media. Aside of the large space demand for ducts and the noise and draft problems, this solutions demands a lot of auxiliary electricity for the fans to feed the cold energy into the spaces. Therefore for the Masdar development any sensible cooling has to be distributed by water, at least to each individual space.
Radiant cooling is the most comfortable and energy efficient system, which allows to use high cooling temperatures up to 17°C to cool a space. Systems can be either directly embedded into the concrete ceiling or integrated into suspended ceilings. In very humid climate like Abu Dhabi the risk of condensation has to be considered, especially in occupancy types like housing, where individual control on facade openings as windows and doors are expected.
For this space types a natural convective system like chilled beams or gravity driven wall shaft coolers are strongly recommended This systems can even run into condensation mode, being equipped with condensate collectors. The silent convective systems can be supported by air flows induced by the fresh air supply, called active chilled beams.

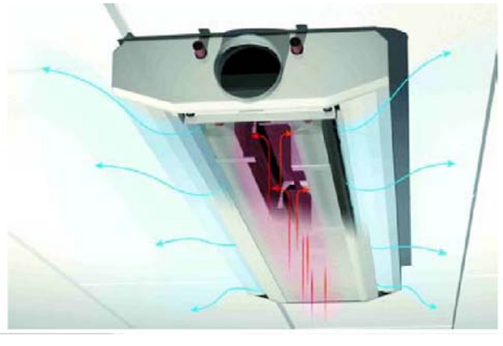
Room latent cooling
Sensitivity studies for different infiltration rates, the largest humidity gain for a building with controlled fresh air supply in Abu Dhabi, have shown, that if the infiltration rate can be kept below 0.3 ac/h, the fresh air supply dehumidification capacity is enough to compensate for this humidity gain and the humidity supplied by people.

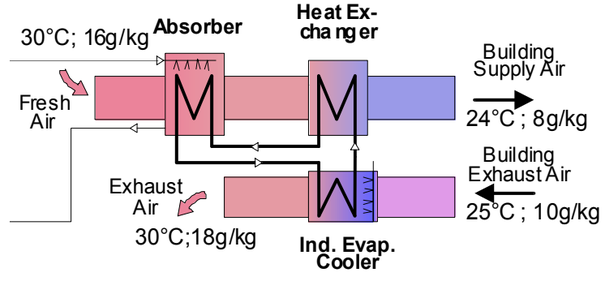
Dehumidification is typically done by supercooling of air below the dew point to cause condensation. This mean water temperatures of typically 6/12°C, which reduce the COP of the chillers and increase the heat gains in a district cooling system.

Therefore for a neutral carbon development the dehumidification has to be based on a simple but very energy efficient system, the adsorption by a liquid desiccant. The system was detailed described in the interception report, uses the hygroscopical effect of a high concentrated Lithiumchlorid water solution, attracting water our of the air and binding it by adsorption. The now low concentrate LiCl solution can be regenerated using heat at 70-80°C to release some of the water. Placed in the fresh air supply flow in combination with a sensible cooling recovery by a runaround system and an adiabatic cooling of the exhaust air, this system needs quite low auxiliary energy to run it.
- Low pressure drop heat exchangers
- High efficient open fluid exchangers for the air-LiCl passage with minimal fluid flows
- return air mode for unoccupied hours and dehumidification demand

Top to bottom:
Daylight and presence controlled lighting
Energy label for efficient appliances
Radiant cooling and active chilled beam
Liquid Desiccant Dehumidification







Central System Recommendations
Based on Load Profiles 1.Iteration

Loads and Limits

Concluding from the first load evaluations the total loads shown in fig1 the rated loads in electricity, assuming a COP – coefficient of operation – for the electrical chiller with 3, end with total 550.000 MWh for the buildings. Including the infrastructure, traffic and water the total electricity consumption ends with ~ 690.000 MWh/a.

Assuming a site area of 650 ha and a solar potential of 2.000 kWh/m²a with a idealized efficiency of 10% - ignoring any further conversion and storage losses – the theoretical solar electrical potential ends with 1.300.000 MWh/a, assuming a 100% coverage of the site.

Considering the free space demand in a city the collection area drops down to around 57% related to the city footprint. Realistic conversion numbers for wind and the solar system show in fig2 that with the today parabolic CSP technology, the site cannot feed the city, by missing 101 ha of land. Even with the new fresnel technology CSP system – never built in a size of 1 MW or larger – only 30 ha free land would be left.

A site reduction to 570 ha therefore demanded a program reduction, still with the system land area demand close to a 100% coverage – fig3.

An incineration of 50.000 tons of waste – ignoring for a moment the connected CO2 emissions – could cover by it's thermal waste energy a heat driven dehumidification and therefore reduce the electricity consumption as shown in fig.4. Combining this with the fresnel CSP approach would still demand 126 ha for that technology and leave only 123 ha or 35% of the land around the city uncovered with solar energy systems.

This whole exercise shows that the electrical loads of the city are still to high and in next steps savings or shifts from electricity into heat had to be identified.

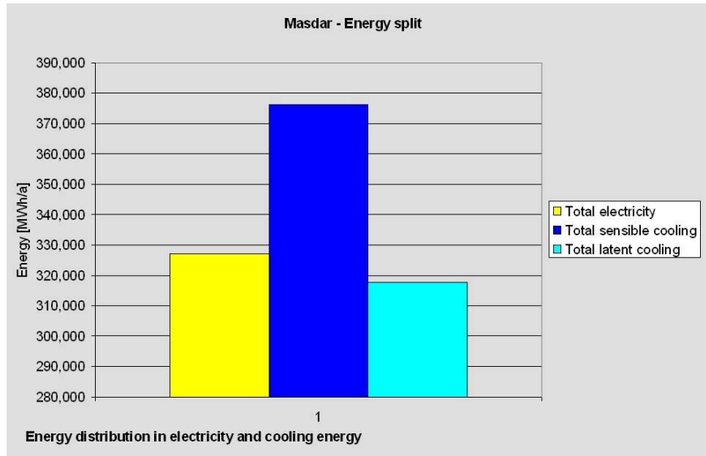
How to Reduce Electrical Consumption?
All thermal based electricity production processes – used in concentration solar thermal plants CSP - are limited to efficiencies of 35 to max.45% comparing the thermal input to the electrical output. The rest of the thermal input is available as waste heat output and has a considerable energy potential.

1. Replace Chiller Dehumidification by Thermal Driven Dehumidification
Instead of cooling the outside or inside air below the dew point to crab the humidity out of the air, a desiccant dehumidification system is based on the hygroscopic attention of solid or liquid materials like silicagels or water based salt solutions like Lithiumchloride LiCl. This materials are able to adsorb a large amount of humidity, and are regenerated or dried off by a heat driven process.

Heat driven liquid desiccant dehumidification systems – as in detail described in the Inception Report in Benchmark Developments: Energy Efficiency – System Optimisation 4.2.4 - work in tropical climate with a COP of 0.8 - the ration between dehumidification potential and heat input - , which means for each 100 MWh latent load we need 125 MWh heat at a temperature level of 70 - 80°C.

For 318.000 MWh dehumidification demand we would need around 400.000 MWh heat of which around 150.000 MWh can be provided from the waste treatment plant. The rest demand of 250.000 MWh should be available from the CSP plant.

Dehumidified desiccant using LiCl in form of a high concentrated solution can be stored as a losses free storage, with a storage density 250 kWh dehumidification per 1 m³ liquid LiCl, a 1 day dehumidification demand for all 6 Mio m² program can be theoretically stored in a 3840 m³ tank - a cube 15 x 15 x 15 m.



Energy distribution in electricity and cooling energy

	energy	electricity		
	MWh/a	MWh/a	ration	
total buildings equipment		325,000	24%	
Sensible cooling	376,000	125,000	9%	optional by heat
Latent cooling	317,000	106,000	8%	optional by heat
distirbution		90,000	7%	
on site traffic		27,000	2%	
desalination	9,000 m³/day	16,425	1%	optional by heat
total		689,425		

2. Replace Electrical Driven Cooling by Thermal Driven Cooling
Comparing the cooling potentials of different solar technologies including their impact on the site, identified a combination of high efficient solar tube collectors with an absorption chiller as an area saving approach.
Chiller driven cooling - COP 3 - based on CSP plant electricity:

- 1 MWH cooling = 0.33 MWh electricity = 7.2 m² ground area, only considering the electrical production of the CSP system

Absorption chiller - COP 0.8 - based on evacuated tube collectors

- 1 MWh cooling = 1.25 MWh heat = 2 m² collector area, ~ 4 m² ground = 45% area reduction!
- Further advantage:
  Heat storage easier than electricity storage.
  Areas below a ETC field can be occupied, below a CSP plant have to closed off from public.

Left top and middle:
Energy consumption electricity and cooling energy based on the first load evaluations.

Right top:
Demand and supply comparison for the original site, showing the limits of the site at the load1 consumption numbers.
Right middle:
Reduced site and reduced program
Right bottom:
Reduced site and reduced program and waste heat from waste and CSP for covering the latent loads

Site			650 ha
City			281 ha
	building program	2.14	6,000,000 m²
Building electricity demand		450,000 MWh	
latent assumed by waste heat	317,000 MWh	105,667 MWh	
distribution		90,000 MWh	
desalination		16,500 MWh	
on site traffic		27,000 MWh	
total (without latent heat)		689,167 MWh	
Renewable coverage			
Wind turbines	35 MW	35,000 MWh	91 ha
Building PV	57%	209,823 MWh	800,850 m²
Waste treatment plant	50,000 tons/a	70,000 MWh	
CSP demand		374,344 MWh	187 MW
	parabolic trough		374 ha
	fresnel system		243 ha
central systems	chiller, waste/water treatment		5 ha
landscape left	with parabolic trough		-101 ha
	with fresnel system		30 ha

Site			570 ha
	reduced size		
City		80%	225 ha
	building program	2.14	4,800,000 m²
Building electricity demand		360,000 MWh	
latent assumed by waste heat	253,600 MWh	84,533 MWh	
distribution		72,000 MWh	
desalination		13,200 MWh	
on site traffic		21,600 MWh	
total (without latent heat)		551,333 MWh	
Renewable coverage			
Wind turbines	35 MW	35,000 MWh	91 ha
Building PV	57%	167,858 MWh	640,680 m²
Waste treatment plant	50,000 tons/a	70,000 MWh	
CSP demand		278,475 MWh	139 MW
	parabolic trough		278 ha
	fresnel system		181 ha
central systems	chiller, waste/water treatment		5 ha
landscape left	with parabolic trough		-29 ha
	with fresnel system		68 ha

Site			570 ha
	reduced size		
City		80%	225 ha
	building program	2.14	4,800,000 m²
Building electricity demand		360,000 MWh	
latent assumed by waste heat	253,600 MWh	0 MWh	
distribution		72,000 MWh	
desalination		13,200 MWh	
on site traffic		21,600 MWh	
total (without latent heat)		466,800 MWh	
Renewable coverage			
Wind turbines	35 MW	35,000 MWh	91 ha
Building PV	57%	167,858 MWh	640,680 m²
Waste treatment plant	50,000 tons/a	70,000 MWh	
CSP demand		193,942 MWh	97 MW
	parabolic trough		194 ha
	fresnel system		126 ha
central systems	chiller, waste/water treatment		5 ha
landscape left	with parabolic trough		55 ha
	with fresnel system		123 ha

Load Reduction Strategy
The clear message of the systems sizing based on the first load iteration was a further reduction demand. Aside of a questioning of all assumed boundary conditions the potential of specific strategies was identified.

The equipment loads in an office – assumed with 10.3 W/m² cross area – lead to an annual electricity consumption of 59 kWh/m² for that equipment. Due to the 100% dissipation of the electricity consumption in the office equipment into heat this demand appears again in the heat loads. So any saving is a double saving in the overall picture.

Based on the experiences at a European office project in Basel, using only laptops as office equipment and as well minimized server technology, the measured energy consumption for a research office could be reduced to 20 kWh/m²a for the equipment, including printers, copy machines and server demand.

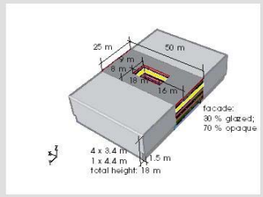
Applying this technology for the Masdar offices the specific electricity demand drops from 59 kWh/m²a to 29 kWh/m²a and parallel the cooling consumption drops down. For the total office areas this leads to 32 MWh/a electricity savings —around 10% of the whole demand – and 33 MWh/a cooling consumption savings, nearly 10% of the total demand.

Further Load Reduction Strategies

- using higher efficient lighting to reduce the 13 W/m² to 10 or even 8 W/m², can reduce the lighting electricity consumption from 24 kWh/m²a to 15 kWh/m²a or even less.
- Check if 50% of the office equipment really has to be active at nighttime, or of a central off switch can be installed.
- Support daylight approach for production facilities and check 24h occupancy
- Increase efficiency of housing ventilation system by demand control.
- Increase building envelop quality to reduce infiltration rates.
- Optimize residential lighting and appliances and demand central laundry service, prohibit electrical driven dryers.
- Review conditioning level outside of occupancy schedules.

Top left:
Energy efficient office equipment boundary conditions
Top right:
Specific energy consumption comparison of energy efficient (ee) office to the standard and the other users.

Bottom left:
Energy efficient office equipment at the reference project in Basel
Bottom right:
Total energy consequences for the electricity and cooling demand.-



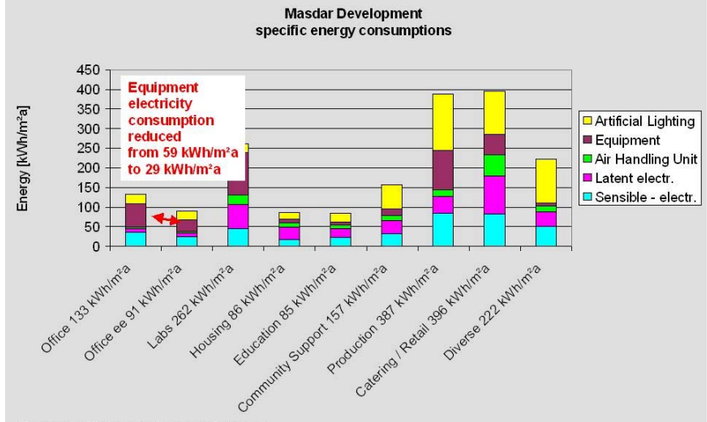
Office floors in 2. to 5. story; 3 m clearance

working hours -	8°° to 18°°; 5 days per week
operation of AHU -	6°° to 19°°; 5 days per week; 1.5 acr based on working area
artificial lighting -	operation controlled depending on outdoor illuminance; 13 W/m² based on net floor area
facade -	30% glass; neutral solar control glass 50/25; 20 % frame ratio; operable, exterior shading device; shading coefficient 0.3
facade -	opaque facade ratio of 70 %; 5 cm thermal insulated (outer surface)
exposed ceiling infiltration -	0.15 acr during working hours; 0.05 acr in non working hours
design temperature -	24 - 26°C
total area -	1,026,863 m²; 20 m² per occupant ~ 51.340 persons
internal heat gains - (office equipment)	5.15 W/m² during working hours; 2.07 W/m² in non working hours
el. demand of AHU -	0.6 kWh/1,000 m³
sens. heat recovery -	80 %
annual averaged chiller-Cop -	3

peak loads:
- sensible - 51.9 W/m²
- latent - 32.3 W/m²
- AHU - 1.33 W/m²
- equipment - 10.3 W/m²
- art. lighting - 11.3 W/m²

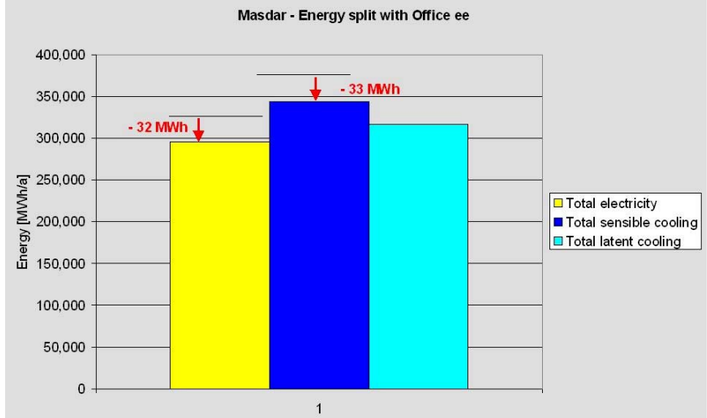
annual demands
- 123 kWh/m²/a (elect.)
- 29 kWh/m²/a (latent)

Boundary conditions - offices energy efficiency



Energy efficient office equipment

Workplace with docking station for laptop and local LCD screen



10% savings in electricity and heat for cooling consumption

Concept 2.Iteration
Based on the team internal review of the boundary conditions and comparison with nowadays system and behavior, the second iteration of the total city demand by 20%. In addition more detailed evaluations of the infrastructure and traffic consumption concluded in a total of 450 000 MWh/a electricity, 425 000 MWh/a sensible cooling and 390 000 MWh/a latent cooling demand.

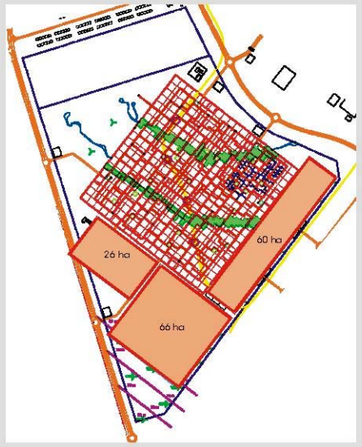
Due to the height limits and neighborhood distances the wind potential had to be reduced.

Even when the use of the high innovative fresnel technology on the small square allowed to keep 164 ha unoccupied by neither the city nor the systems, the layout confirmed, that fare to much of the site was covered for a high quality city surrounding.

Top left:
Energy demands and supply of the 2.iteration.
Top right:
Limits of the site

Masdar Development	New boundary conditions as agreed by September 10th		
Site			550 ha
	reduced size		
City			218 ha
	heat for cooling	electrcity	3,067,957 m²
Building electricity demand	424,800 MWh	270,000 MWh	
latent energy demand	388,800 MWh	77,760 MWh	
distribution		8,900 MWh	
desalination		13,140 MWh	
waste evacuation		10,500 MWh	
on site traffic		62,300 MWh	
street lighting		7,000 MWh	
total (without latent heat)		449,600 MWh	
Renewable coverage			
Wind turbines	4.1 MW	5,700 MWh	11 ha
Small square PV	0.0 MW	0 MWh	0 m²
Building PV	141.0 MW	229,200 MWh	1,206,316 m²
Outside parkings PV	5.4 MW	8,900 MWh	55,625 m²
Waste treatment plant	52,800 tons/a	52,800 MWh	
CSP demand		153,000 MWh	77 MW
	total	449,600 MWh	
	heat (waste+CSP)	411,600 MWh	
	fresnel system		77 ha
central systems	chiller, waste/water treatment		5 ha
	ETC	402,000 MWh	75 ha
landscape left	with fresnel system		164 ha

New boundary conditions pushed energy demand up and so the system sizes, systems are to big



Increased energy demand by less stringent boundary conditions increased energy demand by 20%.

Assuming waste treatment plant with incineration for electricity and heat!

Outside city area demand:

75 ha CSP system

77 ha ETC collectors

Systems do not fit on site or nearly all site covered

Conclusion and Demand for 3.Iteration
To fit the systems on the site ,we have to reduce the energy demand by buildings and other consumers by another 30%!
We do not need to fulfill this for the first phase of the project, but for the final of the whole city.
A pure PV solution - as well on the small square - has no solution for the storage problem, and has to relay on a buffering into the city grid, which is questionable with the demanded power and consumption.
A CSP system on the small square which runs onto thermal storage and is activated at night con cover the sunless periods but have to be sized with storage capacities for 14 - 20 hours.

Bottom left and right:
30% reduced demand and PV or CSP based solution for the small square area.

Masdar Development	New boundary conditions as agreed by September 19th			
Site	30% reduced		550 ha	
	loads thermal and electrical			electrical
City	and all other electricity demands		218 ha	loads
	heat for cooling	electrcity	3,067,957 m²	MW
Building electricity demand	297,360 MWh	189,000 MWh		50 MW
latent energy demand	272,160 MWh	56,952 MWh		
distribution		6,230 MWh		1 MW
desalination		9,198 MWh		2 MW
waste evacuation		7,350 MWh		2 MW
on site traffic		43,610 MWh		??
street lighting		4,900 MWh		6 MW
plasma		24,500 MWh		
total (without latent heat)		341,740 MWh		
Renewable coverage				
Wind turbines	4.1 MW	5,700 MWh	11 ha	
Small square PV	56.0 MW	92,000 MWh	541,176 m²	?? Useful areas
Building PV	150.0 MW	235,000 MWh	940,000 m²	? PV types
Outside parkings PV	5.4 MW	8,900 MWh	55,625 m²	?? Useful areas
Waste treatment plant	52,800 tons/a	0 MWh	no energy from waste	
CSP demand		0 MWh	0 MW	
	total	341,600 MWh		
	heat (waste+CSP)	0 MWh		
	fresnel system		0 ha	
central systems	chiller, waste/water treatment		5 ha	
	ETC	569,520 MWh	107 ha	
landsacpe left	with fresnel system		181 ha	area left

With PV on the small square the waste energy is needed

Masdar Development	New boundary conditions as agreed by September 19th			
Site	30% reduced		550 ha	
	loads thermal and electrical			electrical
City	and all other electricity demands		218 ha	loads
	heat for cooling	electrcity	3,067,957 m²	MW
Building electricity demand	297,360 MWh	189,000 MWh		50 MW
latent energy demand	272,160 MWh	56,952 MWh		
distribution		6,230 MWh		1 MW
desalination		9,198 MWh		2 MW
waste evacuation		7,350 MWh		2 MW
on site traffic		43,610 MWh		??
street lighting		4,900 MWh		6 MW
plasma		24,500 MWh		
total (without latent heat)		341,740 MWh		
Renewable coverage				
Wind turbines	4.1 MW	5,700 MWh	11 ha	
Small square PV	0.0 MW	0 MWh	0 m²	
Building PV	120.0 MW	227,000 MWh	908,000 m²	
Outside parkings PV	5.4 MW	8,900 MWh	55,625 m²	
Waste treatment plant	52,800 tons/a	0 MWh	no energy from waste	
CSP demand		100,000 MWh	50 MW	
	total	341,600 MWh		
	heat (waste+CSP)	200,000 MWh		
	fresnel system		50 ha	
central systems	chiller, waste/water treatment		5 ha	
	ETC	369,520 MWh	69 ha	
landscape left	with fresnel system		226 ha	area left

CSP plant on the small square, areas fit, but energy for waste treatment demands further reductions

Initial Situation.

TransSolar Energietechnik GmbH suggested a liquid desiccant dehumidification for the MASDAR district cooling project in Abu Dhabi. Two different system configurations have to be considered. One system comprises a decentralised dehumidification together with decentralised regeneration. This option 1 means that both units, regenerator and dehumidifier, are located on site and the heat for the regeneration process has to be transported from the central heat source to the individual on-site regenerator units.

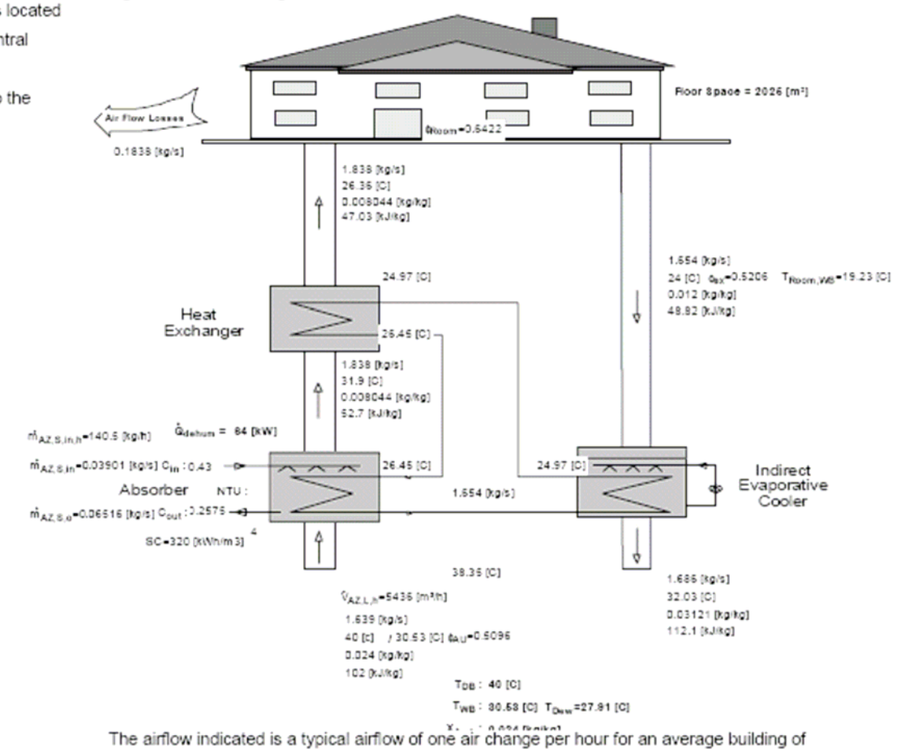
The other system comprises decentralised dehumidification and centralised regeneration. In this option the individual dehumidifiers are located on site and a central regenerator is located at the heat source. In this case the desiccant itself has to be transported form the central regenerator to the individual dehumidification units on site.

The objective of this paper is give a first comparison of the two options with respect to the dimensions, the cost and the general energy use considerations.

Load side boundary condition

As a prerequisite to determine the boundary conditions for the district cooling system a detailed lay out design of the L-DCS system is needed. Figure 1 provides a detailed insight into the configuration of an L-DCS fresh air dehumidification system and the temperature levels, volume flows and air states involved. The outside temperature and dehumidification levels are derived from the Abu Dhabi weather conditions and are agreed upon with Transsolar.

Figure 1 : L-DCS configuration



The airflow indicated is a typical airflow of one air change per hour for an average building of 15mx45m base area and three stories of 2.5m each. The size can be scaled to any building size needed without altering the air states. Therefore this design can be used as an example for any other building design as well. The regeneration process to regenerate the salt solution from the low diluted concentration of about 25-27% to the required concentrated stage of about 43% has a thermal COP of about 0.8.

The temperature levels of the regeneration are T_{Supply}= 85°C and T_{return}=65°C .

Energy Transport options

The two options for energy transport are:

Option 1, transporting hot water for the regeneration process

Opton 2, transporting the salt solution for the dehumidification

In all calculations the flow speed of the transport medium is assumed to be w= 2m/s.

Option 1: Hot Water Piping

In case the hot water is piped from the central heat source to individual regeneration units in the district, the temperature levels of supply and return water flow have to be as indicated above, which means a temperature difference of 20 °C.

Since the heat losses at the individual regenerators have to be provided by the district heating system as well, the actual heat to be transported is higher then just the dehumidification load needed by the factor 1/$COP_{thermal}$. Therfor a given dehumidification load of 90 MW with a $COP_{thermal}$ = 0.8 results in about 112.5 MW transport load for the district heating.

For the 112.5 MW and a DT=20°C a pipe with an inner diameter di = 920mm is needed.

Based on the German safety standards of ADB1 the wall thickness of such a pipe are calculated to a minimum of 8 mm at a pressure PN=10bar.

The cost estimates are the following:

The mass of steel needed for 1km long pipeline is about 184t. At present the market price for raw steel is at 550 €/t. Considering the pipe is available at twice the market price of the raw material, which is a conservative estimate, the cost for the pipe are about 202T€. Since supply and return pipe have the same dimensions the system cost for the pipes would be 404T€.

Assuming the pipe insulation to be 50mm thick and the cost for the insulation to be 25€/m² the overall cost for the insulation is about 78T€ per pipe. For supply and return pipe the overall cost of insulation is then about 156T€.

The overall cost for supply and return pipe system are an estimated 560T€.

Option 2: Liquid Desiccant Piping

Based on the numbers in the design example the boundary conditions are the following:

Supply salt concentration C_{conc} =43% [$kg_{Salt}/(kg_{Salt}+kg_{H2O})$]

Return salt concentration C_{dil} = 25.8%

Resulting in an energy transport capacity (or storage capacity) SC=320 kWh/m³ of diluted solution. For the calculation a more conservative estimate of only 300 kWh/m³, respectively a concentration of C_{dil} = 27% was taken.

Since the regeneration unit is located at the heat source the heat losses of the regeneration process do not have to be transported into the district. Therefore the energy to be transported is only the sole dehumidification power itself. Based on the same 90 MW dehumidification needed in the district, the supply pipe diameter results to d_i=230 mm and a supply pipe size of d_i= 174mm. The dimensions are different since the diluted solution transports all the water absorbed from the fresh air.

The pipeline does not need any insulation, since the salt solution flow rate at the individual dehumidifier is so low (140kg/h), that the heat introduced from that flow has no influence on the dehumidification power of the units.

Costs:

For the same 1km length of pipeline with the same dehumidification energy transport capability as in the Option 1 the piping cost for the concentrated solution is about 45T€ and the cost for the slightly bigger diluted solution is about 72T€. The overall piping cost are 117T€. This cost calculation is based on tenders, not estimated from raw material costs. Since the LiCl salt costs about 5€/kg, the filling of the pipe folue with solution has to be considered as the major cost factor of this option. Since the supply and the return pipe have the same salt content (the difference in between the two pipes being only the added water from the dehumidification process in the return pipe), the cost of the filling volume is the same. The volume of the supply pipe carrying the concentrated solution is about 23.8m³ and with a concentration of 27%, the salt content is about 13000kg, resulting in costs for the filling volume of 65T€. The cost for return and supply pipe filling volume are consequentially about 130T€. The overall cost for the pipes and the filling volume are 247T€.

Comparison:

Comparison for 1km of distribution system with 90 MW of dehumidification power:

Energy Transport:

	Option 1	Option2	Unit
	(Hot water)	(Salt solution)	
Energy Transported	112.5	90	MW

Pipe Size:

	Option 1	Option2	Unit
	(Hot water)	(Salt solution)	
Supply	920	175	mm
Return	920	230	mm
Material	Steel	Plastic (PP, PE)	

Flow rates:

	Option 1	Option2	Unit
	(Hot water)	(Salt solution)	
Supply	4860	172	m³/h
Return	4860	300	m³/h
Medium	H2O	LiCl-H2O	

Investment cost:

	Option 1	Option2	
	(Hot water)	(Salt solution)	
Pipes	404	117	T€
Insulation	156	n.a.	T€
Filling Volume	n.a	130	T€
total	560	147	T€

The following aspects are not discussed, because they need much more detailed insight into the planning of the actual district itself. Nonetheless they are very important to keep in mind, especially in view of their effects to the regenerative power source of the system:

a) The cost comparison does not reflect on the cost of pumps, valves and other fittings, which greatly differ in size in between the two options and also contribute to the cost greatly.
b) The energy losses from heat transfer in option 1are not considered, since they depend too much on the actual design of the whole system. They are expected to be in the range of about 5%-10% and contribute not only to the costs of the district cooling system, but also strongly to the cost of the regenerative heat source.
c) The operating costs of the distribution are not considered at this stage. They consist mainly of the energy for the pumps, which depends on the volume flow of the medium and the pressure losses of the system. They can not be estimated properly without a more detailed knowledge of that system.
d) The changes in the weather, respectively in the outside humidity, are not considered at this stage. The dehumidification power of the L-DCS system depends on the salt solution flow within the dehumidifiers. The L-DCS dehumidifiers are generally delivered with a LiCl-storage for about 1-2h of independent operation. This storage can be used to increase the internal solution flow within the units in order to boost the dehumidification capabilities, without putting additional load on the salt solution supply pipe system. This way peaks in the demand beyond the design conditions can be buffered.

Outlook

MASDAR has demo-project scheme especially for solar cooling technologies. The plan is to install small scale solar cooling applications in Abu Dhabi next year. One possibility to clarify a lot of questions and get experience in the operation of a LiCl based district cooling system is to launch such a system on a small scale. Such a project would provide all the necessary information for the precise planning of a big scale project. A joint application under that scheme would have to be filed with MASDAR by the end of this year.

Annex A: Description of the L-DCS ventilation cycle
Annex B: Lithium Chloride Safety Data Sheet
Annex C: Brief overview of an L-DCS Technology system for Singapore conditions

Data Sheet for Lithium Chloride Solution from Matthias Peltzer, L-DCS, Ismaning

Application Uninhibited Dehumidifying system solution

Appearance Clear colorless solution

Product Specifications

	Typical (Wt%)		Guaranteed (Wt%)	
LiCl	39.8		38.0-42.0	
Alkalinity	0.087	N	0.082-0.093	N
Impurities on LiCl basis				
NaCl	0.2		0.4	max
$CaCl_2$	0.02		0.05	max

Other Data

	Typical		Range	
Density at 25°C	1.256	g/ml	1.235-1.265	g/ml
	10.47	lb/gal	10.3-10.55	lb/gal
Contained LiCl	0.51	g/ml	0.47-0.53	g/ml
	4.26	lb/gal	3.91-4.43	lb/gal

Physical Properties **(40% LIMIT® 101 Solution)**

Density @ 25°C	1.250	g/ml
Crystallization temperature	-3°C	($LiCl\text{-}2H_2O$)
Boiling Point	133°C	
Heat capacity @ 18°C	2.69	joules/g/°C

Vapor Pressure

Temperature (°C)	Vapor Pressure mm Hg
20	3.3
40	13
60	40
80	98
100	210

Toxicity/Safety Data

LIMIT® 101 is very hygroscopic and has a drying effect on the skin, eyes, and mucous membranes with resultant irritation. Avoid contact with eyes, skin, and clothing. On contact the skin should be flushed with water. If the eyes are contacted, flush them thoroughly with copious amounts of water and consult a physician. If taken internally, drink plenty of water, induce vomiting and consult a physician immediately.

Additional information on toxicity and safety is contained in the Material Safety Data Sheet (MSDS) available for this product.

Handling/ Storage/ Disposal

LIMIT® 101 is considered non-hazardous in general handling, but it is advisable to avoid undue exposure. The use of safety glasses, rubber gloves, and adequate clothing to protect the skin is recommended when handling lithium chloride. Clothing wet with solution should be removed to avoid prolonged exposure to the skin. Lithium chloride should be kept from excessive exposure to the atmosphere. Store in a dry place and keep tightly covered when not in use. Spills should be recovered for use or disposed of according to local waste disposal regulations.

Shipping Containers 550 pounds (249.5 kg) solution in a 55 gallon (208 L) plastic cube. European shipments are 140 kg solution in a 125 liter polyethylene lined fiber drum.

Shipping Limitations Shipments of LIMIT® 101 require no hazardous shipping labels. Shipments by post, parcel, air, water, rail, or truck are acceptable within each carrier's weight limits and packaging requirements.

For shipments within Europe labeling for supply requirements are:

Xn	Harmful
R&S phrases	see Material Safety Data Sheet

Responsible Care initiative dictates that all shipments of lithium chemicals must be transported in an approved vehicle in a responsible manner (i.e., no flat bed trucks).

Attention: As fixed in the chemical data sheet LiCl is a very hygroscopic salt. The strong hygroscopic property is the reason for that LiCl does not exist in a crystalline condition in a standard air atmosphere. Therefore emissions by the air handling unit of crystalline salt dust are not possible. Emissions can only occur as aerosol. The AHU / L-DCS must be designed in this manner that aerosol emission are absolutely excluded – e.g. no spraying of the salt solution in the supply air. The Li-Cl non-containing of the supply air must be verified by an independent institutution by measurements. Different manufacturers are able to deliver such documents.

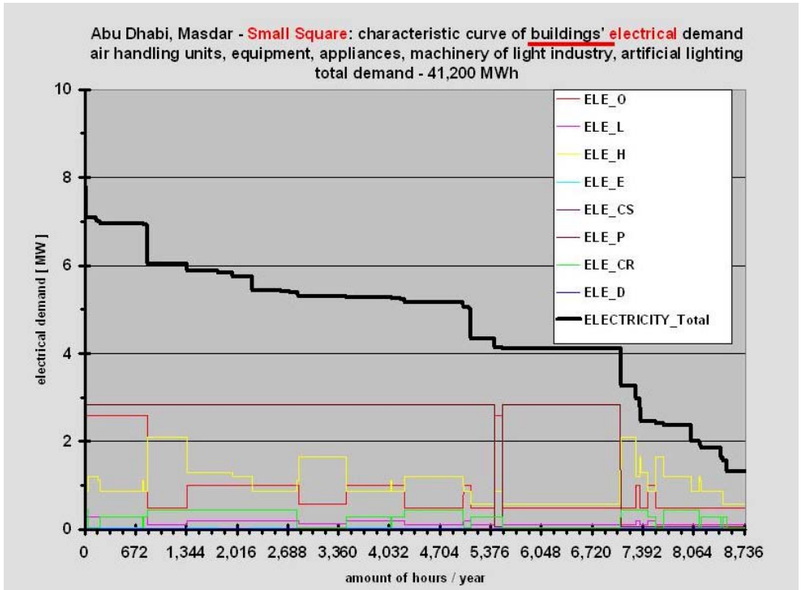
Below:
"Spectrum 2" Building in Woodlands Singapore realized by L-DCS. Technical Data: 540m² solar hot water collector panels (270 panels), 350 kW peak at 80°C serving a 3,000m² factory hall with mandatory air supply of 12,9000m³/hr. The system is in operation since the beginning of 2006 and its function has been monitored and validated.

Proceeding
To be able to discuss a possible development of the “small” square it was important to calculate the energy demand – electrical, latent, sensible, domestic water heating demand.

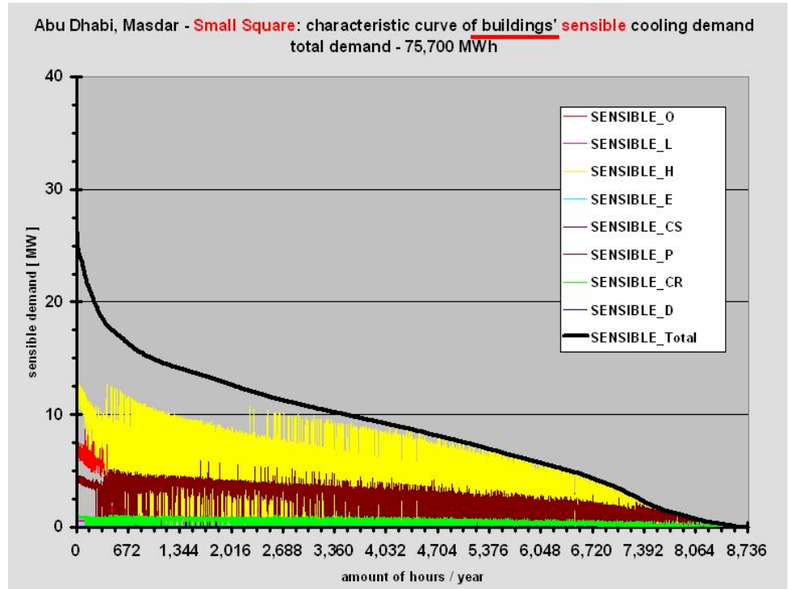
The principle proceeding of the amendment is the same as in the 4. Iteration step. Using the same building typologies, which have the prerequisites for a 80 %-reduction of total annual energy demand compared to the today’s Abu Dhabi building standard.

Boundary Conditions
The boundary conditions are the same as described in the Chapter Building Load Simulation for Total Energy Demand Profile of the City 4.5.4; 4. Iteration.

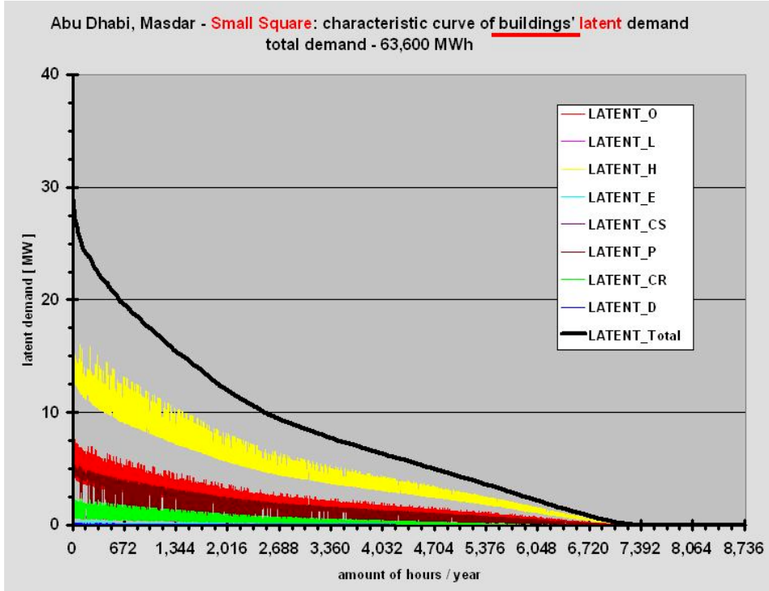
Occupant space	Total BUA [m²]
Housing H	448,844
Offices O	262,728
Retail CR	15,238
Labs L	14,390
Production P	98,379
Education E	5,147
Community CS	2,054
Divers D	2,468
	849,248



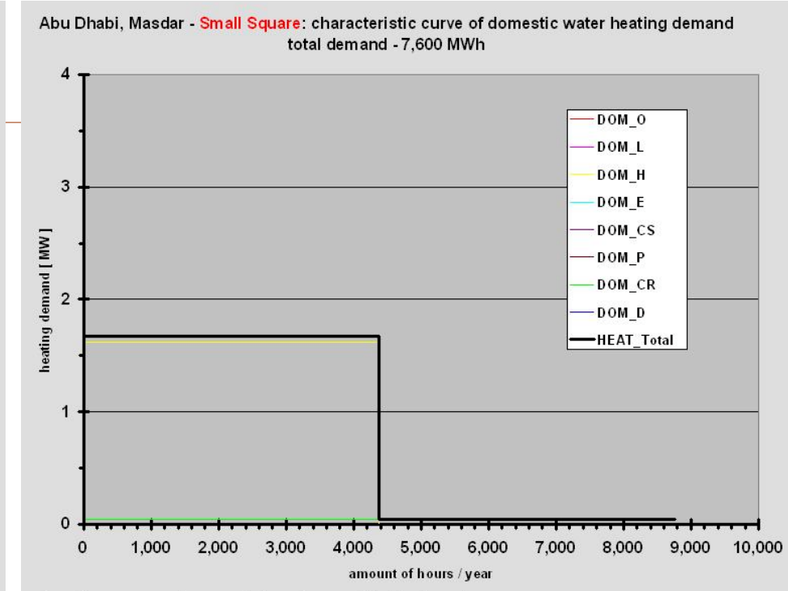
electrical demand without sensible and latent demand



sensible cooling demand



latent cooling demand



heat energy demand for domestic hot water

How to Allow the Option of a Future Development of the Small Square

- Demands small square as photovoltaic

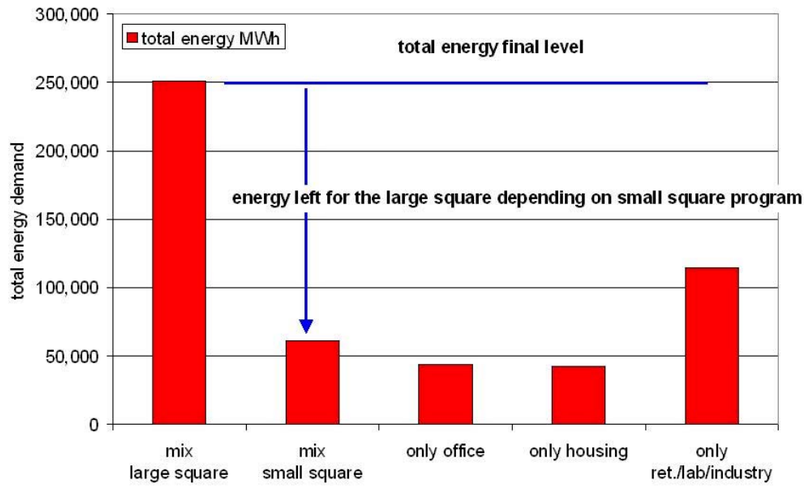
  - low efficiency compared to CSP
  - additional areas outside of the square of ~ 30 ha assuming the same program mix as on the large square. Exact number of program split by Foster confirmed this load distribution.
  30 ha outside the two squares is not acceptable by the urban design

- After final load iteration there are some free areas available on the large square – see appendix ETA
- To fit the systems it on the two square demands further load reduction by 20%: from total 80% to total 84% by
  - either by further improvement (demands technical innovation)
  - or by program shift from industry into housing/office
- A development of the small square has as an additional consequence:
  - loose 50% of PV areas in the small square (~ 20ha)
  - additional energy demand for that additional program
- Solution options:
  - further reduction of energy consumption of large square?
  - shift in program mix
  - preferable housing/office with lower specific consumption
  - a not roof area demanding energy production like deep geothermal system

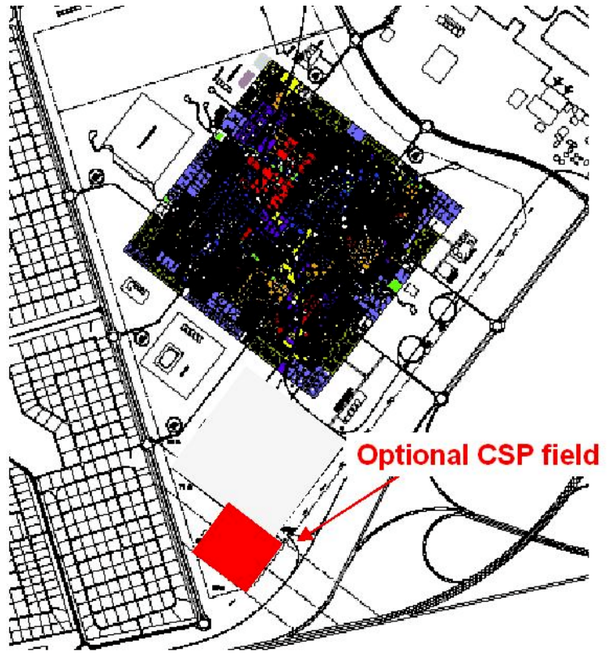
Timeline

To keep the option of a future development of the small square open as long as possible a third square can be the starting point for a smaller CSP plant.
Following the exploration on deep geothermal or other additional non-roof connected CO2 free energy sources till this phase, allows to shift the decision for the CSP plant on the small square to a later point.

A chance to develop the small square?



Extending the development onto the small square



? Reserve the small square until the end

Masdar Development Infrastructures

5

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Summary

Introduction

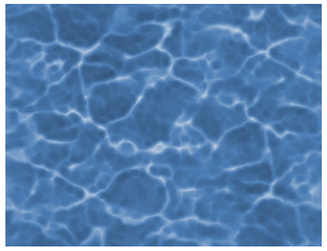
The Masdar development is situated outside the Abu Dhabi main island in a major construction area between the Umm al Nar power station and desalination plants, the Al-Raha beach development, Yas Island and Khalifa City. This zone is destined to be the major expansion zone for the urban development of Abu Dhabi as indicated in the Abu Dhabi Urban Framework Plan for 2030.

It is believed that due to this increased expansion of Abu Dhabi, the local infrastructures will be severely impacted by the addition of another development such as Masdar.

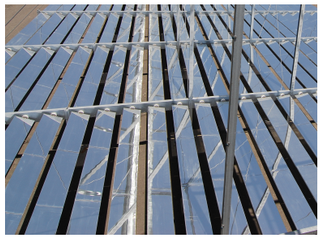
The Masdar development has signed up the ten principles of One Planet Living some of which as very pertinent to the infrastructures design and optioneering; these are:

- Zero Carbon
- Zero Waste
- Sustainable Transport
- Sustainable Water

In effect, the water, waste and energy distribution infrastructures need to be in line with the stringent sustainability aspirations of the development by adopting resource minimisation, self-generation and efficient supply strategies to achieve carbon neutrality and limited environmental impact.



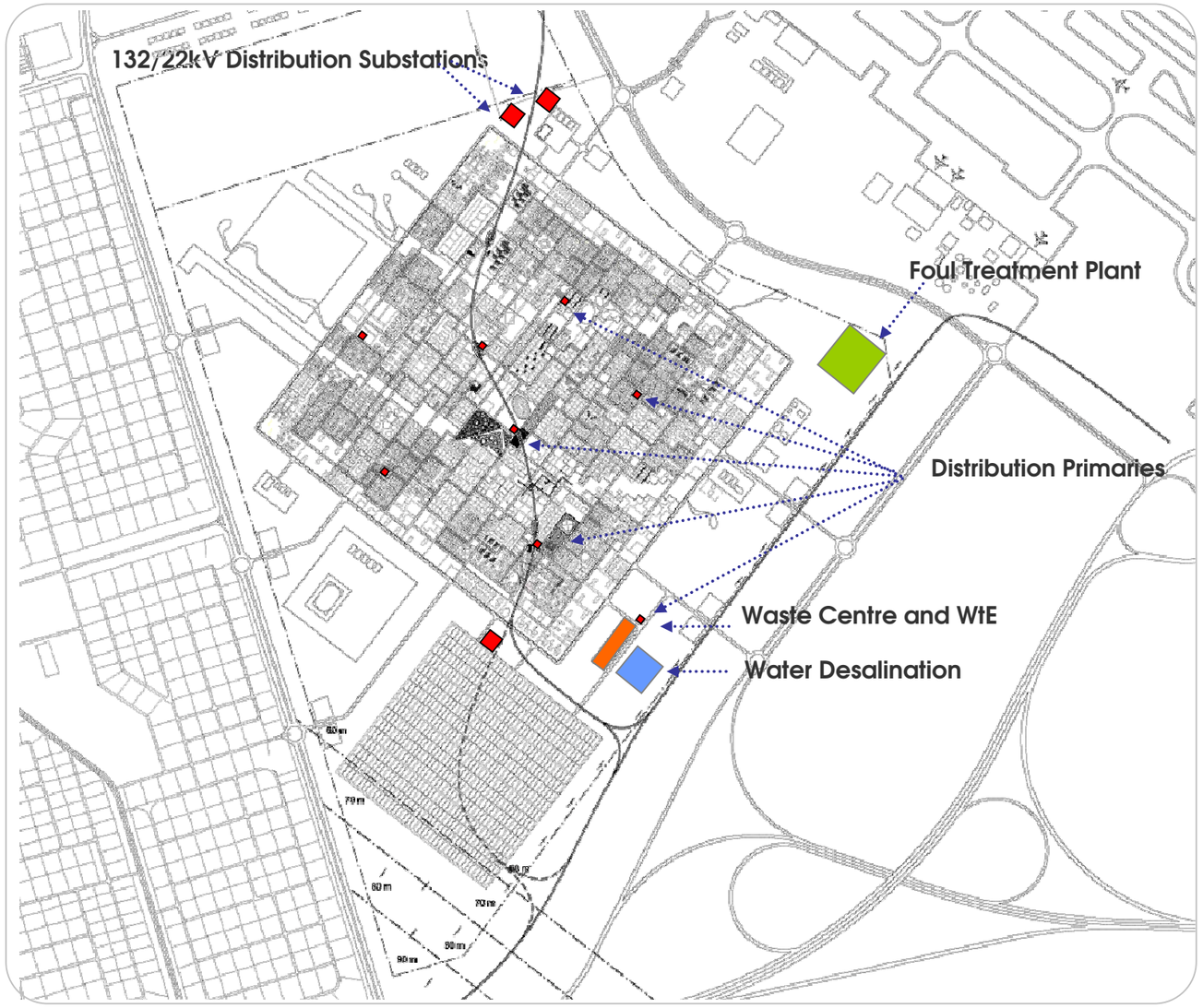
Water



Energy

ICT

Waste



Summary

Water

The Abu Dhabi Water and Energy Company 'ADWEC' has a potable water network that runs from six major desalination plants, three of them in Abu Dhabi Emirate, two in the western territories and one in Fujairah Emirate. The total current production of potable water is at about 2950Ml/d compared to a demand of less than 2730Ml/d.

However, based on the growth of the new developments in Abu Dhabi, it is forecasted that by 2011 the water demand will outstrip the planned upgraded water supply which is due at just over 3640Ml/d. By the time the Masdar development is fully constructed in 2015 it is estimated that the shortfall is estimated at over 910Ml/d. This predominantly due to the Abu Dhabi government adoption a strategy of increasing production to meet the demand rather than reducing the consumption, which is one of the highest in the world, at an average value of 350 litres per capita per day (l/c/d); compared to 120-150 l/c/d in Western Europe.

Water Demand

The base calculation estimated that a total of 35,000 cubic meters would be generated at Masdar every day, or 10.5 million cubic meters per year.

Of this total demand, residential buildings are estimated to consume 32%, non-domestic buildings 37%, industrial 18%, and the rest by other land uses.

Minimisation

Given that these base figures were calculated using current average rates for Abu Dhabi, it was assumed that significantly lower amounts of water would be required at Masdar after the various minimisation measures are applied. For the purpose of the Water Demand Model, irrigation was excluded and it was estimated that the minimisation measures could reduce water by approximately 60% compared to current Abu Dhabi consumption rates i.e., 11,452 m^3/day.

By adopting a mix of green and dry landscaping as well as only using local plantation which require less irrigation and adopting irrigation systems such as drip irrigation the overall irrigation demand could be dropped by up to 60%.

Water Cycle

For a city demand of around 11,452 m^3/day, the following optimised water cycle strategy is adopted which minimises the potable water demand to 9,531 m^3/day by maximising the water recycling and re-use, of which only half will be newly abstracted, the other half will be indirect reuse of treated sewage effluent. It is estimated that over 30% of the buildings demand is covered by grey water recycling, while all the irrigation demand is100% sourced by treated sewage effluent from an external source. Allowing for losses and contingency it is estimated that less than 50% of the overall water demand should be fresh potable water.

Source of Potable Water

The preferred strategy is to undertake an indirect recycling scheme within the site which utilises the brackish groundwater as the primary source of water.

The strategy is to abstract brackish water, desalinate this water and use it as a supply for the city and then collect the used water, treat this and then return it to the ground and therefore reducing the impact on the groundwater levels.

There is an aspiration to then investigate the option for a direct reuse scheme where some of the water is returned to the ground and where some is blended with the supply network as a source of water.

Water Recycling

Grey water treatment

While there are various methods of treating grey water centrally, the strategy we propose would be to decentralise the grey water treatment network as to have each building block responsible for their own water treatment. This was due predominantly to the fact that in residential buildings, the grey water demand is 65 l/c/d while the potential grey water supply is 78 l/c/d. In this respect the recommended systems to use would be either the use of chemical or biological systems combined to membrane reactors.

Foul water treatment

The preferred strategy for the secondary treatment option is a Membrane Bioreactor (MBR) process unit which will allow the flexibility for the plant to obtain a water quality suitable for reuse either indirect or direct within the site.

Tertiary treatment will be required to clean the water to the required level and the preferred method is microfiltration and reverse osmosis. This could be combined with desinfection systems such as clorination or UV if required.

The amount of tertiary treatment and therefore the overall land and energy required will need to be confirmed after further discussion with the Environmental Protection Agency and other key stakeholders.

It is likely that the amount and degree of tertiary treatment will also vary if we are looking at an indirect or/ and direct recycle scheme.

Distribution

Potable water

A direct boosted supply from a single multi-cell reservoir with backup generators will be the most efficient method for supplying the city. The number of cells in the reservoir would be designed to ensure that the system could run with one cell out of service while still maintaining 48hour storage. This allows individual cells to be maintained while ensuring supply. Fire fighting flows can be sustained by use of standby pumps. Backup generators will ensure supply during power failure.

Foul Water

The preferred foul water system for the city will probably be a combination of the gravity system of trunk sewers in and around the city and vacuum systems to collect foul from the buildings and convey it to the trunk sewers.

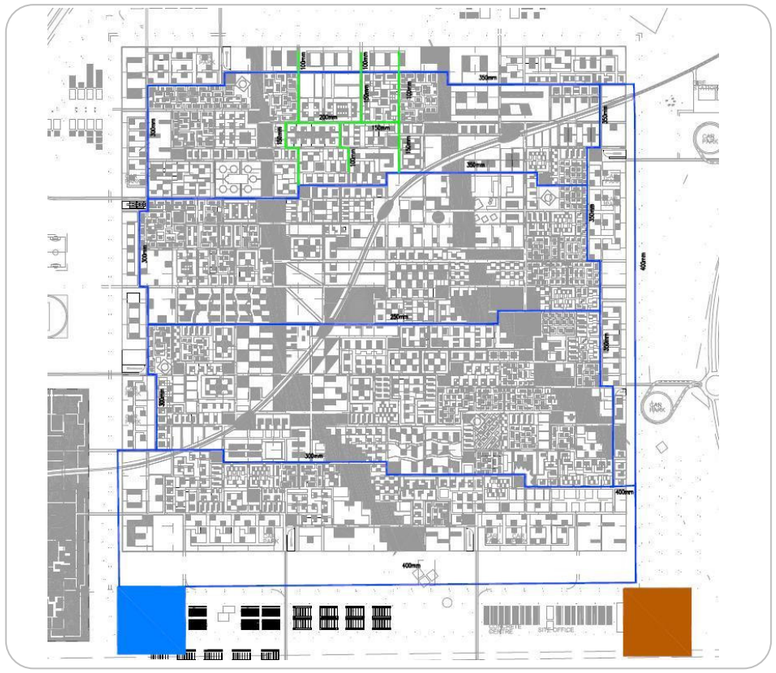
Drainage

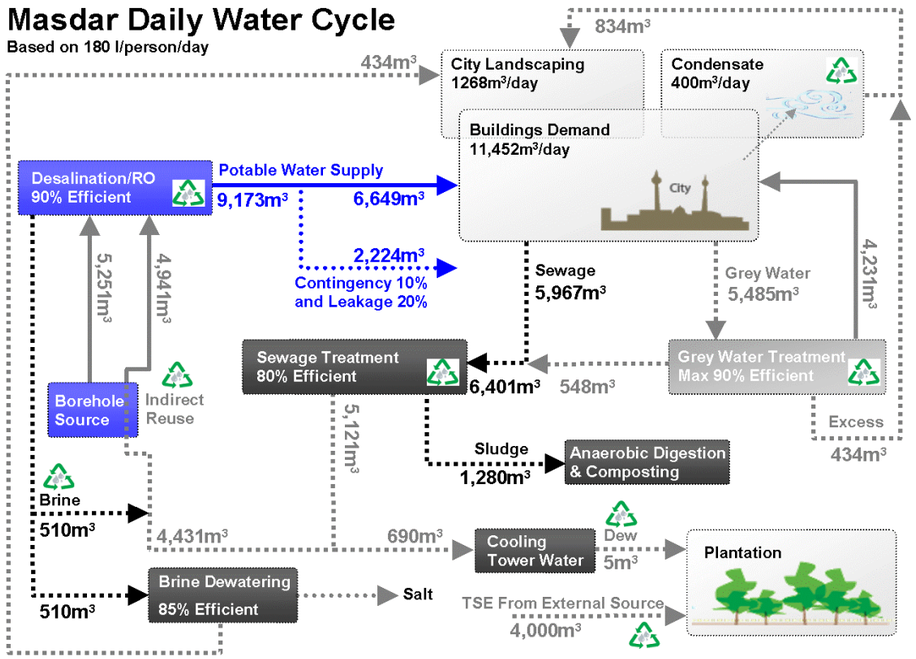
The proposed strategy essentially separates proposed high level podium areas from low level courtyard areas. Source Control methods are proposed for low level areas (courtyard/landscaped areas) with the remaining proposed drainage elements catering for all other runoff i.e. all remaining hard standing areas.

Desalination plant

Direct booster supply network

Grey water for irrigation





Summary

Waste

Within the Masdar development there is a requirement to manage household, commercial and industrial wastes.

Sustainable waste management strategy follows a hierarchy of 'Reduce, Reuse, Recycle, Recover and Disposal'. Masdar aims to eliminate the need for disposal.

The UAE is one of the highest producers of waste per capita in the world and, therefore, minimisation of waste at the outset needs to be the first step.

After minimisation, the next step would be the reuse of this resource for the same purpose for which it was designed and without processing. This is a simple, cost effective and convenient means of minimising waste generation. Recycling comes next where the material composition of the waste is altered for a new use. Recovery of energy in particular, either through direct combustion or from syngas extraction is the final option available to Masdar.

Waste Arising

The base calculation estimated that a total of 245 tonnes of waste would be generated at Masdar every day, or 89,555 tonnes per year. Based on the profiling of the waste, it was estimated that 63% of this total would comprise recyclable material, 21% would be compostable, and 16% 'non-recyclable'.

Waste minimisation

Innovative waste minimisation measures could reduce waste arising by 30% compared to current Abu Dhabi generation rates (i.e., 62,688 tonnes per year). Waste minimisation can be achieved through a range of different instruments including technological, economic, regulatory, social and behavioural change instruments.

Recovery rate

The target rates of recovery of the recyclable and compostable materials were estimated to be 60% for residential waste and 85% for commercial, industrial and 'other' generators of waste.

If the above recovery rate targets are met, 50% of the total waste (i.e., 31,513 tonnes) would be diverted to recycling, 16% (10,273 tonnes) would be diverted to composting, and the remaining 33% (20,902 tonnes) would be diverted to the thermal treatment.

Collection infrastructure

It is recommended to have the waste segregated at source by the end users into three waste streams;

- Dry Recyclable [Paper, Plastic, textiles, glass, etc.]
- Wet Recyclable or Compostable [food and garden waste]; and
- Non-recyclable / recoverable.

It is proposed that the Residents and tenants of Masdar are charged for the disposal of the non-recyclable waste using a pay per bag system where only specific bags are bought, filled and collected.

The segregated waste will then be collected from the service point of each building via the Personal Rapid Transit (PRT) vehicles system. Storage containers will be designed to fit with the PRT vehicles. Where the building density prohibits door to door collection, a gravity chute or automated vacuum system would be deployed on a case by case basis and utilised to transport the waste to a small transfer station pending collection by the PRT.

The waste is transported by the PRT to the following destinations;

- Dry Recyclables to the Material Recovery Facility;
- Wet Recyclables to the Composting Facility; and
- Non-recyclables to the Waste to Energy plant

Collection will be through the night to avoid causing congestion in the transit systems. This activity is associated with the delivery and logistics of goods movements which maximises the efficiency of the PRT infrastructure and represents an innovative resource movement mechanism.

Material Recovery and Treatment

The dry recyclable waste will be separated into (i) Paper and Cardboard, (ii) Metals, (iii), Recyclable Plastics, (iv) Glass, and (v) WEEE streams pending collection by approved private contractors. Preference will be given to companies who will recycle the resources in the UAE.

The wet organic waste component will be composted at a specially designed onsite in-vessel facility. The composting process will be carefully controlled and the product used within the development for landscaping, soil conditioning and biomass fertiliser. Up to 1,000 tonnes of compost per year will be produced which if surplus to requirements can be sold externally subject to testing.

Waste sludge from the wastewater treatment plant will be processed in an-aerobic digesters; the resulting methane will be captured and the residue will be used as a soil fertiliser in the biomass plantations and landscaped areas.

The recoverable component of the non-recyclable waste and other unrecoverable recyclables will be thermally treated in a pyrolysis / gasification unit to generate electricity and waste heat. It is recommended that the energy recovery operation is optimised for maximum overall system efficiency.

For a low calorific value waste feedstock of 16.5MJ/kg, a pyrolysis gasification plant could generate up to 2.75Mwe of net electricity, and 3.85MWth of heat (from the engines and heat recovery systems). The annual electricity and heat production of the gasifier could reach 22GWhe and 30.8GWhth. It is possible to increase the steam and syngas production by feeding the plant with waste with a higher CV, such as paper & card, plastics and wood. Equilibrium needs to be found between the optimisation of the power generation from the plant and the maximisation of the recycling ratio.

The resultant non-hazardous bottom and fly ash will be used in the biomass plantation and incorporated into building materials.

Household hazardous waste will be collected via various drop-off points around the city. This hazardous waste and the residual hazardous ash arising from the pyrolysis and gasification process will be processed in a Plasma Arc unit, vitrified and re-cycled into construction materials.

Should the small square be developed in the future, it has been calculated that approximately 15,215 tonnes of waste would be generated annually The small square would require its own waste transport infrastructure however a common Material Recovery Facility, Composting plant and Waste to Energy plant would be used by both squares.

Waste Management Strategy

Summary

Energy distribution

The Abu Dhabi Water and Energy Company 'ADWEC' has a major 400kV power distribution network that passes in the proximity of the site. However, based on the growth of the new developments in Abu Dhabi, it is forecasted that by 2012 the peak power demand will outstrip the planned upgraded capacity and by the time the Masdar development is fully constructed in 2015 it is estimated that the shortfall is estimated at over 2,500MW.

Electrical Supply

Power is being produced on-site as per ETA's recommendation. 95% of power production only occurs during the day and as mentioned previously the peak production and peak demand are not synchronised, therefore it is necessary to have provision for power storage to be able to supply the night and the peak power demand. In addition, it is found to be very risky to have the city without back-up supply in the case of sever dust storms of system malfunction of the solar plant or the PV array; therefore grid connectivity was deemed essential.

Based on this it is forecasted that during peak production periods, up to 80MW of power will need to be exported to the grid and up to 40MW will need to be re-imported back from the grid.

Distribution Strategy

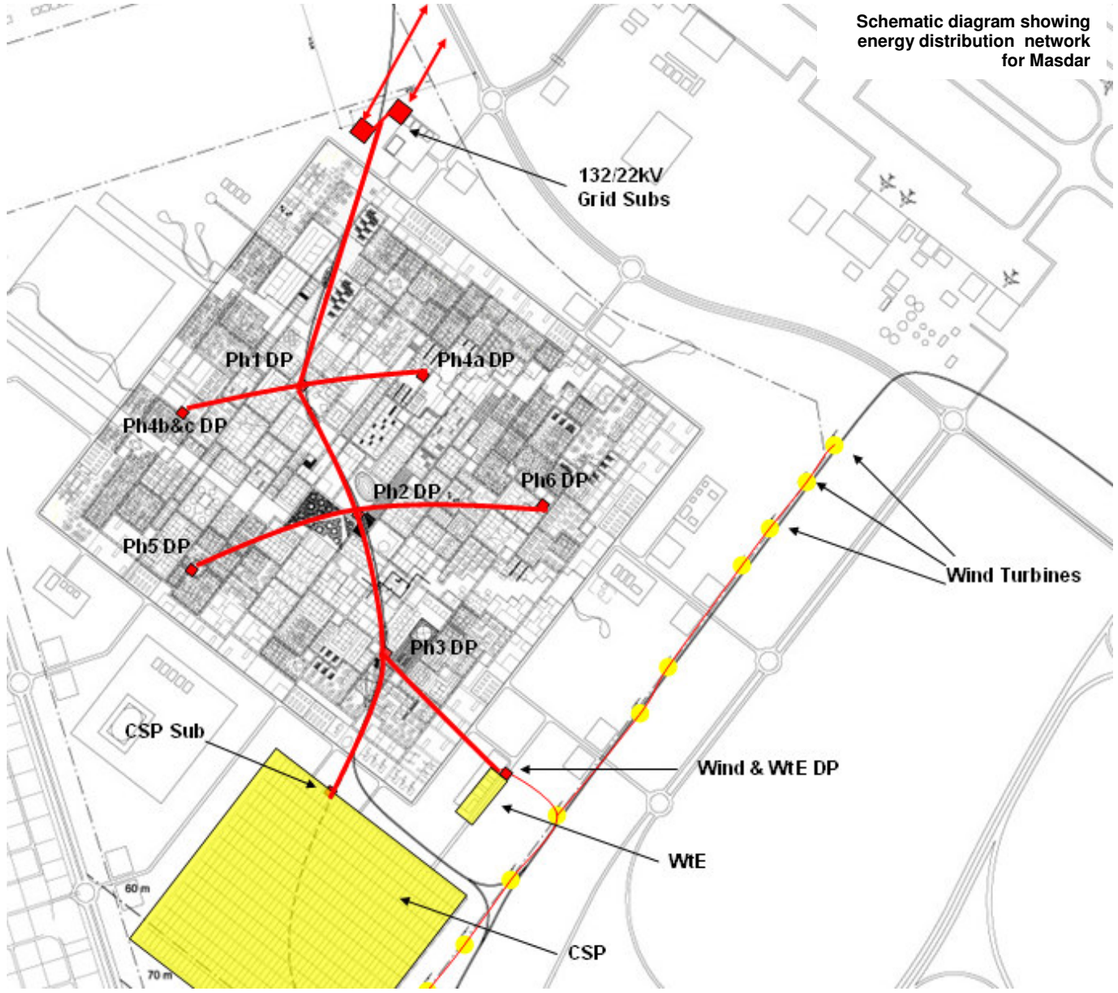
The ADWEA provide supplies at 400/132/22KV for projects with a high electrical demand. At masterplan stage prior to detailed discussions with the authority initial contact has indicated that the supply will be provided at 132kV from an existing 400/132kV sub station at Bahya. The supply will be provided via underground cable circuits to the perimeter of the site and will terminate in a 132/22kV sub station. At this stage it not possible to confirm the number of 132/22kV sub stations.

Each 132/22kV sub station will consist of the termination 132kV switchgear feeding two 132/22kV oil cooled transformers. It is assumed prior to discussions with ADWEA that the transformers will be rated to enable a single transformer to take the full demand load if one of the transformers fails. The additional load under single transformer operation will be provided by force cooling the healthy unit.

The LV output from each transformer will supply the ADWEA 22kV switchgear which will provide the metering point for the cities supplies. The ADWEA 22kV switchgear will supply a series of 22kV switchboards which will supply the primary distribution.

The primary distribution voltage for the City will be 22kV emanating from the grid sub stations which will provide a series of metered 22kV supplies. The metered supplies will feed the cities power distribution grid, which will consist of a series network node points located in the undercroft. The node points will notionally relate to the construction phases, with at least one node being located within each phase.

Within each node connection point a 22kV switchboard will be installed within a dedicated switchroom. The switchboard will feed a string of 22kV ring mains which will supply a series of 22kV/400volt sub stations. The distribution switchrooms will be strategically positioned with respect to the load and the input and export of power. The 22kV distribution will be divided between utilities supplies serving the cities infrastructure and supplies to the various building types.



Schematic diagram showing energy distribution network for Masdar

Summary

Air-Conditioning Supplies

The electrical generation system provides, as a byproduct.. considerable quantities of heat. Thus we have made use of absortion chillers for two purposes;

- To regenerate a liquid desiccant (a substance that absorbs water from the air)
- Absorption chillers to provide chilled water

The liquid desiccant is circulated around Masdar and used within the buildings to dehumidify air supplied to the occupied spaces. The spent desiccant is then returned to a central station where it is regenerated using a proportion of the heat generated by the solar power plant.

The remaining heat is used to drive absorption chillers. These are installed upstream of conventional centrifugal chillers, to ensure maximum use of the available heat. The balance of the cooling is then automatically provided by the electrical chillers. This configuration provides a more efficient system than installing both the absorption and centrifugal chillers in parallel.

The chilled water is distributed to the consumers alongside the liquid desiccant. As a key part if the duty normally served by chilled water (dehumidification) is performed by the liquid desiccant, the chilled water demand is lower than even the low building demands would normally require, and its temperature can also be higher.

The heat losses and gains associated with pipework distribution systems are largely avoided because the liquid desiccant is close to ambient temperature and the chilled water is at a higher temperature than normal.

Air-Conditioning Plant

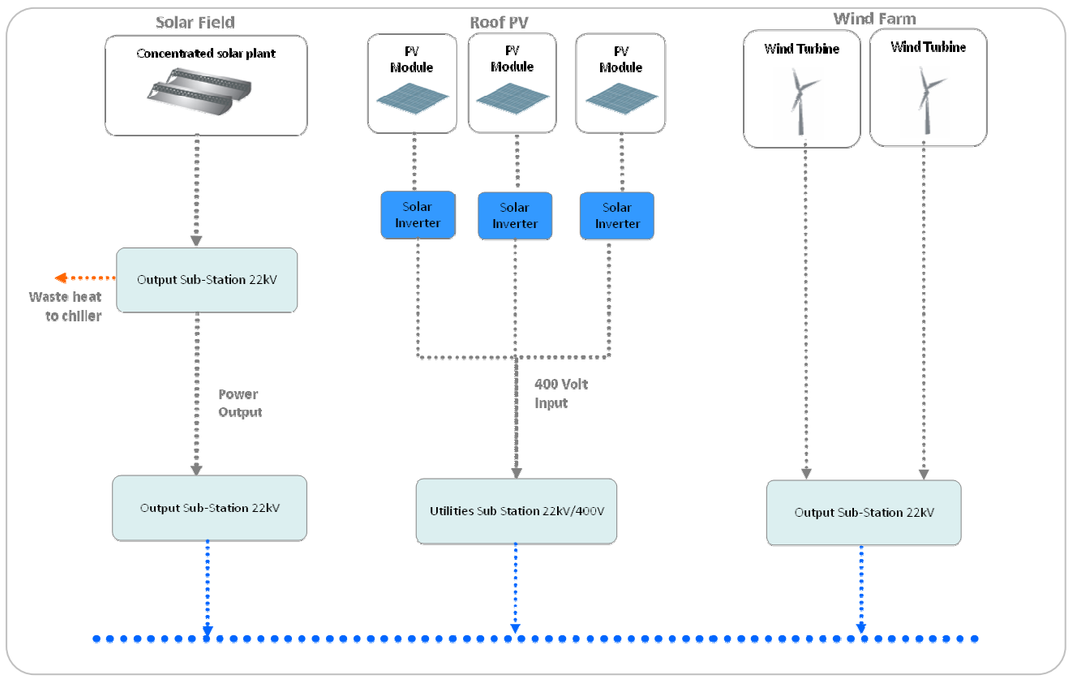
Within the buildings the cooling demand is minimised by the very design of the city and by attention to the design detailing of each building. A cooiling and dehumidification demand remains which is reduced further by optimising the use of heat recovery from extract air and by the use of displacement ventilation in all buildings that are suitable.

This means that use of the piped supplies and chilled water are minimised.

As it is suggested that the sensible heat in buildings is done with chilled water, generated by a combination of electric and thermal chillers and the latent heat removal done by a desiccant system; 95% of the chilled water would be generated using electric motor driven centrifugal chillers, with the balance 5% being generated by thermally driven absorption chillers. The latent heat (dehumidification) removal will be achieved with Lithium Chloride solution. The desiccant system, Lithium Chloride solution is to be re-generated by thermal energy. A dual piping network of chilled water and lithium chloride should be distributed in the city to supply the required medium for cooling.

District Cooling Chiller Plant

Grid Sub Station



On-Site Generation Connectivity to Power Distribution

Summary

IT & Telecommunication

Major developments such as Masdar will require ICT services such as internet access, wired and wireless connectivity, interactive television, building management systems, security and life safety systems as well as remote utilities management systems.

Typically in Abu Dhabi most of the underlying infrastructure and the service provisions are supplied by Etisalat, the local telecommunications provider.

In Dubai, recently a new telecommunications model has taken place in a development called Dubai Media city; where a local utility supplier was created to supply the development with the essential services using their own internal infrastructure; which then connects to Etisalat's country-wide infrastructure.

ICT Network and Ownership

The current regional model is for two ICT infrastructures to distribute services across a city site. Etisalat provide, install and support an ICT network for the distribution of services to all end users within the city. ADFEC provide, install and support an ICT network to distribute ADFEC's required services to ADFEC users across the city. Instead of separate Etisalat and ADFEC networks it is recommended for the city to be serviced by a single unified network which will follow the design proposal for the ADFEC network with ownership and support by ADFEC, Etisalat or a joint venture.

ADFEC is required to provide a Point of Presence room for Etisalat in each of the two stations built in the first phase. ADFEC should then oversee installation of ADFEC network infrastructure for the distribution of the services required by ADFEC across the city, extending from the stations and connected to the Etisalat network. Masdar will require the active involvement and agreement of the service providers for the physical infrastructure and city distribution network.

Passive Optical Networks (PONs) will distribute services across the city taking optical fibre to each premise (Fibre to the Premises, FTTP). The PONs will extend Masdar's network throughout the city as well as connect all the city's end users to service providers. A PON consists of an Optical Line Terminal (OLT), the Optical Distribution Network (ODN) and a maximum of 64 Optical Network Terminations (ONTs).

Optic Fibre will be distributed from two city edge frame rooms utilising the development service corridors. From the southern city edge frame room the fibre will follow a herringbone pattern radiating out from the LRT line. From the northern edge frame room the fibre will circle the city entering to provide diverse routing where resilience and redundancy is required. Service Providers will link to the PONs at two city 'edge' sites. The city edge sites will have access to the city's services undercroft. The two sites will provide redundancy for the city and resilience (dual path with no single point of failure) for end users who require it. The location for the edge sites are the two rail stations proposed in Phase 1.

ADFEC are advised to consider the provision of a single ICT infrastructure for all Masdar service users to avoid duplication ie all ICT infrastructure for tenants and ADFEC delivered in the construction phase allowing interconnectivity. In considering the ongoing requirement for a communication service provider to the tenants, opportunities exist for either engaging with an external supplier or initiating a new service unique to the development as a platform for innovative services.

Innovation in Services

Unified Network

The basis and infrastructure for services to connect and interact.

Wi-Fi Locationing

There's my destination, there's my transport.

Fixed Mobile Convergence

One number anywhere in the city when I'm in work. Same facility, different number when I leave work behind.

Near Field Communications

Carry my Masdar Information point with me.

City Content

TV content binding together the Masdar community.

Interactive Waste and Energy Management

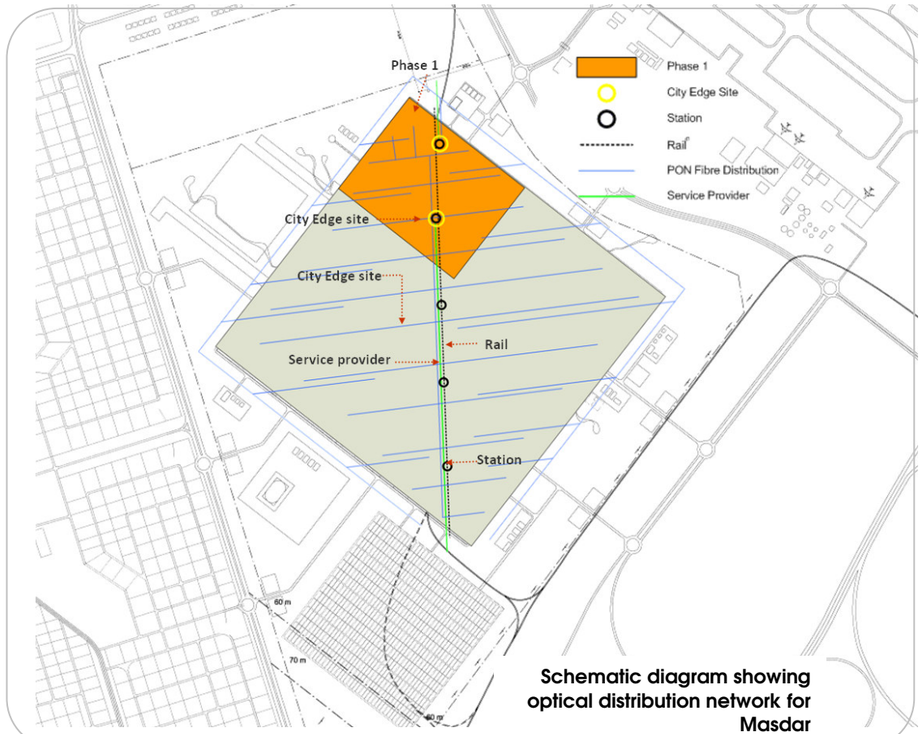
Directly supporting the vision for Masdar. Adfec and their customers learning to make the right environmental lifestyle choices, together.

Flexible CCTV locationing

Responsive and responsible security.

Access Control and Near Field Locationing.

Secure Access control with your Masdar mobile phone.



Schematic diagram showing optical distribution network for Masdar

Optical Line Terminal

Bundled Optical fibres

5.2.1 Introduction

To develop the water cycle for Masdar, the requirements of water within each land use zone across the site have been identified. The proposed strategies aim to minimise water consumption and reuse water so as to minimise the impact on the environment.

The overall aim of the strategy is to minimise the amount of externally sourced water that is required and optimise the reuse of internally generated water.

As there is no natural source of water within the site boundary, the preferred strategy will be indirect reuse of abstracted and desalinated groundwater via recharging in the aquifer, with the aspiration to move to direct reuse in the future.

The desalinated groundwater will provide drinking water for the city. The supply network has been detailed to ensure that the water supply network is able to deliver the flow and pressure required, and maintain supply in emergency situations, such as by mains failure or fire demand.

The study investigated options to minimise the overall use of water at each part of the development, to re-use and recycle water wherever possible and then dispose of the water within the site.

Options for reuse of grey water have been given and a comparison of different treatment systems provides relevant information for decisions at the detailed Masterplan level.

Treated sewage will partly be directly reused in the city for the cooling tower and further indirectly reused through recharging to the aquifer before abstracting.

Rainwater will be collected in storage facilities in the raised platform. This water will be reused for irrigation purposes, either within or outside the city.

Where possible the lower energy option should be implemented, if it meets other criteria such as water quality standards.

The strategy provides benchmarks to be achieved in the later stages of the development, therefore leaving flexibility for the individual developers to implement techniques to meet these benchmarks. This further allows flexibility for phasing and to develop the standards over the lifetime of the development.

Sustainability

The aim of the proposed water strategy is to minimise the impact of the developments on the environment.

Water consumption will be reduced by over 50% of the current design requirements and by 75% of current rates in Abu Dhabi.

The abstraction of water to supply the city will be minimised by maximising reuse and recycling of water. There will be no waste of water as the treated foul water will be recharged into the ground and so indirectly reused.

The brine generated at the desalination plant will be partly blended with treated sewage effluent and put back into the ground and partly further evaporated to create salt.

Therefore, the only external link into the development is the supply of groundwater to the desalination plant and the only link to outside the development is the blended brine and salt.

Surface water runoff will be stored and conveyed in and around the city and despite the rarity of rainfall, all rainfall will be collected and reused.

Cultural shift

For this water cycle to meet the targets, a full and long term public awareness education campaign will have to be undertaken as a cultural shift is required in the approach to water and how it can be conserved.

Further consideration is required to determine which type of public awareness campaign will be best used to raise awareness among residents. It is important to stress that water is a scarce source and to educate them about the various strategies implemented in the city to use and reuse the water in a sustainable way.

The success of such a campaign may affect the end target of water consumption that can be set for the city. It may raise awareness of water use outside the development and could act as a blue print for Abu Dhabi and its future growth.

Innovation summary:

- Water efficiency, reuse and recycling of grey and black water has reduced the required net abstraction of groundwater from 180 l/c/d to 42 l/c/d
- Waste water will be first indirectly reused, which is the first scheme in UAE
- Flexibility to expand the scheme to a mixed direct and indirect reuse scheme for use in the city, which will be the largest in the world
- Dew catchers are proposed to collect water for irrigation
- Condensation water in the city will be collected and reused
- Seawater greenhouses

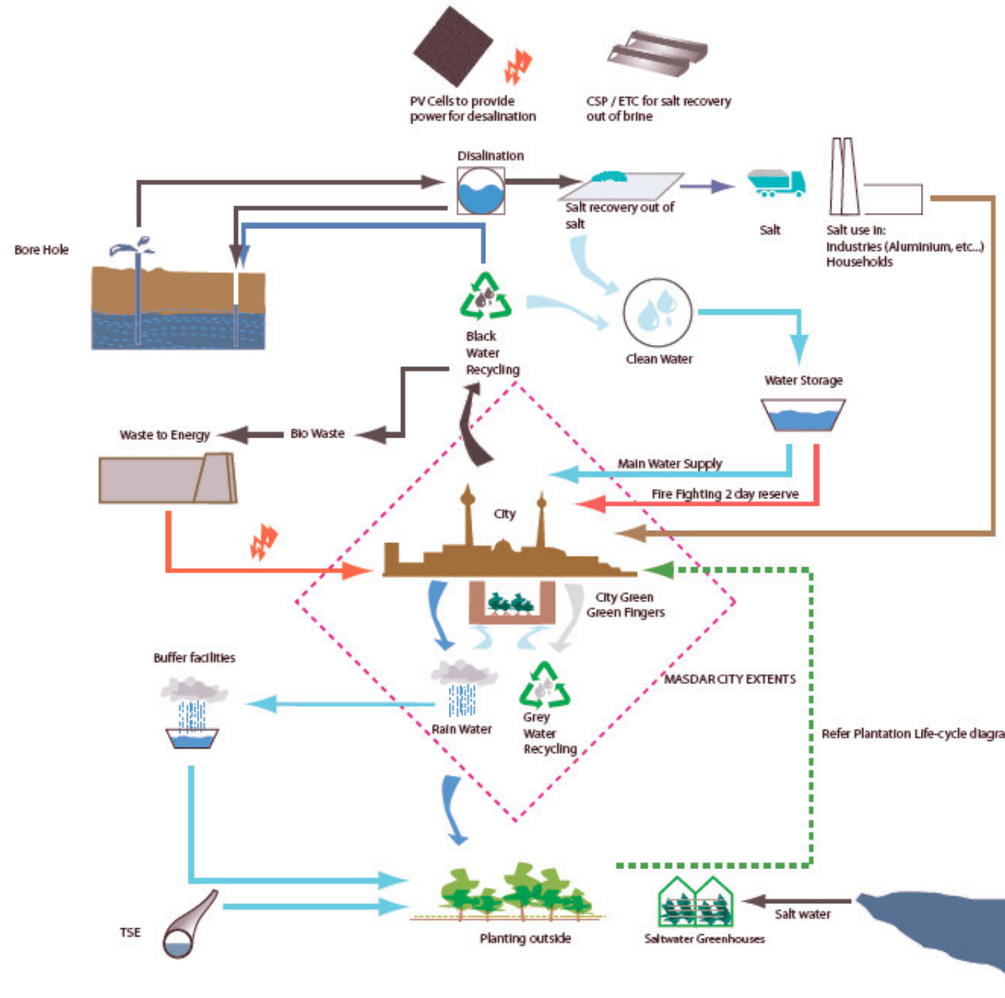


Figure 5.1: Schematic plan of the proposed water infrastructure strategy

5.2.2 Local Context

The water policy in the Abu Dhabi Emirate has largely been based on increasing supply rather than managing demand. As a result, the Emirate has one of the highest per capita water consumption rates in the world at 350 litres per person per day (l/c/d). Compared with, for example, Germany's consumption rate of 150 l/c/d, Abu Dhabi's water consumption rate is extremely high. Countries with a comparative climate, such as Syria and Jordan, are consuming 125 and 85 l/c/d.

EAD expects the consumption rate to almost double by 2015.

Water in Abu Dhabi is supplied by the Abu Dhabi Water and Electricity Company "ADWEC" for both potable water and treated sewage effluent.

Masdar is located outside the main island of Abu Dhabi city in an area between Mussafah City and the Airport, just south of the new developments of Al Raha and Yas Island. Due to the extensive potable water demand that is expected in the near future of the developments in the vicinity of the Masdar development, a detailed investigation of water availability will be required.

Potable water in Abu Dhabi city is predominantly produced via desalination plants at the Umm al Nar Power Station, Taweelah station and ADPS at a rate of 145, 228 and 15 million gallons per day, respectively.

In addition to the three desalination plants mentioned above in Abu Dhabi Emirate, water is being produced in Fujairah and in the western territories. The overall water supply to Abu Dhabi is 630 million gallons per day. For more details please refer to the Water Statistics produced annually by ADWEC.

Based on ADWEC's water demand forecast, it is estimated that today's demand of 630MGD will increase by 4.8% per annum to reach 1100MGD in 2015 when the Masdar development is expected to be complete.

ADWEC's demand vs supply forecast draws a gloomy picture of the availability of water over the next decade. In fact, the current projections show that ADWEC should be capable of supplying the City of Abu Dhabi up to 2012, which is equivalent to 850MGD. This forecast model was produced in 2007 and is in line with the Abu Dhabi Urban Framework Plan for 2030 that was produced in the last quarter of 2007.

Therefore, as of 2013, Abu Dhabi will be in deficit of 50MGD increasing to 300MGD in 2020.

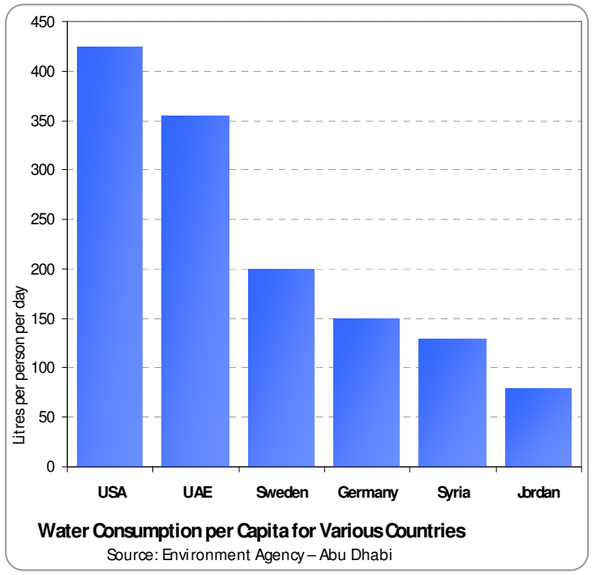
It is clear from this analysis that to manage the demand of potable water supply for the Masdar development, an aggressive water minimisation programme and an auto-production strategy is required.

Target: Sustainable Water

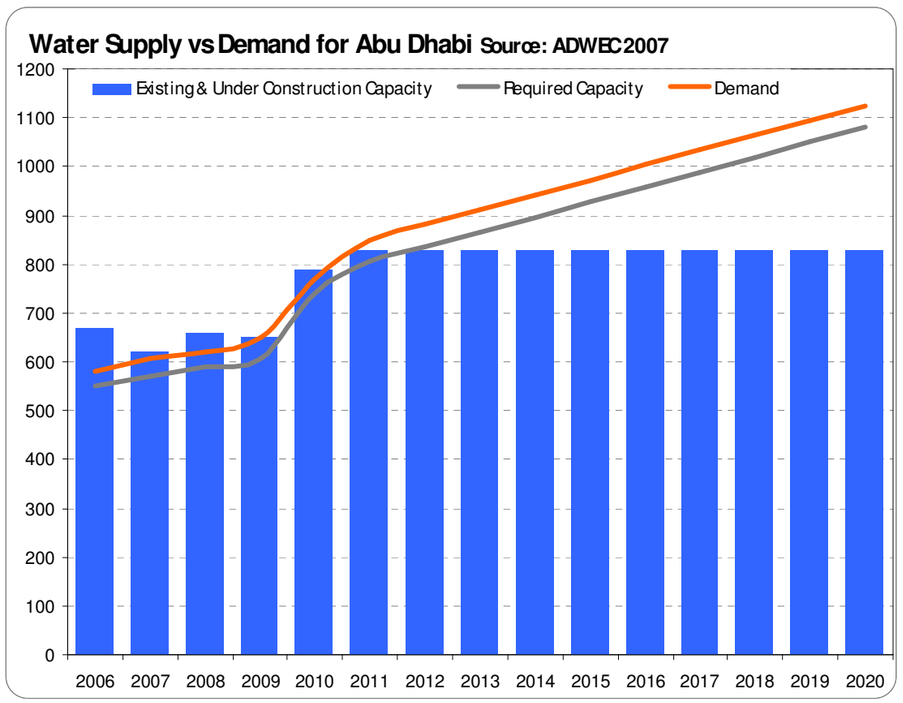
Considering that Masdar is in the middle of a major expansion zone of urban development, the local infrastructure for potable water supply is going to be under significant pressure; therefore it is essential to adopt water minimisation, water recycling and re-use measures, and even to consider off-grid potable water sources.

In addition, the Masdar development has signed up to the principles of One Planet Living, one of which is Sustainable Water Management. The aim is to achieve a positive impact on local water resources and supply: by implementing water use efficiency measures; re-use and recycling; minimising water extraction and pollution; fostering sustainable water and sewage management in the landscape and restoring natural water cycles.

- Each resident in the UAE uses almost double the amount of water a person in Western Europe uses.
- Abu Dhabi will be in deficit of 50MGD by 2013 increasing to 300MGD in 2020.
- Masdar aims to achieve a positive impact on local water resources by implementing water use efficiency measures, re-use and recycling; minimising water extraction and pollution; fostering sustainable sewage management in the landscape and



Water Consumption per Capita for Various Countries
Source: Environment Agency – Abu Dhabi



5.2.3 Water demand model

Potable water in Masdar is used for many purposes including domestic, commercial, industrial, irrigation, fire fighting, energy production and street cleaning.

The base calculation estimated that a total of 35,000 cubic meters would be required at Masdar every day, or 10.5 million cubic meters per year.

Given that these base figures were calculated using current average rates for Abu Dhabi, it was assumed that significantly lower amounts of water would be required at Masdar after the various minimisation measures are applied. For the purpose of the Water Demand Model, irrigation was excluded and it was estimated that the minimisation measures could reduce water by approximately 60% compared to current Abu Dhabi consumption rates i.e., 11,452 m^3/day (see next section for more details on proposed water saving measures).

A breakdown of the water requirements for Masdar is as follows:

Domestic Requirements

- Personal washing
- Toilet flushing
- Bidets
- Food preparation
- General kitchen use
- Cleaning

A consumption rate of 180 litres per person per day was assumed as an average requirement for domestic water demand across the Masdar development. This is the current design guide for apartments in Abu Dhabi. This figure is significantly higher than typical UK figures, but is believed to reflect more accurately the cultural difference in the way water is used within the UAE in recognition of the climatic conditions. Implementing efficient fittings and appliances within the properties reduces the water requirement by 19%.

The above water efficiencies reduce total domestic potable water demand from an initial 5,738m^3 per day to 2,587m^3 per day.

Commercial and Industrial Requirements

- Industrial cleaning
- Amenities for employees
- Food preparation
- Cleaning
- Personal washing
- Toilet flushing
- Irrigation
- Water features
- Street and building washing

Commercial areas have been assigned 4 to 4.5 m^3/m^2/day, industrial areas 6.45 to 10 m^3/m^2/day[1] and sports and community areas 0.3 m^3/m^2/day. The total demand for this portion of the development is 8,873 m^3/day which is reduced to 4,362 m^3/day by implementing water efficiencies and grey water recycling.

Cooling

It is planned to utilise a Concentrating Solar Power (CSP) plant in Masdar. These operate as regular power plants (e.g. coal-fired steam plant), with the exception that the heat is provided by solar energy rather than fossil fuels.

The water requirement for such a plant has been estimated to be a minimum demand of 300 m^3/day for 16-hour night-time operation of 50MW, with a contingency of an additional 200 m^3/day, which results in a requirement of 500 m^3/day.

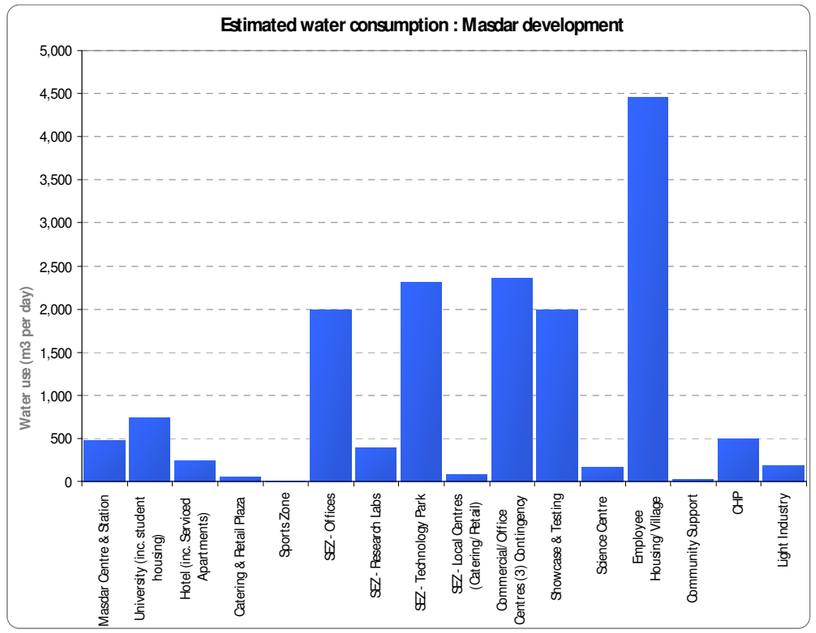
The water requirement for the CSP plant can be sourced from treated effluent and therefore does not have an impact upon the overall city requirement for potable water.

Process

Light industry within Masdar will require process water for the manufacture of various products.

Treated effluent is a suitable source for process water. Waste water from industrial processes may also be recycled internally for further efficiencies. It has been estimated that 190 m^3/day will be required for this use.

Figure 5.4



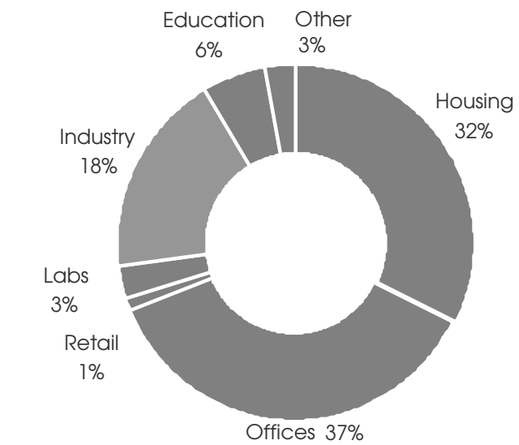


Figure 5.2 Masdar water demand breakdown

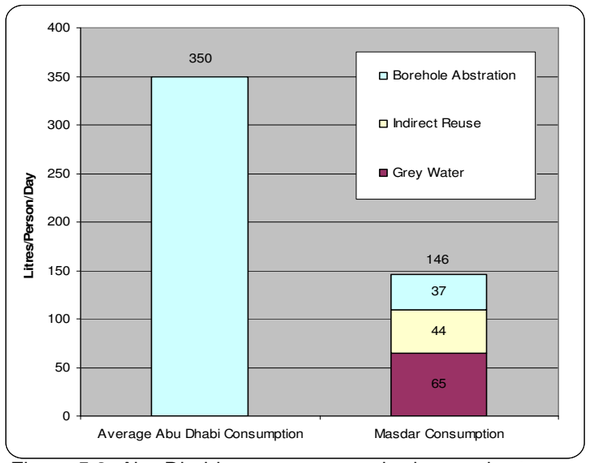


Figure 5.3: Abu Dhabi average vs required groundwater abstraction for Masdar

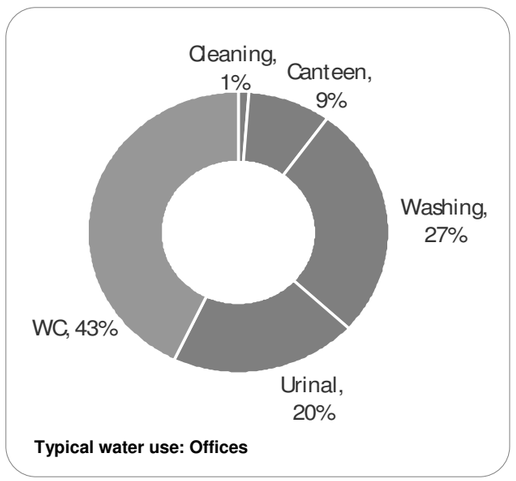


Figure 5.5: Breakdown of water use in offices

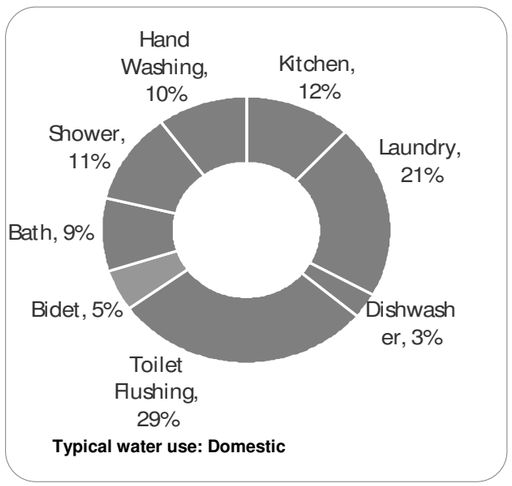


Figure 5.6: Breakdown of water use in residential

[1] BRE Waste Centre, 2001

Irrigation

A entirely green landscape for the city would require an equivalent water demand of 10,000m^3/d; however by adopting a mix of green and dry landscaping, using local plantation which require less irrigation, and adopting systems such as drip irrigation the overall irrigation demand could be dropped by up to 50%.

In order to make calculations more accurate for irrigation the demand has been divided by category. For irrigation demand, an assumed split of 30% hard landscape [e.g., paved] and 70% soft landscape area [e.g., lawn, shrubs] was applied to each plot of open area. An assumption was made that soft landscape is divided into grass [70% of the area], shrub [10%] and tree plantation areas [30%]

The irrigation standard[2]: for open spaces is as follows:

- Normal condition (4 months a year) 12 litres/ m2/day for grass, 35litres/m2/day/ each for trees and shrubs, application over a 12 hour period
- Summer condition (8 months a year) 15 litres/ m2/day for grass, 50liters/m2/day each for trees and shrubs, application over a 15 hour period

An internal city irrigation supply of 1,300 m^3/day and external city and food production supply of 4,000 m^3/day will be required. The external irrigation will be supplied as treated effluent from an external waste water treatment plant.

Water source for irrigation

It is proposed to import treated sewage effluent (TSE), 4,000 m^3/day, from an external source to supply irrigation. This could come from the airport of the Abu Dhabi municipal treatment plant.

The internal city irrigation requirement of 1,300 m^3/day will come from grey water, condensators and TSE.

Reusing wastewater for irrigation is an essential component of a demand management strategy because it conserves freshwater for the highest-value uses. However, treating and reusing domestic wastewater has two other advantages: first, reduced environmental effects, and second, enhanced food production and reduced artificial fertilizer use because of the nutrients contained in the wastewater.

The necessary wastewater quality (World Health Organisation), defined in terms of faecal coliform and helminth egg levels, varies depending upon the intended use of the wastewater. Wastewater used for unrestricted irrigation requires more thorough treatment because it can come into contact with edible crops grown at ground level, as well as in sports fields and public parks. Wastewater for restricted irrigation (i.e., of fruit trees, pasture, and fodder crops) requires less treatment, because these can be irrigated with water of lower quality without posing a threat to human or animal health. The areas for wastewater irrigation must be carefully selected to avoid contaminating shallow aquifers overlain by permeable soils.

The irrigation requirement will be supplemented by Dew catchers. Further, water use can be reduced here by using innovations such as the Seawater Greenhouse, using drip irrigation, and by adapting crop growth to local circumstances.

Food Production

The details of any food production proposed at Masdar are currently unknown; therefore, an assumed allowance for required water supply quantities has been given in the irrigation figures.

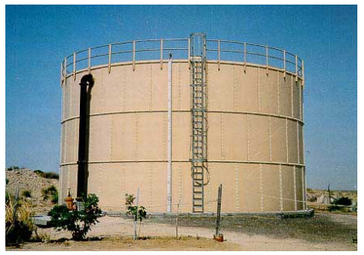
It should also be noted that the water quality used for the irrigation of crops for food production must meet higher standards than water used for general landscape irrigation.

Street Washing

The Abu Dhabi Municipality has an allowance for the washing of streets. Within Masdar, all street washing will be undertaken by vehicle washing facilities rather than by using a hose.

A typical street sweeping machine[3] consumes approximately 0.05litres/m^2 Taking the areas of roads in to account, the water requirement for street washing is estimated to be 30-50 m^3/day, but it is thought that this figure would be low and therefore is covered within the contingency allowance.

Fire Fighting



The availability of water for fire fighting is an important requirement. A minimum flow of 31.5 l/s has been specified for fire fighting purposes. The design standard pressure is 6.9 bars.

The city will hold a 48 hour supply in order to ensure the adequate availability of water to fight fires. Water main sizes must also be sized to allow fire fighting demand to be satisfied anywhere within the city.

Water can be supplied from a potable as well as a recycled source if available. The water distribution network should be designed to be able to supply a fire demand at two locations for a period of 2 hours, while maintaining normal supply to the city. This equates to a total of 454m^3, which must be available from reserve storage.

Leakage and contingency

In addition to the city's water demand, there will be an element of leakage. A figure of 20% leakage has been assumed as a worst case. This equates to 1390 m^3/day.

Despite the fact that the entire city's infrastructure will be new, the design standards prescribe an allowance of 20% for leakage. However, as all infrastructure will be in the raised platforms, leakage detection systems will be picking up leakages at an early stage and leakage can therefore be limited. The leakage allowance is used to design the capacity of the key infrastructure rather than providing the actual water for it.

A contingency of 10% has also been added to the calculations; this totals 934 m^3/day.

Innovation: Seawater greenhouse

Seawater Greenhouse Ltd has developed a greenhouse that uses seawater to cool and humidify the air that ventilates the greenhouse and sunlight to distil fresh water from seawater. This enables the year round cultivation of high value crops that would otherwise be difficult or impossible to grow in hot, arid regions.

The Seawater Greenhouse uses the sun, the sea and the atmosphere to produce fresh water and cool air. The entire front wall of the building is a seawater evaporator. The Seawater Greenhouse converts sea water into fresh water, providing a unique local desalination capability. The water is condensed from water vapour in the air, in much the same way as dew. It is pure distilled water, produced without chemical treatment. The quantity produced depends on the climate - the hotter and sunnier, the more water.

Water Savings

The irrigation rate in Tenerife averaged 1.2 litre/day/m^2 against 8 litres/day/m^2 used by local farmers.

Energy Requirements

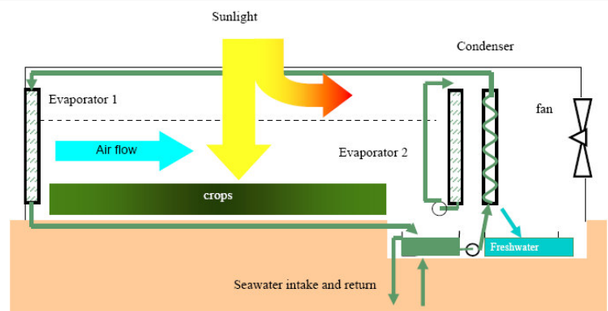
The Greenhouse is driven by solar and wind energy. Sunlight is separated into visible and infrared light. Visible light passes through the roof to drive photosynthesis. Infrared light is trapped in the roof canopy and is ducted from there to the seawater evaporator. Thus solar energy converts seawater to water vapour.

The structure acts as a 'wind-catcher'. It faces into the prevailing daytime wind to assist ventilation. The wind-fan combination moves air through the front evaporator and chills the sea water which then provides cooling for the rear condenser and, thus, the production of fresh water.

The overall process is extremely energy efficient. 1kW of electricity expended on pumping will remove 500kW of heat. Water can be produced at low energy costs (<3kWh/m3).

Options for Masdar- Pilot

Seawater Greenhouse Ltd maintains a policy of continuous innovation and development. They aim to reduce transpiration further by the filtration and attenuation of sunlight and refining the new low cost Watermaker condenser to increase the amount of freshwater produced. A survey of renewable energy technologies will be used to find appropriate solutions that enable the



Seawater Greenhouse Source: Charlie Paton

[2] Abu Dhabi Municipality Irrigation Standard

[3] Schmidt Street Washer product literature

5.2.4 Minimising water use

Water reduction can be achieved through a range of different instruments including use of efficient technology and cultural change instruments.

In Masdar the potable water consumption will be reduced from 350 l/c/d which is the UAE current average, to 146 l/c/d by reducing demand through efficiencies and reusing and recycling water. This is a 60% reduction. Of that 146 l/c/d only 65 l/c/d will be net abstracted groundwater; the rest will be from grey water recycling and indirect black water recycling. Over time, when cultural acceptance grows, the treated sewage effluent could be recycled directly.

User awareness can have a great impact if people accept the advice given. Turning off taps while brushing teeth is one example of how water can easily be saved. The installation of water meters can also have an impact on user awareness, as homeowners will have a financial incentive to save water.

Efficient fittings can take the form of low flow showers and taps, dual flush toilets and smaller baths and basins. Water-efficient appliances in the form of low consumption dishwashers and washing machines can be used to further reduce the demand for potable water.

Cultural

The key to water efficiency is reducing waste, not restricting use. Consumers can help reduce waste by making small behavioural changes and by choosing more water efficient products.

Research has found that in the context of a sustainable supply, many agents hold influence. Water companies, manufacturers of water-using devices, plumbers, builders, consumers and governments all have an impact on the efficiency and sustainability of the supply system.

A Wise Water Use information program for the city can raise the awareness among the new population about the scarcity of water and the particular water situation in Masdar. It can explain the sources of water, and the reasons for reuse of grey water. It can highlight the benefits of water meters: pay for only the water you use, track your water use, detect leaks in your water system, decreased water consumption, etc.

Water efficiency

Challenging but achievable levels must be set for fittings and appliances specification. This will allow for opportunities to increase the level of efficiency at the later stages of the development.

In order to ensure that water is used efficiently, the figures opposite should be adhered to for fittings and appliances specification.

Leak detection systems

Small water leaks can result in significant losses over time, increasing costs as well as causing damage. There is a significant risk of leaks going undetected as toilet accommodation is often unoccupied, particularly during long periods of shutdown or during unoccupied hours. A typical value for a leaking valve toilet might be 4 litres/day[4].

In public and commercial buildings, a proximity detection shut off system should be specified to prevent waste water from minor leaks by shutting off the water supply when toilet accommodation is not occupied.

Valves in cisterns supplying urinals and WCs are especially prone to failure leading to wastage of water via the overflow.

Estimated Water reduction

The above water minimisation strategy can reduce the domestic demand from 180l/person/day to around 146 l/person/day, with around 37 l/person/day being supplied from a grey water source, giving a total potable water consumption of approximately 111 l/person/day.

[4] BREEAM Offices 2006, BRE,UK

Water reuse provides further savings by replacing potable water used for toilet flushing and washing machines with grey water. Grey water is wastewater that is collected from hand basins, showers, baths and laundry. Grey water production in domestic properties is usually greater than its requirement; therefore, it is a good reliable source of water.

The implementation of grey water reuse within the domestic properties could potentially reduce potable water consumption by another 44%, giving a potable water usage figure of less than 90 litres per person per day.
The total demand for this portion of the development is 10,872m^3/day before efficiencies and grey water recycling. With efficient plumbing and the implementation of recycling in place, it may be possible to reduce the demand for potable water by around 53%, making a total requirement of 5,184m^3/day.

Water efficient fittings & appliances

- Dual flush WCs (6 litre full flush, 4 litre reduced flush)
- Low volume baths (no greater than 110 litres to overflow)
- Water efficient showerheads (9 l/minute)
- Reduced flowrate taps on handwash basins (1.7 l/minute)
- Water efficient dishwasher (13 l/use)
- Washing machine (49 l/use)
- Bidet (2.6l/use)
- Future phases could use more efficient fittings and appliances, see table

Innovation

The abstraction requirement of net groundwater (65 l/c/d) is drastically reduced compared to the current average Abu Dhabi consumption (350 l/c/d).

	Suggested Consumption		Future Specification	
Installation Type	**Comsumption**	**l/person/day**	**Comsumption**	**l/person/day**
WC Full Flush (l/flush)	6	9.5	4	6.3
WC Low Flush (l/flush)	4	12.9	2.6	8.4
Bidet (l/use)	2.64	5.3	2.64	5.3
Wash hand basin (l/min)	1.7	10.7	1.7	10.7
Shower (l/min)	9	43.2	7.5	36.0
Bath (l to overflow)	94	22.6	94	22.6
Kitchen Sink (l/min)	4	21.2	4	21.2
Washing Machine (l/use)	49	16.7	39	13.3
Dish Washer (l/use)	13	3.9	10	3.0
		145.9		**126.7**

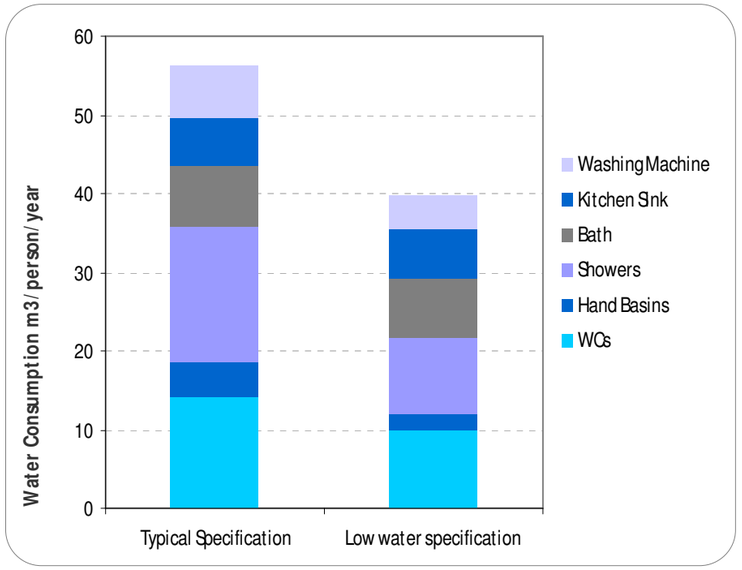


Figure 5.7: Potential reduction in water consumption through water efficient fittings & appliances [Source BRE Water Centre, 2001]

5.2.5 Water Supply Strategy

Water Cycle

The water demand calculations have identified that the overall water demand can be reduced by over 50% using water efficient measures and grey water recycling within the building. Therefore, a strategy is required to provide the remaining demand of 5,251 m^3/day.

