

Opportunities for Energy Efficiency in Buildings

Leon Glicksman

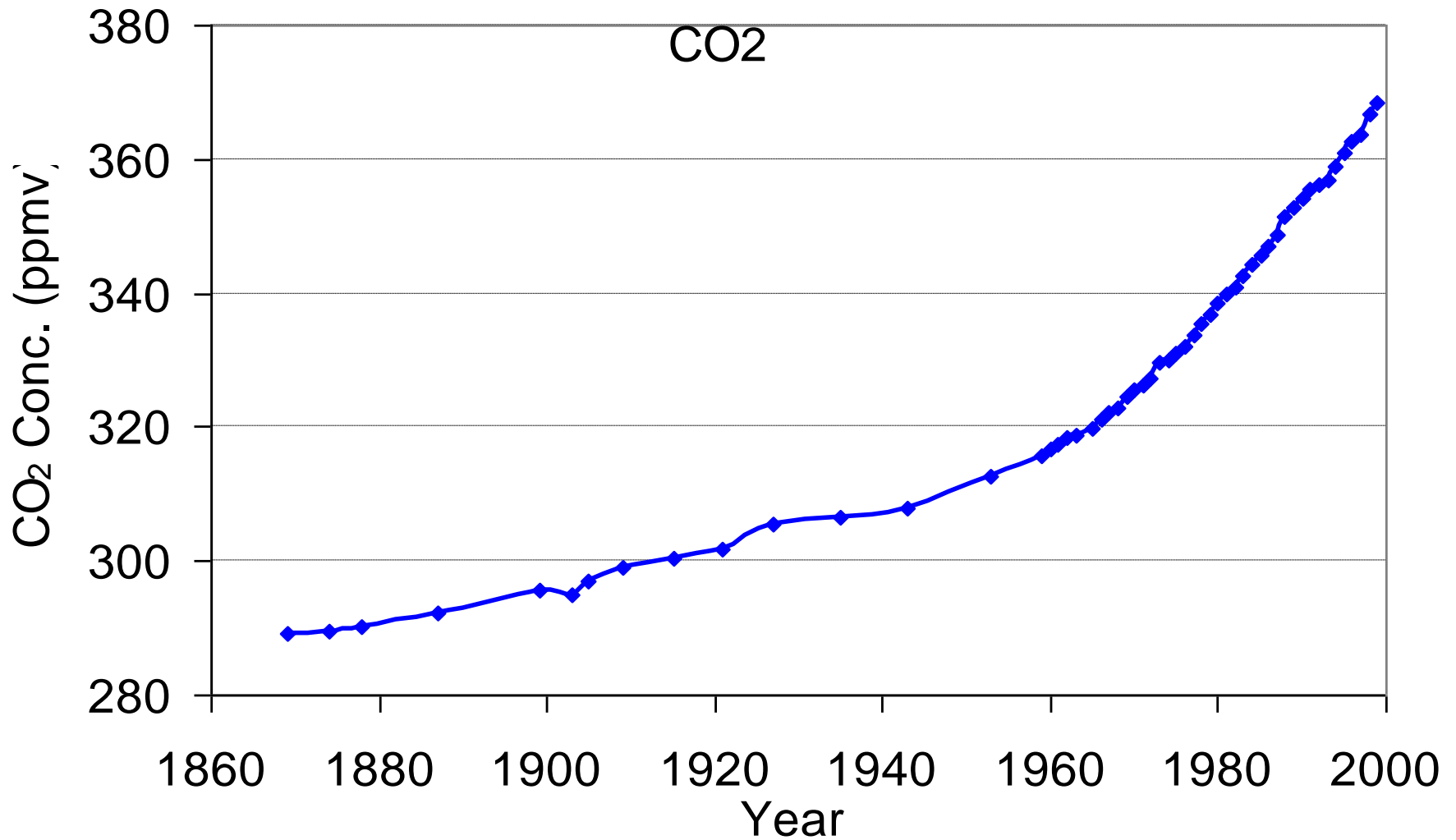
Building Technology Program

School of Architecture and Planning

School of Engineering

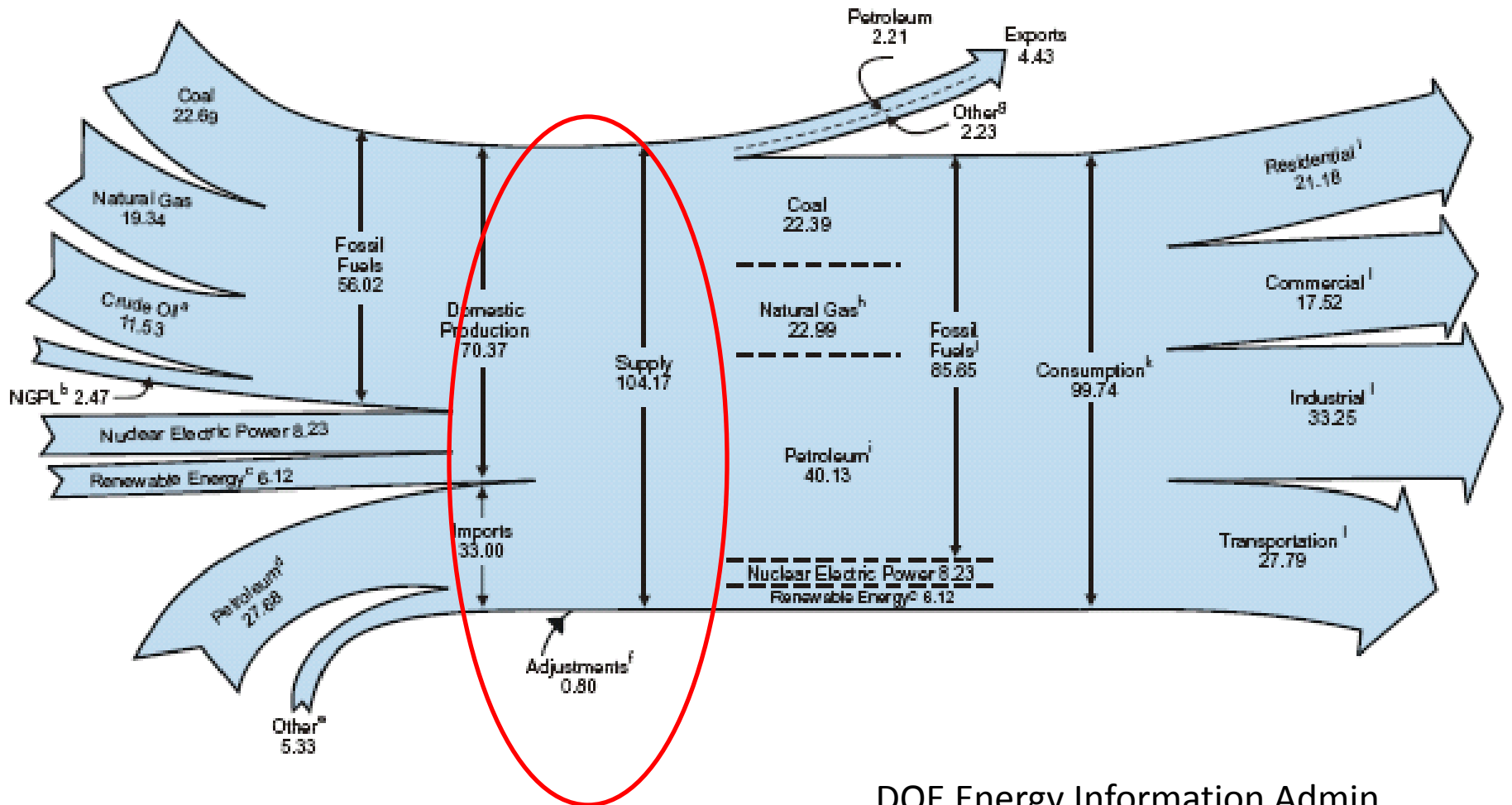
May 26, 2011

Atmospheric CO₂ Concentration



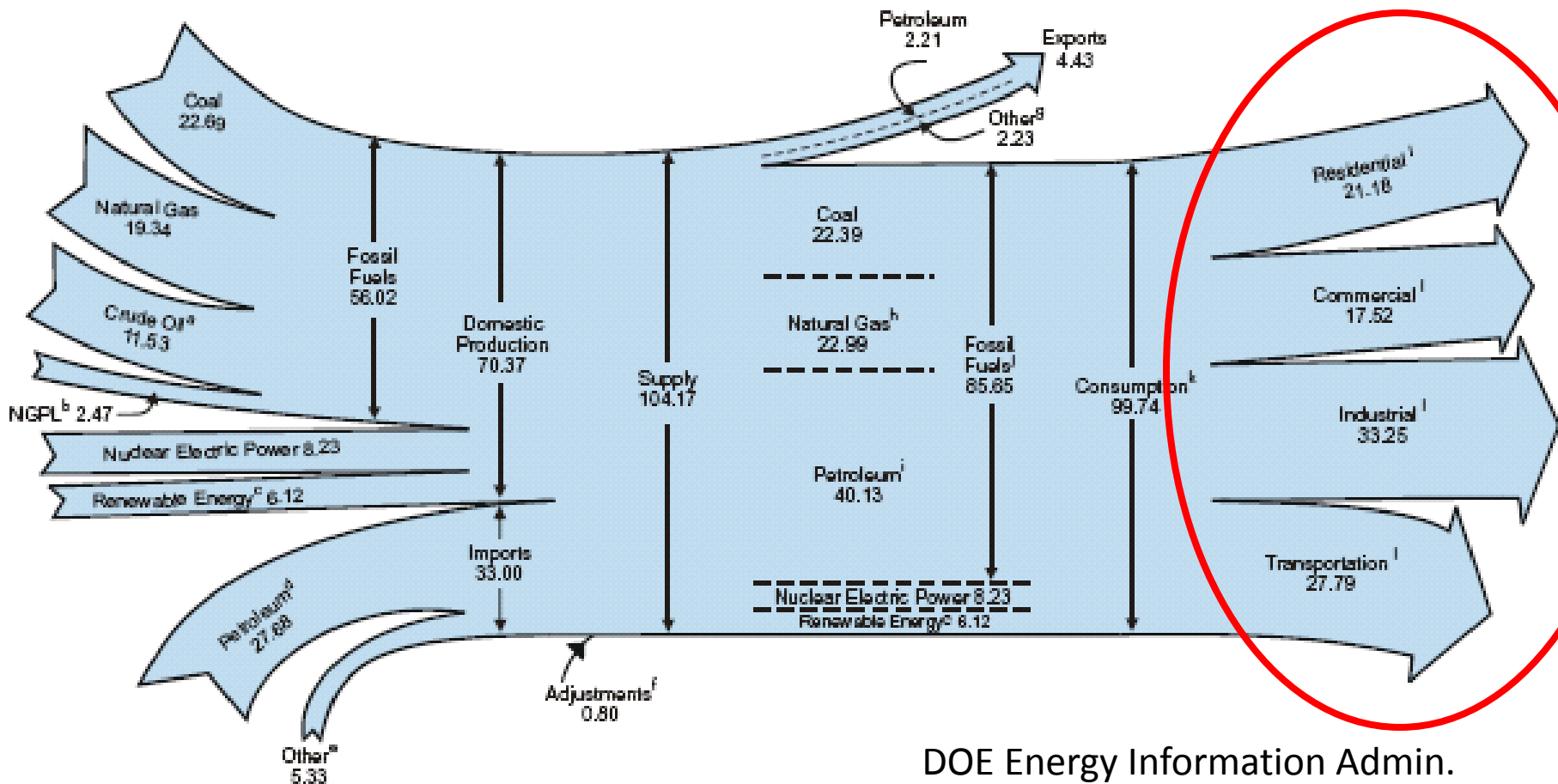
U.S. Energy Flow 2004

Traditional Solution Focus



U.S. Energy Flow 2004

Neglected Focus



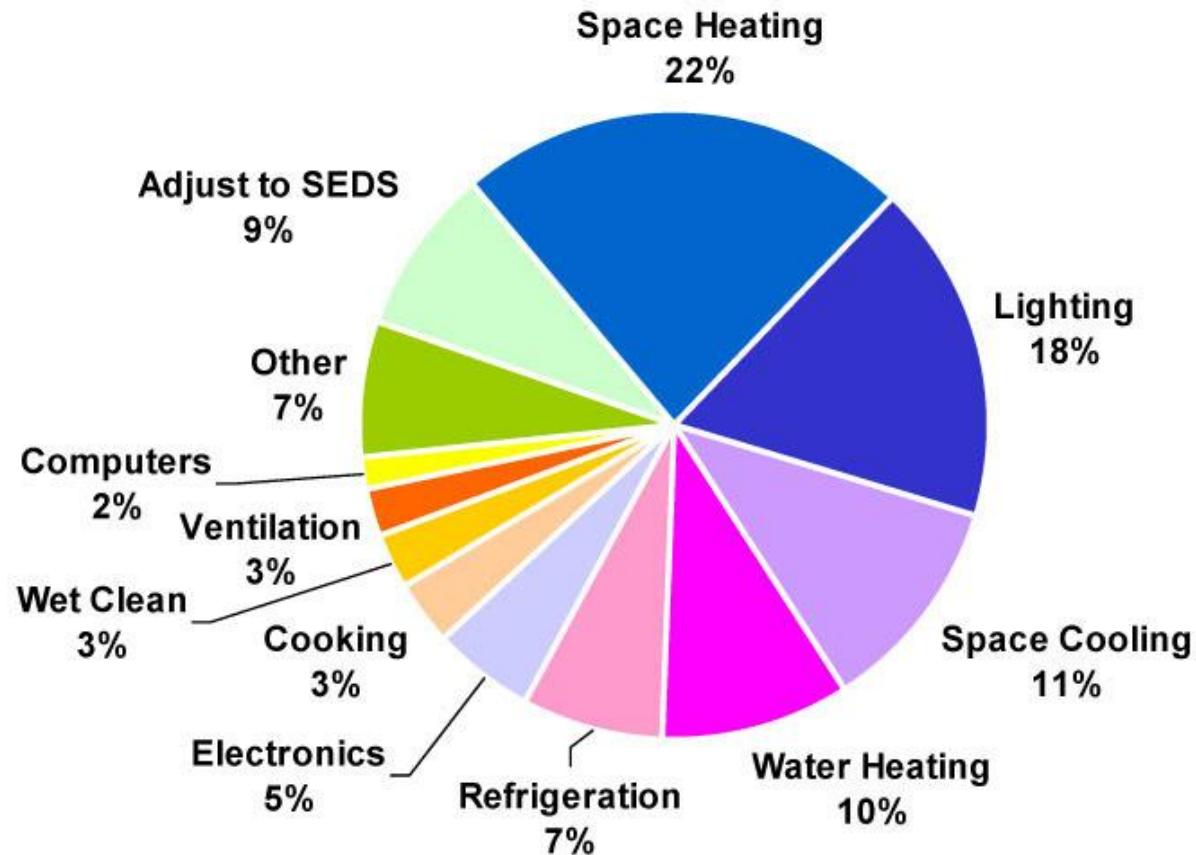
Energy Efficient Buildings

- Building Efficiency is an Important Solution to Energy Problem
