Masdar Institutue of Science and Technology

Concept Design Report

4th March 08

phaconsult

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EXECUTIVE SUMMARY

This report has been prepared to summarise work conducted by PHA Consult during Concept Design stage in collaboration with the Design Team. PHA's appointed scope is identified as Sustainable MEP Design for Phases 1A, 1B, 2 and 3 of Masdar Institute of Science and Technology (MIST), Abu Dhabi, UAE, and effectively commenced in mid December 2007.

- Design input during Concept stage has been explained in detail in this document, and covers the following key elements of work:
- Interpretation of ADFEC's requirements and briefing
- Interpretation of the overall Master Plan design and an understanding its objectives
- Compilation of an Environmental Performance Brief for MIST
- Investigations into relevant aspects of Occupant Comfort
- Microclimatic studies
- Internal and external performance advice and simulation
- Building fabric performance studies and passive responses
- Optimal approach to minimal energy and carbon systems design
- Infrastructure connectivity
- Outline MEP systems design
- Identification of critical path equipment and technologies for MIST Phase 1A
- Focussed studies looking into key low to zero carbon techniques and technologies:
    - Fume cupboard technologies
    - Liquid Desiccant cooling systems
    - Geothermal coupling
    - Parabolic power plants
    - Renewable hot water and power generation
    - Ice and thermal storage systems
    - Optimal utilisation of MIST Phase 1A roof top area
    - Electrical power generation
    - Thermal labyrinth techniques

The key findings of this stage have been as follows:

- Infrastructure provisions for MIST are suitable for connectivity demands long term, however, it has become apparent that a limited number of these central services will be available in time for Phase 1A, which is due for completion Aug 2008. This has placed a significant emphasis for designing a degree of autonomy with regards to power and thermal demands into the first phase of MIST.

- In order to generate the level of cooling needed to treat internal spaces studies have revealed that a combination of liquid desiccant and absorption cooling is necessary within 1A. This places a demand on utilising roof space for solar thermal generation, rather that using this surface for photovoltaic electrical generation. Therefore under this initial phase electrical power generation will be provided from offsite, and initially, temporary PV farms.

- Due to the large volumes of fresh air needed to serve internal spaces, particularly daytime air supply rates for the teaching, labs and office spaces, has identified a need to find passive means of pre-treating this intake air and drawing it from above the heat haze zone generated by the waste heat from solar energy conversion at roof level. The approach recommended here is to install mechanical intake towers reaching above the heat haze zone and passing this intake air through low velocity thermal labyrinths, positioned below the podium deck, prior to reaching air treatment plant which conditions the air ready for supply to internal comfort controlled spaces.

- It has also been discovered that thermal and power loadings required by laboratory activities are significantly higher than the allowances considered during development of the Master Plan. It is currently anticipated that eventual lab loads will be between 3 to 5 times greater than original expectations, and increases in ventilation rates are also expected. These have a consequential impact on annual energy use, both thermally and electrically, and will lead to greater provisions to support this loads in the Master Plan infrastructure. Recent and ongoing meetings between MIT and the appointed specialist lab consultant will reveal more specific lab activities and consequential loadings.

- Studies of the residential blocks have been conducted to examine optimised thermal and daylight performance levels. Whilst these studies are ongoing, it is clear that heat gain limitation is of more importance and benefit than natural light penetration. It was also found that a loosely controlled thermal buffer space connecting residential blocks can significantly improve circulation conditions and thermal performance of adjacent residential units.

- Internal occupant comfort levels and acceptable limits have been studied in detail to test possible performance brief responses. Once the resultant brief has been accepted by ADFEC internal comfort control systems will be developed in detail to offer the lowest energy solutions possible whilst meeting these performance levels. Initial systems options have been examined and recommendation made for all key areas of the programme.

- Public realm microclimate considerations adopted from the Master Plan have been examined and simulated to test the viability of passive performance responses suggested. Initial wind studies reveal a degree of concern over achieving expected air change rates over night to recharge the exposed thermal mass within these public spaces above the Podium. As a result utilisation of wind towers for enhancing necessary night purging of these areas has been recommended to limit peak conditions and potential heat stress. Also, recommendations for using concentrated passive downdraft evaporative cooling (PDEC) tower techniques in key public spaces has been put forward to assist comfort during high ambient conditions. Prior to developing these solutions further a wind tunnel specialist facility will conduct various tests to corroborate our findings and optimise scale and positioning of wind towers where proven necessary.

1 Basis of Design – EPB

The Environmental Performance Brief documents at Concept Design Stage the design criteria for Sustainable MEP engineering for MIST.

It records our understanding of:

- The "Client's Project Requirements"
- Existing site and microclimatic conditions
- Existing and envisaged connectivity to services infrastructure
- Identifies relevant regional, national and international policies on sustainable development
- Sets out the sustainability targets for MIST that are set by work undertaken for Masdar City Masterplan.
- Identifies other relevant sustainability benchmarks and targets and assessment frameworks
- Reviews the applicability of the Client's existing sustainability assessment frameworks to monitor achievement of project targets
- Outlines performance criteria and requirements for internal spaces and the MEP servicing systems

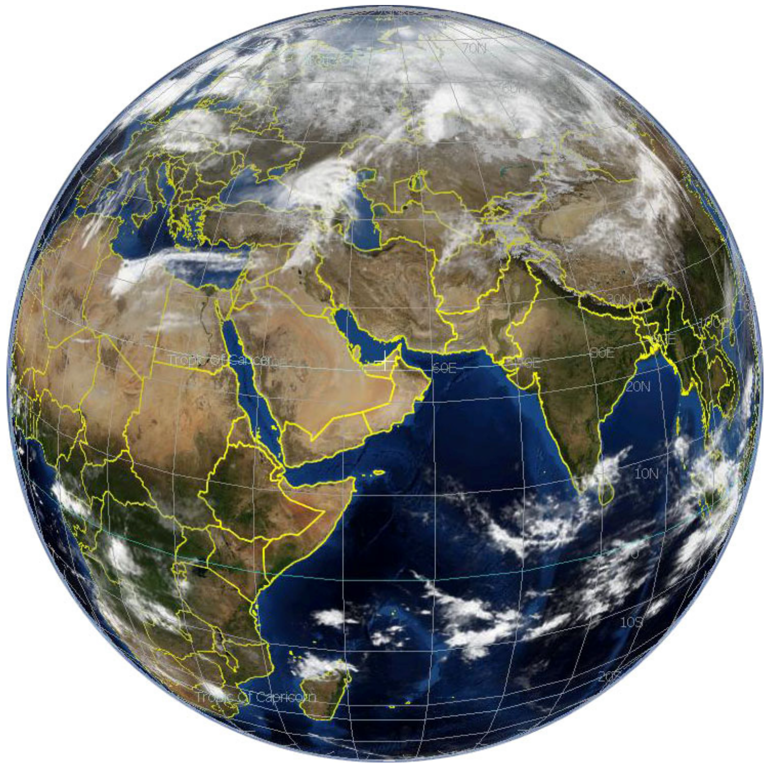
1.1 Site Location

M.I.S.T. is located within the greater conurbation of Masdar city, which is situated to the east of Abu Dhabi's old city sandwiched between the new developments of Raha Beach and Khalifa City and Abu Dhabi International Airport.

Developed by Foster + Partners, the masterplan for Masdar city aims to set a new standard in the development of a sustainable city.

M.I.S.T. will be designed and developed using some of the fundamental strategies behind the greater masterplan of Masdar city and underwritten by strategies that have been evolved from the rich heritage of the Middle East. Traditional techniques and methodologies such as orientation, natural ventilation utilising windtowers and high-density low-rise development providing cool shaded environments have been researched and been adapted to the modern demands of a contemporary city and a sustainable future.

[Extract from F+P Concept Design Report]



Longitude: 54°37'1"E

Latitude: 24°25'45"N

Figure 1-1 Masdar City in the regional context

Figure 1-2 Masdar City in relation to Abu Dhabi

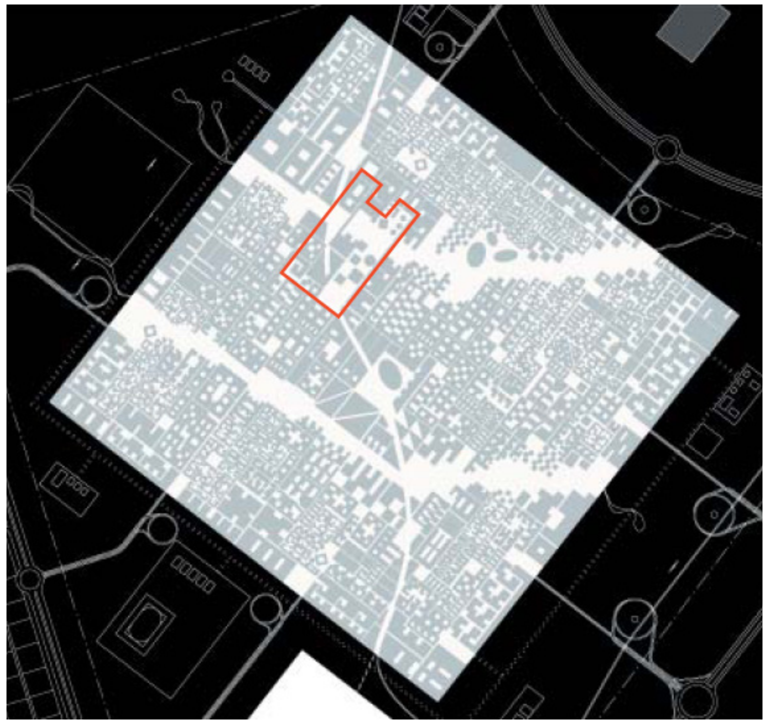


Figure 1-3 MIST Campus Location Functional Program

1.2 Site Climatic Context

1.2.1 Data Availability and Sources

For the purposes of climate analysis and thermal simulation data has been taken from the Energy Plus Weather Database which uses annual hourly IWEC[1] data collected for WMO Station 412170, OMAA Abu Dhabi International Airport. It is this file that is used by ASHRAE to generate design conditions for Abu Dhabi that are detailed later in this section.

(http://www.eere.energy.gov/buildings/energyplus/weatherdata/2_asia_wmo_region_2/zip/ARE_Abu.Dhabi_IWEC.zip)

This weather station is located adjacent to the site at an altitude of 27m, at 54°37'E: 24°25'N

Hourly weather data for this station has also been retrieved from this weather station, accessed via Weather Underground (http://www.wunderground.com/history/airport/OMAA).

This dataset is not fully verified, however it provides a longer-term dataset that is suitable for the analysis of long term climatic trends, in particular it has enabled us to verify seasonal wind regimes that cannot be assessed from annual data alone.

Figure 1-4 IWEC Data Source Location in Relation to Masdar

1.2.2 Climate Classification

ASHRAE classify Abu Dhabi's climate as follows:

- 6254 annual cooling degree-days (10°C baseline)
- 0 annual heating degree-days (10°C baseline)
- 3358 annual cooling degree-days (18°C baseline)
- 24 annual heating degree-days (18°C baseline)
- Climate type "BWh" (Köppen classification) - Arid Subtropica
- Subtropical hot desert (lat. 15-25°N)
- Climate type "4B" (ASHRAE Standards 90.1-2004 and 90.2-2004 Climate Zone)

1.2.3 ASHRAE Design Day Conditions

The table below provides the ASHRAE 'Design Day' conditions for Abu Dhabi International Airport. These figures do not take into account local microclimate effects such as urban heat island impacts.

Data provided by ASHRAE with Energy Plus Weather Data.

	Max Dry Bulb (°C)	Daily Temp Range (°C)	Humidity Indicating Type	Humidity Indicating Condition at Max Dry Bulb	Wind Speed (m/s) design conditions vs. traditional 3.35 m/s	Wind Direction (Deg. N=0)	Clearness (0.0 to 1.1)	Day of Month	Month	Day Type
Annual Heating 99.6%, MaxDB=11.2°C	11.2	0	W-B	11.2	2	110	0	21	1	WDD
Annual Heating 99%, MaxDB=12.8°C	12.8	0	W-B	12.8	2	110	0	21	1	WDD
Annual Humidification 99.6% Design Conditions DP=>MCDB, DP=0°C	30.2	0	D-P	0	2	110	0	21	1	WDD
Annual Humidification 99% Design Conditions DP=>MCDB, DP=2.4°C	29.6	0	D-P	2.4	2	110	0	21	1	WDD
Annual Heating Wind 99.6% Design Conditions WS=>MCDB, WS=10.1m/s	20	0	W-B	20	10.1	110	0	21	1	WDD
Annual Heating Wind 99% Design Conditions WS=>MCDB, WS=9.2m/s	21.1	0	W-B	21.1	9.2	110	0	21	1	WDD
Annual Cooling (DB=>MWB) .4%, MaxDB=44.9°C MWB=23.3°C	44.9	12.5	W-B	23.3	4.3	320	1	21	8	SDD
Annual Cooling (DB=>MWB) 1%, MaxDB=43.2°C MWB=23.5°C	43.2	12.5	W-B	23.5	4.3	320	1	21	8	SDD
Annual Cooling (DB=>MWB) 2%, MaxDB=42°C MWB=23.6°C	42	12.5	W-B	23.6	4.3	320	1	21	8	SDD
Annual Cooling (WB=>MDB) .4%, MDB=35.2°C WB=30.4°C	35.2	12.5	W-B	30.4	4.3	320	1	21	8	SDD
Annual Cooling (WB=>MDB) 1%, MDB=34.6°C WB=29.8°C	34.6	12.5	W-B	29.8	4.3	320	1	21	8	SDD
Annual Cooling (WB=>MDB) 2%, MDB=34.3°C WB=29.3°C	34.3	12.5	W-B	29.3	4.3	320	1	21	8	SDD
Annual Cooling (DP=>MDB) .4%, MDB=33.2°C DP=29.2°C HR=0.0260	33.2	12.5	D-P	29.2	4.3	320	1	21	8	SDD
Annual Cooling (DP=>MDB) 1%, MDB=33°C DP=28.9°C HR=0.0255	33	12.5	D-P	28.9	4.3	320	1	21	8	SDD
Annual Cooling (DP=>MDB) 2%, MDB=32.7°C DP=28.1°C HR=0.0243	32.7	12.5	D-P	28.1	4.3	320	1	21	8	SDD
Annual Cooling (Enthalpy=>MDB) .4%, MDB=35.3°C Enthalpy=102.8kJ/kg	35.3	12.5	Enth	102.8	4.3	320	1	21	8	SDD
Annual Cooling (Enthalpy=>MDB) 1%, MDB=34.5°C Enthalpy=99.9kJ/kg	34.5	12.5	Enth	99.9	4.3	320	1	21	8	SDD
Annual Cooling (Enthalpy=>MDB) 2%, MDB=34.4°C Enthalpy=97.2kJ/kg	34.4	12.5	Enth	97.2	4.3	320	1	21	8	SDD

Winter Design Day WDD
Summer Design Day SDD

[1] International Weather for Energy Calculations (IWEC)
ASHRAE IWEC data files are 'typical' weather files suitable for use with building energy simulation programs for 227 locations outside the USA and Canada.
The files are derived from up to 18 years of DATSAV3 hourly weather data originally archived at the U. S. National Climatic Data Center. The weather data is supplemented by solar radiation estimated on an hourly basis from earth-sun geometry and hourly weather elements, particularly cloud amount information.

1.2.4 Solar Radiation Data

The sun passes almost directly overhead on June 21st, being only slightly north of the Tropic of Cancer[2].

The sunpath for the site is provided below.

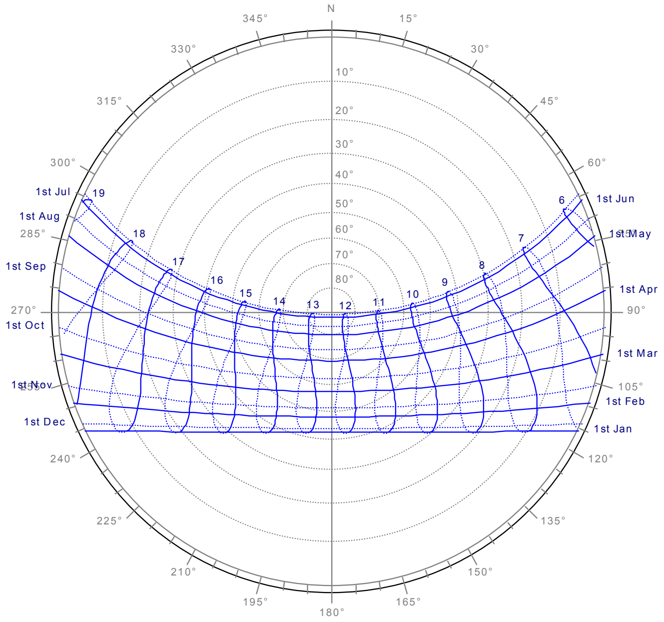


Figure 1-5 Sterographic projection of sunpath diagram for MIST site

Viewing the annual sunpath in three-dimensions allows us to visualise those orientations that look towards the sun at any time of day throughout the year:

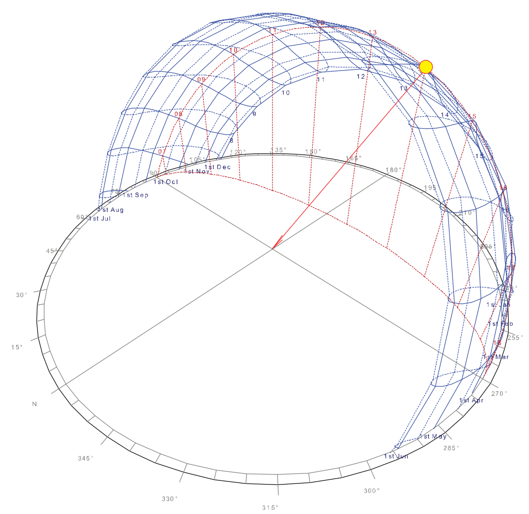


Figure 1-6 3-D Annual sunpath, March 21st highlighted, sun at 1400hrs

Clear skies predominate in Abu Dhabi; however there is a relatively high proportion of diffuse radiation that can be attributed to high levels of humidity rather than significant cloud cover.

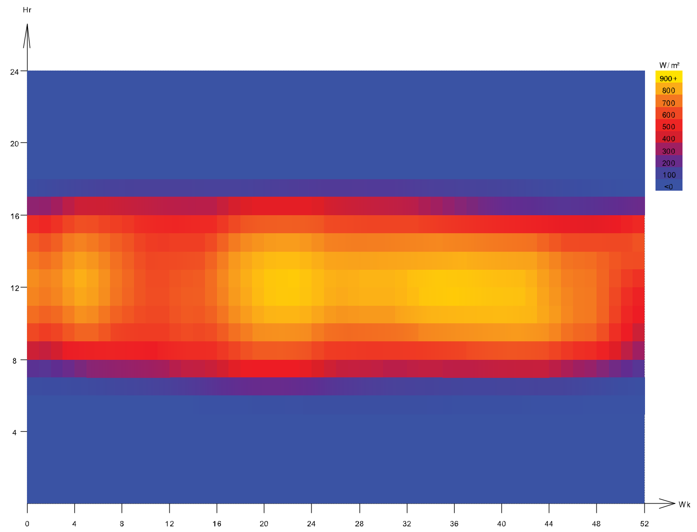


Figure 1-7 Annual hourly distribution of direct solar radiation W/m²

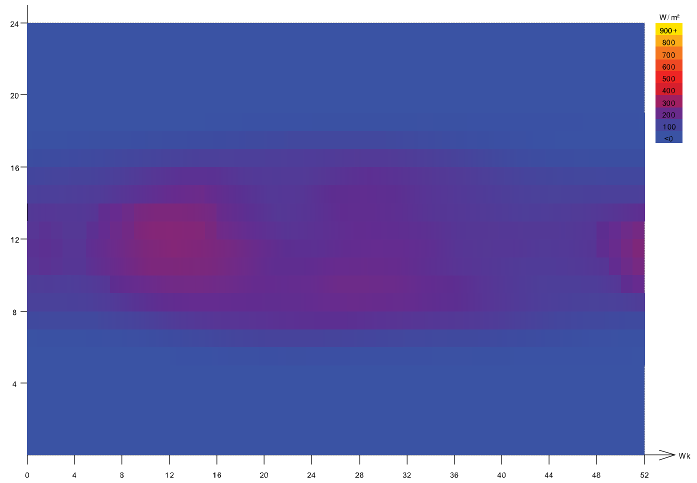


Figure 1-8 Annual hourly distribution of diffuse solar radiation W/m²

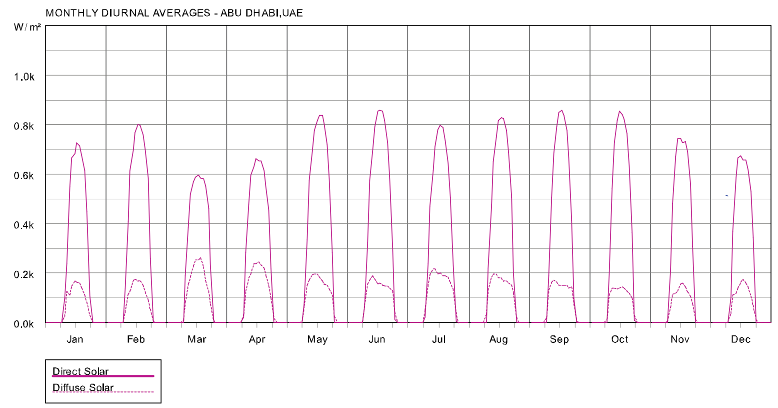


Figure 1-9 Annual diurnal solar radiation profiles

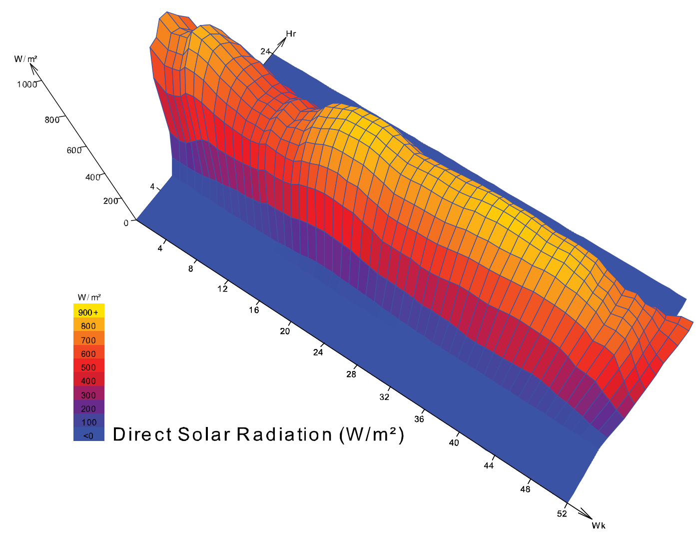


Figure 1-10 3-d representation of annual hourly direct solar radiation

[2] The Tropic of Cancer delineates the north most latitude at which the sun passes overhead at the zenith at midday on June 21st.

1.2.5 Wind

Abu Dhabi has distinct seasonal and diurnal patterns in wind regime.

Generally from around 10pm through to 11am the following day there is a land breeze carrying dry and sometimes dusty air from the desert interior to the south with typical wind speeds of c. 2.5m/s. This is caused by generally lower temperatures in the desert than in the Persian Gulf - due to rapid loss of heat to the night sky in the desert and relatively stable temperatures at sea.

The wind then turns, typically through east to north-northwest bringing hot humid air from over the Persian Gulf at higher speeds – typically 4.2m/s. This sea breeze is due to lower temperatures at sea compared to the land as it is heated up by the sun during the day.

Sand and dust storms generally come from south-east through to east south east. Dust events are more numerous than dust storms – typically 14 per year versus 3 dust storms.

'Shamal' winds can occur in the winter, and in later May to late June. A Shamal is defined as a northwesterly, or northerly, wind with the hourly mean wind speed at, or greater than, 17 knots for at least three hours in a day.

Occasionally a cold northeasterly wind blows from Iran, know locally as the 'Nashi'.

The masterplan makes a number of strategic moves n relation to the prevailing wind environment in Abu Dhabi, most notably the orientation of the green fingers with the diurnal prevailing winds to encourage ventilation.

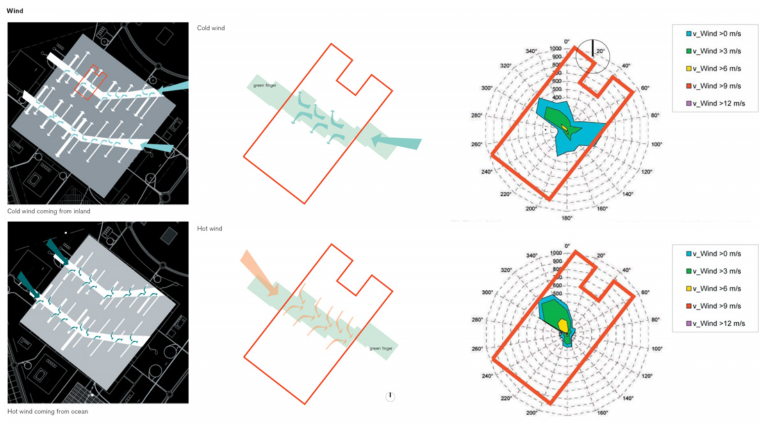


Figure 1-11 Masterplan wind orientation of green fingers

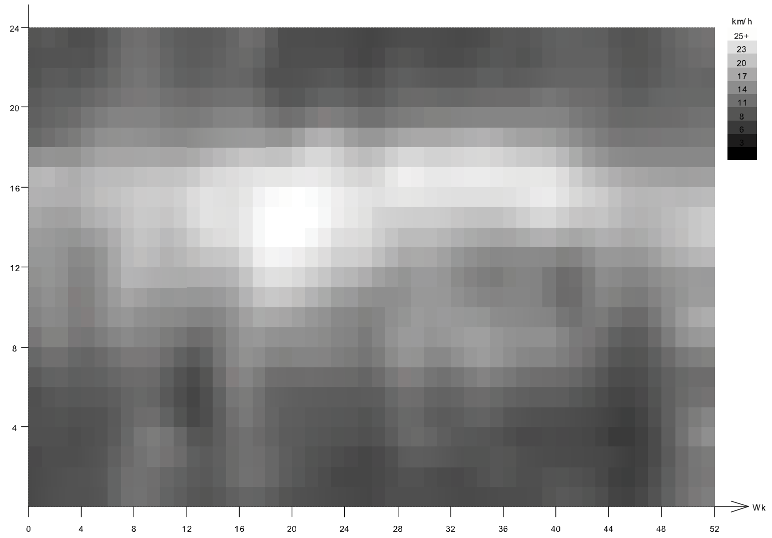


Figure 1-12 Annual hourly windspeed in m/s

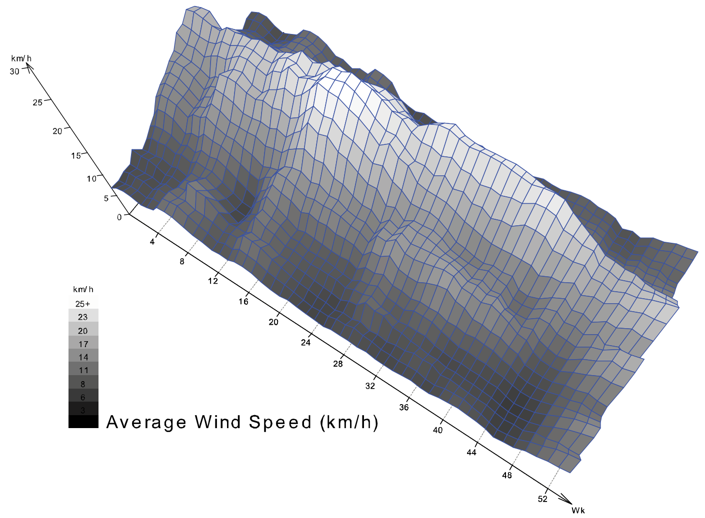


Figure 1-14 3-d visualisation of an annual hourly wind speed in m/s. The diurnal switch from a lower speed land breeze to a stronger northwesterly sea breeze is clearly evident

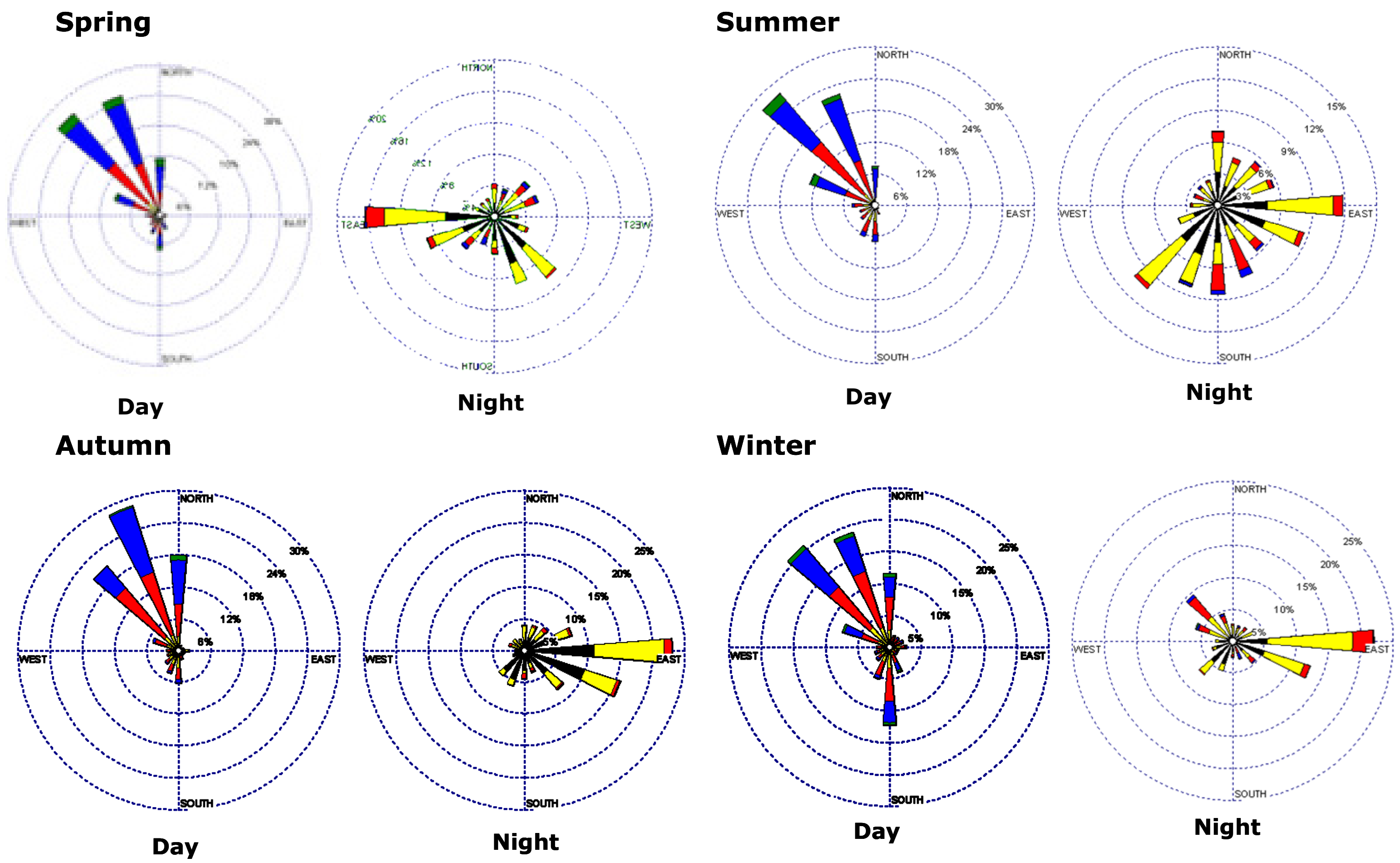


Figure 1-13 Seasonal wind roses for day and night demonstrating the diurnal difference in windspeed and direction

1.2.6 Rainfall

Rainfall in Abu Dhabi is typically below 100mm annually, however there is considerable variability recorded between years

When rainfall occurs in Abu Dhabi it is often associated with thunderstorm events and can be extremely violent, resulting in flash floods in gully systems

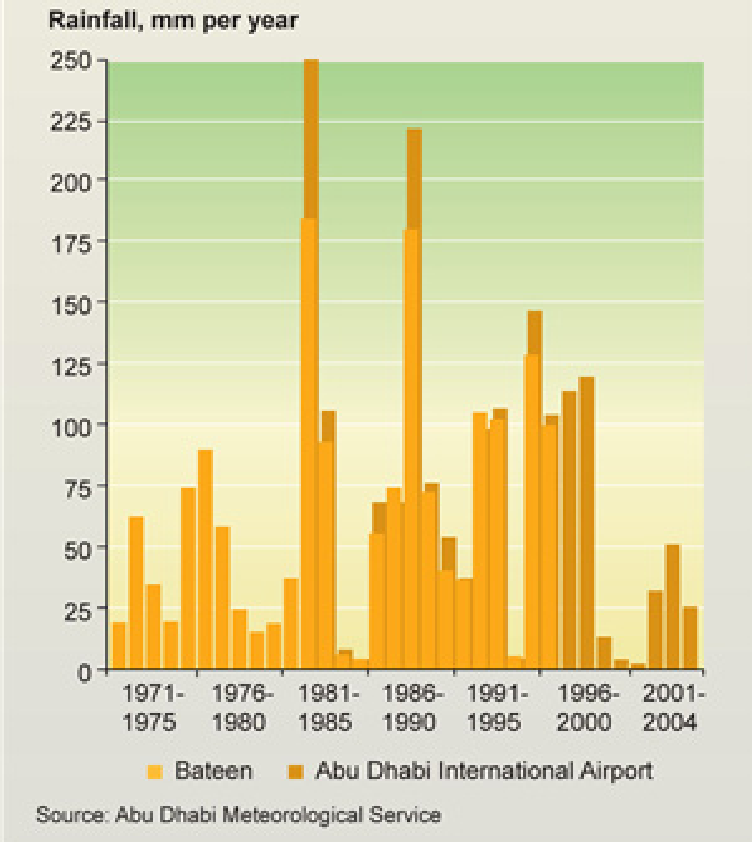


Figure 1-15 Distribution of rain at Bateen and ADIA 1971-2004

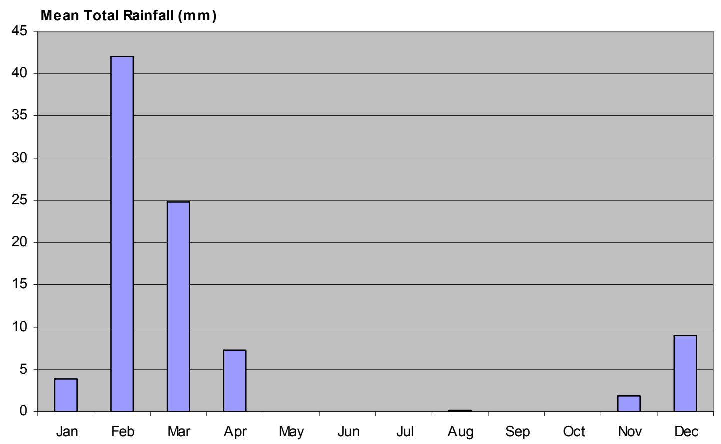


Figure 1-16 WMO Climatological Normals (CLINO) for the 10-year period 1982-1991 record the above annual profile

1.2.7 Cloud Cover

Overall cloud cover is low throughout the year; however there are strong seasonal variations with a peak cloud cover occurring between November and March that is most likely attributable to cooler conditions encouraging mist, haze and fog formation.

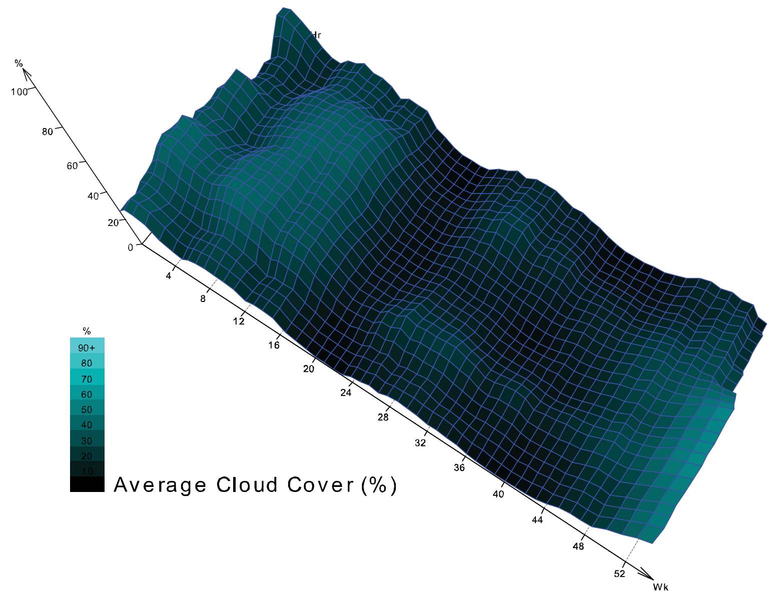


Figure 1-17 3-d graph of week averaged hourly cloud cover

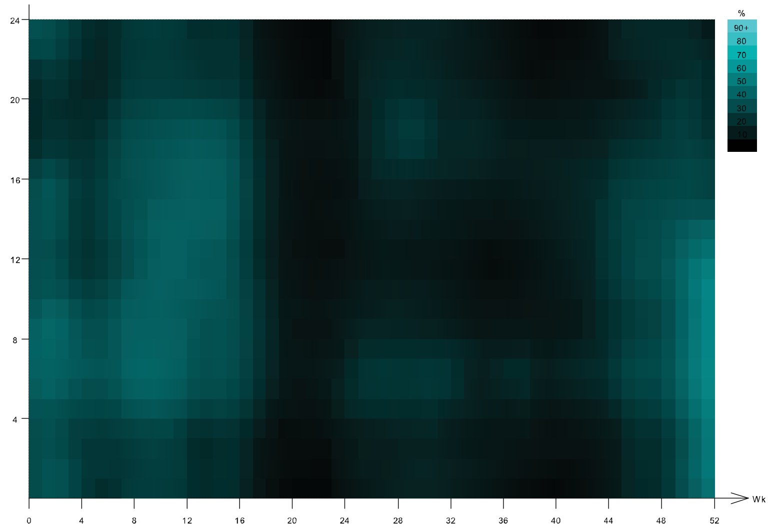


Figure 1-18 Week averaged hourly cloud cover (%). The increased prevalence of cloud cover from November through to March is evident

1.2.8 Fog Occurrence

Fog occurs often enough throughout the year at Abu Dhabi International Airport to be a continual source of concern, although the highest frequency is during the autumn and early winter months and the least in summer. It forms earlier in the night in winter and lasts longer than in summer. Most of the occurrences are between 0100 and 1000 h in winter and 0400 to 0700 h in summer. More often than not the fog clears within about two hours after sunrise.

In accord with local belief, fog is most likely when a north-westerly sea breeze, or Shamal wind, carries moisture inland and the wind then dies away and veers through easterly to light south-easterly during the night. It rarely occurs when the wind backs through westerly. Fog does not occur when the surface wind blows onshore through the night, such as in a persistent Shamal, or when it persists from the south off the desert.

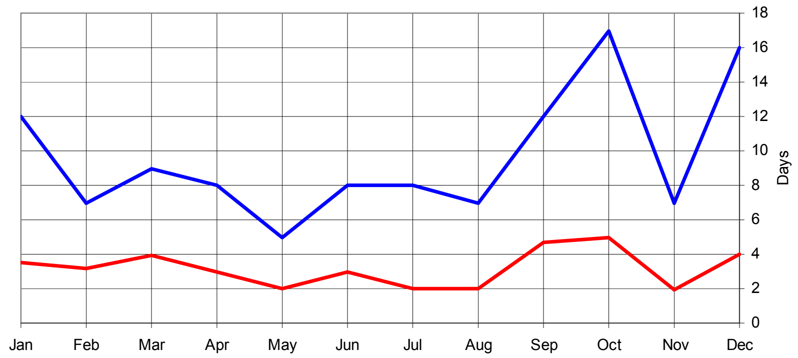


Figure 1-19 The extreme highest number of days with fog per month (blue line) and mean number of days with fog per month (red line)

[Extract from "Fog at Abu Dhabi International Airport", M. P. de Villiers, J. van Heerden, Weather, Volume 62, Issue 8 , Pages 209 - 214]

Figure 1-20 Fog above the Skeikh Zayed Road

1.2.9 Sand and Dust Storms

Observational records kept at ADIA from 1982 to 2001 show that while haze – due to dust, commercial pollutants, or moisture – is very common and occurs on average on 242 days per year, dust storms are far less prevalent, the average being three per year with the most being eight in 2003. However, dust events when the visibility is reduced to less than 5000m are more common and occurred on 141 occasions from 1994 to 2003 as opposed to 32 dust storms.

Year	Dust events	Dust storms	Total
1994	10	5	15
1995	16	2	18
1996	13	1	14
1997	10	2	12
1998	12	2	14
1999	18	7	25
2000	15	3	18
2001	10	0	10
2002	17	2	19
2003	20	8	28
Total	141	32	173

Figure 1-21 Events when dust haze, or dust storms, were observed at ADIA and the visibility was <5000 metres from 1994 to 2003. M. P. de Villiers, J. van Heerden

Directionality

Dust events are most likely when the wind is off the desert to the south, considerably less so when the wind is from the northwest with Shamal conditions and dust has to be transported a considerable distance across the Arabian Gulf.

They are less likely when the wind is from the north-east to east, such as when the Nashi wind brings cold air from Iran. However, this is more likely attributable to the lower frequency than the direction. The distribution of dust storms according to the wind direction is much more random. The problem with forecasting dust storms associated with Shamal and Nashi winds is that the storms are not common.

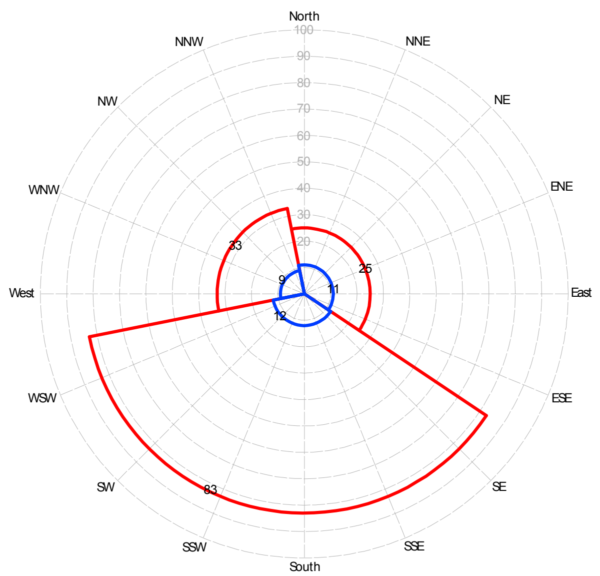


Figure 1-22 Frequency of dust events with the visibility <5000 metres according to wind direction 1994 to 2003

Effect on Visibility

Dust storms, when the visibility is <1000m, do not last long. The average duration is 1 hour 15 minutes and 4 hours 30 minutes at the most. Duration is even shorter during thunderstorms when the average is near to 40 minutes with the longest time being nearly 60 minutes. Poor visibility (<3000 m) during the build-up and lingering aftermath lasts about 3 hours 45 minutes, but has lasted 15 hours, while visibility <5000m can last up to 21 hours.

There is a remarkable frequency increase in dust-reduced visibility during the day and decrease at night.

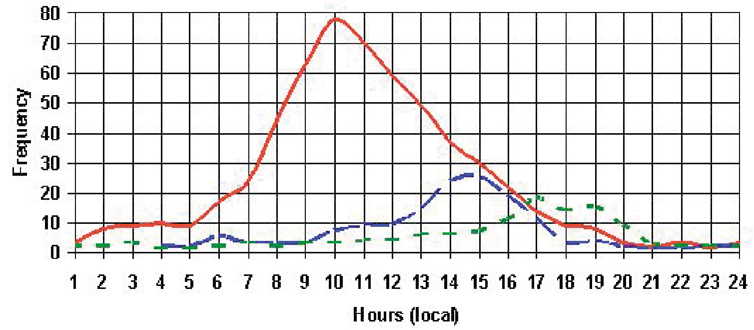


Figure 1-23 Diurnal frequency of dust events (visibility ≠5000 m) from 1994 to 2003, inclusive. southeast-westsouthwesterly wind events – solid red line, west-north-northwesterly – blue long dashed line, north-east-southeasterly – green short dashed line. Annually

Night cooling of the ground and the air immediately above it by radiation, results in increased stability that suppresses the vertical movement of wind eddies, uncouples the surface wind from the stronger wind aloft, and allows surface friction to further reduce the near surface wind speed. Dust is therefore given time to settle. During the day, increased heating and thermally induced turbulent eddies reduce stability and increase mixing with the air aloft, which increases the wind speed and lifts dust.

Poor visibility is most likely from after sunrise during the morning and the early afternoon during the time of surface heating and when thermally induced eddies reduce stability and increase mixing with the air aloft. The peak time is at 10 00 local time. This also coincides with the regular morning land breeze that would reinforce any southerly flow off the desert.

Correlation with Windspeed

There is a distinct negative correlation of –0.64 between wind speed and visibility. That is, the greater the wind speed, the poorer the visibility is likely to be.

It is difficult to establish a clear relationship, due to other factors. These include poor visibility due to dust in suspension after the wind has dropped, or dust carried aloft from elsewhere and the effect of a low sun. The source region of the dust and the type of dust are other factors.

However, there are some loose assumptions that can be made. Above 7.7 m/s the visibility can be below 8000 m and is often less than 5000 m. Above 10.3 m/s the visibility will often be less than 2000 m, but most likely below 1000m and above 15.4 m/s the visibility will be less than 1000m.

Definitions

A dust storm, or sand storm, is a collection of particles of dust, or sand, vigorously lifted to great heights by a strong and turbulent wind and the visibility is reduced to below 1000m. The visibility is most likely to be at its worst during daylight hours when the wind is at its strongest.

The diameter of grains of desert sand usually varies from 0.15mm to 0.3mm with the lower limit being 0.08mm. A diameter below 0.08mm is defined as dust. Dust is more likely to be found in and around inhabited areas where human and vehicular activity tends to break and crush sandy soil to produce finer sand or dust.

Surface turbulence is normally too weak to raise grains of sand more than about a metre above the ground until the 10-m wind speed reaches 10.3 m/s. Sand lifted by the wind is then carried across the surface, but tends to fall back to the ground where the grains bounce back into the air and in the process disturb other grains of sand on the ground, a process known as saltation. The sand falls quickly to the ground when the wind drops and the visibility immediately improves.

Depending upon the condition of the surface and instability, dust, on the other hand, can be easily raised to great heights and, long after the surface wind has dropped, be held in suspension in the atmosphere for hours and even days before settling. Dust grains start to lift when the 10- m wind speed reaches 7.7 m/s.

[Adapted from "Dust storms and dust at Abu Dhabi international airport", M. P. de Villiers, J. van Heerden, Weather, Volume 62, Issue 12 , Pages 339 - 343]

Figure 1-24 Sand storm on Emirates road heading from Abu Dhabi to Dubai

1.2.10 Temperature and Relative Humidity

Abu Dhabi has a sub-tropical, arid climate. Temperatures range from a low of around 10° C, to a high of around 47° C in the summer. The most comfortable conditions are found in the cooler winter months when temperatures are around 24° C during the day and 13° C at night. Temperatures are frequently beyond comfort during the summer with levels of humidity that can be excessive for prolonged stays outdoors, especially uncomfortable during the hottest months (July and August).

Typical monthly diurnal (24h) temperature ranges are illustrated in the graph below. A psychrometric chart showing seasonal distribution of hourly temperature and humidity is also provided overleaf.

There are large variations in the moisture content of ambient air, which is attributed to the impact of prevailing winds - from the north-west bringing hot humid air over the Persian Gulf, and from the east bringing hot, dry air from the inland desert.

The enthalpy of ambient air under extreme summer conditions is extremely high – close to 100 kJ/kg

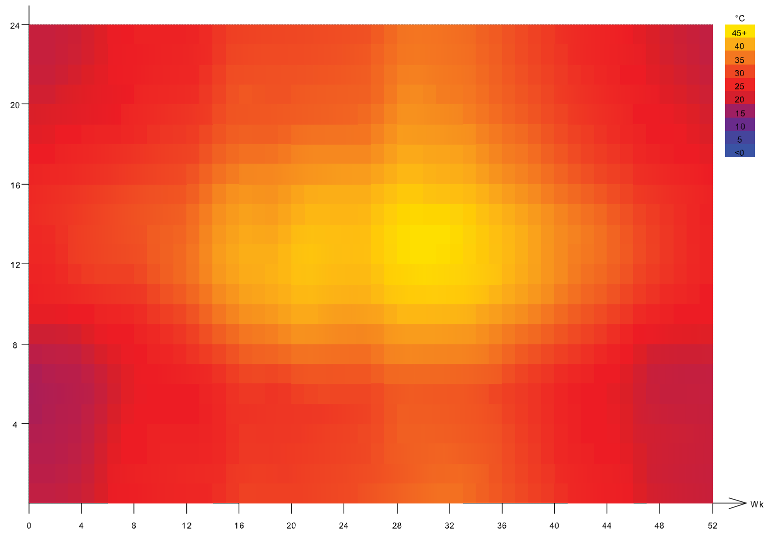


Figure 1-26 Annual Maximum Dry Bulb Temperature Distribution

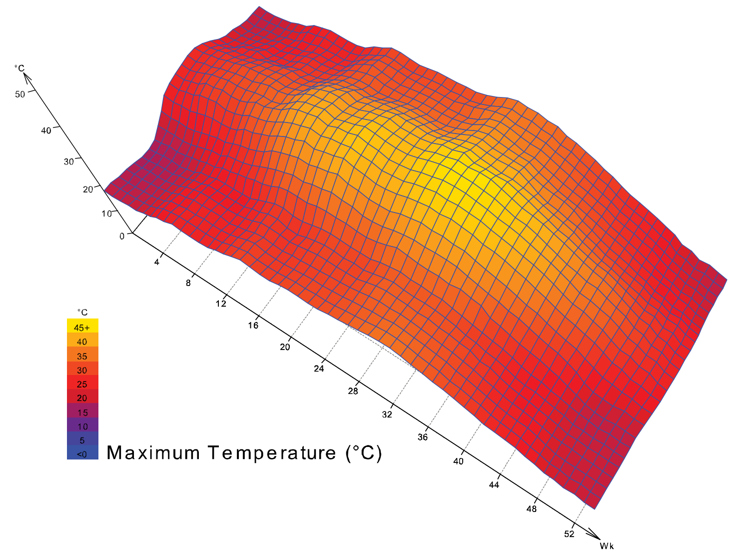


Figure 1-27 Annual Maximum Dry Bulb Temperature Distribution

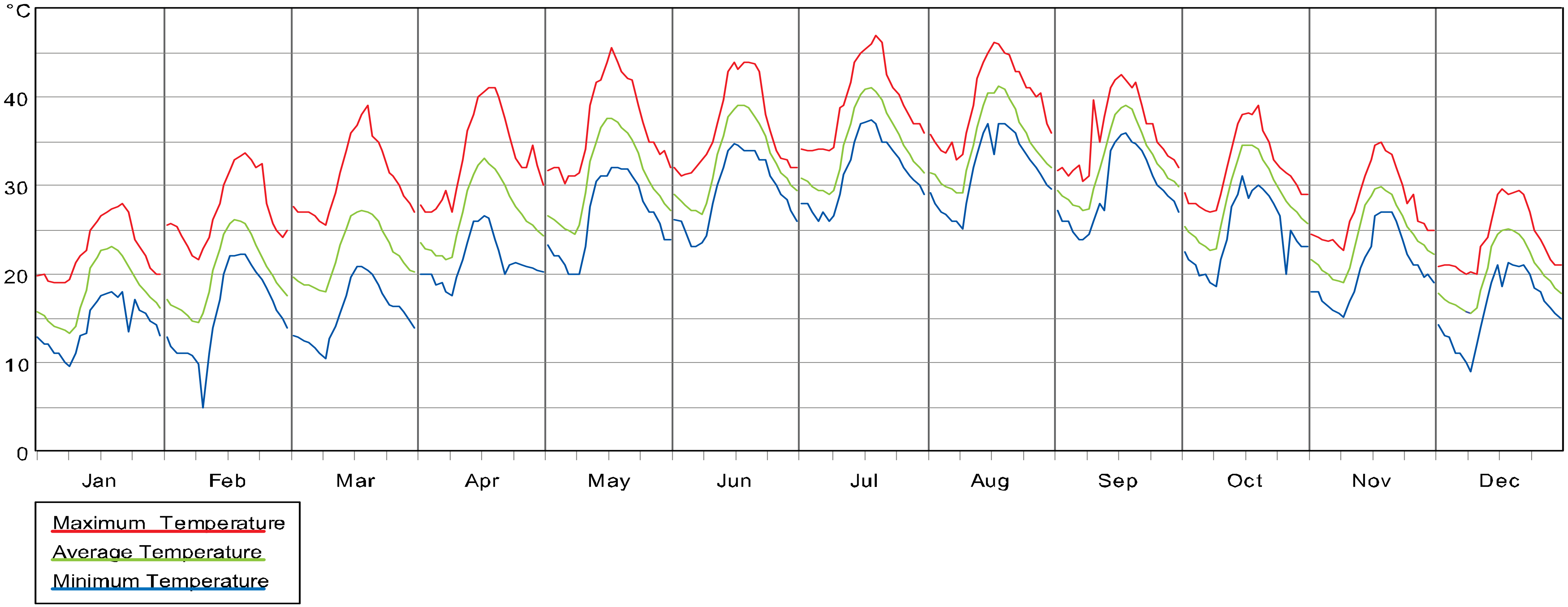


Figure 1-25 Monthly Diurnal Dry Bulb Temperature Averages

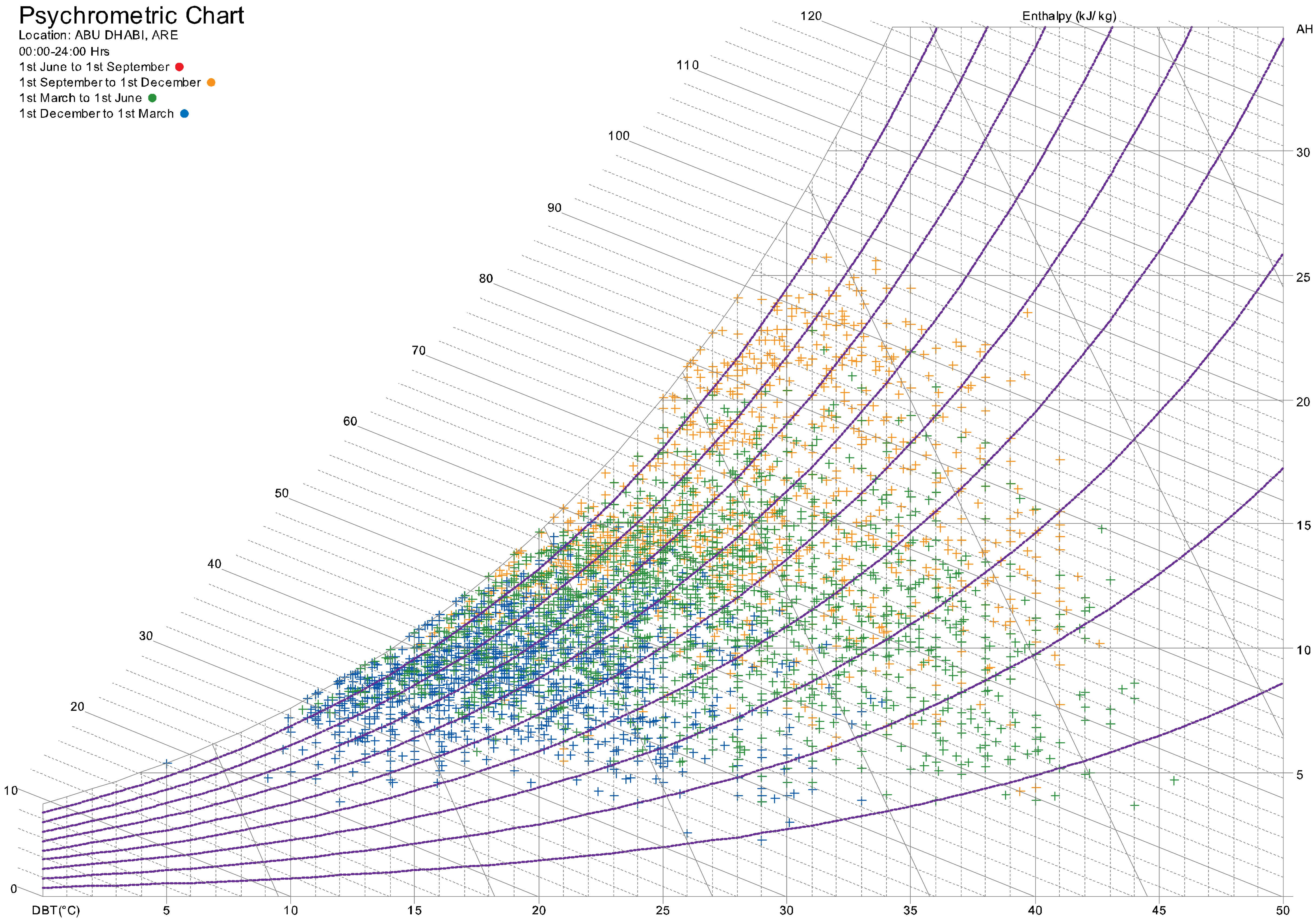


Figure 1-28 Psychrometric Chart showing seasonal distribution of hourly weather data from ASHRAE IWEC Data for Abu Dhabi International

1.3 Masdar Initiative

MASDAR ABU DHABI FUTURE ENERGY COMPANY مصدر شركة أبوظبي لطاقة المستقبل

During April 2006, His Highness Sheikh Mohammed Bin Zayed Al Nahyan, the Crown Prince of Abu Dhabi, announced the "Masdar Initiative". The word Masdar means "the Source" in Arabic.

This Initiative will be the source for an impressive range of innovative Abu Dhabi based industries and research to position Abu Dhabi as a global leader in clean energy and sustainable development.

Masdar complements the vision of the late Sheikh Zayed Bin Sultan Al Nahyan, the founder and the former President of the UAE, who pioneered environmental conservation in the country.

The commitment of the Government of Abu Dhabi to Masdar is clear and strong. Masdar will assist Abu Dhabi in maintaining its position in the global energy market over the long term. Masdar will also be a key resource in nation-building, by developing the human capital that will help create and lead a new UAE scientific and research culture.

Abu Dhabi has had the good fortune to be blessed with substantial natural resources. Sensible development of these assets during the past 45 years, together with valued international partners, has brought many benefits to the people as well as to our customers worldwide. But a new era is now upon us, challenging us to venture beyond the achievements of the past and to lay the groundwork for the next 50 years of progress. We shall accomplish this by channelling our accumulated energy expertise and financial resources into new activities and industries such as Masdar. Under the visionary leadership of the President of the UAE, His Highness Sheikh Khalifa Bin Zayed Al Nahyan, Abu Dhabi will achieve its strategic developmental aims and contribute significantly to a cleaner and sustainable future for all.

Abu Dhabi is leveraging its substantial resources and expertise in global energy markets into the technologies of the future. One key objective of Masdar is to position Abu Dhabi as a world-class research and development hub for new energy technologies, while ensuring that Abu Dhabi maintains a strong position in world energy markets.

A related objective is to drive the commercialization and adoption of these and other technologies in sustainable energy, carbon management and water utilization. In doing so, Masdar will play a decisive role in Abu Dhabi's transition from technology consumer to technology producer. The goal is the establishment of an entirely-new economic sector in Abu Dhabi around these new industries, which will assist economic diversification and the development of knowledge-based industries.

The Abu Dhabi Future Energy Company (ADFEC) is the government-owned organization mandated to develop and execute Masdar. ADFEC will also ensure that Masdar further enhances Abu Dhabi's existing record of environmental stewardship and its contribution to the global community.

The Masdar Initiative aims to play a unique role in that evolution – representing a leading Middle Eastern oil-producing nation that is proactively engaging the world's best minds and organizations to envision a cleaner, more sustainable future.

The initiative embraces a spirit of purpose and focus. Through an extensive series of meaningful achievements, Masdar aims to make an enduring impact on Abu Dhabi, the region and the global community. By providing the leadership, platform and resources to create new ideas, breakthrough technologies and the commercial basis for their widespread adoption, Masdar will also demonstrate Abu Dhabi's continued contribution to the global community.

Through Masdar, we invite the global community to participate in the collective search for creative solutions to some of mankind's most pressing concerns: energy, the environment, and the sustainable use of vital natural resources.

[Extract from F+P Concept Design Report]

1.4 MIST Vision

The Masdar Institute of Science and Technology (M.I.S.T) was established to meet the exceptional and progressive goal of transforming Abu Dhabi's economy from one based on petroleum to one focused on sustainable technology and renewable energy. This new, private graduate Institute positions Abu Dhabi to make an historic transformation and to become a knowledge hub for global innovation.

Developed with the support and cooperation of the Massachusetts Institute of Technology (MIT), the Masdar Institute is an independent, a not-for-profit, research-driven graduate institution focused on science and technology. The Institute will educate a workforce that will be prepared to compete in global markets and participate in research and development with an emphasis on alliances with global corporations and entrepreneurial opportunities.

MIT is assisting the Masdar Institute of Science and Technology in four integral areas:

1. Development of graduate degree programs;
2. Joint collaborative research;
3. Outreach that encourages industrial participation in research and development activities of the Institute; and
4. Support for capacity-building at the Institute in terms of its organization and administrative structure, as well as scholarly assessment of potential faculty candidates for the Institute.

Beginning in September 2009, the Masdar Institute will offer five, 24-month Master of Science degree programs. Additional programs, including PhD programs, will be added as the Institute continues to develop.

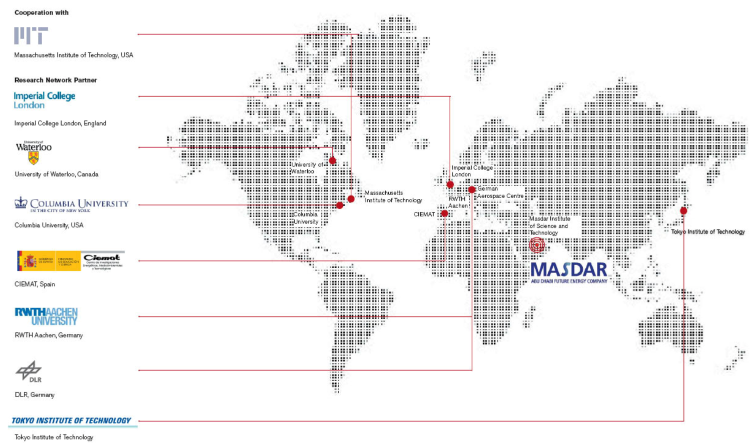
The first batch of graduate students will report in September 2009 to a 16,540 sq.m campus with a gradual expansion of the institute over the next six to seven years to a 102,000 sq.m campus. This will provide a worldwide focal point for the development of renewable energy and sustainable technologies within the environmentally conscious backdrop of the Masdar Initiative.

The Masdar Research Network (MRN) is a unique collaborative research framework between Masdar and leading global scientific institutions. The Network will create a nucleus of world class scientific research in advanced energy and sustainability technologies. It leverages the core research strength of each partner to accelerate innovation and commercial development of the most promising technologies.

The Network's partners include:

- Imperial College London (UK)
- RWTH Aachen (Germany)
- University of Waterloo (Canada
- Tokyo Institute of Technology (Japan)
- Columbia University (USA)
- CIEMAT – Research Centre for Energy, Environment and Technology (Spain)
- German Aerospace Centre – DLR (Germany)

All bring advanced technologies and strong ties to industry, allowing the Network to develop, validate and finance a broad spectrum of research projects. Research tracks currently underway include photovoltaic (crystalline thin film and low-cost poly-silicone), water management (desalination, membrane technologies); solar thermal and carbon management (carbon capture and storage). Projects are jointly financed by Masdar and industrial partners selected by the host institution, with resulting IP rights shared among the parties.



[Extract from F+P Concept Design Report]

1.5 Local Services Infrastructure

MIST will be provided with Utility connections from the MASDAR City Infrastructure system of service tunnels. For the purposes of this concept report, the assumption made is that both 'wet' and 'dry' services will be available in each and every Infrastructure tunnel. The service connections available when the service tunnels are complete are assumed at this stage to include;

Incoming mains HV electrical Supplies

- Chilled water
- Condensing water
- Liquid Desiccant
- Mains cold water and fire services
- Foul and surface water drainage
- Telecoms and data

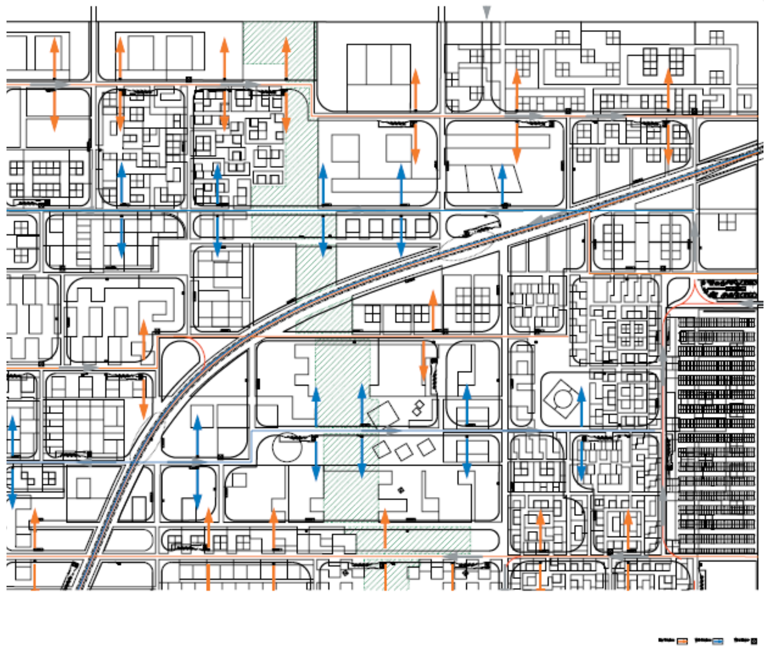
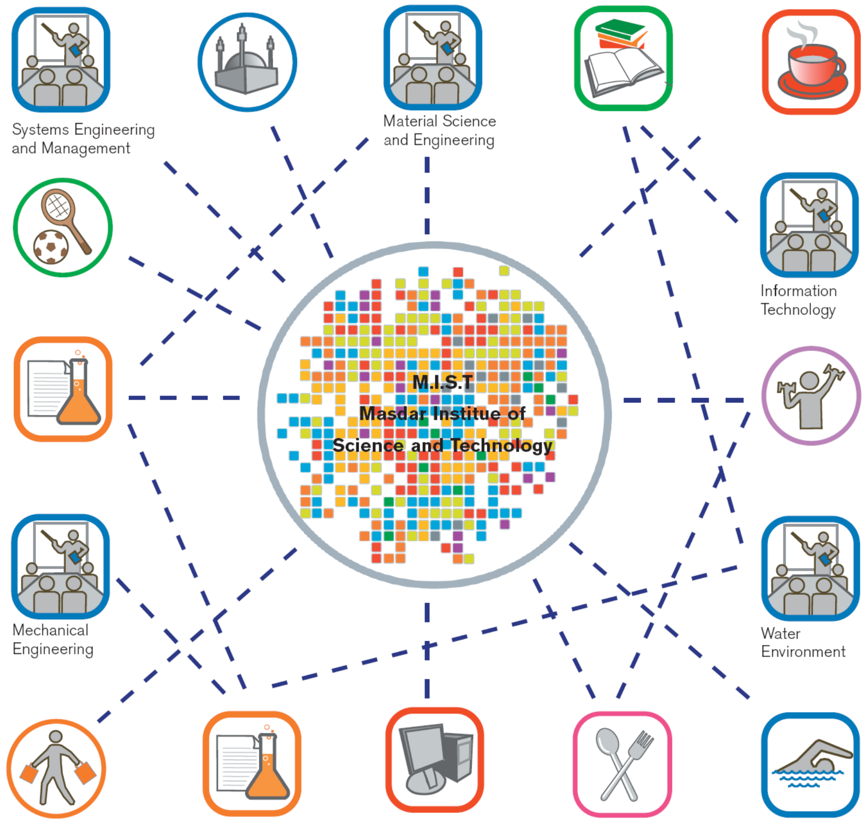


Figure 1-29 Masterplan infrastructure services strategy

Due to the programme of the MASDAR City infrastructure design/installation, only the following infrastructure services will be available for connection by August 2009 (opening of phase 1A);

- Mains cold water
- Foul and surface water drainage
- Telecoms and data

1.6 Functional Brief for MIST



Foster and Partners and MIST have developed a functional programme for the project that sets out the range of activities that are envisaged to occur within MIST.

The typologies identified form the basis for initial development of sustainable MEP options.

1.7 Occupancy + Area Schedules

The following areas schedules are taken directly from Foster + Partners Concept Design Report.

They are used throughout this document as a means by which to estimate area based and occupant based demands on MEP systems.

It should be noted that the envisaged occupant densities within the overall laboratory facilities are far below those envisaged in the masterplan, which assumes 20/m²/person.

For example in Phase 1 there will at least 55 m²/occupant, and by completion of Phase 3 approximately 40m²/occupant.

This has significant impact on the overall energy impact of the development. The applicability of area based measures of performance (impact/m²⁾ versus utilisation based measures (impact/person-h) becomes increasingly relevant.

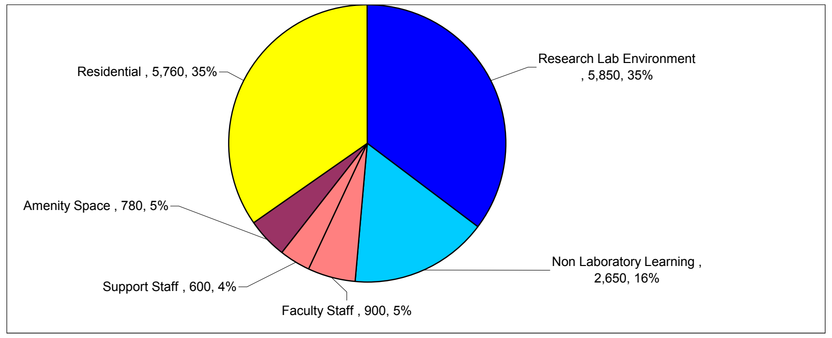
This aspect is addressed further in section 2.

PHASE 1a - Accommodation Requirements 2009

Students	100
Programs	5
Average Program Size	20
Faculty Staff	30
Support Staff (not including technicians)	30

Research Lab Environment	5,850
Non Laboratory Learning	2,650
Faculty Staff	900
Support Staff	600
Amenity Space	780
Residential	5,760
	16,540

Accommodation Type	No.	Size (m^2/p) or (m^2/room)	% Circ.	Size inc. Shared Circ. (NIA)	% Core	Gross Size (m^2)	Total Gross Area (m^2)
Research Lab Environment							
Lab Positions	80	11.9	0.15	14	30%	20	1,600
Write-up Positions	100	5.95	0.15	7	30%	10	1,000
Lab support space	80	14.88	0.15	17.5	30%	25	2,000
Special/machine lab space	1	178.5	0.15	210	30%	300	300
Clean Rooms	1	297.5	0.15	350	30%	500	500
Computer Labs	1	178.5	0.15	210	30%	300	300
Server rooms	1	89.25	0.15	105	30%	150	150
Non Laboratory Learning							
Classrooms	5	102	0.15	120	20%	150	750
Larger classroom	1	340	0.15	400	20%	500	500
Meeting rooms (10 person)	5	27.2	0.15	32	20%	40	200
Library positions	80	10.2	0.15	12	20%	15	1,200
Faculty Staff							
Academic staff cellular offices	30	20.4	0.15	24	20%	30	900
Academic staff open plan desks	0	10.2	0.15	12	20%	15	0
Support Staff							
Non-academic staff cellular offices	10	20.4	0.15	24	20%	30	300
Non-academic staff open plan desks	20	10.2	0.15	12	20%	15	300
Amenity Space							
Multipurpose Hall	0	2.72	0.15	3.2	20%	4	0
Catering facilities	160	2.04	0.15	2.4	20%	3	480
Sports and other shared facilities (inc prayer rooms)	100	2.04	0.15	2.4	20%	3	300
Mosque	0	2.04	0.15	2.4	20%	3	0
Residential							
Students to Accommodate	90		included		included	NA	NA
Student Accommodation-Single	76.5		included		included	60	4,590
Student Accommodation - with Spouse	9		included		included	80	720
Student Accommodation - with Family	4.5		included		included	100	450
TOTAL							16,540

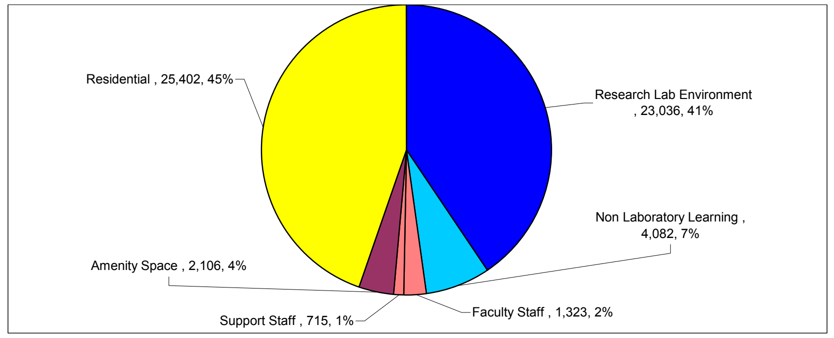


PHASE 1b - Accommodation Requirements 2011

Students	441
Programs	10
Average Program Size	44
Faculty Staff	44
Support Staff (not including technicians)	37

Research Lab Environment	23,036
Non Laboratory Learning	4,082
Faculty Staff	1,323
Support Staff	715
Amenity Space	2,106
Residential	25,402
	56,664

Accommodation Type	No.	Size (m^2/p) or (m^2/room)	% Circ.	Size inc. Shared Circ. (NIA)	% Core	Gross Size (m^2)	Total Gross Area (m^2)
Research Lab Environment							
Lab Positions	353	11.9	0.15	14	30%	20	7,056
Write-up Positions	441	5.95	0.15	7	30%	10	4,410
Lab support space	353	14.88	0.15	17.5	30%	25	8,820
Special/machine lab space	6	178.5	0.15	210	30%	300	1800
Clean Rooms	1	297.5	0.15	350	30%	500	500
Computer Labs	1	178.5	0.15	210	30%	300	300
Server rooms	1	89.25	0.15	105	30%	150	150
Non Laboratory Learning							
Classrooms	10	102	0.15	120	20%	150	1500
Larger classroom	1	340	0.15	400	20%	500	500
Meeting rooms (10 person)	22	27.2	0.15	32	20%	40	882
Library positions	80	10.2	0.15	12	20%	15	1,200
Faculty Staff							
Academic staff cellular offices	44	20.4	0.15	24	20%	30	1323
Academic staff open plan desks	0	10.2	0.15	12	20%	15	0
Support Staff							
Non-academic staff cellular offices	11	20.4	0.15	24	20%	30	330
Non-academic staff open plan desks	26	10.2	0.15	12	20%	15	385
Amenity Space							
Multipurpose Hall	0	2.72	0.15	3.2	20%	4	0
Catering facilities	261	2.04	0.15	2.4	20%	3	783
Sports and other shared facilities (inc prayer rooms)	441	2.04	0.15	2.4	20%	3	1323
Mosque	0	2.04	0.15	2.4	20%	3	0
Residential							
Students to Accommodate	396.9		included		included	NA	NA
Student Accommodation-Single	337.37		included		included	60	20,242
Student Accommodation - with Spouse	39.69		included		included	80	3175
Student Accommodation - with Family	19.845		included		included	100	1985
TOTAL							56,664

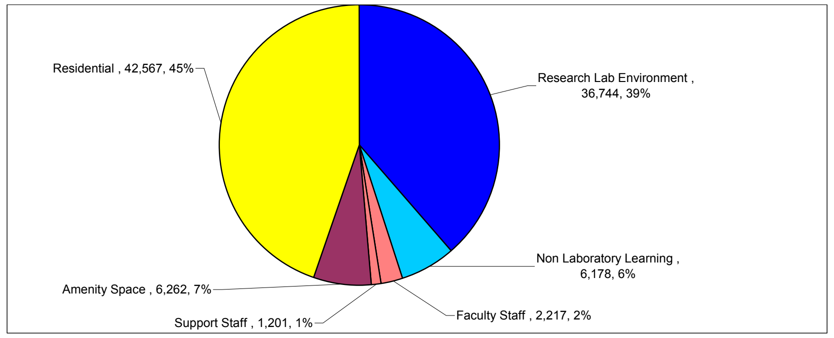


Brief Phase 2 - Accomodation Requirements 2014

Students	739
Programs	10
Average Program Size	74
Faculty Staff	74
Support Staff (not including technicians)	62

Research Lab Environment	36,744
Non Laboratory Learning	6,178
Faculty Staff	2,217
Support Staff	1,201
Amenity Space	6,262
Residential	42,567
	95,169

Accommodation Type	No.	Size (m^2/p) or (m^2/room)	% Circ.	Size inc. Shared Circ. (NIA)	% Core	Gross Size (m^2)	Total Gross Area (m^2)
Research Lab Environment							
Lab Positions	591	11.9	0.15	14	30%	20	11,824
Write-up Positions	739	5.95	0.15	7	30%	10	7,390
Lab support space	591	14.88	0.15	17.5	30%	25	14,780
Special/machine lab space	6	178.5	0.15	210	30%	300	1800
Clean Rooms	1	297.5	0.15	350	30%	500	500
Computer Labs	1	178.5	0.15	210	30%	300	300
Server rooms	1	89.25	0.15	105	30%	150	150
Non Laboratory Learning							
Classrooms	20	102	0.15	120	20%	150	3000
Larger classroom	1	340	0.15	400	20%	500	500
Meeting rooms (10 person)	37	27.2	0.15	32	20%	40	1478
Library positions	80	10.2	0.15	12	20%	15	1,200
Faculty Staff							
Academic staff cellular offices	74	20.4	0.15	24	20%	30	2217
Academic staff open plan desks	0	10.2	0.15	12	20%	15	0
Support Staff							
Non-academic staff cellular offices	18	20.4	0.15	24	20%	30	554
Non-academic staff open plan desks	43	10.2	0.15	12	20%	15	647
Amenity Space							
Multipurpose Hall	300	2.72	0.15	3.2	20%	4	1200
Catering facilities	437	2.04	0.15	2.4	20%	3	1312
Sports and other shared facilities (inc prayer rooms)	800	2.04	0.15	2.4	20%	3	2400
Mosque	450	2.04	0.15	2.4	20%	3	1350
Residential							
Students to Accommodate	665		included		included	NA	NA
Student Accommodation-Single	565		included		included	60	33,920
Student Accommodation - with Spouse	67		included		included	80	5321
Student Accommodation - with Family	33		included		included	100	3326
TOTAL							95,169

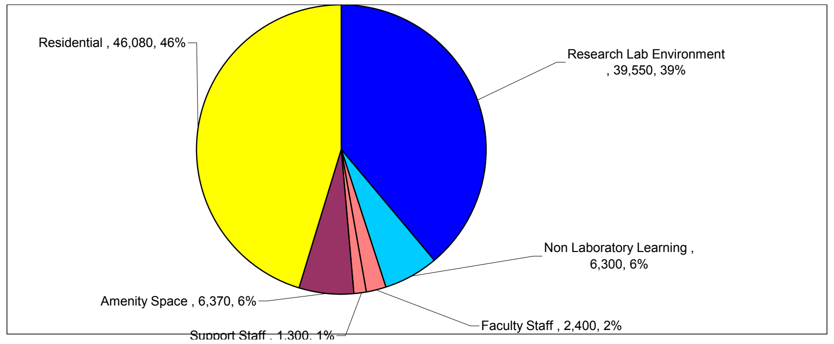


Brief Phase 3 - Accomodation Requirements 2015

Students	800
Programs	10
Average Program Size	80
Faculty Staff	80
Support Staff (not including technicians)	67

Research Lab Environment	39,550
Non Laboratory Learning	6,300
Faculty Staff	2,400
Support Staff	1,300
Amenity Space	6,370
Residential	46,080
	102,000

Accommodation Type	No.	Size (m^2/p) or (m^2/room)	% Circ.	Size inc. Shared Circ. (NIA)	% Core	Gross Size (m^2)	Total Gross Area (m^2)
Research Lab Environment							
Lab Positions	640	11.9	0.15	14	30%	20	12,800
Write-up Positions	800	6	0.15	7	30%	10	8,000
Lab support space	640	14.9	0.15	17.5	30%	25	16,000
Special/machine lab space	6	178.5	0.15	210	30%	300	1800
Clean Rooms	1	297.5	0.15	350	30%	500	500
Computer Labs	1	178.5	0.15	210	30%	300	300
Server rooms	1	89.3	0.15	105	30%	150	150
Non Laboratory Learning							
Classrooms	20	102	0.15	120	20%	150	3000
Larger classroom	1	340	0.15	400	20%	500	500
Meeting rooms (10 person)	40	27.2	0.15	32	20%	40	1600
Library positions	80	10.2	0.15	12	20%	15	1,200
Faculty Staff							
Academic staff cellular offices	80	20.4	0.15	24	20%	30	2400
Academic staff open plan desks	0	10.2	0.15	12	20%	15	0
Support Staff							
Non-academic staff cellular offices	20	20.4	0.15	24	20%	30	600
Non-academic staff open plan desks	47	10.2	0.15	12	20%	15	700
Amenity Space							
Multipurpose Hall	300	2.7	0.15	3.2	20%	4	1200
Catering facilities	473	2	0.15	2.4	20%	3	1420
Sports and other shared facilities (inc prayer rooms)	800	2	0.15	2.4	20%	3	2400
Mosque	450	2	0.15	2.4	20%	3	1350
Residential							
Students to Accommodate	720		included		included	NA	NA
Student Accommodation-Single	612		included		included	60	36,720
Student Accommodation - with Spouse	72		included		included	80	5760
Student Accommodation - with Family	36		included		included	100	3600
TOTAL							102,000



1.8 Sustainability Standards and Targets

MIST must demonstrate excellent performance in terms of sustainability in the context of international, regional and national sustainability targets and standards.

This 'Global to Local' approach ensures that efforts are focused on meeting sustainability commitments at all scales.

1.8.1 International Commitments

The UAE has signed six milestone international conventions. The Federal Environmental Agency is the focal point for all the listed conventions except the UNFCCC for which the Ministry of Energy is the focal point.

- Vienna Convention and Montreal Protocol:
  The Vienna Convention seeks to protect the ozone layer. It entered into force in 1988. The Montreal Protocol came into force in 1989. It dictates measures for reducing and phasing out ozone depleting substances (ODS). The UAE acceded to the Vienna Convention and the Montreal Protocol on 22 December 1989. The UAE also acceded to the amendments of Montreal Protocol on 16 February 2005.
- Convention on International Trade of Wild Species of Fauna and Flora (CITES):
  The convention aims to ensure that international trade in specimens of wild animals and plants does not threaten their survival. UAE acceded to CITES on 8 February 1990.
- Basel Convention on Transboundary Movements of Hazardous Wastes:
  This convention regulates the trans-boundary movements of hazardous waste. It entered into force in 1992. UAE ratified the Basel Convention on 17 November 1992.
- United Nations Framework Convention on Climate Change (UNFCCC):
  The convention entered into force on 21 March 1994. The parties to the convention agreed in Kyoto that developed countries should reduce their collective emissions of six greenhouse gases by at least 5 percent compared to 1990 levels by the period 2012. The protocol also establishes an emission trading regime and a "Clean Development Mechanism". UAE acceded to UNFCCC on 29 December 1995 and to the Kyoto Protocol on 26 January 2005.
- United Nations Convention to Combat Desertification (UNCCD):
  The Convention entered into force on 26 December 1996. The UAE acceded to the UNCCD on 21 October 1998.
- Convention on Biological Diversity (CBD):
  The convention has three main goals: the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits from the use of genetic resources. The convention went into force on 29 December 1993. UAE ratified the CBD on 10 February 2000.

1.8.2 Regional Commitments

The Kuwait Regional Convention for cooperation on the Protection of the Marine Environment from Pollution is the most important legal instrument requiring the eight signatory states Saudi Arabia, Oman, Qatar, Bahrain, UAE, Kuwait, Iraq and Iran to coordinate activities for the protection of the shared marine environment.

The Convention was signed on 24 April 1978 and entered into force on 1 July 1979. The UAE ratified the convention on 1 December 1979.

The Regional Organization for the Protection of the Marine Environment (ROPME) was established on 1 July 1979 to implement the Kuwait Regional Convention and its Protocols

The Convention on the conservation of Wildlife and their Habitats in GCC was approved in December 2001 by the Leaders of the GCC Countries Saudi Arabia, UAE, Qatar, Kuwait, Bahrain and Oman. UAE ratified the convention on 30 January 2003.

1.8.3 Masdar Commitments

An overall commitment to achieving WWF-BioRegional's One Planet Living Community commitments has been made by ADFEC.

1.8.4 Sustainability Benchmarking Context

USGBC's LEED suite of sustainability rating systems are widely used within the UAE.

More recently the Emirates Green Building Council has sought to introduce Emirates LEED – an implementation of LEED for New Construction modified to take into account local legislation and placing a far higher emphasis on measures to reduce potable water consumption. The use of Emirates LEED is now compulsory within the Emirate of Dubai.

The Building Research Establishment's BREEAM system is currently being localised for use on the forthcoming development at Abu Dhabi International Airport. This will involve setting assessment parameters that are weighted to reflect local sustainability issues. It is thought unlikely that this 'bespoke' implementation will be used in other contexts.

In Abu Dhabi, a draft Green Building Guide is being prepared that draws upon international best practice. A 'gap' analysis has been undertaken to establish weightings for key sustainability issues.

In all cases, these benchmarking tools are geared towards wider market transformation. The ambitious targets set for Masdar go far beyond the scope of these systems. In order for meaningful tracking of performance of projects to be undertaken an alternative framework needs to be applied.

From PHA Consult's experience of benchmarking in an international context we have proposed, and it has subsequently been accepted, that the use of iiSBE's SBTools framework would meet the client's needs, whilst ensuring that all relevant best practice criteria from LEED, BREEAM and the Abu Dhabi Green Building Guide are satisfied.

1.9 Masterplan Environmental Performance Brief

MIST sits at the heart of the wider masterplan for Masdar City, prepared by Foster + Partners, supported by a consultant team including:

WSP	Sustainable Site Infrastructure
ETA	Renewable Energy Systems Feasibility
Transolar	Building Energy Performance and Microclimate
Systematica	Transportation
BioRegional	Overarching Sustainability Strategy

Masdar has elected to follow the strategic sustainability framework that has been developed by BioRegional and WWF, known as 'One Planet Living'. This establishes high-level commitments across 10 issues:

1 Zero Carbon

2 Zero Waste

3 Sustainable Transport

4 Local and Sustainable Materials

5 Local and Sustainable Food

6 Sustainable Water

7 Natural Habitats and Wildlife

8 Culture and Heritage

9 Equity and Fair Trade

10 Health and Happiness

The Masdar city consultant team have prepared a masterplan that facilitates the achievement of these objectives; it is now for individual projects such as MIST to demonstrate that these commitments can be achieved on the ground.

In response to the OPL agenda the Masdar masterplan sets physical constraints at an urban scale, such as:

- City block form and orientation in relation to sun and prevailing winds
- Position and alignment of green fingers
- Street widths, sections, shading and ventilation strategies
- Provision of wind towers at strategic locations in public streets
- General development heights
- Location and % coverage of solar collectors at roof level
- Absolute amount of energy – thermal and electric - that can be generated within the site boundary of Masdar

These establish microclimatic 'boundary' conditions for any development parcel within Masdar city, and set an overall 'energy budget' for the city that must each project must play its part in meeting.

The masterplan then provides design guidelines on 'passive' design approaches that may be broadly applicable for individual buildings:

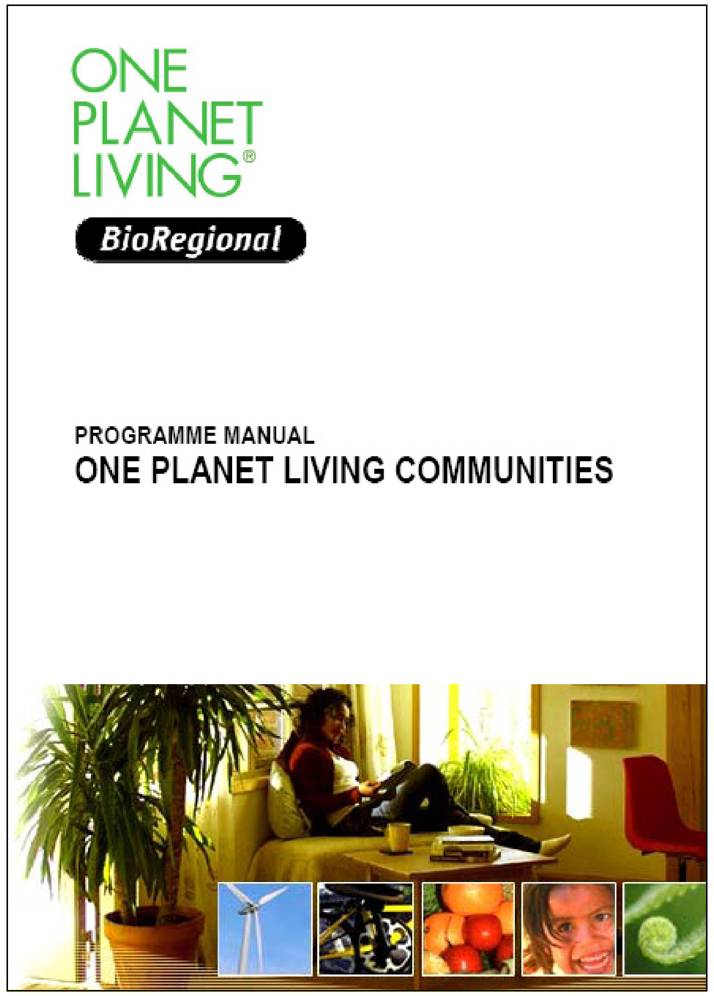
- Use of courtyards for enhanced daylight availability
- Glazing ratios, light and solar transmission targets
- External shading requirements
- Building envelope thermal, inertial and infiltration criteria
- Materials selection in terms of embodied carbon and other environmental aspects

These strategic criteria provide a starting point from which individual design teams can develop specific and alternative solutions that meet the functional performance requirements for their particular project within n One Planet Living development

The masterplan additionally provides guidance on the 'active' centralised utilities infrastructure that can be connected to - for water, waste, cooling and transport, and suggests local MEP and resource management strategies that should be explored on a site-by-site basis.

In aggregate this enables absolute performance targets to be set for

- Embodied carbon
- Operational electrical consumption
- Potable water consumption



1.10 One Planet Living

WWF's Living Planet Report in 2004 identified the UAE as having the highest ecological footprint per capita of any nation on earth. In effect, if every citizen of the earth was to consume in the same manner as a UAE citizen we would need 11 planets to support us.

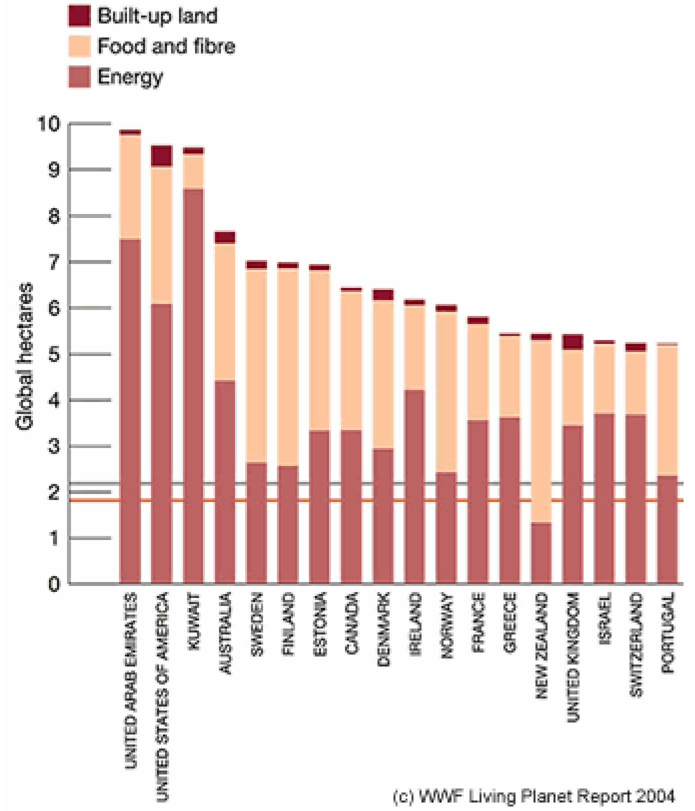
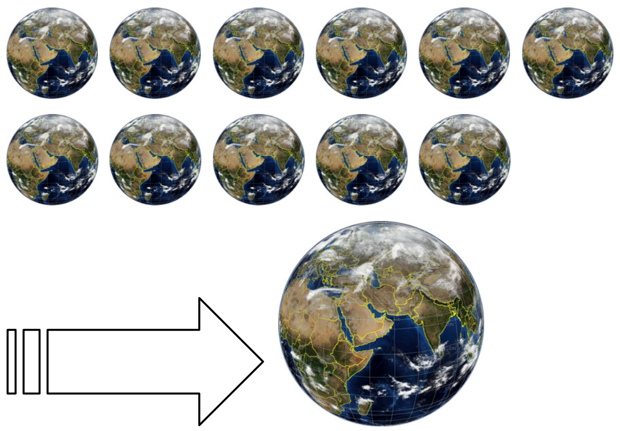


Figure 1-30 Living Planet Index - showing UAE's 11 Planet lifestyle

The challenge then is to move from an eleven planet lifestyle to a one planet lifestyle. BioRegional have developed the One Planet Living Communities standard as a way of defining the measures that are necessary for a development to achieve 'One Planet Living'



Masdar has signed up to ten commitments [right]. In delivering sustainable MEP for MIST, PHA Consult will play its part in delivering project-specific goals [far right].

One Planet Living Commitments	One Planet Sustainable MEP for MIST
1 Zero Carbon	**1 Zero Carbon**
100 per cent of energy supplied by renewable energy - Photovoltaics, concentrated solar power, wind, waste to energy and other technologies	Energy efficiency in design of passive and active measures - building envelope and systems, matched by energy efficient equipment and operation by MIST. On-site renewable energy generation to satisfy maximum possible % of demand
2 Zero Waste	**2 Zero Waste**
99 per cent diversion of waste from landfill (includes waste reduction measures, re-use of waste wherever possible, recycling, composting, waste to energy)	'Design for Recycling' approach to construction. Provision of full connectivity to Masdar waste infrastructure
3 Sustainable Transport	**3 Sustainable Transport**
Zero carbon emissions from transport within the city; implementation of measures to reduce the carbon cost of journeys to the city boundaries (through facilitating and encouraging the use of public transport, vehicle sharing, supporting low emissions vehicle initiatives)	Provision of enhanced microclimate for pedestrians and users leaving or entering the PRT. Incorporation of smoke venting and ventilation to PRT
4 Local and Sustainable Materials	**4 Local and Sustainable Materials**
Specifying high recycled materials content within building products; tracking and encouraging the reduction of embodied energy within materials and throughout the construction process; specifying the use of sustainable materials such as Forest Stewardship Council certified timber, bamboo and other products	Working with appointed Carbon and material lifecycle analysis analysis consultants to weigh operational benefits of active and passive systems against embodied impacts before construction and eventual disassembly for re-use, recycling or responsible disposal Specifying high recycled materials content within building products; tracking and encouraging the reduction of embodied energy within materials and throughout the construction process; specifying the use of sustainable materials such as Forest Stewardship Council certified timber, bamboo and other products
5 Local and Sustainable Food	**5 Local and Sustainable Food**
Retail outlets to meet targets for supplying organic food and sustainable and or fair trade products	*Not Active*
6 Sustainable Water	**6 Sustainable Water**
Per capita water consumption to be at least 50 per cent less than the national average; all waste water to be re-used	Minimise demand for potable water in residential and non-residential applications. Incorporate greywater, condensate and stormwater harvesting systems. Develop strategy for initial wastewater management anticipating full connectivity to Masdar infrastructure. Optimise the use of water within the public realm to maximise microclimate enhancement potential
7 Natural Habitats and Wildlife	**7 Natural Habitats and Wildlife**
All valuable species to be conserved or relocated with positive mitigation targets	*Not Active*
8 Culture and Heritage	**8 Culture and Heritage**
Architecture to integrate local values.	Develop and incorporate passive technologies that capture the vernacular understanding of how to provide comfort in the local microclimate
9 Equity and Fair Trade	**9 Equity and Fair Trade**
Fair wages and working conditions for all workers (including construction) as defined by international labour standards	Not Active
10 Health and Happiness	**10 Health and Happiness**
Facilities and events for every demographic group	Good air quality, and the provision of internal and external environments that provide appropriate levels of visual and thermal comfort, to enhance the well-being and performance of MIST students and visitors

1.11 MIST Sustainability Targets

One Planet Living provides a framework for strategic decision making on city wide sustainability. It does not offer specific guidance on building level sustainability targets.