Several strategies have been considered to supply this water to the site. The individual strategies are described in the following sections starting with the preferred strategy.

Preferred Strategy

The preferred strategy is to undertake an indirect recycling scheme within the site which utilises the brackish groundwater as the primary source of water.

The strategy is to abstract brackish water, desalinate this water and use it as a supply for the city and then collect the used water, treat this and then return it to the ground and therefore reducing the impact on the groundwater levels.

There is an aspiration to then investigate the option for a direct reuse scheme where some of the water is returned to the ground and where some is blended with the supply network as a source of water.

Whilst the water is treated and cleaned to a potable standard, it is recommended that in this direct reuse scheme a second drinking water supply system will be installed to minimise any public perception issues.

The buildings will be supplied by a triple system providing and disposing of drinking, potable water and grey water.

The local ground water is expected to be brackish and therefore could be a good source for potable water after desalination through Reverse Osmosis. Similarly a brine recovery system could be used to maximise the water extraction and salt recovery.

It is assumed for the purposes of the Masterplan that the geology is relatively constant across the site and similar to the ground conditions under the Al Raha Beach development. A site investigation undertaken for the Al Raha development has identified the following ground conditions.

- Silty sand/ poorly graded sand with silt
- Poorly graded sand
- Mudstone
- Crystalline gypsum
- Sandstone

The ground water has been recorded along the eastern section of the proposed highway at the interchanges. This shows that the ground water varies, depending on the location, between 0.5- 2.4m below datum.

However, the results show the ground water is highest at the eastern end (towards the airport) and the minimum ground water depth is 1.4m below ground level.

Below the mudstone layer it is expected that there is a layer of limestone which acts as a primary aquifer for the area and which is likely to contain brackish water, but this will need to be confirmed by site investigations.

Abstracting brackish water as a source of water for the development has several benefits:

- Brackish water has a lower saline content and therefore utilises less energy in purification than sea water.
- Depending on the aquifer and the geological strata, the ground can act as natural filter and therefore as a buffer to sediment, pollution and the very high salinity found at the upper ground levels.
- Proposal for the disposal of the brine

Brine is a waste product from the desalination process which will need to be disposed of in an environmentally sensitive way.

At Masdar, disposal of the brine will be by blending half of the brine with treated sewage effluent and return it to the ground and from the other half salt will be abstracted.

Key requirements

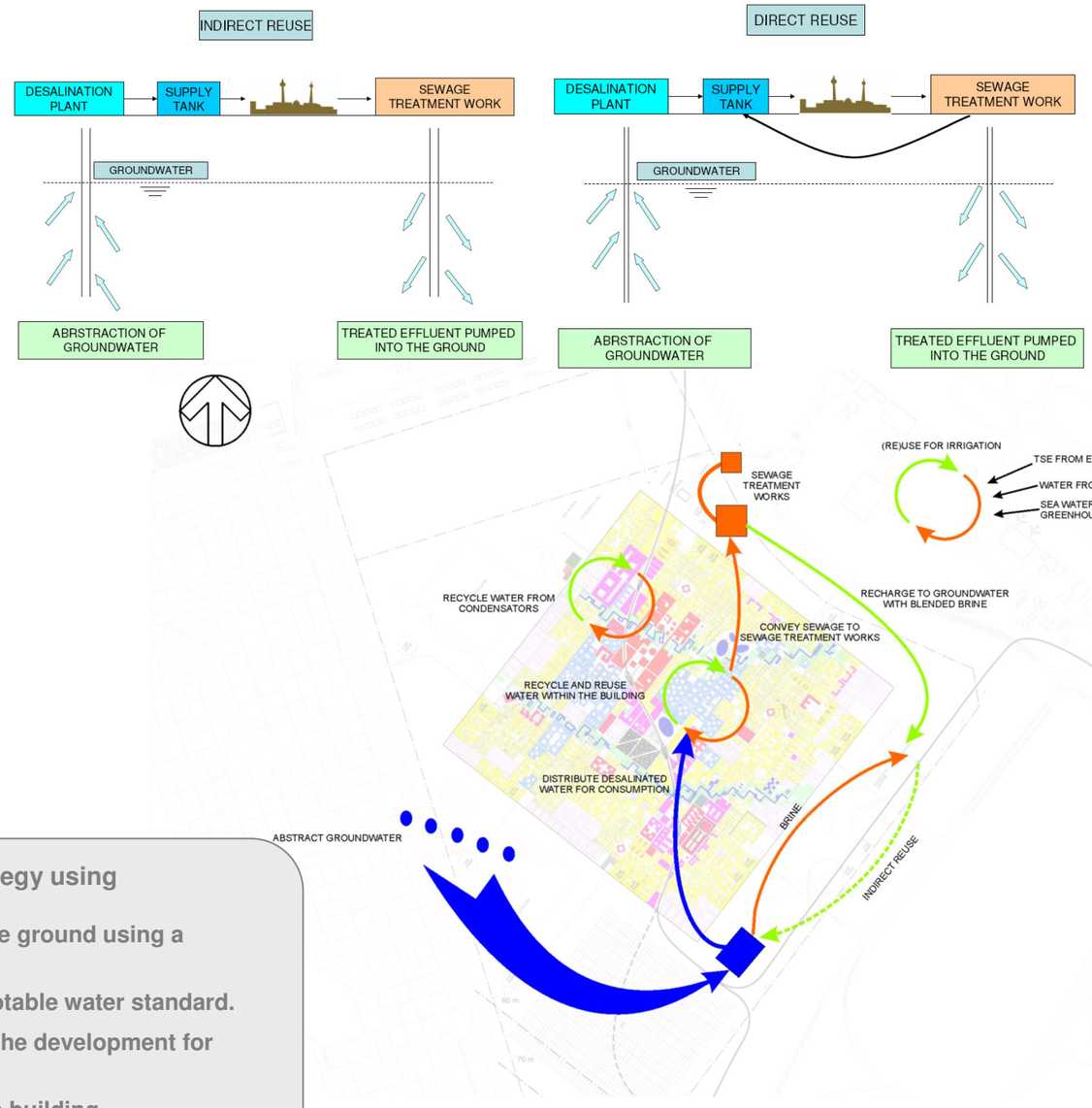
- Sufficient space to locate boreholes. This will need to be confirmed by testing but we suggest five boreholes with the spacing confirmed by site investigation.
- Sufficient plan area for the desalination works and the brine recovery process.
- Enough room to store and transport all the abstracted minerals.
- Sufficient energy to abstract water from the ground and process the water and the brine.

Key Risks to be resolved

- Define the geology under the site and identify if there is an appropriate aquifer which can provide water at the required quantity and quality.
- Define the impact of abstracting groundwater on the surrounding environment.
- Define the impact of discharging both groundwater and blended brine back to the ground.
- Understand the views of the Environmental Protection Agency.

Preferred strategy: on-site strategy using groundwater

- **Water is abstracted from the ground using a number of boreholes.**
- **Water is desalinated to a potable water standard.**
- **The water is distributed to the development for consumption.**
- **Water is recycled within the building.**
- **Sewage is conveyed to the sewage treatment plant.**
- **The brine is processed and the salt and minerals reused.**



5.2.6 Recycled water as a source

One of the key principles associated with the sustainable use of natural resources is to close the 'virtuous circle' by reusing and recycling as much as possible.

This section investigates how much water can be recycled and how this affects the water supply strategy. To achieve significant recycling, any strategy will need to address a number of technical, social, cultural and religious issues.

There are two different approaches to using recycled water as a primary source of water:

Direct Potable reuse can be defined as the reuse of reclaimed water directly with a potable water supply, often implying blending. A further option would be direct reuse where the reclaimed water is piped directly to the point of use without mixing with a natural body of water, for example, agricultural and landscape irrigation.

Indirect Potable Use involves the mixing of reclaimed water with water in a reservoir, lake or river, which is the raw water supply for a potable water treatment plant. Additionally, you can define indirect reuse as the use of reclaimed water indirectly by using a river or groundwater that has been recharged or augmented with reclaimed water.

Reclaimed water has been put to many uses, but may be categorised as follows:

- Agricultural Irrigation
- Landscape Irrigation
- Industrial Reuse
- Groundwater Recharge
- Recreational Lakes
- Non-potable Urban Reuse
- Potable Reuse

It may be noted that the above list is generally in descending order of usage volumes.

There are various technologies which can be used to undertake direct or indirect recycling (these are discussed later in this section); they are unlikely to be a blocker to using this strategy.

It should be noted that the more intensive the treatment the higher the energy demand.

The biggest issue this strategy must address however, is the challenge to social, cultural and religious taboos.

In 1978, the Council of Leading Islamic Scholars of Saudi Arabia issued a special fatwa "to regulate the rules of treated effluents for different purposes. Wastewater reuse was made permissible for all purposes, including wudu, (ablution) provided that the wastewater was treated to the required level of purity for its intended use and did not result in any adverse public health effect".

Innovation: Opportunity to create a pilot

The Masdar project includes a pilot to test and develops a direct re-use pilot system for part of the development to establish how far the cultural and public barriers associated with the direct re-use of treated effluent can be pushed for future phasing.

Pilot testing of candidate treatment processes for grey water reuse is a vital step to ensure that processes are robust as well as effective and efficient.

This would provide an opportunity to test suitability, feasibility (cost, energy, performance), and the social acceptability of directly recycled water. A public awareness campaign would be required to inform and educate the public and developers.

This scheme could learn from and build on successful projects such as the 'New water' project in Singapore where treated effluent is cleaned to a drinkable standard. They have developed

	Discription	Advantages	Disadvantages	Options for Masdar
Indirect Recycling Recycling plant at Orange County California	The indirect reuse of water has happened worldwide for centuries as development has spread along major river catchments. For example, anecdotal reports in the UK press suggest that every glass of tap water in London has already passed through at least 7 people. This is accepted by the population as it is a historic situation. However, when new schemes are introduced they often raise public concerns. The key issue becomes the amount of natural separation between the wastewater treatment works and the potable treatment works. This separation can be created in a number of ways as demonstrated in the examples below: Using a river - Essex and Suffolk Water Company in England discharges treated effluent into the river Chelmer and then abstract 3km downstream. Using Groundwater - discharging treated effluent into the ground to recharge aquifers. An example of this is in Orange County California. Using a water supply reservoir – there are two examples of this approach: the New Water project in Singapore and Toowomba in Australia. Whilst the two projects have some technical differences the biggest contrast is in the public's perception of the two projects. The New Water project has had a successful PR campaign and has been accepted; the Australian scheme has a large amount of public opposition and was originally rejected by a public referendum.	• Likely to be more acceptable to the public. • Will reduce the overall impact of the development on the brackish water levels and aquifer.	• Desalination of the brackish water will still be required (see previous strategy). • Issues regarding the disposal of the brine will still need addressing. • Reduces the capacity to use treated effluent for irrigation.	Within the Masdar site boundary the only option for indirect recycling of water is to discharge the treated effluent into the ground. The effluent would then mix with the brackish groundwater under this site.
Direct Recycling Recycling plant at Windhoek, Namibia	Direct reuse removes the natural buffer between the sewage treatment works and water treatment works and then returns the treated effluent to the development for consumption. This approach raises the highest public perception concerns as well as cultural and religious issues around water being 'unclean'. These issues and concerns increase with the scale of the recycling scheme as people are generally less concerned about reusing their own water rather than their neighbours' water. This concern increases again when a scheme is undertaken on a community scale. The only example of a community direct reuse scheme is in the city of Windhoek in Namibia, where there is no alternative, due to the city's location. Direct reuse closes the 'virtuous circle' as much as possible. However, it is neither practicable nor desirable to close the circle completely. Practically, it is unlikely that the technology for the entire system is likely to have an efficiency greater than 80% and therefore at least 20% water will be required each day to top up the reservoir.	• Innovative approach for the supply of water and fit into the Masdar philosophy for pushing the boundaries. • Maximises the consumption of water on the site.	• Public perception issues • Social issues which therefore may be a block in attracting local workers and residents • Will greatly reduce the water available for irrigation. • A source of water will still be required to replace losses in the system. • If additional water is not added to the system, chemicals and compound would become concentrated and may become harmful to health.	Direct recycling on the site will maximise the use of water for consumption within the development. It is also likely to give the development a very high profile because of the cultural, social and religious norms that the re-use of water will challenge. The technical loop is only likely to be approximately 80% efficient and therefore a second source of water will still be required.
Treated effluent from neighbouring sites Maffraq sewage treatment	The last option is to import raw sewage from one of the neighbouring developments. The Maffraq sewage treatment works currently discharges treated effluent into the sea. We understand that ADWEA currently plans to extend the TSE network to the area around the site by 2010. This could be a possible source of additional water but we are unsure of the quantities available at this time.	• There is currently very limited spare capacity on the city wide foul drainage network and therefore this may be an option which benefits a number of parties.	• However, this approach has potential complications as issues may arise through different adopting and managing bodies being responsible for a number of different parts of the system.	May not be feasible due to uncertainty of availability

Table 5.1: Comparison of options for using recycled water as a source for portable water

5.2.7 Data required to reduce uncertainties

There are several uncertainties associated with using brackish ground water as the primary source.

Preferred strategy

As described in the previous section there are a number of risks associated with the strategy for different sources of water.

Desalinating of groundwater, at this stage, is the preferred option for the site because of the cultural and public awareness issues associated with the direct re-use of treated effluent as a primary supply.

Ground water desalination

There are several uncertainties associated with using brackish water as the primary source.

- The geological strata underlying the site and the suitability of the different strata for the abstraction of water. It is assumed that groundwater would need to be abstracted from the limestone strata below the marl layer. The exact level of this layer will need to be located by intensive site investigation.
- The environmental impact of abstracting this water will also have to be known and understood.
- Will this abstraction lower the ground water level, and if so, over what areas? Could this eventually result in the sea water ingressing further under the land and even under the site or having an impact on surrounding water features?

The main issues to be assessed are the impact on lowering the water level due to the continuous extracting of ground water, whether this would increase the sea water ingression and the effects on surrounding water features such as the open water bodies at the airport.

This will need to be determined by on-site testing, monitoring and hydro-geological modelling.

Details of the water quality will be required, and the ground water tested to World Health Organisation standards. These tests will need to record a suite of data including the salinity of the water (which will have an impact on the desalination plant) and any pollutants that could be harmful to health.

Security of supply

We would recommend that an emergency connection to the main water supply system is made to provide security of supply.

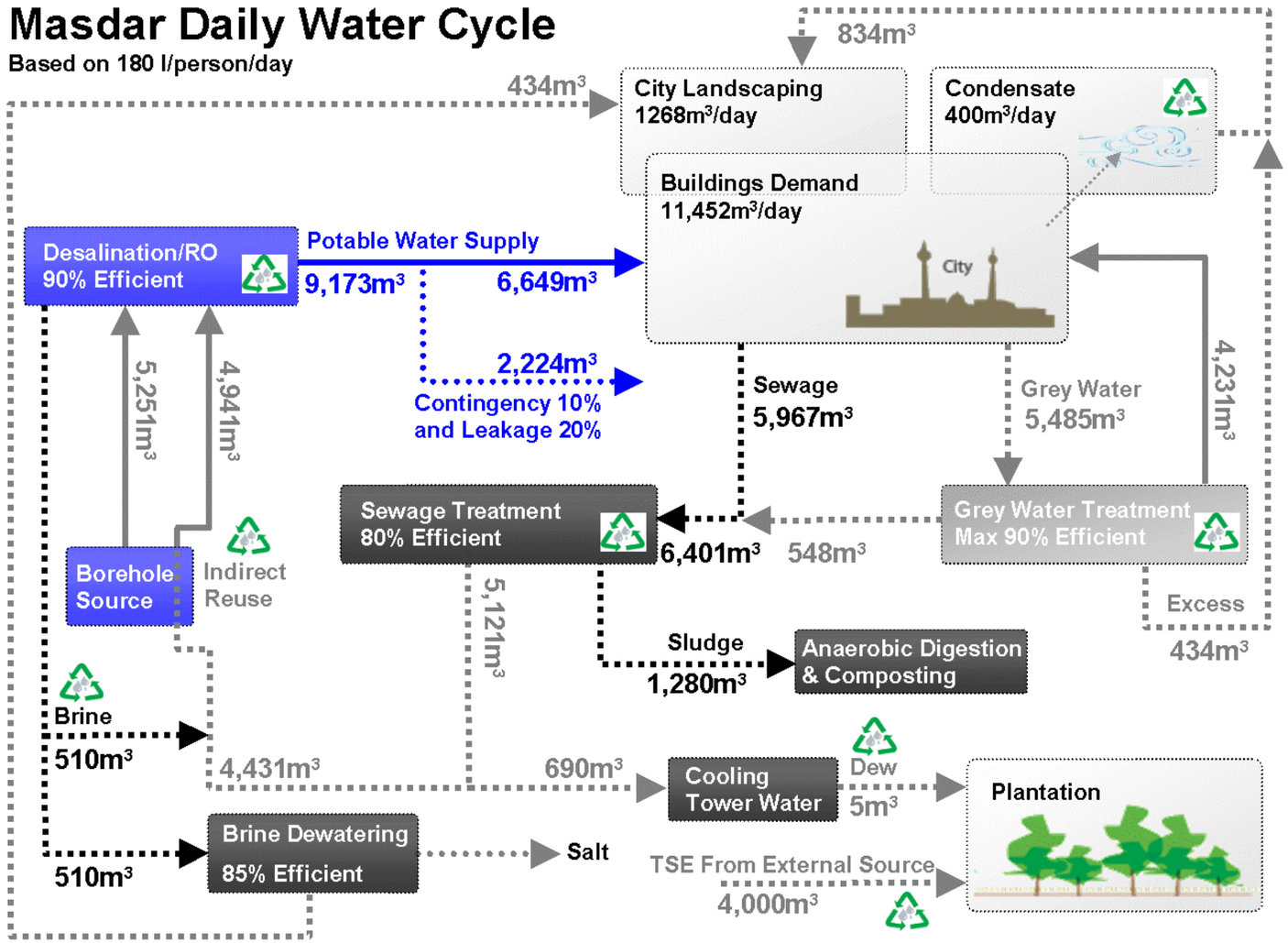
The proposed supply system does have some security within the site but there will be key areas where unforeseen circumstances may greatly increase the redundancy of the system.

Incidents to affect the supply could be: pollution of the source (siltation or chemical); a failure of the desalination plant; or a failure of power.

Implication for the Masterplan

A significant implication on the Masterplan is the additional energy requirements for the treatment and the location for a larger STW plant either within the buildings or around the edge of the city.

Another critical issue with this approach is the need for a comprehensive public awareness and education campaign which addresses the issues around water re-use.



5.2.8 Alternative Sources of Potable Water

Sea water desalination

A source of high quality sea water has been identified north of Yas Island, however access to this zone may be difficult. Under this proposal the sea water would be pumped into the Masdar development or be desalinated using a renewable energy driven Reverse Osmosis system.

Treated sewage effluent

It is understood that a main foul water pumping station for Abu Dhabi is located on or in the proximity of the site. This information needs to be confirmed by the site survey study.

It is possible to use this raw sewage via two distinct processes of recycling to extract high quality potable water: direct recycling and indirect recycling.

There is also a possibility of using the Abu Dhabi municipality treated sewage effluent network (TSE) as a source of water and treating that water to an even higher quality for human consumption.

ADWEC potable water network

The ADWEC network for potable water has as a main source of water large thermal desalination plants at ADWEC's main power stations. It is believed that these desalination plants use waste heat from the power plants to extract the water.

It is possible to use the main potable water network which inherently has a lower carbon coefficient than all the above water source solutions. However, due to the uncertainty of water supply, it would be highly risky to rely on the ADWEC network as a main water source.

Sea water desalination

Sea water is one of the primary sources of potable water for Abu Dhabi. The site for Masdar is not on the coast and therefore the sea water will need to be imported into the site from the nearest sustainable source.

Location of source

The Masdar site is located approximately 22 km from the main coastline of the Gulf. However, it is only approximately 1km from the water front at Al Raha Beach development coastline which is located near the end of a major tidal inlet which runs from the Mira Zeyeel Port to Al Raha Beach and Yas Island.

This tidal inlet could provide the primary source of water for the Masdar development as long as the environmental conditions are conducive to abstract water at this location. However, the tidal inlet is approximately 22km from the main port and therefore the main coastline and, despite being inter-linked with much smaller channels to the north which create a number of large islands, it may not be possible to find the correct conditions to abstract water.

The ideal location for an inlet for a desalination plant is clear, deep water with strong currents which can provide both a clean source of water with low turbidity and an environment where the brine can be dispersed with minimum impact on the environment.

However, the nature of tidal inlets leads to uncertainties over their long term viability as a source of water. We have detailed below the key uncertainties:

The tidal currents are likely to be very complicated; we understand there are very low velocities and the tidal data at Mini Zayed does not have the typical diurnal tidal pattern.

The Al Raha Beach and Yas Island developments are progressing in the area. This increases the uncertainty associated with water quality in the inlet resulting from discharges from these sites.

Any dredging of the waterway for shipping and to maintain access to the marina on Yas Island is likely to increase the sediment loading of the water.

The saline content of the water is predicted to increase in the future and therefore the operational performance of the desalination plant is likely to reduce in the future.

The currents in the inlet may mean it is difficult to return any brine back to the inlet as the environmental impacts are currently unknown.

Key Requirements

- A route and cost for two pipes to the inlet; we suggest that you allow a pipe size of 500 mm for a length of 3km.
- Sufficient plan area for the desalination works and the brine recovery process.
- Enough room to store and transport all the abstracted minerals.
- Sufficient energy to abstract water from the sea and process the water and the brine.

Key Risks to be resolved

- Define a route between the inlet and the site.
- Identify whether the water quality is of a sufficiently high standard to be a primary source of water, both now and in the future. This could include the cumulative impact of all the development in the area.
- Understand the impact of the Masdar development on the tidal inlet.
- Define if there is a use for the minerals abstracted from the brine.

To proceed with the strategy of using sea water as a primary source we will need to understand the following issues:

- The tidal current patterns within the tidal inlet to understand the natural ability of the inlet to refresh the water.
- The existing water quality in the inlet.
- The likely cumulative impacts of Al Raha, Yas Island and Masdar on the tidal current patterns and water quality.
- The likely increases in the salinity of the Gulf.
- Before this solution is implemented it is likely that a detailed modelling study will need to be undertaken as part of the Environmental Impact Assessment.

Brine Management Strategies

Brine is produced as a result of advanced treatment of salt or brackish water.

There are a number of methods available for disposal or reduction of wastewater effluent or brine flows.

The strategy is to partly blend the brine with TSE and recharge to the ground and the other half of the brine will be treated further to abstract the salt.

An innovative solution is the use of the brine in Salinity Gradient Solar Ponds (SGSP). Here, the brine is here used for energy production by recharging the solar pond. The SGSPs have the potential to produce low cost thermal energy from a renewable source at a large scale which can be used in the desalination process.

Innovation: alternative water sources

DEW and Fog Catchers

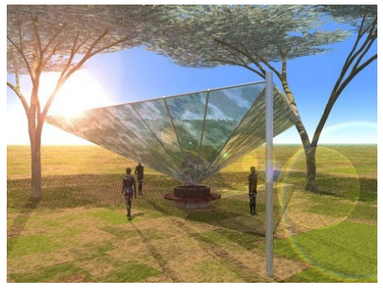
Collecting dew water from the atmosphere has been the goal of several studies, with mitigated success.

Atmospheric water vapour processing (AWVP) extracts water molecules from the atmosphere, ultimately causing a phase change from vapour to liquid. These processes condense water out of naturally occurring humid air, or better yet, fog.

The Aqua-Cycle

There are several patents extant for glorified air conditioners that dehumidify the air to produce potable water, but they all require electrical power. The Aqua-Cycle resembles a drinking fountain and

Figure 5.7: Possible sea water link into Masdar



5.2.9 Management, Monitoring and Training

The Sustainable Water Cycle for Masdar is based on a cyclical looped system. The desalinated water goes into the supply network feeding the building systems in which grey water will be reused and foul water will be treated off site and to supply the irrigation network.

This cyclical system requires all parts of the system to work, as all the water supplies are based on the loops. It is based on a 'water allowance' per resident of the city.

Management

For the management and monitoring of above described system, there are two approaches:

1. Masdar has ownership of, and responsibility for, the whole chain (except efficiency measures).
2. Masdar takes on the key infrastructure and delegates the responsibility for the buildings systems such as efficiency measures and grey water systems.

Design codes or building control could set the standards for the efficient plumbing inside the buildings and requirements for the grey water system based on the above described 'water allowance', whilst keeping flexibility in the technologies used.

The external cycle from the waste water treatment plant to irrigation can be considered as a separate system that has to be managed. The ownership arrangements of the plantation will have an impact on the management of the irrigation water from the rainwater storage areas and the treated waste water. This will have to be developed at a later stage.

The service corridors within the podium are likely to pose a challenge under current adoption standards with regards to the location of utilities, liability and access issues. The development of a new protocol either in isolation or with the local utilities provided may help to inform the Abu Dhabi 2030 plan which is intending to look at this issue of adoption.

Monitoring

It is likely that a metering system would be set up within the buildings to monitor the operation of the system. Both the potable incoming water and the amount of grey water that is being recycled should be metered.

To ensure the minimum water consumption and the maximum grey water reuse, a cultural shift in the use of water is necessary. This can be achieved through an ongoing public awareness campaign. This may be tied in with the campaign for energy use, and can be targeted at schools or the community as a whole.

The public awareness campaign may not be sufficient to meet the water consumption targets for the development. If required, enforcement of the water consumption 'allowance' and grey water reuse can be through two mechanisms:

1. Pricing of the initial water supply at normal rates; and when over consumption takes place exponentially increasing the price.
2. Providing the initial water supply under normal pressure; and when over consumption takes place vastly reducing the pressure, by a 'flow related pressure reducing valve' linked to the water meter.

The second option is probably more effective as under very low pressure people are unlikely use a shower or fill a bath so actual water use will be limited to the 'allowance'. However, a combination of both could be possible.

Training

The required skills of operators and therefore the training requirements depend on the procurement of the infrastructure.

The prevention of breakdown by having skilled operators reduces the vulnerability of the system.

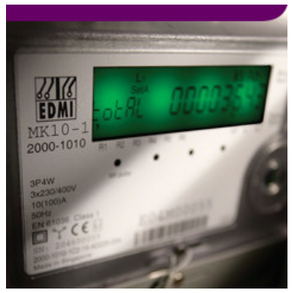
Staff with the skill/ knowledge of innovative techniques will not be readily available. However, as there will be a lead time of at least a year for the delivery of the more innovative systems, there will be time to develop a recruitment and training programme.

The technical training requirements can be split it 3 target groups:

- Technical staff
- Monitoring staff
- Management staff

These staff may be working either on a city or a building scale, which will involve different systems operation skills.

Another aspect of training will be focussed on social behaviour. Both staff and public will have to be educated in the value of water in the city and the various aspects of the sustainable water management cycle. There will be an education programme developed for the social training which may form part of the One Planet Living programme.



5.2.10 Supply Network Strategy

It is important to ensure that the water supply network is able to deliver the flow and pressure required and maintain supply in emergency situations, such as by mains failure, fire demand and reservoir contamination.

The system will initially comprise of one network for potable water, but enough space should be allocated in the service corridors to allow for a second network in the future providing drinking water. Having the dual network in place will ensure flexibility in the future.

Security of Supply

Security of supply can be ensured by creating contingency plans in the event of a pump or mains failure. This can take the form of standby pumps, dual mains, supply loops and cross connections to adjacent supply zones. Reservoirs will also need consideration, as they typically require maintenance every few years, therefore there has to be the capacity to operate the system with any one of the reservoirs out of service. There will also be storage for 48 hours' supply for the city as a whole and one day storage in the buildings.

As Masdar is considered flat, pumps will be required to move water around. Pumps rely on energy to operate and therefore careful consideration is required in order to ensure they are operated efficiently. If there is a total loss of power across the city, water will not be available other than in building storage tanks. To further ensure security of supply, water towers could be considered, as stored water will then be available to most areas even when there is a total loss of power. Alternatively, backup generators could be installed to ensure power for pumping during power failures.

Reuse / Recycling

De-centralised grey water recycling is to be used. This is where each area recycles its own grey water, rather than it being managed centrally for the whole of Masdar. This will require infrastructure to drain, treat and supply recycled water separately from the potable supply. Alternatives include draining grey water and black water (sewage) together and treating these to a standard sufficient for grey water use, or even potable use. The latter would require the least infrastructure, but could pose a psychological barrier.

If all effluent from Masdar were to be treated centrally in order to be recycled as potable water, water supply mains and storage would require an increase in capacity to cope with this. This has not been taken into account at this stage as de-centralised recycling has been assumed to be the preferred option.

The recycling of treated effluent is also being considered as a source of water for industrial processes and irrigation. This will require a separate supply main in order to ensure that recycled and potable water are not accidentally mixed.

System Pressure

The most efficient way to operate a boosted water distribution system is to supply the minimum amount of pressure possible, typically no less than 20m to 25m head at the point of connection. Reducing pressure serves to reduce leakage, reduce the risk of bursts, in some cases reduce consumption, reduce energy required for boosted supplies and increase the service life of the infrastructure.

Tall buildings will require private pumps and tanks in order to provide water throughout the building, as 20m pressure will only supply a private tank less than 20m above the point of connection.

If towers were to be used, their height would be dictated by the required connection pressure taking into account the worst-case pressure losses (due to friction, bends etc). An estimate of height would be between 27m to 30m.

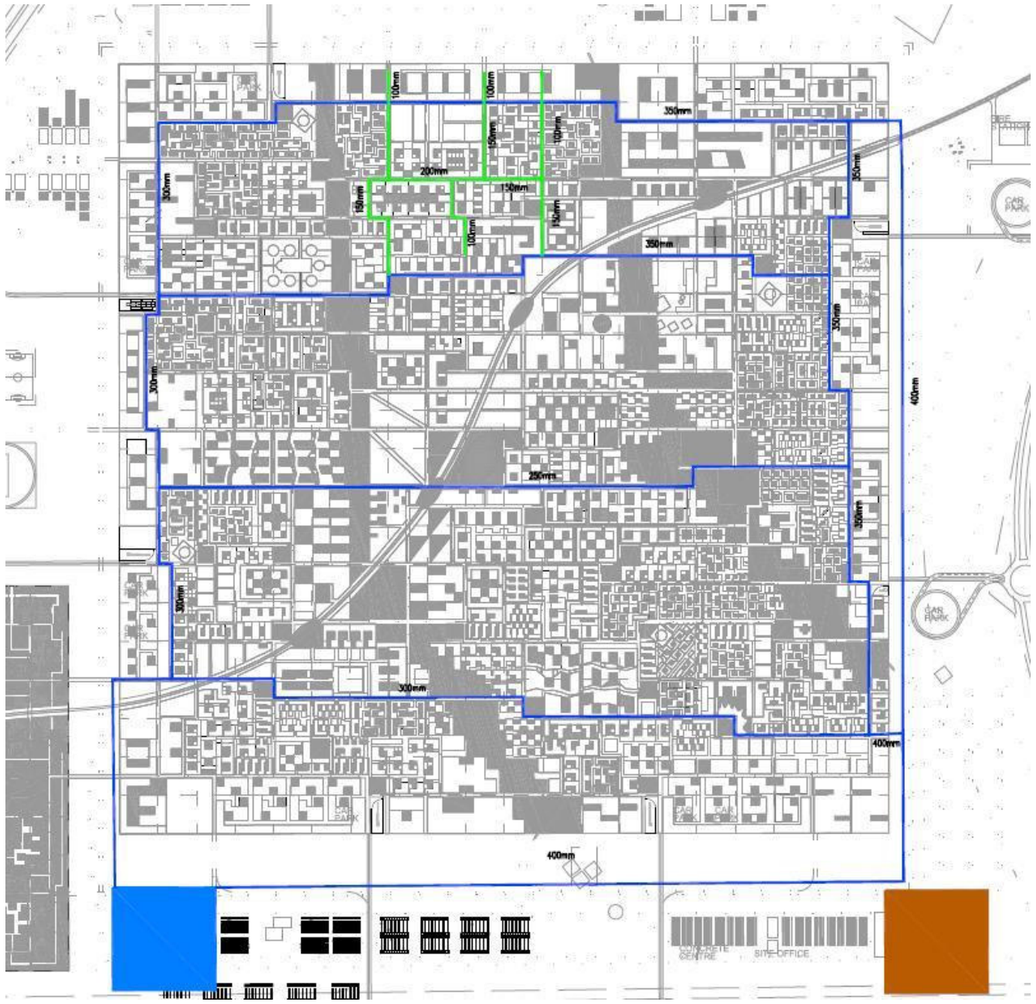
Fire Fighting

It has been assumed that the fire fighting supply will come from the potable water supply network. As such, it is important to ensure that mains sizes are such that they would allow enough flow at any point within the network for the purposes of fire fighting. Fire fighting flow requirements have been set as 31.5 l/s and must be available to tackle two concurrent fires at any location within the network, and to be sustained for a period of 2 hours. This equates to a total water requirement of 454m^3, which must be available from reserve storage.

For a boosted supply network, pumps need to be sized carefully to ensure energy efficiency. As such, the selected pumps may not be suitable to supply a sudden increase in flow as required for fire fighting. In this instance, standby pumps may be required. Water towers are more reliable in this respect, as they rely purely on gravity to supply the flow and pressure required.

Energy requirement for main potable system

The average energy requirement of the system is approximately 32 kWh with a peak demand of approximately 88.5 kWh.



5.2.11 Network design options

There are three main options relevant for water distribution network

- direct boosted supply
- boosted supply from local storage
- boosted and gravity supply with water towers

These have been analysed in the adjacent table.

Preferred Option

A direct boosted supply from a single multi cell reservoir with backup generators will be the most efficient method for supplying the city.

The number of cells in the reservoir should be designed to ensure that the system could run with one cell out of service while still maintaining a 48hour storage. This allows individual cells to be maintained while ensuring supply.

Fire fighting flows can be sustained by use of standby pumps. Backup generators will ensure supply during power failure.

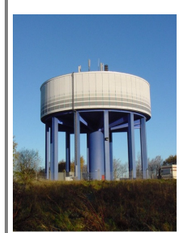
This option allows the main mechanical infrastructure to be located at a single location. This will allow better control with respect to power usage efficiencies. Security of supply can be ensured by using twin mains and loops within the mains infrastructure layout.

Full details on mains sizes and storage required cannot be provided in full until detailed network modelling has been undertaken. Estimates, assuming a boosted supply throughout the city without the use of water towers, are as follow:

- A large underground multi-cell reservoir providing a 48 hour storage totalling 20,500m^3.
- If multiple reservoir sites are to be used, the reservoirs are to be balanced by gravity if ground levels allow, otherwise pumped.
- Twin mains of a maximum of 400mm outer diameter (OD) are to link reservoirs (assuming there is more than one) to allow for balancing and to ensure security of supply in the case of a mains failure.
- Each reservoir is to be responsible for a single strategic supply zone which is to be cross-connected with closed valves to allow for changes to the zone sizes in order to balance demand from the reservoirs, and also to allow for contingency supplies in emergencies.
- Each strategic supply zone would consist of a loop so that supply may flow in either direction, allowing supply to be maintained if a mains burst occurs.
- Distribution zone trunk mains may be as big as 350mm OD. Supply mains will be 250mm OD or smaller.
- Each strategic supply zone would be split into small district meter areas (DMAs) in order to allow for more control over the system and to more easily account for leakage.
- Distribution mains velocities over 1m/s cause excess headloss, therefore, the system should be designed with this in mind taking into account future expansion and increase in demand. This reduces friction, increases service life and reduces the risk of bursts and water quality issues. Larger trunk mains can generally flow at slightly higher velocities.
- The distribution network is to be boosted with variable speed pumps and maintained at a predefined pressure based on the lowest pressure within the network.

Preferred strategy:

A direct boosted supply from a single multi cell reservoir with backup generators is the most efficient

	Discription	Advantages	Disadvantages	Options for Masdar
Direct Boosted Supply	This would involve pumping water directly from the treatment source into supply. This would require a minimum amount of infrastructure, but would rely heavily on the availability of power to run the pumps. Increasing pumping pressure increases leakage and the risk of bursts, while increasing energy consumption. Security of supply would also be an issue as it is all pumped from a single source. Backup generators to run pumps should be installed to ensure that water is constantly available.	• Headloss across the system is estimated to be between 2m to 3m, which is not a significant amount.	• Due to the distances over which the pumps will be operating, there would be head losses at the supply points furthest from the source. As a result, pumps will have to pump at a higher pressure in order to maintain minimum pressure at all locations.	Preferred option; as they need less plant and storage space and lower maintenance.
Boosted Supply From Local Storage	Like the direct boosted option above, this is reliant on the availability of energy to operate the pumps required to maintain supply pressures.	• As areas are supplied from a local source, the total head loss within each supply area is reduced and therefore pumping pressure can be kept lower.	• Extra pumps will be required to move supplies to the reservoirs, unless ground levels permit gravity feeding. • May need higher maintenance due to the distributed nature of water storage	More suitable for site with distributed water source
Boosted and Gravity Supply with Water Towers 	Towers can be located around Masdar and supply via gravity. Towers would be topped up using a boosted trunk main network which can operate when it is most efficient to do so.	• This option would typically be the most energy efficient. • In the case of power failure, water towers are still able to supply water, and the 48h storage should allow plenty of time for power to be restored. • Fire fighting would also benefit from the use of water towers, as they ensure a supply is available, and do not rely on pumps, which may not be able to supply higher flow rates required for fire fighting.	• The downside of water towers is the space they take up, their height and also their impact on the aesthetics of the city.	May not be suitable due to the space requirements

5.2.12 Grey water reuse strategy

Grey water is defined as household sourced wastewater without any input from toilets and so typically includes supplies from baths, showers, hand basins, washing machines, dishwashers and kitchen sinks.

As secondary source, grey water could be partially treated and reused directly as a 'non-body contact' source, for toilet flushing or laundry.

Grey water systems treat and recycle grey water to process water standards.

Grey water treatment

The risk of becoming infected from grey water where it is used for toilet flushing is considered to be low. Infection would require ingestion, or skin contact with untreated grey water.

There is a significantly higher risk if the grey water has been stored untreated for some time and proliferation of bacteria and infective organisms allowed to take place. Grey water must, therefore, be disinfected if it is to be a safe option for use.

Grey water treatment systems can be categorised in three groups, i.e., Chemical, and Physical

Most systems include a screening or sedimentation stage prior to the main treatment and/ or final disinfection stage.

Refer to the table for Comparison of Grey water Treatment Options.

Filtration of grey water

It is essential that grey water is coarse filtered before it is stored. This is to prevent the build up of debris in the storage tank, which would encourage bacterial growth. Coarse filters also ensure that large particles, such as hair, do not impair pump and valve functions, clog pipes, or appear at the point of use.

Disinfection of grey water

It is recommended that no total coliform or *E.coli* counts should be detectable in 100 ml treated reclaimed water. This will require disinfection which can be either chemical or physical (UV).

Innovation:
As part of the research for this section we have identified that Cranfield University have developed a new grey water recycling system which

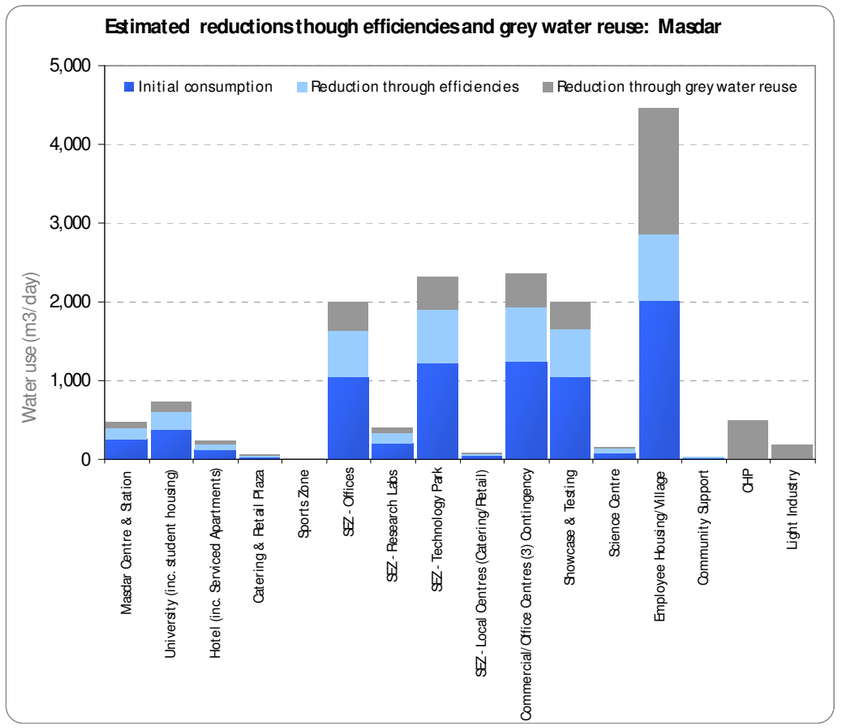
Preferred strategy: biological or chemical treatment

The table identifies different performance criteria of each type to achieve required World Health Organisation standards.

A chemical or biological system, which can include the membrane reactors, will be most suitable for use within the city. Biological schemes reliably achieve excellent organic and solids removal. At larger scales of application and where higher variation in grey water quality can be found, the energy consumption of an MBR compared with other options may be more favourable.

Table 5.3: Grey water treatment systems

	Discription	Advantages	Disadvantages	Options for Masdar
Physical (sand filter, adsorption and membrane)	Physical treatment of grey water typically involves passing it through a filter [sand and gravel] to remove any solids, disinfection by the addition of a small amount of chlorine bleach and/or UV treatment, and then sent to a settling tank. The addition of an electric pump or an aerator can be used to oxygenate the grey water before use which makes it much better for irrigation. Ultrafiltration membranes are a relatively new development; they use polymer film [or active coal] with chemically formed microscopic pores that can be used in place of granular media to filter water effectively without coagulants. The type of membrane media determines how much pressure is needed to drive the water through and what sizes of micro-organisms can be filtered out.	• Low cost • Relatively small footprint required • low maintenance	• May require relatively higher energy • Low performance and reliable	Not recommended
Chemical treatment (photo catalysis, electro-coagulation and coagulation)	Few schemes use chemical technology for grey water recycling. Examples were found on coagulation with aluminium, and photo catalytic oxidation with titanium dioxide and UV. These technologies achieve results in relatively short contact times.	• High performance • Relatively small footprint required	• High cost and maintenance • Requires ongoing addition of chemicals	Suitable option
Biological treatment of grey water (biological aerated filter, rotating biological contactor and membrane bioreactor)	Active biological treatment has, so far, been limited to multi-residential and communal grey water systems. This is because of the need for supervision of this more sophisticated technology. Slow sand filters provide passive biological treatment as a bio-film establishes on the sand. Active biological treatment takes place in a reactor vessel that contains media (usually small plastic shapes with high surface area) on which bacteria are encouraged to grow. A wide range of biological processes can be used for grey water recycling; fixed film reactors, rotating biological contractors, anaerobic filters, sequencing batch reactors, membrane bioreactors and biological aerated filters.	• Medium maintenance • Ecologically sensitive choice as low environmental impact • High performance • Reliably achieve excellent organic and solids removal	• Larger foot print required	Suitable option



5.2.13 Wastewater treatment

The options appraisal for the wastewater treatment works needs to consider the following issues:

- Provide a solution based on the whole life costs.
- Provide assets that are fit for purpose and appropriate for their surroundings which will provide the ability to return treated effluent to the ground as part of an indirect reuse system and the opportunity for the development to undertake a direct recycling scheme in the future
- Provide places of work that are safe and without risk to heath.
- Provide a robust process that will remain functional during times of planned maintenance and outages.
- Meet the following notional consent which is suitable for irrigation uses:

Preferred option

The preferred strategy for the secondary treatment option is a Membrane Bioreactor (MBR) process unit which will allow the flexibility for the plant to obtain a water quality suitable for reuse either indirect or direct within the site.

Tertiary treatment will be required to clean the water to the required level and the preferred method is micro filtration and reverse osmosis. This could be combined with disinfection systems such as chlorination or UV if required.

The amount of tertiary treatment and therefore the overall land and energy required will need to be confirmed after further discussion with the Environmental Protection Agency and other key stakeholders.

It is likely that the amount and degree of tertiary treatment will also vary if we are looking at an indirect or/ and direct recycle scheme.

Masterplan Implications

Plant size: We currently anticipate that the area for the recommended solution will be approximately 2-3 hectares.

Cordon Sanitaire: The Sewage Treatment Work should be sited at least 250m from habitable buildings to avoid the risk of nuisance (including, but not limited to, nuisance from odour or noise) being caused to the occupants of those buildings.

Energy Requirements:

- Primary treatment – 0.75MvA
- Secondary treatment (MBR) – 1400 kWh
- Tertiary treatment -7500 kWh
- Disinfection – 10 kWh

Further details of the above can be found in the Masdar Outline Process Design Feasibility Report.

Preferred strategy:
Membrane Bioreactor combined with micro filtration and reverse osmosis

	Discription	Advantages	Disadvantages
Lagoons (Oxidation Ponds or Stabilisation Ponds)	Lagoons generally comprise a series of ponds which promote the natural treatment of sewage. Algae grow within the lagoons and use sunlight to produce oxygen, which is in turn used by micro-organisms in the lagoon to break down organic material in the wastewater. Wastewater solids settle in the lagoon, resulting in effluent that is relatively well treated, although it does contain algae.	• High biochemical oxygen demand [BOD] removal • Low sludge removal costs • Simple and cheap to construct • Low maintenance and running cost	• Poor ammonia removal • Requires relatively large area
Biological Filters	Trickling filters are beds of coarse media (often stones or plastic) 1-3m deep. Wastewater is sprayed into the air (aeration) and then allowed to trickle through the media. Micro-organisms attached to and growing on the media, break down organic material in the wastewater. Trickling filters drain at the bottom; the wastewater is collected and then undergoes sedimentation in humus tanks.	• Simple and cheap to construct • Ease of maintenance	• Poor ammonia removal • Requires relatively large footprint
Rotating Biological Contactor	Rotating Biological Contactors (RBC) comprise a series of structured plastic media (discs) mounted on a horizontal shaft which slowly rotate whilst partially immersed in a trough filled with effluent to be treated.	• Simple and cheap to construct • Ease of maintenance	• Poor ammonia removal • Requires relatively large footprint
Submerged Aerated Filter	A Submerged Aerated Filter (SAF) is an aerobic reactor. It comprises a force (air from a blower/compressor) aerated tank full of inert media. The media supports a biologically active film for aerobic treatment of the wastewater.	• Simple and cheap to construct • Ease of maintenance	• Poor ammonia removal • Requires relatively large footprint
Traditional Nitrifying Activated Sludge Plant	A Traditional Nitrifying Activated Sludge Plant (ASP) in its simplest form is a plant consisting of a tank (anoxic and aeration) which provides an enclosure for aerating and mixing suspended biomass and wastewater or mixed liquor. A final settlement tank installed after the tank separates the suspended biomass which is either returned to the head of the process in the form of return activated sludge or transferred to sludge holding tanks as surplus activated sludge. Variants of this process include: Extended Aeration ASP, Compact Oxidation Plant, Step Feed ASP, and Biological Nutrient Removal Plant	• Good amonia removal • Simple to operate • The technology is known to the Abu Dhabi Sewage Services Company	• Average overall performance
Sequencing Batch Reactors	Sequencing batch reactors (SBR) typically consist of 4 identical tanks (for a population equivalent of 60,000) in which the whole treatment process is undertaken. The process undertaken in a single tank comprises four cyclic stages which are: the fill stage, the aeration of activated sludge and wastewater stage, the settlement stage and the decanting stage. Excess sludge is then wasted before the cycle begins again. Once a tank has completed the fill stage it commences the treatment process starting with the aeration stage etc. while the incoming effluent sequences onto the next tank. This continues until the first tank is again available for filling.	• Simple and cheap to construct • Required less land area	• Complex operation
Membrane Bioreactors	The MBR process is essentially an activated sludge processes whereby membranes are used for liquid-solid separation instead of the usual final settlement tanks. Suspended solids are removed completely and bacteria-free treated water can be produced.	• High biochemical oxygen demand [BOD] removal • Removes solid particle well	• High capital cost • Complex operation • High maintenance costs
Biological Activated Flooded Filtration	Biological activated flooded filtration (BAFF) is a variant of the SBR. The BAFF offers high biological and solids removal capabilities combined with negligible odour emissions all within a small footprint plant.	• Simple and cheap to construct • Required less land area	• Complex operation
Moving Bed Biological Reactor	The Moving Bed Biological Reactor (MBBR) process involves the growth of the biomass in plastic supports that move in the aeration tank because of the agitation created by the aeration process. The supports are made of plastic and have a density of around 1gr/cm3 which means that they can easily move around the tank even when the percentage occupied by the plastic is 70%. The biomass stays in the tank together with the plastic support so any external sludge recirculation is not required from the final tanks. The quantity of stored	• Required less land area	• Complex operation

Table 5.4: Comparison of waste water treatment

5.2.14 Sewerage network

The sewerage network is the system of foul water sewers that conveys wastewater to a treatment plant or disposal point. It includes all the pumps, rising mains, gravity mains, air release valves, screens, overflows and other associated infrastructure.

All sewers will be laid within corridors that run beneath a raised platform, which, due to its flat topography forms a challenge in terms of draining the site by gravity. Therefore, two options have been considered for the foul water drainage; both gravity and vacuum systems.

The design and sizing of the foul sewage systems considers the developments population in conjunction with commercial and industrial discharges.

Preferred foul water strategy

The preferred foul water system for the city will probably be a combination of the gravity system of trunk sewers in and around the city and vacuum systems to collect foul from the buildings and convey it to the trunk sewers.

The vacuum system could be private and maintained by a management company when adoption by ADSSC could prove difficult.

Preferred strategy:
A combination of the gravity system of trunk sewers in and around the city and vacuum systems to collect foul from the buildings and convey it to the trunk sewers.

Energy requirement

The energy requirement of a vacuum drainage system is typically around 0.015 kWh/ person/ day.

	Discription	Advantages	Disadvantages
Gravity Sewerage	The principle of gravity foul water system is that trunk sewers in the service corridors would convey the wastewater by gravity via the shortest route to a point outside the city walls. From there, foul water would then be conveyed by a gravity fed trunk sewer that runs around the perimeter of the city collecting all sewerage from the trunk sewers to a pumping station in the north western corner of the site that pumps the sewerage to the waste water treatment plant. It should be noted that while this network is mainly drained by gravity, the flat topography in conjunction with a maximum network depth of 4 meters, would mean intermediate pumping stations would be required. With a proposed building platform of 6 m and a maximum distance from the furthest point of each development plot to the network of 150m, it is likely that each plot should be able to gravity drain into the public network. However, pumping may be required for a number of plots. Low pressure systems use a small grinder pump located at the point of connection, typically a building.	• The system is gravity fed • Network depths would be restricted to 4m • The pump station requirements are considered to be minimal when compared to a vacuum system.	• The system is designed to meet minimum self cleansing requirements whilst reducing the network gradients. However, it may be more susceptible to blockages and could therefore reflect on increased maintenance requirements.
Vacuum Sewerage	A vacuum sewerage system is a drainage system that operates under negative pressure to discharge wastewater flows from a property or group of properties. The system may consist of one or more vacuum pumps, a central vacuum reservoir, pipe works and interface units. For strategy purposes the city has been split up into 8 sections, with 8 vacuum stations. Each area/section will have about 100 Vacuflow interface units. Large inefficient diameter pipes and vacuum stations were avoided in order to reduce energy. The size of the trunk sewers depends on the location of the waste water treatment plant. A typical vacuum station for this development would be around 10m x 15m x 3-3.5 m. The size is more or less determined by the size of the vacuum tank, for this each vacuum station would need a $25m^3$-$30m^3$ vacuum tank but it could also be served by 2 smaller vacuum tanks with a by-pass between these tanks to lower the height. The energy requirement of this system is typically around 0,015kWh/ person/day.	• As the system is not tied to gravity, it is more flexible for installation under the raised platform.	• Energy demand may be higher than a gravity system • The consequences of failure of the system are generally more severe than with gravity drainage, as it can flood the property. • Electrical and mechanical equipment will need maintenance and eventual replacement. Some of the mechanical equipment is heavy and bulky and may be difficult to move in a dense city relying on alternative methods of transport. • De-odourising units (biofilters) clean up the exhaust gases from the vacuum system. These take up a reasonable amount of space and must be vented to atmosphere. • ADSSC may reject to adopt vacuum sewer systems. There are no local design standards as none of the sewage companies in the Middle East has used these systems.

Table 5.5: Comparison of the two sewage network options

5.2.15 Sustainable Surface Water Management

A surface water drainage strategy at Masdar must, whilst delivering a sustainable integrated drainage solution, be capable of achieving three fundamental hydraulic requirements:

- The effective receipt and control of rainfall at source
- The efficient conveyance of rainfall runoff away from its source to a suitable receiving body
- The disposal of runoff post conveyance in an efficient sustainable manner

The design approach to strategic drainage master planning for Masdar was to consider a number of different solutions which achieve each of the above but with varying emphasis placed on each whilst maximising the potential for rainwater reuse.

Abu Dhabi experiences low frequency, high intensity rainfall. Any proposed system will require a large amount of storage which could accommodate such high rainfall intensities. The low frequency of rainfall in the area however will mean that this large amount of storage will be used infrequently.

In terms of topography the development area presents a number of challenges to achieving the control, conveyance and treatment of surface water. The site is flat in nature with a high groundwater table. In terms of conveyance of storm water, gradient is a key factor whilst any areas receiving conveyed flow will need to consider the relatively high groundwater table. Therefore the depth and level of proposed drainage is a key issue.

Additionally the high groundwater table precludes the infiltration of surface water runoff to underlying geology and therefore all runoff must be stored prior to reuse or disposal.

Key Considerations

- Low frequency, high intensity rainfall.
- High groundwater table
- Flat topography
- Maintenance issues due to sand
- High consequence of flooding owing to high density development

Retention and reuse of rainfall

This would involve the provision of storage structures at source i.e. local level to attenuate and treat rainfall for reuse within the development area as part of the overall water cycle strategy. Options for retention storage at Masdar include:

- Roof tops
- Landscaped bio retention areas
- Permeable pavement

The main options for rainfall reuse at source are Drinking water and Irrigation of courtyard/gardens.

Development at Masdar will provide a high proportion of impermeable area from which rainfall runoff for reuse may be generated. However, the highly dense nature of development at Masdar coupled with low frequency rainfall dictates that the volume of rainfall available per person within the development will be extremely low. As a stand alone option, development would derive little benefit from the large amount of infrastructure required for rainfall storage for drinking water purposes.

Rainfall may be collected and conveyed away from local development to a central point either within or outside the core development area. Surface water volumes could be stored and further utilised elsewhere through water re-use within the core development area and irrigation of agricultural/green areas.

Options for conveyance

Options for surface water conveyance and storage at Masdar include:

- Open channel conveyance in the form of ditches/swales (to convey excess storm water to storage elsewhere)
- Utilising roadway corridors to route excess storm water away from local areas (to storage elsewhere)
- Traditional surface water sewers (to convey excess storm water to storage elsewhere)
- Large enclosed underground culverting to provide conveyance and storage
- Local or site wide Green corridors/basins
- Natural Wadi areas (to provide a means of strategic site storage)

Proposed Strategy

It is proposed to develop an integrated balanced approach to surface water drainage at Masdar which incorporates source control, conveyance and strategic storage.

A balanced strategic approach will allow for the maximisation of rainfall re-use whilst addressing the constraints posed by existing / proposed topography, proposed development density and flood storage requirements.

The proposed strategy essentially separates proposed high level podium areas from low level courtyard areas. Source Control methods are proposed for low level areas (courtyard /landscaped areas) with the remaining proposed drainage elements catering for all other runoff i.e. all remaining hard standing areas.

Source control techniques

Drainage within built footprints of low level open courtyard and landscaped areas is proposed via source control techniques as providing an outfall is difficult to achieve. The design process has identified bio-retention and porous pavement areas as suitable stand alone source control methods for draining low lying areas in isolation to the remaining strategy. Collected rainwater will be lost naturally through local irrigation, plant transpiration and evaporation.

Storm water storage

It is proposed to drain the remaining impermeable areas via a collector system of traditional surface water sewerage draining to strategic storm water storage situated within the core development area. The drainage of the podium level requires that the podium level itself follows the level requirements of the conveyance system.

As such podium levels vary across the site and create six distinct drainage catchment areas across the development area.

Strategic storm water storage is planned underground beneath the landscape greenways planned through the core development area. It is proposed to provide a series of linked underground tanks which will store all rainwater up to and including the 1 in 50 year rainfall event. This system will ensure that the development can cater for extreme rainfall events without exacerbating flooding outside the development area.

It is proposed that the storage system withholds all storm water up to and including the 1 in 50 year design rainfall event. Stored volumes may be reused within the development itself or discharged to a proposed irrigation channel running adjacent to the development perimeter as and when required. This perimeter channel will allow the development to convey flows around the city perimeter for reuse where and however required. The perimeter channel will also provide flood storage to those catchment areas along the edge of the Masdar development which are not accounted for by the main site storage due to level constraints.

Figure 5.11: Drainage Network

Preferred strategy:

A combination of the following elements:

- Source control drainage using bio-retention and permeable pavement
- Traditional surface water sewers
- Underground strategic storage within the proposed green corridors on-site
- Irrigation channel around the site perimeter

5.2.16 Implications of Developing the Small Square

The small square could be developed independently from the main square but would face the same issues as the main square:

- Having a sustainable source of water
- Disposal of the brine
- Disposal of the treated effluent

Therefore, it would make sense for these issues to be addressed at a development scale rather than having to create a secondary strategic infrastructure system:

- Abstraction boreholes
- Desalination plant
- Sewage treatment works

When these key items are being designed they should be designed so they could be expanded to provide the additional supply requirements.

We have identified below the key impacts of the small square on the proposed strategies.

Water minimisation

No impact on main strategy but likely that greater efficiency can be expected by the end of the project.

Water demand

The development of the small square will have various implications on above detailed strategy. The square will consume 1,871 m^3/d of additional desalinated water, of which half will be indirect reused treated effluent, and the rest will be through grey water recycling.

This additional demand will have to be provided by desalinating approximately 900 m^3/d more 'new' groundwater. This means the desalination demand will increase with approximately 25%.

The strategy is per main square.

Water supply

The system would be linked to the main supply zones but effectively will be independent including its own strategic fire supply reserve.

Foul drainage

The sewage network will be based on the same principles as the main site, using a combination of vacuum and gravity systems to direct the flows out of the city and to the sewage treatment works north of the main site.

Foul treatment

As per large square.

5.2.17 Phasing

The phasing of the water infrastructure to support this development will be critical in terms of both providing water for construction and construction workers but also the individual phases of development. The layout of infrastructure will need to be valid both during construction and once the development is completed.

Phase 0A

- Create a temporary connection to the water mains system for construction.
- Identify the location and number of boreholes to supply the site with water and dispose of the treated effluent.

Phase 0C

- Set up a temporary borehole and supply system
- Install permanent borehole
- Start construction of sewage treatment plant (12-18 months programme)
- Start construction of the desalination plant.

Temporary sewage treatment facilities may be required to deal with construction waste. This could either be via a package plant or via disposal to a local STW.

The supply network for Phase 1a:

- Water supply
- Foul sewerage
- Surface water system

Phase 1A and beyond

Infrastructure will need to be increased with the development to meet the predicted demand.

As can be seen from the table showing the phased water demand, the demand grows gradually; therefore modular implementation of the various systems and networks is feasible.

Phase	Cumulative Demand (m3/d)
1a	687
1b	1,425
1c	1,704
2a	2,342
2b	2,504
2c	3,351
3a	3,732
3b	4,390
3c	4,833
4a	5,262
4b	6,063
4c	6,913
5a	7,330
5b	8,038
5c	8,527
6a	8,767
6b	9,134
6c	9,715

The proposed installed capacity will be driven by the demand growth as shown in the figure overleaf.

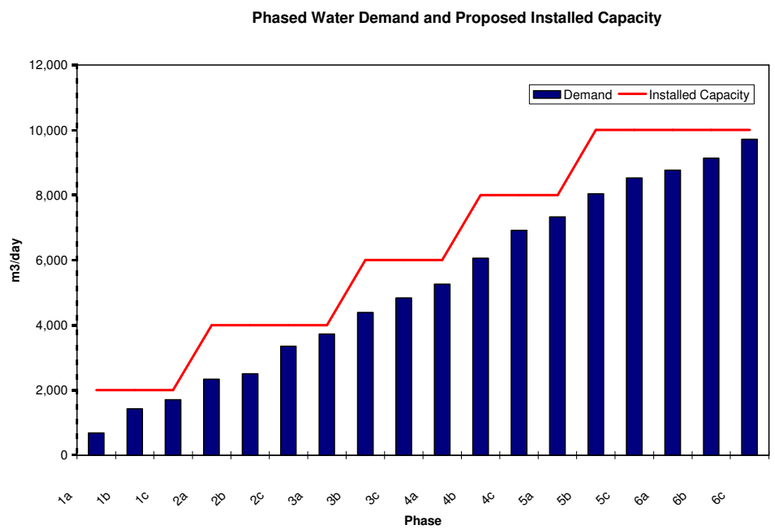


Figure 5.12: Water Demand vs Installed Capacity

Waste

5.3.1 Context

Solid waste can create significant health problems and a very unpleasant living environment if not disposed of safely and appropriately.

Every day each resident in the UAE generates 1.8kg of wastes[1]. This high volume of waste generated is exacerbated by the fact that the Middle East largely abstains from recycling and formal recovery activities; instead opting for traditional landfill disposal of waste.

Target: Zero Waste City

Masdar will be a zero waste city, a blueprint for sustainable urban environment and an inspiration to the pattern of future development. To achieve this, an innovative, effective and challenging waste management strategy has evolved that seeks to close all waste and material cycles so that products and resources flow from cradle to cradle.

Masdar has committed itself to become Zero Waste and Zero Carbon. This has fundamental implications for the design of the development and the lives of its inhabitants.

Within the Masdar development there is a requirement to manage household, commercial and industrial wastes. As a fundamental principal, it should be considered that what are typically referred to as 'wastes' should be understood as materials and resources that have reached a particular stage in their lifecycle. Whereas a society with a linear resource pattern looks to dispose of wastes at this stage, a 'cradle 2 cradle' society will look to reinvest these resources and thus benefiting that society from increased economic activity and environmental improvements.

The success of the Masdar development requires that resource management is approached with this future focused and progressive attitude. This does not necessarily refer to complex or technologically intensive ideas happening today but it does recognise the role of technology and innovation and the power of behavioural change and public engagement.

The principles that have been established to support the conceptual masterplan include;

- Establishing the masterplan driven by a 'cradle 2 cradle' approach;
- Evolving ideas that recognise the role of consumer behaviour and public participation;
- Recognising the contribution of innovation and new technology but also better application of established methods; and
- Working towards zero waste at all times, and contextualising this at local, regional and global levels.

- Every day each resident in the UAE generates 1.8kg of wastes
- Masdar aspires to become a zero

Innovation

- Radical waste minimisation measures
- Target 50% recycling
- Composting of organic waste
- Energy recovery
- Plasma arc

[1] Source: Envac

Figure 5.12: Waste management infrastructure

Waste

Recycling Market in the UAE

Although the Municipality of Abu Dhabi encourages the practice of separation of different types of wastes, domestic waste is not typically separated in households. There are some small scale pilot projects for waste recycling, however the Municipality has not actively promoted source segregation of waste. There is also an absence of policy implementation to control waste generation and disposal quantities.

The waste collected by the Municipality is transported to transfer stations where the garbage is sorted and any metal is removed through the use of magnets. The organic waste is recycled to create garden compost at the Abu Dhabi Compost Plant. In many cases the waste is deposited untreated at landfills.

Recycling in Abu Dhabi has been a purely private sector initiative and therefore is practiced on a small scale and is not monitored or centrally organised. The existing recycling companies operate under different conditions and policies of charging and treatment. Some companies have free of charge recycling while others levy a fee per collection. Sometimes waste is processed and sent overseas.

A list of the approved recycling companies was provided by the Environment Agency Abu Dhabi (EAD) and a research study undertaken through telephone interviews. Special mention must be made of the final disposal practices of those recycling establishments that charge a fee for the collection of waste. In many cases companies report that after charging a fee for the collection, the waste is sent to landfill instead of being recycled, as a way to improve business turnover.

Waste that is sent to other countries should normally not represent a problem (other than the CO_2 generated due to transport) since it is considered to be a raw material for certain processes.

It was reported that Aldar, a property developer in the UAE wants to establish a Material Recovery Facility in Abu Dhabi in the near future.

In Dubai, domestic waste separation and subsequent door to door collection is not practiced in spite of an earlier initiative promoted by Dubai Municipality. There are several recycling centres within the city which allow citizens to drop off paper, glass, aluminium and plastic to labelled containers for further treatment. Some pilot projects established by the municipality are currently running, among them a material recovery facility.

There are established private recycling companies that collect specific types of waste (e.g. printer cartridges) for reprocessing or to be sent to other countries where the waste is used as raw materials. A list of such approved recycling companies has been provided by Dubai Municipality (DM).

Hazardous Waste in the UAE

Hazardous wastes are residues or ash containing substances that are harmful to health or the environment. Most of the hazardous waste in Abu Dhabi Emirate is generated by the oil industry, in agriculture and by households. While the Environment Agency has taken steps to manage import and export of hazardous substances, little attention has been paid to separating hazardous waste from municipal waste.

Since hazardous substances are not collected separately from households in Abu Dhabi, their quantities can only be deducted on the basis of their estimated percentage of total municipal waste.

While industrial hazardous waste has received increased attention in recent years, households continue to pollute their surroundings. Hazardous waste is dumped into the toilets or mixed with regular household waste in landfills.

The EAD is however making efforts to manage hazardous materials before they become waste. The programme started in 2001 includes:

- Permitting of handlers.
- Issuing permits for import export and re-export.
- Customs inspections to monitor both quantity and quality of materials.
- Developing procedures for handling and transport of chemicals

Sustainable Waste Management

Traditional sustainable management of resources follows a well established hierarchy of 'Reduce, Reuse, Recycle, Recover and Disposal'. Masdar looks to evolve this model so as to eliminate 'disposal'.

The first and foremost principle of any waste strategy must aim to minimise waste generation. The UAE is one of the highest producers of waste per capita in the world and, therefore, the challenge is substantial but the opportunity is equally great. Masdar will set an example by pioneering not only its resource management systems but also in the minimisation of waste through innovative measures.

To achieve this at the city-level involves fundamentally challenging accepted Middle East norms such as free collection and disposal of waste, the reconsideration of methods of packaging products, and the purchasing of recycled materials. Significant minimisation is an ambitious goal as it involves fundamental changes in policy and in social behaviour, which often receive the most resistance but it is from these roots that a 'cradle 2 cradle' society will grow.

After minimisation, the next step would be the reuse of this resource for the same purpose for which it was designed and without processing. This is a simple, cost effective and convenient means of minimising waste generation. Recycling comes next where the material composition of the waste is altered for a new use. Recovery of energy in particular, either through direct combustion or from syngas extraction, is the final option available to Masdar.

Benchmarking

Masdar has been benchmarked with similar developments around the world. Dongtan is a 8600 hectare site in China, designed to be a zero waste city. This city aims to recycle and remanufacture most of its solid waste, and the bulk of the organic waste was composted and returned to local farmland to assure long-term fertility.

Another zero waste project was implemented in Northstowe, UK; a 9,500 home community five miles north-west of Cambridge, where a household Waste Recycling Centre was installed. Also the kitchens were provided with chutes for compostable waste which was taken to permanent composters where no space for composters bins was available.

The Zero Waste Kovalam Project, in south India incorporated a zero waste centre, which was a Resource Education Centre with the objective of providing training, product design and development and awareness about resource use.

The Zero waste Communities of San Bernardino County, United States comprises 16 cities and townships which have partnered to educate their residents and businesses on waste reduction, reuse and recycling. Zero waste goals set up were to educate consumers to buy products made of recycled materials and products that can be reused and repaired; they involved the manufacturers in the process and encouraged them to take greater responsibility for the proper disposal of their products.

Figure 5.13: Waste Hierarchy

Masdar Waste Management System;

- Suite of innovative Waste Minimisation Measures;
- Household waste will be segregated at source into (i) Dry Recyclables, (ii) Wet Recyclables, and (iii) Non-Recyclables;
- The waste will be collected door-to-door via the PRT system or by gravity chutes and vacuum chutes;
- Recyclables will be sorted in a Material Recovery Facility and sold to the recycling market;
- Wet recyclables will be composted in in-vessel containers and used in the biomass plantations and landscaped areas;
- Waste sludge will be an aerobically digested and the resulting methane will be captured and the residue used in biomass plantations;
- Non-recyclables will be processed in a Waste to Energy Pyrolysis and Gasification plant;
- Hazardous waste will processed by a Plasma Arc Vitrification unit and the resulting material will be recycled into construction materials;

Waste

5.3.2 Waste Arising

A Waste Arising Model [2] has been developed to calculate both the profile of waste generated from different land uses in the development and the total mass of waste per component of that profile.

Base estimates

The base calculation estimated that a total of 245,356kg of waste would be generated at Masdar every day, or 89,555 tonnes per year. Based on the profiling of the waste, it was estimated that 63% of this total would comprise recyclable material, 21% would be compostable, and 16% 'non-recyclable'.

Given that these base figures were calculated using current average rates for Abu Dhabi, it was assumed that significantly lower amounts of waste would be generated at Masdar after the various waste minimisation measures (see below for further information) are applied. For the purpose of the Waste Arising Model, it was assumed that these minimisation measures would result in a reduction of 30% of current Abu Dhabi generation rates to give a waste generation total of 62,688 tonnes per year. It is difficult to accurately predict the impact that the range of minimisation measures may have on waste generation in the future but a reduction of 30% was chosen as a challenging but achievable target.

Estimated rate of recovery

Finally, the target rates of recovery of the recyclable and compostable materials were estimated to be 60% for residential waste and 85% for commercial, industrial and 'other' generators of waste. These recovery rates are higher than the average rates in Europe and the US; however these challenging targets will need to be set in order to meet the Zero Waste objective.

If the above recovery rate targets are met, then the waste arising model indicates that of the 62,688 tonnes of waste estimated to be generated at Masdar every year, 50% or 31,513 tonnes would be diverted to recycling, 16% or 10,273 would be diverted to composting, and the remaining 33% or 20,902 tonnes would be diverted to the thermal treatment. A fraction of the thermally treated waste and the household hazardous waste would be processed by a Plasma Arc Vitrification unit and then recycled into construction materials.

No waste will be sent to landfill.

- A total of 245 tonnes of waste would be generated at Masdar every day
- A reduction of 30% can be achieved through waste minimisation measures at Masdar

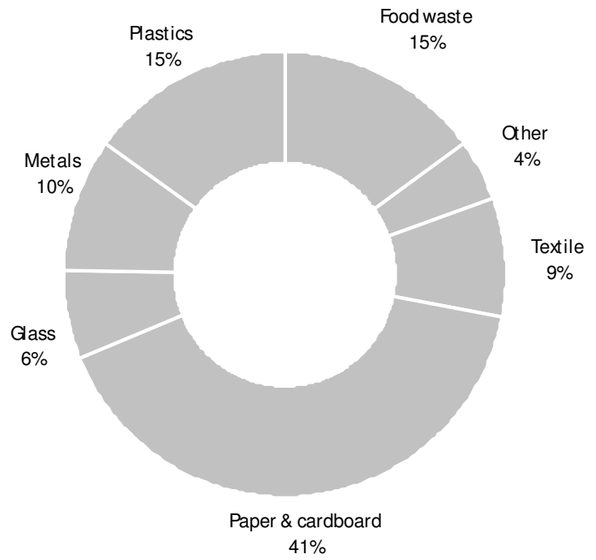
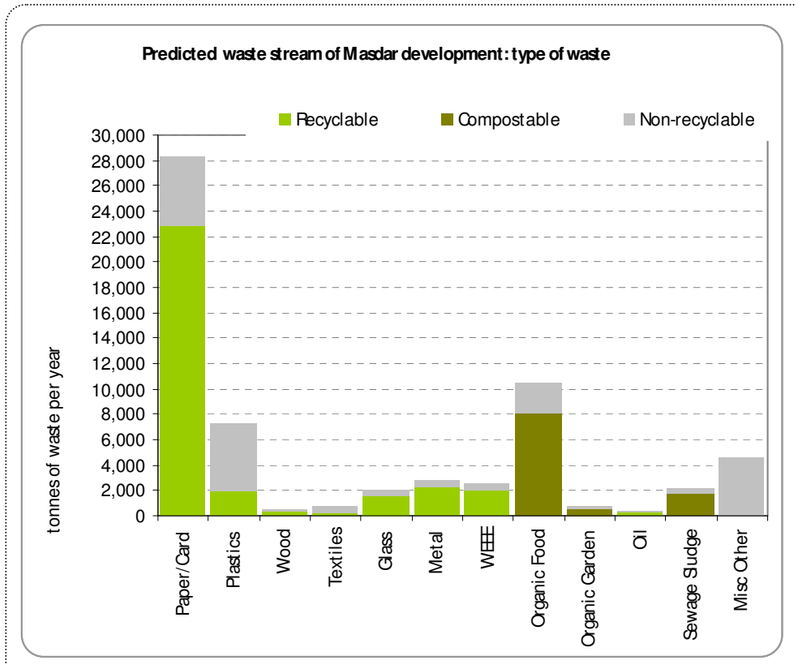


Figure 5.14: Typical Residential waste breakdown: Source: AME (2004)



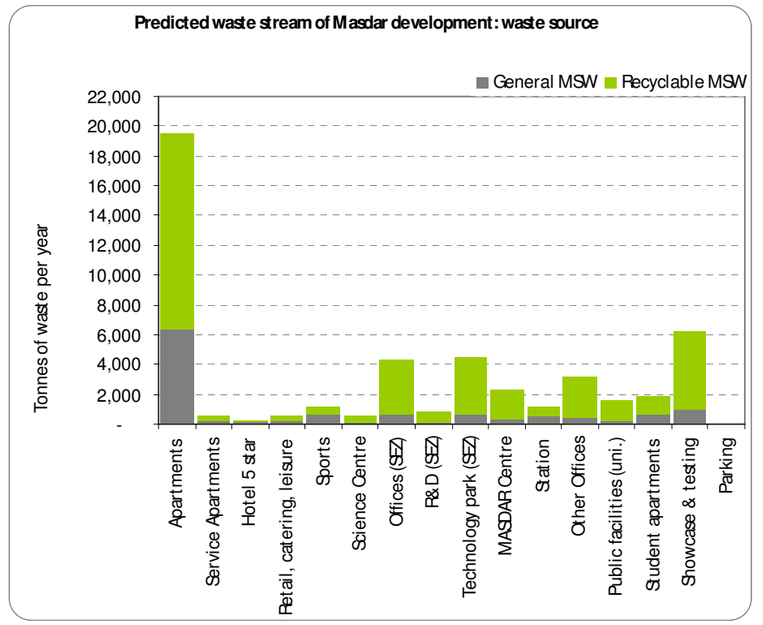


Figure 5.15: Waste stream by type and source

[2] The Model has been developed using available data for the UAE and the Middle East. However, waste data for the UAE is far from accurate and several significant gaps in the data available have been identified, particularly in relation to the profiling of the waste. Where data lacks in detail, global benchmarks have been identified where relevant and best judgement and assumptions have been applied where necessary.

5.3.3 Minimisation Measures

Waste minimisation can be achieved through a range of different instruments including technological, economic, regulatory, social/behavioural change instruments.

It is worth noting that minimisation processes are mainly driven by governments. Considering that in the UAE goods are predominantly imported; there is realistically little that can be done as waste minimisation should be done at the other end of the export/import trail.

Operation Waste Management

In the operational phase different approaches can be implemented, including the following:

Economic Instruments

- Charge tenants for collection of non-recyclable waste; and
- Levy on plastic bags at supermarkets;
- Development of a 'Waste Symbiosis Program' for Masdar and surrounding areas – (for the industries in the SEZ, the airport, Al Raha, etc) by which outgoing resource flows from one factory or process are used as a raw material in another.

Regulatory Instruments

- Shops and supermarkets operating in Masdar required to use re-usable, recyclable or compostable packaging;
- Enforcement of the use of recycled paper (in some proportion) in offices, universities or other businesses;
- Encouragement of double-sided printing. Enforcement of cartridges to be recycled;
- Waste pick-up services to use returnable packing;
- A waste minimization strategy (waste audit as a first step) for every business and implementation of awareness programmes for their employees; and
- Stimulation of local/national recycling market.

Social Changes Initiatives

- Extensive awareness program as part of the acquisition of the property (leaflet with waste reduction and reuse measures, recycling procedures within Masdar) and placed at specific points such as supermarket, schools, university, etc.
- Public information campaigns
- Encouragement of businesses teaming up with retail operators to encourage reduced packaging and obligation/ encouragement to use a percentage of recycled PET (r-PET) in their product lines;
- Second Hand Centre to be set up, where people can buy and/or sell second hand items such as furniture, domestic electronic goods, etc (similar to a flea-market);
- Radio Material Recovery Programme: On-air recycling service at a radio station where people are encouraged to call, email or text what they want to get rid of. The donor's item is promoted on the radio and listeners can call in to recover it;
-
- Waste Information Centre where people can be informed and made aware of the waste problem. It can also be used as a centre to support and help the generator through the segregation process of the waste; and
- Encourage the use of recycled materials, preferably locally sourced, that could be used in Masdar (recycled paper, glass bottles, plastic bottles, etc).

Construction Waste Management

In the construction field the prevention or reduction of waste generation can be achieved in four different construction areas:

Project Planning

- Commitment: The first step towards prevention is the commitment from all concerned parties to achieve a reduction.
- Responsibilities for waste minimisation should be identified and clearly communicated, and the various parties involved such as client, developer designer, builder, project manager, contractors and suppliers should coordinate amongst each other.
- Allow input from personnel involved.
- Analyse and quantify the potential waste arising from each contractor and identify potential uses for the reclaimed or recycled materials.
- Arrange for the establishment of a central logistical materials centre (separation and storage of leftover supplies and materials).
- Identify and use techniques which avoid creating waste.
- Staff induction that promotes waste minimisation.

Pre-Construction

This phase includes different areas such as design, estimating and purchasing in which minimization can be implemented.

Design of the development should consider the following;

- Buildings should be designed to use standard material sizes.
- Design should consider operational waste reduction.
- Design with the whole life cost of the building in mind.
- Future modifications or the decommissioning of the development.
- Eventual deconstruction of the development, aiming to reuse and minimise any waste generated by taking apart the entire structure.
- Waste can be reduced whilst making significant cost savings through best practice estimating and purchasing practices.

Off-site Activities

- Adopt prefabrication; e.g. by prefabricating frames and trusses, timber waste can be significantly reduced.

On-site Activities

- Delivery of material: The amount and condition of the materials must be checked upon delivery in the event that some materials are damaged. Suppliers should be requested to deliver materials when needed. This measure aims to reduce the opportunity for waste to arise through error or change in estimate, and allows for on-site measurement.
- Purchase reclaimed materials and/or environmentally improved materials, e.g. those with energy conserving features or made from recycled content.
- Avoid over-estimating or rounding up of purchasing requirements.
- When compiling procurement and purchasing policy, in order to avoid waste it is necessary to specify clearly to manufacturers and suppliers the exact requirements. A "take back" policy on packaging should be established, whereby the packaging is either reused by the manufacturer or simply treated as the responsibility of the distributor or manufacturer.
- Arrange for the delivery times to be as close to the use as possible.
- Storage of material; the storage must be appropriate in order to avoid material degradation or damage from weathering, sand damage, etc.
- Separation and storage of materials for reuse or recycling on site;
- Proper book-keeping and documentation for the tracking of the materials to be stored for reuse or recycling.
- Separation and storage of waste that cannot be recovered, reused or recycled on site; arrangements should be made with recycling contractors.
- Separation and storage of waste that cannot be recovered reused or recycled and requires landfilling outline the arrangements that will be made with waste contractors to ensure waste is safely recovered and disposed of to licensed landfills.
- Documentation, in the form of landfill receipts, must be kept to support the waste minimization site review and data collection requirements.

Central Logistical Material Centre

In every construction site, large amounts of materials are left over once the construction has been completed. As a result these raw materials are considered as waste and are disposed of. Due to the fact that the construction goes through a series of phases where different contractors are involved, the left over materials from one phase can be further utilised in the following phase, therefore some particular waste of one phase can be made available as a raw material for another phase. This task might not be easy to carry out and will need efficient coordination to avoid delays due to bad pre-planning. It is proposed therefore, that a central logistical materials centre be established for the coordination of potential reclaimed materials.

For this centre to work efficiently, due to the effort and commitment needed by contractors, it would be helpful if the contract tender included a section where the (sub) contractor is committed and agrees to:

- Providing an inventory of the materials which will be required at the construction phase;
- Development of a waste minimisation plan including an analysis and evaluation of the activities, the types and quantities of waste materials generated on site.

Figure 5.16: Image of a Central Logistical Material Centre

5.3.4 Waste Treatment & Disposal Strategies

Treatment Option 1: Maximise Recycling

The first strategy is designed to maximise the recycling rate within Masdar. Whether separation takes place at source or is performed at an MRF, this approach seeks to find markets for the largest possible percentage of the waste stream.

Whilst maximum recycling rates is the preferred outcome when considered in isolation of other elements of the waste hierarchy, we will see that recycling all components of the waste stream to great effect has downstream impacts upon the energy recovery system and ultimately increases the landfilled component.

The first element of this scenario is to collect separately and treat 76% of the organic food waste and 63% of the garden waste generated on site. This is the expected recovery rate from a combination of residential, commercial and industrial organic organic waste streams. This resource will be treated using an in-vessel composter. The output from this aerobic degradation process is compost in the form of a bio-organic soil enricher which may be used for agriculture, horticulture, gardening and landscaping within the Masdar site.

The second element is to collect and recycle as much of the remaining waste stream as possible. A recovery rate of 80% is expected for dry recyclables (plastics, paper, card, glass) which generates an annual tonnage of 31,228 per annum. To achieve this, wastes will be source separated to the maximum extent possible or collected as a co-mingled component. The remaining 20% is deemed unrecoverable based on best practice in leading sustainable developments as contamination and fragmentation occurs. Source separation provides the cleanest recyclable waste streams.

The third element of the waste stream is non-recyclable and can neither be composted nor recycled as there is a large inorganic or ligneous component. Residues from the previous two processes, depending on their nature and if of sufficient volume, will be sent directly to landfill as the calorific value (CV) of the residue will not be sufficient to support energy recovery processes. The mass of this component will be 20,489t/yr or 33% of the total waste generation. Clearly this does not meet the long term landfill diversion target of 2% to landfill by 2020. The mass balance of option 1 can be seen in the figure on the right.

Improvement in the efficiency of recycling for contaminated and fragmented wastes could potentially improve the recycled component further. However this will require extra costly investments in additional recovery plant. The calorific value of the non-recyclable waste in this scenario is not sufficient to support energy recovery.

Advantages
- High levels of recycling achieved
- Helps towards meeting carbon target

Disadvantages
- May lead to higher levels of waste to landfill
- Zero or low energy recovery from waste.

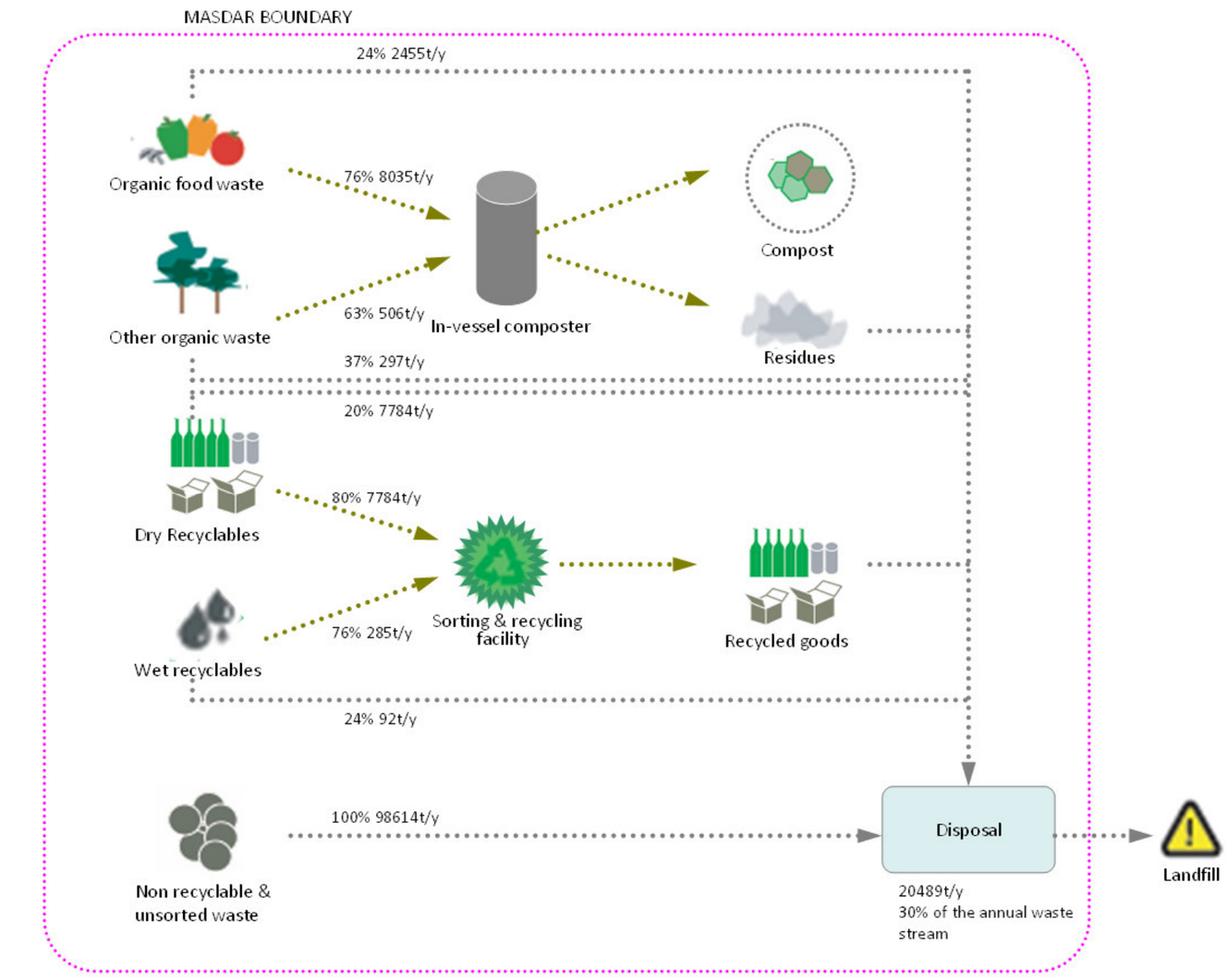


Figure 5.17: Resource flow diagram: Minimise recycling option [tonnes per year]

Waste

Treatment Option 2: Optimise Energy Recovery and Zero Waste to Landfill

The second scenario option is designed to recover optimum energy output from the waste treatment process. This scenario will have a lower recycling rate than option 1 as a portion of the recyclables, particularly those with high CV such as plastics, paper and card, will be oxidised in the thermal treatment plant. Increasing the CV to recover an optimum amount of energy is the controlling variable, however the outcome is one that is more sustainable given the limitations of recycling infrastructure for complex materials in the Emirates.

This scenario was designed assuming that the thermal treatment of the MSW will be achieved by use of a pyrolysis / gasification plant. Mass incineration treatment was discounted, as its thermal recovery capacity is generally lower and public perception of this process is negative even with state of the art emission technologies in place.

The first element of this scenario is similar to option 1 where a large proportion of the organic kitchen and garden waste is composted using an in-vessel unit, the residue from which may again be used for agriculture, horticulture, gardening and landscaping within the Masdar site.

The second step is to recycle that element of the waste stream not required to enable the energy plant. The purpose of this is to still maximise recycling, but on the premise that the minimum requirement for the Waste to Energy plant should be met first. By performing the waste treatment in this way, we follow the principles of the waste hierarchy more accurately by recovering energy rather than disposal to landfill as occurs in option 1.

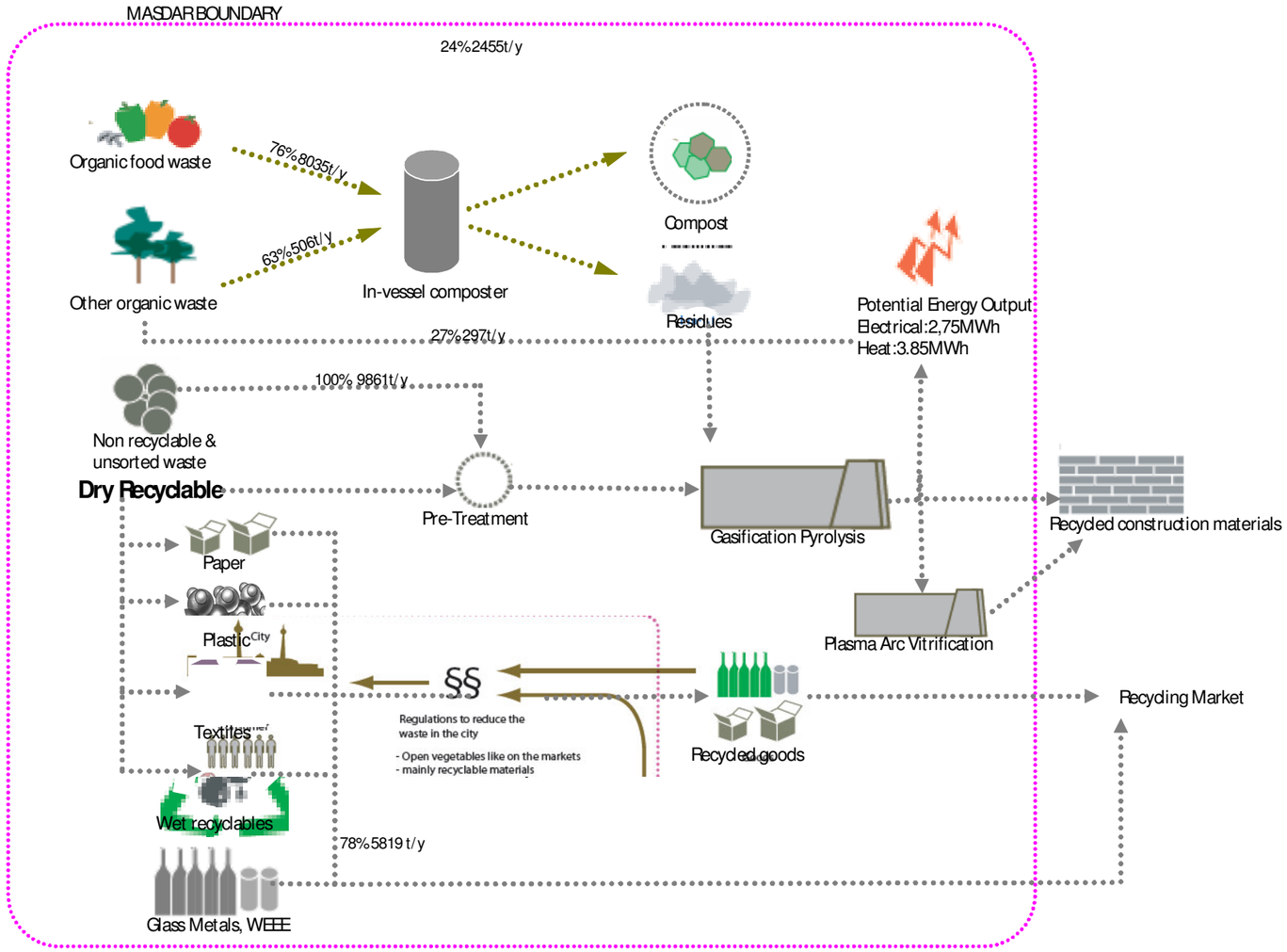
The third step is the pyrolysis and gasification of these combined resource streams including some high CV recyclables, a part of the organic waste, organic residues from the composting process and the residual non-recyclable waste. The pyrolisis and gasification of this waste stream generates high temperature steam and syngas which will be used to generate electricity to supply the city. Prior to entering the thermal system, effective pre-treatment of the waste is required.

The last step is the treatment of the process residues (bottom and fly ash) and the unsorted waste that could not be pre-treated. Where possible, the ash generated by the thermal process will be re-used as construction materials (where inert).

All hazardous residues and other household hazardous waste will be treated in a Plasma Arc Vitrification unit pending recycling in construction materials.

Advantages
- Lowers carbon emissions to as large quantity of energy generated from waste
- Relatively easy to deliver in a reasonable time

Disadvantages
- Low levels of recycling



Resource flow diagram: Optimise Energy Recovery and Zero Waste

Waste

Treatment Option 3: Plasma Gasification Only

The third scenario is intended to prevent sending waste to landfill as a the priority. It is quite similar to the first option; however, the difference lies in the final waste treatment process using the addition of a plasma arc vitrification unit. The treatment of the residual waste from the pyrolysis and gasification process and hazardous waste by a plasma arc vitrification unit has the potential to achieve the zero waste to landfill target.

Composting is paramount once again, and is processed as per options 1 and 2. Because compostable waste has a low calorific value, it is a preferred technology in all three options.

The second step is the collection and recycling of approximately 80% of the recyclable waste generated. This would maintain a near optimum level of recycling.

The third step is to treat in a plasma gasifier, all of the remainder of the organic compounds, the unsorted elements of the recyclables, all the other unsorted and non-recyclable waste including hazardous waste components. This thermal process maximises the destruction of the waste.

The last step is the disposal of the final residual output of the plasma gasification plant. The solid, vitrified inert materials could be re-used as construction raw materials and the rest (a very small part of the waste stream) still required to be sent to landfill.

The plasma gasifier could be an appropriate solution but there are two important factors to consider. Firstly the plant is expensive and still largely unproven technology. Also, the plant has a high energy demand in contrast to the other thermal treatment options. These issues must be set against a target to reduce landfill disposal to 2%.

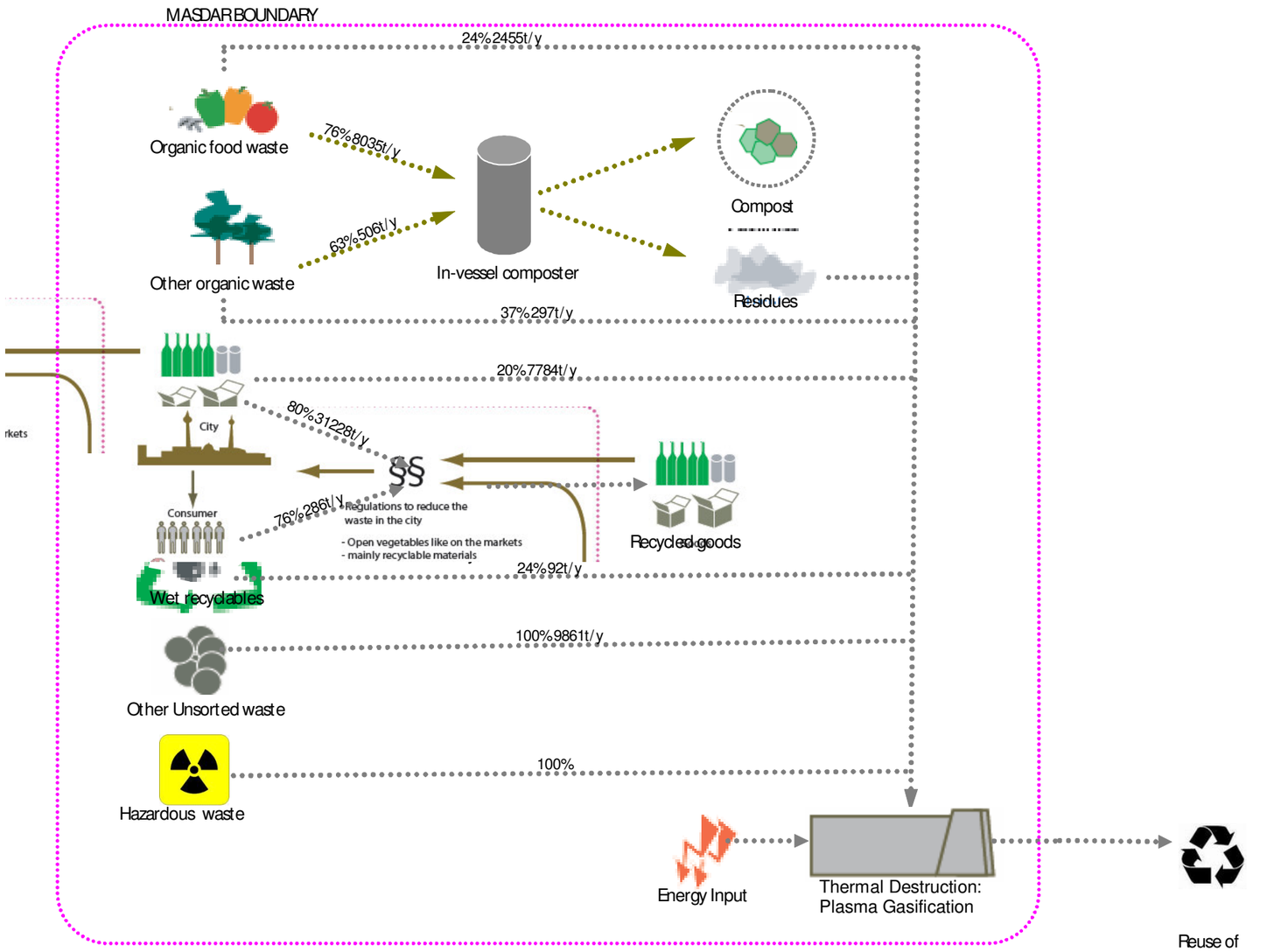
The development of this technology therefore should be tracked carefully so that at the first signs of maturity it can be utilised in a meaningful way to bring about the required performance in advance of 2020. This must not undermine the importance of and the priority given to the minimisation and recycling of virgin resources.

Advantages

- Maximises recycling and minimises waste to landfill

Disadvantages

- Does not promote self-sufficiency
- May not meet the CO2 targets
- Technology not tried and tested
- Large capital cost of Plasma Arc Gasification equipment



Resource flow diagram: Minimise Landfill [tonnes per year]

5.3.5 Recommended Waste Management Strategy

The three scenarios above were assessed according to a number of criteria (see Fig adjacent) including the maximisation of recycling, the minimisation of landfilling, deliverability, compliance, and its carbon emissions. Based on the assessment, the Energy Recovery Optimisation option is the most appropriate for the Masdar development.

Source Segregation

Waste shall be segregated at source into three waste streams;

- Dry Recyclable;
- Compostable; and
- Non-recyclable / recoverable.

Residents and tenants of Masdar will be charged for the disposal of the non-recyclable waste using a pay per bag system where only specific biodegradable bags are bought, filled and collected.

Storage and Collection

The segregated waste will be collected from the service point of each building via the Personal Rapid Transit (PRT) vehicles system. Storage containers will be designed to fit with the PRT vehicles. Where the building density prohibits door to door collection, a gravity chute or automated vacuum system would be deployed on a case by case basis and utilised to transport the waste to a small transfer station pending collection by the PRT.

The waste is transported by the PRT to the following destinations;

- Dry Recyclables to the Material Recovery Facility (MRF);
- Wet Recyclables to the Composting Facility; and
- Non-recyclables to the Waste to Energy

Collection will be through the night during the quietest periods to avoid causing congestion in the transit systems. This activity is associated with the delivery and logistics of goods movements which maximises the efficiency of the PRT infrastructure and represents an innovative resource movement mechanism.

Material Recovery Facility

The dry recyclable waste will be separated into (i) Paper and Cardboard, (ii) Metals, (iii), Recyclable Plastics, (iv) Glass, and (v) WEEE streams pending collection by approved private contractors.

Preference will be given to companies who will recycle the resources in the UAE although companies who export resources to India and China may have to be used initially.

Biological Treatment of Organic Waste Component

The wet organic waste component will be composted at a specially designed onsite in-vessel facility.

The composting process will be carefully controlled and the product used within the development for landscaping, soil conditioning and biomass fertiliser. Up to 1,000 tonnes of compost per year will be produced which if surplus to requirements can be sold externally subject to testing.

Waste sludge from the wastewater treatment plant will be processed in an-aerobic digesters; the resulting methane will be captured and the residue will be used as a soil fertiliser in the biomass plantations and landscaped areas.

Energy Recovery

The recoverable component of the non-recyclable waste and other unrecoverable recyclables will be thermally treated in a pyrolysis / gasification unit to generate electricity and waste heat. It is recommended that the energy recovery operation is optimised for maximum overall system efficiency.

Figure 5.20: Recommended Waste Management Strategy

Some topping up of the calorific content may be required using high CV recyclables to ensure efficient plant operation.

According to the waste profile from the waste arising model, over 21,000 tonnes per year of waste are expected to be treated in the thermal plant (2.39 tonnes/hour). For a low calorific value waste feedstock of 16.5MJ/kg, a pyrolysis gasification plant could generate up to 2.75Mwe of net electricity, and 3.85MWth of heat (from the engines and heat recovery systems). The annual electricity and heat production of the gasifier could reach 22GWhe and 30.8GWhth. It is possible to increase the steam and syngas production by feeding the plant with waste with a higher CV, such as paper & card, plastics and wood. Equilibrium needs to be found between the optimisation of the power generation from the plant and the maximisation of the recycling ratio.

The resultant non-hazardous bottom and fly ash will be used in the biomass plantation and incorporated into building materials subject to toxicity testing.

Household hazardous waste will be collected via various drop-off points around the city. This hazardous waste and the residual hazardous ash arising from the pyrolysis and gasification process will be processed in a Plasma Arc unit, vitrified and re-cycled into construction materials. It is estimated that approximately 1,500 tonnes of household hazardous waste, and 1,393 tonnes of residual hazardous ash will be generated annually.

The electricity generated from the incineration of the Masdar's waste will be reused on site via the local electricity network. The heat recovered from the waste treatment could either feed absorption chillers, which will generate cooling for the site, or supply the district heating loop.

Plasma Arc Technology

A portion of the waste will require to be landfilled until a Plasma Arc Vitrification unit is commissioned.

Plasma arc technology which is at the moment appears to be the only technology that can effectively eliminate the requirement for landfill. This should be considered as a last option and only be used for the residual difficult waste once maximum recycling has been achieved. Plasma arc vitrification is undergoing a rapid development period at the moment and further technological evaluation us required before selection.

Waste

Policy Recommendations

In order to meet the zero waste goal, the following enabling policy recommendations will be essential components of engaging the public and local population with the strategy. The most effective model will be a combination of the most successful measures rather than deploying a large number at any one time. A policy and regulatory team will be required to administer and develop these options as some can be resource intensive. The cost of this can be recovered through the fiscal measures that are deployed. A combination of the following economic, regulatory and participatory measures is suggested:

Economic Measures

- Charging of tenants for non-recyclable waste generation;
- Impose fiscal levies or restriction on plastic bags.

Regulatory Measures

- Every business operation that supplies goods/ services to Masdar shall develop an internal waste minimisation strategy and carry out awareness programmes for their employees or to the public as well.
- Set targets for minimisation of waste generated during construction
- Regulate/Encourage take-away services to deliver goods in returnable packing.
- Establish a minimum amount of recycled paper to be used by offices, the University or other businesses. Find sources of recycled materials, preferably locally sourced, that could be used in Masdar (recycled paper, glass bottles, plastic bottles, etc).
- Architectural design for standard material sizes and operational waste minimisation

Social and Participatory Measures

- A 'Waste Symbiosis Program' for Masdar and surrounding area – for the industries in the SEZ, the airport and local developments.
- Extensive awareness program, as part of the acquisition of the property (leaflet with waste reduction and reuse measures, recycling procedures within Masdar) and placed at specific points such as supermarket, schools, university, etc.
- Teaming up with retail operators to encourage reduced packaging and obligated/ encouraged to use a percentage of recycled PET (r-PET) in their products lines.
- Encourage supermarkets to collect re-usable, recyclable and compostable packaging .
- Stimulation of local/national recycling market

Construction Activities

During the construction phase large amounts of different types of waste will be generated. The prevention of high generation rates will come from early design stages but also during the accomplishment of the project. Refer to section 2 for further information relating to the minimisation of construction waste.

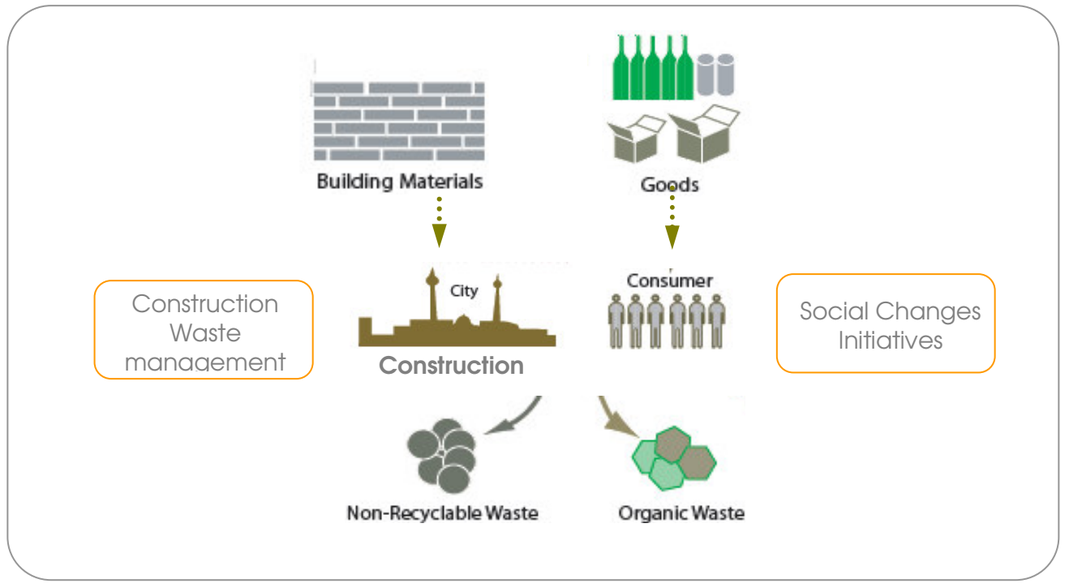


Figure 5.21: Economic and Social measures

5.3.6 Technology Evaluation

The masterplan development process breaks the design options down into three elements:

A. Segregation and storage
B. Collection methods
C. Treatment and disposal options

Each of these has been considered in turn and the options considered. The selection of a final recommended strategy from these options has then been developed having considered the following criteria:

- Carbon intensity
- Energy and water demand
- Behavioural dependency
- Technological feasibility
- Infrastructure pressure
- Maintenance requirement
- Transport impacts / loading

Base Infrastructure

A certain amount of base infrastructure is required for all options. The following elements of infrastructure will be required regardless of which strategy is chosen from the available alternatives;

- Household collection infrastructure to include waste chutes and suitable area for massing and compacting; and
- A Waste Management Facility to accommodate the space and technology necessary to further sort and treat the waste.

Waste

A. Segregation & Storage

At the point of generation, Masdar is presented with a range of options for source control. The level of segregation of wastes is a key determinant of the waste strategy as most processes are determined by this decision. The level of segregation will impact collection and transport methods, treatment options, recycling rates, overall system performance and behavioural change requirements. Each of the following options is based on the assumption that waste must be segregated at some stage in the process to meet the overall programme objectives relating to recycling, energy recovery and landfill diversion.

Table 5.6: Wastes segregation

	Discription	Advantages	Disadvantages	Recom
No segregation	No segregation required at source by waste generators. System input is therefore a single stream for all municipal waste> Sorting will take place at a centralised facility	• As no change in the generator's behaviour will be required, this is the most convenient approach for residents. • Collection infrastructure will be less complex and expensive.	• Contamination of recyclables will occur, reducing the recovery potential and resale value of these materials. • Recycling rates for Masdar will be reduced as a result of ineffective sorting processes. • Increased effort and cost will be required at sorting centres. • Does not raise awareness and engage individuals in the increasing waste problem in Abu Dhabi.	This sys recomm recylabi increase pre=seg
Double Segregation	This scenario would be designed for the following two different streams of waste • Co-mingled recyclable waste (unsorted dry recyclables such as glass, plastic, paper, metals and cardboard). • Non-recyclable waste + organic waste	• This segregation strategy requires one less layer of infrastructure for the collection of waste compared to triple segregation. • A compostable resource component can still be recovered.	• Education programmes will be necessary in order to help/support the people through the segregation will be necessary. • Composting is possible but more difficult and space intensive as separation is required from other wet wastes.	While th allows fo it decrea compos recovery system recomm Masdar.
Double Segregation + Macerator	Three different streams of waste will be segregated but with an alternative for organic food wastes. This will be sink macerator while dry recyclables and other waste will be segregated as follows: • Co-mingled recyclable waste (dry recyclables such as glass, plastic, paper, metals, and card al together). • Non recyclable waste • The organic waste will be removed through a kitchen macerator which is usually installed under one of the sink basins and it is activated from a separate power switch. The macerator system is a motor driven device comprising a gravity feed inlet and a disposer with rotating cutting blades that grind and cut the organic waste. The waste from here is discharged to the foul drainage system. The purpose of this approach is to boost the organic component of the waste stream to facilitate more active anaerobic digestion	• Foul odours that may be associated with organic waste storage will be reduced. • The complexity of the waste collection infrastructure is reduced.	• Installation of macerators for each building will be required which it reflects an additional capital cost. • The macerator cannot grind up shell fish, bones and other tough or large items. • Campaigns and education programs will be necessary in order to help/support the people through the segregation process. • There are some manageable safety concerns associated with installing macerators in all properties although modern and safe systems will be specified. • If the waste water treatment processes are relying on a specific composition, there are risks that this requirement will not always be fulfilled.	This opt be ideal producti foul wat plant; ho far more create c from sew sludge. this stra recomm Masdar.
Triple Segregation	In this option, three different streams of waste will be differentiated such as: • Co-mingled recyclable waste, refereed to as dry recyclables such as glass, plastic, paper, metals and cardboard. • Organic waste including food waste • Non recyclable mixed wastes	• The range of options for waste collection, treatment and disposal are maximised. • Cross contamination of waste will be largely avoided. • The effort required at sorting centres is minimised. • Promotes awareness of the waste problem facing Abu Dhabi among waste generators.	• Education programs and campaigns to encourage segregation will be necessary. These carry a financial and time related cost. • There is a risk that proper segregation practices will not be followed by all individuals requiring a fail safe mechanism established.	In our vi strategy for recyc compos waste to This sys highly recomm

Organic waste collection containers

Some organic waste containers are provided with a ventilation system that stimulates aerobic decomposition while reducing odour problems This system quickly reduces the weight and volume of organic wastes, giving recycling programs the flexibility and cost-savings of less frequent collections.

Waste Storage

There are many different types of containers in the market, each one with specific features according to the type of the waste which they will collect.

Compartment Recycling Container

Container provided with different compartments (three to six).

This type of container can be serviced without specialised collection equipment. It can be used in multi-family and public area recycling programs. These containers are designed to be protected from weather or vandalism.

Igloo Recycling Containers

Igloo Recycling Containers are designed for use at drop-off sites, universities, etc. They can be serviced with build cranes, or there are also models which are emptied manually through a full size, side-mounted door.

Multi-compartment bins

These multi-compartment bins are for the collection of both waste and recyclables at non-residential locations such as parks, and public spaces.

They allow source-separated collection of recyclable beverage containers, recyclable paper products and residue waste products.

Waste

B. Collection infrastructure

Waste collection is the component of waste management which results in the transfer of a waste material from the source of production to either the point of treatment or final disposal. The following section will evaluate the options available for waste collection.

The collection of waste also presents a range of options that respond to the particular needs of the project but also set out some compromises which will influence the recommended solution.

The following shortlist was considered as appropriate to the nature of the project.