- Cost Effective when Done Properly
- Requires Integrated Approach
- Important Contributions
 - New Technology
 - New Assessment Tools: Virtual Building
- Challenges in the future

U.S. Buildings

- **39 % of total energy (in UK 50 %)**
- **72 % of electricity**
- **90% of time spent indoors**
- **Major health problems: indoor climate**

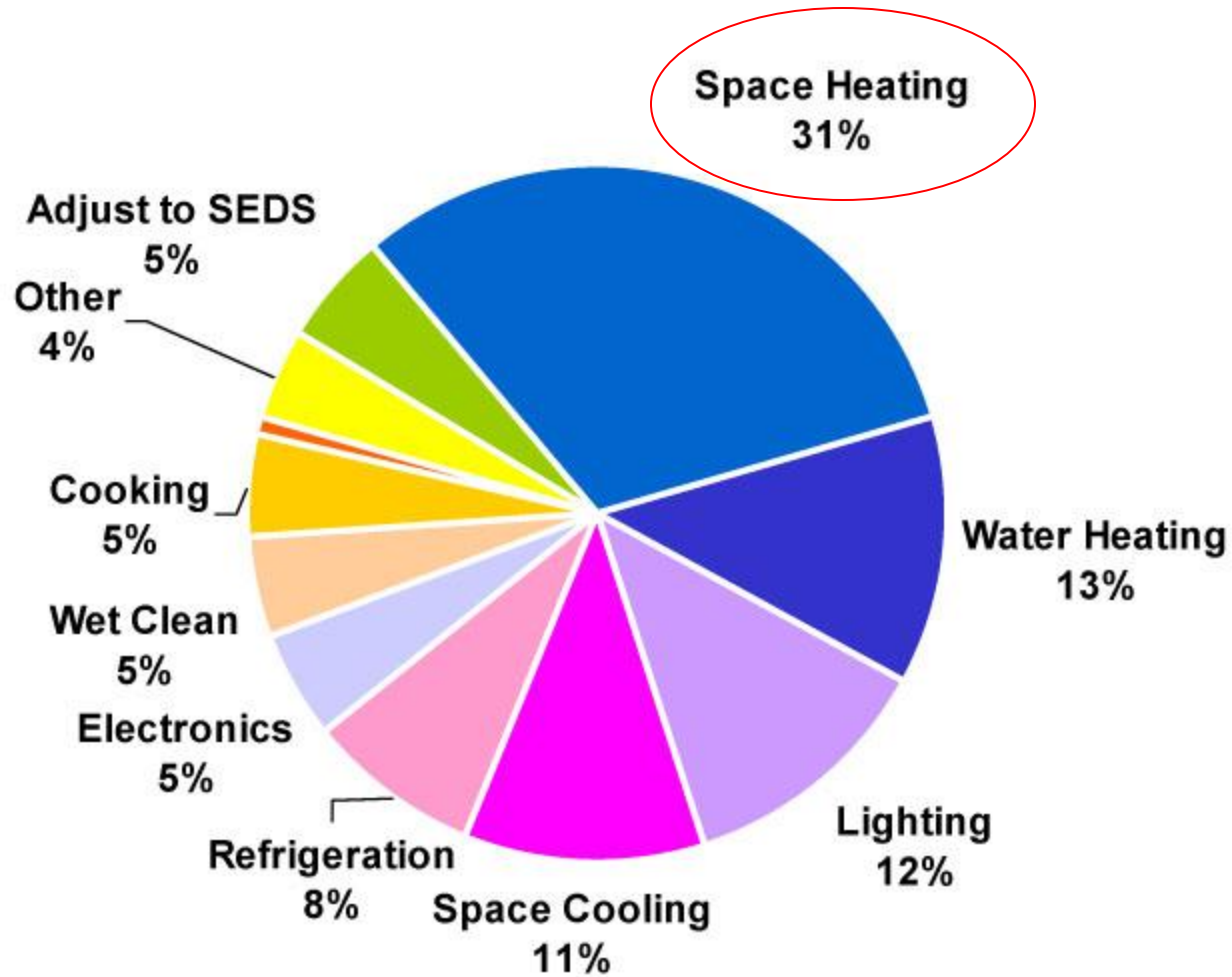
2004 U.S. Buildings End Use



Total Energy Consumption: 38.46 Quadrillion Btu

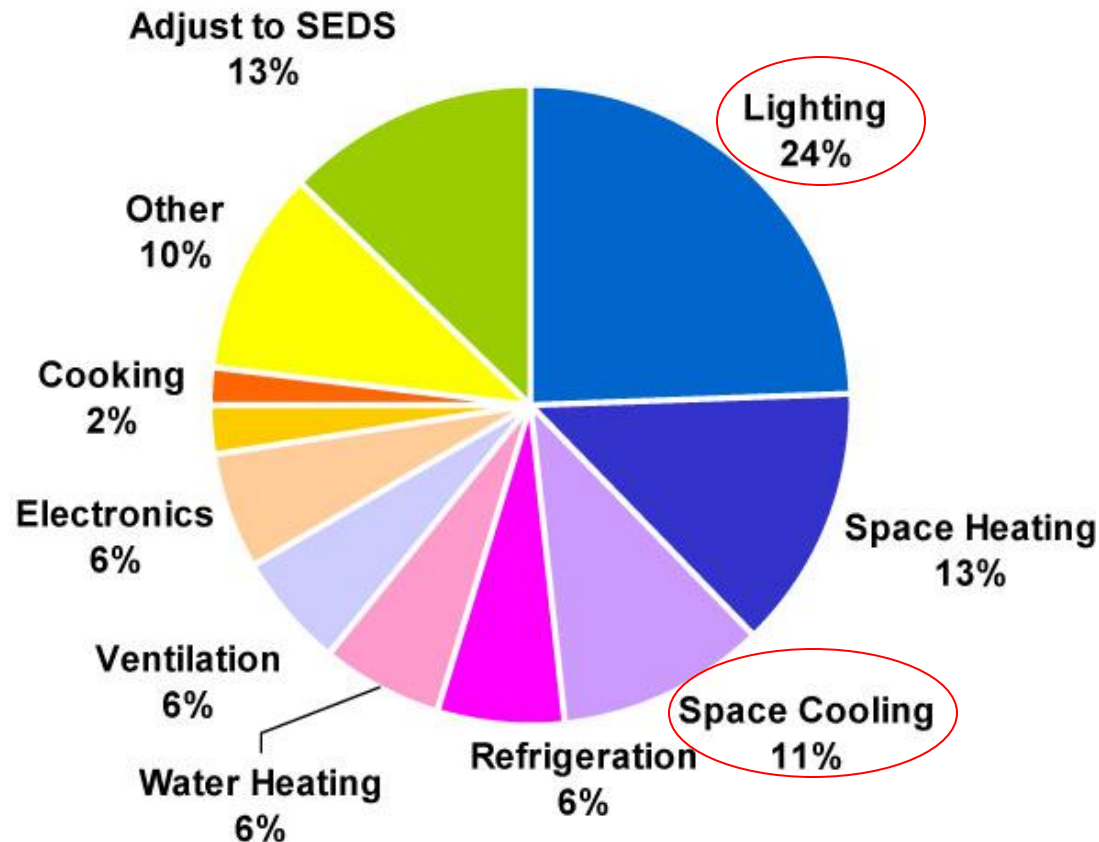
* -- Excludes buildings energy consumption in the industrial sector.