Commercially available building sustainability assessment tools such as LEED and BREEAM are not able to capture the full scope of the One Planet Agenda, and whilst they provide specific performance targets and benchmarks these do not fully account for the context of Masdar in Abu Dhabi.

SBTools offers a flexible framework by which

The process of identifying sustainability targets that are specific to Masdar and can be applied on MIST has begun with workshops with PB, F+P and Nils Larsson of iISBE.

A more formalised sustainability assessment framework will emerge during Scheme Design Stage.

1.12 MIST Water Target

The Masdar target for water consumption for all uses is 180l/day of which no more than 80 l/day can be potable water

1.13 MIST Energy Target

1.13.1 Masterplan Benchmarks

By analysing the interaction between urban-scale and building-scale passive design requirements and performance criteria and matching these to the envisaged energy efficiency of local and central utilities Transolar have defined absolute electrical energy budgets for a range of building typologies.

These values are derived from dynamic thermal and energy simulations that consider the effect of:

- Annual weather data and local microclimate impacts
- 'Passive' design criteria
  (building envelope etc)
- 'Active' design criteria
  ($COP_{electric}$ of sensible and latent cooling systems, efficiency of fans, pumps and lighting)
- Behavioural assumptions
  - Occupant density
  - Hours of occupation
  - Equipment use and efficiency

These assumptions are not be appropriate for all phases of the development of Masdar, and will not adequately represent the activities of many building users.

Nonetheless they provide a baseline or benchmark against which performance can be assessed, much the same as ASHRAE 90,1 or Part L regulations in the UK compare a 'notional' building against an actual design.

However, unlike ASHRAE 90.1 and Part L, it has been proposed that the energy budget that is set by the masterplan fro each plot is absolute and must be achieved irrespective of the specific occupational profiles, activities or behaviours that take place in each development.

For MIST the challenge has been set to beat the energy targets set by the masterplan.

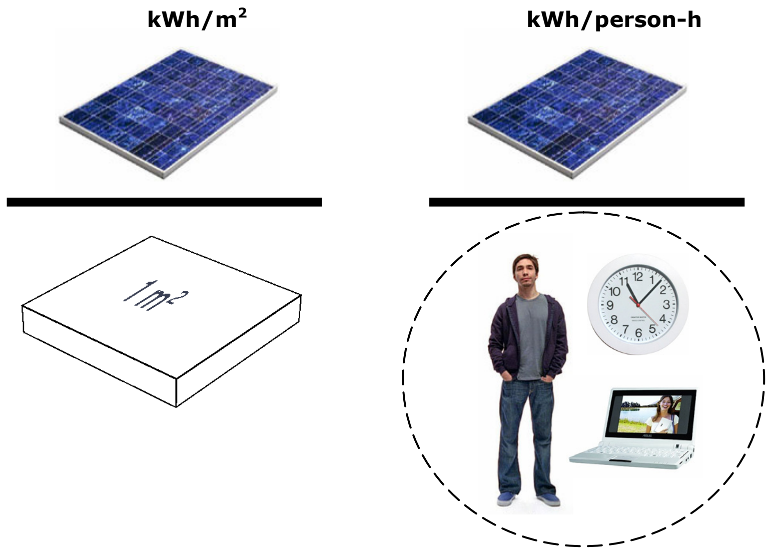
1.13.2 Utilisation Measures

PHA Consult have proposed that the way that energy performance be assessed across Masdar be broadened such that the concept of utilisation is factored in.

Using kWh/m²/year as a measure completely hides the relationship of a building to its occupancy – essentially a building that operates at a lower occupant density than the masterplan, or with shorter occupied hours will appear to be more energy efficient.

This introduces the possibility of 'gaming' the design target, whereby an end-user claims a lower intensity of use than will be the case.

For this reason a utilisation based target – kWh/person-h will also ultimately be assessed. This approach personalises energy and increases individual responsibility levels

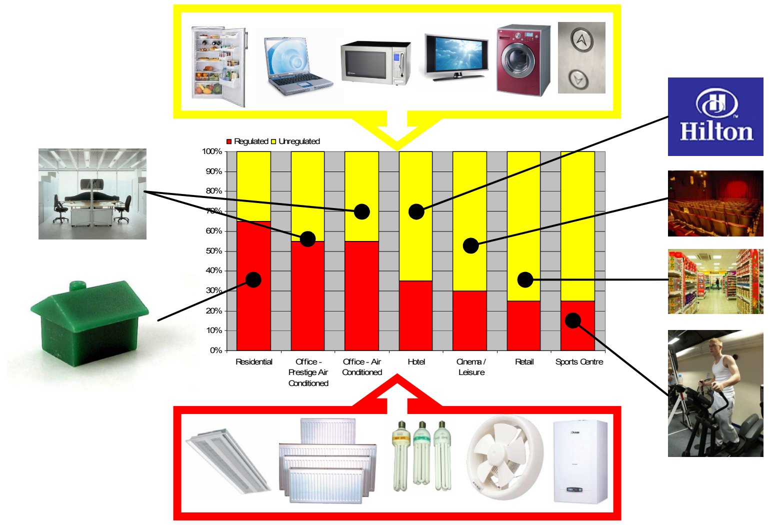


1.13.3 Interaction Between the Occupant and Building Systems

Only a certain portion of the annual energy consumption of a building is under the control of the building systems.

Responsible occupant behaviour is critical if masterplan energy targets are to be achieved. Energy efficiency practices have benefits not only in the reduction of annual equipment energy consumption but also in reducing sensible cooling loads imposed on HVAC systems.

Typical breakdown of 'regulated' and 'unregulated' loads for a range of building typologies in the UK are presented below indicating the significant and often dominant influence of occupant behaviour on overall energy consumption.



Consideration of how best to manage occupant behaviour without negative impacts on health and happiness are discussed in Section 2

1.13.4 MIST Electrical Energy Consumption Budget

Based on the masterplan targets and the area schedule breakdown provided by Foster + Partners the overall annual energy budget for MIST have been calculated.

Overall energy consumption per m² varies between 92kWh/m²/year and 97 kWh/m²/year as the split in e

PHASE 1a - Accommodation Requirements 2009

	Area (m^2)	Energy Use Typology	Masterplan Energy Consumption Target ($kWh/m^2/yr$)	Annual Electrical Energy Budget MWh
Research Lab Environment	5,850	Lab	151	883.35
Non Laboratory Learning	2,650	Education	53	140.45
Faculty Staff	900	Office	53	47.7
Support Staff	600	Office	53	31.8
Amenity Space	780	Retail/Leisure	151	117.78
Residential	5,760	Residential	53	305.28
	16,540			**1,526**

Brief Phase 2 - Accomodation Requirements 2014

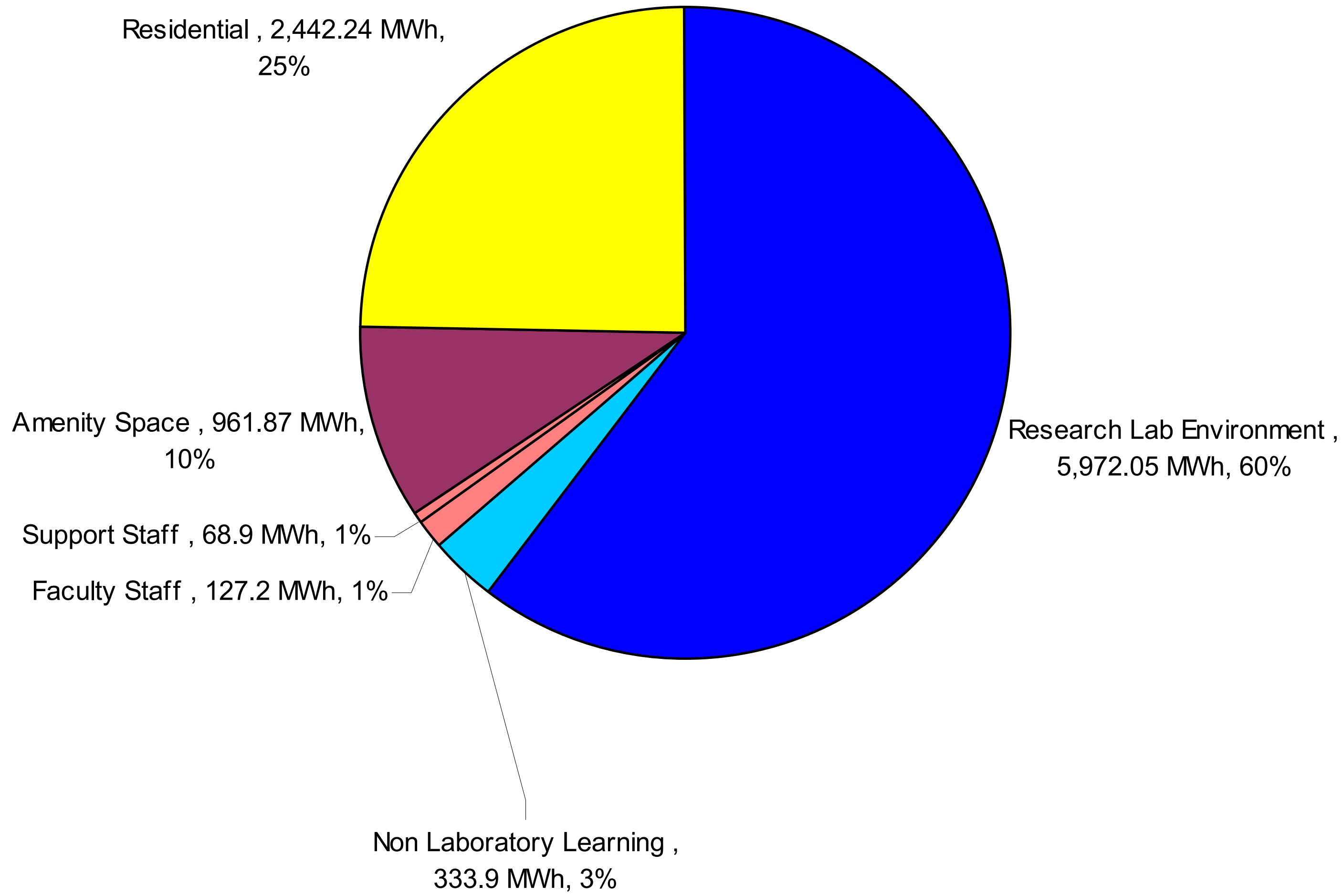
	Area (m^2)	Energy Use Typology	Masterplan Energy Consumption Target ($kWh/m^2/yr$)	Annual Electrical Energy Budget MWh
Research Lab Environment	36,744	Lab	151	5548.344
Non Laboratory Learning	6,178	Education	53	327.434
Faculty Staff	2,217	Office	53	117.501
Support Staff	1,201	Office	53	63.653
Amenity Space	6,262	Retail/Leisure	151	945.562
Residential	42,567	Residential	53	2256.051
	95,169			**9,259**

PHASE 1b - Accommodation Requirements 2011

	Area (m^2)	Energy Use Typology	Masterplan Energy Consumption Target ($kWh/m^2/yr$)	Annual Electrical Energy Budget MWh
Research Lab Environment	23,036	Lab	151	3478.436
Non Laboratory Learning	4,082	Education	53	216.346
Faculty Staff	1,323	Office	53	70.119
Support Staff	715	Office	53	37.895
Amenity Space	2,106	Retail/Leisure	151	318.006
Residential	25,402	Residential	53	1346.306
	56,664			**5,467**

Brief Phase 3 - Accomodation Requirements 2015

	Area (m^2)	Energy Use Typology	Masterplan Energy Consumption Target ($kWh/m^2/yr$)	Annual Electrical Energy Budget MWh
Research Lab Environment	39,550	Lab	151	5972.05
Non Laboratory Learning	6,300	Education	53	333.9
Faculty Staff	2,400	Office	53	127.2
Support Staff	1,300	Office	53	68.9
Amenity Space	6,370	Retail/Leisure	151	961.87
Residential	46,080	Residential	53	2442.24
	102,000			**9,906**



1.14 Design Codes and Standards

The Design will be based on the following Guidelines and Codes;

American Society of Heating, Refrigeration and Air conditioning Engineers (ASHRAE)

Chartered Institute Of Building Services Engineers (CIBSE), where appropriate

National Fire Protection Association (NFPA) Guidelines

British Standards, where appropriate

EITC Telecom Guidelines

Abu Dhabi Electricity and Water Authority - Regulations for Electrical and Water Installations

MIT Design Guidelines

Local Codes

2 Understanding the Occupant's Needs

2.1 A 'One Planet' High Quality Environment

A One Planet approach to MIST is only about meeting resource management targets, it is also about ensuring a high quality environment for occupants and visitors – health and happiness

Whilst it is imperative that the energy and water targets be met there are inevitably functional limits on what can be achieved before occupant dissatisfaction results.

This section considers some of the issues where energy and water efficiency measures can lead to conflict with occupant health and happiness. Specifically it addresses:

- Thermal Comfort
- Water Consumption
- Electrical Consumption within Laboratory Spaces
- Striking the balance between gathering data on the occupant in order to fine tune building performance and safeguarding basic rights to privacy.

In all cases there is a need to consider

- Occupant expectations for service quality
- The willingness to adapt to restrictions on resource availability
- The willingness to engage in communal activities in place of private activities where there is an environmental benefit

We therefore have to imagine two extremes of occupant attitudes towards the building and its immediate environment:

1. The 'willing' user
   Who is happy to behave in an optimal sustainable way
2. The 'unwilling' user
   Who is not yet prepared to amend behaviours to a sustainable model or have their freedom of choice constrained

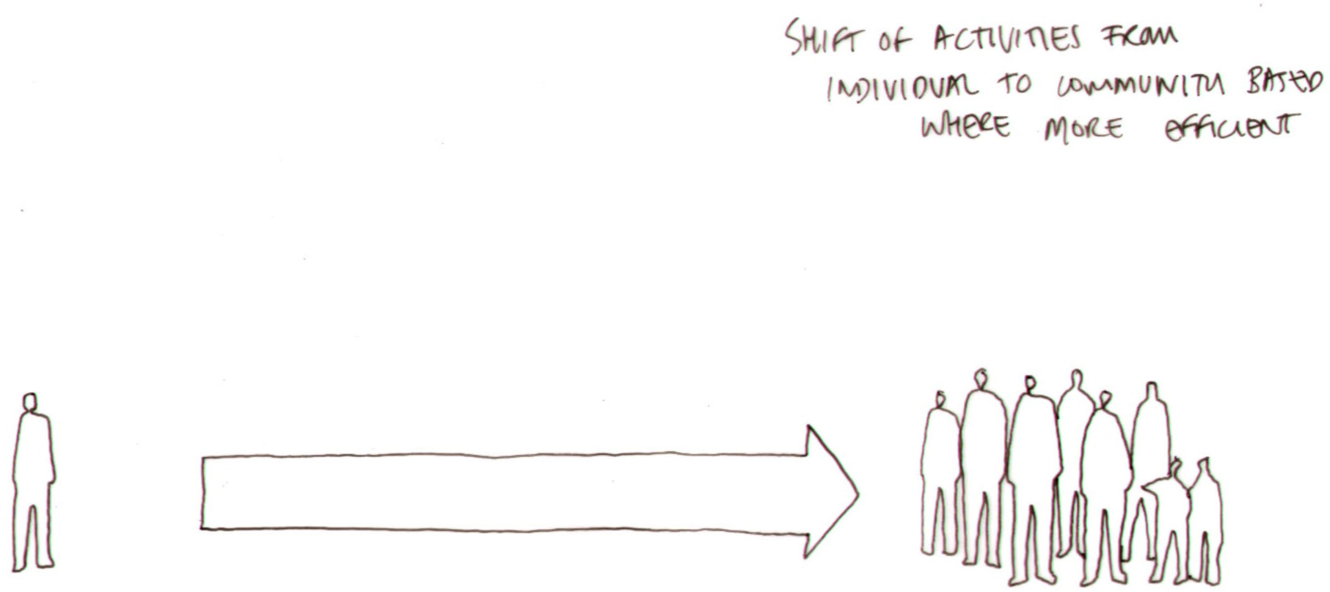
The hope is that MIST will attract predominantly 'willing' users, but is inevitable that some occupants will not.

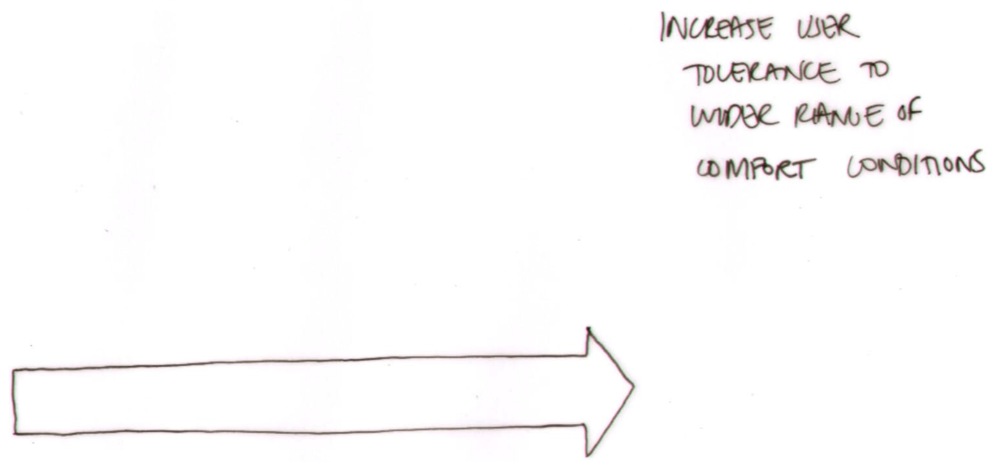
We also have to imagine that in different circumstances there are two types of scenario that are determined by the availability and usability of technologies and the absolute needs of a user for a given resource:

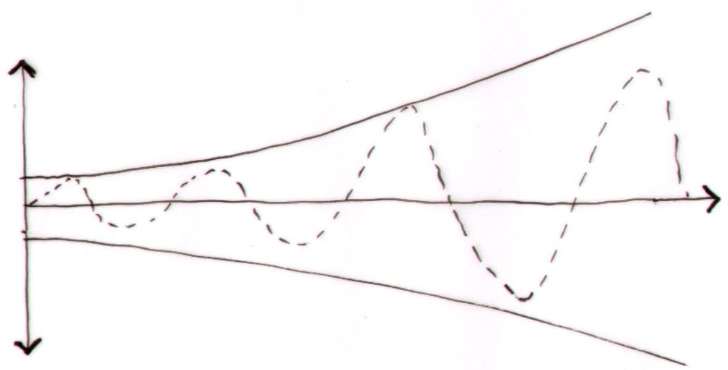
3. The 'able' user
   Who has technologies available that meet their functional needs
4. The 'unable' user
   Who finds that the technologies they need are not available, too hard to use or simply do not meet their absolute need for a given resource

An example of a 'willing' and 'able' user is one that is happy to use a low-flow shower for only 3 minutes, whilst an 'unwilling' and 'unable' user might be a parent needing to bathe children

2.2







Thermal Comfort

Assessing thermal comfort within a climate such as Abu Dhabi's is strongly influenced by the physiological perception of discomfort due to high heat and humidity.

Most empirical models of comfort work on the assumption that comfort can be defined in terms of thermal balance – i.e. that the body is able to lose as much heat as it gains.

The principle factors affecting thermal balance are;

- Clothing level
  ('Clo' value – determined by the amount and type of clothing worn)
- Activity level
  (Metabolic rate – also influenced by age, gender and weight)
- Air Temperature
  ('Dry bulb' temperature)
- Radiant Temperature
  (Surface temperatures and solar radiation)
- Relative Humidity
  (Affects the ability of skin to lose heat by sweating)
- Local wind speed
  (Loss or gain of heat by convection, and influence on sweat evaporation)

Numerous strategies can be applied to analyse climate data to assess comfort/discomfort in relation to the factors above. These are all based on tests undertaken on subjects, with significant variance between results under comparable conditions – defining comfort is far from an exact science.

Fanger

Assesses the predicted mean vote, or the percentage of people dissatisfied under any given combination of the listed factors. This forms the basis of ISO 7730.

Olgyay

Plots a bioclimatic chart of air temperature against humidity, and defines a comfort zone that can be modified by radiant temperature and wind speed.

Givoni

Using the psychrometric chart Givoni plots a comfort zone, and then extends this on the basis of potential passive techniques

These three approaches are particularly useful at defining the opportunity to achieve comfort, however for conditions where comfort cannot be achieved by passive measures they provide limited insight into microclimate safety.

For wind microclimates we consider pedestrian wind comfort, but also safety. Given the extreme ambient conditions observed in full shade in Abu Dhabi it is necessary to assess 'pedestrian heat safety'. This can be done using Steadman's Heat Index.

Figure 2-1 Givoni - Natural Vent Opportunity

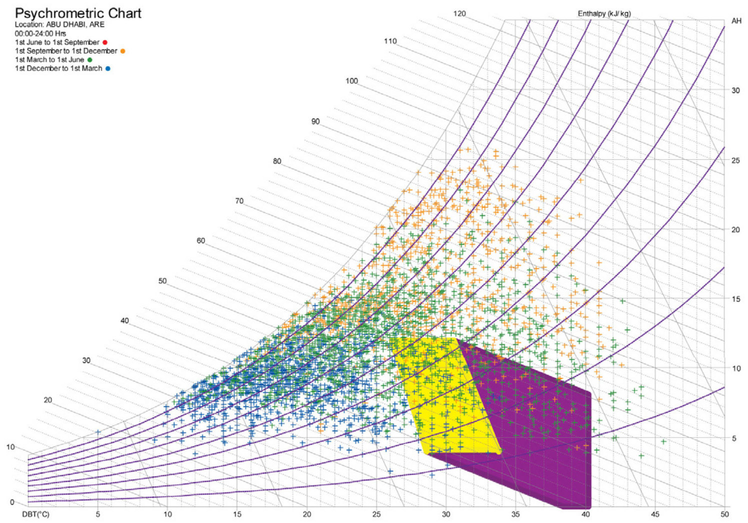


Figure 2-2 Givoni - Evaporative Cooling Opportunity

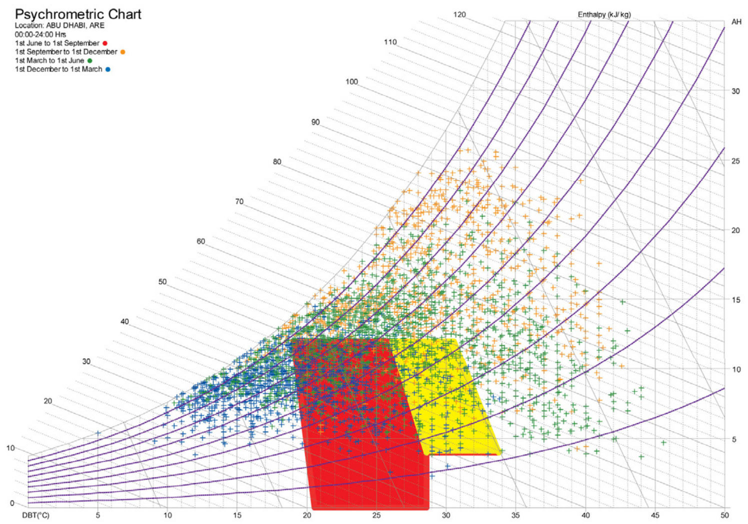


Figure 2-3 Givoni - Passive Solar Opportunity

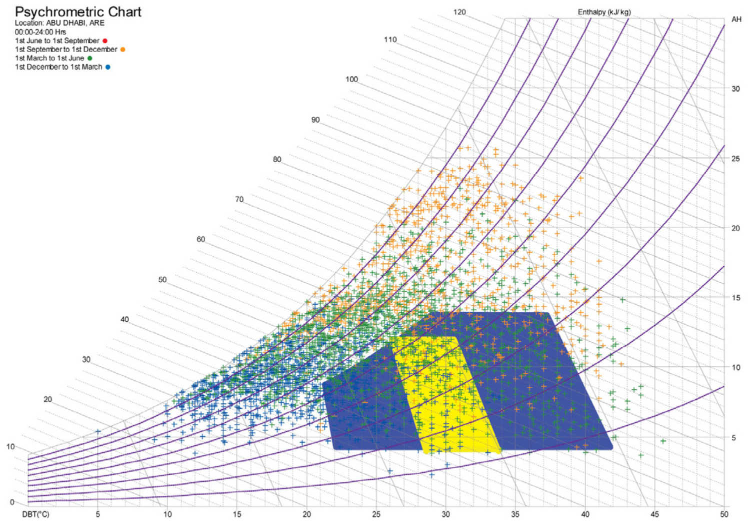


Figure 2-4 Thermal Mass Opportunity

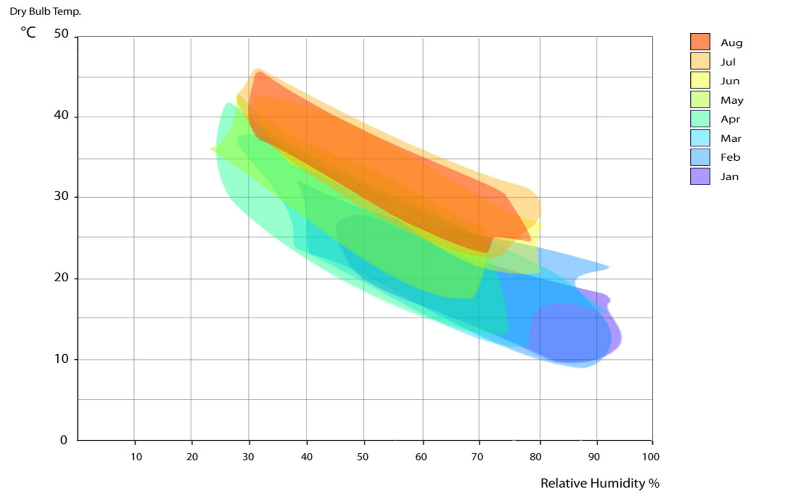


Figure 2-5 Olgyay Bioclimatic Chart for Abu Dhabi

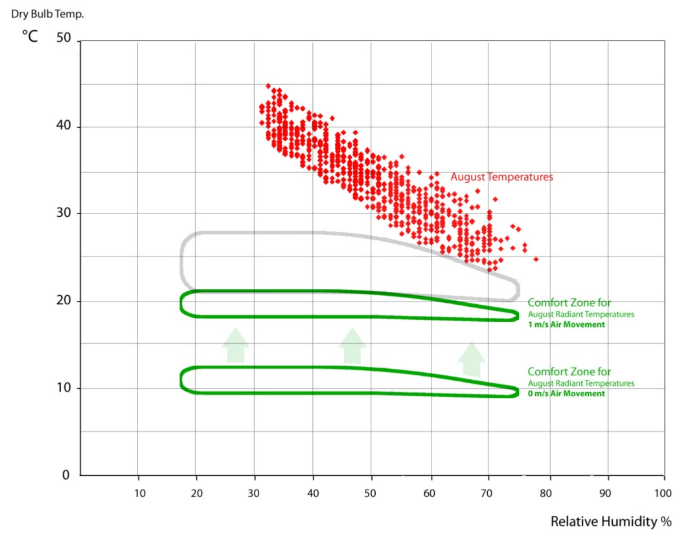


Figure 2-6 Olgyay analysis for August conditions showing the impact of radiant temperatures and wind speed on the comfort zone

2.2.1 Heat Index Assessment

The Heat Index [HI] is derived from work carried out by R. G. Steadman. It contains basic generalised assumptions about the human body mass and height, clothing (trousers and short-sleeved shirt), sweat rate, activity (walking) and the wind speed (2.6m/s) that are applicable to MIST. [3]

The Heat Index looks only at air temperature and relative humidity to determine the human perceived equivalent temperature - how hot it feels, termed the 'felt air temperature'[4]. The terms "apparent temperature" or "relative outdoor temperature" are also sometimes used.

The Heat Index is widely used by meteorological organisations to advise the public on the risk of heat stress levels and their potential impact on health; it is also incorporated into standard ASHRAE weather data statistics.

The human body normally cools itself by perspiration, or sweating, which evaporates and carries heat away from the body. However, when the relative humidity is high the evaporation rate is reduced, so heat is removed from the body at a lower rate causing it to retain more heat than it would in dry air.

Measurements have been taken based on subjective descriptions of how hot subjects feel for a given temperature and humidity, allowing an index to be made which corresponds a temperature and humidity combination to a higher temperature in dry air.

At high temperatures, the level of relative humidity needed to make the heat index higher than the actual temperature is lower than at cooler temperatures. For example, at 27°C the heat index will agree with the actual temperature if the relative humidity is 45%, but at 43°C any relative-humidity reading above 17 % will make the Heat Index higher than 43°C.

Humidity is deemed not to raise the apparent temperature at all if the actual temperature is below approximately 20°C– essentially the same temperature colder than which wind chill is thought to commence.

The Heat Index is based on temperature measurements taken in the shade and not the sun. Exposure to full sunshine can increase heat index values by up to 8 °C.

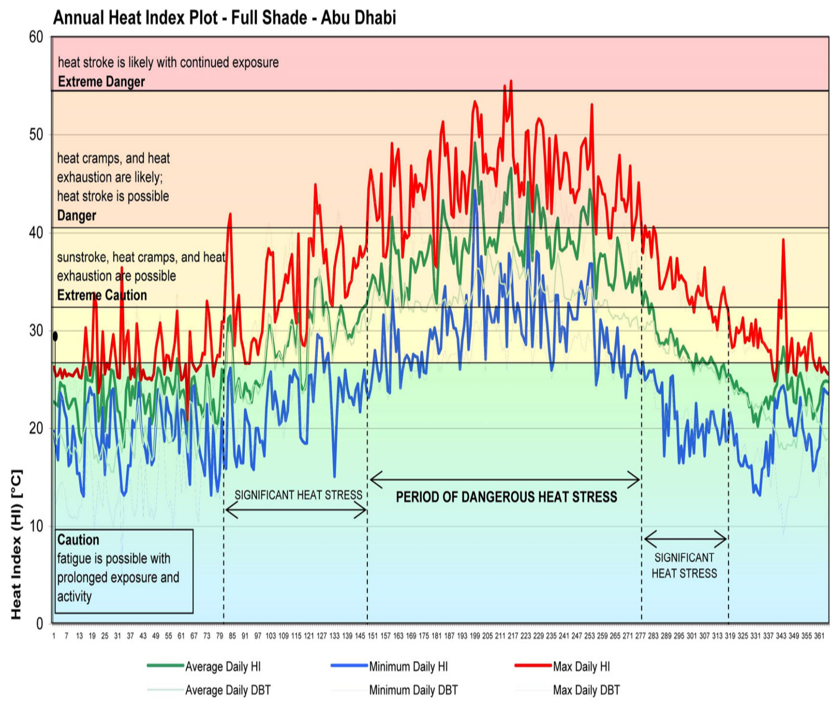
[3] Further information about the assumptions used by Steadman can be found at http://www.srh.noaa.gov/ffc/html/studies/ta_htindx.PDF
[4] It should be noted that the 'felt' temperatures documented in the masterplan studies should more accurately be described as 'operative' or 'resultant' temperatures

The NOAA provides four levels from which an assessment of risk to human health can be made.[5]

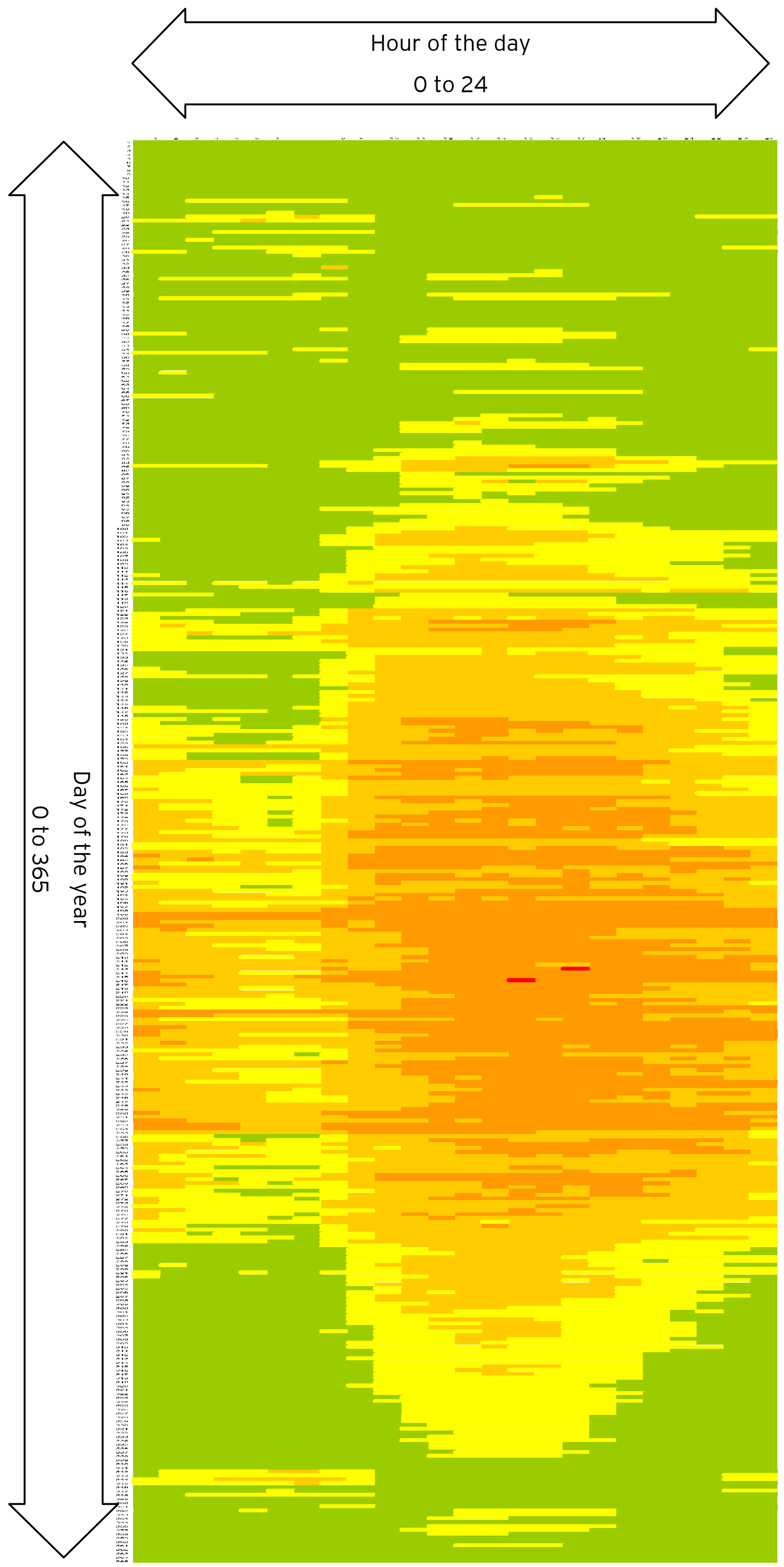
Celsius	Notes
27-32 °C	Caution – fatigue is possible with prolonged exposure and activity
32-41 °C	Extreme caution – 'sunstroke', heat cramps, and heat exhaustion are possible
41-54 °C	Danger – 'sunstroke', heat cramps, and heat exhaustion are likely; heat stroke is possible
over 54 °C	Extreme danger – heat stroke or 'sunstroke' are likely with continued exposure

Using the HI calculation procedure the hourly temperature and relative humidity data for the site have been converted into 'felt air temperatures'.

A plot of daily maximum, average and minimum HI temperatures is shown in the graph below which clearly shows a significant incidence of temperatures that would be classified as 'dangerous' or requiring 'extreme caution' from 0800hrs to 2300hrs between day 120 (30th April) and day 290 (17th October). During this period, using NOAA guidelines it would be medically inadvisable to be outdoors for any prolonged period



[5] http://www.crh.noaa.gov/pub/heat.php



2.3 Water

'Only those who experience acute scarcity at a physical level ever fully acknowledge the value of waters presence'[6].

2.3.1 Existing Context

Current typical domestic water consumption in Abu Dhabi is 350l/day per person. This is amongst the highest rates of potable water consumption in the world.

This level of consumption must be set against the precarious state of Abu Dhabi's natural water reserves, with extraction significantly exceeding the ability of the aquifer to recharge, leading to extensive salinisation of the water table.

Uncontrolled groundwater extraction has adversely affected water quantity and water quality in many areas. Continued extraction at current levels will deplete the fresh and brackish groundwater resources within 50 years.[7]

The lionshare of Abu Dhabi's potable water supply is now generated by desalination which is energy intensive and has negative impacts on salinity levels in the Persian Gulf - although it is thought that desalination is a relatively small contributor to overall increases in salinity.[8]

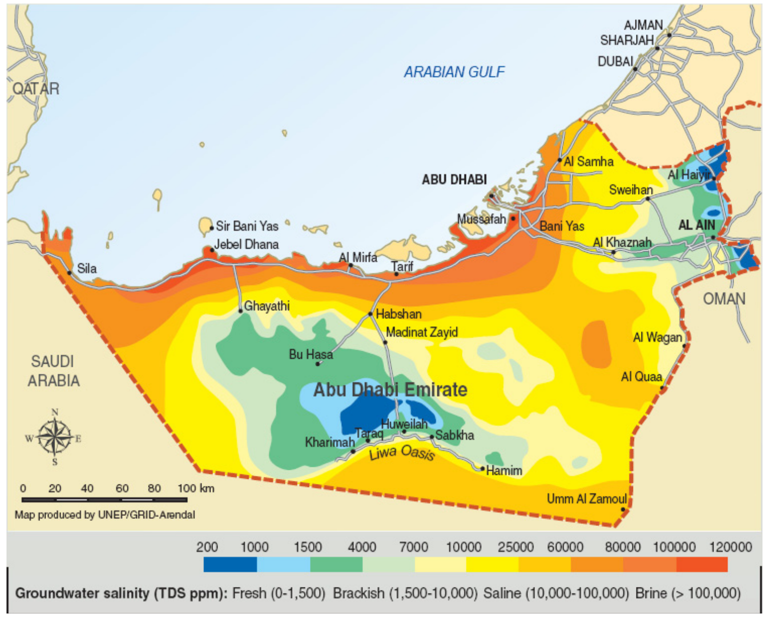


Figure 2-7 Salinity of the shallow aquifer Abu Dhabi Emirate [UAE SOE 2006]

2.3.2 Masdar Target

The Masdar target for per capita potable water consumption is 80l/person/day.

2.3.3 Functional Limits to Maintain 'Health and Happiness'

- Continuous availability of potable water – no cut-offs
- Adequate potable water for drinking
- Adequate potable water to maintain personal hygiene,
- No restrictions in water use required for observing religious practices
- Adequate potable water for cooking

2.3.4 Behavioural Changes Required

- The use of baths for bathing needs to be dramatically reduced or eliminated
- The use of bidets needs to be eliminated
- The duration of showers taken needs to be reduced to not greater than 3 minutes per shower use
- Communal laundries must be used
- Cooking techniques that minimise water consumption – such as steaming of vegetables, absorption cooking of rice, need to become the norm

2.3.5 Technical Measures Required

- Water metering
- Baths only provided for family residences
- Dual flush toilets - 4/2 litre flush
- Flush delays to prevent flush without full cistern
- Greywater used for toilet flush
- Greywater used for communal laundry
- No bidets
- No power showers
- Shower flow rates limited to 6 litres/min
- Flow meters on individual taps
- Flow time restrictors on all taps
- Aerated taps in bathrooms flow limited to 3litres/min
- Variable flow limiters on kitchen taps - 3 litres/min

Figure 2-8 Water saving technologies - individual flow meters, waster metering, show meters, aerated flow restriction taps, waterless urinal technology, dual flush WCs, water efficient cooking and separate potable/non potable supplies

[6] Chatel http://www.ipcri.org/watconf/papers/chatel.pdf
[7] Abu Dhabi State of the Environment Report 2006
[8] http://assets.panda.org/downloads/desalinationreportjune2007.pdf

2.3.6 Analysis of Implications on Lifestyle and Occupant Choice

The BRE's domestic internal potable water use calculation procedure as used in the UK's Code for Sustainable Homes was used as a framework for assessing residential water consumption. To account for the increased need for bathing in Abu Dhabi's climate and to account for increased washing for prayer, adaptations were made to the use factors for these items.

Starting with a 'business as usual' base case, step-by-step water efficiency measures are introduced to assess how the Masdar target could be achieved at MIST:

No Water Savings in Place:

End Use	WC	BIDET						
Consumption	6	2.64	210	12	12	12	18	8.8
Uses per day	4.8	2	0.5	1.5	9.8	7.9	0.3	0.34
Use factor	1	1	0.4	8	41	41	1	6

- Generous bath, 8 minute showers, high-flow shower and taps, single flush 6l WC, least efficient appliances

Daily potable water consumption per occupant: 385.7 l/day

Typical Water-Efficient Practice:

End Use	WC	BIDET						
Consumption	6/3	2.64	175	9	6	6	13	7.5
Uses per day	4.8	2	0.5	1.5	9.8	7.9	0.3	0.34
Use factor	1	1	0.4	5	41	41	1	6

- Reduced volume bath, 5 minute showers, lower-flow shower and taps, dual flush 6/3l WC, typical efficiency appliances

Daily potable water consumption per occupant: 217.3 l/day

Best Practice:

End Use	WC	BIDET						
Consumption	4/2	2.64	135	6	3	3	10	6.2
Uses per day	4.8	2	0.5	1.5	9.8	7.9	0.3	0.34
Use factor	1	1	0.4	3	30	41	1	6

- Smallest volume bath, 3 minute showers, low-flow shower and taps, time limit on bath taps, dual flush 4/2l WC, best efficiency appliances

Daily potable water consumption per occupant: 118.3 l/day

Greywater WCs:

End Use	WC	BIDET						
Consumption	GW	2.64	135	6	3	3	10	6.2
Uses per day	4.8	2	0.5	1.5	9.8	7.9	0.3	0.34
Use factor	1	1	0.4	3	30	41	1	6

- As before, but all WC water use is replaced by grey water

Daily potable water consumption per occupant: 105.5 l/day

No Bidets:

End Use	WC	BIDET						
Consumption	GW	X	135	6	3	3	10	6.2
Uses per day	4.8	X	0.5	1.5	9.8	7.9	0.3	0.34
Use factor	1	X	0.4	3	30	41	1	6

- As before, but all bidets are removed

Daily potable water consumption per occupant: 100.2 l/day

No Baths:

End Use	WC	BIDET						
Consumption	GW	X	X	6	3	3	10	6.2
Uses per day	4.8	X	X	2	9.8	7.9	0.3	0.34
Use factor	1	X	X	3	30	41	1	6

- As before, but all baths are removed

Daily potable water consumption per occupant: 82.2 l/day

Communal Laundry:

End Use	WC	BIDET						
Consumption	GW	X	X	6	3	3	10	GW
Uses per day	4.8	X	X	2	9.8	7.9	0.3	0.34
Use factor	1	X	X	3	30	41	1	6

- As before, with all laundry washed centrally using greywater

Daily potable water consumption per occupant: 69.6 l/day

Centralised Dishwashing:

End Use	WC	BIDET						
Consumption	GW	X	X	6	3	3	5	GW
Uses per day	4.8	X	X	2	9.8	7.9	0.3	0.34
Use factor	1	X	X	3	30	41	1	6

- As before, with communal eating allowing centralised dish washing for all meals

Daily potable water consumption per occupant: 68,1 l/day

Through a combination of increased efficiency, constraints on occupant freedom of consumption, improvement in occupant behaviour and centralising certain functions the Masdar target can be met.

It is clear that baths and bidets cannot be included in the general specification of residential accommodation if the target is to be met. Where baths are necessary – such as in family accommodation for washing of children, then this additional water use must be offset by greater efficiencies elsewhere.

2.3.7 Risks in Implementing Masdar Targets

The strategies outlined for meeting the 80l/p/d potable water target are dependent on:

- acceptance by the user of limits on consumption
- acceptance that bidets and baths are not acceptable uses of water
- acceptance of communal laundry facilities
- acceptance of reduced shower duration

This last aspect is the most difficult to achieve without technical interventions which physically limit the duration of showering, giving advance warning that the water supply will be cut-off.

Such interventions may be perceived as 'rationing' and we invite the client to advise as to the acceptability of such measures at MIST.

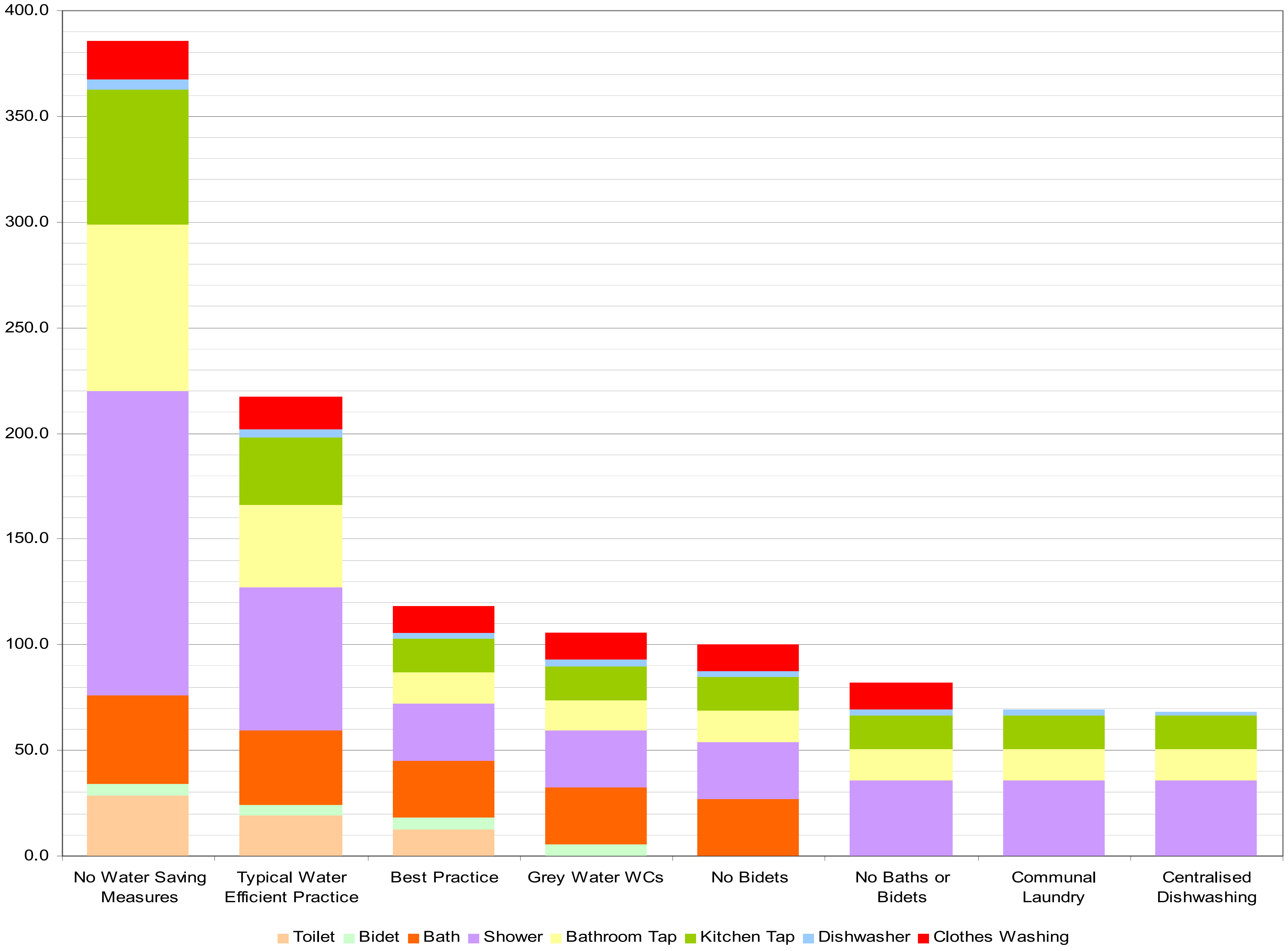


Figure 2-9 Graph showing the effect of incremental changes in water consumption.

2.4 Electrical Consumption - Lab

Non lighting electrical demands within labs can be split between traditional IT loads and laboratory equipment loads.

2.4.1 Existing Context – Lab Equipment

Reported lab equipment energy consumption and peak electrical loads vary wildly between institutions. This is attributable to significant variance in occupant density and research activities.

Measured plug loads by LAB21 project in USA suggest 2 to 4 W/sqft is a reasonable 15minute averaged peak. This equates to 21.5 - 43.0 W/m2.

Typical recorded peak electrical demand 64 W/m² - Lowest Recorded 40 W/m²

Best Practice target (LEED-AGL) Equipment Heat Gains 10.8 W/m2 using a 75% diversity factor.

2.4.2 Masdar Target

Energy benchmarking for the masterplan has assumed typical/peak plug loads of 10.6 W/m² during occupied hours and 5.3 W/m² at other times.

Whilst typical loads are of a similar order to those recommended under LEED-AGL, peak demands are 50-75% lower.

2.4.3 Functional Limits to Maintain 'Health and Happiness'

It has been made clear that it is unacceptable to prevent researchers using specific types of equipment that are essential to the conduct of their experiments.

2.4.4 Behavioural Changes Required – Lab Equipment

- Changes to purchasing criteria

There currently exist no equivalent to the well-established Energy Star rating system for lab equipment; however it would be possible to insist that where there is a choice between laboratory equipment products of functional equivalence that MIST only purchases the most energy efficient model.

This approach to load reduction is advocated by the as yet unpublished LEED NC Application Guide for Labs. It recommends only permitting

"selection of equipment that is above the 75th percentile of its class of functionally equivalent equipment, in terms of efficiency".

2.4.5 Technical Measures Required – Lab Equipment

None – no constraints can be imposed

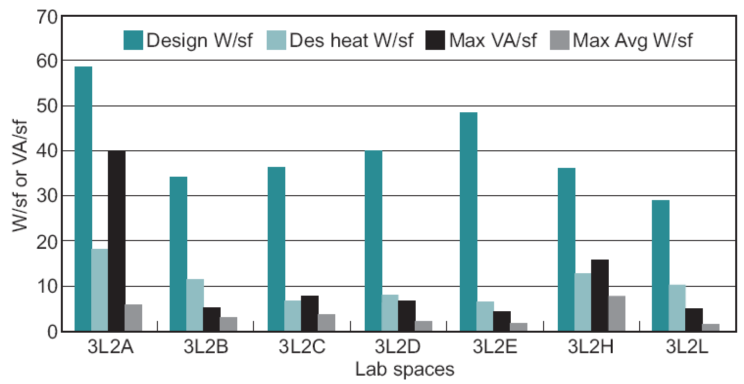


Figure 2-10 Measured and Design Plug Loads for Labs Monitored by the Labs 21 Project

2.4.6 Existing Context – Lab IT

- Unknown mix of desktop and laptop use within work space
- Unknown power management behavioural and technology approaches

2.4.7 Masdar Target

Energy benchmarking for the masterplan has assumed typical/peak plug loads of 10.6 W/m² during occupied hours and 5.3 W/m² at other times.

Whilst typical loads are of a similar order to those recommended under LEED-AGL, peak demands are 50-75% lower.

2.4.8 Functional Limits to Maintain 'Health and Happiness'

Researchers will require IT equipment with sufficient processing power available on demand, and cannot be constrained by network limits.

2.4.9 Behavioural Changes Required – Lab IT

- Changes to purchasing criteria
  - Best in class for energy efficiency
  - Increasing use of laptops
  - Evaluation of 'thin-client' technologies
- Increased awareness of need to shut down inactive terminals

2.4.10 Technical Measures Required

None – no constraints can be imposed

2.4.11 Analysis of Impact of IT strategy on energy consumption

Using the work of Megan Bray[9] which reviewed a broad range of studies into the electrical consumption of IT equipment under full, partial and 'off' use, and varying patterns of occupant behaviour, an analysis has been made of the impact of different IT strategies within the labs.

The analysis assumes a 12 hour occupied period, 6 days per week and compares:

- Typical 'energy star' desktop plus 'energy star' monitor
- 'Jack PC' socket mounted thin client terminal with 'energy star' monitor
- Typical laptop
- Ultra-portable laptop – Asus eeePC
  (no hard drive, reduced screen size)

The results indicate that, contrary to initial assumptions about the energy savings and load reduction benefits of thin client technology, that the most energy efficient approach would be the widespread use of laptop computers.

Inevitably some desktop machines would be required for dedicated processing activities, and some thin-clients could be provided as fixed terminals

[9] "Review of Computer Energy Consumption and Potential Savings - White Paper", December 2006, Megan Bray

Figure 2-11 Overall performance summary of IT technologies - desktop, thin client, laptop, and ultra portable laptop in terms of energy efficiency and processing power

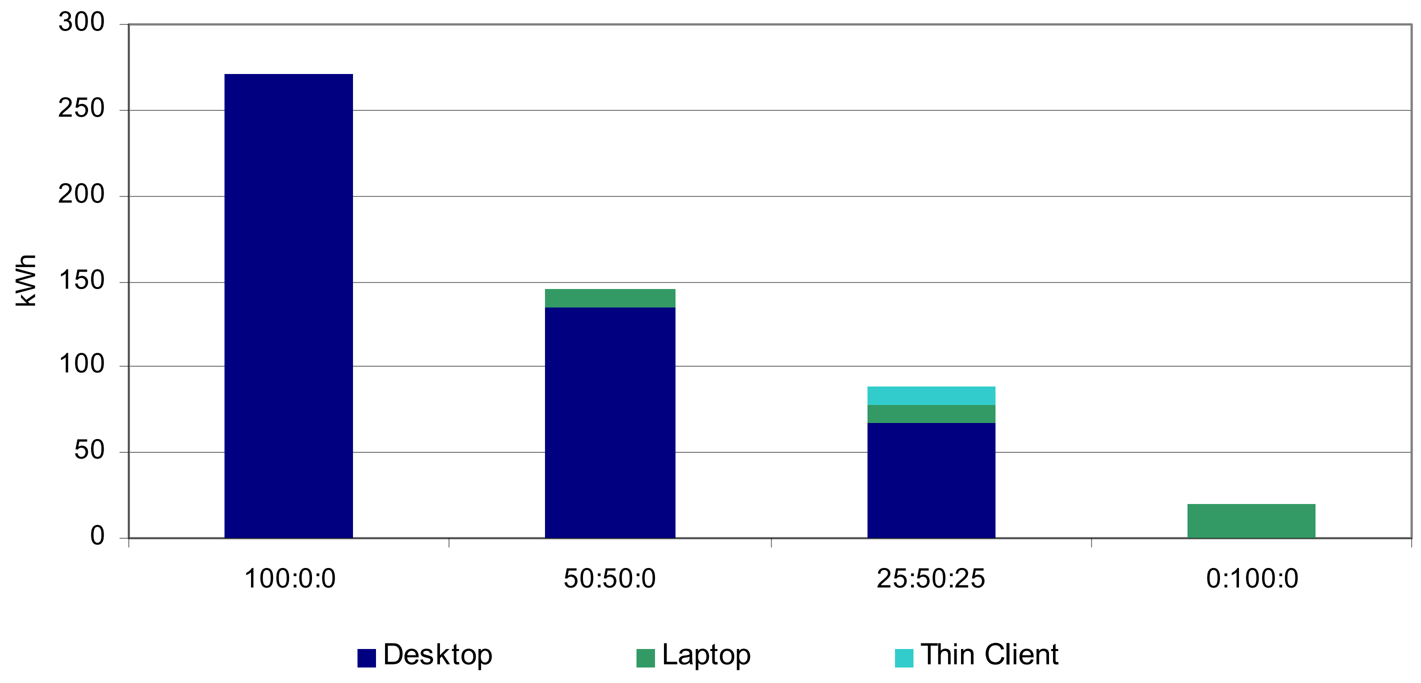
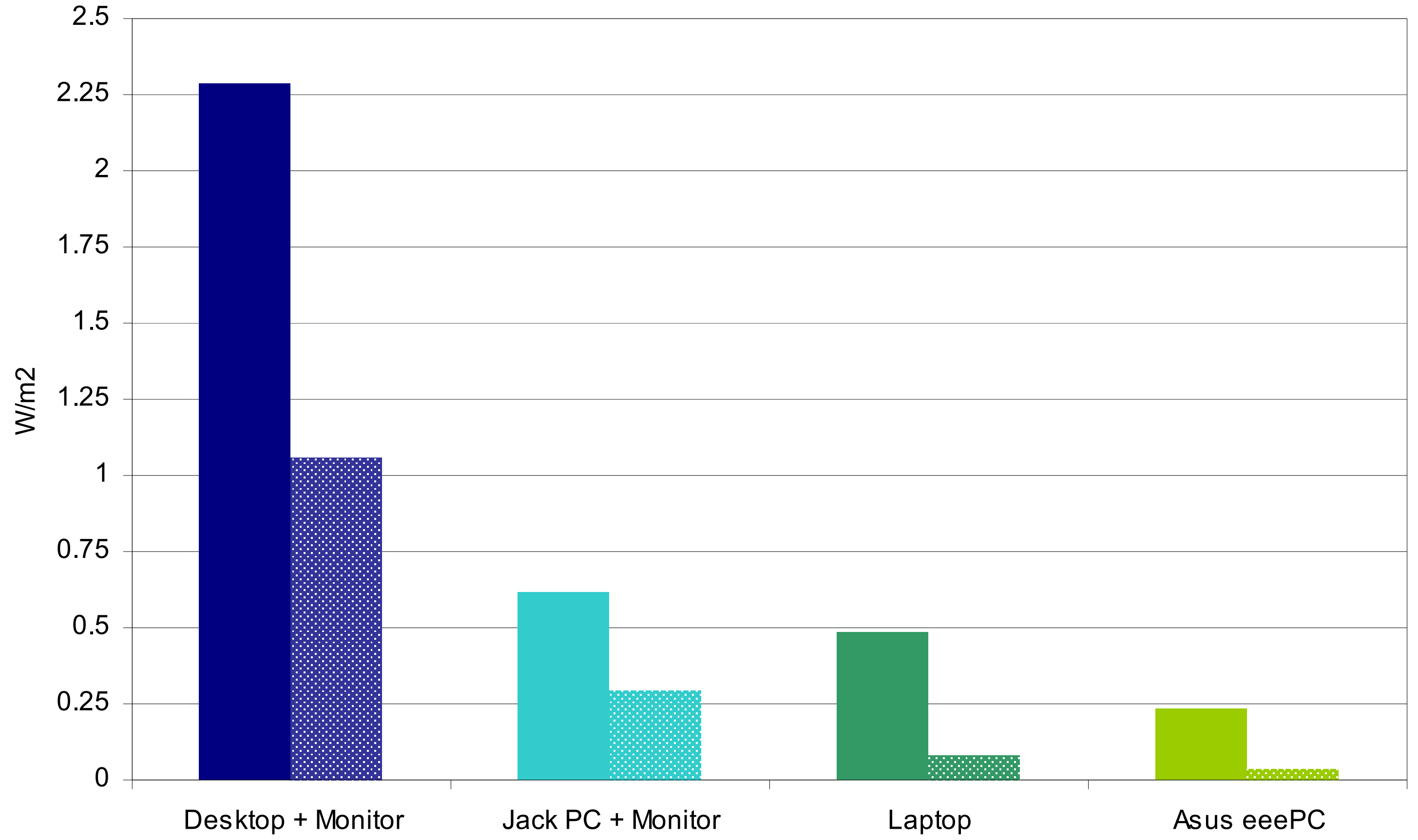
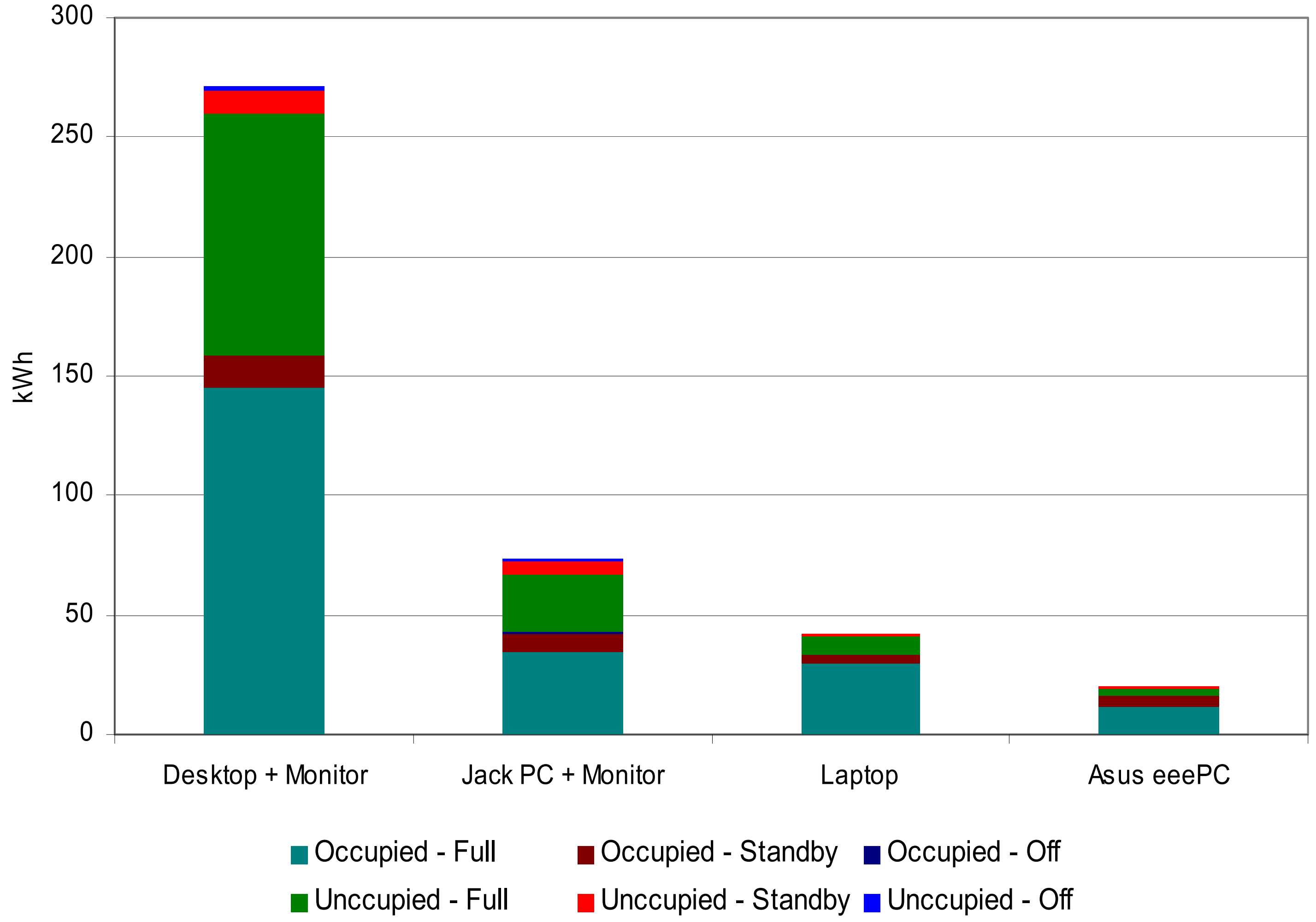


Figure 2-12 Average Annual Energy Consumption per seat comparing mix of IT equipment desktops : laptop : thin client[left}

Figure 2-13 Peak electrical load per m² for each IT technology, assuming an occupant density of 1:20m² day:night [bottom left]

Figure 2-14 Breakdown of annual energy consumption per seat for each IT technology [below]





2.5 Gathering Information on the User

In the drive to optimise the efficiency of building systems and thereby reduce energy consumption it becomes more and more important to understand where the occupant is and what they are doing. With this knowledge we can tailor the provision of services to the time and place that they are required.

There is also the ability to enhance access and security arrangements to prevent tail-gating leading to unkown users entering spaces to which they are not authorised.

It is a conceptual shift from a 'building' management system to one that is centred on the 'user'.

Information can be gathered more easily with the advent of technologies such as RFID tags. RFID tags can be located in space by tracking systems, and have now been miniaturised to the extent that they are being used in a laboratory context to track the movements of individual insects.

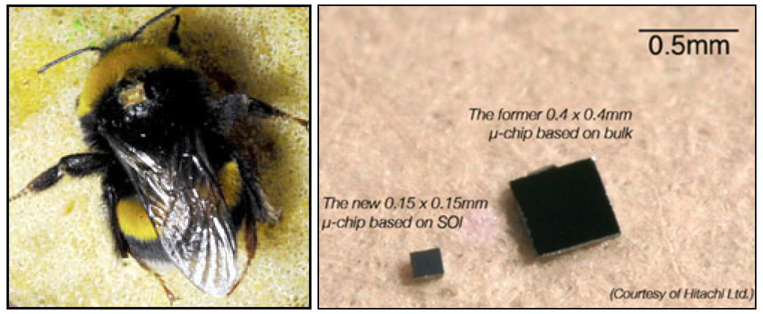
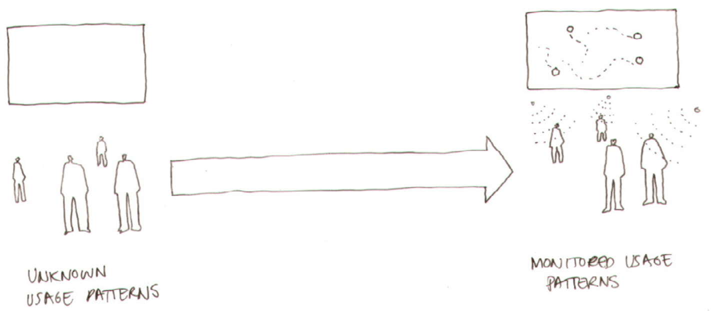


Figure 2-15 RFID chips - Hitachi mu-Chip

Being able to locate every single user within the building allows the building systems to learn about characteristic behaviours, and to begin to anticipate patterns of use.



The use of occupant location has been studied in a research setting at AT&T's labs in Cambridge, UK. PHA Consult have made contact with this research group and hope to explore opportunities to apply their work to MIST.

Work done by Beresford illustrates the movement patterns of occupants in a research environment. The amount of time spent between rooms – and within corridor spaces is not as would be anticipated using conventional assumptions about diversity of occupation for HVAC loads.

Clearly if MIST is to result in new patterns of learning and collaboration, then it is not unlikely that this will result in new patterns of occupation to which the building systems must be able to adapt.

Figure 2-16 Occupant Activity Plot within AT&T's Research Labs [Beresford]

Figure 2-17 Occupant Activity Plot within AT&T's Research Labs [Beresford]

2.5.1 Existing Context

The use of occupant tracking systems is in its infancy, existing occupant sensors tend to be simple on/off motion sensors or reactive – such as CO_2 sensors that detect drops in air quality after the fact.

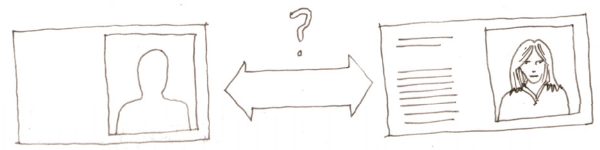
The use of RFID and similar locational systems is widespread in the logistics sector, having applications in product tracking in supply chains and item identification in commercial laundries.

It forms the basis of the London Oyster Card travel user tracking system, and similar schemes around the world.

The application of this technology to human environments has been constrained by concerns over how privacy and anonymity issues are handled

2.5.2 Functional Limits to Maintain 'Health and Happiness'

The key constraint is acceptability of the system for the user – can legitimate privacy, and data protection concerns be adequately addressed?



The issues involved in managing privacy in a pervasive IT environment are considered in depth in the following thesis:

http://www.cl.cam.ac.uk/research/dtg/publications/public/arb33/UCAM-CL-TR-612.pdf

2.6 Lab User Meeting

This section records the comments made by PHA Consult from the initial meeting held with MIT Faculty on 28th and 29th of February @ MIT, Cambridge, MA.

The information gathered from this meeting has come too late to be fully incorporated into the Concept Design Report, however it is presented here as it will have significant impacts on Scheme Design, and on the achievability of the masterplan energy targets for MIST.

- Flexibility and adaptability ultimately important.
- Student numbers will range from 50-200 (different from brief)
- 5 future faculties could be biotechnology, Astro space, nuclear Eng, Electrical Eng.
- If research unknown – infrastructure must be capable of adaptability
- Typical requirements in lab areas as discussed with Faculty;
- Gasification Equipment (needs a minimum of 6 metres floor to ceiling clear)
- Engine rooms (for testing up to 6 engines – diesel and natural gas) – flues/noise issues (estimated at 110 db)
- Depressions needed in slab for certain machines
- Traction machines will be used
- Shakers needed (large heavy, vibrating machines)
- Machine shop required – by all faculty
- Modular power plant testing anticipated
- CNC tool shop needed
- Tensile testing/corrosive testing/high temp testing
- Furnaces needed
- Metal pressing
- Graphics lab
- EMI (electromagnetic interference) may be an issue for certain equipment
- SEM/TEM tools
- Welding (separate exhaust)
- Chiller and AHU test room (large centrif chillers may be tested)
- Access required to roof by most faculties – for testing HVAC equipment along with PV's and wind turbines
- Maximise Revenue metering
- Wood shop/modelling shop
- Diffusion welding furnace
- Sub sonic wind tunnel needed
- Avoid suspended ceilings
- Gases: compressed air, lab air (lab air 20lb and CA is 100lb), argon, nitrogen, natural gas, vacuum pump system, oxygen, hydrogen
- Some of the gases can be bottled locally – not central systems
- Clean rooms – probably 1,000 with pockets down to 100 or 10 within hoods
- Labs more than likely cannot be in basement – fire issues (solvents)
- RO/DI water needed (2-4 M ohm water)
- Liquid nitrogen tank needed
- Process cooling water needed for direct water cooling of certain lab equipment
- Standby power needed – but UPS may be ok for some equipment
- Clean room plant space will be 2/3 the area of the clean rooms. Clean type will be more than likely 'bay and chase'.
- Machine room needs to be by loading bay
- Faculty open to changing behaviour to help reduce energy – i.e. schedule power usage of main electrical equipment to avoid sudden peaks in consumption
- Occupancy roughly 8am to 10pm 5-6 days a week, but there is a suggestion that it could be 24/7 – this needs clarification
- Emergency purge on the vent system may be needed – up to 20-30 ac/hr
- Fume hoods required – but exact type is not known yet
- Server room required in Finance/Carbon trading faculty
- Weather station required
- Some equipment such as the heat transfer experimentation equipment requires a power source of 100kW. The gasification unit will require a 300 Amp power supply. Exact details to be defined by RFD
- Generally high heat emitting equipment can be cooled via process water
- DC power will be required in some areas of the lab
- Desalination testing may occur in the future which could require large power supplies
- Information Technology Issues Raised:
- Radio interference with Airport a concern
- Network interconnection required with New York University in Abu Dhabi when complete
- 2 diverse incoming supplies required for MIST
- All buildings to be connected – fibre optics?
- Throughout buildings either fibre optics or copper used
- Throughout building life, the wire systems will probably be replaced 3 times. Lots of access required and future space
- Thin Client discussed – MIT opinion is that it may not be a viable option
- Data centre – large loads – up to 10kW per rack
- Racks could be located in Europe – to help with reducing cooling but security an issue – would need to be agreed
- Fire protection – gas system preferred – no standards available
- Wireless – accounts for 50% of communications at MIT
- MIT electrical load is approx 37MW (over 11 mil sf)
- Team advised to review following website www.iic.harvard.edu MIT may follow same set up.

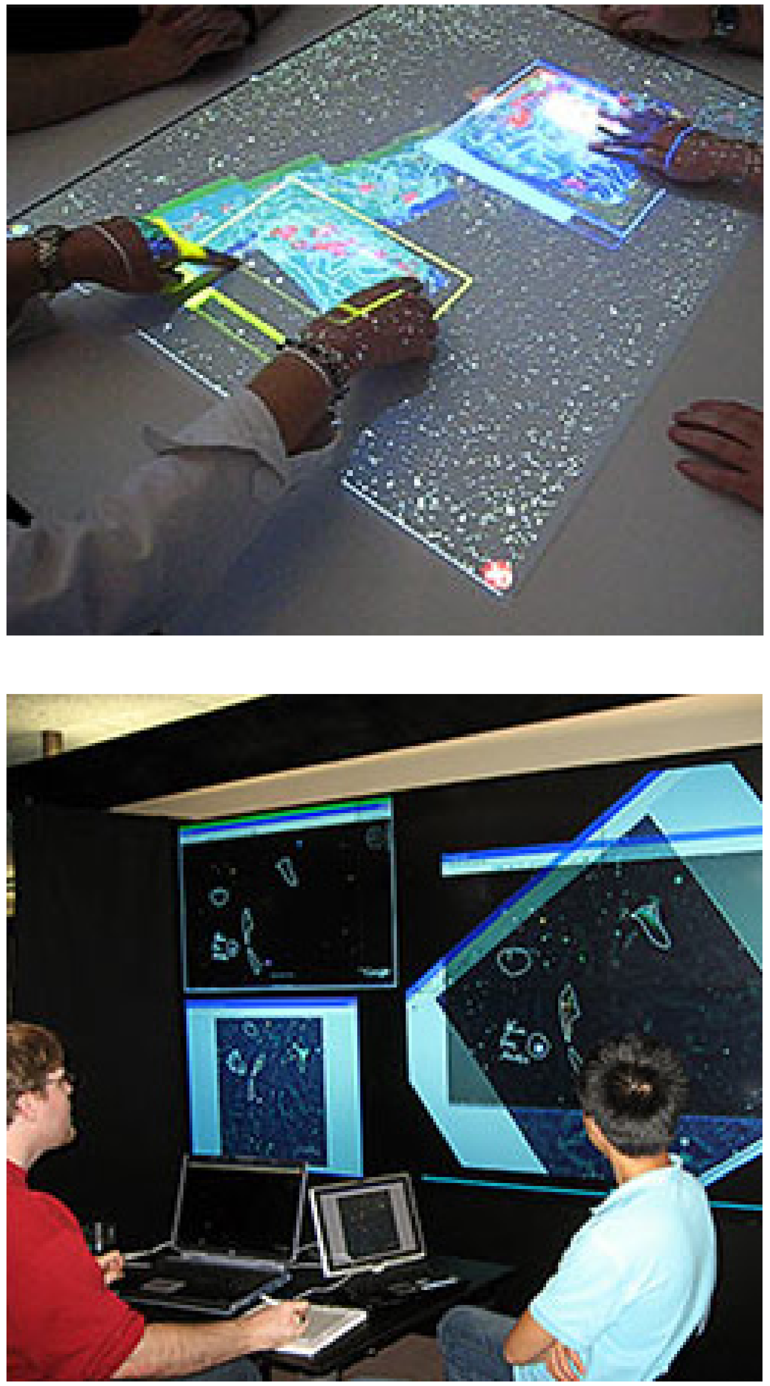


Figure 2-18 Scientists Discovery Room at IIC Harvard

3 Microclimate Enhancement Strategies

3.1 Macro-scale Wind Environment

3.1.1 Introduction

A Computational Fluid Dynamic (CFD) study was conducted to asses the capability of the 'green fingers' to provide enhanced ventilation to the streets that run within and around Phase 1a.

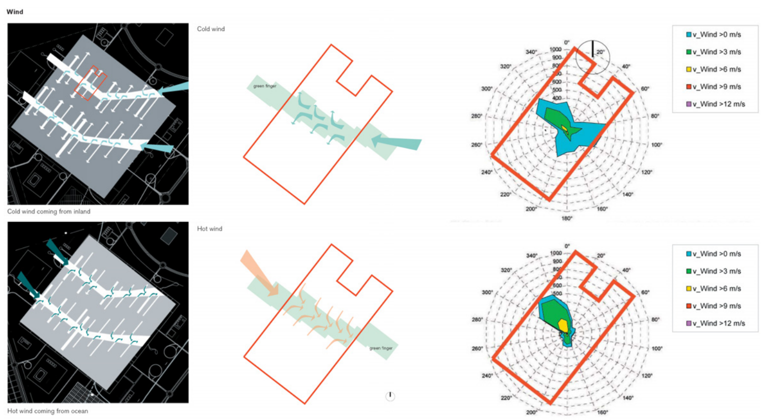


Figure 3-1 Masterplan assumptions about ventilation impacts from the green fingers

5 years worth of wind data was obtained from Weather Underground for the adjacent Abu Dhabi International Airport weather station.

There is a large diurnal variation in the wind pattern for Abu Dhabi:

- Prevailing Northerly wind during the day, which has a mean average velocity of around 4.2m/s at 10m high, and median frequency of around 3.5 m/s to 4 m/s.
- Between midnight and six am the wind consistently changes to being Easterly and South Easterly. This wind is slower than the daytime wind, usually with a mean average of around 2.5 m/s, and a median average frequency of 1.8m/s to 2m/s.

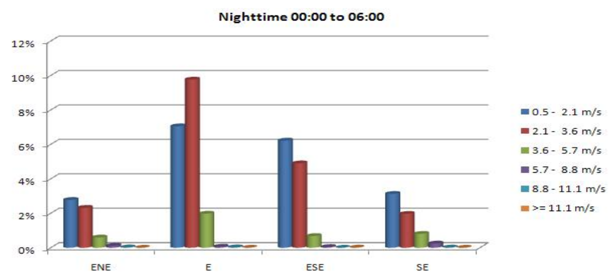


Figure 3-2 Night time wind frequency

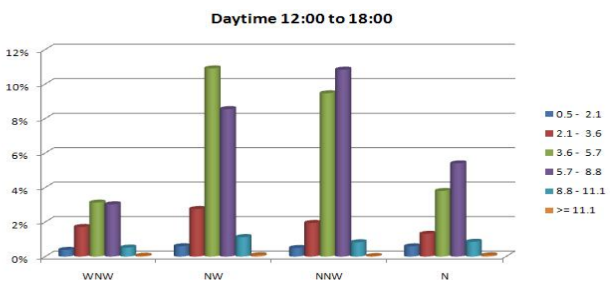


Figure 3-3 Daytime wind frequency

3.1.2 Analysis Method

Since the greatest concern in terms of external comfort is operation under peak design conditions, the daytime wind was put in to the domain at 44°C, from a North-Westerly direction, and at a speed of 4m/s at 10m high. The wind conformed to a logarithmic wind profile.

During the day the anticipated 'heat-haze' based on the Photovoltaic Heat Haze study in this section.

Two separate studies were run for night-time wind:. In the 'base case' night-time wind was input into the domain at 2.5m/s at 10m high, and at a temperature of 26°c, as per the annual average speed, and the peak summer temperature respectively. In the second case the wind was put into the domain at 4m/s to establish a 'high-water' mark for the level of ventilation that can be expected in the streets, for purposes of night-purge, when there are canopies covering the streets.

3.1.3 Results

Please refer to CFD images overleaf.

The wind runs through the 'green finger' very effectively from both directions, however it does not significantly assist ventilation of the streets or the courtyards at street level.

As can be seen from Figure 3-4 and Figure 3-5, wind usually passes by the entrance rather than ventilating through the development. Generally, the wind that does enter into the MIST development is turbulent (as can be seen from Figure 3-7), and does not flow smoothly down the streets.

However, as can be seen from Figure 3-8, much of the low level wind that skirts over the top of the development does drop down, and run through the streets. This can be seen in Figure 3-6 Impact of 50% porous canopy on wind speeds at ground levelFigure 3-6, in which a 50% porous substance was placed over the 'streets' running through Phase 1A, which significantly reduced air movement at ground level.

Similarly, the night time wind from the South East does not provide enhanced levels of ventilation to the streets that would encourage night-time purge, especially when there is a canopy over the streets (Figure 3-6).

3.1.4 Conclusions

The anticipated air movements set forth in the masterplan are not reproduced and their validity remains unproven.

Further detailed analysis is needed in conjunction with a more comprehensive understanding of the Photovoltaic heat haze, in order to make sure that the -already hot- wind which drops down into the courtyards during the day-time is not further heated by the heat-haze.

Given the highly specialised nature of these studies it is understood that these studies will be undertaken by the as yet to be appointed wind consultant for MIST.

In order to better ventilate the streets a study in which quick manipulation of the building massing is needed, CFD provides a comprehensive method of testing a specific environment or development scheme, but is limited in its suitability for a 'quick response' method of testing. This is more suited to a wind-tunnel environment.

Although the streets are well ventilated, the air tends to be turbulent air, which has often dropped down from above the height of the development (see Figure 3-8). Consequently the geometry is not well suited to provide a smooth, predictable flow from either direction – daytime or night-time. There is a risk that hot air from the heat haze will be brought down, unless there is intervention in the building form or in the shading.

The current configuration of the 'green finger' means that if any large scale vegetation (ie. trees or large bushes) is placed on it then the velocity through the fingers, and consequently that which gets distributed around MIST, may drop considerably.

The use of wind towers to enhance night-time purge capacity will be an important aspect to be explored during scheme design stage.

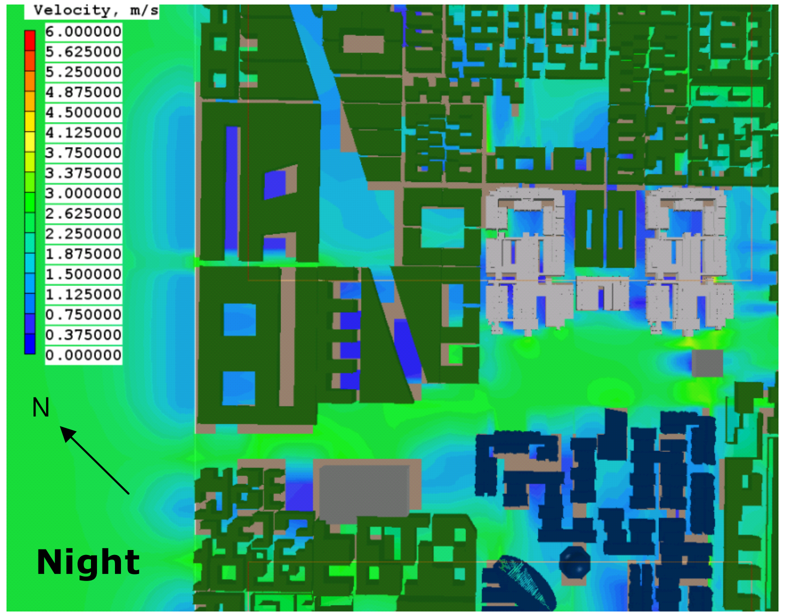
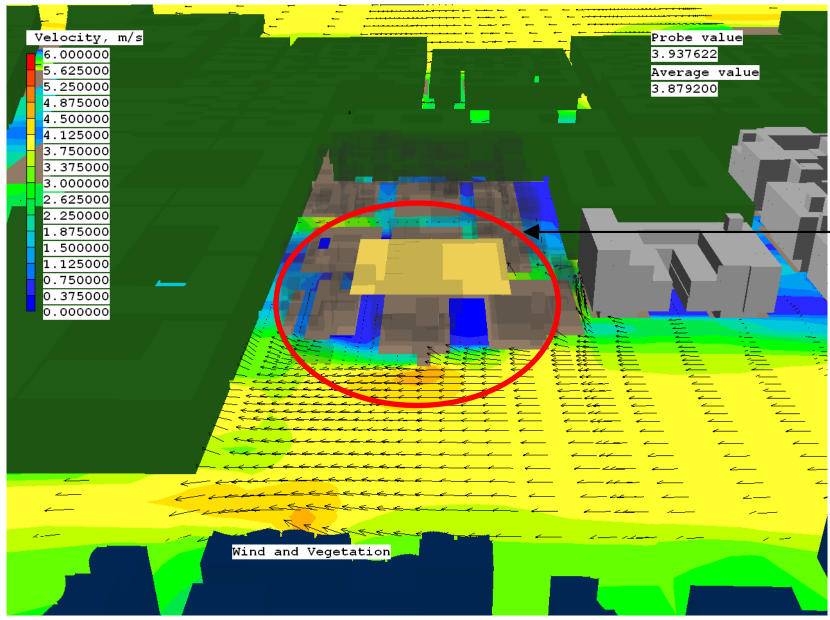


Figure 3-4 Wind speeds observed in occupied zone during night time



Low speed air in the streets underneath the 50% porous shading

Figure 3-6 Impact of 50% porous canopy on wind speeds at ground level

Figure 3-5 Wind speeds observed in occupied zone during day time

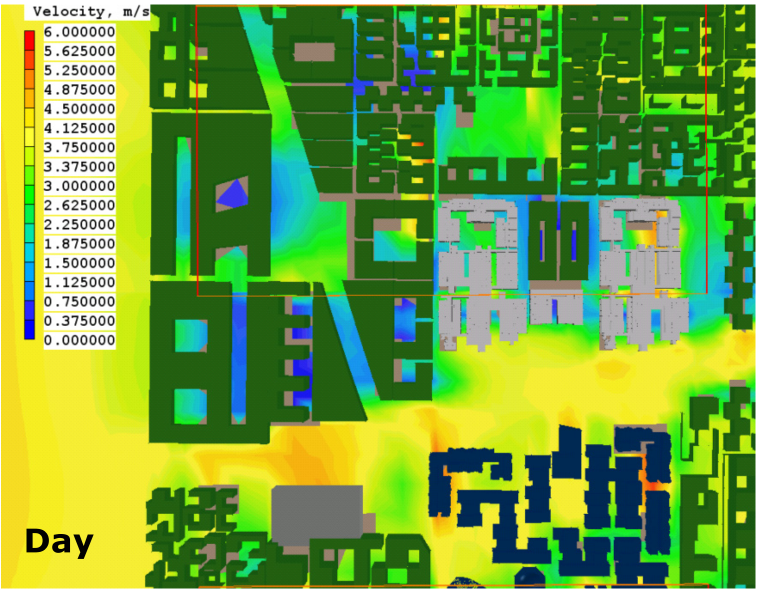
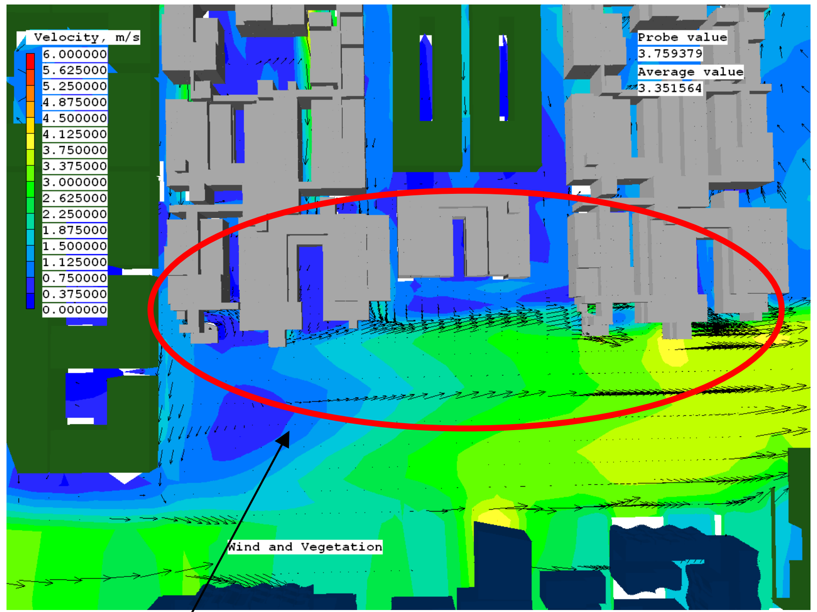
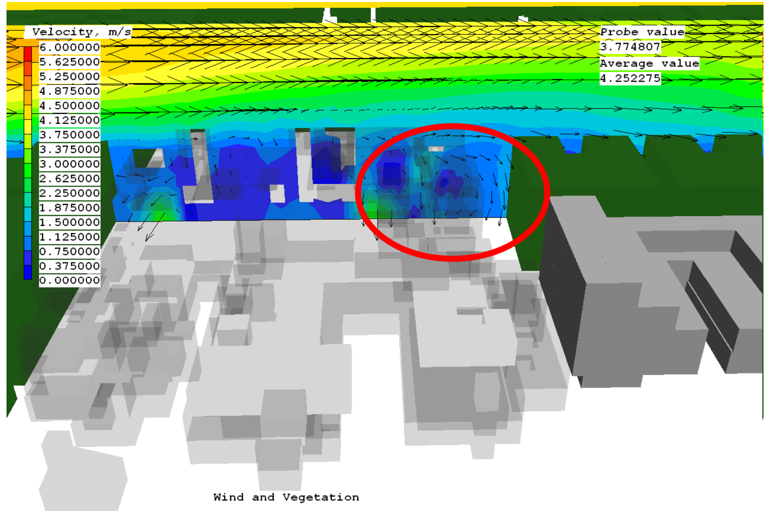


Figure 3-7 Turbulent flow around entrance to streets within Phase 1a



Turbulent air around the entrance to the streets

Figure 3-8 Air dropping into the courtyards from high level



3.2 Macro-scale Heat Island Effects

3.2.1 Introduction

A concern was identified with regards to the likely extent the 'heat haze' above the arrays of Photovoltaic modules. This is vital to establish the estimated ideal height of a wind tower, in order that it may be extracting as cool air as possible to vent on to the streets or directly into the air handling units.

Air extracted from within the heat haze would be detrimental to comfort conditions within the streets, and would force the air handling units to expend more energy preconditioning the supply air.

A preliminary study was conducted based on the Transolar modelling assumptions of an array of Photovoltaic modules having an estimated volume heat flux of 135W/m³.The results from this study can be observed in Figure 3-9.

In order to verify these assumptions, further information on estimated heat outputs from Photovoltaic modules was used to provide corroborative studies.

3.2.2 Method

In order to verify the Transolar assumptions as documented above, we took an assumption that the Photovoltaic panel could be assumed to be a perfect black-body, and therefore using the following formula calculated the difference between the Ambient and the Cell temperature (the 'delta T').

Photovoltaic Temperature Cell Rise

$$G(1-\rho)\propto(1-\cap) = U(t_c - t_a)$$

Therefore for a perfect black body ($\rho = 0$) and $(\propto = 0)$

$$\Delta t = \frac{(1-\cap)G}{U}$$

(Brinkworth et al. 1997)

Nomenclature

G = Solar irradiance normal to cell
Ta = Ambient temperature
Tc = Cell Temperature

U = Overall conductance for cell heat loss referred to Δt

$\propto$ = Solar absorptance of cell

$\cap$ = Overall conversion efficiency of cell, absorbed solar energy to electricity

ρ = Solar Reflectance of cell and cover
The U-Value was assumed to be 12 for, the purposes of this experiment, as per the recommendation of Brinkworth et al. [1997].

The CFD packages 'Phoenics' was used for the modelling.

Phoenics is a well established CFD code, which has reached full product maturity since its foundation in 1974., The photovoltaic modules were modelled with a porosity of 30%.

3.2.3 Results

Estimated resultant temperature of cells for Masdar, based on Peak Global Irradiation value normal to the surface of the panels of 915W/m², and a U-Value of 12:

$$\Delta t = (1 - 0.15)915/12$$
$$\Delta t = 64.8$$

The images to the right show the similarity between the CFD based on the Photovoltaic heat flux of the Transolar Criteria and the calculated surface temperature based Photovoltaics from our own calculations.

They show the heat build up based on a slow day and give an indication that, based on these pessimistic assumptions, it may reach to around 15 metres before it drops off dramatically. This pattern is verified by the CFD graph Figure 3-9

The profile is effectively an example of superadiabatic lapse rate - when the shallow layer of air in contact with the PV panel becomes strongly heated by solar radiation, a temperature lapse rate occurs that may exceed the dry adiabatic lapse rate.

3.2.4 Conclusions

It must be taken into serious consideration that it will not be possible for passive wind towers to extend above the heat haze given the available the wind towers space at ground level.

Assuming that passive wind towers with a diameter of 5m were provided, then for it to be guaranteed to reach above the heat haze a height to width ratio of around 9:1 would be necessary, which is too narrow to be hydraulically efficient.

Nonetheless, wind towers that extend above the PV's would be of

The microclimate has a high adiabatic lapse rate, as verified by the both approaches to modelling the impact of PV's on local microclimate.

References

Thermal regulation of photovoltaic cladding
Solar Energy, Volume 61, Issue 3, September 1997, Pages 169-178
B. J. Brinkworth, B. M. Cross, R. H. Marshall and Yang Hongxing

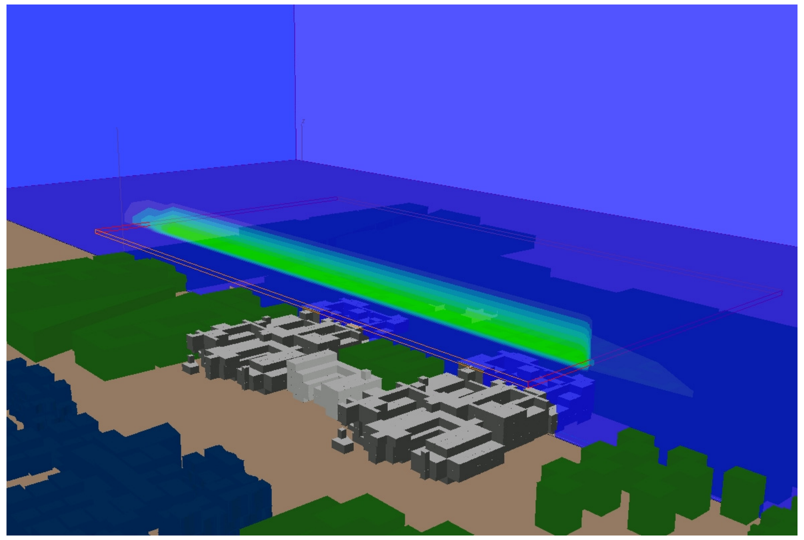


Figure 3-9 Dry Bulb Temperature Profile modelling PVs as per Brinkworth

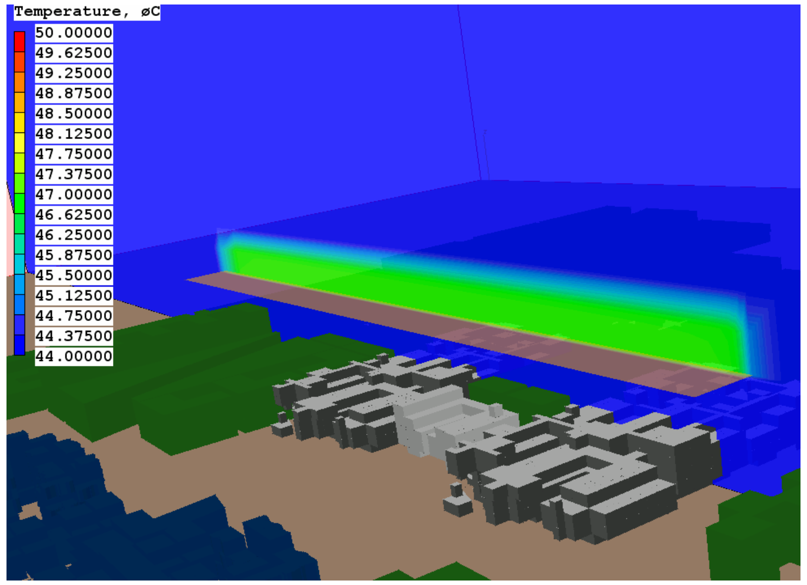


Figure 3-10 Dry Bulb Temperature modelling PVs as per Transolar

3.2.5 Superadiabatic conditions at ground level

'Superadiabatic lapse rate conditions are not only a concern for PV installations. Studies at Abu Dhabi International Airport[10]. Michael de Villiers studied the effect of high surface temperatures at ground level with similar conclusions.