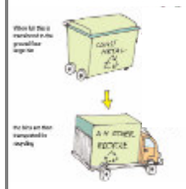
	Discription	Advantages	Disadvantages	Recomendation
Standard Waste Collection Vehicles 	This is a broad category and includes all variations of trucks and light vehicles that are used throughout the world to collect and transport waste. There are five main types of waste collection vehicles: • Front loaders • Rear loaders • Automated Side loaders (ASL) • Pneumatic collection • Grapple trucks The names refer to the various methods by which waste is collected by the vehicle. Pneumatic collection involves 'sucking' the waste from specially designed outlets on the street.	• Relative availability of equipment and expertise compared to alternative or more novel approaches.	• Higher operational cost • Energy used for transport and related carbon emissions	This strategy is not advisable as Masdar has a zero-carbon transport strategy.
Electric Waste Collection Vehicles	Electric (or gas/electric hybrid) vehicles are based on the same technology as standard waste collection vehicles	• Relatively clean fuel compared to diesel making this option for waste collection more applicable to the Masdar development.	• A network of roads would still need to be built to allow these vehicles access to all parts of the development.	Use of electric waste collection vehicles would be ideal; for trained staff to collect the appropriate pre-segregated waste. This system is recommended.
Automated Vacuum Collection	The Automated Vacuum Collection (AVAC) system also known as 'pneumatic waste collection' transports waste at high speed through a system of pipes to waste transfer stations where it can be compacted, sealed in containers and transported away. The process works as follows; • The waste is deposited into waste inlets, located inside buildings or outside at street level. • Waste inlets are connected to an underground steel pipe system that connects to a set of waste transfer stations. Within the system the waste is moved pneumatically at 70km/h. • Each transfer station has three holding vessels that can either be directly connected to a central transfer station through pipeline or transported by means of truck or bespoke PRT. • The energy required for activating and suctioning the waste is 650 kW installed (max operational load is approximately 330 kW) per station. Waste can be separated at source by having separate inlets for each waste fraction. Each fraction enters the same central pipe but is kept separate through a series of electronically timed valves similar to messages in a telecommunication network. Separation at source means that there no - or a reduced - requirement to construct and operate a material recovery facility. However, unless households and businesses are committed to separate their wastes into the various recyclable fractions themselves poor recovery rates can be observed.	• Reduced operational costs compared to convential waste collection with trucks. • It does not require any surface space. • Minimise human exposure, therefore creating a cleaner and safer environment. • Waste segregation at source.	• Higher overall installation costs • The underground infrastructure required is space consuming as the pipe diameters are 500mm. • If buried the ground conditions mean that protective coating is required at extra cost	AVAC systems could provide the solution for waste collection in highly dense areas where waste collection vehicles could not access the buildings This system is recommended for highly dense areas not for the whole site.
Personal Rapid Transport	Personal Rapid Transit is the personal internal transport system that is proposed for Masdar. The nature of the routing and utilisation patterns of the PRT system is such that there is value added utility available from the distribution of goods and services and the collection and transfer of waste. The PRT will need some specialised design alterations to be fully effective. The payload of the draft designs allows for approximately 5-6m^3 of capacity per PRT unit which equates to approximately 1 tonne of waste. The collection of waste can be carried out through these means by deploying a door to door collection service. The PRT can reach the back of the house (BOH) areas on a local service loop. indicate the variable design pattern for the service loops that can be designed to allow for counter clockwise circulation when physical constraints apply. The collection must take place during suitable hours where the loading on the transit system is minimal. This could be during the hours of 12.00 midnight through to 06.00am.	The PRT can operate 24 hours a day and will show large capacity surpluses at night. This slack can be taken up by utilising this downtime for the delivery of goods and the collection of wastes. • The efficiency of this set up means that the energy and carbon intensity of these operations will be significantly reduced. • There is also no need for additional infrastructure.	• Space requirements for access are large although this may have been required for other access reasons. • There may be some very limited disruption to access during collection hours. • City operation becomes very dependent upon the reliability of the PRT system.	Automated Delivery and Collection PRT systems are the ideal solution for waste collection at Masdar considering that PRT are used for goods delivery and public transport. This innovative system is highly recommended

Table 5.7: Options for waste collection infrastructure

C. Treatment and disposal

Waste Management Facility

The Waste Management Facility (WMF) will be comprised of different sections divided as:

- Material Recovery Facility
- Hazardous Waste Section
- Bulky Waste Section
- Information Centre

The Hazardous Section will comprise of an area for the drop of and collection of domestic hazardous waste. This area will be provided with labelled bins for the different typologies of hazardous waste such as batteries, paints, expired medicines, tube lights etc.

The Bulky Waste Section will be provided with an area for the unloading of this type of waste where the inspection of the condition of the item can be undertaken. Two storage areas for the categorised item as reusable or disposable will also be provided.

The Information Centre will be used as an awareness centre and a place where people can get information or help in any cases related to the waste system implemented at Masdar and to understand their role and contribution to the zero waste strategy.

Materials Recovery Facilities

A Material Recovery Facility or MRF is a specialised plant that receives, separates and prepares recyclable materials for marketing to end-user manufacturers.

	Discription	Recomendation
Clean MRF	A Clean MRF is a facility at which components of a mixed waste stream, typically a mixture of source-separated and co-mingled dry recyclables are processed, with co-mingled streams separated using mechanical separation techniques. MRFs may be high or low technology facilities, depending on the nature of the incoming material stream and the sophistication of the plant and equipment employed. Numbers of staff working in the operation can vary significantly. Globally, there has been a steady increase in the numbers of Materials Recovery (sometimes known as Recycling or Reclamation) Facilities (MRF) as more collections of source separated or co-mingled dry recyclables have been introduced and overall recycling tonnages have increased. Within MRFs mixed materials are normally fed into a hopper and then by conveyors to a system of screens or other sorting mechanisms, such as inclined tables and air classifiers, which produce an initial classification of materials. These materials then pass through magnetic and eddy current separators, possibly incorporating advanced optical materials recognition equipment, allowing separation of different types of plastics, to produce quality streams of individual materials. Typically, there will be an element of hand-sorting of materials, in addition to the automatic extraction of materials, as part of the separation process. When sorting has been completed materials may be stored loose, or, more usually, will pass through compaction, baling and wrapping facilities prior to short-term storage and onward transfer to re-processors and end-users. There will always be materials passing through the plant, or resulting from processing within the plant, that are not suitable for recycling and these will be consolidated and transferred to landfill for disposal or to thermal treatment.	Considering the recommendations for waste segregation and collection, a clean MRF is highly recommended for the site.
Dirty MRF	Dirty Materials Recovery Facilities (Dirty MRF) are rare and unlikely to figure prominently in development of future facilities. They are designed to accept mixed, unsegregated waste and combine a number of screening / sorting techniques to divide the received waste stream into a recyclable material stream and a non-recyclable residual waste stream that is disposed to landfill. More advanced plant may be used to produce a third, primarily biodegradable, waste stream suitable for Anaerobic Digestion or In-vessel composting or, alternatively, a relatively high calorific value stream suitable for conversion to Refuse Derived Fuel (RDF). Within these MRFs, as a first phase, waste is fed, by conveyor systems, through bag splitters and various screens and/or trommels to split the waste into different size fractions. These fractions then pass through magnets, eddy current separators, handpicking lines or other sorting techniques, such as air classifiers, to separate the waste into the required constituent streams. It is unlikely that this process will produce recyclate of the same quality as a clean MRF as the separation process is less efficient and contamination from putrescibles cannot be eliminated. Typically, dirty MRFs will only recover some 10 – 25% of the incoming waste stream as recyclables, with the remainder requiring further processing or disposal. Materials recovered through these facilities are usually limited to metals, mixed plastics, paper, glass, card and textiles.	Dirty MRF is not recommended for Masdar due to excessive requirements for maintenance and cleaning. In addition there are foul odours problems with this technology.
Wet MRF	New mechanical biological treatment technologies such as the ArrowBio Process can now utilise wet MRF's. This combines a dirty MRF with water which acts to density separate and clean the output streams. It also hydrocrushes and dissolves biodegradable organics in solution to make them suitable for anaerobic digestion.	Similarly to a dirty MRF, a wet MRF is not recommended for Masdar.

Table 5.8: Types of Materials Recovery Facilities

5.3.7 Biological Treatment

Biological treatment processes can either be aerobic or anaerobic. Composting is the aerobic process with Anaerobic Digestion (AD) being the principal anaerobic process. Both processes can be included as part of Mechanical Biological Treatment (MBT) systems. Descriptions of these processes follow.

	Description	Advantages	Disadvantages	Recomendation
Windrow composting	Windrow composting is an established technology for dealing with green wastes. The incoming waste stream is shredded and then placed in elongated rows, known as windrows, and aerated by turning with mechanical plant or by forcing air through the material in a controlled manner. This may take place under cover or in the open. Under controlled aerobic conditions, the use of microbial inoculants can reduce cycle times to 4 weeks.	• Natural composting process	• Difficult to manage in the Abu Dhabi climate. • Requires land	This solution is not recommended due to climatic conditions and limited land availability.
In-vessel composting	In-vessel composting embraces a variety of techniques whereby kitchen and/or garden derived wastes may be composted in an enclosed vessel or tunnel under controlled conditions. At a typical facility, the waste is fed into a composting tunnel and moved along the tunnel on a tray, being contained within the system for 14 days. Temperatures within the tunnel are maintained at 55-65°C (to facilitate bacteria destruction) and forced air systems are used to maintain aerobic conditions. Exhaust fans extract air from the system and pass it through bio-filter systems to eliminate any odours. The finished product can be used directly as daily landfill cover or matured over a longer period for use in other applications.	• Finished product can be used as garden fertilizer.	• Due to legislative constraints composting in Europe tends only to be used to deal with the organic (garden & kitchen waste) element of the municipal waste stream. • Increased regulation of composting has increased the complexity and costs of composting operations in recent years.	Due to the requirement for compost for the plantations and landscaping, this system is highly recommended.
Anaerobic Digestion (AD)	Waste treated in an Anaerobic Digestion (AD) facility undergoes similar processes to waste deposited in a landfill, but under controlled conditions. AD is a complex bio-chemical process involving the bacterial fermentation of organic material in the absence of oxygen. This produces biogas, which is a combination of methane (CH_4) and carbon dioxide (CO_2) (typically in the ratio 65:35), with traces of nitrogen, sulphur compounds, volatile organic compounds and ammonia. Between 40% and 60% of the organic matter present is normally converted to biogas, which can be combusted directly in modified gas boilers or used to run an internal combustion engine. The residue consists of an odour free material, similar in appearance to peat, which has some value as a soil conditioner and, in some systems, a liquid which has potential as a fertiliser. Mechanical processing and separation of MSW is an essential pre-treatment for most AD systems, with the non-biodegradable materials being removed prior to processing. There may be an element of post digestion extraction of contrary materials for recycling. A typical feedstock comprises biodegradable municipal solid wastes (BMW) plus other enriched organic waste streams including sewage sludge and agricultural and food processing wastes. All anaerobic digesters consist of the following basic components: feedstock storage and handling system, digestion tank, gas and residue recovery systems. The digestion tank requires a mixing system which can either be mechanical or achieved by bubbling the biogas through the organic slurry.	• Electrical power generation and heating can be generated using the biogas	• If not controlled appropriately, odour may be generated at any plant processing the biodegradable elements of municipal waste.	Considering the need for compost, Anaerobic digestion is not a recommended option.
Mechanical Biological Treatment (MBT)	Mechanical Biological Treatment is a generic term for an integration of several processes. Incorporated into the MBT plant will be mechanical processes including Materials Recovery Facilities (MRFs), separators, screens and sorting equipment, and biological treatment processes including composting systems and anaerobic digesters. Equipment to produce Refuse Derived Fuel (RDF) from the residues may also be included. There are a wide variety of systems promoted as part of integrated waste management systems. In the majority of cases, an MBT plant would have to deal with an incoming waste stream that has undergone some form of separation or screening to remove various recyclable elements, with the role of the MBT plant to continue the resource recovery process by stabilising and separating the residual waste stream into less harmful and / or more beneficial output streams and minimising the quantities requiring landfill disposal. In a typical MBT plant, the process would be designed to handle raw 'black bag' municipal waste. In many cases a RDF is produced which can then be used in a co-located or off-site Waste-to-Energy (WtoE) plant or shipped, as a fuel, to a third party user such as a cement works. The RDF/SRF would be suitable for use in different WtoE technologies including combustion, gasification and pyrolysis. Some systems may screen the waste to produce a compostable stream appropriate for in-vessel composting processes. When the waste is to be used as a secondary fuel (e.g.: RDF/SRF) a small non-combustible residue often results, which is sent for disposal to landfill. An alternative MBT approach is the extraction of recyclables, followed by homogenisation of the residue and subsequent processing in an Anaerobic Digestion plant.	• Creates fuel pellets necessary to gasification and pyrolisis Waste to Energy plants.		An MBT plant is required to process the waste stream going to the waste to Energy plant. It is recommended to have a combination of In vessel composting and MBT.

Table 5.9: Types of biological treatment options available

5.3.8 Energy from waste (Thermal treatment)

Energy recovery from waste (waste-to-energy) is a process by which energy stored in the waste is extracted in the form of fuel or electric power. This provides multiple environmental benefits. Firstly, the diversion of waste from landfill provides an environmentally sound approach to waste management. Secondly, the recovery of energy displaces fossil fuel generation alternatives thus reducing greenhouse gas emissions.

There are a number of different technologies used in the thermal treatment of Municipal Solid Waste (MSW). These can be summarised as:

- Mass Burn – with or without energy recovery.
- Pyrolysis
- Gasification
- Plasma

Mass burn is the standard method used in UK and Europe, is well proven and facilities typically handle between 120,000 and 500,000 tpa of MSW, although, some plants can be as small as 20 – 30,000 tpa capacity. For the majority of plants, moving grate technology is used as this can easily cope with the lack of homogeneity and fluctuation in calorific value in the average municipal waste stream. Fluidised bed technology requires a homogeneous feedstock but is able to cope with material of a higher calorific value. With increasing volumes of municipal waste being sorted at the kerbside, and a subsequent improvement in homogeneity, more consideration is being given to the use of fluidised bed incinerators.

Pyrolysis and gasification are proven technologies for burning homogenous material streams but are not yet proven for dealing with heterogeneous waste streams such as municipal waste. Pre-treatment of MSW can make it suitable as a feedstock for these technologies, which tend to be described as Advanced Thermal Treatments (ATT).

		Discription	Advantages	Disadvantages	Recomendation
Mass Burn Incinerators		Energy from waste (EfW) facilities are, in effect, waste treatment plants that combust waste under controlled conditions to reduce volumes and hazard level. Incinerators require extensive pollution control systems to minimise stack emissions from the process. Flue gas cleaning equipment such as acid scrubbing plant, carbon injection systems, electrostatic precipitators or fabric 'type' filters must be provided, depending on the type of control system employed. This equipment can occupy much of the space required by the plant and adds substantially to the capital costs. These emission cleaning processes are now well established in Europe and generally ensure very low emission levels. There is also a requirement to deal with the residues of the combustion process. There are two principal solid residues from thermal treatment systems: the bottom ash, which is the solid remainder of the waste feedstock after processing; and the Flue Gas Treatment residues from the emission control systems. The bottom ash typically amounts to some 25 – 30%, by weight, of the incoming waste stream. The flue gas residues (or fly ash) is difficult material to handle, is generally classified as hazardous, and requires disposal at a specialist hazardous-waste disposal facility. When a suitable local infrastructure is in place, the heat generated can be used for municipal, commercial or industrial purposes and/or be captured as steam and passed through a turbine to produce electricity. The electricity can be used internally within the plant, transmitted to local users and/or supplied to the national grid.	• Heat and electricity can be generated. • The bottom ash can be used as a material within products for the construction industry.	• Incinerators require extensive pollution control systems to minimise stack emissions from the process • Some hazardous output produced that requires disposal at a specialist hazardous-waste disposal facility.	All Mass burn incinerators are not recommended for Masdar.
	moving-grate technology incinerators with energy recovery	The majority of municipal waste incinerators currently operating use moving-grate technology and are designed to handle large volumes of household wastes with minimal pre-treatment. Medium size plants typically comprise two combustion trains with large plants using three or four. Apart from maintenance periods and unplanned downtime, plants need a constant waste feed 24 hours/day, 7 days/week. The moving grates ensure waste continues to move through the system in a controlled manner to ensure maximum burn out with solid residues passing through coolers into the ash collection system. The gases produced are passed through a secondary burner to ensure the maximum destruction of hazardous elements with resulting flue gases passing through the pollution control systems to ensure safe emissions to atmosphere. In effect, the overall process involves initial drying of the waste, its combustion to reduce volume and the burn out of any hazardous elements. Considerable control is required to ensure the necessary conditions for optimum combustion are maintained.	• Greater destruction of hazardous elements • Tried and tested technology	• Relatively higher GHG Emissions	
	Fluidised bed technology incinerators with energy recover	The combustion of MSW using fluidised bed (FB) involves pre-sorting the waste materials to remove heavy and inert objects and non-ferrous metals prior to processing. The incinerator is normally a single stage process and consists of a refractory lined chamber with a granular bubbling bed of an inert material such as coarse sand or similar bed medium. This bed is supported on a distribution plate and fluidised by air or other gas being blown through the plate at a high flow rate. Particles are carried out of the vertical chamber by the flue gas into a cyclone. Most of the particles are sand, which are returned to the fluid bed.	• FB systems offer high thermal efficiency and relatively greater flexibility. • Tried and tested technology		
	Rotary and Oscillating Kilns	Rotary and Oscillating Kilns have been used internationally in EfW plants handling municipal waste. These plants can use technology considered to be smaller scale Energy from Waste, sometimes incorporating district heating. The opposition to smaller scale EfW plant tends to be less vociferous, particularly when forming part of an integrated system designed to provide a more local solution.	• Can be scaled in to smaller EfW plants		
Pyrolysis		Pyrolysis, often incorporating gasification, is a thermal process in which organic materials in the waste stream are broken down under pressure and in the absence of oxygen. The process works best when the input waste has been pre-sorted and is carbon-rich. Best results are obtained from single stream and homogeneous wastes such as sewage sludge, plastics, wood, tyres, or agricultural wastes. When MSW is to be used it should be pre-sorted to remove the majority of non-organics and processed to homogenise the feedstock. The Pyrolysis process produces a liquid residue and gaseous output which may be combusted to generate electricity. A solid slag is also produced which may require disposal or additional processing.	• Output gases may be provide an storable energy sources for electricity generation	• Need carbon rich input wastes to work efficiently and therefore requires removal of non-organic wastes •	A combination of Pyrolisis and Gasification processes are recommended for Masdar.
Gasification		Gasification usually operates at a higher temperature range than pyrolysis, with the addition of an oxidant (either air or oxygen) and the output from a pyrolisis plant may be fed into this process. Gasification of organic derived wastes will produce a gas which can be combusted to generate electricity and a char which usually requires disposal if no markets are available. These processes are still at the development stage, with very few full scale plants operating commercially in the world.	• Output gaseous may be provide an storable energy sources for electricity generation • Relatively higher electricity and thermal output	• Their performance is relatively unproven with MSW • May require higher maintenance	
Plasma gasification		Plasma arc gasification is a waste treatment technology that uses high electrical energy and high temperature created by an electrical arc gasifier. This arc breaks down waste primarily into elemental gas and solid waste (slag), in a device called a plasma converter. The plasma arc gasification process works by passing relatively high voltage, high amperage electricity between two electrodes, spaced apart, creating an electrical arc. Inert gas (air or inert gases under pressure) is passed through the arc into a sealed containment containing waste material, temperatures as high as 13,000°C are reached in the arc. The temperature one meter from the arc can be as high as ~4000°C. At these temperatures most types of waste are broken into basic elemental components in a gaseous form, and complex molecules are atomized - separated into individual atoms. The reactor operates at a slightly negative pressure, meaning that the feed system is complemented by a gaseous removal system, and later a solid removal system. Depending on the input waste (plastics tend to be high in hydrogen and carbon), gas from the plasma containment can be removed as Syngas, and may be refined into various fuels at a later stage. Currently, most plasma gasification plants require more energy in operation than they produce from the thermal destruction of the waste; however, there is one large scale plasma gasification plant in California, that generates more electricity than the quantity required to run efficiently.	• The process can handle and treat efficiently almost all waste feedstock: it could deal with MSW, low calorific value components, inorganic elements, waste with high moisture contents, and hazardous waste with equal effectiveness. In addition, this process allows the largest reduction in waste mass disposed in landfill.	• Only a few plants are in operation worldwide. • Currently, the capital and maintenance costs are very high in comparison with other technologies. • The main disadvantage with this technology is that it may be a net user of energy.	To further maximise landfill avoidance, plasma vitrification could be used. It is not recommended to treat all waste streams by plasma gasification.

Table 5.10: Comparison of options for thermal treatment of Municipal Solid Waste

Pyrolysis Arc Vitrification

Plasma arc is a waste treatment technology that uses high electrical energy and high temperature created by an electrical arc gasifier. This arc breaks down waste primarily into elemental gas and solid waste (slag), in a device called a plasma converter. The major advantages of the plasma arc are that the process can handle and treat efficiently almost all waste feedstock including hazardous waste. The residue from the process is then concerted into an obsidian-like glass material which can be used in construction materials.

5.3.9 Hazardous Waste

Domestic Hazardous Waste Management

Domestic hazardous waste such as batteries, paints, broken tube lights, expired medicines, discarded electrical equipment like televisions and computer monitors, fridges and freezers etc. will be segregated at source and deposited at various drop-off locations around the city pending collection and transport to the Waste Management Facility.

The household hazardous waste will then be processed by the Plasma Arc unit and then vitrified. The resulting glass-like material will then be recycled into construction materials.

Industrial Hazardous Waste Management

Industries located in Masdar will need to set forth their plans for managing their generated hazardous waste. Also certain industrial criteria would be applied to new applicants.

As part of the instruction for a zero waste management plan, the minimisation of hazardous waste generation should be encouraged. Substitution of certain raw materials and processes that will lead to hazardous waste should be avoided.

Hazardous waste contractors should deal with hazardous waste off-site. It is recommended however to employ trusted waste contractors who adopt thermal destruction or recovery processes on the waste stream.

5.3.10 Bulky Wastes

Bulky waste includes a large range of different types of waste. They will have in common the bulky size of the items which will render them unsuitable to be collected by normal means.

Due to their size, they will be required to be collected by specific arrangements (calling system, formulary, etc) so that an empty flat-bed PRT can be provided for the collection. At the request of the collection the size of the item will have to be specified so that the same PRT can collect several items from different generators in one trip if necessary.

All the bulky waste will be transported to the WMF where, after inspection the decision will be taken if it is suitable for reuse (non broken items, good working order), recycling or if it should be disposed of and sent to the Waste to Energy facility. The reusable appliances will be sent to the second-hand store for resale or given to charities for further use.

5.3.11 Construction Waste

The generation of waste during the construction phase should be minimised via the measures outlined in section 5.3.3, including the re-use of materials on site where possible. Those materials that can not be reused but can be recycled (packaging, cardboard, metals) will be stored on site and agreements with approved recycling companies should be made. The collection of such waste will be in labelled skips located at designated areas on the site.

Materials not suitable for any further use will be managed on a case by case basis:

- Inert materials will be sent to landfill;
- Other materials including hazardous waste will be stored on site in designated areas until the various waste management facilities come online.

5.4.12 Small Square

Should the small square be developed in the future, it has been calculated that approximately 15,215 tonnes of waste would be generated annually (after application of minimisation measures), of which 50% would be recycled, 16% composted, and 33% would be processed by the Waste to Energy plant.

This development would follow the same waste management strategy as the larger square, with triple segregation, collection via PRT, recycling in an MRF, composting, and Waste to Energy. The small square would require its own waste transport infrastructure however a common Material Recovery Facility, Composting plant and Waste to Energy plant would be used by both squares.

If development of the small square is anticipated, it is recommended that consideration be given to designing the Material Recovery Facility, Composting Facility, and Waste to Energy plant with enough capacity to handle the waste generated by the small square.

5.4.13 Next Steps

Upon review, discussion and agreement on the above Concept Waste Management Strategy, the following are the recommended next steps;

Waste Analysis Study
In order to obtain more accurate Abu Dhabi-specific waste generation information it is recommended that a Waste Analysis Study be undertaken in the vicinity of the site in order to obtain compositional quantitative data from commercial and municipal waste streams. The results of the study should indicate the total quantity of waste generated and also the organic content of the waste stream, and the percentage of the waste stream which could become recycled material.

In-depth Technology Assessment
Suppliers of In-Vessel Composting, Pyrolysis, and Gasification technologies should be approached and in-depth assessment and field trials undertaken. Significant input will be required into Masdar's PRT design to ensure safe and efficient waste transport.

Legal Review
A legal review of the waste transport and treatment systems should be undertaken to ensure compliance with UAE law.

Retail Operator
World-class and innovative Retail Operators should be approached to gauge interest in teaming with Masdar to provide reduced, recycled packaged goods, packaging return services, and other waste minimisation initiatives.

Waste Minimisation Measures
A final suite of waste minimisation measures will need to be agreed with the various stakeholders including Masdar, the Abu Dhabi Municipal Authorities, the UAE Recycling Industry, the developers, and One Planet Living. An Education and Awareness Programme should be developed, targeted at contractors, labourers, residents and commuters to Masdar.

Construction Waste
Ensure that a Construction Waste Environmental Management Plan (CEMP) is completed before any construction activities begin. The CEMP should include the following measures;

- Minimise waste generation during construction;
- Re-used, recycled, and reclaimed materials during construction;
- Just in time ordering;
- Using construction waste for infill;
- Incorporate Building for Deconstruction principles;
- Incorporate offsite manufactured products and/or modular components;
- Designed to standard material sizes;
- Designed for operational waste minimisation

Waste Strategy Phasing Study
A Waste Strategy Phasing Study should be undertaken of the first constructed Zone of Masdar with the various waste minimisation and management measures adopted. The Study should assess the effectiveness of the waste minimisation measures and the operation of the waste management infrastructure. The study should include awareness and attitude surveys, as well as a waste analysis component.

Energy Distribution

5.4.1 Summary

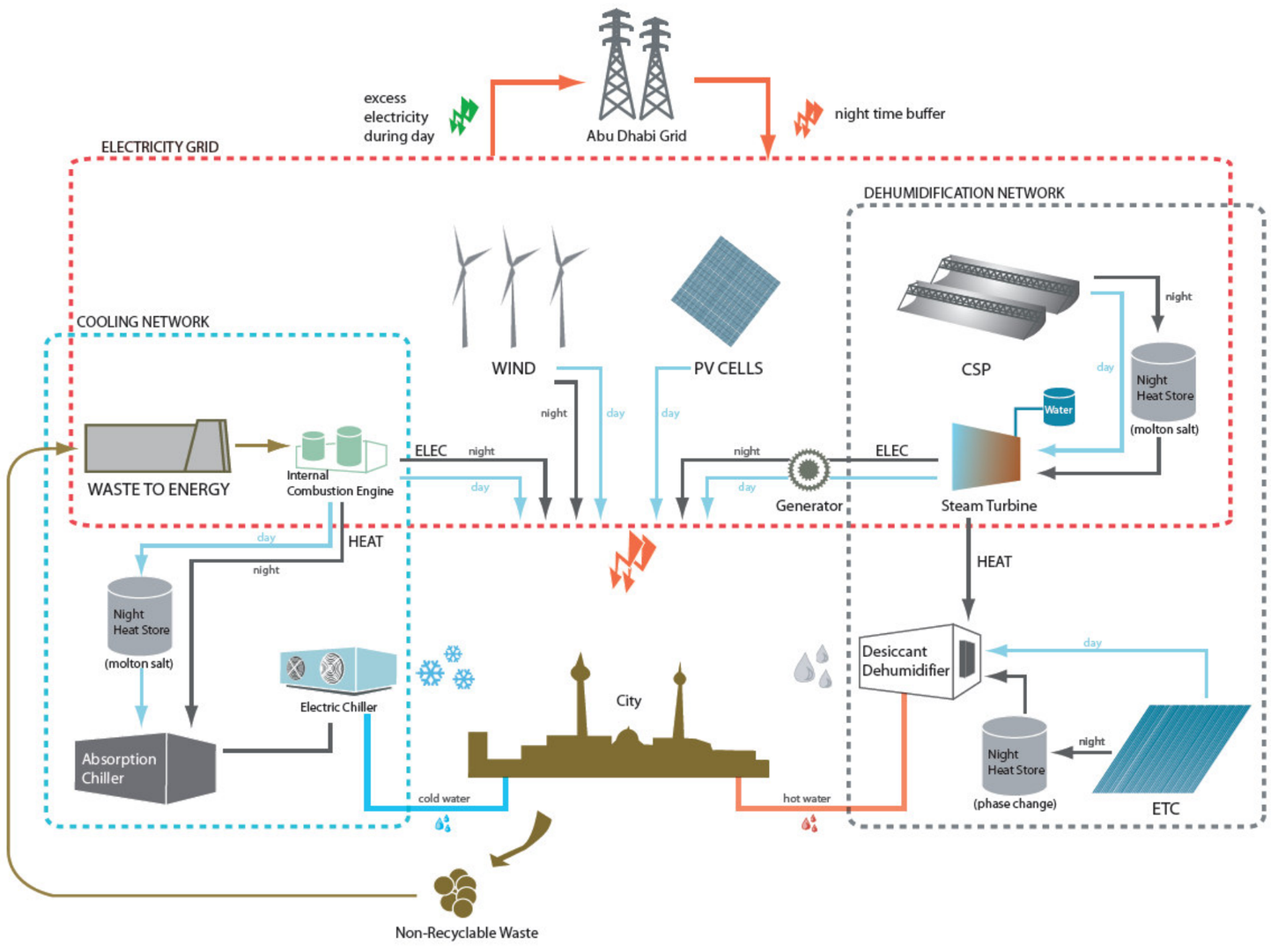
Based on the energy demand requirements for the city of Masdar it is estimated that the electrical demand would peak at just above 35MW and the combined sensible and latent cooling at over 200MW.

In addition, the Masdar development has signed up to the One Planet Living principle of Zero carbon which implies the implementation of energy efficiency in buildings and infrastructure; supplying energy from on-site renewable sources which could be topped up by new off-site renewable supply where necessary. Therefore, the development will self generate its own power and heat for its annual demand via a mix of renewable energy solutions. It is expected to have a CSP with a total capacity of about 60MWp (200MWth) as well as roof mounted photovoltaic arrays of a total of supply capacity of 160MWp, wind turbines of a capacity of 3.5MWp and finally a waste to energy plant capable of producing 2.5MW.

Considering that 95% of power production only occurs during the day it is necessary to have provision for power storage to be able to supply the night and the peak power demand. In addition, it is found to be very risky to have the city without back-up supply in the case of severe dust storms or system malfunction of the solar plant or the PV array; therefore grid connectivity was deemed essential.

In addition, considering the amount of heat available from the thermal renewable systems, it is possible to minimise the electrical demand relating to cooling by maximising the use of thermally driven cooling systems and desiccant dehumidification.

Figure 5.22: Schematic plan of the proposed energy infrastructure strategy



Energy Distribution

5.4.2 Local Context

The Abu Dhabi Water and Energy Company 'ADWEC' has a major 400kV power distribution network that passes in the proximity of the site. The total current system capacity is just above 8,000 MW.

However, based on the growth of the new developments in Abu Dhabi, it is forecasted that the electrical demand will increase on average of 9.5% annually and while there is spare capacity for the next few years, by 2012 the peak power demand will outstrip the planned upgraded capacity which is just over 12,500MW. By the time the Masdar development is fully constructed in 2015 it is estimated that the shortfall will be at over 2,500MW.

Considering that Masdar is in the middle of the major expansion zone of urban development, the local infrastructure for power supply will suffer the most; therefore it recommended adopting severe energy minimisation strategies, and on-site energy and power generation systems.

The chilled water for most of the DCP(s) in the Middle East is produced from units using the vapour compression refrigeration cycle, where the centrifugal compressor is driven by an electric motor. The chilled water for most of the DCP(s) in the U.A.E is produced from refrigeration units with centrifugal compressors, as they offer the highest aerodynamic compression efficiency.

In the U.A.E., these machines would operate at a COP of approximately 5.35 (1.868 kW/kW.r), whilst the COP for the chilled water plant inclusive of cooling tower fans, condenser water pump and primary chilled water pump would be approximately 4.43 (0.2257 kW/kW.r). These ratings are at local conditions, rather than at ARI conditions.

Currently the chilled water development in the region is limited, with the Abu Dhabi International Airport being the only development that uses a central chiller plant. Therefore the current status of district cooling plants or infrastructure in the region is almost non existent.

The projects proposed or being developed in the region are the Al Raha Gardens and Al Raha Beach Development. These projects are being developed by ALDAR Property Developments. The cooling for these neighbouring properties will be provided by a joint venture company formed by Tabreed and ALDAR Properties known as A&T Cool. The total expected cooling capacity of the DCP constructed by A&T Cool for Al Raha Gardens and Al Raha Beach, Central Market and Yas Island would be around 5275 MW (1.5 million tons) of refrigeration.

The concept of District Cooling has been in existence for more than seventy five years and today with the density of the built environment and the demand for Air Conditioning increasing, District Cooling Plants have become a cost effective and preferred solution for generating chilled water required for Air Conditioning. District Cooling has emerged from the concept of district heating of cities in Europe and North America, using one central source instead of distributed systems in each building. District Cooling has proven to be an economical and environmentally responsible solution to the growing demand for Air Conditioning.

A District Cooling System (DCS) consists of three primary components, the central plant, the distribution system and the consumer system. The central source includes the cooling and pumping equipment and in advanced installations, includes power generation, heat generation and heat storage. The distribution or piping network links the central source with the consumer system and usually consists of a network of underground pipe work. The consumer system comprises of a heat exchanger, chilled water piping, air handling units and/or sensible cooling equipment within the building.

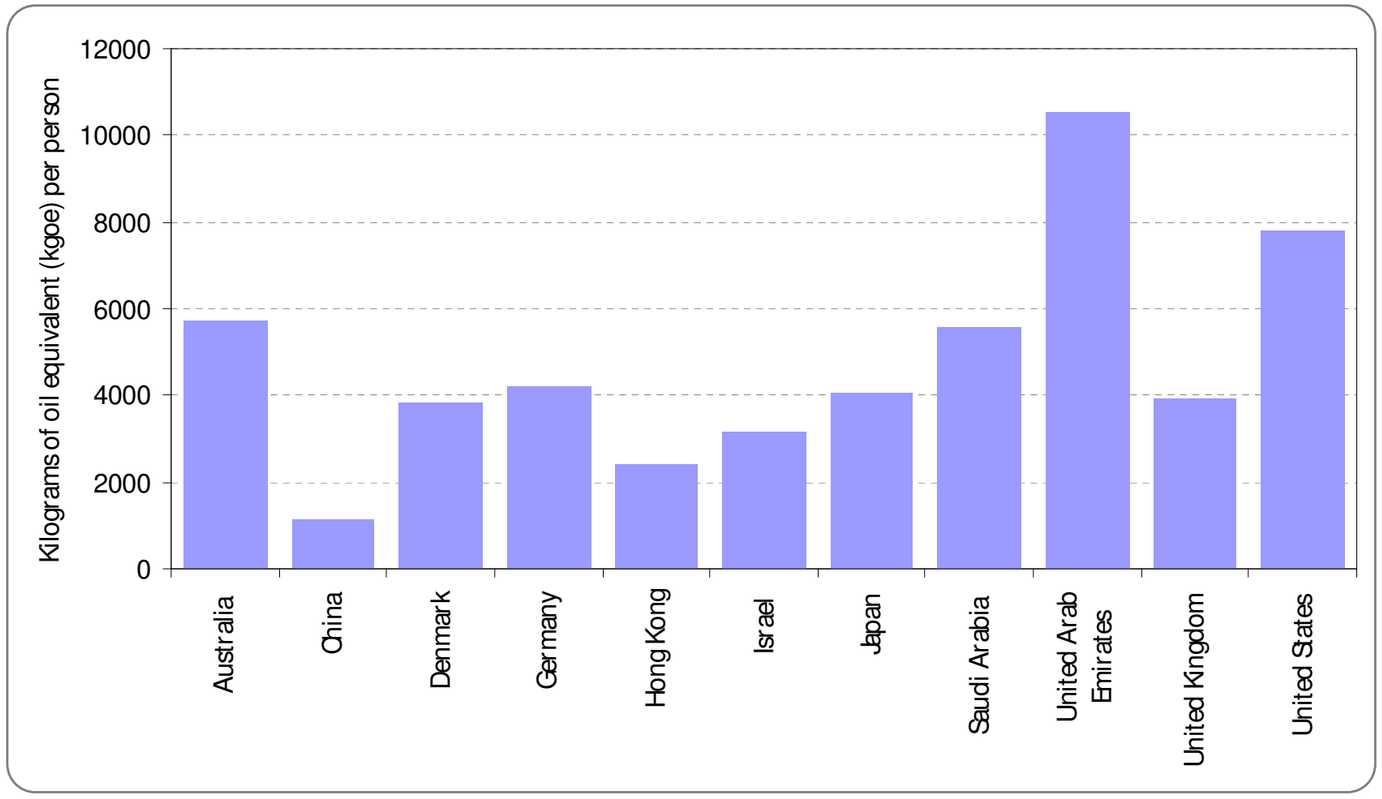


Figure 5.23: Energy Consumption: Total energy consumption per capita

Energy Distribution

5.4.3 Electrical Power Demand

The power infrastructure will enable the supply and distribution of electricity from on-site generation or the Abu Dhabi Water and Electricity Company [ADWEC] network. The design concept is based on a low energy development with a sufficient on site generation to meet the electrical demand with back up from the grid. The on-site generation will comprise mainly of solar power supplemented with wind turbines and waste energy generation.

Estimated Demand

The initial load calculations indicate that if the energy demand targets are achieved the city's power consumption will be the region of 60MW based on the proposed ratio of cooling provided by absorption and electrically driven chillers. However it is estimated that the peak power production from the city is in excess of 120MW. Therefore to allow for the target energy parameters initially being exceeded the power infrastructure will have a capacity for 140MW.

The solar based generation will provide sufficient power during daylight hours to meet the demand of the city and export surplus power to the network. During the hours of darkness and when the sunlight is obscured the on site generation will be limited, under these conditions the network will provide the supply. The transfer of power during the hours of darkness is predicable however when averse weather conditions prevail through daylight hours the power flows will be totally unpredictable and may have adverse impact on the network as the power flow changes direction from export to import. The metering of the supply will be directly related to the import and export of power and whether the system is owned and managed by Masdar or ADWEA.

The electrical power infrastructure will distribute and control the supply of power to the city. A network power connection will be provided by the local supply authority at extra high voltage and terminated on the site boundary. From the network termination point(s) a complex site distribution system will supply the electrical demand. The site distribution will be integrated with the extensive on- site generation systems to enable the import and export of power under differing load and environmental conditions.

In determining the capacity of the connection point to the network the maximum import and export conditions will have to be accommodated. The capacity of the on site generation will depend with the area and type of system adopted.

On the basis that the city load will be in the range of 75-125MW the network connection point will have to have a capacity to import and export power in the order of 100-125MW. At this early masterplan stage the capacity of the network connection must encompass design development and changes during the construction period of this substantial project. It is recommended that initial negotiations with the supply authority are based on a demand range of between 150-180MW.

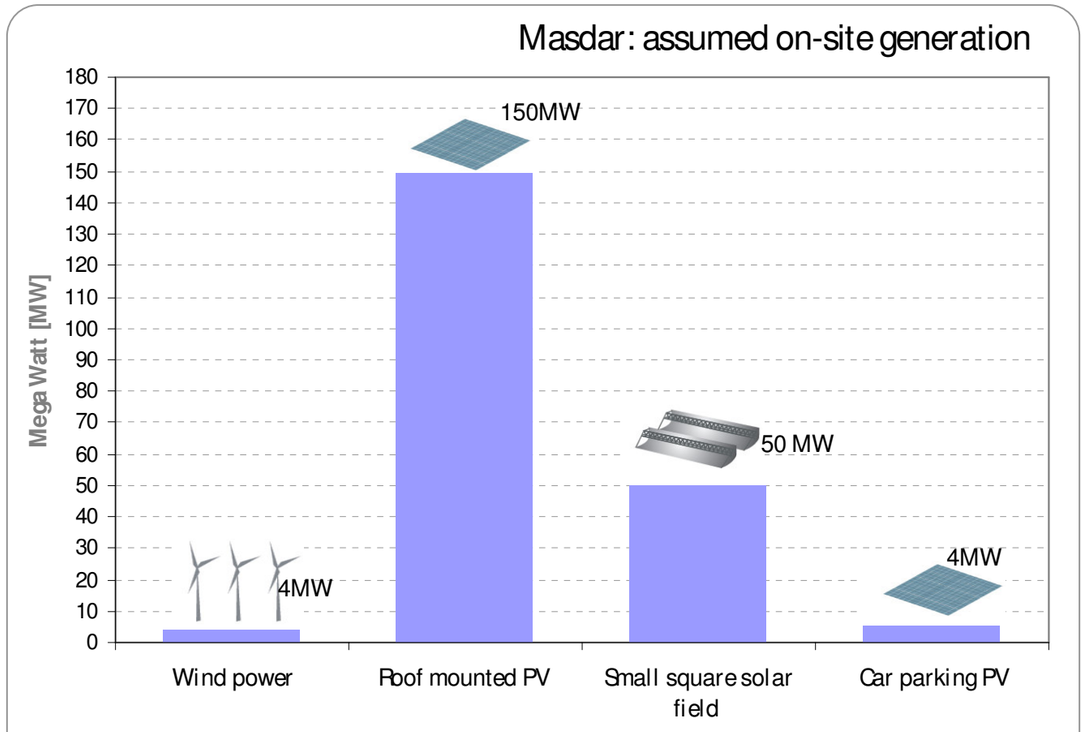


Figure 5.24: On-site Production

The design for the power infrastructure will take the following factors into account:

- Electrical demand
- The availability of a network connection to meet the construction programme
- The integration of the on-site generation with the network supply
- The importation and export of power
- The "non dispatchable" nature of the solar generation
- The effect on the network of fluctuating load flows
- Metering of power
- Adoption of system by ADWEC
- Phasing

Energy Distribution

5.4.4 Power Supply Connections

Connections to the ADWEC network

The Abu Dhabi Water and Electricity Company provides a power supply of 400/132/22KV for projects with a high electrical demand. At masterplan stage prior to detailed discussions with the authority initial contact has indicated that the supply will be provided at 132kV from an existing 400/132kV sub station at Bahya. The supply will be provided via underground cable circuits to the perimeter of the site and will terminate in a 132/22kV sub station. At this stage it not possible to confirm the number of 132/22kV sub-stations.

Each 132/22kV sub-station will consist of the termination 132kV switchgear feeding two 132/22kV oil cooled transformers. It is assumed prior to discussions with ADWEA that the transformers will be rated to enable a single transformer to take the full demand load if one of the transformers fails. The additional load under single transformer operation will be provided by force cooling the healthy unit.

The LV output from each transformer will supply the ADWEA 22kV switchgear which will provide the metering point for the cities supplies. The ADWEA 22kV switchgear will supply a series of 22kV switchboards which will supply the primary distribution.

Discussions are required with the authority to determine the following headline issues which will have a fundamental impact on the detailed planning of the city.

- Predicated electrical demand
- Load profile
- Location of the connection point (s) of the national grid with the city
- Confirmation of the area or areas required for the 132/22kV sub stations
- Cost of providing the network supply
- Lead time for making the supply available. Initial contact indicates that a period of between 30-36months will be required.
- Design requirements of the 132/22kV sub station(s)
- Load availability
- Import and export of power
- Integration of on site generation with the network supply and the impact of varying import/export loads on the network.
- Back up generation

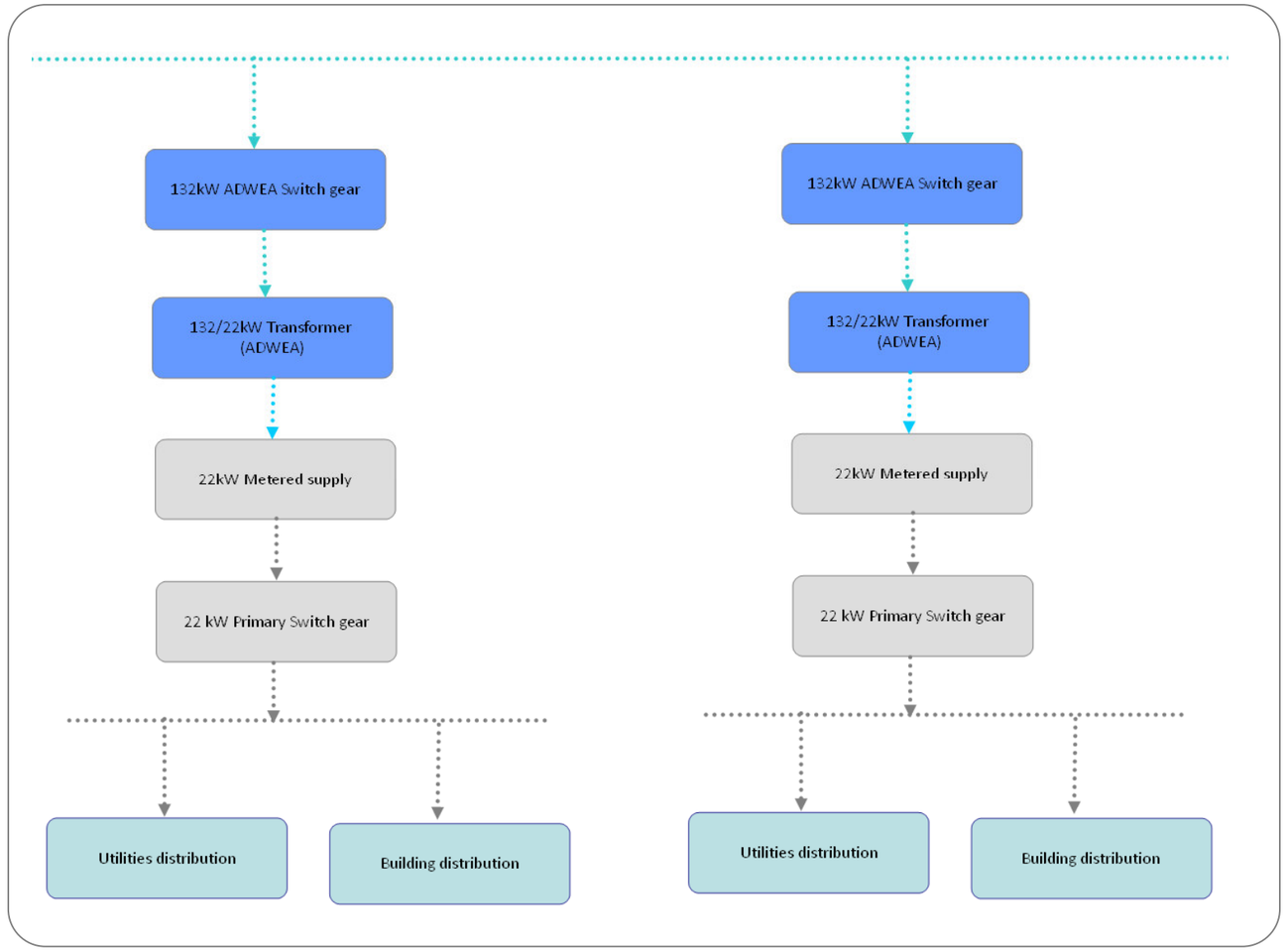


Figure 5.25: 132/22kV High Voltage Network Schematic

Energy Distribution

Integration of on-site generation with the ADWEA network supply

The on-site generation which will consist mainly of PV will have the potential to meet the power demands of the city and generate a surplus for export to the grid under good sun conditions. During the hours of darkness or with the sun obscured by cloud or sand the output will be dramatically reduced. The loss of PV generation during the hours of darkness is of course predictable and the requirement to import power can be fed into the load profiles for the city and the supply authority can plan for the increase in demand. Due to the capacity of the generation available during sunlight hours and the electrical demand of the city the transfer from export to import will have a major impact on the network. With the predicated load in the range of 75 to125MW and a net export capacity in the order of 100MW the impact on the network could be in the order of 200MW as the profile changes from export to importation of power. Consideration will have to be given to controlling the transfer of load from daytime to night time conditions to prevent a large single step load impact on the network.

During the hours of daylight the fluctuations in the on-site generation will be unpredictable; a cloudy or overcast day will have a dramatic impact on generation as there will be an instantaneous reduction in PV output and the complementary instantaneous requirement to import power.

The export of power to the grid will be defined as non-dispatchable as the availability of energy is dependant on weather conditions. In order for the authority to utilise the power from PV and wind power the network requires a percentage of spinning reserve which can take over from the non-dispatchable load instantaneous when the output ceases.

It will be difficult to buffer this transfer in either direction of power flow, detailed discussions will be required with the ADWEA on the impact of the load transfer on the network. If the load impact is a major problem to the network various options will be considered to buffer the loss of supply. This could include large capacity on-site generation via dual fired reciprocating engines. The operation of these units would be linked to the environmental conditions and they would be held as a spinning reserve when required. In addition the units can be utilised for emergency back up for high integrity supplies.

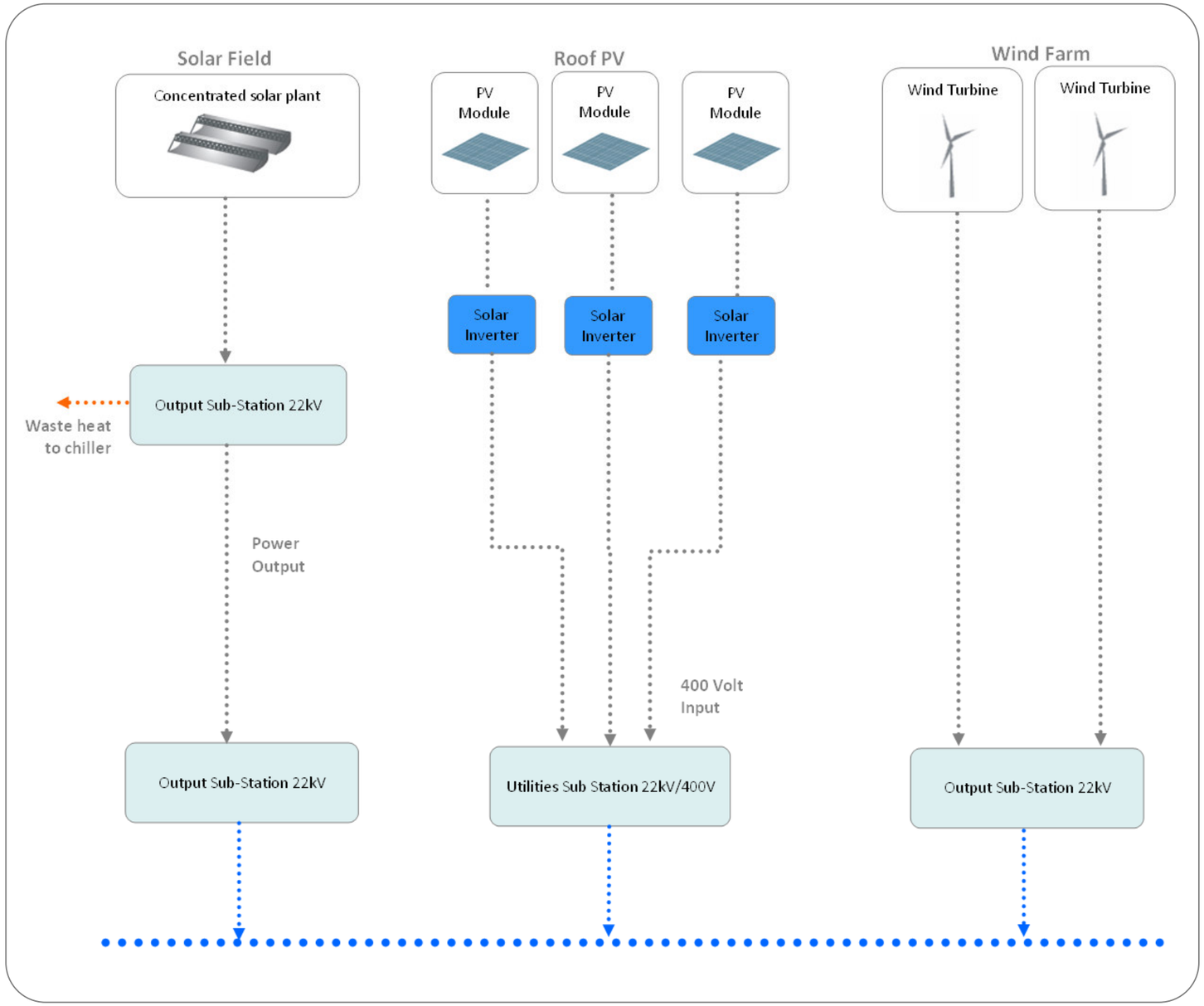


Figure 5.26 On-Site Generation Connectivity to Power Distribution Network Schematic

Energy Distribution

5.4.5 Power Distribution Network

ADWEA have stated that the supply voltage from the network to the City will be provided at 22kV from the 132/22kV grid sub station. A series of distribution voltages have been considered for the city in order to minimise transmission losses and optimise capital expenditure on distribution plant. Generally to distribute power at high voltage reduces losses but increases the cost of the distribution switchgear. The distribution of high capacity power over long distances justifies the expense of very high voltage transmission as in the case of the power demand being remote from the generating source. In the case of Masdar the power demand is concentrated in a relatively small area for electrical distribution.

There is no justification for stepping up the 22kV supply voltage to 33kV or 66kV as the gain from reduced cable losses would be dramatically offset by additional switchgear and transformer costs. Conversely to step down the voltage from 22kV to 11kV would increase cable losses and reduce the distribution capacity of the ring circuits. For the Masdar application the preferred solution will be to utilise the ADWEA 22kV supply as the distribution voltage to minimise losses and capital expenditure

ADWEA will provide from the 132/22kV grid sub stations a series of metered 22kV supplies. Each metered supply will feed a 22kV switchboard comprising a series of vacuum circuit breakers which will provide the supply points for the city 22kV distribution system. The 22kV distribution will be designed to expand as the construction proceeds. Within each construction phase a distribution or node point will be created.

The node point will comprise an expandable 22kV switchboard supplying a series of 22kV ring distributors which will supply the individual loads. Each 22kV switchboard and associated monitoring, metering and control equipment will be installed within a dedicated switch and control room. The 22kV distribution will be divided between utilities supplies serving the cities infrastructure and supplies to the various building types.

Utilities distribution

The utilities distribution will comprise supplies to the following loads:

- Infrastructure plant (water, waste, cooling and heating)
- Transportation systems
- Street and area lighting

The loads will be supplied generally by a series of 22kV/400v sub stations located at the load points connected to the 22kv primary ring feeders. The sub stations will be configured as single or duplicate transformers depending on the connected load and the level of resilience required. Transformer ratings will be selected to minimise system losses and limit fault levels on the LV distribution to 100kA. The transformers will be oil filled, naturally cooled or sealed cast resin depending on the application. Generally oil filled will be selected for external locations and cast resin for internal building supplies. Cast resin transformers located within buildings will be mechanically cooled.

The transformers windings will be monitored for temperature by the central control system via sensors in the windings. Over temperature conditions in the windings will generate an alarm to allow load to be disconnected and reduce the temperature. If the temperature continues to rise the transformer will be disconnected from the distribution system. For loads fed via a single transformer a fault will result in a loss of supply until the fault is cleared. Inherently transformers are highly reliable however for critical supplies duplicate transformers will be provided.

The application of duplicate transformers to protect a single load doubles the iron losses which are independent of load and are only to be considered where the maintenance of the supply is vital.

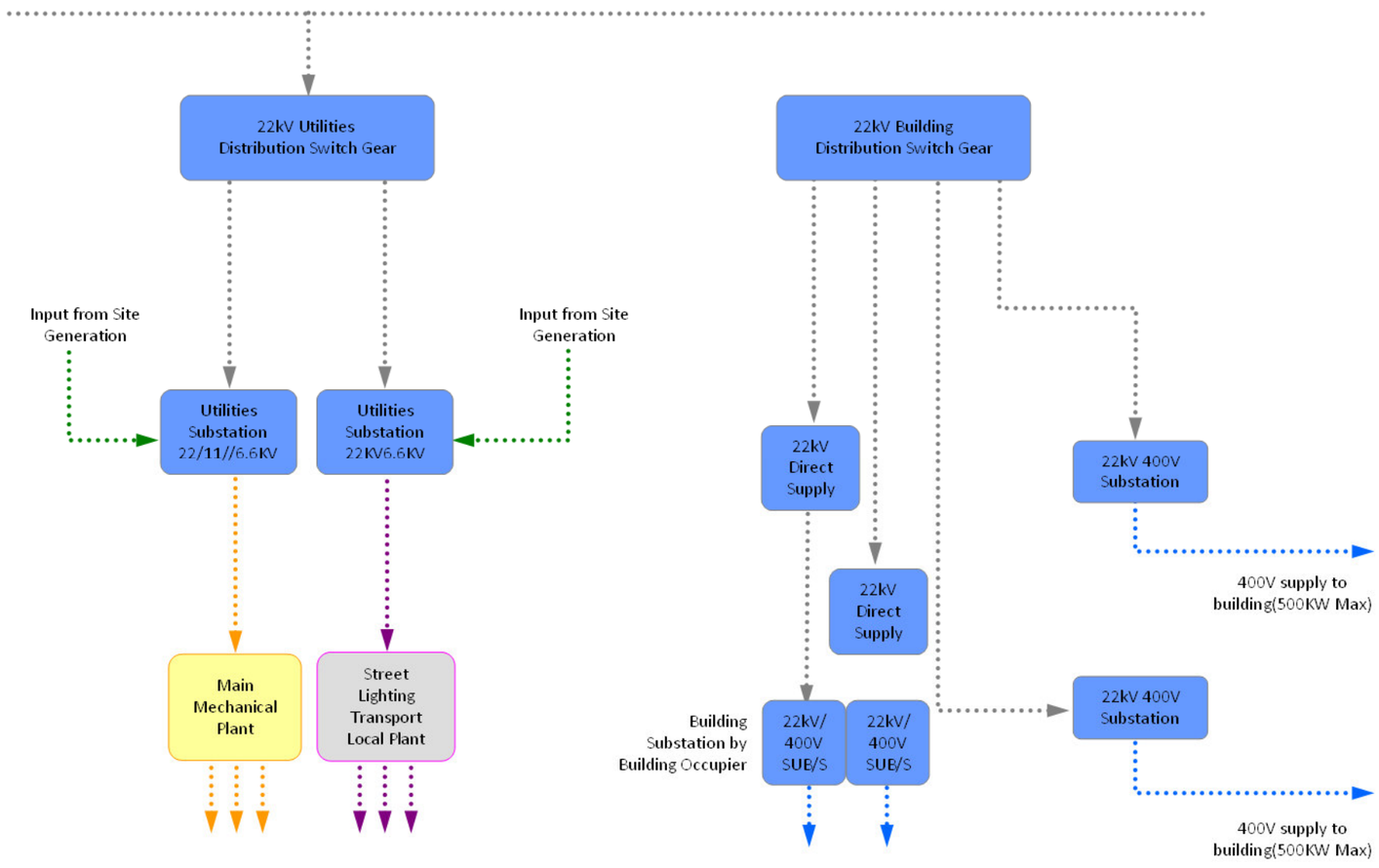


Figure 5.27: 22kV Primary Distribution Network Schematic

For the large infrastructure loads an intermediate voltage of 3.3kV or 6.6kV will be applied to minimise system losses and capital cost. The provision of an intermediate distribution voltage will require additional transformers and switchgear.

Energy Distribution

Building distribution

The electrical infrastructure serving the development phases will be designed to facilitate the connection of power to the developments as the construction proceeds. The prime 22kV distribution will be installed to the phase as part of the enabling works to ensure that when the first building within the phase is completed power is available. The 22kV ring mains serving the phase will be routed via the main service ducts beneath the podium deck. As the construction proceeds the 22kV distribution will be extended into the switchrooms terminating in ring main units. The load on individual ring feeders will be monitored by the central system in order to limit the load on any one ring to 15 to 20MVA reducing the area affected under fault conditions. The disposition of the ring feeders will be determined not only by load but the development pattern within a phase.

The building occupier will apply for a supply and depending on the electrical demand the appropriate connection will be provided. As a guide loads in excess of 500kVA will be provided via a dedicated building 22kV/400volt sub station. Loads up to 500kVA will be provided with a low voltage 400volt supply fed from a non dedicated network sub station. Network sub stations will be in provided generally in areas of multi tenancy construction, for example apartments and small business units.

Where dedicated sub-stations are provided the sub station and the associated switchroom will be located within the building demise. Network sub-stations will be located in common areas.

Fault detection and rectification

The complete city distribution system will be monitored for status enabling the distribution engineers to have in real time the load flows within the system. Under a fault or overload conditions the engineers will be able switch circuits and isolate faults from the system control room. The display of information will be provided via large high definition plasma screen formed into video wall. In addition to system status the video wall will display as separate pages:

- Protection setting data
- Power flows from the on site generation
- Fault indication from the on site generation
- Power flows from the grid
- Comprehensive metering
- Operational maintenance information
- Detailed maintenance information

On site generation

The scope of the power infrastructure in relation to the onsite generation is limited to facilitating the integration of the output into the site distribution network and to allow surplus generating capacity to be exported to the local grid.

The capacity of the CSP field will be in the order of 60MW; this load is substantial and will require a dedicated 22kV primary sub station to enable the generated power to be interconnected with the city grid. The output from the field will be transformed up to 22kV for distribution; however the selection of the input voltage from the field solar generators will be the subject of discussion with the selected suppliers. A series input feeders will be provided on the sub station input switchboard to enable each completed section of generation to be connected to the grid. The switchboard will be configured to enable additional generation to be connected without affecting existing connected generation.

The roof PV will constitute the major source on-site generation with a capacity of 150MW. The available output will be directly related to the construction phasing and will not necessarily correspond to the demand of the building to which it is applied. The proposal therefore is to detach the PV generating capacity from the buildings and treat the roof mounted PV as a single generating resource. The roof PV will be divided for electrical purposes into a series of distribution sections, with each section connected to an infrastructure distribution point. The distribution points will consist of the Utilities 22kV/400 Volt sub stations.

Prior to discussions with the selected PV suppliers the method of connecting the PV systems to the electrical infrastructure cannot be determined. It is assumed however for the purposes of this masterplan that the PV array invertors will feed into the 400Volt distribution system.

Currently the output of the wind farm is relatively small with respect to the PV generation at around 4 to 5MW.
The output from the wind farm will be fed into a dedicated primary sub station to enable connection to the city grid. Similarly the Waste to Energy plant will generate about 2.5MW and the output fed directly into a dedicated primary substation at the Waste Centre.

Energy Distribution

Energy metering and load control

A sophisticated metering system will be provided to monitor the energy consumed by the city. The metering will provide real time information to enable Masdar to charge individual occupiers for the energy consumed. As the Masdar principle is to encourage occupiers to reduce the amount of energy used the metering system will enable charge bands to be implemented that will penalise consumers for excessive energy use. As an example the bands would be adjustable with respect to the availability of on-site generation so when power has to be imported the charges would be increased.

The metering tariffs would also be banded with respect to the type of load i.e.:

- Domestic
- Commercial
- Institutional
- Light industrial
- Specialised

The metering system would also incorporate a load control provision to limit the overall demand of the city to ensure that the energy targets were being achieved. Occupiers would be advised that certain elements of their load would be subject to disconnection if the energy threshold was exceeded. The energy threshold would be adjustable and linked to the on-site generation capacity. Occupiers would be financially rewarded for allowing sections of the load to be switched off.

The metering philosophy of the city's utilities services would follow a similar principle to individual occupiers however the metering would be system related defined as follows:

- District cooling and heating
- Water distribution
- Waste water collection
- Transportation systems
- Street and area lighting
- Miscellaneous

The tariff application to the utilities will have to be developed with Masdar and will form part of the cities operating strategy. Whether it is practical to load shed utility services will be the subject of future detailed discussion, however street and area lighting would be a suitable candidate without adversely affecting the city's operation. Only allowing high capacity loads to be switched on when sufficient on-site generation is available is another possibility.

The metering system would also monitor the import and export of energy into the city. The ADWEA meters located on the 22kV feeders will record the net input to the city and the energy being exported when a surplus is available. The data recorded from the ADWEA meters would be fed into the city's monitoring and control system and would be utilised to drive the tariff selection and load disconnection.

Phasing

The implementation of the primary distribution will be related to the phasing strategy. The current strategy of 6 phases with each phase divided into 3 sub sections has been utilised as the basis for the primary infrastructure distribution. ADWEA has intimated that a 132/22kV grid sub station has a maximum capacity of 120MW. The grid sub station will be the point of connection with the network and will have to have the capacity to import and export the maximum power flows. As the load growth will increase slowly over the 7 year construction period it will be possible from the early stage load figures to predict the final demand and determine whether a second grid sub station will be required.

The ADWEA has stated that a lead time of 30 to 36 months will be required to design and build a new grid sub station. This timescale will compromise the power-on date for the first phase construction and an alternative source of power will have to be provided to meet the electrical demand. It is assumed that sufficient power is available from an existing 22kV sub station at the airport to meet the demand however this has to be confirmed by ADWEA. In the event that power is not available within the timescale then temporary on-site generation will have to be provided.

The primary distribution will expand with the construction. Initially the first sections of the distribution will be connected to an alternative supply and then when the grid sub station is operational the supply will be switched over. To supply Phase1 a 22kV switchroom will be created within Phase 1. The switchroom will be supplied directly from the metered network supply via 22kV feeder cables run on main distribution route within the undercroft. As each additional phase is constructed a switchroom will be created within that phase.

The primary distribution will be the point of connection for the on-site generation. As a consequence of the long build time for the solar systems the level of generation available for the initial phases will be limited. As the construction proceeds the generating capacity will increase. The increased capacity of the generation will affect the power flows within the primary distribution system necessitating constant adjustment to the protection settings of the switchgear.

Procurement

The equipment for the grid sub station will be on a long lead time. At the moment 132/22kV transformers are up to 24 months delivery following full and final design information. The 132KV switchgear will be on a similar delivery time. The bulk of the equipment for the power distribution within the city will utilise 22kV transformers and switchgear which will have a lead time in the order of 12 to 18months.

Construction power

The construction village to be built will utilise roofs covered with PV to provide a percentage of the power needed for construction activities. Sufficient PV will not be available to satisfy the total electrical demand of the site which will have to be supplemented by either a grid connection or on site generation by diesel powered generators. In addition to the limited PV, high starting current construction load will not be suitable for a PV application. It is proposed therefore that the PV is utilised to support passive loads such as lighting and general office power.

Implications of the loss of "small square" CSP generating capacity

The generation within the small square provides 50MWe of load via steam generation. If the CSP plant is removed to enable additional development to take place the generating capacity of the city will be reduced. The impact of the load profile will be to increase the dependence on the grid and reduce dramatically the level of surplus power available for export during the daytime period. Using the latest maximum demand and production calculations for the period of the 6th January and the 23rd July the figures are as follows:

6th January

Production	89MW
Demand	38MW
Export	51MW

23rd July

Production	108MW
Demand	48MW
Export	60MW

From the above figures without taking into account the additional demand created by the construction in the small square the loss of 50MW of generation will reduce the export of energy in the winter to zero and small surplus in the summer. However two balancing factors need to be taken into account: the electrical demand of the construction and the application of PV to the roofs of the additional buildings.

Currently it is calculated that 150MW of energy will be provided by the PV on the roofs of Masdar. Based on an area ratio calculation the small square will provide approximately 15MW of power at peak and the demand will be in the order of 8MW. During daylight hours an additional surplus of 7MW will be available for export: a substantial proportion on the CSP field capacity.

When PV energy is not available the demand on the grid will increase by 8MW to 62MW excluding the additional demand created by the by the reduction in cooling provided by the CSP field. It is estimated that the additional load created by the electrically powered cooling will be in the range of 60-80MW. The total demand on the grid therefore will be in the order of 140 to 150MW. For design purposes the grid connection and the associated internal high voltage network would have a capacity of 180 to 200MW.

With level of demand two network sub stations will be required each rated at 90MW.

Energy Distribution

Next stage

Following the completion of and approval of the masterplan the concepts discussed in the document will be expanded in detail to enable the design to be developed. To move forward from concept will require an analysis of the proposals put forward with respect to the electrical demand during energy cycle during each 24hour period during the year and the complimentary level of on-site generation.

The following areas of the masterplan will require verification and development as part of the next stage:

- Loading assumptions in watts/m^2
- Estimated maximum electrical demand
- Existing capacity of the ADWEA grid and proposals for future enhancements
- The ability of the network to accept exported power
- The ability of the network to accept the load flows as system transfers from export to input
- The integration of the of the grid with the onsite generation
- System protection
- Metering input and output
- Anti islanding and the effect on the on site generation when the load is removed
- The method of network connection and electrical protection of the PV arrays
- The monitoring of the output of individual PV arrays to detect faults
- The method of network connection and electrical protection of the wind turbines
- The method of network connection and electrical protection of the waste generation
- Development of the grid sub stations sites with ADWEA
- The distribution of power within the city related to the construction phasing
- The distribution of power to the development areas including the location of main distribution sub stations
- The distribution of power to infrastructure plant and common areas including the location of main distribution sub stations
- The distribution of power to the transport systems and the consideration of a secondary DC distribution system for DC powered equipment
- Centralised back up power systems for critical systems

Following verification and development of the items listed above a conceptual distribution will be developed which will indicate the type and location of the equipment to be provided and the operational methodology to be adopted. Standard specifications for plant will be provided.

Energy Distribution

5.4.6 Cooling distribution

Introduction

The concept of District Cooling has been in existence for more than seventy five years and today with the density of the built environment and the demand for Air Conditioning increasing, District Cooling Plants have become a cost effective and preferred solution for generating chilled water required for air conditioning. District Cooling has emerged from the concept of district heating of cities in Europe and North America, using one central source instead of distributed systems in each building. District Cooling has proven to be a both economical and environmentally responsible solution to the growing demand for air conditioning.

A District Cooling System (DCS) consists of three primary components, the central plant, the distribution system and the consumer system. The central source includes the cooling and pumping equipment (figures 1 and 2) and in advanced installations, includes power generation, heat generation and heat storage. The distribution or piping network links the central source with the consumer system and usually consists of a network of underground pipe work. The consumer system comprises of a heat exchanger, chilled water piping, air handling units and/or sensible cooling equipment within the building.

Electrical Energy District Cooling Plants

In the Middle East, District Cooling Plants (DCP) are becoming the norm for neighbourhood and city scale developments. These DCP(s) are usually stand alone plants that use grid based electricity to power the equipment generating chilled water.

The centrifugal chillers use the vapour compression refrigeration cycle (input energy to drive refrigeration cycle - Mechanical).

The DCP equipment comprises chillers, cooling towers, chilled water pumps and condenser water pumps. Nominally this equipment cumulatively consumes approximately 0.284 kW of energy to generate a kW of refrigeration (i.e. 1 kW per Ton of refrigeration). Optimized designs in the region claim to achieve 0.21 kW per kW. At the 2007 International District Energy Association Conference held in Scottsdale Arizona, industry professionals made a commitment to better these efficiencies by 25% by the year 2020 making their contribution to the reduction of Global Warming.

Oil-less compressors with magnetic bearings, improved heat transfer surfaces and new generation compressors, are promising developments in the technology of centrifugal chillers which will lead to the reduction of power usage in these plants.

Thermal Energy District Cooling Plants

The use of heat for generating chilled water was practiced in industrial applications for many decades, until the development of energy efficient centrifugal chillers which are usually driven via an electric motor. The most common type of thermally driven chillers are referred to as absorption chillers and use water as the refrigerant. Although water as a refrigerant has very low operational pressure, it is a fluid with a high enthalpy. Either ammonia or lithium bromide solution is used as the absorption medium in these machines. The primary source of thermal energy for the absorption machines is usually derived from either steam or natural gas.

The higher initial costs, the high ambient conditions and allegedly high maintenance costs have been a deterrent to the application of absorption chillers in the Middle East. Also, maintenance requires different skills to those for mechanically driven chillers, necessitating technicians trained on that aspect of maintenance. Once again, chillers with the absorption refrigeration cycle (where the input energy to drive refrigeration cycle is thermal) are being considered as a viable means for generating chilled water for commercial and residential developments, with the development of more efficient and smaller absorption chillers than previously. Due to the growing number of waste to energy generators and built environment requirements to be more sustainable, these thermal systems are being further investigated. In this context, it is very likely that these thermally driven chillers will become more and more popular once the initial hurdles have been cleared.

Although energy for the absorption chiller is traditionally supplied through steam or gas, it is to be noted that steam is not always available in commercial and residential developments and as a result, technologies to use hot water as the heating source have been developed over the recent years. Though the efficiency of hot water driven absorption chillers is not as good as either gas or steam driven units, it is very likely that these low temperature hot water systems will be used in sustainable developments in this region; especially if the hot water is to be generated on site by solar collectors, evacuated solar tubes or waste to energy generators.

Figure 5.28: Eco Friendly District Cooling Chiller Plant at WAFI Mall, Dubai, UAE
Images courtesy of Green Technologies

Figure 5.29: ASHRAE 90.1 Compliant District Cooling Pumping System at WAFI Mall, Dubai, UAE Images courtesy of Green Technologies

Energy Distribution

Current Status

The chilled water for most of the DCP(s) in the Middle East is produced from units using the vapour compression refrigeration cycle, where the centrifugal compressor is driven by an electric motor. These offer the highest aerodynamic compression efficiency available.

Energy analysis of existing operational plants, indicate that centrifugal chillers are the most energy efficient. . In the U.A.E., these machines would operate at a COP of approximately 5.35 (1.868 kW/kW.r), whilst the COP for the chilled water plant inclusive of cooling tower fans, condenser water pump and primary chilled water pump would be approximately 4.43 (0.2257 kW/kW.r).
These ratings are at local conditions, rather than at ARI conditions.

Planned District Cooling Infrastructure Upgrades

Currently the development of district cooling in Abu Dhabi is limited, with the Abu Dhabi International Airport being the only development that uses a central chiller plant. Therefore the current status of district cooling plants or infrastructure in the region is almost non existent.

The projects proposed or being developed in the region are the Al Raha Gardens and Al Raha Beach Development. These projects are being developed by ALDAR Property Developments. The cooling for these neighbouring properties will be provided by a joint venture company formed by Tabreed and ALDAR Properties known as A&T Cool. The total expected cooling capacity of the DCP constructed by A&T Cool for Al Raha Gardens and Al Raha Beach, Central Market and Yas Island would be around 5275 MW (1.5 million tons) of refrigeration.

Possible Plant Configuration

Electricity Driven Centrifugal Chillers
If Electricity is the prime energy source this would be could be used for the production of chilled water, using electric centrifugal chillers

The proposed centrifugal chillers for Masdar DCS are of the series counter flow arrangement type. In this configuration, a packaged chiller comprises two standard chillers connected in series, where the chilled water leaving the first chiller is the chilled water entering the second chiller. Even the condensers are connected in this manner to reduce the cooling tower water foot print and to reduce the condenser water flow rate, thereby reducing the make up water to cooling tower. This configuration is adopted to provide the cooling capacity with a lower water flow rate, which provides a larger temperature difference between the chilled water supply/flow temperature and chilled water return temperature. The reduced chilled water flow rate in turn reduces the chilled water pumping energy requirement.

Thermal - Absorption Chillers
Should thermal energy be available in abundance and as the source of prime energy, the proposed generation of chilled water could be by thermal chillers. The use of hot water to generate cooling would be more economical than generating electricity from thermal energy to operate the chillers. If hot water is to be used as the energy transfer medium to drive the chillers, chilled water could be produced by large hot water driven absorption chillers located in a utility compound.

Should the chilled water be generated from absorption chillers, the chillers' leaving chilled water temperature would be higher than that of a electrically driven centrifugal chiller. In this instance the latent (dehumidification) load should be removed with a desiccant as described in Options 1 and 2.

Absorption Chillers in Series with Centrifugal Chillers
If Thermal energy is available to satisfy only a part of the demand, absorption chillers in series with centrifugal chillers could be used as indicated in figures 3 and 5.

Absorption chillers are installed upstream of the centrifugal chiller, so that the leaving chilled water of the absorption chiller is the entering chilled water of the centrifugal chiller. This configuration would provide a more efficient system than installing both the absorption and centrifugal chillers in parallel.

Absorption chillers are especially useful when used with a source of waste or by-product heat. Therefore using them as proposed enables all of the heat produced by the solar power plant to be used. Their configuration in series with electrically powered chillers ensures that the heat is used as efficiently as possible at optimum cost while ensuring that all cooling demands are met..

5.4.7 Strategies for District Cooling

The project's Energy and System Teams arrived at the following options for the District Cooling System, each of which have been investigated before selection the 'preferred' option. The energy balance and the system are discussed in detail in other sections of this report. The following pertains to the district cooling infrastructure options.

Option 1: Electric chillers & thermal chillers and desiccant humidifier

Option 1 addressed the sensible heat removal with chilled water, generated by a combination of electric and thermal chillers and latent heat removal by a desiccant system.

Under this option 95% of the chilled water would be generated using electric motor driven centrifugal chillers, with the balance 5% being generated by thermally driven absorption chillers.

Latent heat removal (dehumidification) will be achieved with a liquid desiccant such as lithium chloride, lithium bromide or calcium chloride solution. The desiccant solution is to be re-generated by thermal energy.

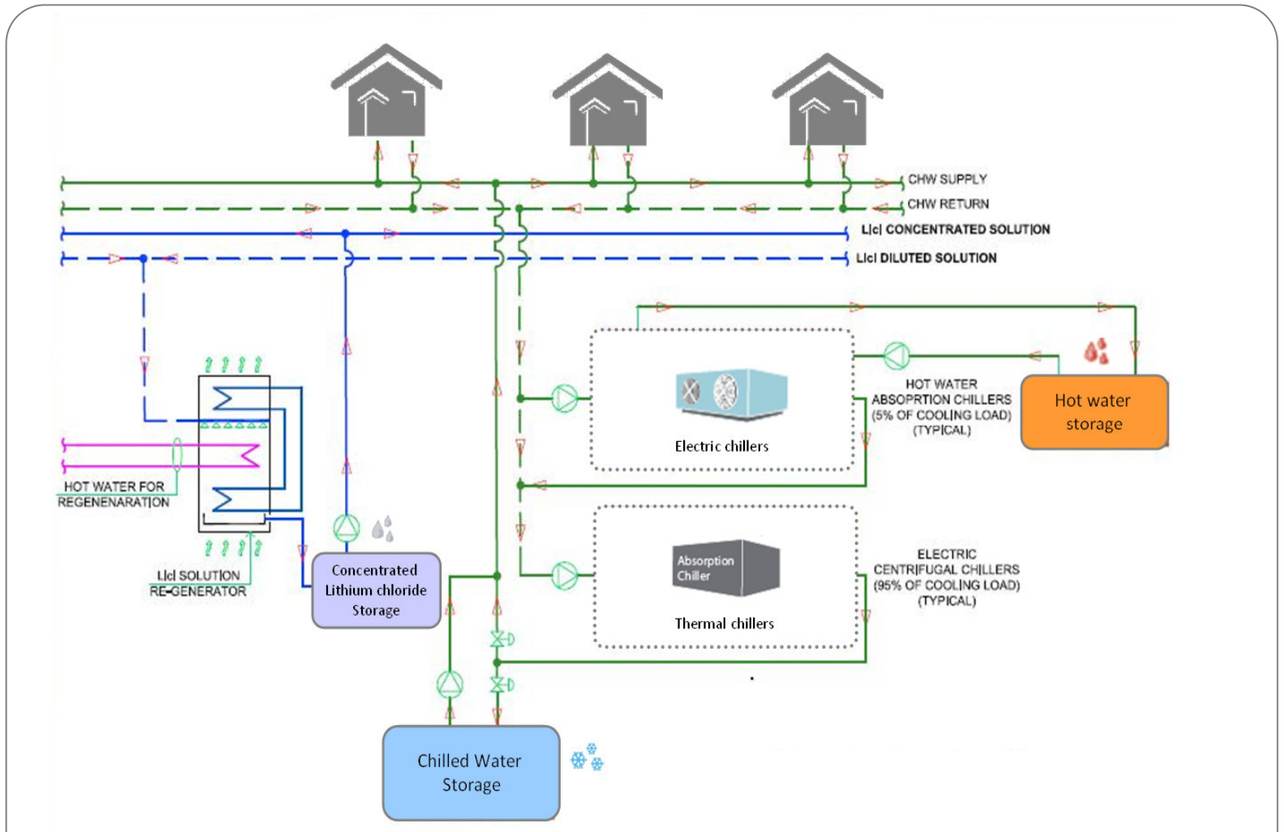


Figure 5.30: Option 1 - Electric chillers & thermal chillers and desiccant humidifier

Advantages
- Higher thermal and electrical efficiency of sensible cooling
- Better dehumidification

Disadvantages
- Complex system
- Potential health risk associated with use of Lithium Chloride

Energy Distribution

Option 2: Thermal chillers and desiccant humidifier

Option 2 pertains to the removal of sensible heat using chilled water, generated solely by thermally driven absorption chillers, with the latent heat removal by a desiccant. The chilled water requirements for sensible load will be generated by absorption chillers, with the latent heat removal (dehumidification) by a desiccant system as for Option 1.

It is to be noted that the use of absorption chillers requires greater quantities of cooling (condenser) water when compared to electric centrifugal chillers and the adoption of this option would depend very much on the availability of water and the overall energy and resource foot print of the cooling process.

Advantages
- Good use of waste heat from plant

Disadvantages
- Lower systems efficiency
- Potential heath risks associated with Lithium Chloride

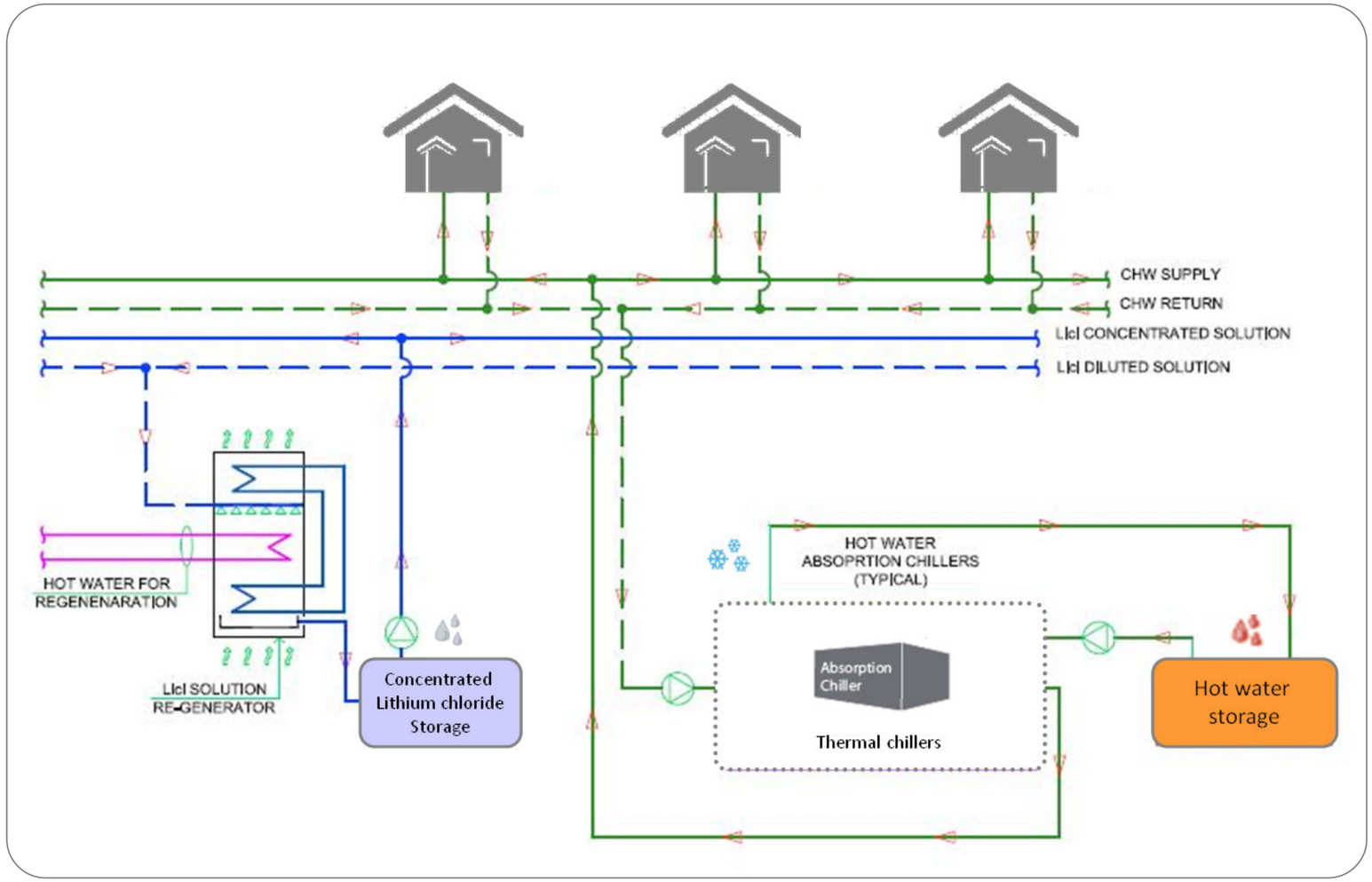


Figure 5.31: Option 2 - Thermal chillers and desiccant humidifier

Energy Distribution

Option 3: Electric chillers & thermal chillers

Option 3 utilised chilled water to remove both the sensible heat and latent loads, with the chilled water being generated by a combination of electric and thermal chillers. Based on the energy balance it is very likely that the bulk of this load will be handled by the electricity driven centrifugal chillers supported by absorption units depending on the availability of heat.

Advantages
- Relatively low health risk
- Simpler distribution

Disadvantages
- Less dehumidification control
- Higher energy requirement

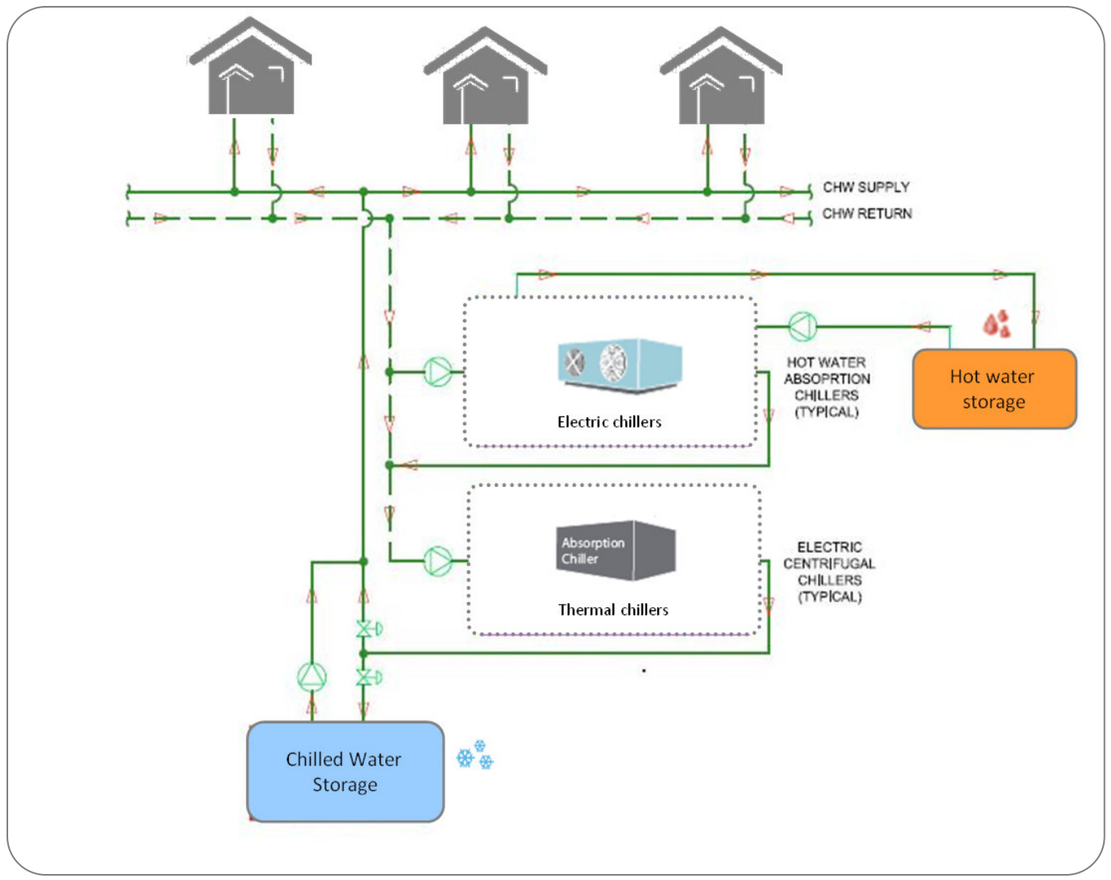


Figure 5.32: Option 3 - Electric chillers and thermal chillers

Energy Distribution

5.4.8 Distribution Strategies

For the Masdar development, the electrical and thermal energy balance is achieved by the following energy forms;

- Electricity from the photovoltaic arrays
- Electricity and thermal energy from the waste thermal treatment process
- Electricity and thermal energy from the concentrated solar plants
- Electricity from wind turbines

Based on ETA's preferred strategy for energy supply, of the two energy types, the availability of electrical energy is greater.

Chilled water

The TransSolar/KlimaEngineering report indicates that electrical and thermal energy balance is achieved by the following energy forms;

- Electricity from PV
- Thermal energy (hot water) from waste incineration process.
- Electricity from desalination plant
- Thermal energy from desalination plant
- Electricity from wind turbines

Of the two energy types, the availability of electrical energy is greater.

The use of chilled water storage as a means of storing energy and achieving higher operating efficiencies of the chilled water plant will be pursued considering the benefits will provide to the overall theme of sustainability and load stabilization.

The chilled water distribution network would adopt a high temperature difference between flow and return so as to minimise the pumping energy and redusing the infrastructure piping sizes. It is expected that a Delta T of 10 degrees K will be endeavored, especially if the chilled water is only used for sensible cooling.

Hot water

Although hot water is not the typical distribution medium used in this region, it would be the most economical to use when thermal energy is produced from the waste to energy plants and solar collectors and is available in abundance.

Hot water at medium temperatures of approximately 120^{o}C could be used, with a much higher supply-return temperature difference than chilled water, keeping the flow rate lower than of a chilled water system, and reducing pumping power requirements. Higher water temperatures require a higher pipe pressure due to increased saturation vapour pressure and also higher rated pipe.

If lower grade hot water at 85^{o}C such as water generated via conventional solar collectors is used, both the thermal transfer rate and chiller efficiency is reduced, making the system less energy efficient than the system using water at 120^{o}C.

Condenser water

If either hot water or electricity is the energy source, condenser (cooling) water is also required by the chillers. Conventionally potable grade cooling water is used in the region. Treated sewerage effluent is also being used by developers as integration of systems is pursued more aggressively. Use of sea water cooling could be considered as an option as against the use of potable or other treated waste water, especially when the chilled water generation building is close to the potable water desalination process.

When the water is either sea water or brackish water, titanium heat exchangers at the energy transfer station should be more economical than providing titanium condensers at the chillers and pumping sea water through DCS. The condenser water could also be used as the reheat water when dehumidification is required.

It is to be noted that the condenser water cooling requirements for thermally driven chillers (absorption chillers) is almost double that of the electric centrifugal chillers and this needs to be addressed in the overall energy balance and resource footprint of the District Cooling System.

Energy Distribution

Distribution Network

The Masdar development is segregated into 9 sections, as indicated in figures 6 and 7. The power required to generate the sensible cooling load as indicated above is from electricity.

The peak sensible load and latent load provided is:
Sensible cooling 114.4 MW
Latent cooling 124.6 MW

Two dehumidification options are considered;

The conventional system adopts the use of chilled water for dehumidification (Option 3)

The second system (Options 1 and 2) is addressed by a liquid desiccant, lithium chloride, lithium bromide or calcium chloride. The specific gravity of the solution used in our calculations is 1.26 kg/litre (lithium chloride solution 43% by mass) in the supply and 1.10 kg/litre (solution 29% by mass) in the return. This type of dehumidification system is new to the commercial and residential industry and also to region. These systems are proprietary in nature and need to be investigated further.

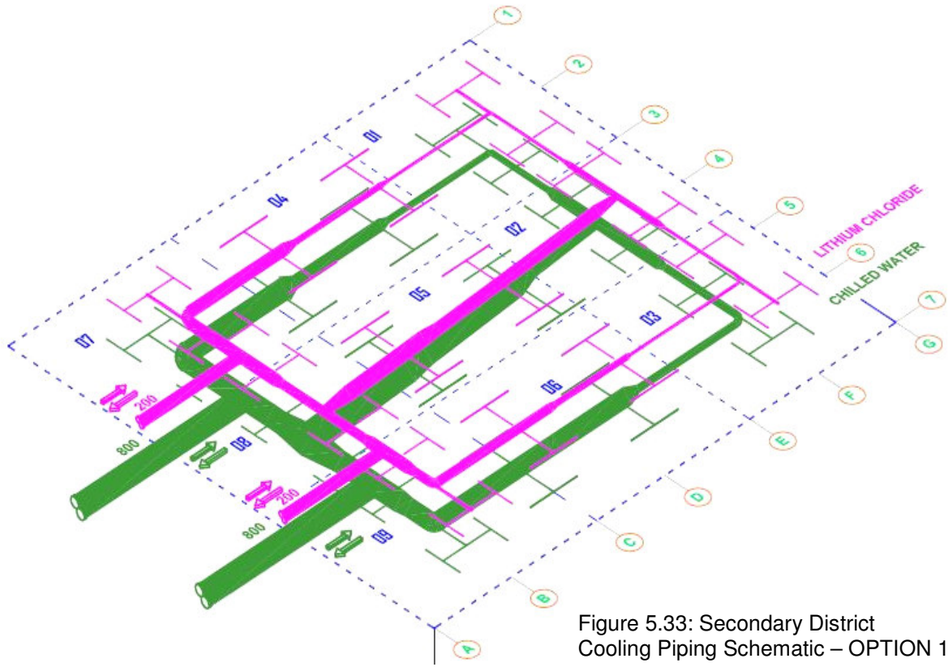


Figure 5.33: Secondary District Cooling Piping Schematic – OPTION 1

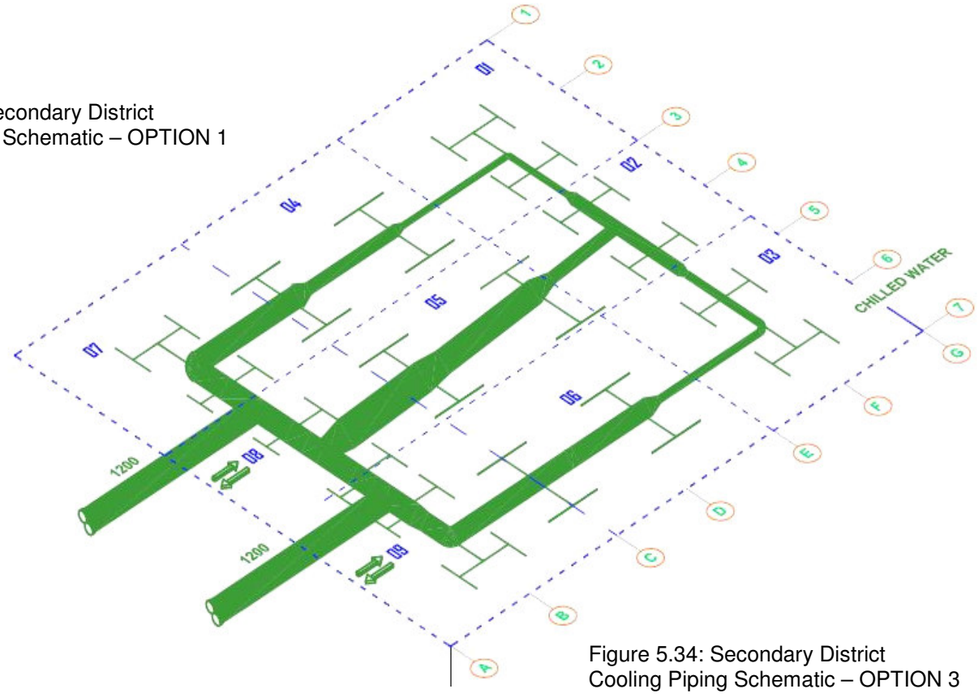


Figure 5.34: Secondary District Cooling Piping Schematic – OPTION 3

Energy Distribution

Preferred Supply Strategy

In developing the project, the team has settled upon a preferred option for the final masterplan development. This is Option 1:

- Latent heat removal (dehumidification) is achieved by liquid desiccant
- Sensible heat is removed by chilled water

Chilled water is produced predominantly from electric motor driven chillers with thermally-driven absorption chillers providing the balance.

Phasing

The phasing of the district cooling infrastructure and the central plant will follow the overall phasing of the site, construction of what is required, as it is built in terms of the primary infrastructure.

It is very likely that the development will consist of several smaller decentralised plants as compared with one central plant. The pumping systems will be configured to meet the demand of the adjacent loads rather than those remote to the respective plant. As for the distribution mains, means for isolating the live system from the extension (next phase to come online) will need to be provided so that the chilled water could be provided without requiring lengthy shut-down periods when the piping system is extended.

Innovation

Innovation is provided most obviously by the use of liquid desiccant systems within a large distributed network. This technology has been used sufficiently to demonstrate its feasibility but there are few examples of its use and none are of a scale such as this with the desiccant regeneration remote from the 'consumer'.

Other innovations involve:

- the use of the combination of absorption and electrical chillers to make the best use of the solar resource
- the concept of splitting the sensible and latent heat demands of cooling and using higher temperature chilled water to provide the sensible cooling only.

These are not new concepts and have been used before, but the novelty lies in the combination of all three points and their application on a city-scale.

Next Steps

The next steps for this scope of work are:

a. Validation of the proposed use of liquid desiccant for latent heat removal.
b. Detailed investigation of equipment required for the distribution of liquid desiccant (bearing in mind corrosive properties of all of the alternatives).
c. Development of a management plan for operation of the two distribution systems.
d. Development of metering details for the two distribution systems.
e. Detailing of the chiller plant required, taking into account phasing issues.

ICT

With a whole new way of thinking, Masdar presents a unique opportunity for innovative communication services. The high aspirations to maximise the use of natural and sustainable resources are supported by open communication between these systems everywhere, yet this will become an accepted part of Masdar daily life.

More apparent for those living and working within the city will be the seamless convergence of all communications over a single scalable platform designed to grow as the Masdar world changes.

The concept for Masdar applies the latest evolving communication technology to unleash the potential for exemplar communications from day one into the foreseeable future not only in the region, but in the known world.

5.5.1 Optical network

Fibre optics are nothing new, we've all come to rely on them for long distance communications today whether we realise it or not. If we take the view that "it's not what you have, but how you use it" then we're opening the door to a whole new world.

The basis of the Masdar communication backbone is a scalable single mode Passive Optical Network (PON) supporting the latest Fibre to the Premises (FttP) or Fibre to the Home (FttH) delivery of services.

The basic technology isn't ground breaking, merely the current best practice for all new mixed use developments having evolved over the last 15 years. The application at Masdar leverages the convergence of communications to support all the data, voice, multimedia streaming and more recent mobile communications over a common Gigabit PON (GPON).

But lets not stop there, why only a Gigabit? This is where a passive optical network comes into its own, with a potential for much more in the future. Simply upgrading the active elements at the edge of the fibres multiplies the size of the virtual "pipe" allowing currently unforeseen services to be accommodated relatively easily by expanding the capacity.

5.5.2 What are the alternative?

We're considering PON as the suitable mechanism as it supports the maximum number of commercial and residential end points with the minimum amount of optical fibre through splitting fibres rather than dedicating each to a single user. This creates a point-to-multipoint architecture preventing any unnecessary fibre installation ensuring the costs of producing the optical fibre itself are kept to a minimum.

The alternative, point-to-point application of IP or Ethernet networks is where each user get's their own dedicated single fibre, rather than sharing this, and therefore its capacity, with others. Typically referred to as an Active Optical Network (AON), every termination of fibre will need to be in a building into a piece of electronic equipment. This typically increases not only the quantity of fibre but also the amount of electronic equipment required to light it up.

In practice, some high bandwidth business users may well require dedicated point-to-point connections; however this can be achieved by segregating their needs into dedicated fibres within the PON

The result is that although we're generally referring to the optical network as a PON, there will be some elements within it that constitute an AON. The outcome however, supports the design concept of using the minimum appropriate quantity of fibre to serve all the services perceived with scalability on all links for future expansion as needs require and electronics advance.

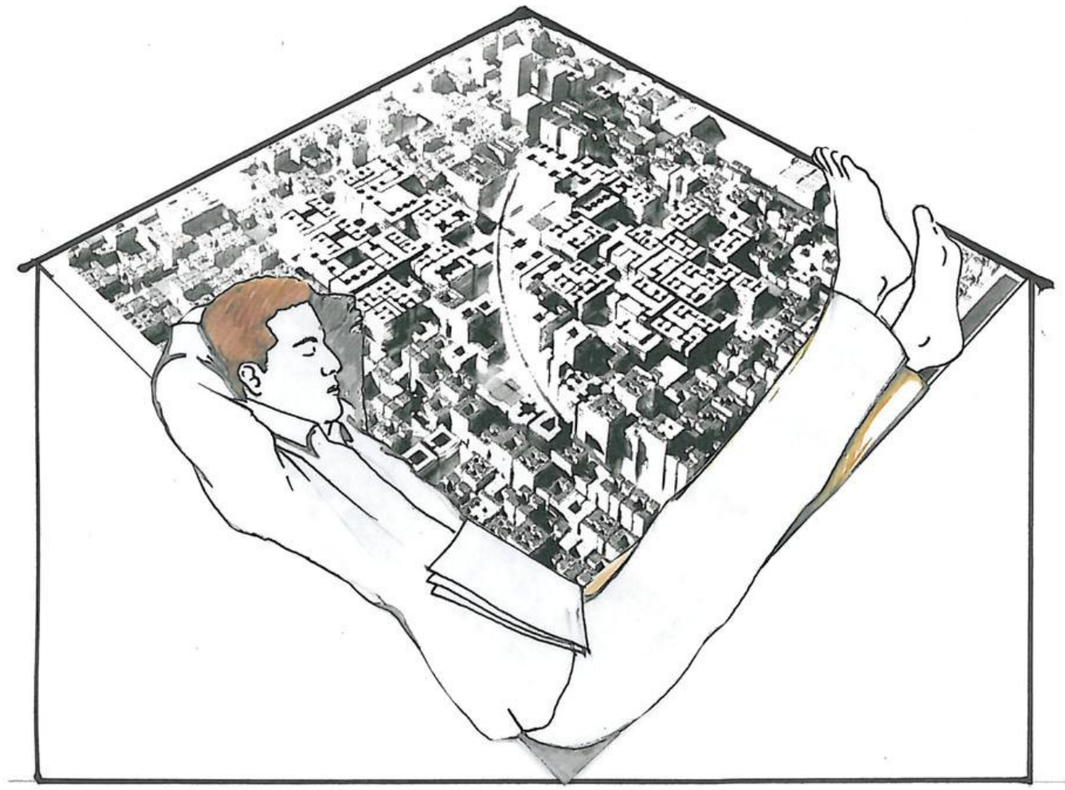
5.5.3 Convergence

What does convergence mean for the city?

Consider the Masdar city as a single workplace for the staff of the Abu Dhabi Future Energy Company rather than a city with a collection of disparate buildings.

With converged or fused open communications available to staff, the whole city becomes the office with a single contact number integrating desk and mobile phones. Calls within the city using either fixed line or mobiles could be considered internal extensions without charge.

Following this train of thought, why not extend this facility for all the residents and workers? Doesn't covering all business and personal mobile and fixed line calls within the city boundary in a single fixed charge become a catalyst to open the channels to develop the community and promote business?



ICT

5.5.4 Ease of Management

When we talk about Facilities Management, typically this is a supporting tool or tools for the landlord or those responsible for maintaining the development wide plant and systems. The applications of Computer-Aided Facility Management (CAFM), Planned Preventive Maintenance (PPM), Monitoring and Targeting (M&T), Building Management or Automation Systems (BMS/BAS), Utility Metering and many other support tools all requires communications so will benefit from a common platform.

The area that then becomes apparent, following on from the converged communications we've already considered, is that system integration becomes a much more practical proposition. Open standard communications transport provided by IP networks means that only the application layer protocol, the actual language each application speaks, needs to be levelled so they can understand each other. For a comparison in the voice world, this means that anyone can call anyone; they just need to be able to speak in the same language.

In the building services world, our application of open standard communications between mechanical, electrical, security, life safety and other systems using open standard application and communication protocols is covered in the integrated Building Management System or iBMS.

The benefits to the user of pulling all this information together come from a single route to extract data from any systems for management reporting, and the ability to port all this information into a common graphical user interface (GUI) across all types of devices through using familiar web services or web pages.

5.5.5 City safe

Everyone needs to feel safe, whether at home or at work. The application of city wide integrated security and life safety systems makes this a reality.

Although there is a temptation to feel that "big brother" is watching, the appropriate application of security makes it feel like we're safe at home, rather than exposed on the street within the city boundaries. This feeling should be closer to an all-inclusive holiday resort than a prison camp as a comfort to those most vulnerable.

The development wide communications also support this, with a common network allowing easy relocation and reconfiguration of CCTV cameras, access control, intruder detection and all other systems. This is almost a "plug-and-go" capability for communications in the same way as electrical power.

As a communication service provider, early indications show that Etisalat are keen to engage in a development which can be a showcase for future communication services. To deliver the concept, a reliable partner for a Masdar Communications Company will certainly be a benefit.

For other systems and services, appropriate partners will need to be selected who will support the future vision to do things better than have ever been done.

5.5.6 Mobile monitoring

Following the theme of safety and security, the application of evolving wireless identification technology such as Wireless (WiFi), Radio Frequency Identification (RF ID) and mobile phones opens a whole new world for asset and personnel identification and tracking across the entire city.

Some might be concerned about this, but it's voluntary, so when you lose a prize possession, you're valuable stock or even your kids isn't it comforting to know you can find them if they're still within the city?

This application of identification technology also means your mobile phone can be your access to transport, buildings, payment for goods and services, all through a single device to carry.

5.5.7 Making it happen

Here comes the challenge… obviously this level of technology integration doesn't come as standard.

The challenge going forward is to select appropriate partners and suppliers that will work together as a team to deliver the dream into the future.

5.5.8 Service providers

Masdar requires an ICT infrastructure that has the potential to offer multiple services from multiple providers to all end users. These include the following services

- Internet Access
- Wide Area Networking
- Wired/Wireless Connectivity
- Fixed & Mobile Voice
- (Interactive) Television
- Building Management Systems
- Security Systems
- Life Safety Systems

The potential providers of these ICT services for Masdar are as follows:

- ADFEC
- Etisalat
- Any future Abu Dhabi service providers
- End users[1]

The users of these ICT services for Masdar are as follows:

- Abu Dhabi Future Energy Company (ADFEC)
- Concessionaires (Local developers granted concessions by Masdar)
- Landlords
- Residential & Commercial Tenants
- Fire Brigade

The infrastructure must retain the flexibility to scale in response to higher or lower demand. The installation needs to be phased in line with the Masdar construction programme.

Proposal

The current regional model in Abu Dhabi is for two ICT infrastructures to distribute services across a city site.

Etisalat provides, installs and supports an ICT network for the distribution of services to all end users within the city.

ADFEC provide, install and support an ICT network to distribute ADFEC's required services to ADFEC users across the city.

Instead of separate Etisalat and ADFEC networks it is recommended for the city to be serviced by a single unified network which will follow the design proposal for the ADFEC network with ownership and support by ADFEC, Etisalat or a joint venture.

The following proposal is for the ADFEC network and can be scaled for the single unified network.

The key element of the proposal is the physical infrastructure of fibre spanning the city. The topology is discussed under 'Physical Infrastructure'. The hardware is discussed under Optical Line Terminal, Optical Distribution Network and Optical Network Terminal.

Ownership & Installation

ADFEC will provide a Point of Presence room for Etisalat in each of the two stations built in the first phase.

ADFEC will oversee installation of ADFEC network infrastructure for the distribution of the services required by ADFEC across the city, extending from the stations and connected to the Etisalat network.

Instead of the current scenario which has a separate Etisalat and AD With a whole new way of thinking, Masdar presents a unique opportunity for innovative communication services. The high aspirations to maximise the use of natural and sustainable resources are supported by open communication between these systems everywhere, yet this will become an accepted part of Masdar daily life.

More apparent for those living and working within the city will be the seamless convergence of all communications over a single scalable platform designed to grow as the Masdar world changes.

The concept for Masdar applies the latest evolving

Internet access

Security Systems

Access Control

Innovation in Services

Unified Network

The basis and infrastructure for services to connect and interact.

Wi-Fi Locationing

There's my destination, there's my transport.

Fixed Mobile Convergence

One number anywhere in the city when I'm in work. Same facility, different number when I leave work behind.

Near Field Communications

Carry my Masdar Information point with me.

City Content

TV content binding together the Masdar community.

Interactive Waste and Energy Management

Directly supporting the vision for Masdar. Adfec and their customers learning to make the right environmental lifestyle choices, together.

Flexible CCTV locationing

Responsive and responsible security.

Access Control and Near Field Locationing.

Secure Access control with your Masdar mobile phone.

[1] End users will also provide network services that will need to be distributed to different sites inside and outside the city

5.5.9 Physical Infrastructure

Masdar will require the active involvement and agreement of the service providers for the physical infrastructure and city distribution network.

Passive Optical Network

For Masdar city, passive optical network (PON) is suggested for the ICT physical infrastructure.

The PONs will extend Masdar's network throughout the city as well as connect all the city's end users to service providers.

A passive optical network is a point-to-multipoint, fiber to the premises network architecture in which unpowered optical splitters are used to enable a single optical fiber to serve multiple premises.

A PON configuration reduces the amount of fiber and central office equipment required compared with point to point architectures.

Passive Optical Networks will distribute services across the city taking optical fibre to each premise (Fibre to the Premises, FTTP).

A PON consists of an Optical Line Terminal (OLT), the Optical Distribution Network (ODN) and a maximum of 64 Optical Network Terminations (ONTs).

The number of PONs required will be calculated from the concessions calculations of ONTs required and their calculation for splits in each PON.

A PON with 1:32 split provides up to 70Mbps (megabits per second) per subscriber. By reducing split ratios the speed can be quadrupled. FTTP standards bodies are currently working on a 10,000 Mbps PON capable of 280 to 1,125 Mbps per subscriber. A further step change in speed is offered by WDM-PON (separating transmission over different light wavelengths). Both current and future technologies use the same Optical Distribution Network (ODN) with different active equipment on the supplier and subscribers ends of the ODN.

Ethernet will be the layer 2 protocol used throughout the city.

Optical Line Terminal

The Optical Line Terminals will use varied laser classes according to the number of splits in each PON.

Assuming a 3.5dB power loss per split:

End users	Class Laser
1 to 8	A
9 to 32	B
33 to 64	C

Where the service provider cannot offer Internet Protocol Television (IPTV) or Voice over IP (VOIP) telephony, bandwidth for the data network will be reduced and the 1,550 nm wavelength will be used for the Radio Frequency (RF) signal.

Sample Optical Line Terminal

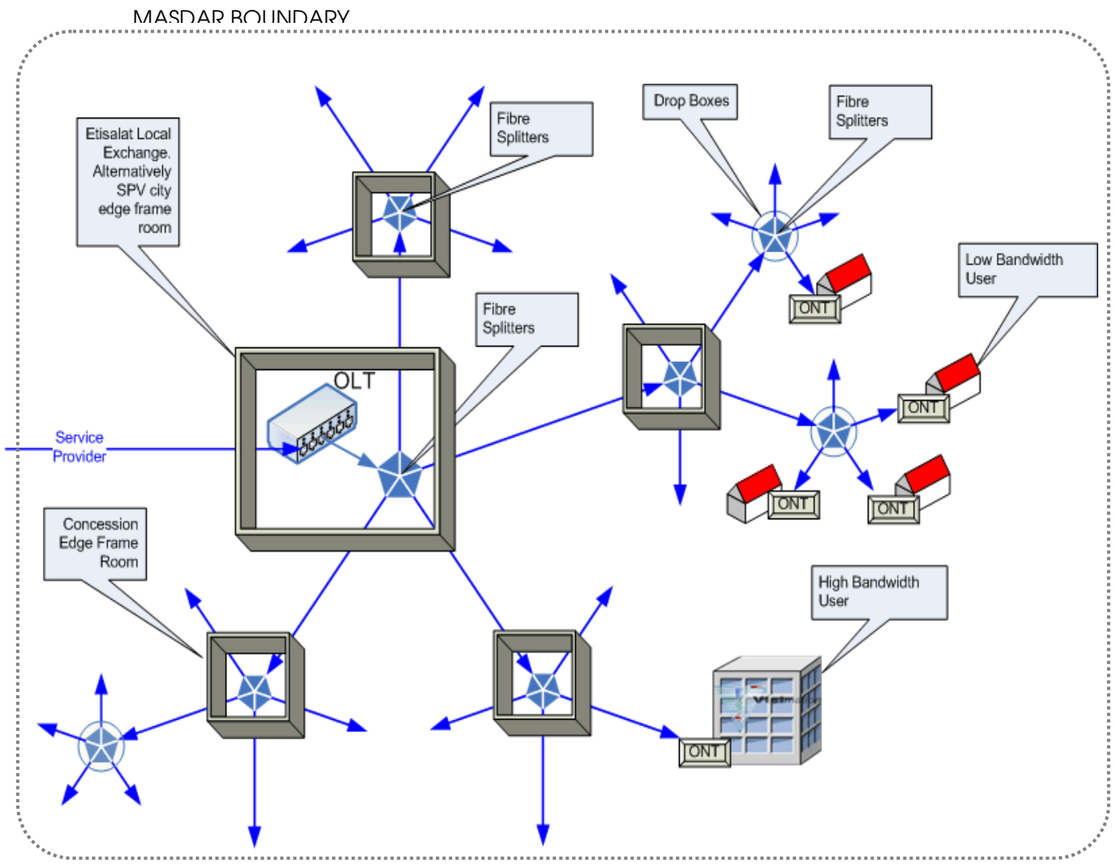


Figure 5.34: PON Overview

Optical Distribution Network

The city edge sites will use fibre splitters to split each PON into 1-4 outgoing 'city to concession' fibres (1st point of flexibility). The outgoing fibres will be distributed to concession edge sites through the service undercroft utilising a blown cable system.

The concession edge sites will house fibre splitters allowing the concessionaire to split each incoming 'city to concession' fibre to 1-4 outgoing 'concession to drop box' fibres (2nd point of flexibility).