2004 Residential End Uses



Total Energy Consumption: 21.07 Quadrillion Btu

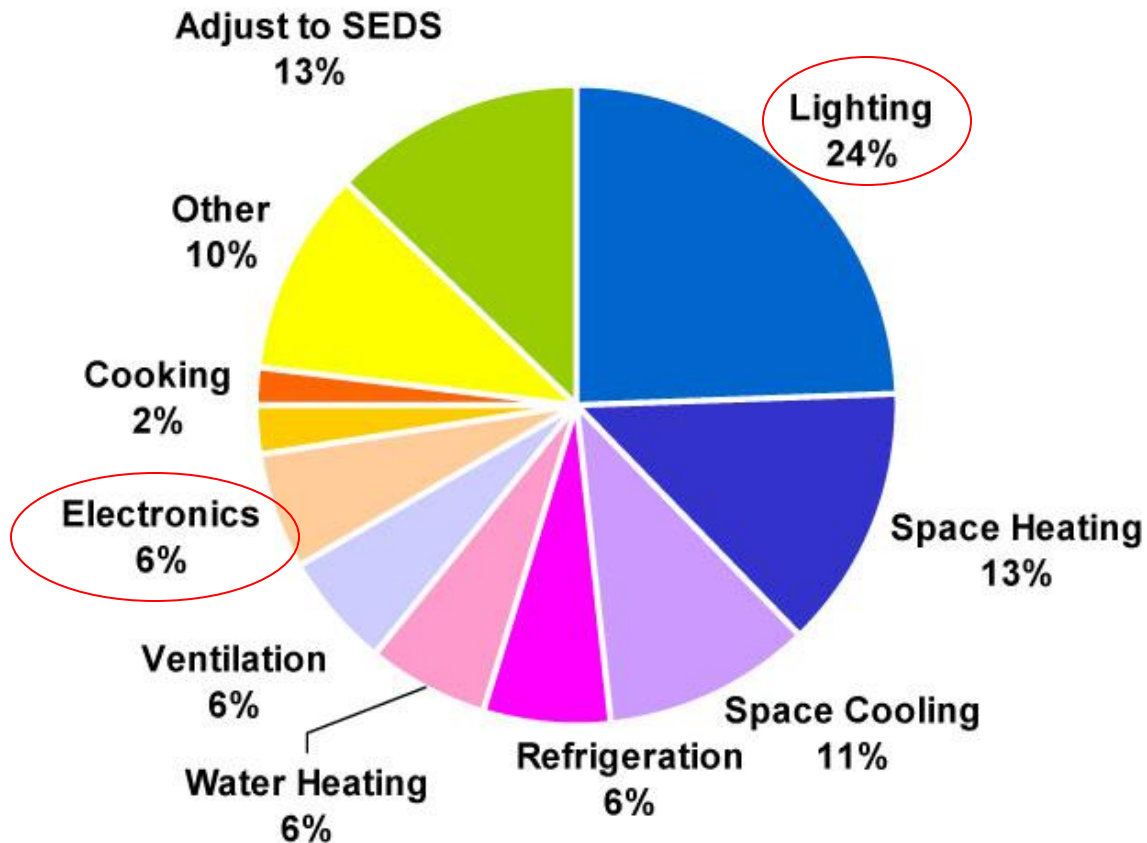
2004 Commercial Buildings End Use



Total Energy Consumption: 17.40 Quadrillion Btu

* -- Excludes buildings energy consumption in the industrial sector.

2004 Commercial Buildings End Use



Total Energy Consumption: 17.40 Quadrillion Btu

* -- Excludes buildings energy consumption in the industrial sector.

Physical Limits of Performance

Commercial Buildings

For example: green roof, cool roof??

Zero net energy high rise?

Cover entire surface with PV,
what % of building energy?



Wind



Economic Limits

Electric Power Costs

Technology	Cents/kWe-hr
Nuclear	4-7
Gas/Combined Cycle	4-6
Coal	4

Sources: Deutch and Moniz, MIT study 2003; Langcake, Renewable Energy World, 2003; Kats, California study, 2003

Electric Power Costs

Technology	Cents/kWe-hr
Nuclear	4-7
Gas/Combined Cycle	4-6
Coal	4
Renewable	
Wind	3-8
Biomass (25MW)	4-9
Small Hydro	5-10
Solar Thermal Electric	12-18
Solar PV	30-80

Sources: Deutch and Moniz, MIT study 2003; Langcake, Renewable Energy World, 2003; Kats, California study, 2003

Electric Power Costs

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Efficiency of Consumption	
Advanced Buildings	0-6

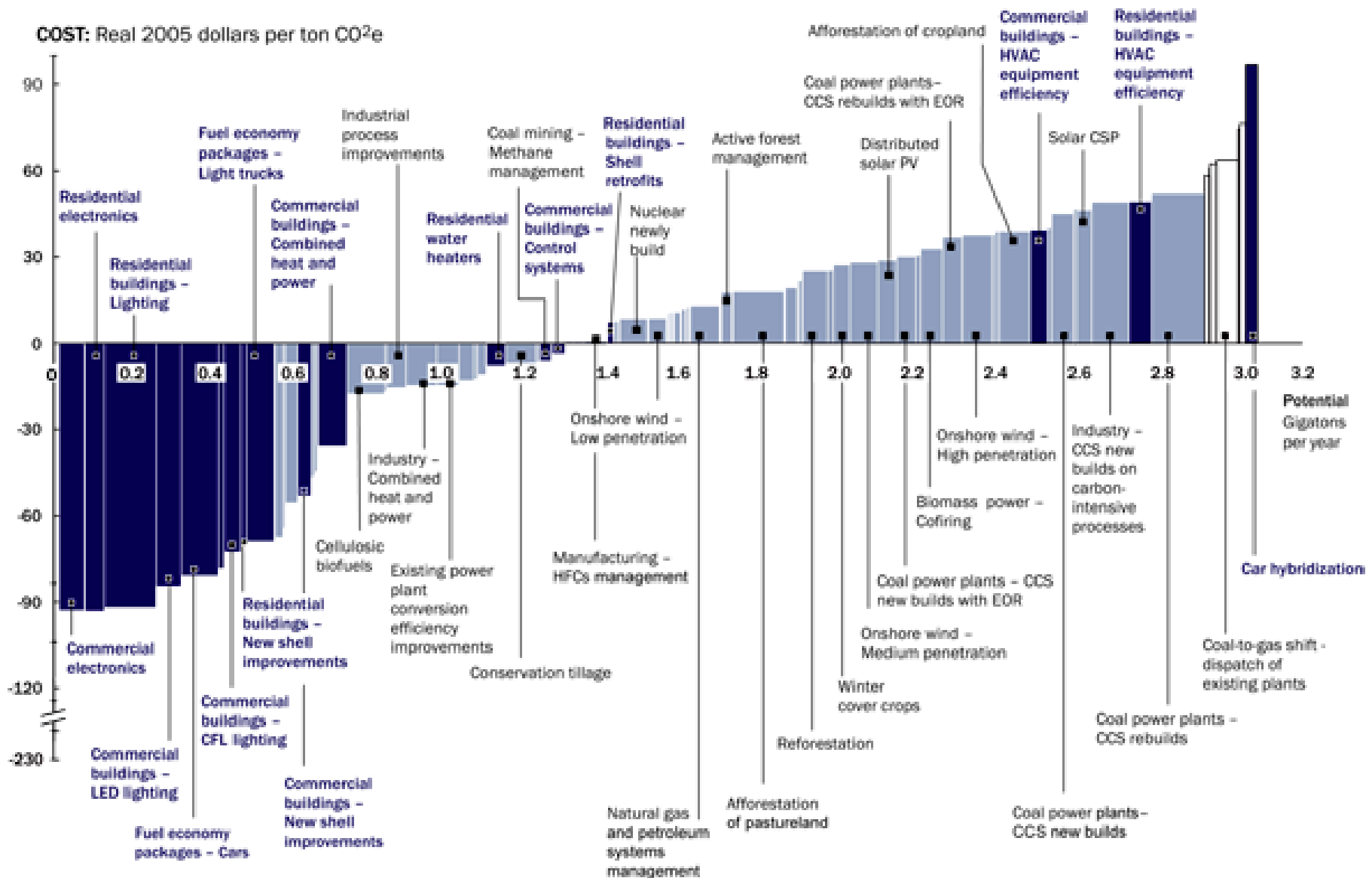
Sources: Glicksman Physics Today 2008 Deutch and Moniz, MIT study 2003; Langcake, Renewable Energy World, 2003; Kats, California study, 2003

Figure 2

U.S. mid-range abatement curve - 2030

Carbon dioxide abatement: estimated removal cost per ton of CO₂ in 2005 dollars and removal potential in gigatons/yr for various strategies.

■ Transportation and building efficiency measures



Energy Efficient Buildings

- Building Efficiency is an Important Solution to Energy Problem
- Cost Effective when Done Properly
- Why don't more US homes adopt efficient measures?

Barriers

- Conservative Industry
- Fragmented Field
- Lowest First Cost
- Lack of Incentives
- Poor Education
- Lack of information
 - Performance Projections
 - Results from New Buildings
- Linear Designs