The earth's surface is a good conductor of heat and its temperature varies considerably during the day. This is especially relevant with respect to sand and stone surfaces, which can become exceptionally hot during the day.

Anyone who has walked barefoot on the beach on a hot summer's day is well aware of this. When the shallow layer of air in contact with the earth's surface becomes strongly heated by solar radiation, a temperature lapse rate occurs that may exceed the dry adiabatic lapse rate.

This is known as a superadiabatic lapse rate. The layer can be very shallow and the difference in air temperature between the surface and the top of the superadiabatic lapse rate can be considerable. Temperature differences of up to 9°C were observed in the first 10m above ground level, after which a normal lapse rate was observed.

The roof experiences similar conditions to those at ground level and therefore traditional wind towers are typically elevated at least 5m above roof level, with heights of up to 15m recorded.

A wind tower at this height, above the top of the superadiabatic lapse rate, would have been at an ideal height to reap the benefits of this cooler air.

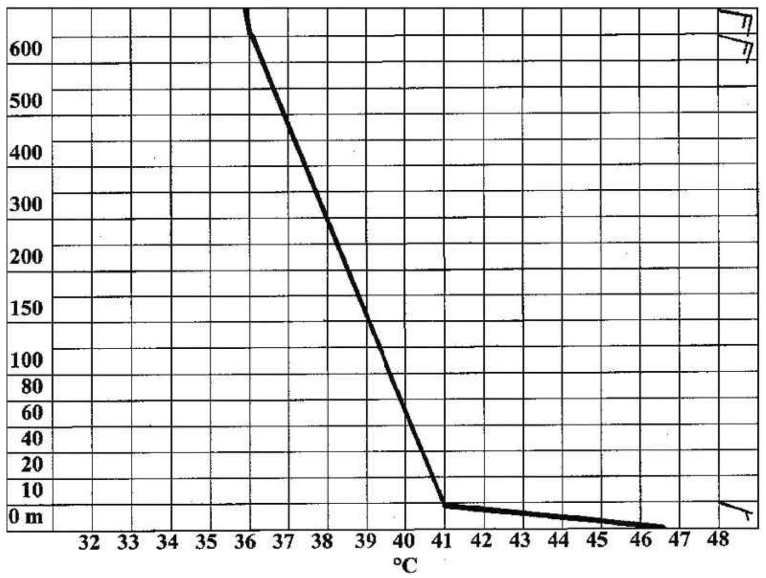


Figure 3-11 De Villiers -Radiosonde-derived temperatures and winds (kn) at Abu Dhabi International Airport on 30 July 2002 showing a marked surface superadiabatic lapse rate

[10] "Meteorological aspects of the wind towers of the United Arab Emirates", Weather vol 57, p.319, Michael de Villiers

3.3 Selective Ventilation Strategies - Canopies

The masterplan identifies a need to control the movement of air within the development on a diurnal and seasonal basis.

The main objective is to limit the ability of hot air to mix with cooler air at ground level within MIST during the day time in summer months, and throughout the year to encourage ventilation at night so as to enable night time purge of exposed thermal mass to be achieved.

For air temperatures above 37°C there is no convective cooling effect on the skin – air above this temperature has the effect of increasing thermal discomfort. Under peak summer conditions it is therefore preferable to minimise infiltration of air into the public realm.

Critical in achieving these objectives is the use of canopy structures to separate air layers at different temperatures, and in so doing to ensure that principle pedestrian routes at ground level are shaded from excess solar gains during the day.

Traditionally this has been achieved by movable canopy devices placed immediately above street level:

Figure 3-12 Examples of traditional canopy structures

At Concept Design Stage canopy structures are indicated generally at high level – having the disadvantage of reducing daylight availability whilst also increasing the volume of air to be maintained as an enhanced microclimate and therefore dissipating the effect of night purged thermal mass.

Figure 3-13 Visualisation of high level canopies by Foster and Partners

During Scheme Design PHA Consult will work with F+P to investigate ways to optimise the location of canopy structures within the street section.

3.4 Selective Ventilation Strategies – Wind Towers

The use of wind towers during the day to bring cooler air from above the development down to street level offers the possibility of enhanced occupant comfort during the mid season (see Figure 2-1).

However, as previously stated, providing increased air movement has very little benefit for air temperatures above 37°C and therefore is not beneficial under peak summer conditions.

CFD studies into the extent of the heat haze above MIST due to the introduction of a solar array at roof level (Section 3.2) indicate that they would need to extend 15m above the solar canopy. Given the space available at ground level for such tower structures they would have a height to width ratio of 9 or more and would therefore function poorly from an aerodynamic perspective.

It is assumed at this stage that the use of wind towers to scoop high level cool air down to ground level within the public realm with diameter less than 10m would not be effective; however without guidance from wind tunnel testing this assumption cannot be verified.

The use of wind towers to provide enhanced night time purging offer much greater potential. After sunset the solar array at roof level will rapidly lose heat to the night sky and the heat haze impact will diminish. Temperatures at ground level will be greater than ambient conditions at roof level resulting in thermal buoyancy. This thermal buoyancy can be wind assisted using wind towers that are oriented to take advantage of the prevailing night-time southeasterly winds.

Wind towers that are designed to operate at night therefore do not need to be sized to sit far above the solar array and may only need to be 3m above mean array height.

Macro scale studies of wind flow under night time typical wind speeds have demonstrated that air movement at ground level would benefit from such measures to enhance night purge capacity. In turn this will enhance thermal comfort within the public realm for the following day.

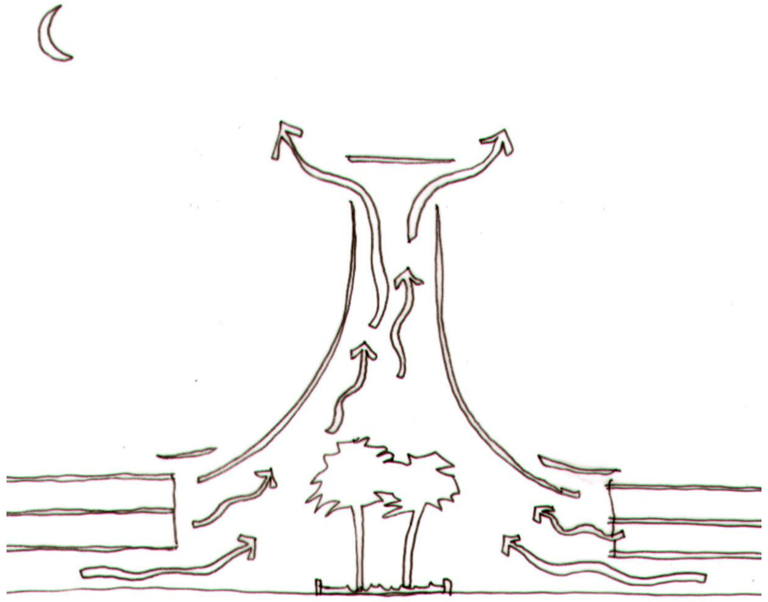


Figure 3-14 Night time purge principles for major wind tower in public square

Night purge wind towers can also be used to enhance night purge of environmental buffer spaces such as the semi-conditioned atrium spaces between residential wings.

Figure 3-15 Solar and wind-assisted wind stack - Endesa, Spain

3.5 Selective Ventilation Strategies – Passive Downdraught Evaporative Cooling

Passive downdraught evaporative cooling [PDEC] is the process by which direct evaporation of water as a mist or spray into an airstream results in it being both humidifying and cooled. In doing so it becomes more dense and will fall to the ground where it can provide enhanced levels of comfort.

The psychrometric chart below shows the range air states for which evaporative cooling could result in an air state that meets occupant comfort expectations in the indoor environment.

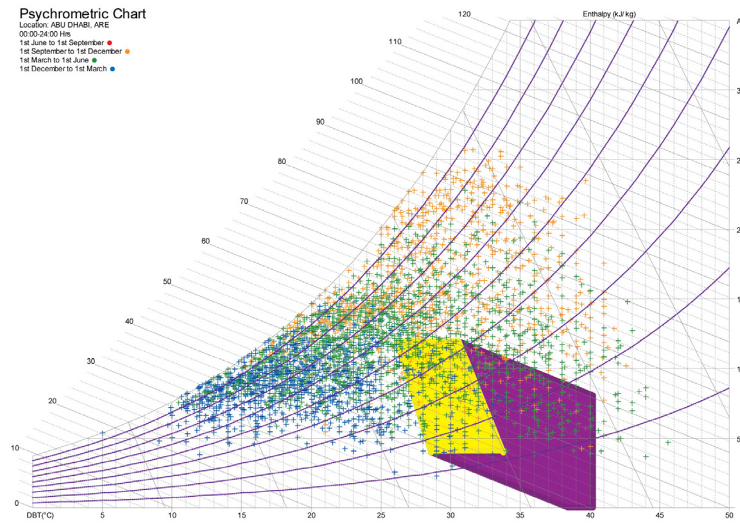


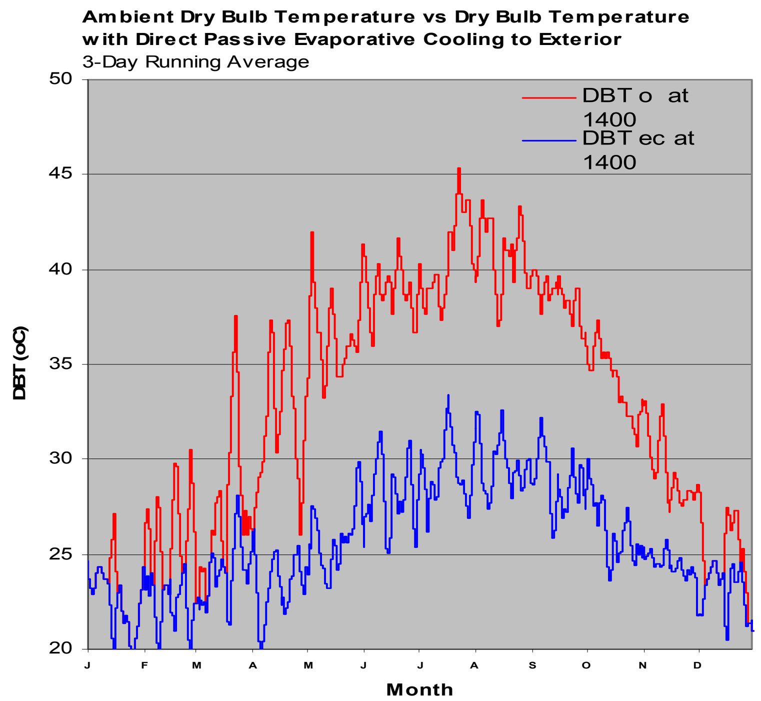
Figure 3-16 Evaporative Cooling Opportunity to provide 'comfort'

Clearly for much of the year evaporative cooling will result in air states that are not 'comfortable'. Nonetheless they result in significant reduction in air temperature – up to 12°C.

The psychrometric charts below illustrate the impact of evaporative cooling on the Abu Dhabi annual climate. It assumes that evaporative cooling is only used when air temperatures are in excess of 27°C, and that evaporation has a saturation efficiency of 80% and does not permit relative humidity levels in excess of 75% to be reached. Above 75% RH discomfort due to the inability to lose heat by sweating can result in decreased levels of comfort.

A temperature drop of up to 12°C can be achieved at 1400hrs.

Figure 3-17 PDEC Towers, Seville Expo, Spain



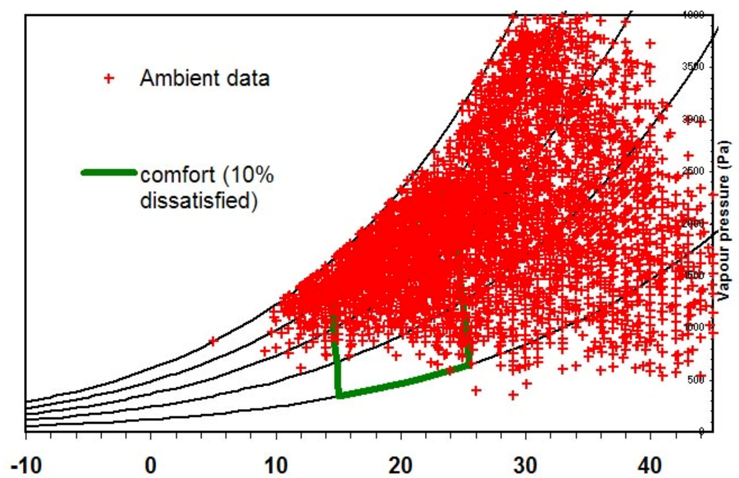


Figure 3-18 Abu Dhabi Psychrometric before Evaporative Cooling

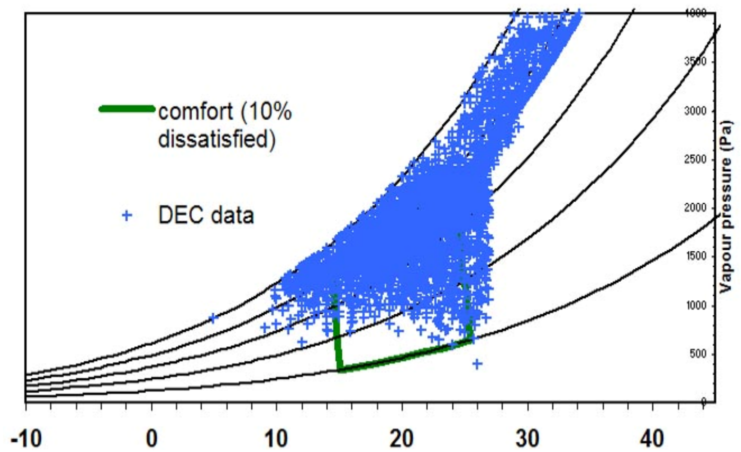


Figure 3-19 Abu Dhabi Psychrometric after evaporative cooling

3.5.1 Heat Index Assessment

To understand whether evaporative cooling is of benefit to external comfort a heat index assessment has been undertaken to compare air temperature and humidity before and after evaporation.

Using the same methodology as outlined in Section 2.2.1 the annual Heat Index assessment is presented below..

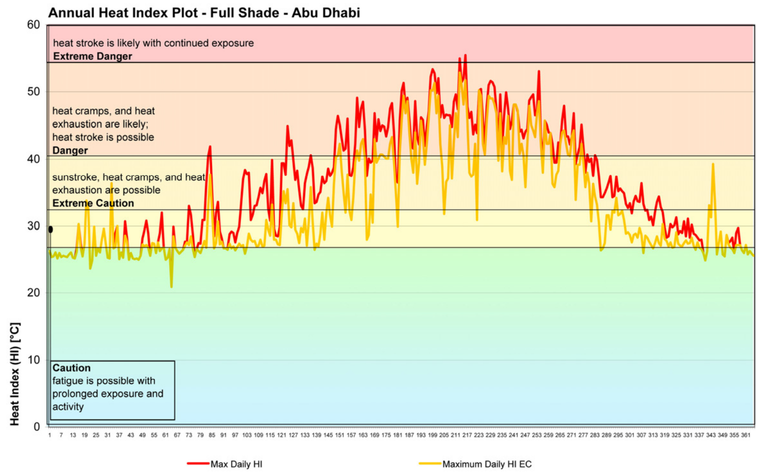


Figure 3-20 Heat Index - impact on daily maximum heat index values

3.5.2 Conclusions for MIST

PDEC cooling cannot provide comfort within the public realm using conventional measures, however it clearly provides significant reduction in heat index and therefore can play an important role in reducing heat stress in the public realm.

A PDEC 'shower tower' has been proposed for the central square in MIST Phase 1a. This has four functions:

1. Reduced heat stress in the public realm
2. Provision of shade
3. Isolation of the courtyard from high temperature superadiabatic layer at roof level
4. Use as a buoyancy and wind assisted night-purge tower

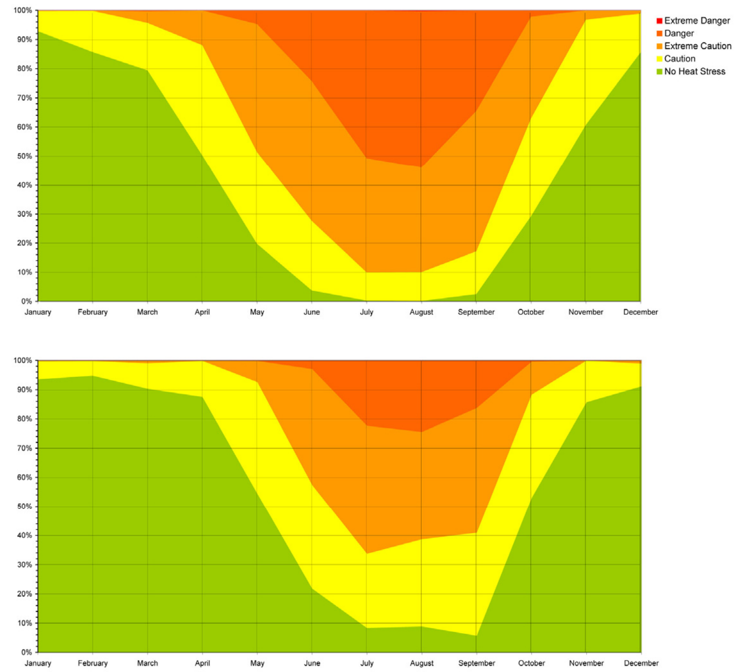


Figure 3-21 Comparison of annual % occurrence of Heat Index safety levels before and after PDEC cooling of microclimate

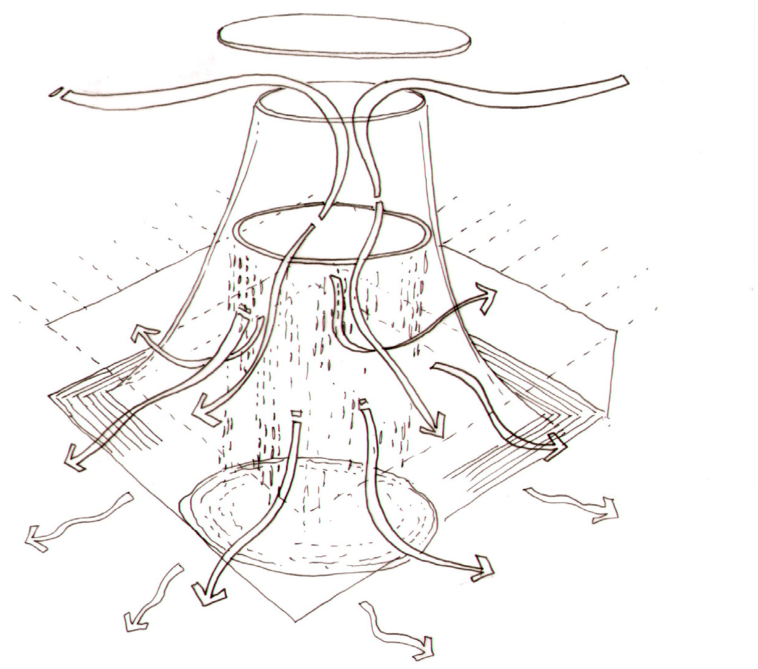


Figure 3-23 Concept for PDEC tower in central square at MIST

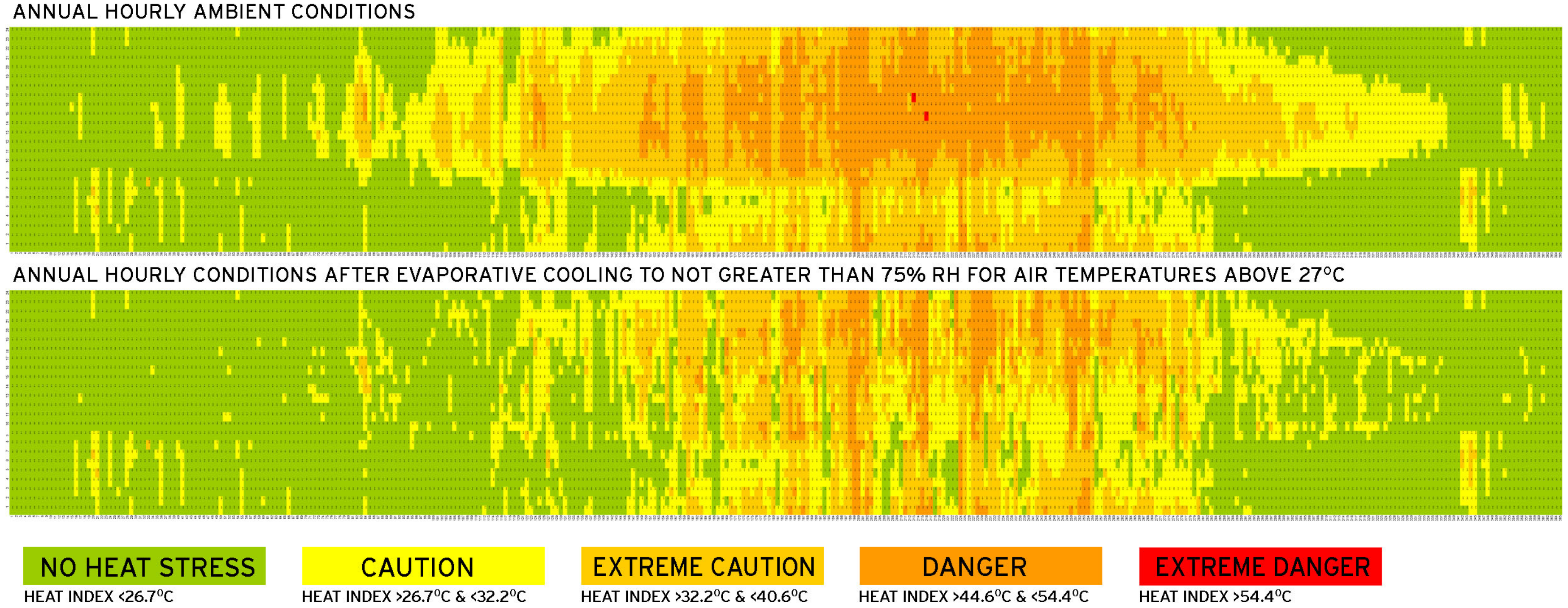


Figure 3-22 Annual hourly plot of heat index categories before and after PDEC

4 Passive Building Design Principles

Harnessing opportunities presented by the project and its bioclimatic context such that a high quality environment is provided with minimal use of finite resources. Demands placed on 'active' systems are thereby significantly reduced or eliminated.

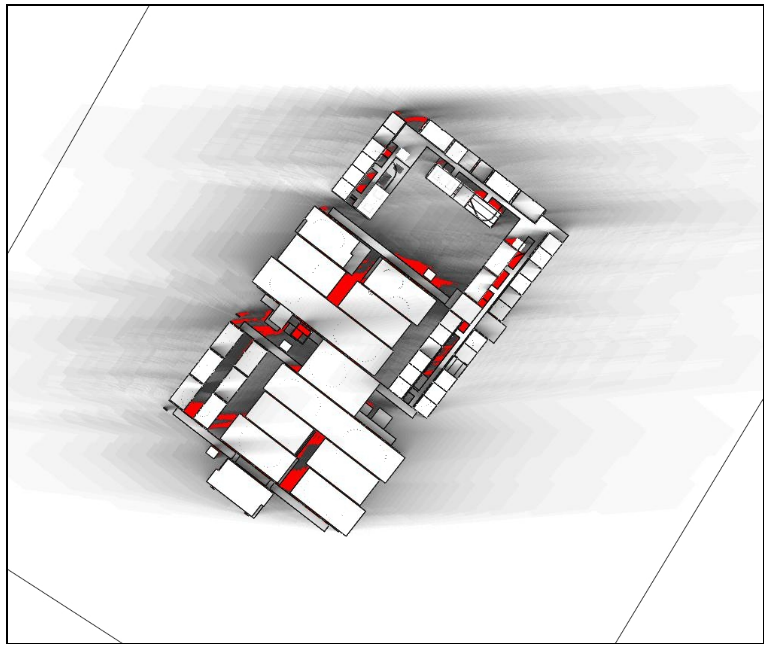


Figure 4-1 Equinox - Heliochronograph - 100% shade indicated in red

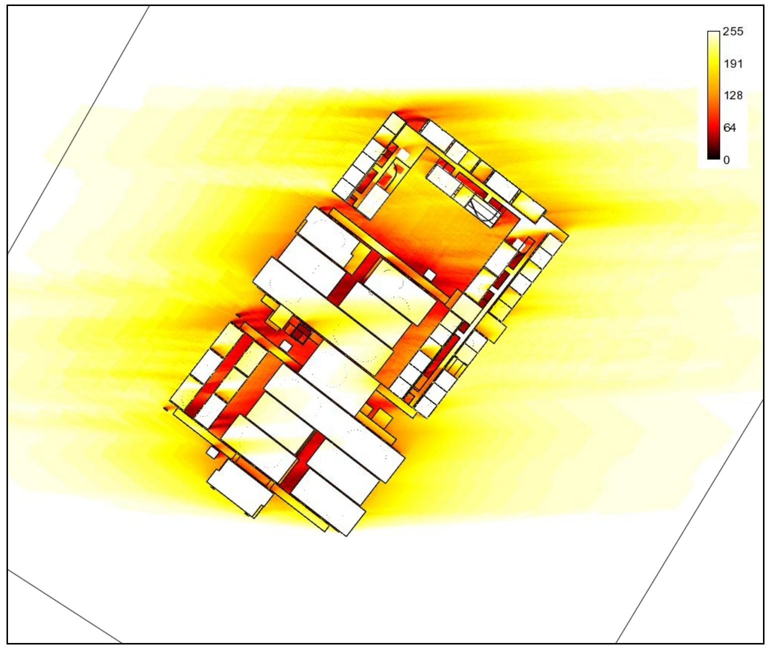


Figure 4-2 Equinox - Heliochronograph - % shade plot

4.1 Building Massing, Form and Orientation

Masterplan design guidelines establish building orientations for MIST, however the massing within the development plot offers opportunities to create a variety of external environments with varying levels of solar exposure, providing an appropriate balance of sunlight and shade throughout the year

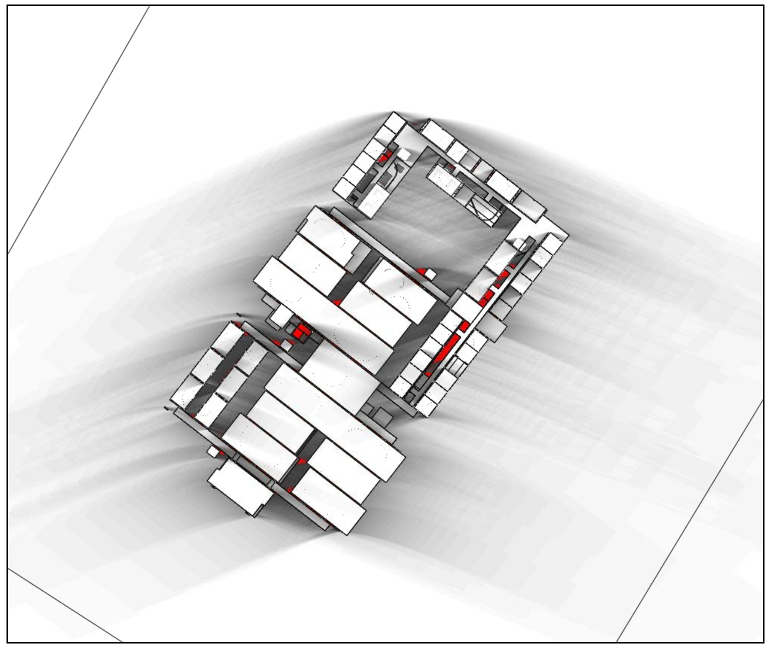


Figure 4-3 Summer Solstice - Heliochronograph - 100% shade indicated in red

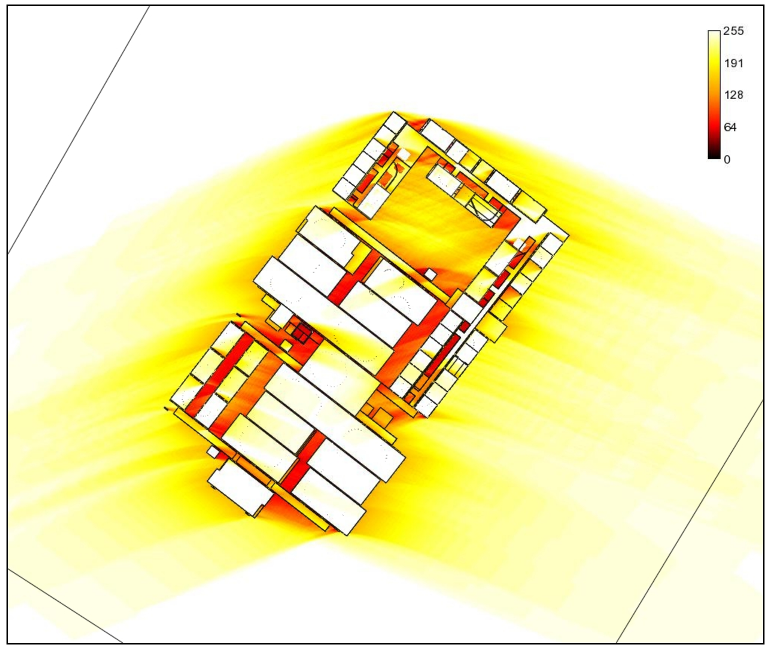


Figure 4-4 Summer Solstice - Heliochronograph - % shade plot

The analysis on this page shows the aggregate overshadowing impact of the building massing of Phase 1a on the ground plane. In general, smaller scale courtyards generally well shaded – whilst the central court is highly exposed. The model does not include the effect of the large-scale passive ventilation and evaporative cooling tower in this area, nor does it include retractable canopies that are envisaged in the masterplan.

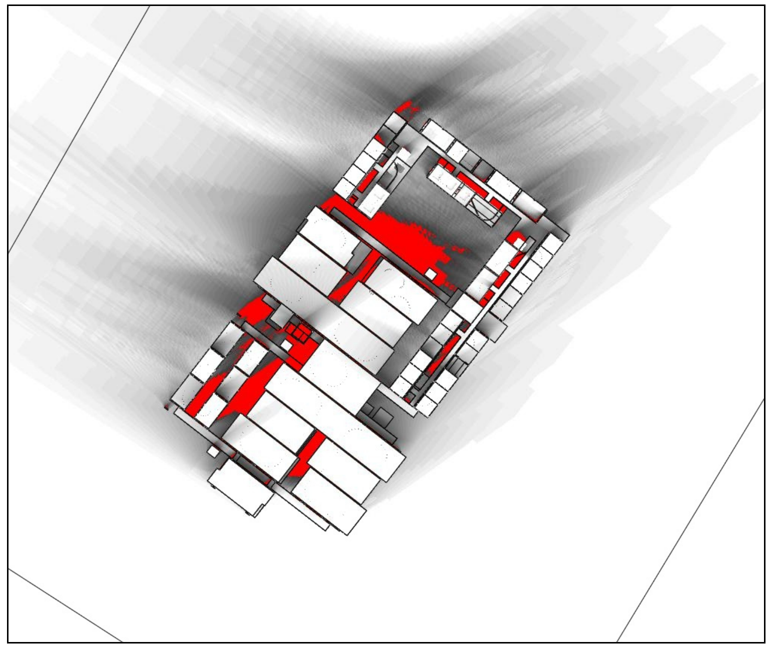


Figure 4-5 Winter Solstice - Heliochronograph - 100% shade indicated in red

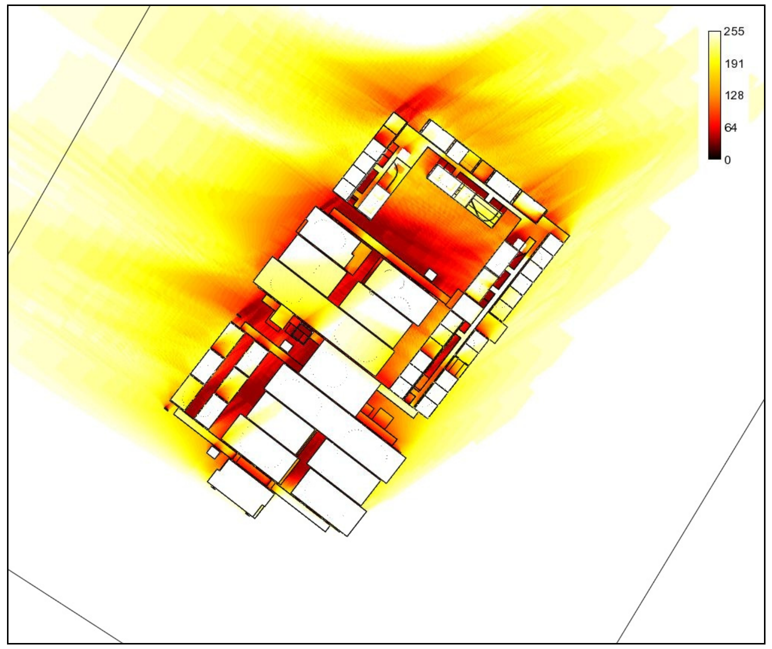


Figure 4-6 Winter Solstice - Heliochronograph - % shade plot

4.2 Optimising Building Envelope Performance – Solar Control

4.2.1 Design Principles

There is an absolute need to provide effective protection from excess solar gains throughout the year in Abu Dhabi. Since there are significant cooling loads experienced even during winter months solar control systems need to be able to cope with summer and winter sun angles

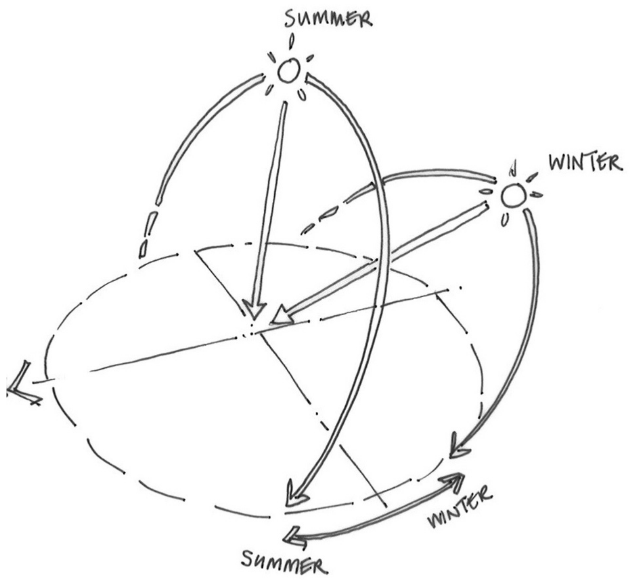
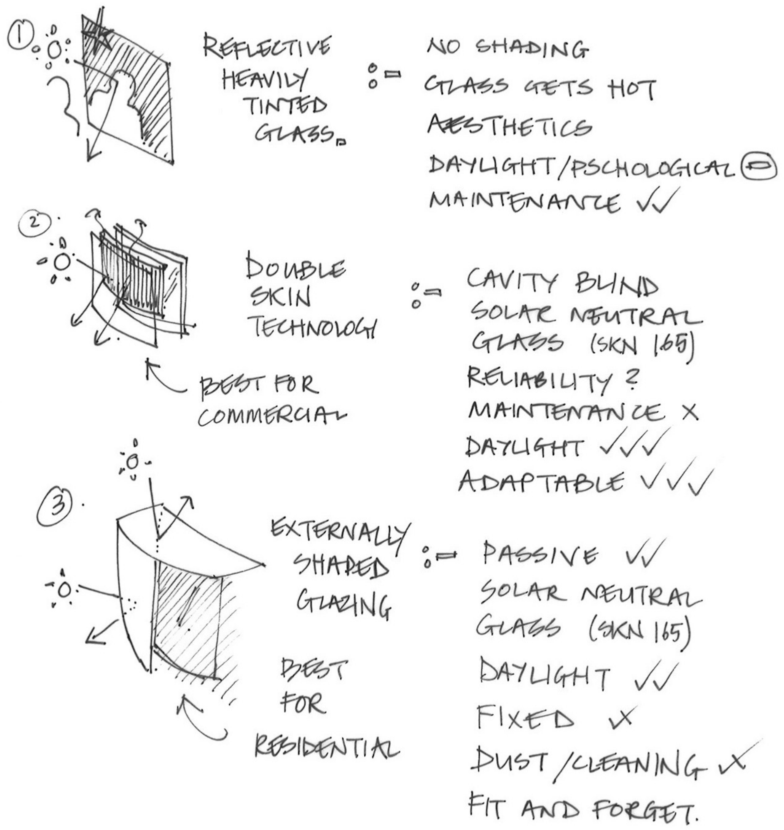


Figure 4-7 Annual sunpath context for MIST

4.2.2 Solar Control Requirements

The masterplan design guidelines suggest that a g-value of 0.15 be achieved for all glazed elements with solar shading in place.

Meeting this g-value target can be achieved in three ways:



Limits on the daylight transmission and colouration of spectrally selective glazing systems are presented below:

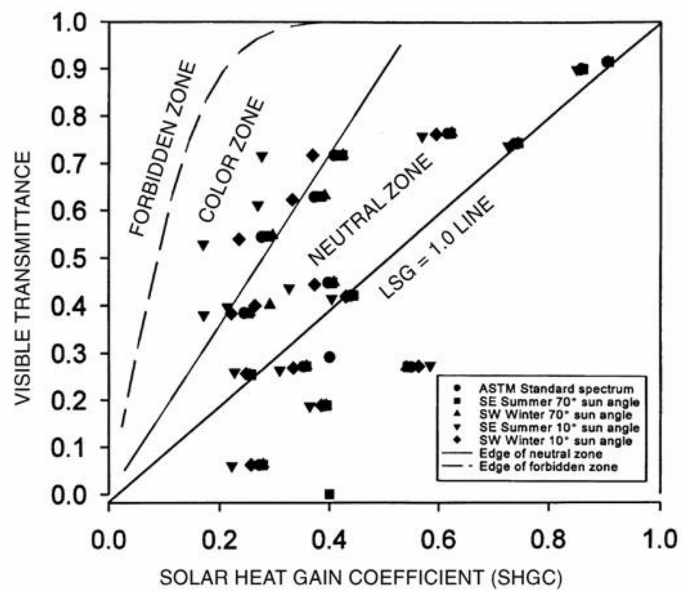


Figure 4-8 Solar heat gain coefficient and relationship to light transmission

To inform the architectural design of fixed external shading devices that are particularly applicable to residential uses, detailed solar geometry studies have been undertaken using Ecotect analysis software.

Tracking shades are not viable in this climate – failure of moving parts in motorised systems is inevitable.

Since cooling is required throughout the year, an annual shading mask is necessary if 100% shading is to be achieved.

For fixed shading devices to work throughout the year they need to obscure the sun from casting direct solar radiation onto glazed elements. At Abu Dhabi's latitude this effectively means that views are directed to either the northern or southern hemisphere of the sky dome and not to the east, west, or towards the zenith.

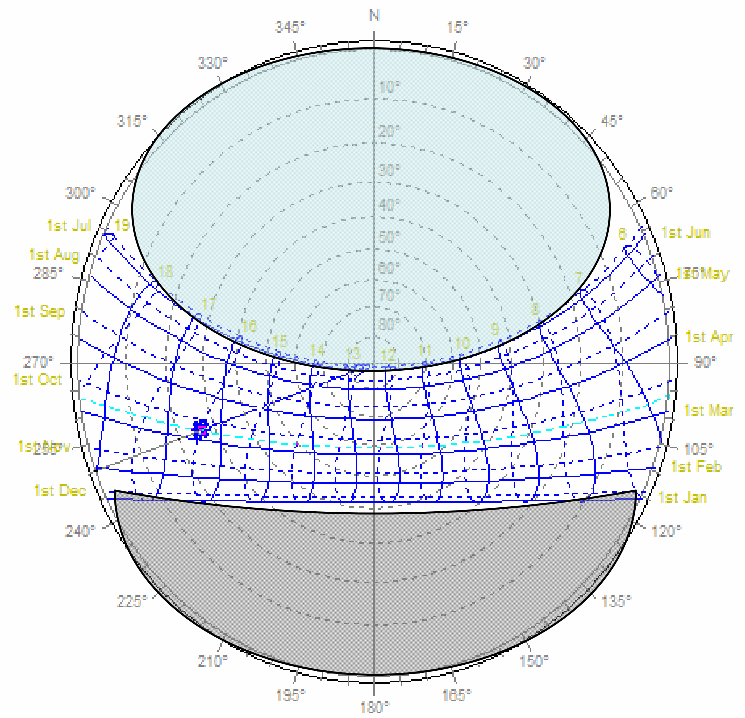


Figure 4-9 Sunpath indicating those portions of the sky that do not give rise to direct solar gains

4.2.3 Shading of horizontal glazed enclosures

For horizontal surfaces there are two typologies of fixed shading device that are viable:

- Lanterns
- Egg-crates

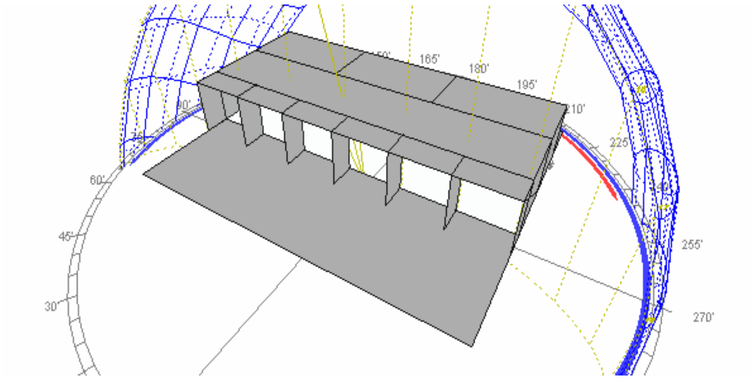


Figure 4-10 Lantern typology

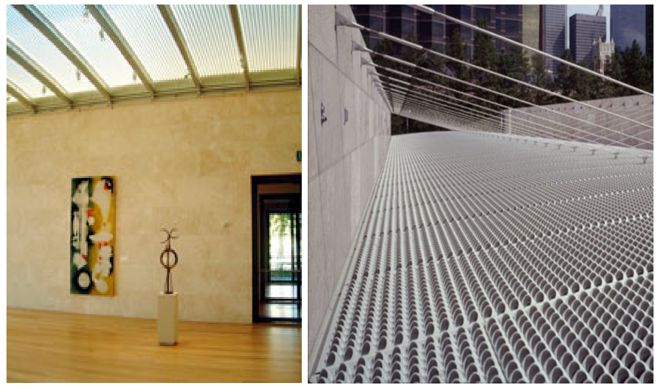


Figure 4-11 Egg Crate typology - used at The Nasher Sculpture Center, Dallas - Renzo Piano

Both strategies work by only permitting views to the sky dome that do not contain the annual sunpath.

Whilst the lantern views to both the south and north, it does so in a less efficient manner than the egg-crate typology looking north-only.

The egg-crate faces north as this offers the largest portion of the sky dome that does not result in direct solar exposure.

Since the lantern typology does not maximise daylight availability to space served by the horizontal glazing, egg-crates are proposed for use in MIST.

Ecotect was used to calculate a hypothetical ideal geometry for such an egg-crate shading system:

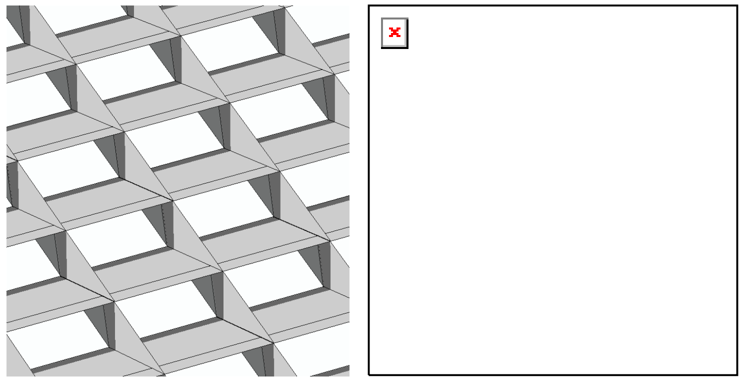
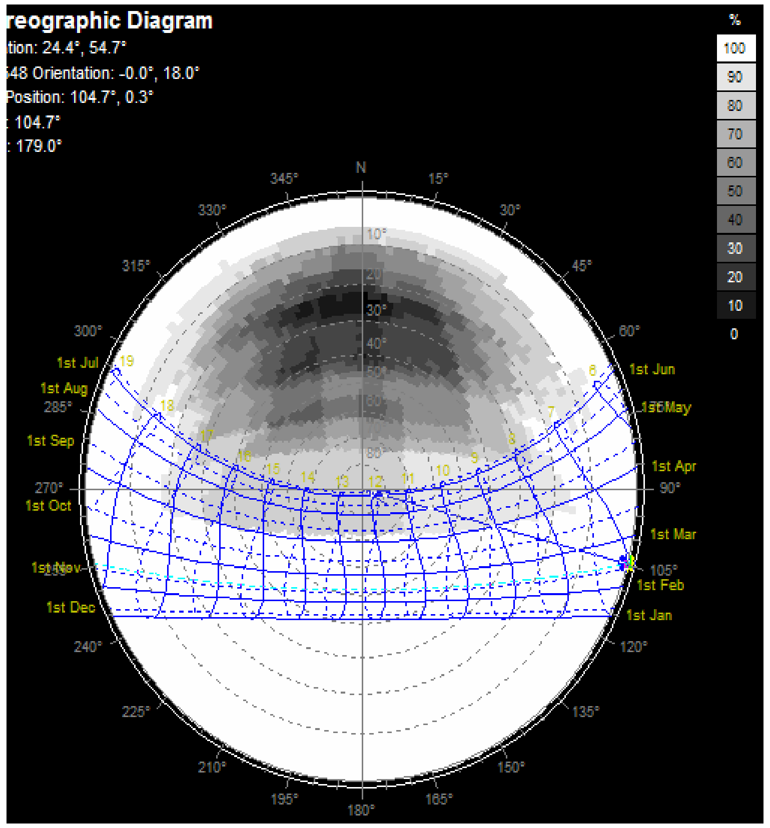


Figure 4-12 3-d view of egg-crate shading device

An evaluation of the efficacy of this geometry in preventing direct solar gains is shown below.

In this assessment a test point was taken on a glazed horizontal surface. The more black the view to the north, the greater the daylight availability – areas shown in white represent complete obstruction to the sky – including the entire annual sunpath.



A visualisation of a notional atrium oriented northwest to southeast and shaded by this typology of shading system was then analysed for daylight levels

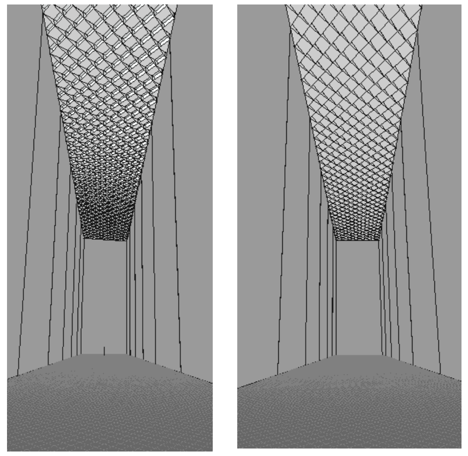
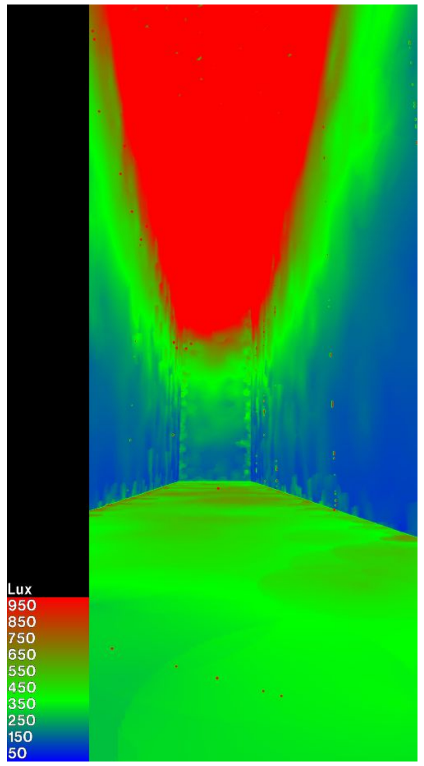


Figure 4-13 View from ground level looking northwest [left] and southeast [right]

Under sunny sky conditions and using pessimistic assumptions for surface reflectance light levels in excess of 500 lux are predicted in an atrium with a height to width ratio of 6:1. In effect the shading device converts a sunny sky into a 100% diffuse light source.



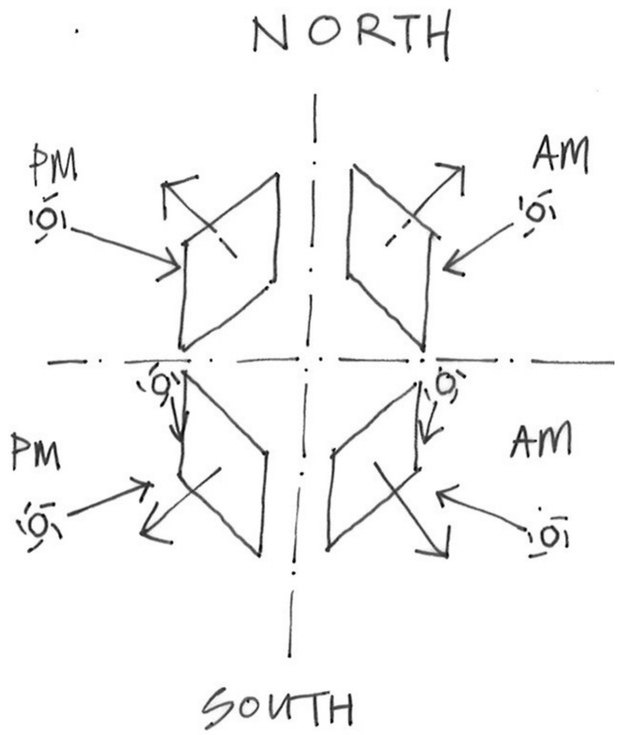
4.2.4 Shading to Residential Facades

Similar design principles apply to the derivation of perfect solar masking geometries for elevations as apply to roof structures.

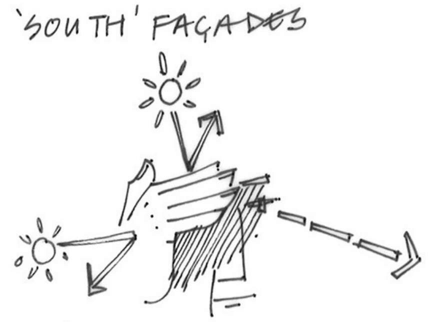
Given the orientation of the residential units within MIST and within the broader Masdar masterplan there emerge two major typologies of external shading device that will provide complete shade throughout the year.

- A 'north' facing typology
  north east and northwest elevations
- A 'south' facing typology
  southeast and southwest elevations

Within these typologies the effect of orientation determines whether the shading device is primarily protecting against the morning sun (east facing elevations) or from the more aggressive afternoon sun (west facing elevations.



The geometric response that characterises these two typologies is summarised in the sketch below:



South facades must shade against both high and low angle sun in the summer and winter, whereas north facades are primarily concerned with low angle sun from March 21st through to September 21st.

This difference in shading mask extent has significant implications for the design of shading devices.

Representative façade elevations that use shading devices that are scaled to the extent of creating balconies were presented to F+P as design guidance. The forms all ensure 100% shade throughout the year

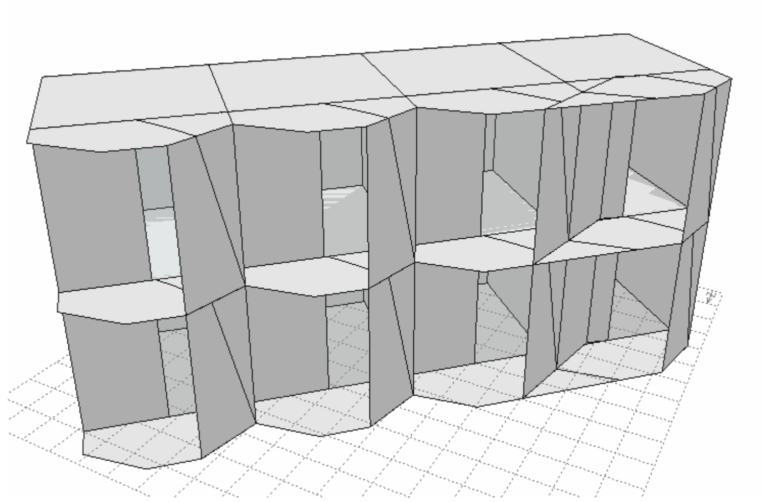


Figure 4-14 North facing shading typology

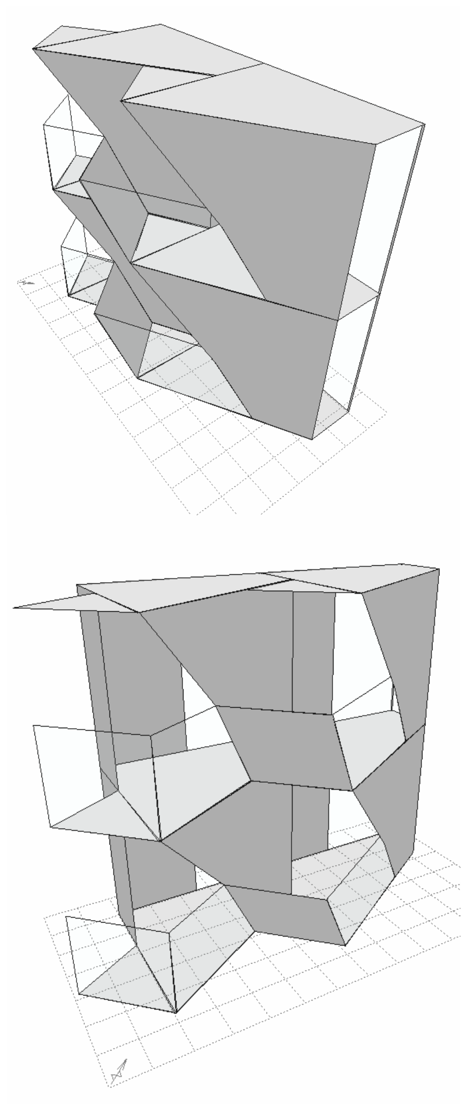


Figure 4-15 South facing shading typology

4.2.5 Relevance of Overshadowing By Adjacent Structures

The optimised shading devices that have been calculated in this study do not take into consideration the 'free' shading effect of adjacent structures. By taking this into account the opacity of any shading device can be reduced where its shading function is already being performed by the surrounding built context. In doing so daylight availability is optimised at the lowest levels compensating for reduced view of the sky in these locations.

Overleaf are studies indicating the impact of adjacent obstructions at different height within MIST on the extent of shading mask required.

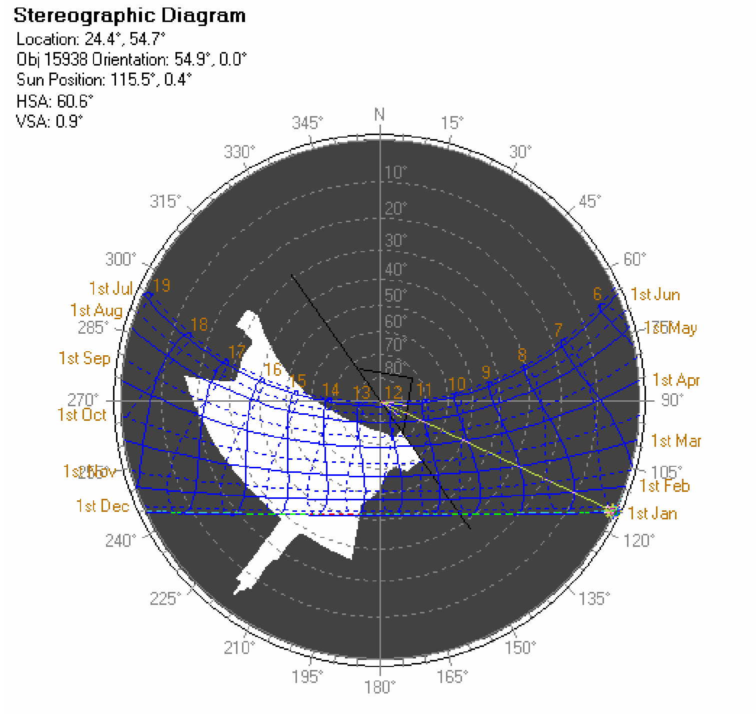


Figure 4-16 View of the sky from first floor residential level for a typical south-west facing room – requires shading primarily for high-angle gains due to shading provided by adjacent structures

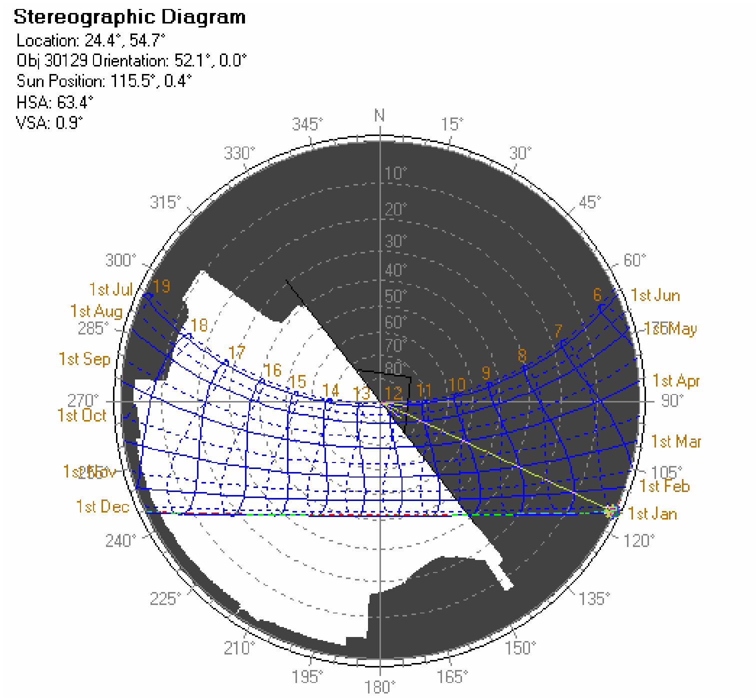


Figure 4-17 View of the sky from the top residential floor for a typical southwest facing room - requires shading to protect from low and high angle solar gains

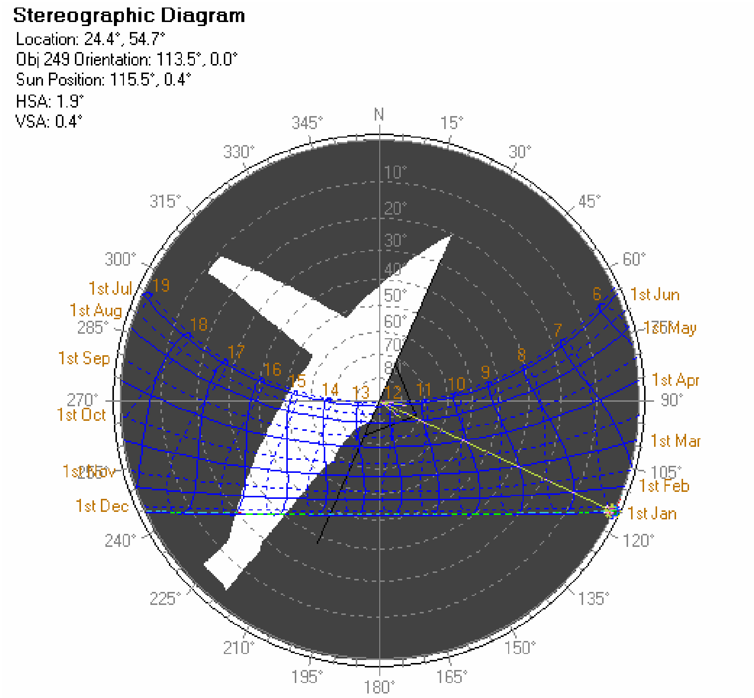


Figure 4-18 View of the sky from first floor residential level for a typical north-west facing room – requires significantly less shading for low angle late afternoon solar gains due to shading provided by adjacent structures

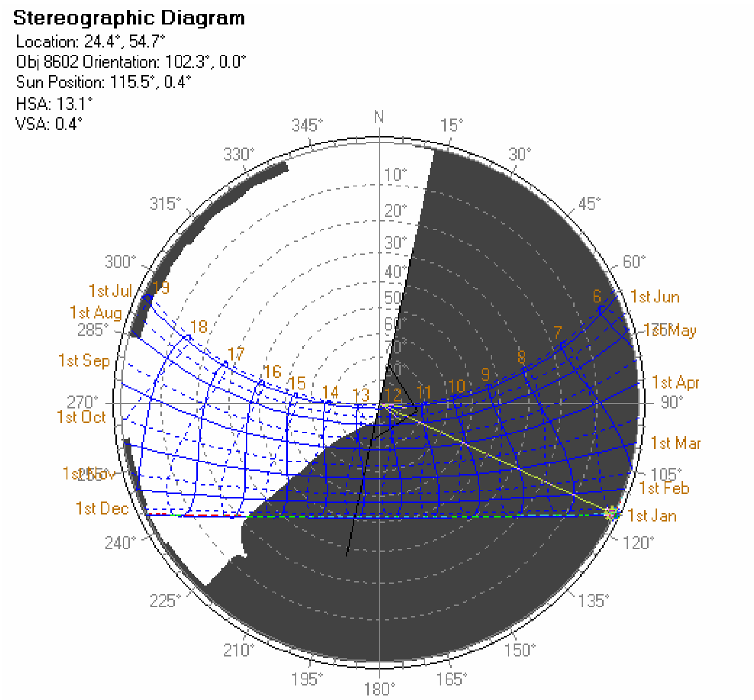


Figure 4-19 View of the sky from the top residential floor for a typical northwest facing room - requires full shading to protect from low and high angle solar gains

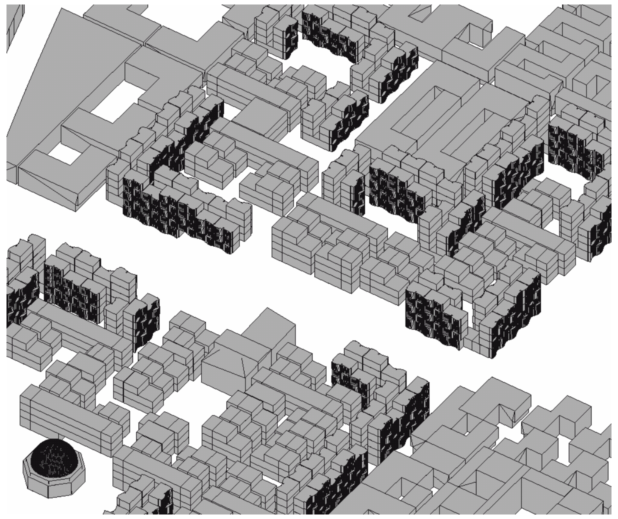


Figure 4-20 December 21st View form the sun - Noon

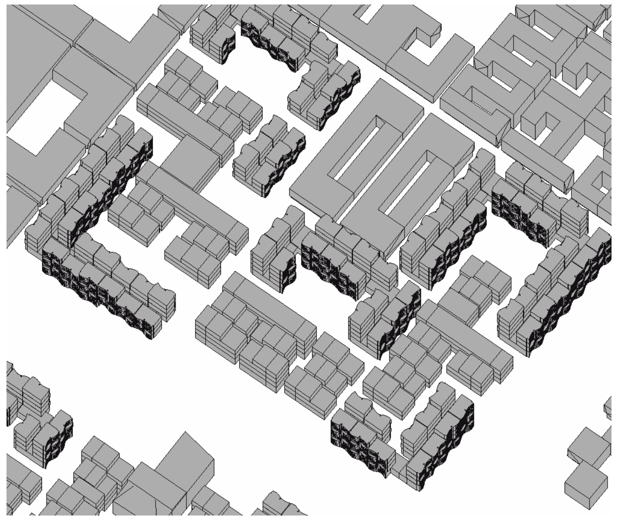


Figure 4-21 March 21st View form the sun - Noon

Figure 4-22 March 21st View form the sun – Noon

4.3 Optimise Building Envelope Performance - Daylight

4.3.1 Daylight Assumptions within the Masterplan

Design guidelines within the masterplan provide general recommendations about glazing ratios and the opportunity for daylighting to reduce electrical consumption from artificial lighting.

The need to prevent excess solar gains leading to unnecessary cooling loads and thermal discomfort there is an absolute requirement for solar shading to all external glazing.

Transolar modelling assumes ‘perfect’ solar shading – blocking 100% of direct sunlight and permitting only diffuse radiation from the sky. If this were possible a clear sky condition in Abu Dhabi would be brighter than an overcast sky condition in Northern Europe.

For fixed shading devices – best suited to atria and residential typologies – a perfect shade is not possible – to shield all surfaces from direct solar gain necessitates obstruction to >70% of sky.

There are also significant geometric differences between the proposals for MIST and the assumptions in the masterplan. Transolar assumes 3m floor to floor of 3m versus MIST of 4.5m

Therefore performance observed at ‘Minus 2’ from roof at MIST will be equivalent to that of ‘Minus 3’ in Transolar’s model

Average daylight factors in the masterplan are calculated over a floor depth that is substantially shallower than at MIST, and for labs assumes courtyard elevations on all sides. These factors also reduce the ability of daylight to offset artificial lighting when compared against the masterplan targets.

In general, daylight through windows can only provide useful daylight to the top floor and rooms facing onto significant courtyard spaces.

4.3.2 Daylight + Views - Residential Facades

Initial visualisation by F+P for the residential facades indicated a comprehensive screening to the façade, working with shading at high level across courtyard street spaces.

Figure 4-23 Visualisation of Residential Facade by Architect

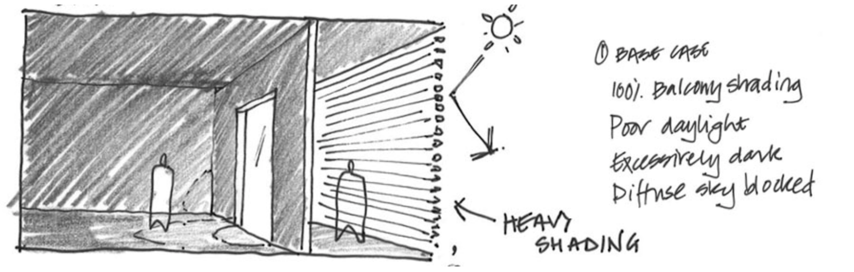
This strategy departs from the masterplan design guidelines that recommend placing shading at low level to maintain daylight access to inhabited zones whilst providing solar control to the pedestrian environment.

Figure 4-24 Traditional shading at street level in Arabic Architecture

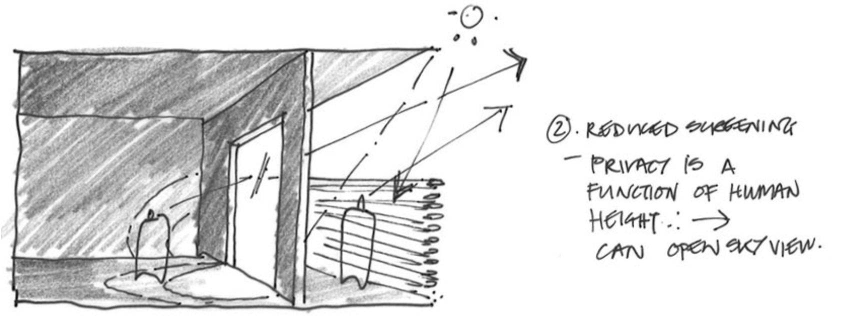
In daylight design workshops with PHA Consult the following strategic evaluation was undertaken to enhance daylight availability within these spaces.

Using computational and physical scale models in an artificial sky the daylight design of the residential accommodation will be developed during Scheme Design.

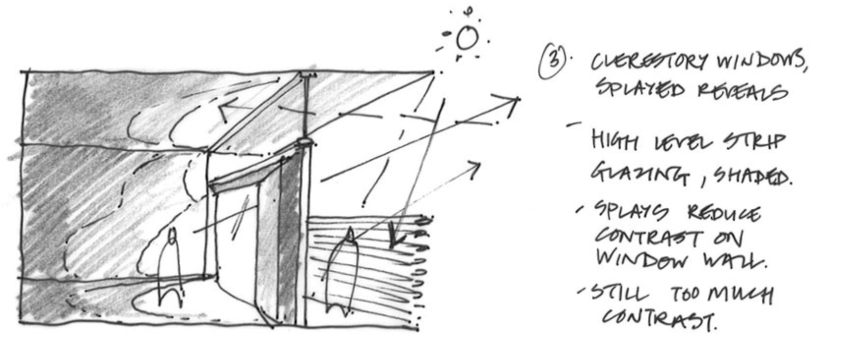
From a starting point of 100% external shading, there are options to increase daylight availability without compromising shading requirements



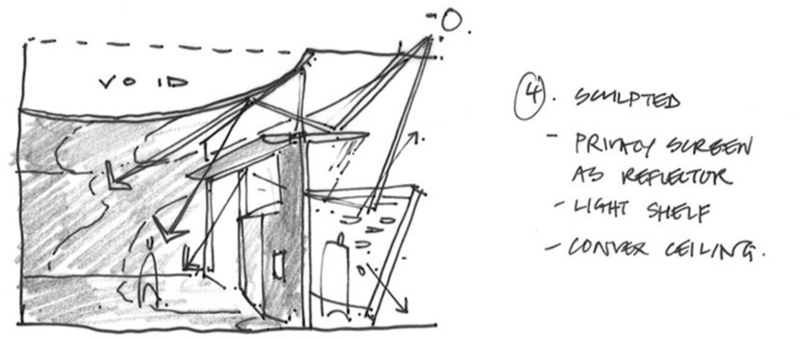
The privacy screens provide little useful shading above head height and no additional privacy. Overshadowing by balcony soffit offers protection from high angle sun



Clerestory windows flood ceiling with light, windows are positioned adjacent to walls to reduce excessive contrasts and have splayed reveals to make the window wall appear less dark



By sculpting the ceiling, and utilising light shelves we can bounce light deeper into the room, whilst reducing excessive brightness by the window



4.3.3 Daylight – Laboratory Elevations

To investigate the availability of daylight to reduce artificial lighting levels within the lab spaces an initial assessment has been undertaken at first floor level.

This level is chosen as it represents worst case performance – all levels above having a greater view of the sky and therefore having greater daylight availability.

A parametric study was conducted to compare daylight levels and distribution under CIE 'Clear Sky' conditions at midday on March 21st. The IES model was used for these assessments.

Glazing ratios of 20%, 40% and 60% were compared using glazing specifications that assume no greater than 50% light transmission.

A daylight factor of 2% was targeted, since under a 15,000 lux diffuse component from the sky this would provide 300 lux.

Results

As expected, there are clear benefits in daylighting availability with the highest glazing ratio of 60%.

At 60% glazing ratio the area that achieves 2% daylight factor is significant and space planning of uses within the laboratory space should be optimised to fully exploit this opportunity

Given that dynamic thermal loads imposed on the cooling systems for the labs are relatively small in comparison to the cooling requirement for equipment loads it is worth considering the benefits of a high % glazing to the labs to enhance visual comfort.

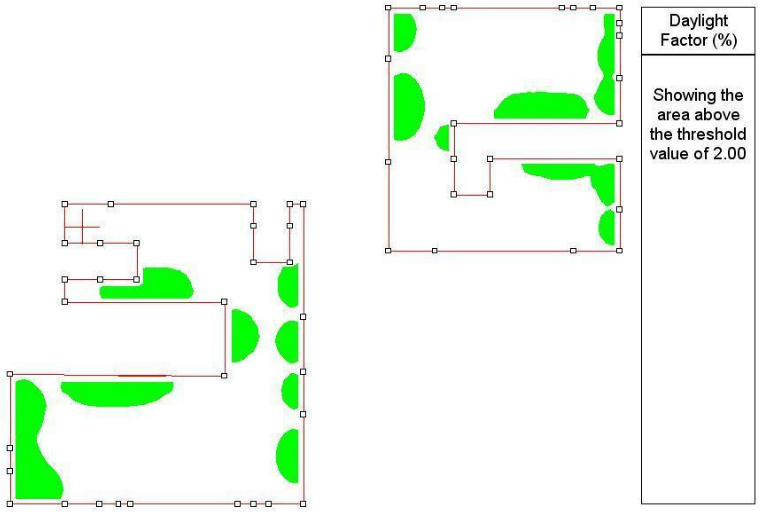


Figure 4-25 20% Glazing - 2% Daylight factor threshold plot

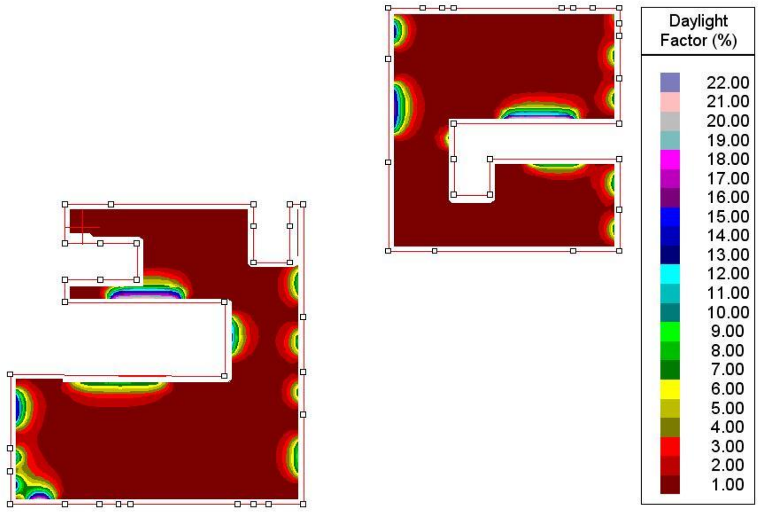


Figure 4-26 20% Glazing - Daylight factor plot

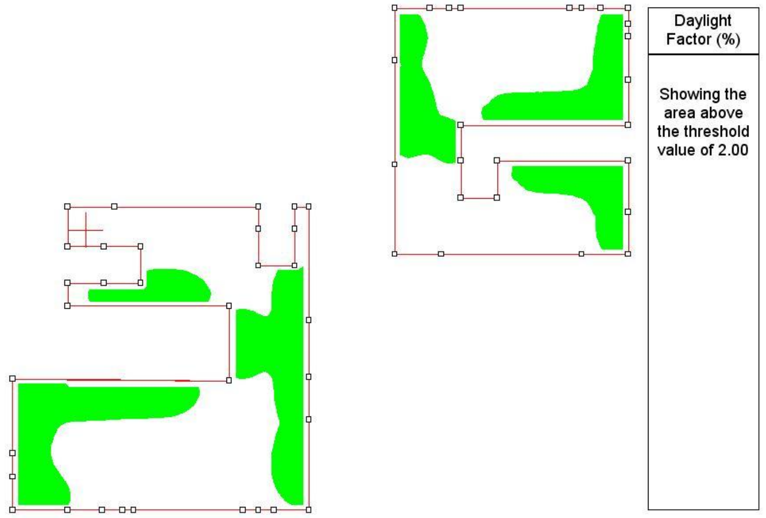


Figure 4-27 40% Glazing - 2% Daylight factor threshold plot

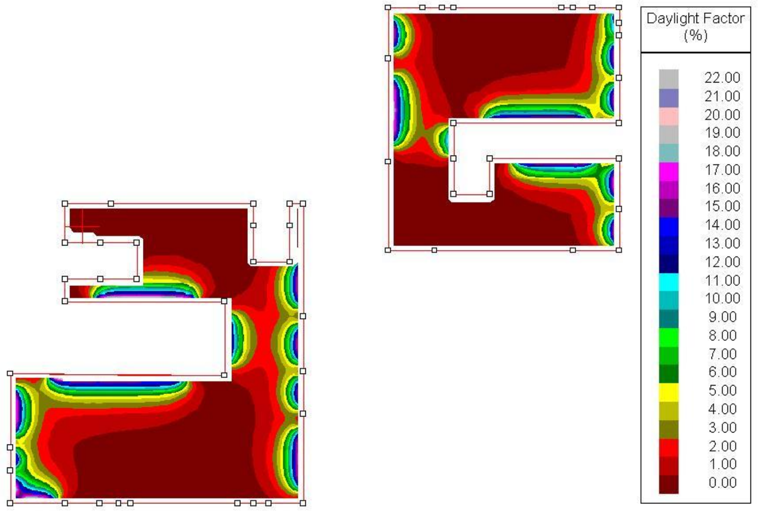


Figure 4-28 40% Glazing - Daylight factor plot

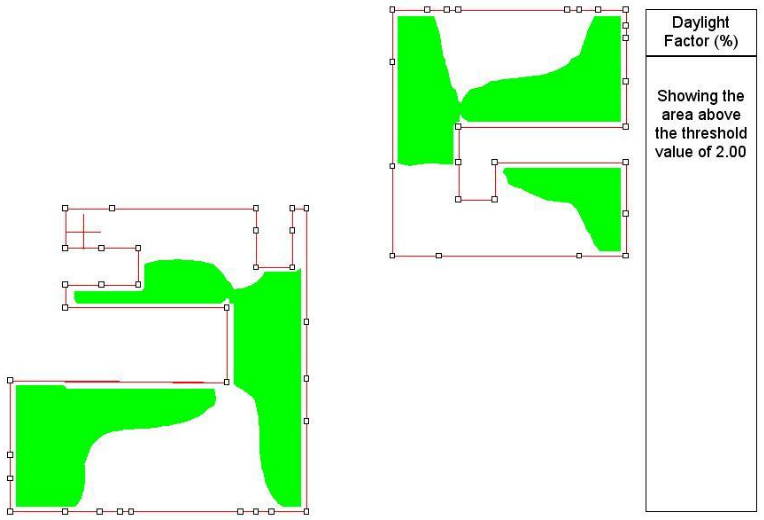


Figure 4-29 60% Glazing - 2% Daylight factor threshold plot

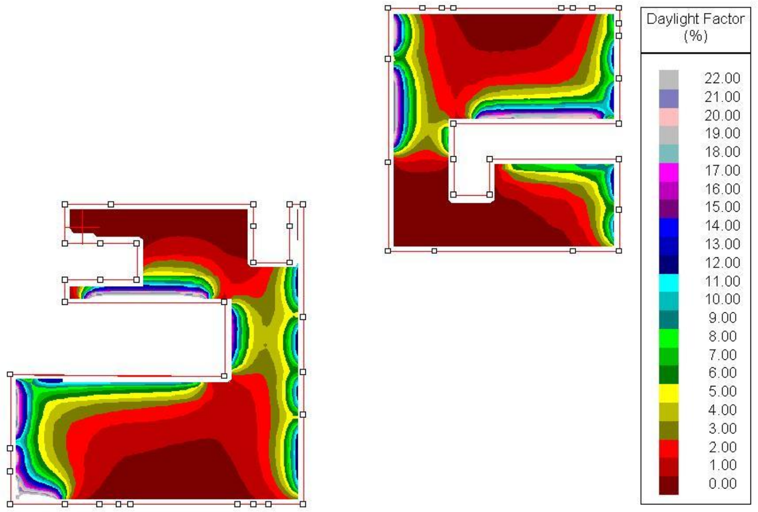


Figure 4-30 60% Glazing - Daylight factor plot

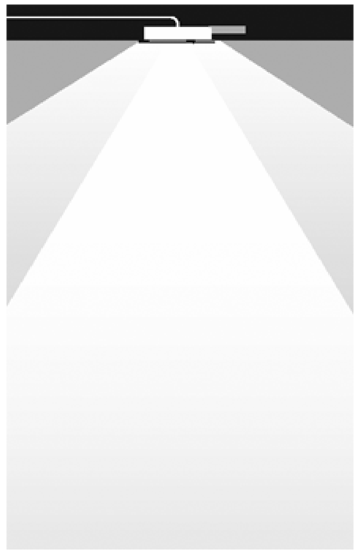
4.3.4 Capturing Sunlight

Taking sunlight directly from roof level and piping it to the interior is a viable technique

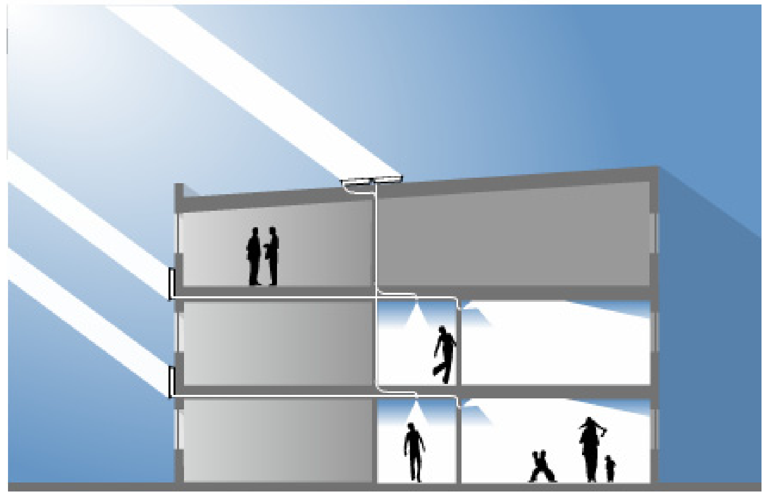
Sunlight has a significantly lower heat intensity for a given unit of illumination, so long as you can avoid excess illumination.

Savings can therefore be achieved in both electrical and cooling loads.

Parans have developed a solar tracking fibre optic system that can be roof mounted.



A summary report on Parans technology prepared after a meeting was arranged at PHA Consult's offices is provided as an Apeendix.



5 Active Systems Overview

5.1 Codes and Regulations

The Design will be based on the following Guidelines and Codes;

American Society of Heating, Refrigeration and Air conditioning Engineers (ASHRAE)

Chartered Institute Of Building Services Engineers (CIBSE), where appropriate

National Fire Protection Association (NFPA) Guidelines

British Standards, where appropriate

EITC Telecom Guidelines

Abu Dhabi Electricity and Water Authority - Regulations for Electrical and Water Installations

MIT Design Guidelines

Local Codes

5.2 Building Envelope Performance

The following insulation values contribute to the strategy for achieving Carbon Neutrality.

	Office	Lab	Housing
External Wall U Value (W/m²K)	0.25	0.25	0.3
External Roof U Value	0.12	0.12	0.1
Ground floor U Value	0.35	0.35	0.4
U-Value of glass	1.2	1.2	0.8
U-Value of Frame	2	2	2
% of Glass to Wall	30	30	30
G-Value (Glass)	0.25	0.25	0.25
G-Value (Shaded)	0.15	0.15	0.15
% Light Transmission	50	50	50
Infiltration (ac/h) *(Working / non working)*	0.15/0.05	0.15/0.05	0.2/0.05

5.3 Building air leakage

In order to satisfy the requirements, air barriers should be installed to minimise air infiltration through building fabric. In addition, building elements shall be constructed in accordance with the document 'Limiting thermal bridging and air leakage; Robust construction details for dwellings and similar buildings', TSO, 2002.

Finished building shall be tested for air leakage in accordance with CIBSE TM23, "Testing Buildings for Air Leakage"

The building shall be constructed such that the air leakage rate shall not exceed 5 m✥/h/m✥ of envelope area at 50 Pa.

5.4 Internal Conditions

5.4.1 Environmental

Offices	24-26°C max RH 65%
Laboratories	24-26°C max RH 65%
Classrooms	24-26°C max RH 65%
Main Reception	24-26°C max RH 65%
Cores and Toilets	24-26°C max RH 65%
Plantrooms	26-28°C
IT Rooms	22°C db ✥ 2°C 24 hours a day max RH 65%
Residential	24-26°C max RH 65%

Out of hours set back temperature is 28°C for working spaces and 26°C for residential areas.

Although cooling is incorporated, there will be no humidity control in the spaces.

5.4.2 Lighting

Office areas	300 lux maintained in open plan working plane
	Uniformity ratio of 0.8 over defined task area
Classrooms	300 – 500 lux
Laboratories	500- 700 lux
Workshops	300 lux maintained level in open plan working plane
Main Reception	150-300 lux
Cores & Toilets	150-200 lux
Corridors & Stairs	150 lux
Plantrooms	150 lux
External	20 lux minimum

5.4.3 Noise

Noise from mechanical/electrical equipment (where installed) will meet the following criteria when measured within the space at a position of 1500mm from any noise emitting source or enclosing structure.

Office areas	NR 35-40
Laboratories	NR 35-40 (not including lab support & core Lab)
Classrooms	NR 35
Machine Rooms	NR 70
Main Reception	NR 45
Kitchens	NR 45
Corridors & Stairs	NR 45
Toilets	NR 45
Plantrooms	NR 70

5.5 External Conditions

ASHRAE Design Conditions are;

Winter	11.2°C dry bulb
Summer	44.9°C dry bulb, 30.4°C wet bulb

5.6 Mechanical Services

The basis of design will be as follows:-

5.6.1 Ventilation Rates

Offices	12 L/s/person via mechanical Ventilation
Bench Lab	12 L/s/person via mechanical Ventilation
Lab Support	Up to 6 ac/hr (dependent on fume hood numbers)
Core Lab	Up to 6 ac/hr (dependent on Installed machinery)
Residential	12 L/s/person via Mechanical/Natural Ventilation
Basement plant	1.5 ac/hr - generally
Toilet Ventilation	12 air changes/hour extract
	10 air changes/hour make-up via core area

5.6.2 Air tightness

All areas 5 $m^3/hr/m^2$ of exposed fabric @ 50 Pa

5.6.3 Occupancy

Offices	1 person/20 sqm NLA
Laboratories	1 person/20 sqm NLA
Lab Write Up	1 person/20 sqm NLA
Lab Support	1 person/20 sqm NLA
Lab Core	1 person/20 sqm NLA
Classrooms	TBA
Residential	As per Residential Type
Meeting Rooms	1 person/4 sqm NLA
Library	1 person/4 sqm NLA

5.7 Electrical Services

Location	Small Power Load (W/M^2)	Maintained Illuminance (Lux)
Offices & meeting Rooms	15	300-500
Laboratories	150 (UPS & DC) (TBC)	500-700
Lab Write-up & support	15	300-500
Classrooms	15	300-500
Server Rooms & Equipment Rooms	40kW per cabinet (TBC)	500-700
Library	10	300-500
Kitchens	As Required	500
Dining Areas	0	200
Entrance halls	0	100
Reception	0	150-300
Circulation & Corridors	0	100
Stairwells	0	150
Store rooms	0	100
Plantrooms	5	200
Loading bays	5	150
Rest rooms	0	200
Mail rooms	5	500
Lounges	5	200
Residential	As required	As required

5.8 Note:

Urgent Input is required from the following consultants to develop the Scheme Design;

Lab Consultant

Vertical Transport Consultant

Acoustic Consultant

Catering Consultant

Facade Consultant

Fire Consultant

AV Consultant

IT Consultant

6 Infrastructure (MEP)

6.1 HVAC Strategy

6.1.1 Ventilation

The supply air is drawn from high level, approximately 44 meters above ground level, using a wind tower that should take advantage of any cool wind velocities. This height should ensure the intake is well above any heat haze stratification located above the roof level. The extract air also uses the tower to conduit extract air with outlet louvers 28 meters above ground level. The extract air is separated from the supply air by an internal division inside the tower. The pressure gradient on the opposite sides of the tower where the supply/extract air passes through the inlet/outlet louvers and the 16 meter height difference shall ensure no recirculation occurs.

The air velocity at the bottom of the towers should be below 2.0 m/s velocity to ensure any sand drops out of the air stream before entering the ductwork system. A similar low air velocity of the extract system shall be beneficial to drop out the condensate from the saturated extract air being cooled, by passing over the heavy mass of the chimney structure.

There shall be two tower structures serving Phase 1A of the MIST, one located each side of the dividing transport system (PRT) tunnel. Each tower shall serve two Primary Air handling units (AHUs); each AHU, with a supporting Liquid Desiccant Absorber, will serve the fresh air requirements of a quadrant of Phase 1A. The Primary AHUs shall condition the air to a 'comfort condition' in the region of 25°C (db) 50% RH (±10%).

The air flow of the supply and extract shall circulate throughout the ductwork distribution by the use of a variable speed fan units, located in the Podium level (Basement) AHU. Any energy gained from the wind will be compensated by lowering the additional static pressure requirement to be generated by the fan units.

The Primary conditioned air shall be distributed to secondary ducts via vertical risers serving each structural bay. The secondary air shall be conditioned further by separate AHU's, which will follow the condition requirements of the occupation patterns of different usage zones such as residential, recreation or academic. Hazardous zones like fume cupboards shall use Primary conditioned air ducted to the front of the hoods.

The air during peak ambient temperature day time hours shall pass through a Labyrinth structure to pre-cool the air before entering the desiccant Absorber unit. The Labyrinth shall be purged of heat, i.e. recharged with passive cooling capacity, during the night time periods. The cool night time air shall cool the concrete thermal mass plus remove latent heat from the encapsulated pcm (phase change material) suspended in the air passage.

Further conditioning of the ventilation air can be made by the space terminal units. The majority of the terminal units shall be active chilled beams which will have integral chilled water and in some cases hot water coils to final conditioning to the local occupant requirement.

The fresh air quantity is based on providing each occupant 12 litres/second, with the air condition passing through three controlled process stages from the Tower to the occupant which will constantly monitored. The control system shall have the ability to provide the optimum energy consumption from each process and supporting HVAC plant.

6.1.2 Cooling and Dehumidification Strategy

Using traditional Air-conditioning refrigeration plant to provide the cooling requirement for the incoming ventilation air, passing into the building envelop, was not an option due to the high energy consumption.

Even though the ambient sensible temperature at the height of summer will reach over 45°C, there will be opportunities to reduce energy consumption due to the high latent heat (moisture content) makeup of the ambient air.

There are now proven applications available using liquid desiccants (liquids that induces or sustains a state of dryness), which uses hot water to provide sensible and latent cooling. The grade of hot water, required between the 90°C and 80°C, can be generated from a waste heat process or solar thermal collectors, which is advantageous due the geographical characteristics of Masdar.

The strategy shall be to ensure cooling capacity in all conditions, which will use the solar thermal energy whenever available, with excess capacity stored for night time periods by regenerating desiccant. Whenever weather conditions do not provide sufficient solar thermal capacity waste heat can be used, generated from electrical power generating plant. The third option would be the use of high efficient electrical Chiller capacity that can produce Chilled water, with COP in the excess of 5.

The primary system of conditioning the air, using Liquid Desiccant and Indirect evaporative cooling, will also generate a supply of potable water. The quantity of water capture from the supply air stream and extract air stream (due to saturation from indirect evaporative cooling, using brackish water from bore-hole water) shall be modelled in the scheme design stage to quantify the overall potable water makeup capabilities.

The Liquid Desiccant system will provide definite advantages in reducing energy consumption (in the range of 2MW for Phase 1A) and potentially generate potable water but it will be untried in terms of reliability. Absorption chiller capacity should be installed to provide resilient cooling capacity if the liquid desiccant system is down for maintenance reasons.

The solar hot water generation characteristics available for the Liquid Desiccant system have the same requirements as for the Absorption chillers i.e. 90°C flow temperature. If the solar hot water system is not functioning an alternative hot water source could be waste heat from the CHP system, located in the Basement.

An additional High efficient electric Chiller shall be installed to provide further resilience to the overall system. The resilient hot water generating system, the waste heat of the CHP system, would also generate electricity via the generator to support the chillers' electrical load. This additional resilience would be used during maintenance shut downs of the desiccant/absorption systems or during bad weather periods.

The indirect evaporative cooling unit, located on the extract air stream, shall be used by both cooling systems on the assumption that evaporative unit is sized for the combined load.

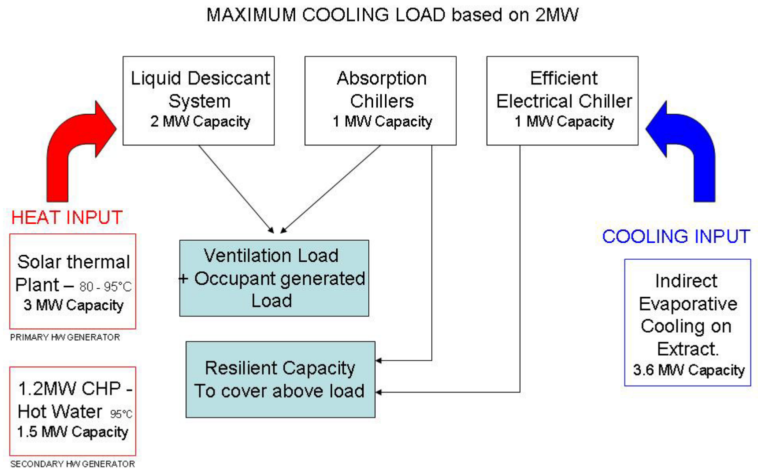


Figure 6-1 Cooling generation Schematic

6.1.3 Control Strategy

The other important method of reducing energy consumption shall be from using a control strategy that ensures assumed energy consumption is directly linked to the real-time usage and occupation of the building. This strategy will ensure that the building will fulfil the energy criteria requirements set by the Master plan.

The principle objective should be to ensure the design of the HVAC services distribution provides the client with the flexibility and ease to change the floor layout, whenever the usage characteristics change at a future date, whilst not compromising the need to conserve energy.

The design capacity of the HVAC plant and infrastructure shall be designed to a maximum 'occupation density criteria' but shall be flexible enough to fluctuate to the variable capacity of an individual occupant's movement, wherever they move through the building. The occupant shall therefore carry their 'HVAC load' around with them as they pass through the complex, throughout the academic, recreation or residential zones. The control system shall be intelligent enough to activate/deactivate the capacity of HVAC systems as the occupant moves through the complex.

The control system shall be based on an interactive network system therefore more flexible than the traditional BMS (Building Management system). The control system should be based on an open type of structure allowing different types of applications, hardware and software, to be interactive in terms of inputs and outputs plus the ability of being able to expand as the city is built around the University. A network system that is sufficiently supported technically on a global scale would be Lonworks.

A short analysis report on the Lonworks system can be found else where in the report.

6.1.4 Psychrometrics of the Supply air condition

The ambient external conditions have a wide variance over the year, ranging from 9°C to over 45°C. The supply air is to be conditioned using a Primary AHU, to a comfort condition in the region of 25°C (db) 50% RH (±10%).

To illustrate the different extreme ambient conditions a Psychrometric charts have been generated.

An example of the hottest time of the year occurs on Day 202 at 3p.m. (from our historical data).

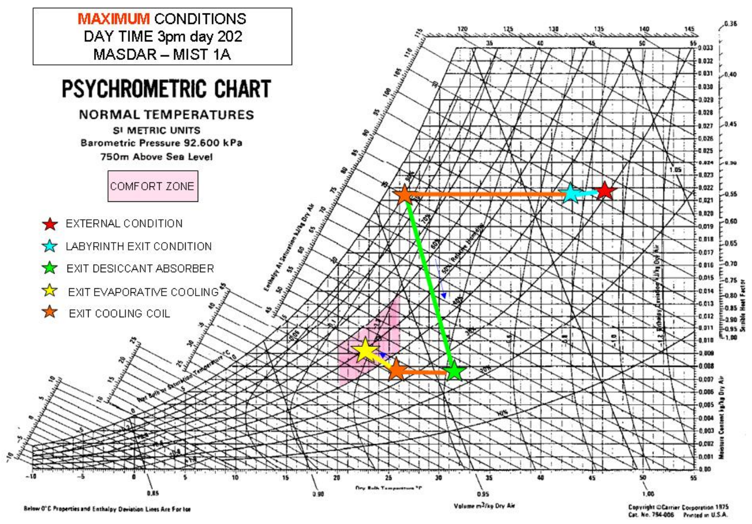


Figure 6-2 Psychrometric chart

The Primary air process to condition the supply air consists of:

Ambient Condition	45.7°C (db) 31%(RH)
Red star to Blue star	Process of cooling the air using Labyrinth, using latent storage of encapsulated PCM and Sensible storage of cool concrete
Blue star to Orange star	Sensible cooling from a cooling coil, cooling capacity sourced from Indirect Evaporative cooling process located in extract air stream.
Orange star to Green star	Dehumidification process from Liquid desiccant system, therefore latent heat (humidity) absorbed by Lithium Chloride.
Green star to Orange star	Sensible cooling from a cooling coil, cooling capacity sourced from Indirect Evaporative cooling process located in extract air stream.
Orange star to Yellow star	Evaporative cooling from water atomiser inside AHU.
Primary Air condition	23°C (db) 50%(RH)

The whole process would be equivalent to 67 kJ/sec (kW) of cooling power, per m^3/sec of supply air flow rate.