The outgoing fibres will be distributed to drop boxes utilising a blown cable system. The drop boxes will be accessible and use ruggedised fibre splitters to provide a 3rd and last point of flexibility. The outgoing fibre will be delivered to a point of presence for the end user.
Single Mode Fibre will be used throughout.

Optical Network Terminal

The ONT will have a battery backup which will in the event of loss of mains power provide power for full service of the ONT for 72 hours. The ONT will be monitored and generate an alarm to Masdar to indicate loss of mains power and low battery life.

ONTs will be provided with two fibre connections for connection to the PON/ODN.

ONTs will be provided with four 8 pin modular jack sockets for end user connection.

Where the service provider requires RF voice an RJ11 socket for voice may replace 1 of the 8 pin modular sockets.

Where the service provider requires RF television an agreed socket (co-axe) for television may replace one of the 8 pin modular sockets.

The ONT may be installed internally or externally. The ONTs will have suitable IP rating and protection for the environment where it is located.

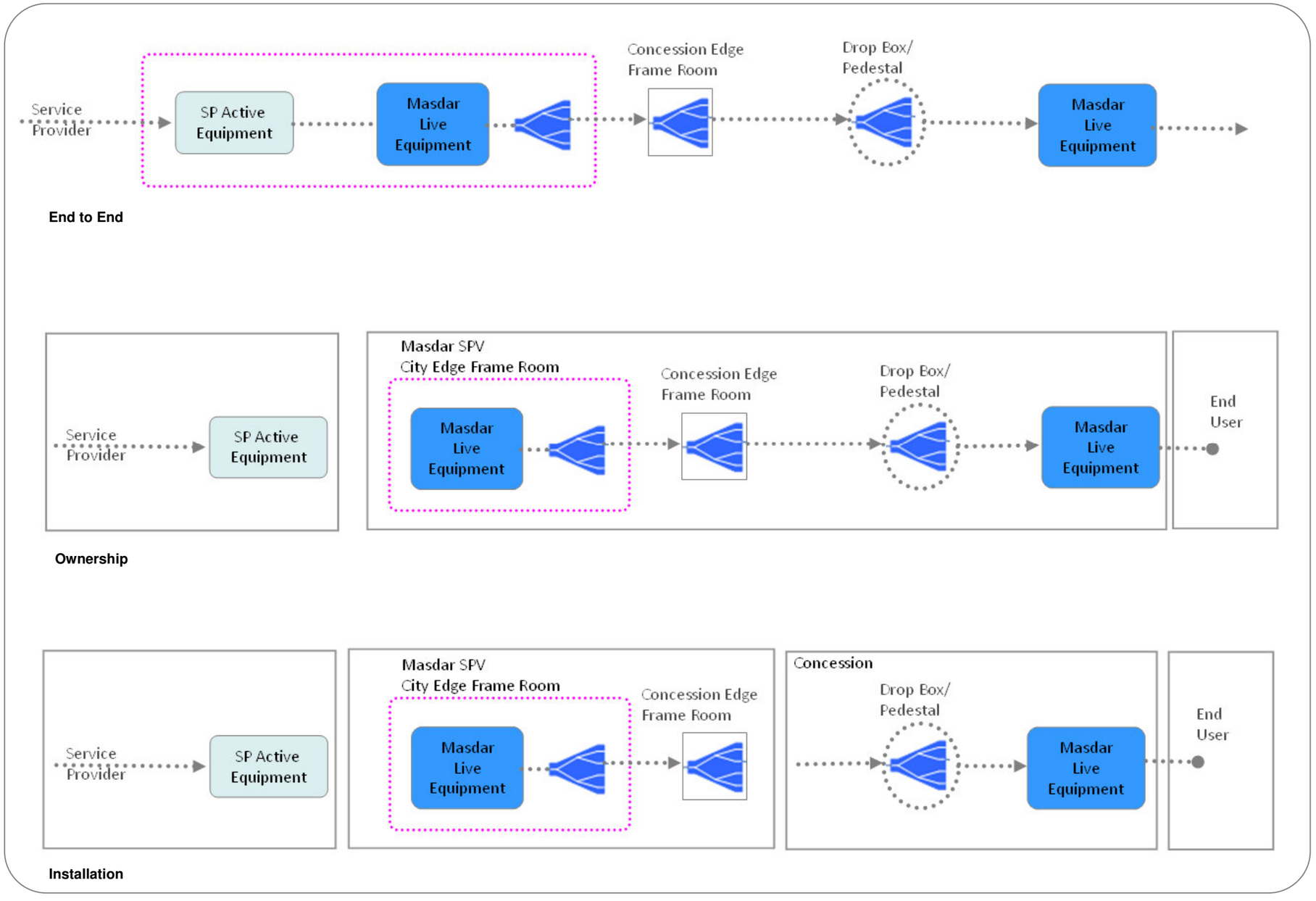


Figure 5.36: Ownership & Installation model

5.5.10 Distribution

Optic Fibre will be distributed from two city edge frame rooms utilising the development service corridors.

From the southern city edge frame room the fibre will follow a herringbone pattern radiating out from the rail line.

From the northern edge frame room the fibre will circle the city entering to provide diverse routing where resilience and redundancy is required.

Service Providers will link to the PONs at two city 'edge' sites. The city edge sites will have access to the city's services undercroft. The two sites will provide redundancy for the city and resilience (dual path with no single point of failure) for end users who require it.

The location for the edge sites are the two rail stations proposed in Phase 1.

In-building Structured Cabling

Buildings may include a structured cabling network to extend the development PON communications from the PoP/ONT incoming location throughout the building using single mode or multimode optical fibre and/or CAT 6 UTP copper cabling as required.

Landlord services within buildings will use the common structured cabling system from the incoming PoP/ONT location to all connected systems.

Tenant services within buildings may also use the common structured cabling for communication services but will remain physically separated from the landlord services.

ADFEC Active Communication Network

Landlord services within buildings will use a dedicated active communication network to communicate locally and link to other locations over the development PON.

The PON creates a hub and spoke topology, connecting ADFEC Local Area Networks across the city.

Routers and switches capable of Layer 2 routing will direct traffic across the PON.

Wireless Connection

Access Points with multiple band capability (802.11a, b, g and n once ratified) will provide connection for Wi-Fi devices either throughout the city or in specific zones.

The access points will be connected by local area networks with a hub and spoke topology and with Ethernet connection.

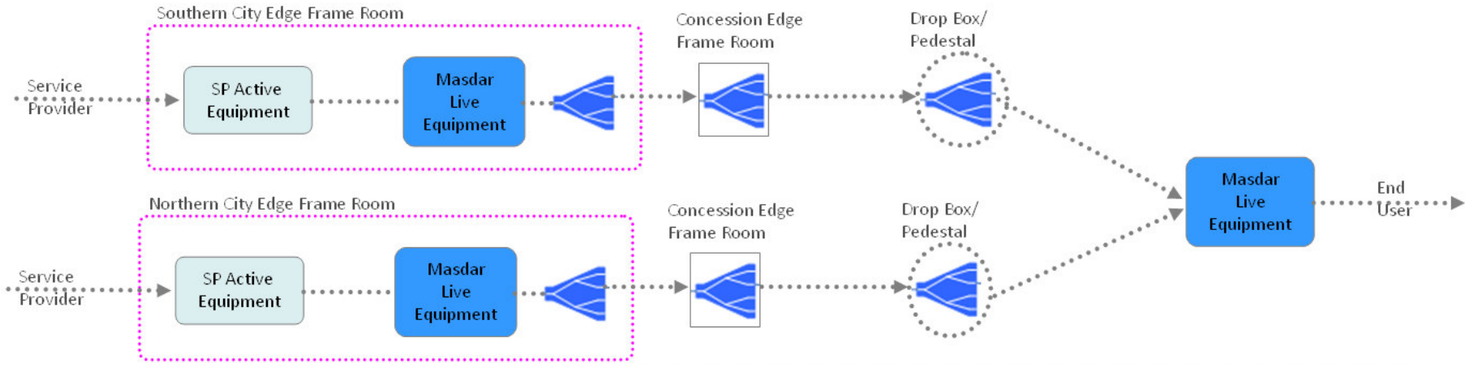


Figure 5.37 : Resilient Distribution

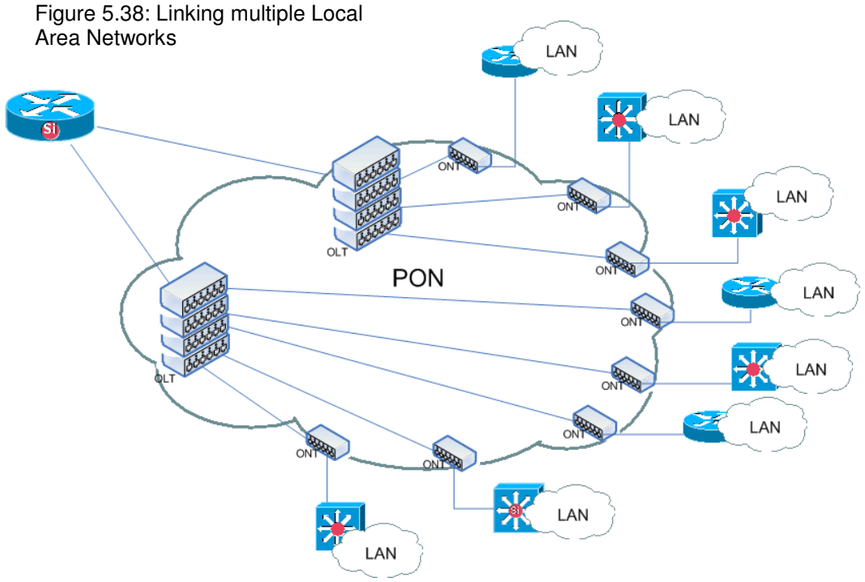


Figure 5.38: Linking multiple Local Area Networks

Figure 5.39: Distribution

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The identification of a comprehensive Renewable Energy Strategy for the Masdar development has led, during all the process of the masterplan design, to define a series of pathways capable of ensuring to the city, in a total annual balance, a 100% supply from renewable energy sources.

Given the ambitious target of the construction phasing, which is expected to be completely deployed in a few years, the design activity has focused on the one hand on the most modern and efficient technologies capable of immediately matching the development's needs from the beginning. On the other hand, the design has not neglected a series of innovative and promising solutions, currently still at a first application stage, but which would, at any time, be included in Masdar's strategy with terrific breakthroughs for innovation.

The overall strategy for the Masdar development envisages the adoption of a series of **solar technologies** (**photovoltaics**, in a certain percentage combined with **solar thermal** for domestic water heating; **Concentrating Solar Power**; **Evacuated Tube Collectors)**, **Wind Power Generation** and a **Waste to Energy System** combined in an precise energy demand/supply balance.

Other important resources and technologies have been identified to integrate and improve the suggested scheme, such as **Geothermal**, **Carbon Capture and Storage,** and **Energy Storage**.

Several critical issues are strictly related and must be considered to make the Renewable Energy Technologies implementation into the whole project as harmonious as possible. The most relevant of these are lead times and energy storage.

Given Abu Dhabi's year-round sunshine, the use of solar energy in one form or another is the most important resource. As such, one must take into account that the large use of these solar technologies, especially photovoltaics, involves the generation of power peaks during daytime hours, considerably exceeding the power demand; on the other hand, during night time hours the power generated by the systems can not cover the demand. The remedies are discussed herein.

The main issues arisen in the aftermath of the delivery of the draft version of the masterplan, which have led to the most significant updates of the present final version, are briefly summarized below:

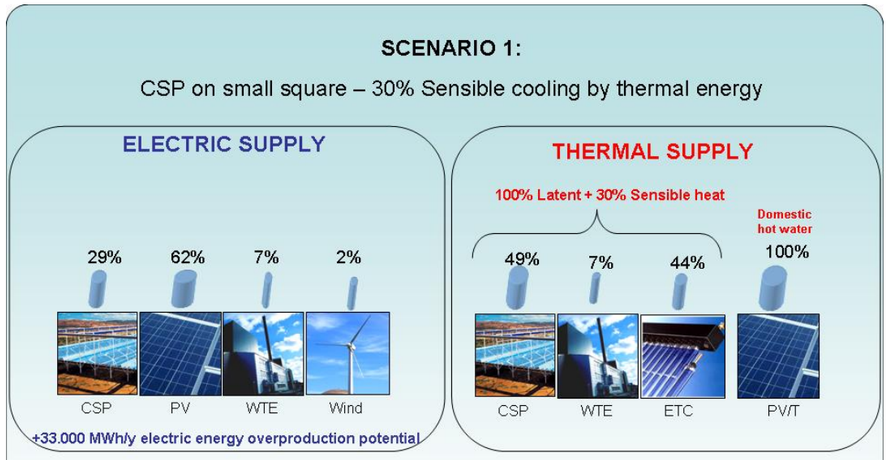
- overall mean 20% reduction of the building loads (see Section 4), enabling a consistent optimisation of the energy balance;
- implementation of semitransparent photovoltaic modules over part of the courtyards and open spaces of the city, to be integrated in movable sunshields and canopies: as a consequence, a further 13 MW of electric power results available, corresponding to 21.000 MWh/y of energy generation;
- preliminary evaluation of the geological data of the subsoil given by ADNOC clearly show that, once proven feasible, the site has the potential of largely self-supplying the thermal energy load of the city, even considering any future development;
- furthering the installation on the small square of an easily removable energy system (PV), offering the possibility of an additional urban development on the site; as partial integration, a 15 ha smaller CSP plant on the southern border of the site is still envisaged.

The following chapters (6.2 to 6.7) describe all the energy supply technologies available that are currently best-suited to meet the needs of Masdar, or may be suited very soon in the near future. These include both technology descriptions and work on specifying their energy potentials at Masdar.

Chapter 6.8 touches on Carbon Capture and Sequestration for the waste to energy plant. Following this, chapter 6.9 presents the Desalination strategy to provide Masdar with clearn water. Finally, 6.10 analyses two comprehensive supply strategies to provide Masdar with all its needs in a 100% carbon-neutral fashion. The options are also summarized in the graphics presented on this page.

SCENARIO 1
Like many others, international electric grids benefit from a certain amount of electricity production by renewable energies. The initial step here *proposes the utilisation of the Abu-Dhabi electric grid as the main energy buffer, storing the overproduced peak time energy , then releasing it during night time short fall*.
The proposed scheme envisages a partial use of *thermally driven adsorption chillers, making use of heat storage to compensate the daily fluctuations between demand and supply*. The solution enables therefore a partial reduction in the electricity peaks managed through the grid, with a shift to an integrated thermal storage system.
The scheme is at any time capable of being integrated with a variety of storage technologies, representing one of the main future challenging options for Masdar.
Furthermore, extra space for energy generation exists on the roofs; a full integration of the energy systems over those spaces is worth 33.000 MWh/y of electric energy overproduction.

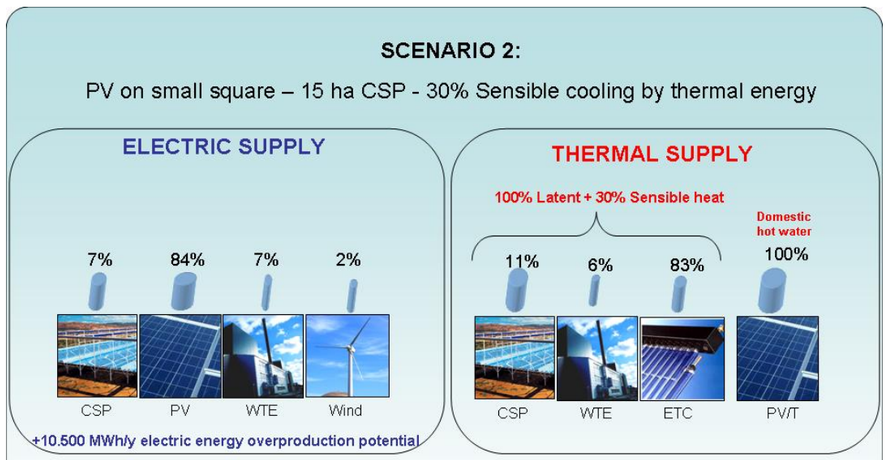
SCENARIO 2
This represents a possible case of a large scale photovoltaic implementation over the smaller square, leaving the future chance to the developer to use the land plot for a further expansion of the built up area. This would be made possible by the removal and reinstallation elsewhere of the PV system. Lacking a major contribution of combined heat and power production by the CSP system, now limited to a 15 ha area, the main detraction from the option consists in a higher land requirement for the installation of all the solar thermal evacuated tube collectors needed to provide the thermal energy.
Although reduced, extra space for energy generation still exists on the roofs; a full integration of the energy systems over those spaces is worth 33.000 MWh/y of electric energy overproduction.



Area requirements: 63 ha City roofs (PV) + Small square (CSP)+ 25 ha City roofs (ETC)

Pros: energy export at peak times, reliability of electric driven chillers, reduced area requirements. Balanced reliance on grid connection. Simple and easily manageable heat storage system.

Cons: dependance on grid connection, higher costs for electricity provided by RE technologies to drive electric chillers



Area requirements: 52 ha City roofs (PV)+Small square (PV)+49 ha City roofs (ETC)+15 ha CSP

Pros: energy export at peak times, reliability of electric driven chillers, reduced area requirements. Possible future development of the small square

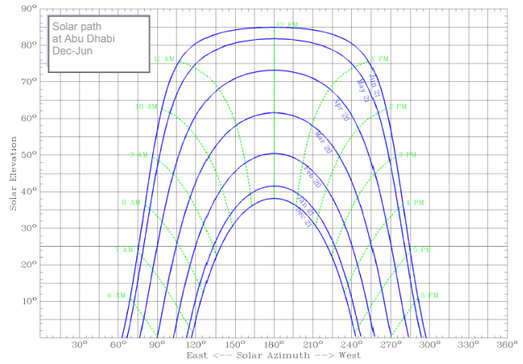
Cons: high reliance on grid connection. No electricity and heat produced by CSP. Higher space requirement for ETC

Solar energy represents the most exploitable renewable enrgy source for the Masdar development.
Given the fortunate UAE's geographic position in the sunbelt region, it is easily predictable that the solar technologies will play a predominant role in the total energy balance of the project. Nevertheless, abundant solar irradiation is only one factor determining the efficacy of solar technologies. If other site-specific environmental indicators (such as humidity and temperature) are not taken into account, Masdar's efforts could be fruitless.
Abu Dhabi receives almost double the annual solar irradiation (on the horizontal plane) with respect to many european cities in which photovoltaics already represent a reliable source of energy.
The solar path at different seasons remains quite high above the horizon, which in turn makes notable the difference in the quantity of energy harvested by vertical and tilted collection surfaces.
Different data sources can be used to evaluate the energetic potential of a large scale photovoltaic implementation for the Masdar development:

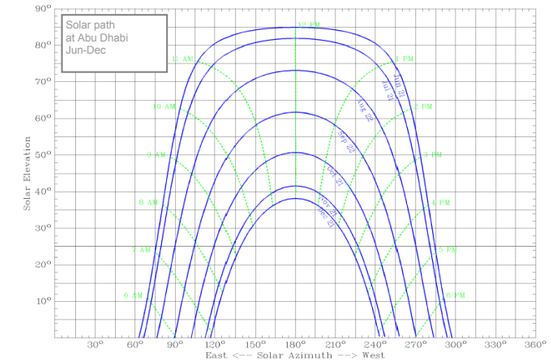
- The IWEC (International Weather Energy Calculation) data;
- The NASA Earth System Science Data;
- The environmental data locally registered by the weather station of the Abu Dhabi Intenational Airport.

As shown in previous reports, for the evaluation of the energy potential relating to the PV technology, there are no significant differences between the aforementioned data sources for the evaluation of the energy potential relating to the PV technology, witch suggest an annual global irradiation value on the horizontal plan of about 2100 kWh/sqm (2179 for Nasa source; 2125 for airport source; 2205 for the IWEC data source).

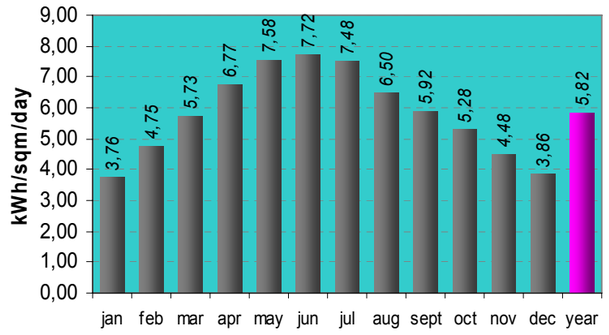
Therefore, for the scope of the present section, the energetic assessment is based on the data measured by the weather station at the Abu Dhabi International Airport (conservative scenario).
As noted before, two influential fundamental weather environmental indicators for the performance of the photovoltaic systems are represented by temperature and humidity. While the first is capable of influencing the power output of the photovoltaic pv systems, it can be theoretically and reliably evaluated; the second represents a potential risk for the sealings and the encapsulation foils, and as a consequence, a risk for the integrity and the stability of the modules themselves.
The following paragraphs of the current section will point out the specific pathways to be set up to address these specific issues.



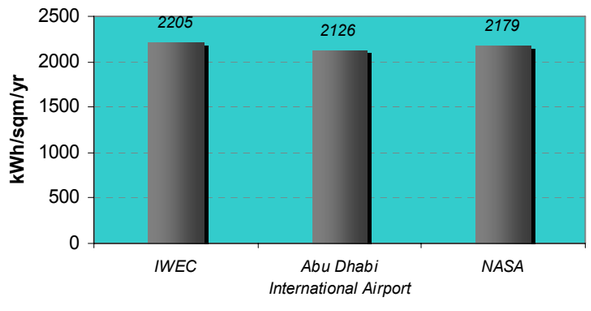
Monthly irradiation data (Abu Dhabi International Airport)

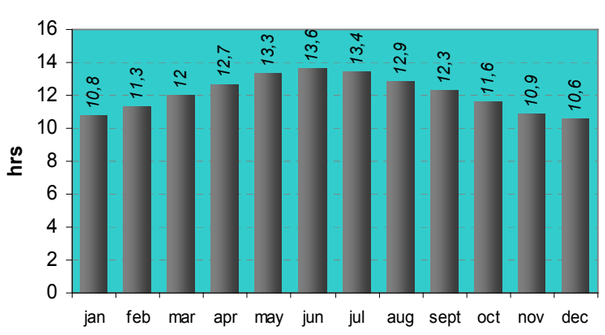


Daylight hours (Abu Dhabi International Airport)

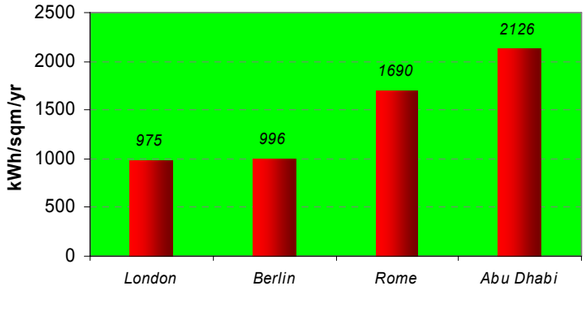


Horizontal irradiation data





Horizontal irradiation data



Since the photovoltaic systems will represent the main energy source for the Masdar development, it becomes almost mandatory to make use of well-proven and reliable solar technologies; nevertheless, given the quite extended length of time in which the whole development will be erected, the implementation of the photovoltaic technology for the project must envisage, anticipate, and possibly lead the future trends of the global photovoltaic sector.
As a result of the activities carried out during the current masterplan phase, six technologies have been identified as capable of supporting the PV strategy:

- crystalline silicone cells:
  - monocrystalline silicone
  - polycrystalline silicone
- combined monocrystalline/thin film cells
  - HIT (Heterojunction with Intrinsic Thin Layer)
- thin film cells:
  - CIGS (copper indium gallium selenide);
  - CIS (copper indium sulfide);
  - CdTe (cadmium telluride);
  - aSi (amorphous silicon).

Wafer-based crystalline silicon

Wafer-based crystalline silicon (c-Si) is by far the most widespread technology, making up more than 90% of the global market.
Highest efficiency level, long term stability and strong reliability have contributed to the success of this technology and the large scale development of the whole PV industry.

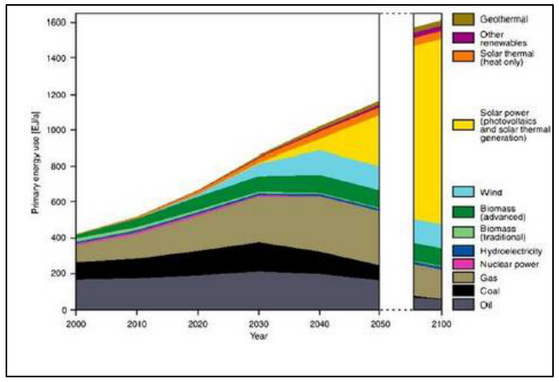
Wafer slicing of silicon ingots, obtained by controlled (or semi-controlled) growing of silicon crystals, represents the fundamental step of the manufacturing of solar cells.
The wafers, currently 200 μm thick, are processed into solar cells, then connected and encapsulated into a supporting pane to form the photovoltaic module.

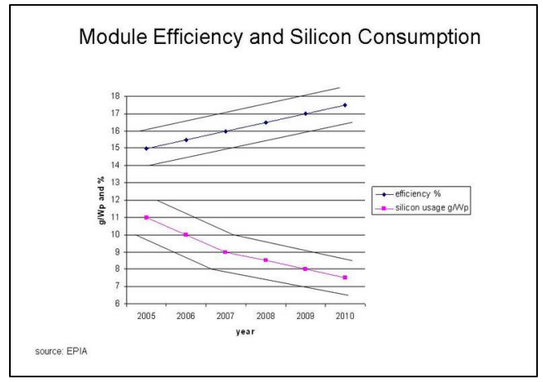
Although laboratory cells have demonstrated efficiency values up to 24,7%, current performance for market available cells are in the range 15-17%, depending on the poly/monocrystalline cells' arrangement; cutting edge components have higher performances (e.g. SunPower A-300 20% minimum efficiency monocrystalline solar cell; Sanyo HIT 19,3% efficiency cells, which combine amorphous silicon to crystalline silicon).

Monocrystalline silicon solar cells are deemed to have the highest efficiency values (15-17%) in the solar market and could provide the major part of the energy needed within a a quite reasonable amount of land area. For the evaluations of the energy output achievable by PV systems installed at Masdar, a combination of different features of crystalline silicon modules has been considered as a reference for the development of the project:

- crystalline techonology 19,3% monocrystalline modules, representing the highest efficiency modules currently available on the market; thanks to a one- of-a-kindmanufacturing process in which all the solar cell electrical contacts are placed on the back of the wafer (and from which the name "all-black all-back" is derived) it has been made possible to achieve the highest conversion rate, ensuring at the same time a quite low temperature coefficient (-0,38%/°C). On the other hand, only one globalworld manufacturer (Sunpower Co.) has developed this unique crystalline technology, therefore other types of photovoltaic modules should be includedenvisaged in the whole project, according to the spirit of the Masdar initiative;
- 16,8% HIT (Heterojunction with Intrinsic Thin Layer) modules, in which the monocrystalline silicon cells are surrounded by an additional thin amorphous silicon layer, have the combined benefits of both the crystalline and the thin film technologies, delivering a high efficiency value while maintaining a low temperature coefficient (-0,30%/°C). Once again, for the philosophy of the development, it must be considered that this specific cutting edge technology is currently managed by one manufacturer (SANYO).
-

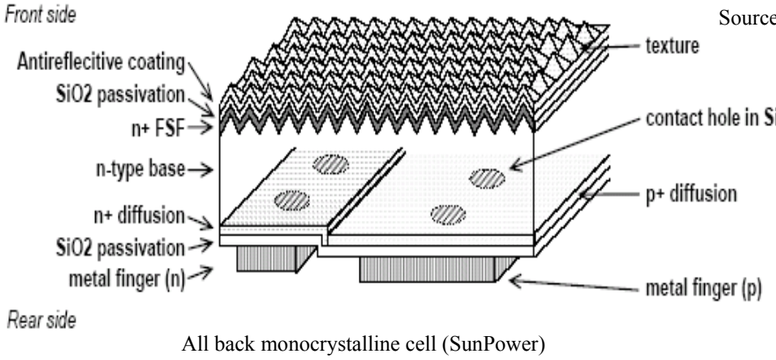
14,10% monocrystalline and polycrystalline modules: a vast range of PV modules are currently available on the market, with widespread values of efficiency; for this category of products, which presumably will play the largest role in the photovoltaic implementation, it becomes important to define the highest level of performance required, in order to ensure that only the best and most technologically advanced modules will be employed for the development. For this reason a minimum efficiency level of 14,10% for both the crystalline technologies has been introduced in the calculations, corresponding to -0,47%/°C and -0,42%/°C temperature coefficient.





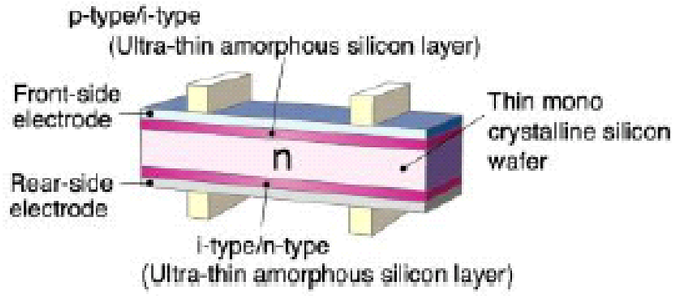
Source: Deutsche Cell

Source: REC



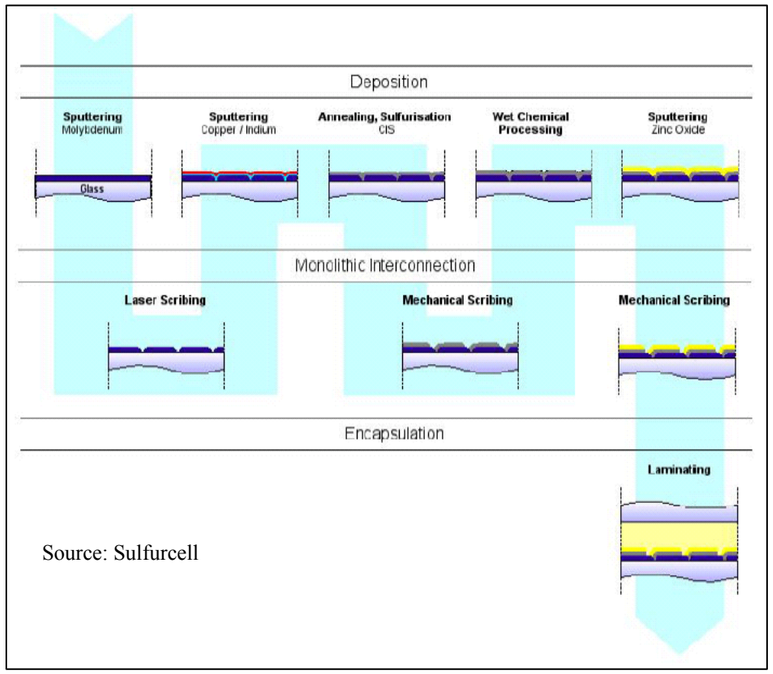
All back monocrystalline cell (SunPower)

HIT cell (SANYO)

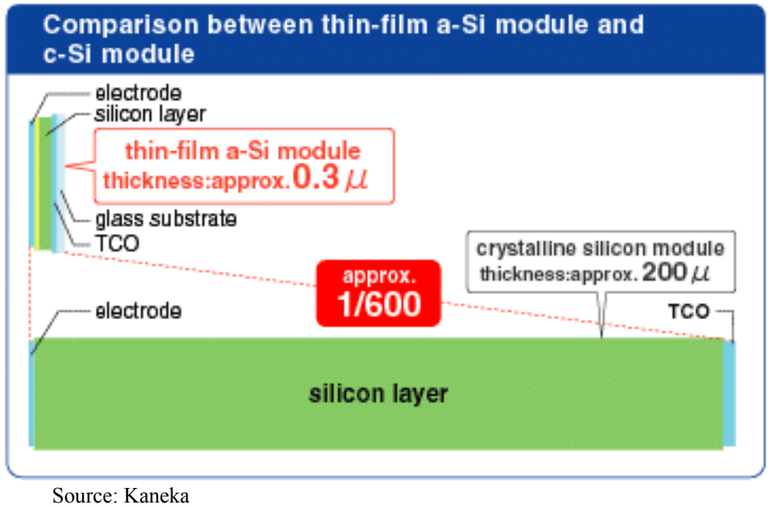


Thin film technology

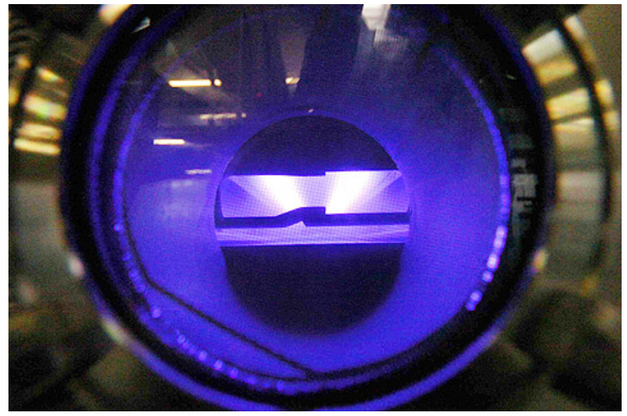
- CIGS (Copper Indium Gallium Selenide): 11% efficiency and -0.36%/°C power temperature coefficient (reference values). Like all other thin film products, the solar cell is directly deposited on a supporting substrate as a very thin layer of semiconductor with a notable savings in energy and material use. In the manufacturing process of a typical CIGS module, the device layers are successively deposited on the previous substrate using some of the most advanced industrial techniques: sputtering, vaporisation, mechanical scribing, and encapsulation.
  Relevant companies: Wuerth Solar, Shell Solar.
  CIS (Copper Indium Sulphide): 7.3% efficiency and -0.28%/°C power temperature coefficient (reference values). A promising alternative to the CIGS thin film modules, this technology makes use of sulphide rather than the most more expensive selenide, in a more simplified manufacturing process which still leads to the realisation of reliable modules capable of long term stability and performance
  Relevant companies: Sulfurcell, Scheuten Solar.
- CdTe (Cadmium Telluride): 9.72% efficiency and -0.25%/°C power temperature coefficient (reference values). The CdTe technology is derived directly from the more expensive GaAs manufacturing process, specifically developed for the spatial applications. The typical CdTe solar cell is made of 4 layers and 3 junctions to improve the solar spectrum absorptivity. Like many other thin film technology modules, CdTe panels have the ability to perform better than conventional modules under the conditions of partial shadowing, indirect irradiation, cloudyness, which results in a higher specific energy production (kWh/kWp).
  Relevant companies: First Solar, Antec Solar, Calyxo
- a-Si (amorphous silicon): 6.32% efficiency and -0.16%/°C power temperature coefficient (reference values). The amorphous silicon has been competing with the crystalline technologies since the birth of the solar market; today it is possible to produce solar cells with half of the efficiency of the corresponding crystalline cells, but at only 1/600 of the thickness. Innovative and technologically advanced solutions developed in the past years (tandem and triple junctions, microcrystalline Si) are finally making thin film silicon as a major player in the market share for the years to come.
  Relevant companies: Kaneka, Unisolar, Mitsubishi.



Source: Sulfurcell



Source: Kaneka



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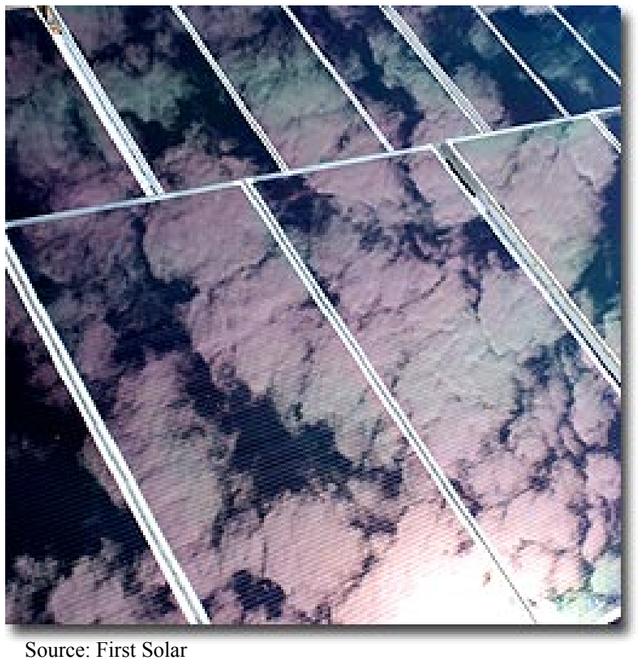
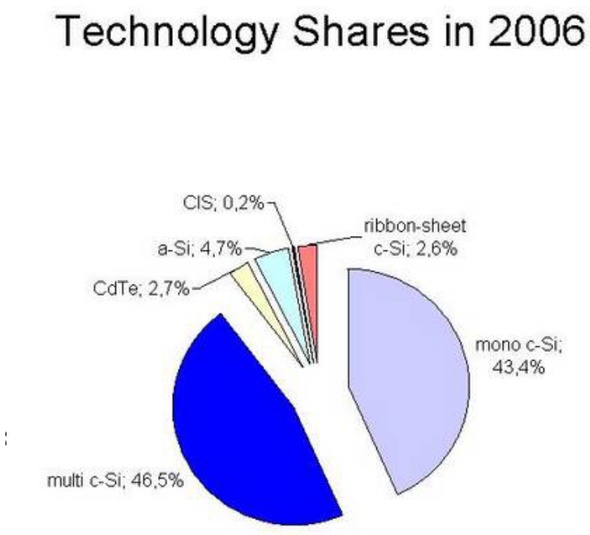


Source: First Solar

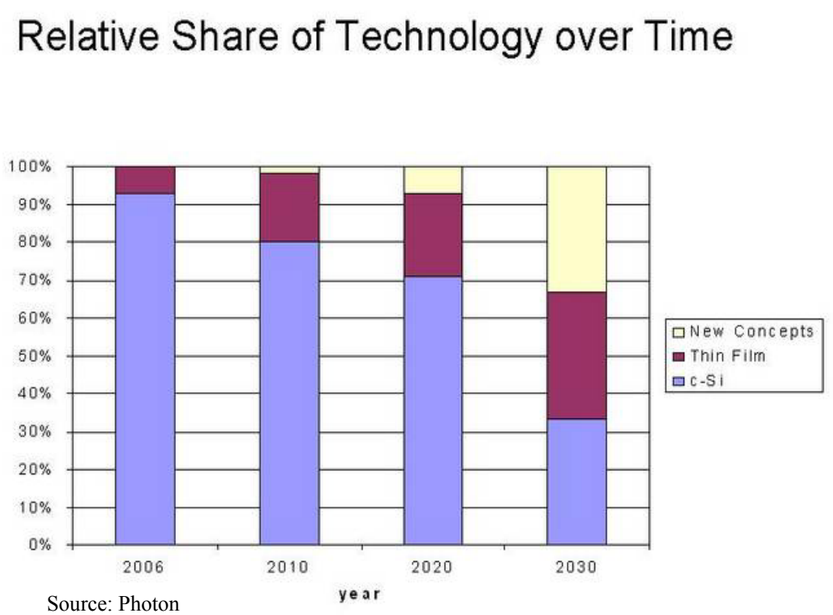
As highlighted by recent surveys, the two major crystalline technologies account for almost the 90% of the global market, leaving a mere 10% to the so-called "emerging" technologies. This trend is unanimously deemed to reverse, since increased market penetration of thin film solutions is expected in coming years. The main reasons providing credibility to the aforementioned future scenario are the already achieved improvements in the manufacturing process, which, compared to the crystalline technology, will definitely make possible the realisation of long-term performing solar cells at lower costs. Therefore, thin film technologies are expected to almost triple their market share, leading the electricity generation cost by the photovoltaic technology to "grid parity" and to its definitive affirmation as the power generation system of the future.
As previously mentioned, it would be ideal for Masdar to anticipate these future trends, since the first design stages offer consistent results for the thin film technologies. Moreover, thin film technologies boast two considerable advantages with respect to the crystalline wafer based modules, which are *high specific energy production* (the electric energy harvested for each installed kW) due to a *lower power temperature coefficient* (indicator of the energy output decrease with respect to the rise in temperature – the higher the temperature, the less energy harvested). In the hot environment of Abu Dhabi, it is predictable that PV cells with lower power temperature coefficients will perform better than components with higher power output decrease in the event of a rise in temperature.

However, the possibility of widespread implementation of the thin film technologies for the Masdar site goes against one of the major constraints that have made the conceptualisation of a comprehensive renewable energy strategy complex: an unbalanced space availability for the implementation of the energy systems.

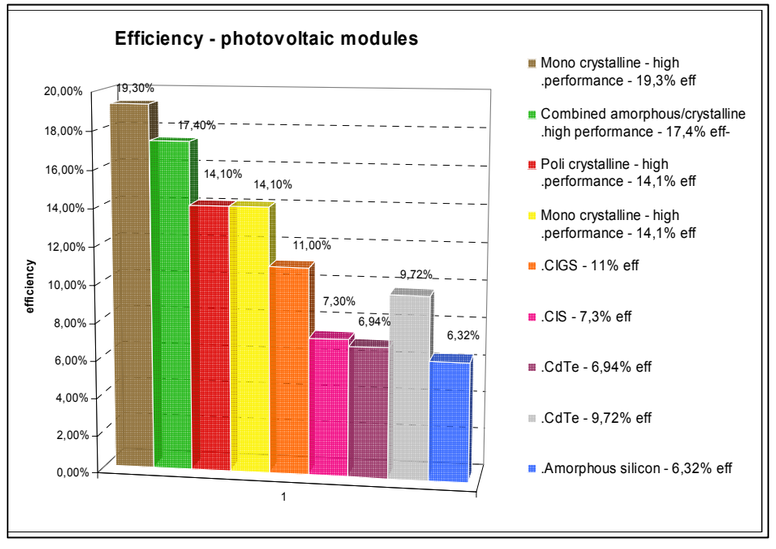
This makes it crucial that power generation systems are as efficient as possible, foreseeing the adoption of technologies granting higher values of installed power, even at the cost of lower specific energy production.
As far as the photovoltaic implementation for Masdar is concerned, addressing the aforementioned issue might involve a widespread adoption of crystalline-based technology, but not at the risk of neglecting the potential of the thin film modules.

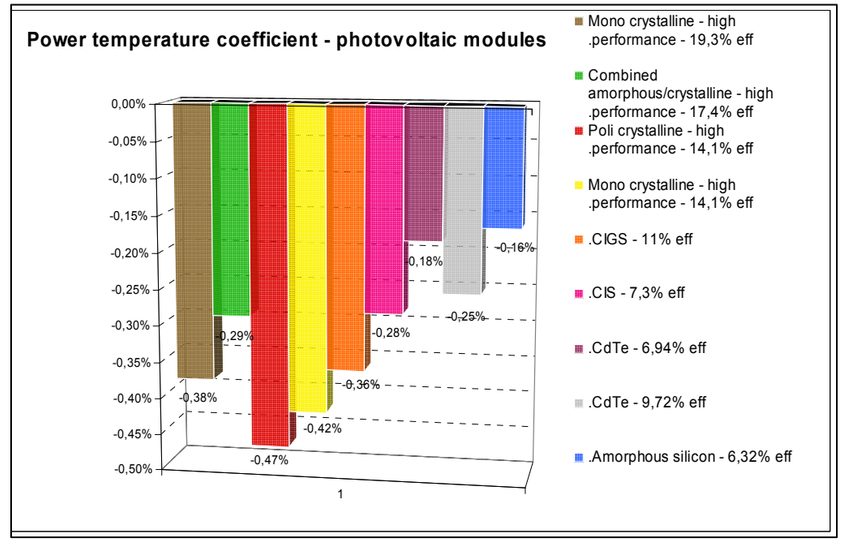


Source: Photon



Source: Photon



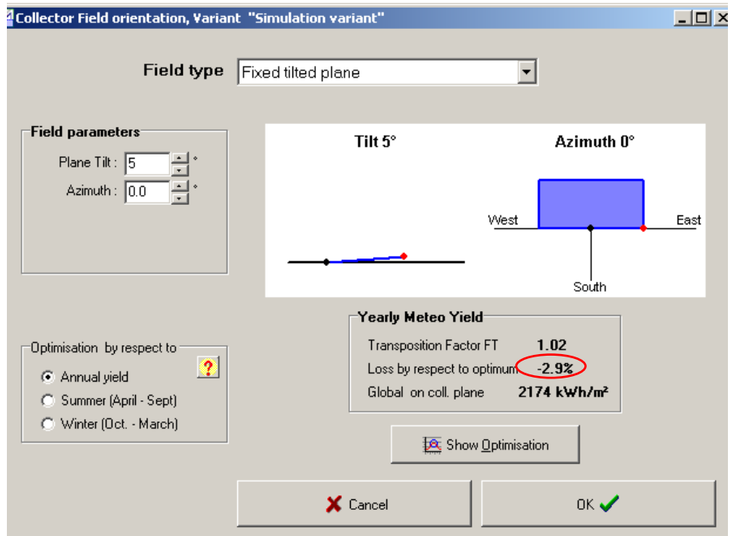


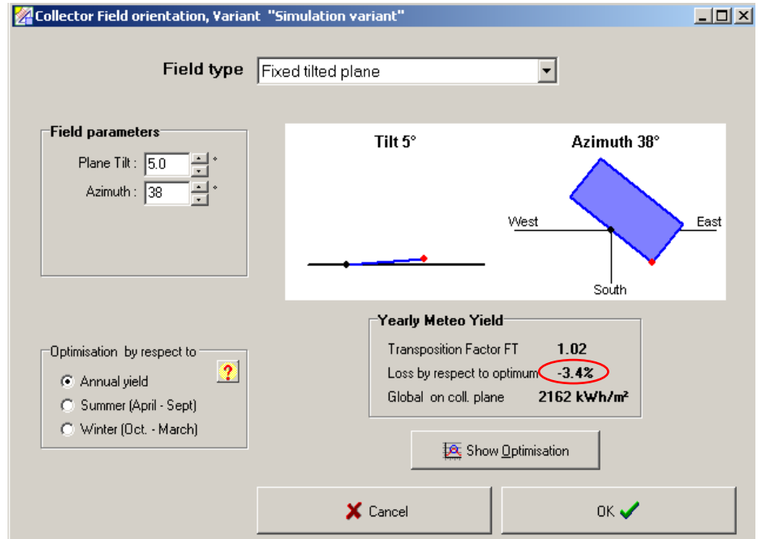
For each one of the technologies presented, a performance simulation has been carried out with the environmental data of Abu Dhabi to determine reliable results such as specific energy production and global systems' efficiency.
The optimal arrangement of any PV field to be installed in the region requires a 20° inclination of the modules, and a perfect N-S alignment; given the specific orientation of the city and of the small square (38 ° NE- SO). The possibility of placing the PV fields according to the developed alignment has also been considered, at the expense of a minor loss in the overall energy production, estimated at a 2 %.
Moreover, especially for the systems to be integrated on roofs, the possibility of a lower than optimal tilt of the module has been explored. It would lead to a larger overall amount of installed power and consequently, of energy produced, but always at the expense of a negligible performance loss, estimated at a 3,4% with respect to the "ideal case".
In the following, the results of the simulations are shown and analysed.

Ground Installation

In the case that a ground installation would be provided for the site in the future phase of the development (as an alternative for the Concentrating Solar Power System proposed) in the small square, either an additional source of energy for the settlement, or the initial power generating system for the construction of the city and the energy supply for the very first inhabitants, the usage of crystalline-based photovoltaic modules seems to better fit for the purpose of obtaining the highest total energy production. In this case, a "conventional" N-S alignment and 20° tilt could be pursued, optimising and pushing the productivity of the system to its limit.

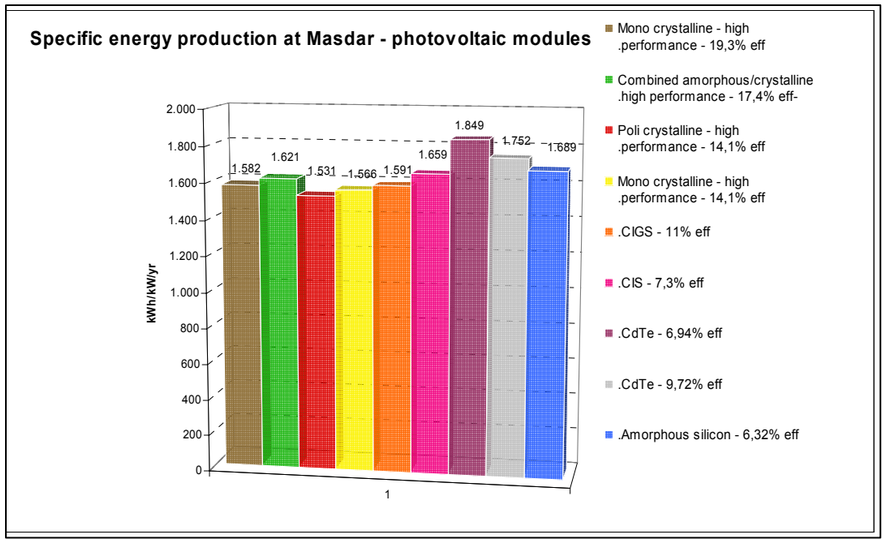
The tables aside shows the relative performance of the different kind of crystalline modules considered under the abovementioned conditions.

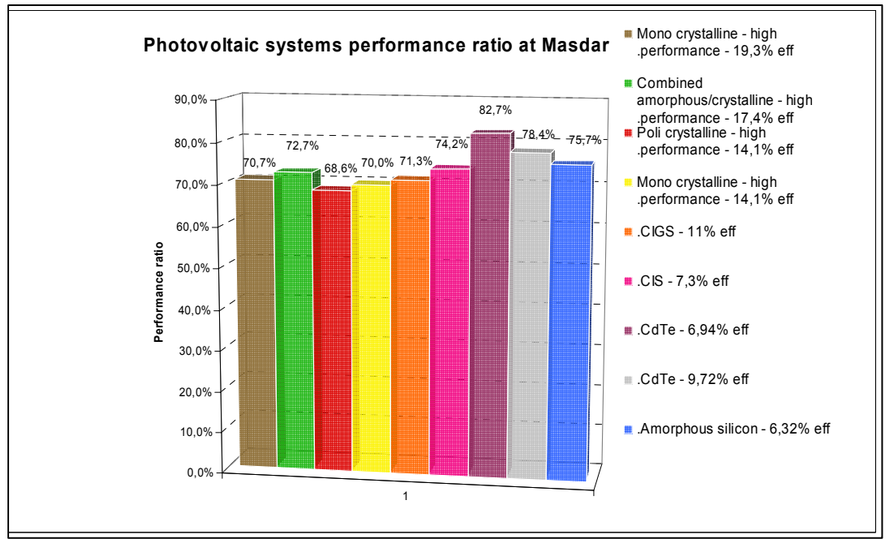




Building integrated photovoltaics

The PV collector systems will be placed mainly on the top of the buildings in the city, over simple and light elevated supporting structures (see guidelines) in the shape of modern canopies and pergolas. As mentioned previously, a 5 ° inclination of the modules has been considered for the city integration, sufficient to prevent the deposition of dust and dirt on the collecting surfaces, and an azimuth (digression by the N-S alignment, coincident with the city's main axis) that would enable an optimal surface exploitation.
In fact, the reduced tilt angle allows a reduction of the required free spacing between each row of modules, while the aligned-with-the-building arrangement leads to an almost full coverage of the top surfaces.
Predictably, the highest performance is reached by the film modules, with CdTe estimated at a notable performance of 1850 kWh/kW, 20% more than polycrystalline modules.





Building integrated photovoltaics
Options A) – B) – C)

On the basic assumption of 120 hectares of exploitable roof areas and 80% of surface use for the renewable energies, the integration of the photovoltaic system on the roof top of the built up area could be done according to different schemes of adopted technologies:

a) High crystalline rate
b) Mixed at current market share
c) Mixed at high thin film rate

Scheme a) envisages the adoption of crystalline-based technology modules only, maximising the installed power and the overall energy production. As a result, a total power of 170,8 MW and an annual energy production of 271.900 MWh can be achieved, corresponding to a specific energy production of 1592 kWh/kW.
Scheme b) mirrors the current market share of the PV technologies with 90% for crystalline (redistributed in favour of the most efficient monocrystalline modules) and a mere 10% for the thin film, with a total power of 119,7 MW and an annual production of 196.400 MWh corresponding to a specific energy production of 1641 kWh/kW.
Scheme c) reflects the expected future trends, giving substantial more room to the thin film technologies to demonstrate their full potential. Even with the lower values of installed power are accounted for (112,9 MW) and energy production (189.100 MWh) the scheme boasts the best specific energy production (1673 kWh/kW).

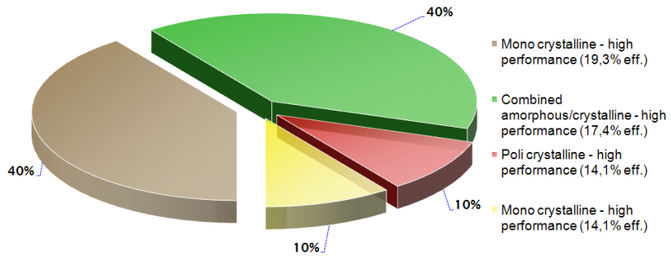
Parking lots
Option D)

Similarly to the BIPV, the parking lots at the access point of the site can host a technology mix of solar collectors; the solutions envisaged in this case consist of an adoption of different technologies for each parking lot, making an interesting future work of performance data analysis possible. In total, the PV systems of the parking lot could account for 5,5 MW installed power and 9.100 MWh for annual energy production, i.e. sufficient enough to feed the street lightning for the entire city.

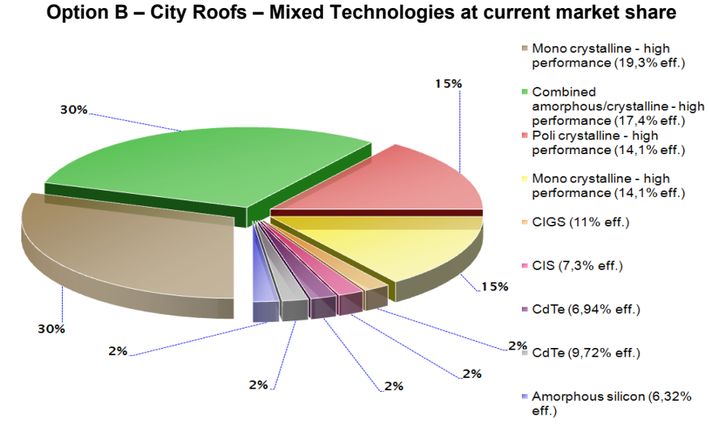
Small Square
Option E)

As an alternative to the realisation of a CSP system in the small square of the development, the option of the implementation of a ground installed PV system can be considered.
The advantage of this kind of solution is that the modules could be easily removed and installed elsewhere in a successive phase of the development, leaving the ground free for further estate initiatives.
Compared to the CSP, the PV option for the small square lacks the production of waste heat, which is valuable for the cooling strategy of the city. This should probably be compensated by an additional power plant or by a size increase of the square itself.
At current figures, the PV system on the small square offers 57,2 MW of installed power, totaling 93.700 MWh of annual energy production.

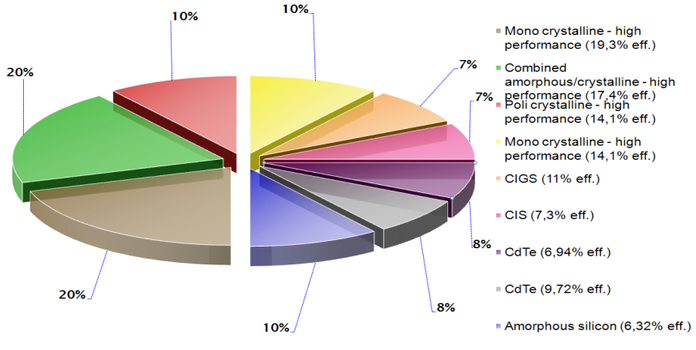
Option A – City Roofs – High efficiency crystalline silicon rate



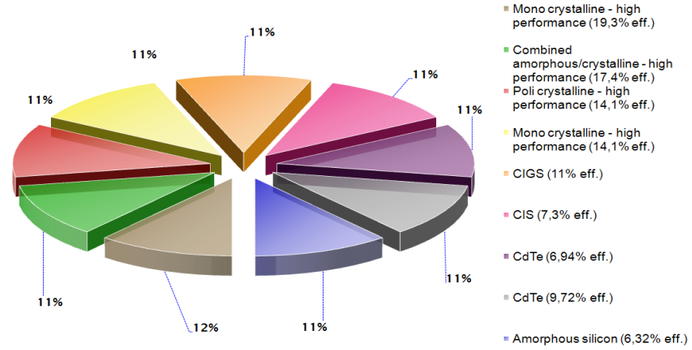
Option B – City Roofs – Mixed Technologies at current market share



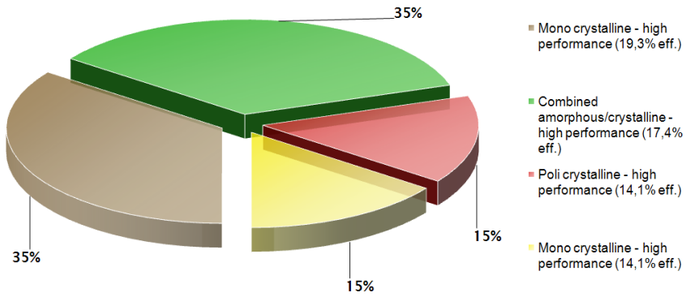
Option C – City Roofs – Mixed Technolgies at high thin film rate



Option D – Parking lots – Balanced mix of all PV technologies



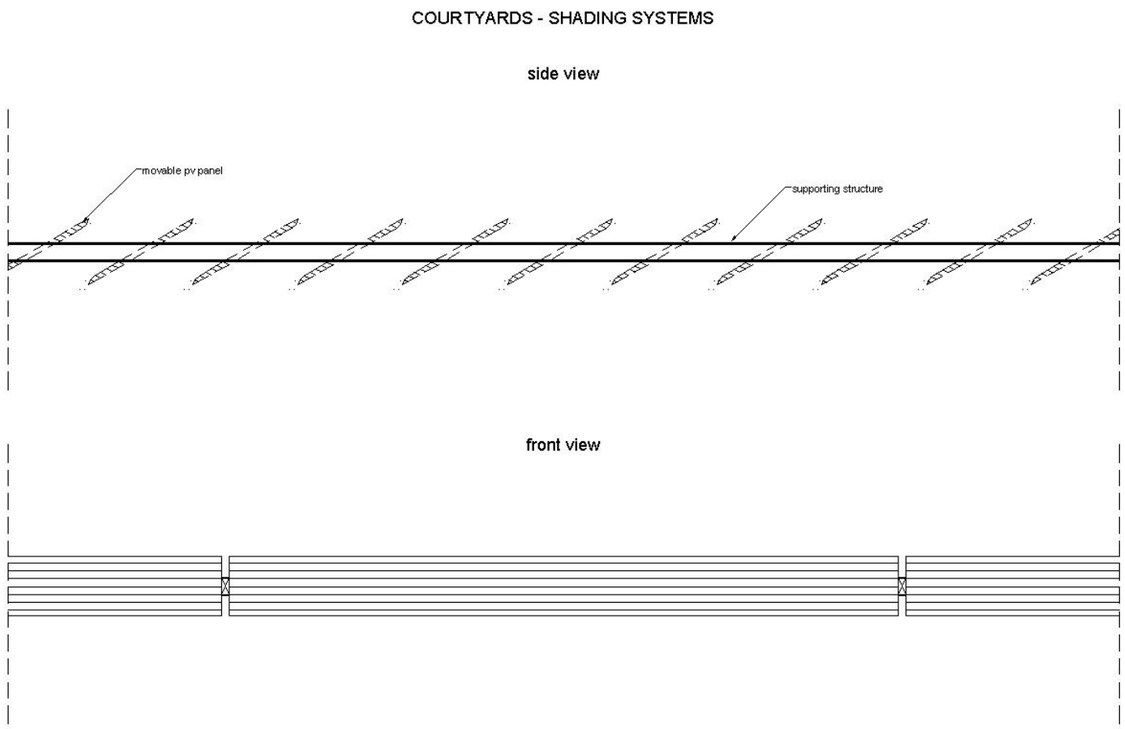
Option E – Small square – High efficiency crystalline silicon rate

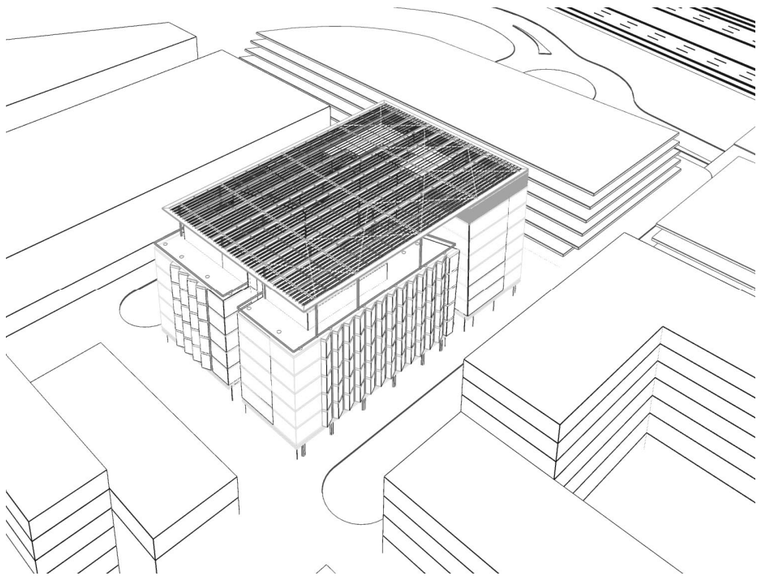


Courtyards
Option F)

A further possibility for the implementation of the PV thechnology is offered by covering part of the courtyards and the open spaces around the city.
A system of shading devices integrating photovoltaic modules can be specifically designed and realized, with several related benefits, such as:
- improvement of outdoor conditions during the day thanks to partial shading;
- energy production;
- reduction of cooling load for the buildings.

The shading systems should be movable, offering maximum sunshielding to the open areas during the day, while opening at night, enabling a better ventilation and natural cooling.
In terms of photovoltaic technology, semitransparent modules, realized both in a thin film feature (i.e. amorphous silicon, CIGS with laser scribing), and crystalline cells based modules, with adequate spacings specifically designed to gurantee sufficient light permeability, can be deployed. For the latter option, Photovoltaic cells in each panel can be arranged according to specific patterns, specifically defined to optimize visual and shielding effects.
The choice of the cells itself can represent an option, ranging from “traditional” mono or multi-crystalline cells to most innovative high performing new generation “all black” cells, and to special semi-transparent cells, presenting a certain number of pin-holes freely made through the silicon wafers.
At current figures, the PV system on the cortyards offers 13,3 MW of installed power, totaling 21.000 MWh of annual energy production, which correspond almost to 90 kWh/sqm of specific energy production, see table in the following page.





Overview of the photovoltaic potential for Masdar

As pointed out in the previous paragraphs, it is possible to consider different strategies for the implementation of the photovoltaic technology at Masdar. The study carried out in the present masterplan has focused on several combinations of different technologies, deemed suitable for the forthcoming years of the development.

The first three options are specifically referred for the built-up area and have led to the following results:
A) High efficiency silicon crystalline rate:
Total power of 170,8 MW and annual energy production of 271.900 MWh;
B) Mixed at current market share:
Total power of 119,7 MW and annual production of 196.400 MWh;
C) Mixed at high thin film rate:
Total power of 112,9 MW and annual production of 189.100 MWh;

The fourth option has been set foreseeing an even distribution of different type of modules for the parking lots, whose potential result:
D) Balanced mix:
Total power of 5,5 MW and annual production of 9.100 MWh;

The fith option is reserved in case of a ground installation over the smaller square:
E) High efficiency silicon crystalline rate
Total power of 57,2 MW and annual production of 93.700 MWh.

The last option refers to the implementation of semitransparent modules over a fraction of the city courtyards and open spaces:
F) Total power of 13,3 MW and annual production of 21.000 MWh.

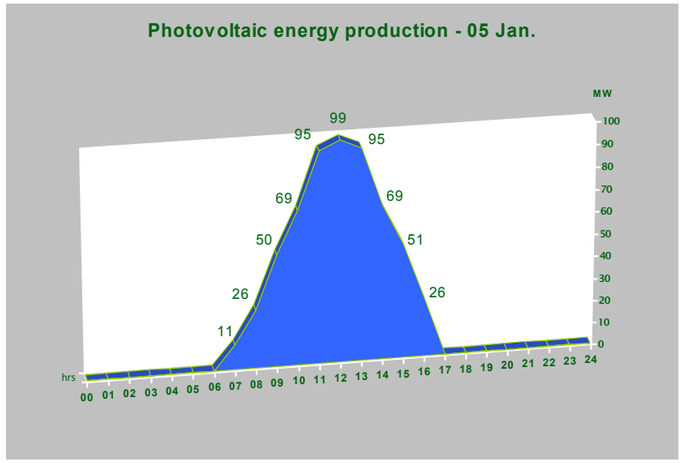
The table aside summarizes the aforementioned scenarios.

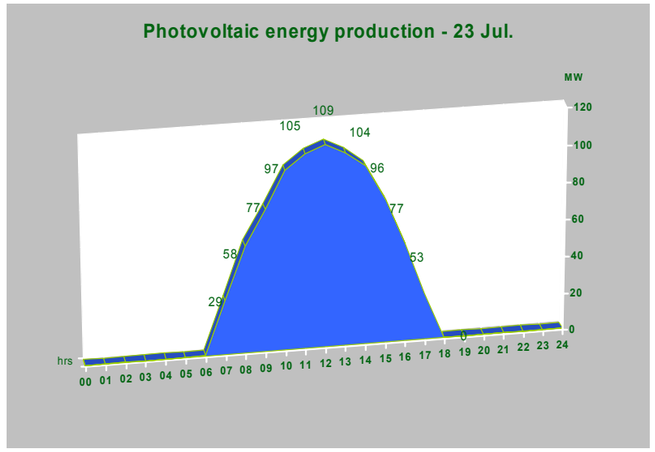
Trends in daily productions Option E)

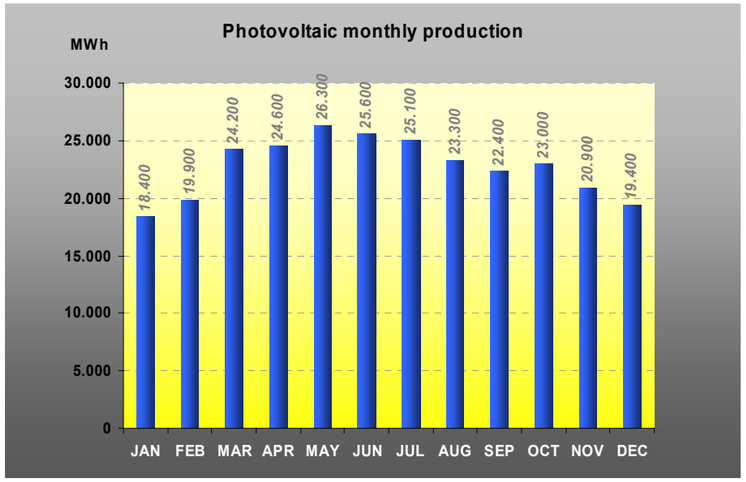
The graphs aside show the trends of the electric energy produced by photovoltaics, for two reference days in the winter and the summer seasons (5th January and 23rd June), for an overall 171 MW installation (165,5 MW option A + 5,5 MW option D).
The bar chart highlights the trend of the monthly electric energy production.

BREAKDOWN OF THE PHOTOVOLTAIC POTENTIAL FOR THE MASDAR DEVELOPMENT

Site	PV Technology Combination	Overall available area for pv (modules + spacing)	Modules' tilt	Power (MW)	Annual Energy Output (MWh)	Specific energy output
City roofs - option A	A	1.065.000 sqm	5°	170,8	271.900	255 kWh/sqm
City roofs - option B	B	1.065.000 sqm	5°	119,7	196.400	184 kWh/sqm
City roofs - option C	C	1.065.000 sqm	5°	112,9	189.100	178 kWh/sqm
Parkings	D	52.200 sqm	5°	5,5	9.100	174 kWh/sqm
Small Square	E	478.100 sqm	20°	57,2	93.700	196 kWh/sqm
Courtyards	F	241.000 sqm	5°	13,3	21.000	87 kWh/sqm





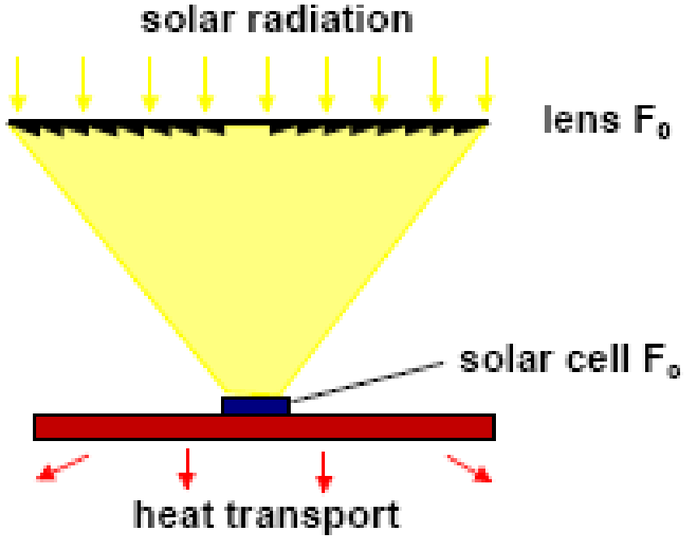


Already available on the market and capable of substantial improvement in PV performance are several innovative solutions that have so far represented only a niche share in the global photovoltaic industry.
Among those worth mentioning are tracking systems, concentrated technologies and combined photovoltaic/thermal solutions.

Following the sunpath at any time of the day, tracking systems are capable of delivering higher energy production compared to conventioned fixed systems; however, given the site latitude, the slight increase in performance could not justify the higher system cost of the trackers. The sandstorms and the aggressive environmental conditions could predictably hamper, or at least severely test, all the moving mechanisms of rotating parts. Not to mention that, as a principle, tracking system require a much larger space than conventional fixed installations.
Concentrator technologies (CPV), consist of optical devices to enhance the irradiation hitting the solar cells. Even though these technologies are theoretically capable of improving system efficiencies up to 30%, they have so far played a marginal role, which is in turn represented by a reduced global manufacturing capacity (less than 1 MW/year). The open issue remains of how to assess how high ambient temperatures might influence the effective performance of CPV.
For the scope of the Masdar development, it would be nevertheless appropriate to foresee at least a testing field for these and for others new technologies that, once proven suitable for the site, could be directly transferred into proper operation.
Regarding the photovoltaic/thermal combined technology (PV/T), the concept is undoubtedly more promising: the simple idea of extracting the heat generated by the solar cells effectively doubles the the performance of the photovoltaic modules while providing at the same time hot water for domestic use.

The PV/T technology can be designed in a simple and reliable shape for modules and piping, and are becoming increasingly more popular on the markets: the energy strategies for Masdar itself rely on this system to produce the hot water needed for domestic use.

Source: CEH de Navarra



Source: Fraunhofer ISE

Source: Fraunhofer ISE

Connection to the electric distribution network

BIPV
The PV systems installed inside the city will be run independently from the electric systems of the buildings: the electric energy locally generated will be directly supplied into the grid at various points (see infrastructure section for more details). Assuming the mean plot surface of the buildings foreseen for the development, it is predictable that energy produced by each system will be transferred at a low voltage level to the nearest connection point and then fed into the medium voltage distribution network.

Ground Installation
In case of large scale ground installations, namely the small square, the workers village and some other possible implementations, the electric distribution of the generated power can take place through a series of lv/mv transformer substations (each of 1-2 MW of installed power as a general rule) which will host the photovoltaic inverters for the dc/ac current conversion.

Environmental issues

The photovoltaic implementation at the Masdar site will inevitably cope with harsh environmental condition related to elevated temperatures and correlated sharp thermal cycles, to high humidity, to high salinity level (due to vicinity to the sea), and to site-specific and severely trying occurrences (e.g. sand storms).

Thus, all the modules destined to be installed on site should be capable of complying with specific criteria in order to ensure adequate performances and long term stability.
Masdar has recently started an on-site testing initiative in order to evaluate the performances of different types of PV modules, the result of which will be extremely significant for the following construction phases.
It might be advisable for the results of this test to be used to set a future minimum pre-requirement for any type of PV module that would be allowed to be installed in the zone, and perhaps the whole country as well.

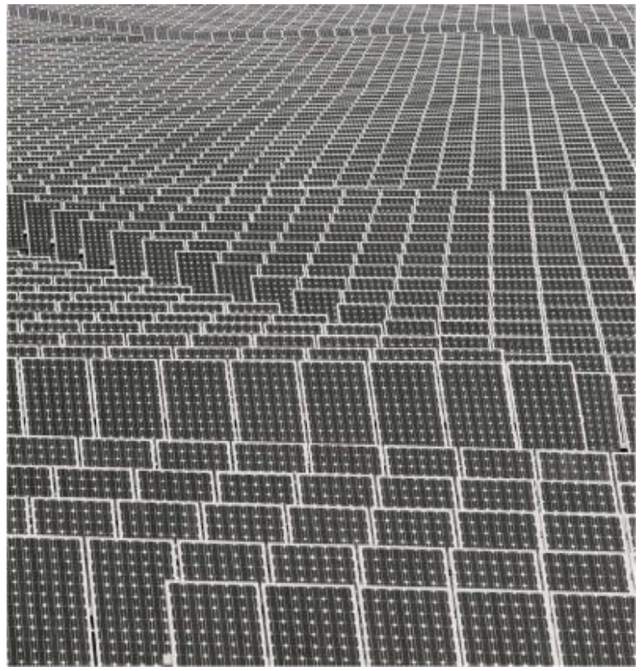
Photovoltaic modules are currently tested according to standardized procedures aiming at the assessment of the influence of mechanical, thermal and electric stress on efficiency and life cycle of PV modules.

For the implementation at Masdar a specific scheme of accelerated life test, defined on the base of the aggressive environmental conditions of the region (UV, T, relative humidity) should be set in order to achieve reliable lifetime predictions ensuring long term modules' performance.

Source: SMA

Source: Kaneka

Source: Kaneka


Source:Powerlight

Concentrating Solar Power (CSP) has the potential to satisfy a very large part of the world's energy requirements, in terms of electric and thermal demand. In fact, a small portion of the Sahara desert could theoretically satisfy the world's electricity demands (see Figure 1). There is an active group of researchers (TREC - Trans-Mediterranean Renewable Energy Cooperation) examining the possibility of a Europe-North African-Middle Eastern electric power grid, whereby each of part of the region's strengths are exploited to benefit all inhabitants by way of a high-voltage DC distribution grid. For example, the grid is fed by a variety of renewable energy, from northern Europe's wind energy to the Sahara's concentrating solar plants. See Figure 2 (source TREC) for an image.

Furthermore, CSP is the cheapest form of solar electricity currently available, with current costs about 0.20 to 0.25 EUR/kWh, and projected costs of 0.06 EUR/kWh in the next fifteen years if development increases. Current operating costs are on the order of 0.05 EUR/kWh, meaning that after amortization, the cost of electricity is lower than most options, as the plants can continue working for 40 years.

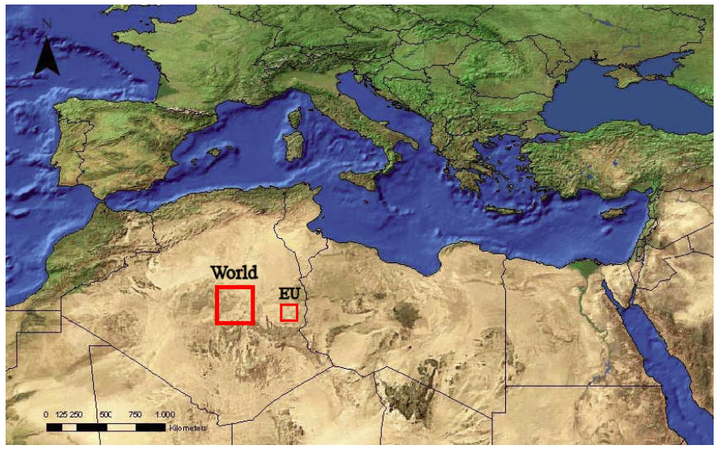


Figure 1: The squares represent the space needed for the EU and world's energy demand (Source: DLR)

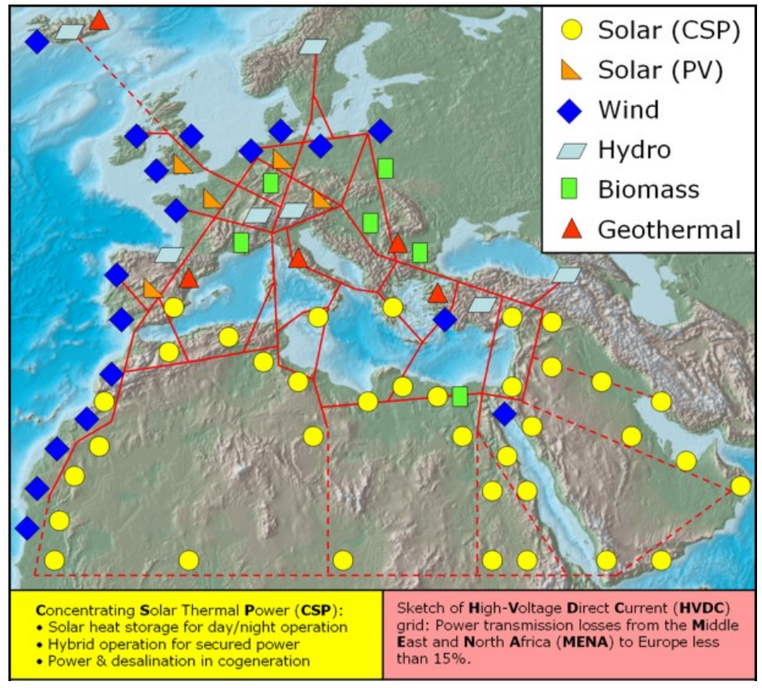


Figure 2: A possible future power generation scenario featuring CSP and HVDC transmission between Europe and the MENA region, with grid price predicted at 5 to 7 EuroCent/kWh (Source: Trans-Mediterranean Renewable Energy Corporation, more details at www.TREC-EUMENA.net)

A parabolic trough CSP system in the desert.

Solar Tower Farm Concept.

The basic concept of CSP is mostly the same regardless of the concentrating technology being applied: solar energy provides heat to run a steam power plant (See Figure 3).

A field of mirrors concentrate the incoming sunlight. This concentrated power either heats a heat-transfer fluid that is used to later boil water, or the concentrated sunlight can boil water directly. If a molten salt storage system is involved (as in the figure), this heated fluid can heat molten salt in order to store the energy in a two-tank system for use when less sun is available (or when there is none at all). The fluid continues afterwards where it generates high temperature steam to run a steam turbine. The steam turbine works exactly as in a "normal" coal-fired steam power plant.

The major benefit of CSP plants over PV-solar plants is that the exhaust steam can be utilised for thermal processes (so-called "Combined Heat and Power" CHP, or "Combined Cooling Heat and Power" CCHP). One could thus provide cooling through thermally-driven cooling systems. Furthermore, the high temperature heat created by the mirrors can actually be stored, allowing power generation even during the night to provide a constant power output for CSP plants. While this is technically possible with Wind and PV as well, those technologies require electricity storage, which is much more complex and expensive and not commercially mature for large scale power plants.

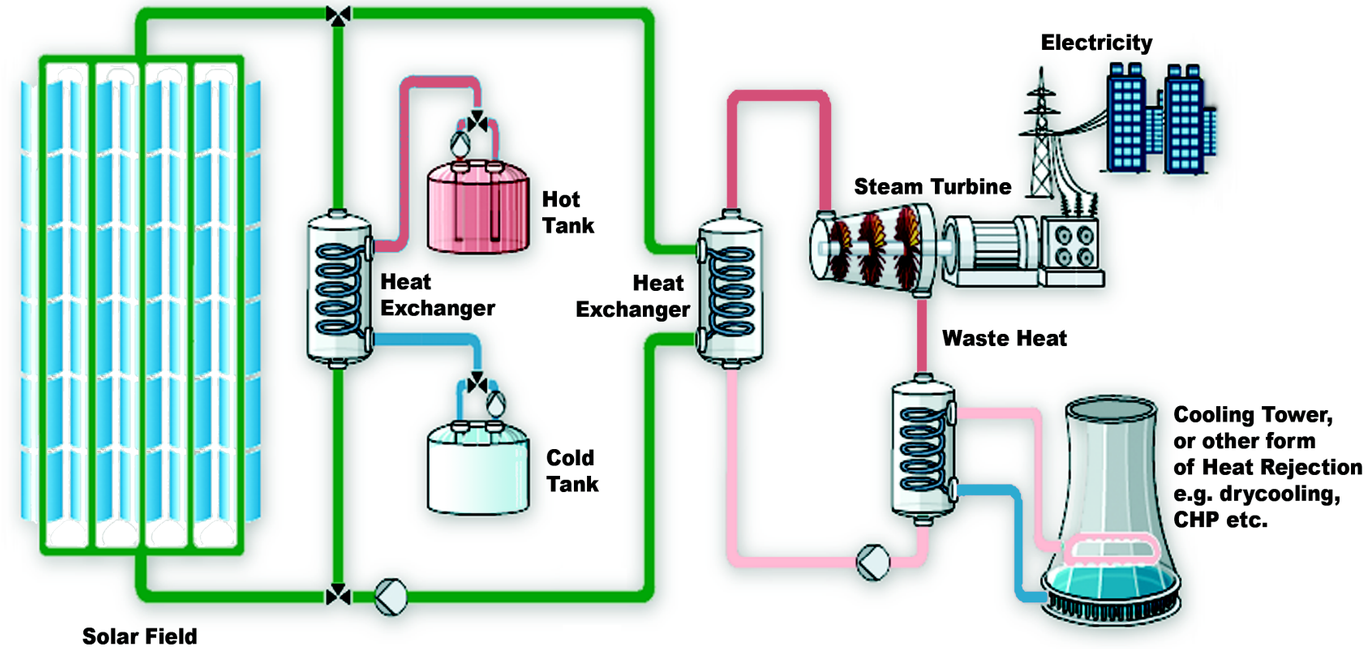


Figure 3: CSP concept with Molten Salt Storage (Modified from Solar Millennium original images)

Parabolic Trough
The most mature option for the solar field is the parabolic trough. Figure 4 and Figure 5 show an illustration. The parabolic mirrors concentrate the sunlight onto a tube that runs at the focus of the mirror, which is then used in the process previously described (Figure 6).

354 MW of this type of plant have been operating for decades in the Mohave desert of California (Solar Electric Generating System, SEGS, originally by Luz, currently operated by Solel (Figure 7).

Reference plants include Solar Millennium's Andasol 1 and 2 plants in southern Spain. Each is 50MW, on a 1.3x1.5km field, capable of running during the night with 7.5 hours of molten salt storage. While 2000 full-load hours would be possible with storage, 3589 are possible using the 7.5 hour reserve.

The disadvantage to the parabolic trough system is its lower efficiency in comparison to other mirror systems (21%), and traditionally limiting value of temperature due to the heat-transfer medium (up to 400°C).

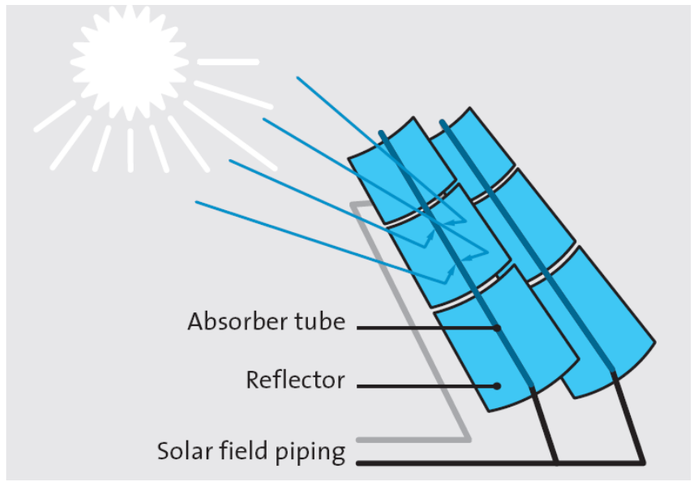


Figure 4: Concept of a Parabolic Trough (Source: Solar Thermal Power Industry Association (ESTIA) - IEA SolarPACES - Greenpeace)

Figure 7: Solar Electric Generating System in California: decades of successfully running CSP systems

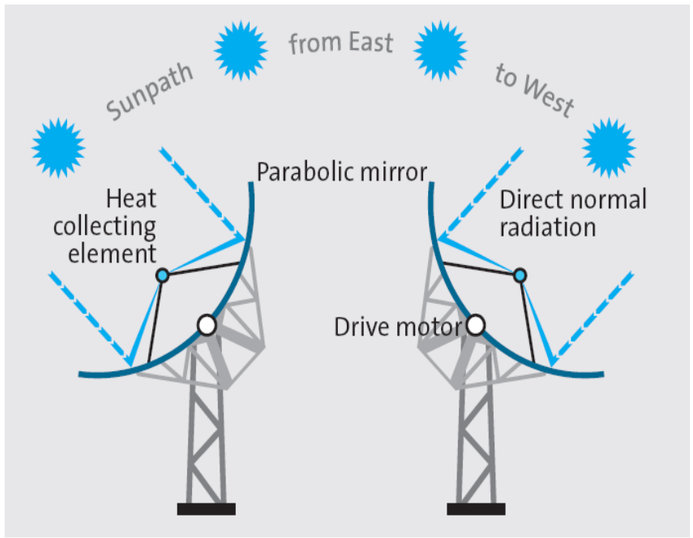


Figure 5: Concept of rotating Parabolic Systems (Source: ESTIA - IEA - Greenpeace)

Figures 6: Tube carrying the heat-transfer fluid that is heated by the mirrors

Central Receiver (Solar Tower)
Here large tracking mirrors concentrate the sunlight to a high tower (Figure 8).

The advantages are a higher efficiency than parabolic trough (23%), direct steam generation possible, and also higher temperatures (over 500°C). Molten salt operation is more efficient as it can be used directly as the heat transfer fluid.

Large developments include Solar One and Two in the USA, as well as a commercial development in Spain (See Figure 9).

However, this system is not possible at Masdar due to the height restrictions from the airport. Furthermore, the land-usage per MW is higher than parabolic trough.

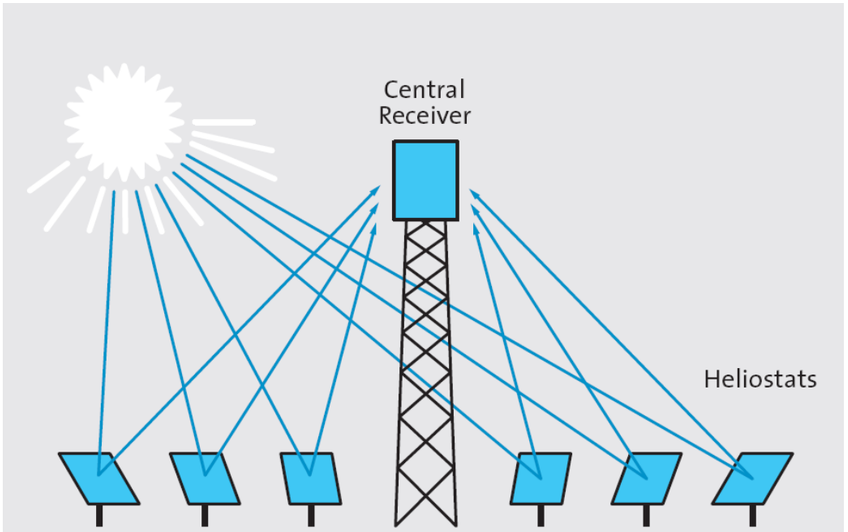


Figure 8: Concept of Solar Tower System (Source: ESTIA - IEA - Greenpeace)

Figure 9: 11 MW Solar Tower Plant in Spain, utilizing a 20MWh steam storage system.

Parabolic Dish (Dish-Sterling)
This system resembles a large satellite antenna system. The sunlight is concentrated to a receiver, which usually powers a Sterling Engine (external combustion).

The systems have high conversion efficiency (30%). However, the total space required for them makes them inefficient for land use, although for stand-alone systems they can be idea. Molten salt storage is impractical.

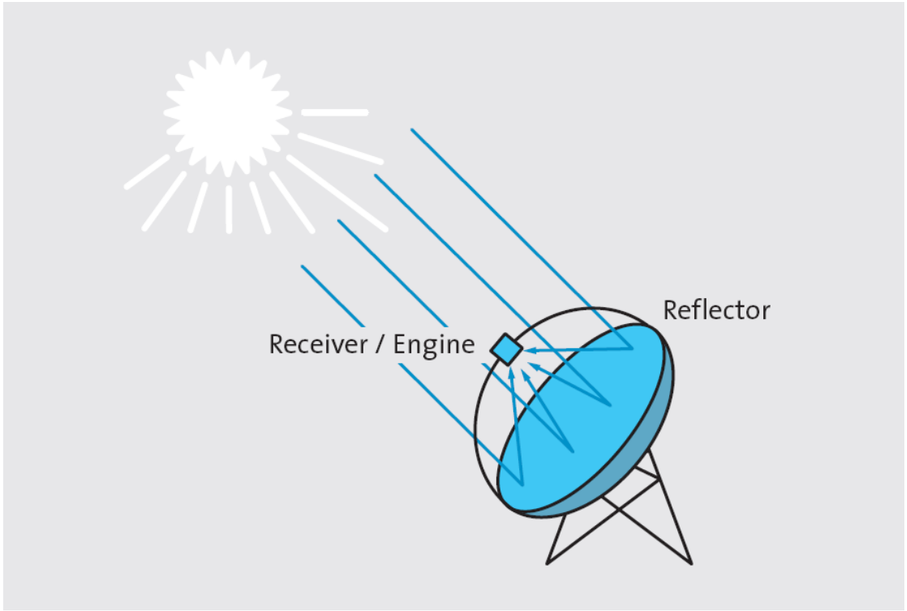
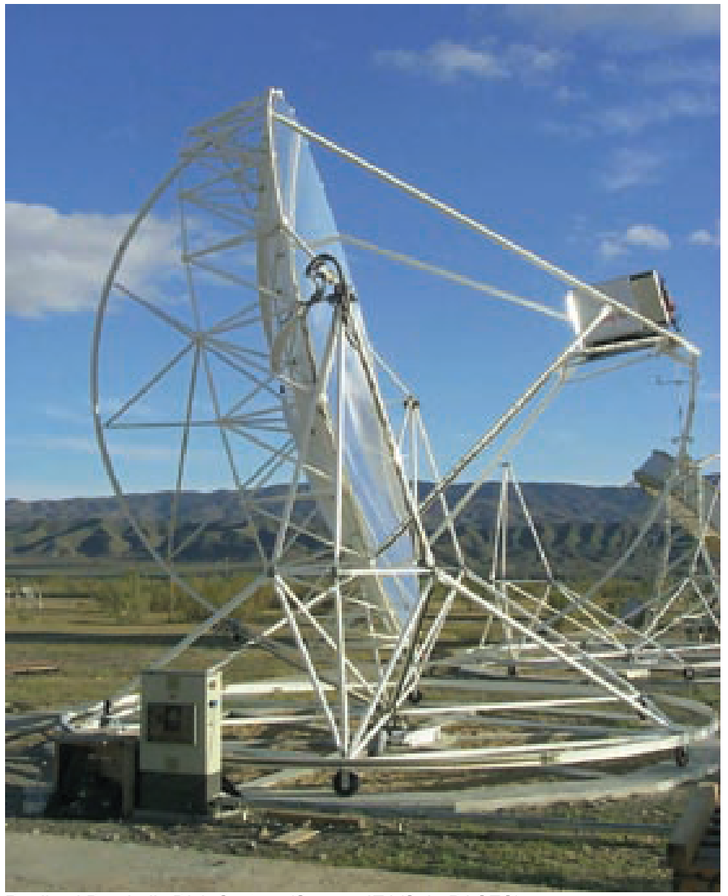


Figure 10: Concept of Parabolic Dish (Source: ESTIA - IEA - Greenpeace)



Realized Parabolic Dish System (Source: IEA/SolarPACES)

Linear Fresnel
These systems also concentrate the sunlight on to a tube, although a series of flat mirrors are used instead of parabolic ones. (See Figure 11 and 12).

The concentrated sunlight can heat a fluid (as in parabolic trough), or even generate steam directly. Direct steam generation is preferred if no storage is to be used. Steam can be generated to over 400°C.

The main advantages are the much lower land-use per MW as compared to the other technologies. Linear Fresnel uses between 25 and 50% less land per MW than parabolic trough. In a space-constrained site such as Masdar, this makes a significant difference.

Theoretically, the space underneath could be used for other purposes, such as parking; due to high fluid temperatures, this option should be considered with very high safety precautions. Such an option is not proposed for Masdar.

These systems are also theoretically significantly cheaper than parabolic trough. A large part of this due to the flat mirrors used being less expensive than parabolic ones. Relative to parabolic trough, electricity generation costs are expected to be 15% less once production for the two technologies is at the same scale.

Several small pilot plants exist in Europe, and a $1MW_{th}$ peak pilot was put into commission in Almeria, Spain this past summer by Solar Power Group (owned in part by MAN-Ferrostaal, which also owns part of Solar Millennium). SPG modules can produce steam temperatures on the order of those for parabolic troughs (See Figure 13)

Another advantage due to the flat mirrors is the potential for autonomous robots to easily clean the mirrors automatically (from sand, dirt, etc), rather than more costly human maintenance that is required for parabolic trough systems. This is still in the developmental stage, but may be available at a point during the plant's operation at Masdar.

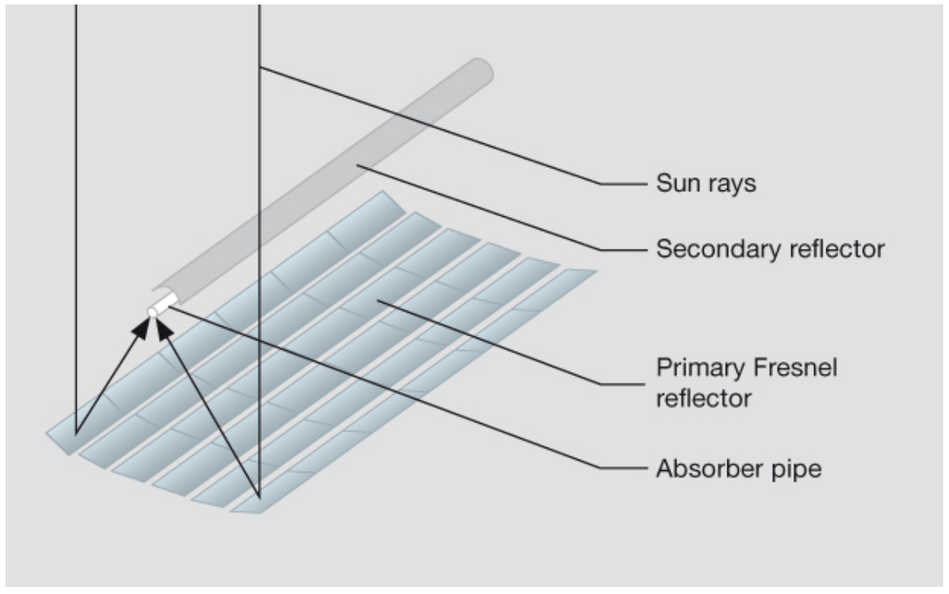


Figure 11: Concept of a Linear Fresnel System (Source: MAN-Ferrostaal).

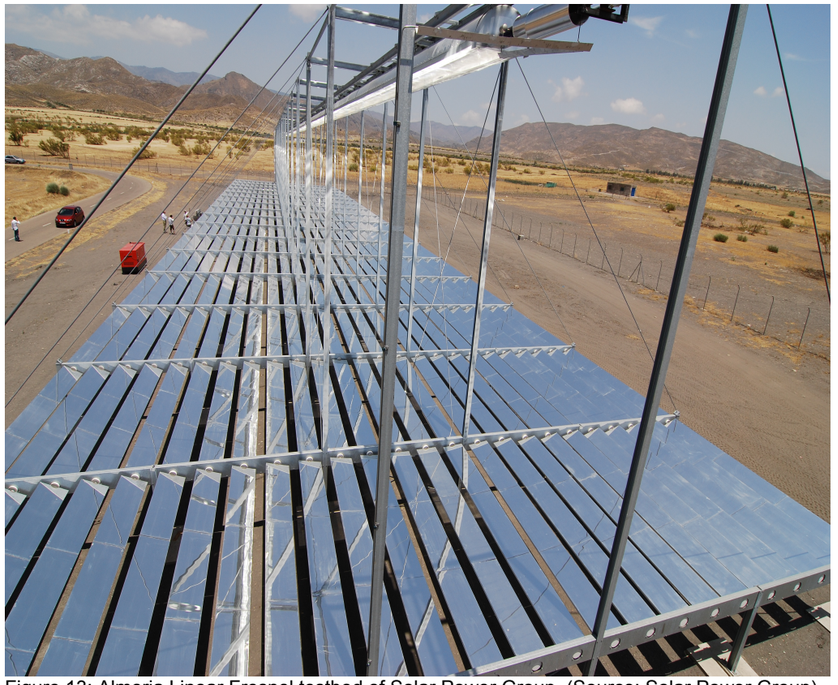


Figure 13: Almeria Linear Fresnel testbed of Solar Power Group (Source: Solar Power Group)

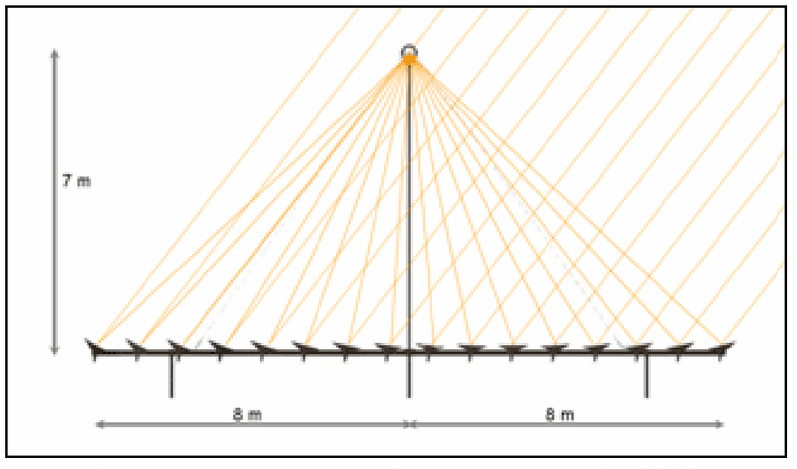


Figure 12: Sunlight concentrating in a Linear Fresnel array (source: NOVATEC-Biosol)

Technology of choice: Linear Fresnel
Due to the inherent advantages of Linear Fresnel in a space-constrained environment, Linear Fresnel has been selected as the most appropriate CSP technology for Masdar. Furthermore, Masdar's role as an incubator of innovative technology will be greatly enhanced by providing the emerging technology of Linear Fresnel the opportunity to showcase its potential over rival schemes.

As such, Solar Power Group with partners MAN-Ferrostaal, were extensively consulted to provide pertinent data for the Master Plan. Solar Power Group, in conjunction with the expertise in molten salt storage from MAN-Solar Millennium, are the most competent players in the field to provide the system envisioned.

Storage: Molten Salt
Molten salts can be used to store excess heat generation during the day. It has a large ability to absorb heat, which can then easily be transferred out during the night to produce superheated steam for power generation.

Figure 14 and Figure 15 show a typical two-tank salt storage system, one being the "hot tank", and the other the "cold tank". Refer also to Figure 3 to see it in schematic form. A heat-transfer fluid from the solar field transfers energy through a heat-exchanger to the "hot tank". This heated salt is then used later (via another heat exchanger) to produce the steam to run the turbine. The used salt after this process is then stored in an insulated "cold tank", still in liquid form. When the sun's heat is available again, this "cold" salt is pumped to where it will be heated by the heat-transfer fluid, and the process repeats. Up to a week of storage is possible.

Different molten salts are technically possible. The Andasol plants in Spain by Solar Millennium use a nitrate salt mixture of 60% $NaNO_3$ and 40% KNO_3, with a melting point of 223°C. The cold tank is kept at 292°C, the hot tank at 386°C [Source: Flagsol].

The solar plants heat the salt considerably, with parabolic trough plants up to 400°C, and Solar Tower plants capable of temperatures above 500°C.

Studies show that a 99% efficient salt storage could be possible for CSP tower plants [Source: Sandia National Laboratories, National Solar Thermal Test Facility]. In the preliminary calculations for Masdar, a target of 97% was assumed.

In systems where steam is created directly (e.g. as possible in Linear Fresnel plants), direct steam storage is a possibility. This would take advantage of the direct steam generation without the storage losses of heat transfer to salt. However, such systems are not as of yet available, and would take 2 to 3 years to develop.

The EU project DISTOR coordinated by the German DLR focuses on advanced phase-change materials for solar power energy storage.

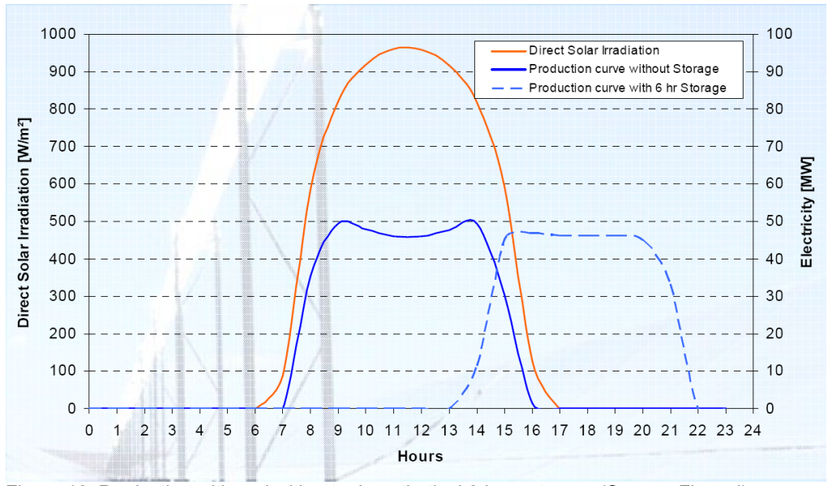


Figure 16: Production with and without a hypothetical 6-hour storage (Source: Flagsol)

Figure 14: Two-tank Salt Storage (Source: Flagsol)

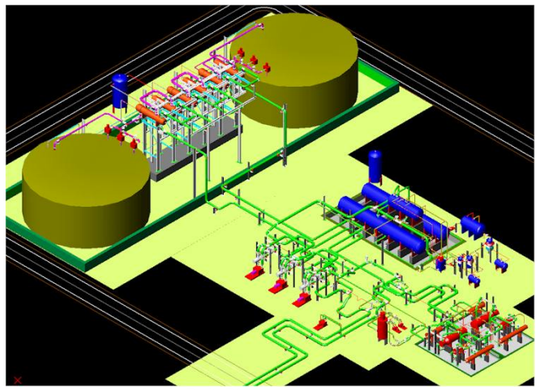


Figure 15: Two-tank Salt Storage (Source: Flagsol)

CSP operates on direct radiation, whereas PV can also operate with diffuse radiation. This means that the CSP would be less effective on hazy days, as the mirrors are unable to concentrate diffuse sunlight.

Insolation

Table 1shows the average daily insolation for each month), as well as the average daily sunshine.

	Insolation [kWh/m_2/day][1]	Daylight hours[2]
January	4.30	10.8
February	5.00	11.3
March	5.70	12.0
April	6.70	12.7
May	7.60	13.3
June	7.60	13.6
July	7.00	13.4
August	6.70	12.9
September	6.50	12.3
October	5.70	11.6
November	4.80	10.9
December	4.00	10.6
Yearly	2180	12.1

Table 1: Daily averaged insolation figures for each month.
1. Abu Dhabi Ground Measurements
2. NASA Earth-Sun System Division

The plot where the CSP is to be located is approximately 56ha to the south-west of the city (See Figure 17).

Alignment
In order to optimise the use of the sun, which traverses a path from east to west, Linear Fresnel (as well as parabolic) mirrors are placed in a north-south alignment. This allows them to rotate from east to west, tracking the daily movements of the sun. However, the site eligible for CSP in the case of the Masdar Master Plan is not a north-south aligned square, but rather aligned NW-SE.

Figure 18 shows a scenario with Linear Fresnel mirrors optimally aligned for solar efficiency. The empty space represents the power block, which contains the turbine. Parabolic trough arrangements would also be north-south aligned. Linear Fresnel can theoretically be placed in other alignments (with reduced efficiency). Figure 19 shows the arrangement for optimal space usage within the confines of the square, which results in a more aesthetically pleasing layout. Figure 20 shows another option slightly overstepping the bounds.

Airport Issues
A well-designed CSP system should technically not be directing sunlight anywhere other than the receiver. Thus the amount of reflected sunlight into the sky should be minimal (See figure 21). In general the solar field should look like a body of water from above.

That said, protective measures would be advised, especially to reduce any "stray" sun rays. A second cover may be considered above the receiver tube to block the sun rays, although this would lead to loss of sunlight. Furthermore, during potential times of reset in the morning (where the mirrors must turn from the last night time position to face the sun), the resetting regime should be coordinated with the airport authority to avoid any adverse affect on air traffic.

Vicinity of the city
Since the city is very close, noise from the power plant operation may be an issue to residents. Special housing design for the turbine could be considered with materials for increased noise-insulation.

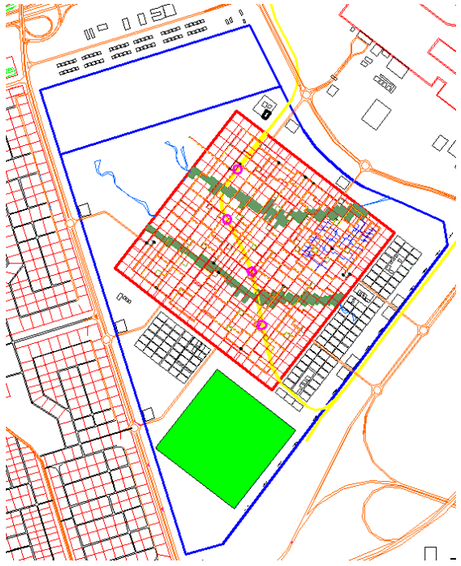


Figure 17 – Location of CSP plant

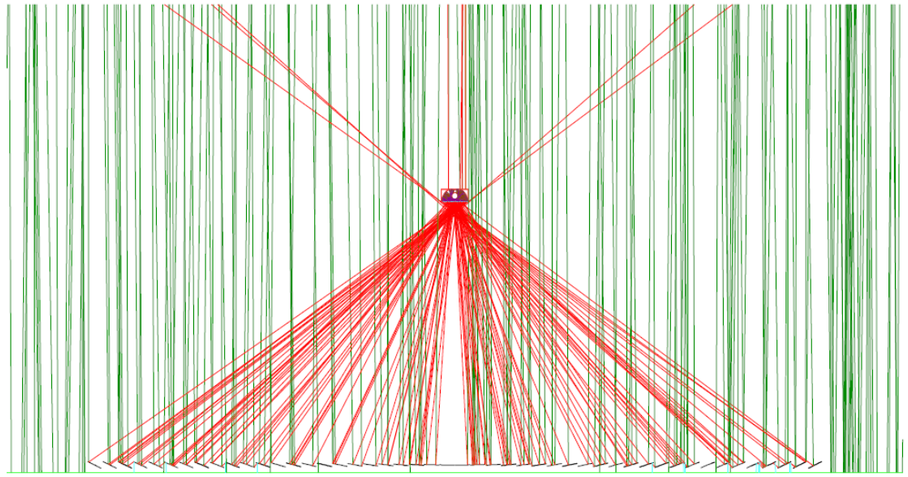


Figure 21: Ray-tracing diagram of the reflected sun (Source: "The Solarmundo line focussing Fresnel collector. Optical and thermal performance and cost calculations.", Häberle, Andreas, PSE GmbH, Fraunhofer ISE, DLR)

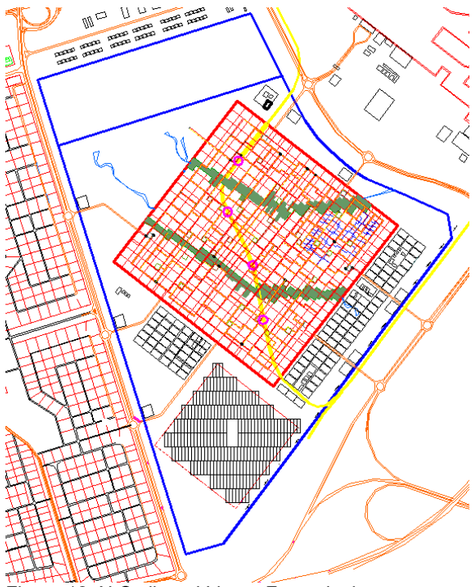


Figure 18: N-S aligned Linear Fresnel mirrors, overstepping the bounds, with 213MW_{th} peak.

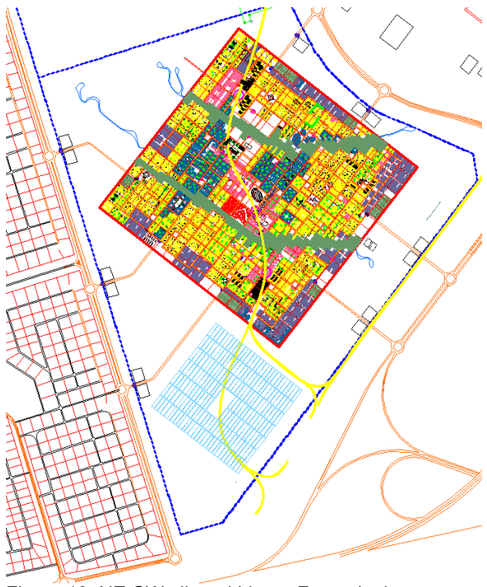


Figure 19: NE-SW aligned Linear Fresnel mirrors completely within the bounds, with 193 MW_{th} peak

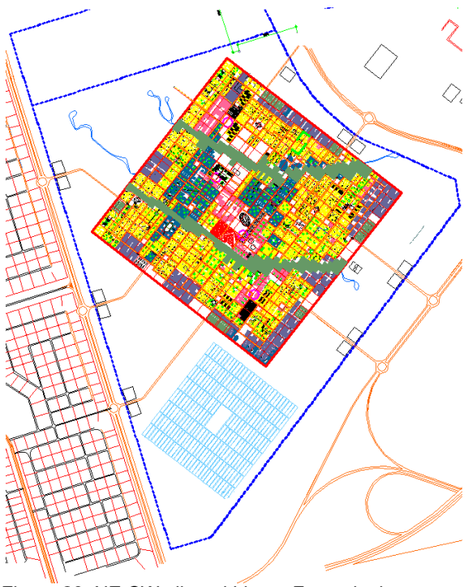


Figure 20: NE-SW aligned Linear Fresnel mirrors slightly outside the bounds, with 222 MW_{th} peak

Combined Heat and Power
The CSP turbine will operate in combined heat and power mode, that is both the electricity and heat shall be produced. Systems using the heat for thermally-driven cooling processes are often known as Combined Cooling Heat and Power (CCHP).

Figure 22 shows the input-output characteristics of a steam turbine used for electric power generation (for example, in a coal-fired power plant). The majority of input energy is lost to the environment through heat and grid losses.

Figure 23 shows the input-output characteristics of CHP turbine. A large part of the previously "lost" energy is recuperated for use, allowing for a very high "overall efficiency". This can be used for many heat loads, including thermally-driven cooling (see Figure 24).

While steam turbines generally have a maximum overall efficiency of 80%, internal combustion engine CHP systems can achieve overall efficiencies of over 90%.

District Cooling
The waste heat from the turbine will be used in heat exchangers to provide the necessary thermal energy to power the absorption chillers and desiccant air dehumidification system. The exhaust heat of a steam turbine is adequate to run this. In addition, the waste heat can also be used to power the single-stage absorption chillers.

For this stage of the Master Plan, we have assumed operation of the turbine for maximum electricity production, that is all the steam output of the mirrors to be used to generate electricity. It should be noted, however that this can be changed with implementation, taking away some of the earlier stage high temperature steam (e.g. 450°C), for high temperature processes; this would obviously result in a loss of electricity production. If the demand for waste heat were to change in the future at Masdar (for industrial purposes for example), this option could be pursued. It should also be noted that more thermal energy is available in winter than in summer (due to lower cooling demand).

China has several large scale CCHP systems at the district level (powered by coal however), with a 49.6MW system in Jinan, and 120MW in Hangzhou (See: "Combined cooling, heating and power: A review", D.W. Wu, R.Z. Wang, Progress in Energy and Combustion Science 32 (2006) 459–495).

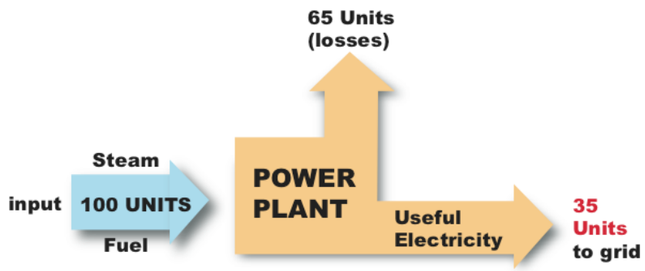


Figure 22: Normal Energy Input/Output at a power plant.