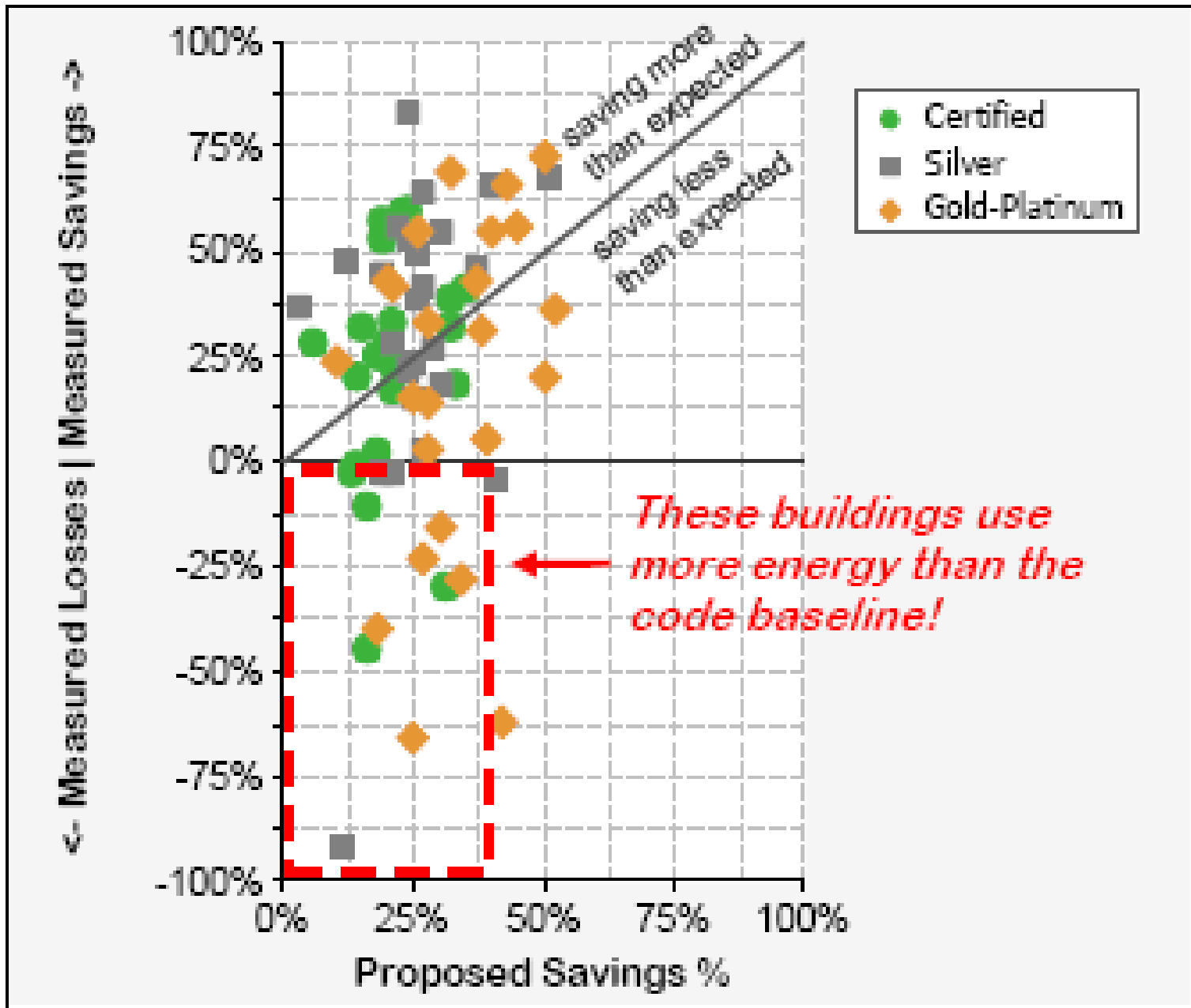


Figure ES- 5: Measured versus Proposed Savings Percentages

There's no single silver bullet to solve the energy problem



There's silver buckshot



Building Technology Program at MIT

- Joint program Architecture and Engineering
- 5 full time faculty
- 25 graduate students
- Research on the next generation of technology
 - Materials
 - Energy efficient operations
 - Community level impact
- Research on integrated design
 - Optimized design
 - Trade off: energy efficiency- renewables

Virtual Design Tools - some examples:

MIT Design Advisor

The screenshot displays the MIT Design Advisor interface with the following sections:

- Navigation:** Introduction, Setup, Comfort, Energy, Daylighting, Report.
- Description:**
 - Typology: single glazed (no blinds), double glazed (no blinds), triple glazed (no blinds), single glazed, double glazed, triple glazed, inside vent., outside vent.
 - Glazing Type: low-e
 - Window Area: 75 % - the percentage of the room wall that the window takes up
- 2a Wall Description:**
 - Insulation Type: foam
 - Insulation Thickness: 2.0 (standard) cm
- 3 Building:**
 - Location: by city (Boston) or by climate
 - Building Dimensions: North-South Length: 12 m, East-West Length: 12 m
- 4 Occupancy:**
 - Occupancy Load: 0.10 people per m²
 - Lighting Requirements: 400 - office work (EU std.) lux
 - Equipment Load: 5.00 W/m²
- 5 Representative Room:**
 - Room Depth: 7 m - perpendicular to windowed surface
 - Room Width: 5 m - parallel to windowed surface
 - Room Height: 3 m - vertically parallel to windowed surface
 - Orientation: North (N), South (S), East (E), West (W)
- 6 Natural Ventilation:**
 - Pure Mechanical Energy System
 - Pure Naturally Ventilated System
 - Joint Natural Ventilation and Mechanical Energy System
- 7 Thermal Mass:**
 - High Thermal Mass: exposed ceiling and floor, concrete slab system
 - Low Thermal Mass: carpeting/ wood, stone systems
- 8 Overhang:** Overhang Depth: 0 m - (0 indicates no overhang)

Design Advisor for Architects

Different Design Scenarios

Scenario One	Scenario Two	Scenario Three	Scenario Four
low-e 3 meters	low-e 3 meters	low-e 3 meters	low-e 3 meters
Boston	Boston	Boston	Boston
Choose an occupancy type... 0.10 pp/m ² - 400 lux - 5.00 W/m ²	Choose an occupancy type... 0.10 pp/m ² - 400 lux - 5.00 W/m ²	Choose an occupancy type... 0.10 pp/m ² - 400 lux - 5.00 W/m ²	Choose an occupancy type... 0.10 pp/m ² - 400 lux - 5.00 W/m ²
room: 5 m x 7 m	room: 5 m x 7 m	room: 5 m x 7 m	room: 5 m x 7 m

Commercial Roof Types



modified bitumen roof



ballasted roof



cool roof

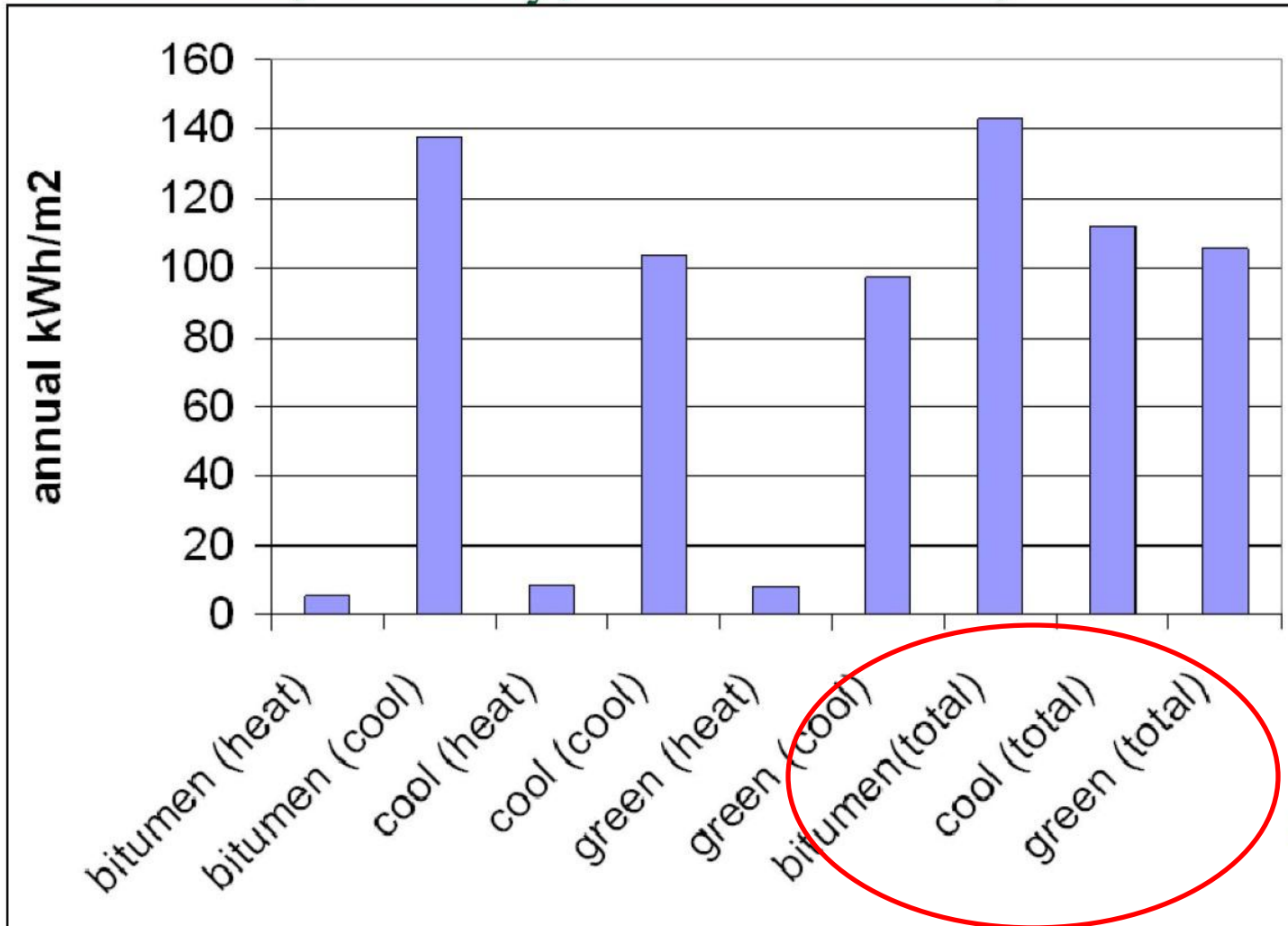


green roof

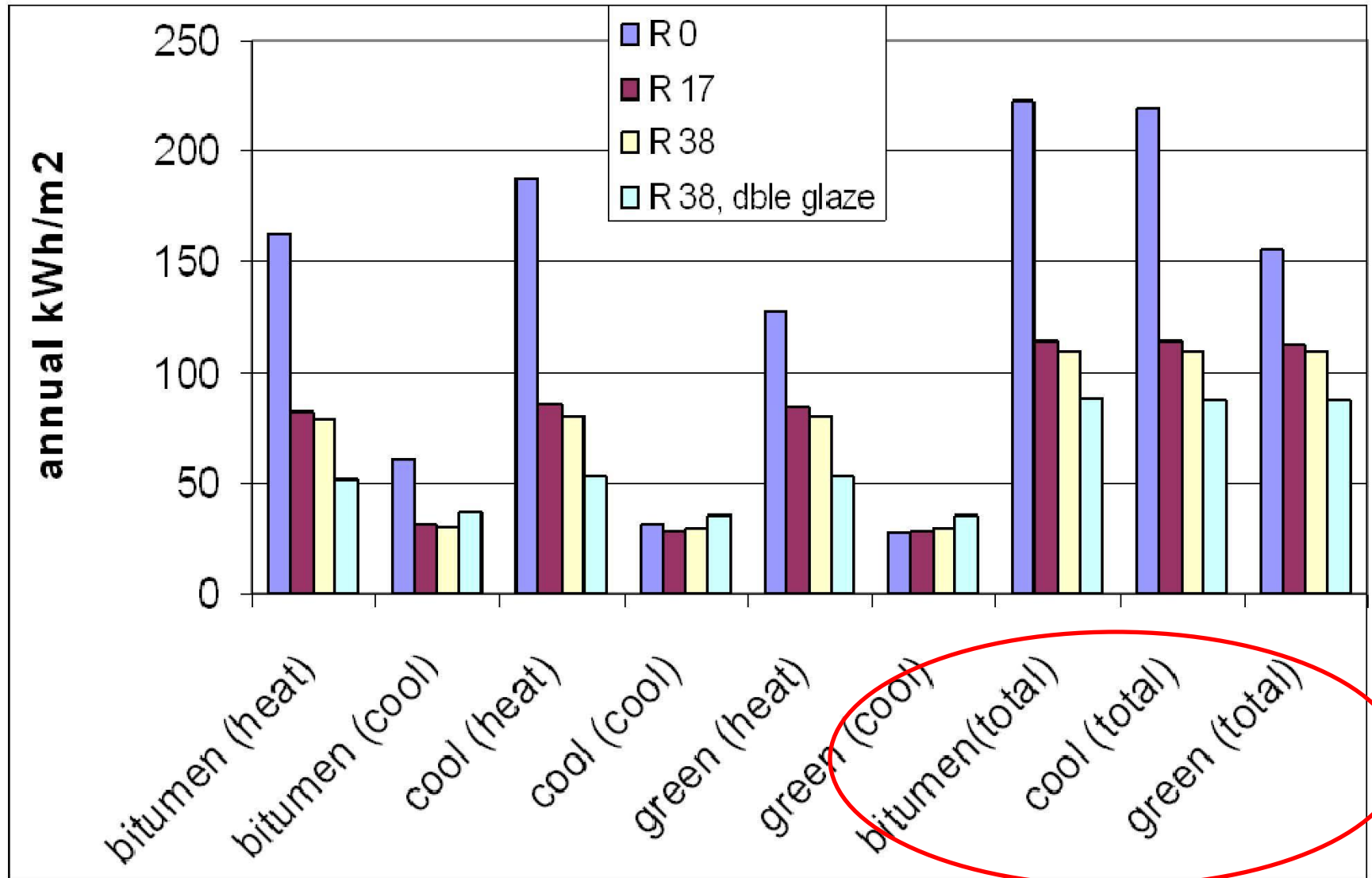
<http://www.lexiscoatings.com/wp-content/uploads/mod-splash.jpg>
<http://home.att.net/~wavetrader/spf6.JPG>