The initial concept layouts estimation of supply air requirements provided an indication of potential savings being in the region of 2,200 kW, during this extreme condition.

6.2 Ventilation Systems

6.2.1 Mechanical Assisted Wind tower

The average wind speed 49 meters above the tower base has been calculated at 4 m/s, which will assist the flow of supply and extract passing through the tower, as long as louvers are installed on all sides of the tower.

The tower shall be dimensioned to the estimated volume of air passing through the tower at different maximum velocities. For the majority of the tower length the air velocity would be in the region of 6 m/s, whilst at the base in basement the air velocity should 2 m/s. The slow air velocity will ensure any sand entrapped in the supply air stream falls to the base of the tower and assist the condensation and capture near potable water from the extract stream.

The base of the tower, located at Podium level (Basement), should be built of heavy mass material with the dividing wall between the supply and extract air streams insulated. These characteristics should provide some passive cooling at certain times of the year and also help the water condensation process of the saturated extract air stream. The condensed water should of a reasonably potable condition but shall require filtration for reuse.

6.2.2 Air Handling Units (AHUs)

There shall be two stages of conditioning the air using AHUs. The Primary system in Phase 1A shall consist of four AHUs that shall take the pre-conditioned supply air from the outside, via the ventilation tower, Labyrinth and Desiccant Absorber. The Primary AHUs shall condition the air further, if required, to a constant condition of 25°C 50%RH using cooling and heating coils and a rotary atomiser humidifier. In some winter conditions the constant condition dry bulb temperature can be reduced to above 21°C to reduce the need for heating the supply.

The air from the Primary AHU shall be distributed, via ducting to secondary smaller AHUs that serve areas on the four floors above. Each AHU shall be located high level in the Basement level, under the related distribution riser. The number of secondary AHUs shall depend on the number of defined usage areas, for example Academic, Residential and Recreation, as each usage area will have a different occupation model. Each Secondary AHU shall have a cooling coil to reduce the air temperature to suit the terminal units located in the conditioned space.

All AHUs shall have variable speed centrifugal fans that will be controlled directly by the occupation pattern of the occupants, as they move through the different usage areas.

Hazardous areas, example high air volume usage applications such as Laboratory Fume cupboards, shall directly use the conditioned air directly from the Primary AHUs.

The Extract section of the Primary AHU shall only consist of an extract fan and an indirect Evaporative cooling system (similar application as a cooling water tower). The supply air system shall provide 100% full fresh air, therefore with no recirculation of extract.

The Indirect Evaporative cooling system will be the sole method of rejecting heat from the cooling systems, such as Absorption Chiller, Liquid Desiccant Absorber, Electrical Chiller and CHP system. As the overall cooling system has backup capacity there may be a requirement to install an additional the Indirect Evaporative cooling system, as it could be a potential point of failure of the entire HVAC system.

There shall be four Primary and Secondary AHU systems, each serving a quadrant of MIST Phase 1A. This shall require four plant rooms to be located in the Basement, sufficient for the Primary and Secondary AHUs and supportive Hot water, Chilled water and Desiccant systems that serve each system.

6.3 Cooling Options

6.3.1 Energy Piles

The Energy Pile concept is based on using the ground/foundation piles as a thermal reservoir. In cooling mode heat is rejected into the piles and in heating mode the heat is removed again.

By the use of a Heat Pump unit the low grade heat/cooling capacities can be amplified to provide some useful applications such as cooling and domestic hot water capacity.

Even though the total capacity from this process is relatively small (500 kW) compared to the other HVAC plant, it would be useful in terms of providing additional capacity that is not dependant on the solar/weather external conditions.

There is a study report in the Appendix section.

6.3.2 Indirect Evaporative cooling

This is a very useful concept as the use of air blast condensers to reject heat is not a realistic option, due to the high external ambient temperatures at roof level.

The principle of Indirect Evaporative cooling depends on a quantity of water being evaporated whilst passing over water coils inside the extract air stream. The water coils circulates water from plant such as the Liquid Desiccant Absorber, Absorption Chiller and CHP system, which require heat rejection to function effectively. The act of evaporating water over the water coils has the effect of absorbing heat at a rapid rate, by changing the phase condition of water from a liquid to steam.

Using potable water for this process is not a real option as water is a precious resource. The use of the abundant ground water, which will be brackish and undrinkable, can be used for this process. A bore hole should be provided to pump the ground water to the surface for this application. Other applications from the use of bore hole water are also available and shall be investigated.

As the extract air stream will be saturated with water vapour there is a possibility of condensating the water content, when the air passes through the base of the ventilation tower. This condensed water would be of a reasonable condition to add to the potable recycling system.

6.3.3 Liquid desiccant (LiCl) Cooling

In certain geographical zones around the world that have high external ambient temperature there are also reasonable high relative humidity levels. If traditional refrigeration equipment is used to remove this thermal load a large amount of energy is used to reduce the humidity (remove latent heat).

The liquid desiccant system uses Lithium Chloride (LiCl), which is a salt solution, to absorb the humidity by passing the supply air over an impregnated LiCl surface. This humidity reduction in happens in an Absorber unit located in the Basement, situated before the AHU.

The liquid desiccant is pumped up to the roof level where the Regenerator unit of the system is located. The salt solution (desiccant) is re-concentrated by heating the solution to 80°C, by passing an air stream next to the heated LiCl impregnated panels will transfer the moisture content to the air stream.

Combining the latent heat (moisture) removal with the sensible cooling of the Indirect Evaporative cooling using this method, could provide the majority of the cooling capacity, over the annual period. (see report in Appendix)

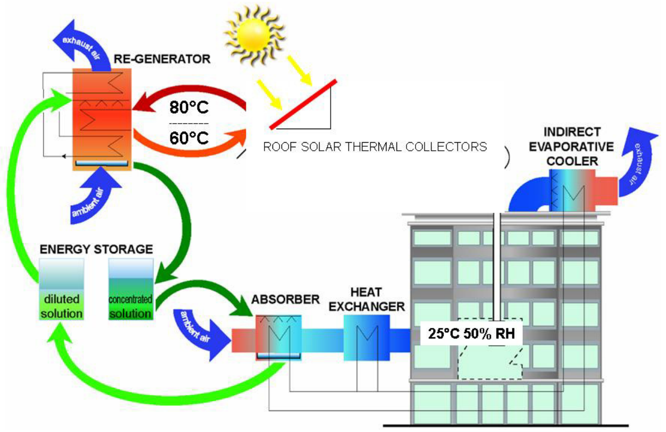


Figure 6-3 Schematic energy systems

The main limitation of the system is the available roof place for solar thermal collectors. As Phase 1A will be a standalone building with the requirement to be self sufficient as possible in terms of energy, the solar PV installation (specified in the master plan) has been replaced by solar thermal collectors. A report (in Appendix) shows that the roof area is more effective for this solar application.

The most effective area of solar thermal collectors, based on using high efficient Vacuum/Heat Pipe, has been calculated to be 3,000 m^2 using a 2,000MW Liquid Desiccant system capacity. We have calculated that we have approximately only two thirds of the effective area requirement therefore the cooling shortfall would be made up by the CHP/Absorption Chiller/Efficient electrical Chiller systems.

The alternative would be to provide additional hot water capacity by installing solar thermal installation outside the city, with additional HW distribution pipework infrastructure to the Phase 1A site. If this additional solar collector area was installed on the future plot phases of MIST, that are to be built at a later stage, the main problem will be the dust generation from the construction of Phase 1A. This lack of thermal capacity to regenerate the liquid desiccant system would not be a problem in the long term, as the master plan specified that a central Desiccant Regeneration plant is to be built, therefore providing a liquid desiccant distribution system as infrastructure.

6.3.4 Solar Single Stage Absorption Cooling

Absorption chillers differ from compression chillers in that they use a thermal compression instead of a mechanical one.

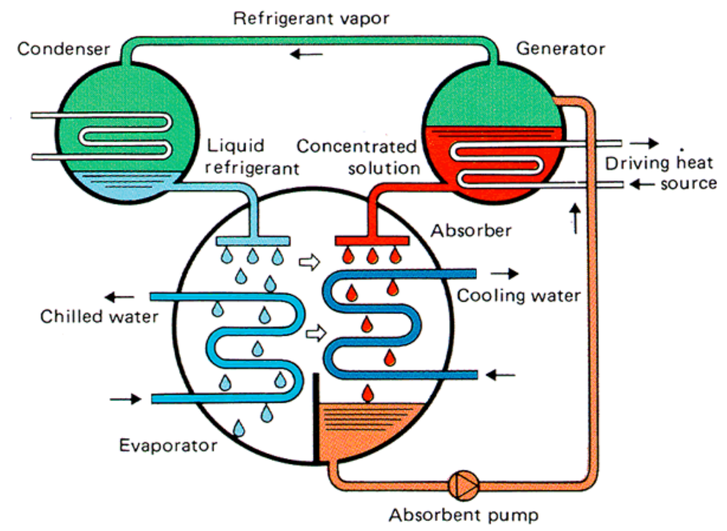


Figure 6-4 Simplified absorption cycle

Apart from the electrical power requirements of the solution pump, the chiller is driven only by thermal energy. The other input is the requirement to provide cooling capacity to the condenser part of the system.

The condenser can be cooled from the using the Indirect evaporative cooling system installed on the extract air ductwork (as described in the liquid desiccant section).

Absorption Chiller capacity will be primarily used when insufficient cooling is available from the Liquid Desiccant system. On the assumption that hot water generation will be limited from the available roof area, hot water source for the Absorption chiller would be the CHP system. The CHP would also provide sufficient electrical power to be used by the electrical distribution or by the electrical chiller.

6.3.5 High Efficiency Electric Chillers

Some major advances have been made in the construction of compressors and related influence on efficiency and energy consumption. A large refrigeration company, Danfos, has recently developed a new type of compressor (Turbocore) that uses electromagnet bearings and synthetic refrigerant R134a.

Subsequently different Chiller manufactures have used the compressors to produce very efficient Chilled water Chillers with Coefficient of Performance (COP) above 6, under different conditions. Therefore a COP of 6 would equate to providing 6kW of cooling with 1kW of electrical energy.

As with the Absorption chiller the CHP system would be used to provide the electrical capacity if the chiller is required to cover the sensible cooling load.

7 Mechanical

7.1 Infrastructure - Summary

MIST will be provided with Utility connections from the MASDAR City Infrastructure system of service tunnels. For the purposes of this concept report, the assumption made is that both 'wet' and 'dry' services will be available in each and every Infrastructure tunnel. The service connections available when the service tunnels are complete are assumed at this stage to include;

Incoming mains HV electrical Supplies

- Chilled water
- Condensing water
- Liquid Desiccant
- Mains cold water and fire services
- Foul and surface water drainage
- Telecoms and data

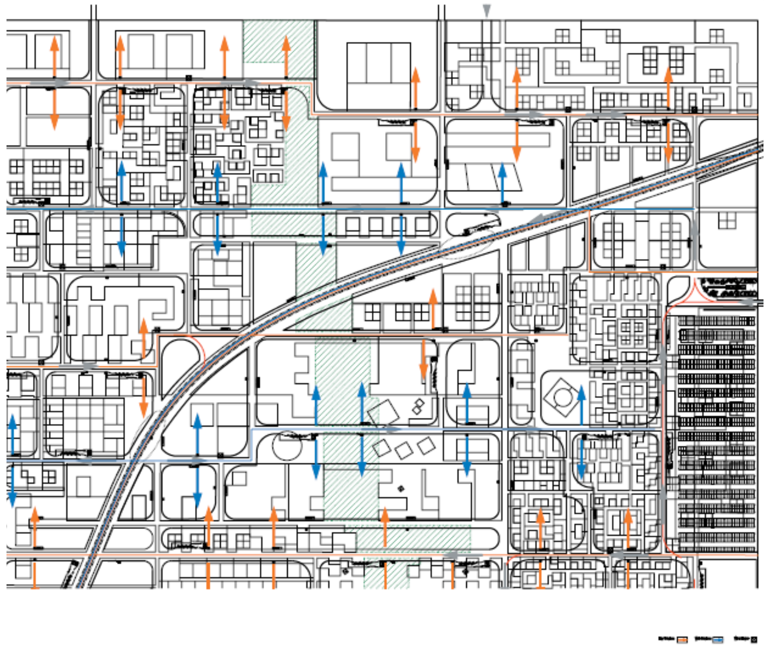


Figure 7-1 Masterplan infrastructure services strategy

Due to the programme of the MASDAR City infrastructure design/installation, only the following infrastructure services will be available for connection by August 2009 (opening of phase 1A);

- Mains cold water
- Foul and surface water drainage
- Telecoms and data

Note: These service will be required approximately 8 weeks prior to completion of Phase 1A (i.e. July 2009) to enable commissioning to be commerce in good time for completion.

7.2 HVAC Option Studies

The Mechanical systems which have been reviewed include;

Laboratories;

i. Active Chilled Beams
ii. Embedded Cooling pipes within Slab

Residential;

i. Radiant Ceilings
ii. Active Chilled Beams
iii. Displacement Ventilation

Classrooms;

i. Radiant Ceilings
ii. Active Chilled Beams

As a brief introduction to the alternative system types, a summary is given below;

7.2.1 Radiant Ceilings

With radiant cooling, heat exchange from the room to the ceiling happens mainly via radiation and convection. Radiation of energy takes place between objects with different surface temperatures. In all cases, the warmer object radiates heat to the cooler object. Just as the hot sun radiates to the cooler earth, in a radiant cooled environment, computers, people, and other sources of heat radiate that heat to the cooler surface of the ceiling. As an added benefit, humans perceive heat transfer via radiation as particularly comfortable. Convection occurs when the room air is cooled as it flows beneath the cooling panels. The cooler air is heavier than the warmer air rising from the heat sources, which creates natural, high volume, low-velocity air currents.

Figure 7-2 Example of installed radiant ceiling

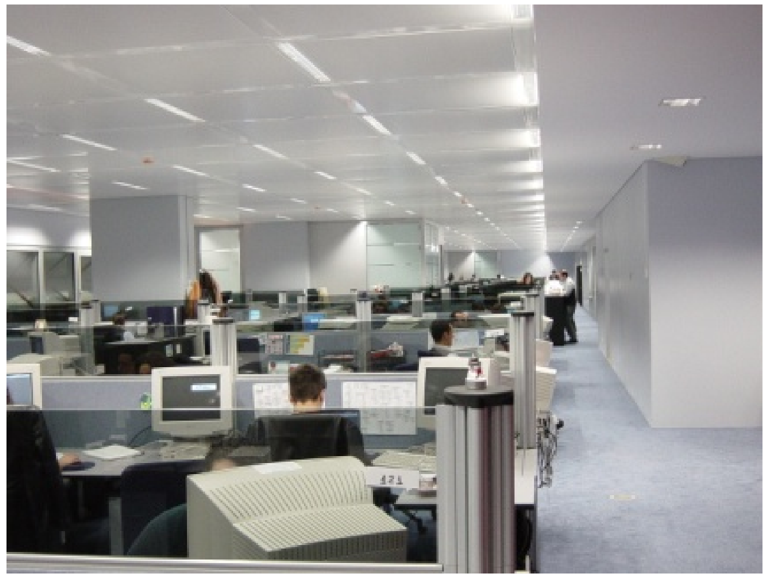


Figure 7-3 Example of installed radiant ceiling

7.2.2 Chilled Beams

Chilled beams are essentially a convective (negative buoyancy) with some radiant cooling system, but can achieve much higher cooling capacities compared to chilled ceilings. The chilled beams can be either active or passive. Active chilled beams have air induced through the centre of the beam which enhances their cooling output. Chilled beams offer several advantages over other system options. A multi service beam can accommodate sprinkler heads, luminaries, PA/VA etc which allows for offsite construction and quick installation. Some example images are included below.

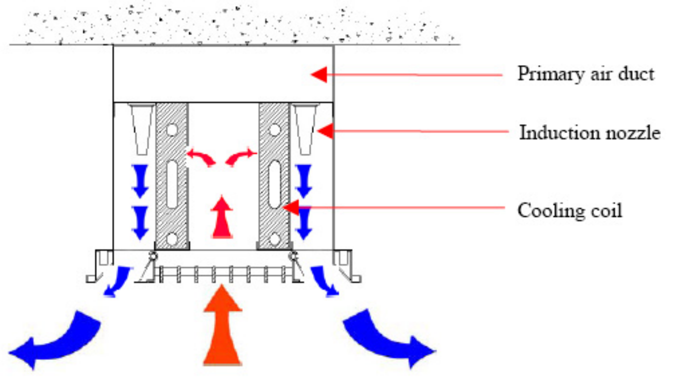


Figure 7-4 Sectional diagram of chilled beam in operation

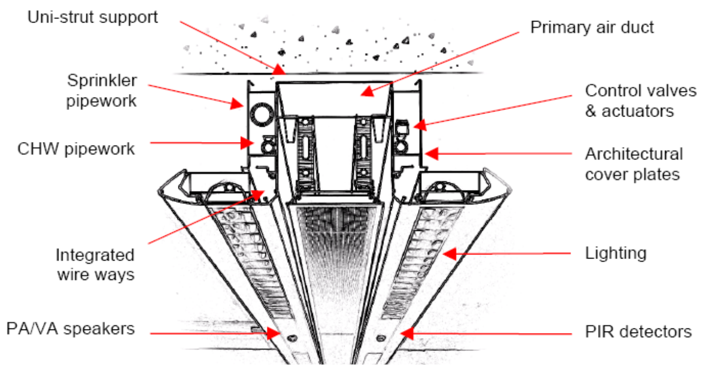


Figure 7-5 Sectional diagram of chilled beam components

Figure 7-6 Example of installed chilled beam

Figure 7-7 Example of installed chilled beam

7.2.3 Displacement Ventilation

The characteristic of a displacement ventilation system is the provision of fresh cool air (no lower than 18ºC), directly into the occupied zone at a speed and temperature that does not cause discomfort. Once the air enters, it spreads across the floor forming a reservoir of fresh cool air. The movement of air within the space is primarily buoyancy driven such that heat sources (particularly people) generate vertically rising plumes which entrain surrounding air. The reservoir of fresh air cool air at floor level flows to replace that which was warmed and lifted into the thermal plume. The overall result is a vertical stratification of temperature and pollutant concentration such that the best conditions are achieved and maintained in the occupied zone.

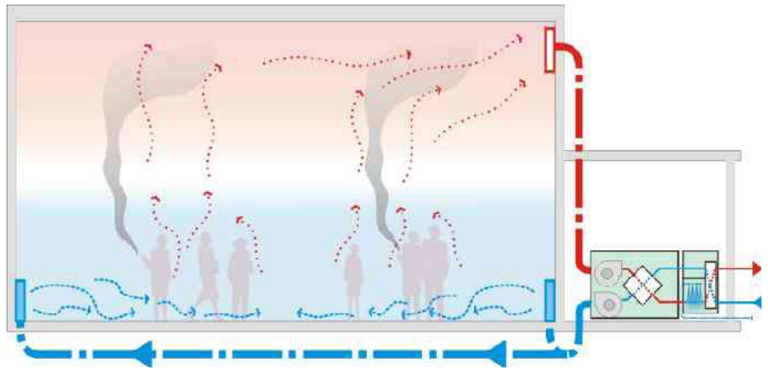


Figure 7-8 Sectional diagram of displacement air flows

7.3 Residential

Ventilation to the residence rooms will be provided by air handling units located within the basement plantrooms (our assumption is that no cooking facilities will be located within these rooms). The air handling unit will incorporate supply and return air sections and include heat recovery sections.

Via low velocity ductwork distribution systems routed vertically through the residence area, supply air will be admitted to the rooms and corridor areas, and extracted via the washrooms. Heating and cooling to the rooms could be provided by either (1) radiant chilled ceilings (2) active chilled beam (for example, such as developed by Halton, see Figure 7-9 and Figure 7-10), (3) Displacement ventilation

Figure 7-9 Example of installed Halton chilled beam

Figure 7-10 Example of Halton chilled beam unit

The advantages and disadvantages of each system are described below.

Chilled Ceiling

Advantages

- Low energy use
- Lowest power requirements
- Suitable for higher temperature chilled water systems
- High comfort conditions
- High Indoor Air Quality
- Reduced ceiling void
- Low noise
- Low maintenance
- Minimal ductwork

Disadvantages

- Reduced capacity
- Condensation risk and compatibility with operable windows
- Slow thermal response
- Reduced control accuracy
- Overhead heating with potential discomfort

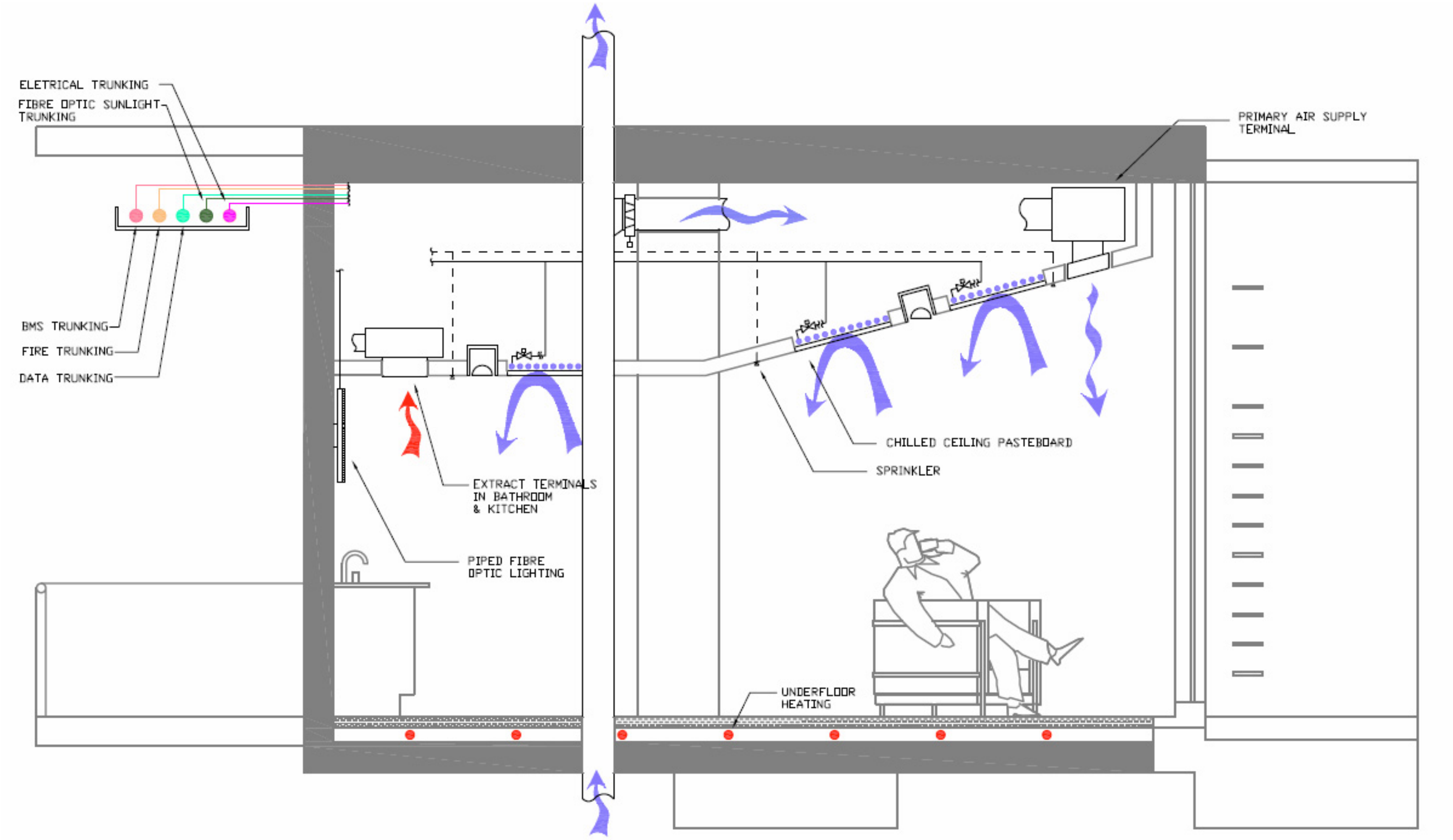


Figure 7-11Student accommodation ventilation section 1: chilled ceiling with perimeter fresh air supply

Chilled Beam

Advantages

- Low energy use
- Lowest power requirements
- Suitable for higher temperature chilled water systems
- High comfort conditions
- High Indoor Air Quality
- Reduced ceiling void
- Low noise
- Low maintenance

Disadvantages

- Condensation risk and compatibility with operable windows
- Slow thermal response
- Reduced control accuracy

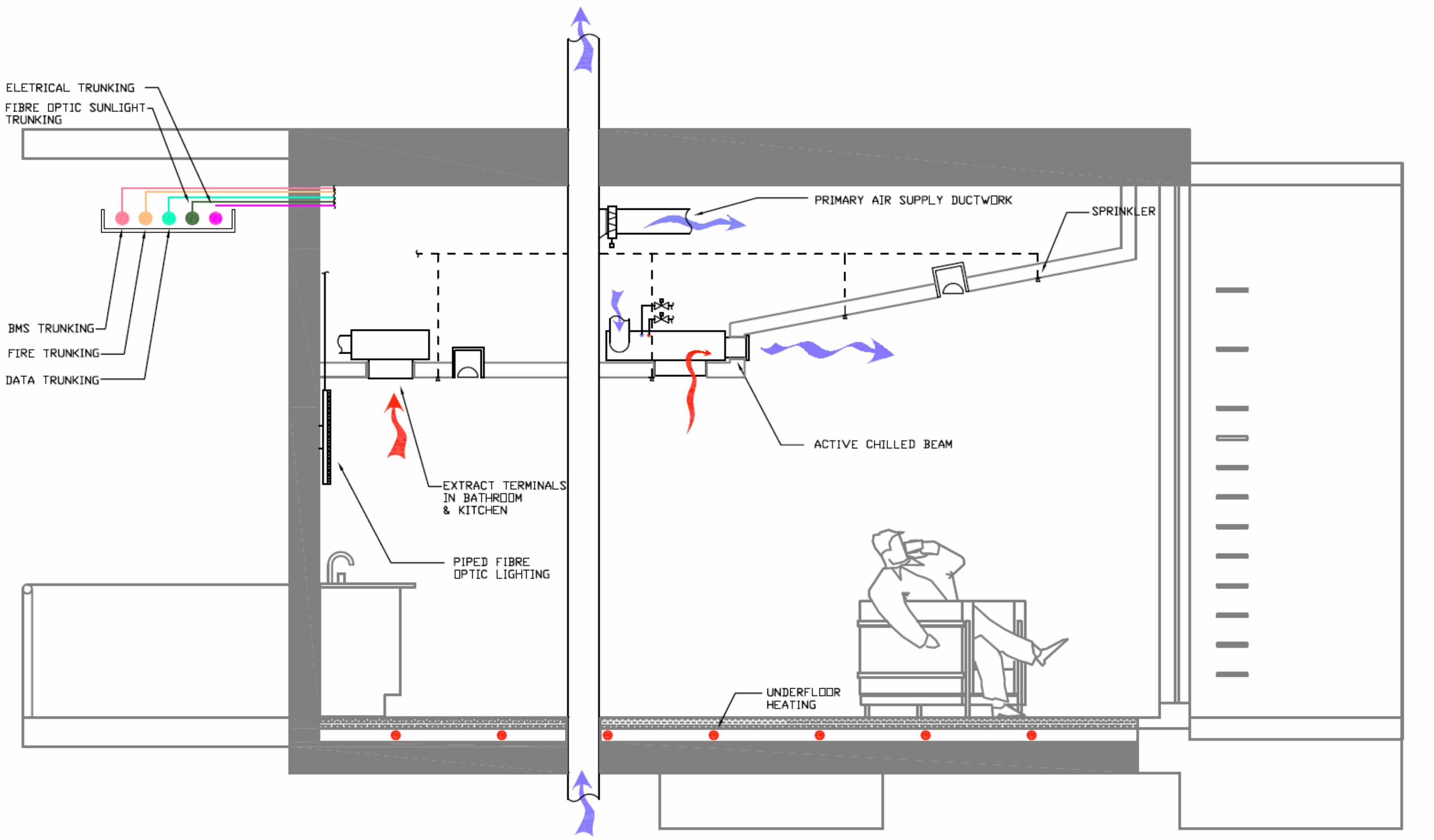


Figure 7-12 Student accommodation ventilation section 2: active chilled beam with fresh air supply

Displacement Ventilation

Advantages

- Low energy use
- Suitable for higher temperature chilled water systems
- High comfort conditions
- High Indoor Air Quality
- Low noise
- Low maintenance

Disadvantages

- Raised floor required or thicker walls for air paths
- Large ceiling void required
- Limited cooling capacity
- Large riser space and plant space required

Facility will be provided for natural ventilation to all residential rooms via openings in the façade. Automatic controls will be provided to isolate the local comfort cooling systems on manual opening. This could be controlled by enthalpy sensors or window contacts which would isolate the control valves to the terminal unit.

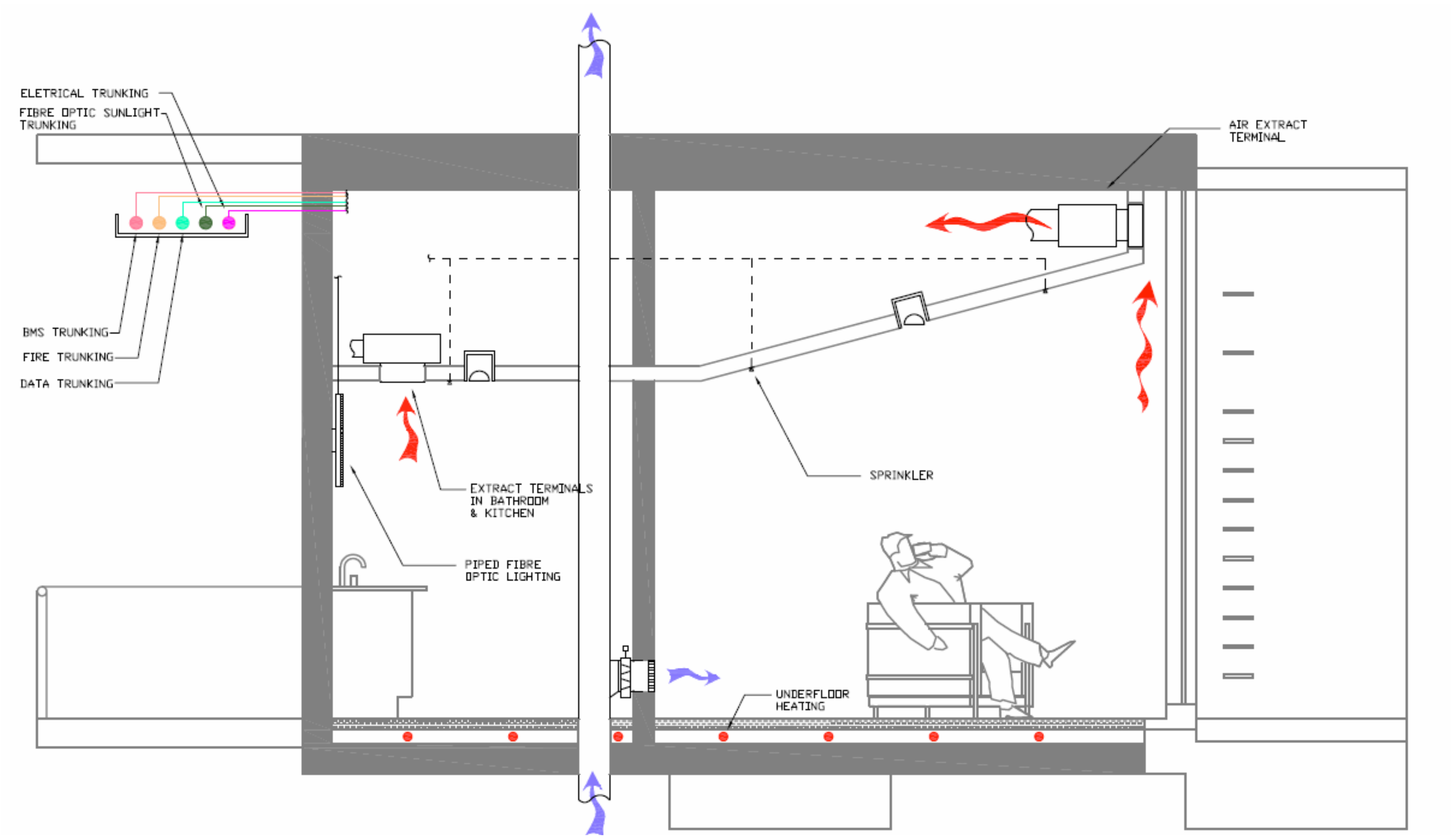


Figure 7-13 Student accommodation ventilation section 3 : displacement ventilation

Space Heating

Heating will be required during certain periods of the year, in particular within the residential areas. Although the load will be relatively small, internal comfort conditions could be affected if not considered.

Options for providing heating include;

i. Underfloor heating – electric or wet system options
ii. High level radiant heating (not recommended)
iii. Provision of hot air to the space (not recommended)

The recommendation would be to progress with underfloor heating, in particular with electric heating which will be relatively easily and quickly installed. If a wet system is preferred, then a source of low grade heat could be provided from the CHP system.

The general lab areas will have heating hot water supplied to each of the chilled beams to maintain comfortable conditions within each space.

The hot water for both the lab and residential areas will be generated from the waste heat from the CHP system.

7.4 Laboratories

7.4.1 Laboratories – General

Laboratories, due to the nature of research and experimentation work in these areas they are usually high energy consumers, potentially in the order of 200-300 W/m^2. The laboratory spaces at MIST are being designed to be as energy efficient as possible, but without any adverse impact on the researchers work. This creates several challenges. The main items the MEP design will focus on are;

- Avoid reheat
- No over sizing of main plant items
- Reduction in outside air load
- Fume hood design
- Applying sensible diversity for the Mechanical and Electrical loads
- Working with the researchers to establish if scheduling of the main lab equipment can be agreed between faculties, to reduce day time peak loads
- Segregating tasks with mini environments
- Separate AHU's for bench lab, lab support and core lab areas
- Ensuring that Maintenance and Commissioning can be carried out in the most effective and cost efficient way
- Allowing flexibility and adaptability: Designing the MEP systems such that should future expansion of labs or offices take place, minimal disruption will be imposed on the existing spaces.

From discussions with the Faculty, the following infrastructure services may be required to the lab areas;

- Nitrogen
- Argon
- Compressed air (100 lb)
- Lab air (20 lb)
- CO gas
- Hydrogen
- Natural gas (for engine testing and other experiments)
- De-ionised water
- Process water

7.4.2 Laboratories – General Supply and exhaust

To reduce energy consumption within the lab bench areas, it is proposed to utilize active chilled beams. The chilled beams will cool the lab space only – it is not intended for the fresh air supplied via the active chilled beams to be used as make up air for any exhaust air fume hoods. The chilled beam will contain other service elements such as sprinkler heads, PA/VA, fire alarm detection, lighting. The spacing and location of the chilled beams will be such, that access and maintenance is easily done along with future partition relocation.

The ability to enhance the air change rate, in the event of an emergency will be incorporated into the system design. By means of a panic button, the air change rate within a particular zone of the lab can be increased to 20 air changes/hour to ventilate safely the space from any potentially toxic fumes.

To reduce the amount of air cooling required, process cooling water will be circulated to the lab areas. This water will take the heat away from any major heat emitting equipment within the labs. Equipment such as X-Ray equipment, electron microscopes, mass spectrometers, gas chromatographs etc. The process cooling water will reject the majority of the process loads created by lab equipment. Whereas Chilled water will be used to finely control the cooling water temperature. Plate frame heat exchangers located in the mechanical equipment room spaces will reject heat to both the process cooling water system. Process cooling water will be distributed around each lab space.

The options of rejecting this heat are;

i. Dedicated packaged chiller (recommended)
ii. Using an air condenser (not recommended)
iii. Re-circulate through Cooling Towers

7.4.3 Laboratories – Embedded Cooling Coils within Slab - Option

If the slab in the lab areas remains exposed, slab cooling could be incorporated. Although the cooling capacity from this system is limited, it could assist with leveling out the peak internal summer time temperatures.

Chilled water pipe is distributed within the slab as shown below. The temperature of the chilled water is approximately 14-15°C. With the large surface area within the waffle slab, the amount of cooling provided to the room could be significant.

Figure 7-14 Cut away section of coils embedded in slab

It could also prove advantageous to incorporate a small element of this in one area of the lab for testing and monitoring by the Faculty.

7.4.4 Laboratories – Fume hood/Specialist exhaust systems

It is currently assumed that the following specialist exhaust systems will be required throughout the lab spaces;

- Fume hood exhaust
- Welding Exhaust
- Engine Exhaust (Diesel and Natural Gas engines)
- Gasification equipment exhaust
- Furnace exhaust

Each of these specialist exhaust systems will require dedicated ductwork/flues routed through the building to roof level.

To enable a low energy approach to servicing each of these exhausts, careful planning and analysis will be required to minimize duct/flue runs and bends, in order to reduce Fan Power requirement.

As information on the various exhaust systems is limited at this stage, concentration has been given to how the exhaust from the fume hoods can be made more efficient. The proposal here is to adopt a 'Berkeley' fume hood, often referred to as an auxiliary exhaust system. This works by supplying air directing to the hood entrance and exhausting from the rear, whilst maintaining a velocity of 0.25m/s. The air which is supplied to the hood need not be cooled to 21°C, but at a slightly higher temperature of 26-28°C, to reduce cooling capacity on the main plant. Also, because of the lower velocity requirements, lower volumes of air make up air are required. Energy savings of between 50-70% can be achieved with this hood arrangement.

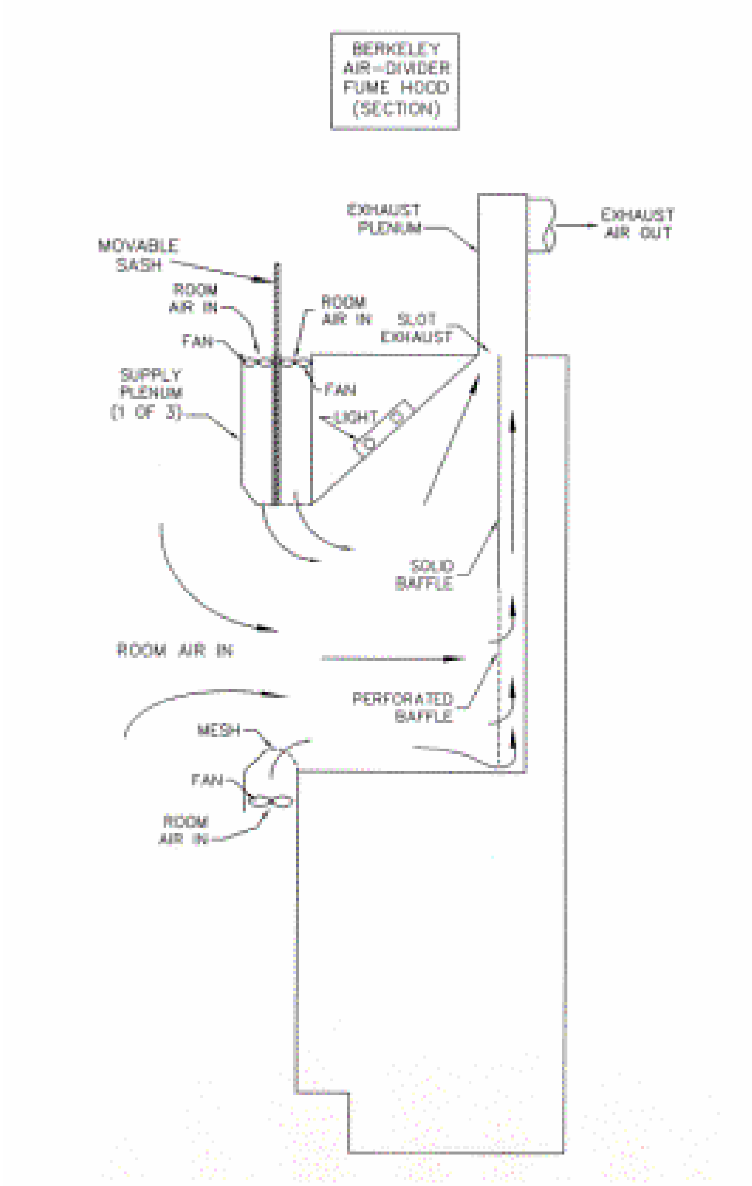


Figure 7-15 Schematic of the Berkeley Hood; side view show airflow patterns

7.5 Amenities

The amenity areas on the ground floor will be comfort cooled via a dedicated AHU system supplying air to high level chilled beams.

7.5.1 Clean Rooms

It is anticipated that the clean rooms located within the basement will be class 1,000, with localized fume hoods giving class 100, where required. The clean rooms will be modular and will be designed by the Lab Consultant. The clean rooms will be expanded over a period of time, and will be available for use for students from phases 1b, 2 and 3. The infrastructure (power/cooling/IT/etc) will be provided for the fit out of the clean room. Depending on the solvent materials being used, a review of the location of the clean rooms may need to take place, due to fire safety issues. The clean room will be protected from fire by use of a gas fire protection system.

7.5.2 Basement Ventilation

The basement will be generally ventilated to 1.5 air changes per hour, supplied from a dedicated Air Handling Unit.

7.5.3 Kitchen/Restaurant

A designated air handling unit will be provided to serve the kitchen and food preparation areas interlocked for operation with the kitchen exhaust systems.

Vitiated air from the kitchen areas will be routed to discharge at roof level. The kitchen supply and exhaust ventilation systems will be of the variable volume type with energy saving controls provided integral with the kitchen extract canopies. Based on temperature and obscuration sensors the exhaust volume will match the incident load. The supply air system will track incident exhaust volumes via localized VAV control devices.

7.5.4 General Toilet Areas

General toilet areas will be served with supply and exhaust air systems, sized at 12 air changes per hour. Heat recovery will be incorporated within each of these systems.

7.5.5 Classrooms

In the current Architectural Concept, there are 2 main classroom types. The larger type is the stepped classroom on the boundary of Phase 1a. It is proposed that this classroom will be ventilated and cooled via a dedicated displacement air handling unit located within the basement area. The supply diffusers within the Classroom will be positioned in the rise of the step, with hot exhaust air being extracted at high level. This system type works perfectly with high floor to ceiling spaces where the primary cooling load is occupants, lights and small plug loads.

The smaller classrooms will be comfort cooled via a radiant high level system (either chilled beams or chilled ceiling) with outside air provided at high level or at low level (displacement diffusers in walls)

7.5.6 IT Room Cooling

The cooling loads for the IT /Server rooms at MIST are yet to be established. However, following discussion with the VP of IT at MIT, the typical loadings per IT rack is in the order of 10kW. This heat load needs to be rejected in the most efficient way possible, whilst providing N+1 standby power and cooling.

The traditional method of cooling IT rooms is to supply chilled water at low temperatures (in the region of 6°C) to either downflow or upflow air conditioning units. This system type takes up large amounts of space and is inherently high energy consuming.

The alternative low energy option is to use CO2 cooling. Liquid Carbon Dioxide is electrically benign and non hazardous to servers and cabling. CO_2 has a very high capacity to remove heat. It can absorb up to 7 times more heat than chilled water. Reduced space requirements are also an attractive benefit.

The principle of CO_2 cooling is relatively simple. A system of fans and CO_2 pipework is attached to each IT cabinet as shown below; the fans pull the room air over the servers and onto the CO_2 pipework which then absorbs all the heat emitted by the servers. The liquid CO_2 transports this heat to the chilled water system within the building or a dedicated chiller to enhance resilience. At MIST, the option of a dedicated chiller is sensible as, the main building chillers will be sized to generate higher chilled water temperatures (in the region of 14-15°C)

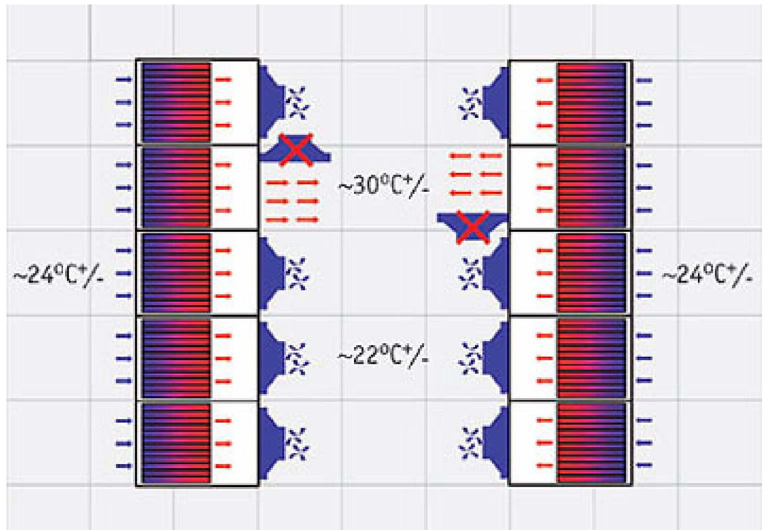


Figure 7-16 IT racks showing the fan attachments and air movement

7.6 'Tertiary' Air handling units

The tertiary ventilation plant serving the building will generally be located within designated plantrooms at basement level. To reduce the length of ductwork distribution runs, (thereby reducing fan power and increasing overall efficiency), 4 plant rooms are required as indicated on the concept drawings. The final location and size of these plant areas will be established at Scheme Design stage. Fresh air for ventilation will be drawn from the mechanical driven wind tower systems described elsewhere within this report.

Tertiary ventilation air handling units located within the basement plantrooms will include (as a minimum);

- Residence (AHU 01)
- Residence (AHU 02)
- Ground floor Amenities (AHU 03)
- Bench Laboratory (AHU 04)
- Support Laboratory (AHU 05)
- Core Laboratory (AHU 06)
- Bench Laboratory (AHU 07)
- Support Laboratory (AHU 08)
- Core Laboratory (AHU 09)
- Circulation Space (AHU 10)
- Auditorium and Classrooms/Library (AHU 11)
- Basement Areas (AHU 12)
- Student Services (AHU 13)

The final number and configuration of Air Handling Units will be dependent on the occupancy schedule of the various different areas.

The tertiary air handling units will incorporate cooling/heating coils, and supply fans along with attenuation. These air handling units will enable each of the main areas within the building to be zoned as described above according to use and occupancy schedule.

A low velocity ductwork distribution system will be routed vertically through the building. Supply air will be admitted to each of the spaces via high or low level diffusers located within each space. Return air will generally be ducted from the conditioned space via exhaust diffusers at high level.

Each of these air handling units will incorporate variable speed fans to allow adjustment of volume flow according to the occupancy scheduling of the various areas within the building.

7.7 Smoke Ventilation

Subject to the advice from the Fire Consultant (not yet appointed), Smoke Ventilation from the main building is achieved by running a smoke venting fan within the Mechanical Ventilation Towers. The fan will be rated to 200°C. Access and maintenance issues will need to be agreed during scheme design.

Throughout the building, the supply and exhaust ductwork will have a series of fire/smoke dampers which will be monitored and operated from a main smoke ventilation panel.

The details of the system operation and specification will be completed once the Fire Consultant has been appointed.

7.8 Building Management System – using a network platform

Technology is rapidly replacing the traditional GUI software typically installed on desktop PCs to manage a building or facility which can be standalone or provide some remote support access. Increasing use remote control and monitor is being made using embedded controllers which connect to and store their historical and real time data on secure servers.

Another requirement is cost where the BMS software should be open source therefore not licensed or protected by a sole manufacturer. Open source allows the software and hardware application usage to expand at a quicker rate, by third parties, than under a corporate marketed model.

7.8.1 Lonworks – Global wide provider

The most advanced globally used networked platform available is Lonworks, which was initially developed by Echelon Corporation in 1999 since then it has been gained certification under global codes such as ANSI, CECED (European) and AIS.

Lonworks can network devices over media such as twisted pair, power lines, fiber optics, and RF.

By 2006 approximately 60 million devices were installed with LonWorks technology. Manufacturers in a variety of industries including building, home, transportation, utility, and industrial automation have adopted the platform as the basis for their product and service offerings.

Statistics as to the number of locations using the LonWorks technology are scarce, but it is known that products and applications built on top of the platform include such diverse functions as embedded machine control, municipal and highway street lighting, heating and air conditioning systems, intelligent electricity metering, subway train control, stadium lighting and speaker control, security systems, fire detection and suppression, and newborn location monitoring and alarming.

How it works - Summarised

As Web Servers become more readily adopted in the market place Systems Integrators and End Users are looking for more functionality from this device.

A Web Server can provide as little functionality as serving up an html page with static data over the Internet, right through to providing dynamic detailed graphics using Java™ along with browser configurable applications such as alarm handling, data logging, scheduling and optimum start stop. By selecting the latter, an area controller is provided that will replace individual discrete devices e.g. Data Logger, Scheduler, etc. and enable direct configuration and presentation of these applications through a standard web browser such as Internet Explorer™. This enables cost effective solutions to be provided for a wide range of applications.

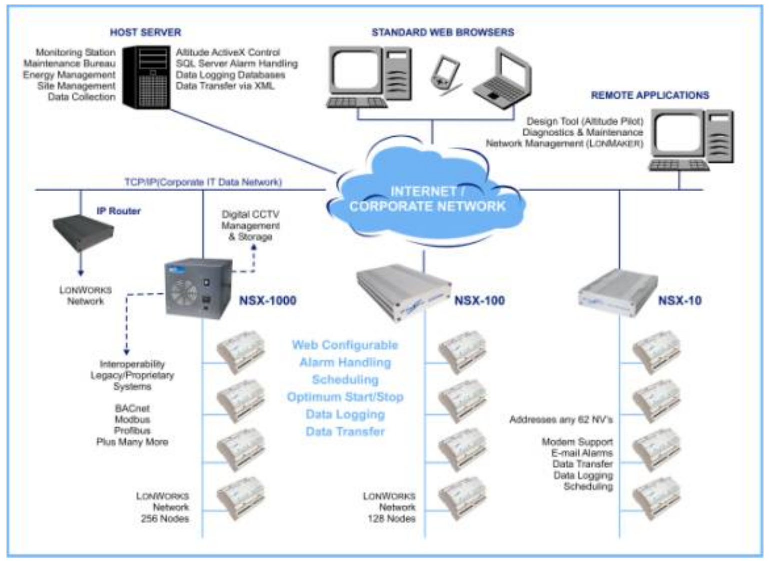


Figure 7-17 Schematic of LonMark network

Providers – Applications, Products and services

LonMark International and its Affiliate Organizations have grown to over 500 members today. Membership includes consultants, end users, integrators and manufacturers including major controls companies in the building, home, industrial, transportation, telecommunication and utilities industries worldwide.

In summary it is proposed that a fully automatic BMS will be provided to serve all the mechanical and electrical services installations within the building. The system will be of the electronic type operating over a communication network. All items of plant and equipment will be capable of fully automatic operation on a standalone basis. Via the communication network all systems will be monitored and addressed from a central station and from remote locations.

The system will provide for energy monitoring and interactive maintenance and service scheduling. The system will address all HVAC and PH distribution systems plant and equipment, electrical power distribution and generation, lifts, lighting, security and fire alarm interface.

As MIST will be a centre of innovation and research, the full capabilities of energy monitoring will be applied.

As a minimum, the following monitoring is initially proposed;

- Chilled water flow
- Liquid desiccant flow
- Condensing water flow
- Potable water flow

Power consumption (Mechanical plant, lighting and plug load being monitored separately)

These main items will be monitored separately within the building as follows;

- Residential (unit by unit)
- Bench Lab
- Support Lab
- Core Lab
- Offices
- Classrooms
- Amenities

8 Public Health

8.1 Infrastructure

From information available it is assumed that primary utility services will be available of adequate capacity and within program.

The following infrastructure connections are required for the Public Health services building design:

- Potable water main
- Fire main (potable main could be used until fire main infrastructure is complete)
- Black water drainage connection
- Surface water drainage connection for overflow from harvesting system (could discharge into black water connection)
- Hazardous laboratory waste water connection (could discharge into black water connection if hazard level is low)
- Borehole water for evaporative cooling systems

8.2 Domestic Hot and Cold Water Services

8.2.1 Potable Water Installation

The incoming potable water main will serve a bulk storage tank located within the basement with a nominal capacity of 40 m3.

This will provide storage for one day's water requirement for a building population of 200 at a consumption rate of 200 l/person/day. Please note that this is an overall figure and includes an allowance for café and laboratory use. The target which will be met during scheme design will be 80 l/person/day.

A booster pump set draws water from the tank to serve the laboratory water purification plant, treated grey water storage tank make up, hot water plant and all potable water building outlets : sinks, wash hand basins, showers, baths, washing machines & dishwashers.

All fittings will be provided with flow restrictors on supply pipe work. Restrictors will be fitted with union fittings allowing for easy replacement to enable further reduction of water flows in the future.

Wherever possible water for cooling and evaporative purposes will not be supplied from the potable supply but from grey water or from a dedicated water supply derived from a local borehole.

All pump sets will be provided as duty and standby / assist with inverter drive motors for variable volume energy efficient operation.

8.2.2 Laboratory Purified Water Installation

Allowance has been made for a primary treated laboratory system comprising:

- potable fed first stage primary water treatment plant located within the basement,
- purified water storage tank for one days consumption estimated at 7 m3 approx,
- booster pump set,
- Purified water distribution system to all laboratory fittings.

The type of primary treatment plant & storage capacity will be developed with the specialist.

It is anticipated that any requirement for secondary treatment can be accommodated via small point of use water purification units.

8.2.3 Treated Grey Water Installation

A treated grey water bulk storage tank will be provided within the basement with a nominal capacity of 40 m3.

This will provide storage for two days water requirement for a building population of 200 at a consumption rate of 100 l/person/day.

Two days storage will allow for planned shutdown of the treatment plant for maintenance without having to discharge valuable grey water to the black water sewer system.

A booster pump draws treated water from the tank to distribute grey water via a designated pipe work service to serve all WCs, urinals and irrigation points / systems.

All pump sets will be provided as duty and standby / assist with inverter drive motors for variable volume energy efficient operation.

8.2.4 Domestic Hot Water Installation

Domestic secondary hot water storage will be provided via a minimum of two central hot water storage cylinders located within the basement.

A highly insulated pumped flow & return system will distribute hot water to all outlets within the building.

The total hot water cylinder capacity will be determined from further study into the most efficient balance between storage times, generation capacity and peak draw off periods.

The complete hot water storage and distribution system will be of potable standards throughout and supplied to all hot water fittings.

All fittings will be provided with flow restrictors on supply pipe work. Restrictors will be fitted with union fittings allowing for easy replacement to enable further reduction of water flows in the future.

Details of primary hot water generation are described elsewhere in this report.

8.3 Drainage Installations

8.3.1 Black (Foul) Water Drainage

A gravity black water drainage system will be provided to serve all WCs and urinals.

Black water will be collected via down pipes & a horizontal collection system prior to discharge to the local infrastructure sewers.

Should the infrastructure not be available for Phase 1A, or be installed at a shallow depth, then black water will be collected into concrete tanks located below basement floor level of the building. Each tank will be fitted with at least two submersible drainage pumps arranged as duty & standby.

Black water will then be pumped to external sewers for onward travel to the sewage treatment plant.

8.3.2 Grey (Waste) Water Drainage

A gravity grey water drainage system will be provided to serve all wash hand basins, sinks, showers, baths, washing machines & dishwashers.

Grey water will be collected via down pipes & a horizontal collection system prior to discharge to an onsite grey water storage tank of 40 m3 capacity located within the basement.

The tank will provide storage for two days grey water drainage for a building population of 200 at a consumption rate of 100 l/person/day. Two days storage will allow for planned shutdown of the treatment plant for maintenance without having to discharge valuable grey water to the black water sewer system.

From the storage tank grey water passes through a treatment plant that will typically comprise aerobic treatment, filtration / micro filtration and sterilization.

Treated water then passes to a 40 m3 capacity treated storage tank & booster pump set to distribute treated grey water via a designated pipe work service to serve all WCs, urinals and irrigation points / systems.

Black & grey water drainage outlets from basement toilets & plant rooms will be collected via separate gravity collection systems to a number of sumps below basement slab level.

Waste from the black water sumps is then pumped either to the local gravity sewer or to the central black water storage sump.

Waste from the grey water sumps is then pumped to the grey water drainage storage tank for treatment.

8.3.3 Laboratory Waste Water Drainage

Waste water from the laboratory sinks will be installed in corrosion resistant pipe work and discharge via local dilution pots.

Depending on the hazard rating of the discharged waste water the laboratory drains can be arrange to discharge as follows :

i. Low hazard waste: discharge waste water to the gray water system for treatment and reuse.

ii. Medium hazard waste: discharge waste water to the black water system for treatment & reuse via the main sewage treatment works.

iii. High hazard waste: discharge waste water to a secure storage tank within the basement for removal by pumps to a roadside tanker for specialist offsite disposal.

At this stage allowance has been made for a 40 m3 nominal capacity high hazard waste water storage tank and discharge pumps within the basement.

The 40 m✣ storage capacity will allow for approximately one weeks storage at an estimated 7 m3/day laboratory water consumption. This will limit the movement of roadside tankers required for specialist offsite disposal.

If the laboratory benches require the flexibility to be easily repositioned then small local packaged drainage pumps will be located beneath each bench. The pump discharge will rise to high level & connect to a gravity collection drain with the ceiling void.

Advantages:

- no need to core drill holes through floor slab for drain each time a bench is repositioned,
- no need to take down the ceiling below to reroute the gravity drain to the drain stack.

Disadvantages:

- Energy consumption of multiple drainage pumps,
- Maintenance of pumps,
- Greater capital cost than fixed gravity system.

8.3.4 Rainwater Drainage

Surface water from the building roofs, terraces and ground floor podium areas will be collected via gravity drainage pipes & a horizontal collection system to a central rainwater holding tank at basement level. A filter & sediment retention unit will be installed on the inlet to the tank.

At this stage the rainwater holding tank has been sized with a nominal storage capacity of 200 m3. With a total building roof / podium area of approximately 10,000 m3 this will provide storage for the following rainfall periods assuming an 80% permeability and no draw off during the fill time :

20 minutes at 75 mm/hr intensity,

10 minutes at 150 mm/hr intensity.

From the holding tank rainwater will pass through a filtration & sterilization unit before being pumped to the treated grey water storage tank.

Controls within the tank will be interfaced with the grey water treatment plant to enable the rainwater transfer pumps to operate whenever rainwater is available.

Once the holding tank reaches full capacity excess rainwater will overflow to the black water sump where it will be pumped to the external sewer system.

8.4 Active Fire Fighting Systems

8.4.1 Sprinkler System

It has been assumed that a fully automatic sprinkler installation will be required generally to all areas of the building, including the residential. Please note that subsequent development of the Fire Strategy for the building may determine that sprinkler protection to part, or indeed the whole of the building, is not required.

A bulk sprinkler water storage tank will be provided at Basement Level supplied from the infrastructure fire main. If the infrastructure main is not available for Phase 1A then the incoming potable main could be used to feed the tank.

At this stage a full capacity sprinkler tank with a usable capacity of 160m3 has been allowed for. This is in accordance with Loss Prevention Council requirements for an Ordinary Hazard Group 3 classified building not exceeding 30m in height. This will be reviewed against other Local Codes at detailed design stage but is likely to be close to the maximum storage requirement.

The main components of the sprinkler system will be:

- a bulk water tank as described above,
- duty and standby sprinkler pumps with the standby pump of the direct drive diesel type,
- central installation control valve set(s),
- distribution pipe work to rising mains located within or adjacent to staircases,
- branches at all floors each with a zone control valve set comprising of a monitored isolation valve and a monitored flow switch with test facility.
- on floor sprinkler pipe work & sprinkler heads.

Sprinkler heads may be omitted from essential electrical, communications & computer rooms subject to suitable compartmentation and automatic fire detection being provided. In addition a gaseous fire extinguishing system may be required.

8.4.2 Wet Hydrant / Riser System

It has been assumed that a fully automatic wet riser / external hydrant installation will be required to the internal and external areas of the building, including the residential. Please note that subsequent development of the Fire Strategy for the building may determine that wet hydrant protection to part, or indeed the whole of the building, is not required.

At this stage it is assumed that the fire main infrastructure will not be installed for Phase 1A and therefore external fire hydrants will not be provided in time for building occupation.

Therefore allowance has been made for a bulk wet hydrant water storage tank and booster pumps to serve both external fire hydrants and an internal wet riser installation. These are for use by Fire Fighting Personnel only.

Allowance has been made for a wet hydrant storage tank with a usable capacity of $160m^3$. This will provide a water supply for approximately 2 hours assuming 3 hoses are in use simultaneously with a total flow of 1500 l/min.

Please note that Local Codes may permit the storage capacity to be reduced to 80 m3 or 1 hour's consumption. In addition they may require the wet riser system within the building to be replaced with a simpler hose reel installation that is more suitable for building occupants to use.

The main components of the wet hydrant / riser system will be:

- a bulk water tank as described above,
- duty and standby pumps with the standby pump of the direct drive diesel type,
- central installation control valve set(s),
- distribution pipe work to external fire hydrants located at strategic positions around the building perimeter,
- distribution pipe work to rising mains located within or adjacent to staircases,
- branches at all floors each with a pressure regulated landing valve & a folded length of hose within a wall mounted cabinet.

8.4.3 Gaseous Fire Extinguishing Systems

Local Codes or the Client may require an automatic gaseous fire extinguishing system within essential electrical, communications & computer rooms where sprinklers are undesirable.

A gaseous fire extinguishing system would typically comprise of:

- bottled inert gaseous fire extinguishing agent such as Inergen,
- piped distribution & gas discharge heads within the room to be protected with zone control as necessary,
- dedicated automatic fire detection installation,
- manual gas safety shut off points,
- pressure relief and gas extract ventilation systems.

8.5 Alternative Public Health System Design Options

There are several alternative options for the "base" design systems described which will reduce water consumption. These are summarized as follows and should be considered together with the above:

8.5.1 Potable & Grey Water

i. Provide additional treatment to grey water to enhance quality to potable water standard.

ii. Supply all hand wash basins, showers, baths, washing machines & dishwashers from enhanced grey water.

iii. Standard grey water treatment can remain for WC & irrigation use.

iv. Omit individual washing machines to residential units & instead provide central washing machine facilities supplied from the grey water system.

8.5.2 Domestic Hot Water

i. Omit hot water from wash hand basins in Campus & basement toilet areas. Supply with cold water only via spray tap.

ii. Omit central hot water storage cylinders & building wide pumped flow & return system.

iii. Instead provide small local hot water cylinders in each residential unit, café & toilet block. Local residential cylinders to have limited storage capacity to discourage hot water consumption. Central primary hot water to be used as principle energy supply but with an electrical immersion heater as a backup facility on restricted time period use.

8.5.3 Water systems generally

i. All taps and shower controls to be fitted with timed flow discharge. Either through mechanical concussion fittings or infra red controlled fittings.

8.5.4 WC`s

ii. Provide vacuum drainage system for WCs in all areas. Vacuum drains to terminate in collection system in basement and wasted pumped to black water sewer system.

iii. For: Vacuum WC`s typically use 1.3 ltr water per use compared with 4 or 6 ltrs for conventional WCs.

iv. Against: capital cost of separate vacuum drainage system and additional cost of specialist WCs. Energy consumption of vacuum pumps and discharge pumps.

9 Electrical Systems

9.1 Energy Initiatives

Given the project objective of a zero carbon installation a number of initiatives have been considered in the Electrical design to minimise energy consumption and the use of fossil fuels.

9.1.1 Zero Carbon Back-up power

It is currently assumed that the grid power distribution system cannot be used for emergency power. Traditionally back-up power would be provided by a diesel standby generator however since no fossil fuels are to be used on the site, alternative systems must be used. The table opposite outlines the systems considered for as alternatives to diesel powered generators.

The conclusion is that Biofuel powered generators are the most likely solution. Hydrogen fuel cells should also be investigated further to see if they can be applied now or in the future if a safe supply system can be devised.

9.1.2 DC power Distribution

Consideration has been given to the use of DC power distribution to make use of the DC power generated by Photovoltaic cells.

DC power distribution would avoid the need for the inverters required to convert the DC voltage produced by the PV cells to AC voltage required for sitewide distribution. These inverters result in power loss (About 3%) which generates heat.

For the DC voltage to be useable for normal appliances (Lighting mostly) and not to suffer significant losses through volt drop it is likely that a voltage of around 120V DC will be required.

As the voltage output from the PV cells will vary, a regulator will be required to maintain the voltage within limits. This would take the form of a battery or rectifier to convert AC power to DC power.

During hours of low solar radiation the DC voltage will need to be maintained by other sources of power (AC inverter) or the DC distribution switched to AC. Switching the DC power to AC would create difficulties with some appliancies and therefore limit the application of the DC distribution.

Our conclusion is that a DC distribution system will be less efficient and less practical than an AC distribution system apart from a few applications such as pumps which could be considered further.

EVALUATION OF ALTERNATIVES TO DIESEL GENERATORS FOR				
	Description	**Space**	**Cost**	**Comments**
Diesel Generators	Traditional Diesel powered Standby generation	Small	Low	Although the volume of fuel used for emergency applications would be small the use of fossil fuels not acceptable
Bio-fuel Powered Generation	Engine powered by Bio-fuel	Medium	Medium	Biofuels have some environmental concerns due to need for landmass taken away from food production and resulting increase in de-forestation, however for emergency purposes the consumption of Biofuel will be minor for emergency purposes.
Hydrogen Fuel Cells	Fuel Cell powered by Hydrogen. Hydrogen storage container.	Medium	High	The technology is developing rapidly. Currently large scale hydrogen fuel cells have a long warm up time meaning that the fuel cell must be on-line continuously for use as an emergency power source or linked to a UPS system.
				Hydrogen storage is a concern that needs to be resolved. The opportunity for Hydrogen Fuel cells should be considered further perhaps with provision for the future.
Large Scale Stored energy	Various options have been considered	Large	High	No stored energy systems are considered practical for emergency power applications.
	Stored water			
	Stored steam			
	Flywheels			
	Batteries.			
Solar & Wind Energy	Using PV's and Wind turbines	Medium	Medium	Systems are not practical for emergency power applications due to the reliance on availability of wind and solar

Figure 9-1 Evaluation of alternatives to diesel generators

9.1.3 Low Energy Lighting Systems

Various methods for low energy lighting are being evaluated for their most efficient application. These are summarised below.

Lamp Photo	Light Source	Typical Efficacy (lm/W)	Applications
	Incandescent	15 – 20	Will not generally be used. May be some applications such as in a domestic fridge or other appliance where alternatives are not practical
	Mains voltage halogen	15 –20	Will not generally be used. May be some applications such as decorative lighting inside wine cupboard or others where alternatives are not practical
	Low voltage halogen	25	Will not generally be used. May be some applications such as decorative lighting inside wine cupboard or others where alternatives are not practical
	LED	20-30	Low power accent lighting where fluorescent and metal halide is not suitable
	Energy saving replacement lamp	40 - 60	Ambient lighting for domestic areas Dimmable versions are now available
	LED (new generation)	60 -70 (150 in lab conditions)	Low power accent lighting where fluorescent and metal halide is not suitable. This LED is still under developing and is not currently commercially available but will be considered for widespread application in the MIST project..
	Compact fluorescent	50 - 70	General lighting where uniform illumination is required
	Linear fluorescent (T5)	70 - 100	General lighting where uniform illumination is required
	Metal Halide	60 -100	Accent lighting where dimming and controllability is not needed. Instant re-striking doubled-ended lamp can be used in external area
	High pressure sodium	70 - 150	External areas where good colour rendering is required
	Low pressure sodium	100 - 200	External areas where good colour rendering is not required..

9.2 Electrical Design Objective

Electrical services will be designed to meet the following standards:

- Abu Dhabi Electricity and Water Authority - Regulations for Electrical Installations.
- CIBSE Codes
- NFPA Regulations For Fire & Life Safety Systems
- Codes and strategies adopted for the Masdar masterplan

All areas of the building will be designed as completed installations apart from Laboratories and data centres. In these areas requirements are likely to change right up to occupancy of these spaces and it it therefore planned that basic electrical services will be provided for later design and fit out to suit the applications and requirements when they are defined.

Electrical systems will include the following:

- Temporary generation for use until the campus is connected to the electricity grid. These will serve as utility supplies in conjunction with the on-site PV cells.
- Incoming Utility High voltage supplies and High Voltage Distribution System;
- Substations
- Low Voltage distribution system
- Standby generation for life safety systems and specific critical lab loads only
- Main electrical distribution and containment
- Small power electrical distribution.
- Daylighting systems
- Lighting, external lighting and lighting control systems.
- Main containment routes for Telecommunications, Security, and Telecommunications containment.
- Security systems including intruder detection and CCTV.
- Fire detection and alarm systems
- Lightning protection

9.3 Maximum Demand Requirements

The Electrical maximum demand is closely related to which energy efficiency measures can be adopted in both the electrical and mechanical systems and also what the laboratory loads are. The calculation opposite shows estimate for a "Best Practice" design and also target figures of what may be achievable. These calculations will developed in detail during the next phase of the project.

ELECTRICAL LOAD ESTIMATE (MW) BY PHASE FOR BEST PRACTICE AND MIST TARGET					
	Phase 1a	Phase 1b	Phase 2	Phase 3	Total
BEST PRACTICE DESIGN					
Laboratories	1	2.7	2.2	0.4	6.3
Non-Laboratories	0.4	0.3	0.6	0.1	1.4
Residential	0.4	1.3	1.1	0.2	3
Mechanical	1.7	4.2	3.9	0.7	10.5
Total (Best Practice)	3.5	8.5	7.8	1.4	21.2
MIST TARGET DESIGN					
Laboratories	1	2.7	2.2	0.4	6.3
Non-Laboratories	0.4	0.3	0.6	0.1	1.4
Residential	0.1	0.2	0.1	0.1	0.5
Mechanical	1.1	2.7	2.4	0.5	6.7
Total (Target)	2.6	5.9	5.3	1.1	14.9

Figure 9-2 Electrical load estimation

Masdar City Infrastructure Supplies

Currently the city infrastructure design is at an early design stage and limited standards for electricl infrastructure have been confirmed..

The Masdar City is currently planned to be supplied from 2No 400kV grid connections terminating at receiving stations at the north end of the city. From here 22kV supplies will be distributed to each phase of the city development.. It is assumed at this stage that the electrical infrastructure will be a private utility network and international design practices will be adopted rather than the requirements of ADEWA (Abu Dhabi electric utility).

The grid connection is not due to be commissioned until 2012. Since the phase 1a project is due to be completed in 2009 a temporary power solution will be established for this phase of the project. This will comprise supplies from the city PV installation supplying in parallel with Biofuel powered combined heat and power Generators on to the 22kV infrastructure.

9.4 MIST Incoming Electrical Supplies

The phase 1a campus will be supplied at 22kV from the High voltage network supplying the city.

Two incoming supplies will be provided from separate 22kV circuits each rated to supply the essential loads in the building, such that critical systems will continue to operate in the event of failure or fire affecting one of the supplies.

The 22kV supplies will each serve a 22kV High Voltage switchboard. These switchboards will provide a metered service to a packaged substation at basement level.

9.5 Main Distribution

The packaged substations will comprise close coupled 22kV ring main unit, cast resin transformer and low voltage switchboard.

The transformer will be provided with forced cooling to enable the transformer to serve the full critical load in the event of failure of one transformer.

The switchboard will be form 4 type 6 construction with MCCB outgoing ways. Cabling from the main switchboard will be Steel Wire Armoured cables on cable ladder and cable tray.

9.6 LV Distribution

From the Low Voltage Switchboards supplies will be provided to different load centres and risers throughout the building.

Where practical, bus risers will be provided to maximise flexibility for the Lab equipment.

9.7 Connection of Distributed Generation

Connection of distributed generation is yet to be agreed with the electricity utility who currently do not allow such a practice. Since distributed generation is a key element of the philosophy of Masdar it is assumed that this will be allowed for the project.

Distributed generation will include Combined heat and power from Biofuel or Hydrogen plant; roof mounted PV cells, wind turbines and other forms of generation.

Distributed generation will be connected to local main distribution panelboards through inverters or other controllers. Wherever distributed generation is connected, a protection unit will be connected to the supply circuit breaker to disconnect the supply in the event of the supply voltage or frequency going outside of limits or in the event of a failure of the supply to prevent backfeeding of a faulty circuit.

9.8 Electrical Metering

Figure 9-3 Example of electric metering device

A networked metering system will be provided. All equipment and distribution panels over 8kVA will be individually metered. The metering system will provide the following benefits:

- Ability to monitor how and where energy is being used and thus identify opportunities for energy savings and evaluate energy saving initiatives.
- Allow department energy accountability
- Monitor maximum demand and thereby identify spare capacity for future flexibility
- Monitor power quality and disturbances allowing remedial action to be taken in areas with high harmonics or poor power factor.

It is likely that energy metering network will be combined with other forms of metering such as metering of chilled water or liquid desicant and water metering. Metering will comprise CT's and voltage connections

9.9 Generation

A central Emergency Generator will be provided powered by Biofuel.. This will be a Class 1, Type 60 system as per the requirements of NFPA 101. This will serve the following Life Safety Systems

- Fire Pump
- Passenger and Fire lifts (Passenger lifts will be sequentially grounded in the event of utility power failure).
- Smoke extract and stair pressurisation systems.
- Emergency lighting and illuminated exit signs.
- Essential Loads
- Sump Pumps

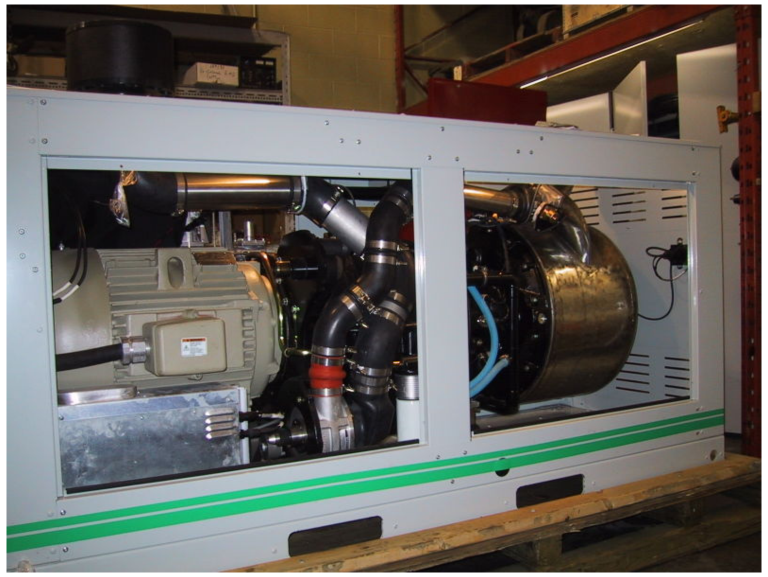


Figure 9-4 Example of installed emergency generator

The generator will be located at basement level in a plantroom with direct ventilation to ambient. The generator will include a 3 hour fuel day tank and a remote bulk storage tank with 24 hour capacity.

A generator switchboard will be provided adjacent to the generator for distribution of supplies to transfer switches.

Supplies to life safety equipment will be installed in separate fire rated shaft.

9.10 Uninterruptible Power Supplies

Provision will be made to provide uninterruptible power supplies. For lab spaces and server room equipment. Detailed requirements will be developed with the lab consultant.

For all UPS systems, batteries will be kept in separate rooms to the UPS inverters and rectifiers to minimise cooling requirements (Batteries must be kept at a lower temperature to the UPS panel)

9.11 Small Power Distribution

Small power distribution will be provided to all areas

20A radial circuits will be provided for all circuits serving socket outlets. Conductors shall be a minimum of 4mm^2.

Sockets shall be single phase shuttered type complying with BS 1363.

10A circuits will be provided for all lighting circuits. Conductors will be a minimum of 2.5mm^2.

Electrical accessories shall generally be of the metal clad type. Accessories in lift lobbies and other "finished" areas shall have a decorative finish selected by the architect.

Fixed equipment shall be served via either flex-outlet spur units and/or fixed base connectors. The contractor will provide all final connections to fixed equipment.

Wiring will generally be single core cables installed in conduit and trunking from distribution boards. Armoured cables installed on cable tray or clipped direct will also be used.

9.11.1 Labs Power Distribution

Small power requirements in Labs and Special Areas will be developed in conjunction with the lab consultant and MIT. It is likely that in lab areas, overhead busbar will be provided with facility for connection of mobile lab benches.

Overhead busbars may include Normal Power, UPS power and 48V DC power in some labs.

9.12 Lighting

Lighting design will be developed in conjunction with the Architecture and Mechanical systems and following the concepts for lowest practical energy lighting solutions.

Lighting criteria will be based on BSEN 12464 Lighting Places of Work. There is scope within BSEN 12464 for reducing designed light levels where increased apparent brightness can be achieved through use of light surfaces and high levels of illumination on ceilings and walls. Lighting design using high efficiency downlights only results in poor environment and a need to overlight to counter the effects of low apparent brightness. (If the field of vision – Walls and ceilings – are dark the apparent light level is lower). This can lead to a less efficient light solution than one with some indirect lighting.

The following table outlines the target design criteria for lighting design subject to adjustment for appaent brightness.

Location	Maintained Illuminance
Entrance halls	100 lux
Reception	300 lux
Circulation & Corridors	100 lux
Stairwells	150 lux
Store rooms	100 lux
Plantrooms	200 lux
Loading bays	150 lux
Canteens	200 lux
Rest rooms	100 lux
Toilets	200 lux
Mail rooms	500 lux
Offices	500 lux
Lounges	200 lux

Figure 9-5 Illuminance shcedule

For each area the lighting will be developed to consider the most appropriate light source both in terms of energy efficiency, lighting functionality and life cycle cost.

Where usable daylight is available, luminaires with dimmable ballasts will be provided with integral photocells to dim or switch off lighting when daylight levels are adequate.

9.13 Lighting Controls

The lighting control system will play an important part in minimising energy use. It is important that light levels provided are appropriate for the tasks of each area whether the light is provided by natural or artificial light however effective lighting controls can ensure that lighting is only provided in the areas where it is needed and for safety purposes.

All lighting will be connected to a lighting control system.

All areas will be provided with occupancy sensors where practical. Time delays on occupancy will vary depending on occupancy type. In corridors and areas of rapid movement, occupancy sensors will be set to a short time delay. In areas of small infrequent movement such as library or lounge area, delays will be longer. Where daylight is available, motions sensors will incorporate photocells to hold lighting off when daylight levels are adequate.

In areas where partial daylight is available, dimmable lighting will be provided linked to photocells to maintain illuminiation at a preset level when the area is occupied.

Each area will be provided with a light switch to turn lights off and on only (All dimming will be automatically controlled)

The lighting control system will have provision for connection of window blinds and also linked to HVAC systems to notify that an area is unoccupied, thus minimising fresh air and cooling loads.

9.14 Emergency Lighting

Emergency lighting will be provided complying with NFPA 101.

Emergency luminaires will be connected to the life safety distribution system

Illuminated exit signs along escape routes will be provided with integral batteries to provide a 1hour minimum duration.

9.15 Site Telecommunications Infrastructure

The telecommunications infrastructure will be designed in accordance with EITC guidelines.

Two EITC entry points will be provided into the building for incoming telecommunication services. These will be located in diverse locations in the basement to an EITC main telecom room.

From this rooms cable tray will be provided at high level throughout the building to floor by floor telecom rooms.

Cable tray will be provided in the telecoms riser for tenants telecom cabling.

9.16 Fire Detection Alarm and Communication

9.16.1 General

The Fire Detection, Alarm and Communication strategy will be developed in conjunction with the Fire strategy for the city.

The system will comprise the following components:

- Fire detection and alarm system
- Voice evacuation system
- Fire fighter's telephone system
- Disabled Refuge telephone system
- Fire fighters control and indicating panel

A central Fire Command Centre (FCC) will be provided to monitor all these components. This will include:

- Main Fire detection and alarm control panel (FACP)
- Voice communication system control panel (VCS)
- Fire fighter's control and indicating panel (FCIP)
- Fire fighter's telephone system (FTS)
- Generator Status Panel (GSP)
- Fire Pump Status Panel (FPSP)
- Lift Status Panel and all required keys (LSP)
- Telephone with direct outside line

9.16.2 Fire Detection and Alarm

A fire detection and alarm system will be provided complying with NFPA 72 (National Fire Alarm Code)

The system will comprise analogue addressable devices loop connected to distributed control panels in each building. The distributed control panels will be loop connected back to the FCC

Devices will include the following:

- Smoke and heat detectors. This will include detectors covering all protected escape routes and areas leading on to escape routes; within 1 meter of lift shafts and doors on magnetic hold opens; and other locations to operate the smoke management system.
- Break glass call points adjacent to each stairway and at the final exits.
- Sprinkler flow and tamper monitoring on each sprinkler zone valve to monitor activation of a sprinkler head and tamper switches
- Speakers incorporated into detector bases for broadcast of evacuation messages
- Flashing beacons in noisy areas (plant rooms) and toilets and other areas where people may be in isolation.

Activation of any initiating device will initiate the appropriate smoke control sequence and voice evacuation message, unlock stairwell doors, release doors on magnetic hold open devices.

The Voice Evacuation Control Panel (VCS) will be initiated by the FACP and will provide phased evacuation dependant on the fire zone. The VCS will be monitored by the FACP.

Speakers will be surface mounted in plant areas and mounted in ceiling tiles elsewhere.

9.16.3 Fire Telephone System

The Fire Fighting Telephone System (FTS) will be provided to allow two way communication with the Fire Command Centre and local fire fighting phones situated at each level in the fire fighting cores. This will also be used for communication with the disabled refuge.

9.16.4 Fire System Cabling

All fire alarm cabling between FACP, VCS panels and for the FTS will be enhanced category to BS5839-1. All other cabling will be standard category to BS5839-1.

9.17 Earthing

A comprehensive earthing system will be provided complying with local codes.

All low voltage distribution shall be TN-S (To be confirmed)

A main earth bar will be provided in each switchroom. Each earth bar will be connected to the following.

Main earthing conductor to the step down transformer star point.

Earthing conductor to the LV switchboard earth bar

Main equipotential bonding conductors to the lightning protection system, incoming services connections and between each earth bar.

Equipotential bonding conductors to all other extraneous metalwork in the building.

9.18 Lightning Protection

A lightning protection system will be provided complying with BSEN 62305:2006.

The protection system shall make use of metallic roof finishes for air termination, structural steelwork for down conductors and steel in foundations for earth termination.

Protection will be provided in accordance with the 60m radius rolling sphere method requiring protection to the sides of the building against side strikes.

9.19 Security

9.19.1 General

Security System deign will be developed in conjunction with the security consultant.

Wireways will be provided as required for CCTV, intruder detection, and access access control systems.

The system design should pay particular attention to the most energy efficient system design. A fully distributed system may save on cabling but will require extra power supplies and batteries which may consume more power than a centralised system.

10 Long Lead Items which may need to be Pre Ordered

The following items may require pre order subject to the final project programme;

i. Liquid desiccant System Air Handling Plant

ii. Generators

iii. HV/LV transformers

iv. Concentrated Solar Power system

v. Absorption Chillers

11 APPENDICES

11.1 APPENDIX 1
Selection of lab fume hoods for laboratory space

11.1.1 Backgrounds of Laboratory fume hood:

Laboratory fume hoods are partially enclosed workspaces that are exhausted to the outside. The efficiency of a laboratory hood is measured by its hood face velocity and required air flow. Hood face velocity is a measurement of air flow speed across the imaginary plane running between the bottoms of the sash to the work surface. The greater the hood face velocity, the more quickly toxins and other vapours can be flushed from the system. Required airflow is related to hood face velocity in that it is a measurement of the amount of air flow required to achieve a laminar flow velocity of 100 feet per minute (fpm) or 0.5m/s.

There are five main hood construction types: conventional, bypass, auxiliary air, variable air volume, and ductless.

i. Conventional hoods represent the original and most simple of the hood design styles. With a conventional hood the volume of air exhausted is constant, regardless of sash height.

ii. Bypass hoods have an added engineering feature and are considered a step up from conventional hoods. An air bypass incorporated above the sash provides an additional source of room air when the sash is closed.

iii. Auxiliary air hoods have attached dedicated ducts to supply outside air to the face of the bypass hood. The main advantage of an auxiliary air hood is the energy savings realized by reducing the amount of heated or air conditioned room air exhausted by the hood.

iv. Variable air volume (VAV) hoods are the most sophisticated hood types, requiring technically proficient design, installation and maintenance. The primary characteristic of VAV hoods is their ability to maintain a constant face velocity as sash height changes.

v. Ductless laboratory fume hoods have a conventional hood design but are self contained to re-circulate air back into the lab after filtration occurs. These hoods use either High Efficiency Particulate Air (HEPA) filters or Activated Carbon Filtration (ACF) technology to remove contaminants from the hood air.

11.1.2 Available models:

Frontier® Guard Fume Hood (Berkeley Hood)

Manufacture/ Supplier: ESCO
(http://www.escoglobal.com/fumehoods/product_8.asp)

Availability: 3rd Quarter 2007 (developed by the US Lawrence Berkley National Laboratory.)

Energy efficiency: Providing 50-70% reduction in exhaust airflow requirements. It was estimated that the Berkeley Hood could save 360 gigawatt-hours (GWh or billion watt-hours) of electricity in California, and 2,100 GWh in the US. At $0.08 per kWh, the annual electricity savings per hood is about $1,000 (approx. 8,500 kWh saved per hood).

(http://www.lbl.gov/ScienceArticles/Archive/fume-hood-elec-movie.html)

More details can be found at http://eetd.lbl.gov/l2m2/hood.html

VORTEX II®, Bi-Stable Vortex Fume Safety Cabinet

Manufacture/ Supplier: Flow Safe
(http://www.flowsafe.net/index.html)

Energy efficiency: Saving up to 60% energy consumption compared with conventional fume hoods: It operates at face velocities 40 FPM, compared with 100 FPM of those from conventional fume hoods. It can be used as a direct replacement for auxiliary air fume hoods.

More information can be found at
(http://www.flowsafe.net/bistablevortexfsc.html)

Figure 11-1 Frontier

Figure 11-2 Vortex

Pioneer®

Manufacture/ Supplier: Hamilton

Energy efficiency: N/A, information is already requested.

Pioneer is the first "low flow" laboratory fume hood to utilize Directed Airflow Technology™ to provide lower face velocities by purging the area in front of the user's body with a controlled airflow of recycled room air.

Figure 11-3 Frontier

More information can be obtained from the manufacturer at (http://www.hamiltonlab.com/fisherhamilton/products/airflow+products/fume+hoods/pioneer.asp)

Protector® XStream Laboratory Hoods

Manufacture/ Supplier: Labconco Corporation
(http://www.labconco.com/index.shtml)

Energy efficiency: Operates at face velocities from 60 to 100 FPM. Energy savings can be obtained when operated at OSHA-approved 60 FPM (indicating up to 40% energy savings).

Figure 11-4 Protector

11.1.3 Selection recommendation:

By comparing various models, *Frontier® Guard Fume Hood* (Berkeley Hood) is recommended for MIST laboratory application since it has the highest Energy efficiency by providing 50-70% reduction in exhaust airflow requirements.

Traditional fume hood design shows the incapability of the airflow system to control the intake air causing turbulent rolls and eddy currents within the work zone and ultimately resulting in concentrations of noxious fumes and possible back drafts. The solution to keeping the face velocity constant is to increase extract air volume. Esco's high performance fume hood incorporates a progressive bypass airflow system that maintains superior containment at low face velocity. It is based on the principle of redistribution of intake air hence stabilizing the vortex. Its containment property is further enhanced with a combination of aerodynamic components - upper and lower baffle system, front louvers and steel airfoil. In combination, the system addresses high volume intake without having to increase extract volume.

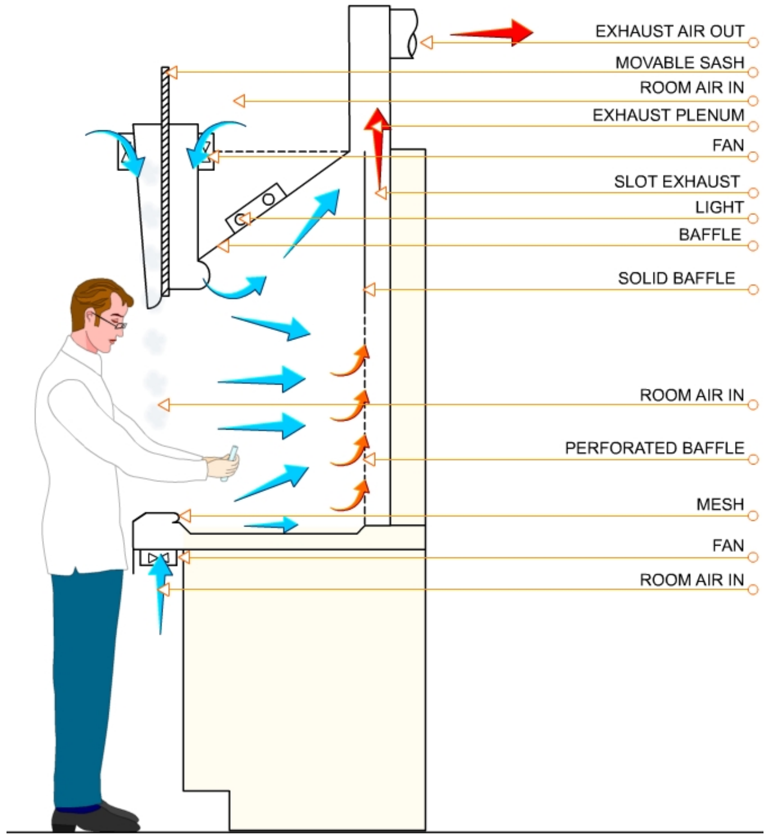


Figure 11-5 Cross section of Berkeley fume hood

Benefits:

- "Push-pull" method of containing and exhausting fumes, uses small supply fans built-in at the top and bottom of the sash to produce low-velocity airflow that gently push air into the fume hood.
- Efficient air divider that separates the fume hood's interior from the exterior, assuring the user of continuous supply of clean air towards the breathing zone.
- Easy outflow of contaminated air with the main baffle aligned at the middle of exhaust plenum.
- Advanced baffle system with perforations at the lower half of the fume hood in front of the sash opening, flushes air out at the first instance, eliminating the need to contain contaminated air longer than necessary.
- No retention or recycling of the fumes and air happens because of the diagonal cross baffle.
- Supply airflow patterns reduce currents and vortexes, improving containment and exhaust performance.
- Fluorescent lighting mounted out of air stream for better airflow uniformity, angled in a fashion that it shines down on the work surface and not on the operator. Improved lighting quality and reliability hence reducing maintenance.
- Less volume of air to exhaust, the prototype has undergone the ASHRAE110- 1995 test protocol and achieved containment with 70% flow reduction at 0.2m/s airflow velocity.
- A highly-efficient energy-saving equipment, cutting energy costs by about USD2100 per year per fume hood.

11.2 APPENDIX 2
Liquid Desiccant Cooling Systems

11.2.1 Subject Area (Category)
Air cooling and dehumidification

11.2.2 Specific Info Required
Application with energy from solar thermal collectors for air conditioning.

11.2.3 Background
In many countries, air conditioning is the main energy consumption in buildings. It is required for cooling and dehumidification of the air inside building envelopes. Most conventional air cooling technologies consume high energy and cause high electricity peak load, while some normally use refrigerants that may contribute to the increase in greenhouse gases.

An alternative, appearing to overcome those problems caused by the conventional systems, is utilising liquid desiccant for air dehumidification and cooling systems. Their thermal energy use replaces the need of high electrical demand, whilst their electrical demand for fans and pumps can be reduced to 1/5 of that of conventional systems.

The liquid desiccant cooling systems provide direct conditioned air without condensation occurring. Moreover, in dry climates, it is suggested that their regeneration can be effectively used with solar thermal energy at the temperatures obtained from unglazed solar collectors (Lowenstein et al. 1998). The cooling load can be reduced directly by heat and the systems can deliver approximately up to 100% latent cooling. The systems have been shown to be easily maintainable due to their few moving parts. Their main required maintenance would be on pumps and filters.

However, there are some concerns over the corrosive property of the liquid desiccants and their carryover with the supply air, which consequently can be harmful to human health and the immediate environment when exposure occurs. The first drawback can be avoided by using plastic components in liquid-desiccant contacting parts of the systems, and possibly cupronickel or titanium in the heat exchangers. The second can be evaded by implementing more advance versions of the liquid desiccant systems using "low-flow liquid desiccant technology". Furthermore, this advanced technology has been estimated to have approximately 40% less operational costs than the general liquid desiccant and solid desiccant systems (Lowenstein et al. 1998).

11.2.4 System operations - typical liquid desiccant systems

Basically, a liquid desiccant system contains an absorber (or conditioner), a regenerator, two pumps, and two heat exchangers.

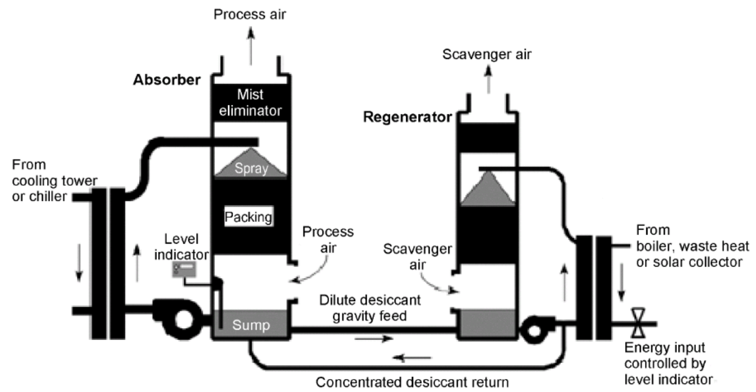


Figure 11-6 Schematic of conventional liquid desiccant system configuration (Source Lowenstein et al. 1998)

In the absorber, air is directed through packing that is being sprayed with chilled concentrated liquid desiccant. As a result of that, the cooled and dehumidified supply (or processed) air is released into an occupied space through mist eliminators on its outlet to prevent unintended droplets of desiccant from entering the ductwork or air-conditioned space.

In the regenerator, scavenger air passes through another packing, being sprayed over with heated desiccant, then it carries the water vapour through mist eliminators before travelling to the outside.

Desiccant fluid dripping from the packing in the absorber and the regenerator is collected in sumps, where it is connected to allow water collecting in the absorber sump flow to the regenerator by gravitational force. The sprays in the absorber and regenerator are produced by pumps that also drive the fluid desiccant between each sump through the heat exchangers.

The amount of sensible cooling required by the supply air determines the absorber desiccant flowrate. This requires relatively low energy input, which can be supplied from waste heat, natural gas, or solar collectors, to operate the dehumidification process. This energy input is controlled by a level indicator in the absorber sump. When the moisture load in the absorber sump increases, the fluid level rises. Then, its level indicator sends a signal requesting more energy input at the regenerator to maintain constant dehumidification performance. The regenerator desiccant flowrate is set to gain the adequate dehumidification rate required by the supply air while the regenerator pump also delivers a small amount of concentrated desiccant to the absorber sump to maintain the balance of liquid concentration.

11.2.5 System operations - low-flow liquid desiccant systems

A low-flow liquid-desiccant air conditioner consists of a conditioner, a regenerator and an interchange heat exchanger.