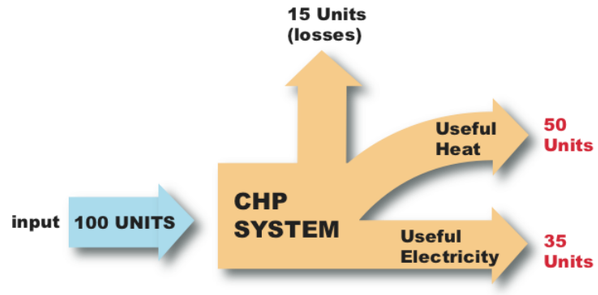


Figure 23: Energy Input/Output at a CHP power plant.

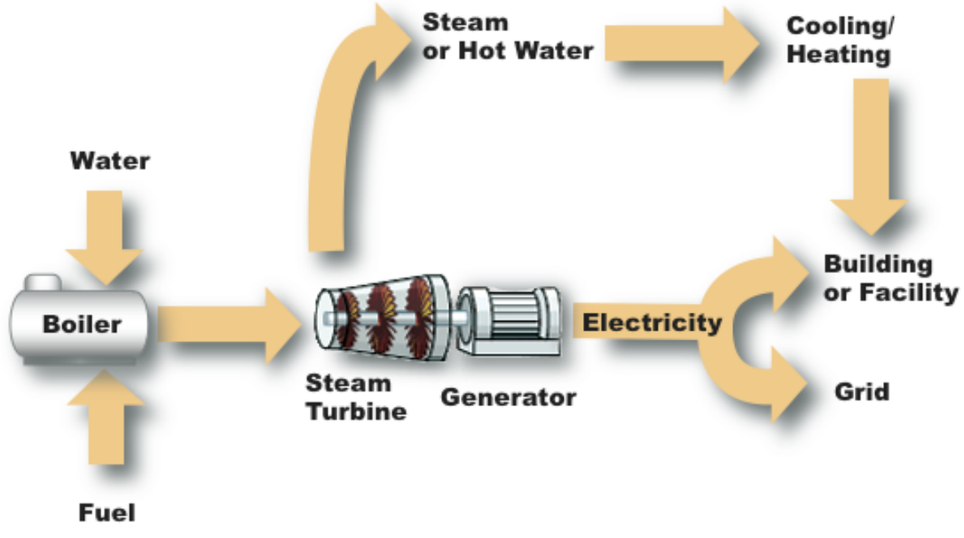


Figure 24: A steam turbine CHP plant in operation.

Layout

We have considered a N-S aligned Linear Fresnel plant at 200MW_{th} peak (in the vein of Figure 18)

A NE-SW alignment, while not optimal, will also produce quite similar results.

The Linear Fresnel block arrangements have been assumed from Solar Power Group / MAN-Ferrostaal: 100x21m blocks, with 4m distance between each one. A block can produce up to 1MWth peak output.

Furthermore, the diagram to the right shows the hypothetical situation of the small square being developed into an urban center, with the CSP being confined to a smaller space. In such a case, a 2.7 MWe (24-hour) plant is simulated.

Note on Power Island and Storage Tanks
The power island, which consists of the steam turbine, generator and cooling towers, is usually set in the center of the development in order to reduce the amount of piping and losses. Due to the nature of the Linear Fresnel power blocks, it may be possible to place these elements, along with the storage tanks, under the mirrors, provided the mirrors are placed high enough. This allows a complete coverage of the square with mirrors, thus allowing greater energy and power production.

Operational Regime
Two options could be considered for operating the plant:
Operation without Storage
24-hour operation

Some CHP parameters

Thermal Efficiency: 52%
Electrical Efficiency: 22%

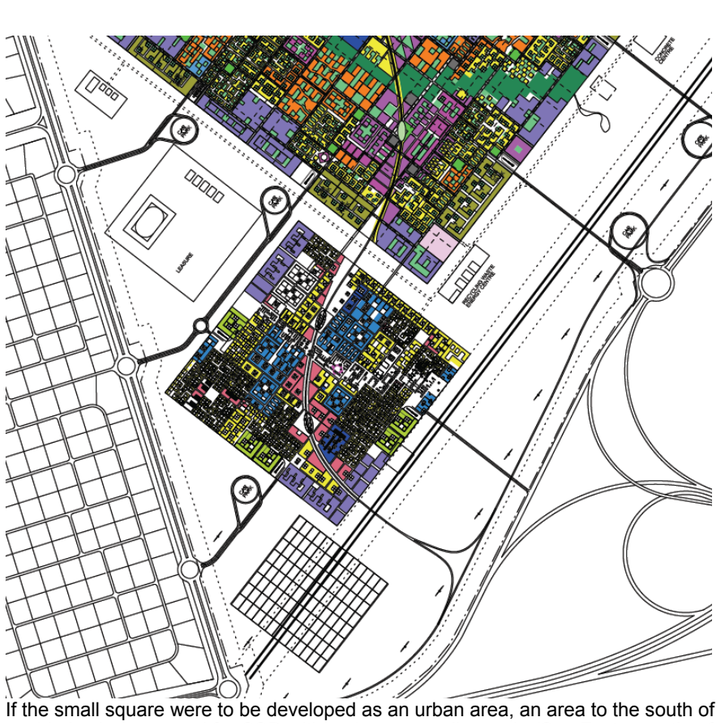
Table 2 shows numbers of the potential setups. It also includes the production possible from a parabolic trough system on the small square. Due to the tighter spacing of Linear Fresnel mirrors, the power possible for the parabolic trough is of course less.

Storage Requirements

The largest case of storage is for night-only operation, which varies between 13.4 hours in winter to 10.5 hours in summer. Assuming a 11.2MWe system, a 13hour storage would require a two-tank system with tanks of approximately 24m diameter and 14m height. The height and diameter are variable with the space constraints. Up to one week of storage is possible.

Layout	Sizing	Operating hours (avg)	Electric Power (MW_e)	Electricity Produced (MWh_e)	Thermal Energy produced (MWh_{th})
NS or NE-SW Linear Fresnel: on small square	Day	2000	44	88 000	208 000
NS or NE-SW Linear Fresnel: on small square	24-hour	7800	11.2	86 700	204 900
Parabolic Trough	Day	2000	22	44 000	104 000
NS or NE-SW Linear Fresnel: small square is a city (see figure below)	24-hour	7800	2.7	21 000	49 100

Table 2: Energy Produced by CSP



If the small square were to be developed as an urban area, an area to the south of it could also be proposed for CSP, although on a smaller scale (See Foster section for more information on the city square).

Water Requirements
Water is required to run the turbine, to clean the mirrors (of sand), and to possibly reject heat arising from the steam power generation process.

Evaporative cooling could be used for heat rejection for the steam plant, but this is the most water-intensive and also this requires a high quantity of high quality water. Dry cooling is another option to consider, which requires significantly less water; however, cost increases and efficiency suffers. Table 3 summarises the water needs. Considering that the solar plant will mostly be operating in CHP mode, a large part of the waste heat will be utilised for thermal purposes, and this thus reduces the need for heat rejection in general. Geothermal tubes could also be considered for heat rejection. A minimum amount of 60 000 m^3 of water per year should be considered.

Maintenance and Lifetime
Maintenance consists of clearing the mirrors of sand to avoid low reflectivity (and thus reduced energy production); daily cleaning would be needed in times of increased sand movement. A water truck operating at night would do such a job. Automatic robotic systems have also been suggested for Linear Fresnel systems.

The lifetime of the systems are much longer than the amortisation period (typically 20 to 25 years). However, CSP systems can last for 40 years or more. CSP plants are thus similar to hydroelectric plants in that they will continue to produce cheap electricity well into the future, only requiring periodic maintenance and replacement of parts. Costs of 5 cents per kWh would be normal, with no effect coming from fossil fuel price increases.

Construction times
Lead time on a Linear Fresnel system, apart from the detailed feasibility study, would be two to three years.

Environmental Conditions
Sandstorms represent considerable problems for mirror scratching. In the case of these events, the mirrors can be turned downwards. Sandstorms could also cause power outage problems for many of the systems. In the case of a complete blackout, the system could technically still be run using a fuel backup (see Figure 25) providing emergency electricity and thermal energy to critical systems. Gas from the waste-to-energy plant could be stored for this purpose, or even biofuel could be imported. Even the use of natural gas in emergency situations is within the One Planet Living guidelines, and this would only need to happen in extreme situations.

Environmental Impact
The impact of CSP is minimal on the environment. After the useful life, most of the components can be reused or recycled (turbine components, metal, glass). The molten salt can be recycled, with one option being fertiliser.

Disposal of the heat transfer fluid should be carefully done.

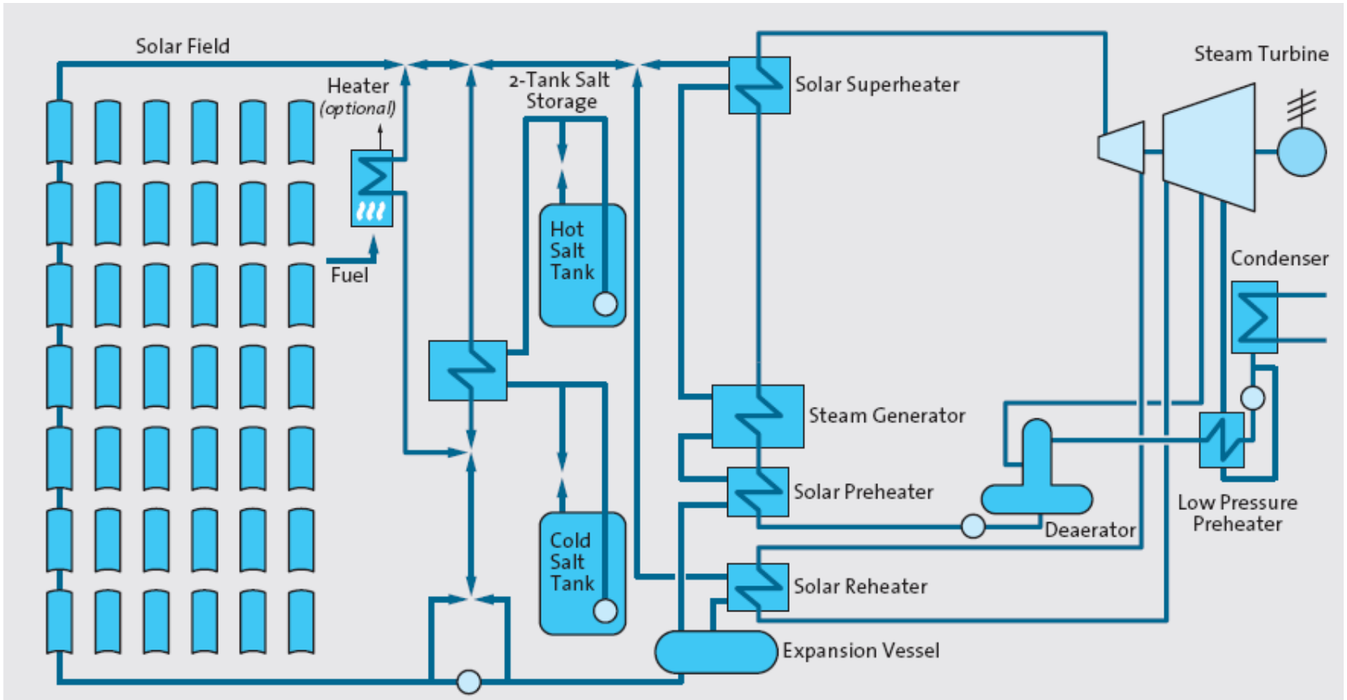


Figure 25: CSP schematic showing an auxiliary fuel backup (Source: ESTIA - IEA - Greenpeace)

Use	Water Consumption	Maximum Water Requirement
Mirror Cleaning	0.14 m^3/MWh[1]	12 100 m^3/year
Evaporative Cooling of entire output	2.8m^3/MWh1 to 5m^3/MWh	435 000 m^3/year
Dry Cooling	0.5 m^3/MWh	45 000 m^3/year
Evaporative Cooling of CHP output only	0.95 to 1.7 m^3/MWh	145 000 m^3/year

Table 3: Water consumption of CSP plants
1"Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California", NREL, 2006

Utilities
The plant requires connections to the following utilities:
Water
22kV MV grid
Heat/cooling loop

See the WSP chapter for further details on the utilities connections.

Future Steps
The following steps are required to move ahead:

- On-site weather data acquisition
- one-year hourly insolation values, with temperature and humidity data (should be available by late next year)
- Contract detailed feasibility study from a Linear Fresnel manufacturer, for example Solar Power Group GmbH

The importance of the on-site weather data (being conducted by ADFEC currently) is absolutely crucial, as the direct normal radiation can change significantly depending on how close the site is to the shore. The only data available up to this point has been data from Abu Dhabi in general.

Additional Future Development
The wind turbines in the south-west corner of the site may, with either further consultation with city/airport authorities or through the further analysis with the wind-mast data, be deemed not appropriate for implementation. In this case, the CSP plant could be expanded in this area as an option, or a separate plant itself could also be considered. The latter option is presented in Figure 26, showing a hypothetical 49MWth development.

Organic Rankine Cycle as an option
Smaller steam turbines operating with lower temperature steam can use the organic rankine cycle instead of the normal cycle. This is typical in geothermal binary steam power plants. Typical ORC plants are in the 100kW to few MW range.

In the case of Masdar, if a large scale CSP project were to be developed, over 10 MW, the application would be limited for ORC. This is especially true considering the high steam temperatures possiblke from parabolic trough collectors and linear Fresnel (on the order of 400°C). However, some studies have been made that consider using parabolic troughs to produce lower temperature steam that show a decrease in solar field area for the same amount of power output (A. McMahan, S. Klein and D. Reindl, “Design and Optimization of Parabolic Trough Organic Rankine Cycle Powerplants”, Solar 2006 ASES Conference Proceedings). In any case, ORC turbines would only be applicable for lower MW sizes.

In addition, if another type of solar collector were to be used that produces lower temperature steam were to be used, an ORC turbine could also be considered during the engineering study.

Relevant Research Projects
Certain research projects funded by the European Commission could potentially be interesting to Masdar in the future relating to the production of hydrogen using solar energy. These include:

- HYDROSOL and HYDROSOL II: Solar Hydrogen via Water Splitting in Advanced Monolithic Reactors for Future Solar Power Plants.

- SOLHYCARB: Hydrogen from solar thermal energy: high temperature solar chemical reactor for co-production of hydrogen and carbon black from natural gas cracking.

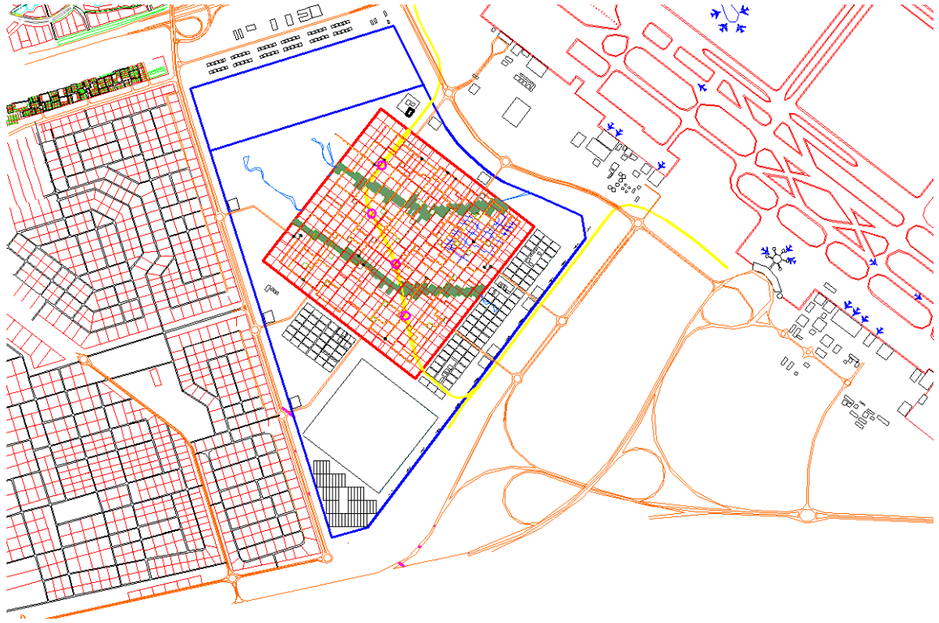


Figure 26: CSP implemented instead of Wind Energy, 49MW_{th} peak.

A small-scale CSP plant could be made for the MIST campus as part of an innovation hub. Pictured is an MIT Organic Ranking Cycle parabolic trough plant in Lesotho (Source: MIT / Popular Mechanics).

The technology

Solar thermal energy may be used to provide energy for a variety of applications including building space heating, refrigeration and air conditioning, domestic hot water, hot water and steam for industrial processes, drying and electric power generation.

Thermally driven cooling technology for Masdar can be designed and implemented to achieve the overall 100% target for the cooling thermal loads of the entire development. Basically, the indoor air treatment will be carried out through desiccant and absorption (and/or adsorption) components powered by solar thermal collectors and a combined system of heat storage.

Like many other solar thermal systems, the process requires a heat-transfer fluid, heated by solar collectors, then stored to cover night time and irradiation shortfall periods, and is finally circulated through the air conditioning equipment where the energy is used.

The solar thermal collector field at Masdar will consist of high performance evacuated-tube collectors (ETC) and concentrating collectors, chosen due to the fact that they are typically more efficient at higher temperatures than the other kind of collectors, even at low radiation. In fact, given the large operating temperature range for the fluid (from 90° for single effect absorption chillers and liquid dessicant systems, up to 120° for double stage thermally driven chillers), the ETC represent the most appropriate technology to be deployed for this purpose.

WORKING PRINCIPLE OF ETC

In an evacuated-tube collector, sunlight enters through the outer glass tube and hits the inner absorber, where the energy is converted to heat. While the outer tube is transparent allowing light rays to pass through with reduced reflection, The inner tube is coated with a special selective coating to maximise solar radiation absorption and minimise reflectivity.The heat is transferred to the liquid flowing through the absorber. A series of parallel transparent glass tubes, containing an absorber covered with a selective coating, is joined to obtain a single collector. The absorber typically is of tin-tube design, although cylindrical absorbers can also be realised.

During the manufacturing of evacuated tubes, the two tubes are fused together at the top and the air is evacuated from the space between the two tubes, forming a vacuum. This process ensures the convective and conductive heat losses are eliminated because of the absence of air,which would otherwise convect or conduct heat away from the fluid.

As a result, evacuated-tube collectors are more efficient at higher temperatures than conventional flat-plate collectors, performing well under both the conditions of direct and diffuse solar radiation. Therefore evacuated-tube collectors are among the most appropriate and technologically advanced solar thermal generating systems exploitable for many application in commercial, industrial and large scale domestic field.

Figure 1: Evacuated Tube System (Source: Silicon Solar)

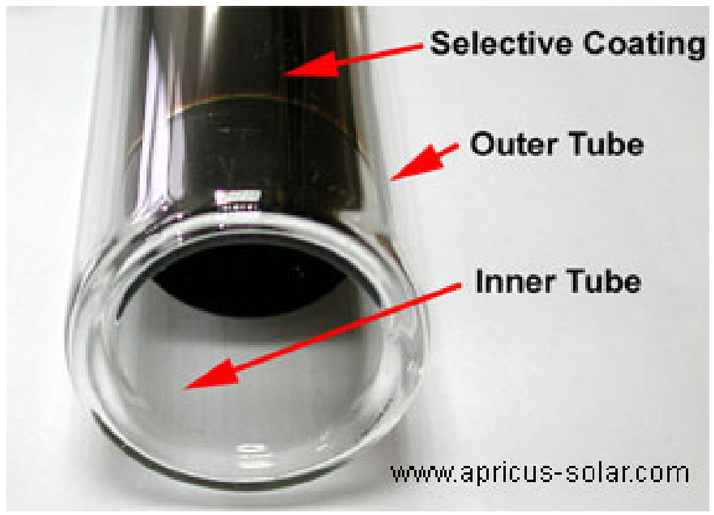


Figure 3: Tube Construction (Source: www.apricus-solar)

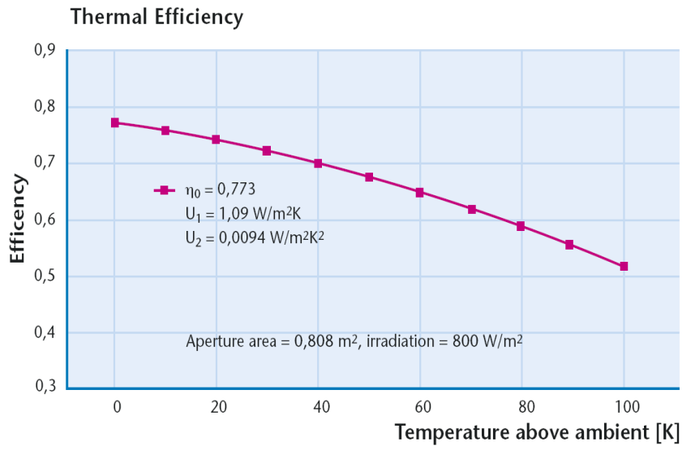


Figure 2: Efficiency curve of an ETC (source: Schott Solar)

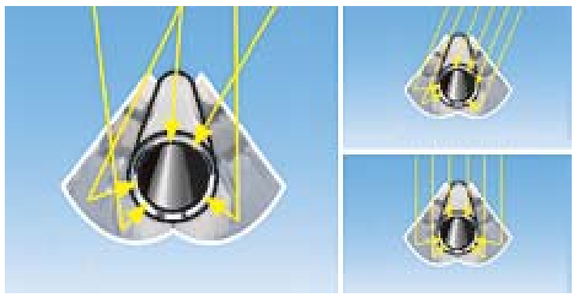


Figure 4: CPC Evacuated Tube Collector (source: Ritter Solar)

Moreover, although the inner tube can reach elevated temperature when exposed to the sun's radiation, the outer tube keeps cold to touch because of the vacuum technology; therefore, due the reduced potential risks in the case of direct contact, the ETC can be easily mounted even on the roofs of buildings with minimum accessibility restrictions.

Due to the reduced convective and conductive losses, the ETC technology is capable of performing well even during the winter, supplying the energy needed to satisfy the sensible and latent cooling loads.

For the ease of maintenance, during the manufacture of the evacuated tube, in order to maintain the vacuum between the two glass layers, a barium getter is used. During the high temperature process, the barium deposits itself at the bottom of the evacuated tube, coating the terminal part. The barium layer is capable of absorbing most of the gases released from the evacuated tube during storage and operation, helping to maintain the vacuum and directly giving a visual indication of the vacuum status; the bottom coating shows a silver to white colour shift in the occasion of vacuum degradation.
Evacuated tubes are mounted in parallel rows, with a tilt angle that can be optimized according the latitude of the location, like all the other kinds of solar collectors.

In terms of system's performance, the efficiency of a solar collector (defined as the quantity of usable thermal energy divided by the received solar energy) is influenced by various factors such as thermal and optical losses. Thermal losses (indicated by the thermal loss factor or k-value) are strictly related to the temperature difference between the collector and the surrounding ambient, (the larger the difference, the more heat is lost), until the amount of heat lost equals the energy yield of the collector, completely negating the usable thermal energy.
For the installation at Masdar, only collectors with a high conversion factor and a low k-value will be deployed.

A further technological improvement in the ETC field could be achieved through the adoption of highly reflective back placed mirrors, in the CPC shape (Compound Parabolic Concentrator). These are simply ETC panels with a reflect sheet underneath (see Figure 4). These would allow the maximun irradiation absorption even at unfavourable irradiation angles, improving the energy yield of the solar collectors. In this way higher fluid temperature can easily be reached (up to 120° C), with consistent enhancement in the chillers' performance, giving way to further system's optimization in the case of solar cooling (i.e. reduced thermal storage and area requirement) . While the yield would improve theoretically, the presence of sand may decrease actual performance, as the tight spaces between tubes and reflectors.

Lastly, Parabolic Trough Collectors (PTC), could also be used to generate heat (See Figure 7). Their operation is similar to that described in Section 6.3, although the temperatures generated are higher for CSP trough systems. The advantage of PTC is the ability to generate temperatures higher than ETC or CPC, with over 200°C steam. This heat could thus drive double-effect absorption chillers, which have a higher COP than single-effect, in the range of 1.1 to 1.3. PTC combined with double-effect absorption chillers can thus achieve a higher performance for cooling per collector surface than other technologies. However, PTCs must track the sun (using electric motors), and in order to avoid shadowing cannot be placed as close to each other as with stationary ETC. Thus, the actual benefit in terms of total area required for the systems is less significant. Considering the rooftop conditions at Masdar, ETCs are presently suggested.

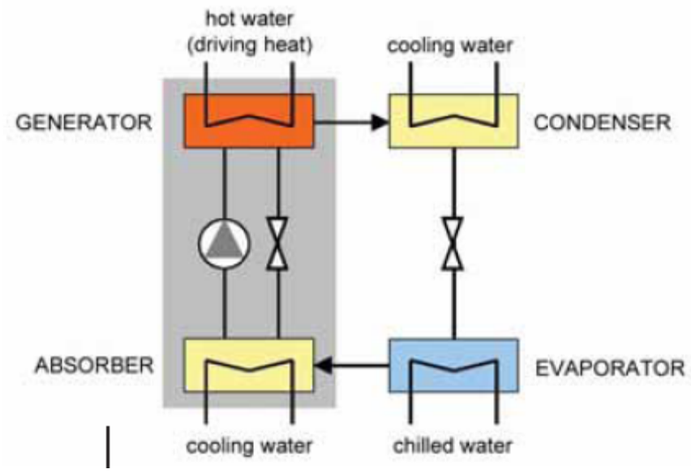


Figure 5: Chiller Functioning (Source: Climasol)

Figure 6: ETC integrated into a roof (Source: CLIMASOL)

Figure 7: Linear Parabolic Concentrators (Source: SHAP S.p.A.)

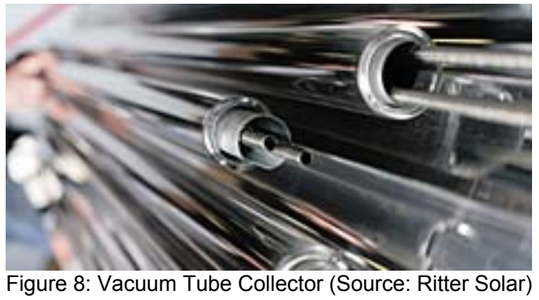


Figure 8: Vacuum Tube Collector (Source: Ritter Solar)

HEAT STORAGE

In order to compensate for the daily fluctuations in the energy produced by the collectors' system, and to provide an adequate reserve of energy for the night time cooling period, the solar thermal strategy includes the utilisation of heat storage technologies.

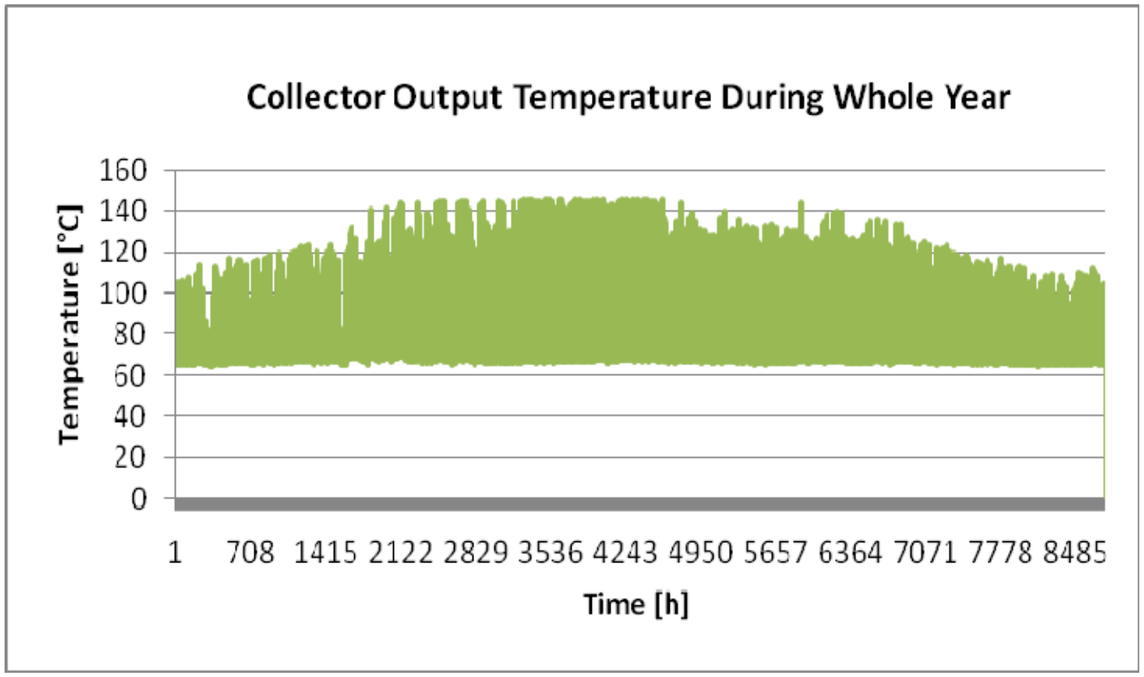
Heat Storage boasts many applications in space heating, crop drying, cooking, electric power generation, industrial process heat (air and steam), waste heat utilisation, and solar energy utilisation, etc.
The most common heat storage materials used for thermally driven cooling applications enable the storage of thermal energy as sensible or latent heat.
Thermal storage in water is currently the most economical and well-developed technology for sensible heat storage, with tanks commonly made of epoxy-lined steel, fiberglass reinforced polymer, concrete with plastic liner, and even wood material. Other sensible heat storage materials are organic oils, rocks, ceramics, and molten salts.

Otherwise, a quite extended range of Phase Change Materials (PCM) can be used as a valid alternative to water, the most commonly used being paraffin waxes, non-paraffins, inorganic salts, for latent heat storage. During melting, they absorb high amounts of thermal energy ("loading" phase), which they emit again during congealing ("unloading" phase). Some salts show a similar behaviour. The temperature of the PCM itself changes only slightly during "loading" phase before reaching the melting point.

The two important parameters to be considered for energy storage applications are duration of storage and specific energy or energy density, which is a critical factor for the size of a storage system.

Typically for solar energy systems, the requirement of energy storage may be on an hourly, daily, or weekly basis. For the Masdar development, the thermal storage could be sized on a daily basis in order to ensure an all-day supply to satisfy the thermal loads related to indoor air treatment.

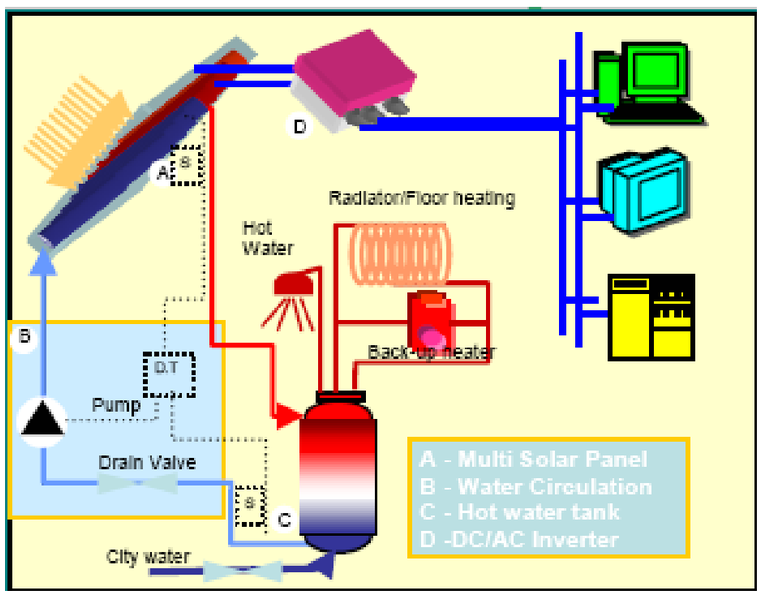
Specific calculations have been carried out to evaluate the possible performance of an evacuated tube collector system at Masdar, thus determining the expected values of the specific solar factor and energy produced for a solar cooling application. The tables and graphs aside highlight the results of the simulation, which lead to a 47.5% value for the solar factor, corresponding to 742 kWh/m^2 (collector area) of specific energy production. The numbers obtained will then be used for the calculation of the overall area requirements (see 6.10 subchapter) as showed in the final part of this section.



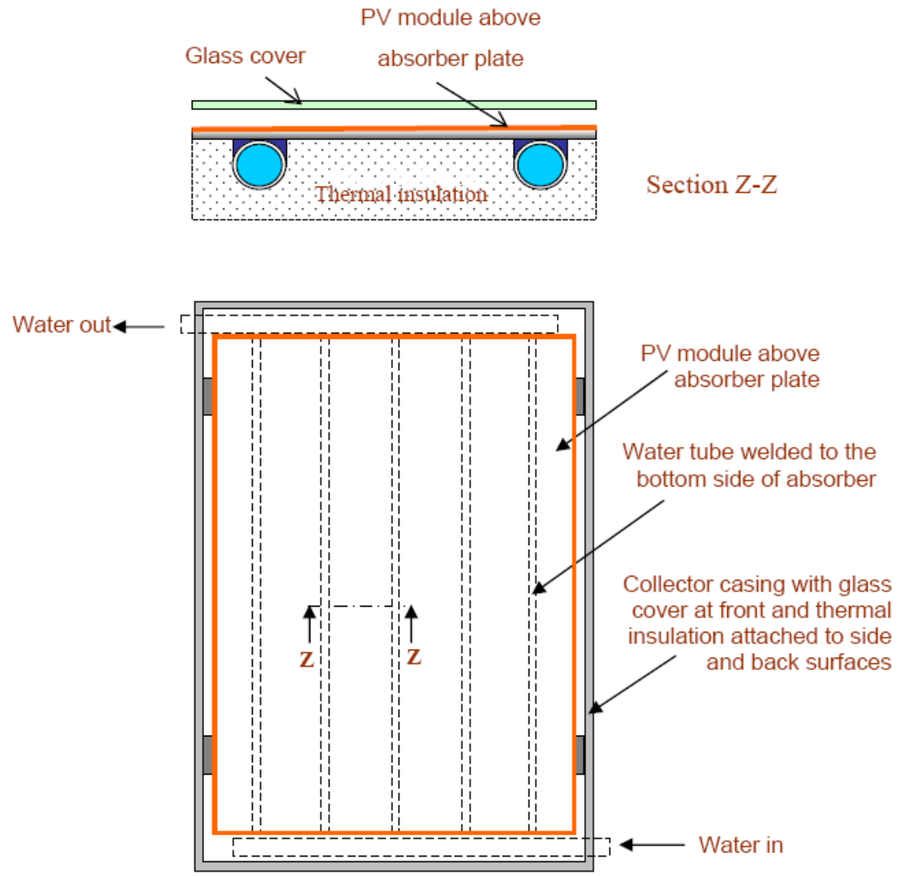
PHOTOVOLTAIC THERMAL for domestic water usage
Also known as total energy systems, Photovoltaic-Thermal (PV/T) systems consist of photovoltaic and solar thermal collectors integrated into one single system, in a particular arrangement through which thermal and electrical energy are produced, delivering both heat and electricity in usable form. Typically, the back side of a PV module is directly attached on to a solar thermal collector surface.
PV/T modules work on the basic principle that a PV solar cell converts only 6-15% of the incoming solar radiation into electricity, and therefore a significant amount of the remaining radiation is available to be converted into heat and collected by a thermal transfer fluid. As a consequence, the hot water carries away the heat and cools the solar cell, enhancing the PV cell efficiency and improving in the electrical output.
For a given collector surface area, the overall system energy performance is expected to be higher than the conventional "side-by-side" PV and solar thermal systems.
As already proved by many field tests, the addition of a solar thermal component to a PV module boosts the total solar efficiency to over 50%, as compared with the 10 to 15% efficiency for most PV modules alone.
Beyond the electric energy production, the PV/T systems will provide the thermal energy for domestic water heating; therefore with an estimated thermal need of 25.000 kWh/y, around 4,7 ha of the PV systems already foreseen over the city roofs will be integrated with thermal collectors, involving also an improvement in the electric energy yield of the panels.

PV/T systems for Domestic Hot Water	
Thermal need (incl. storage)	28.125 MWh/y
PV/T yield / PV-elec yield	2,33
Area requirement	4,7 ha

Source: Solarwall



Source: Milennium Solar



Front view of a PV/T collector with single glazing.

Wind energy is a potentially great resource in producing renewable electricity at an economical price. New large-scale installations in adequately windy sites can even lead to electricity costs competitive with conventional generation from fossil fuels in Europe.

Unfortunately in the case of Masdar, there are several factors that lead to a limited application of the wind resource.

Wind energy has reached an unprecedented level of maturity over the past 30 years of development, with competing technologies that eventually gave rise to the standard horizontal-axis design that is common across many landscapes worldwide.

A wind turbine consists of, at bare minimum, a rotor, blades and a generator. This is illustrated for two types of turbines (explained below) in Figure 1.

Wind blows on to the rotor blades, which due to the aerodynamic principle of lift, causes them to turn, which makes the rotor rotate. The rotor is connected to a generator that converts the rotating mechanical energy into electrical energy, which is then used immediately or fed into an electric grid.

The higher the wind speed, the more electricity can be produced. Low speeds can render wind turbines uneconomic and unproductive. However, the relationship between wind speed and energy is cubic, meaning that for a doubling of wind-speed, energy production increases 8 fold. Thus, while 3 m/s average speed at site would not be economic, 8 m/s would theoretically lead to 18 times more energy production. Wind speed increases with height, and so turbines become higher as they become larger to capture the more favourable wind. In any case, the higher any size turbine can be placed will result in higher energy production.

A site is classified according to its average wind speed as well as its turbulence intensity, according to specifications by the IEC (International Electrotechnical Commission) and/or Germanischer Lloyd. A higher wind speed leads to increased production, but obstacles in the vicinity of the turbines (e.g. buildings) can create turbulence effects in the wind, which causes more vibrations in the turbine and leads to drastically reduced lifetimes.

In the electric power generation sector, there have been two types of turbines:

1) **Horizontal Axis Wind Turbines (HAWT)**
   These turbines consist of a rotor that is horizontal, with blades on a vertical plane (see Figure 2), turning perpendicular to the wind direction. The turbine is placed upon a tower, high in the air. Since the blades need to be perpendicular to the wind to turn, the turbine itself must turn towards the wind to generate energy.

2) **Vertical Axis Wind Turbines (VAWT)**
   These turbines consist of a rotor that is vertical, and blades that turn on a horizontal plane (see Figure 3), turning in the plane of the wind direction. There are some theoretical advantages for VAWT, such that one can place the device at ground-level without a tower, and that one can capture the wind from all directions without having to turn to face the wind.

Despite some of the theoretical advantages of VAWT, HAWT have steadily become the industry standard due to a number of reasons. HAWT have much lower maintenance costs, as replacing the main bearing of the rotor for a VAWT necessitates taking down the entire structure down; HAWT simply need a tower for support, whereas VAWT require guy wires, which may be a disadvantage depending on location; HAWT blades are focused on the higher winds up high; HAWT efficiencies have been higher.

The economic viability of wind is constantly increasing, with costs having fallen precipitously over the past 20 years, with installed costs in Europe about 1000 to 1300 EUR per kW. In good wind sites, the cost can be as low as 3 to 4 EUR cents per kWh, with 6 being typical.

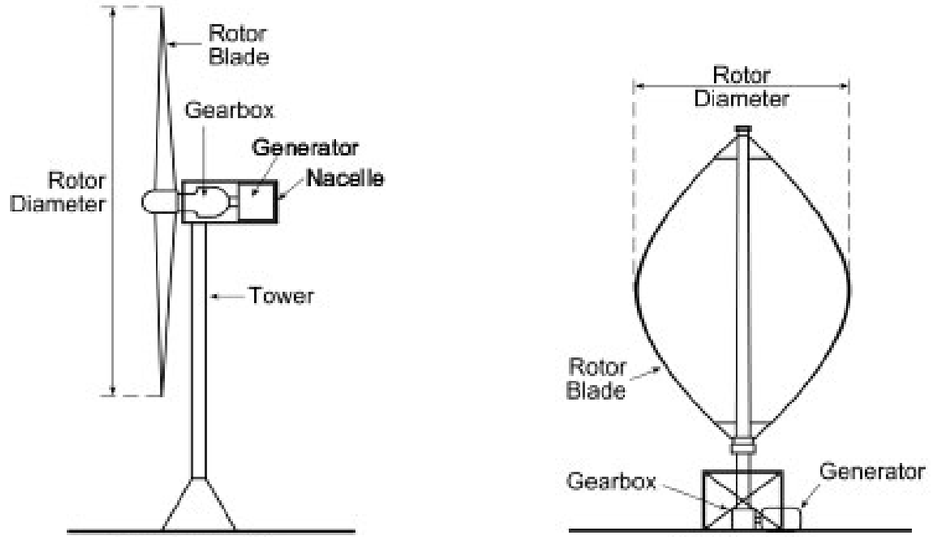


Figure 1: Wind Turbine Concept (source: Scottish government)

Figure 2: Nordex HAWT

Figure 3: Flowind VAWT, using the “Darrieus” design (Source: Ecopower USA)

Wind Speed Resource
As direct measurements on site are not currently available, the data from the adjacent airport were analyzed, with the results summarised in Table 1 and Figure 4.

Suitability of Measurements for Energy Prediction
The airport data can only be used as a general guide for wind at Masdar. Firstly, the standard deviation of the wind speed is not available, which makes advanced simulation not possible without a very large margin of error. Secondly, the measurements are only for one year, and there can be perennial fluctuations in wind. Thirdly, the airport measurements are about 4km from the site of the highest possible turbines. These factors limit the accuracy to which a proper energy assessment can be made. The proper measurement of on-site wind conditions, as suggested in our communications to Masdar, will allow the development of a more accurate picture of the energy potential for a commercial wind developer to go ahead with development.

Example speeds at possible turbine hub-heights
The measurement site corresponds to a *roughness length* of 0.01 to 0.02 m, corresponding to airport runway areas, and airport areas with buildings and trees. Table 2 shows a list of extrapolated speeds at higher hypothetical turbine heights.

Height (m)	Extrapolated Average Speed (m/s)
40	4.78
44	4.84
46	4.86
49	4.90
50	4.92
55	4.97
56	4.99
60	5.03

Table 2: Some example hub-heights and extrapolated average wind speeds (Hellmann method)

Despite the distance of 4km, the average wind at Masdar should be approximately the same, due to the flat terrain around the airport, leading to a similar profile across the site.

Analysis
Generally, an average annual wind speed of 3.91m/s at 10m would not be considered economically viable by a commercial wind farm developer. Furthermore, the lowest wind turbine class is for the IEC Level IV winds speed of 6 m/s (International Electrotechnical Commission – see Table 3). Wind turbines themselves are certified for operation in specific wind classes, almost all of them for Levels I, II and III, with no major manufacturer producing Level IV turbines. From the previous table, Masdar would have a hub-height wind speed of 4.8 to 5.0 m/s, which places the site in a sub-Level IV category.

Wind energy can still technically be exploited at Class IV speeds, even if this is quite low compared to standard developments. However, it must be noted that turbine manufacturers will often refuse to sell turbines to a developer if the site conditions are below the minimum stated for the turbine's wind class, with the motive of avoiding bad publicity of low operational hours (see section 6.5.6).

Nevertheless, the analysis is continued below to consider all possible options for Masdar, especially if Wind is desired as at least a "beacon" technology.

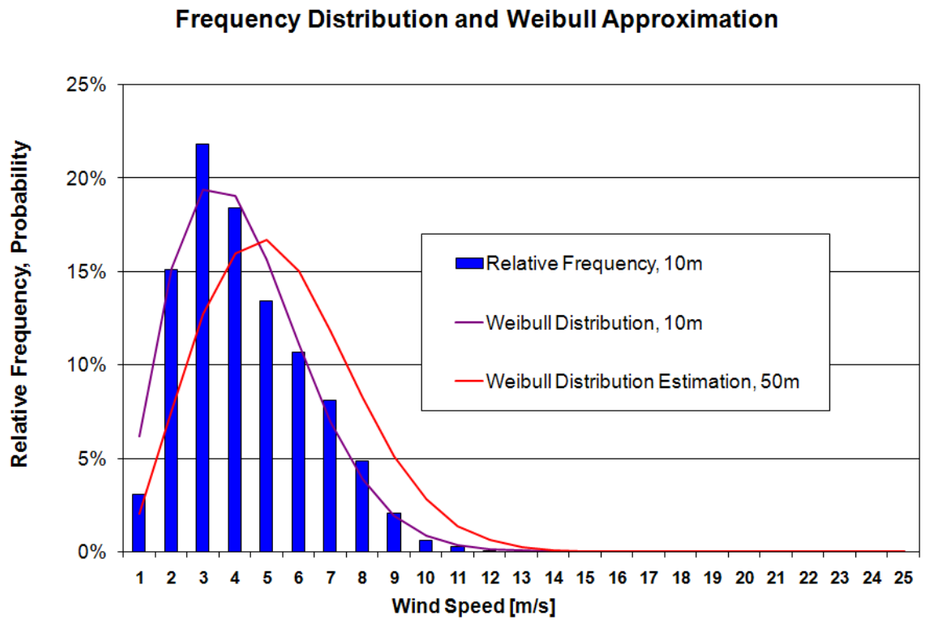


Figure 4: Frequency of Wind Speeds, at 10m and extrapolated to 50m

Location	Abu Dhabi International Airport
Dates available	1 Jan 2006 to 31 Dec 2006
Height	10 m
Prevailing Direction	NW
Average Speed	**3.91 m/s**

Table 1: Basic Airport Wind Data

	Class I	Class II	Class III	Class IV
Reference Wind Speed	10 m/s	8.5 m/s	7.5 m/s	6.0 m/s

Table 3: Wind Speed Parameters for Wind Turbine Classes [source: IEC]

Height Restrictions
Due to the vicinity of the airport, almost the entire Masdar zone is restricted to a height of 60m. This limits the exploitation of the wind resource significantly. Firstly, the lower height allows only the more limited wind speeds. Secondly, turbine manufacturers have largely abandoned smaller turbines in favour of larger ones (greater than 800kW). A sub-60m height would only be suitable for sub-350kW turbines. This has resulted in a limited selection of manufacturers that could offer a turbine within the 60m height restriction.

Enercon and Suzlon still produce sub 350 kW machines (the Enercon E-33 330kW, and the Suzlon S350 350kW machine). However, Enercon has stated its unwillingness to enter the Middle Eastern market, which would make acquisition difficult for Masdar. Suzlon's S350 *may* be possible to acquire, although it would only available with a lattice tower (see Figure 6). The height required for the 60m restriction is not normally available (see section 6.5.4 for a further discussion).

Airport Radar Regulations
Aside from height restrictions, airport authorities may deem a wind installation a hazard for radar. In the UK this is particularly enforced within 30km of any airport, while in many other countries regulations are much less strict when it comes to radar impacts of wind turbines. Many countries follow the International Civil Aviation Organization guidelines which simply limit tall structures in the vicinity of airports (e.g. Germany).

It is absolutely crucial that the airport authority be brought into the discussion early on before any detailed park planning takes place. Questions from the Inception report should be posed to the authority; currently, no feedback has been received and this must be left to the next stage.

Below are a list of interference mechanisms mentioned by the British Civil Aviation Authority:

- "In turning down the sensitivity of a radar to remove extra clutter (unwanted echoes) caused by windfarms, a radar operator can lose returns from poorly-reflecting targets such as small aircraft."
- "A wind turbine within direct line of sign of a radar station can create a radar echo strong enough to swamp the radar receiver, thereby causing a large point to appear on the screen which masks aircraft echoes."
- "A turbine disc can also cause a radar shadow, preventing visibility of targets beyond it on the same line of sight. Beams multiply reflected from blades and terrain features can cause aircraft to be reported at incorrect bearings."
- "An aircraft flying behind a turbine and partly obscured by it can jitter on the radar screen, or appear in a location skewed from its real one, due to beam diffraction. Rotating turbine blades can pass through radar filters designed to enhance aircraft detection by removing any targets that are not moving; controllers can then confuse the moving blades with aircraft. False targets can appear on the screens of secondary surveillance radars."

Figure 5 – Enercon E-33 Turbine (source: Enercon)

Figure 6: Suzlon S350 with a lattice tower (Source: Suzlon)

Turbine Spacing and Turbulence
A turbine requires a certain minimum distance between itself and the next turbine because they affect each other's energy production from the wind. When wind passes over an obstacle (building, turbine, etc), the wind in the area behind it becomes "turbulent". This essentially means that the wind is very chaotic with constantly changing velocity and pressure. Wind turbines operating in turbulent conditions will break down more quickly because they cause significant strain on the mechanical components, creating large problems for bearings, blades, gearboxes, etc. The energy production of the turbine downwind is also negatively affected by the obstacle.

The wind data from the airport does not allow the modeling of turbulence effects (the standard deviation of the wind speed is required), but in general turbines should be spaced at least three to five rotor diameters from one another in order to avoid too much turbulence and corresponding loss in energy production. In the prevailing wind direction, five to nine rotor diameters are best due to the increased wind and resulting turbulence in that direction. Loss of electricity production results from the "park effect", whereby the energy production of a wind park is less than the sum of theoretical energy production of the individual turbines.

In our analysis, we have assumed the lower bounds (three and five rotor diameters), for spacing requirements. A more detailed analysis would be possible with the proper wind mast measurements that will soon begin to be made on site.

Distances from buildings
The other limiting factor is the proximity of urban development to the possible wind turbine locations. There are two factors involved: turbulence and regulation.

As explained in the previous section, turbulence is to be avoided in the planning of a wind park. Considering the average 20m heights of Masdar, there would be an area of strongly distorted airflow for about 400m downwind, for which placement of turbines should be avoided.

In addition, turbulence would be generated by Khalifa city to the west of Masdar; however, these are generally low-rise developments (single homes), which would not create very large obstacles.

The second factor is regulation. With no history of wind turbine installations, the UAE does not have regulation with regards to turbines and the built environment. The regulations in countries such as Germany are in place for safety and human comfort. A turbine too close to a settlement can cause a very irritating shadow flicker when it blocks the sun to the residents. Furthermore, turbines are known to fail occasionally, especially in turbulent conditions, and blade detachment not impossible.

Table 4 shows the regulations for the northern German state of Schleswig-Holstein for turbines under 100m height.

	Distance required
Single Homes	300m
Settlement	500m
City, camping grounds	1000m
Street / highway	50 to 100m

Table 4: Distance requirements for turbines in Schleswig-Holstein [source: "Einschränkungen für das Repowering unter Berücksichtigung der genehmigungsrechtlichen Rahmenbedingungen", Technische Universität Berlin, 2005]

If the German regulations were chosen to be followed, there could technically be no exploitation of wind on site. However, it is not *strictly* necessary to follow the German guidelines. For example, one of the world's first urban-sited turbine is in Toronto, Canada, operated by WindShare, has been in operation at the city's lakefront for 5 years, only 550m from the city's houses (See Figure 7: "Toronto Turbine). Hull, Massachusetts has also been operating a wind turbine in an suburban environment next to a high school for 6 years.

In any case, the turbines that could be located at the south-west corner of Masdar are all closer than 500 m of Khalifa city homes (the 90m height section being only 100 to 300m from the homes). The city authorities of Khalifa city will invariably be consulted during the pre-planning stage before any project goes ahead.

Lastly, if the smaller square were to eventually be developed into an urban settlement instead of a power generation site (be it CSP or PV), this would add a considerable constraint to implementing wind at the south-west corner, as the relatively high development (20m) would cause significant turbulence effects on the wind turbines, which would be only 200 to 400 m from that city block. In such a case, PV or CSP may instead be a better option in the south-west corner.

Figure 7: Toronto Turbine - Paul Gipe Wind Works. Source: Paul Gipe, Wind Works]

Figure 8: Turbine next to a building in Groningen, Netherlands [source: Paul Gipe, Wind Works]

Taking into account the last section, only a few turbines can be postulated. These would not make up a significant fraction of the energy supply, but would provide at least an iconic image for the site. Presented is a *technically* feasible solution, but of utmost importance is to bring in the relevant city zoning authorities mentioned before in order to determine if these are *"socially"* feasible. It is urged once again that planning is not recommended without a detailed feasibility study carried out after the detailed wind data is available from one year of measurements onsite.

South-West corner
It must be first stressed that the following turbines are only suggested if the small square to the north-east is left as a solar power production plant, rather than a city, for which the turbine distances would be then unacceptably close, both in terms of turbulence and safety distances.

A market study was carried out for all the major turbine manufacturers to see what turbines could be possible within the height limits (90m, 80m, 70m, 60m). The height limit sections are shown in the Figure 9.

An analysis was carried out on the extrapolated airport wind data in order to provide an estimate of the wind speeds at turbine hub-heights; the statistical wind data is organized into a "weibull curve" that is then used to estimate energy generation. More detailed analysis is not possible with the supplied airport data without a large margin of error.

90m height section
This section allows the tallest turbines for the entire site. The height would allow for, at maximum, one 950kW turbine to be placed. Placing only one turbine in this section is advisable due to the distance limits mentioned before. Furthermore, the elevation from sea level is about 2m, and thus if the height limit is firmly enforced to be only 90m from sea-level, only turbines with total heights of less than 88m can actually be considered.

A Suzlon S64 950kW turbine was simulated (56m hub-height, 64m rotor diameter: 88m total height), as a representative turbine that could be applied in the 90m section. The calculations result in approximately 1800 MWh_e production at 1900 full-load hours. See Figure 10.

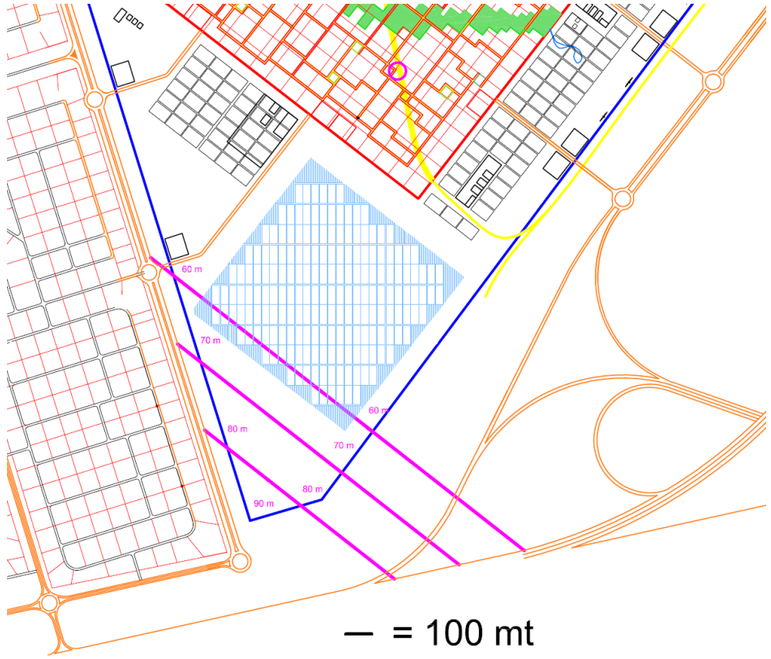


Figure 9: Height Limitations at Masdar

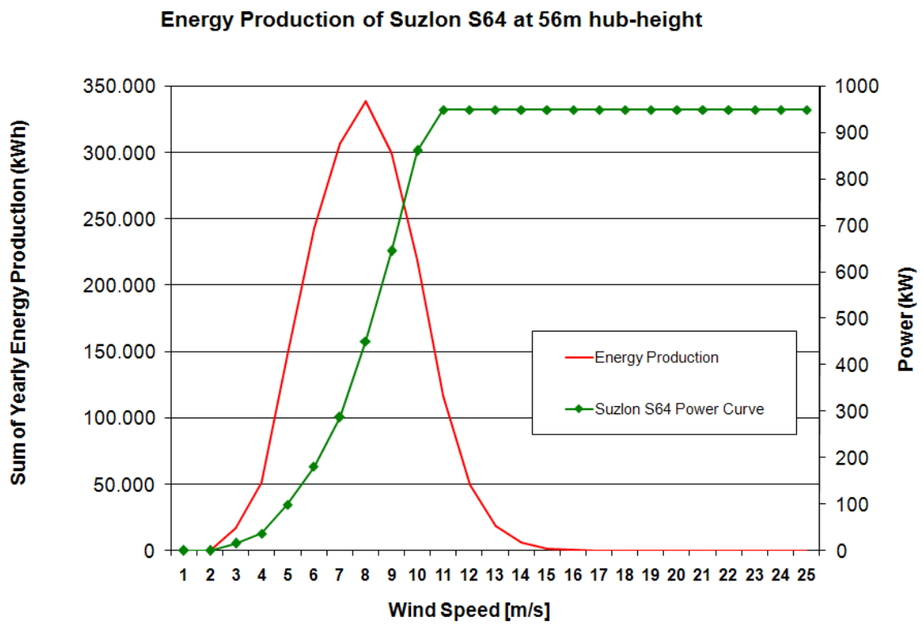


Figure 10: Power Curve with Energy Production of Suzlon S64: 1800 MWh_e, 88m total height

80m height section
At this height level, turbines of the 850kW class could be considered. However, due to the limited space and the spacing requirements between turbines, a maximum of two could possibly be considered.

A Gamesa G58 850kW turbine was simulated (44m hub-height, 58m rotor diameter: 73m total height), as a representative turbine that could be applied in the 80m section. The G58 is actually a Class III turbine, which enables it to better take advantage of lower wind sites (although Masdar does seem to be Class IV). The calculations result in 1400 MWh_e production at 1650 full-load hours. See Figure 11.

70m height section
Part of this section is taken up by the CSP development (refer to Figure 9). As such, placement of turbines right next to the CSP would be inadvisable due to the shadowing, as well as because the distances would be quite close to the others. One larger turbine could be considered at the south-eastern end of the section; the 70m height restriction limits development to sub-850kW class turbines.

A Vestas V52 850kW turbine was simulated (44m hub-height, 52m rotor diameter: 70m total height), as a representative turbine that could be applied in the 70m section, but only if the height of the ground-level with respect to the sea (2m) is not an enforced guideline from the airport authority. The calculations result in 1160 MWh_e production at 1360 full-load hours. See Figure 12.

Figure 13 shows a potential layout of four turbines in the south-west corner.

Another possibility would be to place sub 350kW class turbines, which generally could be below 70m. A Suzlon S350 350kW turbine was simulated (50m hub-height, 33.4m rotor diameter: 66.7m total height), showing 440 MWh_e at 1270 full-load hours. See Figure 14.

A better option in this section could be to consider expanding the CSP system to utilise this space instead, which would provide more energy (along with thermal energy, which wind does not provide) than the equivalent land use by the turbines. PV systems could also be considered.

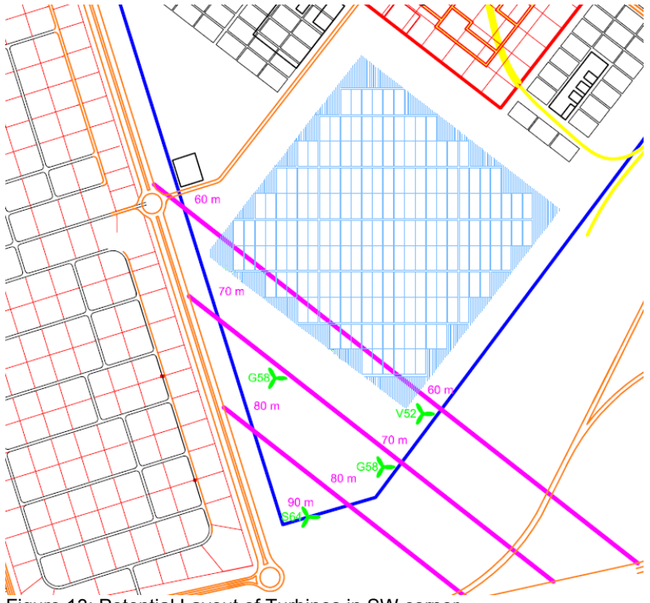


Figure 13: Potential Layout of Turbines in SW corner.

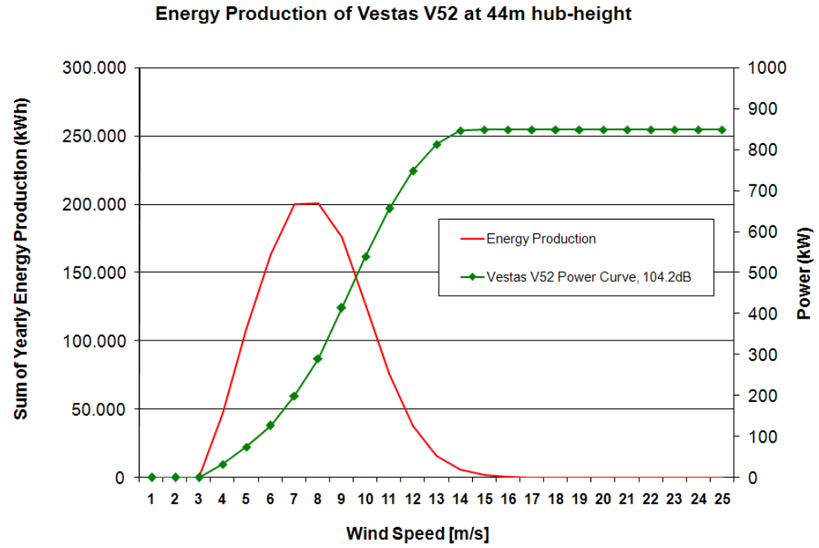


Figure 12: Power Curve with Energy Production of Vestas V52: 1160 MWh_e, 70m total height

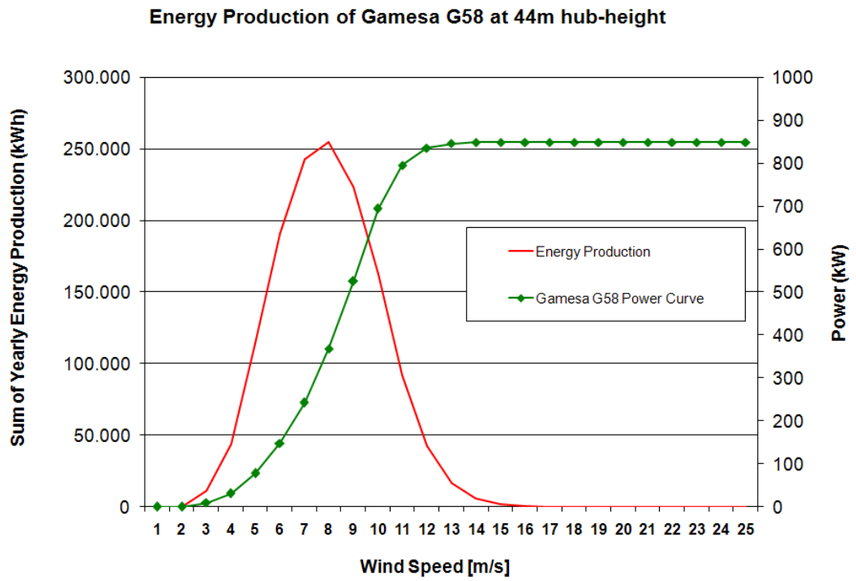


Figure 11: Power Curve with Energy Production of Gamesa G58: 1400 MWh_e, 73m total height

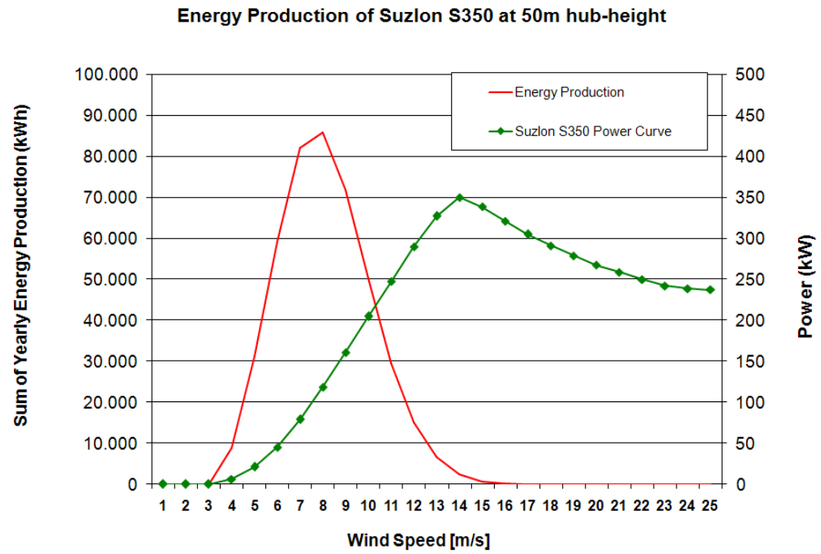


Figure 14: Power Curve with Energy Production of Suzlon S350: 440 MWh_e, 66.7m total height

Rest of site (under 60m height)
No turbine from a major manufacturer is precisely suitable for this application. Technically, a sub-350kW class turbine could be used, but the only major manufacturer for this is Enercon, for which acquisition problems exist, as explained previously.

However, a number of smaller manufacturers do produce turbines that could be used, although perhaps lower than 350kW. One example is a Fuhrländer 250kW.

Otherwise, due to the low height and low-wind speeds in the first place, turbines here would most likely operate significantly under 1200 full-load hours when discussing urban turbines (see next section).

These turbines could be placed at various locations, but are restricted by the city itself. The area of high turbulence to the south-east of the city necessitates placing the turbines at the border of the site. The presence of the parking lots at that location results in turbulent obstacles that limit development.

Moreover, another issue to be resolved with the airport authorities is the minimum distance at which they would accept a turbine, which may limit the placement of turbines closer to it. Some turbines could also theoretically be placed to the north-west of the city, but this largely depends on the type of development at Al-Raha beach, as higher structures would result in a shadow of turbulence (if 20m high buildings like at Masdar were to be made in the north-western block, no turbines would be advisable).

To the right a hypothetical placement of some smaller sub-350 kW turbines are shown. One of the main problems, though, is the lack of turbines at this height commercially available. As manufacturers have all gone to "bigger is better" modes of production, smaller turbines have mostly been left out of the development pipeline.

In the simulation, four 250kW turbines have been used in such random locations across the green space of the site for an approximate reference figure. Figure 15 shows such a power curve.

Larger turbines could be a possibility if a special agreement could be made with the manufacturer to recertify their turbines for tower heights under 50m. For example, the Suzlon S350 referred to in the previous section (Figure 6) could be made with a shorter lattice tower. To offer such a product would require the manufacturer though to receive new certification for it (e.g. from Germanischer Lloyd), which would be a significant cost for the company, which it may not be willing to take.

Total Expected
Wind Energy Production

The assumption for wind production was for the installation of 4 turbines as illustrated in Figure 13, with representative turbines from Suzlon, Gamesa and Vestas. In addition 4 smaller turbines, with representative turbines from Fuhrländer. A summary of production is listed in Table 5.

It must be stressed that the values presented are approximate, and may vary significantly after the proper turbulence assessment could be made (e.g. in the WAsP software package). Accurate data from a measurement mast is required for this purpose, and so it is not recommended to place any orders for turbines before such detailed analysis has first been carried out by an experienced developer (i.e. one year after the installation of the measurement mast).

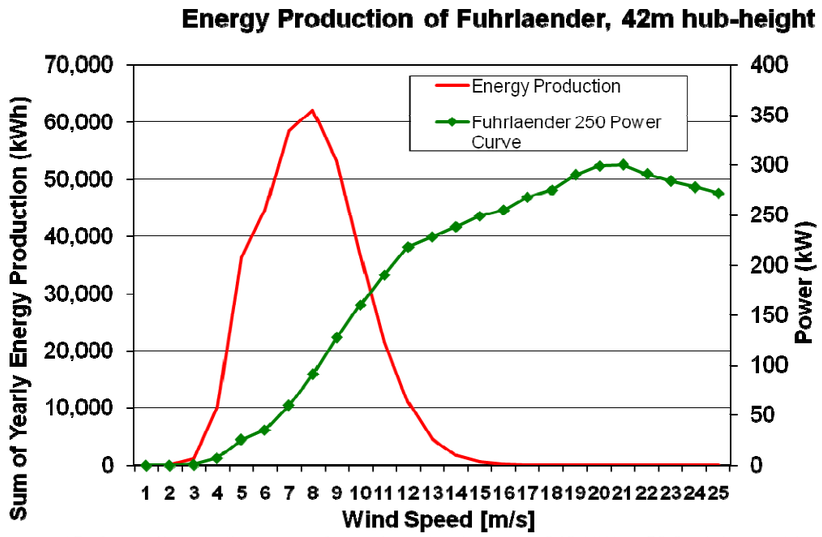
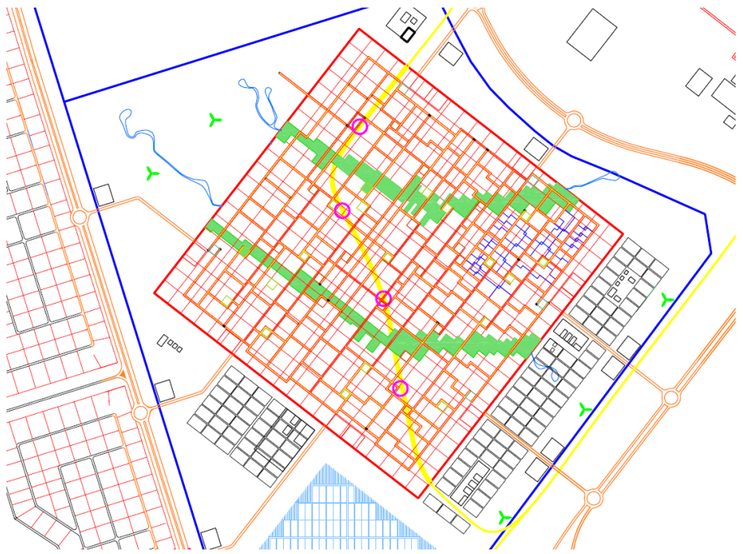


Figure 15: Power Curve with Energy Production of Fuhrländer: 342 MWh_e, 56.8m total height

Turbine	Power	Total Installed Power	Full-load hours	Total Energy Production
Suzlon S64	950kW	950kW	1912 h	1,816 MWh
Gamesa G58	850kW	1700kW	1653 h	2,811 MWh
Vestas V52	850kW	850kW	1367 h	1,162 MWh
Fuhrländer 250	250kW	1000kW	1369 h	1,369 MWh
Total	**--**	**4.5 MW**	**--**	**6,443 MWh**

Table 5: Indicative values for Wind Energy in the South West of Masdar
Due to the low mean wind speed at the site, the total full-load hours are expectedly low (compared 3000 hours for good wind sites). The park effect was also estimated to decrease total energy production at 10 %.



Some example locations of smaller wind turbines in the parks of the city

Urban Turbines
Urban turbines were initially explored as a possibility, but a more thorough analysis has deemed the potential to be marginal. Industrial development simply does not exist at the level that would provide a sufficient guarantee of performance for Masdar, nor with sufficient numbers to supply a significant fraction of the energy demand. Furthermore, many claims for urban wind have remained unsubstantiated, with proponents often downplaying the low energy production.

However, as Masdar is to be an incubator of technological development in the RE field, some installations could be considered in the gardens around the city. Two recent urban wind companies have arisen that claim to address the earlier failures, Turby (an offshoot from Delft University) and Quiet Revolution. (Figures 16 and 17, respectively).

However, both companies have only marginal production lines, with Quiet Revolution still to publish a power production curve as of this writing (necessary to calculate energy potential). Turby claims to allow low vibration operation on roofs, but the power is marginal (2.5kW) and valuable space needed for solar energy is compromised in such a way because of the mast supports. Studies would also have to be carried out to determine possible building vibrations from mounted turbines on roofs.

If the Quiet Revolution power curve turns out to be favourable for the Masdar wind resource, some turbines could be considered for the park space (see Figure 18). This could only be examined in the next year when such data would be available from Quiet Revolution. In any case, considering the small size of the turbine (6kW), the installations would not generate a significant fraction of the total energy.

Another recent developer includes AV AeroVironment, developing the “Architectural Wind” product. It is 6kW modular system that could be placed on building edges (See Figure 18). Large scale development does not yet exist.

Thus, immediate large-scale installation is not advised, especially considering the lower wind speeds of Masdar. However, the option for pilot installations of urban wind is left open for future development in the environs around the city.

The following is a list of some small urban-scale turbine manufacturers and also sub-50kW turbines:

Quiet Revolution
Turby
Wind Energy Solutions (WES)
Southwest Windpower
Ropatec AG
Fuhrländer
Entegrity Wind Systems
Energie PGE

Figure 16: Turby brand wind-turbine based on the VAWT concept, potentially on roofs (Source: Turby)

Figure 17: Quiet Revolution brand wind-turbine, also based on the VAWT concept

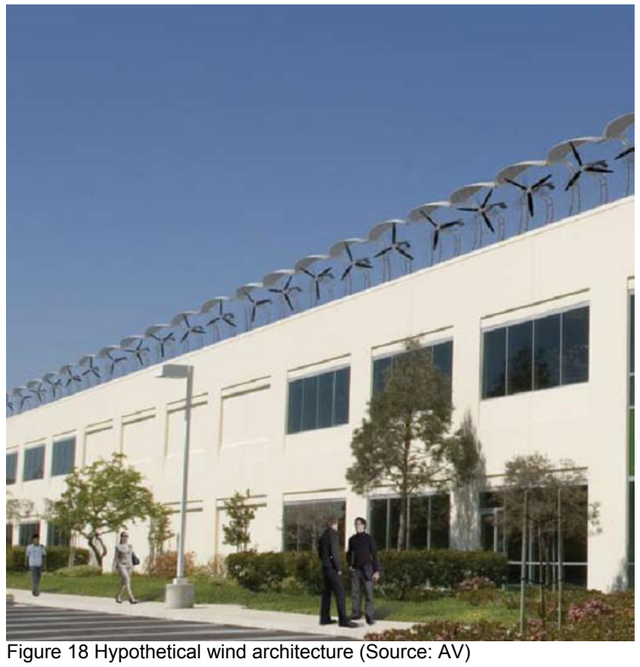


Figure 18 Hypothetical wind architecture (Source: AV)

Figure 18: “The Beacon”: A potential application of the Quiet Revolution Turbine, using a 40 metre high mast. The Beacon was designed by various London architects and engineers, and they are promoting to install it in locations like the hypothetical one above. (Source: Quiet Revolution)

Temperature Effects
Another factor for Abu Dhabi is the air density. The power of a wind turbine is characterized by the following equation, which shows the direct correlation to air density:

$$P_{WT} = \frac{1}{2}\rho \cdot c_p A u^3$$

ρ = density of medium (air)
c_p = turbine power coefficient
A = area
u = velocity

European-equivalent testing conditions and power curves are not directly transferable on a one-to-one basis to Abu Dhabi because the temperature of the air plays a role. i.e. there are more air molecules in cold air, as opposed to the relatively constant hot air in Abu Dhabi. Therefore, in a site of a certain velocity in Germany with a certain Weibull distribution versus the same situation in UAE will not result in similar energy production due to “less air” being available. For example, 20-degree winter temperatures in Abu Dhabi compared to 0 degree winter temperatures in Germany mean 7% less air density, which means 7% less instantaneous power during those winter months.

Sand
Special weather-proofing for the hub should be requested from the manufacturer as sand can enter the turbine there and damage components. In any case, higher operating and maintenance costs should be anticipated than for turbines in European wind parks.

Ordering Times
Orders for wind turbines take typically 2 years, from the point of order. The first turbines could thus be available in approximately 3 years, considering a one-year measurement period with more detailed wind potential analysis.

In addition, due to the UAE being an atypical market for wind manufacturers (for the time being), this may also add to order delays as well as additional capital costs.

Ordering and Wind Classes
As mentioned in the Wind Resource section, many wind turbine manufacturers will refuse to sell a turbine to site that is *not* in the same class as what the turbine is certified for. Wind turbines are certified for usage in certain wind classes (the lowest generally being IEC Level III, e.g. Gamesa G58), and their power production curves are not necessarily “guaranteed” for levels lower than their certification. That said, some manufacturers will still sell the turbines; this requires a solid procurement strategy. This also stresses the need for a proper wind mast measurement campaign for the site to be able to present to suppliers a clear idea of the wind class at the site.

Staging of Wind Development
The wind turbines can be staged, as each turbine is modular, in order to come online as more power is needed. However, since the potential is small, it does not make a very large impact in the total balance in any case.

Waiting with the wind installations would be recommended if the square were to be considered for development into another urban development. In such a case, the turbulence would cause problems with the turbines, in addition to the flicker effect for the residents.

Trying conditions for Wind Energy Converters

Geothermal energy can be a bountiful energy source, coming from deep below the surface of the earth. Unlike at the earth's surface, the temperature deep under the ground remains remarkably stable, unaffected by season or surface variations. This constant temperature is the essential element behind the exploitation of geothermal energy.

Theoretically, the amount of heat that is available at 5km depth around the world is 140,000,000 EJ per year, with 4.5% of this in the Middle East and North Africa (Source: UNDP World Energy Assessment). Within 50 years, 5000 EJ of this global number is expected to become economical (approx. 1.4 billion GWh_{th}/year); 500 EJ is expected to be economic within 20 years.

Furthermore, even at shallow depths of two to three meters, the constant temperature of the earth can be used for heating and cooling using ground-sourced heat pumps.

The first use of geothermal energy by humans was directly from hot springs, even from ancient times. (Yellowstone Hot Springs shown, source: NASA)

The earth itself can be used for heating and cooling in place of traditional space conditioners, with greater efficiency that current technology has made possible.

The concept is to exchange the heat between the relatively hot surface and the relatively cool earth below the ground surface: enter Geothermal Heat Pumps (GHP), also known as Ground-Sourced Heat Pumps (GSHP). The temperature deep below ground is at a constant temperature all year. Figure 1 illustrates the concept operating in winter; summer operation is simply the reverse (warm air is drawn in, with cold air coming out).

In this way, even when it is hot, the ground temperature would still be lower, allowing a system to transfer heat from above with the colder temperature below. The reverse is true during winter. Figure 2 shows a vertical loop GSHP system, whereby several deep (100m) boreholes are used to move heat from above the ground to the constant temperature below.

Applicability

Firstly, the applicability at Masdar depends on the properties of the soil below the site. Different soil and rock types can affect heat transfer rates, which requires consideration when designing the ground loop. Secondly, the ground temperature at Masdar has yet to be measured. However, an estimate of the shallow depth ground temperature can be made from the average annual ground temperature.

The average earth temperature at Masdar is approximately 27°C. While variations can be expected, the temperature several meters below ground would not be significantly different. As such, the usage of GSHP is not as attractive as in more temperate climates that have average ground temperature of 15°C less. At daytime peak temperatures in summer of 45°C, the temperature difference could provide a source of heat rejection, but in most summer periods where average temperature is 30 to 35°C, the temperature difference is very small for a significant amount of heat rejection. As such, the use of GSHP for direct cooling is not considered. However, GSHP may be considered for recooling of the compression or absorption chillers.

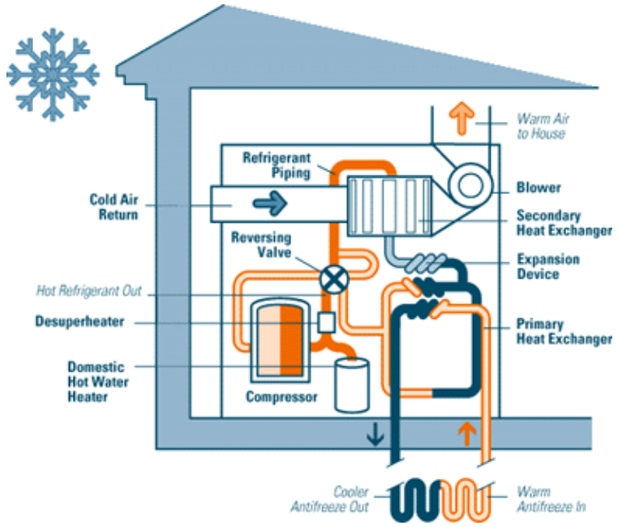


Figure 1: A Ground-Sourced Heat Pump System, system shown operating in winter mode (Source: Ministry of Natural Resources Canada)

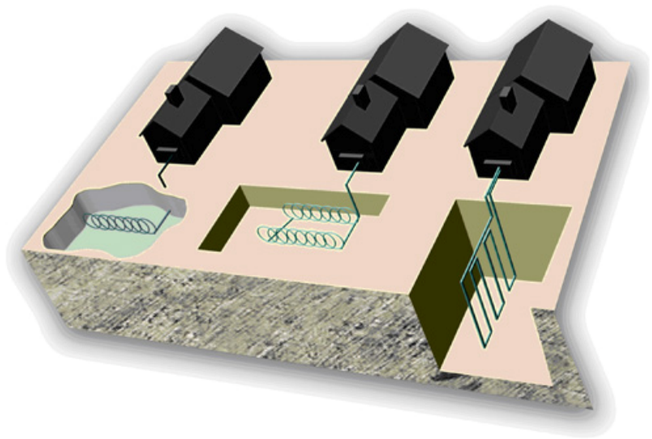


Figure 2: Possible variations on making heat-exchanging loops in the ground (Source: University of Buffalo). Using a body of water (left), horizontal shallow loops (middle), and vertical loops (right)

Deep in the earth, bodies of hot water can provide a very large source of energy. This water can be used directly for heat, and also be used to generate electrical power.

The principle is simply to use the hot thermal water, converted to steam after it is pumped to the surface, and use it to run a turbine.

The cost of such generation is low among renewable energies, with new developments generally costing $2500/kW working out to about $0.055/kWh. Geothermal plants are also available nearly constantly, with greater than 90% availability. Furthermore, some configurations are possible that utilise no fresh water resources, which is especially important in water-stressed areas such as the UAE.

Investigation Required
Very recently, the Abu Dhabi National Oil Company (ADNOC) provided initial information about the temperature that can be expected at depths around the region. 160°C could be expected at 3.5km depths from nearby oil well measurements. However, it is not clear if water would be present at that depth.

A preliminary assessment of the geothermal potential of the site is possible with the following data from a geological investigation of the subsoil:

- Stratigraphy
- Lithography
- Hydrogeology
- Temperature gradient profile

ADNOC almost certainly has this data from the nearby oil wells. Following this, an actual exploratory well borehole could be made on site for further investigation. If water is found, the geothermal fluid must be analysed chemically as it plays a large role in the materials and planning, for example with corrosion.

Geysers letting off steam provided the first way to tap geothermal energy for electricity

Hot-water sourced power plants
Hot water may exist at far depths on the site, although this has not yet been determined. If water were to be found, then a "traditional" geothermal plant could be considered, depending on the temperature of said water.

Flash and Dry Steam Power Plant
If high-temperature water were to be found, a process as illustrated in Figure 3 is possible. For Dry Steam plants, the steam is used directly without any separation. These are the most widely implemented systems around the world, but they required water above 182°C.

Early applications include in Larderello, Tuscany, Italy (Larderello), producing power since almost 100 years ago; the Larderello site produces 4.8 billion kWh per year, 10% of the world's geothermal production in 2003 (utilizing 220°C steam in a dry steam plant). Other notable areas include the Philippines, New Zealand, Japan and the United States.

Toshiba systems, for example, are responsible for over 30% of the output of worldwide geothermal plants.

One consideration in a system like this is that the geothermal fluid is not simply water vapour. In the Larderello plant, for example, the fluid includes up to 7% CO2 by weight, as well as smaller amounts of methane, ammonia, chlorides, arsenic and mercury [Source: Eros Bacci, "Sustainability and Energy Use: The Role of Geothermal Energy", International Conference on Geothermal Energy and Territory, Pomarance, Italy, 2004]. Thus, even if high temperature water were to be found, such a consideration may deem a plant of this nature less desirable for Masdar. However, the emissions are much less than fossil fuel plants.

Binary Plants
New developments in Binary Cycle have allowed the utilisation of sub 150°C water. Instead of direct usage, the hot-water pumped to the surface is used in a heat exchanger with lower boiling-point fluids, such as pentane or butane, which are afterwards vaporised to drive a turbine. The geothermal fluid is pumped afterwards back downwards through another borehole. In such a way, there are also essentially zero emissions since the geothermal fluid is not vaporized and released into the atmosphere. See Figure 4.

ORMAT group, for example, develops binary plants, with over 800MW installed worldwide, with an Organic Rankine Cycle process.

Using a binary-cycle, with a 35L/s geothermal well at a fluid temperature of 149°C and 16°C air temperature, about 1MW is possible; with a lower temperature of 100°C, 88 L/s would be needed for 1MW [source: US DOE].

Even lower temperature water can be used in the Kalina Cycle, a patented process of Exergy, Inc. (Dr. Alexander Kalina being the eponymous inventor). The Kalina cycle uses an ammonia/water working fluid in the binary cycle, which allows a more efficient utilisation of heat than typical binary plants.

Siemens is developing a power plant based on this principle in Unterhaching, Germany. Here 122°C water is pumped from 3.3km, using 125 L/s for electric power generation of 3.36 MWe, and another 25L/s for district heating for 16 MW of heat. According to Siemens, over 4MWe is possible from 150°C water flowing at 100 L/s.

The main constraint for application at Masdar is the presence of hot water at depths. More comprehensive data from ADNOC is necessary to determine if water could exist at Masdar.

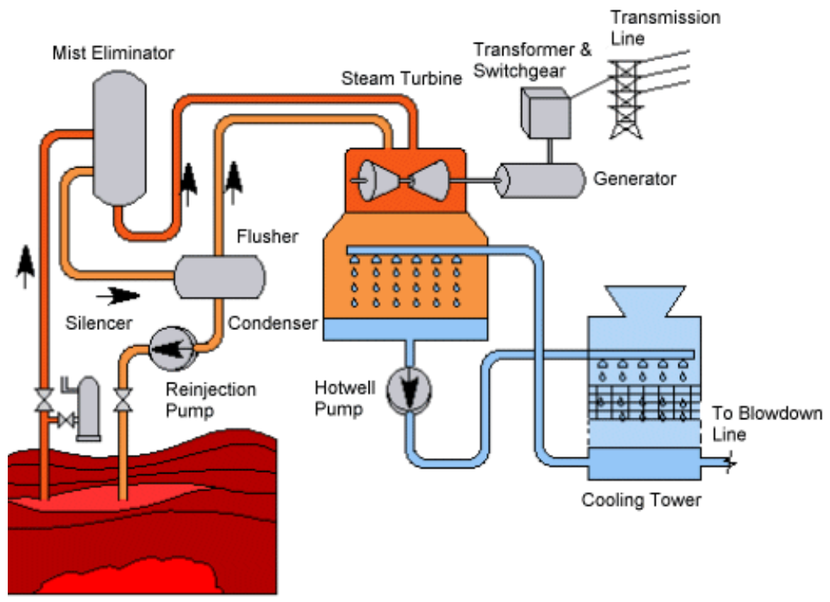


Figure 3: A geothermal electric power system concept (Source: Toshiba): Hot water is pumped from deep in the ground up to the Mist Eliminator, after which the vapour runs a steam turbine, which generators electricity. The water is then run back into the deep-ground reservoir.

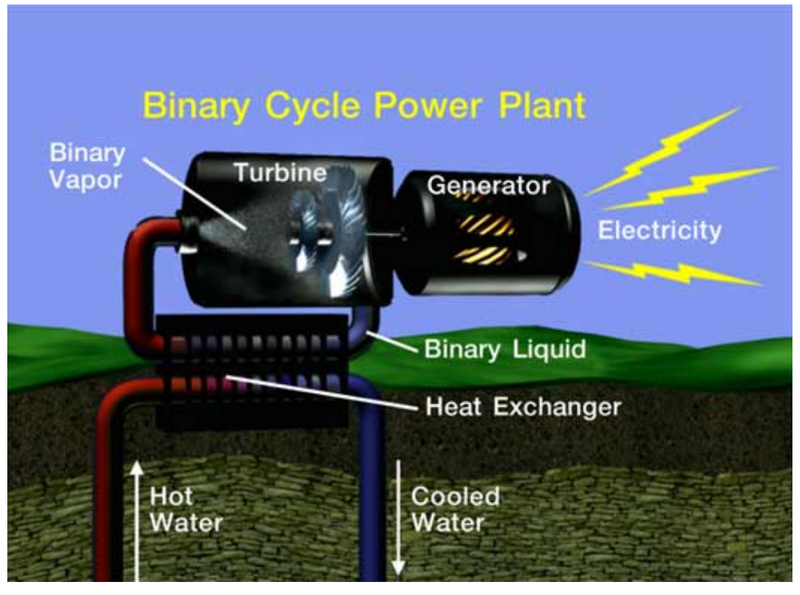


Figure 4: Binary Cycle Geothermal Plant (Source: US Geothermal Energy Association).

Where hot water does not exist, another possibility could be to use “hot dry rock” geological formations 3 to 5 km deep, that contain no water, but are very hot. These type of systems are also known as “Enhanced Geothermal Systems” (EGS).

Cold water is pumped down below, where it is heated; it is then pumped back up where it is used much like in the other geothermal systems (see Figure 5). Initially the rock must be fractured to allow space for the water to flow, in a process similarly used in oil and gas production.

The potential benefit is that many more “hot rock” resources exist than hot hydrothermal resources worldwide. The concept was first proposed in the US in the 70s; however, the technology is still in its infancy in terms of application. The lead-times on such a system would therefore be quite long, and thus can only be left as a point of further study for the future of Masdar.

Since the water from the ground is used through a heat-exchanger, emissions are similar for binary-cycle, that is essentially zero. However, in some of the applications made so far, mild tremors have been noticed in the surrounding area.

Examples include at California’s Coso field, producing 20MW more (from 260MW) by the application of EGS. In Bad Urach Germany, 170°C at 4.5km is being used to develop a 1.3 MW EGS power plant by EnBW.

In Australia, their program is termed “hot fractured rock”, with the Australian National University working on research in the Cooper Basin and Hunter Valley. Geodynamics Ltd of Australia is heavily involved in developing the technology.

One of the most studied examples is in Soutlz, France, where the European EGS project has been carried out since 1987. The system will be a 50MWt / 6MWe , using up to 100 L/s at 5km depths. See Figure 6.

While the ADNOC numbers show high temperatures at considerable depths, there must be a geological study conducted to see if an EGS system could be possible at Masdar.

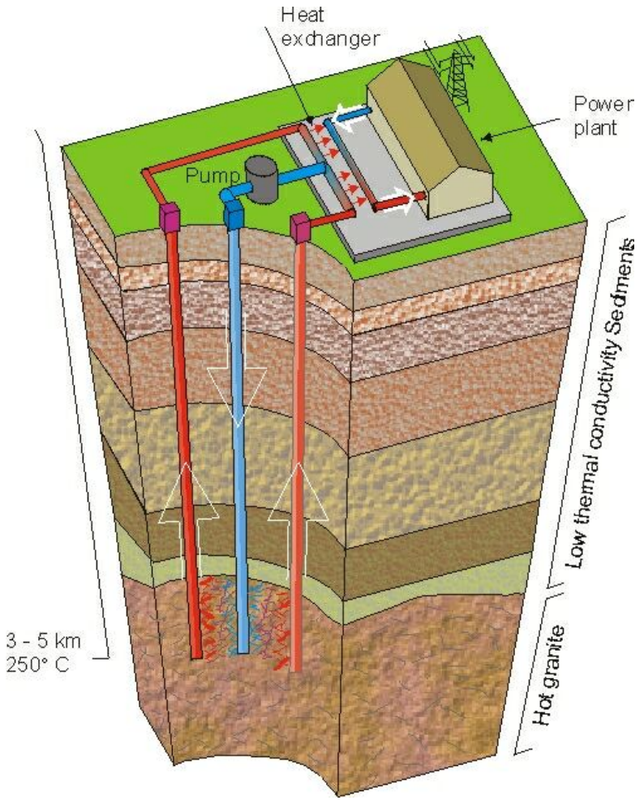


Figure 5 “The Hot Rock Geothermal Power system (source: Australian National University). Cold water is pumped to the hot granite, after which it is pumped back up to run a steam power plant..

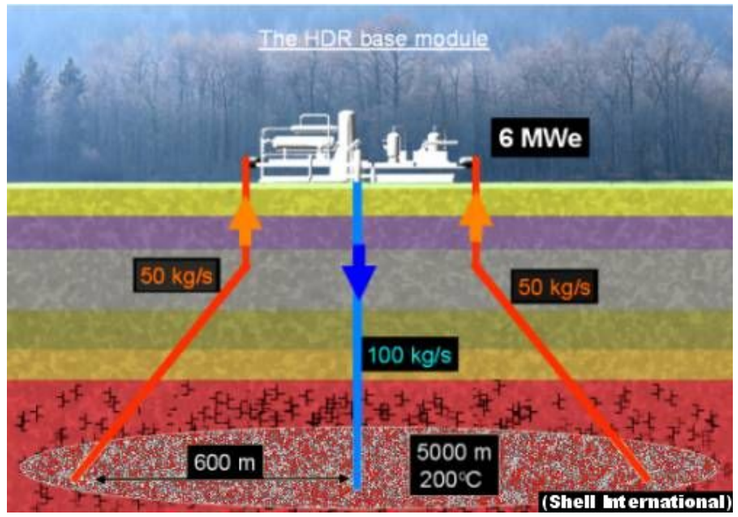


Figure 6: The European EGS project’s latest development (Source: European Deep Geothermal Energy Programme)

Energy potential and pathway for the implementation of geothermal systems at Masdar(*)

Potential

The optimal utilisation of geothermal energy for electrical or non electrical uses at Masdar depends on:

1. The geothermal gradient present in the area where the construction of the "Walled City" is planned.

2. The occurrence, at depth, of an aquifer with a temperature suitable for production of electricity (binary cycle power plant), i.e. 120-180°C. For the air conditioning (dehumidification and refrigeration) of the compound a lower temperature is required. The estimated need of thermal energy for the air conditioning of the entire compound is approximately of 500.000 MWh/year, at a temperature of 110-130°C.

3. Good flow rate of the aquifer and the lack of hydraulic continuity with shallower aquifer used for civil uses (agriculture, drinking water etc.). Recharge can not be an issue if a proper reinjection and artificial recharge program is implemented.

The main issue, at Abu Dhabi, is the lack of a sufficient amount of water. The UAE annual rainfall is very poor, and the water supply requires the use of non-conventional resources, such as seawater or brackish groundwater desalinisation, as well as treated wastewaters. Surface and shallow groundwater are alarmingly impoverished (Murad et al., 2007).

On the other hand, UAE and Abu Dhabi are gifted with large resource of hydrocarbons, and connate waters associated with oil and gas fields can be used as a geothermal resource. Enhanced or Engineered Geothermal Systems (EGS) can also be developed, after an accurate study of feasibility. This option is proposed by Murphy (2007), but EGS projects needs to be carefully assessed. The geothermal gradient at Abu Dhabi, claimed to be slightly higher than the terrestrial average in places, actually seems to be well in the normal range, after inspection of the available studies and maps. So, we have to expect temperatures over 120°C at more than 3 km depth. This seems to be confirmed by the oil well data given by ADNOC for a preliminary evaluation of the potential. Clearly a precise assessment of the underground temperatures requires a much more complete investigation.

As order of magnitude, the development of an EGS project requires a subsurface volume reservoir of 1.5 to 5 km^3 for a 25 to 100 MWe power plant respectively (these values are for electricity production, see MIT, 2006). The thermal energy stored in a given volume of rock depends on the rock heat capacity (average = 2.06 MJ/(m^3 °K), the rock volume and the temperature difference between the reservoir and the mean annual value at the surface (ΔT).
The annual energy need for the project at Abu Dhabi is estimated in 500,000MWh/y. A rough estimate made for a 2 km^3 reservoir gives figures of thermal energy of the order of 160-320 as much the amount of energy necessary for one year. However, only a fraction of the thermal energy stored in the rock can be exploited, depending both on the rock porosity (primary or secondary) and ΔT. Fractions in the range 3-10% for a porosity of 15% can be estimated. Given these conservative, but realistic figures, it is clear that an EGS project at Abu Dhabi is feasible only in the presence of temperatures over 140°C, high permeabilitiy and a large volume of the reservoir (at least 2 km^3). Note that the energy conversion efficiency (heat to power conversion), the cost of the drilling and the distance from the well to the surface water to be injected is not considered in the above estimate.

Future steps

In order to minimize risks a step-by-step project could be carried out, on a three phases schedule:

1) Phase. Feasibility.
1.a.Temperature data collection from the existing oil and gas wells drilled by the oil company of Abu Dhabi ADNOC. Also data on the petrophysical rock characteristics and permeability should be gathered. On the basis of temperature gradients and rock thermal conductivity it will be possible to revise the heat flow distribution map on the area of interest.
1.b. Field work for a survey of the existing and reported "thermal spring indicating deep-seated aquifers". Sampling and analysis of these waters, in order to estimate the deep reservoir temperature on the basis of the chemical composition (geothermometry). In any case sampling of surface and shallow wells waters will be collected for isotopic studies.
Depending on the ADNOC availability also samples of deep reservoir waters will be collected.
1.c. To confirm, on the basis of the available ADNOC well, the occurrence of deep waters (likely connate saline aquifers) with temperatures in the range 110-180°C.

2) Phase. Assessment.
2.a. If ADNOC well are not available for hot water exploitation and reinjection it will be necessary to drill one exploration/production well and one reinjection well. A previous geophysical study (geoelectric sounding, or a magnetotelluric study, depending on the estimated depth of the aquifer) will help in identify the extent of the reservoir.
2.b. Evaluation of the reservoir performance with a well testing study.

3) Phase. Numerical modelling
This is done using computer codes able to describe the flow of multiphase, multicomponents fluids in porous or fractured rocks (e.g. TOUGH2), also coupling the geochemical reaction inducing processes able to increase (mineral dissolution) or decrease (mineral precipitation) the rock permeability. The same codes also predicts the thermal and chemical evolution of the reservoir during the exploitation, and allows an optimisation of the resource exploitation.

(*) Contribution by National Research Council of Italy - Institute of Geosciences and Earth Resources

Figure 7: Hydraulic stimulation at an EGS (MIT report, 2007)

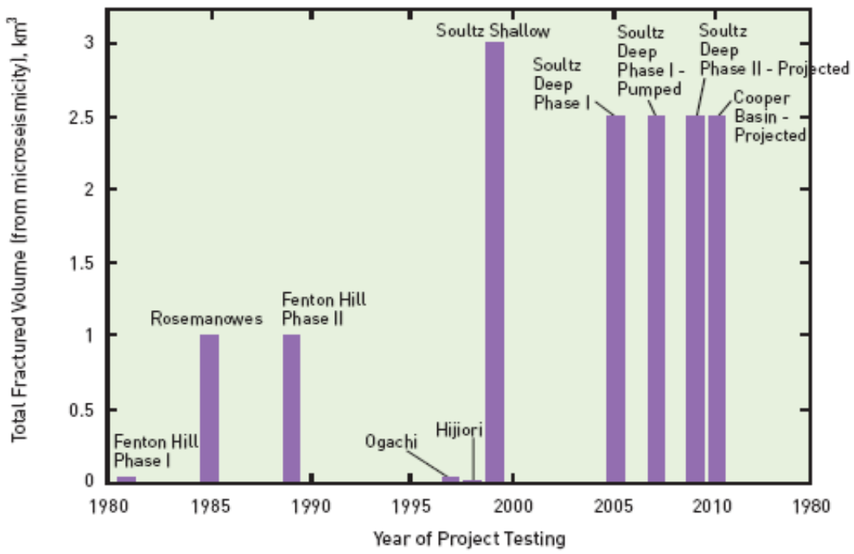


Figure 8: Stimulated volume for representative EGS projects (MIT report, 2007)

Introduction

One hundred percent of the required energy of Masdar will be generated by renewable energy resources. However, the intermittent nature of many renewable energy technologies makes it very difficult to always exactly match supply and demand. Thus, the idea of storing energy must be applied.

As Masdar relies on large centralised systems for much of its infrastructure (e.g. transport, cooling), the city requires a very large "backup". There are essentially two types of large-scale storage that are well-established and able to provide the power/energy supply for a large city-scale load: pumped storage, and compressed air storage. The central grid itself can be considered as a third form of large-scale "backup".

Pumped Storage

In countries with hydrological resources, pumped storage can be used, whereby water is pumped up to a higher location when excess electrical energy exists. When there is later a lack of electrical supply, the pumped water is used in a hydropower installation (See Figure 1). This can provide on the order of several hundred megawatts of capacity and is a mature technology in many parts of the world.

However, due to the lack of such a resource in the UAE, pumped storage does not have any applicability in Abu Dhabi/Masdar. We note it anyway because many 100% renewable energy plans for other regions are contingent on the availability of pumped storage (e.g. the recent Business Institute Solar Strategy report on a large-scale 100% RE strategy for some of Germany).

Compressed Air Storage

Another form of large storage could be compressed air storage.

The principle is simple: air is compressed and stored during periods of excess electrical energy; it is released to turn an expansion turbine when energy is needed (see Figure 2). The efficiency can be up to 70%.

The idea would be promising, if an underground reservoir were to be found during the geological examination of the site. This is probably unlikely, so the technology has not been considered. If, however, a large underground cavern were to exist in the vicinity of Masdar, this extra site could be considered as a "storage plant" for the city; although this would be obviously "off-site".

While the compressed air could technically be stored above ground, the losses would be too significant for such an application, thus the use of underground caverns (compare capital costs of $10/kWh stored in caverns, versus $250/kWh in vessels). One example is the current use of an underground cavern at a 110MW / 26-hour plant in McIntosh, Alabama, USA, utilizing a salt-deposit cavern of 538.000 m^3.

The Grid as principal "virtual storage" for Masdar

In order to aspire to a carbon-neutral strategy, the recommended proposal is to use the grid as the principal "storage". Excess energy produced would be fed into the national grid; and at times of insufficient energy production, the energy would be "extracted". While this is not a "storage" in a strict sense, it is a "virtual battery" of sorts. Carbon-neutrality is maintained provided that all the energy imported had previously been generated by renewable energy.

For example, at the peak of a sunny day, all the photovoltaic panels will be producing energy. However, this energy will exceed the total consumption of the city at that instant. This extra energy will be sold to the national electrical grid. During the night, when PV panels are no longer producing electricity but there would still be energy demand, the city can import the electricity again from the national grid. The key is that the total energy produced at Masdar, over one year, should equal the energy demand. As such, we can assure carbon neutrality of the city's energy consumption, and ensure the zero carbon goal.

Such a strategy does require a reliance on the grid; however, there are several benefits:
Power is sold to the grid when Abu Dhabi needs it most (during noon peak hours), where electricity price is at its highest.
Unexpected demand peaks can be handled independent of the renewable power supply.
Assuming a feed-in tariff will be established in Abu Dhabi to support renewable energies (e.g. as a result of Masdar's study into RE incentives), the sold RE electricity will earn significant income for the city.

Alternative Storage Technologies
There are several other technologies that are available for storage, none of which has been tested at a large scale. Some implementation is possible at Masdar, and the technologies are considered in the following sub-chapters.

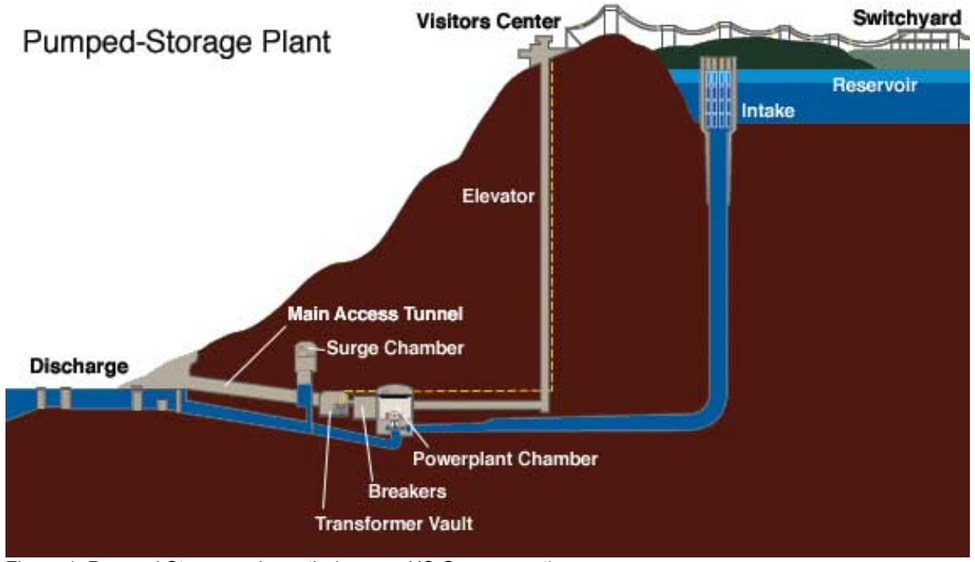


Figure 1: Pumped Storage schematic (source: US Government)

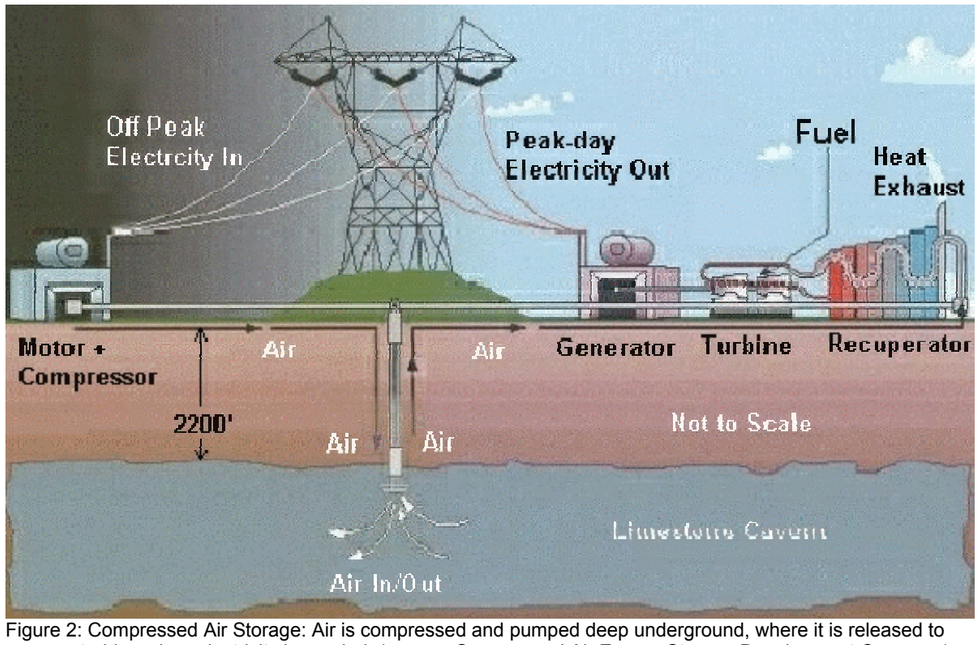


Figure 2: Compressed Air Storage: Air is compressed and pumped deep underground, where it is released to power a turbine when electricity is needed. (source: Compressed Air Energy Storage Development Company).

Battery technology has been available for the past hundred years, with various improvements being made over the years. Batteries are used to provide rapid uninterrupted power supply (UPS) functionality; however, as a large-scale storage it is not ideal, due to the usual high expense and extensive maintenance requirements due to limited life-spans. The efficiency of conversion can be high though, even greater than 90% in some cases. At Masdar, batteries may be used for mission-critical backup systems, where rapid functionality from loss of power would be required, for example in hospitals.

Traditionally, PV systems have been used with lead-acid batteries in remote locations for many years, also in combination with back-up diesel generators, in so-called “Hybrid Systems”. Failure has been prevalent in remote PV systems largely due to battery life problems, but there has been recent progress in the field, with inverter companies such as SMA offering solutions for battery-operated mini-grids to extend the life of the batteries in such off-grid systems. Given that the operating range is from -15°C to 50°C, the units should optimally be kept in a cool room. Furthermore, the use of lead requires careful post-use treatment (sent for recycling to manufacturers). Even still, lead-acid batteries are very common in UPS systems, with many different manufacturers providing UPS systems.

Beyond UPS systems for stationary applications, lead-acid batteries have seen few applications in large-scale developments, and mostly in peak-shaving or load-leveling. Puerto Rico Electric Power Authority operated a 20MW / 20-minute system; Chino California operated a 10MW /4-hour system. In Berlin, which before the unification of Germany was in many ways an “island” system, Bewag operated a 17MW / 14MWh system, for frequency-control and spinning reserve; the former Berlin isolated power grid did have other grid-forming generators as well. Commercial applications thus remain very isolated, and the suitability of very large scale adoption for Masdar questionable. 1 to 3 MW battery systems with two to three hours storage have been proposed for use at substations to defer upgrades/growth (Source: US Sandia Labs). A pilot system could be considered for operation, which may allow for an expanded use in the future. This has not been treated in the analysis of Masdar however, as other large storage options are more appropriate (see the following sections).

Other advanced batteries such as Lithium-ion and Zinc-Air may see application in stationary applications in the future, but are quite far from this type of development at the current state.

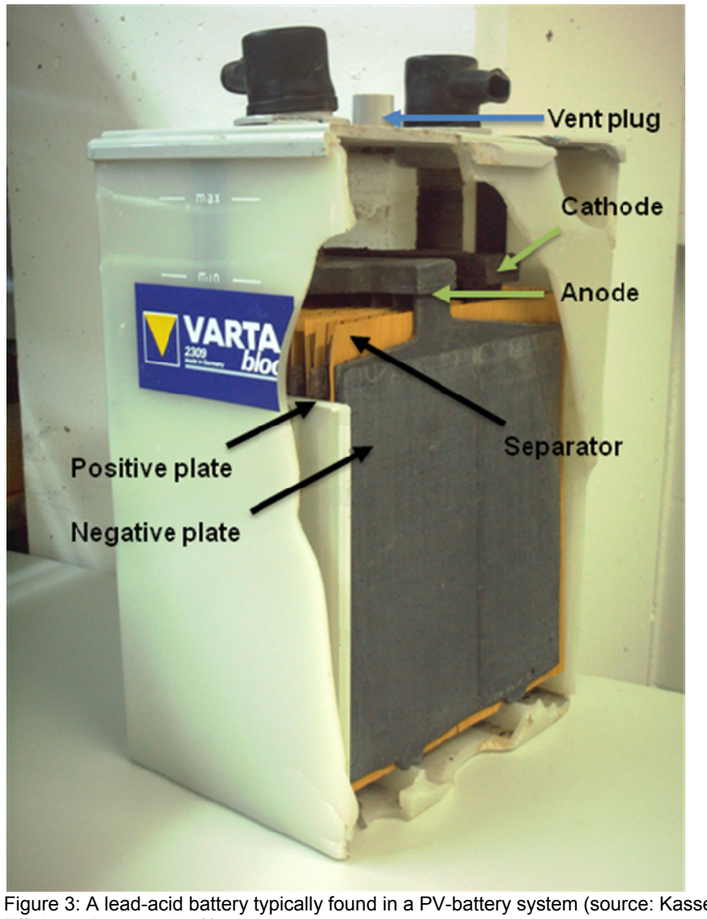


Figure 3: A lead-acid battery typically found in a PV-battery system (source: Kassel University). Efficiency is around 80%.

A Flow-cell is a special type of battery that resembles a fuel-cell in operation. The electrolytes are stored externally in tanks, and they are pumped to a reactor/ “regenerative fuel cell”, to produce electricity. The difference with a fuel-cell is that the reaction is reversible, thus making the process “rechargeable” using the same reactor. The electrolyte can also be added from an external source if more energy is needed, although, in general, the electrolyte is not replaced. Figure 4 shows an illustration of the functioning of a flow battery. Several tens of MW are possible.

The technology is much more mature than other proposed storage systems for renewable energy (e.g. hydrogen storage), thus offering immediate application. VRB Power Systems manufactures vanadium-based redox regenerative fuel cell storage systems of 8MWh units, but might be able to provide 100MWh units (10MW by 10 hours). Efficiencies of Vanadium Redox Flow batteries are upwards of 85%. Such systems are often used for load-leveling, but an expanded use is possible. The charge/discharge window, for example, is a fraction of other battery systems, making their combination with wind-generation for off-peak charging and on-peak dispatch ideal.

Most applications for this technology are intended for leveling out wind-generation, as in the case of the 30.6MW Tomamae wind park on Hokkaido that is capable of providing 4MW for 90 minutes.

Longer term availability is a possibility, with examples such as a 6-hour 2MW system being planned by VRB for the 6.9MW Sorne Hill Wind Farm.

A VRB system can also be used as a total backup for a remote power system with wind. In such a way, a wind farm/flowcell system can produce a near constant output of approximately 30 to 40% of its installed peak power. Such a system could be applied as part of an innovation hub for Masdar.

A vanadium-based flow-cell unit could be applied immediately at Masdar with a 1 to 5MW_p PV plant built at the beginning of construction to provide several hours of energy during non-daylight hours.

The Zinc-bromine battery is an emerging technology that Masdar may consider for demonstration installations (Figure 5). It is classified as a “hybrid flow” battery, with efficiencies of 75%. Advantages included being able to fully discharge the battery without damage (unlike lead-acid). The ZBB Energy Corporation has developed such a 500kWh battery that fits in a shipping container (as well as a power conversion system). A 2MWh demonstration system began construction 2 years ago in California.

Lastly, another regenerative fuel-cell technology is the Polysulfide Bromide flow battery (PSB), although commercial development is less advanced than VRB and ZBB.