<https://ssl2.msstate.edu/vpfa/admin/fm/conprojects/conprojimages/00000441.jpg>
http://www.epa.gov/region8/images/greenroof_terrace.jpg

Phoenix, 1-story, no windows, R 9



Boston, 3-story, 50% glazing in each room



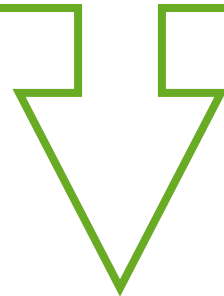
Supply



Demand

- Renewables
- Distributed generation

- “Negawatts”
- Energy efficiency
 - Smart controls
 - Smart people



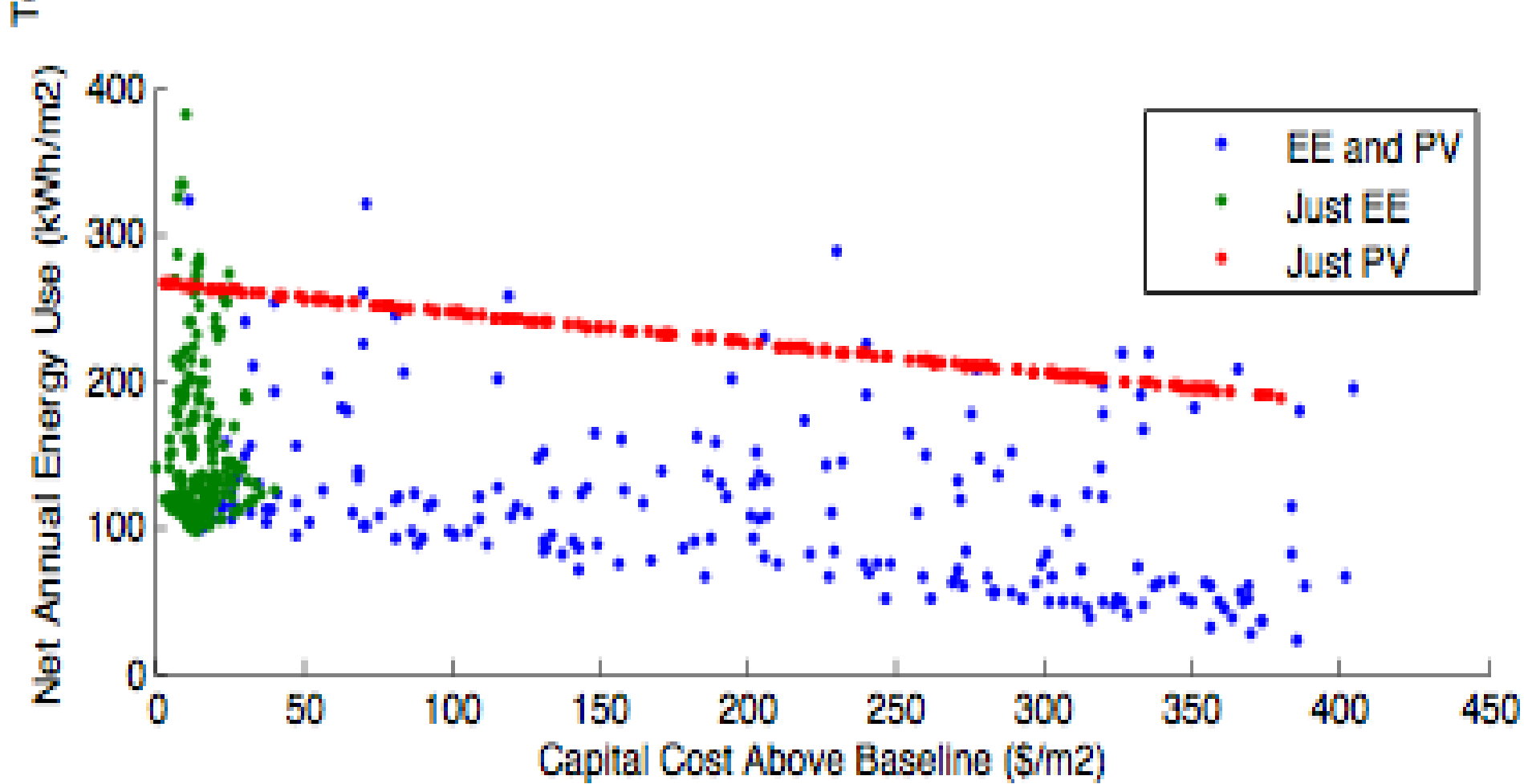
Toward net zero energy systems

ABU-DHABI MASDAR DEVELOPMENT

Goal: Zero Carbon