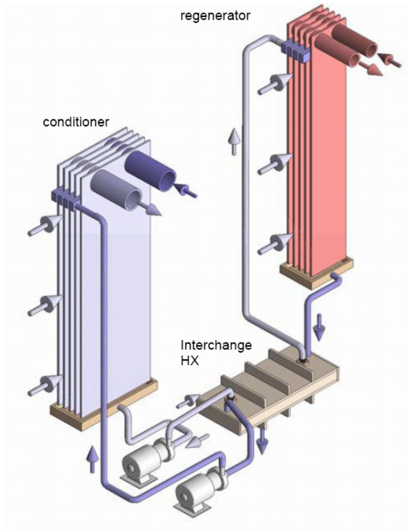


Figure 11-7 Schematic of low flow liquid dessicant system configuration (Source: Lowenstein et al 2006)

The conditioner is normally a polymer parallel-plate heat exchanger containing flowing water (either from a cooling tower, a geothermal well, lake, sea or chilled water loop) within the plates, while thin films of liquid desiccant flow in wicks on the outer surfaces of the plates. When air with high moisture content is blown through the gaps between the plates, the moisture is absorbed into the desiccant. The heat released from this absorption process is transferred to the water inside the plates. Consequently, the supply air leaves the conditioner at much lower wet-bulb temperatures and humidity levels.

The weak desiccant, then, leaves the conditioner and is pumped to the regenerator. The regenerator has the same configuration as the conditioner except flowing heated water (supplied by a gas-fired boiler, solar thermal collectors, recovered heat from an engine or fuel cell, or other energy source) within the plates instead. When the temperature increases, water evaporates from the desiccant into an air stream and is subsequently discharged outdoors.

The interchange heat exchanger performs thermal energy exchange between the hot, strong (concentrated) desiccant from the regenerator and the cool, weak (dilute) desiccant from the conditioner. This helps increase the efficiency of the regenerator and decrease the cooling load on the conditioner. To further increase the regenerator's efficiency, the scavenger air can be pre-heated before entering the regenerator.

With low desiccant flowrate in both the regenerator and conditioner, the desiccant flows completely within the thin wicks on the plates and the low air velocity through the gaps does not appear to entrain desiccant droplets. Therefore, this zero-carryover technology does not require mist eliminators.

11.2.6 Liquid desiccant

Different liquid desiccants have been suggested for use in air dehumidification and cooling systems. These include lithium bromide, lithium chloride, magnesium chloride, triethylene glycol, a mixture of calcium chloride and lithium chloride, and a mixture of lithium bromide and lithium chloride. Table 1 (Davies & Knowles, 2006) summarises some of the properties of desiccants under 25°C and hygroscopicity control at 50% (except NaCl).

Lithium chloride has been shown to be the most stable liquid desiccant. It has a large dehydration concentration

(30-45%), and can reduce relative humidity to 15% (Etras et al., 1992)). With its zero vapour pressure, it can be regenerated at high temperatures without loss and reduce chance of evaporation into the supply airstream (Lowenstein et al. 1998).

At 25°C, lithium chloride solution can reduce humidity in the air to 11%, whereas, other desiccants, such as calcium chloride and magnesium chloride can only perform down to 29% and 33% RH, respectively (Davies & Knowles, 2006).

One of the cheaper options for liquid desiccant is glycols, which is much less corrosive than lithium chloride, but it has significant vapour pressure at regeneration temperatures, so significant amounts of it can evaporate into the scavenging air.

The mixture of two types of liquid providing alternatives for the desiccant used in dehumidification and cooling systems is also available. (Etras et al. (1992)) has found that the mixture of calcium chloride and lithium chloride appear to be stable and cost effective.

Recently, Hassan & Hassan (2008) have proposed a new type of mixed desiccant containing 50% by weight of water calcium chloride and 20% calcium nitrate. Its vapour pressures at temperatures 30°C, 40°C, 50°C, and 60°C were found as being 14.7, 20.6, 34.4, and 47.3 mmHg, respectively

Property	Unit	Liquid desiccants					
		$CaCl_2$	LiBr	LiCl	$MgCl_2$	$ZnCl_2$	NaCl
Concentration (mass solute/mass solution)		0.36	0.39	0.26	0.31	0.52	0.26
Hygroscopicity (equilibrium RH)	%	50	50	50	50	50	75
Cost	US$/m³	560	7300	4600	450	1400	180
Abundance in seawater[a]	m³/m³	0.0023	$4x10^{-6}$	$3x10^{-6}$	0.013	$1x10^{-9}$	0.09
Density	kg/m³	1.35	1.38	1.40	1.29	1.58	1.20
Viscosity	mPa s	4.6	1.8	2.5	6.0	4.7	1.8
Specific heat capacity	kJ/kg °C	2.6	2.6	3.0 0.56	2.1	2.3	3.4
Thermal conductivity	W/m °C	0.56	0.48	0.9	0.52	0.46	0.58
Diffusivity of water in the solution	10^{-9} m²/s	0.54	1.17	no data	0.91	0.80	1.86
Differential heat of dilution	kJ/kg	80	no data	65	65[d]	no data	no data
Water absorption capacity[b]	kg/m³	85	84	91	76	120	n/a
Human toxicity[c]	L	0.14	0.23	0.10	0.49	0.03	0.66
Ecotoxicity (*Daphnia magna*)	ml/L	4.9 (2)[e]	no data	0.06 (2)[e]	4.3 (1)[e]	0.001 (6)[e]	20 (5)[e]

[a] Volume of desiccant solution that could theoretically be extracted from unit volume of seawater, assuming 100% recovery rate.
[b] Mass of water that, on absorption in the solution, will cause a 10% relative increase in equilibrium relative humidity.
[c] Estimated lethal dose in humans scaled from LD50 values for rats.
[d] At 50°C.
[e] Number of studies

Figure 11-8 Source: A Review by Davies & Knowles (2006) comparing liquid dessicants at 25°C

11.2.7 Application to MIST

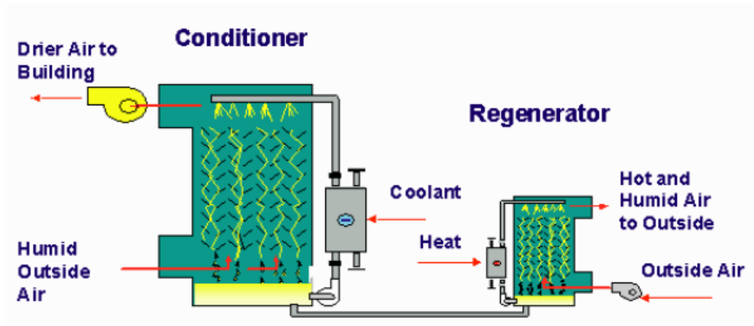


Figure 11-9 Liquid desiccant system

Solar yield

- The Liquid Desiccant System will use evacuated tubes as its primary heat source.
- The graph on the side shows the annual solar energy on a collector depending on tilt and orientation.
- 0° is flat and 90° is vertical.
- The best output comes for south facing between 15°-30° and an orientation of SE to SW would have very high yield.

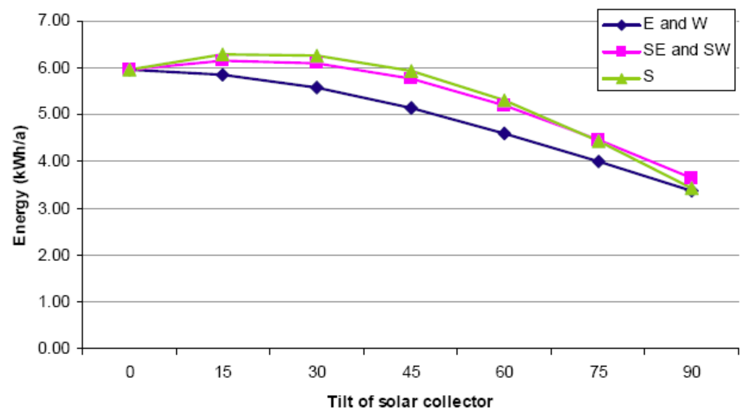


Figure 11-10 Best orientation for annual solar yield in Abu-Dhabi

The liquid desiccant system will be powered by of solar collectors with an average efficiency of 70%. The collectors will be of the evacuated tube type able to provide water at the elevated temperature required for the regenerator to operate.

A system with quantity of desiccant capable of 1000kWh of cooling powered by solar panels covering the whole roof, would deliver 1,123,721kWh of cooling or 62% of the annual demand.

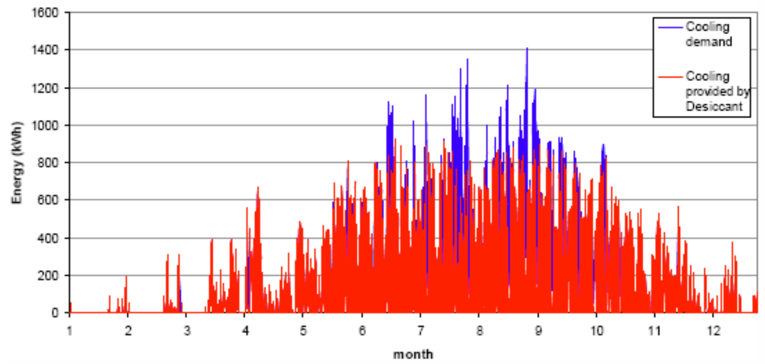


Figure 11-11 Annual cooling provided by desiccant cooling against total cooling requirement in Abu-Dhabi. (whole roof solar collectors, 1000kWh desiccant cooling capacity)

If the system had no "buffer" quantity of desiccant and was only powered by 2000 sqm of solar panels covering the whole roof, its performance would drop to 976,138kWh of cooling or 54% of the annual demand.

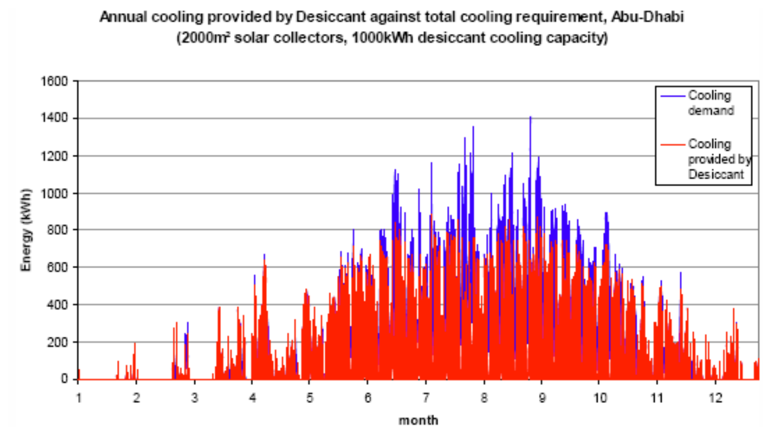


Figure 11-12 Annual cooling provided by desiccant cooling against total cooling requirement in Abu-Dhabi. (2000sqm solar collectors, 1000kWh desiccant cooling capacity)

The same figures for 1000m✢ of solar panels.

A system with quantity of desiccant capable of 1000kWh of cooling powered by 1000 sqm of solar panels, would deliver 660,898kWh of cooling or 36% of the annual demand

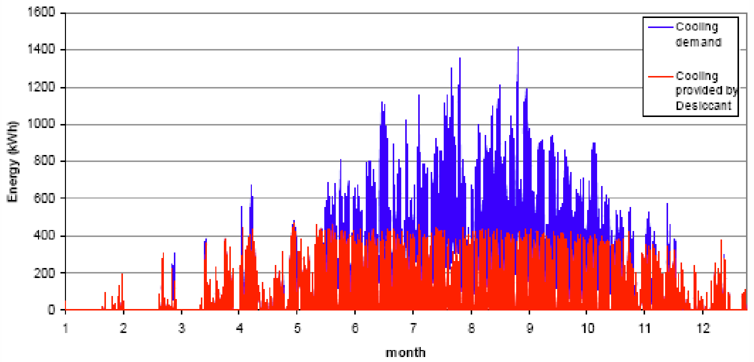


Figure 11-13 Annual cooling provided by desiccant cooling against total cooling requirement in Abu-Dhabi. (1000sqm solar collectors, 1000kWh desiccant cooling capacity)

The same system with no "buffer" quantity of desiccant would deliver 621,087kWh of cooling or 34% of the annual demand

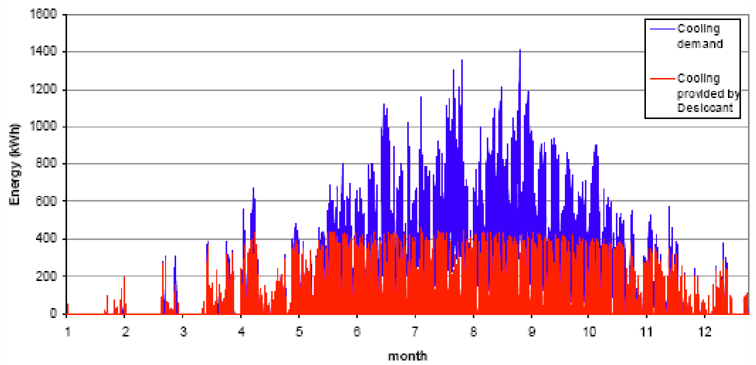


Figure 11-14 Annual cooling provided by desiccant cooling against total cooling requirement in Abu-Dhabi. (1000sqm solar collectors, 1000kWh desiccant cooling capacity)

The great advantage of the solar powered liquid desiccant system is that it delivers its cooling when it is most needed.

The vast cooling demands of the middle-eastern climate render impractical any strategy of large desiccant storage which is also very expensive.

The important aspect is a solar collector array sufficiently large to regenerate the liquid desiccant when it is required the most.

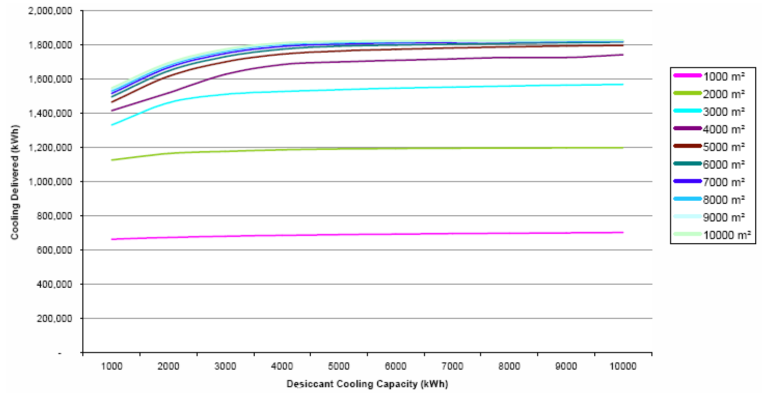


Figure 11-15 Cooling delivered from the liquid desiccant system depending on capcity and area of solar collectors, MIST Abu Dhabi.

It would take 10,000m✢ of solar collectors and 10,000kWh of cooling potential of desiccant to provide 100% of the annual cooling.

It 5,000 sqm of collectors and 2000kWh of cooling potential of desiccant would deliver 89% of the annual cooling.

Manufacturers

DuCool (Israeli): http://www.ducool.com/HTMLs/home.aspx

American Genius (US)/ Jilier Technology Development: http://www.geniusac.com/

AIL Research (US)- CaCl: http://www.ailr.com/

L-DCS (Germany)- LiCl: http://www.l-dcs.com/index.html

Kathabar (US)- LiCl: http://www.kathabar.com/

Niagara Blower Company (US)- glycols: http://www.niagarablower.com/

Please note: Niagara Blower Acquires Kathabar, Inc. 15 January 2008, http://www.niagarablower.com/Niagara%20News.htm

Albers Air conditioning Corp. (US) – LiCl+LiBr

7755 S. Research Drive, Suite 123, Tempe, AZ 85284, Tel: 602-820-4280.

11.2.8 References

Davies P.A. & Knowles P.R. 2006 Seawater bitterns as a source of liquid desiccant for use in solar-cooled greenhouses, *Desalination*, 196, 1-3, 266-279.

Hassan A.A.M. & Hassan M.S. 2008 Dehumidification of air with a newly suggested liquid desiccant, *Renewable Energy*, In Press, Corrected Proof.

Lowenstein A., Slayzak S. & Kozubal, E. 2006 A zero carryover liquid-desiccant air conditioner for solar applications, a draft version of ISEC2006-99079 conference paper for the ASME/SOLAR06 conference, July 8-13, 2006; Denver, USA.

Lowenstein A., Slayzak S., Ryan J., & Pesaran A. 1998 *Advanced Commercial Liquid-Desiccant Technology Development Study*, the National Renewable Energy Laboratory, the U.S. Department of Energy, NREL/TP-550-24688.

*Etras A, Anderson EE & Kiris I. 1992 Properties of a new liquid desiccant solution-lithium chloride and calcium chloride mixture. *Solar Energy Operation,* 49, 3, 205-12.

11.3 Appendix 3 Boreholes and Ground Coupled Heat Exchanger Report

11.3.1 Introduction

The purpose of this brief report is to give a synopsis of the option of utilising the ground as a means of cooling the Masdar Institute of Science and Technology (MIST) – Phase 1a development in Abu Dhabi, United Arab Emirates.

Essentially there are two types of ground coupled heat exchanger. One type uses the temperature of the ground itself as a heat source and/or heat sink, this type is known as a closed loop system. The other type of system utilises groundwater stored in below ground aquifers as a heat source and/or heat sink, this type in known as an open loop system.

11.3.2 Closed Loop Systems

A closed loop system is a pressurised system that is kept completely separate from any internal water systems (Chilled Water, Heated Water) and any available groundwater. The closed loop of fluid, transfer heat to and from the ground (in western European countries ground temperature below 3 meters in depth is a relatively consistent 12 degrees Celsius; in UAE it is approximately 26-28 Degrees Celsius).

This constant temperature allows a water to water heat pump to take heat from the ground during winter and transfer it to the buildings internal systems (Low Temperature Hot Water circuits) at a relatively high coefficient of performance (COP[11]) of between 3.5 and 4.

This process can be reversed during summer where the low ground temperature provides a heat sink for the rejection of the heat removed from the building by cooling. Once again high coefficients of performance are obtainable during this process.

11.3.3 Ground coupling can be done in three ways: -

Horizontal loops; pipes are laid at an agreed depth of between 2-3m in a lattice beneath the available site space. Heat exchange via this system will be approximately equal to 600 W per every 10 meters of laid pipe. This system requires large areas of land if high loads are desired and pipe runs should be spaced approximately 10 meters apart to ensure that they do not affect the heat transfer potential of each other.

Vertical Loops; pipes are sunk into deep boreholes to a depth of between 70 and 100 meters. Heat exchange via this system will be approximately equal to 1000W per every 10 meters of borehole. Boreholes should be spaced approximately 15 m apart to insure that they do not affect the heat transfer potential of each other.

Heat Exchanger piling; pipes are sunk into the piling of the building. This is a tidy solution as extra excavation is not required as the piling is already part of the building and therefore costs can be substantially reduced. However, due to the proximity of the piles to one another yields can be low. 400mm diameter piles 15 meters deep will exchange approximately 500 W of heat, 600mm diameter piles 15 meters deep will exchange approximately 1000W of heat as two pipe coils can be sunk into the pile.

Closed loop systems are best suited to small scale developments where the costs are cheaper than the equivalent open loop systems and required yields are not high unless large amounts of piling can be utilised for low cost.

Figure 11-16 Cut-away section of a closed loop vertical system

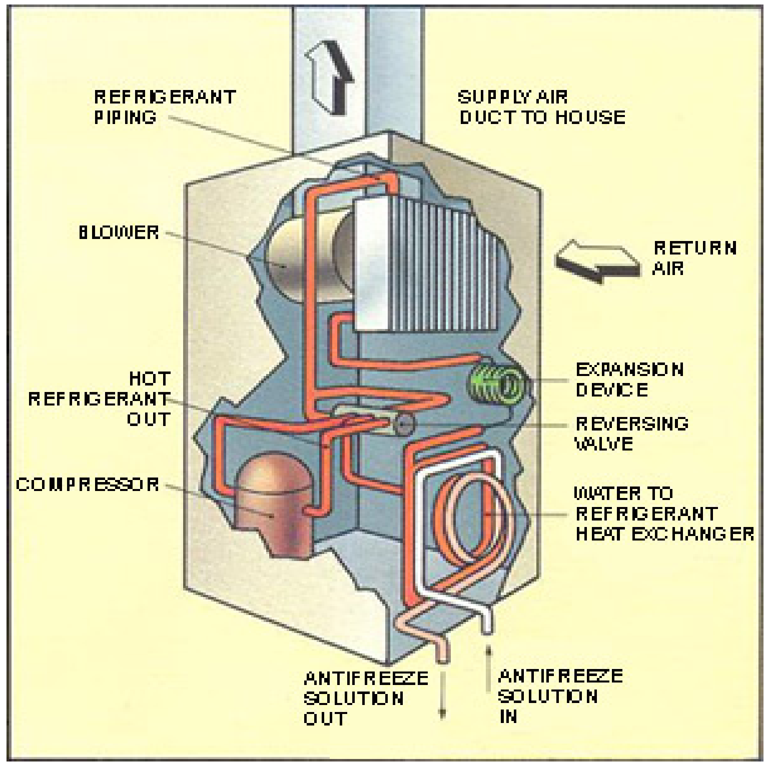


Figure 11-17 The inner workings of a typical heat pump

11.3.4 Open Loop Systems

Open loop systems use naturally occurring groundwater stored within the geological rock strata. These pockets of water are known as aquifers and have been used for many hundreds of years as a source of water for all types of domestic and industrial usage. This water is removed from the ground via an abstraction borehole and passed through a heat exchanger which either takes or rejects heat to it. The water is then returned to the ground via a separate recharge borehole located some distance away from the abstraction borehole (typically 100 meter or more) thus giving the ground water the chance to reject heat or absorb heat from the ground before being pumped back up to the building. The water on the other side of the plate heat exchanger is then connected to a heat pump or chiller for heat absorption or rejection. Coefficiencies of performance obtained are similar to those in closed loop systems (3.5-4.5).

In the UK open loop systems are subject to far more stringent guidelines than closed loop systems due to the possibility of ground water pollution. We are currently unsure as to the nature of borehole licence agreements in the United Arab Emirates however we suspect that groundwater will be sparse with low yields in areas of desert.

An open loop system can allow large amounts of heat rejection / absorption for the placing of relatively few boreholes in comparison to a closed loop system as the medium is ground water and not the ground if there is sufficient groundwater and pressure present.

Open loop systems can be used to "Free cool" if ground water temperature are lower than 15 degrees Celsius. Free cooling occurs when installed cooling systems require chilled water with a higher temperature than the traditional 6 - 8 degrees Celsius flow temperature. Chilled Beams for example require chilled water at approximately 15 Deg C flow temperature. If ground water temperatures are very similar to those required , groundwater can be used directly via a plate heat exchanger without any need to be run through a heat pump or chiller thus saving the electrical energy required to transfer the heat from one circuit to another. This leads to extremely high coefficiencies of performance based upon pumping power alone.

Open loop systems are best suited to large scale developments as costs are cheaper than closed loop systems once a certain size is reached (approximately 150kW) and required yields are higher.

[11] Coefficient of performance (COP) refers to the efficiency of a system with regards to the amount of electrical energy that must be consumed to produce a desired output. A COP of 4 implies that for every 1kW of electrical energy, 4kW of heating / cooling will be transferred from the ground giving the heat pump/chiller an efficiency of 400%. This high efficiency is what qualifies water-to-water and heat pump technology to be considered a renewable as more energy is transferred than that required to drive the system.

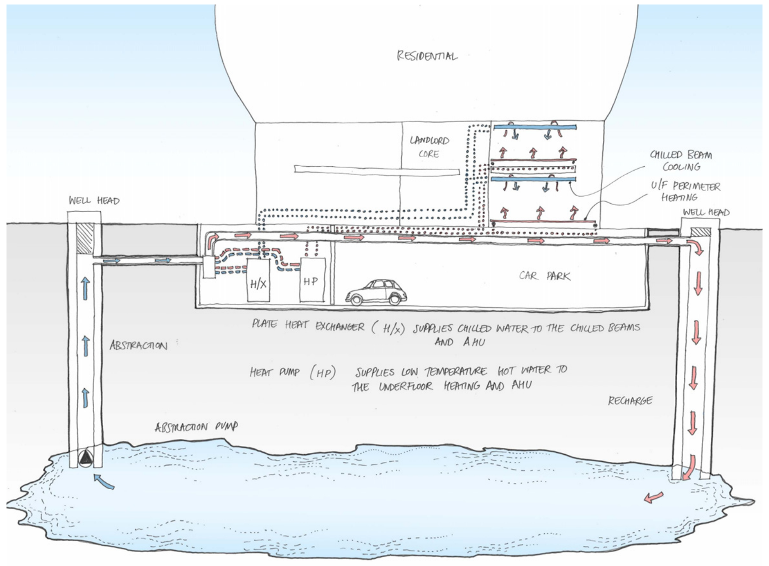


Figure 11-18 Section of typical open loop borehole system

11.3.5 Geological Information

Existing Geological Assumptions

A geological borehole test is being carried out at this moment in time using 3 test boreholes spaced out over the MIST development. The report generated from these tests will be able to confirm or refute the assumptions that shall be made to calculate what potential ground coupled solutions are available to the Masdar Institute of Science and Technology.

ASSUMPTION 1:-

Low depth ground water (sub 2 kilometres) is not available for use in MIST. The high volume of perched seawater in the first layer of topsoil / sand shall not be designated as an aquifer and will not be offered for use.

ASSUMPTION 2:-

Ambient ground temperature (sub 100 meters) is 28 degrees Celsius.

ASSUMPTION 3:-

The geological rock strata in the Abu Dhabi area can be easily bored and does not require specialist equipment to cut through tough layers.

11.3.6 MIST Ground Coupled Solution

Open Loop Borehole Potential

Currently it is assumed that there is no scope for the use of aquifer cooling due to a lack of moving groundwater at reasonable depths (This assumption shall be confirmed by the impending geological survey).

Therefore an open loop borehole solution is unlikely to be suitable for this site.

Piling Potential

The proposed development will have approximately 200 piles, 25 meters deep and 600mm in diameter (to be confirmed by the structural engineer). This piling system allows a potential 400 pipe loops to be laid within them connected up as a ring main to water-to-water chillers in the plant area.

For loops of a depth of 25m there is potential for 800 W of heat transfer. Therefore the potential achievable heat transfer between the ground and the pile shall be in the order of 320 kW or 0.32 MW.

Although the potential load is 0.32MW chiller efficiencies will be affected by the high ambient ground temperatures. This high ground temperature of 28 degrees Celsius forces the water temperature within the pipe loops up by 16 degrees Celsius thereby seriously compromising the chiller efficiency. Some of this efficiency reduction will be offset by the building chilled water requirements also being at high temperature (14 Degrees Celsius) due to the potential desiccant cooling air handling plant being installed.

Note: Based on very preliminary cooling loads, the total cooling load for Phase 1a is in the region of 2.3MW, so the potential % of cooling provided by the energy piles is in the region of 14%.

Therefore we would expect the chillers to have a COP in the region of 2.5 – 3 (This figure will vary from manufacturer to manufacturer and final confirmation will be required once equipment has been specified) Larger chillers will be required due to the higher ambient and ground temperatures increasing the energy required to run the chillers compared to a UK system – but the system will produce cooling using less electricity compared with an air cooled chiller.

The energy pile solution requires an energy balance of the ground to be achieved so as not to create an area of heat build up beneath the building, which will make the system ineffective over time. We have assumed at the moment no moving groundwater and all below ground water is shallow and assumed to be perched.

Creating an energy balance will involve dissipating heat from the ground during the night via coils in air handling plant (this low grade heat has no usefulness within the MIST development). This process will be required until the ground temperature returns to ambient effectively releasing all the daytime rejected heat into the night air.

Horizontal / Vertical Loop Boreholes

The heat rejected to “energy piles” could be supplemented by the introduction of vertical or horizontal closed loop systems if the space is available to do so.

For a horizontal loop system to provide 0.5MW of heat rejection 8.3 km of pipework will be required, effectively a plot of land of 100m by 100m (2 football fields). However this option would not be recommended due to low efficiencies achieved.

For a vertical loop system to provide 0.5MW of heat rejection 50 borehole loops of 100 meters deep will be needed requiring a plot of land of 70m by 70m.

Both systems would suffer from the efficiency problems associated with the high ambient ground temperatures although it is possible that the deep (100m) boreholes may find ground at much lower temperatures.

11.4 APPENDIX 4
Parabolic Trough Power Plant

In a parabolic trough power plant, trough-shaped mirrors focus the incident solar radiation onto a pipe along the focal line of the collector. Absorption of this radiation causes a heat transfer fluid to be heated in the pipe, generating steam in the power block via heat exchangers. As with conventional power plants, the steam is utilized in a turbine to generate power; through the integration of thermal storage, this power can then be supplied on demand. Solar power plants are therefore also able to generate electricity after sunset.

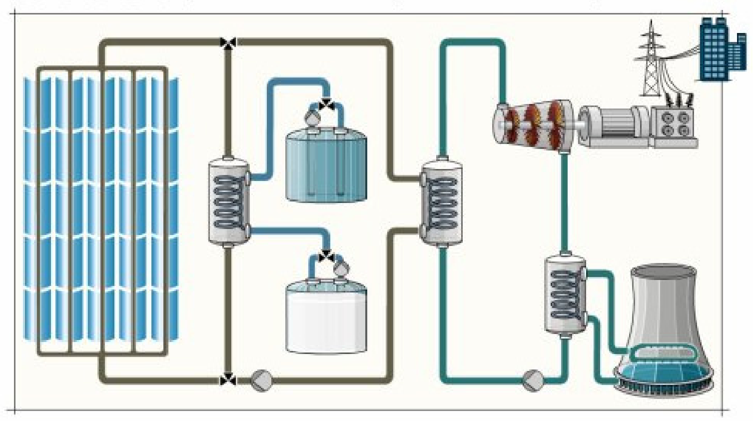
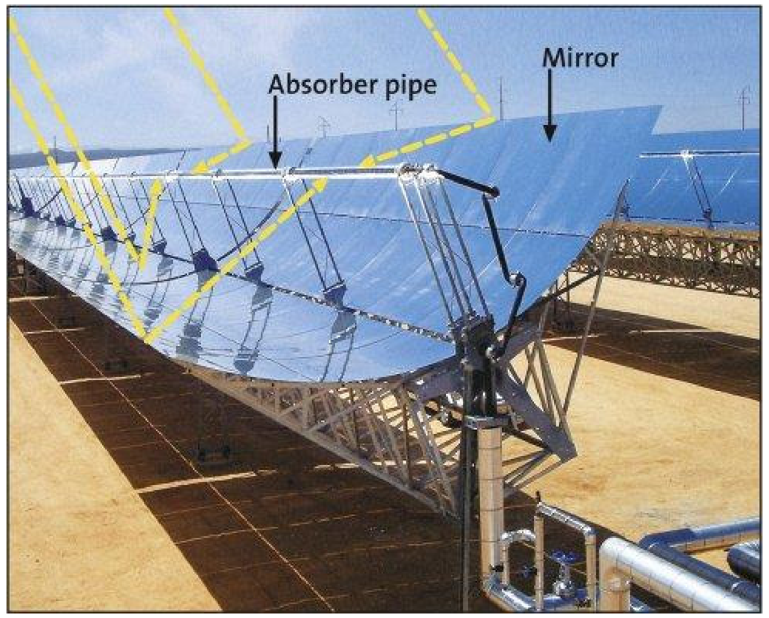


Figure 11-19 Schematic of parabolic trough power network



11.4.1 Solar Field

The solar field of a parabolic trough power plant is comprised of many rows of parabolic troughs around six meters high and several hundred meters long. Despite their enormous size, these high-precision optical devices are aligned with millimeter precision. The rows run in a north-south direction and track the sun from east to west during the course of the day.

Special components are used for the collectors. The concave mirrors are made from silver-coated white glass which is about 4 to 5 mm thick and 2 to 2.8 square meters in size.

Over 98% of the solar radiation that arrives at the mirrors is reflected onto the absorber pipe along the focal line of the collectors. The absorber pipes contain a heat transfer medium which is heated to around 400 °C by the concentrated sunlight.

The absorber pipes, also known as receivers, consist of a metal pipe which contains the heat transfer medium, surrounded by a glass pipe. Between the two pipes is a vacuum which insulates the metal pipe, thus reducing heat loss. The glass pipe is composed of special materials and coatings to enable as much solar radiation as possible passing through to be absorbed by the metal pipe rather than being reflected.

11.4.2 Operation

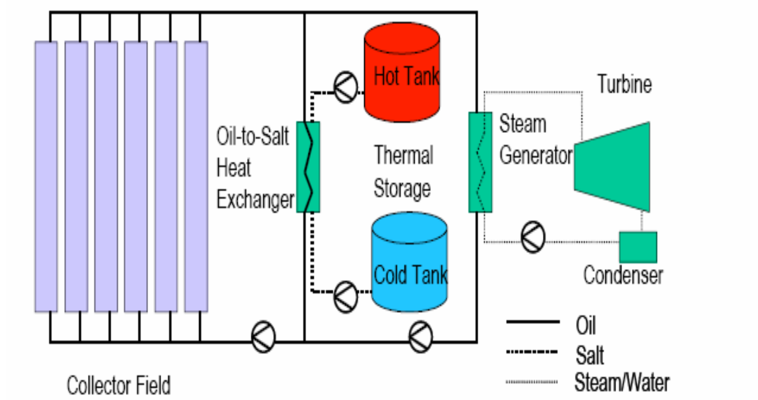


Figure 11-20 Schematic of parabolic trough system

In the mornings

After sunrise, the collectors begin to follow the sun. Parabolic mirrors concentrate the solar radiation to absorber tubes, in which a heat-resistant, synthetic oil circulates as heat transfer fluid. This fluid then transmits its thermal energy to heat exchangers. The steam, which is generated there, drives a turbine and electricity is generated by the connected generator.

During the day

If sun radiation is strong enough, the solar field supplies energy to generate electricity and fill up the storage system simultaneously. The storage system is filled with liquid salt. It consists of a "hot" tank and a "cold" one. When the storage system is being filled up, cold salt is pumped into the hot tank through an oil to salt heat exchanger.

In the evenings and on cloudy days

In the evenings or when the sky is cloudy, the solar field can supply the energy, which is required to drive the turbine, together with the storage system. For this purpose, the hot salt is pumped into the cold container, thus giving back the thermal energy to the oil circuit.

At night

After sunset thermal energy is exclusively supplied by the storage system. If the storage system and the solar field have been dimensioned accordingly, the power plant can be operated up to 24 h with solar energy. Also hybrid operation is possible by the combustion of e.g. biomass.

11.4.3 Advantages of Using Molten Salt

A variety of fluids was tested to transport the sun's heat, including water, air, oil, and sodium, before molten salt was selected as best. Molten salt is used in solar power tower systems because it is liquid at atmosphere pressure, it provides an efficient, low-cost medium in which to store thermal energy, its operating temperatures are compatible with todays high-pressure and high-temperature steam turbines, and it is non-flammable and nontoxic. In addition, molten salt is used in the chemical and metals industries as a heat-transport fluid, so experience with molten-salt systems exists for non-solar applications.

The molten salt is a mixture of 60 percent sodium nitrate and 40 percent potassium-nitrate, commonly called saltpeter. The salt melts at 221ºC and is kept liquid at 289ºC in an insulated cold storage tank. The salt is them pumped to the top of the tower, where concentrated sunlight heats it in a receiver to 565ºC. The receiver is a series of thin-walled stainless steel tubes. The heated salt then flow back down to a second insulated hot storage tank. The size of this tank depends on the requirements of the utility; tanks can be designed with enough capacity to power a turbine from two to twelve hours. When electricity is needed from the plant, the hot salt is pumped to a conventional steam-generating system to produce superheated steam for a turbine/generator.

The uniqueness of this solar system is in de-coupling the collection of solar energy from producing power, electricity can be generated in periods of inclement weather or even at night using the stored thermal energy in the hot salt tank. The tanks are well insulated and can store energy for up to a week. As an example of their size, tanks that provide enough thermal storage to power a 100-megawatt turbine for four hours would be about 30 feet tall and 80 feet in diameter. Studies show that the two-tank storage system could have an annual efficiency of about 99 percent.

All pipes, valves, and vessels for hot salt were constructed from stainless steel because of its corrosion resistance in the molten-salt environment, while the cold-salt system is made from mild carbon steel.

11.4.4 Benefits of Parabolic Trough

Like all solar technologies, solar parabolic troughs are fueled by sunshine and do not release greenhouse gases. Parabolic troughs are unique among solar electric technologies in their ability to efficiently store solar energy and dispatch electricity to the grid when needed, even at night or during cloudy weather and sand storms.

11.4.5 Environmental Impacts of Parabolic Trough

No hazardous gaseous or liquid emissions are released during operation of the parabolic trough plant. If a salt spill occurs, the salt will freeze before significant contamination of the soil occurs. Salt is picked up with a shovel and can be recycled if necessary. If the parabolic trough is hybridized with a conventional fossil plant, emissions will be released from the non-solar portion of the plant.

11.5 APPENDIX 5
Hot water and Electrical Power Generation

11.5.1 Application
Provide resilient supply of Hot water and Power Electrical Generation

11.5.2 Study
Title: Study the process of Combined Heat and Power (CHP) and application

11.5.3 Description:
Combined heat and power (CHP), also known as cogeneration, is the name applied to processes which from a single stream of fuel simultaneously generates heat and Electric power. The typical cm' plant consists of a reciprocating internal combustion engine directly driving a generator to produce electrical power. The excess heat liberated in combustion is recovered via heat exchangers as usable heat, rather than being rejected to atmosphere. The ability to recover this heat yields efficiency gains together with the cost differential, of the fuel price of using raw fuels against purchasing grid electricity, makes CHP' schemes an attractive proposition.

Recent developments in the electricity generating, distribution and supply markets allow individual users to generate a proportion, or all, of their electrical power requirements using generating plant running in parallel with the grid system.

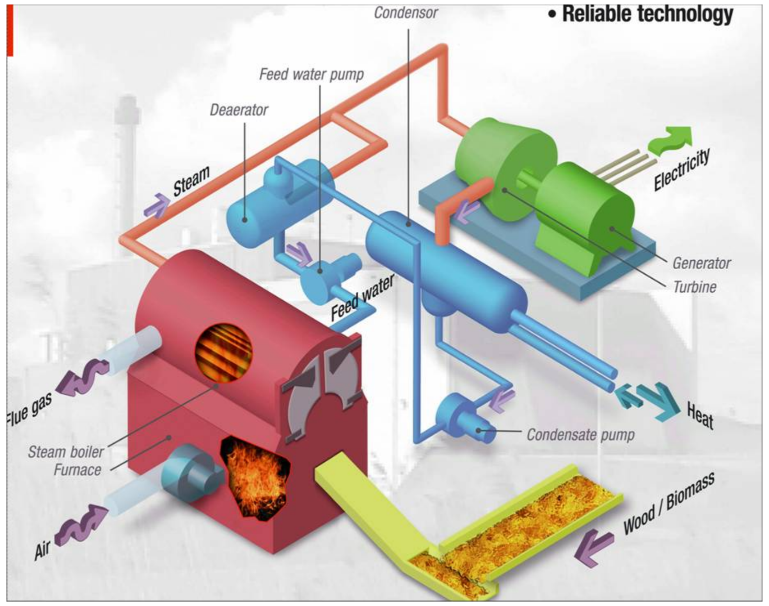


Figure 11-21 Schematic of CHP in operation

CHP systems have benefited from developments in engine technology, principally in the development of gas fuelled spark ignition reciprocating engines and PC based control systems linked by modem to remote monitoring. These developments have encouraged ever greater numbers of users to adopt CHP schemes as a sound method of providing a significant proportion of their energy needs in a way which is economically advantageous from the efficient in the use of energy, with environmental benefits.

11.5.4 Application to Masdar Phase 1A:
Considering the zero carbon strategy of Marsdar city planning, CHP plant using renewable energy is proposed as a backup system to provide thermal output (priority) and electricity when the primary energy supply is insufficient, in order to supply liquid desiccant cooling or absorption chillers cooling, at the same time reduce electrical load form the grid.

Comparing with conventional CHP plant, CHP shall run on dual Renewable fuels- Digester Gas (harvested from black water treatment system) and a Bio fuel (example used: Palm oil) or a combination of both, has much less climate impact.

Energetic efficiency of producing liquid energy-carriers such as traditional producing technologies of vegetable oils is generally reasonable, but the final energy input-output factors of typical bio-ethanol production hardly exceeds 1.0-1.2 value.

11.5.5 Fuel
Digester Gas from black water contains large portion of methane (50%-70%). If methane is released into the atmosphere it is a potent greenhouse gas, with the global-warming potential being 21 times greater than that of carbon dioxide. Digester gas can be flared (the simplest option) therefore converting the methane to CO✢ but using it as an energy resource both displaces fossil fuel use, minimizes emission to atmosphere and encourages more efficient collection. The CO2 released from the combustion process can be reduced by passing through a urea liquid. For this reason energy recovery from Digester gas methane has considerable benefit to the environment by reducing global warming on two fronts.

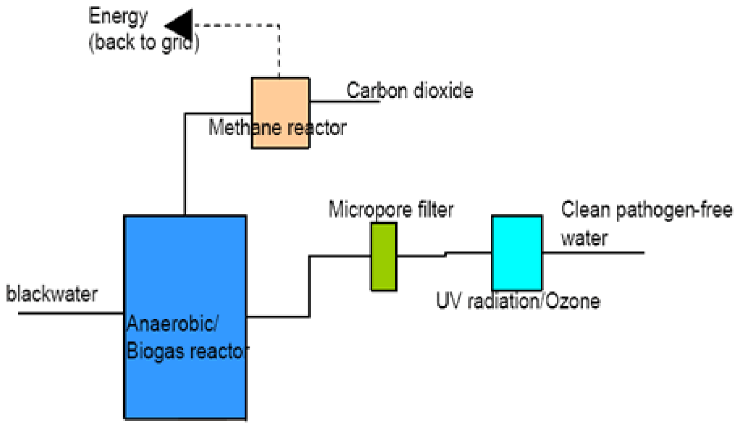


Figure 11-22 Digester Gas Production

Palm oil, like other vegetable oils, can be used to create bio fuel for internal combustion engines. The Calorific value of refined Palm Oil is 39.3 MJ/kg compared to the fossil fuel Diesel of 44.3 MJ/kg. Bio fuel has been promoted as a form of biomass that can be used as a renewable energy source to reduce net emissions of carbon dioxide into the atmosphere. Therefore, bio fuel is seen as a way to decrease the impact of the greenhouse effect and as a way of diversifying energy supplies to assist national energy security plans. Scientists have found that bio fuel made from palm oil grown on sustainable non-forest land and from established plantations can effectively reduce greenhouse gas emissions.

11.5.6 Options Available:
Three bio fuel CHP manufacturers are studied, regarding to the condition of Masdar.

1. Dordtech Engineering

Bamendaweg 22

3319 GS Dordrecht

Postbus 9001

3301 AA Dordrecht

Tel: +31 (0)78 6305505

Fax: +31 (0)78 6305506

http://www.d/www.Dordtech.nl

General

A bio-oil installation is a complete system that transforms a clean bio-oil into both electrical and thermal power. A typical output for an installation is about 41%- electric energy; 46% thermal energy; 13% losses.

The installation also includes a process to reduction the particle emmission levels from the flue gases and are therefore seen as form of 'durable' energy production.

Installation is delivered in a completely in a sound-subdued container suitable for out-or inside positioning and is delivered 'ready for use'.

Bio-oil

The applications of bio-oil in combustion engines are relatively new techniques, developed particularly from the need of using oils and rest-fat processing. The bio-oil used in the installation is a filtered purely vegetable palm oil, provided with a RSPO certificate. The energy contents (combustion value) of this bio-oil are approximately right to those of diesel oil. Because the viscosity of bio-oil is considerably higher then of standard diesel-oil, resulting in the combustion process being relative less as well. This requires approximately 10% more bio-oil in comparison with standard diesel-oil. Also the level of exhaust gas temperatures on average is higher, resulting into a small reduction of capacity.

Good functioning of the machine is guaranteed on bio fuel 'ppo' of the company Biox – Vlissingen (The Netherlands), or perceptible equivalent bio-oil of other suppliers.

Consumption of ppo is approximately 250 kg per hour. A tank with heating system of 60m✢ is sufficient. In combination with a dual fuel configuration biogas/ppo 50%/50% a smaller tank can be used.

Engine

The engine is a Cummins modified diesel engine with the following specifications:

Engine type:	CUMMINS KTA 50 G8
Generator:	Stamford PI 734D
Electric capacity:	1014 KW (e) +/- 1%
Cos phi:	0.9

Thermal capacity:	ca. 975 kW (th) +/- 5% - HT circuit (95°C)
	ca. 175 kW (th) +/- 5% - LT circuit (60°C)
Fuel:	Bio-oil
Energy input required:	2543 KW
Expected electric output:	41, 0%
Expected thermal output:	46, 0%

The capacities and performance DATA have been given up by Cummins and have been delivered by means of diesel no. 2 fuel and with ISO – 3046 part 1 standard conditions by 100kPA (29, 53 in Hg) barometric press; (110 meter altitude, 25°C air meddles temperature and relative air humidity of 30%) and for a fuel to diesel no. 2 according to ASTM D975 standard.

Figure 11-23 Dordtech Engineering

Fuel system:

The fuel system on the standard engine will be adapted and is arranged for the processing of bio-oil. All fuel lines and pipes will be traced, isolated and brought with flanges and valves to a fixed position of the unit side. The installation is equipped with a heated bio-oil and bio-diesel day tank.

The bio-diesel is used to clean the fuel system and the engine. In this way we can use the bio-diesel for cleaning purposes.

The bio-oil and bio-diesel day tank are equipped with automatic level measuring devices and leak detection system.

After treatment:

SCR system including dust filtration.

Consumption of urea 22 liter per hour, a tank of 6m³ is sufficient.

2. KUHSE

Alfred Kuhse GmbH

E-Mail: kuhse@kuhse.de

An der Kleinbahn 39

21423 Winsen

Tel: +49 (0)4171 / 798-0

Fax: +49 (0)4171 / 798-117

http://www.kuhse.de

Model: KUHSE GreenPower 400 - Single Fuel: Vegetable Oil

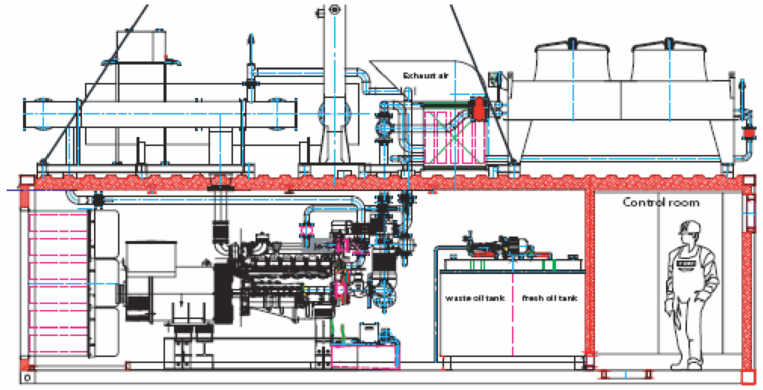


Figure 11-24 Kuhse

General:

Fuel	Vegetable oil
Operating modes mains	parallel; isolation
Electric capacity	400 kW
Thermal capacity	396 kW ± 8%
CHP coefficient	1, 01
Fuel consumption	237 g/kWhel ± 5%
Generator	3-phase synchronous
Temperature level (heating circuit)	70/90° C
Volume flow (Heating circuit)	18 m³/h
Noise emissions Container (10m distance)	65 dB (A) ± 5%

Engine:

Mechanical power	416 kW
Mean effective pressure	16.3 bar
Engine cooling water	30 m³/h
Temperature level (engine)	82/88° C
Exhaust gas volume flow	1.787 m³ i.N. / h
Exhaust gas mass flow	2,100 kg/h
Exhaust gas temperature	490° C
Combustion air	1,670 m³ i.N./h
Supply air volume (ΔT=15K)	12,000 m³ i.N./h

Generator:

Cooling	Air
Voltage	400 V
Frequency	50 Hz
Insulation class	H
Type of enclosure	IP 23
Type of construction	Md 35
Degree of interference suppression	N (acc. to VDE 0875)
Performance	40°C RT (acc. to VDE)

3. ENER•G

ENER·G House
Daniel Adamson Road
Manchester
M50 1DT
UK

T: 44 (0) 161 745 7450
F: 44 (0) 161 745 7457
E: info@energ.co.uk

Figure 11-25 Ener-G

General

ENER·G has developed a system of portable, modular units with outputs ranging from 300kW to 1.15MW, with the larger generators having integral transformers.

ENER·G supplied generators up to 1.15MW to sites, which is capable of operating at 50% methane. We can have several units operating on their own, with several together or in conjunction with larger existing generators (1MW) to follow more closely the digester gas production curve and maximize gas utilization.

System

ENER·G approach to the recovery and utilization of digester gas as following:

Gas Management

- Simple, low cost wells remotely controlled at the manifold - gives fast monitoring and optimized adjustment of the gas field.
- No wellhead chambers - means minimum impact on cap integrity and access for site after-use.
- Frequent monitoring and quick response to potential problems - gives confidence that migration issues are being properly addressed.
- A pro-active approach for every project - including managing the gas throughout the site, not just at the engines.

Generator Utilization

- Modular generator units (from 300kW to 1150kW) and a "hire fleet" approach, ensures, where grid connections allow, a mix of generators can be cost-effectively used - even for short periods - to capitalize on peaks or manage gaps in site gas production.
- This flexible use of movable generators can maximize use of the gas resource and extend the period of gas utilization.

Remote Management

- The proven, state-of-the-art, intelligent, remote generator management system minimizes down-time and maximizes operating benefits.
- Trend monitoring, automatic resetting of minor trips and telemetry links to on-call engineers; enhance management of engine availability and gas - 24 hours a day, 365 days a year.

11.5.7 Application to concept Design:

Based on the MIST phase 1A design parameters, an estimated feasibility assessment is taken and highlighted as below:

System	Bio fuel CHP plant
Objective	To provide backup thermal output (priority) for Liquid desiccant cooling or absorption chillers and electricity
Capacity	2MW
Operation time:	10 hours /day, weekly supply
Fuel:	1. Bio fuel (Palm oil) Typical oil density 900kg/ m^3 Consumption for producing 1MW electrical power: 250kg/hour 2. Digester gas (from black water treatment) Generation 28m^3 per 1000 people per day Calorie value 22,400 kJ/ m^3

Generator model:

Calculation is based on 1MW Dordtech bio-oil generator set. Key figures are listed as below:

Fuel	Bio-oil
Electric capacity	1014 kW (e) +/- 1%
Energy input required	2543 kW
Expected electric output	41, 0%
Expected thermal output	46, 0%

Generation strategies:

In order to find out the most appropriated option of using available fuel to run the system, three generation strategies have been testified. The CHP plant is proposed locate on basement level of the building with bio fuel storage tank nearby, digester gas will be harvested and stored from black water treatment (offsite) and piped to the plant.

i. 100% bio fuel (Palm oil) generations

ii. 100% digester gas generations

iii. 50% bio fuel, 50% digester gas generations

11.5.8 Fuel use strategies comparison:

Generation Strategy		100% Bio Fuel	100% Digester Gas	50% Bio Fuel	50% Digester Gas
Backup Thermal Capacity Required (W)		2	2	1	1
No. of Operation Hours Per Day		10	10	10	10
No. of Operation Days Per Supply		7	7	7	7
Total Energy Input Required (KJ)	2543KW Per 1MW Electrical Output	1281672000	1281672000	640836000	640836000
Bio Fuel Consumption (kg)	250kg/hour bio fuel per 1MW electrical output	35000	-	17500	-
Vol. of bio fuel storage required (m3)	Density of bio fuel palm oil =900kg/m3	39	-	19	-
Vol. of digester gas storage required (m3)	Calorie value of Digester Gas =22400kJ/m3	-	57218	-	28609
Value of digester gas generated per man/day (m3/man/day)	From black water only 28m3 digester gas produced by 1000 people per day	-	0.028	-	0.028

Figure 11-26 Summary performance of bio-fuels

11.5.9 Advantages/Benefits

i. Using bio fuel CHP provides a reliable method to generate resilient (backup) capacity to provide cooling, hot water and electrical power.

ii. Provides a use for the digester gas that will be produced by the initial Black water treatment plant, located adjacent to the North side construction camp.

iii. Test technology that could be utilized throughout the city to provide resilient generation capacity that has a short ramp up period.

iv. The plant does not require a large area for installation and can be installed at Podium level.

v. Duel fuel provides flexibility and security. The primary fuel would be to City generated digester gas with an adjacent storage tank of bio-fuel that can be refilled rapidly.

vi. The bio fuel CHP systems would be simple method of providing a usage of overflow gas from the compressed digester storage tanks. The storage tanks could be sized to provide a secure period of emergency power for the city, if bad weather conditions are prolonged.

vii. The method of generating electrical power has been tried and tested therefore simple to control and integrate into the electrical distribution infrastructure.

viii. Simple and known system to maintain therefore would not require specialist maintenance.

ix. Digester gas generated from black water alone is unlikely to be a sufficient fuel resource for CHP, regarding to the small value of the man/day that Digester gas is generated. However, other alternative plans are worth to be considered, such as increase number of people in the city, recovery of digester gas from house hold waste.

11.5.10 Disadvantages/Risks

i. Initially the bio CHP system would be served by the Palm oil (or other vegetable based oil) as the population of the construction camp and MIST campus would take time to populate.

ii. Bio-fuel such as Palm oil would require site security and fire precautions with a tank storage in the Basement.

iii. Would require an additional piped service to be installed in the City infrastructure trench system, to distribute the digester gas.

iv. This process still emits carbon dioxide, even though it may be sourced from a natural process. Palm oil production can be suspect in terms of sustainability.

11.6 APPENDIX 6
Ice Thermal Storage

Thermal storage, or energy storage, is defined as the charging and discharging of a store of finite thermal capacity in response to the flow of heat to and from the system where supply and demand for heat are out of phase.

Thermal storage may involve energy collection from the sun, ground, air or water. Air and water (or water mixtures) are typically used for transporting energy to and from the store. The storage/discharge cycle is dependent on the building load and the availability of energy to be stored from later use. Most systems use a daily cycle, although weekly and seasonal cycles are also used.

Ice storage store energy when it is available at a lower cost ready for use during higher tariff periods. These systems are generally considered to load shift rather than to conserve energy. However at MIST, an interesting combination can be investigated;

Depending on the time of year, ice could be made either during the night when the electricity tariff is competitive and conversely ice could actually be made during the day when sufficient PV power is available for use at night time.

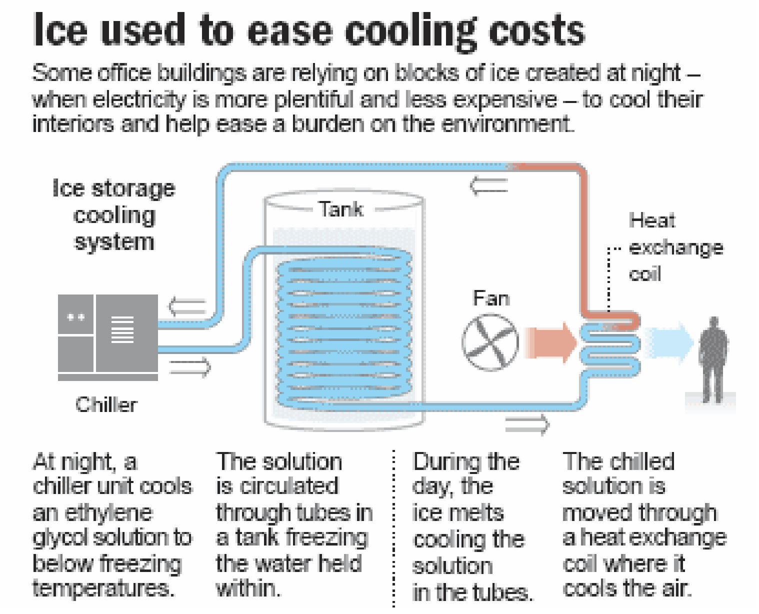


Figure 11-27 Schematic of ice storage process (Source CALMAC Manufacturing Corporation)

The principle of ice storage is to provide some or the entire buildings daily cooling requirement from the ice store. The primary advantage of this technique is that the chiller can operate totally or partially, during the off peak period and deliver cooling for less cost than a conventionally plant.

11.6.1 Main advantages of ice storage;

It allows chillers to operate at greater efficiency at night due to lower condensing temperatures and the operation of the chiller at full load

Ability to use cheaper off peak electricity and to reduce maximum demand charges

Reduction in chiller size (partially or completely offsets increased cost of storage system) – typically half or two thirds of that required for a conventional system

Reduction in the amount of refrigerant in use

Flexibility of using the store only, chiller only, or a combination of both to meet load requirements

Ability to negotiate future low electricity tariffs

Provision of a back up cooling source in the event of chiller failure

The main disadvantages include;

There will be distribution and storage vessel losses that would not occur with a conventional system – pumping to both charge and discharge the store

Operation of chiller plant to produce ice requires a chiller capable of depressing its evaporating temperature to -6ºC as opposed to +6ºC with conventional chiller plant. This reduces the chiller COP.

Ice Storage technology has been used with UAE – the most recent example being the Burj Dubai, where the ice storage system ensures low chiller water temperatures (due to distribution losses) and acts as a back up to the main building chilled water system.

For Scheme design, the recommendation would be to fully review the integration of ice storage within phase 1a (as a test bed) and determine if this option is viable within the constraints of this project.

11.7 APPENDIX 7
Optimum use of roof area MIST Phase 1A

There are three possibilities of how to optimally use roof area:

i. Solar PV panels

ii. Solar thermal collectors – vacuum/heat pipe

iii. Natural Light Transmission system - Parans

11.7.1 Solar PV panels

Depending on the type of cells and their module design, solar cells have different levels of efficiency. Amorphous silicon (a-Si) solar cells appear to be the least efficient (<10%), while mono-crystalline silicon (c-Si) cells demonstrate normally the better performance (14%-19%). Although c-Si cells with 42.8% efficiency at standard test conditions (STC) have been achieved by the research consortium led by the University of Delaware, they are not yet available commercially. Meanwhile, GaAs cells have been shown to be the most efficient solar cell types commercially available, with efficiency of ~31% by themselves and 37% at STC with concentrating optics, so called, Concentrator or Concentrating Photovoltaic (CPV) cells.

The cell performances also decrease with their temperature gain. Generally, the temperature coefficient is approximately 0.4-0.5% efficiency reductions for every 1ºC increase of temperature from STC temperature (25ºC) for typical c-Si cells. The coefficients of -0.32%/ºC have been shown in c-Si Sliver cell type with its innovative cell design (cell efficiency >19% STC) from 25ºC, whilst that of CPV has been reported as low as from -0.05%/ºC to -0.15%/ºC.

For PV cells to be used with MASDAR climate, the annual cell temperatures estimated may rise as high as 68.7ºC, which consequently can severely reduce the efficiencies of most typical c-Si cells (see figures below).

	Maximum Ambient Temp (ºC)	Estimated Air Temp at roof level (ºC)	Estimated Cell Temp at roof level (ºC)	PV Cell Efficiency Comparison (%) c-Si (1a), %	CPV (3b), %	c-Si (1b), %	c-Si (2a)
STC	n/a	n/a	25	14.7	35	14.7	19
January	27.8	37.8	53.7	1.8	34.3	8.2	9.8
February	32.1	42.1	59.8	-0.9	34.0	5.4	7.9
March	37	47	66.7	-4.1	33.6	2.3	5.6
April	41	51	72.4	-6.6	33.3	-0.2	3.8
May	42.5	52.5	74.6	-7.6	33.2	-1.2	3.1
June	42.3	52.3	74.3	-7.5	33.2	-1.1	3.2
July	45.7	55.7	79.1	-9.6	33.0	-3.2	1.7
August	44.9	54.9	78.0	-9.1	33.1	-2.7	2.1
September	42.2	52.2	74.1	-7.4	33.3	-1.0	3.3
October	39.6	49.6	70.4	-5.7	33.4	0.7	4.5
November	34.1	44.1	62.6	-2.2	33.8	4.2	7.0
December	31.4	41.4	58.8	-0.5	34.0	5.9	8.2
Year	38.4	48.4	68.7	-5.0	33.5	1.4	5.0

Figure 11-28 Estimated PV cell efficiencies in MASDAR climate

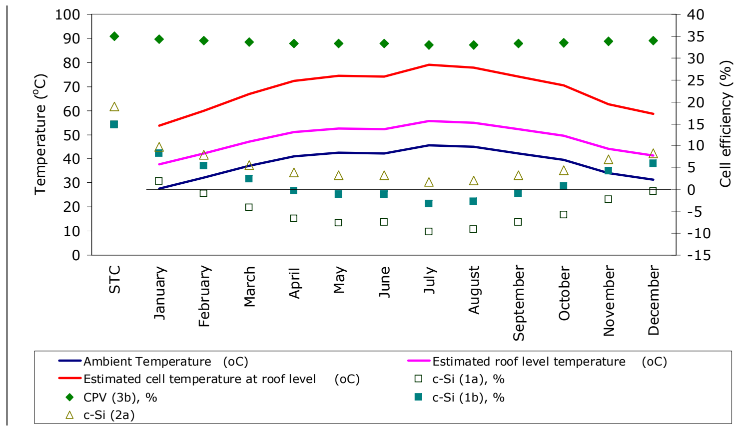


Figure 11-29 Estimated PV cell efficiencies at roof top and ground levels in MASDAR climate

From the available information, it is suggested that if c-Si cells are to be installed for the PV systems at roof level, the rating efficiency should be at least 18-19% STC. Moreover, the selection of the PV modules has to take into account other factors affecting the PV system efficiency such as, module production tolerance, dirt/dust, module mismatch, wiring losses, battery system losses, and conversion losses. To date, CPV cells have shown to have the best performance amongst commercial units, however, they are ground-mounted modules.

PVT size and performance

The PVT (Photovoltaic/Thermal) panel is single unit combining photovoltaic cells with a solar thermal collector to produce electricity and heat from solar radiation. Its thermal output can be in delivered through air and/or water depending on the systems specified. The system can also be used in areas where only limited space available (see below).

Roof-mounted PVT	Unit size area (m^2)	Electricity output (W)	Thermal output (W)	Electricity output/unit size area (W/m^2)	Thermal output/unit size area (W/m^2)
Unit A	3	300	2000	109	726
Unit B	8	750	3840	99	506
Unit C	10	500	2250	50	225

Figure 11-30 Examples of unit sizes and power outputs commercially available

11.7.2 Solar Thermal

Solar thermal panels absorb the sun's radiation which is used to heat water for liquid desiccant and absorption chiller.

The panels transfer heat through a series of pipes, to a hot water cylinder. Solar thermal panels are roof mounted and (aside from the capital cost and a very occasional maintenance) provide free, clean energy all year round.

Figure 11-31 Image of evacuated tube solar collector

Heat pipe panel

The most advanced solar system on the market with up to 80.6% efficient. The heat pipe tubes are inserted into a small diameter header manifold which contains a reduced quantity of water (1.5 liters). This allows very efficient collection of even the smallest amount of energy.

Water is passed through an evacuated tube, which contains a black absorber plate. Vacuum tubes are more efficient and therefore a smaller area of collector is required. Solar vacuum tubes are capable of operating at higher working temperatures than with flat plate collectors. Thermal losses are also small due to improved heat insulation. The vacuum provides insulation and this allows the water to be heated to much higher temperatures, and remain very effective even on cloudy days.

Key Benefits:

The most discrete solar installation with only the tube panels being exposed,

Highest Efficiency system with very low standing losses,

Highest degree of flexibility with modular interconnectivity.

Technical information

- Absorption 0.94-0.96
- Emittance 0.04
- Stagnation Temperature 250ºC
- Solar radiance exposure 2.46MJ/m2
- Average heat loss co-efficient 0.60W/m2 x C
- Vacuum 3 x 10-3 Pa
- Operating pressure 1.5 Bar

11.7.3 Natural Light Transmission system – Parans

Background of natural lighting

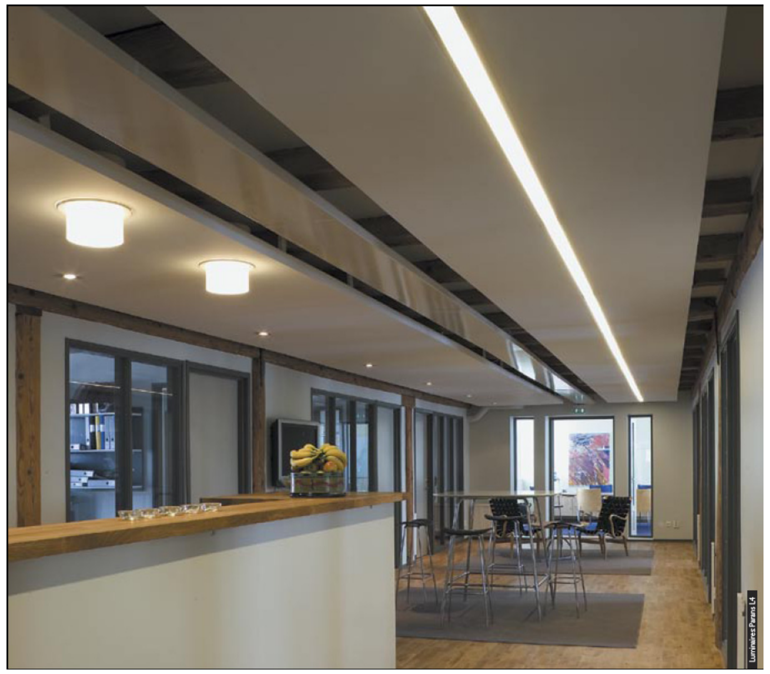
Illuminating interiors with natural light brings many benefits such as:

i. Natural lighting saves energy during the daytime occupy hours.

ii. Sunlight gives improved visibility from improved light, better color rendering, and the absence of flickering from electrical lighting.

iii. Pure sunlight is dynamic and has a full spectrum that triggers certain chemicals within the human body, which can help with synchronizing the body clock.

iv. Staff productivity might increases when natural light is added to a workplace.



Piped sunlight system comparison and analysis

Objectives:

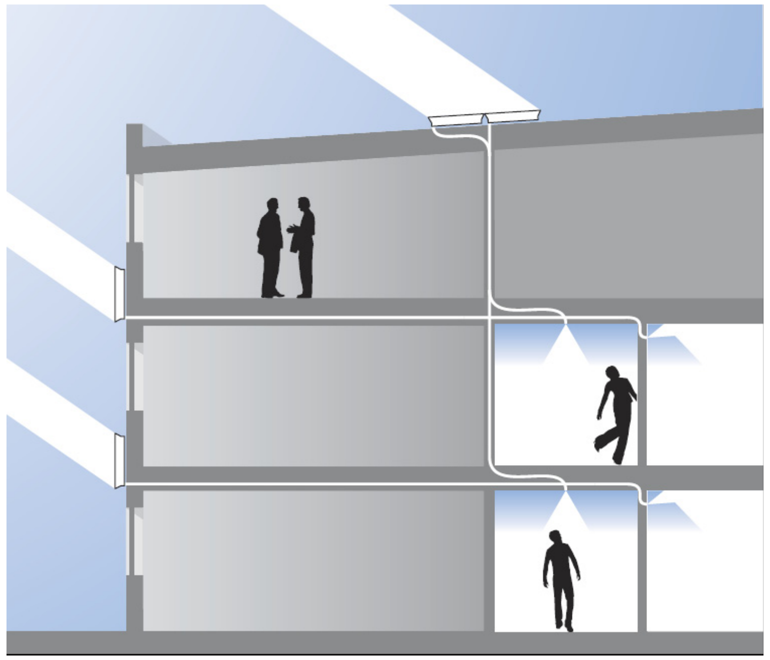
The aim of this report is to review the feasibility of using a piped sunlight system at MIST. The Proposal of optic fibre piped sunlight system is to bring natural lighting in the spaces to benefit building users from energy saving from lighting, contributing healthier and better quality built environment.

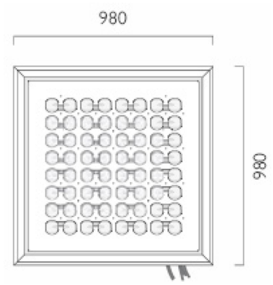
Comparisons are made for different piped sunlight systems applications in spaces like the lab and residence; along with energy efficiency between PV and piped sunlight, to examine which is the more worthwhile consideration.

11.7.4 Manufacturers:

Parans piped sunlight system

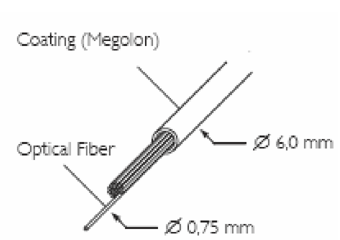
The Parans Solar Panels are 1 m2 modules that are mounted on roofs or facades. Inside the panel, 64 Fresnel lenses move uniformly around their axis, tracking and concentrating sunlight. The tracking system is achieved with three motors, consuming on average under 2 W.





11.7.5 Fibre optic cable:

From each Parans Solar Panel come four optical cables. These are 6 mm in diameter, a density of 30 g/m and can be ordered up to 20 m long. The bending radius can be as small as 50 mm, making light work of tight corners



11.7.6 Luminares

Parans provides various luminaries indicated as followed. Some luminaries are able to integrate q Hybrid system so that artificial light will be automatically turned on when the sunlight is insufficient.

11.7.7 Optic fibre piped sunlight in residence area

Parans piped sunlight hybrid luminance system is proposed to provide general lighting in both large and small units in MIST phase 1A residence spaces as shown below:

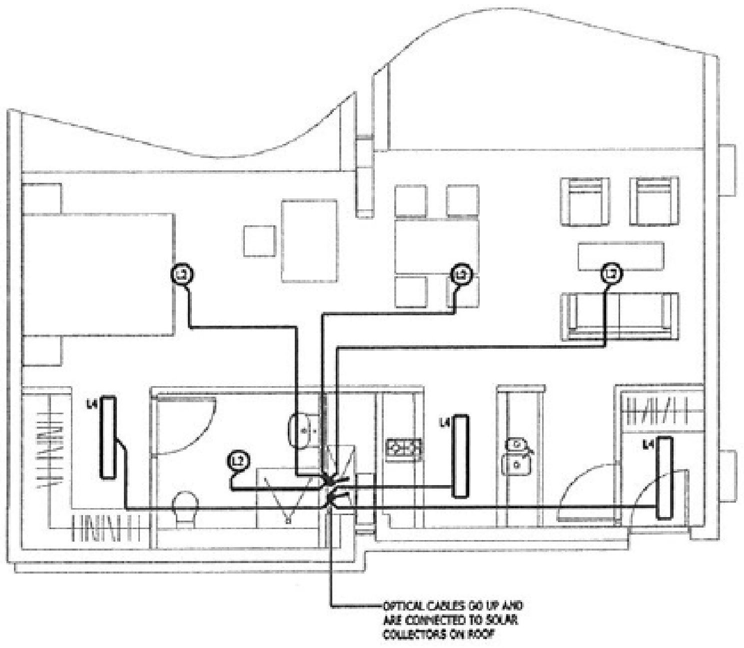


Figure 11-32 Typical light layout for small unit on level 1

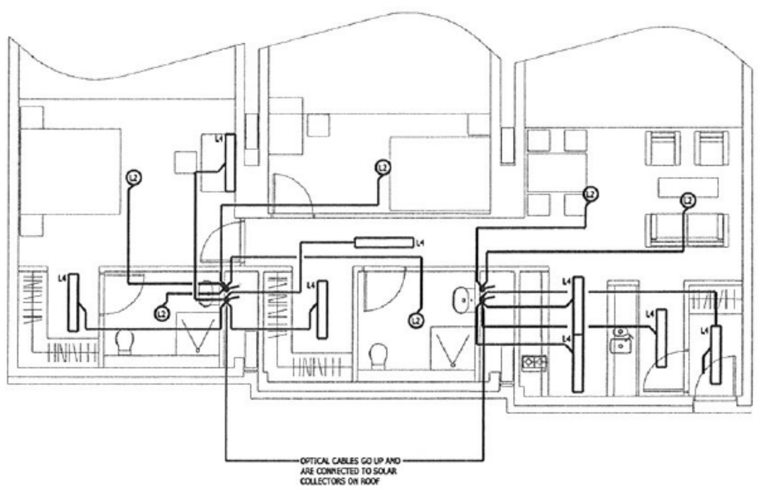


Figure 11-33 Typical light layout for large unit on level 1

Residence piped sunlight schematics:

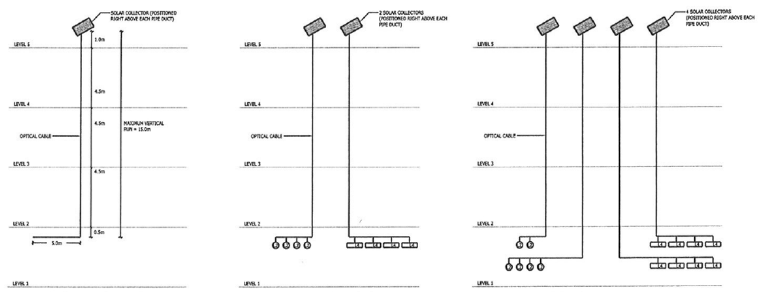


Figure 11-34 Optical cabling structure on level 1, optical illumination schematic for small unit, optical illumination schematic for large unit

Cost estimation

Installation cost for small residence unit	No. units	price per unit	Total price
L2	344	668.2	229,864.20
L4	344	533.3	183,462.10
panel	172	7,357.00	1,265,404.00
cable	2,666.00	50	133,300.00
in. cost	172	300	0
			1,812,030.30
unit cost (£/unit)=			21070.12

Installation cost for large residence unit	No. units	price per unit	Total price
L2	24	668.2	16,037.00
L4	32	533.3	17,066.20
panel	16	7,357.00	117,712.00
cable	212	50	10,600.00
in. cost	16	300	4,800.00
			166,215.30
unit cost (£/unit)=			41553.82

Figure 11-35 Cost estimation comparison

Advantages:

- Natural daylight can be brought into the residence space to save lighting energy during daytime without adding more cooling load to the space.(infra red is blocked by going through the optic fibre).
- The day lit environment benefits building users from healthier, more satisfying living spaces and might increase work productivity.

Disadvantages:

- The Parans piped sunlight system only works on direct sunlight condition.
- The capital cost of the system is high as shown above; maintenance is needed. Payback period assessment is unavailable at this stage due to unknown life cycle of the product.
- The optic fibre cable has a limitation of good performance at 20m in length, which can only server from level 1 to level 4. Using higher standard optic fibre might improve the system.
- It is suggested that the piped sunlight system is not suitable for residence area since the spaces are unlikely to be occupied during the daytime when sunlight is available.

11.7.8 Optic fibre piped sunlight in laboratory areas

In the laboratory zone two solar lighting strategies were tested by using piped sunlight system to provide standard illumination to the whole space/ circulation spaces only.

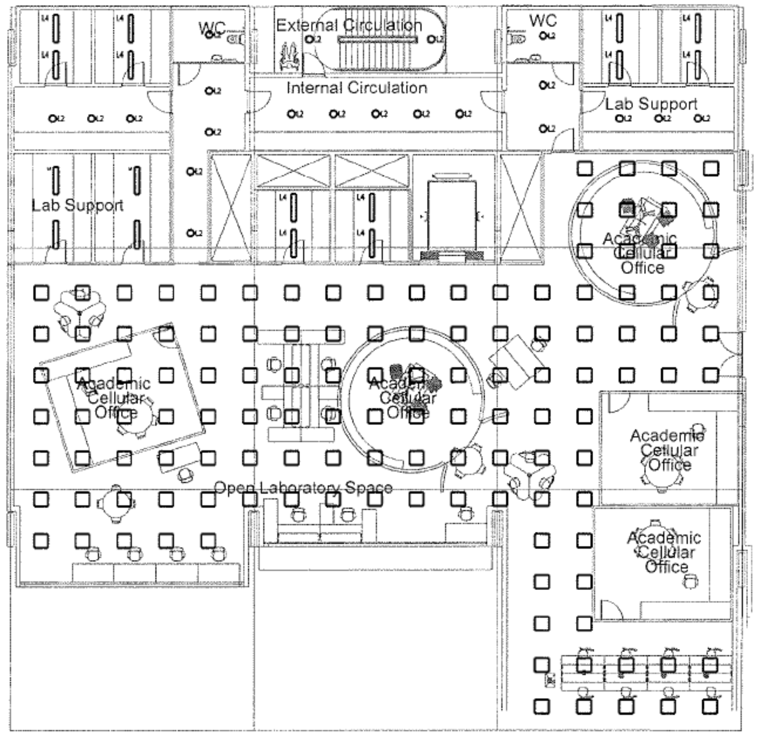


Figure 11-36 Proposed solar lighting layout for laboratory

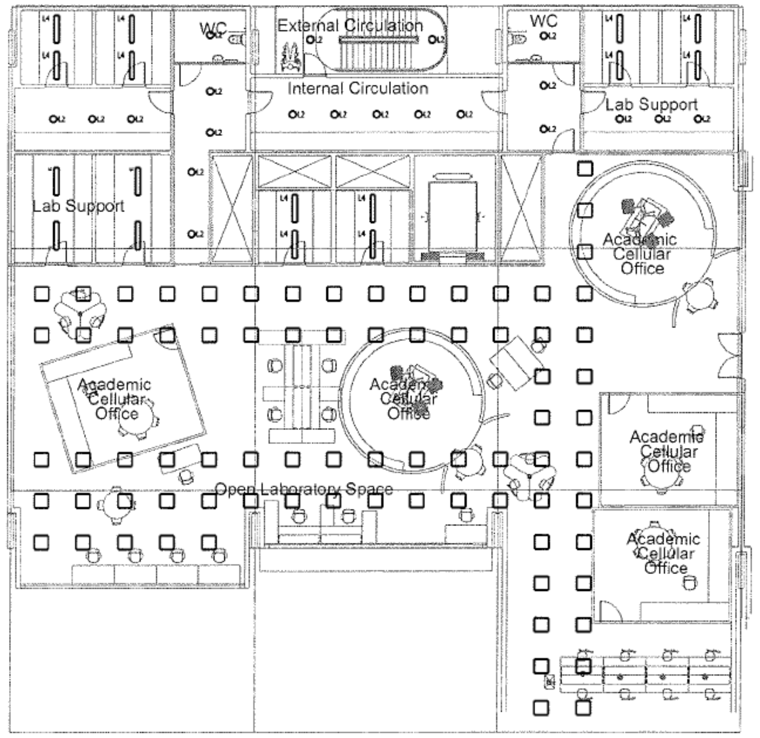


Figure 11-37 Proposed soalr layout for laboratory corridor space

Lab piped sunlight schematics:

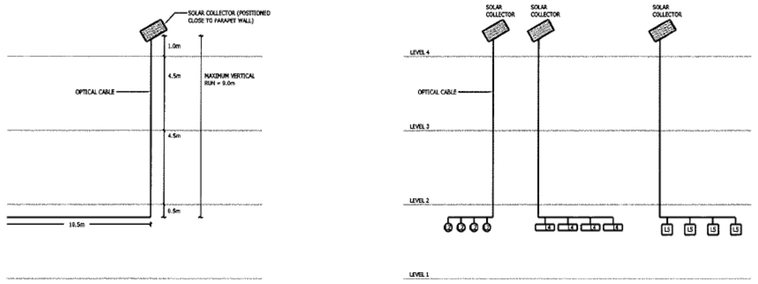


Figure 11-38 Optical cabling structure for laboratory, optical illumination schematic for laboratory.

Cost estimation

Installation cost for small residence unit	No. units	price per unit	Total price
L2	80	668.2	53,456.80
L4	64	533.3	34,132.48
L5	576	803.4	462,741.12
panel	180	7,357.00	1,324,260.00
cable	3,500.00	50	175,000.00
in. cost	180	300	54,000.00
			2,103,590.40
unit cost (£/m2)			601.03

Installation cost for large residence unit	No. units	price per unit	Total price
L2	80	668.2	53,456.80
L4	64	533.3	34,132.48
L5	320	803.4	257,078.40
panel	116	7,357.00	853,412.00
cable	2,000.00	50	100,000.00
in. cost	116	300	42,688.00
			1,340,767.68
unit cost (£/m2)			383.08

Advantages:

- Natural daylight can be brought into the residence space to save lighting energy during daytime without adding more cooling load to the space.(infra red is blocked by going through the optic fibre).
- The day lit environment benefits building users from healthier, more satisfying working spaces and may increase work productivity.
- Piped sunlight system is suitable for the lab zone since occupant density is high during daytime.

Disadvantages:

- The Parans piped sunlight system only works on direct sunlight condition.
- The capital cost of the system is high as shown above; maintenance is needed. Payback period assessment unavailable at this stage due to unknown life cycle of the product.
- The optic fibre cable has a limitation of good performance at 20m in length, which can only server from level 1 to level 4. Cables are proposed running from riser shaft and parameters (façade) of the building, to be agreed with architects for façade design.
- Internal luminaries design needs to be coordinated and integrated with the lab consultant.

11.7.9 Other manufactures

Monodraught sunpipes

Monodraught SunPipes have had a great success In Dubai, Abu Dhabi and Bahrain. The British School at Al-Khubairat in Abu Dhabi, is currently completing a third phase of a major extension and has opted for a total of 70 number Monodraught SunPipe system, which pipe in sunlight deep into the building – but without the attendant problems of solar gain associated with the Middle East.

SunPipes consist of a silver plated, mirror finish aluminium tube, which reflects sunlight down into the area below. The Diamond shaped roof dome is sealed to the top of the SunPipe with a special gasket to prevent the ingress of sand and dust. There is virtually no limit to the length of SunPipe that can be used and adjustable elbows can be used to allow the SunPipe to twist and turn internally, so as to avoid internal obstructions, such as water pipes and services, etc. The Monodraught SunPipe systems are highly cost effective and are fabricated entirely in the UK. The design of the system is to eliminate the transfer of solar gain, since the long, tall column of still air acts as an excellent insulator against heat transfer. Not only does the system bring in pure, natural daylight, without glare, but use of the SunPipe systems means that electric lighting is no longer needed during daytime use and this in turn leads to a reduction in the cooling load required, which would otherwise be necessary to remove the heat generated by the artificial lighting. The savings are, therefore, considerable:-

- saving the cost of electricity that would otherwise be used for electric lighting;
- saving the cooling load that would otherwise be necessary to remove the lighting heat load;
- eliminating the need for maintenance associated with replacement of light bulbs, etc.

11.7.10 Comparison between PV and piped sunlight system

A comparison between PV and Panrans piped sunlight system is carried out to investigate more adoptable use of limited roof space in teams energy saving and environmental quality.

Systems	Parans piped sunlight system
Max External solar illuminace (lux)	110000
Internal lumen provided by single optical fiber	420
Area illuminated per optic fibre (m2)	6.54
NO. of optic fibre per collector	4
Total lumens generated per 1m2 solar collector	10987.2
Max energy save per 1m2 collector (w)	112
Operation energy demand (w)	2
Total energy saved (w/m2)	110

Figure 11-39 Key performance data for Parans piped sunlight system

Unit	Average radiation (W/m2)	System efficiency (%)	System inefficiency (%)	Total system efficiency (%)	Thermal output (W/m2)
Solar thermal collectors – vacuum/heat pipe	700	80.6	10.6	70	**490**
Solar PV Panels	700	18	4	14	**98**

Figure 11-40 Performance comparison

11.7.11 Conclusion:

From the above analysis, it can be seen that to gain the best use from the roof area, in terms of energy production, solar thermal collectors is the optimum solution.

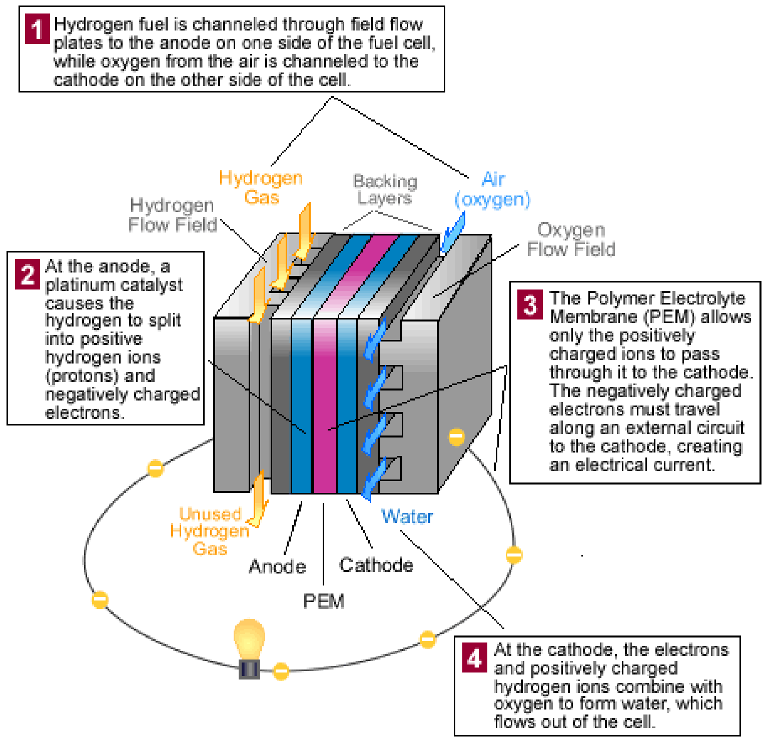
11.8 APPENDIX 8
Technology Sector: Electrical Generation

11.8.1 Application
Provide resilient supply of electrical power generation

11.8.2 Study Title
Study the process of Fuel Cells and investigate their use for electrical generation or a power back-up application.

11.8.3 Description:
This technology was investigated because of the heralded potential start of the hydrogen economy and the possibility of storing hydrogen outside the city.

There are several different types of fuel cells, each using a different chemistry. Fuel cells are usually classified by their operating temperature and the type of electrolyte they use. Some types of fuel cells work well for use in stationary power generation plants, whilst others may be useful for small portable applications or for powering cars.



Schematic of one type: PEM Fuel cell

Polymer Electrolyte Membrane (PEM) fuel cells—also called Proton Exchange Membrane fuel cells—are the type typically used in automobiles and small back up applications. A PEM fuel cell uses hydrogen fuel and oxygen from the air to produce electricity.

Phosphoric acid stationary fuel cell - manufactured by UTC

Carbonate fuel cell - manufactured by Fuel Cell Energy

PEM fuel cell - manufactured by Hydrogenics

The efficiency of a fuel cell is dependent on the amount of power drawn from it. Drawing more power means drawing more current, which increases the losses in the fuel cell. As a general rule, the more power (current) drawn, the lower the efficiency. Most losses manifest themselves as a voltage drop in the cell, so the efficiency of a cell is almost proportional to its voltage. For this reason, it is common to show graphs of voltage versus current (so-called polarization curves) for fuel cells. A typical cell running at 0.7 V has an efficiency of about 50%, meaning that 50% of the energy content of the hydrogen is converted into electrical energy; the remaining 50% will be converted into heat. (Depending on the fuel cell system design, some fuel might leave the system unreacted, constituting an additional loss.

11.8.4 Application to Masdar Phase 1A:
There is a requirement on the site for Generating capacity and or back up capacity for emergency power requirements.

Large Generation capacity 1.2 MW – Manufactured by Fuel Cell Energy

The DFC3000 power plant uses carbonate fuel cell technology which operates at high temperatures and allows hydrocarbon fuels (natural gas and anaerobic digester gas) to be used without an external reforming system. The DFC3000 power plant takes advantage of this by reforming the hydrocarbon fuel into hydrogen directly in the fuel cell stacks. The hydrogen generated by the internal reforming process is consumed nearly immediately as it reacts with carbonate ions in the fuel cells. The anode exhaust gas is then combined with fresh air and oxidized in a catalytic oxidizer on route to the cathodes. In the fuel cell cathodes, oxygen, carbon dioxide and electrons are consumed as they react to form carbonate ions. These carbonate ions migrate through the carbonate electrolyte to the anode side of the fuel cells, replacing the carbonate ions consumed by the anode half of the fuel cell process. Cathode exhaust gases leave the fuel cell stack modules and are utilized to provide heat energy for the incoming natural gas. The exhaust is then vented to the atmosphere or used as input energy for Combined Heat and Power applications.

For MIST we where looking for a 1.2 MW Generation capacity.

- The physical size of unit would have meant to generation capacity would have been outside the city (15.3m (W) x 22.3m (L) x 7.7m (H)).
- Output & Efficiency decreaseases by 10% per year. Replacement of DFC stacks would be the only method of preventing the fuel decreasing in capacity.
- Limited to 15 full power to Hot standby ramps per year before stack life is effected.
- Fuels: Only uses Natural Gas which is outside project scope and also uses Digester Gas.
    - In Backup mode and full capacity the flowrate of digester gas required would require to 6.85 m^3/min. For one day of full capascity output would be the equivalent blackwater turnover dailey output of a population of 352,000. To ramp up from cold to full capacity would take 80 hours.
    - To have the fuel in a mode of Hot Standby i.e. On-line but the capacity not used. Just to keep the fuel cell in the standby mode would require a digester consumption of 3.5 m^3/min. For one day of full capascity output would be the equivalent blackwater turnover dailey output of a population of 180,000. To ramp up from standby to full capacity would take 10 hours.
    - Water useage would require potable water of 19 m^3/day with 50% discharge

Conclusion

Not suitable due to limited production of digester gas, not flexible in terms of ramp up times and high water usage rate

Medium Generation capacity 400 kW – manufactured by UTC

Disadvantages/Risks after system performance analysis:

- Fuel use only from Natural Gas. Methane gas fuelled system planned for 2010
- Ramp up time ranges between 8 to 24 hours

Conclusion

Not suitable due to fuel type

Back up power generation 12 kW – manufactured by Hydrogenics

For continuous power (24 x 365), the current state of PEM Fuel Cell technology development greatly falls short of the 40,000 or 50,000 hours of operation without the need for a major maintenance occurrence.

However, for backup power, the current state of PEM Fuel Cell technology development greatly exceeds (you could say extremely comfortably and reliably exceeds) the requirements for critical loads. The expected lifetime is comfortably more than 1000 hours, which is very unusual to be needed in backup applications. Starts/stops are unlimited.

That PEM fuel cells need to be kept warm is true, specifically: above 0 Celsius, otherwise the excess water in the stack channels and balance of plant will freeze and just like any conventional water system exposed to freezing temperatures without protective measures, will "crack the pipes" as well as the stack channels.

The fuel cells start in 4 seconds "warm", and up to 24 seconds from "cold". We use either batteries or ultra-capacitors for the bridging power for this short time, then the fuel cells take over.

Conclusion

Suitable Technology...if used in quantity to provide backup capacity for critical loads such as IT server backups. Would still require the use of a battery style UPS to provide the instantaneous backup capacity until the fuel cells ramp up.

11.9 APPENDIX 9 Thermal Labyrinths

11.9.1 Description

- The thermal labyrinth will be supplying air in an air handling unit with a capacity of 14m³/s.
- The thermal labyrinth will be made out of concrete, possibly with added panels of Phase Change Material (PCM) for increased thermal capacity.
- The Pre-cooled air from the thermal labyrinth will be used during the day when the temperature is at its height.
- The thermal labyrinth is purged for an equal period during the night to be re-charged.
- The analysis was performed using TAS v9.0.9d; this software provides dynamic thermal analysis.
- The climate file is that of Abu-Dhabi.

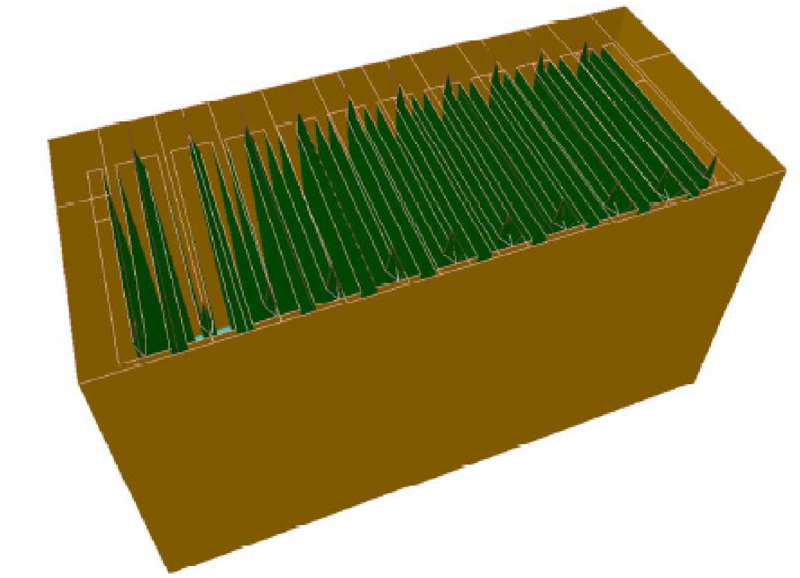


Figure 11-41 A simplified model of a thermal labyrinth

- From the results, it can be seen that as the switching temperature of the PCM increases, more cooling will be delivered during the warmer period of the year.