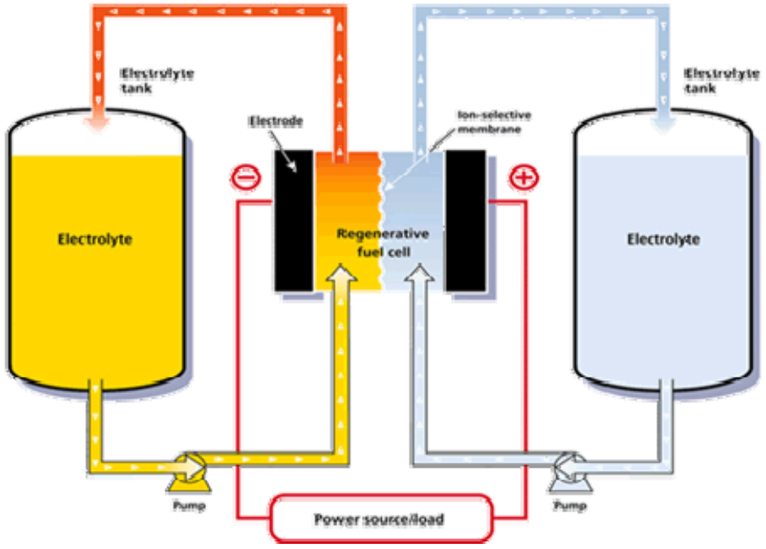


Figure 4 - A Redox Flow Battery: Electrolytes are used continuously in a regenerative fuel cell to produce power when needed, and store it when available (source: VRB Power Systems, VRB Vanadium-based Energy Storage System)

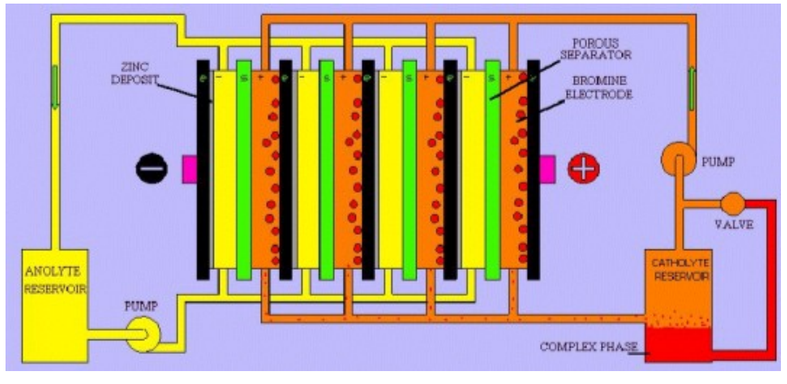


Figure 5: Zinc-bromine concept (Source: Sandia Labs)

Figure 6: 50kWh Zinc-Bromine Battery from ZBB (Source ZBB).

Sodium-Sulfur can be used to make a high temperature battery suitable for grid-storage applications.

The operating temperature of the battery is very high, between 300 and 375°C, but has a very high energy density of almost four times that of lead-acid batteries in theory (664 Wh/kg vs. 171 Wh/kg), and almost three times in practice; NaS is 10 times lighter by weight. Cycle life is also twice that of lead-acid (2500 cycles), with a comparable efficiency (90% cycle efficiency; 75% in/out electrical efficiency). See Figure 7 for an illustration of a NaS cell.
Long discharge times of over 8 hours are possible. Lastly, costs are lower on a €/kW-yr basis than traditional batteries.

NaS batteries have already seen application for grid storage at several sites in Japan, including a 6MW unit at Tsunashima (See Figure 8). Last year, American Electric Power installed a 1.2MW at Charleston, Virginia. The latest development is the world's largest NaS battery by Honda at Tochigi, at 12MW. Grid storage on a large scale may be possible with such a technology in the future.

The sole commercial supplier of batteries this large is currently is NGK Insulators, Ltd. of Japan. The batteries consist of their 52.6kW NaS modules, each one weighing 3.6 tonnes (2.2x1.76x0.64m), with a capacity of 421 kWh. Efficiency is over 86% at 8hr discharge.

The latest developments using NGK NaS technology include a 34MW system of 17 2MW units in Rokkasho, Japan. This system will provide wind fluctuation stabilisation and load-leveling for a 51MW wind park, scheduled for completion in 2008.

In terms of long-term, *large-scale* storage, the most promising of emerging commercially available technologies is the NaS battery above all other options.

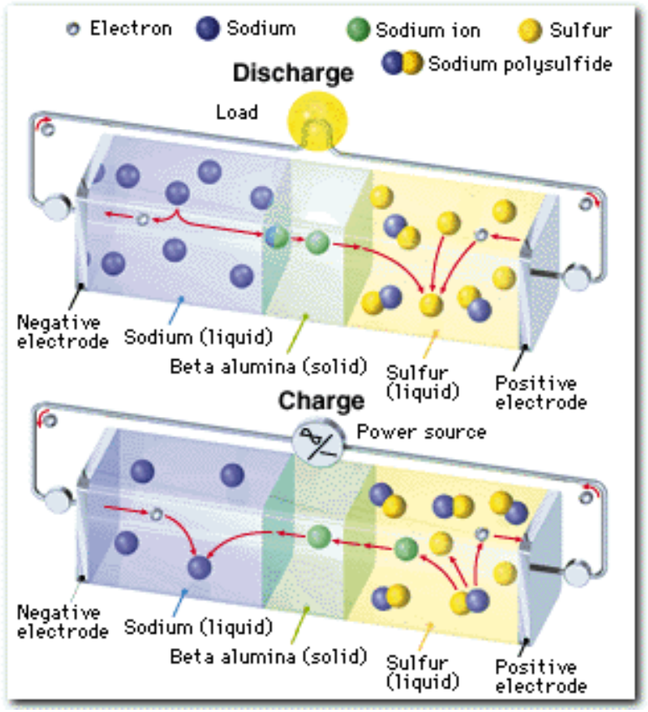


Figure 7: Concept of a NaS cell (Source: NGK)

Figure 8: 6MW NaS battery unit in Japan (Source: NGK)

The principle of this storage type is that hydrogen is produced in times of excess energy, and stored in a fixed or portable storage. The process is then reversed when energy is needed, using hydrogen to create electricity with only water as the by-product. Figure 9 shows the principle of a hydrogen storage system.

Hydrogen Production from Renewables

Water electrolysis is an often cited form of hydrogen production, which involves splitting water into hydrogen and oxygen by applying an electrical current. This form is quite expensive with costs for a large plant being about $3.25/kg H. High-temperature electrolysis is an active research and development topic, with potential application for solar and geothermal heat sources.

Alkaline electrolysers are also possible, being more mature technology.

Photolysis is an advanced process where light is used directly to create hydrogen, instead of with electricity. Hydrogen Solar, for example, is developing such products (See Figure 11). In general, large-scale production is still far off, with still much R&D required for the field. 16% efficiencies have been shown in the lab. Biophotolysis has also been proposed (see Figure 12).

While the most commercial technology is the electrolyser, other forms can be supported at Masdar with research and pilot installations.

Storage of Hydrogen
Stationary applications generally store hydrogen as compressed gas, with liquid often used in vehicular propulsion.

There is currently much research and development also in storage in solid materials, such as metal hydrides, and even with carbon nano-tubes. Metal hydrides have the most future potential.

Fuel Cells
Fuel cells appropriate for larger scale generation include Phosphoric Acid (PAFC) and Solid Oxide (SOFC). Polymer Electrolye Membrane (PEMFC) has also been applied for distributed generation, combining several units in the 200kW range, although they are more common for smaller mobile applications.

Fuel cells can not only provide power, but also heat, thus CHP operation is ideal. They are also theoretically more efficient than normal power plants, with SOFC promising over 60% electrical efficiency in the future. PAFCs are generally 34% efficient, with SOFCs at 45%. SOFCs require a high operating temperature.

PAFCs are installed in hundreds of locations worldwide, mostly in the 200kW range. Example manufacturers include UTC (Toshiba). UTC previously developed a 1.3MW plant. HydroGen LLC develops 400kW cells, claiming to offer 6 to 30MW plants.

SOFCs are generally larger than PAFCs, with multi-megawatt systems being developed. Siemens Westinghouse is an example manufacturer

Conclusion

Despite the promise since many years, fuel cell technology is still far from large scale deployment. Problems include reliability, lifetime and costs. Costs are 2.5 to 20x those of competing stationary systems.

The total efficiencies when using electricity derived hydrogen are very low, considering the lower solar-electric efficiency, coupled with an electrolyser (50 to 70%), finally run with a fuel-cell (35% to 50%). In terms of efficiency for stationary applications, other forms are more efficient.

Fuel cells and hydrogen storage could provide an option for both stationary and mobile applications in the future, but the current limitations hinder their widespread application for a city like Masdar. Test and pilot applications can be recomended, especially to incubate innovative H2 production technologies. Systems on a smaller scale for single buildings are becoming mature enough to consider adoption. However, a large-scale adoption cannot be recommended for 2008 compared to competing technologies.

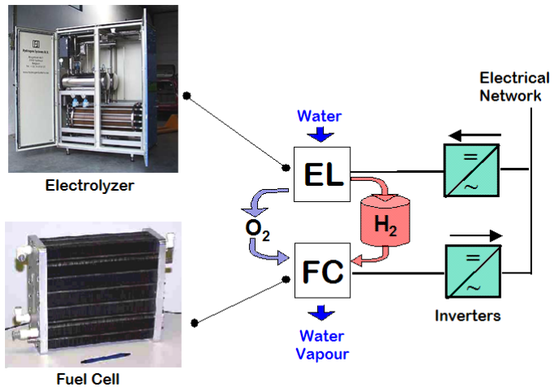


Figure 9: Hydrogen is created from water and stored when energy from the network is in excess; it is used later in the fuel cell to create electricity for the network when needed. (Images courtesy of Kassel University)

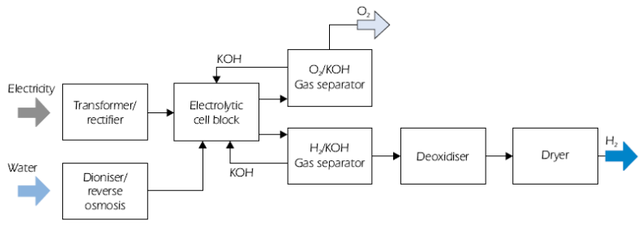


Figure 10: Alkaline Electrolyser Process (Source: IEA-OECD)

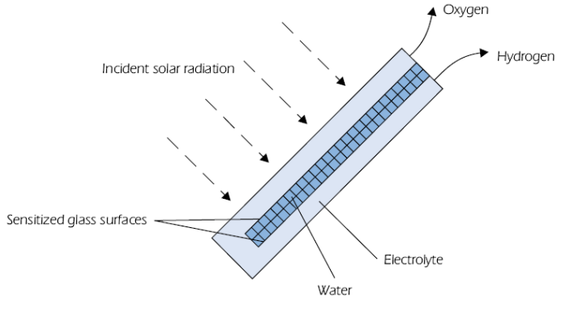


Figure 11: Hydrogen production by photolysis (Source: Hydrogen Solar Production Company Inc.)

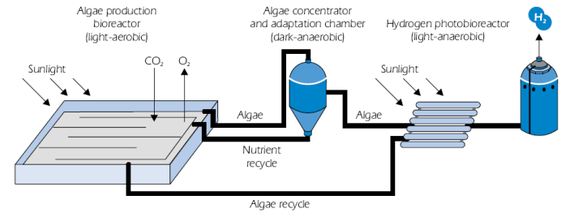


Figure 12: Hydrogen production by photo-biological reaction (Source: IEA-OECD)

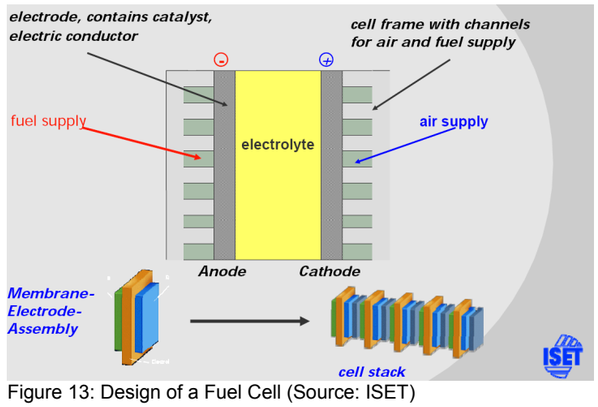


Figure 13: Design of a Fuel Cell (Source: ISET)

Flywheels

A flywheel is essentially a large wheel that stores mechanical energy by spinning. Electrical energy is stored by adding mechanical energy to the spinning wheel: more energy makes the flywheel go faster. In times of need, energy is “removed” by slowing down the flywheel. Efficiencies can be high, up to 90%, with hundreds of thousands of cycles.

The application is good for power quality applications, to apply voltage and frequency stability to small grids, but not designed to allow for storage for long periods of time, as power loss happens quickly. The technology has not been used at a very large scale and capital costs are rather high. The grid stability qualities make it potentially attractive for a renewables-dominated grid. The ability for quick response is especially promising. Such systems could be considered to even out RE power fluctuations at Masdar.

Beacon Power is an example of manufacturer that makes flywheels for frequency regulation, with a 250kW/25kWh product. The Smart Energy Matrix is capable of providing 1MW for 15 minutes.

Other providers include Active Power and Pentadyne, which makes UPS systems using flywheels.

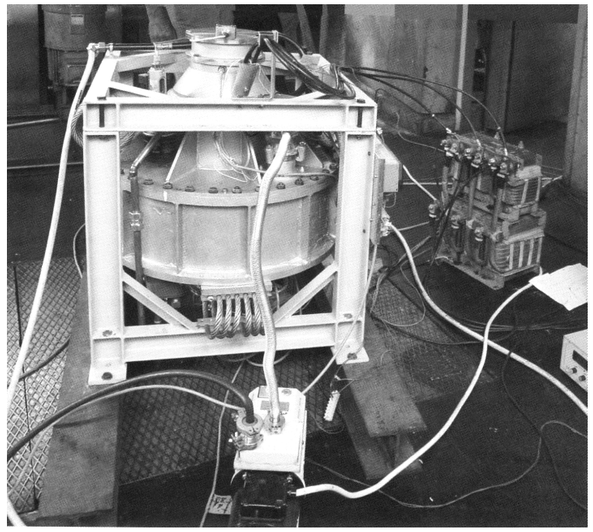
The scale of Masdar is quite large for previous implementations of flywheels; however, a demonstration plant consisting of several smaller units could be considered for Masdar for grid stabilisation from the renewable generation. Demonstration plants on the order of 20MW are being planned.

Superconducting Magnetic Energy Storage (SMES)

This type of system stores energy in a magnetic field. It operates at very low superconducting temperatures at which wires have zero electrical resistance (and thus low losses). These extreme sub-zero temperatures (below -200°C) require special casings. Theoretically, energy losses are less than for flywheels (95% efficiency), making SMES also appropriate for power quality control applications, including for voltage stability, power flow and the provision of quick real and reactive power. The number of charge/discharge cycles has essentially no limit.

Systems on the order of megawatts are commercial, and applications on the order of 100s of MW are being considered by using multiple units. One of the largest manufacturers is GE. Their D-SMES unit provides 3MW of real power, with up to 18.4 MVAr reactive power (8 MVAr continuous). The size is quite compact, and can fit in a 18.6m sized trailer. The units can be combined modularly for 10s of MW of grid capacity.

SMES represents another solution for grid stability at Masdar, although there have been less applications with RE as with flywheels.



Figures 14: Rosseta T1 Flywheel: 150kW/1 minute system for tramways

Figure 15: GE/American Superconductor SMES system in Antigo, WI, USA (Source: GE)

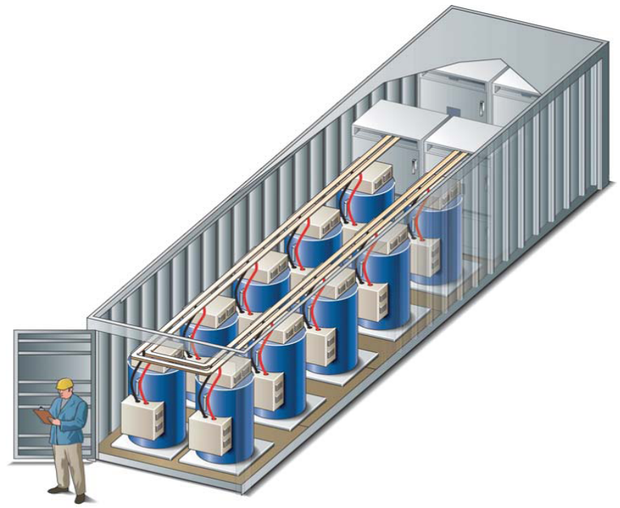


Figure 16: Smart Energy Matrix System from Beacon Power, 1MW/ 250 kWh (Source: Beacon Power)

CCS technology, also known as carbon sequestration, aims to reduce CO2 emissions in the atmosphere by capturing them at major point sources and storing them to prevent their escape into the atmosphere. This promising emission reduction option has important potential environmental and economic advantages. The process occurs in three steps:

Capture CO2 streams emitted before or after combustion (before in the case of creating hydrogen from fossil fuels, after in the case of flue gases).
Transport CO2 in pipelines or tankers to storage.
Store CO2 underground in deep saline aquifers, depleted oil and gas reservoirs or unmineable coal seams.

CO2 Capture Sources
There are three sources of CO2 that are considered for CCS technology, because they emit a large amount of concentrated CO2 that can be captured in an efficient, centralised way: electricity generation, industrial processes and fuel production. Fossil-fuelled power production (from coal, natural gas, and oil) results in 29% of CO2 emissions, and is the primary target of CCS technologies. Industrial processes contribute 23% of CO2 emissions, and in some cases, the costs for CCS are less for industry than for electricity production. Finally, the CCS storage is also considered for the CO2 emitted from fuel production in oil refineries, natural gas processing installations and synfuel production.

CO2 Capture Technology
CCS is currently widely used in industrial manufacturing processes, refining and gas processing and is based either on chemical absorption, in combination with heat-induced CO2 recovery, or physical absorption in combination with pressure-induced CO2 recovery. Emerging technologies include membrane separation, oxyfuelling in combination with new oxygen production technologies, chemical looping and fuel cells.

Current available technology is very energy intensive and the technologies used must be demonstrated on a much larger scale than has been required so far by the chemical industry. Ideally, CCS should be combined with highly efficient power plant technologies, like the Integrated Gasification Combined Cycle (IGCC). Negative net emissions can be achieved if CCS is used for flue gas produced by biomass-fuelled power plants.

CO2 Transportation Technology
Pipelines are the most established technology for transport, although proper siting is the best way to save on transport costs. Also, pipeline networks can be set up to allow multiple power plants to use a connected pipeline system and make transport economical. CO2 transport by ships may also be possible.

CO2 Storage technology
The realistic options for CO2 storage locations include deep saline aquifers, depleted oil and gas reservoirs and coal seams that are not mineable. Other options considered include oceanic storage or above-ground storage, but these are not as of yet adequately developed nor publically accepted.

Aquifers could offer enough storage for decades to hundreds of years with the capacity to store between 1000 and 10000 Gt. Depleted oil and gas reserves, although less evenly distributed, could hold decades of CO2 emissions.

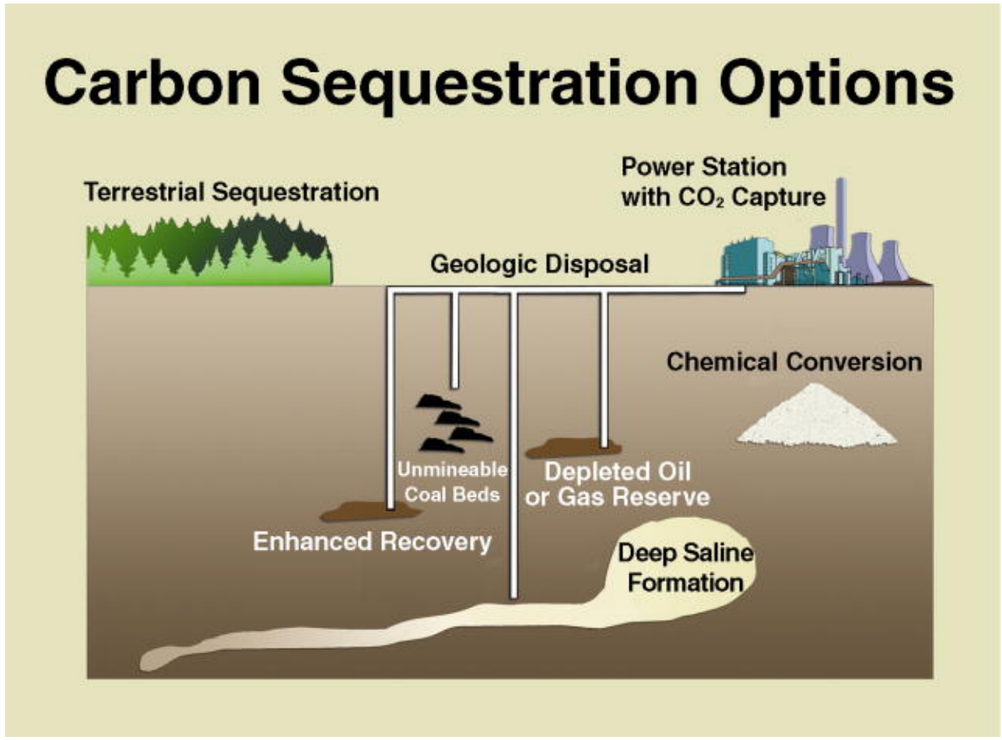
CO2 can also be used in enhanced oil recovery (EOR) and enhanced gas recovery (EGR) to extract fossil fuel resources in Middle Eastern oil-producing nations. Certain countries also have the potential to store CO2 underground, depending on the geological characteristics.

Permanence of Storage and Monitoring

More studies are needed to confirm the permanence of aquifer storage, to develop criteria to select the most suitable sites, and to establish adequate monitoring procedures. An upper bound for leakage rates must be set to ensure that stored CO2 does not return to the atmosphere.

Potential Costs

As only a handful of demonstration projects exist worldwide, cost estimates vary. With current technology, high end estimates reach $100/tonne CO2 avoided. The majority of the cost comes from capture. Shorter distances to storage sources involve of course a reduced cost. In addition, if being used in Enhanced Oil Recovery, earnings could offset the cost significantly.



Source: White House

CO2 Capture
At Masdar, the waste-to-energy plant is a technically CO2-neutral operation, if one considers that the emissions from normal waste management in the UAE outweigh the GHGs emitted by the plant.

Furthermore, the organic/biomass fraction that is being burned in the plant has a neutral balance in that the CO2 released is simply the CO2 that it had absorbed when the plants. Capturing the CO2 from burnt biomass actually offers negative net CO2 emissions.

In the current design, 11400 tonnes of non-organic CO2 are released by the waste to energy plant (see WSP chapter).

The method of capture depends on the concentration of CO2 in the flue gases, which would have to be analysed for the power plant in question. For lower concentrations (less than 10% such as flue gases from gas-fired power plants), chemical absorption is preferred because its energy use is not particularly sensitive to low concentrations and low partial pressure of CO2. For higher concentrations of CO2 (more than 15%), physical absorption is preferred, because it is much easier. The concentration of CO2 in the flue gas can be increased by using pure oxygen instead of air in the combustion, or by converting the fuel gas into CO2 and H2 before combustion.

CO2 Transportation
The appropriateness and cost effectiveness of CCS technology depends on the transportation requirements from the specific electricity generation plant to the storage. Since there are no depleted oil and gas fields on-site, nor aquifers, the costs and logistics would be higher.

A pipeline would be the most suitable way to transport the CO2 to a storage location, since transportation by ship isn't an option in this region. CO2 has a much higher density than natural gas or hydrogen, so transportation costs are lower and more akin to those for oil.

Even for up to 5000km distances, transportation would be about $20 USD/tonne CO2 (source: IEA-OECD).

CO2 Storage
Due to the presence of oil and gas excavation in the larger surrounding region, there maybe some opportunities for storage in hydrocarbon fields. Depleted oil and gas reserves could be available for CO2 storage; also, CO2 gas could be sold for EOR in the region, which could make it an economic asset. CO2 however should be used in reservoirs with temperatures under 120°C for miscibility (see Table 1).

If construction were to go ahead on a geothermal power plant, if underground cavities were to be found, they may be appropriate for CO2 storage after further study. Furthermore, there have been proposals to use CO2 in Enhanced Geothermal Systems (see Chapter 6.6), which may be applied to a future plant at Masdar. The CO2 in this case would act as the heat transfer fluid instead of water. However, this is still at a research stage.

CO2 Usage
Instead of storage, the CO2 emitted from the waste to energy plant can be used directly.

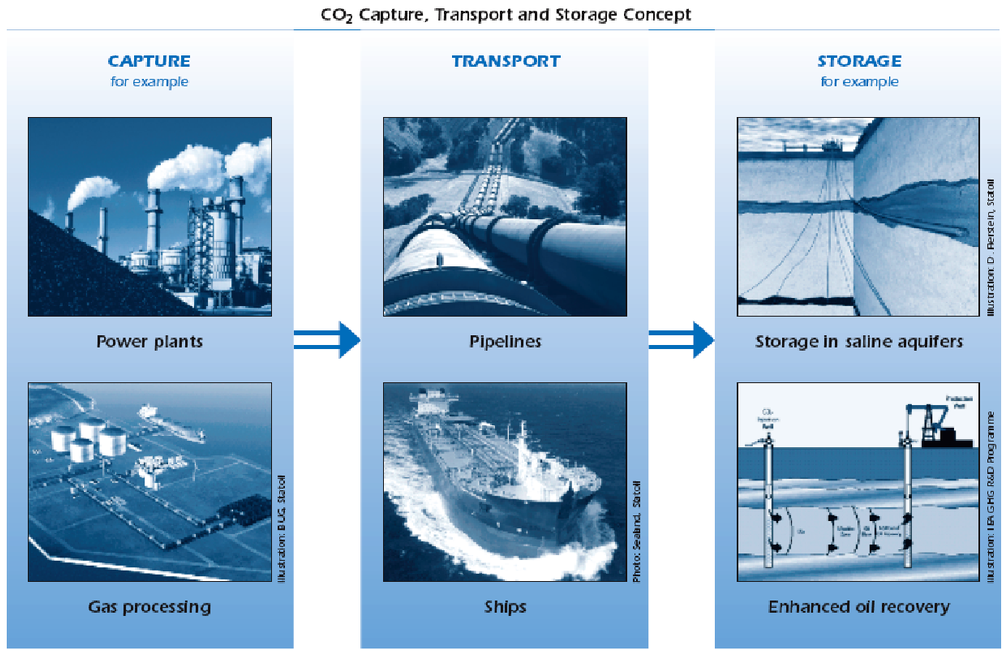
In Iceland for example, CO2 is captured from some plants and used in greenhouses, as well as in industrial applications. Examples include soft drink production and use in other food industries.

Final Note

If CCS is to be selected as the option for Masdar's carbon neutrality, further study is required for:

- regional acceptability
- acceptability according to sustainability institutes and international standards

Large scale CCS technology is experimental (for large coal plants, for example), but on the small scale of the Masdar waste to energy unit, it could be considered for application, at least as a demonstration project. . Considering that some CO2 will be emitted even in a "renewable" future, Masdar could provide a lead on such initiatives.



CO2 Capture, Transport and Storage Concept (Source: IEA-OCED)

°API Gravity	> 22 / 36
Viscosity (cp)	< 10/1.5
Composition	High % C5-C12
Oil saturation (% Pore Volume)	> 20/55
Formation type	Sandstone / Carbonate
Depth (m)	> 600
T (°C)	120 (for miscible CO2 floods)
Cost (USD/bbl)	$7 - $30 (low-end assuming "free" CO2)

Table 1: Screening Criteria for Enhanced Oil Recovery with CO2 (Source: IEA-OECD)

Desalination (*)
Introduction

Water is an essential component for the survival of mankind on earth and has generally considered as an abundantly available resource. However, many countries in the world, particularly of the Gulf Region are suffering for water scarcity. Moreover, countries with abundant water resources are facing problems due to deteriorating quality of the available water resources and their uneven geographic distribution.

The serious need for new resources of freshwater for human consumption has been widely recognized for some time, leading to a rapidly growing use of the desalination processes[1], in particular reserve osmosis (RO) for seawater desalination as well as significant advances in membrane technology itself. RO has become a popular water treatment technology in nearly every industry requiring separation of a dissolved solute from its solvent.

A variety of desalination technologies has been developed over the years on the basis of thermal distillation, membrane separation, freezing, etc. Commercially, the most important technologies are based on the MSF, MED and RO processes. It is viewed that MSF and MED processes have dominated the Middle East years ago. However, now and in the next future, the RO process is experiencing increasing interest primarily due to its lower cost, energy efficiency and simplicity. These are the reasons to propose RO technology instead of any thermal process.

The main objective of this report is to describe the RO technology and illustrate the recommendations to implement this water treatment technology within the *Masdar Initiative* in Abu Dhabi (Cityscape Abu Dhabi 2007 - United Arab Emirates). Specifically, it is a new sustainable development that uses the traditional planning principals of a walled city, together with existing technologies, to achieve a zero carbon and zero waste community. This new settlement will be built over an area of 6.5 million square meter and about 90,000 people will work and live daily on the site.

For this development it would be necessary to design and install a seawater RO (SWRO) desalination plant according to sustainable environmental criteria and the lowest possible energy consumption. The RO plant capacity is estimated between 9,000 and 12,000 m^3/d.

SWRO Ghalilah plant views (Ghalilah plant (U.A.E.)

[1] The production of desalinated water in United Arab Emirates reached more than 950 million cubic meters annually (Speech by Dr M S Al Kindi – Minister of Environment and Water of the United Arab Emirates at the 1st Singapure Desalination and Wastewater Reuse Leadership Forum – April 11-12, 2007).

RO is a fundamental component of treatment systems for the water used in the industry, domestic supply and irrigation. The RO serves as an extremely fine filter. Its pores are believed to be less than 0.001 micron in diameter (The diameter of a human hair is greater than 30 micron). These pores give RO the ability to remove suspended solids, particulates, bacteria, virus and endotoxin.

The success of the RO technology has been due mostly to the economics of its operation and to its simplicity. Compared to other salt-removal technologies, it is relatively inexpensive to purchase and to operate. It requires neither an energy-intensive phase change such as distillation nor a large volume of strongly acidic and caustic chemicals like those required for ion-exchange systems.

The basic process of RO uses a pump (high pressure pump – HPP) and a limited semipermeable membrane (spiral-wound membrane mainly) in series. In practice, the saline feed water is pumped into a closed vessel where it is pressurized against the membrane. As a portion of the water passes through the membrane, the remaining feed water increases in salt content. At the same time, a portion of this feed water is discharged without passing through the membrane (brine discharge).

Continuous improvements in the RO membranes used as well as the reduction of the energy consumption have caused at the same time dramatic improvements in the economics and efficiency of the technology. Newer membranes reject more salts and let pass more water at a particular pressure. This fact, combined with the implementation of the new brine energy recovery devices, results in a higher energy efficiency.

Before an RO system is designed, it is important to understand the needs and limitations of the particular application. The system permeate water recovery and permeate quality, as well as maintenance requirements, will depend significantly on the quality of the water source. The quality of the potential RO feedwater will thus dictate the requirements of the RO pretreatment system for the particular application, and may affect the design of the RO itself. Given the wide variability in the quality of water sources, a thorough understanding of the water source and how it might impact the needs of the RO application will assist in designing successful the RO pretreatment and the entire system.

Two parameters that first have to be determined are the desired *RO permeate flowrate (F_p)* and the desired *freshwater quality (C_p).* The *RO permeate recovery (% R)* is defined as the ratio of F_p to feed flow (F_f). It is an expression used to describe how efficiently the system is being operated. Higher recoveries will result in using less pump electricity, pretreatment chemicals, or water. The recovery also affects freshwater quality. Because of the higher concentration of salts present in the feedwater side of the downstream membrane stages of the RO, higher concentrations of salts will permeate the membrane. The recovery is commonly chosen based upon the potential for scale formation of the brine. Thus, *seawater systems will operate up to 50 %,* limited by the high osmotic pressure of the seawater.

A complete SWRO process begins with *seawater catchment*. After that, that water has to be treated to adapt to the RO membrane requirements (*pretreatment*) (A). With the aid of a *HPP* (C) *and a Booster Pump (BOP)* (D) the seawater flows to the RO membranes (*membrane assembly*) at the desired pressure (E). The brine goes through the *energy recovery device* (G) and the freshwater is *post-treated* before being supplied (F).

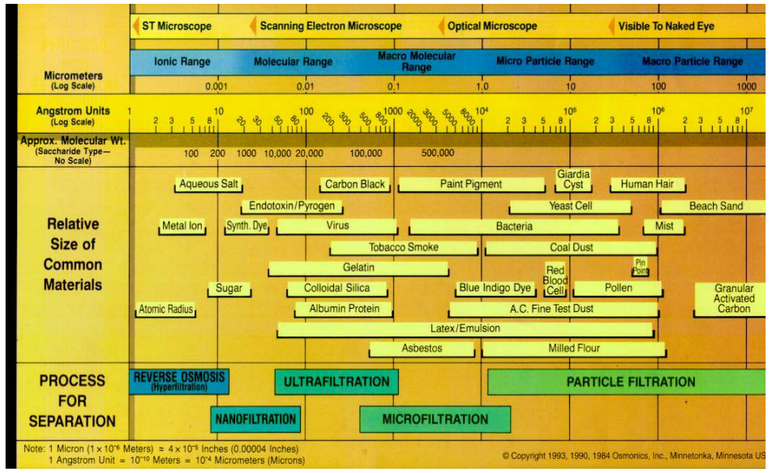


Figure 1. Filtration spectrum.

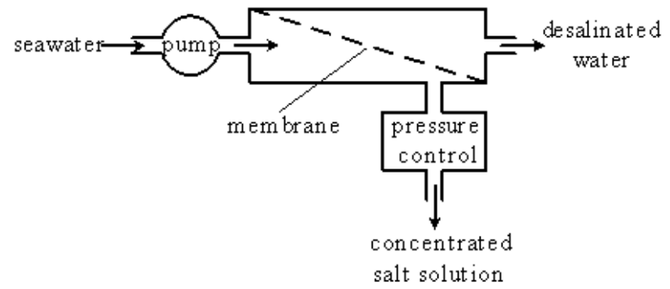


Figure 2. Basic RO desalination plant scheme.

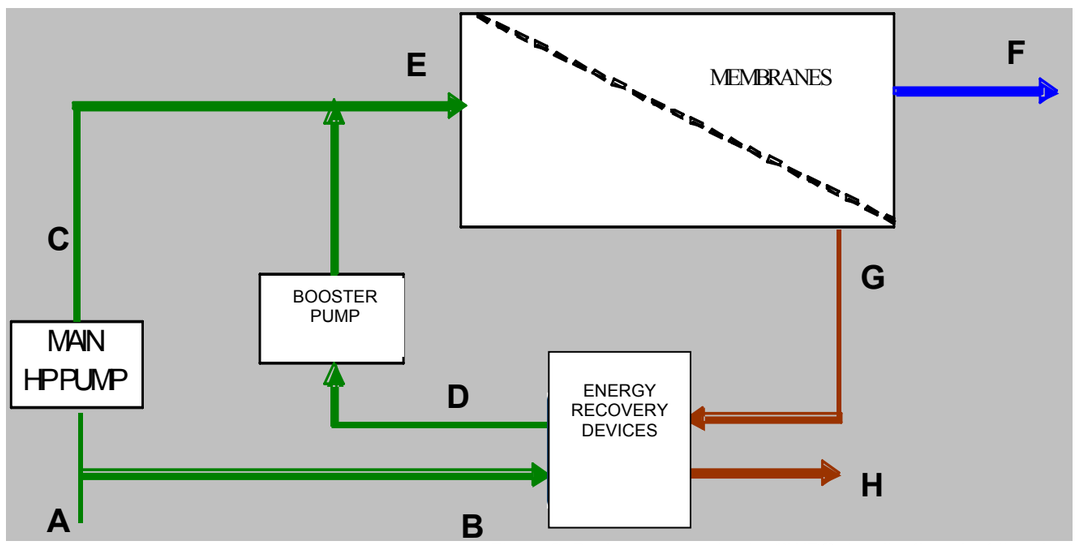


Figure 3. Basic components of a SWRO desalination plant flowchart.

Seawater Intake and Quality

In a SWRO process feed water catchment and pretreatment are essential in order to remove all the potential membrane foulants from the feed. The degree of pretreatment, however, is dependent on the raw water quality (particularly its content in suspended and biological matter), as well as on the designed membrane configuration. Water quality tends to be site dependent. In view of this, the correct election of the seawater intake will reduce the pretreatment required.

Seawater desalination plants can receive feed water from different sources. Open seawater intakes are the most common option, but not the recommended one, given to the high silt density index (SDI)[2] in this kind of intake. The use of open intakes may result in losses of aquatic organisms when these collide with intake screens (impingement) or are drawn into the plant with the source water (entrainment). The construction of the intake structure and piping causes an initial disturbance of the seabed, which results in the resuspension of sediments, nutrients or pollutants into the water column. After installation, the structures can affect water exchange and sediment transport, act as artificial reefs for organisms, or may interfere with shipping routes or other maritime uses.

(Beach)-well intakes must be the first option for catching the seawater (Fig. 4). The intake water quality is often better in these locations than in near shore and surface waters, with the warranty that the subsoil could perform a natural filtration. In these cases, only minimal or no chemical pretreatment may be required. However, the initial soil disturbance during construction of below ground intakes or long pipelines may be higher, especially when this involves drilling or excavation activities. (Beach)-well intakes are adaptable to small or medium-sized plants only.

Persian Gulf seawater has much higher total dissolved solids (TDS) (over 45,000 ppm) than normal seawater (35,000 ppm). The average ionic ratio of normal seawater is 1.253 : 1 and consequently, the concentration of all ionic species is proportionally higher in the Gulf seawater than it is in the normal seawater. The SDI of an (open intake) untreated Gulf seawater is higher than 5.4, so that a beach-well is recommended and/or the design of a specific pretreatment.

Ions	Concentration
Chloride	23,000
Sodium	15,850
Sulfate	3,200
Magnesium	1,765
Calcium	500
Potasium	460
Bicarbonate	142
Bromide	80
Silicate	1,5
TDS	45,000

Table 1. Major ion composition of Gulf standard seawater (mg/l) (Al-Mutaz, 2000).

Besides, seawater temperature has a dramatic effect on the RO permeate flowrate. Low temperatures require more energy and operating expense, but result in a reduced need for membrane elements in the RO system. Below 18 ºC, it may be desired to increase the HPP output. On the contrary, high temperatures increase the permeate flowrate (3% per ºC) but lead to worse quality. For spiral-wound membranes, the higher limit of operation is 45ºC.

Although RO desalination process removes the majority of salts and minerals, it does not remove residuals of certain constituents, such as boron, sufficiently. The rejection ratio of boron ranged 90 % for RO membranes. Two main reasons for the limiting and removal of the boron content in product water are:

- As boron in humans can represent reproductive dangers, the WHO has set a preliminary limit of 0.5 mg/l for drinking water; meanwhile the EU established a maximum value of 1.0 mg/l.
- In desalted irrigation waters boron concentration has to be controlled. Boron is an essential oligoelement for crops but has a narrow range of concentration between deficiency and toxicity. Different plants can withstand different boron levels. Among the more sensitive crops are citrus trees, which show massive leaf damage at levels of more than 0.3 mg/l in the irrigation water.

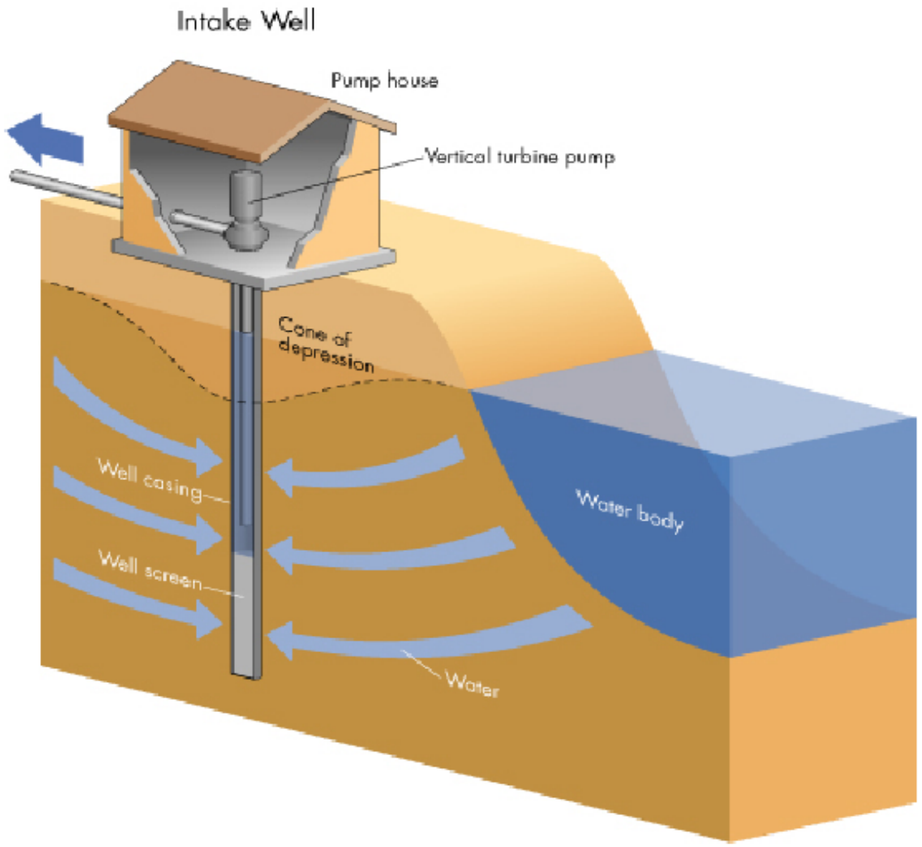


Figure 4. Vertical intake well.

[2] Also known as the fouling index. This parameter has been commonly used in the water treatment industry as an indicator of the potential for membrane fouling. For a SWRO process, SDI must be between 3 to 5 after the pretreatment process.

Pretreatment

The purpose of RO pretreatment is to optimize the performance and life of the RO membrane elements. Pretreatment equipment is engineered to accomplish this task by meeting the following three objectives:

- Insure the compatibility of the feed stream with the RO membranes.
- Reduce or eliminate the potential for scale formation on the RO membrane or in the element flow channels.
- Reduce the RO cleaning frequency by reducing the fouling potential of the seawater.

Therefore, suspended solids must be removed and the water pretreated so that salt precipitation or microbial growth does not occur on the membranes.

At least, the pretreatment consists of media and cartridge filter and the addition of acid or antiscalant to inhibit precipitation and the growth of microorganisms (commonly used in the case of beach-well seawater intake with SDI<6). In any case, the seawater quality has to be analysed to consider the optimum pretreatment to install. In the case of open intakes with very high SDI, a more efficient process is recommended. Concretely, a chemical pretreatment including chlorine, ferric chloride coagulant, sulphuric acid, sodium bisulfite, and antiscalant, and, probably, an ultrafiltration (UF) or microfiltration (MF) treatment, which has a better performance that the media and cartridge filtration. The UF/MF increases the RO flux[3] in more than 20% in comparison with conventional pretreatment and requires less constructed area. The only limitation to use UF/MF is the relative high cost of this treatment, in spite of achieving a better seawater treated (reducing the chemical cleaning needs) and an increase of the permeate flowrate.

Membranes Assembly

The membrane assembly consists of a pressure vessel and a membrane that permits the feed water to be pressurized against the membrane. The membrane must be able to withstand the entire pressure drop across it. The semi-permeable membranes vary in their ability to let fresh water and reject the passage of salts. No membrane is perfect in its ability to reject salts, so a small amount of salts passes through the membrane and appears in the product water.

RO membranes are made in a variety of configurations. Commercial SWRO membranes produced world wide are made of cellulose triacetate (CTA) or polyamide (PA) in an asymmetric type structure or are made in thin film composite (TFC) structure mainly of polyamide composition. The asymmetric type is made in hollow fine fiber (HFF) configuration while the TFC is made in a spiral-wound (SW) configuration. SW configuration is most used to desalt seawater, due to costs and efficiency reasons, and can reject 99.5 % or more of the TDS in the source water. Standard membrane elements have limitations with respect to a number of performance parameters such as: feed water temperature (45°C); pH (minimum of 2 and maximum of 10); silt density index (less than 4); chlorine content (not tolerant to chlorine in measurable amounts); and feed water pressure (maximum of 80 to 100 bars).

SW elements require an external housing (*high pressure vessels*), designed to withstand RO operation pressures (Fig. 5). A typical housing will contain 6 or 7 elements in series (8” diameter x 40” in length); the sum of several vessels in parallel with independent high pressure lines is called a *train* (Fig. 6, 7). The number of membranes in series is a variable that will have a major impact on other aspects of the RO design. It will affect the structural frame requirements, the flow hydraulics of the system, and the size of the HPP, energy recovery device and BOP.

In our case, 2 trains should be necessary to design for the 9,000 m^3/day plant (2 x 4,500 m^3/day) and two for the 12,000 m^3/day (2 x 6,000 m^3/day) configuration. Each train would be conformed by a HPP, the structural frame with the vessels, the energy recovery system and the BOP. With this design it is warranted the water production with at least one train when the other it is breakdown or in maintenance. It could be estimated a total permeate recovery rates between 35 and 42% (i.e. between 21,000 and 35,000 m^3/day of seawater required).

Probably with configuration the total boron concentration should be up to 1 mg/l. Only in the case of the local regulations restrict the boron concentration less than 1 mg/l, it must be considered any of the following solutions:

- Operation at high seawater pH (up to 9).
- Additional RO stage to treat the freshwater partially.

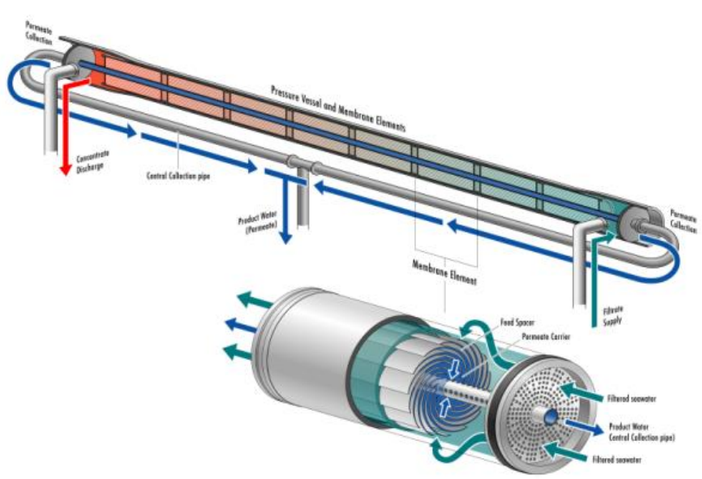


Figure 5. Spiral-wound membrane and vessel configuration scheme.

Figure 6. RO vessels detail.

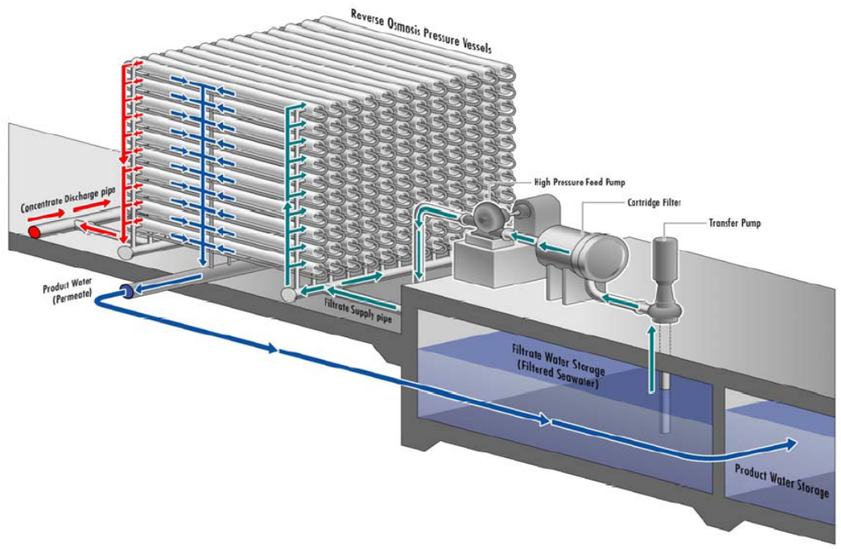


Figure 7. SWRO train scheme.

[3] Permeate flow per membrane area.

Energy Recovery Devices

It is common now to use energy recovery devices (ERDs) connected to the concentrate stream as it leaves the pressure vessel at about 1 to 4 bar (15 to 60 psi) less than the applied pressure from the high-pressure pump. These energy recovery devices are mechanical and generally consist of work or pressure exchangers, turbines, or pumps of some type that can convert the pressure difference to rotating or other types of energy that can be used to reduce the energy needs in the overall process. These have a significant impact on the economics of operating. They increase in value as the cost of energy increases.

Turbines were the first ERDs deployed in municipal-scale SWRO plants. Initially, Francis turbines were applied, but they were replaced in the 1980s by Pelton turbines that operated at higher efficiency in high-head applications like SWRO.

The turbine wheel is mounted on the high-pressure pump shaft, which together with a motor drives the pump that pressurises the SWRO system.

Another type of centrifugal ERD is the hydraulic *turbocharger*, which has been used for SWRO energy recovery since the early 1990s. Turbochargers are similar in concept to Pelton turbine ERDs with a turbine and an impeller on the same shaft but they do not have a motor.

One or more nozzles direct the SWRO reject stream onto a tangential-flow pump-turbine directly connected to a centrifugal impeller spinning in the SWRO feed stream. The feed stream, partially pressurised by a high-pressure pump, is boosted by the turbocharger impeller to the SWRO feed pressure. The turbocharger and the high-pressure pump are not directly connected, providing a degree of flexibility in the operation of these devices. Also, turbochargers have a relatively small footprint and are easy to install.

To avoid the efficiency losses associated with the energy-conversion steps inherent in centrifugal devices, engineers have developed *positive-displacement (PD) piston isobaric devices* for SWRO in the 1980s. These devices place the SWRO reject and seawater in contact with an intervening piston in pressure-equalising or isobaric chambers. Pressurised seawater from the ERD combines with the discharge of the high-pressure pump to feed the membranes. The high pressure pump operates at the full membrane pressure but supplies only the flow rate of the permeate. A booster pump in series with the ERD is necessary to circulate high pressure water through the membranes.

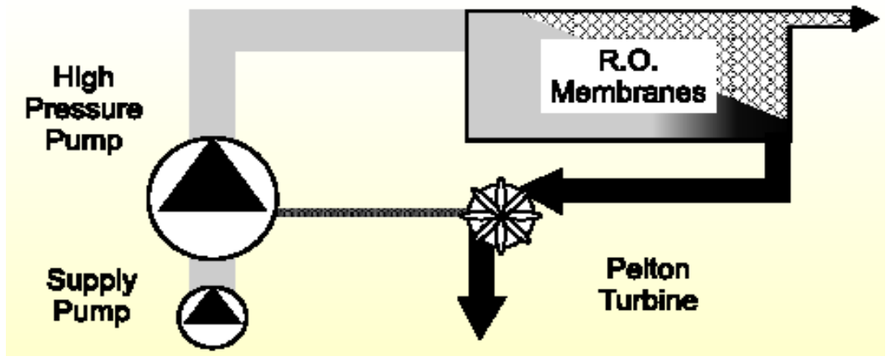


Figure 8. SWRO process with Pelton Turbine.

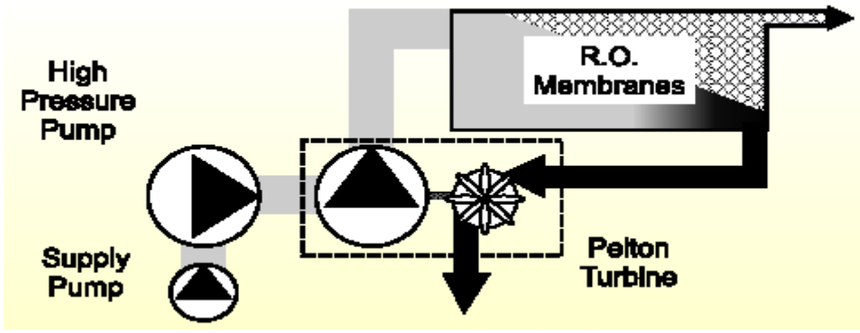


Figure 9. SWRO process with turbocharger.

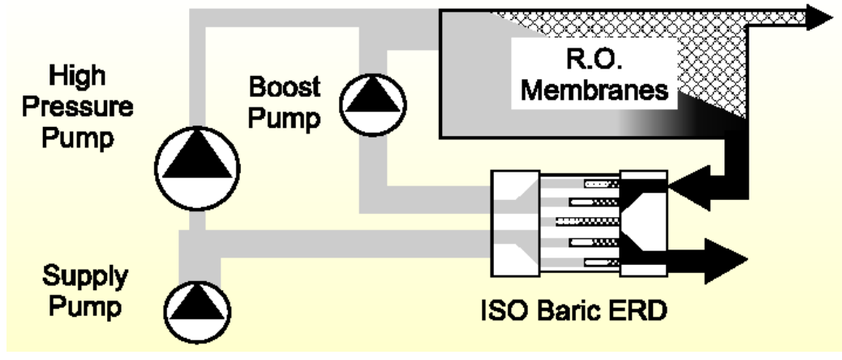


Figure 10. SWRO process with isobaric ERD.

High Pressure Pump and Booster Pump

Piston isobaric devices completely decouple the ERD and the high-pressure pump. The advantage of this feature has been taken with the advent of the pressure centre SWRO designs. In these systems, the high pressure pump or pumps feed a manifold, which in turn feeds multiple SWRO trains. For example, two high pressure pumps could feed four or more SWRO trains. The design accommodates larger and more efficient high pressure pumps. Alternately, an unlimited number of isobaric ERDs can be operated in parallel in a large SWRO train sized to run with the largest, most efficient high-pressure pump available.

The piston isobaric devices require dynamic control to operate their valves and to limit piston movement. Each ERD must be operated individually and in conjunction with the other devices in the array to minimise overflush/bypass and to prevent excessive pulsations and water hammer. Despite the piston, the long contact time (20 to 60 seconds) between the brine and seawater in the isobaric chambers results in some intermixing, resulting in an increase in the membrane feed salinity of up to 1.5%.

The high efficiency of an isobaric PD device and the operational simplicity of centrifugal ERDs are combined in the *rotary isobaric device*, first applied to the SWRO systems in 1997 (Energy Recovery Inc. is the sole manufacturer of rotary isobaric devices; with the trade name PX Pressure Exchanger). In an SWRO system equipped with a rotary isobaric device, the membrane reject is directed to the membrane feed. A rotor, moving between the high-pressure reject stream and a low-pressure seawater supply stream, removes the brine and replaces it with the seawater. Pressure transfers directly from the high-pressure reject stream to a feed stream with no intervening piston in the flow path. This results in a slightly higher degree of mixing between the streams than in a piston isobaric device (1 to 2.5%), eliminating the friction and wear that occurs on the pistons. Mixing is minimised with long, small diameter chambers and short brine-seawater contact time (0.05 seconds).
A direct comparison of the performance of various ERDs based on field data is virtually impossible because of the inherent differences between SWRO systems and operating conditions. But, for the case of our SWRO desalination plant from 9,000 to 12,000 m^3/day at recovery rates from 35 to 42%, it could be estimated the ERDs efficiency and the specific energy consumption (kWh/m^3) based on the information published in several references related to operating data and equipment manufacturer's data.

EDR type	Efficiency (%)	kWh/m^3
Pelton Turbine	75 - 82	3.00 – 3.50
Turbocharger	75 - 84	3.00 – 3.30
Piston Isobaric	95 – 97	1.93 – 2.75
Rotary Isobaric	95 – 98	1.92 – 2.75

Table 2. Efficiency and specific energy consumption of a medium capacity SWRO desalination plant.

In general, the specific energy of systems with Pelton turbines and turbochargers (centrifugal systems) is higher than in isobaric systems because the efficiency of isobaric ERDs is much higher.

Centrifugal systems have larger, higher-efficiency, high-pressure pumps than the isobaric systems, but the higher efficiency of isobaric ERDs results in lower specific energy with the latter. Isobaric systems operate with higher membrane feed pressures than centrifugal systems because of the mixing in the ERDs in the former. The difference is overwhelmed by the higher efficiency of the isobaric ERDs. Rotary and isobaric systems operate at approximately the same specific energy. Mixing and efficiency are higher in the former and tend to cancel out.

High Pressure Pump And Booster Pump

The HPP is a fundamental component of the installation. It must provide smooth, uninterrupted flow to the RO trains (equal to permeate flow). It must be sized to provide the necessary flowrate at the various system operating conditions over the life of the RO membrane. Its energy consumption is one of the major expenses of RO plant operation.

The BOP is other important device, which must increase slightly the pressure of the seawater flow (equal to brine flow) after passing through the ERD. At the inlet of the vessels the pressure of this flow must be the same that the pressure of the seawater flow being pumped by the HPP.

In both cases, horizontal centrifugal pumps, which operate by spinning the fluid with the pump impellers, are most commonly used for SWRO applications requiring less than 70 bar of pressure. A multistage centrifugal pump, which uses a number of impellers in series to build up the pressure, is the recommended pump to use in the SWRO desalination plant. The pumps are intended for continuous duty in the most difficult and corrosive seawater conditions. They incorporate non-corrosion materials as supper duplex or 904L stainless steel materials.

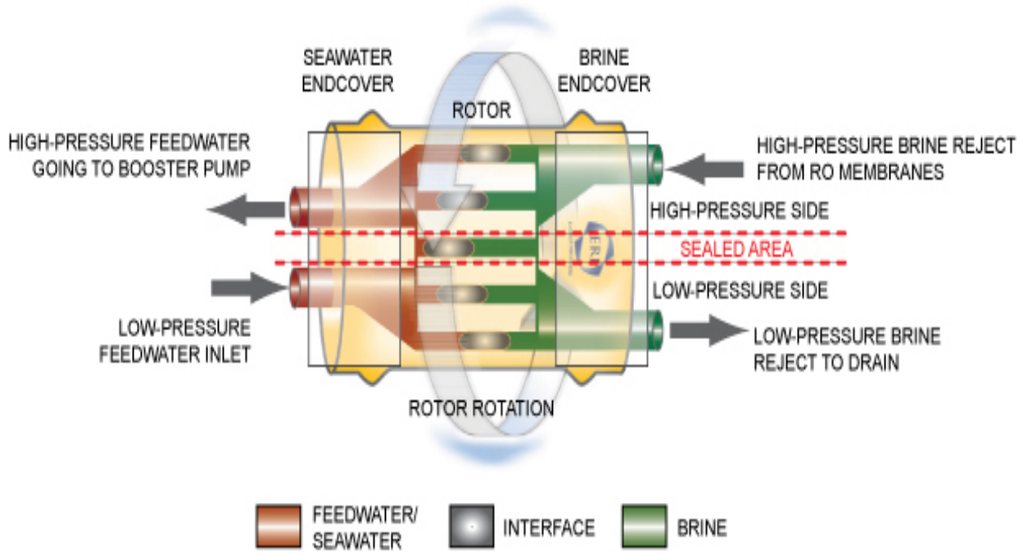


Figure 11. Rotary isobaric functioning.

Freshwater Post-Treatment

The freshwater produced will have less than 500 mg/l TDS and is characteristically low in mineral content, alkalinity, and pH. Therefore, desalinated water must be conditioned (post-treated) prior to final distribution and use. The final post-treatment depends of the final use of it, and in this case the water will be for human supply. There are many regulations that apply to freshwater. A thorough understanding of the regulations governing the particular application is required before a design evaluation can be performed. Typically, post-treatment of product water includes one or more of the following processes:

- Stabilization by addition of carbonate alkalinity
- Corrosion inhibition
- Re-mineralization by blending with high mineral content water
- Disinfection
- Water quality polishing for enhanced removal of specific compounds (i.e., boron, silica, DMA, etc.).

Besides, the post-treatment generally must address the aggressive nature (low pH) of the permeate. It can destroy certain types of piping materials, such as galvanized steel. Chemicals must be injected to raise the pH and balance the chemical nature of the water.

Calcium carbonate salts, supplied by upflow limestone contactors, are commonly used for this purpose. A limestone contactor is a layer or bed of limestone which water flows through. It stabilizes water to reduce the uptake of lead and copper from pipe and plumbing fixtures. Lead and copper can pose health impact if present higher than the concentration allowed in the Lead and Copper Rule. Limestone contactors may offer advantages over other corrosion control methods including conventional chemical addition such as: (1) pH and alkalinity adjustment using lime; (2) calcium adjustment; and (3) silica or phosphate-based corrosion inhibition. Compared to conventional chemical addition, a limestone contactor is easier and safer to operate, reduces operating cost, self adjusts the water pH without risk of alkali overdose, requires minimal maintenance and operator skills, and does not require continuous feed of chemicals.

Figure 12. PRFV limestone contactor.

Brine discharge vs. Potential uses

Wastes from a SWRO desalination plant include concentrated brines, backwash liquids containing scale and corrosion salts and antifouling chemicals, and pretreatment chemicals in filter waste sludges. Depending upon the location and other circumstances including access to the ocean and sensitive aquifers, concentrations of toxic substances etc., wastes could be discharged directly to the sea or through a well, mixed with other waste streams before discharge, discharged to sewers or treated at a sewage treatment plant, placed in lined lagoons and dried and disposed in landfills. Concentrates disposal is one of the most challenging issues with respect to desalination processes. Recovery of important minerals from concentrates is possible and may be economically viable in some cases, because it also reduces waste disposal costs.

The constant discharge of reject streams with high salinity and temperature levels can thus be fatal for marine life, and can cause a lasting change in species composition and abundance in the discharge site. Marine organisms can be attracted or repelled by the new environmental conditions, and those more adapted to the new situation will eventually prevail in the discharge site. Due to their density, the brine streams of SWRO affect different realms of the sea. The concentrate of SWRO plants, which has a higher density than seawater, will spread over the sea floor in shallow coastal waters unless it is dissipated by a diffuser system. Benthic communities, such as seagrass beds, may thus be affected as a consequence of high salinity and chemical residues.

There are several approaches to mitigate the environmental effects of the waste discharges. To avoid impacts from high salinity, the desalination plant reject stream can be pre-diluted with other waste streams where applicable, such as power plant cooling water. To avoid impacts from high temperature, the outfall should achieve maximum heat dissipation from the waste stream to the atmosphere before entering the water body (e.g. by using cooling towers) and maximum dilution following discharge. For a SWRO medium capacity desalination plant, the most widely used concentrate disposal alternatives are:

- Discharge to surface waters or beach-well near of the coast
- Deep well injection
- Evaporation ponds (solar ponds)
- Zero liquid discharge - Technologies for beneficial use of concentrate.

In principle, the first listed solution way to discharge the brine could be the more recommended in areas near the coast. Mixing and dispersal of the discharge plume can be enhanced by installing a diffuser system, and by locating the discharge in a favourable oceanographic site which dissipates the heat and salinity load quickly. To analyze plume spreading in this site, the environmental and operational conditions should be investigated by hydrodynamic modelling, accompanied by salinity and temperature measurements for density calculations before and during operation of the desalination plant.

In this case, negative impacts from chemicals can be minimized by treatment before discharge, by substitution of hazardous substances, and by implementing alternative treatment options. Especially biocides such as chlorine, which may acutely affect non-target organisms in the discharge site, should be replaced or treated prior to discharge. Chlorine can be effectively removed and different chemicals, such as sodium bisulfite. Filter backwash waters should be treated by sedimentation, dewatering and land-deposition, while cleaning solutions should be treated on-site in special treatment facilities or discharged to a sanitary sewer system.

As mentioned before, the use of alternative pretreatment methods should be considered where feasible, such as prefiltration with UF/MF membranes, or the use of subsurface intakes such as wells which naturally pre-filtrate the seawater. This may eliminate or significantly reduce the need for chemical pretreatment. A non-chemical treatment option is irradiation of the intake water with UV light at 200–300nm wavelength for disinfection, which damages the DNA structure of microorganisms. A major advantage of UV-light is that storage, handling and disposal of toxic chemicals are avoided, but some highly reactive and short-lived active substances are also produced in seawater (i.e. free radicals) which may form by-products. However, to date UV irradiation has not been found to be an effective pretreatment for larger desalination plants.

The zero-liquid discharge alternative includes options such as brine concentrators, crystallizers and dryers convert concentrate to highly purified water and solid dry product suitable for landfill disposal or perhaps recovery of useful salts. The cost of energy for concentrate evaporation and crystallization is high (25 to 66 kWh/m^3), and the equipment costs are usually several times larger than the capital investment needed for the other concentrate disposal alternatives. Because of the high capital and operation and maintenance costs, the zero-discharge technologies are not practical unless no other concentrate management alternatives are available. Usually, the zero-discharge concentrate management systems are justifiable for in-land brackish water desalination plants where the site-specific constraints limit the use of natural evaporation or wastewater treatment plant disposal. Use of high recovery desalination systems in front of the evaporators can reduce energy and capital costs.

Other possible alternative is based on an integral industrial – recreational – environmental zero-liquid brine cycle. It consists in the creation of a brine complex in which the fluid is used for producing salt, in saltwater artificial wetlands[4] (including bathwater recreational areas), fish farms, cooling water in any industrial process and cultivating microalgae for food source and nutritional value (i.e. *Dunaliella* to obtain *β-carotene* or *Spirulina* as a nutritional supplement) or Artemia Salina[5], a brine-shrimp originates in salt lakes and evaporation flats.

Technologies for beneficial use of concentrate:
Concentrate from the SWRO plant contains large quantities of minerals that may have commercial value when extracted. The most valuable minerals are: magnesium ($Mg(OH)_2$), calcium sulfate ($CaSO_4 \cdot 2H_2O$), sodium chlorides (NaCl), and bromine (Br_2). Magnesium compounds in seawater have agricultural, nutritional, chemical, construction and industrial applications. Calcium sulfate (*gypsum*) is used as construction material for wallboard, plaster, building cement, and road building and repair. Sodium chloride (NaCl) can be used for production of chlorine and caustic soda, highway de-icing, and food products. Technologies for beneficial recovery of minerals from concentrate can be used for management of concentrate from both inland brackish water desalination plants and coastal seawater desalination plants. These technologies have the potential to decrease the volume and cost of transporting concentrate as well.

Usually, the process starts with an Electrodialysis application. The brine of this process uses for the minerals production. In this case, the brine concentrated obtain in the SWRO plant may be sufficiently concentrated (must be concentrated 20% NaCl). NaCl is crystallized by evaporation. After that the brine flow has a high concentration in Br^-. With a Cl_2 treatment the Br^- oxides to Br_2.
Other process consists in the recuperation of Mg^{2+} to obtain $Mg(OH)_2$) with the use of NaOH. (See figure 13 a basic scheme). Although the individual processes are extended, nowadays there are not any industrial applications of the whole process (only laboratory tests are carried out).

South Carolina University has recently analysed the costs of this process with the results obtained in the figure 14.

I.E.S. company - German company specialises in advanced eco-technologies - commercials a technology for recycling of brines with receiving high-quality drinking water and valuable minerals, such as table salt, magnesium chloride, magnesium-sulphate, potassium chloride, gypsum and other more valuable minerals such as lithium. The technology does not require any chemical adding and is totally safe, ecological for the environment. It is also profitable because the salt and minerals received during the recycling process are in commercial quantities. The technology can be attached to any existing desalination plant and can operate with any desalination plant capacity.

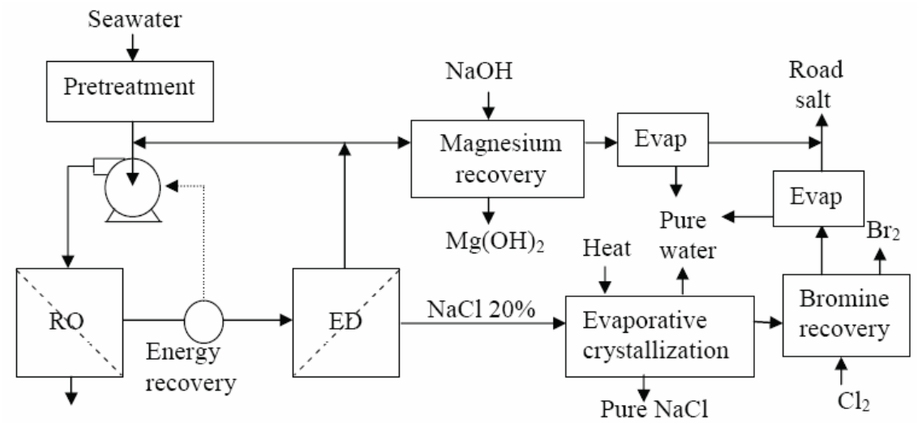


Figure 13. Industrial minerals production through brine applications scheme.

Unit	Material Recovered	Annualized Capital Cost	Annual Operating Cost	Annual Value of Product
Pretreatment		$11,000	$18,000	
RO Unit		$377,000	$1,370,000	
	Potable water			$2,460,000
Electrodialysis		$1,654,000	$3,431,000	
Crystallization		$209,000	$1,737,000	
	NaCl			$9,121,000
	Potable water			$363,000
Bromine Unit		$87,000	$66,000	
	Bromine			$405,000
$Mg(OH)_2$ Unit		$61,000	$1,973,000	
	$Mg(OH)_2$			$6,616,000
Totals		$2,400,000	$8,600,000	$19,000,000
Profit				$8,000,000

Figure 14. Brine application for mineral production: Economic analysis including SWRO plant cost. Market raw materials: NaCl, 60 $/Tn; $Mg(OH)_2$, 673 $/Tn; Br_2, 900 $/Tn.

[4] Environment "at the interface between truly terrestrial ecosystems and aquatic systems making them inherently different from each other yet highly dependent on both". In essence, wetlands are ecotones. Wetlands often host considerable biodiversity and endemism

[5] The nutritional properties of newly hatched brine shrimp make them particularly suitable to be sold as aquarium food as they are high in lipids and unsaturated fatty acids (but low in calcium). These nutritional benefits are likely to be one reason that brine shrimp are found only in highly salinated waters, with reasonable temperatures, as these areas are uninhabitable for potential predators

The key element of the technology is the Self-Sustaining Process of deep decalcination (softening) of the brine (a cycle regime - while one group of columns with sorbents works in the regime of calcium sorption, the saturated sorbent from the second column group is regenerating and vice-versa). The sorbents are produced in such a manner that concentrated NaCl brine obtained in the result of desalination is enough for the recovery of their sorption capacity. After such a unique pre-treatment, the brines are passed to the thermal distillation unit, thus we receive separately the drinking water and the highly concentrated (180 g/l TDS) tail brines. The highly concentrated brines are passed further again through the self-sustaining system and become ready for recovery of valuable mineral by-products (such as gypsum, high-purity table salt, magnesium-potassium liquid concentrates), the final process takes place in the crystallization chamber to receive dry products. The whole process is automatic. See Figure 15 for a schematic.

In the case of a 530 m^3/day SWRO plant (960 m^3/day brine flow), the following benefits are obtained with the I.E.S. technology:

- 530 m^3/day of drinking water is coming from the RO desalination plant
- 600 m^3/day of drinking water is coming from the recycling system
- Commercial amounts of high-purity table salt and other valuable minerals are extracted: 2,160 kg/day of Gypsum, 50,400 kg/day of Table salt and 10,080 kg/day of Magnesium – Potassium concentrate.

Geo-Processors company - American company which integrates wastewater treatment and CO_2 capture systems – has patented SAL-PROC™. This process is used for the sequential or selective extraction of dissolved elements from inorganic saline waters in the form of valuable salts and chemical compounds (mineral, slurry, and liquid form). Depending on the chemical composition of the saline feed water the process route may involve one or more steps of reaction and evapo-cooling supplemented by conventional mineral and chemical processing steps. The technology is based on simple closed-loop processing and fluid flow circuits, which enable the partial or comprehensive treatment of inorganic saline streams for recovery of valuable byproducts. These process steps lead to significant salt load and volume reduction which minimize the requirements for effluent discharge.

SAL-PROC™ technology has gone through extensive periods of development and improvements. Field trials, piloting and operational analysis have confirmed its capacity to convert a number of saline waste streams into saleable products and achieve zero or regulated discharges. See Figure 16 for a flowchart.

American *AquaSonics International* company has positioned itself to become a dominant force in the single most important struggle mankind will face in this century: the cost-effective and rapid desalination of water. AquaSonics has developed and patented the Rapid Spray Evaporation™ (RSE) technology. RSE does not use membrane technology; is environmentally friendly; and utilizes waste heat. The technological and economical benefits of the method make it attractive for a variety of desalination and brine applications.

RSE™ achieves water recovery efficiencies of 95% versus approximately 40% for RO technology. When coupled to suitable low-cost or waste heat, the cost for RSE™ is expected to be less than $2.00 per 1,000 gallons[6] (0.19 $/$m^3$). The heat required for RSE™ could be generated from geothermal, gas-turbine, heat pump, electrical heating element or electrical power generation, solar methods such as salt ponds or a combination of these and other technologies. RSE™ technology is capable of cost-effective separation of solids from various types of waters; including wastewaters having up to 25% dissolved solids.

The RSE™ technology is based on a patented method of producing very small droplets of saltwater that are rapidly evaporated in a heated air stream. The evaporation results in water vapour and precipitated salt particles. The salt particles are collected in a slurry or dried form; and the water vapour is condensed, resulting in potable water. The process is environmentally friendly, in that it returns no concentrated brine to the saltwater source. Also, unlike reverse osmosis, RSE™ does not use membrane technology, which requires expensive periodic maintenance. In the case of an RO-RSE™ combination, the brine should be introduced in RSE™ at 5.5 MPa and 38ºC. See Figure 17 for a diagram.

When sufficient waste heat is available, no other technology equals the advantages of RSE™ in terms of operating and capital costs, potable water volume recovery, and recovery of solids, based on published literature and test demonstration results. The technological and economical features of the RSE™ method make it attractive for a variety of applications. For example, certain wastewater applications, especially those having high concentrations of dissolved solids, may be uniquely treated by RSE™.

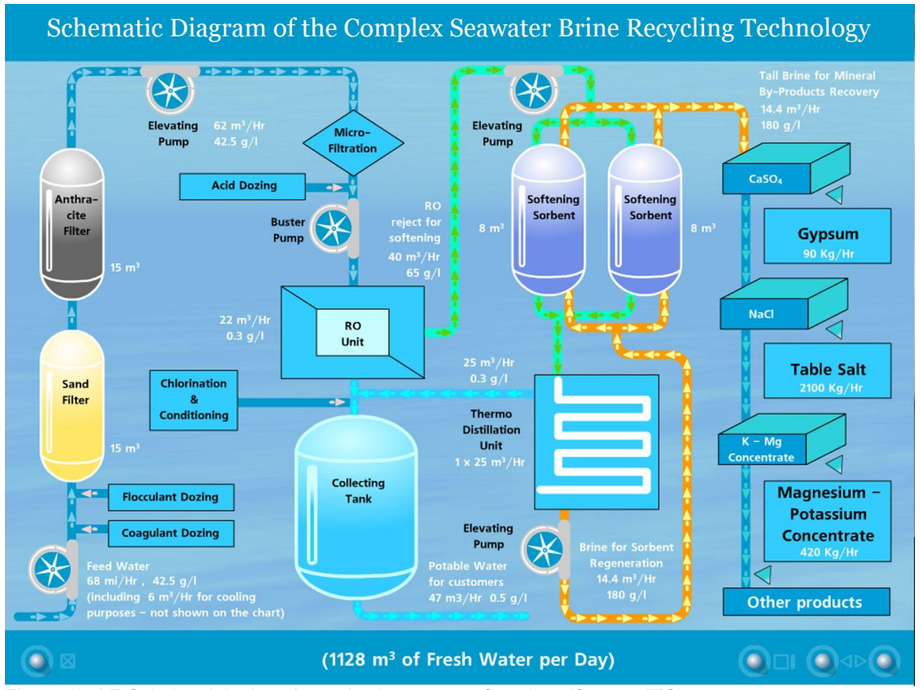


Figure 15. I.E.S. industrial minerals production process flowchart (Source: IES)

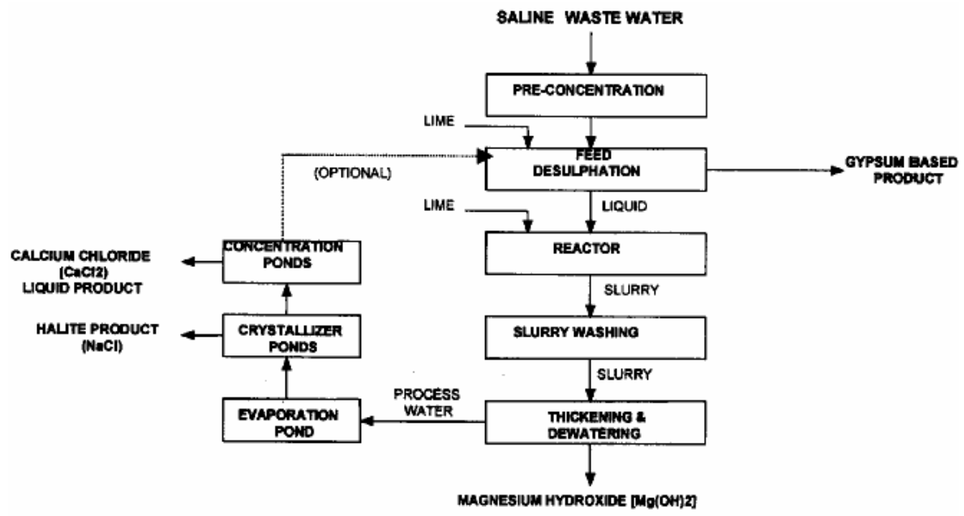


Figure 16. Basic SAL-PROC™ process flowchart (Source: Geo-Processors)

[6] 1 gallon = 3.786 liters.

Total Energy Requirement

Energy use is a main cost factor in any water desalination and has already been reduced by some technological innovations, such as the use of ERD or variable frequency pumps in the HPP and BOP.

A low specific energy consumption of *2.2 to 3.0 kWh/m*^{3} should be aimed at in the desalination process and a total of *3.5 to 4.0 kWh/m*^{3} energy consumption in the whole process, including seawater catchment, desalination process, post-treatment, control and auxiliary devices consumption. In this case, the total electric power to be installed should be 1.3 to 1.5 MW (9,000 m^3/day) or 1.7 to 2.0 MW (12,000 m^3/day).

Site Requirements

When selecting a site for a desalination project, a large number of site-specific features must typically be considered depending on the specific operational aspects of the plant in question. In order to minimize the impacts of the project on the environment, it is generally recommendable to take at least the following biological and oceanographic site features into account. Ecosystems or habitats should be avoided, if they are unique within a region or worth protecting on a global scale, inhabited by protected, endangered or rare species, important in terms of their productivity or biodiversity, or if they play an important role as feeding or reproductive areas in the region. The site should furthermore provide sufficient capacity to dilute and disperse the salt concentrate and to dilute, disperse and degrade any residual chemicals. The load and transport capacity of a site will primarily depend on water circulation and exchange rate as a function of currents, tides, surf, water depth and shoreline morphology. In general, exposed rocky or sandy shorelines with strong currents and surf may be preferred over shallow, sheltered sites with little water exchange. The oceanographic conditions will determine the residence time of residual pollutants and the time of exposure of marine life to these pollutants. Moreover, the site should be close to the sea, to water distribution networks and to consumers to avoid construction and land-use of pipelines and pumping efforts for water distribution. It should allow easy connection with other infrastructure, such as power grid, road and communication network, or may even allow the co-use of existing infrastructure, such as seawater intakes or outfalls, while conflicts with other uses and activities, especially recreational and commercial uses, shipping, or nature conservation, should be avoided.

Environmental Impacts

Effects more specific to RO desalination plants are the impingement and entrainment of organisms due to the intake of large quantities of seawater, and the emission of air pollutants due to a considerable energy demand of the processes. A key concern of desalination plants are the concentrate and chemical discharges to the marine environment, which may have adverse effects on water and sediment quality, impair marine life and the functioning and intactness of coastal ecosystems.

A general overview on the composition and effects of the waste discharges is given in a recent WHO guidance document – Guidance for Safe Health and Environmental aspects applicable to desalination. In recent publications, special attention is furthermore given to some regional seas with high or increasing desalination activity, such as the Arabian Gulf, the Red Sea, the Mediterranean or the coastal waters off California. Based on these and other sources, a synopsis of the potential impacts of desalination on the environment is given.

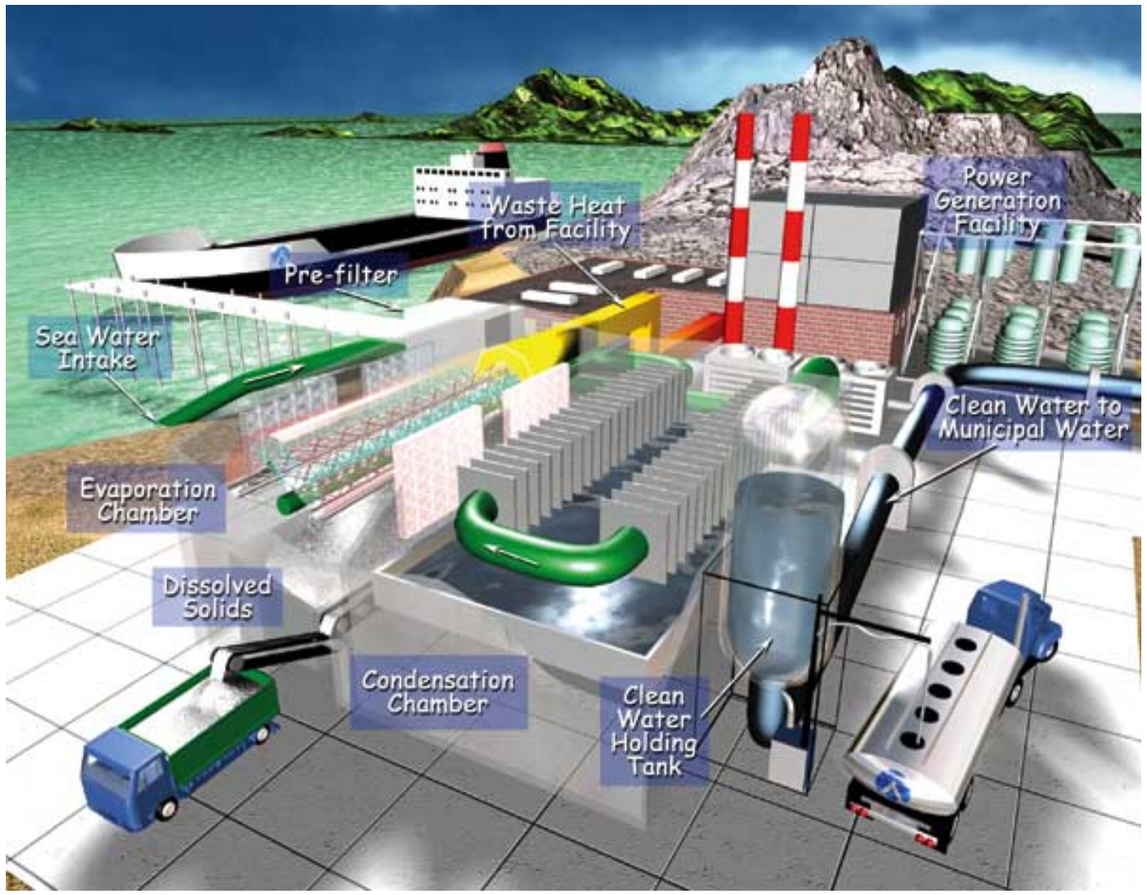


Figure 17. RSE™ basic scheme. (Source: Acquasonics)

CONCLUSIONS AND GENERAL RECOMMENDATIONS

Main Conclusions

- This section has described the RO technology and illustrated recommendations to implement a SWRO from 9,000 to 12,000 m^3/d within the *Masdar Initiative*. This plant must consider sustainable environmental criteria and less energy consumption.
- Between 21,000 and 35,000 m^3/day of seawater will be necessary; leading to a brine production of 12,000 to 23,000 m^3/day.
- Due to an increased demand for fresh water and a trend to use desalinated seawater source, there have been significant advances in the development of seawater desalination technology. These have led to cost reductions in the past (further reductions are possible) and to new developments in RO membranes (reaching up to 50% higher productivity and significantly increased salt rejection). The potential use of these products will depend on the site conditions (feed water salinity, temperature), design and operation conditions (recovery, flux) and the permeate quality requirement.
- (Beach)-well intakes must be the first option for catching the seawater. The intake water quality is often better in these locations than in near shore and surface waters, with the warranty that the subsoil could be realised a natural filtration.
- A multistage centrifugal pump, which uses a number of impellers in series to build up the pressure, is the recommended pump to use for the SWRO desalination high pressure circuit. The pumps are intended for continuous duty in the most difficult and corrosive seawater conditions. They incorporate non-corrosion materials as supper duplex or 904L stainless steel materials.
- Energy recovery devices have become essential to SWRO operations, primarily because they significantly reduce energy consumption in these systems. Quantifying device performance involves employing relatively straight-forward hydraulic calculations. ERD selection, like all other aspects of engineering design, involves some degree of compromise. Isobaric ERDs lead to higher efficiency than centrifugal devices, but centrifugal devices are generally better characterised and are easier to maintain and operate. Rotary isobaric devices provide a unique combination of isobaric and centrifugal features with high energy transfer efficiency, no maintenance, and easy operation.
- ERD maintenance must be considered in SWRO system operation because of the direct costs and the associated system downtime. Centrifugal ERDs and the rotary isobaric device require no periodic maintenance. Isobaric ERDs require periodic maintenance of the piston and the all the valves and subsystems necessary for device operation.
- The total electric power to be installed should be around 1.3 to 1.5 MW (9,000 m^3/day) or 1.7 to 2.0 MW (12,000 m^3/day).
- Different technical options exist to mitigate environmental impacts, including advanced systems for the intake of the seawater and the diffusion of the waste products, nonchemical pretreatment options such as UF/MF treatment, and wastewater treatment technologies.
- For the freshwater post-treatment, limestone contactors may offer advantages over other corrosion control methods including conventional chemical addition such as: (1) pH and alkalinity adjustment using lime; (2) calcium adjustment; and (3) silica or phosphate-based corrosion inhibition.
- In principle, the typical first alternative to dispose the brine is through (beach)-wells; a zero-liquid discharge alternative could be environmental and economically feasible. In this case, it should be considered whole potential industrial, recreational and environmental uses, such as brine concentrators ponds, magnesium ($Mg(OH)_2$), calcium sulfate ($CaSO_4 \cdot 2H_2O$), sodium chlorides (NaCl), and bromine (Br_2) productions, disposal in saltwater artificial wetlands (including bathwater recreational areas), cooling water in any industrial process and cultivating microalgae and brine-shrimp for food source and nutritional value together.

Relevant Companies

- **SWRO Membranes**: Filmtec, Toray, Hydranautics, Koch, Toyobo, Trisep
- **High Pressure Vessels**: Bekaert, Bel Composites, Codeline, Sidmas
- **Hpp & Bop**: Calder Ag, Danfoss, Eri, Sulzer, Grundfos, Ksb
- **Erds**: Eri, Ro Kinetics, Calder Ag, Ksb, Danfoss
- **Filters**: Codeline, Fluytec, Exstar
- **Desalination Suppliers (BOO/BOT/BOOT)**: Aqualia, Befesa, Cadagua, Cetare, Degremont, GE Water, Veolia Water

Swro Desalination Plant With Similar Production Capacity

Ghalilah plant (U.A.E.) – February 2005 (see pictures in 6.9.1)

- 13,650 m3/day (3 trains)
- Recovery rates from 35 to 41%
- Energy consumption < 4.0 kWh/m3
- 18 ERI – PX-220 (ERD)

(*)Contribution by Baltasar Peñate and Gonzalo Piernavieja – Instituto Tecnólogico de Canarias

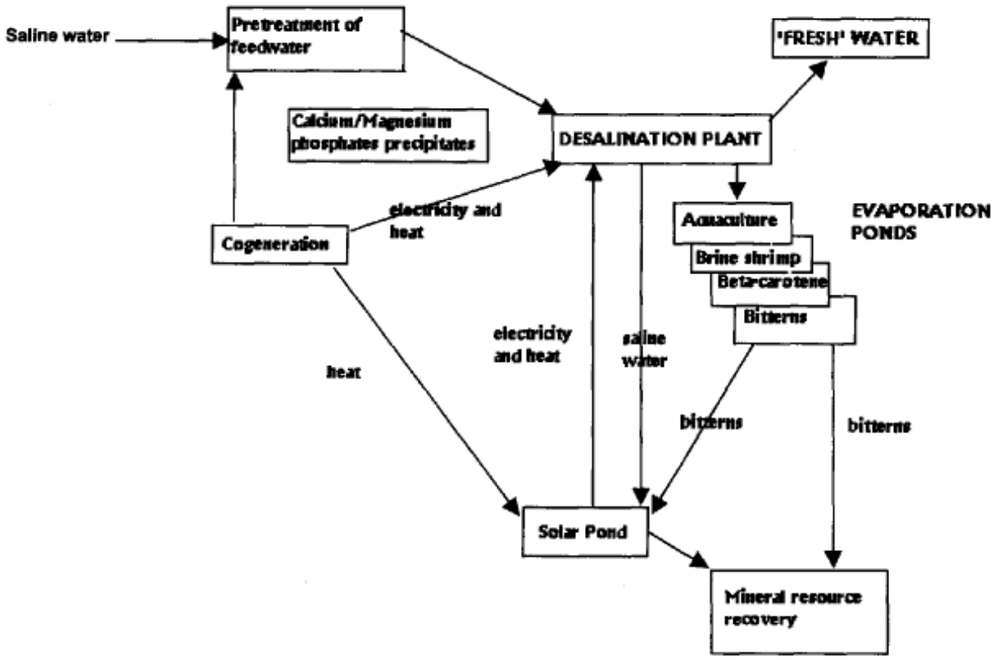


Figure 18. Zero-liquid discharge alternatives.

SWRO DESALINATION PLANT COSTS

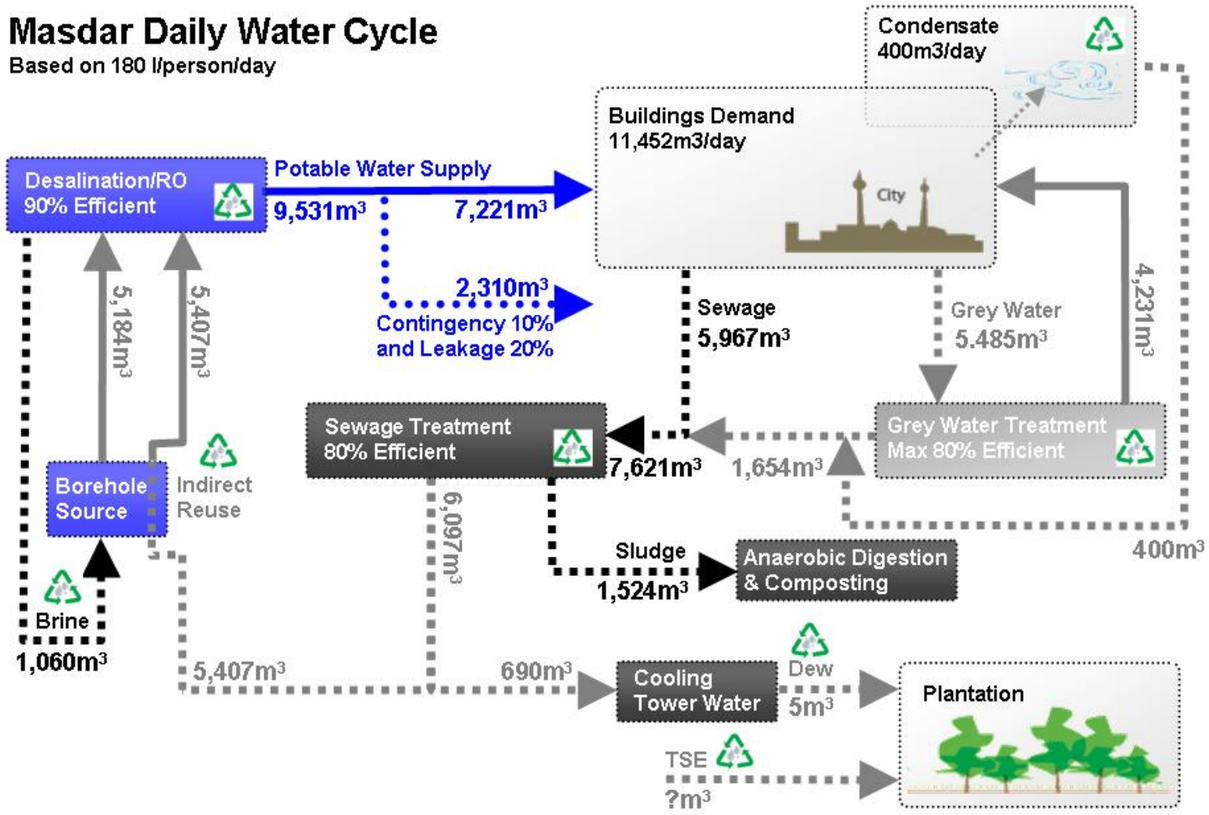
INVESTMENT:

○ Civil works:	15-25%
○ Mechanical equipments:	35-43%
○ Electrical equipments:	10-14%
○ Membranes:	12-18%
○ Control and monitoring:	2-4%
Cost estimation:	**1,000 – 1,400 $/$m^3$/d**

PRODUCTION COST:

○ Amortization:	15-25%
○ Personnel:	10-15%
○ Maintenance and conservation:	3-6%
○ Energy:	35-45%
○ Membranes replacements:	5-10%
○ Chemical products:	5-8%
Water cost estimation:	**0.60 –1.0 $/$m^3$**

The revised water strategy currently being defined in its reference section (see WSP section) envisages a reverse osmosis desalination of the groundwater source, capable of higher levels of recovery fraction for the process, and consequently of lower amount of concentrates disposal.
Based on the result of the hydrogeological investigation of the site, a 90% RO desalination would result in a notably reduced amount of 1060 m^3/d of brine, if compared with SWRO, making it possible the deployment of a strategy for the beneficial use of concentrate, based on one of the technologies previously discussed, which will be precisely identified in the future phases of the development.
In terms of energy requirements, the thermal energy to be supplied (on the conservative assumption of 66 kWh/m^3 of concentrate) results in nearly 25 MWh/y, achievable i.e. with a dedicated 4ha ETC field, conveniently placed in the nearby of the water treatment facility.



Energy Supply Scenarios

Two scenarios are presented for Masdar's energy supply, each with unique advantages and disadvantages.

1. The recommended proposal developing the small square as an energy production field.

2. Leaving the small square for future urban development.

The main supply technologies considered are:

1. PV
2. Concentrating Solar Power
3. Wind Energy
4. Waste to Energy
5. Solar Thermal Collectors
6. Storage

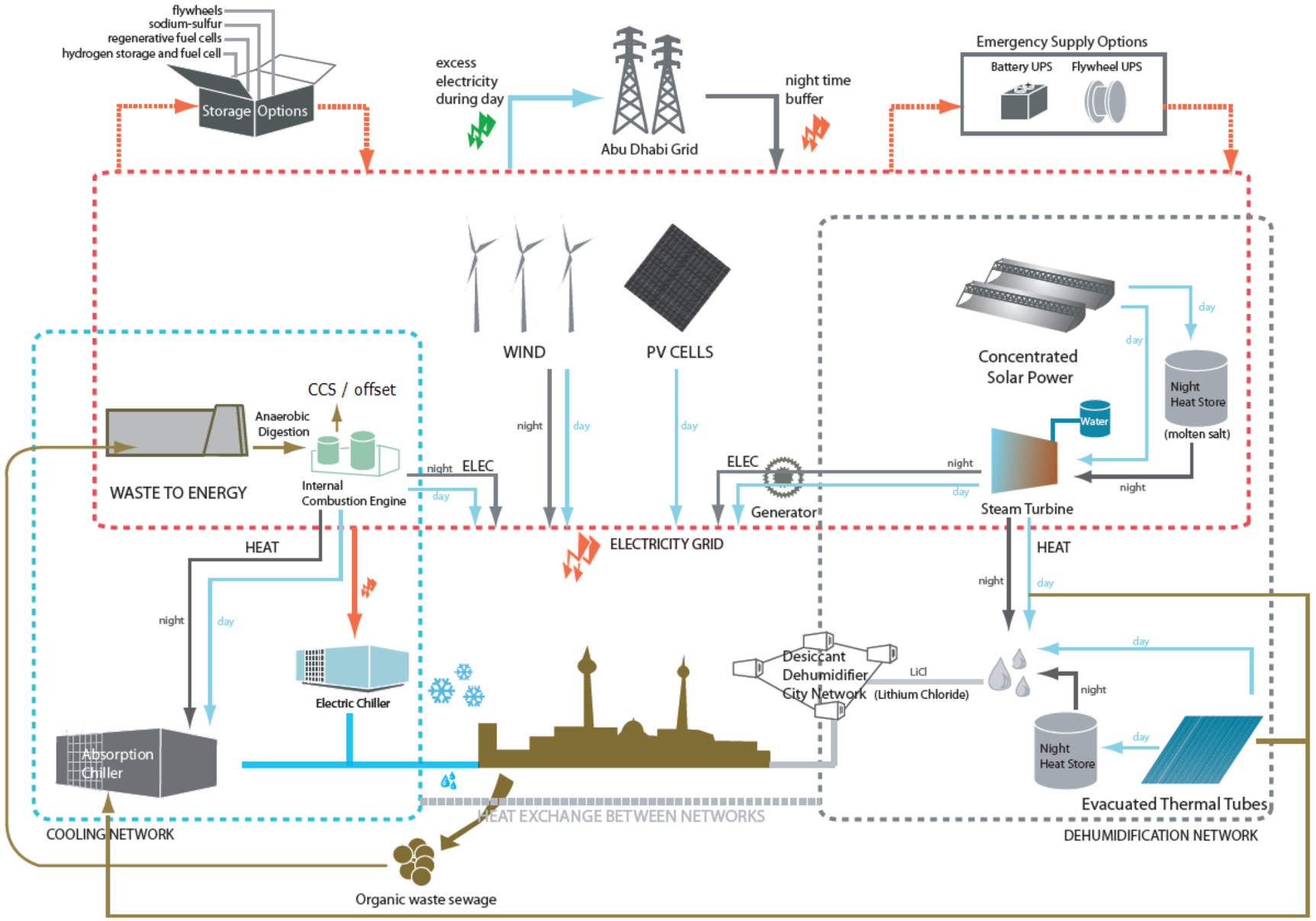
Each of these technological options and their application to Masdar has been assessed in the previous chapters.

While a geothermal potential may exist, it is still not considered in the energy balances presented in the following sections, as the actual power possible cannot yet determined (see Chapter 6.6 for a discussion).

In addition to the "core" technologies, there are several other supply technologies that can be applied in various innovation hubs throughout the zone. These are also addressed in the following pages.

Urban Development on the Small Square

The implications of developing the small square into an urban area are considered separately in Section 6.10.6.



The integrated energy supply scenario is shown above. All the generation and storage technologies are connected to the Masdar city grid, which in turn is connected to the Abu Dhabi grid.

This is the base case scenario of the consultant team.

A CSP plant is located in the small square to the south-west of the city, producing both heat and power. The waste to energy plant also provides CHP.

PV is in located on the building roofs and on the parking roofs. In addition, semi-transparent PV modules cover the courtyards during the day, allowing some light to pass through and providing shading. During the night, they are tilted to allow heat to vent out of the courtyards (See Transsolar chapter for a description).

Wind Energy turbines are located in the south-west corner, along with a few smaller ones across the site.

Cooling demand is separated into sensible and latent (i.e. for dehumidification). 100% of the dehumidification load is covered by thermal sources, using a desiccant dehumidification system (see Transsolar chapter for a description). 30% of the sensible cooling load is satisfied by thermal sources, by using absorption chillers. The thermal sources are the CSP, the waste to energy plant, and solar thermal collectors (here, ETC). The cooling systems themselves are centralized (see WSP chapter).

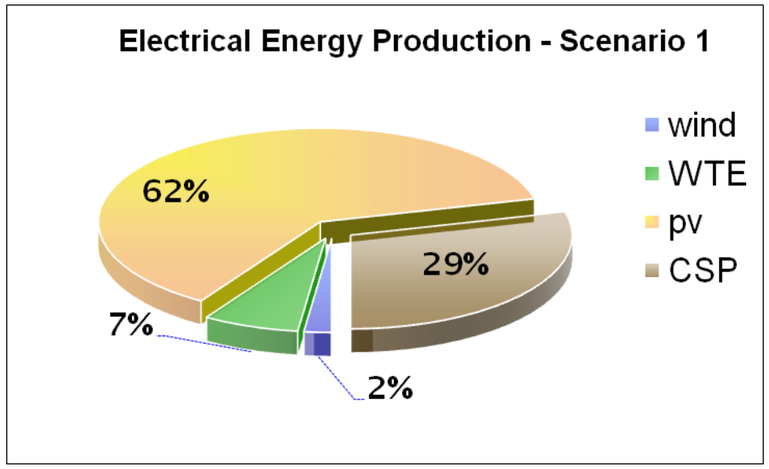
In addition, domestic hot water for buildings can be covered by combined PV/Thermal systems. In this scenario, approximately 7.5% of the building PV systems would have to be of this combined type to cover this demand (i.e. 4.7ha of the 62.6 ha of building PV).

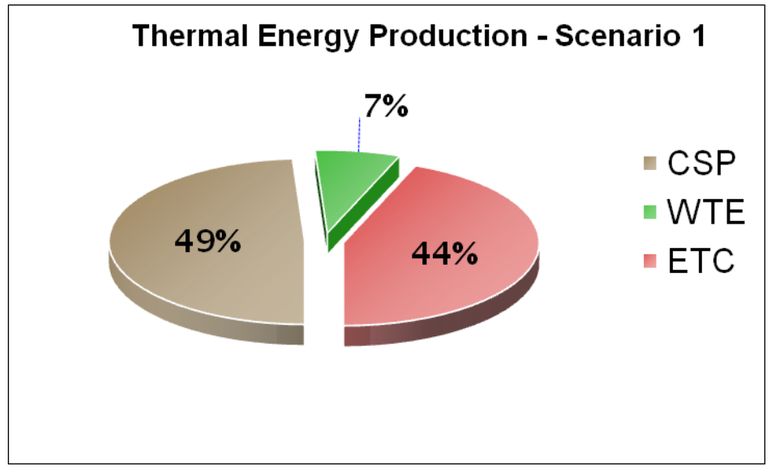
Large scale thermal and cool storage is envisioned to store thermal energy from the ETC collectors during the day for application at night. This required oversizing the solar collectors in order to compensate for the night time.

No large-scale electrical storage is envisioned, aside of course from the grid as a "virtual" storage. Pilot installations for innovative technologies should be installed as described in chapter 6.7, for example flowcells, NaS, hydrogen or flywheel storage.

Concordant with the further demand reductions stipulated in the Transsolar chapter, not all roof-top space is required. Approximately 19ha is free, which is a useful "buffer" for contingencies. Masdar could consider building further energy producing systems (PV) if desired for earning a potential feed-in tariff.

The results in terms of demand versus supply on an annual basis are presented in the table to the right.





DEMAND		**Heat [MWh_th]**			**Electricity [MWh_e]**			
		total	day	night	**total**	day	night	**Peak**
Building non-space energy demand		25,000	12,500	12,500	158,000	92,019	65,981	29.8 MW_p
building sensible demand	278,000 MWh_cool	139,000	90,016	48,984	60,638	39,269	21,369	98.3 MW_p
building latent energy demand	234,000 MWh_cool	260,000	127,920	132,080	4,680	2,303	2,377	113.0 MW_p
distribution					3,160	1,580	1,580	
desalination	9,600 m3/day				14,016	7,008	7,008	
on site traffic, PRT					50,000	37,500	12,500	
street lighting					4,900	0	4,900	
waste treatment					2,950	1,475	1,475	
water distribution					6,600	3,300	3,300	0.8 MW_p
Total		**424,000**	*230,436*	*193,564*	**304,944**	*184,454*	*120,490*	
SUPPLY	**Peak**							**Area**
Wind turbines	4.5 MW_e				6,443	3,544	2,899	0 ha
Small square PV	0.0 MW_e				0	0	0	0.0 ha
Building PV	100.4 MW_e				159,836	159,836	0	62.6 ha
Outside parkings PV	5.5 MW_e				9,065	9,065	0	5.2 ha
Courtyard PV-shading	13.3 MW_e				21,000	21,000	0	24.1 ha
PV/T systems for DHW		28,125	12,500	15,625				*4.7 ha*
Waste treatment plant	2.74 MW_e	29,108	14,554	14,554	21,920	10,960	10,960	
CSP	11.2 MW_e	204,880	104,000	100,880	86,680	44,000	42,680	56.25 ha
ETC needed		186,650	104,613	82,037				24.9 ha
Heat Store from Waste								
Extra PV if all building area used	20.0 MW_e*				33,172 MWh_e			19.0 ha
Total		**448,763**			**304,944**	*248,404*	*56,539*	

*Assuming a mix of crystalline and thin-film (174 kWh/m^2). It is not included in the energy totals.

On this page, and the following one, 6 days are presented as representative situations:

- **Jan 6**: a typical winter day
- **March 26:** a large demand from the Abu Dhabi grid
- **May 27:** a large peak in production to be supplied to the Abu Dhabi grid
- **July 23:** a typical summer day with some cloud
- **Aug 5:** a typical large summer production day
- **Dec 22:** a day in which no power is exported to the Abu Dhabi grid due to low on-site production

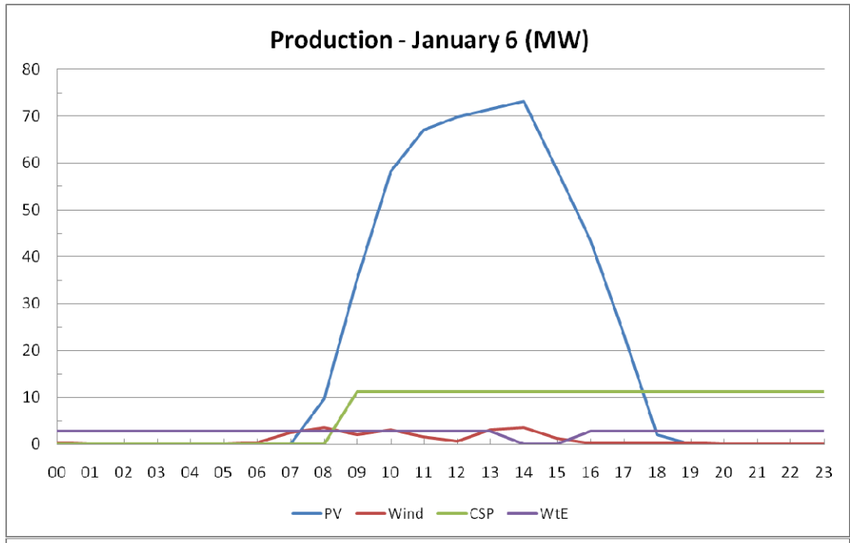
Grid Sales refers to the excess of supply to demand, and Grid Purchases refers to the deficit of supply to demand, here "grid" referring to the Abu Dhabi grid and not the Masdar internal grid.

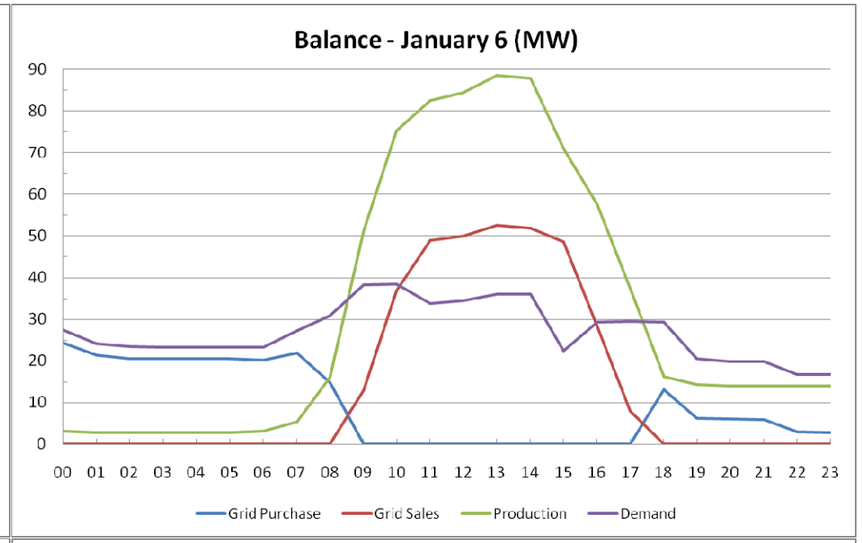
Even on a typical winter day (Jan 6), there is normally a very large excess production, with upwards of 50MW exported to the grid.

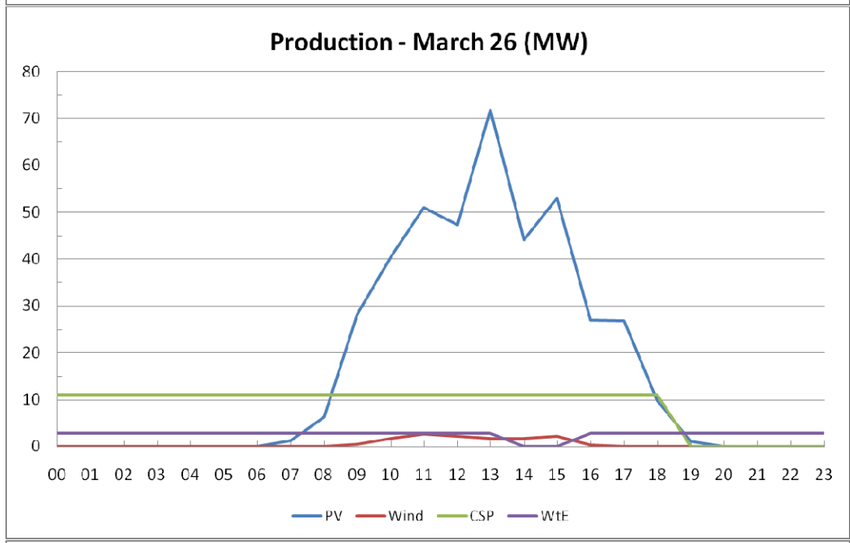
On a very sunny day such as May 27 or Aug 5, the Abu Dhabi grid must be able to accept high amounts of sales, on the order of 85MW.

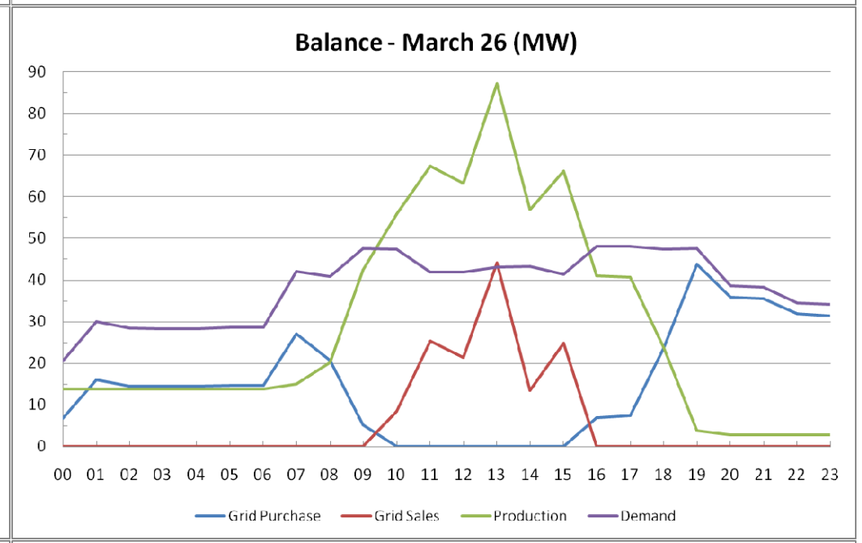
On a day with very low insolation, such as Dec 22, there is no ability to export power, with power being imported all day. Even on such a low sun day, at noon the systems are able to produce a significant amount to reduce the peak demand from the grid to 10 MW.

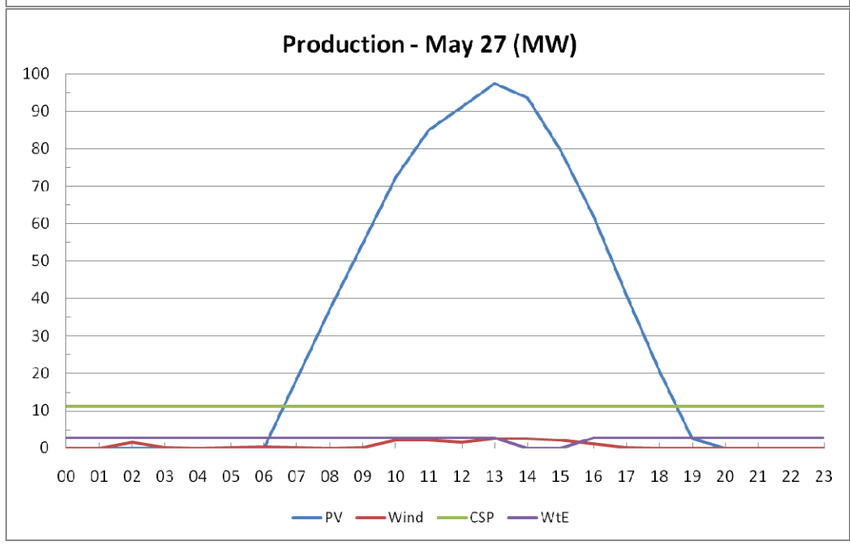
On sunny summer days, the CSP shows continuous energy production, as the storage always contains enough stored energy to keep the plant running, while on very low insolation winter day production can halt.