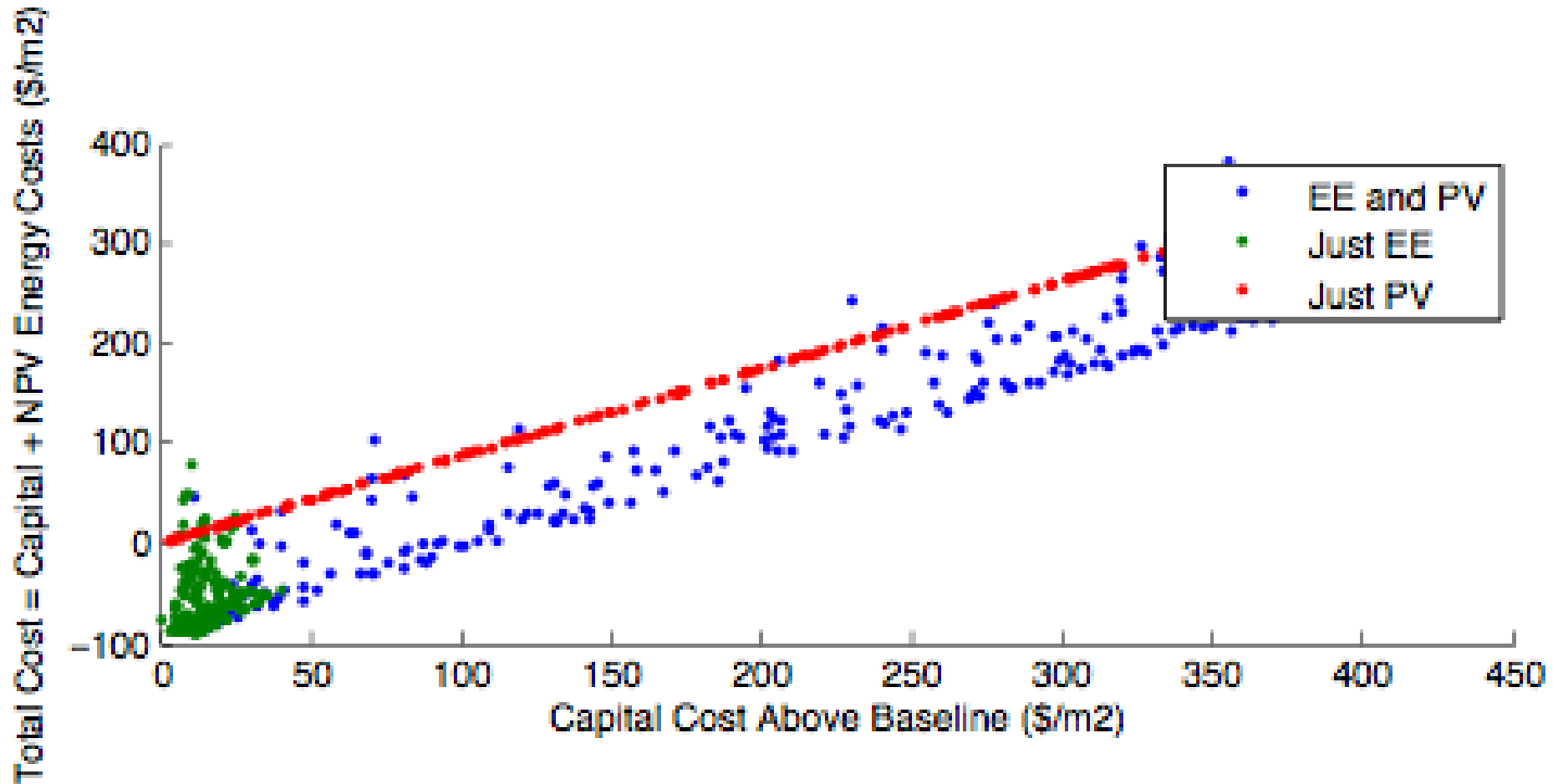


Foster and Partners



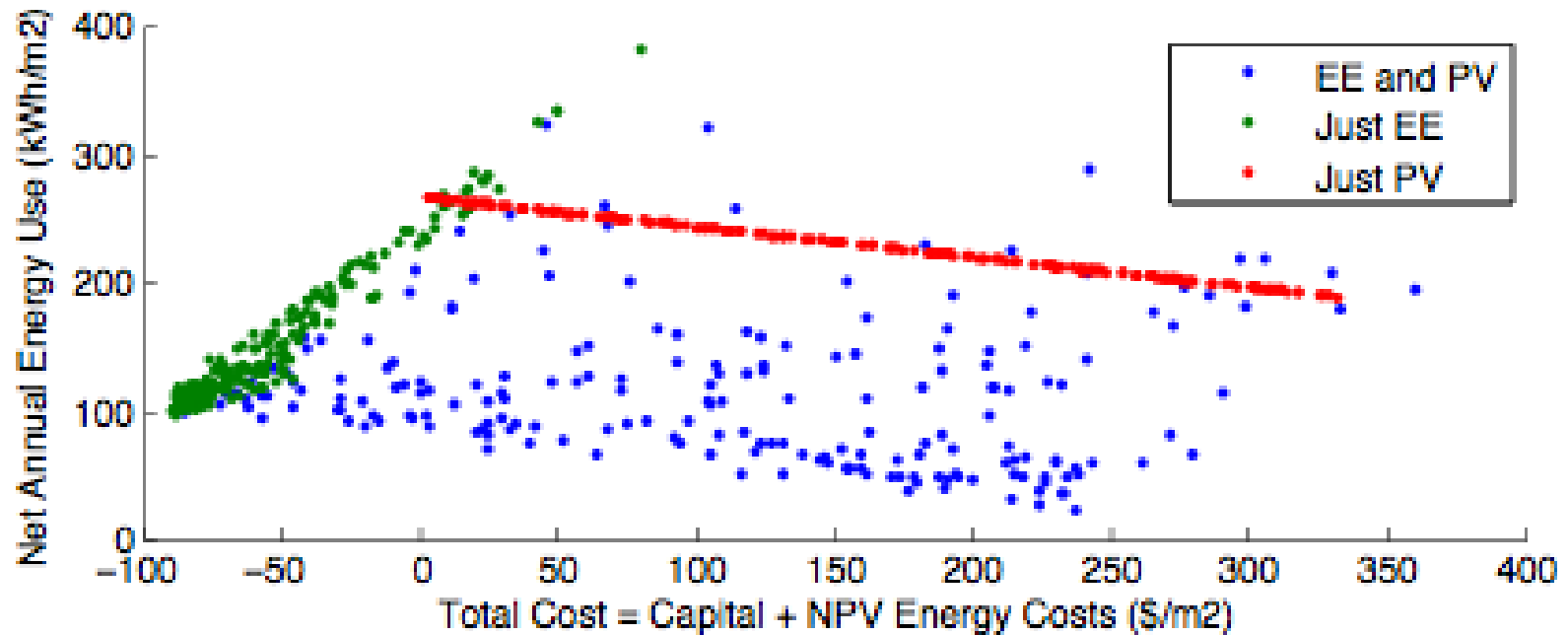
Energy Use vs Additional Capital Cost Above Baseline Commercial Building
PV \$4/W over 5 years.

Total Cost vs Capital Cost



Updated output

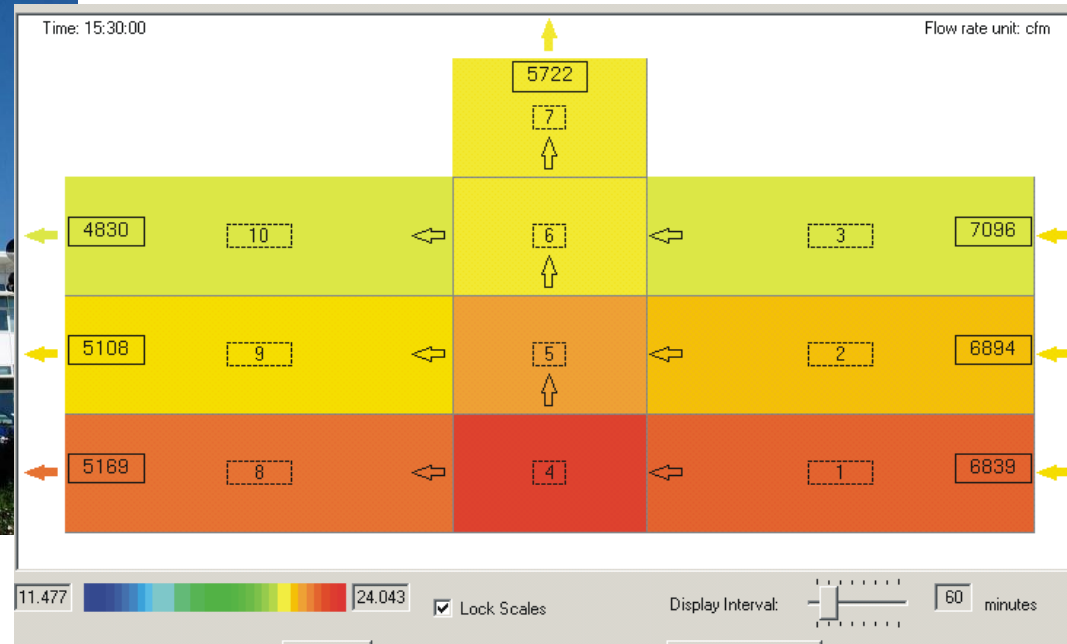
\$4/W over 5 years.



Natural Ventilation



Luton, England
MIT- Cambridge University
Monitoring and Simulation



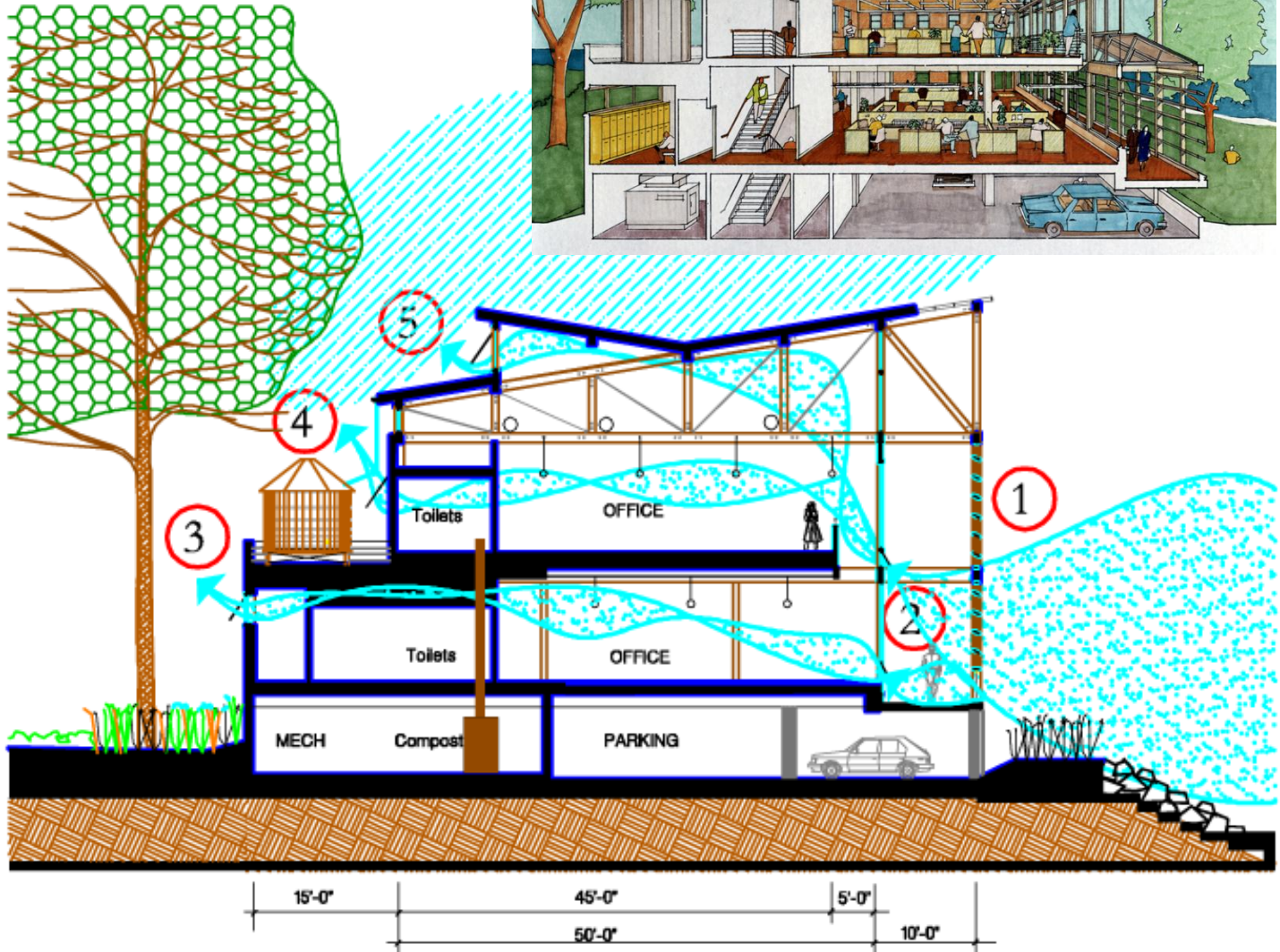
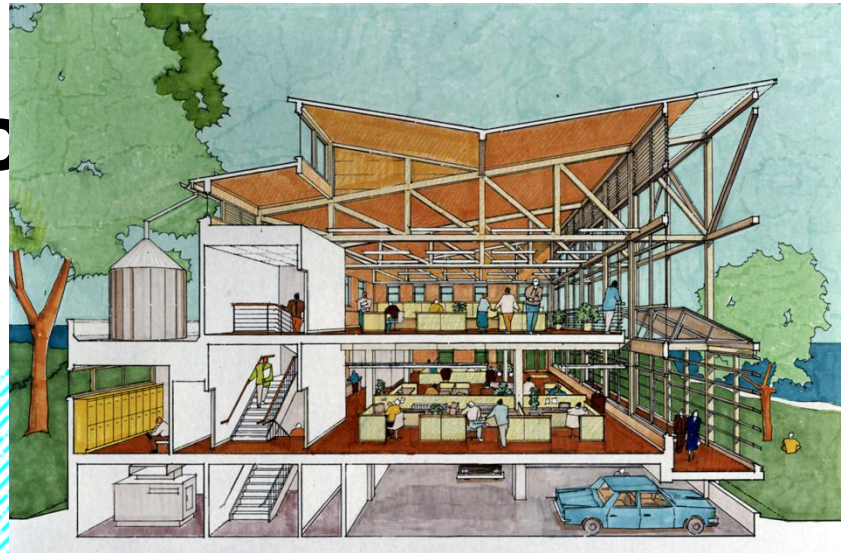
MIT CoolVent Design Program