11.9.2 Sensitivity of switching temperature 6hr daily operation – 6hr night purge

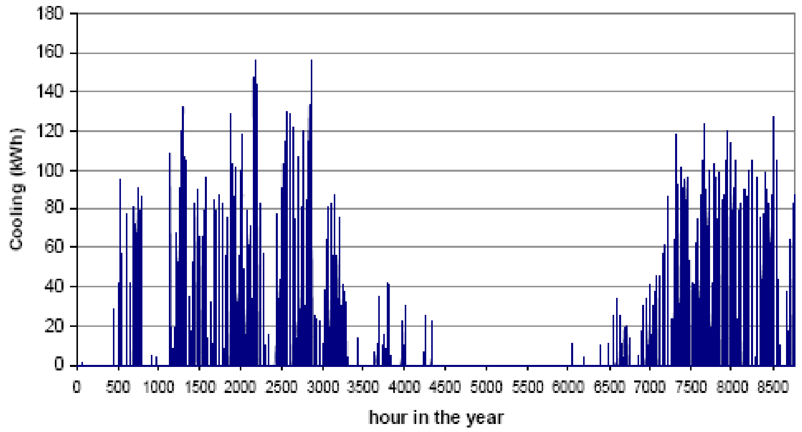


Figure 11-42 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=24°C

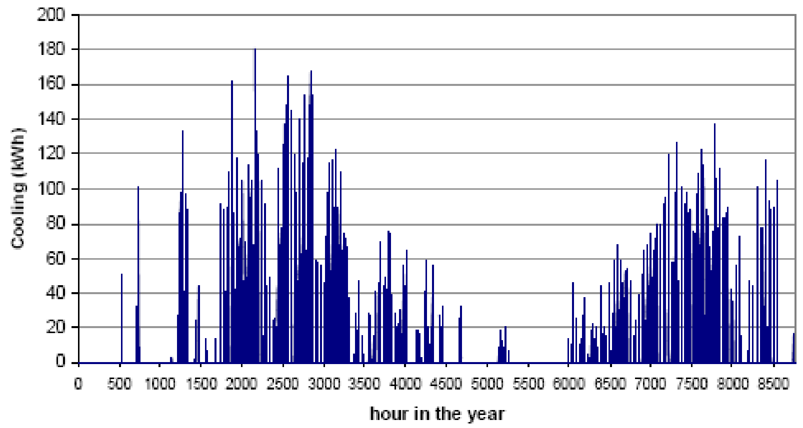


Figure 11-43 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=26°C

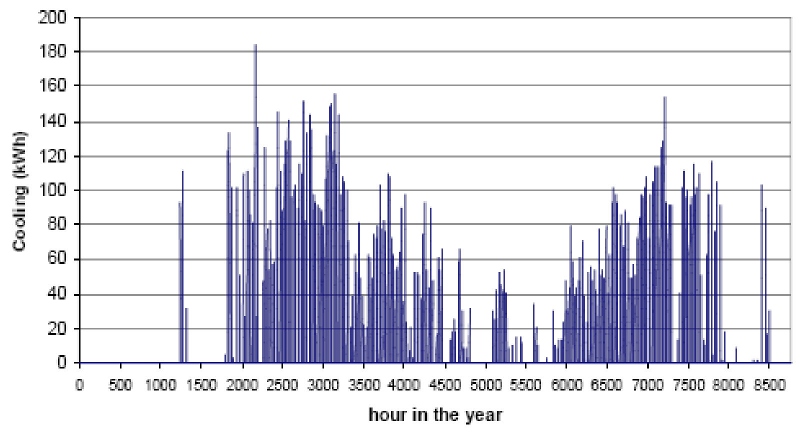


Figure 11-44 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=28°C

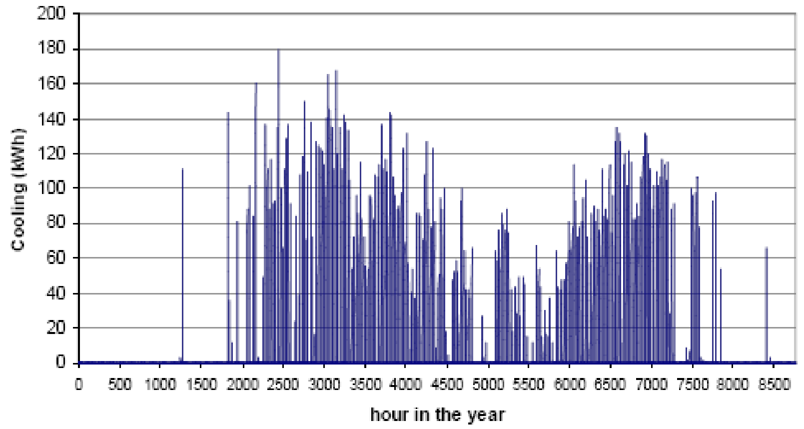


Figure 11-45 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=30°C

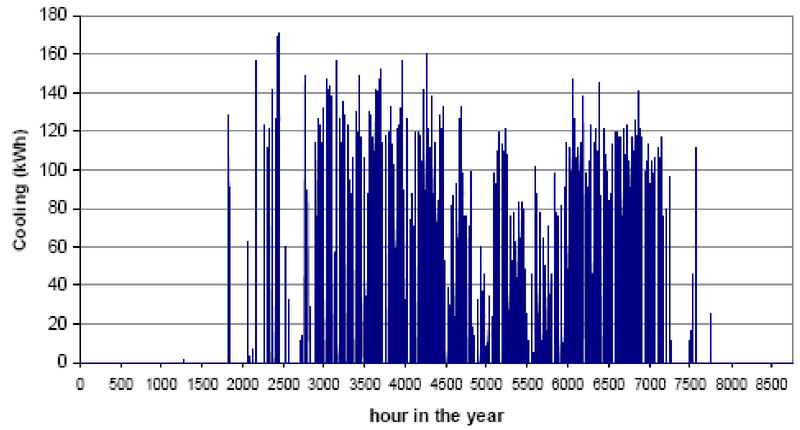


Figure 11-46 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=32°C

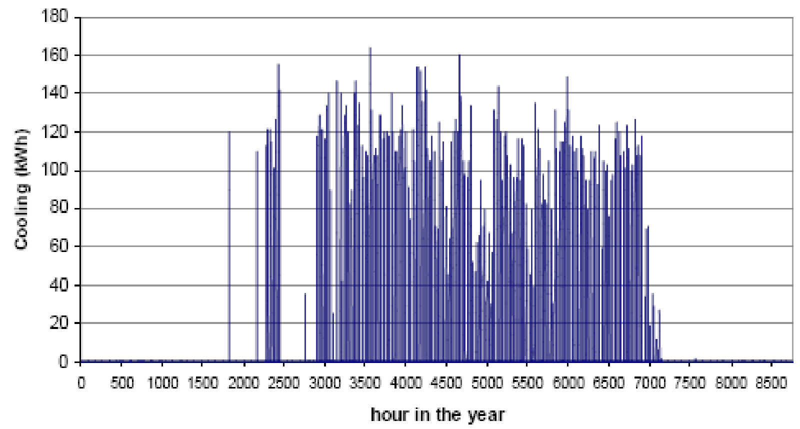


Figure 11-47 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=34°C

7hr daily operation – 7hr night purge

- For 7hr operation the day and night the cooling effect is greater than expected. As before higher switching temperature PCM's work better in warmer periods of the year.

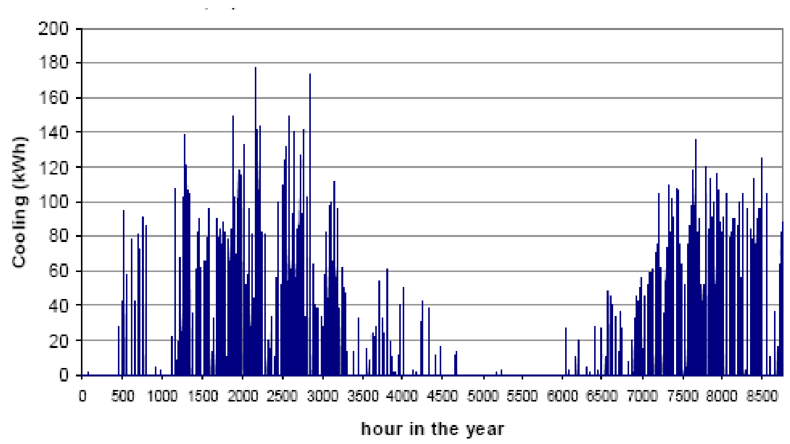


Figure 11-48 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=24°C

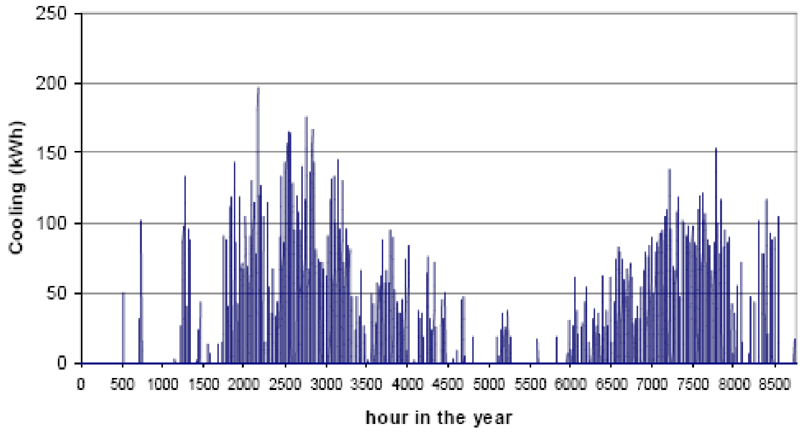


Figure 11-49 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=26°C

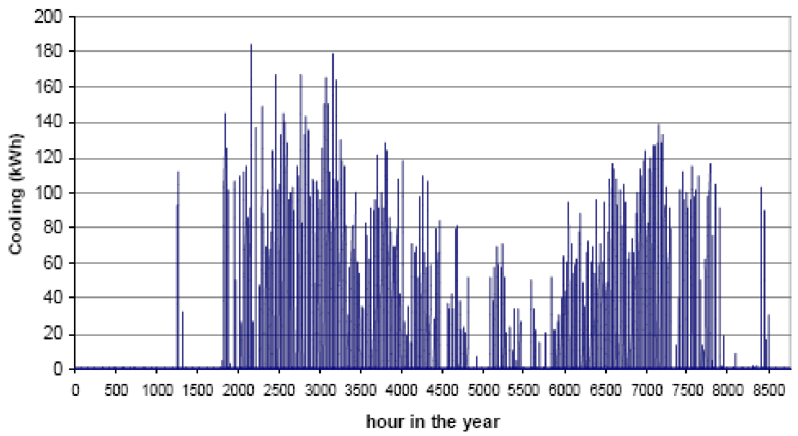


Figure 11-50 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=28°C

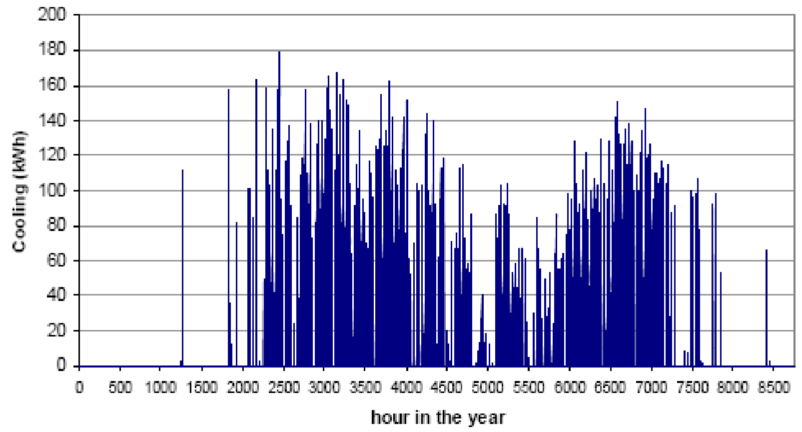


Figure 11-51 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=30°C

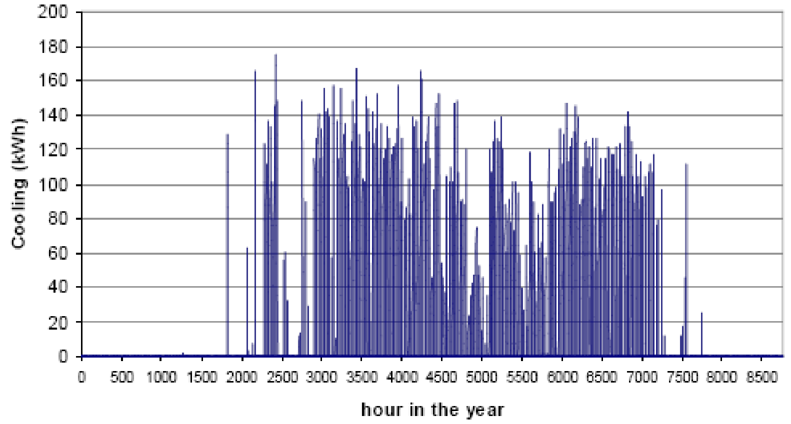


Figure 11-52 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=32°C

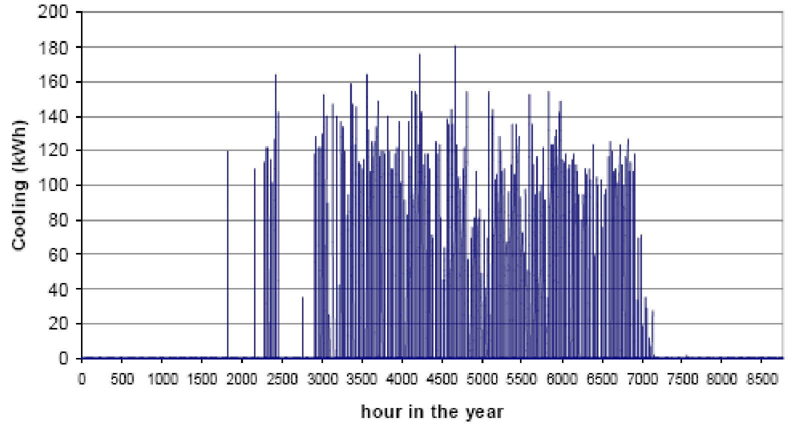


Figure 11-53 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=34°C

8hr daily operation – 8hr night purge

- For eight hour operation the trend continues, with the harvested cooling energy being more than the previous two cases.

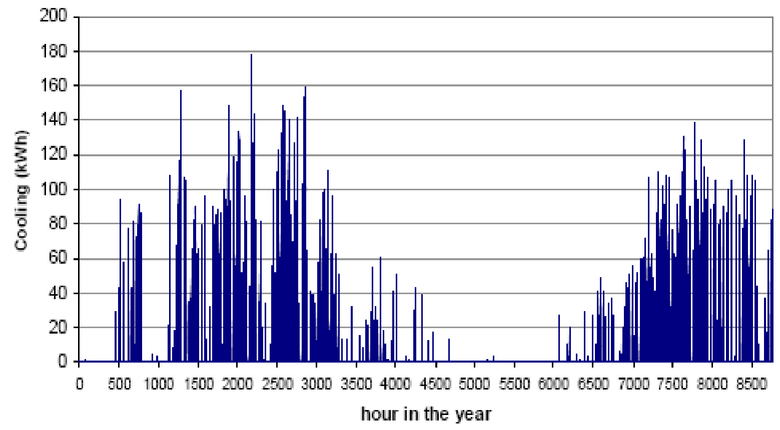


Figure 11-54 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=24°C

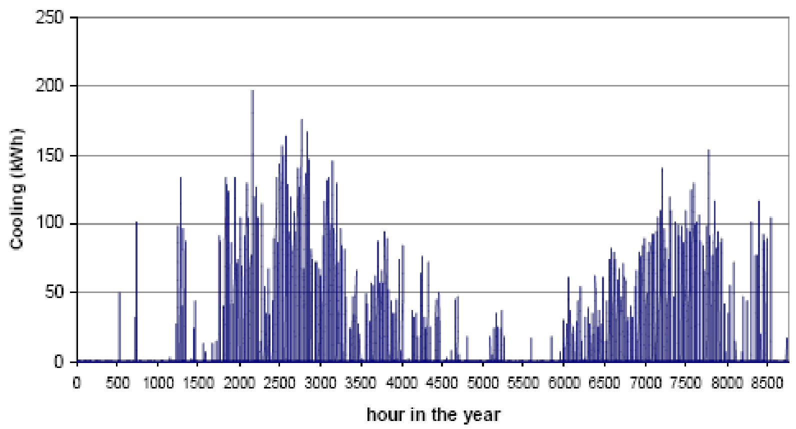


Figure 11-55 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=26°C

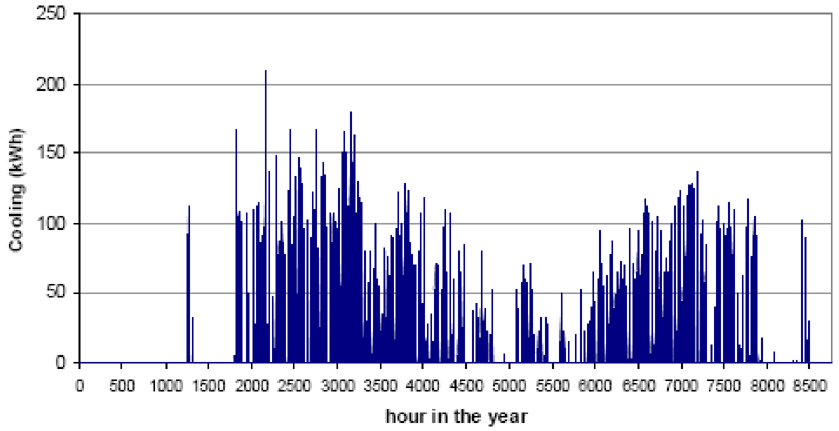


Figure 11-56 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=28°C

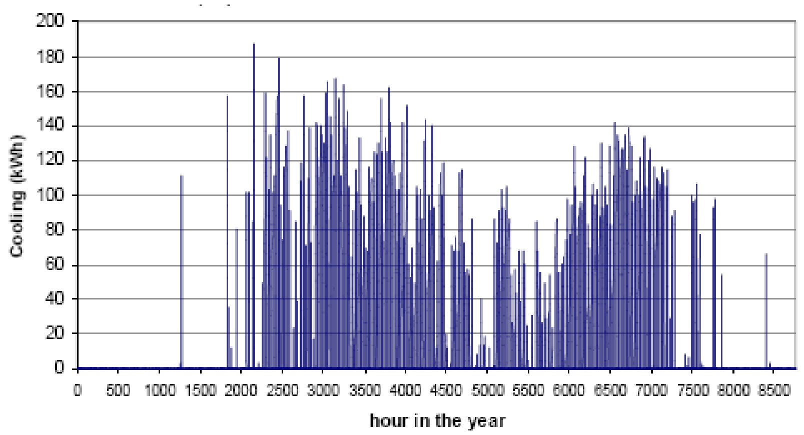


Figure 11-57 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=30°C

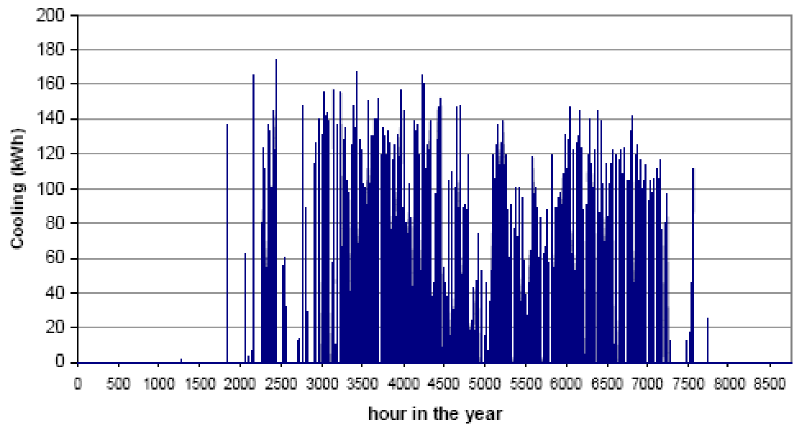


Figure 11-58 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=32°C

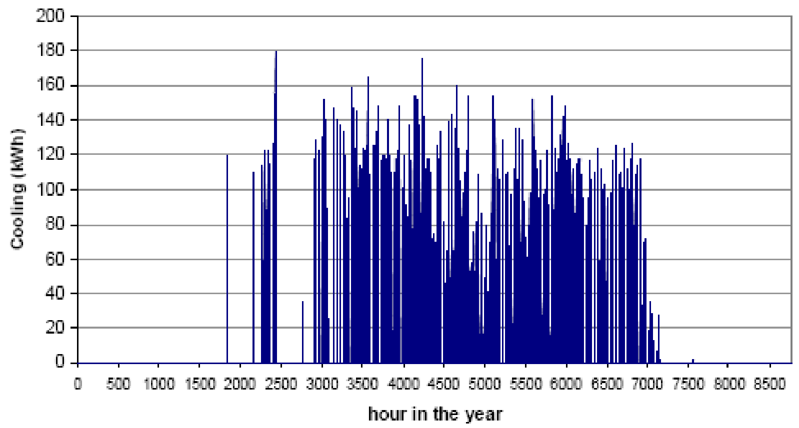


Figure 11-59 Cooling distribution by the PCM in the year. $PCM_{heat.capacity}$=840kWh, T=34°C

Annual cooling delivered

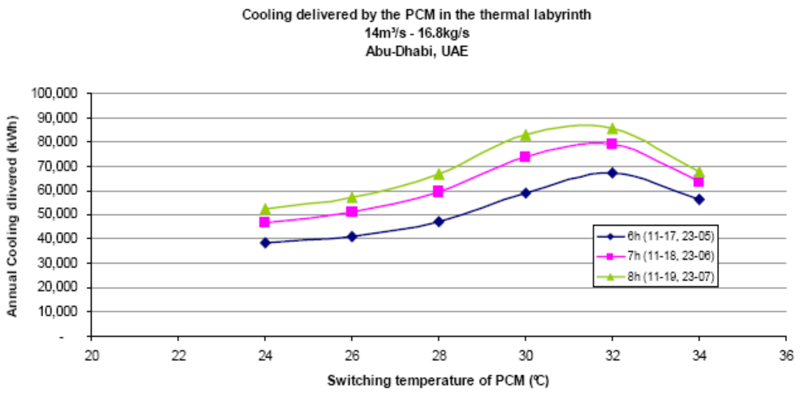


Figure 11-60 Annual cooling delivered by only the PCM

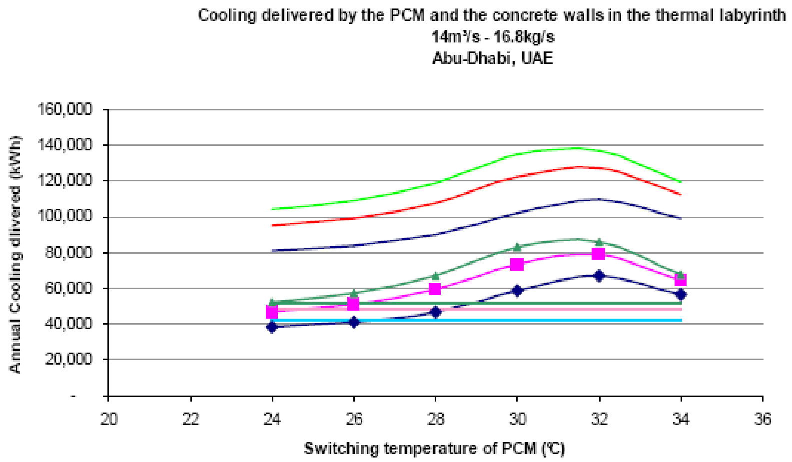
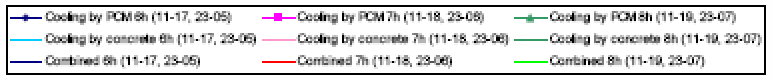


Figure 11-61 Annual cooling delivered by PCM and concrete component



As can be seen from these results;

- The highest cooling potential comes for a switching temperature of 32°C
- For very low switching temperatures - 24-26°C - the concrete walls delivers more cooling than the PCM
- The added cooling effect when increasing the operational period from 6 to 7 hours is greater than when increasing from 7 to 8 hours.

Annual cooling delivered with double airflow for purging

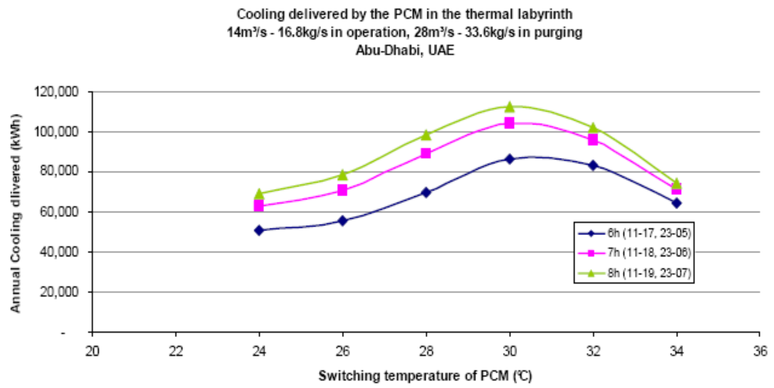


Figure 11-62 Annual cooling with double airflow for purging, delivered by only the PCM

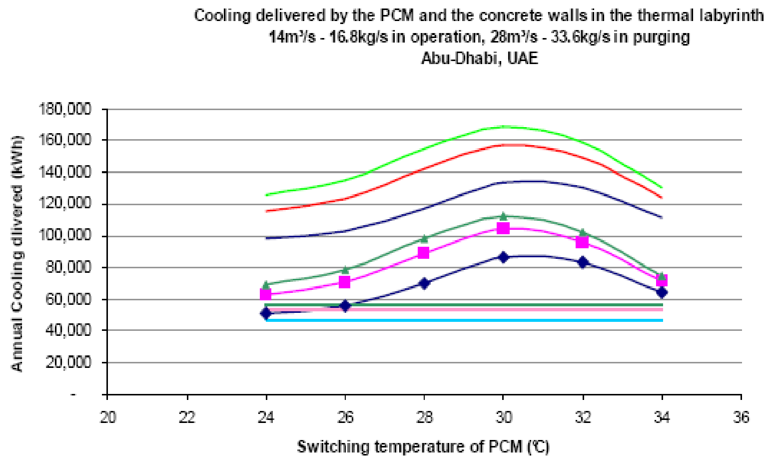
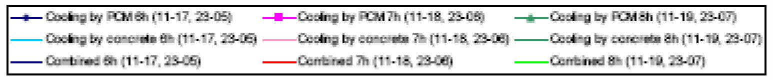


Figure 11-63 Annual cooling with double airflow for purging, delivered by PCM and concrete component



As the airflow for purging is doubled, the following conclusions can be drawn:

- The delivered cooling energy is increased
- The highest cooling potential comes at a slightly lower temperature of 30°C
- The additional electrical energy for driving the fans can not be justified

Combination of different switching temperatures

- Mixing equal portions of PCM with alternative switching temperatures was examined; combining the good performance of higher switching temperature PCM's in summer with the operation of lower switching PCM's during colder periods of the year.
- Figure 1-24 shows the annual cooling energy delivered by such a set up, identified in Blue.
- This analysis shows there is little any benefit and the best practice is to use only PCM with 32°C switching temperature.

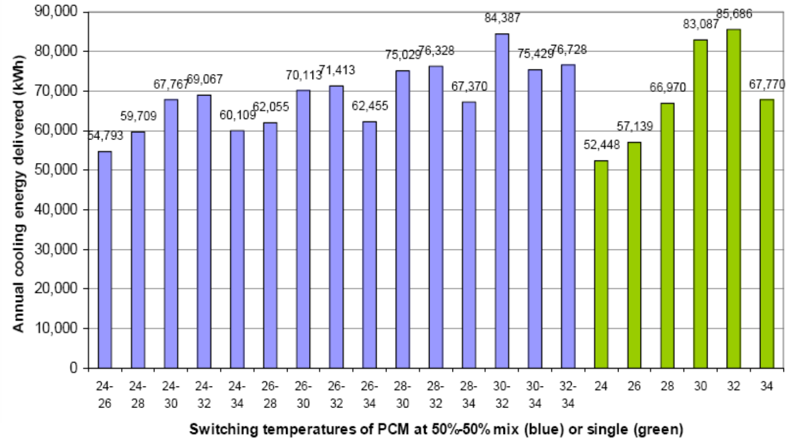


Figure 11-64 Annual Cooling energy from a mix of PCMs with different switching temperatures

11.9.3 Quantity of PCM

- The total heat capacity of the PCM in the thermal labyrinth is a function of the total mass of the PCM. Because PCM is capital intensive, it is imperative to use the optimum quantity of the material.
- The three graphs show the total cooling delivered for daily and night operation of 6, 7 and 8 hours respectively, as a function of switching temperature and heat capacity.
- The optimum is between 400kWh and 600kWh of total heat capacity for a switching temperature of 32°C.

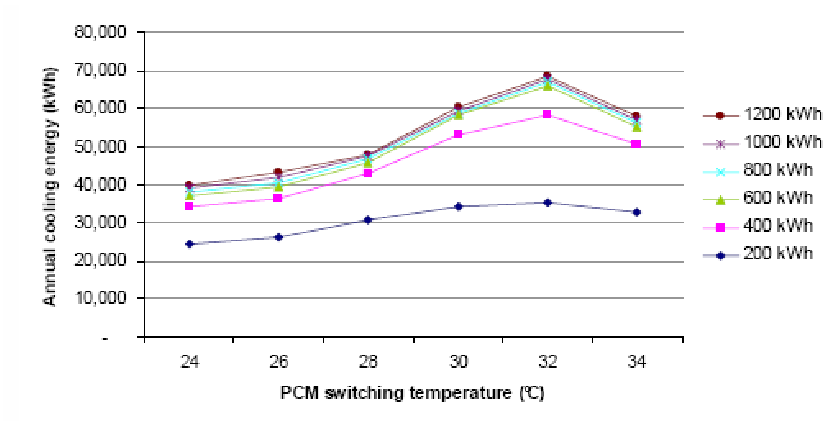


Figure 11-65 Annual cooling delivered switching temperatures and total heat capacity of the PCM, 6hr daily operation and 6hr night purge

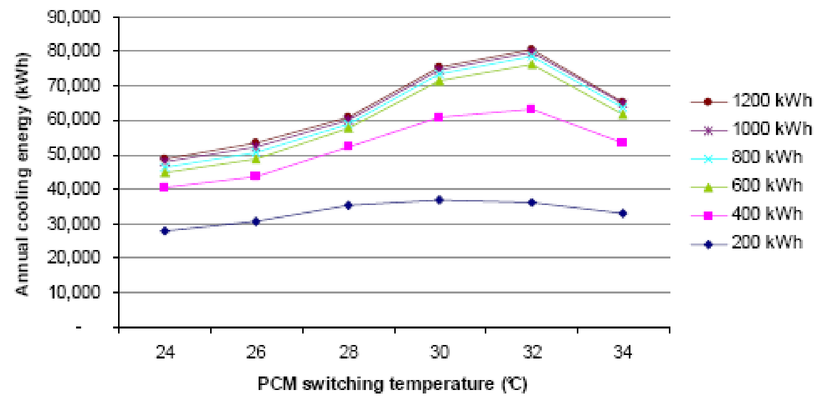


Figure 11-66 Annual cooling delivered switching temperatures and total heat capacity of the PCM, 7hr daily operation and 7hr night purge

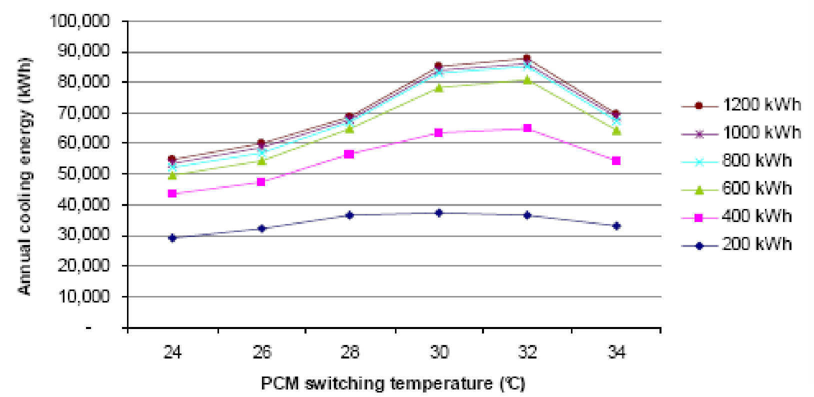


Figure 11-67 Annual cooling delivered switching temperatures and total heat capacity of the PCM, 8hr daily operation and 8hr night purge

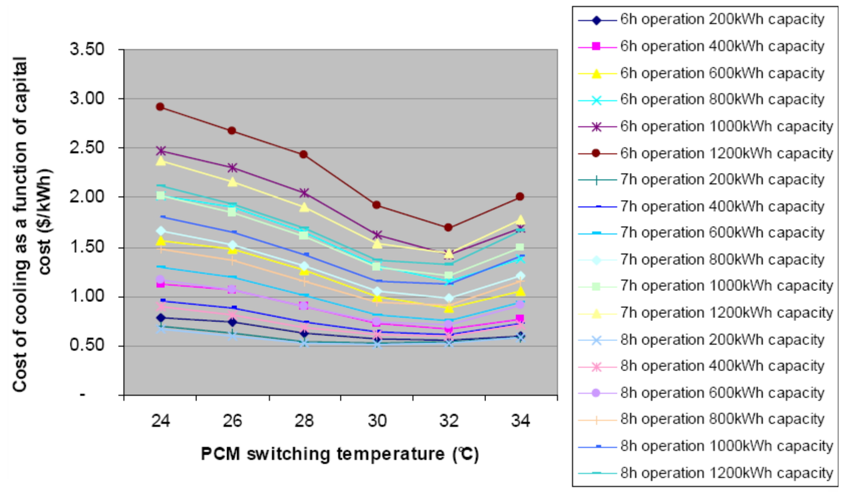


Figure 11-68 Cost of cooling delivered as a function of capital cost of PCM for different quantities of PCM, switching temperatures and daily duration of operation

- It comes as no surprise that the lowest cost of cooling comes from a PCM with an installed heat capacity of 200kWh, operating for 7 or 8hrs a day with a switching temperature of 32°C. That way the PCM is maximised.
- In terms of engineering, a 400kWh capacity PCM will deliver more cooling without worsening its financial benchmarks significantly.
- The option to operate for 7 or 8hrs will have to be weighed against the cost of electricity for this additional hour of operation.

12 Building Simulation Studies

12.1 Phase 1a Global Model

12.1.1 Introduction

A dynamic thermal model was built of MIST Phase 1A to allow a comprehensive evaluation of total annual HVAC and equipment loads and peak cooling loads for key zones.

IES Virtual Environment [IESVE] thermal modelling software was used to model Phase 1a, and for the subsequent studies on specific areas of the building which were felt at this stage to hold special interest or cause for concern.

IESVE is an integrated environment containing a variety of building simulation modules, including thermal, artificial lighting and day-lighting, solar and computational fluid dynamics (CFD). The 'thermal' module was used to create a dynamic thermal model of MIST Phase 1a concept design proposals by Foster + Partners.

This modelling approach allows us at an early stage to interrogate the assumptions contained within Transolar's masterplan building energy modelling reports.

Energy consumption targets for key building typologies have been imposed on the basis of Transolar's analysis. Their modelling approach incorporates a number of critical, but generally reasonable, assumptions about building envelope performance, occupant behaviour and systems efficiencies for both HVAC and occupant controlled equipment loads.

Applying these assumptions to the specific circumstances of MIST Phase 1a allows us to assess the performance of the Concept Design against the Masterplan energy targets, to identify areas that do not perform to the anticipated level, and to investigate further opportunities for reductions in energy consumption.

In essence, the design guidance and performance criteria set out in the masterplan – Transolar's 'outputs' - are used as the 'inputs' for this initial modelling exercise for MIST. The only variance between the two models is that the real geometry of the Phase 1a is used for analysis, rather than the notional building form used in the masterplan analysis.

Inevitably the assumptions made for generic typologies at masterplan will not be an exact fit for every specific project. Refining these assumptions and exploring their implications for architectural and HVAC design will be a key part of the next stage of work.

The key zones that were analysed were:

1. The Residential zones on the perimeter of Phase 1a on each of the relevant orientations
2. Both main Laboratory spaces
3. A typical open plan office.

			Office		Laboratory		Housing	
Issue	Item	Units	Working	Non-Working	Working	Non-Working	Working	Non-Working
Building Geometry	Floor to Floor Height	m	4.5	4.5	4.5	4.5	4.5	4.5
	Floor to Ceiling Height	m	3.9	3.9	3.9	3.9	3.9	3.9
Density	Occupants	m²/pers.	20	20	20	20	50	50
Working Hours	Range (from)	hrs	0800	1900	0800	1900	1800	0800
	Range (to)	hrs	1900	0800	1900	0800	0800	1800
	Days per week	#	6	6	6	6	5	5
Operation of AHU	Range (from)	hrs	0000	0000	0000	0000	0000	0000
	Range (to)	hrs	0000	0000	0000	0000	0000	0000
	Days per week	#	7	7	7	7	7	7
	Air Change Rate	ach	1.5	0.75	6	3	1.0	1.0
Artificial Lighting	Power Density	W/m²	7	7	7	7	0.8	0.8
Building Envelope	Glazing Ratio	%	30	30	30	30	30	30
	g-value (glass)	%	25	25	25	25	25	25
	shading	-	external	external	external	external	external	external
	g-value (shaded)	%	15	15	15	15	15	15
	Light Transmission	%	50	50	50	50	50	50
	Glass Equivalent		SKN154	SKN154	SKN154	SKN154	SKN154	SKN154
	Frame Ratio	%	20	20	20	20	20	20
	U-value (glass)	W/m2/K	1.2	1.2	1.2	1.2	0.8	0.8
	U-value (frame)	W/m²/K	2	2	2	2	2	2
	U-value (wall)	W/m²/K	0.25	0.25	0.25	0.25	0.3	0.3
	U-value (roof)	W/m²/K	0.12	0.12	0.12	0.12	0.1	0.1
	U-value (floor)	W/m²/K	0.35	0.35	0.35	0.35	0.4	0.4
	Infiltration	ach	0.15	0.05	0.15	0.05	0.2	0.05
Equipment Heat Gains	Sensible	W/m²	3.1	1.55	10.6	5.3	0.86	0.86
Temperature Range	Air Temperature	?C	24	28	24	28	24	26

Figure 12-1 Summary of modelling assumptions used within the study

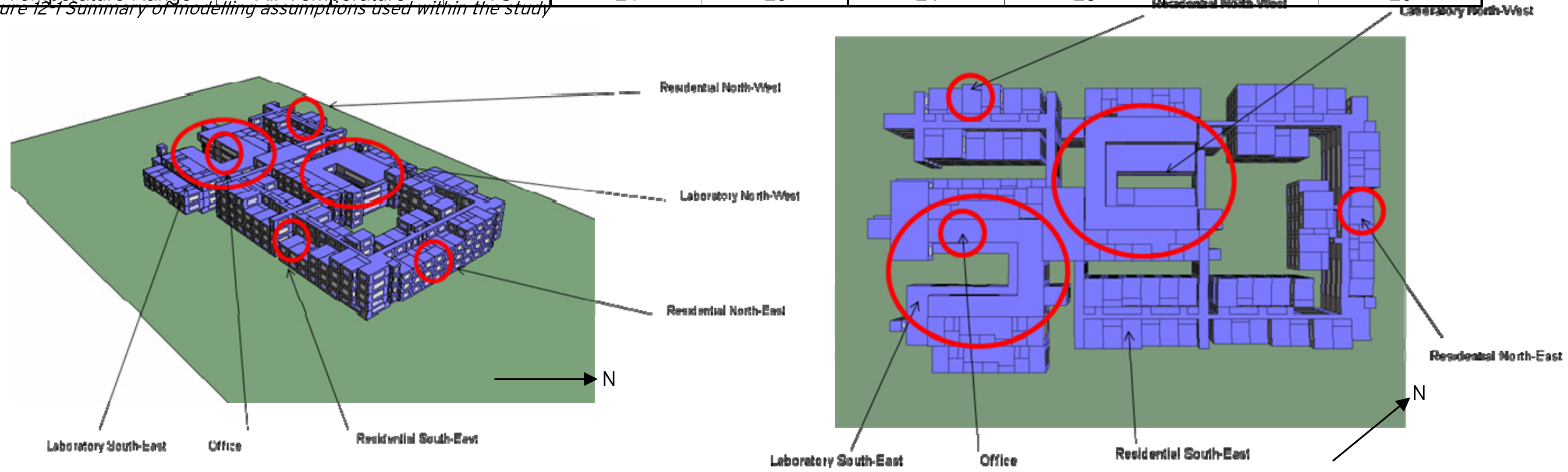


Figure 12-2 IESVE Model View showing the location of key zones assessed within the model

Model Inputs

Climate Data:
The climate data that was used in the model was from the ASHRAE IWEC hourly climate file for energy simulation from Abu Dhabi International Airport.

Building Element Composition, Sensible Loads and Operational Schedules:
All of the assumptions for the model were inputted as per the Masterplan report, with the exception of the building geometry, as is documented in the spreadsheet to the top-right of the previous page.

The geometry used for the full building model was based on the drawing obtained from Foster + Partner's during Concept Design Phase and is deemed to be sufficiently representative of the final Concept Design submission by F+P to be valid for the purposes of this analysis.

12.1.2 Results

Overall performance has been evaluated by assessing annual cooling and dehumidification requirements (sensible and latent cooling loads).

To calculate the required COP for cooling to meet the masterplan energy target, the annual electrical consumption due to equipment and lighting is subtracted from the kWh/m^2 target, the annual cooling and dehumidification load is then divided by this figure to provide a target COP.

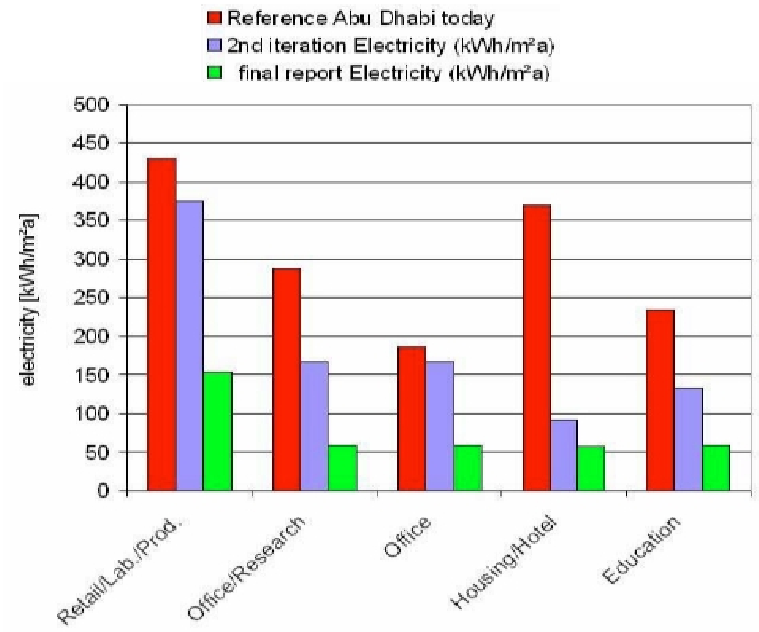


Figure 12-3 Masterplan annual electrical consumption targets for key building typologies

ResidentialZones:

Residential zones:
The comparatively low assumed equipment and lighting loads for the Residential zones, coupled with a low occupant density significantly lower the imposed sensible cooling load, the primary focus is therefore on reducing dynamic gains - Solar, External and Internal conduction. The model assumes a very high specification for the building envelope in terms of solar control (g=0.15), thermal insulation (triple glazed windows) and infiltration (0.15 ach). The real challenge is therefore to achieve the performance targets set by Transolar whilst maintaining a high quality environment - rather than expecting to greatly improve upon them.

The Residential zones of Phase 1a perform very well under the stated assumptions, needing an electric COP (Co-efficient of Performance) of only ≥1.2 to achieve the masterplan targets (54 kWh/m^2/yr),

Laboratory Zones:

Lab and Office zones:
Dynamic gains are less of an influencing factor in the sensible cooling load for the Laboratories and Open Plan Office spaces, the latter of which are usually located within another internal space and do not have an external facade.

The offices and the labs spaces have higher equipment and lighting loads, and higher occupancy density than the residential zones, but are less susceptible to changes of the building fabric. This can be attributed to the large floor area:façade area ratio for the labs and the fact that the office spaces are not currently adjacent to the building façade and therefore are only indirectly affected by its performance.

Further evidence of this can be seen in Section 12.2 within this report, which explores the relationship between the dynamic gain and the glazing ratio on the facades of the laboratories. The comparatively high required electric COP for the Open Plan Offices is not as severe as it first appears, as the required floor area for these spaces is considerably less than the Residential and the Laboratories, and therefore is expected to have much less of an impact on the overall Phase development than the aforementioned areas.

as do the Laboratories, which would require an electric COP of ≥2.5 to meet masterplan targets (154 kWh/m^2/yr).

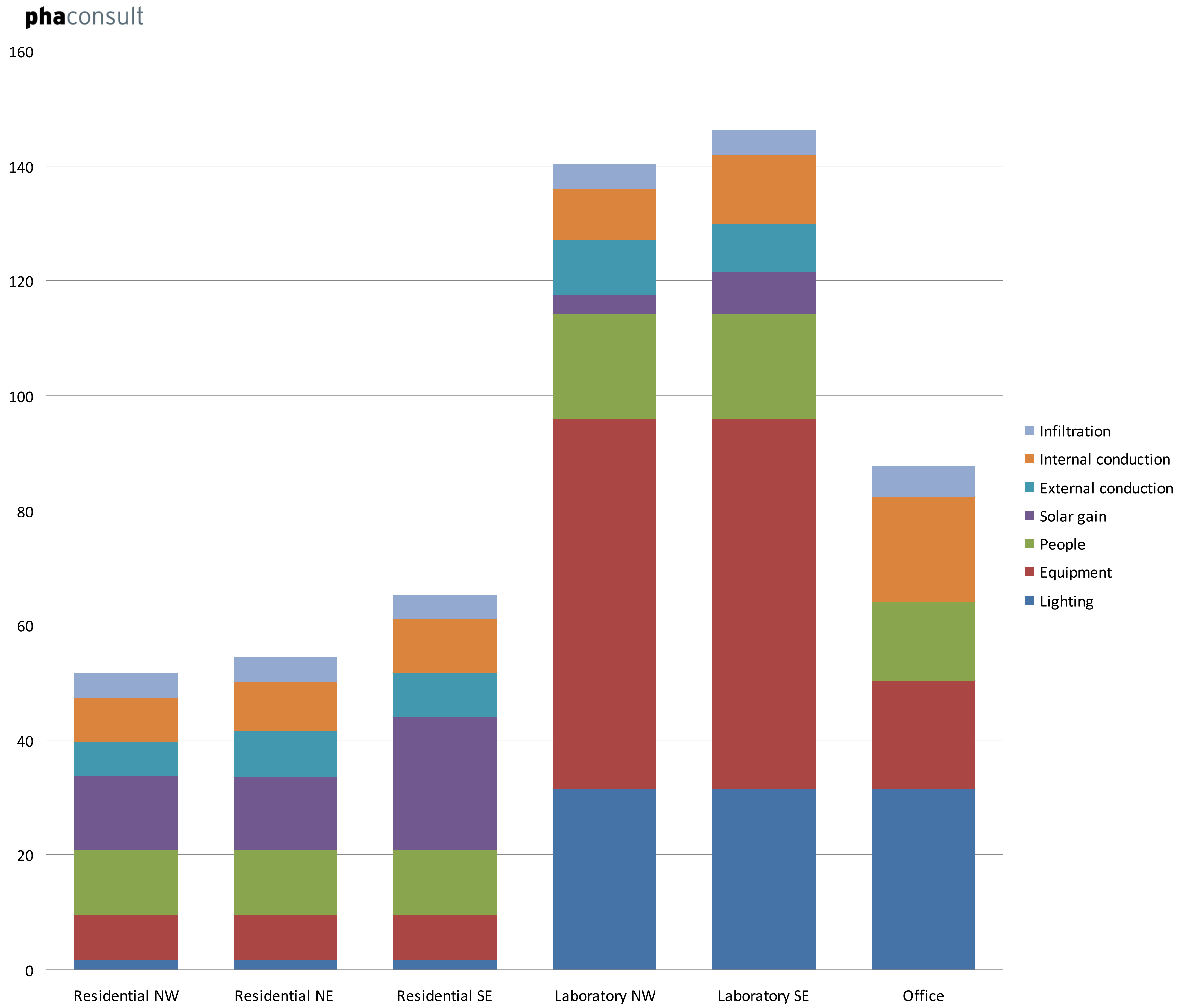
Office Zones:

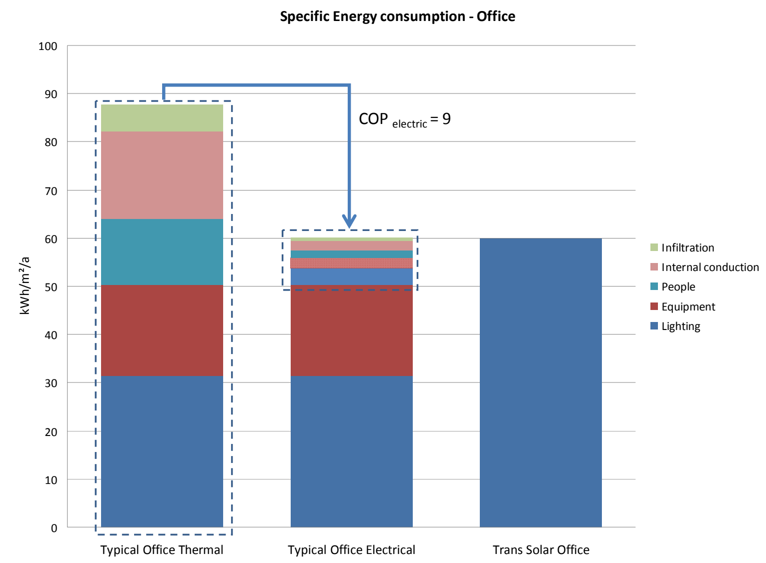
High equipment and lighting loads, coupled with the ambitious energy consumption masterplan target for offices uses, results in the Open Plan Offices located within the Laboratories requiring an electric COP of ≥9.0 in order that it may stay within the targets.

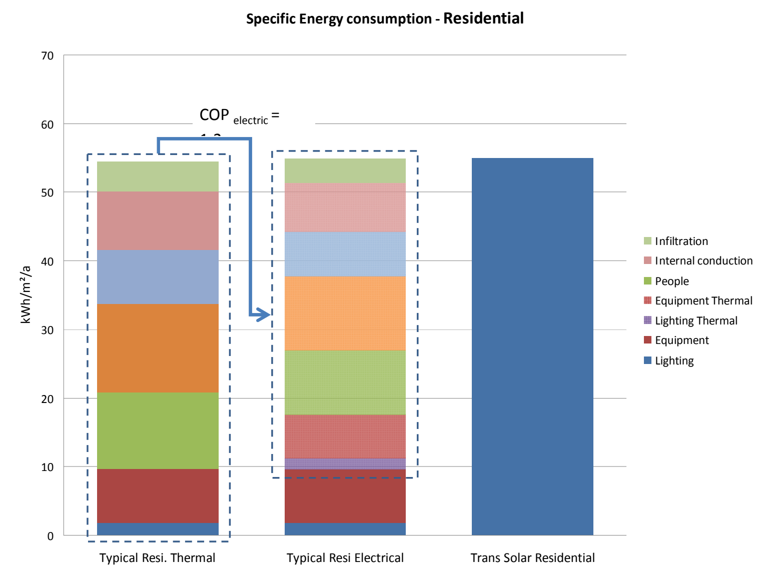
Conclusion

As demonstrated in Figure 12-4, the key variables to control in order to maintain the total electrical consumption of the development below the proposed targets are the Equipment load and the Lighting load. If the combination of these two were to go above the target then the regardless of the electrical COP of the proposed system, reaching the target will not be possible. The energy which is saved in having efficient Residential areas with low casual gains allows for the possibility of their being able to compensate for the potential inclusion of more equipment and greater occupancy loads within the laboratories that were not fully costed for in the Masterplan.

Although the electrical loads for the open plan Office spaces are high in comparison to its target and require a higher electrical COP, the relative floor area for these proposed spaces is signicantly less than the Residential and Laboratories, and therefore they are not expected to have as significant an impact on the holistic design.







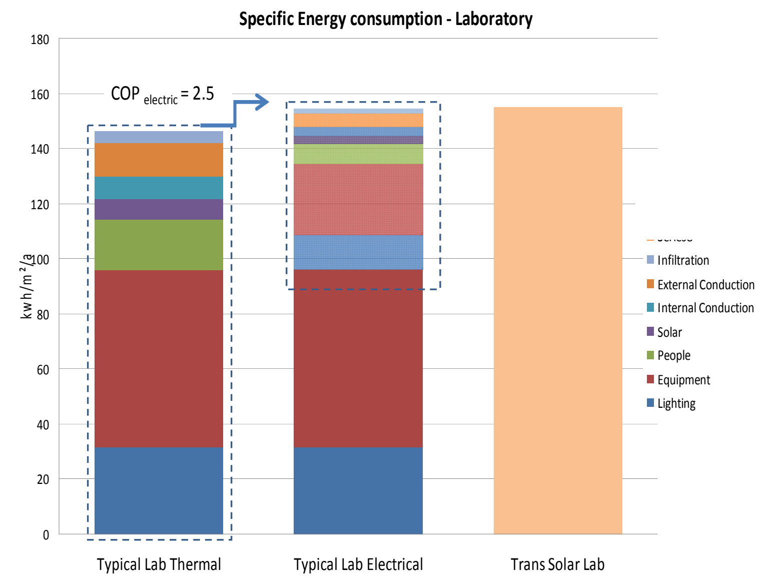


Figure 12-4 Annnual cooliing loads breakdown for key zones in Phase 1a [above]

Figure 12-5 Derivation of minimum COP for Offices [top right]Figure 12-6 Derivation of minimum COP Residential [middle right]

Figure 12-7 Derivation of minimum COP Laboratory [bottom right]

12.2 Laboratory Thermal and Electrical load Study

12.2.1 Introduction

Review of benchmark data for energy consumption within comparable laboratory spaces raises significant doubts over the viability of the masterplan assumptions for equipment use within lab spaces - 10.6 W/m².

This has been further reinforced by conversations held with MIT faculty in Boston, and with the input of the recently appointed Lab Consultant.

The impact of increased electrical conumption has additional impacts on overall cooling loads, so cannot be separated from overall energy performance.

In order to demonstrate the effect of the variation of casual loads on the laboratory areas, a series of data manipulation and separate studies were undertaken.

The IES dynamic thermal model used for this analysis was as per Section 12.1.

12.2.2 Summary

This study established the importance of keeping the electrical loads to a minimum, in order to keep the required electric COP for the cooling load down to a figure that can be achieved.

Should the equipment electric load go above the target usage for the laboratories, then in order to meet the overall energy budget for MIST it will have to be compensated for in other areas of the functional brief, for example the Residential zones, which has the potential to perform below the masterplan target.

Clearly there are physical, technological and behavioiural limits on making reductions in other areas of the brief without significant impacts on health and happiness, and the functional performance of the institution.

That being the case it may not be possible to meet the masterplan targets, being as they have possibly been set on the basis of unachievable efficiencies in operation on the part of the user.

12.2.3 Model Inputs

The following studies were run in sequence:

1) Doubling the electrical and lighting loads
giving more realistic lab electrical consumption

2) Increasing the occupancy run from 8 am to 10 pm
matching the occupancy profile as advsied by MIST

3) Doubling the occupancy density
challenging the relatively low occupant density assumptions within the masterplan

4) Doubling the infiltration rate
reflecting more typically achieved performance

The studies were conducted iteratively, meaning that each study was conducted in addition to, rather than in lieu of, the preceding studies.

In order to keep a control study, the same parameters were applied in this study as were applied in the Full Model study (Section 12.1 above), in line with the Masterplan, with the exception of the following test variables being changed:

			Laboratory	
Issue	**Item**	**Units**	**Working**	**Non-Working**
Building Geometry	Floor to Floor Height	m	4.5	4.5
	Floor to Ceiling Height	m	3.9	3.9
Density	Occupants	m²/pers.	**10**	**10**
Working Hours	Range (from)	hrs	**0700**	**2200**
	Range (to)	hrs	**2200**	**0700**
	Days per week	#	6	6
Operation of AHU	Range (from)	hrs	0000	0000
	Range (to)	hrs	0000	0000
	Days per week	#	**14**	**14**
	Air Change Rate	ach	6	3
Artificial Lighting	Power Density	W/m²	7	7
Building Envelope	Glazing Ratio	%	30	30
	g-value (glass)	%	25	25
	shading	-	external	external
	g-value (shaded)	%	15	15
	Light Transmission	%	50	50
	Glass Equivalent		SKN154	SKN154
	Frame Ratio	%	20	20
	U-value (glass)	W/m2/K	1.2	1.2
	U-value (frame)	W/m²/K	2	2
	U-value (wall)	W/m²/K	0.25	0.25
	U-value (roof)	W/m²/K	0.12	0.12
	U-value (floor)	W/m²/K	0.35	0.35
	Infiltration	ach	**0.3**	**0.1**
Occupant Heat Gains	Occupants (sensible)	W/person	73.2	73.2
	Occupants (latent)	W/person	46.8	46.8
Equipment Heat Gains	Sensible	W/m²	3.1	3.1
Temperature Range	Air Temperature	?C	24	28
Equipment Heat Gains	Sensible	W/m²	**21.2**	**10.6**
Temperature Range	Air Temperature	?C	24	28

Key
Study 1
Study 2
Study 3
Study 4

12.2.4 Results

The largest impact of the 4 iterations can be observed in the change between the baseline figure and iteration 1: doubling the equipment and lighting loads. By doing so the annual electrical assumption for equipment and lighting alone significantly exceeds the masterplan target - it becomes impossible to deliver energy savings from increased COP of HVAC systems that could enable the target to be achieved.

Comparatively, iterations 2 and 3- increasing the occupied hours and the occupied density respectively, have less of an impact, but both are large enough as to be considered non-negligible.

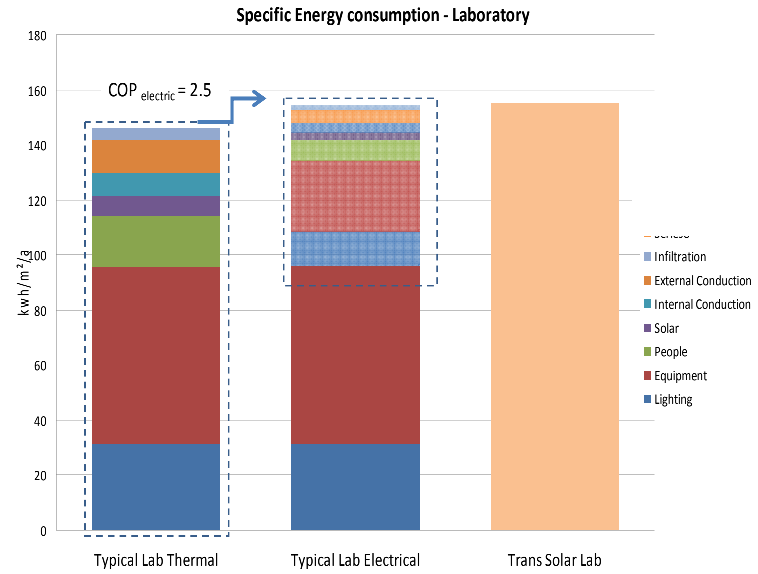
Doubling the infiltration gain can be seen to have the least impact.

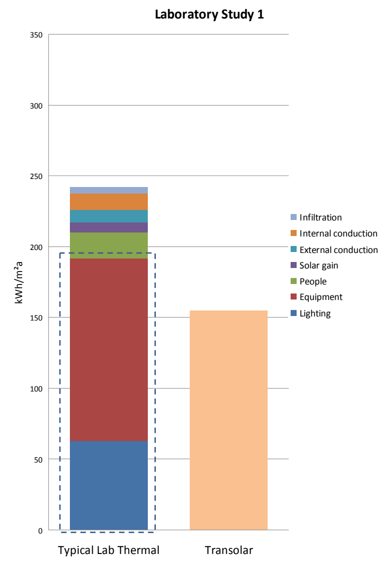
12.2.5 Conclusions

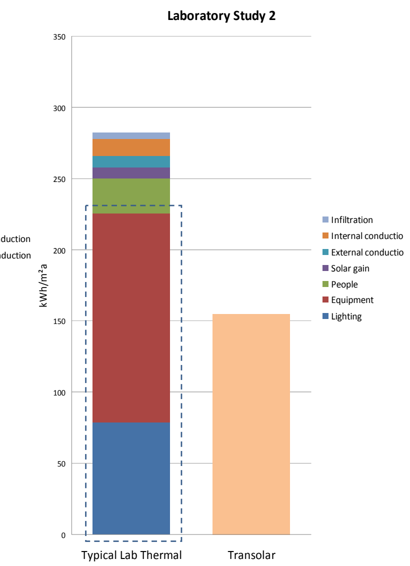
The studies on the casual gains within the laboratories demonstrate the importance of maintaining these loads to as low as possible in order that the development's energy targets can be met.

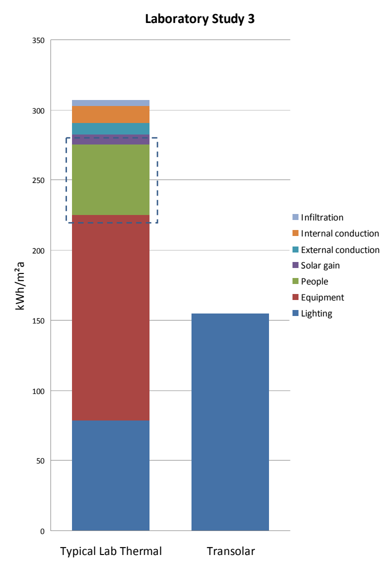
These studies conclude that any further increase on the equipment and lighting loads that have not been costed into the masterplan will result in energy savings gaving to be achieved in other spaces.

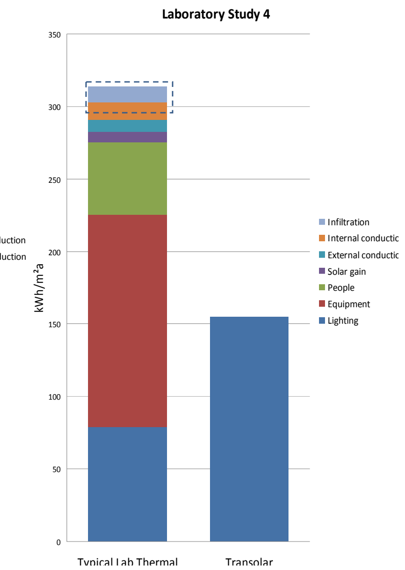
The source of these additional energy savings is not apparent at this stage.











12.3 Residential Atrium Study

12.3.1 Introduction

Initial studies were conducted on the Atrium to compare the effect of the proposed shading strategy above the Atrium in the subsection of the model as shown in Figure 12-8 . The shading device, documented earlier in this report, was designed to block the maximum amount of direct sunlight into the atrium, whilst maximising the visual access to the diffuse sky, thereby making it feel adequately daylit during the day, whilst minimising solar gains.

After the first 'baseline' study ran, it was found that the air temperature in the Atrium was being consistently maintained at an abnormally low level even when unconditioned. Further studies were devised to determine the effect that insulation, shading and thermal mass had on the Atrium had on the dry resultant temperature when it was unconditioned, and it's subsequent effect on the cooling load of the Residential zones adjacent to it.

For consistency, the area of Phase 1A selected for testing was the same as in the Residential Glazing Ratio study in Section 12.4, as shown below.

12.3.2 Summary

It was found that the cooling load in the adjacent Residential areas were increased as the insulation decreased, but when insulation was used on the internal walls, night purge was needed to clear the excessive heat build-up in the Atrium.

12.3.3 Method

Five studies were conducted:

Study 1) Baseline day one pass

Study 2) Site Context (surrounding developments) added

Study 3) External Shading added on to the atrium

Study 4) Insulation added

Study 5) Insulated thermal mass (with night purge) used

The night purge was conducted by naturally ventilating the atrium between the times of 11pm and 6am.

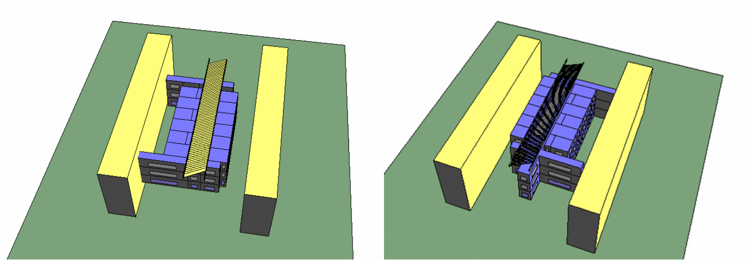


Figure 12-8 Overview of the Thermal Model showing roof shading structure

			Housing	
Issue	Item	Units	Working	Non-Working
Building Geometry	Floor to Floor Height	m	4.5	4.5
	Floor to Ceiling Height	m	3.9	3.9
Density	Occupants	m²/pers.	50	50
Working Hours	Range (from)	hrs	1800	0800
	Range (to)	hrs	0800	1800
	Days per week	#	5	5
Operation of AHU	Range (from)	hrs	0000	0000
	Range (to)	hrs	0000	0000
	Days per week	#	7	7
	Air Change Rate	ach	1.0	1.0
Artificial Lighting	Power Density	W/m²	0.8	0.8
Building Envelope	Glazing Ratio	%	30	30
	g-value (glass)	%	25	25
	shading	-	external	external
	g-value (shaded)	%	15	15
	Light Transmission	%	50	50
	Glass Equivalent		SKN154	SKN154
	Frame Ratio	%	20	20
	U-value (glass)	W/m2/K	0.8	0.8
	U-value (frame)	W/m²/K	2	2
	U-value (wall)	W/m²/K	0.3	0.3
	U-value (roof)	W/m²/K	0.1	0.1
	U-value (floor)	W/m²/K	0.4	0.4
	Infiltration	ach	0.2	0.05
Equipment Heat Gains	Sensible	W/m²	0.86	0.86
Temperature Range	Air Temperature	?C	24	26

12.3.4 Results

The day one pass of the results showed that the unconditioned corridor stays low., as can be seen in Figure 12-12 With a peak temperature of around 28°C, however the cooling load of the adjacent rooms are very high. After the second study with the context on, the cooling load dropped slightly due to a lower solar gain load within the room, and the temperature in the adjacent corridor stayed slightly slower.

After the third study the cooling load within the room dropped due to a lower internal conduction from the corridor. After the fourth study there was a dramatic drop in the cooling load of the room, however the frequency distribution of the air temperature of the corridor remained consistently higher than the previous iterations. After the fifth study the cooling load of the room was slightly less than the previous iteration, but the corridor maintains a consistently lower temperature.

Conclusions

The corridor: The corridor takes cooling from the adjacent residential rooms when they are not insulated, however this is not 'free' cooling, as it first appears, but instead is 'paid' for with a considerably higher temperature in the residential zones. When the partition between the corridor and the residential zone is insulated then there is a considerable heat build-up within the corridor. The final iteration provides the optimum solution, as it keeps the cooling load of the rooms low, whilst maintaining a consistently low temperature in the corridor in comparison to the external air temperature.

The adjacent Residential zones: The cooling loads drop most dramatically when the following two criteria are applied when surrounding context is added (Study 2- context provides considerable shading on the rooms due to the narrow streets between phases, and within the Phases themselves), and when insulation is added to the walls in-between the rooms and the corridor. This enables the rooms to cool only it's own space, and therefore the internal conduction gains drop severely.

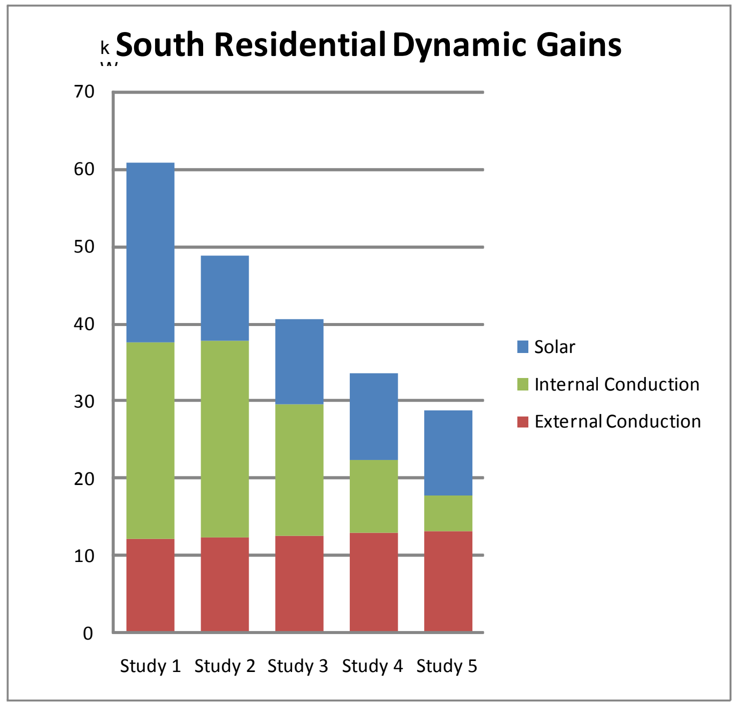


Figure 12-9 Floor two south east Residential Dynamic gains

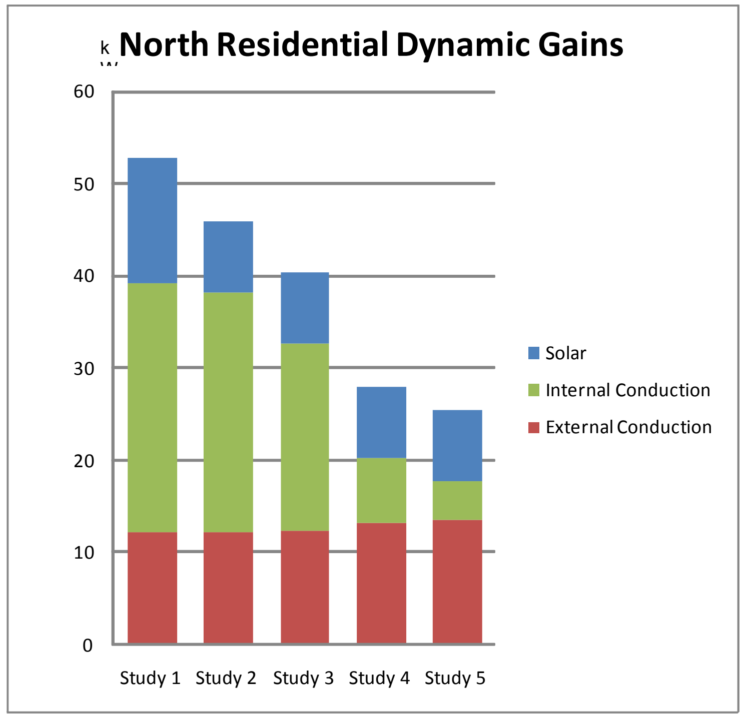
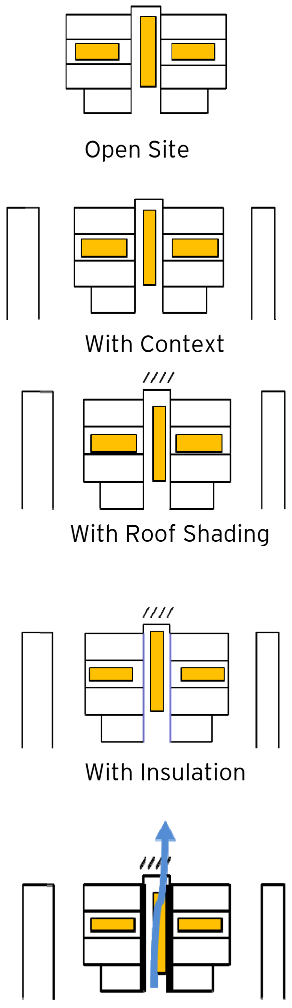


Figure 12-10 Floor two north-west Residential Dynamic gains



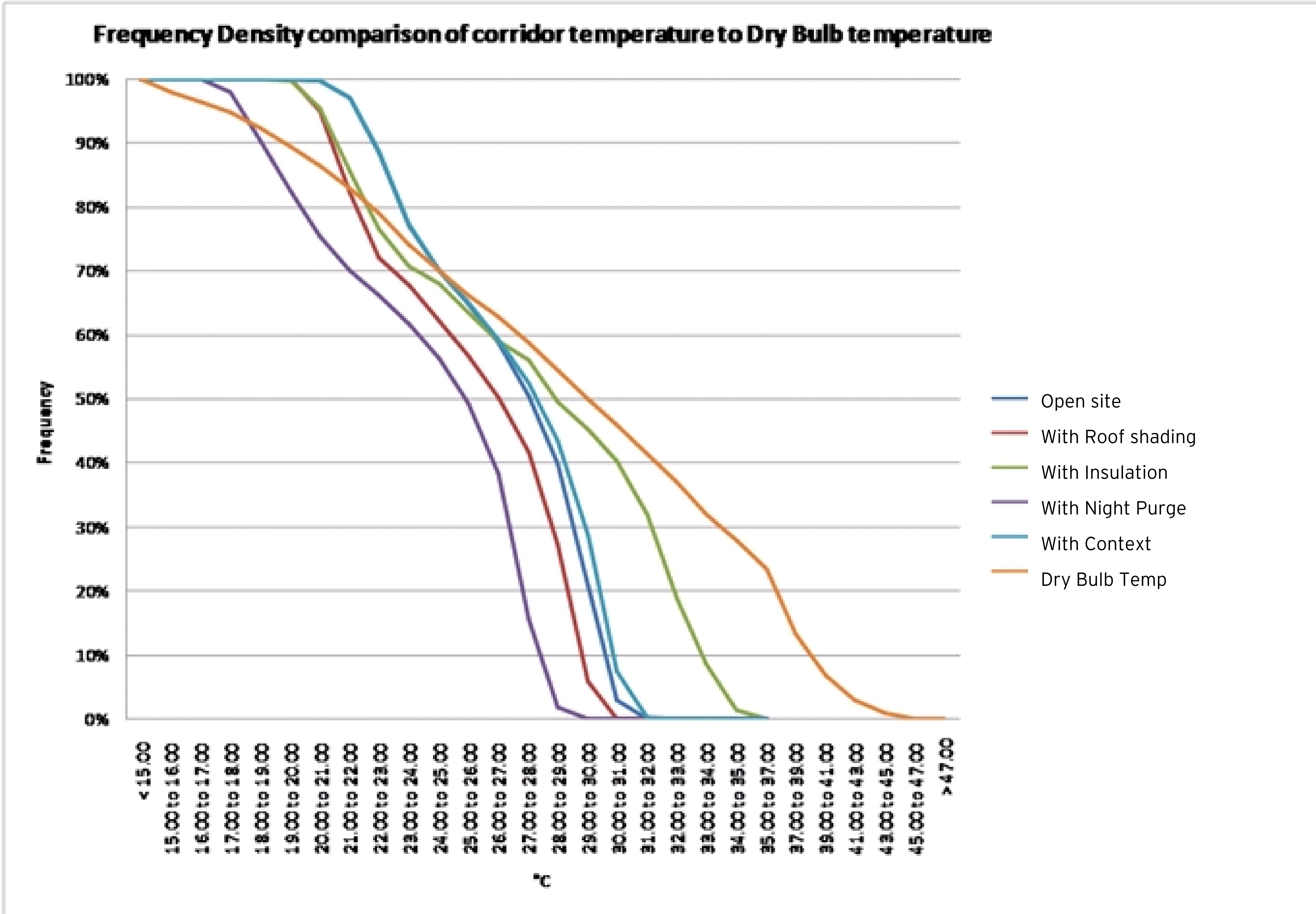


Figure 12-11 Frequency distribution of corridor air temperatures

12.4 Glazing Ratio Residential

12.4.1 Introduction

Two key zones were identified for the Residential area to be studied, as can be seen at the bottom right of this section. In order to establish a solar gains 'budget', the following glazing ratio's were tested in relation to the overall size of the facade: 20%, 30%, 40%60% and 80%.

12.4.2 Summary

By selecting a wide range of glazing ratios it was possible to establish a 'solar gains' budget that we could aim for in the Residential spaces. The observed Solar gains increased linearly as the percentage was increased, and in combination with the increase in external conduction gave us a desired glazing ratio of between 20% and 40%, for a typical Residential room.

12.4.3 Method

As with the previous study, the dynamic thermal modelling software IES was used to conduct the studies, as detailed at the top of this section. The model used to conduct the studies was a subsection of the Full model, based on the model for Foster and Partners Concept Design Report.

We decided on the following glazing ratios to carry out the study:

1) 20%

2) 30%

3) 40%

4) 60%

5) 80%

Incrementing the glazing ratio by 20% allows a wide range of study should any dramatic non-linearity be observed, whilst providing enough data to allow accurate conclusions to be drawn. The 30% value is to provide consistency with the Trans Solar Masterplan document].

			Housing	
Issue	**Item**	**Units**	**Working**	**Non-Working**
Building Envelope	Glazing Ratio	%	**20/30/40/60/80**	**20/30/40/60/80**
	g-value (glass)	%	25	25
	shading	-	external	external
	g-value (shaded)	%	15	15
	Light Transmission	%	50	50
	Glass Equivalent		SKN165	SKN165
	Frame Ratio	%	20	20
	U-value (glass)	W/m²/K	0.8	0.8
	U-value (frame)	W/m²/K	2	2
	U-value (wall)	W/m²/K	0.3	0.3
	U-value (roof)	W/m²/K	0.1	0.1
	U-value (floor)	W/m²/K	0.4	0.4
	Infiltration	ach	0.2	0.05

12.4.4 Results

The results indicate a linear increase in solar gains as the glazing ratio of the facade is increased. The increase in the sensible cooling load of the room between 20% and 40% provides a rational point for setting a budget for which to optimise the glazing ratio.

12.4.5 Conclusions

A combination of the solar gains and the external conduction gains causes the cooling load for the room to drop significantly between 60% and 40%. When compared to the overall room loads in the first study – the Full Building – it is self-evident that the dynamic loads become the significant factor to consider in the residential spaces. The drop in cooling load does between 40 and 20 is not severe enough to justify extending the study beyond 20%, which would compromise the quality of the space in terms of daylight, nor is it enough to warrant studying further areas in between these values:.

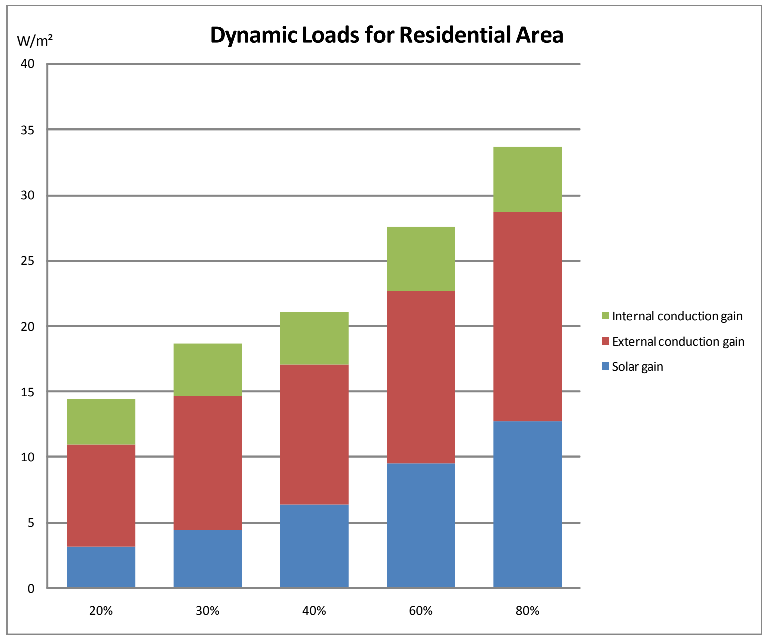
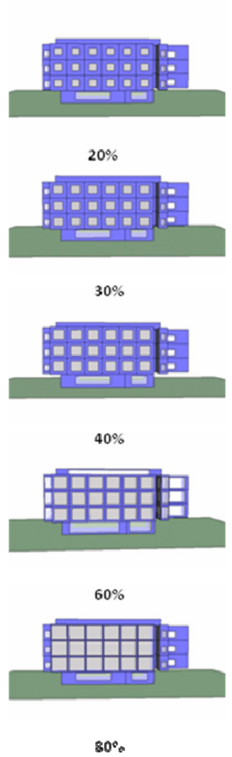
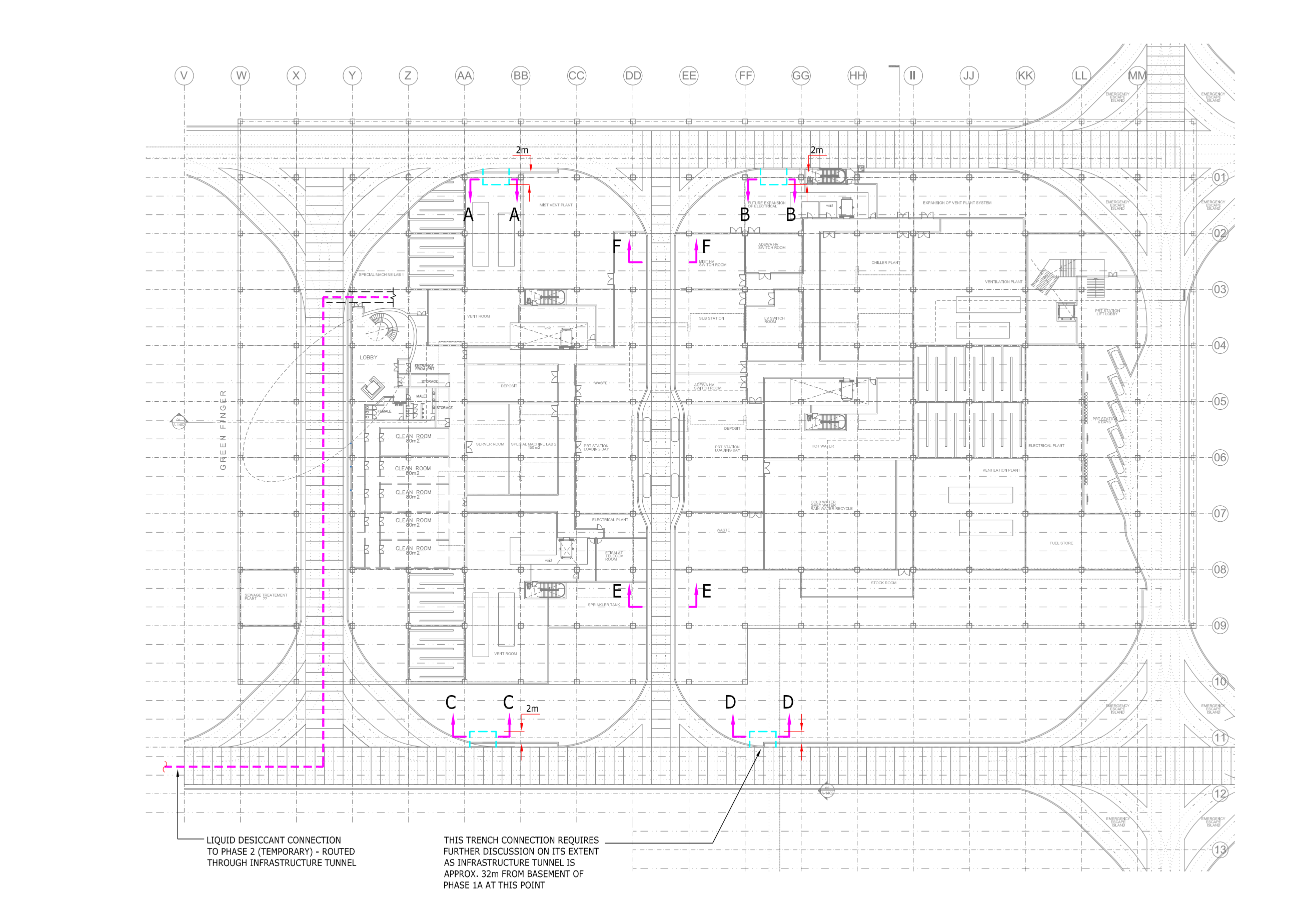


Figure 12-12 Typical Residential Area Dynamic Thermal Loads



13 DRAWINGS



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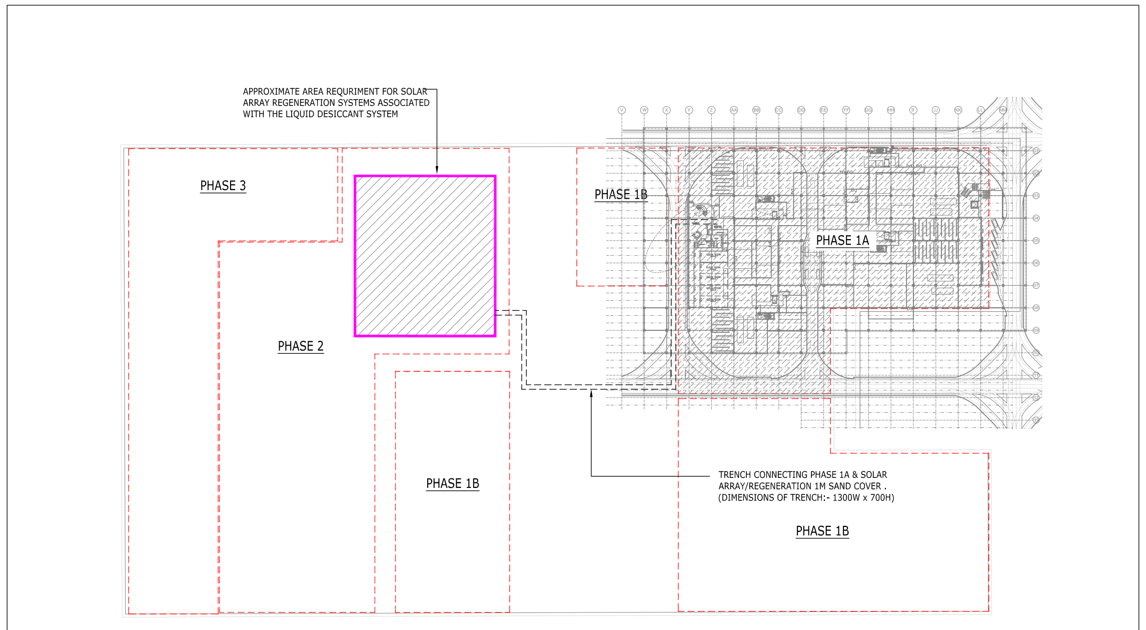

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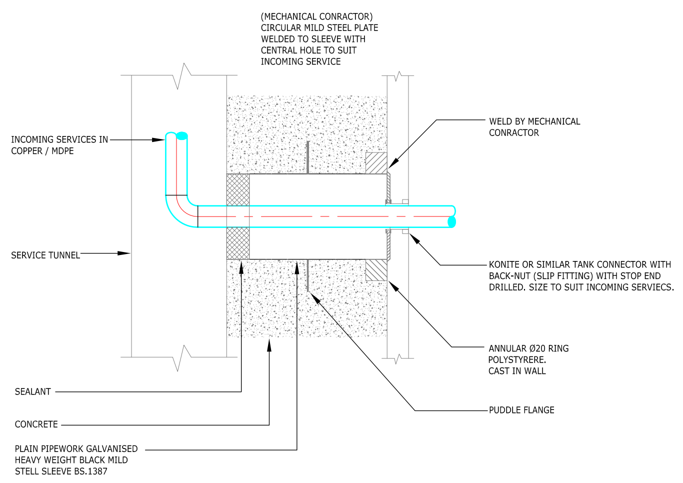
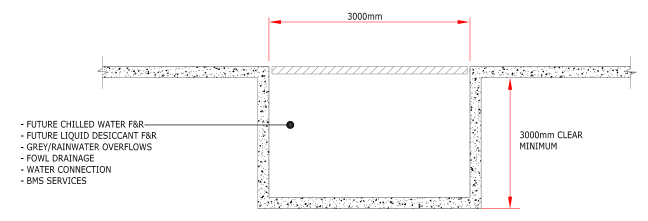
NOTES:

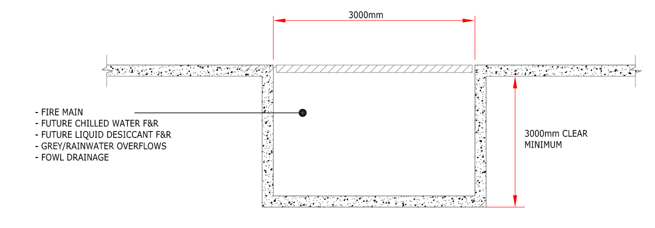
1. ALL SERVICES CONNECTIONS & TRENCHES ARE INDICATIVE & WILL BE CONFIRMED DURING SCHEME DESIGN.
2. PLANTROOM ALLOCATION IS PRELIMINARY.
3. ASSUMPTION: HAZARDOUS WASTE WILL BE TRANSPORTED FROM BUILDING VIA PRT SYSTEM
4. SURFACE WATER COLLECTION SYSTEM REQUIRES INPUT FROM INFRASTRUCTURE ENGINNER.
5. THE FOLLOWING INFRASTRUCTURE SYSTEMS ARE ASSUMED WITHIN EACH SERVICE TUNNEL:-
   - CHILLED WATER FLOW & RETURN.
   - CONDENSING WATER FLOW & RETURN.
   - LIQUID DESICCANT FLOW & RETURN.
   - FIRE MAIN.
   - POTABLE WATER SUPPLY
   - SURFACE WATER DRAINAGE.
   - FOWL DRAINAGE.
   - IRRIGATION MAIN.
   - IT/TELECOMS CONNECTIVITY.
   - H.V MAIN.
   - EMERGENCY POWER MAIN.
   - CONNECTIONS MADE AVAIABLE FOR OVERFLOWS FROM GREYWATER AND RAINWATER RECYCLING.
6. WET & DRY SERVICES ARE ASSUMED IN EACH INFRASTRUCTURE TUNNELS.