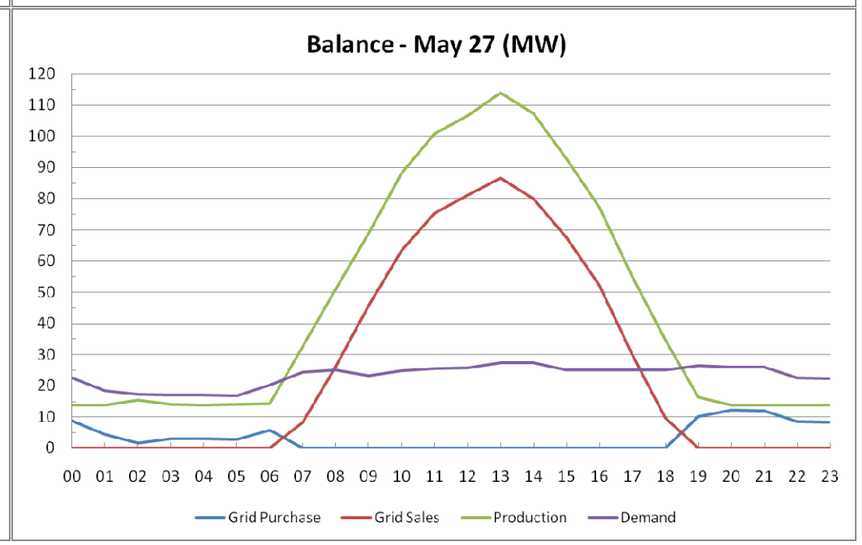




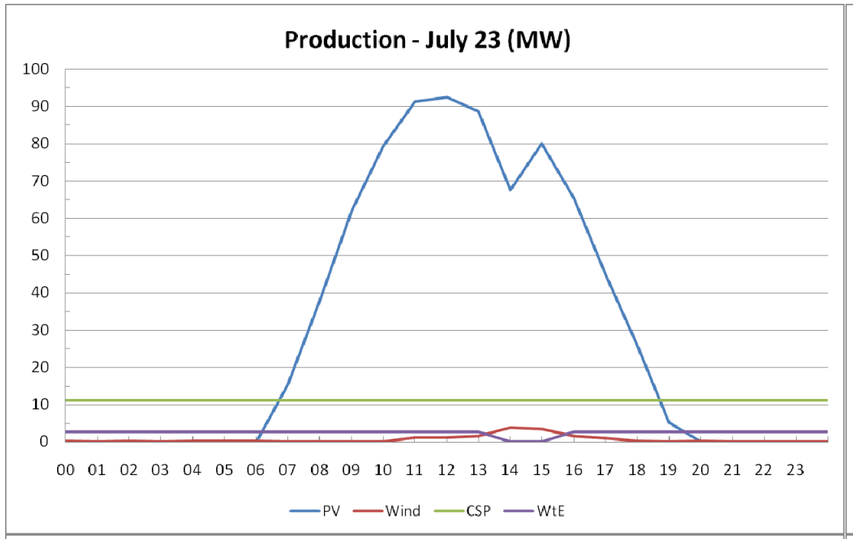


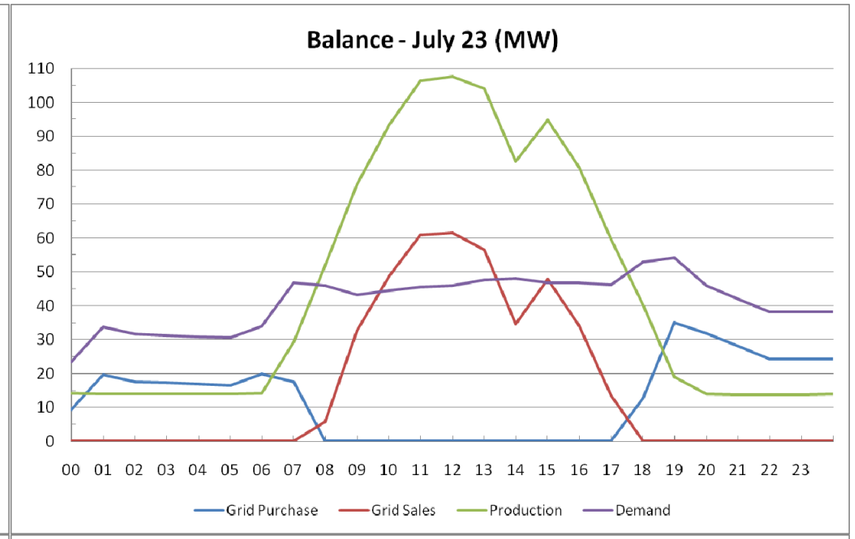


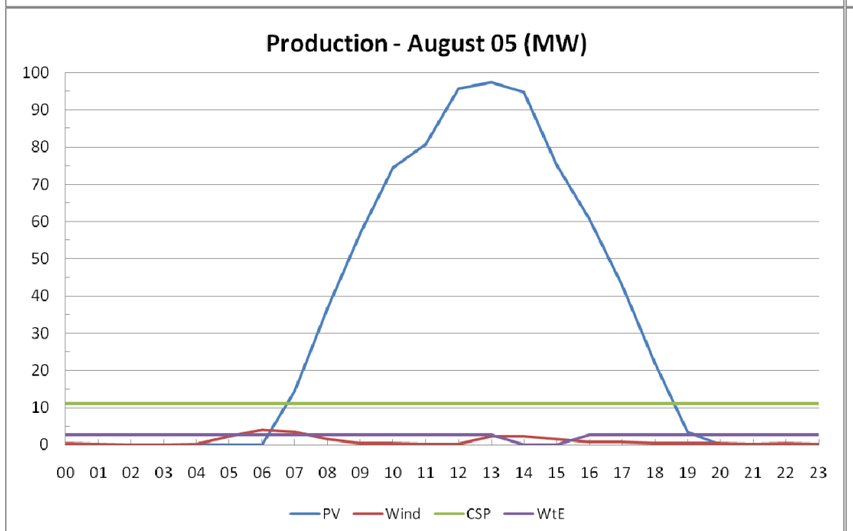


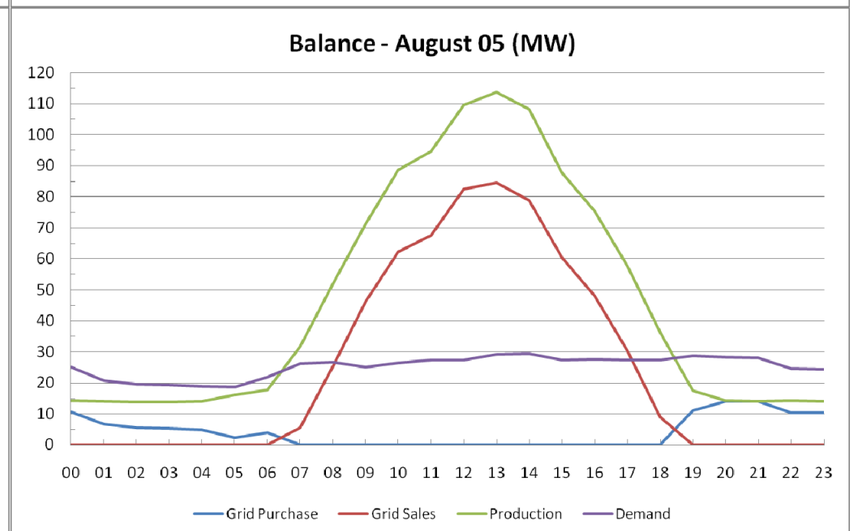


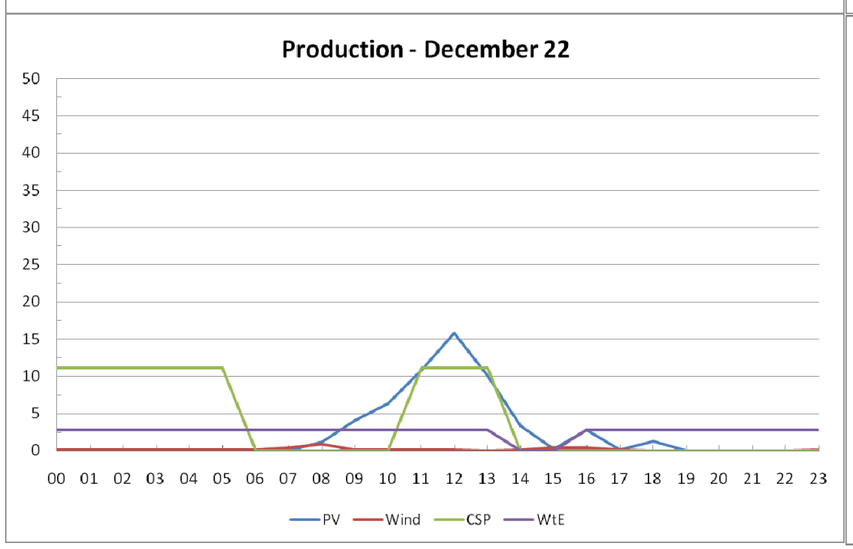
Comprehensive Energy Strategy
Scenario 1

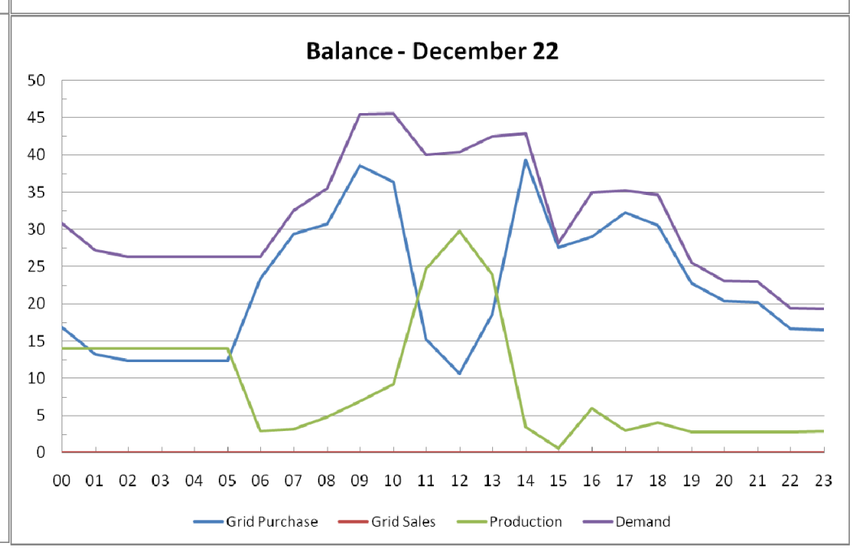






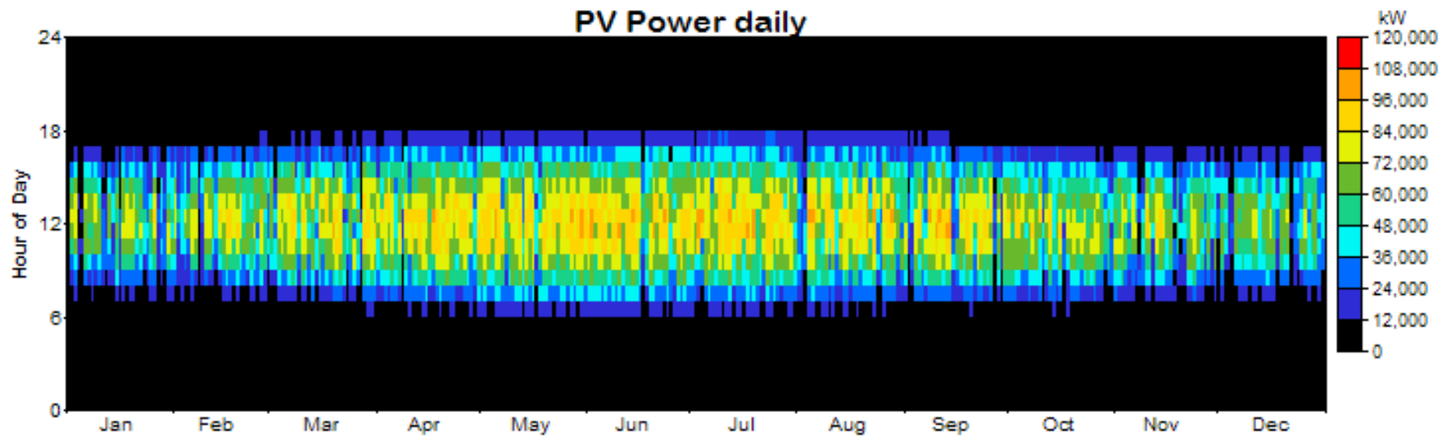


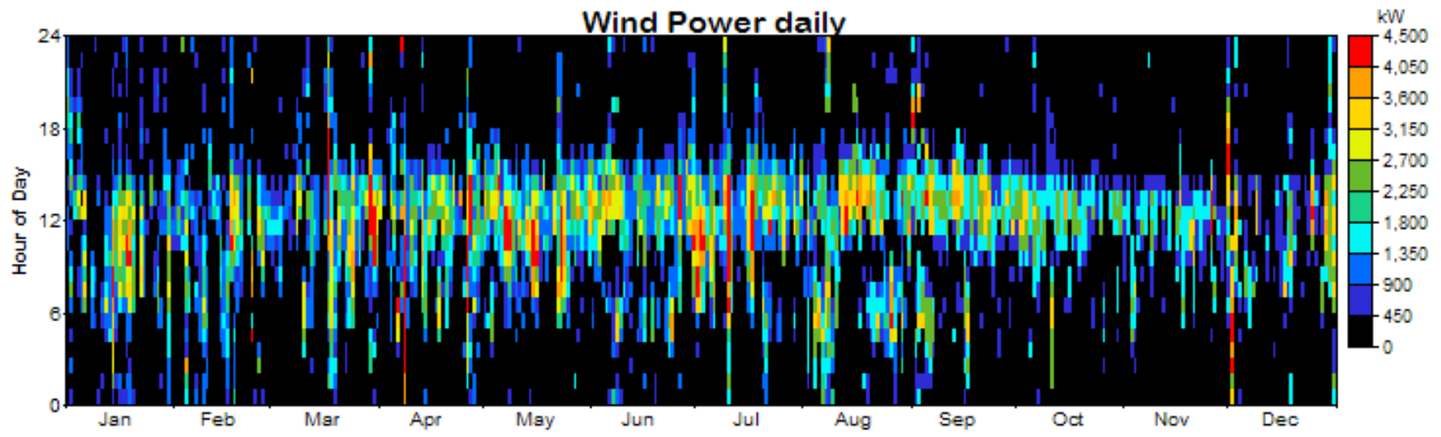




Presented here is the daily power production of PV and wind, shown over the year.

The wind power clearly correlates with the data being collected by Transsolar, showing a high amount of wind during the day (noon), with very little wind during the night, at which point most wind production ends. In such a way, it is quite similar to the solar profile of energy production.





The tables on the right outline the general requirements for the utility operator in terms of buying and selling electricity from the Abu Dhabi grid.

Advantages

As Masdar will be recommending the adoption of state renewable support mechanisms, exporting 100% renewable electricity during peak-demand hours represents an enormous earning opportunity. If a feed-in tariff similar to Germany or Italy is adopted by Abu Dhabi, the very large excess electricity supply during the day could be sold at an attractive rate. In addition, grid prices at peak-demand times (e.g. noun) are several times higher than average, approaching the cost of RE generation in some cases. Thus, the combined earning from a feed-in tariff, in addition to the grid selling-price will make the RE generation a very large net-earner, without regard to carbon-credits or any other mechanism that would be applied as well.

Another advantage is that sensible cooling is mostly independent of thermally-driven chillers, the source of which would partly be distributed solar collectors throughout the city. Especially during excessive demand peaks, electric-driven chillers have a lower risk of not meeting the demand, as opposed to a large solar-driven thermal system. Furthermore, in the case of a multi-day sandstorm, Masdar can rely on the grid for enough energy to provide space-conditioning and electric power, as the PV and CSP would be unproductive. In any case, the innovative solar absorption system is still supported to some extent by Masdar.

If a deep geothermal resource is exploitable, geothermal energy could be used to provide near constant thermal energy for the city's systems. Furthermore, they may be able to run double-effect absorption chillers, thereby increasing efficiency dramatically. The amount of solar thermal collectors would be drastically reduced as well, leaving roof-top space for other purposes (for example more PV if a future feed-in tariff exists). Currently, this is only a future option that may be possible.

Disadvantages

The system is heavily reliant on the grid-connection during the night, and for morning/afternoon spikes in demand, as well as for unexpected peak demands outside of day-time hours (see March 26 as an example). However, these spikes could be smoothed out with implementation of a smaller fraction of the storage systems proposed in Chapter 6.7.

The larger source of energy for sensible cooling comes from a distributed network of solar collectors scattered throughout the roofs of the city. A system of this type, at such a scale, involves a risk, as it not normally applied at such size. One must ensure the utmost care in the detailed design phase. While up to 75% of the sensible cooling could be met by solar thermal collectors, the amount was capped at 30% in order to decrease the risk.

In the event of a severe sandstorm on the order of 3 days, the electric chillers must provide for the lack of solar thermal supply. Otherwise, the city would require on the order of 3 days thermal storage, which would be excessive, and require further oversizing of the solar collectors (currently sized for one day). Thus, grid purchases will rise significantly in these instances. An alternative would be to provide such thermal energy with a backup boiler, fueled by biogas, imported biofuel, or even natural gas for absolute emergencies.

PV power, which provides the bulk of the electricity in this scenario, is more expensive than solar heat on a kWh basis. However, given the low efficiency of absorption chiller systems with respect to electric systems (compare 0.6 for single-effect absorption for the systems proposed in the WSP chapter in Abu Dhabi conditions, or 1.1 for double-effect vs. over 4 for normal electric-driven systems), the cost savings are less significant. Regardless, if a feed-in tariff law were applied to Abu Dhabi, the extra expense of more PV would become a large economic net-benefit that more thermal-based chilling would not provide.

Selling and buying from the Abu Dhabi Grid in average numbers

	Demand	PV	Wind	CSP	WtE	Total Production	Grid Purchases	Grid Sales
MAX MW	**55.2**	**100.3**	**4.2**	**11.1**	**2.7**	**117.9**	**46.9**	**86.6**
AVG MW	34.7	21.7	0.7	9.9	2.5	34.8	11.4	11.4

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)	Peak Demand (kW)
Jan	8,472,729	5,606,568	2,866,162	36,888
Feb	6,448,158	6,822,920	-374,762	40,071
Mar	7,596,701	9,111,202	-1,514,502	43,703
Apr	6,575,013	10,192,520	-3,617,508	33,550
May	7,879,093	11,752,992	-3,873,899	36,143
Jun	7,933,244	10,846,224	-2,912,980	36,320
Jul	8,554,980	10,753,609	-2,198,629	35,722
Aug	9,678,793	8,516,794	1,161,999	46,903
Sep	9,689,809	7,853,880	1,835,930	40,727
Oct	8,945,172	7,128,495	1,816,678	42,202
Nov	9,095,472	5,798,351	3,297,122	43,344
Dec	8,692,337	5,513,779	3,178,558	41,170
Annual	99,561,504	99,897,328	-335,831	46,903

The Electrical Storage option

Masdar could consider a large scale implementation of electrical storage. Not simply for innovation hubs, but in general using some of the new technologies mentioned in Chapter 6.7.

Since centralized electrical systems are being considered, such as centralized electric chillers in order to maximize efficiency of distribution, the storage must also be quite large on a centralized scale. As described in 6.7.1, the traditional stand-alone systems for this are not applicable at Masdar. However, as Masdar is to be a leader in innovation, a large-scale adoption of emerging technologies could be carried out to minimize dependence on electricity import from the grid.

On May 27, for example, 626 MWh excess energy is produced during the day; theoretically this could be stored. NaS batteries could theoretically store this; 1487 modules would be needed, each with a 3.87 m^2 footprint (5 750 m^2 total). 40 2MW units could be considered at this size, essentially providing for 8 hours of bulk storage backup power. Realistically however, this is very excessive and will be extremely expensive. The previous lack of experience at this scale with NaS is another hindrance. In addition to NaS systems, VRB-type flow cells would also be applied to smooth out power flow from stochastic wind and PV generation.
Moreover, a large flywheel system can be used for frequency regulation as described in 6.7.6. Hydrogen storage is not considered here for large-scale deployment, as the other options are more mature, with higher reliability. However, a part of the bulk storage could still be considered using fuel cell systems.

The Masdar internal grid design becomes *very* important if such a large scale electrical storage system is to be applied. The city will essentially be a massive island system with only renewable energy sources, which requires significant planning.

Storage might be considered for one day. As several day storage at this scale would prove too large, both economically, but more importantly physically in a space-constrained site. In the event of a severe power emergency (e.g. 3-day sandstorm), the steam-turbine from the CSP and the gas-turbine of the Waste-to-Energy plant could be operated to satisfy a minimum base-load of essential services. The rest could be provided by the grid. The power for the CSP steam turbine would be provided by an auxiliary boiler (fueled by stored bio-gas, imported bio-fuel, or even natural gas in severe need, which is not contradictory to One Planet Living standards).

Advantages
Masdar becomes much more grid-independent with the use of storage.

In terms of innovation, the latest developments in storage technology are pushed en masse.

Disadvantages

The storage technologies able to make the scenario a reality are only recently becoming commercial, and such application at this scale has rarely been seen. Thus, increased risk is a significant factor, as much more detailed planning is required to avoid grid-failures. Such a pathway is very high risk.

Masdar loses the earning opportunity offered by selling excess electricity to the grid. This is especially significant with the passing of feed-in tariff legislation. In theory, storage could be implemented and the storage technology simply not used in favour of selling electricity to the grid, leaving it as an emergency backup; the cost of such a measure would however be excessive.

Conclusions
The recommendation to use the grid as a virtual storage for the city remains. It satisfies the carbon neutrality aim of the city.

However, as Masdar does aim to be an innovator, certain buildings/sections can be completely grid independent using such storage solutions. MIST for example may consider an option of combined NaS and VRB systems to provide for continuous power.

In this scenario, we examine the energetic implications for the main city square of leaving the 56ha square to the south-west with the option to be developed later. Note that we do not consider here the energy demands of this additional urban development, as this is a future unforeseen development. It is considered an independent "self-sufficient" block. An analysis of the large square *plus* the small square urban developments is carried out in Chapter 6.10.6.

During the first phases of development, a PV-farm is placed in the 56ha square.

From the Foster chapter, there is still space allocated to the south-west of the small square for a smaller CSP system. This system is similar to the one from Scenario 1.

Otherwise, the supply systems are the same, and the cooling system remains as with scenario 1, as presented in the WSP chapter.

Domestic hot water demands in this case require that 9.1% of building roof PV systems be PV/Thermal (i.e. 4.7ha of the 51.7 ha of building PV).

In this scenario, if the small square were then to be sold off later on for development, the PV panels in the farm would clearly need to be moved. The panels could be dismounted, and remounted on the new urban development. However, since less than 50% of the space would be available roof-top space, 50% of the ground-mounted panels would have to move to another setting (to the parks around the city for example).

The energy systems, along with their contributions, are shown in the graphs aside.

The results in terms of demand versus supply on an annual basis are presented in the table to the right.

Advantages
The development can begin immediately with a large PV farm to the south of the city, providing renewable electricity during the construction. This could also be coupled with some storage, e.g. flow-cells, in order to provide continuous power also during the night. More income is generated from PV electricity if a feed-in tariff is instituted.

If geothermal were to prove viable, much of the thermal demand could be covered by such a source, leading to a lack of need of the extra power generator space.

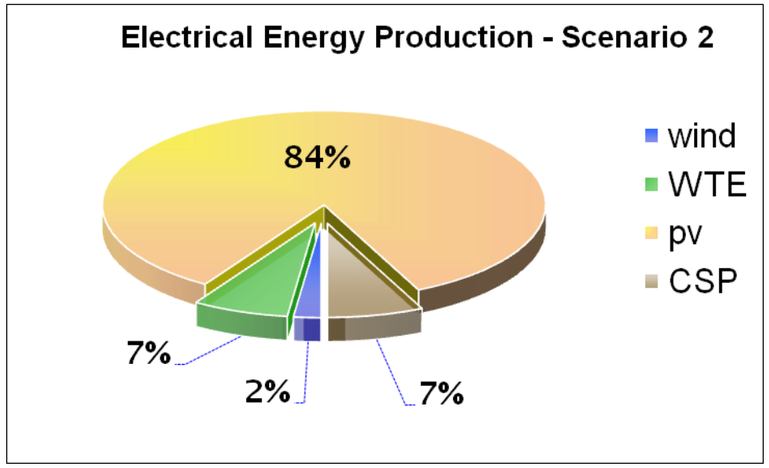
Disadvantages
This type of development is not recommended. The dismounting of PV panels from the ground installation, and remounting onto the roofs could present several problems. The placement of the excess panels that do not fit onto the new development presents a significant problem to solve for Masdar.

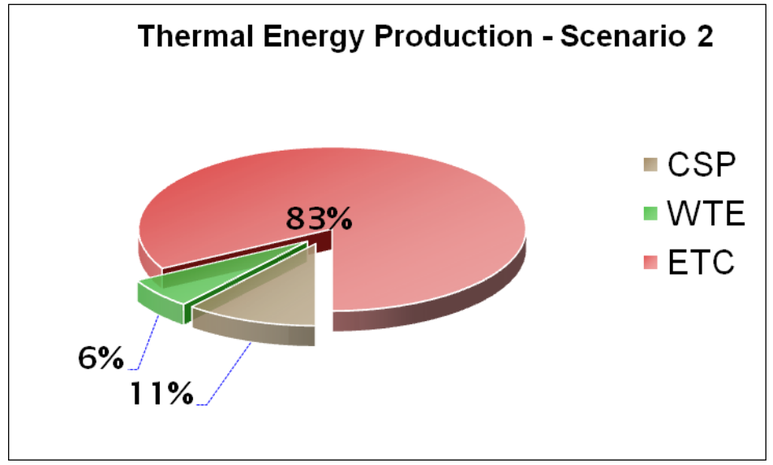
Total PV installations are higher in this scenario, which incur higher costs and do not have easy storage options.

Furthermore, this limits the energy production potential of one of the city's most innovative components: CSP. As CSP is set to become one of the largest sources of energy in the next century, Masdar will not be supporting this development, especially for the very innovative Linear Fresnel systems.

The lack of a significant CSP thermal generating source essentially requires a very great number of solar thermal collectors, which at 49ha presents more infrastructural problems. This could change if the geothermal option were to become viable.

The construction of buildings on the small square would almost certainly lead to problems for the wind farm. The three turbines closest to it would certainly have to be removed, or rather not implemented in the first place. The largest one would also most certainly be abandoned as an option after a turbulence study is possible, being very close to a tall urban development. However, in this case, the extra PV from the PV-farm could be placed in the area formerly occupied by the turbines.





DEMAND		**Heat [MWh_th]**			**Electricity [MWh_e]**			
		total	day	night	**total**	day	night	**Peak**
Building non-space energy demand		25,000	12,500	12,500	158,000	92,019	65,981	29.8 MW_p
building sensible demand	278,000 MWh_cool	139,000	90,016	48,984	60,638	39,269	21,369	98.3 MW_p
building latent energy demand	234,000 MWh_cool	260,000	127,920	132,080	4,680	2,303	2,377	113.0 MW_p
distribution					3,160	1,580	1,580	
desalination	9,600 m3/day				14,016	7,008	7,008	
on site traffic, PRT					50,000	37,500	12,500	
street lighting					4,900	0	4,900	
waste treatment					2,950	1,475	1,475	
water distribution					6,600	3,300	3,300	0.8 MW_p
Total		**424,000**	*230,436*	*193,564*	**304,944**	*184,454*	*120,490*	
SUPPLY	**Peak**							**Area**
Wind turbines	4.5 MW_e				6,443	3,544	2,899	0 ha
Small square PV	57.2 MW_e				93,680	93,680	0	47.8 ha
Building PV	82.9 MW_e				132,032	132,032	0	51.7 ha
Outside parkings PV	5.5 MW_e				9,065	9,065	0	5.2 ha
Courtyard PV-shading	13.3 MW_e				21,000	21,000	0	24.1 ha
PV/T systems for DHW		28,125	12,500	15,625				*4.7 ha*
Waste treatment plant	2.74 MW_e	29,108	14,554	14,554	21,920	10,960	10,960	
CSP	2.7 MW_e	49,171	24,960	24,211	20,803	10,560	10,243	15 ha
ETC needed		365,686	187,813	177,873				48.8 ha
Heat Store from Waste								
Extra PV if all building area used	6.4 MW_e*				10,536 MWh_e			6.0 ha
Total		**472,090**			**304,944**	*280,841*	*24,103*	

*Assuming a mix of crystalline and thin-film (174 kWh/m^2). It is not included in the energy totals.

On this page, and the following one, 6 days are presented as representative of situations:

- **Jan 6**: a typical winter day
- **March 26:** a large demand from the Abu Dhabi grid
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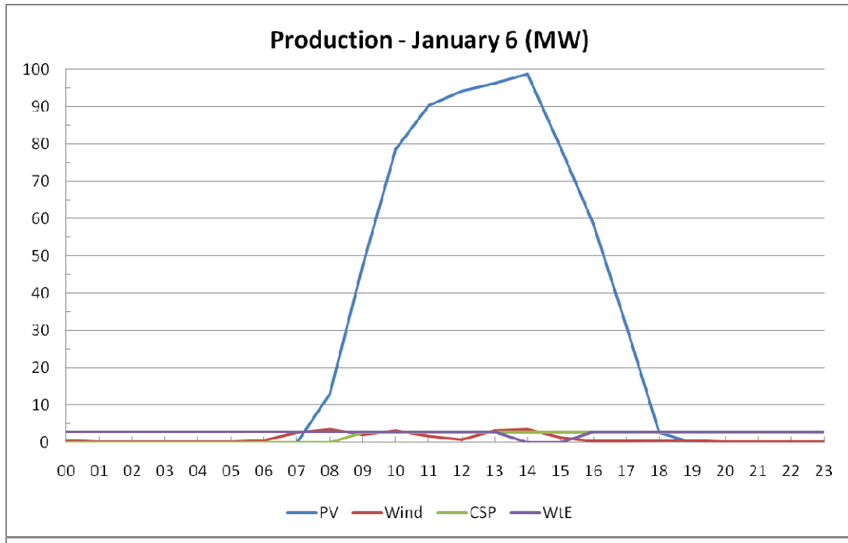
Grid Sales refers to the excess of supply to demand, and Grid Purchases refers to the deficit of supply to demand, here "grid" referring to the Abu Dhabi grid and not the Masdar internal grid.

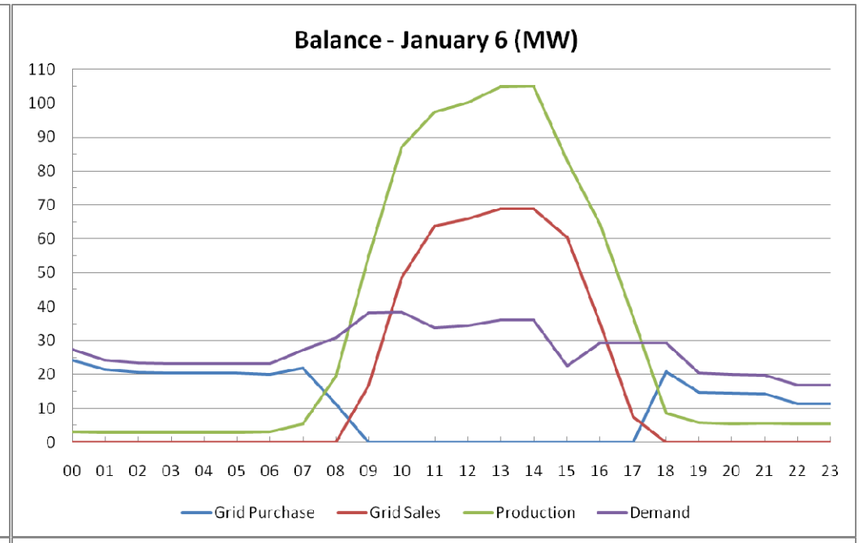
Even on a typical winter day (Jan 6), there is normally a very large excess production, with almost 70MW exported to the grid.

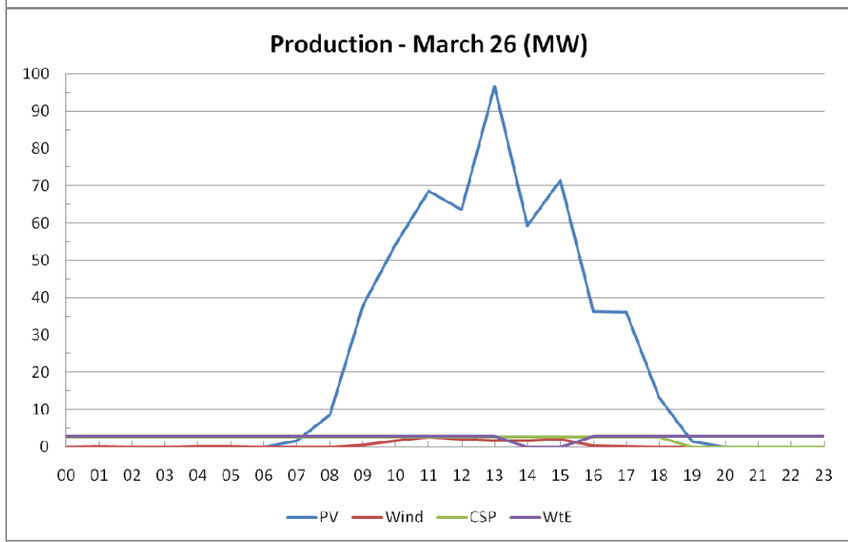
On a very sunny day such as May 27 or Aug 5, the Abu Dhabi grid must be able to accept high amounts of sales, on the order of 110MW.

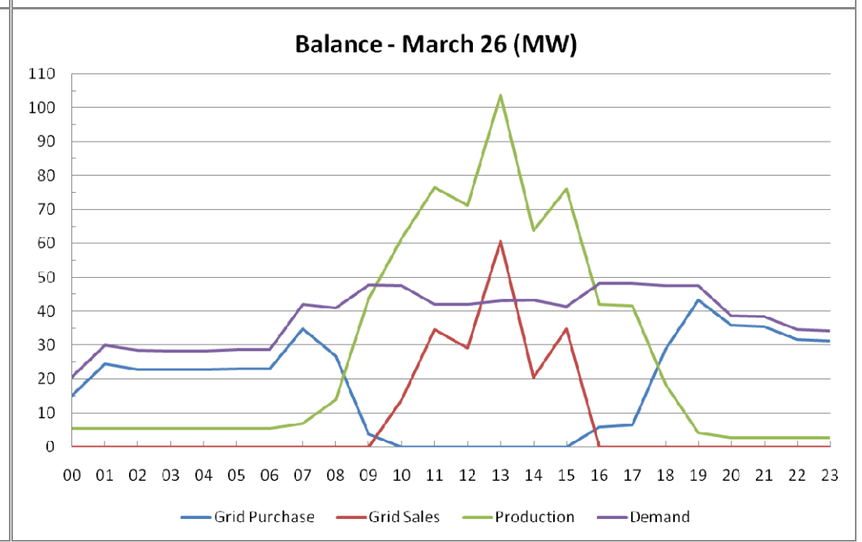
On a day with very low insolation, such as Dec 22, there is no ability to export power, with power being imported all day. Even on such a low sun day, at noon the systems are able to produce a significant amount to reduce the peak demand from the grid to under 15 MW.

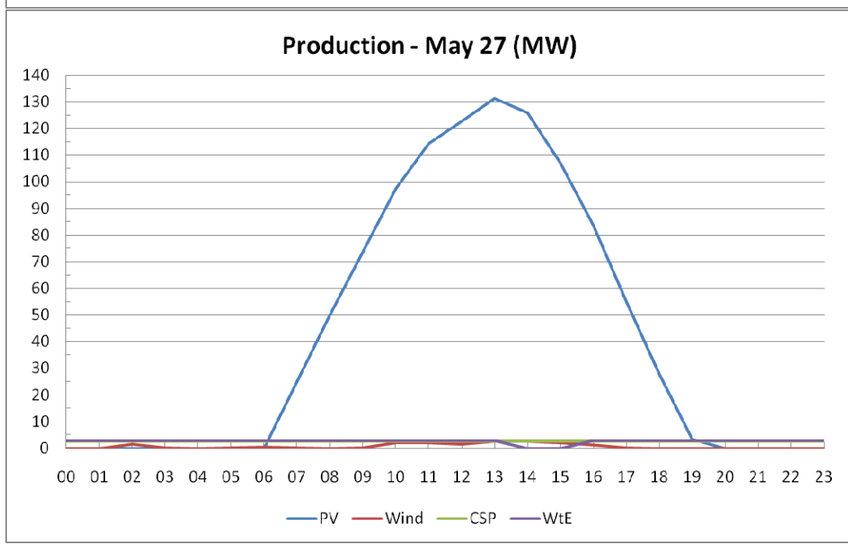
On sunny summer days, the CSP shows continuous energy production, as the storage always contains enough stored energy to keep the plant running, while on very low insolation winter day production can halt. However, it is a very small fraction of total supply in this instance.

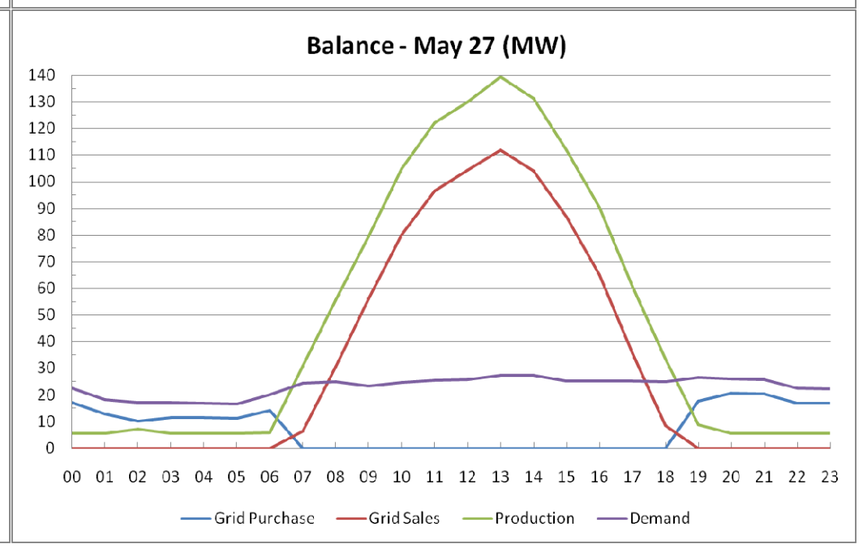


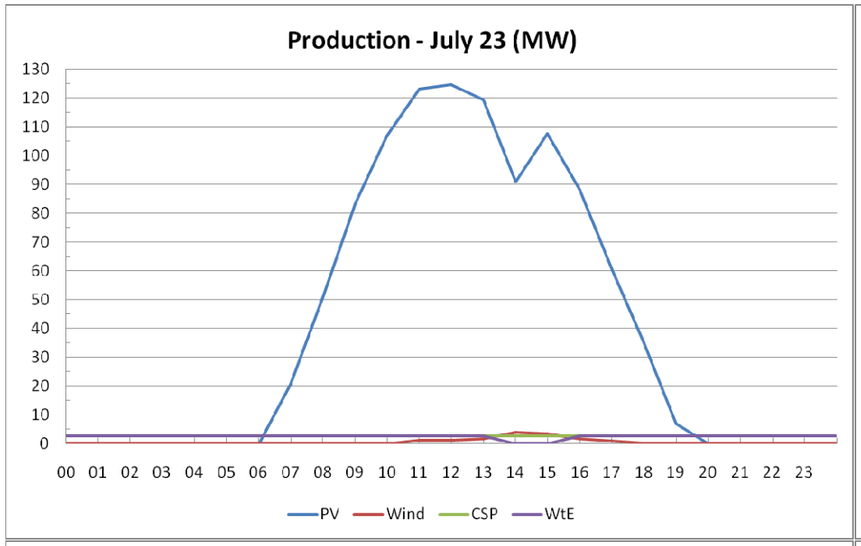


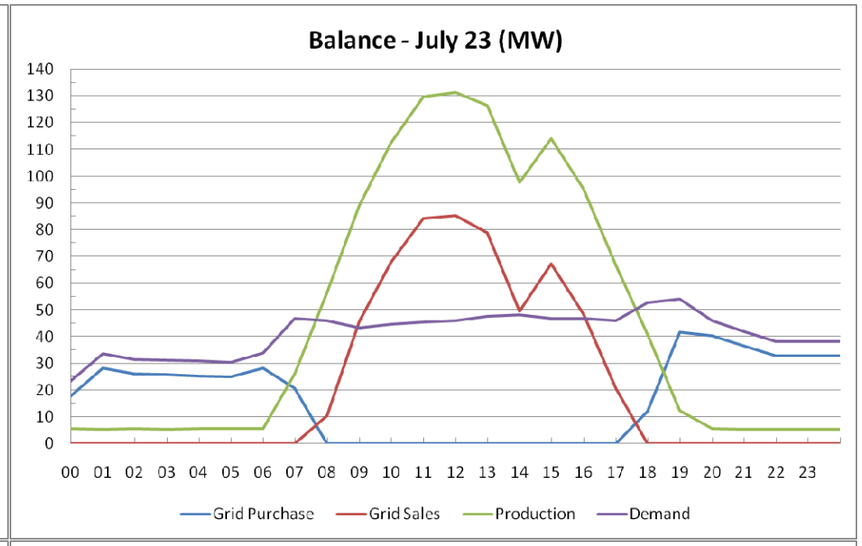


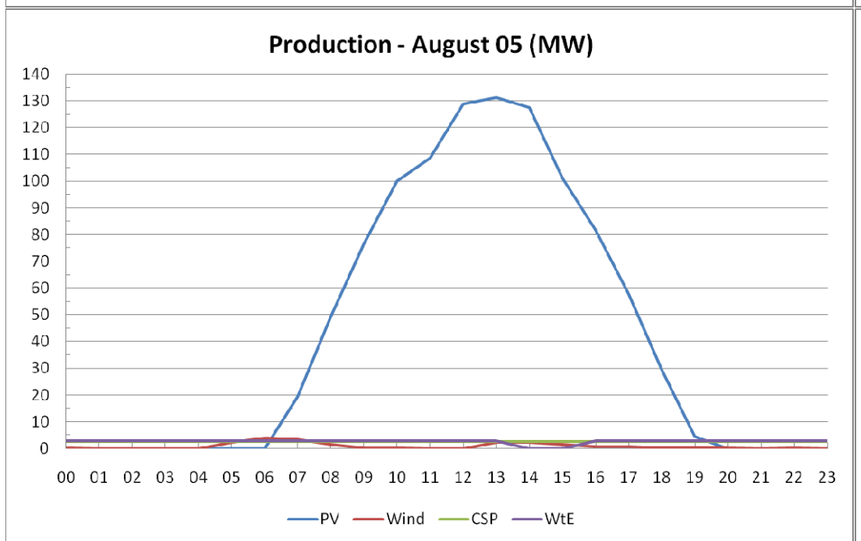







Production - July 23 (MW)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23
PV
Wind
CSP
WtE


Balance - July 23 (MW)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Grid Purchase
Grid Sales
Production
Demand


Production - August 05 (MW)
140
130
120
110
100
90
80
70
60
50
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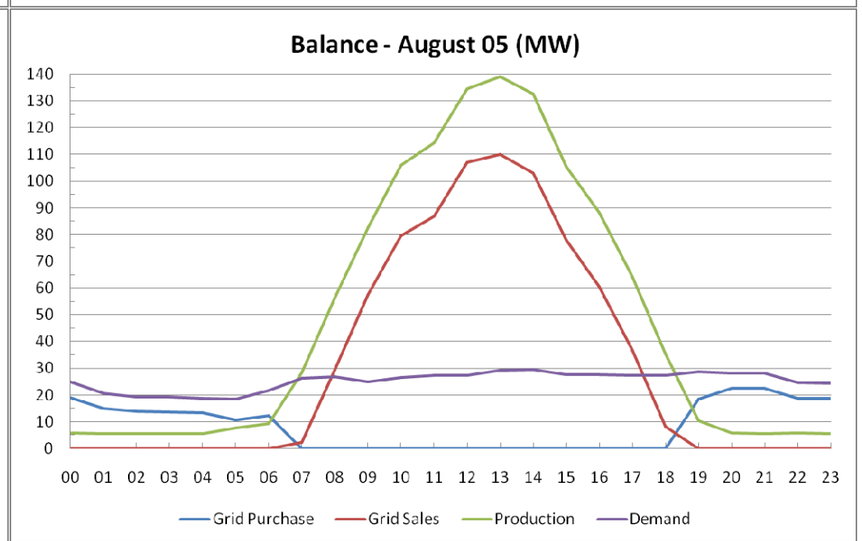
PV
Wind
CSP
WtE


Balance - August 05 (MW)
140
130
120
110
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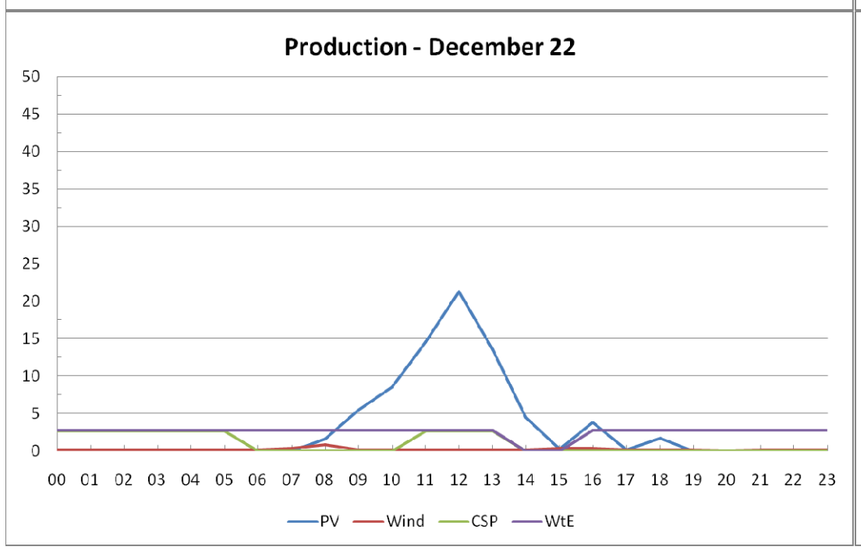
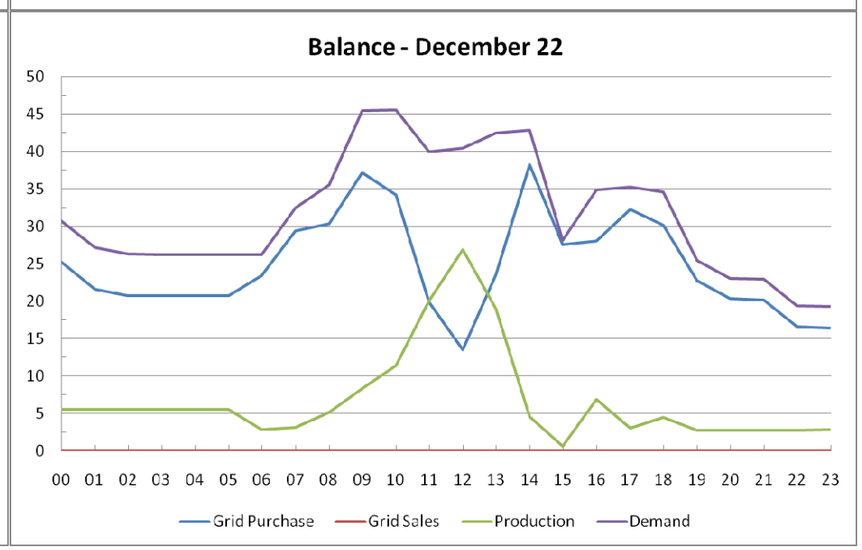
Grid Purchase
Grid Sales
Production
Demand


Production - December 22
50
45
40
35
30
25
20
15
10
5
0
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23
PV
Wind
CSP
WtE


Balance - December 22
50
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35
30
25
20
15
10
5
0
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Grid Purchase
Grid Sales
Production
Demand

On the right, the daily power production of the PV is shown over the year.

The table outlines the general requirements for the utility operator in terms of buying and selling electricity from the Abu Dhabi grid.

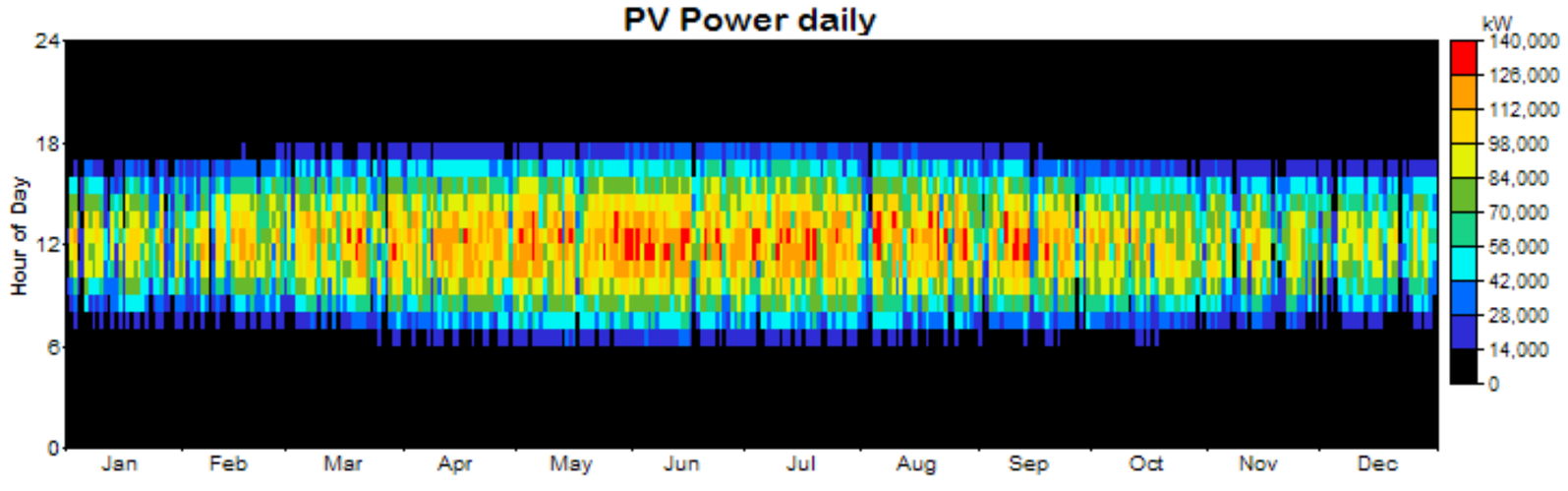
Compared to Scenario 1, there is a larger maximum production, at 144 MW (compare 118 MW), while the demand from the grid is only slightly higher (compare 48 vs.47 MW). This is due to the majority of the demand from the grid taking place in non-sun hours, for which the greater amount of PV in this scenario does not assist.

If of course electrical storage were installed as discussed previously, such peaks would decrease.

Selling and buying from the Abu Dhabi Grid in average numbers

	Demand	PV	Wind	CSP	WtE	Total Production	Grid Purchases	Grid Sales
MAX MW	**55.2**	**135.2**	**4.2**	**2.7**	**2.7**	**144.1**	**48.1**	**112.0**
AVG MW	34.7	29.2	0.7	2.4	2.5	34.8	15.3	15.4

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)	Peak Demand (kW)
Jan	10,594,983	7,217,373	3,377,611	35,851
Feb	8,935,694	8,816,867	118,827	40,071
Mar	10,416,455	12,059,735	-1,643,280	43,341
Apr	9,697,855	13,647,544	-3,949,689	41,469
May	11,019,283	15,908,330	-4,889,047	44,204
Jun	10,907,449	14,888,963	-3,981,514	44,051
Jul	11,779,065	14,757,142	-2,978,077	42,471
Aug	12,722,853	11,798,753	924,100	47,264
Sep	12,431,093	10,770,097	1,660,996	48,139
Oct	12,359,782	9,704,101	2,655,681	45,757
Nov	11,938,835	7,794,091	4,144,744	43,344
Dec	11,118,455	7,160,465	3,957,990	41,170
Annual	133,921,808	134,523,456	-601,658	48,139



There are several novel renewable energy technologies that are not directly considered for Masdar. Many of these might have been considered with different constraints (e.g. larger land-size, or less density, off-site generation possible), while many others are simply not ready for implementation at a large scale for the needs of Masdar. However, many of these technologies are still worthwhile pursuing for experimental purposes. As Masdar aspires to be a hub of innovation for sustainable energy technology, it could consider at least some smaller scale installations, if not on-site, on off-site locations as well.

Ocean and Tidal Energy

Both tidal and ocean energy technologies are reaching commercial application, and while inapplicable at Masdar for on-site generation, could be considered for off-site application.

Ocean Power Delivery Ltd. (recently became "Pelamis Wave Power") is building a 3MW "wave farm" using their Pelamis prototype. According to the company, a 30MW would occupy 1km^2.

Low Temperature Solar-Powered Electricity

Traditionally, solar energy can be converted to electricity directly with semiconductor-based PV technology, or by concentrating the sun's power to make high temperature heat to run a steam turbine. New systems are being proposed to use instead low temperature solar energy to drive a Stirling engine at below 200°C. These systems could be promising, but are mainly at the research stage. Masdar may want to support R&D on such efforts. BSR Solar and INNOWIF GmbH are simply two examples of firms that propose such systems, with BSR having even some rough prototypes in initial development.

Please refer to B. Kongtragool, S. Wongwises / Renewable and Sustainable Energy Reviews 7 (2003) 131–154 for a review of low temperature differential Stirling Engines for solar power.

Solar Desalination

Water can be desalinated directly by solar energy with no chemicals or emissions. Multi-effect humidification systems can produce potable water from only 85°C, and commercial applications do exist. However, the system sizes are generally under 50 m^3/day, which is quite small, and in addition not suited for spaced constrained areas. For example, a 10m^3/day system would require about 500m^2 of solar collectors (i.e. for Masdar's entire water supply, 70 ha would be needed). However, the technology could be implemented on small scale, with manufacturers including Tinox.

Other techniques for solar desalination include using high temperature heat from concentrating collectors (similar to the heat produced for CSP systems, see Section 6.3). This could drive established thermal desalination processes, as used already in the UAE. However, to meet the water demands of Masdar would require space on the order of 80 ha, which again makes application at the space-constrained site difficult.

Other ideas include "Solar Ponds", whereby large bodies of saline water are created that provide heat and allow desalination.

Manolakos et al. (Desalination 203 (2007) 366–374) experimentally evaluate Reverse Osmosis desalination powered by a low-temperature solar organic Rankine cycle. The technology is still at the /experimental stage, but may one day be commercial.

Please also refer to S. Al-Hallaj et al. / Desalination 195 (2006) 169–186, and S. Parekh et al. /Desalination 60 (2004) 167-186 for further discussions on humidification-dehumidification techniques for desalination.

Novel Solar Electric Conversion Technologies

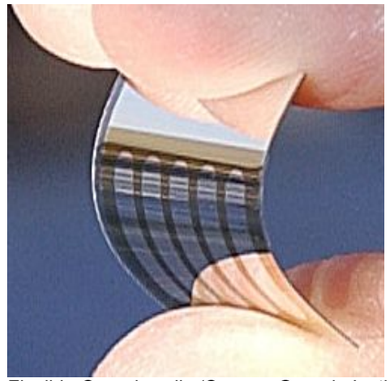
Novel technologies for direct-solar electricity include Titania cells, which operate through an "artificial photosynthesis" process. These devices work with an electrolyte, and are essentially a photo-electrochemical cell. Dyesol of Australia is developing such technology for commercial production.

Other novel technologies that could be implemented at small scale at Masdar include Organic Cells.

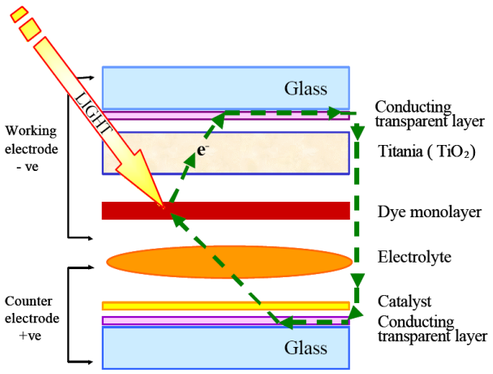
Other Technologies

Other novel technologies for wind and storage have been mentioned in their respective sections

"Sunpulse" solar-thermal pumping system by BSR Solar Technologies (Source: BSR)



Flexible Organic cells (Source: Georgia Institute of Technology)



Titania Solar Cell Structure (Source: Dyesol)

Titania Solar Modules (Source : Dyesol)

Pelamis 750kW Wave Energy Converter (Source: Ocean Power Delivery Ltd.)

Hypothetical Wave Farm (Source: Ocean Power Delivery Ltd.)

The whole Masdar initiative arises from an ambitious vision which enacts constant leadership and focus on the aims of the project.

It is thus essential, for the full success of the initiative that the same vision will continue to support the development once it has begun to come to life, especially as far as its strategic infrastructure backbone is concerned.

The high level of technologies involved at Masdar, and the degree of innovation and integration envisaged, clearly require a direct management of almost all the infrastructures, for all the phases of planning, realization and operation of the initiative, in order to ensure the achievement the proposed goals of the project.

For instance, the widespread implementation of solar panels over almost all the roofs of the city will require the execution of a detailed and accurate maintenance programme which, if left to the “good willing” of the various developers, might not be completely carried out, endangering the energy balance of the entire city.

Like the most common public utilities, the Masdar company should act as a major player with the other utilities of the region, being the only responsible of the main infrastructures of the development:
- electricity distribution and generation;
- heat distribution and generation;
- water purification and distribution;
- sewage and waste treatment.

The “Masdar Utility” should be implemented to oversee the distributed energy production facilities, the biggest infrastructures such as the CSP and the WtE plants, the distribution networks, constantly monitoring and managing the internal loads and the supply and the exchanges with the external networks.

If the small square is developed, the energy picture of the city changes rather drastically.

The main problem is that the small square is lost as an energy generation facility, be it CSP or PV or any other source.

Furthermore, the placement of an urban development almost certainly excludes the possibility of placing wind turbines in the south-west corner due to both turbulence for the turbines and the vicinity to the city. Some smaller turbines could still be placed in the parks around the city as discussed in Chapter 6.5, but amounts to very little in any case.

The extra electrical and cooling loads requested by the small square now not only have to be accounted for, but also the the lost generating capacity. Essentially, extra land for generating power will be necessary.

The only probable possiblity for the combined large and small square to function would be if a geothermal plant could be possible. Depending on the size, such a system could provide both the missing cooling and electric loads that were previously satisfied by the CSP. However, it is still not possible to evaluate the viability of the geothermal option at this stage.

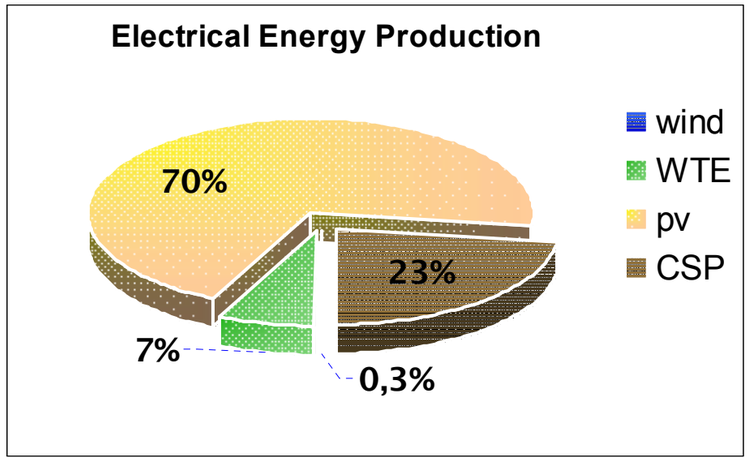
A high level analysis was carried out on the combined large and small square urban loads. The demands for the whole city were scaled up by a factor related to the energy demand of the large square versus the small square. However, no detailed simulations were carried out as presented in the previous sections.

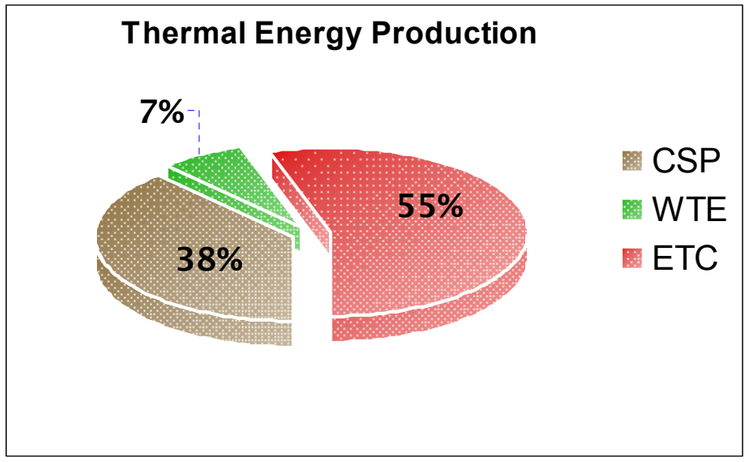
To the right is a preliminary analysis of the energy implications for the new city arrangement.

The configuration shown here is the same in terms of sensible and desiccant cooling, which remain driven by thermal sources at 30% and 100%, respectively.

If all cooling was done electrically, the total area requirement of PV and ETC would be less, but still much greater than the total available roof-space (133.3ha).

To sum up, what is clear from the preliminary analysis carried out is that the demands of both the large *and* small square cannot be met by roof-top systems alone, be they electrical or thermal. An extra generating capacity *must* be present. In the table presented, an 11.2 MWe CSP system operating with night-time storage is proposed. Geothermal may also be able to play this role. If no geothermal capability ends up being possible, then additional land somewhere outside of the city must be allocated to some form of PV, Wind, or CSP energy generators. CSP may be avoided if all-electric cooling is carried out, but there would still be the need for more electricity generation.





DEMAND		**Heat [MWh_th]**			**Electricity [MWh_e]**			
		total	day	night	**total**	day	night	**Peak**
Building non-space energy demand		32,527	16,263	16,263	199,179	116,002	83,177	
building sensible demand	353,631 MWh_cool	176,816	114,506	62,310	77,134	49,952	27,182	
building latent energy demand	297,507 MWh_cool	330,563	162,637	167,926	5,950	2,927	3,023	
distribution					4,807	2,404	2,404	
desalination	12,102 m3/day				17,669	8,834	8,834	
on site traffic, PRT					63,030	47,273	15,758	
street lighting					6,177	0	6,177	
waste treatment					3,719	1,859	1,859	
water distribution					8,320	4,160	4,160	
Total		**539,905**	*293,406*	*246,499*	**385,985**	*233,411*	*152,574*	
SUPPLY	**Peak**							**Area**
Wind turbines	1.0 MW_e				1,232	678	554	0 ha
Small square PV	0.0 MW_e				0	0	0	0.0 ha
Building PV	148.0 MW_e				235,698	235,698	0	92.3 ha
Outside parkings PV	5.5 MW_e				9,065	9,065	0	5.2 ha
Courtyard PV-shading	16.3 MW_e				25,677	25,677	0	29.5 ha
PV/T systems for DHW		36,592	16,263	20,329				*6.1 ha*
Waste treatment plant	3.45 MW_e	36,694	18,347	18,347	27,632	13,816	13,816	
CSP	11.2 MW_e	204,880	104,000	100,880	86,680	44,000	42,680	56.25 ha
ETC needed		301,704	162,943	138,761				40.2 ha
Heat Store from Waste								
Extra PV if all building area used	0.8 MW_e				1,243 MWh_e			0.7 ha
Total		**579,870**			**385,985**	*328,934*	*57,051*	

*Assuming a mix of crystalline and thin-film (174 kWh/m^2). It is not included in the energy totals.

Innovation at Masdar

Masdar with its sustainability goals and 100% renewable supply is a city like no other. A complete renewable supply for such a large community in such harsh conditions is a world's first.

Masdar is innovative on many levels, and the report has discussed the most innovative technologies being considered for application.

While there are many areas of innovation, we present a brief discussion of three:

1. **Large-scale roof-top generation:** The master plan shows that, with a concomitant decrease in demand, a large share of the energy supply of a city can come from its roofs, in terms of PV electricity and solar thermal energy. Semi-transparent thin-film PV will be a large player in the future of BIPV, whose application is suggested in the Master Plan. Another particular innovation here is using PV for both electricity, and for domestic hot water production through the usage of combined PV/T systems. Lastly, an extended network of ETC/PTC collectors is also distributed on the roofs, providing thermal energy for cooling.

2. **Combined Cooling, Heating and Power:** The city will have in its vicinity a concentrating solar energy power plant providing both heat and power. In particular, the Linear Fresnel which is an emerging technology at the cutting edge. CSP in general will in the future provide a large share of the world's energy requirements, and in this way Masdar is paving the way for the energy supply system of the future. In addition, the system will operate during the evening with the use of innovative molten salt storage. These points to the future where no fossil fuel generation will be possible. In addition, the use of the heat in a distributed network (along with the roof-top solar collectors) to provide district cooling for the entire city has not been applied at such a large scale using solar energy. In particular, the usage of a distributed liquid desiccant system for dehumidification is at the cutting edge of application.

3. **Beneficial use of concentrate:** The salinity level of the Persian Gulf is alarmingly increasing, due to the massive brine discharge occuring as disposal of the process of the seawater desalination.
The implementation of an environmental friend technology for the brine treatment, aimed at reducing all the potential risks, would be the first on a city scale level, and a leading example for the region.

The residents of Masdar will *see* the energy generation technologies which are enabling life in the city. Residents in normal cities are largely unaware of the support structures required to enable life in the city, but with wind and solar power very close by, they only need to look out their wind to remember what makes the city function.

Innovation Hubs

In addition to the "core" supply for the city suggested, several innovation zones, or "hubs", should be considered by Masdar. The most innovative supply and storage technologies have been discussed throughout the various chapters. These can be used in a variety of ways in independent parts of the city as showcases for Masdar's support for clean energy development.

Some examples include:

- Buildings autonomous from the Masdar grid, using hydrogen fuel cells for combined heat and power. The hydrogen could be produced by a variety of innovative ways discussed in Chapter 6.7.
- Urban wind turbines on specific buildings, as outlined in Chapter 6.5.
- Usage of innovative flowcell and sodium sulphur battery solutions to provide sections of the city with 100% renewable electricity all day long.
- Small-scale concentrating solar power to power an organic rankine cycle turbine
- Low-temperature solar thermal powered electricity as outlined in 6.10.4
- Solar desalination as outlined in 6.10.4
- Concentrating PV and thermal photovoltaics
- A fuel-cell could be considered to replace the turbine in the waste-to-energy plant, thereby increasing the plant's electrical efficiency.
- An Enhanced Geothermal, or "Hot Dry Rock" system can be built as a prototype plant if the geological survey provides positive results, as explained in Chapter 6.6. Such technology has only a handful of applications worldwide and would position Masdar as an innovator for the future of geothermal energy.
- Carbon Capture and usage or storage, as explained in Chapter 6.8.

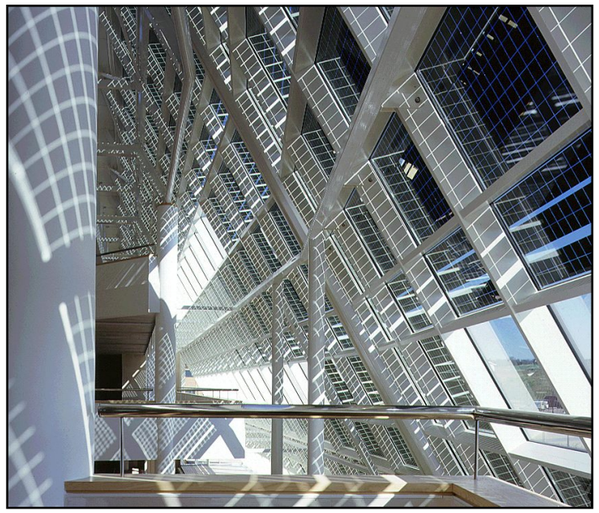
MIST Campus

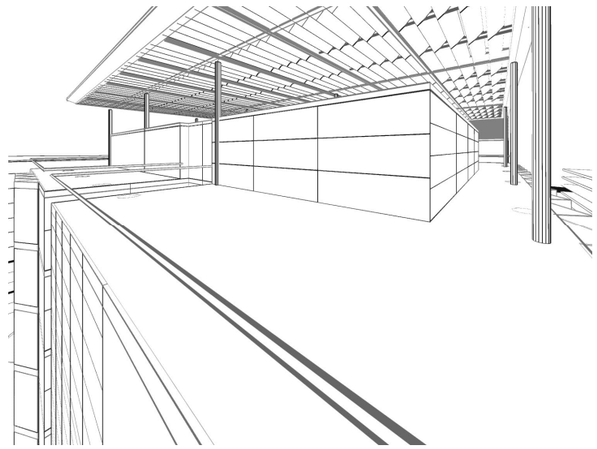
Construction begins almost immediately for the MIST university research complex. As the institute will strive to be a leader in sustainable technology, the innovative technologies described within this report should be supported, especially a mixture of what is suggested for innovation hubs.

In particular, the MIST campus could be designed as a 100% independent power system. With the initial PV farm being put into operation during the construction phase, electricity could be stored for night time usage using a combined VRB and NaS storage system. For cooling demand, high temperature parabolic trough collectors could be installed on the roof to power double-effect absorption chillers operating at high COP. In addition, night operation could also be achieved with a hydrogen fuel cell working in combined heat-and-power mode. A mini-grid on the campus could also have a connection to the Masdar city grid (which is itself connected to the Abu Dhabi grid), but in times of need the MIST campus could go into island mode without need for support.

In order to size the electrical and thermal storage options for MIST, a detailed analysis of the exact buildings being proposed should be undertaken, in order to have a precise energy demand curve.

MIST can therefore act as the initial catalyst and beacon for the further development of Masdar, pushing the boundaries even further than what has been done for the entire city.





One of the central aims of Masdar is carbon neutrality.

Currently on-site a waste-to-energy plant is proposed. Such a plant will emit far fewer greenhouse gases (GHG) during operation than the normal waste treatment options in Abu Dhabi (landfill). In any case, a small amount of CO2 is emitted.

According to the estimates in the WSP chapter, 11 400 tonnes of non-organic CO2 are emitted. These emissions need to be mitigated in some fashion to reach carbon neutrality.

An explanation is needed as to why only non-organic CO2 is under consideration. In the lifecycle of organic material (plants, for example), CO2 is absorbed from the atmosphere. Eventually, the CO2 absorbed is released when, for example it is eaten, or decomposed. In such a way, biomass-fired generation is considered carbon-neutral by international emissions standards, as the material being combusted is only releasing carbon that had already existed in the atmosphere. The next generation of plants will reabsorb this CO2. In the waste-to-energy plant, a significant portion of the input material is from organic sources (roughly one third). Thus, only the other two thirds are considered in GHG calculations.

One can calculate the approximate amount of electricity that would generate such emissions. Considering that the Abu Dhabi grid will have considerable oil-fired generation by the time of Masdar's operation, the grid electricity may have emissions of up to 850 g CO2 per kWh (see WSP chapter). Assuming 800g, 14 250 MWh_e would be equivalent to 11 400 tonnes.

Renewable energy "emissions"

Renewable energy systems are generally emission free during their lifetime. PV and Wind emit absolutely no GHGs.

However, the process of manufacturing the renewable energy systems *does* produce emissions. Firstly, since electricity is not 100% renewable today, any usage of electricity in manufacture has emissions related to it. Secondly, many manufacturing processes use fossil fuels. Thus, while zero-emissions during usage, there are "life-cycle emissions".

PV manufacture used to have very significant emissions, as parts of production can be very energy intensive; life-cycle CO2 emissions of 200 g per kWh were realistic in the past. In the past 10 years however, many efforts have been made to tackle such issues, and current life-cycle emissions under 50 g per kWh. Thin-film PV, which has less energy intensive manufacturing, is projected to fall much lower.

Other renewable energy generation options generally have lower lifecycle CO2 emissions. Wind: 12 g per kWh, solar thermal: 20g per kWh, hydro: 8 g per kWh.

In any case, the emissions from renewable energy generation are still at least 10 times less than gas-fired generation (comparing PV), and 20 times less than coal. As more RE is used in national grid networks, the life-cycle emissions of RE will decrease even further.

Mitigation options

1. The first option for producing carbon neutrality is actually for *zero*-carbon onsite:
   Direct Carbon Capture

   Carbon Capture is outlined in detail in Chapter 6.8. It can either be used in industry or agriculture, or it can be stored in deep reservoirs, or even used for enhanced oil/gas recovery. The carbon capture option is the only way to physically have zero CO2 coming out of the waste-to-energy plant.

Instead of capture, there are two forms for offsetting the carbon that would take Masdar to carbon neutrality.

2. *Plantations*
   The urban greenery of Masdar will absorb certain amounts of CO2. In addition, specific plantations could be considered that absorb CO2 faster than others (for example algae). Such plantations will absorb CO2 from the air around Masdar and thus contribute to reducing emissions. These plantations can also be considered off-site. Please see the Foster chapter for further detail.

3. *Renewable Energy Offsetting*
   In this option, excess renewable energy is produced to offset the CO2 emissions. The rational here is that when the RE is exported to the Abu Dhabi grid, it will replace the generation from a fossil-fuel plant, in which case the emissions caused by the grid are not created. For example, to offset the 14 250 MWh_e, about 8.9 MW of PV would be required at Masdar. In the first scenario, there is sufficient extra roofspace to place such panels. However, one must of course remember that even with producing renewable energy, some life-cycle emissions would be created in any case, and thus absolute zero emissions not possible over the entire life.

GHG Definition

Before a GHG mitigation option is pursued, the actual emissions boundary must be drawn. Here only emissions during usage are considered. If emissions from construction, or embedded carbon of buildings were to be considered, there would be significant implications for mitigation options.

Risks

Masdar, being a completely new, unique development like no other has many risks associated with it.

There are four main risks involved with energy supply. They are outlined briefly in the upper table on the right.

1. **Availability**
   Procurement of several of the technologies takes time and a good overall strategy. In the case of rooftop PV, if several individual contractors independently search for PV they may hit a problem in acquiring their modules in time. A wise procurement would potentially initiate supply arrangements with major PV manufacturers for the entiretly of Masdar in order to ensure supply to the building developers.

   Furthermore, the lead-times of some of the technologies can be very long; this creates pressure with the currently short construction time-frame of Masdar. This is especially true as many of the energy supply options are at the cutting edge. Hot Dry-Rock Geothermal systems are not off-the-shelf and can require several years of development before construction can even begin. CSP is limited by the small amount of suppliers around the world. Lead-time is also limited by the further measurement studies needed before design can begin.

2. **System O&M**
   The decentralized energy supply system at Masdar requires very special operation and maintenance structures; otherwise, the systems risk malfunctioning. This should not be left to developers themselves; rather, Masdar needs a concrete strategy to address the issue, as outlined in Chapter 6.10.5. In the case of PV, generation failure would result in increased grid reliance. However, the risk is higher for the solar thermal collectors, as the cooling load would risk not being met.

3. **Integration**
   Previous experience integrating so many RE technologies at such a scale does not really exist. This is particularly true for the distributed solar thermal collectors, for which the hot water is transported to a centralized cooling unit for the city, rather than decentralized systems for each building. The viability of such distributed heat generation must be further studied in detail at this scale.

   Furthermore, the ability of the Abu Dhabi grid to accept the amounts of power being generated as described earlier must be postively confirmed.

4. **Production Decreases / Increases**
   The best efforts were made to estimate the energy potential at the site with the data available. However, no site measurements are currently available, aside for two months data from the new Transsolar measurement station. Thus, data had been collected from the Airport and from Abu Dhabi city. Discpreancies between the estimated data, and the real on-site data can have a significant effect on energy produciton potential. The risk is that the energy production may be over or even under-estimated. One example is for the CSP plant, which uses direct normal radiation (DNI). Due to the vicinity of the sea, the DNI may be different than the assumption used. This risk is mitigated by 1) a detailed insolation study, which is currently being done by Transsolar and will be ready next year, and 2) a detailed wind-mast study, which will begin shortly.

   Furthermore, PV panel perfromance varies greatly with temperature and humidity, and the trying conditions of Masdar have not been the tradtional environment. The results of the Masdar PV competition will help to mitigate the risk of PV failure by identifying the best performers.

Lead Times Summary

The lead times have been discussed throughout the report, but are presented again for completeness on the discussion of risks.

PV: 4 to 6 months, 1 MW per month conservative installation
Wind: 2 years after 1 year site measurement
CSP: 2 to 3 years
ETC: 6 months
Geothermal: Binary plant (using deep water resource) - 2 years after study.
Hot Dry-Rock – up to 4-7 years.
Flowcells: 18 months
NaS: 18 months

Future Casting

The bottom table on the right outlines the current energy technologies that are being applied today, along with the probable future technologies that will be more widespread in 2015 and beyond.

	Risk	Instrument	Today	2015	2030	Opportunity
1	Availability (procurement, lead times)	PV Rooftop & Geothermal	M-H	M-L	L-L	Provision of cooling from geothermal, no rooftop
2	System O&M (ownership issues)	PV & ETC	M-H	M-H	M-M	System integration with the provision of MASDAR ownership
3	Integration (distributed heat for central-ized system)	ETC	M	L	L	Viability of distributed heat generation (central sys-tem)
4	Production reduction/ increase	PV, CSP, Wind	M	L	L	Resource study

Risks involved with Energy Supply

Today	2015	Beyond
Rooftop PV	Thin film	• HVDC to ME, NA, EU • Decentralized grid district CHP
Trough CSP	Fresnel, tower CSP	Other CSP?
WtE	Conc. PV, Organic PV	
Flow Cells elec storage	NaS elec storage, etc.	
Thermal Storage – molten salt	Thermal Storage – other	
	Hydrogen transport	Solar/low-energy H2 – photoly-sis, etc.
	Tidal/Marine in Persian Gulf	
RO desal	Solar desal	Other desal (organic rankine, etc.)
Utility Wind	Urban Wind	
	Offshore Wind	
Geothermal Power, “regular”	Enhanced (hot-dry rock)	

Future Casting Energy Supply Technologies

Comprehensive Energy Strategy

Next steps to proof of concept

The conceptual Master Plan just presented shows a vision for the site's development using some of the most innovative techniques and practices crossing several interdisciplinary boundaries. To go from the vision, to proof of concept, requires still much further work. We state below the issues that must be addressed in the next detailed work regarding renewable energy deployment:

- Detailed feasibility study for Linear Fresnel CSP system using one-year insolation data from on-site measurements being carried out now.
- Detailed feasibility study for Wind Energy with one-year proper on-site wind-mast measurements being carried out now.
- Detailed system planning for distributed solar collector system.
- Detailed geothermal investigation to gauge the feasibility of Enhanced Geothermal (Hot Dry-Rock) Systems.
- Detailed planning of grid system with advanced storage systems, either for the city if a large amount of autonomy is decided, or for the innovation hubs that are to be energy self-sufficient.
- Further examination of brine treatment/recycling options for desalination.
- Detailed planning of CO2 transport and storage system, if CCS with deep storage is chosen as the mitigation option of choice.
- Phase One detailed plan for the specific building

The following next steps were also defined at the November Abu Dhabi workshop:

- Links with ADWEA:
  - Construction Supplies
  - Export/ Import
  - Infrastructure for interconnect
- Implementation Plan
  - Changes in use
  - Changes in demand
- Equipment Availability
  - PV Modules and inverters
  - Linear Fresnel Equipment
  - Transformers
  - Liquid Desiccant Equipment
- Integrated Transmission and Distribution Plan
  - Equipment
  - Management
  - Metering details
- Detailed Building Guidelines
  - Structure/ envelope
  - Appliances/ consumers
  - Building systems
- Identifying the specific technologies that Masdar would like to support in the innovation hubs and follow-up details
- Contingency Plan
  - Grid connection
  - Equipment availability

7.1 Existing context

In terms of individual buildings for Masdar, there is no existing context, as the buildings do not exist. Standard practices for buildings in the region is based around 'conventional air conditioning systems ranging from variable air volume (VAV) systems for larger buildings through systems based around fan-coil technology to small domestic 'split' units.

All of these technologies are energy intensive in terms of electricity, chilled water or both, and in order to meet the objectives of the project it is necessary to consider departures form this into other solutions. The likely mix of technologies is described below.

There are a number of options still under discussion for the utilities to be supplied top the buildings, which may be reduced for the purposes of this chapter to two, where the supplied utilities are:

Option A: hot water and chilled water,

Option B: Lithium chloride and chilled water.

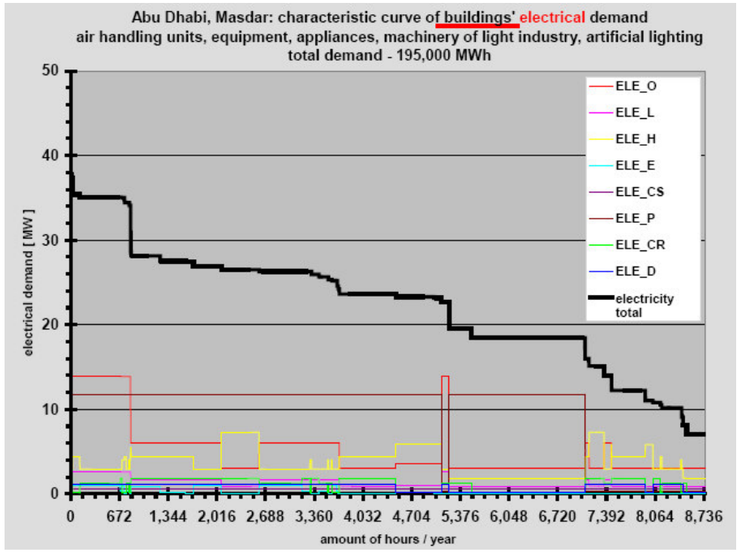
The following discussion reflects these two options and the buildings systems that can accommodate either.

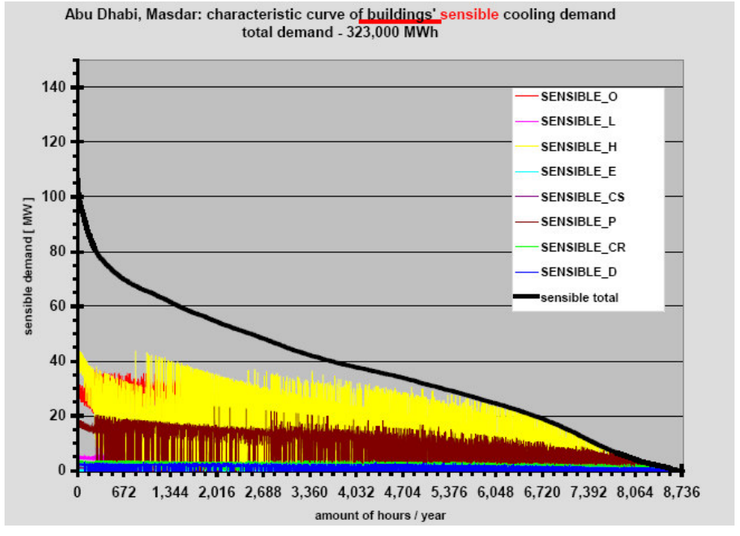
7.2 Demand Profile

The demand profiles for different types of buildings and their derivation are described more fully by others. However, the electricity and cooling demands may be summarised in a small number of graphs, shown to the right.

The domestic hot water demand amounts to about 7.5MW over about 4,400 hours per year.

These data define the size of the respective demands, allow for determining the plant that may be required to serve the demands, and indicate the utilisation of that plant. Other data from the same source defines the distribution of these demands through the day and the year.





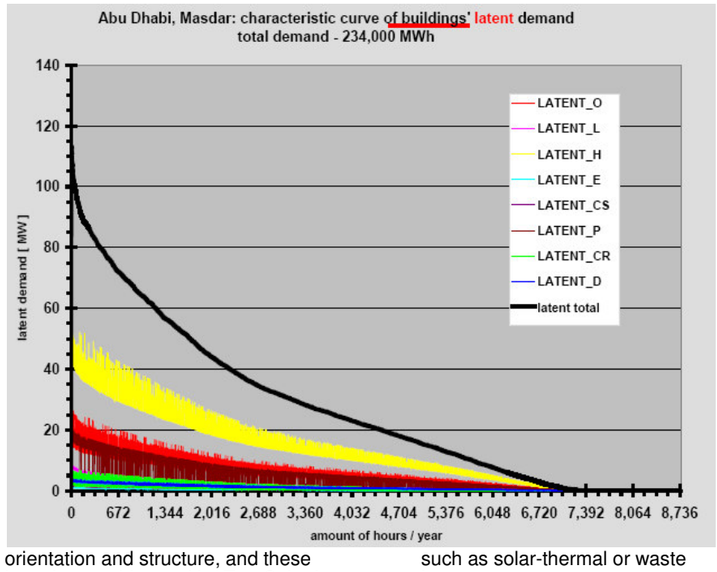
Resource Requirements

In considering the services at building level, these graphs are insufficient to inform decisions for different types and sizes of buildings. Table 5.1 overleaf therefore presents the breakdown of this information by building type and type of demand.

This is the basis of following discussions about the type of equipment to be provided to serve individual buildings

Demand Reduction Strategies

Many of the available demand reduction strategies relate to the building layout,



orientation and structure, and these have been addressed by TranSolar in developing the demand graphs shown:

a) Glazing ratios, orientation and shading devices should be designed to optimise the conflicting requirements of useful daylight penetration and solar over-heating.

b) Infiltration should always be minimised: 5m/h would be a realistic target.

Energy efficient equipment should be specified. The following presents some technologies that must be considered:

a) Lighting should automatically dimmed when there is sufficient daylight penetration or extinguished when the space is unoccupied. This requires careful attention to the sizing and zoning of lighting circuits.

b) Generally luminaries should have a luminous efficacy of at least 45 lm per circuit-Watt. Consider LEDs over tungsten-halogen where sparkle is sought.

c) Domestic hot water should be produced from a renewable source, such as solar-thermal or waste heat.

d) Ensure that all pumps and fans have efficient selections. All motors should be high efficiency and generally variable speed via frequency inverters. Pumped circuits should be configured to reduce mains pressure as well as flow (i.e. the pressure sensor should be at the index circuit rather than in the main flow pipe).

e) If vapour compression chillers are to be used, consider magnetic cushion bearings in inverter-driven compressors and continuously variable condensing pressures to maximise the benefit when the ambient air temperature is below the design figure.

7.3 Incoming Services

The infrastructure team have decided that the buildings will be supplied with electricity, medium temperature chilled water and a liquid desiccant - such as lithium chloride, lithium bromide or calcium chloride.

All building services described in the following sections are compatible with the incoming services.

Exhaust Air Cooling Reclaim

The cool conditioned air exhausted from the building can be used to pre-cool the hot and humid fresh air using any one of a number of heat transfer devices within the fresh and exhaust air-handling unit. There are three common devices, each of which can approximately halve the fresh air cooling load, especially if combined with exhaust air evaporative cooling. Each are described below.

a) Cross-flow recuperator: air paths are formed between parallel plates; hot humid fresh air and cool treated exhaust air are passed through alternate paths bringing the two air streams into close proximity but without mixing. The two air streams leave with similar enthalpies (energy contents).

b) Run-around coil: one heat transfer coil in the exhaust air duct and another in the fresh air intake. Water circulates between the two coils to transfer energy from the warm and humid fresh air stream to the cool conditioned exhaust air stream.

c) Thermal wheel: a wheel slowly rotating between the fresh air and exhaust air streams. Heat is absorbed from the hot and humid fresh air and released in the cool and dry exhaust duct.

Each of these cooling reclaim devices can be improved upon by simply evaporatively cooling the exhaust air stream with a spray humidifier prior to the device. If the room air is 24°C, 50 percent relative humidity, then evaporative cooling can reduce the air temperature to about 18°C : this is a very cool surface relative to the hot and humid outside air and gives rise to a significant amount of sensible and latent cooling (as shown on the psychrometric chart)

Table 1: Power Demands by Building Type and type of Demand

	Area	Sensible cooling	Latent cooling	Air Handling	Equipment	Lighting	Total per m^2		Overall Total	
	m^2	W/m^2	W/m^1	W/m^0	W/m^1	W/m^2	W/m^2 eletricity	W/m^2 cooling	MW electricity	MW cooling
Office	905,000	37	31	0.7	3.1	6	9.8	68	8.9	61.5
Labs	115,000	48.4	74.2	3.7	10.6	5.6	19.9	122.6	2.3	14.1
Housing	1,466,000	30.9	35.4	1.2	2.7	0.8	4.7	66.3	6.9	97.2
Production	357,000	59.4	55.9	2.3	20	6.7	29	115.3	10.4	41.2
Catering/Retail	44,000	70	152.3	9.1	10.1	9.5	28.7	222.3	1.3	9.8
Education	59,000	41.2	63.6	1.5	2.4	6.1	10	104.8	0.6	6.2
Community support	50,000	23.7	39.1	0.8	1.8	7	9.6	62.8	0.5	3.1
Divers	66,000	32.6	56.9	2.3	1	6.7	10	89.5	0.7	5.9
Totals	**30,622,000**								**31.4**	**239.0**

Table 2: Annual Energy Demands by Service

Total Electricity	GWh/a	157	22.7 % exlcluding cooling
Sensible cooling	GWh/a	278	40.2 %
Latent cooling	GWh/a	232	33.5 % (latent ratio 45%)
Total cooling	GWh/a	510	73.6 %
DHW	GWh/a	25	3.6
Total Energy		**692**	

There are a range of evaporative cooling devices, from stationary wetted materials to spinning wheels (illustrated here). In all cases precautions must be taken against Legionnaires disease, just as in a cooling tower. Water should be directly from the mains, avoiding any dead-legs. It might also be necessary to install an ultra-violet filter and water conditioner in the feed.

Direct evaporative cooling uses much less water than water-cooled chillers.

Feasibility and Availability of Exhaust Air Cooling Reclaim

Exhaust air heat reclaim devices are installed routinely in Europe. They are widely available, very easy to maintain and have few moving parts. Spray humidifiers are less frequently used but are also very simple and have been proven over many decades.

Advantages and Disadvantages of Exhaust Air Cooling Reclaim

The advantages of this technology are:

- Approximately halves fresh air cooling demand
- Very low cost
- Very simple
- Easy to maintain
- Readily available
- Uses less water than would be used if the load was met by water-cooled chillers

Their only weakness is that they cannot provide all of the cooling, and other cooling methods are required in addition.

Assumptions and Uncertainties of Exhaust Air Cooling Reclaim

None: this is a very well proven technology.

For those buildings beyond the economic reach of the liquid desiccant distribution system, desiccant dehumidification can be achieved at the building level. There are two primary methods; liquid and solid.

Liquid Desiccant Dehumidification/Cooling

A liquid-desiccant air conditioner has three main components: the conditioner, the regenerator and the interchange heat exchanger. The conditioner is a parallel-plate liquid-to-air heat exchanger. A coolant, typically cooling tower water (but possibly water from a geothermal well, lake or chilled water loop), flows within the plates and a very-low flow of liquid desiccant flows down the outer surfaces of the plates. Thin wicks on the plate surfaces create uniform desiccant films. The air to be processed flows horizontally through the gaps between the plates. As this humid air comes in contact with the desiccant, the desiccant absorbs moisture from the air. The heat released by this absorption is transferred to the coolant so that the air leaves the conditioner drier but without being hotter (could even be slightly cooler).

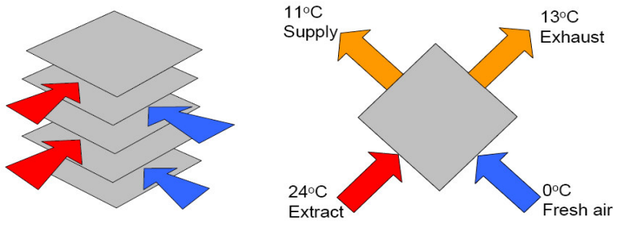
The dilute desiccant that leaves the conditioner is pumped to the regenerator. The regenerator has the same configuration as the conditioner: a parallel-plate liquid-to-air heat exchanger. Again, very thin films of desiccant flow in wicks on the outer surfaces of the plates, and air flows in the gaps between the plates. For the regenerator, however, a hot heat transfer fluid flows within the plates.

This hot fluid can be supplied by a gas-fired boiler, solar thermal collectors, recovered heat from an engine or fuel cell, or other energy source. As the temperature of the desiccant increases, water evaporates into an air stream that is then discharged to outside. This regenerator is commonly referred to as a scavenging-air regenerator.

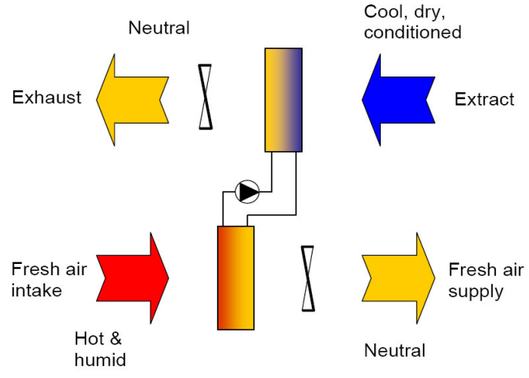
The hot, concentrated desiccant that leaves the regenerator, and the cool, dilute desiccant that flows to the regenerator, exchange thermal energy in the interchange heat exchanger.

This exchange increases the efficiency of the regenerator and decreases the heat rejection at the cooling tower.

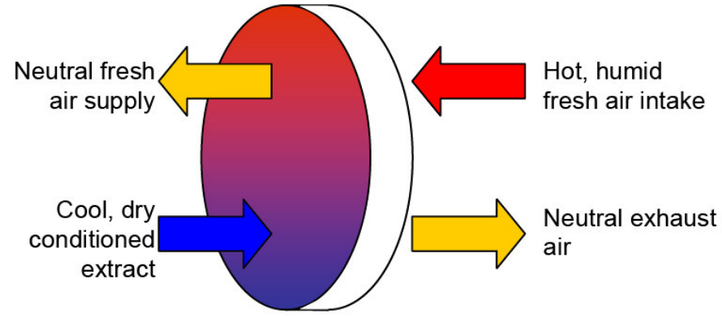
The efficiency of the regenerator can also be increased by adding an air-to-air heat exchanger to pre-heat the air that enters the regenerator using the warm, humid air that leaves it. (This air-to-air heat exchanger is not shown in the diagram.



A cross-flow recuperator – mode of operation

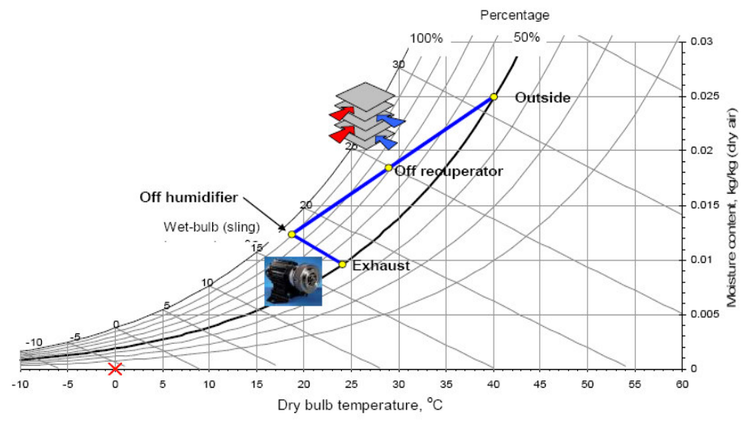


A Run-around Coil



A Thermal Wheel

An Evaporative Humidifier (Spinning Wheel Type)



A Psychrometric Chart Showing Evaporative Cooling and "Cooing" Reclaim

In both the regenerator and conditioner, the flow rate of desiccant is so low that the falling films on the plates are contained completely within the thin wicks. The air velocity over the films is far too low to entrain desiccant droplets. Since both the desiccant delivery to and collection from the plates are done without creating droplets, desiccant does not carryover and there is no need for droplet filters.

The Implementation of Low-Flow Liquid-Desiccant Technology

Although many liquids have desiccant properties, solutions of halide salts, particularly lithium chloride, lithium bromide and calcium chloride are the most viable liquid desiccants for HVAC applications. However, the high chloride or bromide concentrations in solutions of these salts eliminate even most stainless steels from service in contact with the desiccant. If maintenance is to be acceptable, all wetted surfaces should be a plastic with suitable properties.

A low-flow regenerator functions similarly to a conditioner, the major difference being that now a hot fluid flows within the plates instead of a coolant. The high operating temperatures forces several design changes.

As with the conditioner, polymers can best deal with the corrosiveness of the liquid desiccant. Since both the efficiency and water-removal capacity of a scavenging-air regenerator increase with operating temperature, a polymer should be selected that withstands high temperatures, e.g., temperatures on the order of 100 oC.

The Benefits of a Liquid-Desiccant Air Conditioner

A liquid-desiccant air conditioner can help insure that a building gets adequate ventilation while keeping indoor humidity at healthy and comfortable levels. The liquid-desiccant air conditioner will deliver close to 100 percent latent cooling. In many applications this deep drying of the ventilation air will handle the entire latent load on the building. Since the central air cooling system now does not need to dehumidify, it can operate with a dry coil at higher temperatures.

The electrical demand for pumps and fans will be typically less than one-fifth that for a conventional compressor-driven electric air conditioner. The liquid-desiccant air conditioner can provide additional cooling to buildings where electrical service is limited or electrical demand charges are high.

The heat needed to regenerate the desiccant can come from many sources. If used as part of a solar hot-water system or a CHP system, recoverable thermal energy between 70 and 100°C can be used in a scavenging-air regenerator at COPs between 0.60 and 0.80.

Space Cooling

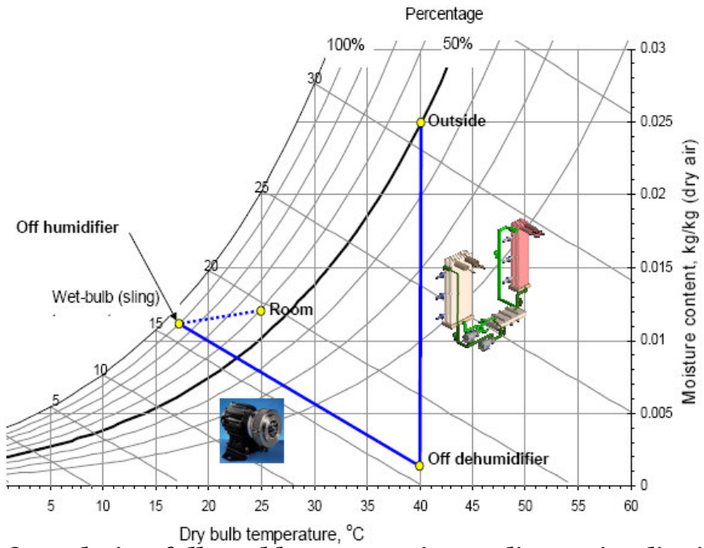
Rather than just dehumidifying the air to the required room moisture content, it would be possible to dehumidify much further. Again, because of the condenser water cooling, this dehumidification would be at near - constant temperature. Cooling could then be achieved by spray humidification.

Solid Desiccant Dehumidification

Instead of using a liquid desiccant it is possible to use solid desiccant in a wheel rotating between the fresh air and air exhaust streams. Entering air is hot and humid, but when it traverses the desiccant wheel it becomes dry – just as required.

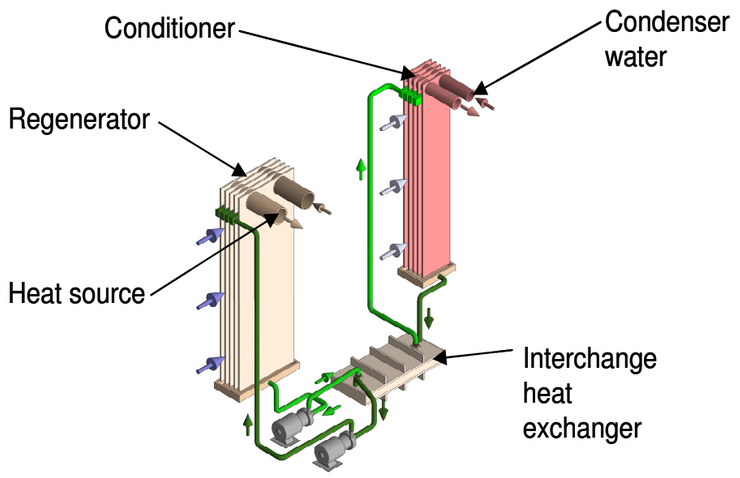
In the same way that evaporation into air causes air to cool, absorbing moisture from air causes air to warm – the process is virtually reversible up and down the wet-bulb line. So in drying the air it has become too hot; so hot that it will readily transfer heat to the exhaust air stream via a cross-flow recuperator, thermal wheel or run-around coil. At this point the air is about the same temperature as it started but drier.

As with liquid desiccant systems, the system can be used to dehumidify the air to the required moisture content and provide sensible (temperature) cooling by other means, or the air can be over-dried at approximately constant temperature making it suitable for cooling with a spray humidifier.



Over-drying followed by evaporative cooling, using liquid desiccant

Liquid desiccant systems



Advantages and Disadvantages of Liquid Desiccant Dehumidification

Advantages:

- Uses heat to directly reduce cooling loads
- Waste heat off the parabolic CHP plant or heat off evacuated tubes could be used to power the system
- Few moving parts; easy maintenance
- Can over-produce dry desiccant when there is a surplus of waste heat or solar energy, for use at other times. Dry desiccant can be stored over very long periods, unlike thermal stores which quickly degrade.
- The de-humidified air is isothermal (constant temperature) because the liberated latent heat is transferred directly to the coolant water.

Disadvantages:

- If used only to dehumidify to the room condition the equipment is expensive to simply eliminate the fresh air dehumidification load. Half of this benefit could be achieved simply with exhaust air cooling reclaim (see above). To justify this technology it should be used to sub-dry followed by evaporative spray cooling (adiabatic humidification).
- The liquid desiccant is very corrosive. Wetted surfaces should be kept to a minimum.

Assumptions and Uncertainties of Liquid Desiccant Dehumidification

None; it is a well-demonstrated technology.

Feasibility and Availability of Solid Desiccant Dehumidification

There are manufacturers supplying this equipment as packaged units, so procurement should not be a problem with reasonable lead times.

Although it is unlikely that the region has personnel with specific expertise of desiccant wheel dehumidification, the maintenance is not inherently onerous, comprising as it does not much more than a motor. Provided that the technology was widely deployed, maintenance personnel would quickly become familiar with what needs to be done.

Dry-terminal Cooling

It is a well known fact that when conditioned room air comes into contact with a cold surface, such as a cold window, condensation forms. This is equally true when the room air comes into contact with a cold cooling coil. What is perhaps less widely known is that condensing moisture out of air requires a lot of energy. It takes as much energy to condense a litre of water out of an air sample as it does to boil a litre of water in a kettle.

At normal room temperatures of around 22 to 24°C, the upper limit of human comfort is around 65 percent relative humidity (65% RH), but air-conditioning systems generally dehumidify down to about 50% RH – not because this is desirable for comfort, but simply as a consequence of the cooling process. The coil is so cold that moisture is removed, and the greater the heat gains, the greater the amount of cooling and the drier the conditioned space becomes. Merchant bank trading floors often operate at about 30% RH on hot humid summer days.

If the dehumidification can be undertaken centrally using waste or renewable heat sources, such as desiccant dehumidification (see above), it is possible to keep the space cooling process dry – thereby reducing cooling loads by about 30 percent. This requires higher than normal chilled water temperatures, which in turn requires larger cooling coils.

The maximum chilled water temperature is dictated by the required room temperature and supply air volume flow rate. The higher the acceptable room temperature and the higher the supply air flow rate, then the higher the chilled water temperature can be.
At a maximum room air temperature of 24°C, the chilled water flow and return temperatures can usually be about 14 and 17°C respectively, rather than the more common 6°C and 12°C. To keep the space cooling totally dry, the fresh air should be dehumidified to around 9 g/kg of dry air.

Because the temperature differential between flow and return water is half that which is normal, the water flow rate, and therefore pumping power, will be twice the normal. To mitigate this, variable speed pumping should be used with pressure sensed across the index load (see Demand Reduction Strategies in the previous section).

Increasing the air flow rate will allow the chilled water temperature to increase, but this will increase fan power. This is not especially important for fan-coil units because they operate against such low pressures that the fan power is low even with high flow rates. However centralised VAV systems should be avoided.

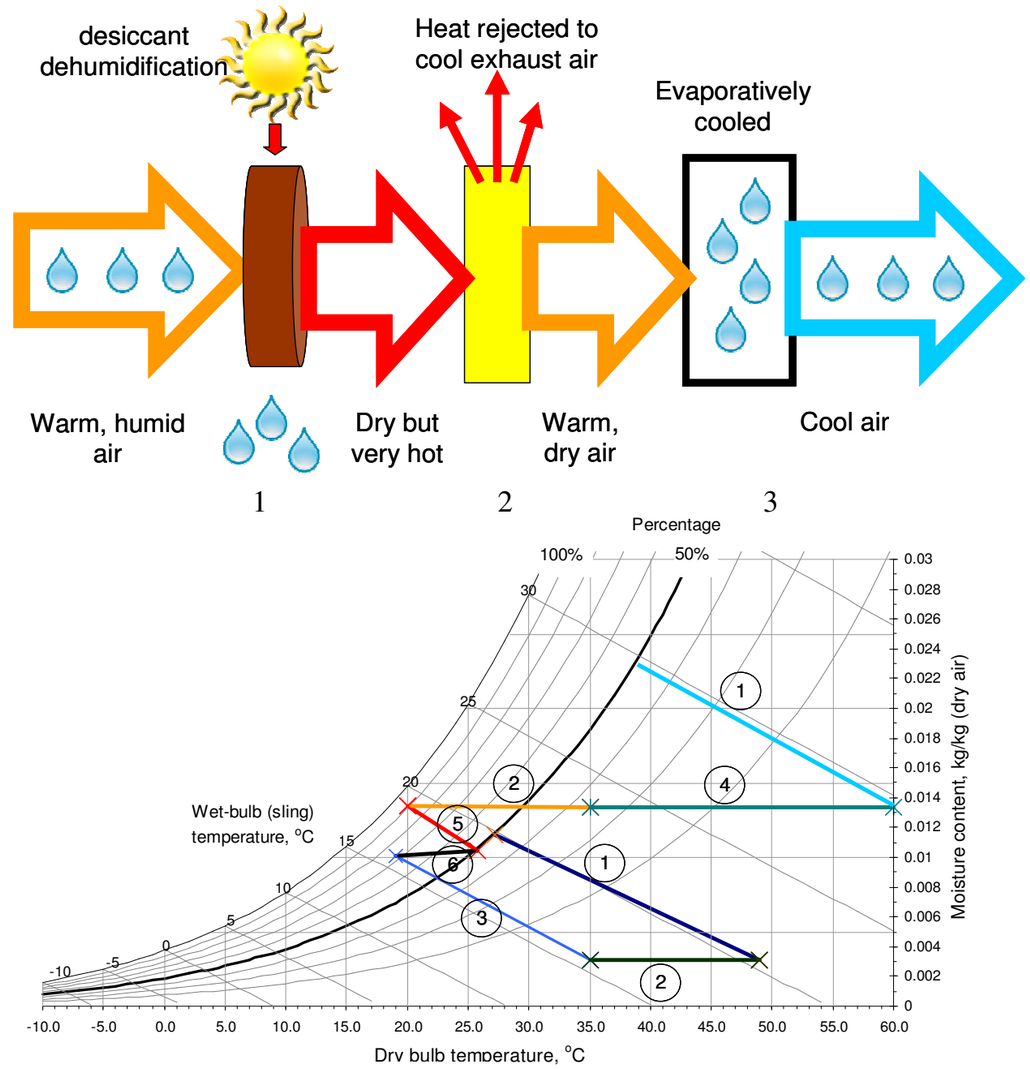
Elevated chilled water temperatures also reduce the energy used at chillers. A chiller cooling down to 14°C should use up to 20% less energy than one cooling to 6°C.

Dry terminal cooling can be supplied by dry fan-coil units, passive chilled beams, active chilled beams and chilled ceilings. Of these, dry fan-coils are recommended for Masdar because:

a) Fans allow a high rate of supply air, which in turn allows for higher chilled water temperatures, which in turn means that the fresh air needs less dehumidification. The pressure across the fans is low, so the fan power is also low.

b) Dry fan-coil systems can be designed to be always dry, or usually dry. In the latter case a condensate system would be installed for use only when cooling loads are very high. None of the other options can accommodate a condensate installation, so they must be always dry.

Solid desiccant systems



1. Desiccant wheel. Fresh air is dried and exhaust air gets warm and humid
2. Sensible heat transfer between fresh air and exhaust
3. Evaporatively cooled fresh air
4. Purging of desiccant wheel using renewable heat.
5. (on psychrometric chart) Not always required, but evaporative cooling can be used to pre-cool the exhaust air
6. (on psychrometric chart) Supply air enters the room and gets warmer and slightly more humid.

c) Fan-coils can deliver higher cooling loads

Feasibility and Availability of Dry Terminal Cooling

The technology is quite common in Europe. It is tried, tested and proven. There are many manufacturers and maintenance is straight-forward.

Advantages and Disadvantages of Dry Terminal Cooling

Advantages:

- Reduces space cooling loads by about 30 percent
- Improves chiller efficiency
- Works with the site-wide elevated chilled water temperatures
- No chance of condensation dripping off blocked trays on to space below
- Low or zero fan power

The sole disadvantage is that the chilled water temperature differential must be small, say 3°C rather than the normal 6 or 7°C. This increases pump power, but this can be mitigated by variable speed pumps.

Assumptions and Uncertainties of Dry Terminal Cooling

That the fresh air will be dried from waste or renewable heat sources. The benefit is greatly reduced if the fresh air needs to be dehumidified conventionally.

Displacement Air-Conditioning

Displacement systems work by using the natural buoyancy of warm air to "displace" unwanted heat, rather than fighting it with conventional fully mixed type systems. Air is introduced at low level and at a neutral temperature of say 20°C. Of those heat gains emanating above the occupied zone, only the radiant component needs to be cooled; the convective component is simply extracted. This halves the spatial heat gains from rooflights and effectively eliminates the spatial heat gain from electronic equipment and lighting; however this heat is available to be reclaimed at the air handling plant to pre-heat the supply air if required.

Conventional fully mixed air conditioning systems involve cooling air down to about 14°C; this requires a great deal of energy, especially as latent energy must be absorbed to condense embedded moisture. By supplying air at 20°C, displacement systems have lower peak cooling loads and lower latent fractions. The efficiency is improved still further if the minimum fresh air rate is not fixed but varied to satisfy air quality (CO_2) sensors.

Fan power is a major energy consumer in any large centralised air conditioning system. Displacement systems are essentially constant speed, variable temperature systems, although significant savings in fan energy can be achieved if the flow rate is also varied.

Variable- or multi-speed displacement systems would work with a form of cascade control to avoid instability. The supply temperature is continuously varied to match the demand, not the fan speed. The fan speed is controlled much more coarsely, so that. on a hot day the fan runs at a faster speed than on a moderate day. Reducing the fan speed by one-quarter reduces fan power about 50 percent.

The limitations with this technology are: that the minimum storey height is 3.5 to 4.0 metres and benefits from up to 6 metres; floor or low level wall space is required for supply air diffusers. This technology would be ideal in theatres, restaurants and atria.

The figure shows a displacement air supply system with cooling reclaim and partial evaporative cooling. Equally, the air could be dried with desiccant technology.

Feasibility and Availability of Displacement Air-Conditioning

Displacement cooling has been used in Europe for many decades. The introduction of variable speed control will require some design development, but it is nothing other than a system that adapts its maximum capacity to suit a readily measurable criterion.
The products are much like any other centralised air-conditioning system; it is the system design that is different. Despite working very differently, it is still amounts to ductwork, fans and pumps.

Advantages and Disadvantages of Displacement Air-Conditioning

Advantages:

- Displaces heat gain rather than "fighting" them with chillers
- Uses elevated chilled water temperatures with lower latent fractions
- Improves chiller efficiency
- Works with the site-wide elevated chilled water temperatures
- No chance of condensation dripping off blocked trays on to space below
- Opportunities for free cooling
- Displaces odours.