Test Building 2

Philip Merrill Environmental Center



Airflow



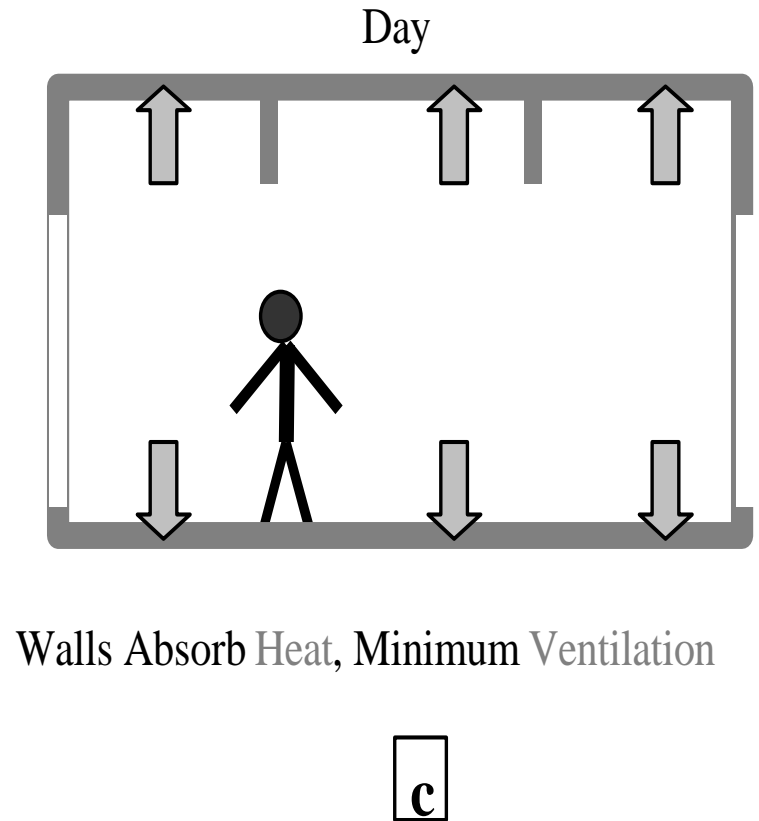
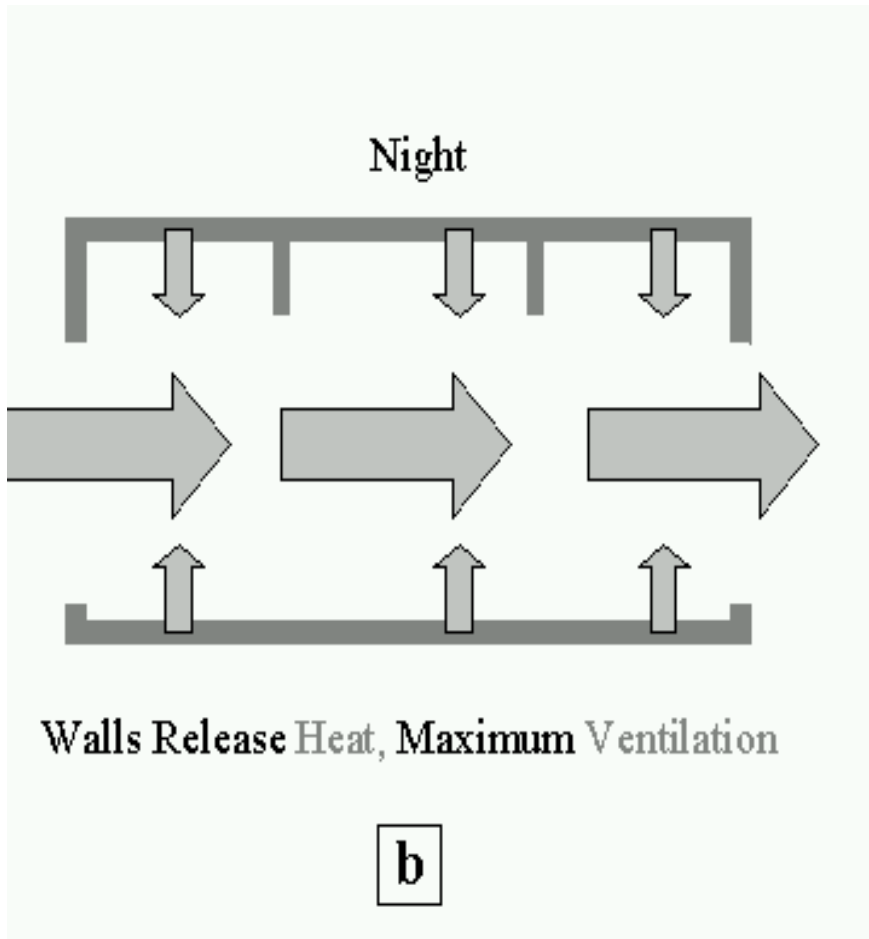
Natural Ventilated Building, Luton England