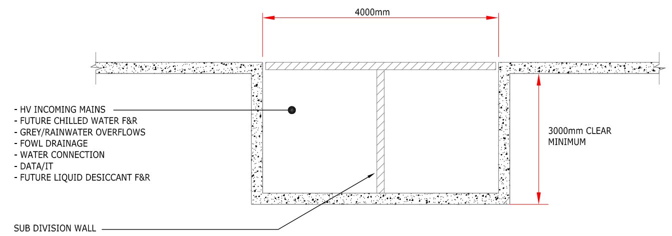
INCOMING SERVICES THROUGH WATER TIGHT CONCRETE WALL



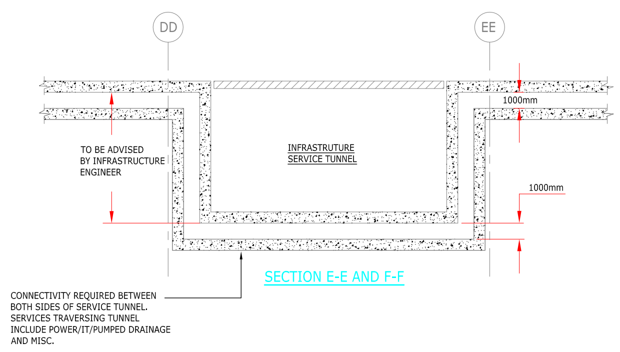
SECTION A-A -(N.T.S)
WET SERVICES ONLY



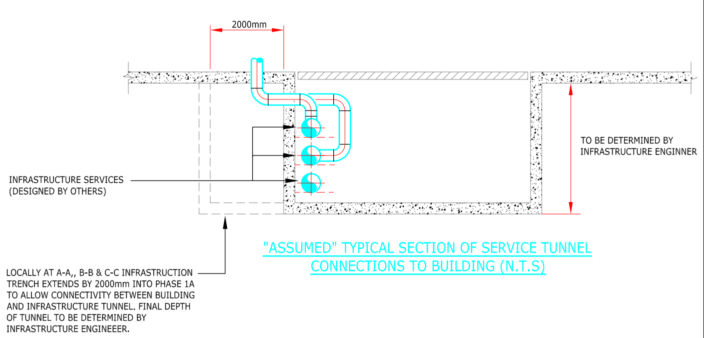
SECTION D-D -(N.T.S)
WET SERVICES ONLY



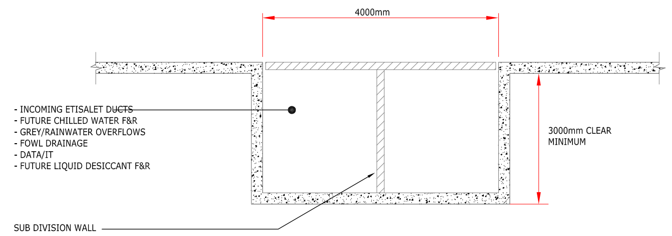
SECTION B-B -(N.T.S)
WET AND DRY SERVICES



SECTION E-E AND F-F



"ASSUMED" TYPICAL SECTION OF SERVICE TUNNEL
CONNECTIONS TO BUILDING (N.T.S)



SECTION C-C -(N.T.S)
WET AND DRY SERVICES

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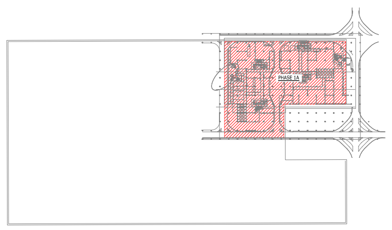

KEY PLAN

Revision	Description	Date

Work Stage
CONCEPT DESIGN ISSUE

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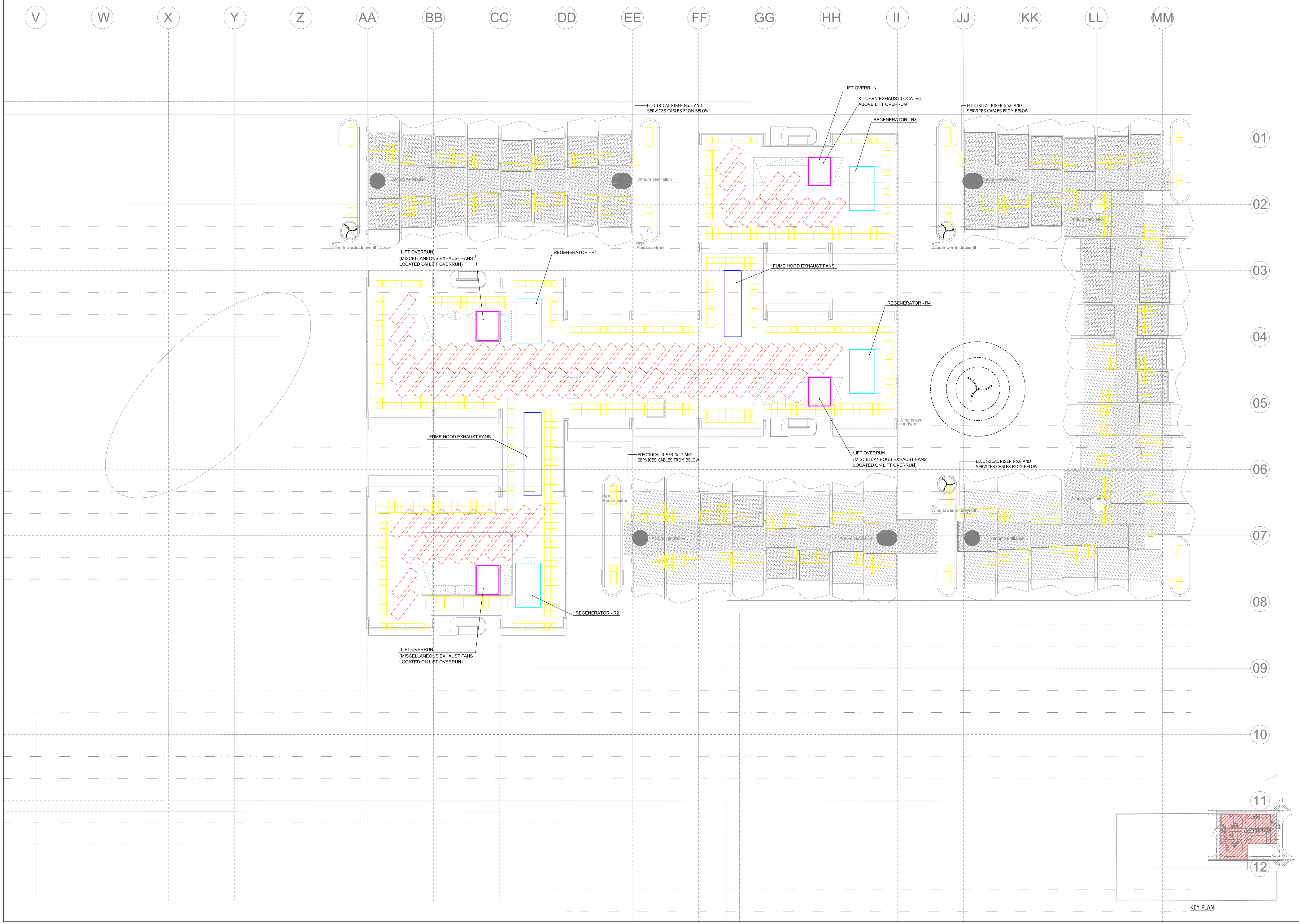
Project
Masdar Institute Of Science And Technology - Phase 1A

Title
COMBINED INCOMING SERVICES
BASEMENT LEVEL VENTILATION

Drawn by	Checked by	File Name	
AS	FD	1076-SK-C100	
Drawing Number		Revision	Scale: AS SHOWN @ A0
SK-C-100			Date: FEB 08



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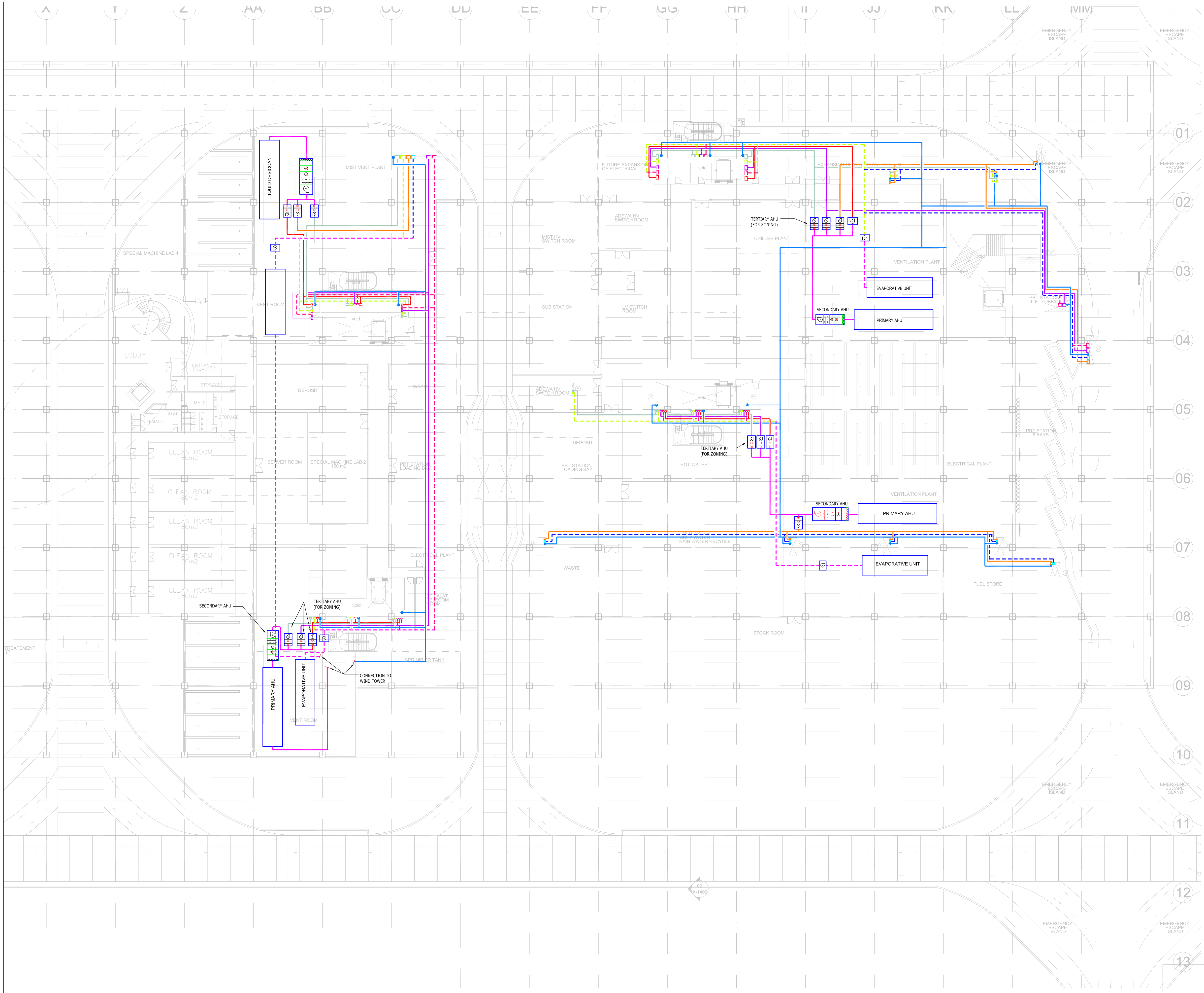
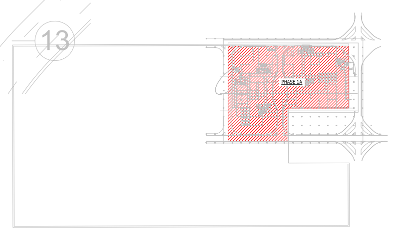
Project
Masdar Institute Of Science And Technology - Phase 1A

Title
COMBINED SERVICES
ROOF LEVEL

Drawn by	Checked by	File Name
AS	-	1076-SK-C101

Drawing Number	Revision	Scale / Date
SK-C-101		1:200 @ A0 / FEB 08





KEY PLAN

NOTES:

1.0 ONLY PRIMARY SUPPLY AND EXTRACT DUCTWORK SHOWN.

2.0 RESIDENTIAL AREAS TO HAVE THE ABILITY TO BE NATURALLY VENTILATED DURING MID-SEASON AND WINTER.

3.0 EXHAUST SYSTEMS FOR KITCHEN, LAB SUPPORT, CORE LAB AND FUME HOODS NOT INDICATED.

4.0 ACCESS REQUIRED TO ALL RISER SHAFTS

SCHEDULE OF SUPPLAY AND EXTRACT DUCTS

COLOUR	DESCRIPTION
(grey-green)	SUPPLY DUCT - LIBRARY, CLASSROOM, LAB & SUPPORT
(yellow-green)	EXTRACT DUCT - LIBRARY, CLASSROOM, LAB & SUPPORT
(red)	SUPPLY DUCT - FUME CUPBOARD (HAZARDOUS SUPPLY)
(purple)	SUPPLY DUCT - RESTAURANT, SPORT, CAFE
(pink)	EXTRACT DUCT - RESTAURANT, SPORT, CAFE
(orange)	SUPPLY DUCT - RESIDENTIAL
(cyan)	EXTRACT DUCT - RESIDENTIAL
(blue)	EXTRACT DUCT - TOILET, KITCHEN

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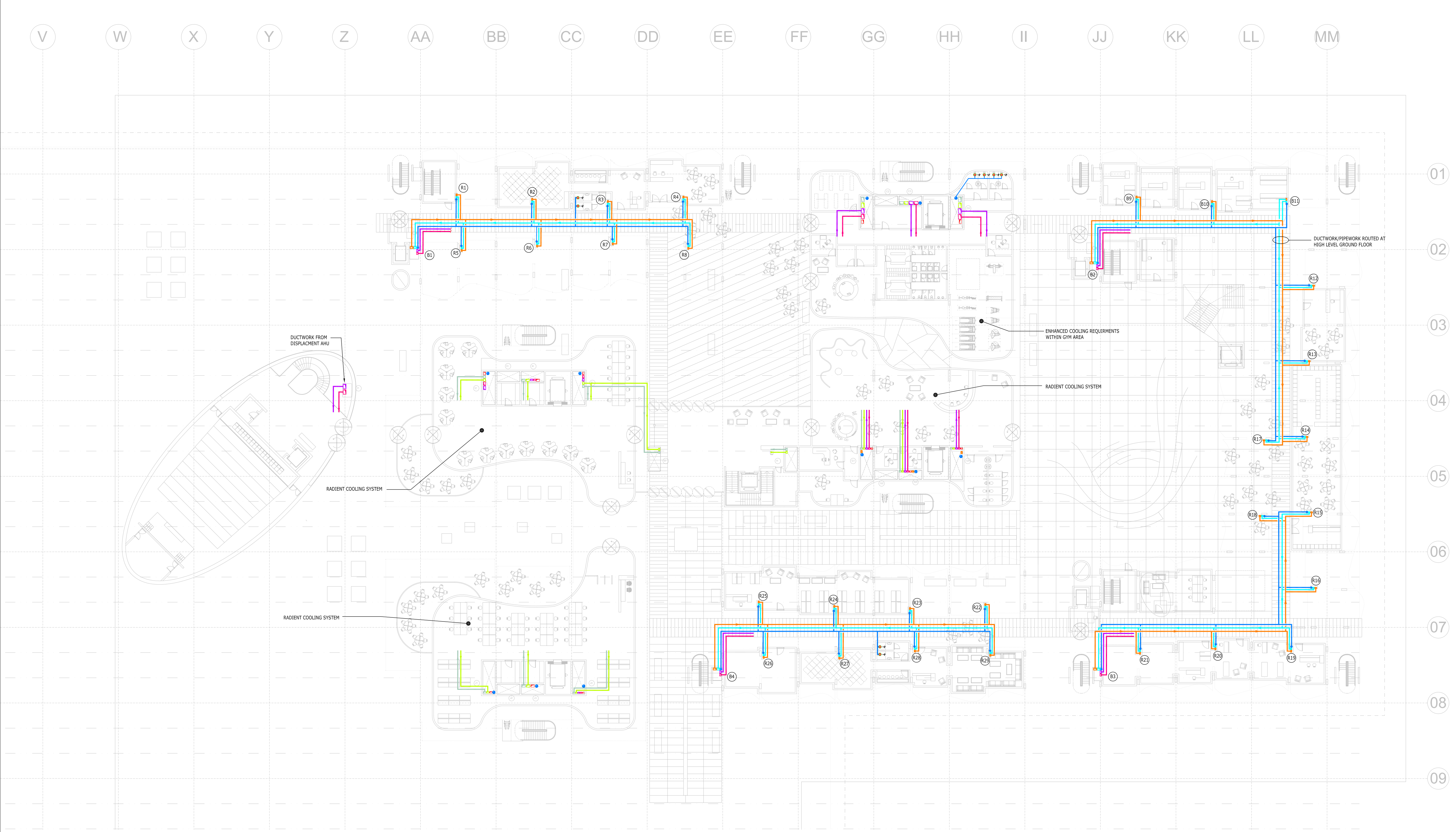
Project
Masdar Institute Of Science And Technology - Phase 1A

Title
MECHANICAL SERVICES
BASEMENT LEVEL VENTILATION

Drawn by	Checked by	File Name
AS	-	1076-SK-M100

Drawing Number	Revision	Scale	Date
SK-M-100		1:200 @ A0	FEB 08



NOTES:

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SCHEDULE OF SUPPLAY AND EXTRACT DUCTS

COLOUR	DESCRIPTION
(grey-green line)	SUPPLY DUCT - LIBRARY, CLASSROOM, LAB & SUPPORT
(yellow-green line)	EXTRACT DUCT - LIBRARY, CLASSROOM, LAB & SUPPORT
(red line)	SUPPLY DUCT - FUME CUPBOARD (HAZARDOUS SUPPLY)
(purple line)	SUPPLY DUCT - RESTAURANT, SPORT, CAFE
(pink line)	EXTRACT DUCT - RESTAURANT, SPORT, CAFE
(orange line)	SUPPLY DUCT - RESIDENTIAL
(cyan line)	EXTRACT DUCT - RESIDENTIAL
(blue line)	EXTRACT DUCT - TOILET, KITCHEN

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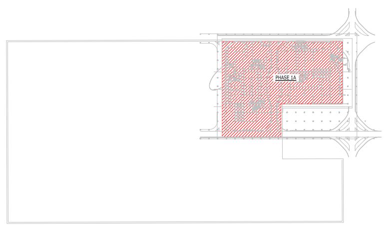

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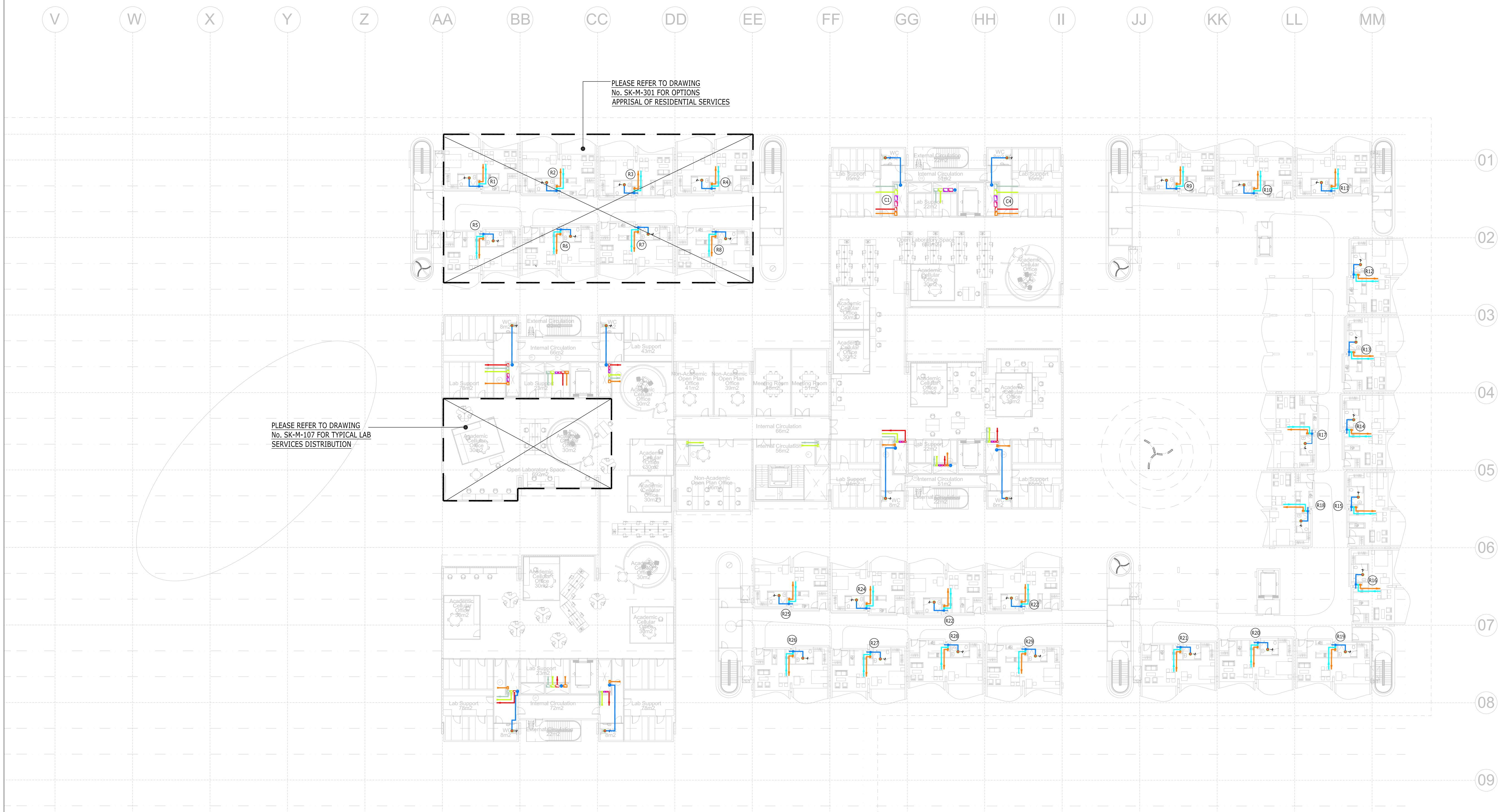
Project
Masdar Institute Of Science And Technology - Phase 1A

Title
MECHANICAL SERVICES
GROUND FLOOR VENTILATION

Drawn by	Checked by	File Name
AS	-	1076-SK-M101

Drawing Number	Revision	Scale	Date
SK-M-101		1:200 @ A0	FEB 08



NOTES:

1.0 ONLY PRIMARY SUPPLY AND EXTRACT DUCTWORK SHOWN.

2.0 RESIDENTIAL AREAS TO HAVE THE ABILITY TO BE NATURALLY VENTILATED DURING MID-SEASON AND WINTER.

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SCHEDULE OF SUPPLAY AND EXTRACT DUCTS

COLOUR	DESCRIPTION
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(yellow-green line)	EXTRACT DUCT - LIBRARY, CLASSROOM, LAB & SUPPORT
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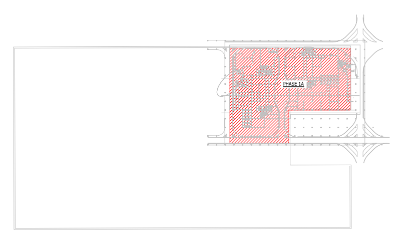
(pink line)	EXTRACT DUCT - RESTAURANT, SPORT, CAFE
(orange line)	SUPPLY DUCT - RESIDENTIAL
(cyan line)	EXTRACT DUCT - RESIDENTIAL
(blue line)	EXTRACT DUCT - TOILET, KITCHEN



KEY PLAN

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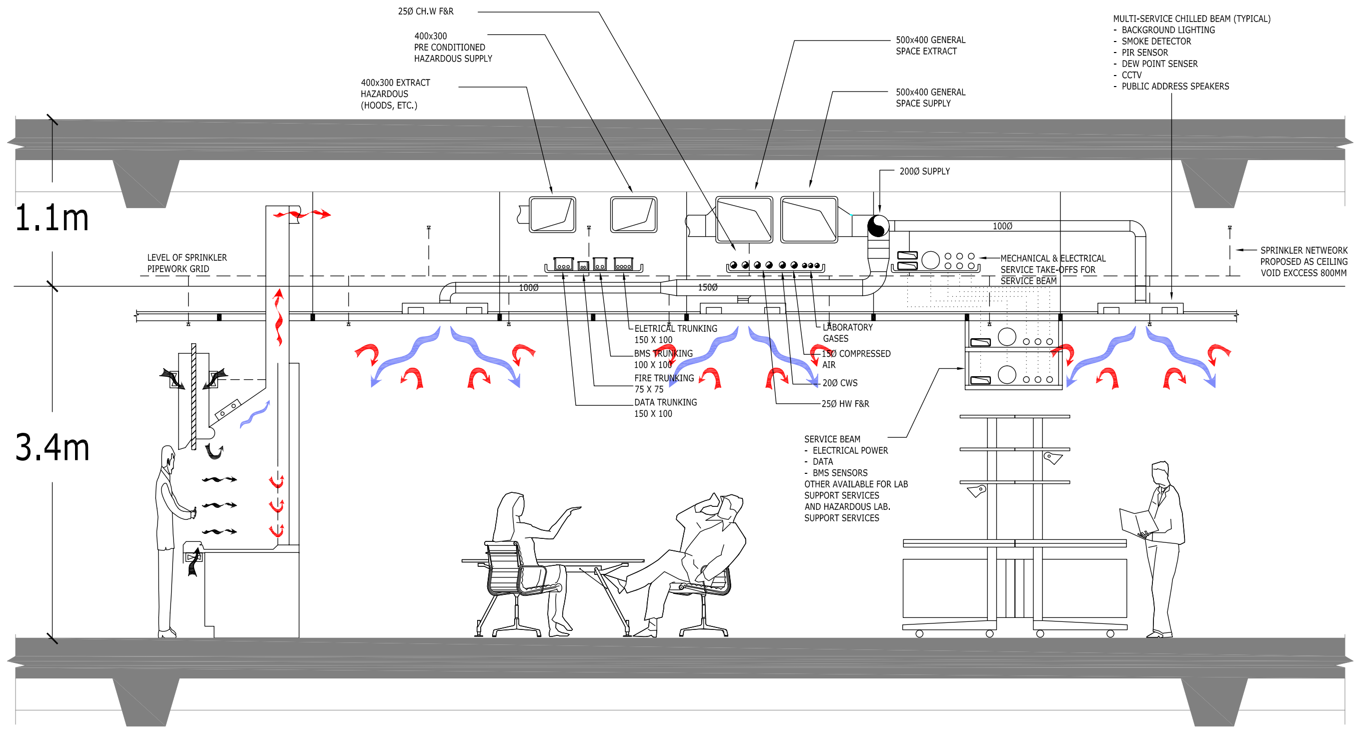
Project
Masdar Institute Of Science And Technology - Phase 1A

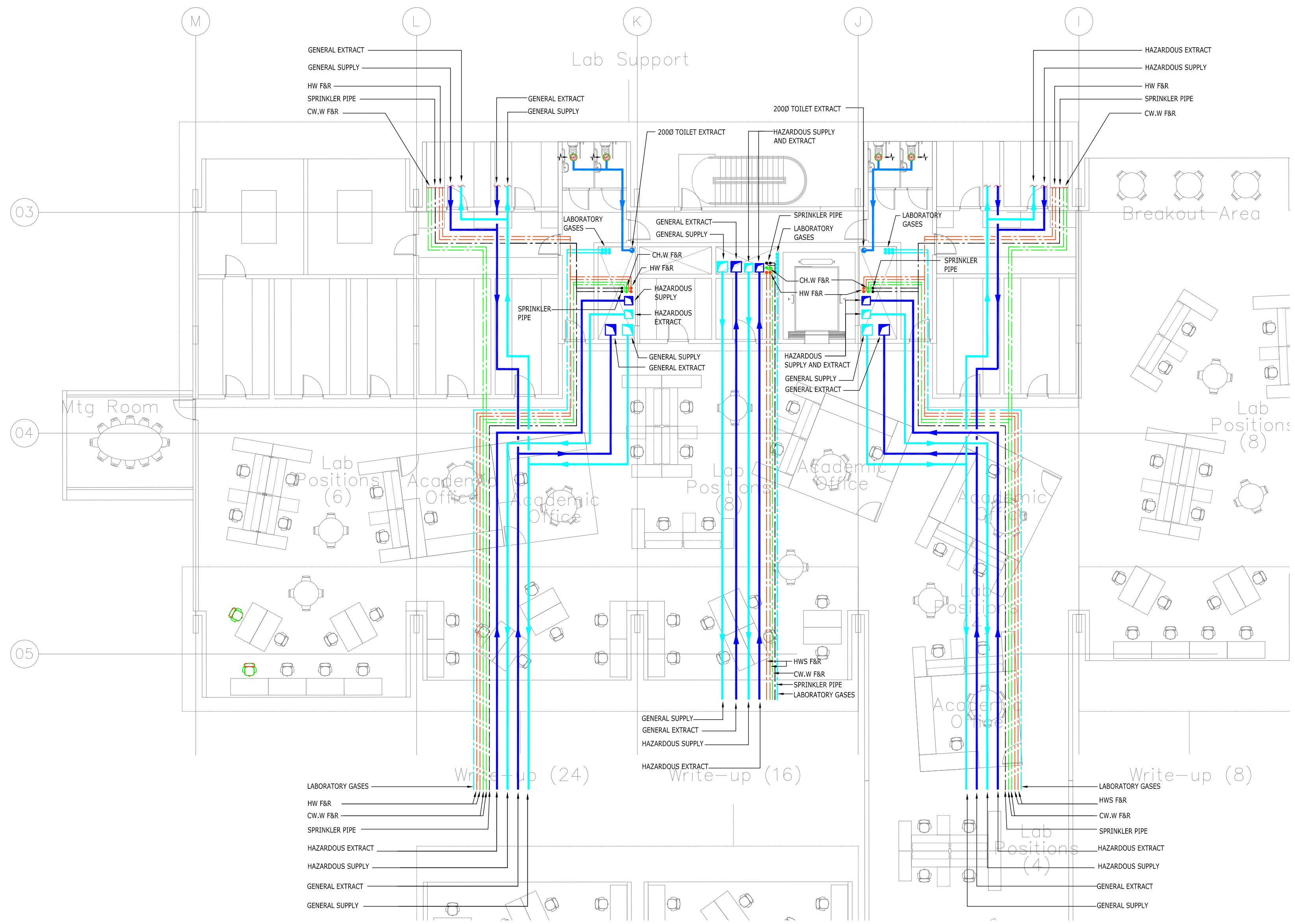
Title
MECHANICAL SERVICES
FIRST FLOOR

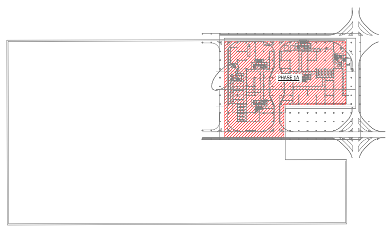
Drawn by	Checked by	File Name
AS	-	1076-SK-M102

Drawing Number	Revision	Scale	Date
SK-M-102		1:200 @ A0	FEB 08



DRAFT MIST 1A LAB SERVICES SECTION CONCEPT DRAWING





KEY PLAN

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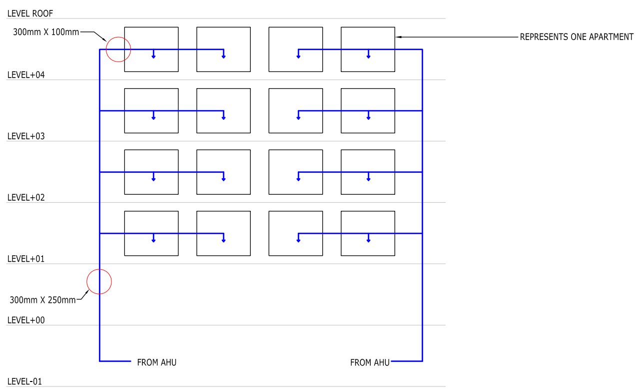
Project
Masdar Institute Of Science And Technology - Phase 1A

Title
**MECHANICAL SERVICES
LAB AREA (TYPICAL)
PHASE 1**

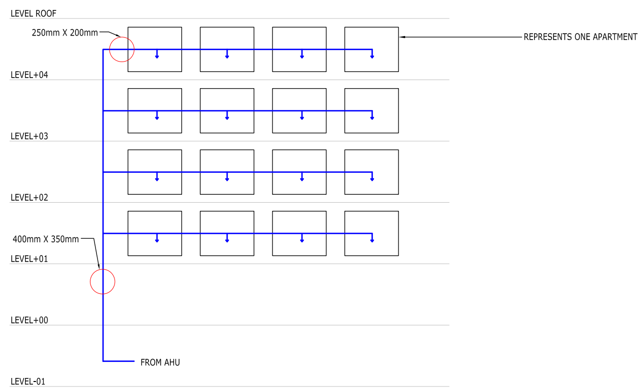
Drawn by	Checked by	File Name	
AS	-	1076-SK-M107	
Drawing Number		Revision	Scale
SK-M-107			1:100@ A0
			Date: FEB 08

MIST 1A STUDENT RESIDENCE VENTILATION RISERS SIZING



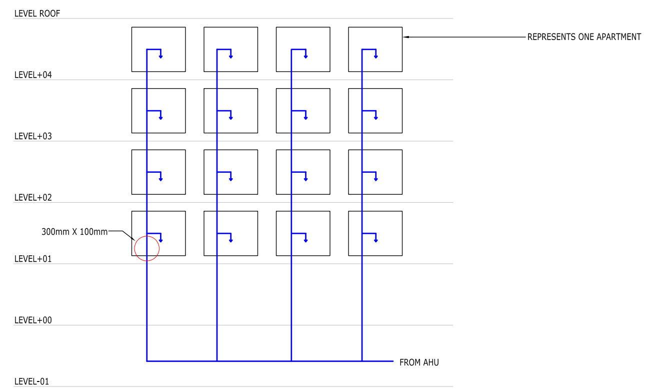
OPTION1 SCHEMATIC DIAGRAM

MIST 1A STUDENT RESIDENCE VENTILATION RISERS SIZING

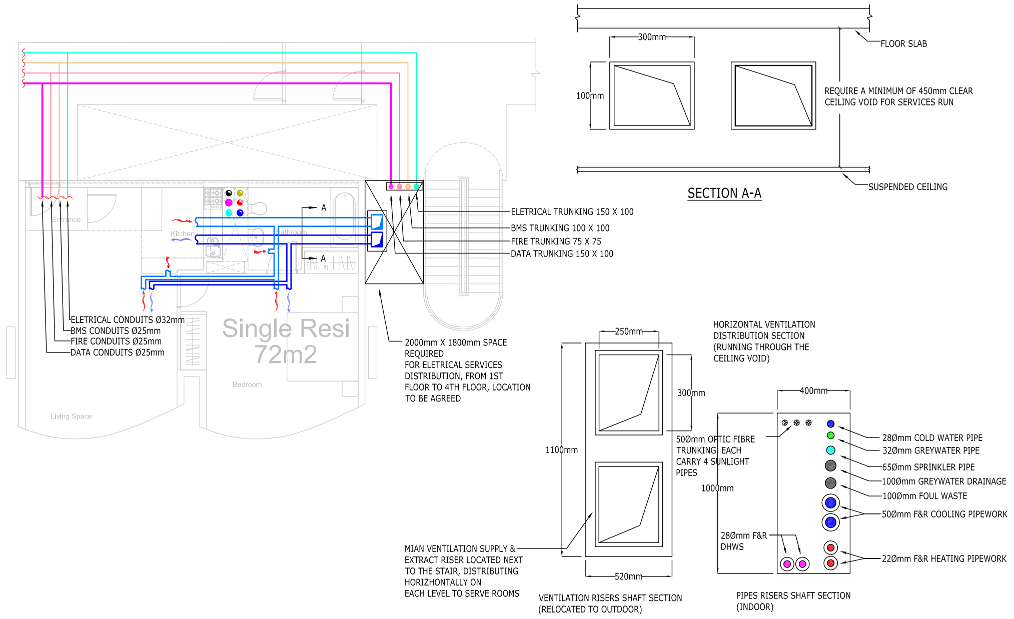


OPTION2 SCHEMATIC DIAGRAM

MIST 1A STUDENT RESIDENCE VENTILATION RISERS SIZING

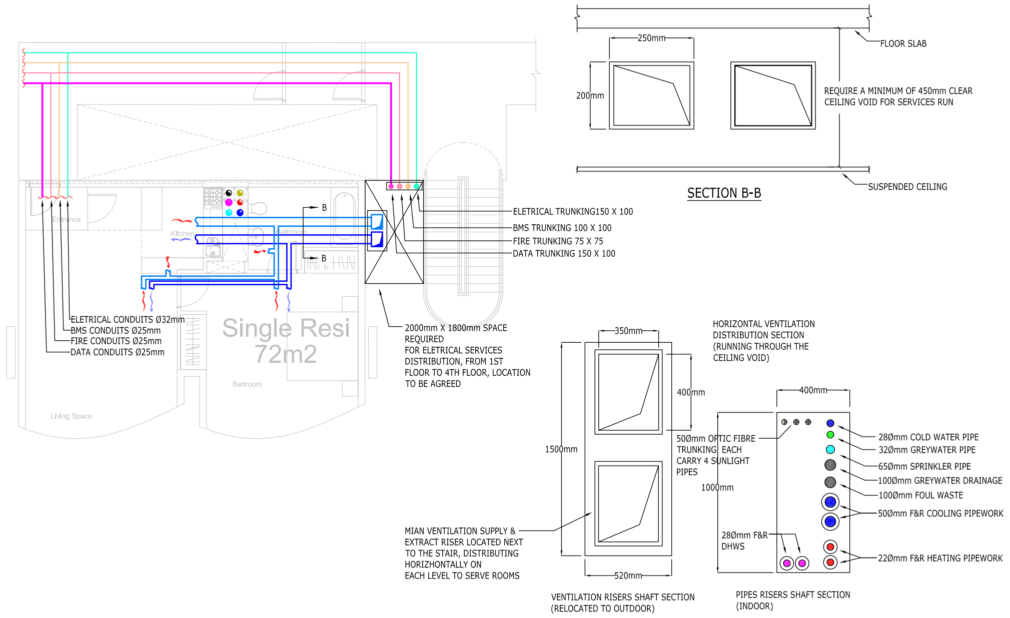


OPTION3 SCHEMATIC DIAGRAM



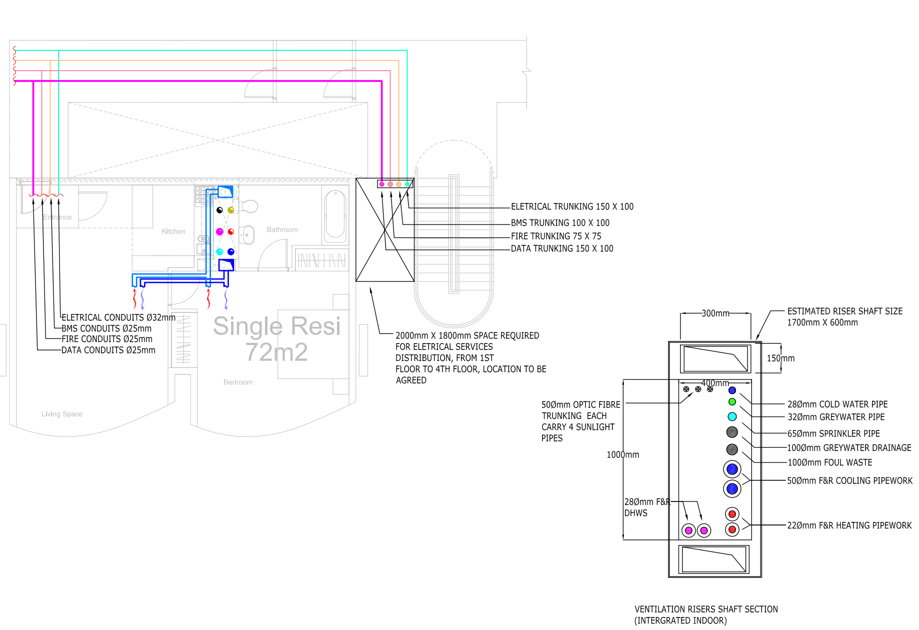
OPTION 1 - DETAIL OF RISER & LAYOUT

DISADVANTAGES: -FIRE SEPARATION ISSUE
-ACOUSTIC SEPARATION ISSUE



OPTION 2 - DETAIL OF RISER & LAYOUT

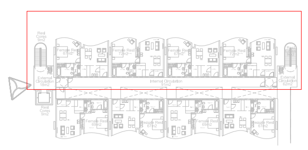
DISADVANTAGES: -FIRE SEPARATION ISSUE
-ACOUSTIC SEPARATION ISSUE

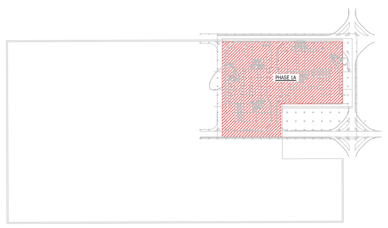


OPTION 3 - DETAIL OF RISER & LAYOUT

PREFFERED OPTION

WORSET CASE ASSUMING 12L/s/p 3 PEOPLE PER BEDROOM, 4 FLAT UNITS PER LEVEL AND TOTAL 4 LEVELS OF STUDENT RESIDENCE WHICH NEEDS TO PROVIDE VENTILATION RATE AT
48 X 12L = 576L/S = 0.58M3/S





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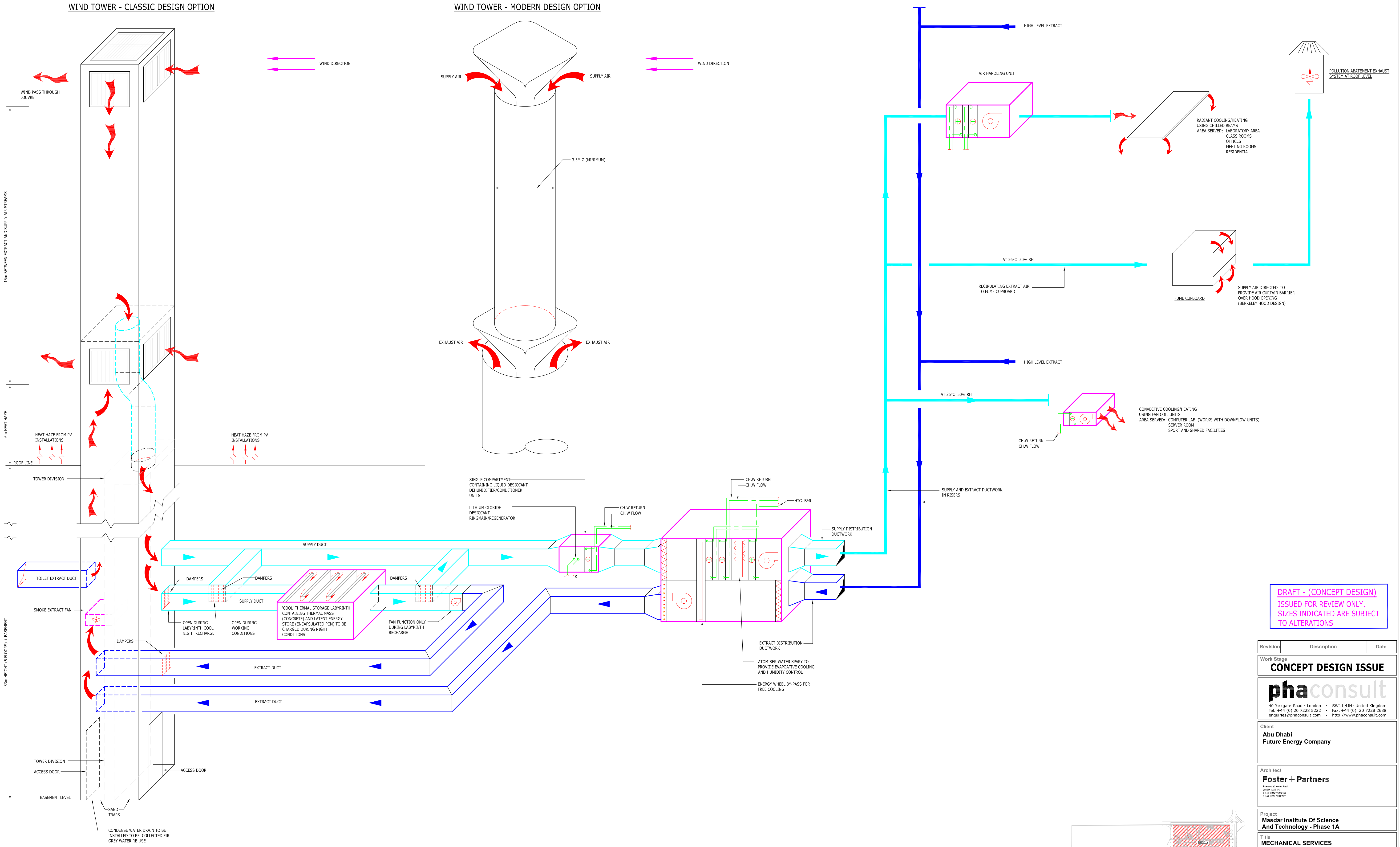
Project
Masdar Institute Of Science And Technology - Phase 1A

Title
MECHANICAL SERVICES
OPTIONS FOR SERVICING
RESIDENTIAL BLOCKS

Drawn by	Checked by	File Name
AS		1076-SK-M301

Drawing Number	Revision	Scale / Date
SK-M-301		N.T.S @ A1 / MARCH 08



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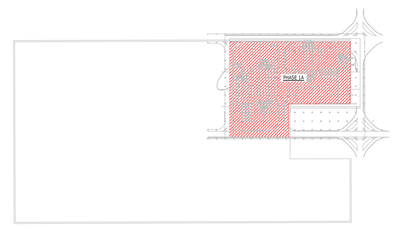

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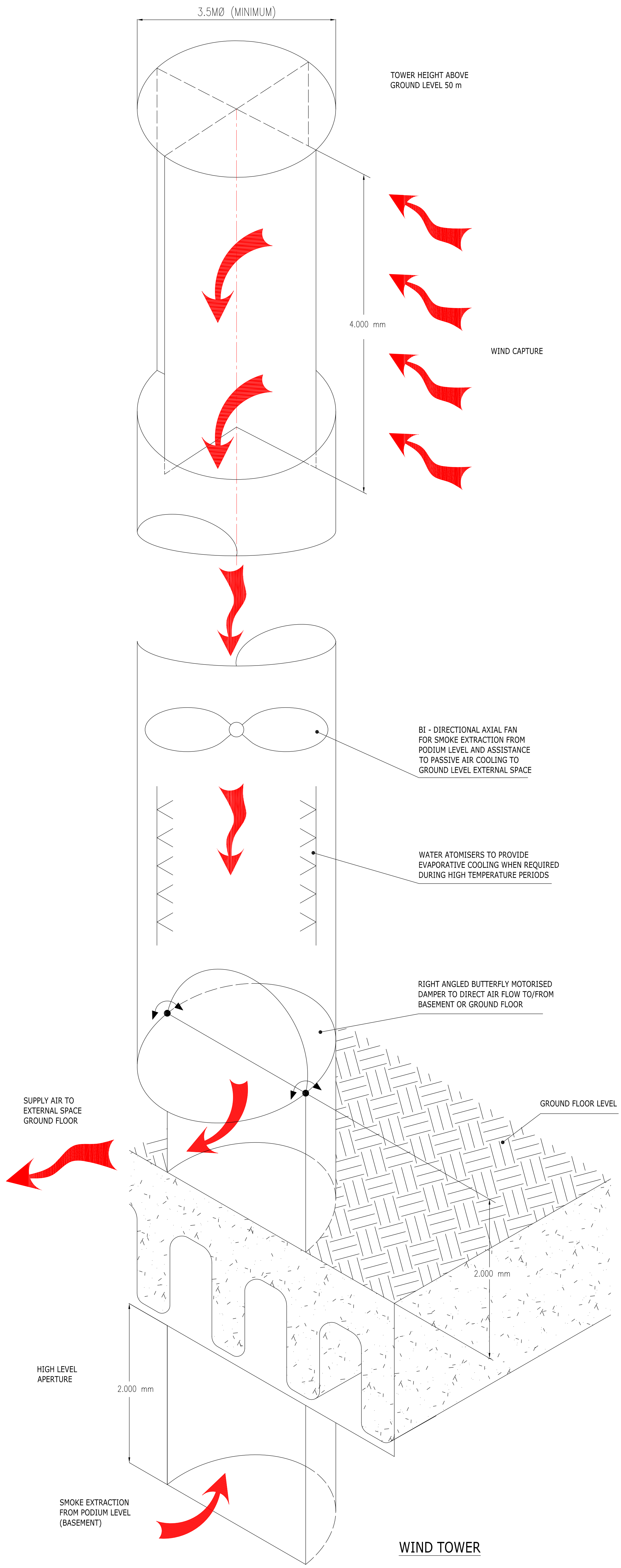
Project
Masdar Institute Of Science And Technology - Phase 1A

Title
MECHANICAL SERVICES
VENTILATION CONCEPT DESIGN SCHEMATIC
MECHANICAL WIND TOWERS

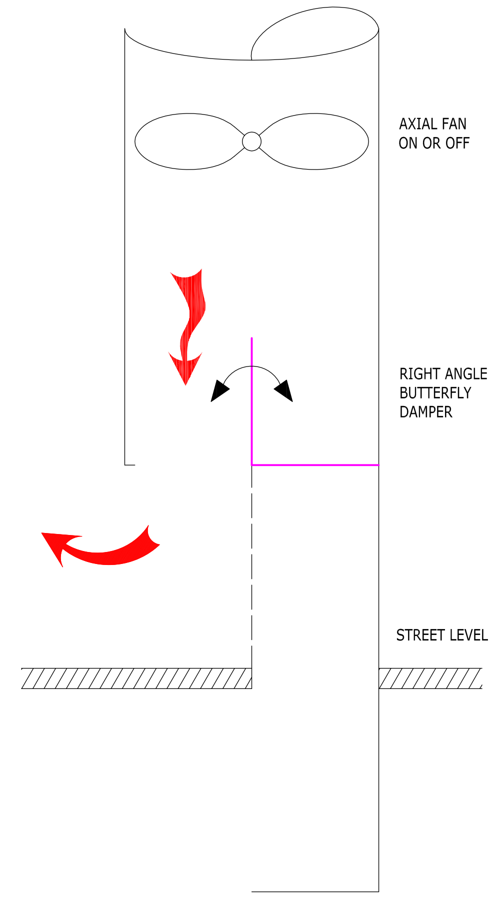
Drawn by	Checked by	File Name
AS	-	1076-SK-M500

Drawing Number	Revision	Scale	Date
SK-M-500		NTS @ A0	FEB 08

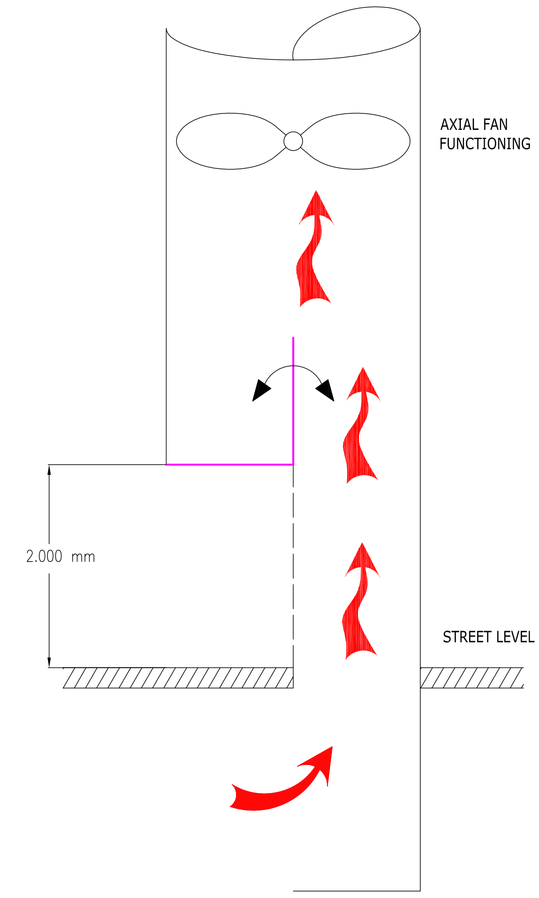


WIND TOWER

SCHEMATICS ILLUSTRATING DAMPER CONTROL FUNCTIONAL MODES



AIR FLOW COOLING TO STREET LEVEL



SMOKE EXTRACT FROM PODIUM (BASEMENT) LEVEL

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Client: Abu Dhabi Future Energy Company

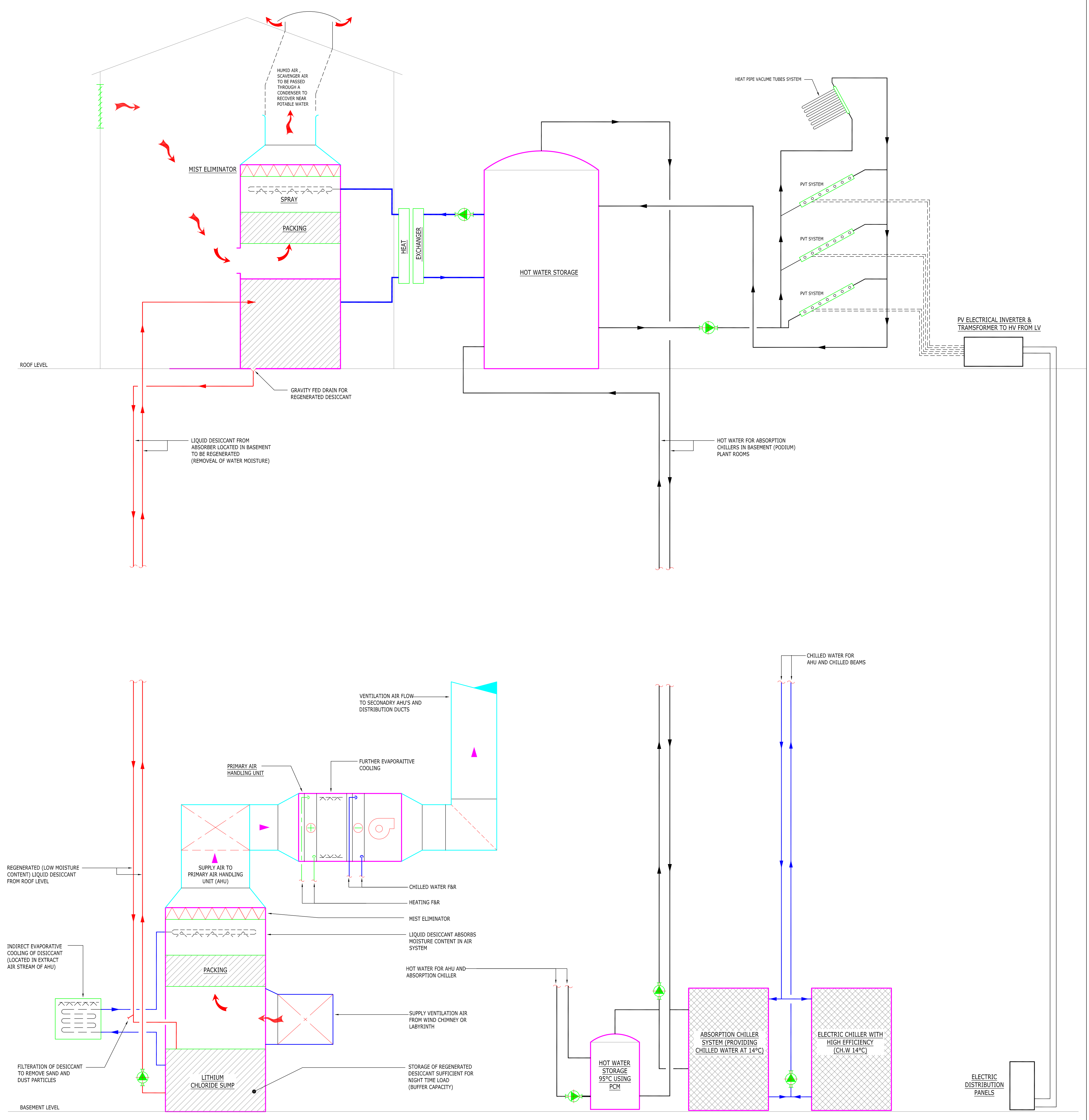
Architect: Foster + Partners

Project: Masdar Institute Of Science And Technology - Phase 1A

Title: MECHANICAL SERVICES PASSIVE VENT/SMOKE EXHAUST FOR PRT TUNNEL - OPTION

Drawn by	Checked by	File Name
AS	-	1076-SK-M501

Drawing Number	Revision	Scale
SK-M-501		NTS @ A0
		Date: FEB 08



SCHEMATIC ILLUSTRATING HOW DIFFERENT SUPPORTIVE SYSYTEMS INTERACT
TO PROVIDE COOLING/HEATING TO VENTILATION AIR STREAM

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Future Energy Company

Architect
Foster + Partners

Project
Masdar Institute Of Science
And Technology - Phase 1A

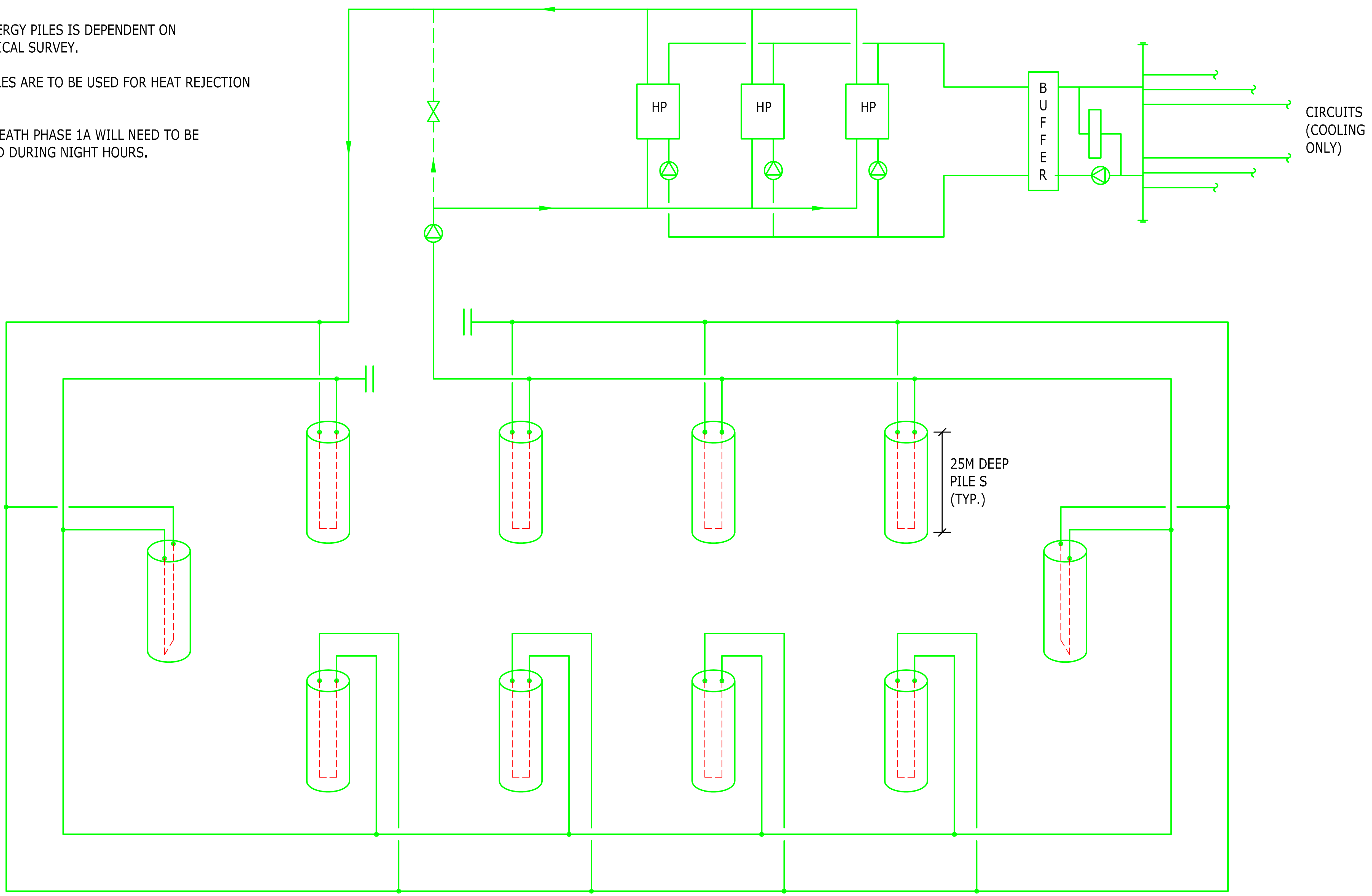
Title
MECHANICAL SERVICES
VENTILATION SCHEMATIC
LIQUID DESSICANT OPTION

Drawn by	Checked by	File Name
AS	-	1076-SK-M502

Drawing Number	Revision	Scale	Date
SK-M-502		NTS @ A0	FEB 08

NOTES:

1. USE OF ENERGY PILES IS DEPENDENT ON GEOTECHNICAL SURVEY.
2. ENERGY PILES ARE TO BE USED FOR HEAT REJECTION ONLY.
3. EARTH BENEATH PHASE 1A WILL NEED TO BE RECHARGED DURING NIGHT HOURS.



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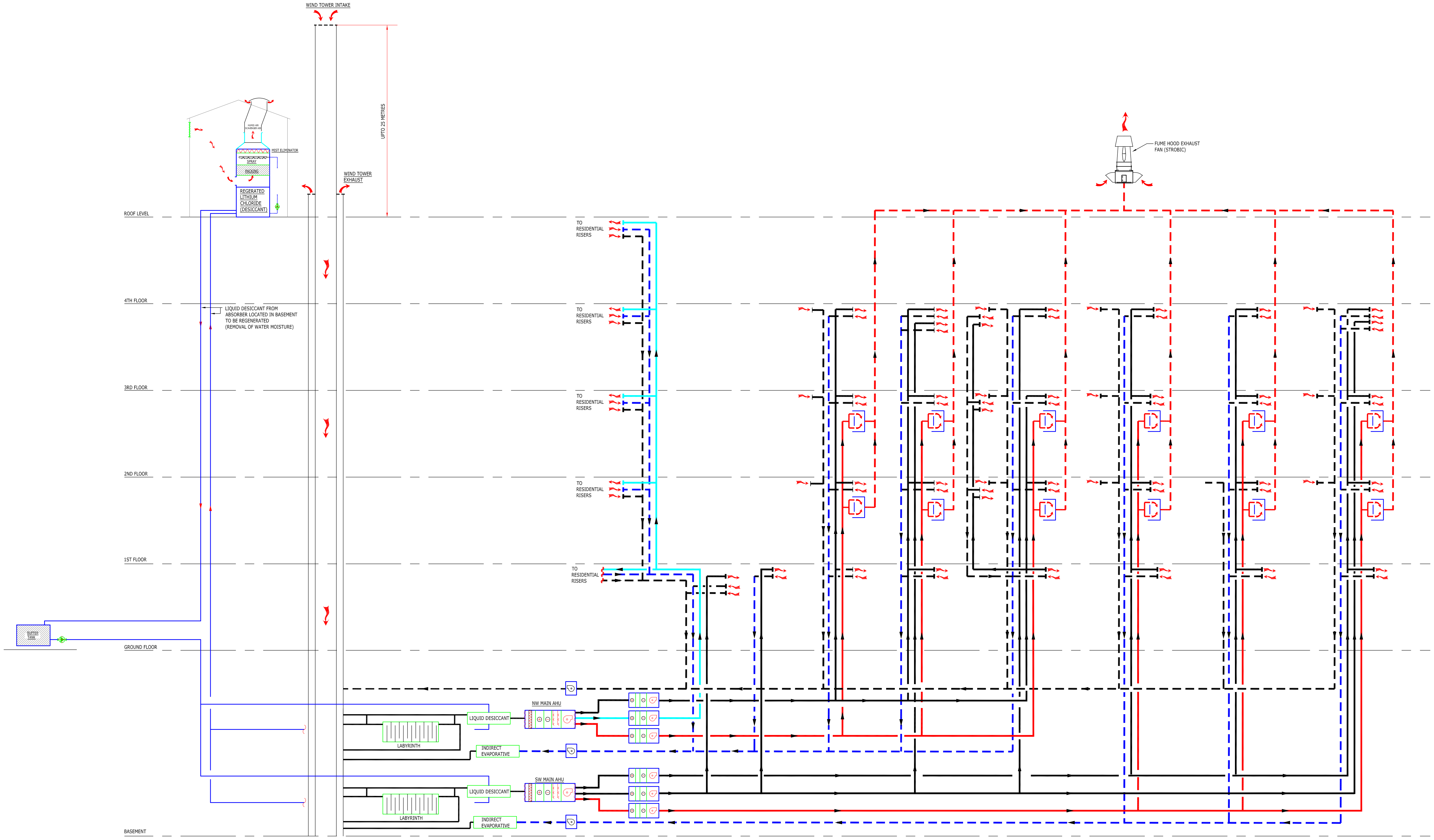
phaconsult | MIST PHASE 1A | ENERGY PILE HEAT REJECTION OPTION | SK-M-503

NOTES:

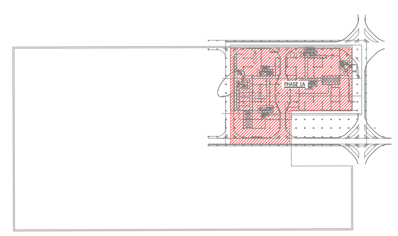
1.0 FIRE/SMOKE DAMPERS ASSUMED IN THE VERTICAL WALL OF EACH VENTILATION SHAFT.

2.0 ALL FUME HOOD EXHAUST DUCTWORK TO BE STAINLESS STEEL .

3.0 NUMBER OF AHU'S INDICTIVE ONLY.



SCHEDULE OF SUPPLAY AND EXTRACT DUCTS	
COLOUR	DESCRIPTION
(black line)	SUPPLAY DUCT - LIBRARY, CLASSROOM, LAB & SUPPORT
(black line)	EXTRACT DUCT - LIBRARY, CLASSROOM, LAB & SUPPORT
(red line)	SUPPLAY DUCT - FUME CUPBOARD (HAZARDOUS SUPPLAY)
(black line)	SUPPLAY DUCT - RESTAURANT, SPORT, CAFE
(black line)	EXTRACT DUCT - RESTAURANT, SPORT, CAFE
(blue line)	SUPPLAY DUCT - RESIDENTIAL
(cyan line)	EXTRACT DUCT - RESIDENTIAL
(light blue line)	EXTRACT DUCT - TOILET, KITCHEN



KEY PLAN

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Revision	Description	Date

Work Stage
CONCEPT DESIGN ISSUE

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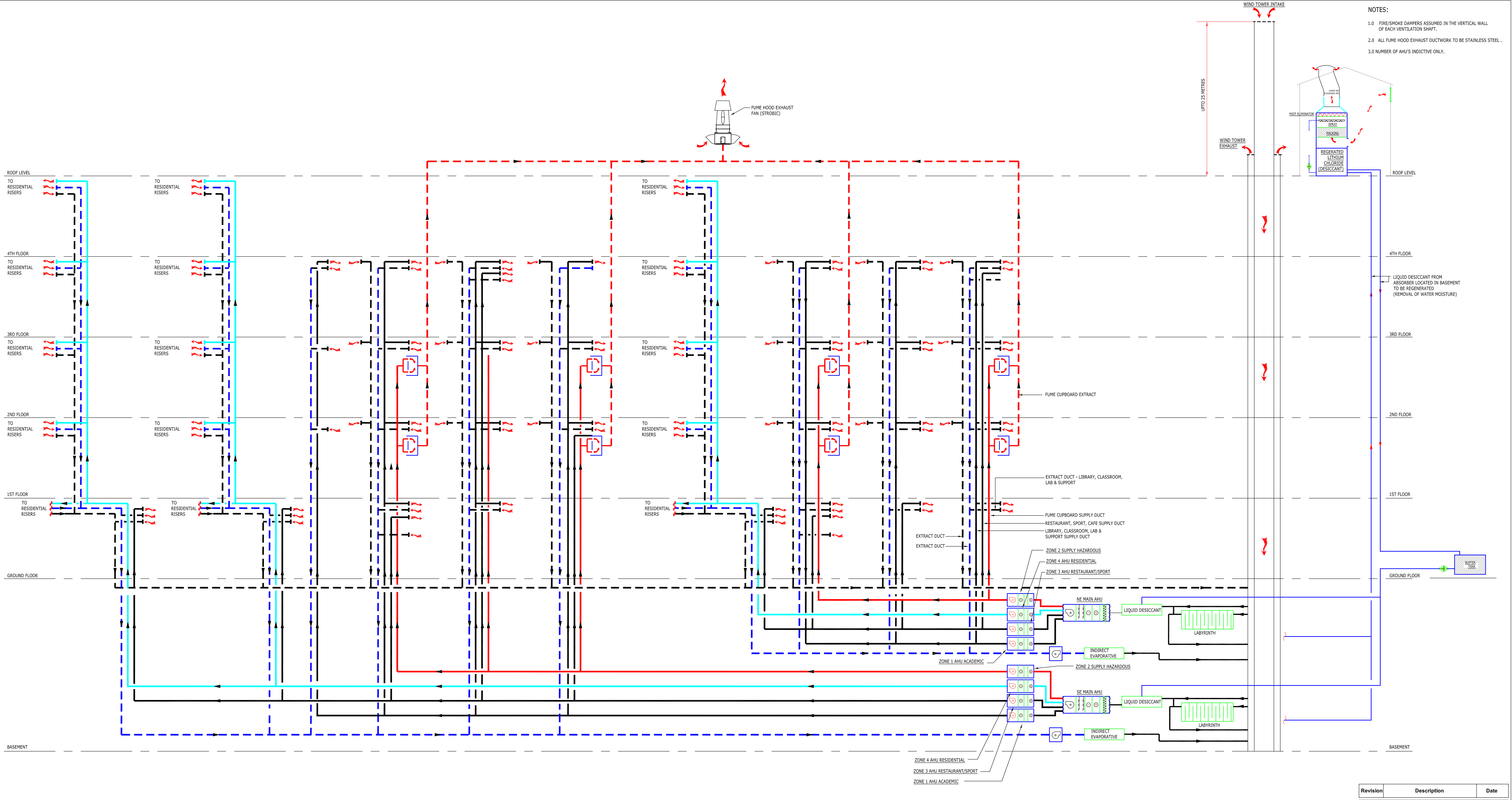
Project
Masdar Institute Of Science And Technology - Phase 1A

Title
MECHANICAL SERVICES
VENTILATION CONCEPT DESIGN SCHEMATIC
SHEET 1 OF 2

Drawn by	Checked by	File Name
AS	-	1076-SK-M506

Drawing Number	Revision	Scale / Date
SK-M-506		Scale: NTS @ A0; Date: FEB 08



NOTES:

1.0 FIRE/SMOKE DAMPERS ASSUMED IN THE VERTICAL WALL OF EACH VENTILATION SHAFT.

2.0 ALL FUME HOOD EXHAUST DUCTWORK TO BE STAINLESS STEEL .

3.0 NUMBER OF AHU'S INDICTIVE ONLY.

SCHEDULE OF SUPPLAY AND EXTRACT DUCTS

COLOUR	DESCRIPTION
black line	SUPPLAY DUCT - LIBRARY, CLASSROOM, LAB & SUPPORT
black line	EXTRACT DUCT - LIBRARY, CLASSROOM, LAB & SUPPORT
red line	SUPPLAY DUCT - FUME CUPBOARD (HAZARDOUS SUPPLAY)
black line	SUPPLAY DUCT - RESTAURANT, SPORT, CAFE
black line	EXTRACT DUCT - RESTAURANT, SPORT, CAFE
blue line	SUPPLAY DUCT - RESIDENTIAL
cyan line	EXTRACT DUCT - RESIDENTIAL
light blue line	EXTRACT DUCT - TOILET, KITCHEN

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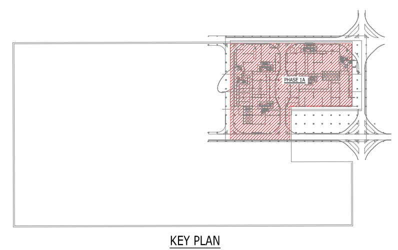

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Project
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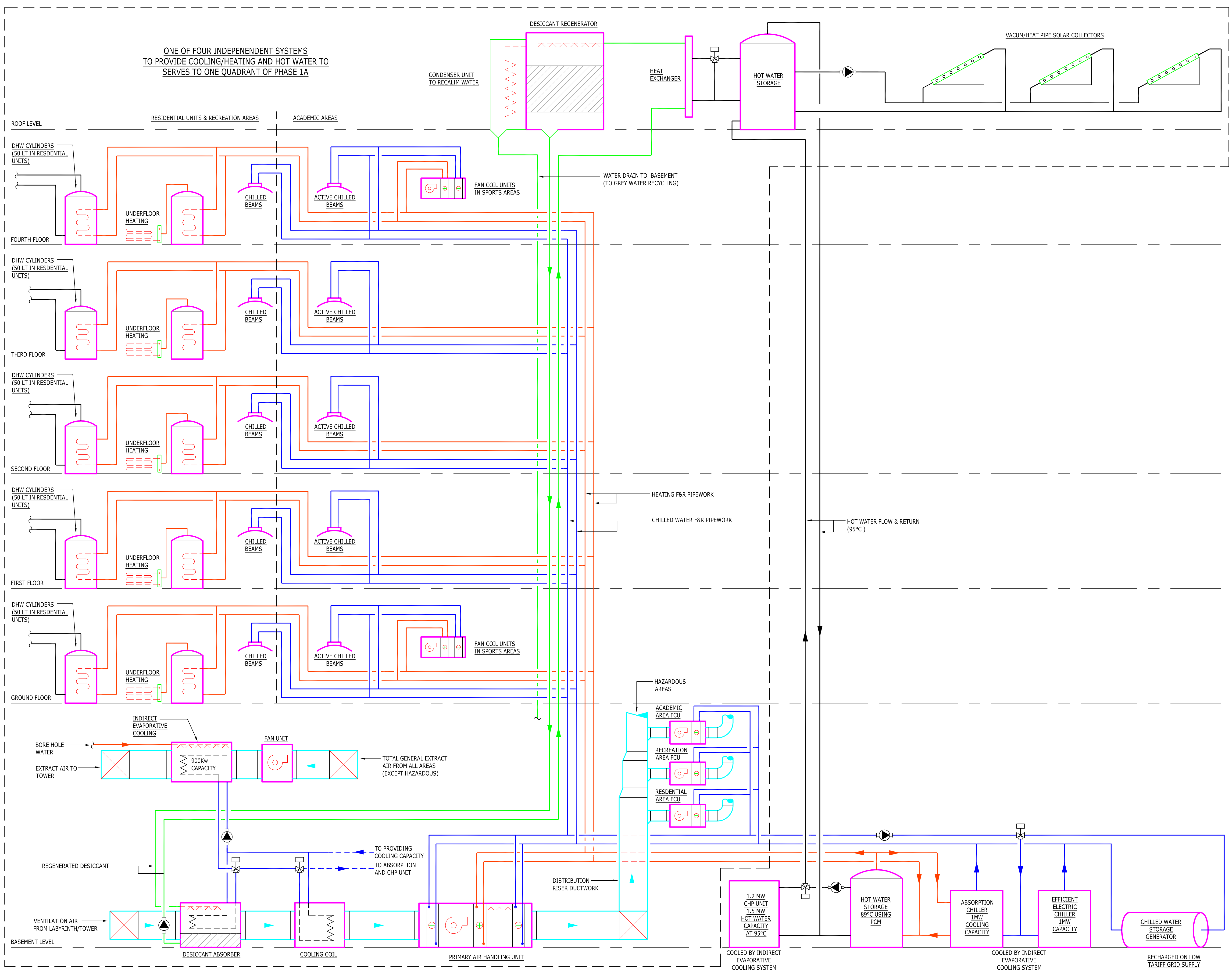
Title
MECHANICAL SERVICES
VENTILATION CONCEPT DESIGN SCHEMATIC
SHEET 2 OF 2

Drawn by	Checked by	File Name
AS	-	1076-SK-M507

Drawing Number	Revision	Scale / Date
SK-M-507		Scale: NTS @ A0; Date: FEB 08



LEGEND:

- HOT WATER F&R PIPEWORK
- HEATING F&R PIPEWORK
- CHILLED WATER F&R PIPEWORK
- DESICCANT PIPEWORK
- DOMESTIC HOT WATER PIPEWORK
- MOTORISED 3-PORT VALVE
- PUMP

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And Technology - Phase 1A

Title
SCHEMATIC SHOWING PIPEWORK SERVICES
PROVIDING HOT WATER, CHILLED WATER
AND DESICCANT

Drawn by	Checked by	File Name
AS	FG	1076-SK-M508

Drawing Number	Revision	Scale
SK-M-508		N.T.S @ A1
		Date: MARCH 08

ELECTRICAL LV - SWITCHGEAR

- No Way Type — MAIN DISTRIBUTION BOARD
- No Way SP&N — DISTRIBUTION BOARD SP&N
- No Way TP&N — DISTRIBUTION BOARD TP&N
- MAIN LV SWITCH PANEL
- MECHANICAL CONTROL CENTRE
- Rating Type — SINGLE PHASE ISOLATOR (Type INDICATES 'SP' OR 'WP')
- Rating Type — THREE PHASE ISOLATOR (Type INDICATES 'SP' OR 'WP')
- Rating — MANUALLY OPERATED CHANGEOVER SWITCH
- Rating — STARTER
- Rating — STARTER / ISOLATOR SWITCH (MANUALLY OPERATED)
- Rating — ISOLATOR OF UNDEFINED TYPE
- Rating — SINGLE POLE & NEUTRAL ISOLATOR
- Rating — DOUBLE POLE & NEUTRAL ISOLATOR
- Rating — TRIPLE POLE & NEUTRAL ISOLATOR
- Rating — SINGLE POLE & NEUTRAL FUSED SWITCH
- Rating — DOUBLE POLE & NEUTRAL FUSED SWITCH
- Rating — TRIPLE POLE & NEUTRAL FUSED SWITCH
- EQUIPMENT KNOCK OFF SWITCH
- Rating — FAN ISOLATOR
- CONTACTOR
- CHANGEOVER SWITCH
- TX Rating — TRANSFORMER (VA RATING ADJACENT)
- EARTH BOND PIT
- CE — EARTH POINT. (CE ADJACENT INDICATES CLEAN EARTH)
- FAN STOP/START CONTROLLER
- PFCP — POWER FACTOR CORRECTION PANEL
- TX Rating — TRANSFORMER (HV/LV)
- Rating — GENERATOR
- Rating — METER - ELECTRICITY
- Rating — LANDLORDS CHECK METER
- Rating — BUS BAR TAP OFF UNIT
- BUSBAR CHAMBER
- RISING BUSBAR
- HORIZONTALLY RUN BUSBAR

ELECTRICAL COMMUNICATIONS

- X — TELEPHONE POINT
- P — PAYPHONE POINT
- P — PAYPHONE POINT WITH ACOUSTIC SHIELD
- F — FIREPHONE
- PD — COMBINED TELEPHONE AND DATA POINT
- M — DEDICATED MODEM POINT
- FX — DEDICATED FAX POINT
- D — DATA POINT
- FM — FM OUTLET
- TV — TV OUTLET
- IT — MAIN I.T. COMMS RACK
- DPP — DATA PATCH PANEL
- UPS — UNINTERRUPTED POWER SUPPLY UNIT
- Ref — MAIN FRAME TELEPHONE POINT
- FB 3 — FLOOR BOX. No. ADJACENT INDICATING COMPARTMENTS
- AERIAL
- BELL TRANSFORMER
- BELL
- BELL PUSH
- I — INTERCOM
- M — MICROPHONE
- P — MICROPHONE (PAGING)
- F — MICROPHONE (FIRE)
- NOISE SENSOR
- A — AMPLIFIER
- PUBLIC ADDRESS SPEAKER (CEILING)
- PUBLIC ADDRESS SPEAKER (CABINET)
- WALL CLOCK
- TS — TIME SWITCH

ELECTRICAL SOCKETS

- 13A SINGLE UN-SWITCHED SOCKET OUTLET
- 13A SINGLE SWITCHED SOCKET OUTLET
- C — 13A SINGLE UN-SWITCHED CLEANERS SOCKET OUTLET
- C — 13A SINGLE SWITCHED CLEANERS SOCKET OUTLET
- C — 13A SINGLE SWITCHED SOCKET OUTLET - CLEAN SUPPLY
- E — 13A SINGLE SWITCHED SOCKET OUTLET - ESSENTIAL SUPPLY
- RCD — 13A SINGLE SWITCHED SOCKET OUTLET - RCD
- SP — 13A SINGLE SWITCHED SOCKET OUTLET - SPLASH PROOF
- N — 13A SINGLE SWITCHED SOCKET OUTLET - WITH NEON INDICATOR
- 2 — 13A TWIN UN-SWITCHED SOCKET OUTLET
- 2 — 13A TWIN SWITCHED SOCKET OUTLET
- 2 C — 13A TWIN SWITCHED SOCKET OUTLET - CLEAN
- 2 E — 13A TWIN SWITCHED SOCKET OUTLET - ESSENTIAL
- 2 RCD — 13A TWIN SWITCHED SOCKET OUTLET - RCD
- 2 SP — 13A TWIN SWITCHED SOCKET OUTLET - SPLASH PROOF
- 2 N — 13A TWIN SWITCHED SOCKET OUTLET - WITH NEON INDICATOR
- 13A UN-SWITCHED FUSED CONNECTION UNIT
- F — 13A UN-SWITCHED FUSED CONNECTION UNIT - WITH FLEX OUTLET
- 13A SWITCHED FUSED CONNECTION UNIT
- N — 13A SWITCHED FUSED CONNECTION UNIT - WITH NEON INDICATOR
- F — 13A SWITCHED FUSED CONNECTION UNIT - WITH FLEX OUTLET
- FN — 13A SWITCHED FUSED CONNECTION UNIT - WITH FLEX OUTLET AND NEON
- 32A WEATHERPROOF EXTERNAL SOCKET
- 20/30A DOUBLE POLE SWITCH
- N — 20/30A DOUBLE POLE SWITCH - WITH NEON INDICATOR
- F — 20/30A DOUBLE POLE SWITCH - WITH FLEX OUTLET
- FN — 20/30A DOUBLE POLE SWITCH - WITH NEON INDICTOR & FLEX OUTLET
- 3 PHASE SOCKET OUTLET
- 240/110V SWITCHED SOCKET OUTLET & TRANSMITTER & RCD
- S — SHAVER OUTLET
- C — COOKER OUTLET
- Rating — UN-SWITCHED SOCKET OUTLET TO BS4343
- Rating — SINGLE POLE SWITCHED SOCKET OUTLET TO BS4343
- Rating — DOUBLE POLE SWITCHED SOCKET OUTLET TO BS4343
- Rating — TRIPLE POLE SWITCHED SOCKET OUTLET TO BS4343
- Rating — TRIPLE POLE, NEUTRAL + EARTH SWITCHED SOCKET OUTLET TO BS4343

ELECTRICAL WIRING

- STANDBY BATTERY UNIT
- SWITCH / ISOLATOR
- FUSED SWITCH / ISOLATOR
- CHANGEOVER CONTACTOR
- PUSH TO MAKE CONTACTOR
- M — CURRENT TRANSFORMER
- 3 PHASE DELTA WINDING AND 3 PHASE STAR WINDING TRANSFORMER
- TRANSFORMER
- PLUG AND SOCKET
- BLANK SOCKET (FOR FUTURE EXTENSION)
- INVERTOR
- RECTIFIER
- UNINTERRUPTED POWER SUPPLY
- NEON LIGHT
- INDICATOR LIGHT
- kVA — GENERATOR
- EARTH POINT
- WITHDRAWABLE PATTERN CIRCUIT BREAKER
- FIXED PATTERN CIRCUIT BREAKER
- CIRCUIT BREAKER
- CONNECTION
- MINITURE CIRCUIT BREAKER
- M — MECHANICALLY OPPERATED
- I — INTERLINKED
- 32A — FUSE
- LINK

ELECTRICAL FIRE

- BREAKGLASS CALL POINT
- BREAKGLASS CALL POINT FOR SMOKE VENT
- K — KEY OPERATED MANUAL CALL POINT
- F — FIRE TELEPHONE CALL POINT
- SMOKE DETECTOR
- SMOKE DETECTOR (with sounder)
- SMOKE DETECTOR (with sounder & xenon becon)
- I — SMOKE DETECTOR (Ionisation)
- O — SMOKE DETECTOR (Optical)
- SMOKE DETECTOR WITHIN VOID.
- SMOKE DETECTOR WITHIN SMOKE VENT
- S — DUCT SMOKE DETECTOR
- R — HEAT DETECTOR FIXED TEMPERATURE. 'R' ADJACENT INDICATES RATE OF RISE
- IR — HEAT DETECTOR (INFRA RED)
- HEAT DETECTOR (with sounder)
- HEAT DETECTOR (with sounder & xenon becon)
- S H — COMBINED SMOKE AND HEAT DETECTOR (NETURAL)
- Tx — BEAM SMOKE DETECTOR (TRANSMITTER)
- Rx — BEAM SMOKE DETECTOR (RECEIVER)
- FD — FLAME DETECTOR
- DH — MAGNETIC DOOR HOLD (FIRE ALARM OPERATED)
- FIRE ALARM BELL
- FIRE ALARM SIREN
- FIRE ALARM BUZZER
- FIRE ALARM SOUNDER
- FIRE ALARM CEILING MOUNTED VOICE EVACUATION SPEAKER AND STAFF ADDRESS
- FIRE ALARM WALL MOUNTED VOICE EVACUATION SPEAKER AND STAFF ADDRESS
- REMOTE INDICATOR
- XENON FLASHING BEACON
- FAP — FIRE ALARM PANEL
- FARP — FIRE ALARM REPEATER PANEL
- SS — SYSTEM STATUS INDICATOR PANEL
- INT — INTERFACE MODULE
- SCI — SHORT CIRCUIT INDICATOR
- PSU — POWER SUPPLY UNIT

ELECTRICAL SECURITY

- ACCESS CONTROL & ALARM PANEL
- CR — ACCESS CONTROL SWIPE CARD READER
- CR — ACCESS CONTROL SWIPE CARD READER WITH ADDITIONAL KEYPAD
- FIU — FIRE ALARM INTERFACE UNIT
- SDP — SECURITY MAIN DISTRIBUTION PANEL
- MAGNETIC DOOR / WINDOW CONTACTS (Reed switch)
- ML — MAGNETIC DOOR LOCKS (Cord access doors)
- EML — EMERGENCY ELECTROMAGNETIC DOOR LOCKS
- DOOR LOOP DETECTOR (READER)
- ACCESS CONTROL DOOR RELEASE UNIT
- EMERGENCY BREAK GLASS DOOR RELEASE
- PB — PANIC BUTTON
- PAB — PERSONAL ATTACK BUTTON
- VD — VIBRATION DETECTOR
- PD — PRESSURE DETECTOR
- I — INFRA RED DETECTOR
- PD — PASSIVE INFRA-RED MOVEMENT DETECTOR (CEILING MOUNTED)
- PD — PASSIVE INFRA-RED MOVEMENT DETECTOR (WALL MOUNTED)
- P — PROXIMITY MOVEMENT DETECTOR
- US — ULTRA-SONIC DETECTOR
- DD — DOOR DETENT
- SECURITY ALARM SOUNDER
- INTRUDER ALARM
- CCTV — CCTV MONITOR EQUIPMENT
- FIXED CCTV CAMERA
- PTZ — CCTV CAMERA. P=PAN, T=TILT, Z=ZOOM
- PTZ — CCTV CAMERA. P=PAN, T=TILT, Z=ZOOM (WITH PIR)
- PTZ — CCTV CAMERA. P=PAN, T=TILT, Z=ZOOM (WITH INFRA RED LIGHTS)
- CCTV CAMERA. (WITHIN DOME)
- CCTV CAMERA. (WITHIN DOME) 'SWIVEL'
- 360 deg CAMERA
- K — MECHANICAL SECURITY KEY PAD
- UHF TRANSCEIVER (OUTPUT) MODULE
- UHF TRANSCEIVER (INPUT) MODULE
- PSU — POWER SUPPLY UNIT

ELECTRICAL SWITCHES

- Ng — 20A ONE WAY SWITCH (Ng :- INDICATES NUMBER OF GANGS)
- Ng — 20A TWO WAY SWITCH (Ng :- INDICATES NUMBER OF GANGS)
- I Ng — ILLUMINATED SWITCH (Ng :- INDICATES NUMBER OF GANGS)
- Ng — 20A INTERMEDIATE SWITCH (Ng :- INDICATES NUMBER OF GANGS)
- WP Ng — 10A WEATHER PROOF SWITCH (Ng :- INDICATES NUMBER OF GANGS)
- K Ng — 20A KEY SWITCH ('N' ADJACENT INDICATES NEON INDICATOR)
- K Ng — DOUBLE POLE KEY SWITCH ('N' ADJACENT INDICATES NEON INDICATOR)
- D Ng — DIMMER SWITCH (Ng :- INDICATES NUMBER OF GANGS)
- INFRA RED SWITCH/SENSOR
- ONE WAY PULL CORD SWITCH
- TWO WAY PULL CORD SWITCH
- Ng — 20A DOUBLE POLE SWITCH (Ng :- INDICATES NUMBER OF GANGS)
- T Ng — TIMED SWITCH (CLOCK CONTROLLED) (Ng :- INDICATES NUMBER OF GANGS)
- TIME DELAY SWITCH
- MOMENTARY PUSH BUTTON
- N — MOMENTARY PUSH BUTTON WITH NEON INDICATOR
- 2W — 2 WAY MOMENTARY PUSH BUTTON
- ON/OFF RESET PUSH BUTTON / KNOCK OFF SWITCH
- PC — PHOTO ELECTRIC CELL
- PASSIVE MOVEMENT DETECTOR
- DISABLED / DISTRESS ALARM
- R — DISABLED / DISTRESS ALARM EMERGENCY PUSH BUTTON
- R — DISABLED / DISTRESS ALARM PUSH BUTTON (R :- DENOTES RESET SWITCH)

ELECTRICAL LIGHTING

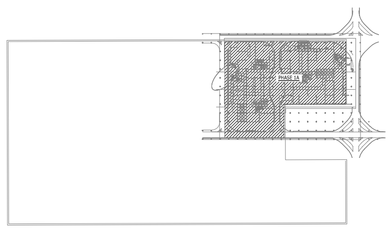
- dd
- T — SINGLE BATTEN FLUORESCENT LUMINAIRE. LETTER ADJACENT INDICATES TYPE
- T — SINGLE BATTEN FLUORESCENT LUMINAIRE WITH EMERGENCY CONVERSION PACK. LETTER ADJACENT INDICATES TYPE
- T — TWIN BATTEN FLUORESCENT. LETTER ADJACENT INDICATES TYPE
- T — TWIN BATTEN FLUORESCENT LUMINAIRE WITH EMERGENCY CONVERSION PACK.
- T — WALL MOUNTED LUMINAIRE. LETTER ADJACENT INDICATES TYPE
- T — WALL MOUNTED LUMINAIRE WITH EMERGENCY CONVERSION PACK. LETTER ADJACENT INDICATES TYPE
- T — FLUSH/CEILING MOUNTED LUMINAIRE. LETTER ADJACENT INDICATES TYPE
- TE — FLUSH/CEILING MOUNTED LUMINAIRE WITH EMERGENCY CONVERSION PACK. LETTER ADJACENT INDICATES TYPE
- T — WALL MOUNTED, SINGLE BATTEN FLUORESCENT LUMINAIRE. LETTER ADJACENT INDICATES TYPE
- T — WALL MOUNTED UPLIGHTER. LETTER ADJACENT INDICATES TYPE
- OVER DOOR WARNING LIGHT
- T — WALL MOUNTED FLOOD LIGHT. LETTER ADJACENT INDICATES TYPE
- T — POLE MOUNTED FLOOD LIGHT. LETTER ADJACENT INDICATES TYPE
- EXIT — EMERGENCY EXIT SIGN. LETTER ADJACENT INDICATES TYPE
- MODULAR RECESSED FLUORESCENT LUMINAIRE. LETTER ADJACENT INDICATES TYPE
- MODULAR RECESSED FLUORESCENT LUMINAIRE WITH EMERGENCY CONVERSION PACK. LETTER ADJACENT INDICATES TYPE
- MODULAR RECESSED FLUORESCENT LUMINAIRE. LETTER ADJACENT INDICATES TYPE
- MODULAR RECESSED FLUORESCENT LUMINAIRE WITH EMERGENCY CONVERSION PACK. LETTER ADJACENT INDICATES TYPE
- T — EXTERNAL BOLLARD LIGHTING. LETTER ADJACENT INDICATES TYPE
- FIBRE OPTIC PROJECTOR & LENS. LETTER ADJACENT INDICATES TYPE
- T — COLD CATHODE OR NEON LIGHTING. LETTER ADJACENT INDICATES TYPE
- T — 1200 TRACK LIGHT SECTION & LUMINAIRE. LETTER ADJACENT INDICATES TYPE
- T — LOW VOLTAGE LIGHTING TRANSFORMER

ELECTRICAL ANCILLARY

- WH — WATER HEATER
- LOCAL EXTRACT FAN
- TUBULAR HEATER
- THERMOSTAT
- HD — HAND DRYER
- MAC — MACERATOR
- FH — WALL MOUNTED FAN HEATER
- LIGHTNING SURGE PROTECTION UNIT
- IH — TANK MOUNTED IMMERSION HEATER
- TIMER SWITCH FOR IMMERSION HEATER
- PERSONAL COMPUTER

ELECTRICAL CONTAINMENT

- ELECTRICAL CABLE TRAY
- ELECTRICAL TRUNKING
- DADO RAIL TRUNKING
- ELECTRICAL DATA BASKET
- ELECTRICAL LADDER RACKING



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Project
Masdar Institute Of Science And Technology - Phase 1A

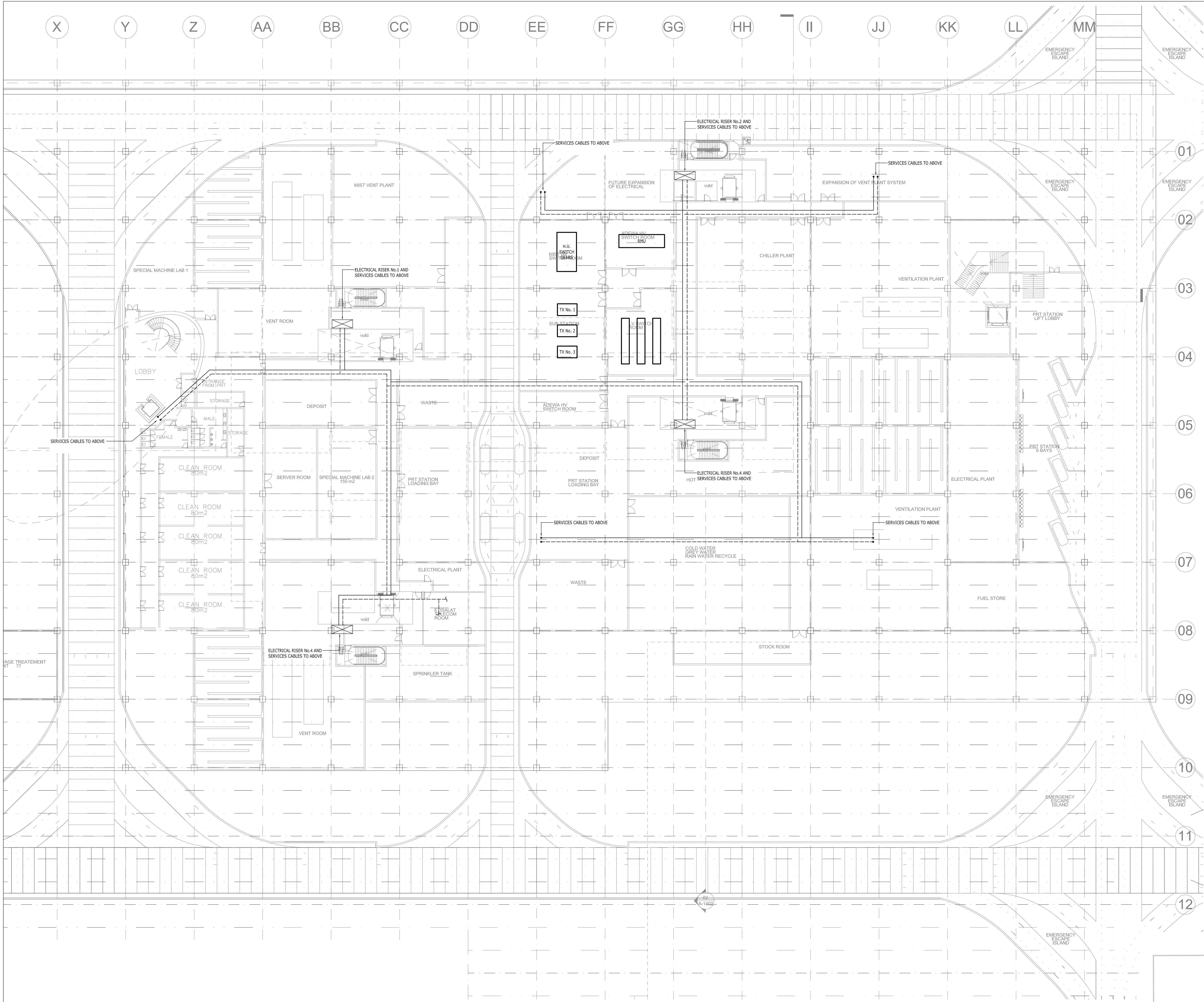
Title
ELECTRICAL SERVICES
LEGEND

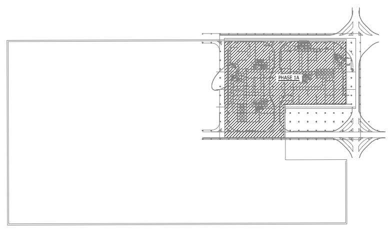
Drawn by	Checked by	File Name
OA	-	1076-SK-E001

Drawing Number	Revision	Scale / Date
SK-E-001		NTS @ A0 / FEB 08

LEGEND:

- ELECTRICAL RISER
- ELECTRICAL CONTAINMENT
- TELECOM CONTAINMENT ROUTING





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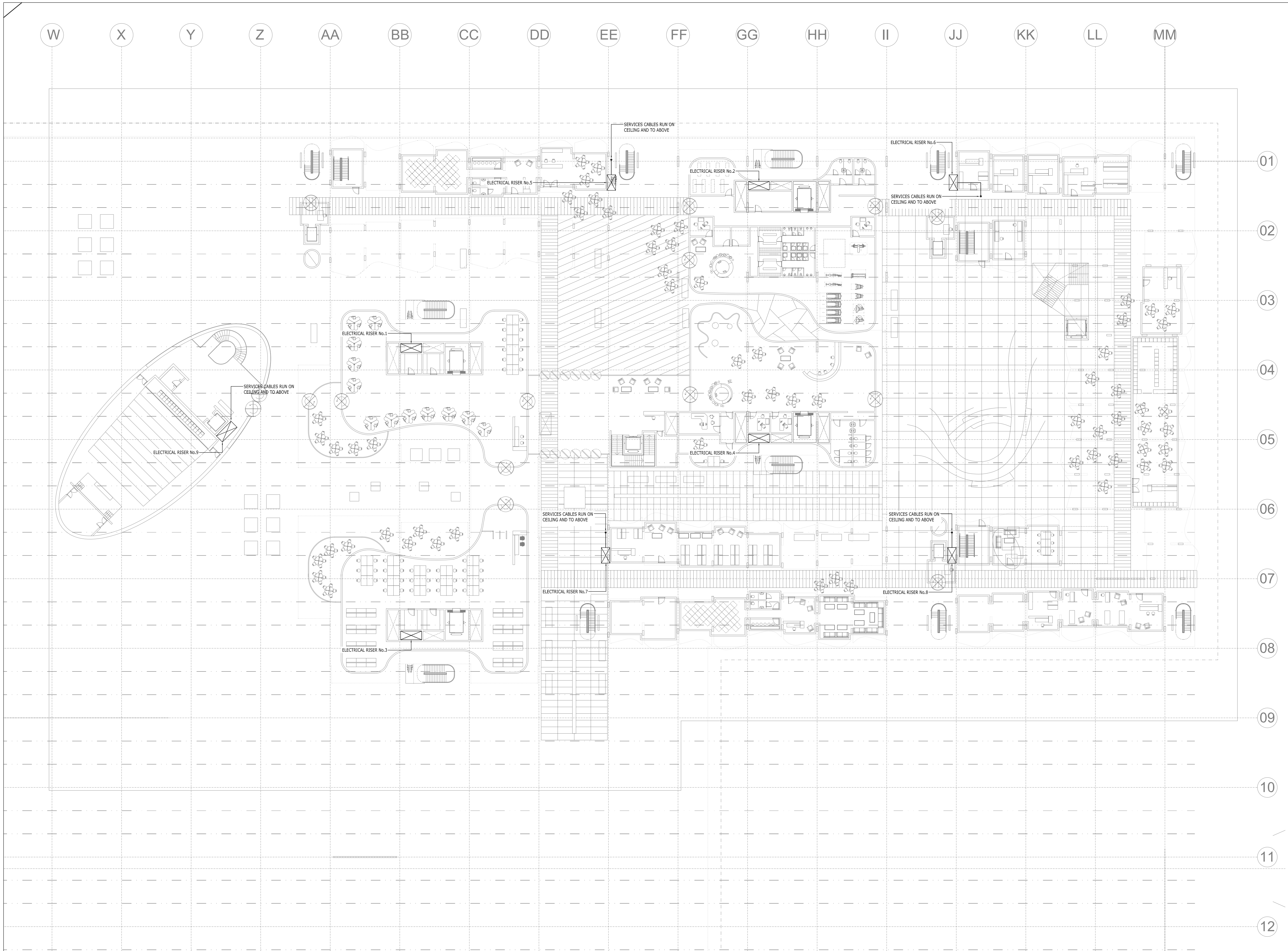
Project
Masdar Institute Of Science And Technology - Phase 1A

Title
ELECTRICAL SERVICES
ELECTRICAL DISTRIBUTION
BASEMENT

Drawn by	Checked by	File Name
OA	-	1076-SK-E300

Drawing Number	Revision	Scale / Date
SK-E-300		1:200 @ A0
		FEB 08



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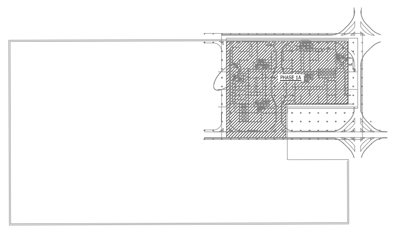
Project
Masdar Institute Of Science And Technology - Phase 1A