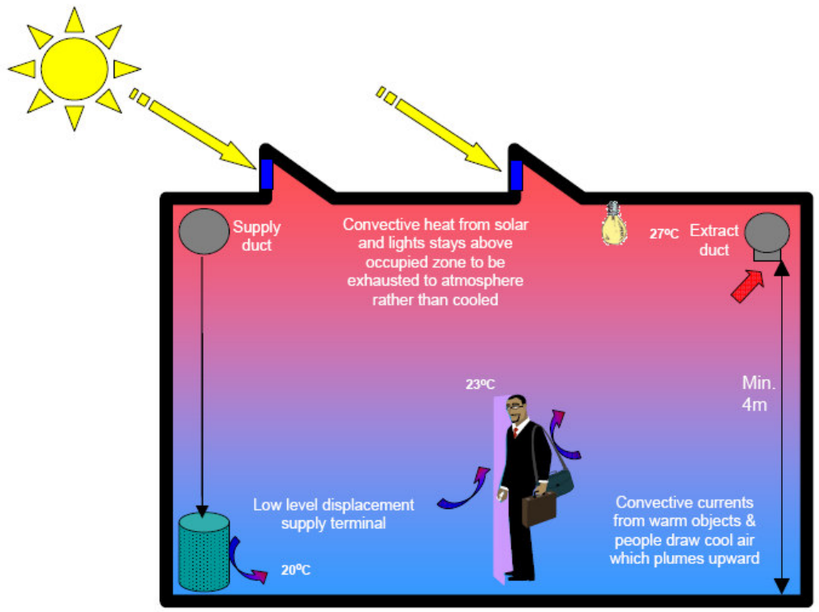
Disadvantages:

- Requires floor space or unobstructed portions of walls
- Requires minimum ceiling heights
- Can have high fan power, but this is mitigated with cascade variable- or multi-speed fan control
- Ductwork can be voluminous.

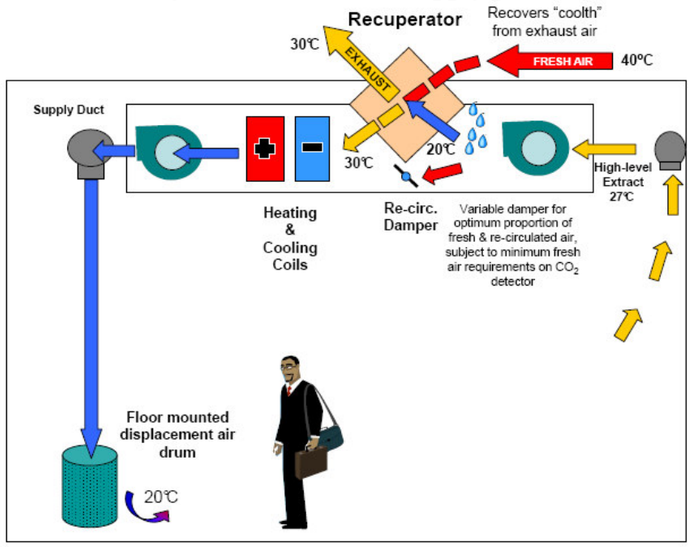
Assumptions and Uncertainties of Dry Terminal Cooling

There are none.

The principle of Displacement Ventilation



Displacement Ventilation from a central air-supply plant



7.4 Technology selection

As noted above, the site-wide infrastructure will deliver medium temperature chilled water and liquid desiccant.

The low-energy technologies described above can each provide the required temperatures and humidity within the buildings. In the following we suggest how the technologies can be applied.

Air pre-treatment

For all types of buildings we recommend the application of cooling reclaim from the exhaust. Whether this is provided through a recuperator, run-around coil or thermal wheel will largely depend upon the constraints within each building.

This will provide a substantial proportion of the cooling required by the system.

For larger buildings such as offices, apartment blocks, laboratories and larger retail establishments, evaporative humidifiers (mechanical, not thermal types) should be used to enhance the effectiveness if the system.

Air cooling and dehumidification

The remaining dehumidification should be provided by desiccant systems. If the building is beyond the economical reach of the distributed liquid desiccant system, then building-integrated systems can be used. Solid systems may be more applicable to smaller buildings.

Final cooling is provided by 'dry terminal units' as described above.

Air delivery

The use of displacement ventilation is recommended for all buildings with a storey height greater than 4m. For storey heights below 3.5m, dry-fan coil units should be used. For storey heights between 3.5 and 4m, the solution will depend upon the individual circumstances pertaining to the particular building.

7.5 Phasing

Since individual buildings are not discussed, phasing issues are not relevant. The technologies described here are infinitely scalable.

7.6 Assessment of preferred strategies

All of the technologies described here for application in buildings are proven. Their use is not widespread in the region because engineers and suppliers around the world have traditionally favoured standardisation.

Whilst global standardisation of technology is expedient and cost-effective for suppliers and designers alike, by not taking advantage of local site conditions opportunities for reducing carbon emissions are lost.

Individually, none of the technologies described here are new – they are all tried and tested. What is innovative is the way in which they have been packaged together from the supply strategy through to the demand systems.

Perhaps the least well established of the technologies is the use of liquid desiccants for drying air. There are reference installations in smaller networks, as described in TransSolar's report, but no installations of this scale have been identified.

There are a number of engineering challenges to its use associated with the corrosive properties of most suitable desiccants, yet these all have solutions that are readily available and easy to understand.

7.7 Innovations

Standardisation of products for the purpose of volume-sales and design expediency has led to standard solutions being imposed all over the world with little or no adaptation to local site and project specific conditions.

It might be assumed for example, that because air-conditioning is a climate modifier, solutions would be vastly different in different climates; but this is not the case. The standard solution in most countries involves a chiller producing chilled water at around 6^{o}C and rejecting heat to atmosphere at around 45^{o}C (or 35^{o}C if water-cooled). This is common in areas as different as Boston USA, Southern California USA, Dubai UAE and the United Kingdom.

True innovation comes not from specifying evermore complex technology, but from an informed approach. The first step is to establish the "real" challenge – what is it that really needs to be achieved, rather than what apparently needs to be done.

The second step is to identify the opportunities which are peculiar to the project and its location.

The final step is to "align" the technologies for optimum effect: choosing technologies compliment each other. For Masdar a complete coherent strategy has been achieved from supply through to demand.

'Upstream' of the buildings we have an integrated system of electricity, heat and cooling generation based on solar power. These resources are used to provide utilities that can be distributed efficiently. These systems are described more fully elsewhere in the Masterplan.

The buildings too are integrated into the system using the distributed liquid desiccant and higher temperature chilled water to best advantage by:

a) Pre-treatment of the air to pre-cool and partially dehumidify incoming air using heat recovery.
b) Optimised use of the liquid desiccant provided.
c) The use of 'dry terminal units' for final cooling.

All of the technologies upstream of and within the buildings are used elsewhere and hence are proven. However, their use is not widespread, and they have never, as far as our team know, been used together.

The building equipment described is rarely used in combination, and certainly is truly innovative in the middle-east region.

A further innovation is the use of building roofs for solar power generation on this scale. Many towns and cities have some buildings using this technology, but its use on this scale introduces many technical and practical challenges that heave never been faced before.

7.7 Next steps

Moving forward from this report, the next steps are:

1. Validate the building load demand model. The targets set are extremely challenging, not only for cooling and ventilation equipment, but also for installed equipment (appliances, lighting, etc).

2. Validate the use of liquid desiccant and confirm selection of the fluid. Distributing a corrosive liquid across a city and using it within all buildings has never been done before. There are many detailed aspects of its use that require detailed investigation.

3. In particular the sourcing and availability of the required equipment for liquid desiccant dehumidification requires detailed investigation and development.

4. Detailed building guidelines need to be prepared for the buildings themselves, the fittings and appliances within the buildings and for the building services equipment described in this section. This work need to be done collaboratively between the different companies within the team.

Contents

1.0 Executive Summary

2.0 Draft Master Plan Cost Report (Phased)

3.0 Second Square draft cost plan

4.0 Outline Building and Infrastructure Specification

5.0 Key Risks, Assumptions and Exclusions

6.0 Life Cycle Costing

7.0 Z^2 Philosophy

8.0 Construction Management

9.0 Contingency

10.0 Professional Fees

11.0 Inflation Statement

12.0 Information Used

13.0 Example of typical preliminaries break down for a large project.

DRAFT MASDAR MASTERPLAN COST REPORT

1.0 EXECUTIVE SUMMARY

07 December 2007

Area	Total Cost $	Phase 1 A	1 B	1 C	2 A	2 B	2 C	3 A	3 B	3 C	4 A	4 B	4 C	5 A	5 B	5 C	6 A	6 B	6 C
OFF SITE WORKS	323,880,000	31,874,167	49,874,167	66,874,167	43,174,167	24,736,667	24,736,667	33,136,667	24,736,667	24,736,667	-	-	-	-	-	-	-	-	-
GENERAL SITE PREPARATION	491,177,000	53,967,554	43,395,167	40,995,867	50,764,100	5,017,200	24,618,800	20,802,200	27,560,100	24,549,300	31,206,000	21,940,800	20,577,300	21,561,600	21,873,800	28,555,500	12,339,700	15,402,400	26,048,400
INFRASTRUCTURE WITHIN THE SITE	2,875,936,000	590,011,767	212,365,567	191,334,586	296,265,200	91,543,720	136,213,600	110,450,540	136,209,648	122,708,603	143,163,488	108,359,240	106,819,300	106,774,640	112,238,900	131,053,656	71,556,273	84,359,573	124,507,489
WALLED CITY ZONE	6,122,743,000	517,447,975	355,591,900	244,239,175	777,129,025	76,809,050	376,873,300	318,453,320	349,376,225	287,856,725	434,866,225	335,879,425	315,008,125	330,075,350	334,854,580	337,710,100	188,903,075	235,787,125	305,882,875
ADDITIONAL ALLOWANCE FOR Z2 PHILOSOPHY TO BUILDINGS - **See Breakdown**	867,300,000	73,297,600	50,370,400	34,597,000	110,082,000	10,880,200	53,384,900	45,109,600	49,489,900	40,775,600	61,599,800	47,578,000	44,621,600	46,755,900	47,432,900	47,837,400	26,758,500	33,399,800	43,329,000
UNDERCOFT TO PRT AND CITY	1,416,966,000	119,751,200	82,293,500	56,523,500	179,848,400	17,775,700	87,218,500	73,698,500	80,855,000	66,617,700	100,639,700	77,731,500	72,901,300	76,388,200	77,494,300	78,155,100	43,717,200	54,567,400	70,789,400
CONSTRUCTION MANAGEMENT	1,209,800,000	138,635,000	79,389,000	53,456,000	145,726,000	22,676,000	70,305,000	60,165,000	66,823,000	56,724,000	77,148,000	59,149,000	55,993,000	58,156,000	59,389,000	62,331,000	34,327,000	42,352,000	57,056,000
FEES	1,330,780,000	152,499,000	87,328,000	69,802,000	160,299,000	24,944,000	77,335,000	66,182,000	73,505,000	62,397,000	84,862,000	65,064,000	61,592,000	63,971,000	65,328,000	68,564,000	37,760,000	46,587,000	62,761,000
CONTINGENCY	1,463,858,000	167,748,000	96,061,000	76,782,000	176,329,000	27,438,000	85,069,000	72,800,000	80,856,000	68,637,000	93,349,000	71,570,000	67,751,000	70,368,000	71,861,000	75,421,000	41,536,000	51,246,000	69,037,000
TOTAL AT CURRENT COSTS (Main Scheme)	**$16,102,440,000**	**$1,845,232,262**	**$1,056,668,700**	**$844,604,294** #	**$1,939,616,892**	**$301,820,537**	**$935,754,767** #	**$800,797,827**	**$889,411,539**	**$755,002,594** #	**$1,026,834,213**	**$787,271,965**	**$745,263,625** #	**$774,050,690**	**$790,472,480**	**$829,627,756** #	**$456,897,748**	**$583,701,298**	**$759,411,164**
OPTIONS TO MAIN SCHEME																			
1. Develop the Small Square (Total Cost including Construction Management Fee, Design team fees and contingency at above levels)	3,663,700,000	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC
2. Geothermal - Close surface for recooling (Total Cost including Construction Management Fee, Design team fees and contingency at above levels) - assume 150mm dia bore	532,400,000	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC
3. Geothermal - Deep bore system (circa 4km deep) - This system is currenlty at the experimental stage and little information is known, at this stage in the products development the cost can not accurately by quantified	TBA	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC
4. Provide the tunnel for the High Speed Rail link within the Masdar boundary - Note cost for tunnel only, no track etc (Total Cost including Construction Management Fee, Design team fees and contingency at above levels)	#REF!	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC	TBC

Notes

The above costs have been compiled in conjunction with Ernst & Young and the Foster & Partners design team

All areas are based on the F+P Schedule of Areas dated 27/11/07. Similarly all phasing (1A to 6C) are based on the same area schedule dated 27/11/07.

No allowance for inflation is included in the above figures

Please review the Notes & Exclusions

Report dated 7th December 2007

The principal changes to the cost plan issued on the 1st September 2007 are as follows:-

Total Cost change between the two reports	$1,294,440,000
1. Revised Photovoltaic panel capacity & split of efficiency	$150,075,000
2. Reduced wind turbine capacity	($11,000,000)
3. Increased Evacuated Tune Capacity	$350,000,000
4. Introduction of waste to Energy Systems	$20,500,000
5. Introduction of Plasma gasification system	$10,000,000
6. Introduction of a back up water supply	$15,000,000
7. Ervac system no longer in the scheme	($60,000,000)
8. Introduction of a heat based dehumidification system	$25,000,000
9. Alterations to the walled city layout	$561,000,000
10. Increase in LRT costs	$123,000,000
11. Reduction in general site preparation costs	($50,000,000)
12. Increase in district cooling	$28,000,000
13. Reduction in electrical distribution costs	($215,000,000)
14. Increase in add-ons	$343,438,000
14. Other minor changes - totalling	$4,427,000
15. Inflation Sept 07 to Dec 07 (at 3.75%) absorbed through revised	-
Total adjustment since last report	**$1,294,440,000**

2.0 DRAFT MASDAR MASTERPLAN
COST REPORT
07 December 2007

COST DETAILS	Quantity	Unit	Rate ($)	Total ($)	Total $	PHASE 1 A	1 B	1 C	2 A	2 B	2 C	3 A	3 B	3 C	4 A	4 B	4 C	5 A	5 B	5 C	6 A	6 B	6 C
OFF SITE WORKS AND INFRASTRUCTURE																							
~~Piped saline supply from coast to site. Inlet from the sea, 1300mm dia pipe~~						0	0	0	0														
~~E/O allowance for pipe into the sea, say 1.5km~~						0	0	0	0														
Allowance for bore holes to extract water for declination	1.0	Item	3,000,000	3,000,000		750,000	750,000	750,000	750,000														
Allowance for maintenance chambers etc	1.0	Item	750,000	750,000		187,500	187,500	187,500	187,500														
~~E/O to tunnel inlet pipes under roads etc~~						0	0	0	0														
Pump Station, including equipment, building and compound	1.0	Item	20,000,000	20,000,000				10,000,000	10,000,000														
Brine recover system	1.0	Item	15,000,000	15,000,000				7,500,000	7,500,000														
Road connecting pumping station to public highway	1	item	1,000,000	1,000,000		500,000	500,000																
Note: Main road between the Masdar site and the Kalifa city is excluded from this cost plan																							
New flyovers to connect to existing highway	9,000	m2	1,500	13,500,000		4,500,000	4,500,000	4,500,000															
Road widening	9,000	m2	400	3,600,000		1,200,000	1,200,000	1,200,000															
New peripheral roads outside the site boundary- **by others**																							
New roundabouts -**outside the site boundary- by others**																							
LRT SYSTEM																							
Allowance for works to incorporate Masdar within the proposed Abu Dhabi LRT Network (Note no specification for proposed network exists)																							
Elevated permanent way installation including structure (2 roads)	4.5	km	34,000,000	153,000,000		17,000,000	17,000,000	17,000,000	17,000,000	17,000,000	17,000,000	17,000,000	17,000,000	17,000,000									
Control, signalling and power installations	1.0	item	5,630,000	5,630,000		625,556	625,556	625,556	625,556	625,556	625,556	625,556	625,556	625,556									
Elevated stations (note central station included within Masdar City's building section)	5	nr	12,000,000	60,000,000		6,666,667	6,666,667	6,666,667	6,666,667	6,666,667	6,666,667	6,666,667	6,666,667	6,666,667									
Additional train carriages to service the Masdar branch of the proposed Abu Dhabi LRT, Say	4	nr	2,100,000	8,400,000								8,400,000											
Enlarge depot facility to cater for additional rolling stock	1	item	4,000,000	4,000,000		444,444	444,444	444,444	444,444	444,444	444,444	444,444	444,444	444,444									
<u>Back-up utilities connections</u>																							
Back up electricity supply infrastructure and connection to grid, **assumed connection at new airport upgrade**																							
Cabling to above, say approx 2km	2	km	500,000	1,000,000			500,000	500,000															
Contribution towards new Sub station	1	Item	20,000,000	20,000,000			10,000,000	10,000,000															
Back-up water supply infrastructure - allow for connection to Abu Dhabi main water supply for use in the event of contamination or plant failure	1	Item	15,000,000	15,000,000			7,500,000	7,500,000															
Back-up gas supply infrastructure - **Not applicable**				Exc																			
TOTAL OF SITE & INFRASTRUCTURE					323,880,000	31,874,167	49,874,167	66,874,167	43,174,167	24,736,667	24,736,667	33,136,667	24,736,667	24,736,667	-	-	-	-	-	-	-	-	-

2.0 DRAFT MASDAR MASTERPLAN COST REPORT					07 December 2007	PHASE																	
						1			2			3			4			5			6		
COST DETAILS	Quantity	Unit	Rate ($)	Total ($)	Total $	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
GENERAL SITE PREPARATION																							
Cut and fill to new levels																							
Excavation & Disposal, assume 500mm deep, 50% of area	2,750,000.0	m2	5	13,750,000		4,583,333	4,583,333	4,583,333															
Fill , assume 500mm fill, 50% area	2,750,000.0	m2	15	41,250,000		13,750,000	13,750,000	13,750,000															
Compact	5,500,000.0	m2	1	5,500,000		1,833,333	1,833,333	1,833,333															
Landscaping - Outside the walled city																							
Shelter belt planting																							
Hard landscaping - 10%	51,020.00	m2	200	10,204,000		862,300	592,600	407,000	1,295,100	128,000	628,100	530,700	582,300	479,700	724,700	559,800	525,000	550,100	558,100	562,800	314,800	393,000	509,800
Soft landscaping - 90%	459,180.00	m2	100	45,918,000		3,880,300	2,666,800	1,831,700	5,828,100	576,000	2,826,400	2,388,300	2,620,200	2,158,800	3,261,300	2,519,000	2,362,400	2,475,400	2,511,300	2,532,700	1,416,700	1,768,300	2,294,000
City entrances																							
Hard landscaping - 60%	85,896.00	m2	200	17,179,200		1,451,940	997,700	685,300	2,180,500	215,500	1,057,400	893,500	980,300	807,700	1,220,100	942,400	883,900	926,100	939,500	947,500	530,000	661,600	858,200
Soft landscaping - 40%	57,264.00	m2	100	5,726,400		484,280	332,600	228,400	726,800	71,800	352,500	297,800	326,800	269,200	406,700	314,100	294,600	308,700	313,200	315,800	176,700	220,500	286,100
Research Field																							
Hard landscaping -20 %	24,610.00	m2	200	4,922,000		415,700	285,900	196,300	624,700	61,700	303,000	256,000	280,900	231,400	349,600	270,000	253,200	265,300	269,200	271,500	151,900	189,500	245,900
Soft landscaping - 80%	98,440.00	m2	100	9,844,000		831,700	571,700	392,700	1,249,400	123,500	605,900	512,000	561,700	462,800	699,200	540,000	506,500	530,700	538,400	543,000	303,700	379,100	491,800
Nursery production																							
Hard landscaping - 20%	10,460.17	m2	200	2,092,034		176,841	121,500	83,500	265,500	26,200	128,800	108,800	119,400	98,400	148,600	114,800	107,600	112,800	114,400	115,400	64,500	80,600	104,500
Soft landscaping - 80%	41,840.68	m2	100	4,184,068		353,582	243,000	166,900	531,100	52,500	257,500	217,600	238,800	196,700	297,200	229,500	215,300	225,600	228,800	230,800	129,100	161,100	209,000
Wadi corridors																							
Hard landscaping - 20%	46,934.00	m2	200	9,386,800		793,160	545,200	374,400	1,191,400	117,800	577,800	488,200	535,600	441,300	666,700	514,900	482,900	506,000	513,400	517,700	289,600	361,500	469,000
Soft landscaping - 80%	187,736.00	m2	100	18,773,600		1,586,920	1,090,300	748,900	2,382,800	235,500	1,155,600	976,400	1,071,300	882,600	1,333,400	1,029,900	965,900	1,012,100	1,026,700	1,035,500	579,200	723,000	937,900
Food production																							
Hard landscaping - 20%	N/A			Exc																			
Soft landscaping - 80%	N/A			Exc																			
Timber Production																							
Hard landscaping - 20%	53,915.40	m2	200	10,783,080		911,396	626,300	430,100	1,368,600	135,300	663,700	560,800	615,300	507,000	765,900	591,500	554,800	581,300	589,700	594,800	332,700	415,300	538,700
Soft landscaping - 80%	215,661.60	m2	100	21,566,160		1,822,492	1,252,500	860,300	2,737,300	270,500	1,327,500	1,121,700	1,230,600	1,013,900	1,531,700	1,183,100	1,109,600	1,162,600	1,179,500	1,189,500	665,400	830,500	1,077,400
Recreation																							
Hard landscaping - 30%	121,064.70	m2	200	24,212,940		2,046,328	1,406,200	965,900	3,073,200	303,700	1,490,400	1,259,400	1,381,600	1,138,400	1,719,700	1,328,300	1,245,700	1,305,300	1,324,200	1,335,500	747,000	932,400	1,209,600
Soft landscaping - 70%	282,484.30	m2	100	28,248,430		2,387,216	1,640,600	1,126,800	3,585,400	354,400	1,738,800	1,469,200	1,611,900	1,328,100	2,006,300	1,549,600	1,453,300	1,522,900	1,544,900	1,558,100	871,500	1,087,800	1,411,200
Unallocated area - assumed soft landscaping	854,166.00	m2	100	85,416,600		7,218,716	4,960,800	3,407,300	10,841,500	1,071,500	5,257,700	4,442,600	4,874,000	4,015,800	6,066,700	4,685,800	4,394,600	4,604,800	4,671,500	4,711,300	2,635,300	3,289,400	4,267,300
Form walls in the green seams to store surface water	1.00	Item	500,000	500,000		42,216	29,000	19,900	63,500	6,300	30,800	26,000	28,500	23,500	35,500	27,400	25,700	27,000	27,300	27,600	15,400	19,300	25,000
Roads - outside the city																							
Form access roads to the proposed car parks	5,000.00	m2	400	2,000,000		200		317,400	-200			0	308,400	374,100	182,200					422,900	0		395,000
Form new access roads	23,800.00	m2	400	9,520,000		100		1,510,600	0			0	1,468,200	1,780,500	867,500					2,012,800	0		1,880,200
Other access roads	6,000.00	m2	400	2,400,000		0	0	380,800	0	0	0	0	370,100	448,900	218,700	0	0	0	0	507,400	0	0	474,000
Flyovers to car park	11,200.00	m2	1,500	16,800,000		0	0	2,666,100	0	0	0	0	2,590,900	3,142,100	1,530,800	0	0	0	0	3,552,000	0	0	3,318,000
Surface water culvert for plantation areas Excavation to for culvert																							
Forming dry waddy	20,000	m2	50	1,000,000		84,400	58,100	39,900	126,900	12,500	61,600	52,000	57,100	47,000	71,000	54,900	51,400	53,900	54,700	55,200	30,900	38,500	50,000
Paving & handrail along both sides of the culvert - **Assumed not required**				Exc																			
Allowance for additional irrigation systems to landscaping outside the city No design to date, or review - **scope to be confirmed, Say**	1	Item	100,000,000	100,000,000		8,451,100	5,807,700	3,989,000	12,692,500	1,254,500	6,155,300	5,201,200	5,706,200	4,701,400	7,102,500	5,485,800	5,144,900	5,391,000	5,469,000	5,515,700	3,085,300	3,851,000	4,995,800
TOTAL SITE PREPARATION					491,177,000	53,967,554	43,395,167	40,995,867	50,764,100	5,017,200	24,618,800	20,802,200	27,560,100	24,549,300	31,206,000	21,940,800	20,577,300	21,561,600	21,873,800	28,555,500	12,339,700	15,402,400	26,048,400

2.0 DRAFT MASDAR MASTERPLAN COST REPORT				07 December 2007		PHASE																	
						1			2			3			4			5			6		
COST DETAILS	Quantity	Unit	Rate ($)	Total ($)	Total $	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
ENERGY GENERATION AND SITE																							
ENERGY GENERATION																							
Solar farm: CSP technology Fresnel	50	MW	6,500,000	325,000,000		162,500,000	40,625,000	40,625,000	40,625,000	40,625,000													
Solar panels, inc support structures Infrastructure to transfer power to the grid Associated control and maintenance buildings Maintenance access ways under solar equipment				Included Included Included Included																			
Hard standing under panels	562,500	m2	50	28,125,000		28,125,000																	
Solar Panels																							
Solar panels to buildings - High efficiency	98	MW	8,000,000	784,000,000		66,257,700	45,532,500	31,274,100	99,509,200	9,835,200	48,257,600	40,777,000	44,736,600	36,859,300	55,683,400	43,008,400	40,335,900	42,265,200	42,877,200	43,242,800	24,188,500	30,191,900	39,167,400
Solar panels to car parks - mix of efficiency	5.5	MW	7,500,000	41,250,000		3,486,100	2,395,700	1,645,500	5,235,700	517,500	2,539,100	2,145,500	2,353,800	1,939,300	2,929,800	2,262,900	2,122,300	2,223,800	2,256,000	2,275,200	1,272,700	1,588,500	2,060,800
Semi Transparent thin film PV	6.7	MW	9,000,000	60,300,000		5,096,100	3,502,100	2,405,400	7,653,600	756,500	3,711,600	3,136,300	3,440,800	2,835,000	4,282,800	3,307,900	3,102,400	3,250,800	3,297,800	3,325,900	1,860,400	2,322,200	3,012,500
Semi Transparent Crystalline PV	9.0	MW	9,600,000	86,400,000		7,301,900	5,017,900	3,446,500	10,966,300	1,083,900	5,318,200	4,493,800	4,930,200	4,062,000	6,136,500	4,739,700	4,445,200	4,657,800	4,725,200	4,765,500	2,665,700	3,327,300	4,316,400
Infrastructure to transfer the power to the grid Allowence for separate maintenance access to the roof of buildings	1	Item	10,000,000	Included 10,000,000		845,100	580,800	398,900	1,269,200	125,400	615,500	520,100	570,600	470,100	710,200	548,600	514,500	539,100	546,900	551,600	308,500	385,100	499,600
Carbon offset - additional 6MW of roof mounted PV's to provide over capacity which will be used to offset the carbon emissions from the city	6	MW	9,000,000	54,000,000		4,563,700	3,136,200	2,154,100	6,853,900	677,400	3,323,900	2,808,600	3,081,400	2,538,800	3,835,300	2,962,300	2,778,200	2,911,100	2,953,300	2,978,500	1,666,000	2,079,500	2,697,800
Wind turbines	4.5	MW	2,000,000	9,000,000		3,000,000	3,000,000	3,000,000															
Form foundations for wind turbines Infrastructure to transfer power to the grid Associated maintenance buildings Maintenance access paths to turbines	2.5	km	500,000	Included 1,250,000 Included Included		416,667	416,667	416,667															
Evacuated tubes	25	hectares	20,000,000	500,000,000		42,256,200	29,038,600	19,945,200	63,462,500	6,272,400	30,776,500	26,005,800	28,531,000	23,507,200	35,512,400	27,428,800	25,724,400	26,954,900	27,345,100	27,578,300	15,426,300	19,255,000	24,979,200
Hot water distribution pipe work to above				Included																			
Waste recycling plant	1	item	80,000,000	80,000,000		64,000,000	8,000,000	8,000,000															
Allowance for building to house equipment Form ancillary buildings Form waste storage compound Waste recycling plant equipment Access roads to plant Infrastructure to transfer power to the grid				Included Included Included Included Included Included																			
Waste to energy generation	2.7	MW	7,500,000	20,550,000								6,850,000	6,850,000	6,850,000									
Plasma gasification system - Assumed small system (similar to a Westinghouse mobile unit) to cope with the waste produced by Masdar only and not from the surrounding areas. Including necessary ancillary buildings and connections to the grid - budgetary allowance subject to receipt of further information	1.0	Item	10,000,000	10,000,000																	3,333,333	3,333,333	3,333,333
Heat based district dehumidification system - - budgetary allowance subject to receipt of further information	1.0	Item	24,750,000	24,750,000		2,091,700	1,437,400	987,300	3,141,400	310,500	1,523,400	1,287,300	1,412,300	1,163,600	1,757,900	1,357,700	1,273,400	1,334,300	1,353,600	1,365,100	763,600	953,100	1,236,500
Envac system - ***To be provided by developers if they so wish.***				Exc																			
Allowance for Design Development Issues - Including Test bed technology areas - These include green houses and Algae farm trails for potential carbon offsetting methods	*1*	*item*	*75,000,000*	*75,000,000*		12,500,000	12,500,000	12,500,000	12,500,000	12,500,000	12,500,000												
UTILITIES SUPPLIES																							
Temporary Supplies - Excluded				Exc																			
Electrical distribution including transformers etc																							
Form ducts for cabling				Included																			
Install electrical distribution cabling, 22kva cables	45,000	m	200	9,000,000		5,400,000	900,000	900,000	900,000	900,000													
Install sub stations - 132 to 22 kva	2	No.	5,000,000	10,000,000		6,000,000	1,000,000	1,000,000	1,000,000	1,000,000													
Install secondary substations 132 to 22 kva	3	No.	3,000,000	9,000,000		5,400,000	900,000	900,000	900,000	900,000													
Install 22 to 11 kva	260	No.	200,000	52,000,000		31,200,000	5,200,000	5,200,000	5,200,000	5,200,000													
Form transformer enclosures				Included																			
Fit-out of energy centre	1	Item	5,000,000	5,000,000		3,000,000	500,000	500,000	500,000	500,000													

2.0 DRAFT MASDAR MASTERPLAN COST REPORT					07 December 2007	PHASE																	
						1			2			3			4			5			6		
COST DETAILS	Quantity	Unit	Rate ($)	Total ($)	Total $	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Desalination plant including tanks 12,000m3 per day	12,000	m3	1,400	16,800,000		1,419,800	975,700	670,200	2,132,300	210,800	1,034,100	873,800	958,600	789,800	1,193,200	921,600	864,300	905,700	918,800	926,600	518,300	647,000	839,300
Form connection to piped saline supply	1	Item	500,000	500,000		42,300	29,000	19,900	63,500	6,300	30,800	26,000	28,500	23,500	35,500	27,400	25,700	27,000	27,300	27,600	15,400	19,300	25,000
Form main declination building				Included																			
						$0		$0															
Form ancillary buildings	500	m2	2,000	1,000,000		84,500	58,100	39,900	126,900	12,500	61,600	52,000	57,100	47,000	71,000	54,900	51,400	53,900	54,700	55,200	30,900	38,500	50,000
Install declination plant equipment				Included above																			
Allowance for compound	1,000	m2	250	250,000		21,100	14,500	10,000	31,700	3,100	15,400	13,000	14,300	11,800	17,800	13,700	12,900	13,500	13,700	13,800	7,700	9,600	12,500
Form clean water storage tanks, say	1	Item	2,000,000	2,000,000		169,000	116,200	79,800	253,800	25,100	123,100	104,000	114,100	94,000	142,000	109,700	102,900	107,800	109,400	110,300	61,700	77,000	99,900
Allowance for Bore hole wells across the site to abstract and dispose of water - Assume 10 No; size and depth to be determined following surveys.	10	No.	250,000	2,500,000		211,300	145,200	99,700	317,300	31,400	153,900	130,000	142,700	117,500	177,600	137,100	128,600	134,800	136,700	137,900	77,100	96,300	124,900
Allowance for additional storage tanks to attenuate for peaks of abstraction and/ or disposal waters; size, volume and number to be determined	2	No.	500,000	1,000,000					500,000					500,000									
Allowance for Dew catcher around the city, allow say $750,000	1	Item	750,000	750,000		63,400	43,600	29,900	95,200	9,400	46,200	39,000	42,800	35,300	53,300	41,100	38,600	40,400	41,000	41,400	23,100	28,900	37,500
Drinkable water supply pipe work						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Form connection to desalination plant	1	Item	1,000,000	1,000,000		84,500	58,100	39,900	126,900	12,500	61,600	52,000	57,100	47,000	71,000	54,900	51,400	53,900	54,700	55,200	30,900	38,500	50,000
Lay pipe work supply - main runs	40,000	m	100	4,000,000		338,000	232,300	159,600	507,700	50,200	246,200	208,000	228,200	188,100	284,100	219,400	205,800	215,600	218,800	220,600	123,400	154,000	199,800
Form branch connections to individual buildings	5,000	m	50	250,000		21,100	14,500	10,000	31,700	3,100	15,400	13,000	14,300	11,800	17,800	13,700	12,900	13,500	13,700	13,800	7,700	9,600	12,500
Allow for maintenance access to pipe work supply	1	Item	750,000	750,000		63,400	43,600	29,900	95,200	9,400	46,200	39,000	42,800	35,300	53,300	41,100	38,600	40,400	41,000	41,400	23,100	28,900	37,500
Sewage treatment plant, 3.3 hectares	1	item	40,000,000	40,000,000		40,000,000																	
Form sewage storage tanks				Included																			
Form connection from sewage pipe work to treatment plant				Included																			
Construct main treatment plant building				Included																			
Form ancillary building	1	item	500,000	500,000		500,000																	
Install treatment plant equipment				Included																			
Foul sewage and surface water collection pipe work																							
Install main sewage runs, average 350mm dia pipes	45,000	m	40	1,800,000		0	0	285,655	0	0	0	0	277,598	336,657	164,018	0	0	0	0	380,574	0	0	355,498
Install rainwater collection runs	45,000	m	40	1,800,000		0	0	285,655	0	0	0	0	277,598	336,657	164,018	0	0	0	0	380,574	0	0	355,498
From branch connections from individual buildings				Included																			
Attenuation tanks	1	Item	2,500,000	2,500,000		0	0	396,743	0	0	0	0	385,552	467,579	227,803	0	0	0	0	528,574	0	0	493,747
Allowance for manholes	400	No.	6,500	2,600,000		0	0	412,613	0	0	0	0	400,974	486,282	236,915	0	0	0	0	549,717	0	0	513,497
Allowance for Acco (Gulley Drain) or similar	45,000	m	80	3,600,000		0	0	571,310	0	0	0	0	555,195	673,314	328,037	0	0	0	0	761,147	0	0	710,996
Allowance for 50 year storm water tanks - to be also used for grey water storage for irrigation of the landscaping	1	Item	1,500,000	1,500,000		126,800	87,100	59,800	190,400	18,800	92,300	78,000	85,600	70,500	106,500	82,300	77,200	80,900	82,000	82,700	46,300	57,800	74,900
District cooling distribution pipe work																							
Install pipe work, inc return pipe work, 200mm pipe	45,000	m	800	36,000,000		0	0	5,713,103	0	0	0	0	5,551,954	6,733,141	3,280,367	0	0	0	0	7,611,470	0	0	7,109,960
Allowance for pumping stations and associated buildings	1	Item	5,000,000	5,000,000		0	0	793,486	0	0	0	0	771,105	935,158	455,607	0	0	0	0	1,057,149	0	0	987,494
I.T & Telecoms	1	item	32,000,000	32,000,000		0	0	5,078,314	0	0	0	0	4,935,071	5,985,014	2,915,882	0	0	0	0	6,765,751	0	0	6,319,965
Allowance for installation of back bone IT and Comms systems				Included																			
Allowance for branch connections to individual building				Included																			
Allowance for telecoms signal exchanges				Included																			
Allowance for manholes/ maintenance chambers and the like				Included																			

2.0 DRAFT MASDAR MASTERPLAN					07 December 2007	PHASE																	
COST REPORT						1			2			3			4			5			6		
COST DETAILS	Quantity	Unit	Rate ($)	Total ($)	Total $	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
PRT system																							
Ground level road (4 lanes), including directional magnets, power supplies and signal cabling back control centre	35.2	km	1,680,000	59,136,000		8,870,400	5,913,600	5,322,240	2,956,800	1,182,720	2,956,800	2,365,440	2,956,800	2,956,800	2,365,440	2,365,440	2,956,800	2,365,440	2,956,800	2,956,800	2,365,440	2,365,440	2,956,800
Control systems	1	item	15,300,000	15,300,000		2,295,000	1,530,000	1,377,000	765,000	306,000	765,000	612,000	765,000	765,000	612,000	612,000	765,000	612,000	765,000	765,000	612,000	612,000	765,000
Ground level stations	83	nr	500,000	41,500,000		6,225,000	4,150,000	3,735,000	2,075,000	830,000	2,075,000	1,660,000	2,075,000	2,075,000	1,660,000	1,660,000	2,075,000	1,660,000	2,075,000	2,075,000	1,660,000	1,660,000	2,075,000
Passenger vehicles	1,000	nr	210,000	210,000,000		31,500,000	21,000,000	18,900,000	10,500,000	4,200,000	10,500,000	8,400,000	10,500,000	10,500,000	8,400,000	8,400,000	10,500,000	8,400,000	10,500,000	10,500,000	8,400,000	8,400,000	10,500,000
Freight vehicles	250	nr	250,000	62,500,000		9,375,000	6,250,000	5,625,000	3,125,000	1,250,000	3,125,000	2,500,000	3,125,000	3,125,000	2,500,000	2,500,000	3,125,000	2,500,000	3,125,000	3,125,000	2,500,000	2,500,000	3,125,000
Waste vehicles	60	nr	250,000	15,000,000		2,250,000	1,500,000	1,350,000	750,000	300,000	750,000	600,000	750,000	750,000	600,000	600,000	750,000	600,000	750,000	750,000	600,000	600,000	750,000
Form maintenance depot and remote service yards	1	item	Included in above costs			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Allowance for power supplies	1	Item	12,500,000	12,500,000		1,875,000	1,250,000	1,125,000	625,000	250,000	625,000	500,000	625,000	625,000	500,000	500,000	625,000	500,000	625,000	625,000	500,000	500,000	625,000
Transport - Temporary buses																							
Bus - Traditional diesel	3	No.	280,000	840,000		840,000																	
Bus - CNG	10	No.	364,000	3,640,000		3,640,000																	
Bus - diesel hybrid	10	No.	420,000	4,200,000		4,200,000																	
Bus - CNG Hybrid	10	No.	476,000	4,760,000		4,760,000																	
Bus - Fuel Cell	2	No.	1,750,000	3,500,000		3,500,000																	
Bus recovery and maintenance facility	2,835.00	m2	1,000	2,835,000		2,835,000																	
Fuelling facility serving all types	1.00	No.	2,000,000	2,000,000		2,000,000																	
Showcase and testing enhancements to area	1	item	5,000,000	5,000,000		2,500,000	625,000	625,000	625,000	625,000													
Goods consolidation centre and other ancillary buildings	1	item	80,000,000	80,000,000		6,761,000	4,646,200	3,191,200	10,154,000	1,003,600	4,924,200	4,160,900	4,565,000	3,761,100	5,682,000	4,388,600	4,115,900	4,312,800	4,375,200	4,412,500	2,468,200	3,080,800	3,996,700
Form consolidation centre compound				Inc																			
Form storage units				Inc																			
Allowance for connections to PRT system				Inc																			
Allowance for connection to underground service zone				Inc																			
Allow to form dedicated route from the edge of the city boundary to the central spine to transport hotel guests and VIPs in electric vehicles. Assume 15 No. charging points required along the central spine and 15 No. at the perimeter of the city. Form a dedicated controlled entrance in the city boundary to allow only electric vehicles to enter the city	1	Item	500,000	500,000					500,000														
TOTAL ENERGY GENERATION AND SITE					2,875,936,000	590,011,767	212,365,567	191,334,586	296,265,200	91,543,720	136,213,600	110,450,540	136,209,648	122,708,603	143,163,488	108,359,240	106,819,300	106,774,640	112,238,900	131,053,656	71,556,273	84,359,573	124,507,489

2.0 DRAFT MASDAR MASTERPLAN					07 December 2007	PHASE																	
COST REPORT						1			2			3			4			5			6		
COST DETAILS	Quantity	Unit	Rate ($)	Total ($)	Total $	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
WALLED CITY ZONES																							
Perimeter wall/screen; 6.5m high, with accessible path, complete with handrail	78,000	m3	300	23,400,000		1,977,600	1,359,000	933,400	2,970,000	293,600	1,440,300	1,217,100	1,335,300	1,100,100	1,662,000	1,283,700	1,203,900	1,261,500	1,279,800	1,290,700	722,000	901,100	1,169,000
Utilities distribution to individual buildings	1.0	item	50,000,000	50,000,000		4,225,600	2,903,900	1,994,500	6,346,200	627,200	3,077,700	2,600,600	2,853,100	2,350,700	3,551,200	2,742,900	2,572,400	2,695,500	2,734,500	2,757,800	1,542,600	1,925,500	2,497,900
Allowance for forming wind towers in the street	1.0	Item	10,000,000	10,000,000		845,100	580,800	398,900	1,269,200	125,400	615,500	520,100	570,600	470,100	710,200	548,600	514,500	539,100	546,900	551,600	308,500	385,100	499,600
Landscaping																							
Landscaping - Inside the walled city																							
Linear Park																							
Hard landscaping - 50%	104,901.00	m2	480	50,352,500		4,255,400	2,924,300	2,008,600	6,391,000	631,700	3,099,300	2,618,900	2,873,200	2,367,300	3,576,300	2,762,200	2,590,600	2,714,500	2,753,800	2,777,300	1,553,500	1,939,100	2,515,500
Soft landscaping - 50%	104,901.00	m2	240	25,176,200		2,127,700	1,462,200	1,004,300	3,195,500	315,800	1,549,700	1,309,500	1,436,600	1,183,600	1,788,100	1,381,100	1,295,300	1,357,200	1,376,900	1,388,600	776,800	969,500	1,257,800
Urban squares																							
Hard landscaping - 80 %	17,552.00	m2	480	8,425,000		712,000	489,300	336,100	1,069,300	105,700	518,600	438,200	480,700	396,100	598,400	462,200	433,500	454,200	460,800	464,700	259,900	324,400	420,900
Soft landscaping - 20%	4,388.00	m2	240	1,053,100		89,000	61,200	42,000	133,700	13,200	64,800	54,800	60,100	49,500	74,800	57,800	54,200	56,800	57,600	58,100	32,500	40,600	52,600
Public gardens																							
Hard landscaping - 40%	9,373.60	m2	480	4,499,300		380,200	261,300	179,500	571,100	56,400	276,900	234,000	256,700	211,500	319,600	246,800	231,500	242,600	246,100	248,200	138,800	173,300	224,800
Soft landscaping - 60%	14,060.40	m2	240	3,374,500		285,200	196,000	134,600	428,300	42,300	207,700	175,500	192,600	158,600	239,700	185,100	173,600	181,900	184,600	186,100	104,100	130,000	168,600
Private Courtyards																							
Hard landscaping - 90%	257,310.00	m2	480	123,508,800		10,438,000	7,173,000	4,926,800	15,676,400	1,549,400	7,602,300	6,423,900	7,047,700	5,806,700	8,772,200	6,775,400	6,354,400	6,658,300	6,754,700	6,812,300	3,810,600	4,756,300	6,170,300
Soft landscaping - 10%	28,590.00	m2	240	6,861,600		579,900	398,500	273,700	870,900	86,100	422,400	356,900	391,500	322,600	487,300	376,400	353,000	369,900	375,300	378,500	211,700	264,200	342,800
Leisure area Football pitch etc	20,925.00	m2	100	2,092,500		176,900	121,500	83,500	265,600	26,300	128,800	108,800	119,400	98,400	148,600	114,800	107,700	112,800	114,400	115,400	64,600	80,600	104,500
E/O allowance for forming green fingered zones	180,000.00	m2	150	27,000,000		2,281,900	1,568,100	1,077,000	3,427,000	338,700	1,661,900	1,404,300	1,540,700	1,269,400	1,917,700	1,481,200	1,389,100	1,455,600	1,476,600	1,489,200	833,000	1,039,800	1,348,900
Allowance for wind screens along streets	1.00	Item	5,000,000	5,000,000		422,700	290,400	199,500	634,600	62,700	307,800	260,100	285,300	235,100	355,100	274,300	257,200	269,500	273,500	275,800	154,300	192,600	249,800
Masdar Centre - ADFEC Headquarters - Tower	32,431	m2	2,800	90,806,800					90,806,800														
Masdar centre - low level offices	46,811	m2	1,750	81,919,300					81,919,250														
Central Station	30,915	m2	2,600	80,379,000					80,379,000														
Station Retail	7,729	m2	1,200	9,274,800					9,274,800														
University - Generally	145,299	m2	2,200	319,657,800		319,657,800																	
University hall of residence	48,433	m2	1,450	70,227,850		70,227,850																	
Hotel - 5*	13,313	m2	2,900	38,607,700					38,607,700														
Convention Centre	7,636	m2	5,000	38,180,000					38,180,000														
Hotel - 4*	23,949	m2	2,400	57,477,600					20,095,200						37,382,400								
Service Apartment - 4*	9,294	m2	1,900	17,658,600					17,658,600														
Retail																							
Food Court; Shell only	10,620	m2	1,400	14,868,000			5,471,200							2,062,200	5,132,400						2,202,200		
Retail units; Shell only	3,908	m2	1,200	4,689,600			4,689,600																
Sports Zone																							
Sport Hall	2,984	m2	2,500	7,460,000						4,570,000					2,890,000								
Gym Pool	5,175	m2	2,650	13,713,800												13,713,750							
Leisure - External Space 20,925m2												0											
SEZ -Offices	464,253	m2	1,500	696,379,500			17,859,000				206,755,500	15,814,500	13,236,000	7,335,000	5,929,500	187,249,500	100,132,500	12,738,000	91,351,500	7,656,000	8,715,000	2,625,000	18,982,500
SEZ- Research Labs	61,140	m2	2,300	140,622,000			2,343,700				51,984,600	4,949,600			2,150,500	46,149,500	15,085,700		17,958,400				
SEZ Light Manufacturing (Air-conditioned warehouse environment) Shell and core only, fit-out by tenants	354,132	m2	800	283,305,600			19,680,800					8,506,400	28,236,800	25,452,800	6,014,400		60,232,000	27,172,800	23,504,000	28,063,200	4,648,000		51,794,400
SEZ- Local Centre																							
Food Court; Shell only	9,845	m2	1,400	13,783,000							10,911,600					2,871,400							
Retail units; Shell only	9,845	m2	1,200	11,814,000							9,352,800					2,461,200							
Other offices	249,247	m2	1,500	373,870,500			82,672,500		24,639,000	39,769,500	897,000	47,967,000	104,235,000	2,668,500	1,750,500	59,613,000						4,282,500	5,376,000
Show Case and Testing (464,000m2 exc)	Exc		Exc	Exc																			
Science centre	40,068	m2	3,200	128,217,600											128,217,600								
Residential - high quality - 30%	410,317	m2	1,600	656,507,000		2,920,800	63,544,320	54,704,160	7,838,880	9,497,280	25,599,360	28,162,560	29,603,040	52,940,640	47,120,160	1,727,520	41,103,840	45,376,320	49,737,600	56,297,280	32,013,600	64,113,120	44,206,560
Residential - Medium quality - 35%	478,703	m2	1,450	694,119,400		3,088,138	67,184,880	57,838,253	8,287,983	10,041,395	27,065,990	29,776,040	31,299,048	55,973,696	49,819,753	1,826,493	43,458,748	47,976,005	52,587,150	59,522,645	33,847,713	67,786,268	46,739,228
Residential - Low quality- 35%	478,703	m2	1,250	598,378,800		2,662,188	57,918,000	49,860,563	7,144,813	8,656,375	23,332,750	25,669,000	26,981,938	48,253,188	42,948,063	1,574,563	37,464,438	41,358,625	45,333,750	51,312,625	29,179,063	58,436,438	40,292,438
Community Facilities																							
Community Centre inc creche	13,476	m2	2,320	31,264,300								31,264,320											
Place of worship	14,779	m2	2,200	32,513,800				2,780,800				21,177,200						2,780,800		3,088,800		2,686,200	
Library/ adult education facility	1,345	m2	2,560	3,443,200					3,443,200														
Schools and education facilities	43,207	m2	2,300	99,376,100									26,818,000							25,760,000	24,062,600	22,735,500	
Police station	8,477	m2	2,400	20,344,800			14,438,400						5,906,400										
Fire Station	1,000	m2	2,650	2,650,000		2,650,000																	
Community Hospital	6,901	m2	2,680	18,494,700															18,494,680				
Health Centre	8,626	m2	2,000	17,252,000															17,252,000				
Entertainment Centre	12,758	m2	2,900	36,998,200					36,998,200														
Car park - Internal - Assumed lower areas in undecroft	550,003	m2	750	412,502,300				65,463,000					63,616,500	77,151,000	37,587,750					87,215,250			81,468,750
Car Park External - Round buildings	739,158	m2	900	665,242,200		87,444,000			268,606,800			87,444,000			43,722,000			134,303,400			43,722,000		
TOTAL WALLED CITY ZONE	4,344,480				6,122,743,000	517,447,975	355,591,900	244,239,175	777,129,025	76,809,050	376,873,300	318,453,320	349,376,225	287,856,725	434,866,225	335,879,425	315,008,125	330,075,350	334,854,580	337,710,100	188,903,075	235,787,125	305,882,875

2.0 DRAFT MASDAR MASTERPLAN					07 December 2007	PHASE																	
COST REPORT						1			2			3			4			5			6		
COST DETAILS	Quantity	Unit	Rate ($)	Total ($)	Total $	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Z2 PHILOSOPHY																							
Allowance for complying with Z^2 philosophy - assume 15% - **See section 7 of Cyril Sweett Report**	1	Item		867,299,978		73,297,600	50,370,400	34,597,000	110,082,000	10,880,200	53,384,900	45,109,600	49,489,900	40,775,600	61,599,800	47,578,000	44,621,600	46,755,900	47,432,900	47,837,400	26,758,500	33,399,800	43,329,000
TOTAL Z^2					867,300,000	73,297,600	50,370,400	34,597,000	110,082,000	10,880,200	53,384,900	45,109,600	49,489,900	40,775,600	61,599,800	47,578,000	44,621,600	46,755,900	47,432,900	47,837,400	26,758,500	33,399,800	43,329,000
UNDERCROFT																							
Reinforced concrete podium slab and supporting columns to building areas	1,726,666	m2	340	587,066,319		49,614,400	34,095,200	23,418,400	74,513,400	7,364,700	36,135,700	30,534,200	33,499,200	27,600,500	41,696,200	32,205,100	30,203,900	31,648,600	32,106,800	32,380,600	18,112,600	22,607,900	29,328,900
Reinforced concrete suspended slab/roof and columns with block work infill; reinforced concrete trench; steel access walkways; services with PRT running through; av 7.5m wide, included for lighting, power, ventilation etc	45,000	m	18,350	825,750,000		69,786,100	47,957,300	32,939,600	104,808,300	10,358,900	50,827,400	42,948,500	47,119,000	38,822,100	58,648,700	45,298,700	42,483,900	44,515,900	45,160,500	45,545,600	25,476,600	31,799,700	41,253,200
Allowance for fire doors every station	83	No.	50,000	4,150,000		350,700	241,000	165,500	526,700	52,100	255,400	215,800	236,800	195,100	294,800	227,700	213,500	223,700	227,000	228,900	128,000	159,800	207,300
TOTAL UNDERCROFT					1,416,966,000	119,751,200	82,293,500	56,523,500	179,848,400	17,775,700	87,218,500	73,698,500	80,855,000	66,617,700	100,639,700	77,731,500	72,901,300	76,388,200	77,494,300	78,155,100	43,717,200	54,567,400	70,789,400
TOTAL					$12,098,002,000	$1,386,350,262	$793,890,700	$634,564,294	$1,457,262,892	$226,762,537	$703,045,767	$601,650,827	$668,227,539	$567,244,594	$771,475,213	$591,488,965	$559,927,625	$581,555,690	$593,894,480	$623,311,756	$343,274,748	$423,516,296	$570,557,164

2.0 DRAFT MASDAR MASTERPLAN

SMALL SQUARE OPTION - (Approximately 25% of the Main Square) **07 December 2007**

COST DETAILS	Quantity	Unit	Rate ($)	Total ($)	Total $	PHASE 7 A	NOTES
Allowance for bore holes to extract water for declination	1.0	Item	750,000	750,000		750,000	Allowance for increased capacity
Allowance for maintenance chambers etc	1.0	Item	187,500	187,500		187,500	Allowance for increased capacity
~~E.O to tunnel linlet pipes under roads etc~~							
Pump Station, including equipment, building and compound	1.0	Item	5,000,000	5,000,000		5,000,000	Allowance for increased capacity
Brine recover system	1.0	Item	3,750,000	3,750,000		3,750,000	Allowance for increased capacity
Road connecting pumping station to public highway	1	item	250,000	250,000		250,000	Allowance for increased capacity
Note: Main road between the Masdar site and the Kalifa city is excluded from this cost plan							
New flyovers to connect to existing highway	2,250	m2	1,500	3,375,000		3,375,000	Allowance for additional roads to new Square
Road widening							No Change
New peripheral roads outside the site boundary- **by others**							
New roundabouts -**outside the site boundary- by others**							
LRT SYSTEM Allowance for works to incorporate Masdar within the proposed Abu Dhabi LRT Network (Note no specification for proposed network exists)							
Elevated permanent way installation including structure (2 roads)	1.1	km	34,000,000	38,250,000		38,250,000	Assume No LRT stop in the small square
Control, signalling and power installations	1.0	item	1,407,500	1,407,500		1,407,500	Assume No LRT stop in the small square
Elevated stations (note central station included within Masdar City's building section)	1	nr	12,000,000	15,000,000		15,000,000	Assume No LRT stop in the small square
Additional train carriages to service the Masdar branch of the proposed Abu Dhabi LRT, Say	1	nr	2,100,000	2,100,000		2,100,000	Assume No LRT stop in the small square
Enlarge depot facility to cater for additional rolling stock	1	item	1,000,000	1,000,000		1,000,000	Assume No LRT stop in the small square

2.0 DRAFT MASDAR MASTERPLAN SMALL SQUARE OPTION - (Approximately 25% of the Main Square)				07 December 2007		PHASE 7	
COST DETAILS	**Quantity**	**Unit**	**Rate ($)**	**Total ($)**	**Total $**	**A**	**NOTES**
Back-up utilities connections Back up electricity supply infrastructure and connection to grid, **assumed connection at new airport upgrade**							
Cabling to above, say approx 2km							No change envisaged
Contribution towards new Sub station	1	Item	5,000,000	5,000,000		5,000,000	Increase capacity allowance
Back-up water supply infrastructure - **Not applicable**				Exc			
Back-up gas supply infrastructure - **Not applicable**				Exc			
TOTAL OF SITE & INFRASTRUCTURE					**76,070,000**	**76,070,000**	
GENERAL SITE PREPARATION							
Cut and fill to new levels Excavation & Disposal, assume 500mm deep, 50% of area	280,000.0	m2	5	1,400,000		1,400,000	Additional area of small Square
Fill , assume 500mm fill, 50% area	280,000.0	m2	15	4,200,000		4,200,000	Additional area of small Square
Compact	560,000.0	m2	1	560,000		560,000	Additional area of small Square
Roads - outside the city							
Form access roads to the proposed car parks	1,250.00	m2	400	500,000		500,000	Additional access roads to small square car park
Form new access roads	5,950.00	m2	400	2,380,000		2,380,000	Allowance for miscellaneous access roads around the small square site
TOTAL SITE PREPARATION					**9,040,000**	**9,040,000**	

2.0 DRAFT MASDAR MASTERPLAN SMALL SQUARE OPTION - (Approximately 25% of the Main Square)			07 December 2007			PHASE 7	
COST DETAILS	**Quantity**	**Unit**	**Rate ($)**	**Total ($)**	**Total $**	**A**	**NOTES**
ENERGY GENERATION AND SITE							
ENERGY GENERATION							
Solar farm; CSP technology Fresnel	13	MW	6,500,000	81,250,000		81,250,000	Increased capacity for small square
Solar panels, inc support structures				Included			
Infrastructure to transfer power to the grid				Included			
Associated control and maintenance buildings				Included			
Maintenance access ways under solar equipment				Included			
Hard standing under panels	140,625	m2	50	7,031,250		7,031,250	Increased capacity for small square
Solar panels to buildings	40	MW	8,000,000	322,000,000		322,000,000	Increased capacity for small square
Infrastructure to transfer the power to the grid				Included			
Allowance for separate maintenance access to the roof of buildings	1	Item	2,500,000	2,500,000		2,500,000	Increased capacity for small square
Wind turbines	0.9	MW	2,000,000	1,750,000		1,750,000	Increased capacity for small square
Form foundations for wind turbines				Included			
Infrastructure to transfer power to the grid	0.6	km	500,000	312,500		312,500	Increased capacity for small square
Associated maintenance buildings				Included			
Maintenance access paths to turbines				Included			
Evacuated tubes	3	hectares	40,000,000	100,000,000		100,000,000	Increased capacity for small square
Hot water distribution pipe work to above				Included			
Waste recycling plant	1	item	20,000,000	20,000,000		20,000,000	Increased capacity for small square
Allowance for building to house equipment				Included			
Form ancillary buildings				Included			
Form waste storage compound				Included			
Waste recycling plant equipment				Included			
Access roads to plant				Included			
Infrastructure to transfer power to the grid				Included			
Envac system - ***No longer applicable to the scheme***				Exc			
Allowance for Design Development Issues	***1***	***item***	***18,750,000***	***18,750,000***		18,750,000	Increased capacity for small square
UTILITIES SUPPLIES							
Temporary Supplies - Excluded				Exc			

2.0 DRAFT MASDAR MASTERPLAN SMALL SQUARE OPTION - (Approximately 25% of the Main Square)				07 December 2007		PHASE 7	
COST DETAILS	Quantity	Unit	Rate ($)	Total ($)	Total $	A	NOTES
Electrical distribution including transformers etc							
Form ducts for cabling				Included			
Install electrical distribution cabling, 22kva cables	11,250	m	200	2,250,000		2,250,000	Increased capacity for small square
Install sub stations - 132 to 22 kva	0.5	No.	5,000,000	2,500,000		2,500,000	Increased capacity for small square
Install secondary substations 132 to 22 kva	0.8	No.	3,000,000	2,250,000		2,250,000	Increased capacity for small square
Install 22 to 11 kva	65	No.	200,000	13,000,000		13,000,000	Increased capacity for small square
Form transformer enclosures				Included			
Fit-out of energy centre	1	Item	1,250,000	1,250,000		1,250,000	Increased capacity for small square
Desalination plant including tanks 12,000m3 per day	3,000	m3	1,400	4,200,000		4,200,000	Increased capacity for small square
Form connection to piped saline supply	1	Item	500,000	500,000		500,000	
Form main declination building				Included			
Form ancillary buildings	125	m2	2,000	250,000		250,000	additional ancillary buildings for the small square
Install declination plant equipment				Included above			
Allowance for compound	250	m2	250	62,500		62,500	additional compound for the small square
Form clean water storage tanks, say	1	Item	500,000	500,000		500,000	Increased capacity for small square
				0			
Drinkable water supply pipe work							
Form connection to declination plant							No Change
Lay pipe work supply - main runs	10,000	m	100	1,000,000		1,000,000	Increased capacity for small square
Form branch connections to individual buildings	1,250	m	50	62,500		62,500	Increased capacity for small square
Allow for maintenance access to pipe work supply	1	Item	187,500	187,500		187,500	Increased capacity for small square
Sewage treatment plant, 3.3 hectares	1	item	10,000,000	10,000,000		10,000,000	Increased capacity for small square
Form sewage storage tanks				Included			
Form connection from sewage pipe work to treatment plant				Included			
Construct main treatment plant building				Included			
Form ancillary building	1	item		0			No Change
Install treatment plant equipment				Included			

2.0 DRAFT MASDAR MASTERPLAN SMALL SQUARE OPTION - (Approximately 25% of the Main Square)				07 December 2007		PHASE 7	
COST DETAILS	Quantity	Unit	Rate ($)	Total ($)	Total $	A	NOTES
Foul sewage and surface water collection pipe work							
Install main sewage runs, average 350mm dia pipes	11,250	m	40	450,000		450,000	Increased capacity for small square
Install rainwater collection runs	11,250	m	40	450,000		450,000	Increased capacity for small square
From branch connections from individual buildings				Included			
Attenuation tanks	1	Item	625,000	625,000		625,000	Increased capacity for small square
Allowance for manholes	100	No.	6,500	650,000		650,000	Increased capacity for small square
Allowance for Acco (Gulley Drain) or similar	11,250	m	80	900,000		900,000	Increased capacity for small square
District cooling distribution pipe work							
Install pipe work, inc return pipe work, 200mm pipe	11,250	m	500	5,625,000		5,625,000	Increased capacity for small square
Allowance for pumping stations and associated buildings	1	Item	1,250,000	1,250,000		1,250,000	Increased capacity for small square
I.T & Telecoms	1	item	8,000,000	8,000,000		8,000,000	Increased capacity for small square
Allowance for installation of back bone IT and Comms systems				Included			
Allowance for branch connections to individual building				Included			
Allowance for telecoms signal exchanges				Included			
Allowance for manholes/ maintenance chambers and the like				Included			
Note No allowance has been made for any geothermal system - No Scheme has been developed to date							
PRT system							
Plasma gasification system - Assumed small system (similar to a Westinghouse mobile unit) to cope with the waste produced by Masdar only and not from the surrounding areas. Including necessary ancillary buildings and connections to the grid			50,000,000				
Ground level road (4 lanes), including directional magnets, power supplies and signal cabling back control centre	8.8	km	1,680,000	14,784,000		14,784,000	Increased capacity for small square
Control systems	1	item	3,825,000	3,825,000		3,825,000	Increased capacity for small square
Ground level stations	21	nr	500,000	10,375,000		10,375,000	Increased capacity for small square

2.0 DRAFT MASDAR MASTERPLAN

SMALL SQUARE OPTION - (Approximately 25% of the Main Square) — **07 December 2007**

COST DETAILS	Quantity	Unit	Rate ($)	Total ($)	Total $	PHASE 7 A	NOTES
Passenger vehicles	250	nr	210,000	52,500,000		52,500,000	Increased capacity for small square
Freight vehicles	63	nr	250,000	15,625,000		15,625,000	Increased capacity for small square
Waste vehicles	15	nr	250,000	3,750,000		3,750,000	Increased capacity for small square
Form maintenance depot and remote service yards	1	item	Included in above costs				
Allowance for power supplies	1	Item	3,125,000	3,125,000		3,125,000	Increased capacity for small square
TOTAL ENERGY GENERATION AND SITE					**713,540,250**	**713,540,250**	
WALLED CITY ZONES							
Landscaping							
Landscaping - Inside the walled city							
Hard landscaping - 50%	140,000.00	m2	480	67,200,000		67,200,000	Assume 50% built area 50% landscaped
Soft landscaping - 50%	140,000.00	m2	240	33,600,000		33,600,000	Assume 50% built area 50% landscaped
Hotel - 4*	13,751	m2	2,400	33,002,400		33,002,400	
Retail							
Food Court; Shell only	3,876	m2	1,100	4,263,050		4,263,050	
Retail units; Shell only	3,876	m2	800	3,100,400		3,100,400	
Sports Zone							
Sport Hall	2,468	m2	2,500	6,170,000		6,170,000	
SEZ -Offices	110,973	m2	1,500	166,459,500		166,459,500	
SEZ- Research Labs	14,390	m2	2,300	33,097,000		33,097,000	
SEZ Light Manufacturing (Air-conditioned warehouse environment) Shell and core only, fit-out by tenants	98,379	m2	800	78,703,200		78,703,200	
SEZ- Local Centre							
Food Court; Shell only	3,744	m2	1,100	4,117,850		4,117,850	
Retail units; Shell only	3,744	m2	800	2,994,800		2,994,800	
Other offices	151,755	m2	1,500	227,632,500		227,632,500	
Show Case and Testing (464,000m2 exc)			Exc	Exc			
Science centre		m2	3,200	0		0	
Residential - high quality - 30%	130,528	m2	1,600	208,844,640		208,844,640	
Residential - Medium quality - 35%	152,283	m2	1,450	220,809,698		220,809,698	
Residential - Low quality- 35%	152,283	m2	1,250	190,353,188		190,353,188	

2.0 DRAFT MASDAR MASTERPLAN						PHASE	
SMALL SQUARE OPTION - (Approximately 25% of the Main Square)					07 December 2007	7	
COST DETAILS	**Quantity**	**Unit**	**Rate ($)**	**Total ($)**	**Total $**	**A**	**NOTES**
Community Facilities							
Place of worship	1,052	m2	2,200	2,314,400		2,314,400	
Schools and education facilities	5,147	m2	2,300	11,838,100		11,838,100	
Police station	1,002	m2	2,400	2,404,800		2,404,800	
Car park - Internal - Assumed lower areas in undecroft		m2	750	0		0	
Car Park External - Round buildings	119,236	m2	900	107,312,400		107,312,400	
TOTAL WALLED CITY ZONE	**968,484**				**1,404,218,000**	**1,404,217,925**	
Z2 PHILOSOPHY							
Allowance for complying with Z^2 philosophy - assume 15%	1	Item		195,512,689		195,512,700	
TOTAL Z^2					**195,513,000**	**195,512,700**	
UNDERCROFT							
Reinforced concrete podium slab and supporting columns to building areas	431,666	m2	340	146,766,580		146,766,600	allowance for podium under small square
Reinforced concrete suspended slab/roof and columns with block work infill; reinforced concrete trench; steel access walkways; services with PRT running through; av 7.5m wide, included for lighting, power, ventilation etc	11,250	m	18,350	206,437,500		206,437,500	Increased to take into account small square
Allowance for fire doors every station	21	No.	50,000	1,037,500		1,037,500	Increased to take into account small square
TOTAL UNDERCROFT					**354,242,000**	**354,241,600**	Increased to take into account small square
TOTAL					**$2,752,623,250**	**$2,752,622,475**	

4.0 Outline Building and Infrastructure Specification

Building Type	Assumed Specification
ADFEC – Head office tower	High quality competition designed building by a signature architect; concrete frame, glass and metal cladding; finished to a CAT B
Masdar Centre – Low rise offices	Externally the buildings will complement the design of the tower; concrete frame, finished to a Cat A standard; common areas to be fitted out to a standard office spec.
Central Station	Concrete structure; glass/metal panel cladding where appropriate; high quality natural stone flooring; air conditioned, full voice announcement & Life safety systems.
Station retail	Shell and core only – block work walls; finishes by tenant, shop front glazing by client, services terminated within the demise (fitted out by tenants)
University	Concrete structure with rendered external finish; mixture of building uses, all to include air conditioning
Hotel – 5*	A Quality in town 5* business hotel, concrete frame, high quality internal and external finishes, both FOH & BOH fitted out, includes allowance for FF&E.
Hotel – 4*	A Quality in town 4* hotel, Concrete frame, good quality internal and external finishes, both FOH & BOH fitted out, includes allowance for FF&E.
Serviced Apartments	Concrete frame, block and rendered buildings, internal fit-out as 4* hotel, fully air conditioned and life safety systems
Food courts	Shell and core only – block work walls; finishes by tenant, shop front glazing by client, services terminated within the demise (fitted out by tenants)
Retail Units	Shell and core only – block work walls; finishes by tenant, shop front glazing by client, services terminated within the demise (fitted out by tenants)
Sports Hall	Concrete structure, block and render externally, painted block walls internally, sports hall flooring, fully air conditioned
Spa, Gym and pool	Concrete structure, glass, metal cladding & render finish; air conditioned, sports hall flooring to gym, swimming pool fully fitted out inc plant, spa rooms etc (exc. equipment)
SEZ offices	Concrete structure; glazed, block and render externally; fully air conditioned; finished to a Cat A spec; common areas to be fitted out to a standard office spec.

Building Type	Assumed Specification
SEZ Research Labs	Assumed similar specification to SEZ offices with allowance of $1,000 per m2 for lab facilities
SEZ Manufacturing units	Concrete structure, block and render finish externally, concrete sealer finish internally, air conditioned (shell only)
Apartments – Low Cost	Concrete Frame, block and render finish, air conditioned, basic internal finishes, minimal external space
Apartments – Average Cost	Concrete Frame, aluminium cladding externally, air conditioned, good quality finishes throughout, landscaped external space, with small terraces
Apartments – High Cost	Concrete Frame, Large expanses of glazing with metal cladding, air conditioned, high quality finishes through out, landscaped public areas, large balconies/terraces.
Mosque	Concrete fame, with block render externally, enhanced internal finish (assumed local not central mosque)
Library	Concrete Structure, Block and render finishes, internally – air conditioned, basic finishes complete with shelving, computer desks, etc (no books or the like).
Schools and education facilities	Concrete Structure, Block and render finishes, space split between Class rooms, library, gym, assembly hall, durable finishes to be used throughout, allowance for FF&E
Police Station	Concrete Structure, Block and render finishes, space split between open plan offices, Cells, interview rooms and public lobby, durable finishes throughout – air conditioned.
Fire Station	Concrete Structure, Block and Render externally, Basic internal finishes, Air conditioned, Housing for 3 engines, complete with external yard for training facility
Community Hospital	Concrete structure, block and render finish, air conditioned, clinical finishes internally. Includes hard standing for ambulances; excludes FF&E
Health Centre	Concrete structure, block and render finish, air conditioned, clinical finishes internally.
Multi storey Car Park - internally	Concrete Structure; forms part of the Undercroft; naturally ventilated; vehicle management system
Multi storey Car Park - Externally	Round Concrete Structure, Punched metal cladding, Naturally ventilated, Vehicle management system

4.0 Outline Building and Infrastructure Specification - Continued

Infrastructure Description	Assumed Specification
Bored Saline Supply	Saline supply to be provided by bore holes. Brine recovery system to produce saleable salt
Roads outside the site boundary	New flyovers to connect to existing highways and roads to be built by others; allowed for the existing road to be widened to allow for new traffic; includes drainage and some street lighting; note the main road between Masada and Kalifa city is excluded from our cost plan
LRT System	All Track assumed elevated; 5 stations allowed for along with the provision of 4 additional carriages for the system; specification based on current UAE schemes however reduced specification for stations
Back-up Utilities	Back-up electrical supply has been allowed for (connection back to the Abu Dhabi main grid); A connection to the main Abu Dhabi water supply has been included for as a safe guard to failure of the Masdar declination plant; no back-up gas supplies have been envisaged
Roads within the city boundary	Included for access roads to the city branching off the main roads around the perimeter of the site boundary (by others), along with access roads to the new Multi storey car parks and service areas.
Surface water culvert for plantation areas	Allowance for forming dry waddys to provide run off areas; allowance for additional irrigation to areas outside the walled city zone
Solar Farm – CSP Fresnel technology	50 MW CSP facility allowed for Including structure, maintenance and management buildings, hard standing under panels, etc
Solar panels to Buildings	117 MW facility allowed for to be installed on roofs as the buildings are constructed; separate allowance for separate maintenance access
Wind Turbines	Installation of turbines to generate 4.5MW of power; allowed for ancillary buildings, infrastructure to transfer power to the grid; associated maintenance buildings and access paths.
Evacuated Tubes	25 Hectare facility; including storage systems; connection to network distribution
Waste Recycling Plant	Included installation of main equipment and buildings; waste compound, access roads and infrastructure to transfer the power to the grid.
Temporary Utilities	Excluded

Infrastructure Description	Assumed Specification
Electrical Distribution	Installation of 22 KVA cable network; 132 to 22 KVA transformers, 22 to 11kva transformers to each plot and principal building areas outside city walls.
Desalination Plant	A 12,000m³ a day system has been allowed for , included connection to saline supply, compound and clean water storage tank; brine recovery system
Drinkable water supply	Main pipe runs from desalination plant, branch connections to individual buildings, maintenance access to supply pipe work; buffer storage tanks
Sewage treatment plan	Allowance for 3.3 hectares site, including storage tanks, ancillary buildings and treatment plant equipment
Foul Sewage and surface water	Allowance for main and branch runs, average 350mm pipe work, includes rainwater connection, includes for manholes and channel drainage; allowance for attenuation tanks
District cooling distribution pipe work	Allowance made for distribution pipe work and pumping stations; assumed pipework to run in the undercroft
I.T and Telecoms	Installation of backbone system and branch connections to individual buildings
PRT System	Ground level 4 lane system measured, 35km of track. Cost includes for an allowance for stations, all control systems, power supplies, maintenance yard, vehicles etc.
Temporary Transport	In accordance with Systamtica's recommendations we have included the capital cost of purchasing buses to transport workers and students to the site in the early phases.
Undercroft	Concrete column structure, with block infill walls, fire doors, lighting, naturally ventilated, fire hydrants; designed to accommodate the PRT system and utility distribution runs.
Goods Consolidation Centre & Ancillary Buildings	Allowance made for a goods consolidation centre and ancillary buildings, team to comment on actual requirements
Perimeter wall	Perimeter wall/screen; to under croft only 6.5m high, Gabion wall construction
Utilities distribution to individual buildings	Allowance for distribution cabling from main runs to individual buildings
Plasma gasification system	System sized for waste produced in Masdar only – No waste to be accepted from the surrounding area – Allowed for connection to the grid and ancillary buildings
Heat Based district dehumidification system	Limited detail – design to be developed
Waste to Energy system	Limited detail – design to be developed

5.0 Key Issues, Assumptions and Exclusions

The following are a number of key risks/issues that require review and action. Any additional costs arising will need to be incorporated during the Draft review period.

Number	Description	Potential Actions
1	Currently the landscaping design has not been developed using trees as a carbon sink; no specific allowance is included within the estimate.	The design team and Gustafson Porter will need to develop a design detailing the types of tree species to maximise carbon absorption within the limited free space and with the limited spare water resource for irrigation.
2	No allowance for temporary services to the University whilst the main services are being installed/constructed; assumed sharing of the temporary supplies with the workers city; all associated costs are deemed part of the preliminaries element of the Construction Management allowance.	The design team will need to develop a strategy with CH2M Hill's input.
3	No site survey information is available to date and therefore have assumed good ground conditions across the site generally that are suitable for the scheme; no allowance has been made for poor ground conditions, underground caverns, antiquities, removing contaminated waste, effect of the water table, or the like.	Once site surveys have been completed a structural engineer will need to be appointed to interpret the information and develop a site wide substructure design.
3	The Undercroft is at a preliminary/ conceptual stage only with no input from structural/ services engineers; current provisional cost allowances will therefore be subject to review following engineering input into the preliminary/conceptual design.	As above a structural engineer will need to be appointed to review the concept design and develop a co-ordinated structural solution for the undercroft area.
4	We note that the Envac system has now been omitted from the scheme and replaced with gravity waste tubes which are collected in each building; no allowance for automated loading of waste onto the PRT system.	If an automated loading of waste is required this will need to be designed out.
5	Assumed all works to the offsite highways/roads will be undertaken by others; allowed for new branch connections to existing adjacent roads.	Assumed all allowances for off site costs and contributions have been accounted for in the Ernst & Young's Project Financial Model.
6	All works associated with the proposed high speed rail link, tunnel, station, etc are excluded. – *See below the line costs on the cost summary page*	Assumed these works will be centrally funded outside of the Masdar project.
7	The current services design only allows for a back up electrical supply through connection to the Abu Dhabi main grid; no allowance for back up water or gas supplies the city.	
8	Allowance has been made for providing temporary buses until the LRT and PRT systems are up and running.	

5.0 Key Issues, Assumptions and Exclusions – Continued

Exclusions

The following are excluded, but need to be covered by other budgets within the overall Project Financial Model Where appropriate.

1. Site acquisition costs
2. Legal fees
3. Financial costs
4. Taxes & Duties etc
5. Developers Contributions to tenant fitting out costs
6. Any tax allowances, government or local grants
7. The benefit of capital allowances or similar
8. Fund monitoring/ 3rd party advisor team costs
9. Professional fees and Expenses (Other than design team allowance included)
10. Surveys
11. Site investigation/ monitoring costs
12. Studies (e.g. Environmental Impact/ Wind Flood etc)
13. Planning application Fees
14. Building control fees
15. Models/ visuals
16. Client site supervision/ Clerk of works
17. Agency/ appraisal and marketing costs
18. Bespoke and project insurance's
19. Special bonds
20. Special contract conditions
21. Show rooms/ Marketing suites/ Mock ups
22. Contractors/ developers design fees
23. Exchange rate fluctuations

The following works are currently omitted outside the scope of this scheme:

1. Highways & Access roads off site
2. High speed rail link
3. We have not costed for additional foundation costs associated with building in and around an existing/ future tunnel.
4. Any works to the site that are required from the site investigation over and above a minimal cut & fill exercise currently included.
5. Additional above ground PRT network that may be required if third party transportation infrastructure works are not completed to the required programme.

The following works are assumed by tenants or operator:

1. All fitting out of retail or catering units
2. All hotel operators supplies and equipment
3. All hotel pre-opening expenses
4. Conference centre supplies and equipment
5. Office fit-out beyond CAT A (Excludes Headquarters)
6. Light manufacturing units to shell and core only, though includes air conditioning installation.

Assumptions

1. Design team fees allowed at 10% - See indicative fee breakdown under section 10.
2. All new offsite roads are by others
3. Assume LRT works are carried out as part of the wider Abu Dhabi installation. LRT civils work will be installed in line with the phasing diagram
4. Landscaping design at inception stage whereby areas have been costed based on a split between hard and soft landscaping (no specification details have been received to date)
5. Assumed excavation exercise only to Waddys with no lining or the like, Waddy to find it's own natural course in time
6. We have made an allowance for a site wide irrigation system but no details to date
7. All temporary services required to be installed prior to the main service infrastructure becoming operational are assumed covered under CH2MHills scope of works.
8. Perimeter wall to city – walkway around perimeter.
9. Landscaping specification within the walled city is of a higher standard than the provision for landscaping outside the city zone.
10. ADFEC Headquarters design is currently out to competition and the high cost allowance anticipates the involvement of a signature architect.
11. Assumed all sports pitches are open air with no enclosed areas of stadium.
12. All building construction costs have been reviewed with F+P and Ernst & Young.
13. All energy provision costs have been developed in conjunction with contributing members of the design team.
14. The cost plan allows for a higher rate for soft and hard landscaping within the walled city zone as we understand this will be designed to a higher specification than the landscaping outside the walled city which will be more space.

Masdar City

6.0 Building Use - Maintenance and Life Cycle costing

	New BUA (Gross Area) m2	Total Cost of Life Cycle Per and maintenance	PHASE 1 A	1 B	1 C	2 A	2 B	2 C	3 A	3 B	3 C	4 A	4 B	4 C	5 A	5 B	5 C	6 A	6 B	6 C	Total
Masdar Centre																					
Masdar Centre - ADFEC						3,038,952															
Headquarters - Tower	32,431	3,038,952																			3,038,952
Allowance for upgrade for user occupier to Tower only	N/A	-																			0
Masder centre - low level offices	46,811	3,413,501				3,413,501															3,413,501
Allowance for upgrade for user occupier	N/A	-																			0
Central Station	30,915	2,287,022				2,287,022															2,287,022
Station (retail)	7,729	571,774				571,774															571,774
University - Generally	145,299	8,752,670	8,752,670																		8,752,670
University hall of residence	48,433	2,531,835	2,531,835																		2,531,835
Hotel 5*	13,313	787,893				787,893															787,893
Hotel 5*: Convention Centre	7,636	556,824				556,824															556,824
Hotel 4*	23,949	1,417,355				495,533						921,822									1,417,355
Service Apartment - 4*	9,294	550,039				550,039															550,039
Retail		-																			0
Mall common services		-																			0
Retail space		-																			0
Anchor tenant; shell only	-	-																			0
Cinema/leisure; fully fitted out	-	-																			0
Food Court; shell only	10,620	104,378		38,410							14,477	36,031						15,460			104,378
Retail units; shell only	3,908	26,019		26,019																	26,019
Sports Zone	-	-																			0
Football/Rugby Pitch (Not Covered)		-																			0
400m running track	-	-																			0
Sport Hall	2,984	186,060					113,981					72,080									186,060
Spots Hall 1 - Double Height		-																			0
Spots Hall 2 - Double Height		-																			0
Spots Hall 3 - Double Height		-																			0
Gym Pool	5,175	322,675											322,675								322,675
Leisure - External Space 20,925m2		-																			0
SEZ Offices	464,253	33,853,758		868,197				10,051,202	768,805	643,454	356,583	288,256	9,102,938	4,867,836	619,244	4,440,957	372,188	423,671	127,612	922,814	33,853,758
SEZ Research labs	61,140	4,199,928		69,999				1,552,613	147,829			64,229	1,378,338	450,561		536,360					4,199,928
SEZ Light Manufacturing (Airconditioned warehouse environment) Shell and core only. fit-out by tenants	354,132	26,572,144		1,845,926					797,843	2,648,420	2,387,300	564,110		5,649,353	2,548,624	2,204,516	2,632,138	435,951		4,857,963	26,572,144
SEZ Local Centre	-	-																			0
Food Court; shell only	9,845	1,074,705						850,813					223,892								1,074,705
Retail units; shell only	9,845	1,074,705						850,813					223,892								1,074,705
Other offices	249,247	18,175,322		4,019,037		1,197,799	1,933,352	43,607	2,331,865	5,067,275	129,726	85,099	2,898,023						208,189	261,349	18,175,322
Show Case and Testing - exclud	-	-																			0
Science centre	40,068	3,006,485										3,006,485									3,006,485
Residential - high quality - 30%	410,317	14,299,547	63,619	1,384,075	1,191,525	170,741	206,863	557,586	613,416	644,791	1,153,113	1,026,336	37,628	895,293	988,353	1,083,347	1,226,225	697,296	1,396,464	962,874	14,299,544
Residential - Medium quality - 35	478,703	17,200,780	76,526	1,664,890	1,433,274	205,382	248,833	670,715	737,872	775,613	1,387,069	1,234,570	45,262	1,076,939	1,188,880	1,303,148	1,475,014	838,771	1,679,793	1,158,232	17,200,782
Residential - Low quality- 35%	478,703	25,024,199	111,333	2,422,131	2,085,169	298,796	362,010	975,776	1,073,478	1,128,385	2,017,948	1,796,088	65,848	1,566,763	1,729,618	1,895,857	2,145,894	1,220,268	2,443,812	1,685,030	25,024,202
Community Facilities		-																			0
Community Centre inc creche	13,476	484,220							484,220												484,220
Place of worship	14,779	531,040			45,418				345,882						45,418		50,449		43,873		531,040
Library/ adult education facility	1,345	48,329				48,329															48,329
Schools and education facilities	43,207	1,552,516								418,968							402,439	375,921	355,188		1,552,516
Police station	8,477	304,596		216,167						88,429											304,596
Fire Station	1,000	35,932	35,932																		35,932
Community Hospital	6,901	247,967														247,967					247,967
Health Centre	8,626	309,950														309,950					309,950
Entertainment Centre	12,758	458,421				458,421															458,421
Car park - Internal - Assumed lower areas in undecroft	550,003	1,743,771			276,732					268,926	326,140	158,895					368,685			344,393	1,743,771
Car Park External - Round buildi	739,158	2,343,482	308,043			946,235			308,043			154,022			473,117			154,022			2,343,482
																					0
																					0
																					0
																					0
																					0
																					0
																					0
																					0
	4,344,480	**177,088,797**																			177,088,797

Masdar City

6.0 Infrastructure - Maintenance and Life Cycle costing

COST DETAILS	Quant	Unit	Total Cost of Maintenance and life cycle costing Per annum using Average quality materials		PHASE 1 A	1 B	1 C	2 A	2 B	2 C	3 A	3 B	3 C	4 A	4 B	4 C	5 A	5 B	5 C	6 A	6 B	6 C	D
OFF SITE WORKS AND INFRASTRUCTURE																							
Allowance for bore holes to extract water for Decelination plant	1	Item	79,200			19,800	39,600	59,400	79,200														
Allowance for maintenance chambers	1	item	19,800			4,950	9,900	14,850	19,800														
Pump Station, including equipment, building and compound	1	Item	528,000					264,000	528,000														
Brine recover system	1	Item	396,000					198,000	396,000														
Road connecting pumping station to public highway	1	Item	15,400			7,700	15,400																
New flyovers to connect to existing highway	9,000	m2	207,900			69,300	138,600	207,900															
Road widening	9,000	m2	55,440			18,500	37,000	55,500															
New peripheral roads outside the site boundary- by others																							
New roundabouts -outside the site boundary- by others																							
LRT SYSTEM																							
Allowance for works to incorporate Masdar within the proposed Abu Dhabi LRT Network (Note no specification for proposed network exists)																							
Elevated permanent way installation including structure (2 roads)	4.5	km	5,654,880			622,200	1,300,800	1,922,800	2,544,800	3,166,800	3,788,800	4,410,800	5,032,800	5,654,880									
Control, signalling and power installations	1.0	item	208,085			22,800	47,800	70,700	93,600	116,500	139,400	162,300	185,200	208,085									
Elevated stations (note central station included within Masdar City's building section)	5	nr	2,217,600			243,900	510,000	753,900	997,800	1,241,700	1,485,600	1,729,500	1,973,400	2,217,600									
Additional train carriages to service the Masdar branch of the proposed Abu Dhabi LRT, Say	4	nr	310,464			34,200	71,500	105,700	139,900	174,100	208,300	242,500	276,700	310,500									
Enlarge depot facility to cater for additional rolling stock	1	item	147,840			16,300	34,000	50,300	66,600	82,900	99,200	115,500	131,800	147,800									
Back-up utilities connections																							
Back up electricity supply infrastructure and connection to grid, assumed connection at new airport upgrade																							
Cabling to above, say approx 2km	2	km	26,400				13,200	26,400															
Contribution towards new Sub station	1	Item	528,000				264,000	528,000															
Back-up water supply infrastructure	1	Item	396,000			198,000	396,000																
Back-up gas supply infrastructure - Not applicable																							

6.0 Infrastructure - Maintenance and Life Cycle costing

COST DETAILS	Quant	Unit	Total Cost of Maintenance and life cycle costing Per annum using Average quality materials		PHASE 1 A	1 B	1 C	2 A	2 B	2 C	3 A	3 B	3 C	4 A	4 B	4 C	5 A	5 B	5 C	6 A	6 B	6 C	D
GENERAL SITE PREPARATION																							
Cut and fill to new levels																							
Excavation & Disposal, assume 500mm deep, 50% of area	2,750,000.0	m2																					
Fill , assume 500mm fill, 50% area	2,750,000.0	m2																					
Compact	5,500,000.0	m2																					
Landscaping - Outside the walled city																							
Shelter belt planting																							
Hard landscaping - 10%	51,020	m2	228,978			17,860	31,828	41,445	70,754	73,731	88,156	100,063	113,802	125,251	141,508	154,331	166,009	173,336	185,930	198,982	206,538	216,384	228,978
Soft landscaping - 90%	459,180	m2																					
City entrances																							
Hard landscaping - 60%	85,896	m2	385,501			30,069	53,585	69,776	119,120	124,131	148,418	168,464	191,594	210,869	238,240	259,828	279,488	291,824	313,027	335,001	347,722	364,299	385,501
Soft landscaping - 40%	57,264	m2																					
Research Field																							
Hard landscaping -20 %	24,610	m2	110,450			8,615	15,353	19,991	34,129	35,565	42,523	48,267	54,893	60,416	68,258	74,443	80,076	83,610	89,685	95,981	99,626	104,375	110,450
Soft landscaping - 80%	98,440	m2																					
Nursery production																							
Hard landscaping - 20%	10,460	m2	46,945			3,662	6,525	8,497	14,506	15,116	18,074	20,515	23,332	25,679	29,012	31,641	34,035	35,538	38,120	40,795	42,345	44,363	46,945
Soft landscaping - 80%	41,841	m2																					
Wadi corridors																							
Hard landscaping - 20%	46,934	m2	210,640			16,430	29,279	38,126	65,088	67,826	81,096	92,050	104,688	115,220	130,175	141,971	152,714	159,454	171,040	183,046	189,997	199,055	210,640
Soft landscaping - 80%	187,736	m2																					
Food production																							
Hard landscaping - 20%	N/A																						
Soft landscaping - 80%	N/A																						
Timber Production																							
Hard landscaping - 20%	53,915	m2	241,972			18,874	33,634	43,797	74,769	77,915	93,159	105,742	120,260	132,359	149,539	163,089	175,430	183,173	196,482	210,274	218,259	228,664	241,972
Soft landscaping - 80%	215,662	m2																					
Recreation																							
Hard landscaping - 30%	121,065	m2	543,338			42,380	75,524	98,344	167,892	174,955	209,185	237,439	270,039	297,206	335,783	366,210	393,920	411,307	441,191	472,161	490,091	513,455	543,338
Soft landscaping - 70%	282,484	m2																					
Unallocated area - assumed soft landscaping	854,166	m2																					
Form walls in the green seams to store surface water	1	Item	11,220			875	1,560	2,031	3,467	3,613	4,320	4,903	5,576	6,137	6,934	7,562	8,135	8,494	9,111	9,750	10,120	10,603	11,220
Roads - outside the city																							
Form access roads to the proposed car parks	5,000	m2	44,880			2,109		5,924	18,715			22,889	25,312	29,711	33,929					38,866	40,931		44,880
Form new access roads	23,800	m2	213,629			10,041		28,199	89,083			108,951	120,487	141,422	161,503					185,003	194,829		213,629
Other access roads	6,000	m2	53,856			2,531		7,109	22,458			27,467	30,375	35,653	40,715					46,639	49,117		53,856
Flyovers to car park	11,200	m2	376,992			17,719		49,763	157,206			192,266	212,623	249,569	285,006					326,475	343,817		376,992
Surface water culvert for plantation areas																							
Excavation to for culvert																							
Forming dry waddy	20,000	m2	22,440			1,750	3,119	4,062	6,934	7,226	8,639	9,806	11,153	12,275	13,868	15,125	16,269	16,987	18,221	19,500	20,241	21,206	22,440
Paving & handrail along both sides of the culvert - Assumed not required																							
Allowance for additional irrigation systems to landscaping outside the city No design to date, or review - scope to be confirmed, Say	1	Item	2,640,000			205,920	366,960	477,840	815,760	850,080	1,016,400	1,153,680	1,312,080	1,444,080	1,631,520	1,779,360	1,914,000	1,998,480	2,143,680	2,294,160	2,381,280	2,494,800	2,640,000
ENERGY GENERATION AND SITE INFRASTRUCTURE																							

6.0 Infrastructure - Maintenance and Life Cycle costing

COST DETAILS	Quant	Unit	Total Cost of Maintenance and life cycle costing Per annum using Average quality materials	PHASE 1 A	1 B	1 C	2 A	2 B	2 C	3 A	3 B	3 C	4 A	4 B	4 C	5 A	5 B	5 C	6 A	6 B	6 C	D
ENERGY GENERATION																						
Initial solar farm; CSP technology	50	MW	22,880,000		11,440,000	14,300,000	17,160,000	20,020,000	22,880,000													
Solar panels to buildings - High efficiency	98	MW	48,294,400		3,766,963	6,712,922	8,741,286	14,922,970	15,550,797	18,593,344	21,104,653	24,002,317	26,417,037	29,845,939	32,550,426	35,013,440	36,558,861	39,215,053	41,967,834	43,561,549	45,638,208	48,294,400
Solar panels to car parks - mix of efficiency	5.5	MW	2,541,000		198,198	353,199	459,921	785,169	818,202	978,285	1,110,417	1,262,877	1,389,927	1,570,338	1,712,634	1,842,225	1,923,537	2,063,292	2,208,129	2,291,982	2,401,245	2,541,000
Semi Transparent thin film PV	6.7	MW	3,714,480		289,729	516,313	672,321	1,147,774	1,196,063	1,430,075	1,623,228	1,846,097	2,031,821	2,295,549	2,503,560	2,692,998	2,811,861	3,016,158	3,227,883	3,350,461	3,510,184	3,714,480
Semi Transparent Crystalline PV	9.0	MW	5,322,240		415,135	739,791	963,325	1,644,572	1,713,761	2,049,062	2,325,819	2,645,153	2,911,265	3,289,144	3,587,190	3,858,624	4,028,936	4,321,659	4,625,027	4,800,660	5,029,517	5,322,240
Infastructure to transfer the power to the grid	1	Item	616,000		48,048	85,624	111,496	190,344	198,352	237,160	269,192	306,152	336,952	380,688	415,184	446,600	466,312	500,192	535,304	555,632	582,120	616,000
Carbon offsett - Additional 6MW of PV on spare roof area to provide over capacity which can be used to ofset the excess carbon dioxide the city produces	6	MW	3,326,400		259,459	462,370	602,078	1,027,858	1,071,101	1,280,664	1,453,637	1,653,221	1,819,541	2,055,715	2,241,994	2,411,640	2,518,085	2,701,037	2,890,642	3,000,413	3,143,448	3,326,400
Wind turbines, 250kw each	4.5	MW	356,400		118,700	237,400	356,400															
Infrastructure to transfer power to the grid	2.5	km	49,500		16,500	33,000	49,500															
Iconic wind towers		item	0																			
Evacuaterd Tubes (solar Heat)	25	Hectares	24,200,000		1,887,600	3,363,800	4,380,200	7,477,800	7,792,400	9,317,000	10,575,400	12,027,400	13,237,400	14,955,600	16,310,800	17,545,000	18,319,400	19,650,400	21,029,800	21,828,400	22,869,000	24,200,000
Waste recycling plant	1	item	4,224,000		3,379,200	3,801,600	4,224,000															
Plasma gasification system	1		528,000								176,000	352,000	528,000									
Heat based district dehumidification system	1		1,782,000																	593,994	1,187,935	1,782,000
Envac system - Exc																						
UTILITIES SUPPLIES																						
Install electrical distribution cabling, 22kva cables	45,000	m	237,600		142,560	166,320	190,080	213,840	237,600													
Install sub stations - 132 to 22 kva	2	No.	264,000		158,400	184,800	211,200	237,600	264,000													
Install secondary substations 132 to 22 kva	3	No.	237,600		142,560	166,320	190,080	213,840	237,600													
Install 22 to 11 kva	260	No.	1,372,800		823,680	960,960	1,098,240	1,235,520	1,372,800													
Form transformer enclosures																						
Fit-out of energy centre	1	Item	132,000		79,200	92,400	105,600	118,800	132,000													
Desalination plant including tanks 12,000m3 per day	12,000	m3	443,520		34,595	61,649	80,277	137,048	142,813	170,755	193,818	220,429	242,605	274,095	298,932	321,552	335,745	360,138	385,419	400,055	419,126	443,520
Form connection to piped saline supply	1	Item	13,200		1,030	1,835	2,389	4,079	4,250	5,082	5,768	6,560	7,220	8,158	8,897	9,570	9,992	10,718	11,471	11,906	12,474	13,200
Form main declination building																						
Form ancillary buildings	500	m2	26,400		2,059	3,670	4,778	8,158	8,501	10,164	11,537	13,121	14,441	16,315	17,794	19,140	19,985	21,437	22,942	23,813	24,948	26,400
Install declination plant equipment																						
Allowance for compound	1,000	m2	6,600		515	917	1,195	2,039	2,125	2,541	2,884	3,280	3,610	4,079	4,448	4,785	4,996	5,359	5,735	5,953	6,237	6,600
Form clean water storage tanks, say	1	Item	52,800		4,118	7,339	9,557	16,315	17,002	20,328	23,074	26,242	28,882	32,630	35,587	38,280	39,970	42,874	45,883	47,626	49,896	52,800

6.0 Infrastructure - Maintenance and Life Cycle costing

COST DETAILS	Quant	Unit	Total Cost of Maintenance and life cycle costing Per annum using Average quality materials	PHASE 1 A	1 B	1 C	2 A	2 B	2 C	3 A	3 B	3 C	4 A	4 B	4 C	5 A	5 B	5 C	6 A	6 B	6 C	D
Allowance for bore hole wells - Assume 10 No.	10	No.	66,000		5,148	9,174	11,946	20,394	21,252	25,410	28,842	32,802	36,102	40,788	44,484	47,850	49,962	53,592	57,354	59,532	62,370	66,000
Allowance for additional storage tanks to attenuate fir peaks of abstraction/ and or dispoal of water	2	No.	26,400					13,200					26,400									
Allowance for dew catchers around the city - allow $750,000	1	Item	19,800		1,544	2,752	3,584	6,118	6,376	7,623	8,653	9,841	10,831	12,236	13,345	14,355	14,989	16,078	17,206	17,860	18,711	19,800
Drinkable water supply pipe work																						
Form connection to declination plant	1	Item	13,200		1,030	1,835	2,389	4,079	4,250	5,082	5,768	6,560	7,220	8,158	8,897	9,570	9,992	10,718	11,471	11,906	12,474	13,200
Lay pipe work supply - main runs	40,000	m	52,800		4,118	7,339	9,557	16,315	17,002	20,328	23,074	26,242	28,882	32,630	35,587	38,280	39,970	42,874	45,883	47,626	49,896	52,800
Form branch connections to individual buildings	5,000	m	3,300		257	459	597	1,020	1,063	1,271	1,442	1,640	1,805	2,039	2,224	2,393	2,498	2,680	2,868	2,977	3,119	3,300
Allow for maintenance access to pipe work supply	1	Item	9,900		772	1,376	1,792	3,059	3,188	3,812	4,326	4,920	5,415	6,118	6,673	7,178	7,494	8,039	8,603	8,930	9,356	9,900
Sewage treatment plant, 3.3 hectares	1	item	792,000		792,000																	
Form sewage storage tanks																						
Form connection from sewage pipe work to treatment plant																						
Construct main treatment plant building																						
Form ancillary building	1	item																				
Install treatment plant equipment																						
Foul sewage and surface water collection pipe work																						
Install main sewage runs, average 350mm dia pipes	45,000	m	29,700		1,396		3,920	12,385		15,147	16,751	19,661	22,453						25,720	27,086		29,700
Install rainwater collection runs	45,000	m	29,700		1,396		3,920	12,385		15,147	16,751	19,661	22,453						25,720	27,086		29,700
From branch connections from individual buildings - included																						
Attenuation tanks	1	Item																				
Allowance for manholes	400	No.																				
Allowance for Acco (Gulley Drain) or similar	45,000	m																				
Gas distribution pipework	10,000	m	0																			
Allowance for 50 year storm water tanks to ve also used for grey water storage for irrigation of the landscaping	1	Item	24,750		1,931	3,440	4,480	7,648	7,970	9,529	10,816	12,301	13,538	15,296	16,682	17,944	18,736	20,097	21,508	22,325	23,389	24,750
District cooling distribution pipe work																						
Install pipe work, inc return pipe work, 200mm pipe	45,000	m	475,200		22,334		62,726	198,158		242,352	268,013	314,582	359,251						411,523	433,382		475,200
Allowance for pumping stations and associated buildings	1	Item	66,000		3,102		8,712	27,522		33,660	37,224	43,692	49,896						57,156	60,192		66,000

6.0 Infrastructure - Maintenance and Life Cycle costing

					PHASE																	
					1			2			3			4			5			6			
COST DETAILS	**Quant**	**Unit**	**Total Cost of Maintenance and life cycle costing Per annum using Average quality materials**		**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**D**
I.T & Telecoms	1	item	2,393,600			112,499		315,955	998,131			1,220,736	1,349,990	1,584,563	1,809,562					2,072,858	2,182,963		2,393,600
Allowance for installation of back bone IT and Comms systems - included																							
Allowance for branch connections to individual building - included																							
Allowance for telecoms signal exchanges - included																							
Allowance for manholes/ maintenance chambers and the like - included																							
PRT system																							
Ground level road (4 lanes), including directional magnets, power supplies and signal cabling back control centre	35	km	1,561,190			234,179	390,298	530,805	608,864	640,088	718,148	780,595	858,655	936,714	999,162	1,061,609	1,139,669	1,202,117	1,280,176	1,358,236	1,420,683	1,483,131	1,561,190
Control systems	1	item	403,920			60,588	100,980	137,333	157,529	165,607	185,803	201,960	222,156	242,352	258,509	274,666	294,862	311,018	331,214	351,410	367,567	383,724	403,920
Ground level stations	83	nr	1,095,600			164,340	273,900	372,504	427,284	449,196	503,976	547,800	602,580	657,360	701,184	745,008	799,788	843,612	898,392	953,172	996,996	1,040,820	1,095,600
Passenger vehicles	1,000	nr	5,544,000			831,600	1,386,000	1,884,960	2,162,160	2,273,040	2,550,240	2,772,000	3,049,200	3,326,400	3,548,160	3,769,920	4,047,120	4,268,880	4,546,080	4,823,280	5,045,040	5,266,800	5,544,000
Freight vehicles	250	nr	1,650,000			247,500	412,500	561,000	643,500	676,500	759,000	825,000	907,500	990,000	1,056,000	1,122,000	1,204,500	1,270,500	1,353,000	1,435,500	1,501,500	1,567,500	1,650,000
Waste vehicles	60	nr	396,000			59,400	99,000	134,640	154,440	162,360	182,160	198,000	217,800	237,600	253,440	269,280	289,080	304,920	324,720	344,520	360,360	376,200	396,000
Form maintenance depot and remote service yards	1	item																					
Allowance for power supplies	1	Item	330,000			49,500	82,500	112,200	128,700	135,300	151,800	165,000	181,500	198,000	211,200	224,400	240,900	254,100	270,600	287,100	300,300	313,500	330,000
Transport - Temporary buses																							
Bus - Traditional diesel	3	No.	22,176			22,176																	
Bus - CNG	10	No.	96,096			96,096																	
Bus - diesel hybrid	10	No.	110,880			110,880																	
Bus - CNG Hybrid	10	No.	125,664			125,664																	
Bus - Fuel Cell	2	No.	92,400			92,400																	
Bus recovery and maintenance facility	2,835	m2	74,844			74,844																	
Fuelling facility serving all types	1	No.																					
Showcase and testing enhancements to area	1	item	132,000			66,000	82,500	99,000	115,500	132,000													
Goods consolidation centre and other ancillary buildings	1	item																					
WALLED CITY ZONES																							
Perimeter wall/screen; to undercroft only 6.5m high, Gabion wall	78,000	m3																					
Allowance for forming wind towers in streets	1		224,400			17,503	31,192	40,616	69,340	72,257	86,394	98,063	111,527	122,747	138,679	151,246	162,690	169,871	182,213	195,004	202,409	212,058	224,400
E/O allowance for green fingers	180,000		605,880			47,259	84,217	109,664	187,217	195,093	233,264	264,770	301,122	331,416	374,434	408,363	439,263	458,651	491,975	526,510	546,504	572,557	605,880
Allowance for wind screens along streets	1		112,200			8,752	15,596	20,308	34,670	36,128	43,197	49,031	55,763	61,373	69,340	75,623	81,345	84,935	91,106	97,502	101,204	106,029	112,200

6.0 Infrastructure - Maintenance and Life Cycle costing						PHASE																	
						1			2			3			4			5			6			
COST DETAILS	**Quant**	**Unit**	**Total Cost of Maintenance and life cycle costing Per annum using Average quality materials**			**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**D**
Allowance for forming access to the central spine to carry VIP and hotel guests in electric vehicles; assume charging points for electric vehicles along the city spine and at the city perimeter; form dedicated entrance on the boundary of the city to control vehicles entering the city - only electric. ***Cost of providing the electric vehicles not included in this estimate***	1.0		11,220																				
			0																				
Landscaping - Inside the walled city																							
Linear Park																							
Hard landscaping - 50%	104,901	m2	1,129,910				88,133	157,058	204,514	349,142	363,831	435,015	493,771	561,565	618,061	698,284	761,559	819,185	855,342	917,487	981,892	1,019,179	1,067,765	1,129,910
Soft landscaping - 50%	104,901	m2																					
Urban squares																							
Hard landscaping - 80 %	17,552	m2																					
Soft landscaping - 20%	4,388	m2																					
Public gardens																							
Hard landscaping - 40%	9,374	m2																					
Soft landscaping - 60%	14,060	m2	75,724				5,906	10,526	13,706	23,399	24,383	29,154	33,091	37,635	41,421	46,797	51,038	54,900	57,323	61,488	65,804	68,303	71,559	75,724
Private Courtyards																							
Hard landscaping - 90%	257,310	m2	2,771,537				216,180	385,244	501,648	856,405	892,435	1,067,042	1,211,162	1,377,454	1,516,031	1,712,810	1,868,016	2,009,365	2,098,054	2,250,488	2,408,466	2,499,927	2,619,103	2,771,537
Soft landscaping - 10%	28,590	m2																					
Leisure area	20,925.00	m2	88,387				6,894	12,286	15,998	27,312	28,461	34,029	38,625	43,928	48,348	54,623	59,573	64,081	66,909	71,770	76,808	79,725	83,526	88,387
Football pitch etc																							
Reinforced concrete podium slab and supporting columns to building areas	1,742,523	m2	2,613,785				203,875	363,316	473,095	807,659	841,639	1,006,307	1,142,224	1,299,051	1,429,740	1,615,319	1,761,691	1,894,994	1,978,635	2,122,393	2,271,379	2,357,634	2,470,026	2,613,785
Reinforced concrete suspended slab/roof and columns with block work infill; reinforced concrete trench; steel access walkways; services with PRT running through; av 7.5m wide, included for lighting, power, ventilation etc	45,000	m	506,250				39,488	70,369	91,631	156,431	163,013	194,906	221,231	251,606	276,919	312,863	341,213	367,031	383,231	411,075	439,931	456,638	478,406	506,250
Allowance for fire doors every station	83	No.	41,500				3,237	5,769	7,512	12,824	13,363	15,978	18,136	20,626	22,701	25,647	27,971	30,088	31,416	33,698	36,064	37,433	39,218	41,500
TOTAL PER YEAR			**113,060,813**																				

7.0 Z^2 Philosophy

The previous 15% Z-Squared allowance has now been broken down into its component parts to show how we propose this money may be spent complying with the Bioregional principles, achieving Zero waste/ Zero carbon, reducing energy consumption by up to 80%, etc

As part of the main preliminaries we have included allowances that will allow the set up and running of facilities to manage all materials going in and out of the site to improve distribution (Goods consolidation centres). Organise all waste materials to minimise waste (Waste management facilities) and aid in recycling (recycling centres), these are key to achieving Zero waste/ Carbon etc.

Description	Percentage	Total allowance	Total allowance per year (7 year programme)
Setting up and running a waste management facility		Inc in Prelims	
Setting up and running site consolidation/ distribution centre for the construction phase		Inc in Prelims	
Setting up and running construction material recycling facility		Inc in Prelims	
Increased insulation to buildings	11.00%	$95,403,000	$13,629,000
Triple glazing/ coated glazing residential & Enhanced double glazing elsewhere	16.00%	$138,768,000	$19,824,000

Description	Percentage	Total allowance	Total allowance per year (7 year programme)
E/O cost for sustainable plant and equipment	10.00%	$86,730,000	$12,390,000
E/O cost for sustainable fuel to above - i.e. bio diesel	9.00%	$78,057,000	$11,151,000
E/O for sustainable transport for the site workers	4.00%	$34,692,000	$4,956,000
E/O cost for providing locally grown sustainable food for the worker city	9.00%	$78,057,000	$11,151,000
Protection of local wildlife and habitat	1.00%	$8,673,000	$1,239,000
Provide better welfare facilities to the labour city - to promote health and happiness and provide fair working conditions	4.00%	$34,692,000	$4,956,000
Allowance for creating solar shading to reduce the reliance of mechanical methods of cooling	30.00%	$260,190,000	$37,170,000

Description	Percentage	Total allowance	Total allowance per year (7 year programme)
Enhanced fixtures to units to achieve 80% energy consumption approach – done through aerated taps, controls and the like.	1.50%	$13,009,500	$1,858,500
Enhanced energy efficient office equipment to achieve 80% energy consumption approach - Part of tenant fit out			
Enhanced fresh air systems to achieve 80% energy consumption approach – through enhanced controls and the like	2.00%	$17,346,000	$2,478,000
Increased wall massing to reduce energy loads	2.50%	$21,682,500	$3,097,500
Total	**100.00%**	**$867,300,000**	**$123,900,000**

8.0 Construction Management

Under the allowance of construction management we have assumed a construction management company(s) will be employed to manage the entire development process. We assume the scope to include: -

- The provision of worker village
- Temporary services and infrastructure to site
- Management and service gangs to manage waste strategy and general site conditions
- Management and service gangs to manage goods consolidation centre and distribution of materials
- All common welfare facilities with separate facilities for labourers and management
- Central site offices & meeting facilities for construction team, management design team and Client
- Construction of all site energy and infrastructure
- Construction of University & ADFEC Headquarters
- Programme management
- Procurement issues
- Site wide plant, lifting equipment and the like (bio fuelled)
- All Construction Management profits and overheads on construction expenditure.

Please refer to section 13 for an example of.a typical large project preliminaries breakdown for construction management allowance which will have to be reviewed with CH2MHill in due course.

9.0 Contingency

For the purpose of this estimate the following allowances have been included:

Design and construction contingencies 7.5%

Programme and procurement contingency 2.5%

Development contingency Excluded

10.0 Professional fees

We have retained a 10% allowance for all professional design team fees for the project.

Below is a typical fee break down for example only.

Discipline	Percentage of construction cost	Projected Value
Architect	3.60%	$479,080,872
Structural Engineer	1.60%	$212,924,832
Services Engineer	1.10%	$146,385,822
Project Manager	1.00%	$133,078,020
Quantity Surveyor	1.00%	$133,078,020
Landscape Architect	0.50%	$66,539,010
Highway Consultant	0.20%	$26,615,604
Fire consultant	0.06%	$7,984,681
Energy Consultants	0.30%	$39,923,406
Marketing - Excluded		
Planning - Excluded		
Lawyers - Excluded		
Surveys - Excluded		
Other Consultants TBC	0.64%	$85,169,933
TOTALS	**10.00%**	**$1,330,780,200**

11.0 Inflation Statement

We have previously advised that inflation is currently running at 15% per annum in the Abu Dhabi construction market.

Since the cost plan was first developed construction inflation in Abu Dhabi has been rising at unprecedented levels; figures of 2% per month are currently being experienced. The Dirham is tied to the US Dollar at a rate of 3.671. The weakening of the US Dollar against other world currencies has undoubtedly contributed to the inflation within the Middle East, where a large proportion of construction materials must be imported from the international market. For example the USD has lost around 3% against the Euro since June 2007, making imported European products more expensive.

12.0 Information Used

Foster & Partners - drawings

Drawing No.	Description
1250	Draft Site Plan
1770	GA Site Plan
1771	GA Undercroft
1774	GA Undercroft
1775	GA Plot Definition
1776	GA Sub phase plan
1777	GA Plot Plan

Foster & Partners – other information

Draft Master plan containing all consultant reports (November 2007)
MIT Presentation
Masdar area design guide and phasing workbook (27/11/07)
Master plan site phasing sheets
Typologies – section – master plan drawings
Information posted of F&P's FTP Site
Meetings held with the team in Abu Dhabi 18-20th November 2007

WSP

Meetings held on 19/10/07 and 31/10/07 with WSP and F&P to discuss the phasing and infrastructure – Emails received 30/11/07

Systamatica

Systamatica report received 01/11/07

Transola

E-mails received 5/11/07, 19/11/07 & 30/11/07 responding to queries

ETA

E-mails received 31/10/07, 2/11/07 & 30/11/07 responding to queries

13. Example of a typical large project preliminaries breakdown for construction management allowance

EXAMPLE PRELIMINARY BREAKDOWN FOR MASDAR						
tab	Section	Labour $	Plant $	Materials $	Staff $	Total $
1	INSURANCES			9,400,000		9,400,000
2	BOND					0
3	SIGNBOARD	200,000	100,000	400,000		700,000
4	TEMPORARY FENCING / HOARDING	9,400,000		9,400,000		18,800,000
5	TEMPORARY ROADS	400,000	100,000	1,900,000		2,400,000
6	MAINTAIN PUBLIC ROADS	4,800,000	12,100,000	400,000		17,300,000
7	SITE ADMINISTRATION & LABOUR				523,800,000	463,800,000
8	RATES ON TEMPORARY BUILDINGS			5,800,000		5,800,000
9	EMPLOYERS ACCOMMODATION			3,700,000		3,700,000
10	CONTRACTORS ACCOMMODATION	16,000,000	4,000,000	16,800,000		36,800,000
11	CONTRACTORS TELEPHONE			13,200,000		13,200,000
12	EMPLOYERS TELEPHONE					0
13	UNLOAD & DISTRIBUTE	94,400,000	11,500,000	500,000		106,400,000
14	SCAFFOLD	40,300,000		40,300,000		80,600,000
15	GENERAL PLANT	69,300,000	95,100,000	6,700,000		171,100,000
16	WATER FOR THE WORKS	300,000		5,500,000		5,800,000
17	TEMPORARY ELECTRICS/ ENERGY	28,100,000	6,500,000	57,400,000		92,000,000
18	PROTECTION OF THE WORKS			4,600,000		4,600,000
19	DRYING THE WORKS			1,200,000		1,200,000
20	REMOVE RUBBISH & RECYCLING/ GOODS DISTRIBUTION			45,700,000		45,700,000
21	FINAL CLEAN	5,600,000				5,600,000
22	SITE IT			19,100,000		19,100,000
23	GENERAL EXPENSES & SUNDRIES	54,500,000		20,800,000		75,300,000
24	WORKER VILLAGE			60,000,000		60,000,000
		323,300,000	129,400,000	262,800,000	523,800,000	1,239,300,000
			O.H. & P. (Included)			
			TOTAL FIXED PRICE PRELIMS			$1,239,300,000