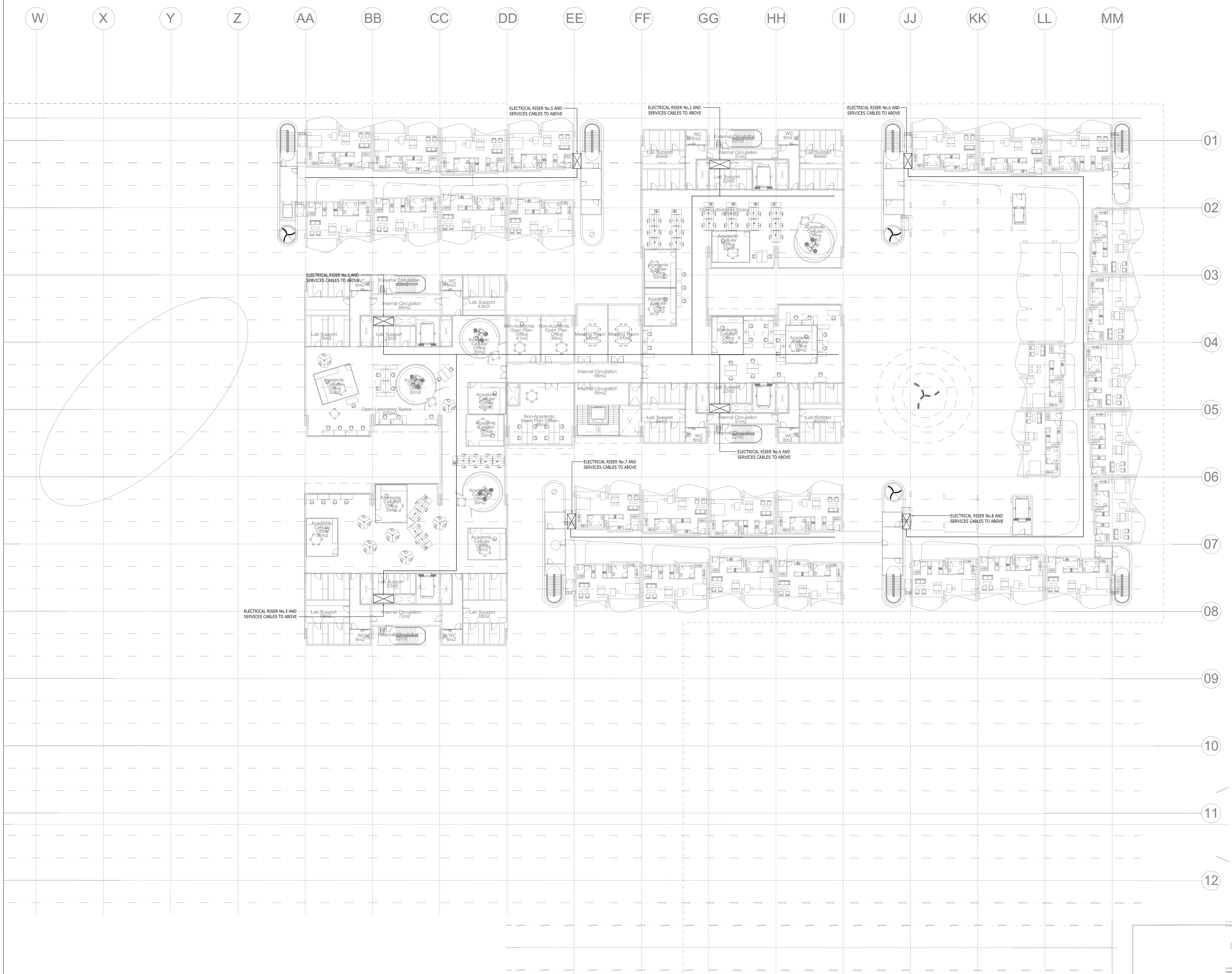
Title
ELECTRICAL SERVICES
ELECTRICAL DISTRIBUTION
GROUND LEVEL

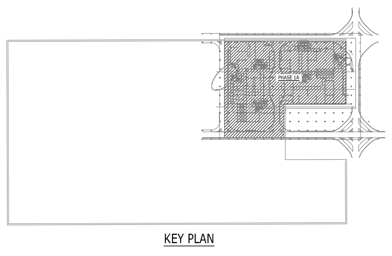
Drawn by	Checked by	File Name
OA	-	1076-SK-E301

Drawing Number	Revision	Scale
SK-E-301		1:200 @ A0
		Date: FEB 08



KEY PLAN





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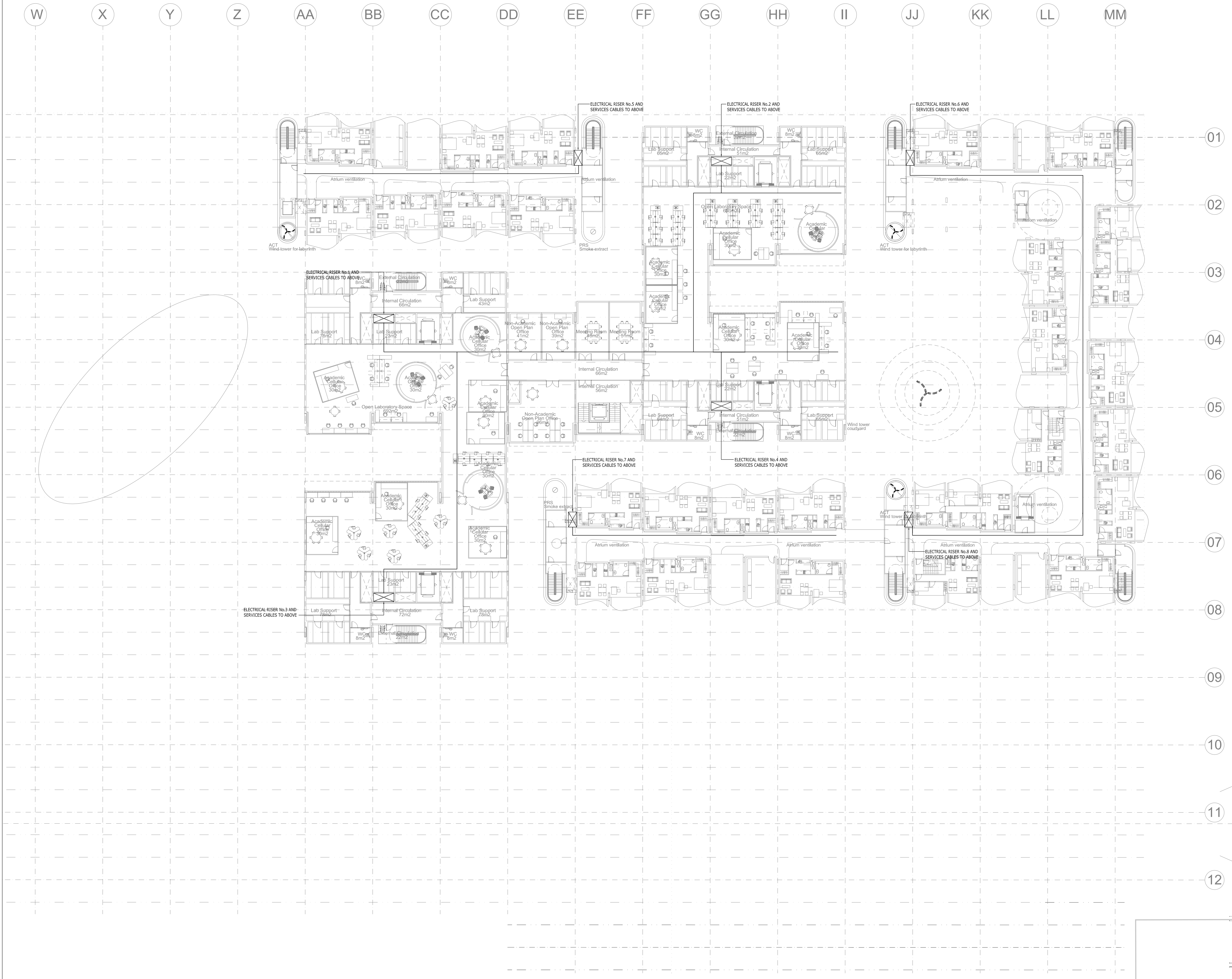
Project
Masdar Institute Of Science And Technology - Phase 1A

Title
ELECTRICAL SERVICES
ELECTRICAL DISTRIBUTION
FIRST FLOOR

Drawn by	Checked by	File Name
OA	-	1076-SK-E302

Drawing Number	Revision	Scale	Date
SK-E-302		1:200 @ A0	FEB 08



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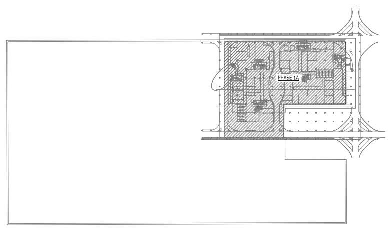
Foster + Partners

Project
Masdar Institute Of Science And Technology - Phase 1A

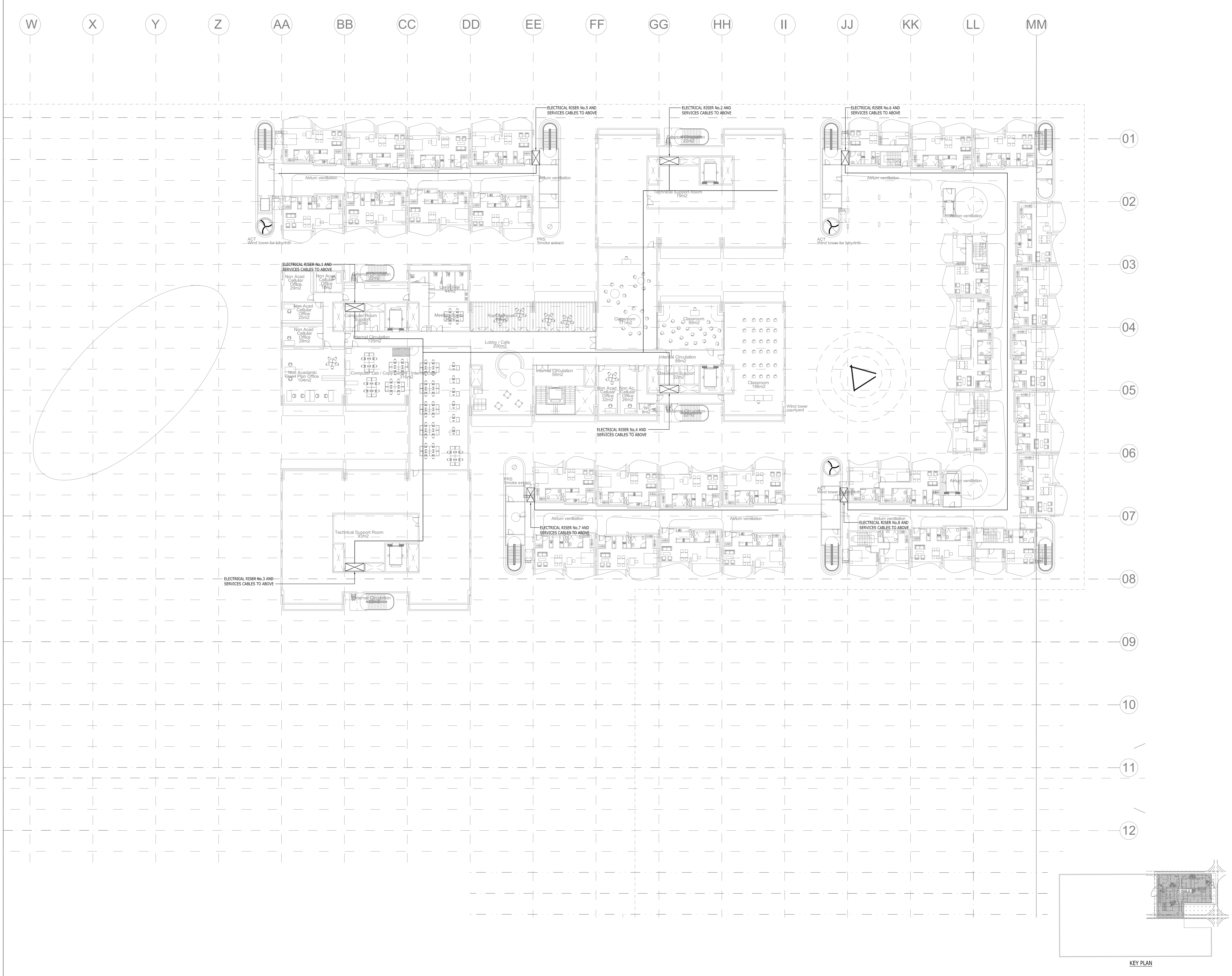
Title
ELECTRICAL SERVICES
ELECTRICAL DISTRIBUTION
SECOND FLOOR

Drawn by	Checked by	File Name
OA	-	1076-SK-E303

Drawing Number	Revision	Scale
SK-E-303		1:200 @ A0
		Date: FEB 08



KEY PLAN



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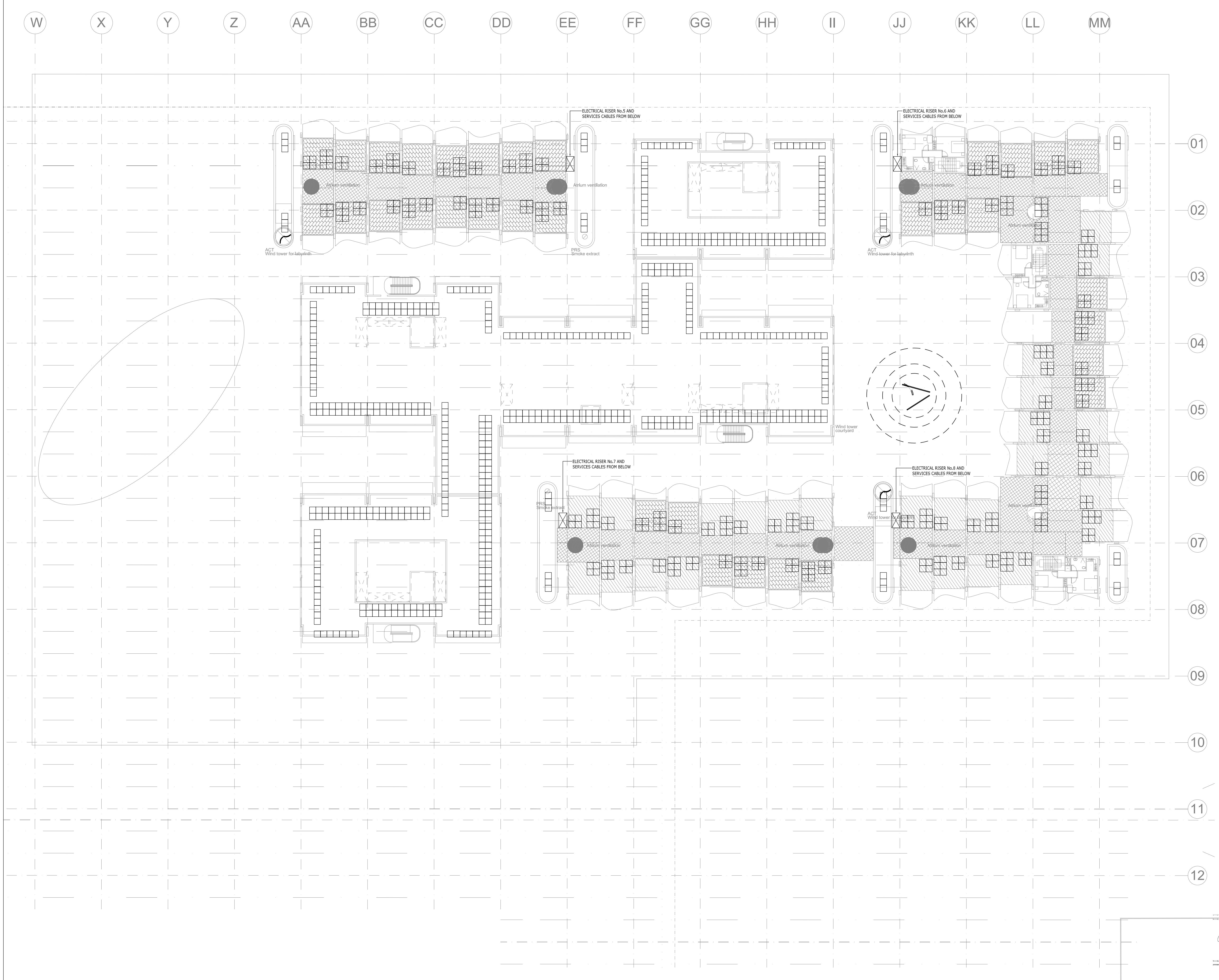
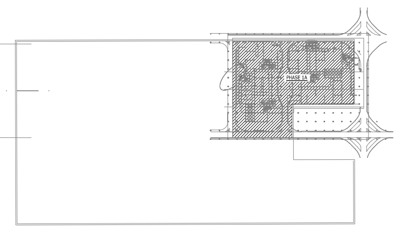
Project
Masdar Institute Of Science And Technology - Phase 1A

Title
ELECTRICAL SERVICES
ELECTRICAL DISTRIBUTION
THIRD FLOOR

Drawn by	Checked by	File Name
OA	-	1076-SK-E304

Drawing Number	Revision	Scale
SK-E-304		1:200 @ A0
		Date: FEB 08





KEY PLAN

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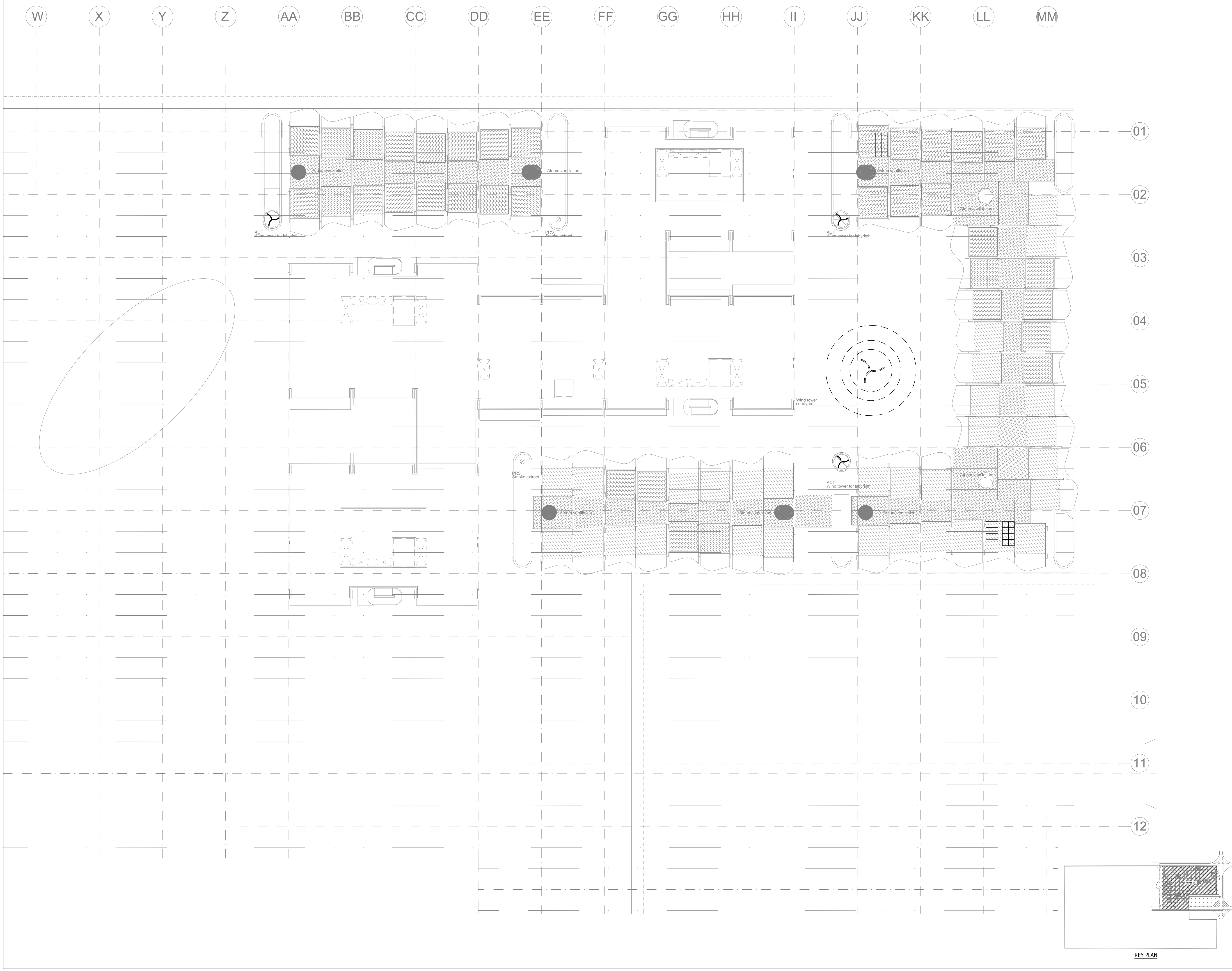
Title
ELECTRICAL SERVICES
ELECTRICAL DISTRIBUTION
FOURTH FLOOR

Drawn by	Checked by	File Name
OA	-	1076-SK-E305

Drawing Number	Revision	Scale	Date
SK-E-305		1:200 @ A0	FEB 08



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Project
Masdar Institute Of Science And Technology - Phase 1A

Title
ELECTRICAL SERVICES
ELECTRICAL DISTRIBUTION
FIFTH FLOOR

Drawn by	Checked by	File Name
OA	-	1076-SK-E306

Drawing Number	Revision	Scale	Date
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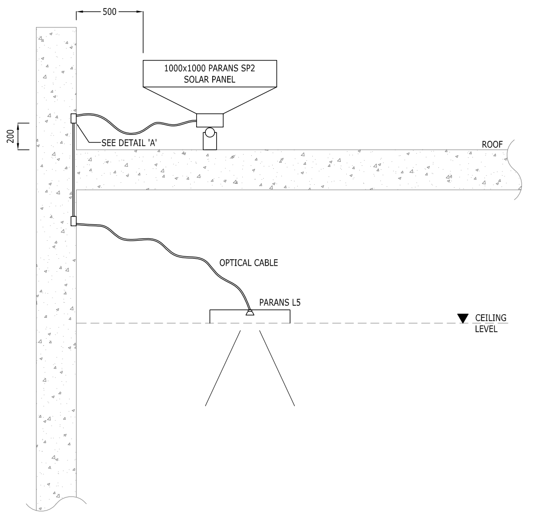
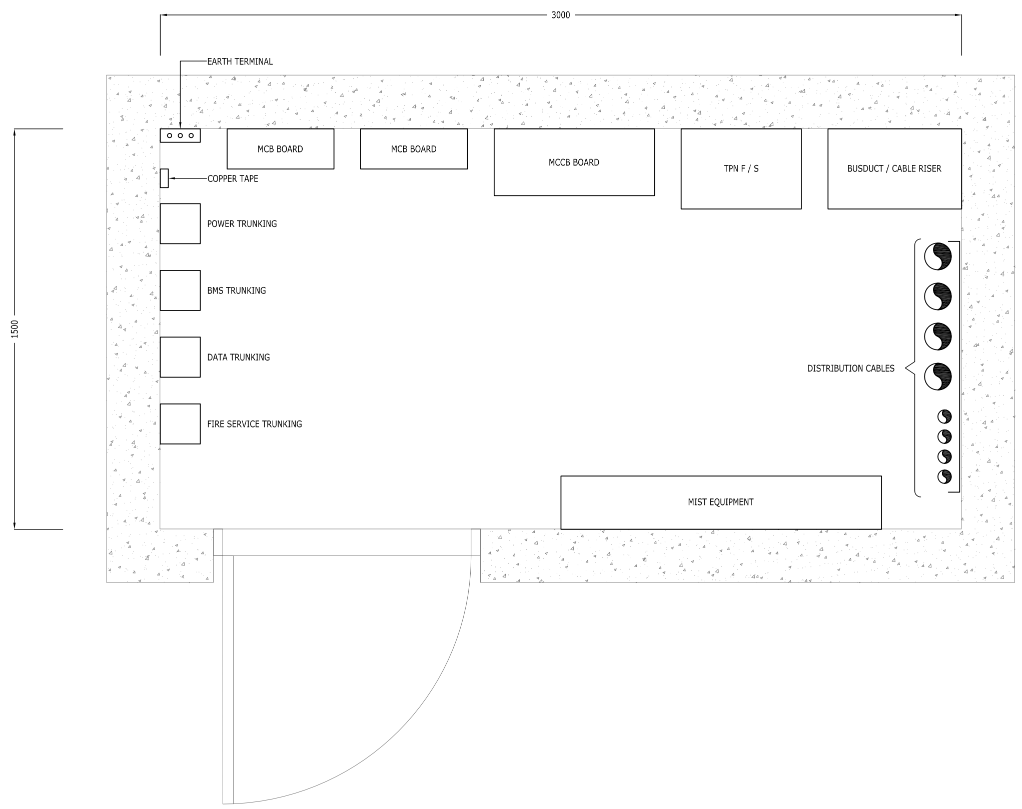
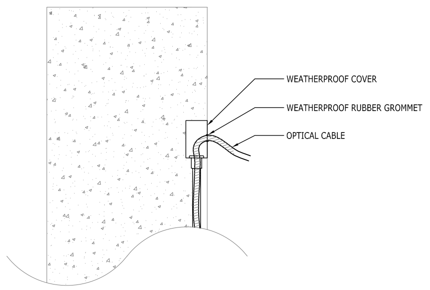


TYPICAL INSTALLATION DETAIL FOR SOLAR LIGHTS IN LABORATORY
SCALE 1:20



TYPICAL ELECTRICAL RISER
SCALE 1:10



DETAIL 'A'
SCALE 1:5

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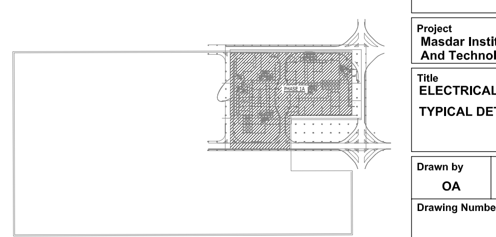

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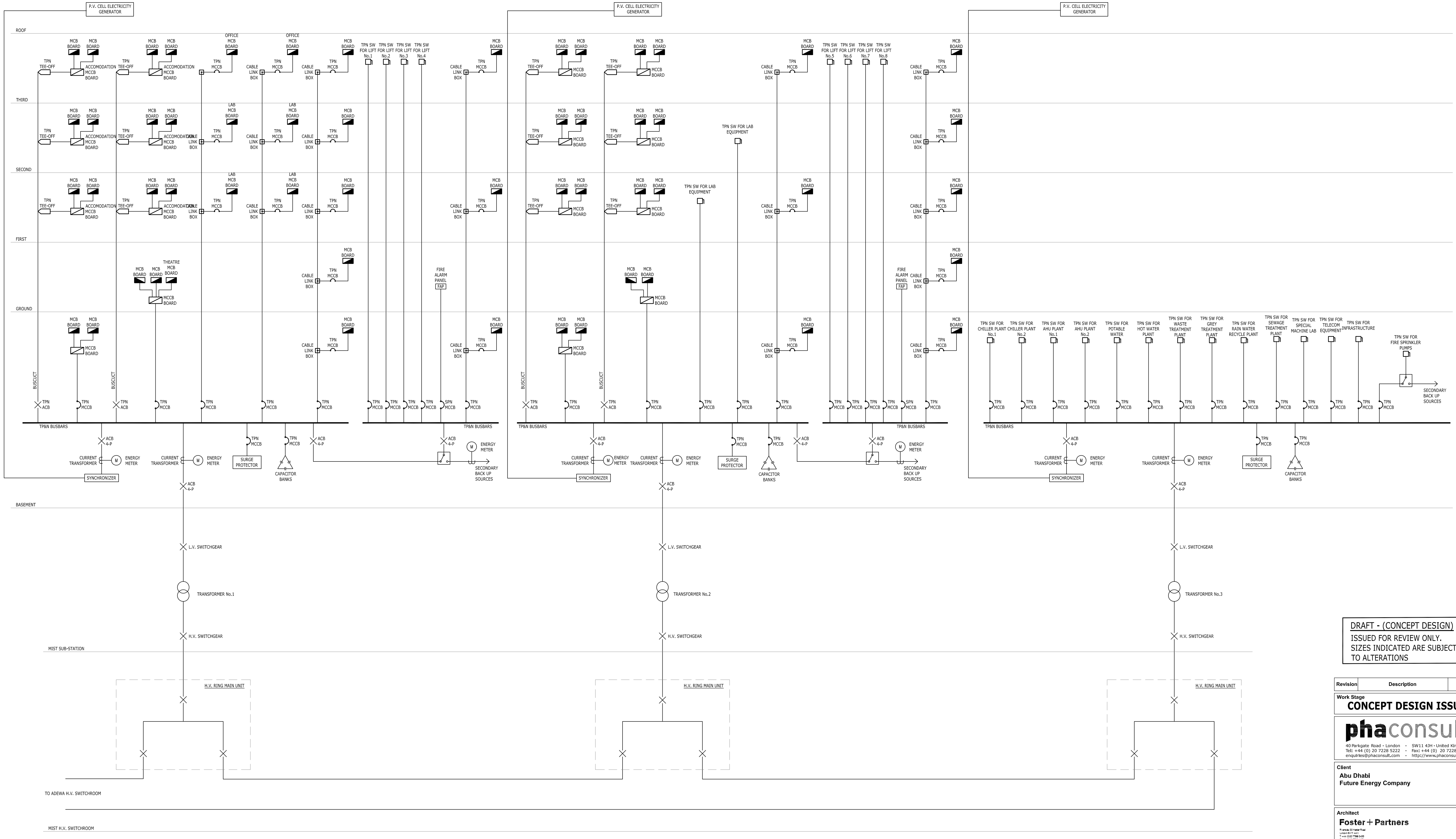
Title
ELECTRICAL SERVICES
TYPICAL DETAILS

Drawn by	Checked by	File Name
OA	JL	1076-SK-E400

Drawing Number	Revision	Scale
SK-E-400		NTS @ A0
		Date: FEB 08



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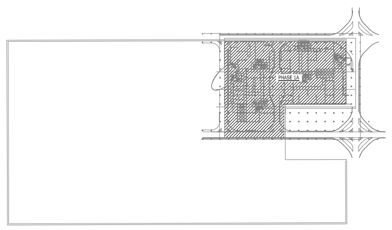
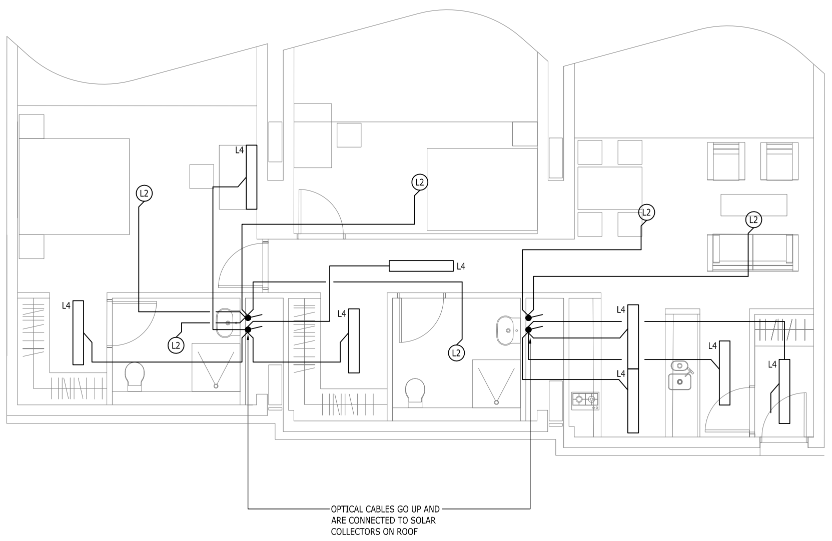
Title
ELECTRICAL SERVICES
ELECTRICAL SCHEMATIC

Drawn by	Checked by	File Name
OA	-	1076-SK-E500

Drawing Number	Revision	Scale / Date
SK-E-500		Scale: NTS @ A0
		Date: FEB 08

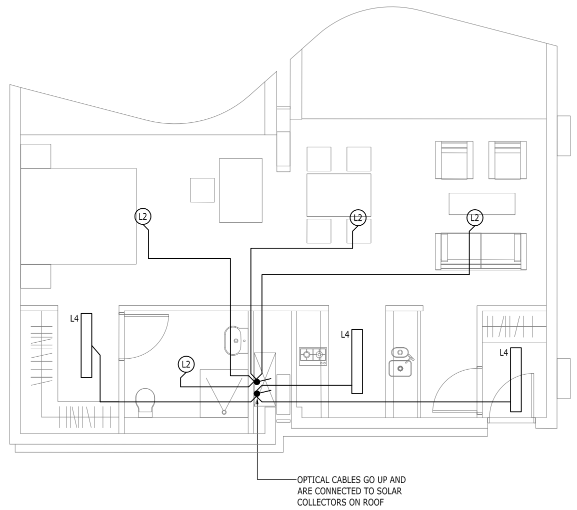


KEY PLAN



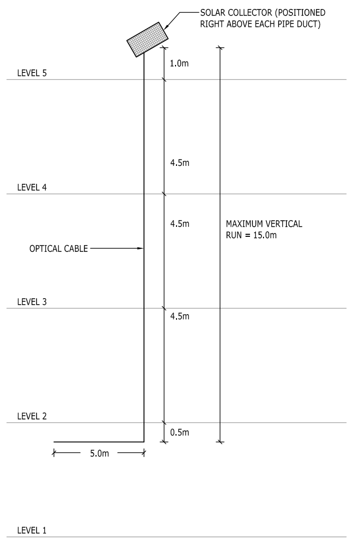
TYPICAL LIGHT LAYOUT FOR LARGE UNIT ON LEVEL 1

SCALE - 1:50

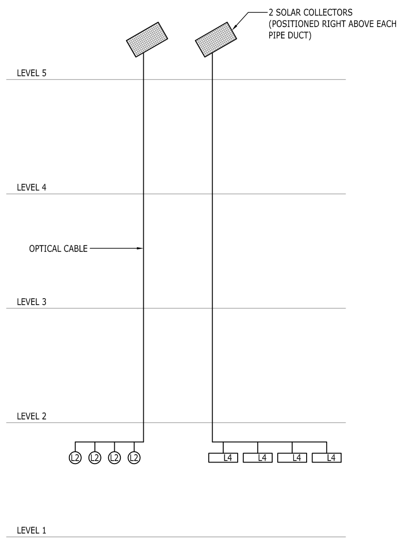


TYPICAL LIGHT LAYOUT FOR SMALL UNIT ON LEVEL 1

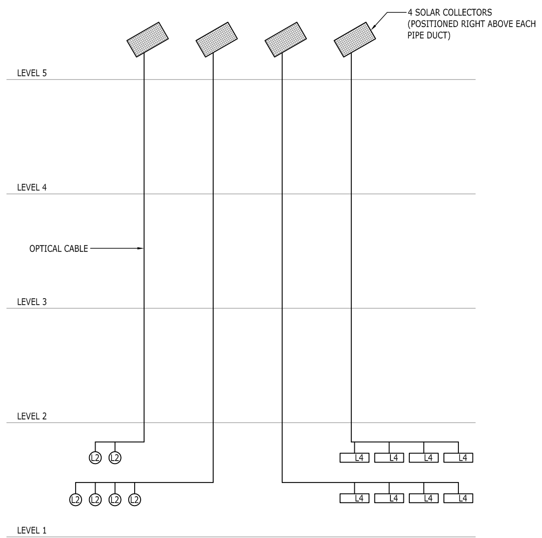
SCALE - 1:50



OPTICAL CABLING STRUCTURE ON LEVEL 1



OPTICAL ILLUMINATION SCHEMATIC
FOR SMALL UNIT

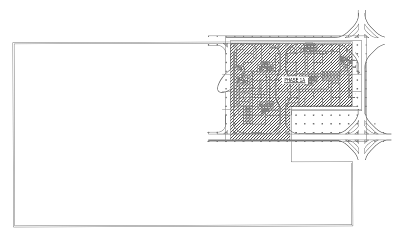


OPTICAL ILLUMINATION SCHEMATIC
FOR LARGE UNIT

LEVEL	SMALL UNIT	No. OF L2	TOTAL OF L2 USED	No. OF L4	TOTAL OF L4 USED	SOLAR PANEL	TOTAL SOLAR PANEL USED	CABLE RUN (m)	TOTAL CABLE RUN LENGTH(m)
L4	-	-	-	-	-	-	-	-	-
L3	29	4	116	4	116	2	58	11.0	638.0
L2	28	4	112	4	112	2	56	15.5	868.0
L1	29	4	116	4	116	2	56	20.0	1160.0
TOTAL	86		344		344		172		2666.0

LEVEL	LARGE UNIT	No. OF L2	TOTAL OF L2 USED	No. OF L4	TOTAL OF L4 USED	SOLAR PANEL	TOTAL SOLAR PANEL USED	CABLE RUN (m)	TOTAL CABLE RUN LENGTH(m)
L4	-	-	-	-	-	-	-	-	-
L3	2	6	12	8	16	4	8	11.0	88.0
L2	2	6	12	8	16	4	8	15.5	124.0
L1	0	6	0	8	0	4	0	20.0	0.0
TOTAL	4		24		32		16		212.0

LIGHTING AND SOLAR PANEL SCHEDULES



KEY PLAN

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Masdar Institute Of Science
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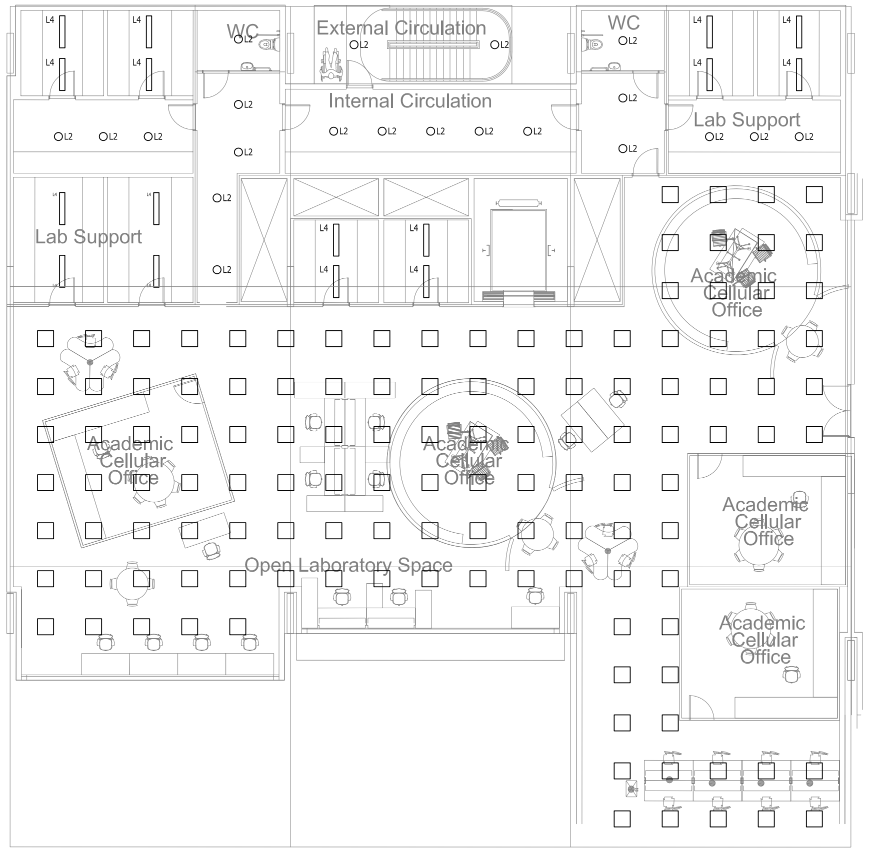
Title
ELECTRICAL SERVICES
OPTICAL LIGHTING SCHEMATICS AND
PART PLANS FOR ACCOMMODATIONS

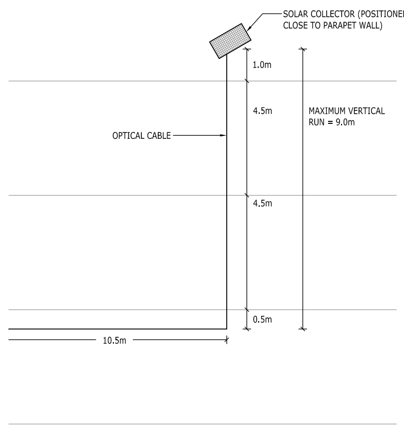
Drawn by	Checked by	File Name
OA	-	1076-SK-E501

Drawing Number	Revision	Scale	Date
SK-E-501		NTS @ A0	FEB 08

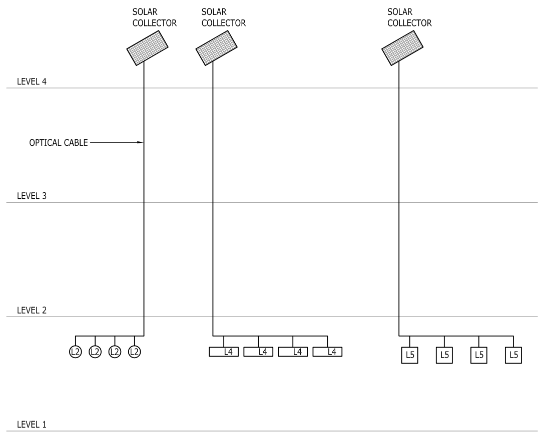


PROPOSED SOLAR LIGHTING LAYOUT FOR LABORATORY

SCALE = 1:100

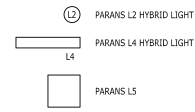


OPTICAL CABLING STRUCTURE FOR LABORATORY



OPTICAL ILLUMINATION SCHEMATIC FOR LABORATORY

LEGEND:



PHOTO

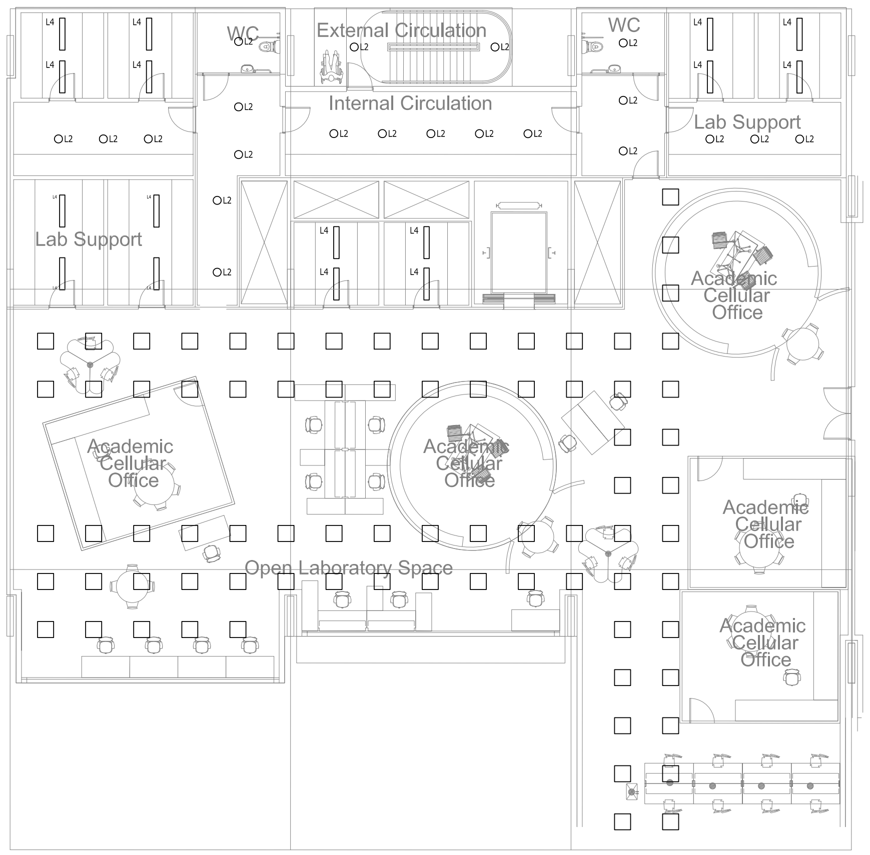
Solar collector

Parans L2 Hybrid Light

Parans L4 Hybrid Light

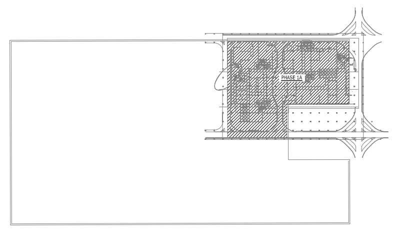
Optical cable

Parans L5



PROPOSED SOLAR LIGHTING LAYOUT FOR LABORATORY CORRIDOR'S SPACE

SCALE = 1:100



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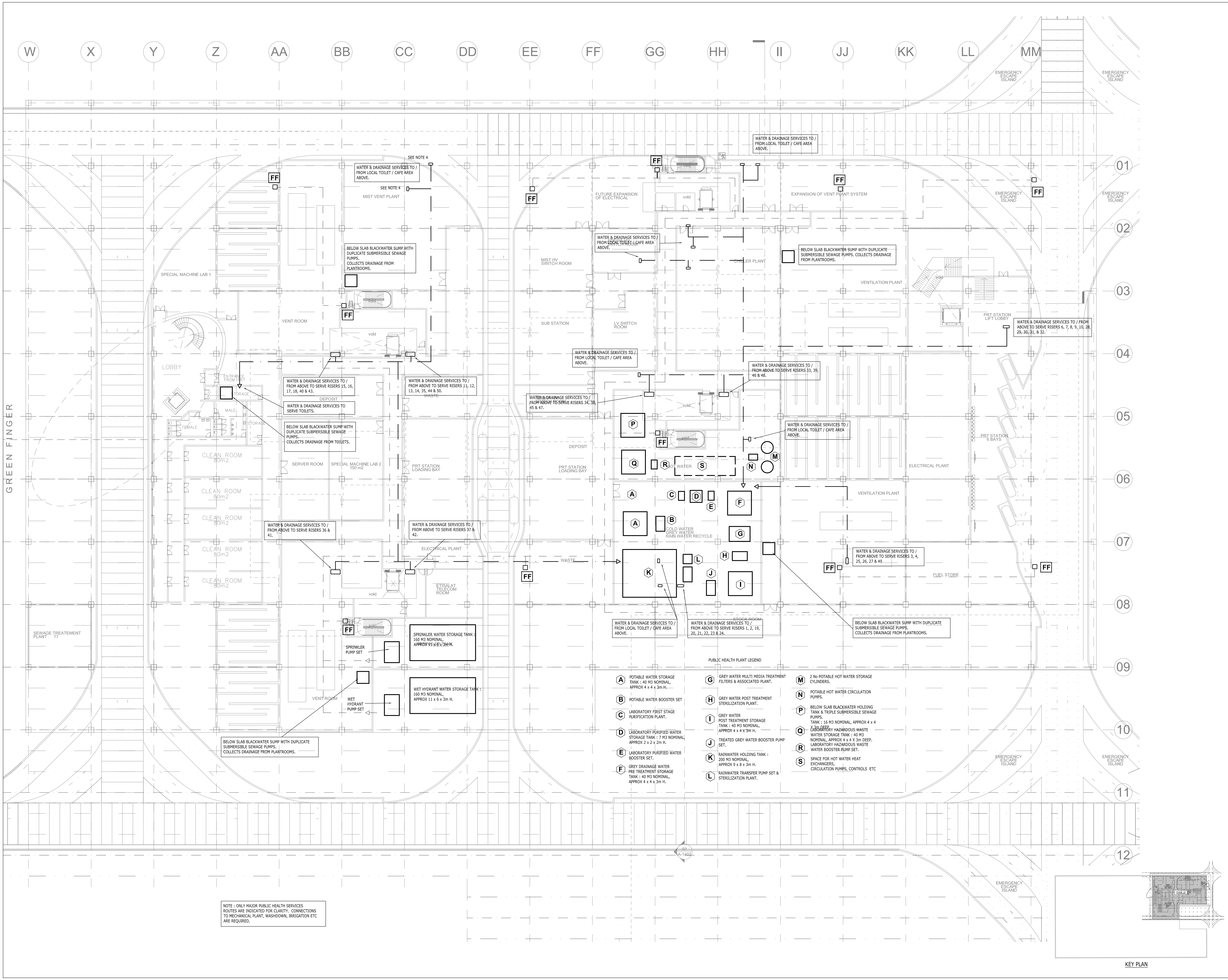
Project
Masdar Institute Of Science And Technology - Phase 1A

Title
ELECTRICAL SERVICES
OPTICAL LIGHTING SCHEMATIC AND PART PLAN FOR LABORATORY

Drawn by	Checked by	File Name
OA	-	1076-SK-E502

Drawing Number	Revision	Scale
SK-E-502		NTS @ A0
		Date: FEB 08



LEGEND

PUBLIC HEALTH RISER PIPEWORK

25 PUBLIC HEALTH RISER NUMBER

FF FIRE FIGHTING RISER COMPRISING SPRINKLER & WET OR DRY RISING MAINS WITH LANDING VALVES

RISER No.	RISER TYPE	RISER No.	RISER TYPE
1	A	26	A
2	A	27	A
3	A	28	A
4	A	29	A
5	A	30	A
6	A	31	A
7	A	32	A
8	A	33	A
9	A	34	A
10	A	35	A
11	A	36	A
12	A	37	A
13	A	38	A
14	A	39	A
15	A	40	B
16	A	41	B
17	A	42	B
18	A	43	B
19	A	44	B
20	A	45	B
21	A	46	B
22	A	47	B
23	A	48	B
24	A	49	A
25	A	50	A

MAIN PH RISER TYPES :

A : BLACK WATER DRAIN
GREY WATER DRAIN
ANTISYPHON VENT
POTABLE WATER COLD MAIN
POTABLE HOT WATER FLOW
POTABLE HOT WATER RETURN
GREY WATER COLD MAIN
RAINWATER DRAIN (TYPICAL)

B : LABORATORY HAZARD DRAIN
ANTISYPHON VENT
POTABLE WATER COLD MAIN
POTABLE HOT WATER FLOW
POTABLE HOT WATER RETURN
GREY WATER COLD MAIN
PURIFIED POTABLE LAB MAIN

NOTE 1 : RISERS FROM HIGH LEVEL TO ABOVE.

NOTE 2 : RISERS FROM ABOVE TO HIGH LEVEL.

NOTE 3 : VENT PIPE FROM HIGH LEVEL RISE T0 ATMOSPHERE.

NOTE 4 : DRAINAGE & WATER SERVICES TO SERVE LOCAL TOILETS / CAFES.

MAJOR WATER & DRAINAGE DISTRIBUTION ROUTES AT HIGH LEVEL.

MAJOR FIRE MAIN DISTRIBUTION ROUTES AT HIGH LEVEL.

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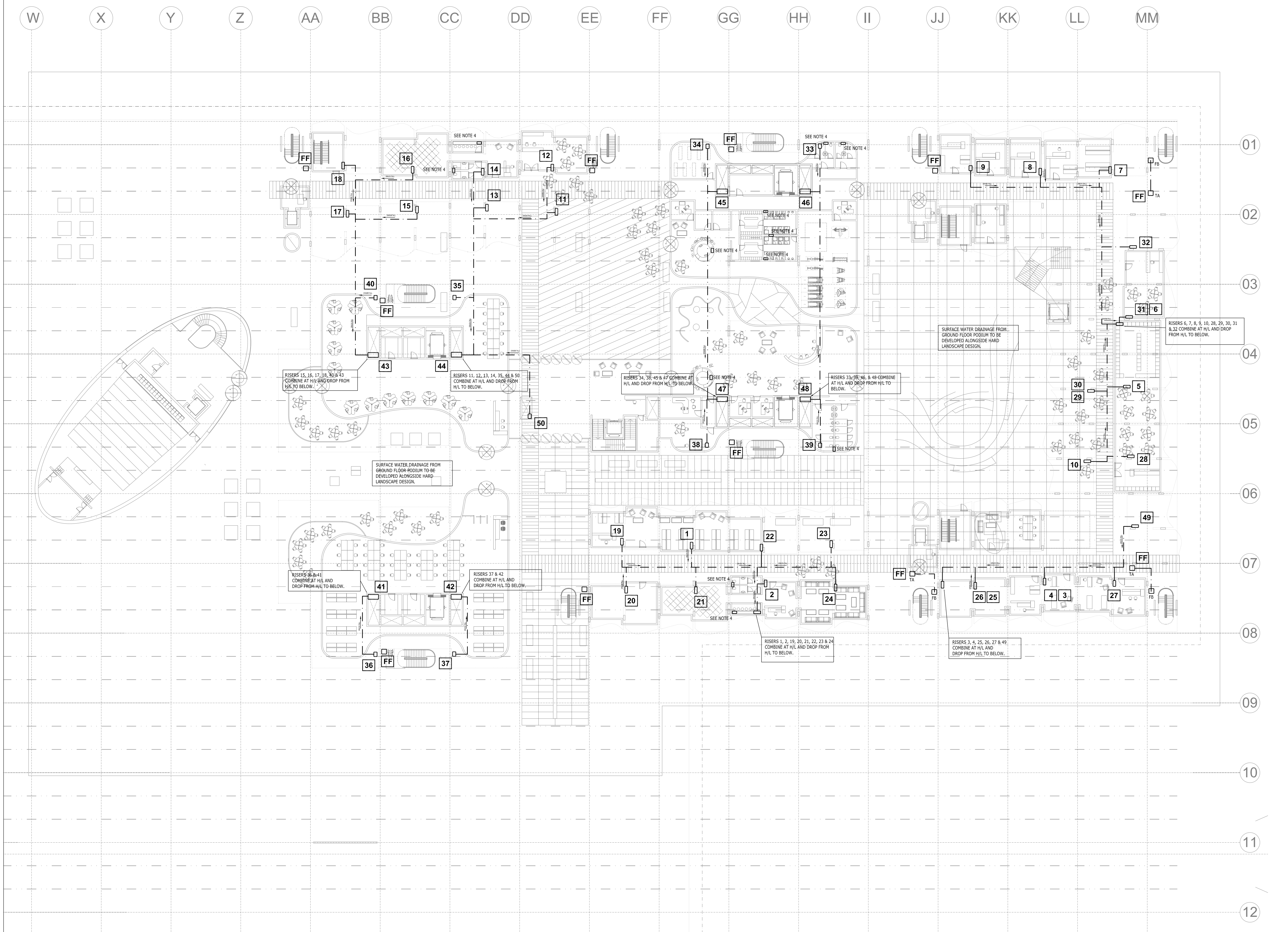
Title
PUBLIC HEALTH SERVICES
BASEMENT LEVEL

Drawn by	Checked by	File Name	
AS	FD	1076-SK-P100	
Drawing Number		Revision	Scale
SK-P-100			1:200 @ A0
			Date: FEB 08



LEGEND

PUBLIC HEALTH RISER PIPEWORK

25 PUBLIC HEALTH RISER NUMBER

FF FIRE FIGHTING RISER COMPRISING SPRINKLER & WET OR DRY RISING MAINS WITH LANDING VALVES

RISER No.	RISER TYPE	RISER No.	RISER TYPE
1	A	26	A
2	A	27	A
3	A	28	A
4	A	29	A
5	A	30	A
6	A	31	A
7	A	32	A
8	A	33	A
9	A	34	A
10	A	35	A
11	A	36	A
12	A	37	A
13	A	38	A
14	A	39	A
15	A	40	B
16	A	41	B
17	A	42	B
18	A	43	B
19	A	44	B
20	A	45	B
21	A	46	B
22	A	47	B
23	A	48	B
24	A	49	A
25	A	50	A

MAIN PH RISER TYPES :

A : BLACK WATER DRAIN
GREY WATER DRAIN
ANTISYPHON VENT
POTABLE WATER COLD MAIN
POTABLE HOT WATER FLOW
POTABLE HOT WATER RETURN
GREY WATER COLD MAIN
RAINWATER DRAIN (TYPICAL)

B : LABORATORY HAZARD DRAIN
ANTISYPHON VENT
POTABLE WATER COLD MAIN
POTABLE HOT WATER FLOW
POTABLE HOT WATER RETURN
GREY WATER COLD MAIN
PURIFIED POTABLE LAB MAIN

NOTE 1 : RISERS FROM HIGH LEVEL TO ABOVE.

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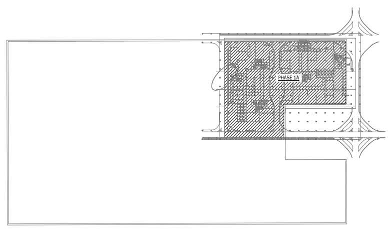

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Project
Masdar Institute Of Science And Technology - Phase 1A

Title
PUBLIC HEALTH SERVICES
GROUND FLOOR

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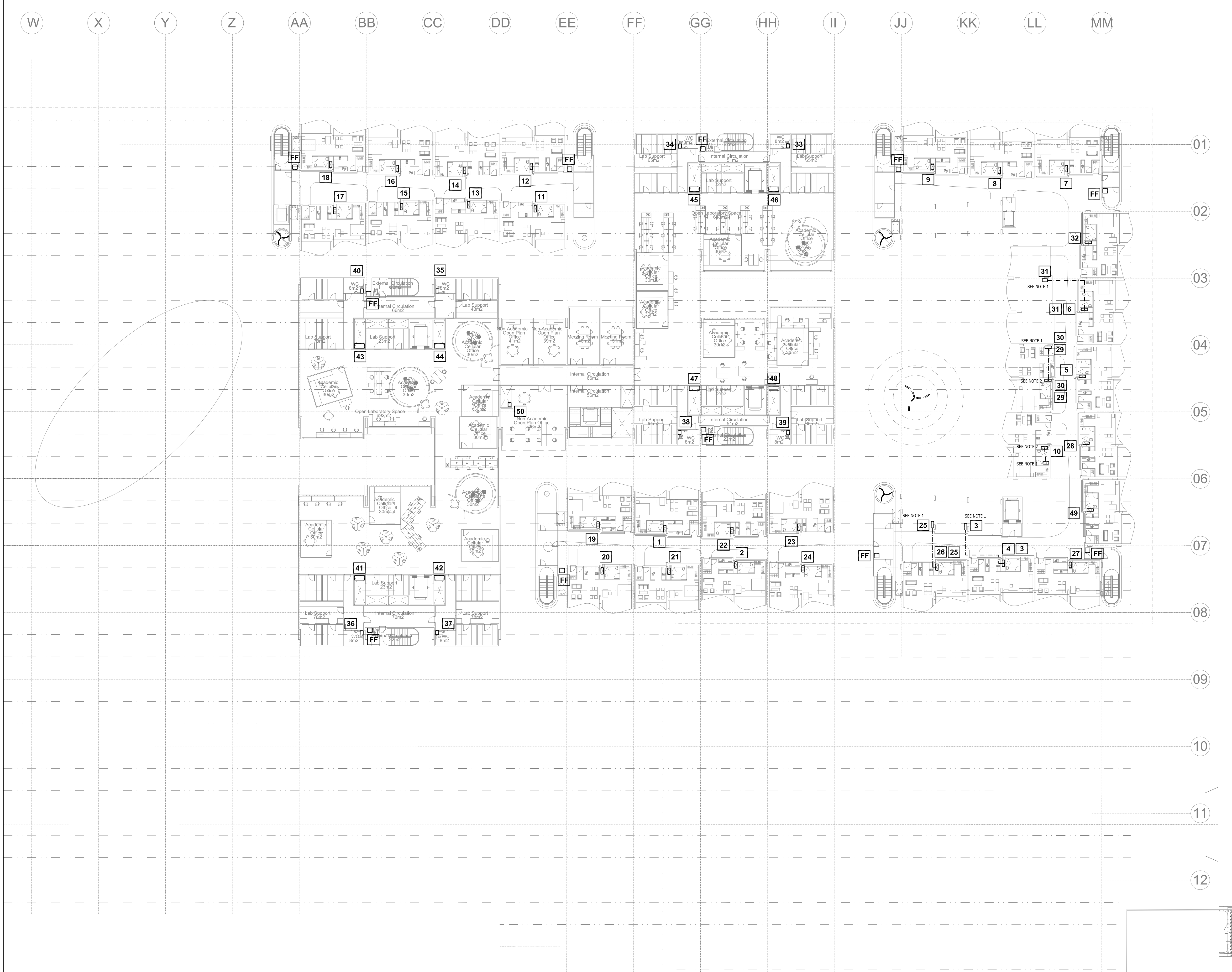
AS	FD	1076-SK-P101	
Drawing Number		Revision	Scale
SK-P-101			1:200 @ A0
			Date
			FEB 08



LEGEND

PUBLIC HEALTH RISER PIPEWORK

25 — PUBLIC HEALTH RISER NUMBER

FF — FIRE FIGHTING RISER COMPRISING SPRINKLER & WET OR DRY RISING MAINS WITH LANDING VALVES

RISER No.	RISER TYPE	RISER No.	RISER TYPE
1	A	26	A
2	A	27	A
3	A	28	A
4	A	29	A
5	A	30	A
6	A	31	A
7	A	32	A
8	A	33	A
9	A	34	A
10	A	35	A
11	A	36	A
12	A	37	A
13	A	38	A
14	A	39	A
15	A	40	B
16	A	41	B
17	A	42	B
18	A	43	B
19	A	44	B
20	A	45	B
21	A	46	B
22	A	47	B
23	A	48	B
24	A	49	A
25	A	50	A

MAIN PH RISER TYPES :

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GREY WATER DRAIN
ANTISYPHON VENT
POTABLE WATER COLD MAIN
POTABLE HOT WATER FLOW
POTABLE HOT WATER RETURN
GREY WATER COLD MAIN
RAINWATER DRAIN (TYPICAL)

B : LABORATORY HAZARD DRAIN
ANTISYPHON VENT
POTABLE WATER COLD MAIN
POTABLE HOT WATER FLOW
POTABLE HOT WATER RETURN
GREY WATER COLD MAIN
PURIFIED POTABLE LAB MAIN

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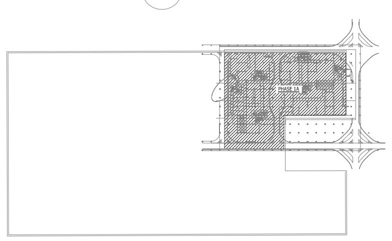

KEY PLAN

Revision	Description	Date

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CONCEPT DESIGN ISSUE

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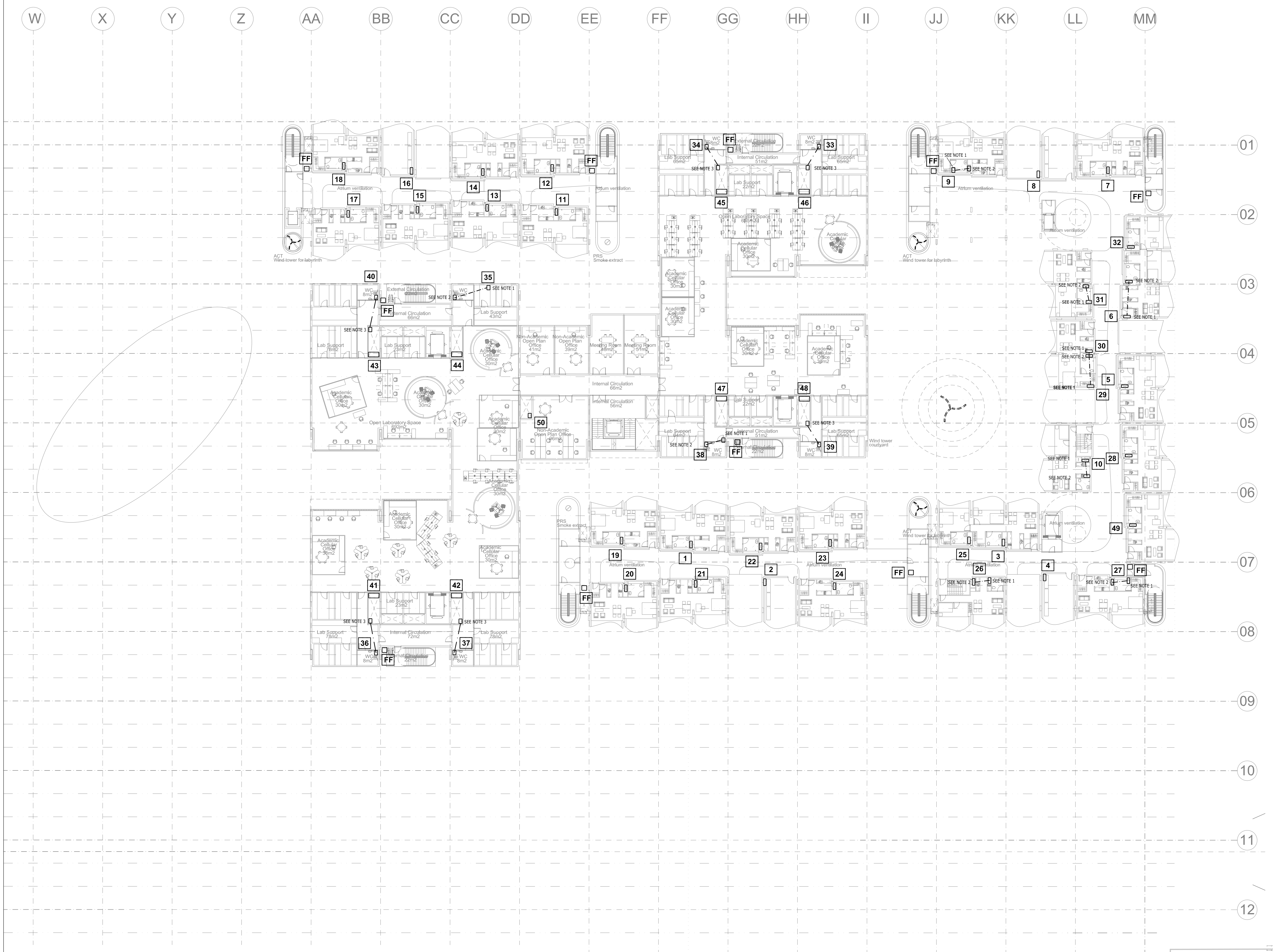
Title
PUBLIC HEALTH SERVICES FIRST FLOOR

Drawn by	Checked by	File Name
AS	FD	1076-SK-P102

Drawing Number	Revision	Scale	Date
SK-P-102		1:200 @ A0	FEB 08



LEGEND

PUBLIC HEALTH RISER PIPEWORK

25 PUBLIC HEALTH RISER NUMBER

FF FIRE FIGHTING RISER COMPRISING SPRINKLER & WET OR DRY RISING MAINS WITH LANDING VALVES

RISER No.	RISER TYPE	RISER No.	RISER TYPE
1	A	26	A
2	A	27	A
3	A	28	A
4	A	29	A
5	A	30	A
6	A	31	A
7	A	32	A
8	A	33	A
9	A	34	A
10	A	35	A
11	A	36	A
12	A	37	A
13	A	38	A
14	A	39	A
15	A	40	B
16	A	41	B
17	A	42	B
18	A	43	B
19	A	44	B
20	A	45	B
21	A	46	B
22	A	47	B
23	A	48	B
24	A	49	A
25	A	50	A

MAIN PH RISER TYPES :

A : BLACK WATER DRAIN
GREY WATER DRAIN
ANTISYPHON VENT
POTABLE WATER COLD MAIN
POTABLE HOT WATER FLOW
POTABLE HOT WATER RETURN
GREY WATER COLD MAIN
RAINWATER DRAIN (TYPICAL)

B : LABORATORY HAZARD DRAIN
ANTISYPHON VENT
POTABLE WATER COLD MAIN
POTABLE HOT WATER FLOW
POTABLE HOT WATER RETURN
GREY WATER COLD MAIN
PURIFIED POTABLE LAB MAIN

NOTE 1 : RISERS FROM HIGH LEVEL TO ABOVE.

NOTE 2 : RISERS FROM ABOVE TO HIGH LEVEL.

NOTE 3 : VENT PIPE FROM HIGH LEVEL RISE T0 ATMOSPHERE.

NOTE 4 : DRAINAGE & WATER SERVICES TO SERVE LOCAL TOILETS / CAFES.

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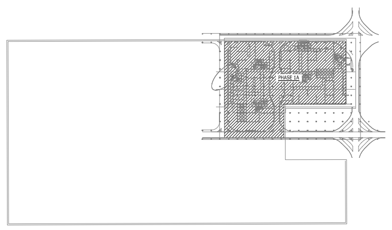
KEY PLAN

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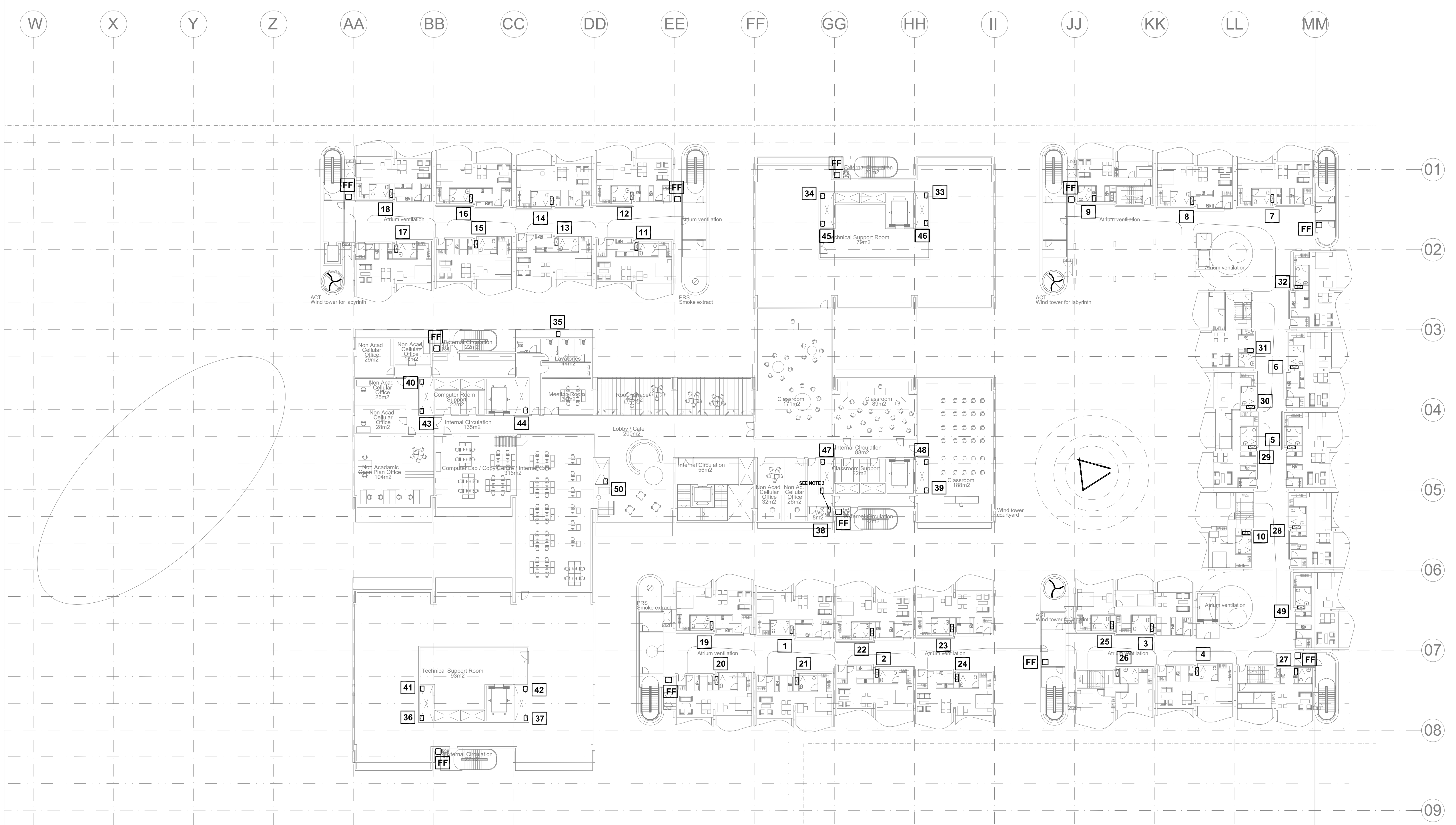
Project
Masdar Institute Of Science And Technology - Phase 1A

Title
PUBLIC HEALTH SERVICES
SECOND FLOOR

Drawn by	Checked by	File Name
AS	FD	1076-SK-P103

Drawing Number	Revision	Scale / Date
SK-P-103		Scale: 1:200 @ A0; Date: FEB 08



LEGEND

- PUBLIC HEALTH RISER PIPEWORK
- 25 — PUBLIC HEALTH RISER NUMBER
- FF — FIRE FIGHTING RISER COMPRISING SPRINKLER & WET OR DRY RISING MAINS WITH LANDING VALVES

RISER No.	RISER TYPE	RISER No.	RISER TYPE
1	A	26	A
2	A	27	A
3	A	28	A
4	A	29	A
5	A	30	A
6	A	31	A
7	A	32	A
8	A	33	A
9	A	34	A
10	A	35	A
11	A	36	A
12	A	37	A
13	A	38	A
14	A	39	A
15	A	40	B
16	A	41	B
17	A	42	B
18	A	43	B
19	A	44	B
20	A	45	B
21	A	46	B
22	A	47	B
23	A	48	B
24	A	49	A
25	A	50	A

MAIN PH RISER TYPES :

A : BLACK WATER DRAIN
GREY WATER DRAIN
ANTISYPHON VENT
POTABLE WATER COLD MAIN
POTABLE HOT WATER FLOW
POTABLE HOT WATER RETURN
GREY WATER COLD MAIN
RAINWATER DRAIN (TYPICAL)

B : LABORATORY HAZARD DRAIN
ANTISYPHON VENT
POTABLE WATER COLD MAIN
POTABLE HOT WATER FLOW
POTABLE HOT WATER RETURN
GREY WATER COLD MAIN
PURIFIED POTABLE LAB MAIN

NOTE 1 : RISERS FROM HIGH LEVEL TO ABOVE.

NOTE 2 : RISERS FROM ABOVE TO HIGH LEVEL.

NOTE 3 : VENT PIPE FROM HIGH LEVEL RISE T0 ATMOSPHERE.

NOTE 4 : DRAINAGE & WATER SERVICES TO SERVE LOCAL TOILETS / CAFES.

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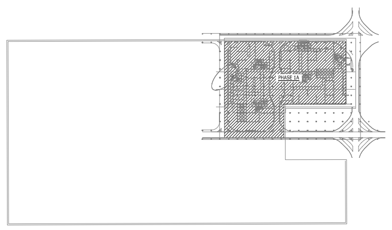
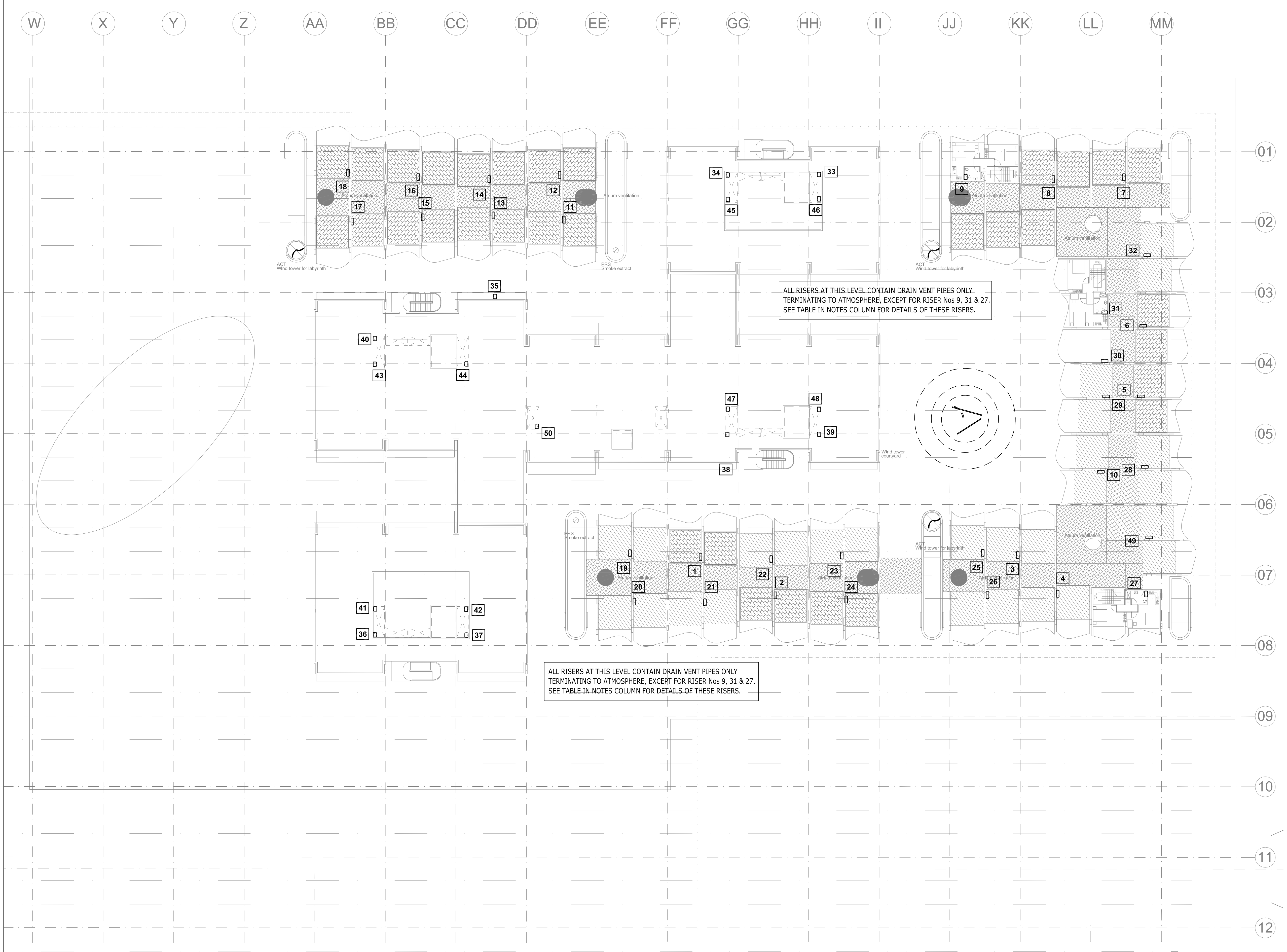
Title
PUBLIC HEALTH SERVICES
THIRD FLOOR



KEY PLAN

Drawn by	Checked by	File Name
AS	FD	1076-SK-P104

Drawing Number	Revision	Scale
SK-P-104		1:200 @ A0
		Date: FEB 08



LEGEND

PUBLIC HEALTH RISER PIPEWORK

25 — PUBLIC HEALTH RISER NUMBER

FF — FIRE FIGHTING RISER COMPRISING SPRINKLER & WET OR DRY RISING MAINS WITH LANDING VALVES

RISER No.	RISER TYPE	RISER No.	RISER TYPE
1	A	26	A
2	A	27	A
3	A	28	A
4	A	29	A
5	A	30	A
6	A	31	A
7	A	32	A
8	A	33	A
9	A	34	A
10	A	35	A
11	A	36	A
12	A	37	A
13	A	38	A
14	A	39	A
15	A	40	B
16	A	41	B
17	A	42	B
18	A	43	B
19	A	44	B
20	A	45	B
21	A	46	B
22	A	47	B
23	A	48	B
24	A	49	A
25	A	50	A

MAIN PH RISER TYPES :

A : BLACK WATER DRAIN
GREY WATER DRAIN
ANTISYPHON VENT
POTABLE WATER COLD MAIN
POTABLE HOT WATER FLOW
POTABLE HOT WATER RETURN
GREY WATER COLD MAIN
RAINWATER DRAIN (TYPICAL)

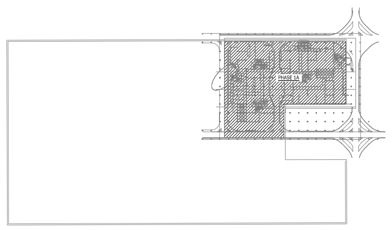
B : LABORATORY HAZARD DRAIN
ANTISYPHON VENT
POTABLE WATER COLD MAIN
POTABLE HOT WATER FLOW
POTABLE HOT WATER RETURN
GREY WATER COLD MAIN
PURIFIED POTABLE LAB MAIN

NOTE 1 : RISERS FROM HIGH LEVEL TO ABOVE.

NOTE 2 : RISERS FROM ABOVE TO HIGH LEVEL.

NOTE 3 : VENT PIPE FROM HIGH LEVEL RISE T0 ATMOSPHERE.

NOTE 4 : DRAINAGE & WATER SERVICES TO SERVE LOCAL TOILETS / CAFES.



KEY PLAN

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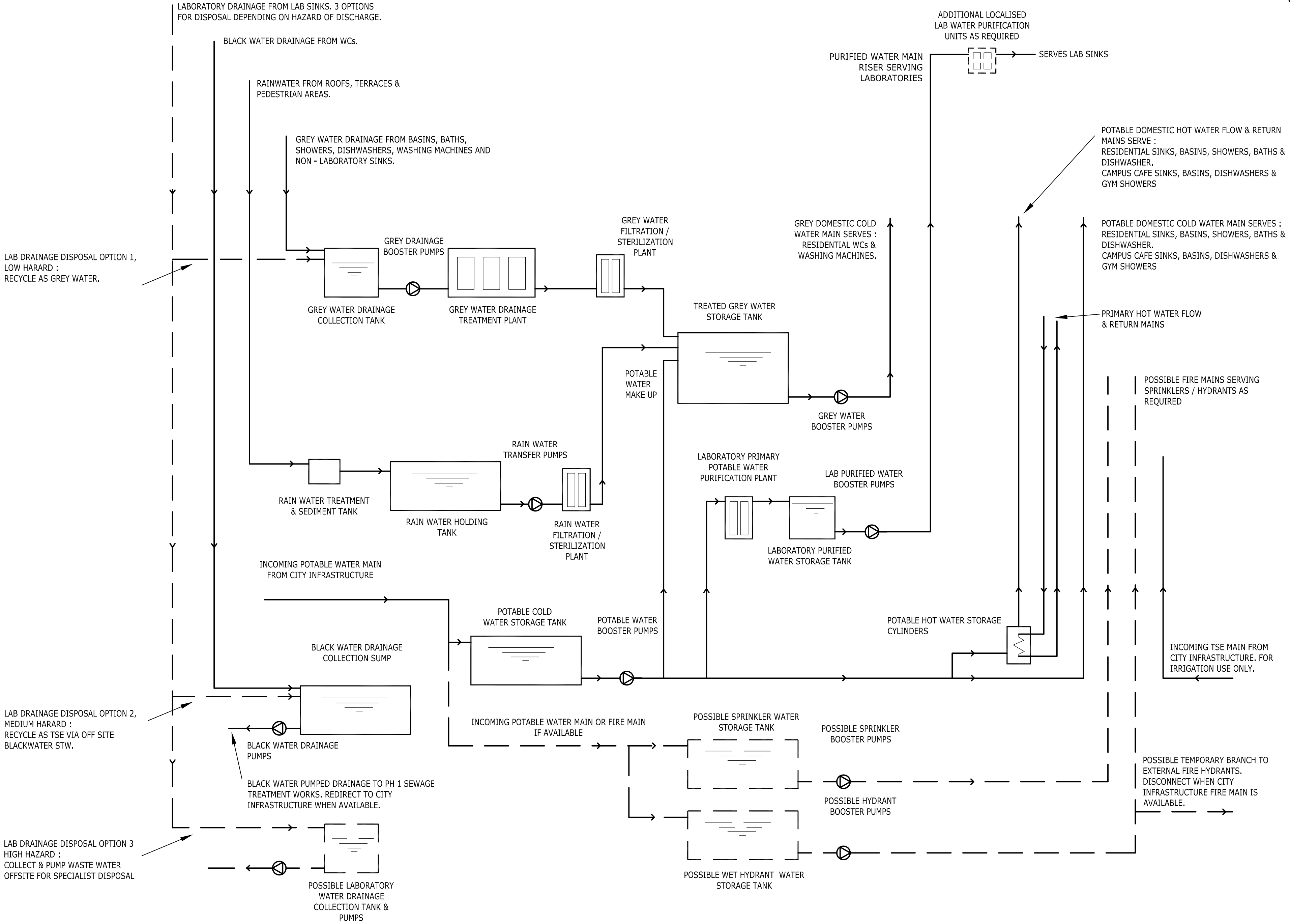
Title
PUBLIC HEALTH SERVICES
FOURTH FLOOR

Drawn by	Checked by	File Name
AS	FD	1076-SK-P105

Drawing Number	Revision	Scale
SK-P-105		1:200 @ A0

Date
FEB 08

NOTE :
THIS DRAWING INDICATES THE "BASE" SCHEME AT CONCEPT STAGE. FOR ALTERNATIVE SYSTEM ARRANGEMENTS REFER TO OPTIONS DESCRIBED WITHIN THE REPORT.



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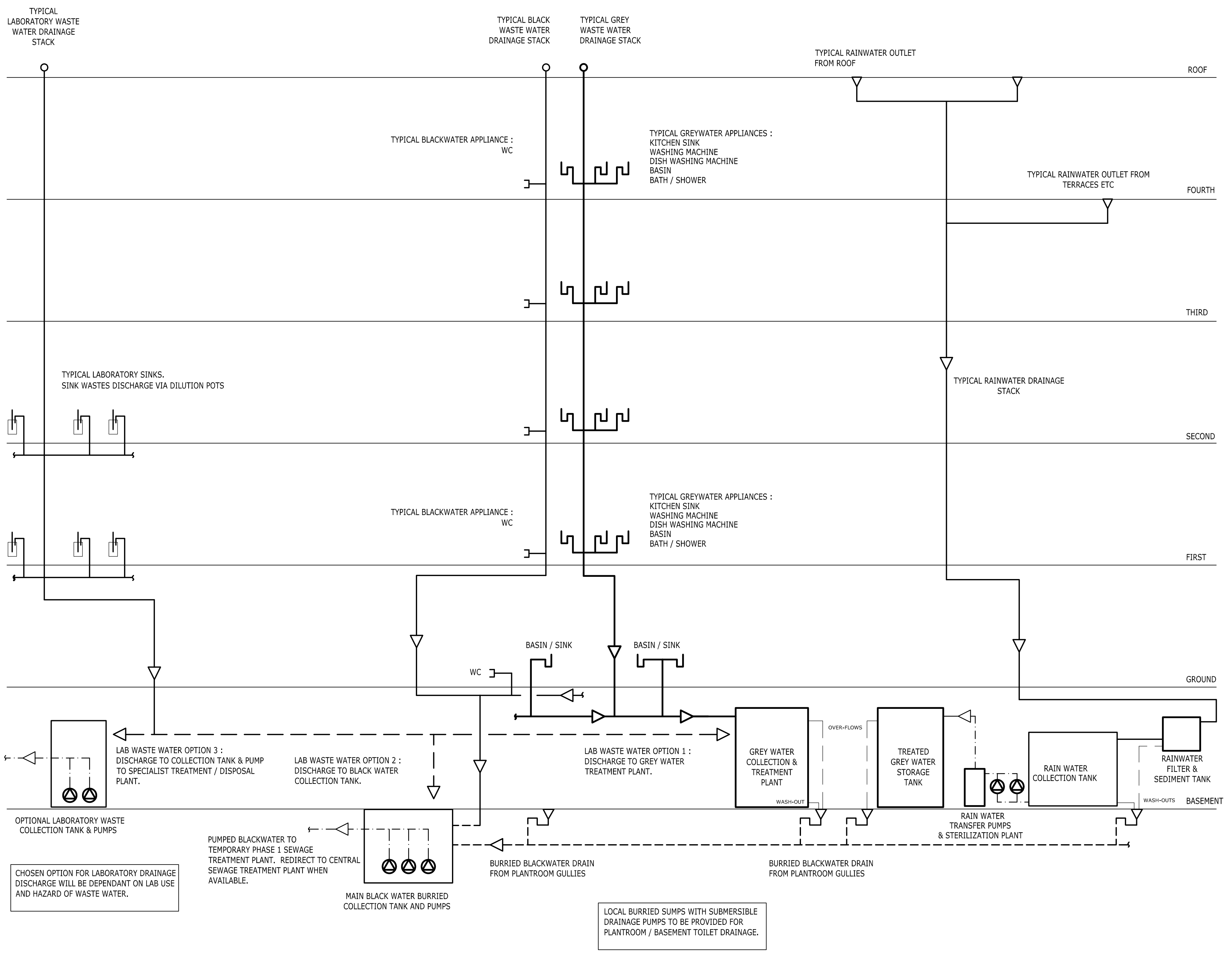
Title
PUBLIC HEALTH SERVICES
WATER DRAINAGE SCHEMATIC
PRINCIPLES OF SUPPLY, REUSE & DISPOSAL

Drawn by	Checked by	File Name
C.L.	FD	1076-SK-P500

Drawing Number	Revision	Scale / Date
SK-P-500	-	Scale: NTS @A1; Date: FEB 2008



NOTE :
THIS DRAWING INDICATES THE "BASE" SCHEME AT CONCEPT STAGE.
FOR ALTERNATIVE SYSTEM ARRANGEMENTS REFER TO OPTIONS DESCRIBED WITHIN THE REPORT.

VENT PIPES, ANTI SYPHON PIPES AND TANK / SUMP VENTS NOT SHOWN FOR CLARITY.

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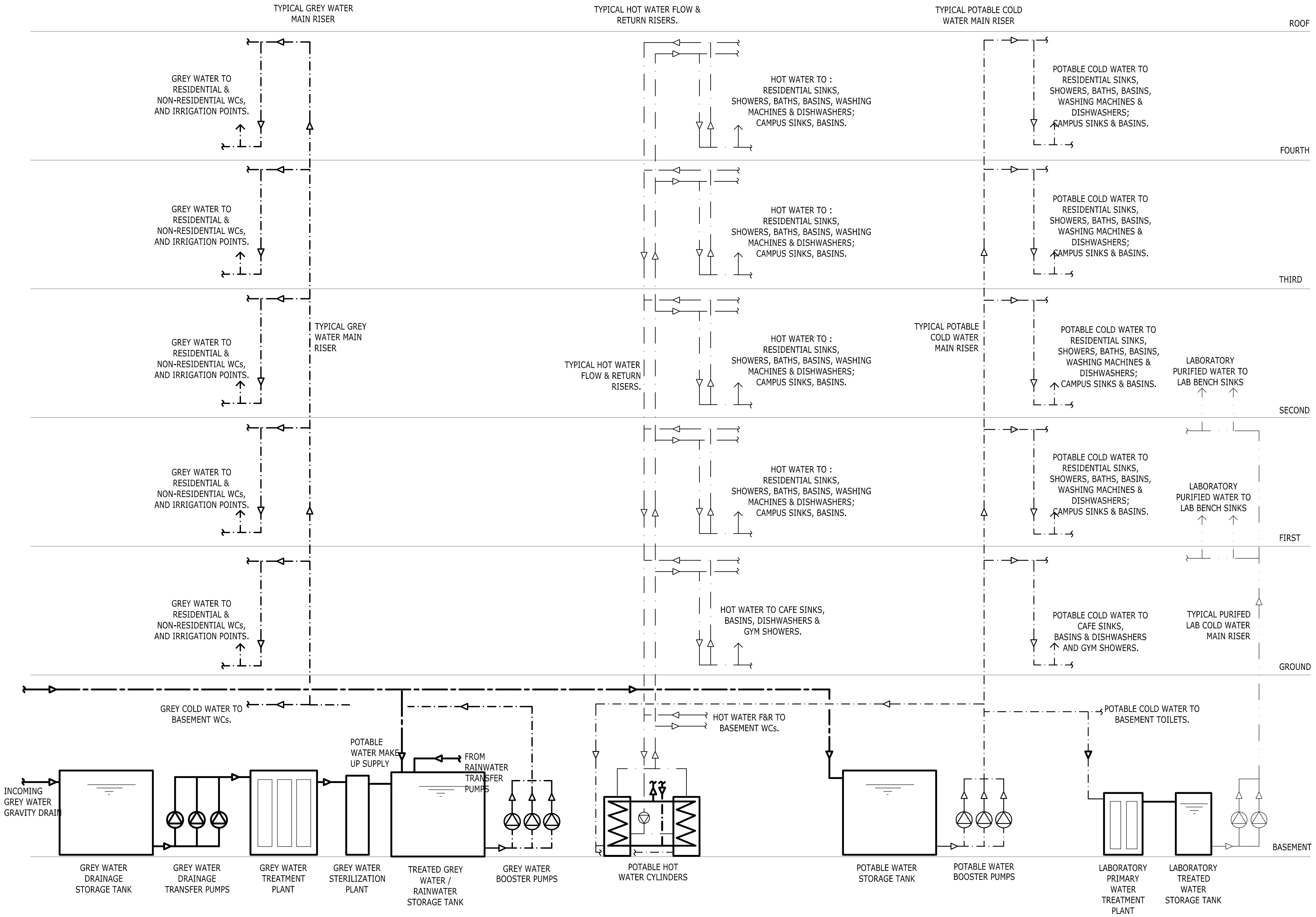
Title
PUBLIC HEALTH SERVICES
DRAINAGE SCHEMATIC

Drawn by	Checked by	File Name
C.L.	FD	1076-SK-P501

Drawing Number	Revision	Scale / Date
SK-P-501	-	Scale: NTS @A1; Date: FEB 2008



ONLY MAJOR WATER SERVICES DISTRIBUTION SHOWN FOR CLARITY. CONNECTIONS FOR MECHANICAL PLANT, WASHDOWN, IRRIGATION ETC ARE NOT INDICATED.

NOTE :
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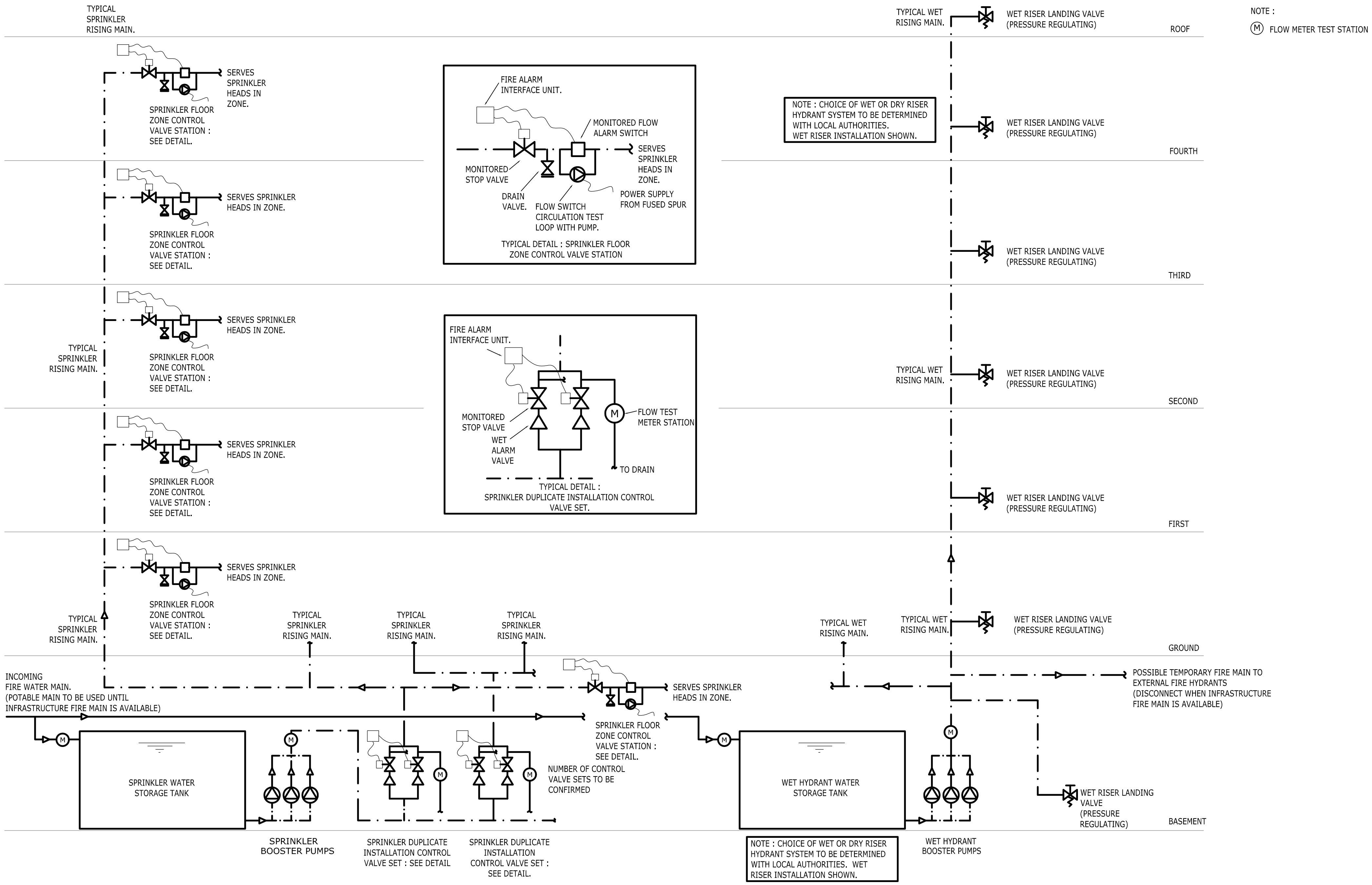
Title
PUBLIC HEALTH SERVICES
DOMESTIC WATER SERVICES SCHEMATIC

Drawn by	Checked by	File Name
C.L.	FD	1076-SK-P502

Drawing Number	Revision	Scale / Date
SK-P-502	-	NTS @A1 / FEB 2008



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Title
PUBLIC HEALTH SERVICES
FIRE FIGHTING SERVICES SCHEMATIC

Drawn by	Checked by	File Name	
C.L.	FD	1076-SK-P503	
Drawing Number		Revision	Scale: NTS @A1
SK-P-503		-	Date: FEB 2008