Luton Building Interior

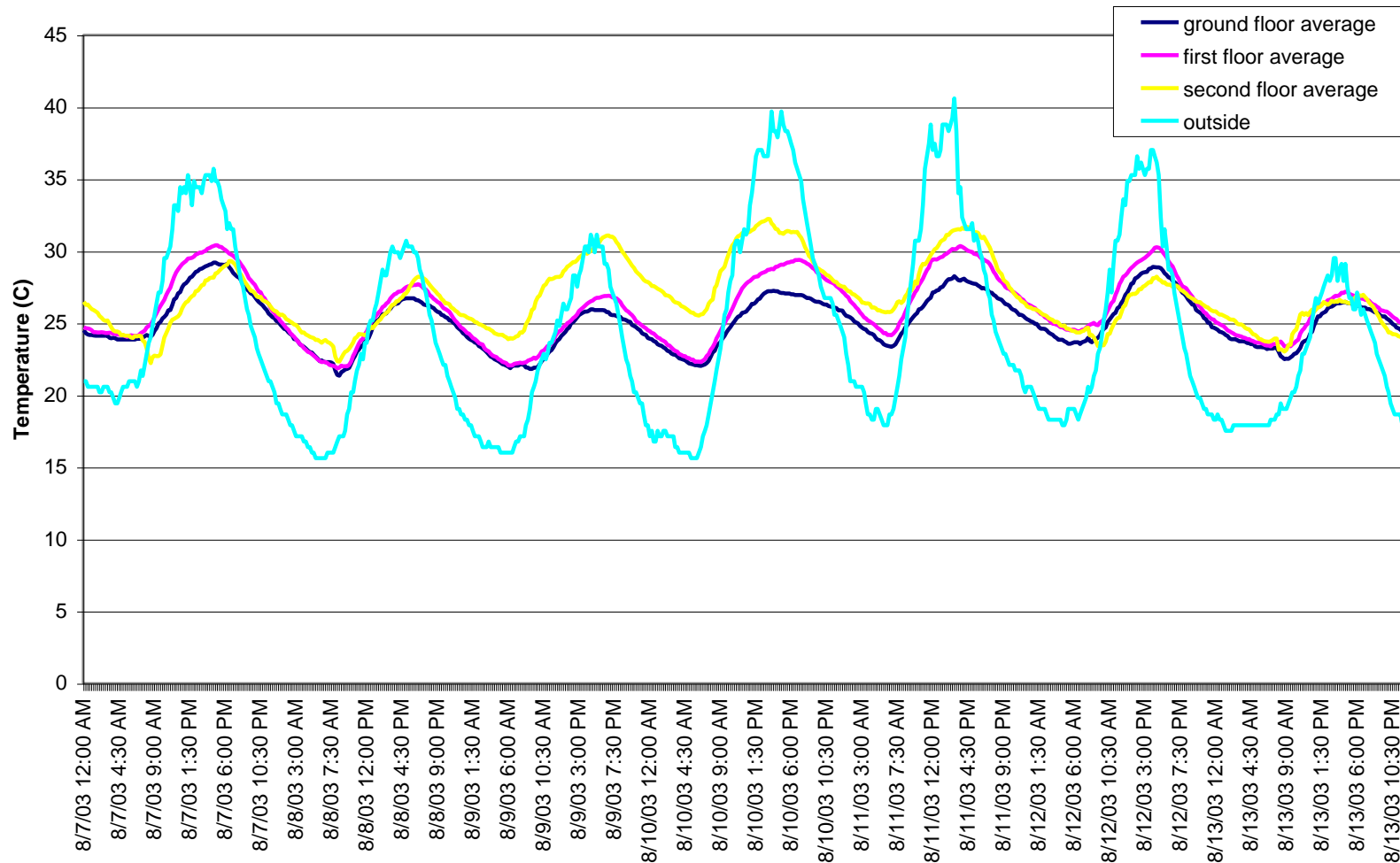


Cross Ventilation Design: Night cooling



Luton Interior Temperatures: August 2003

Luton August 2003

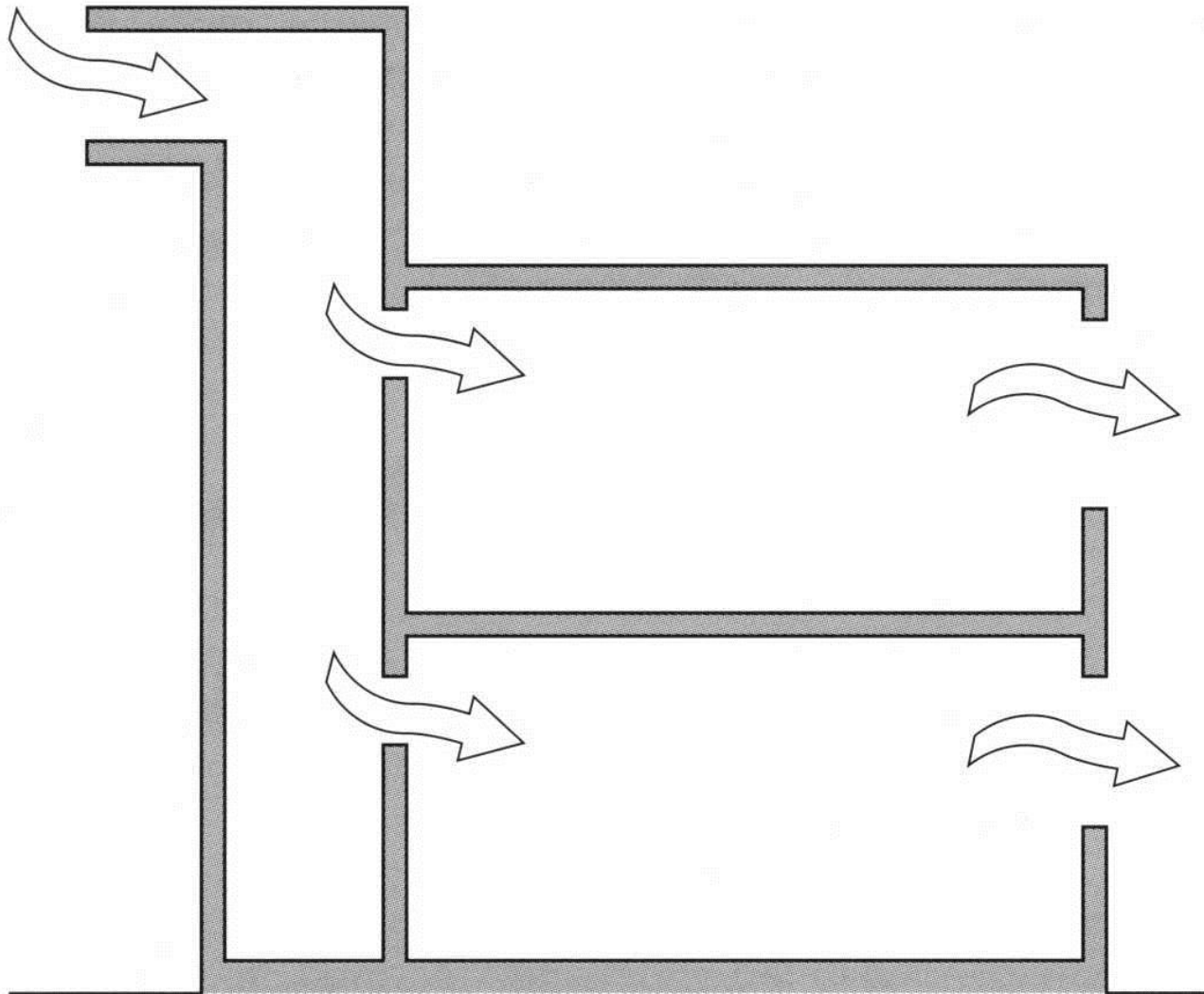


Natural Ventilation: Wind scoop

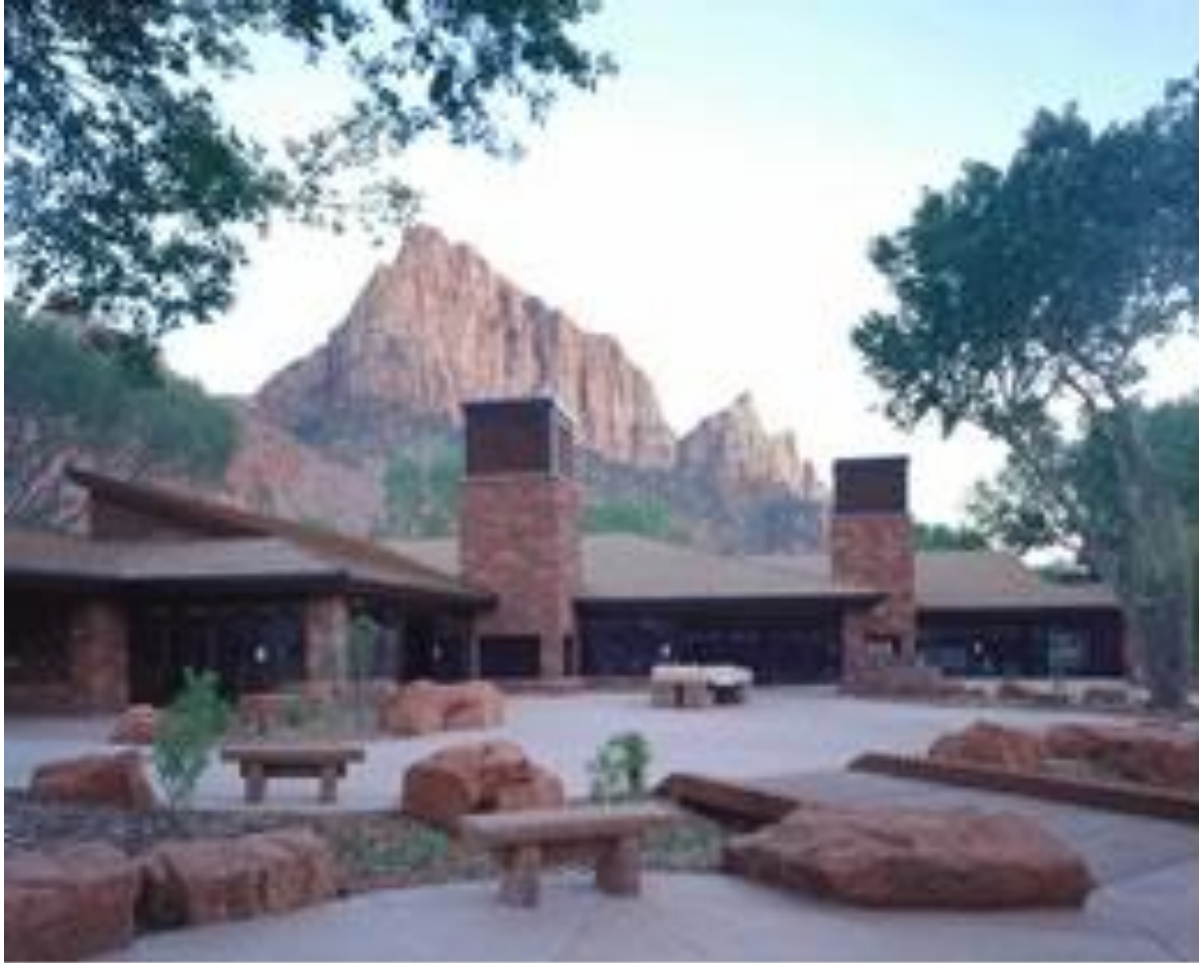


Natural Ventilation:

Wind scoop



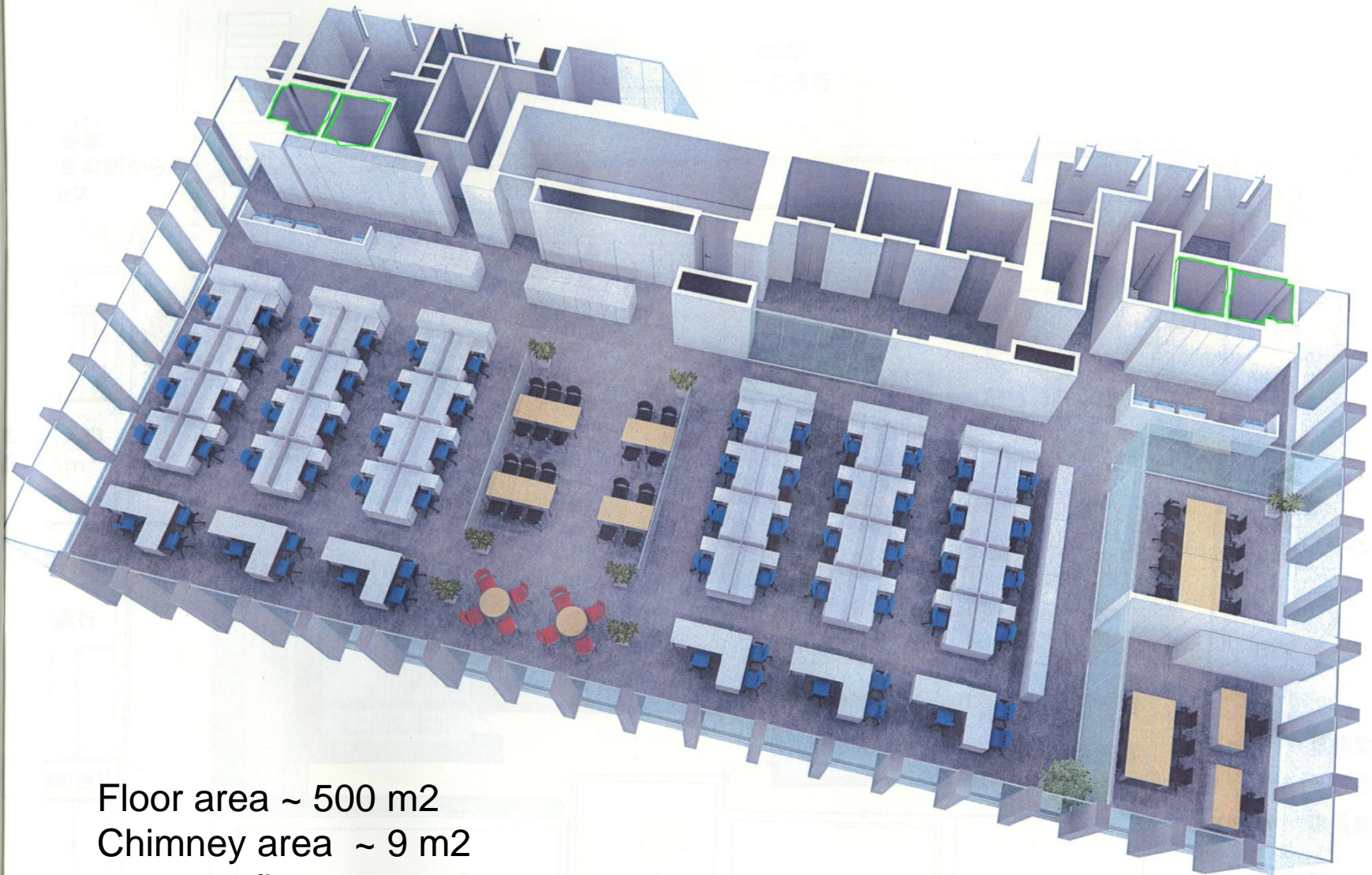
Zion National Park Visitor Center





01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100

地を使い切った配置計画とホスピタリティを持つゲストエリア



Floor area ~ 500 m²
Chimney area ~ 9 m²
to vent 5 floors

CoolVent

- Ventilation and Air Flows

The screenshot displays the CoolVent software interface, which is used for simulating ventilation and air flows in buildings. The interface is divided into several sections:

- Building Type:** A 3D perspective view of a building with a central atrium. The building is colored in green, yellow, and orange. Labels include "Height", "Width", and "Length".
- Orientation:** A 2D diagram showing the building's orientation relative to North. The orientation angle α is set to 45 degrees (NE). Labels include "Window", "Roof", "Length", "Width", and "Building Orientation".
- Simulation Settings:** Includes a checkbox for "Transient Simulation", "Select a City" (Boston, MA), "Select a Month" (July), "Wind Direction β " (270 Degree or E), "Wind Velocity", "Terrain Type", "Surrounding I", "Ambient Temp", "Heat Source I", and "Initial Temper".
- Visualization:** A 3D view showing air flow patterns at 15:30:00. The flow rate unit is cfm. The visualization shows air entering from the left and exiting through the top and right. A color scale at the bottom indicates flow rates from 11.477 to 24.043. A "Display Interval" slider is set to 60 minutes. Buttons for "Visualize" and "Report Results" are present.

Flow rate data from the visualization:

Zone	Flow Rate (cfm)
1	6839
2	6894
3	7096
4	5169
5	5108
6	4830
7	5722
8	5169
9	5108
10	4830

Zone 0 Temperature is: 21.42 Degree Celsius.
Zone 1 Temperature is: 23.03 Degree Celsius.

Open fume hoods: Energy Loss



Energy Efficient Ventilation Design for New Cancer Research Facility



Swedish Homes



Comfortable

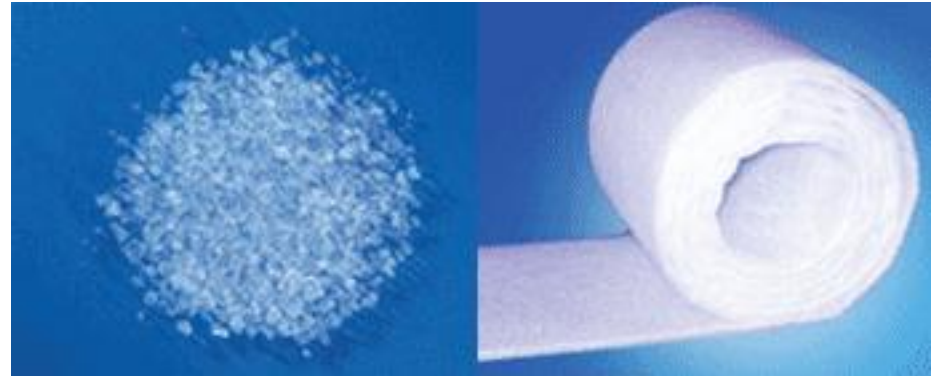
No Central
Heating
System!



Aerogel insulation using nanotechnology



Commercially available aerogel for insulation purposes



Cabot Nanogel[®] particles and Thermal Wrap[™]

Aspen Aerogel[™] Spaceloft[®]

- Granules or aerogel particles embedded in a fiber blanket
- Thermal properties: 14-20 mW/mK
- Our objective: practical aerogel insulation systems with improved performance

Straw Insulation

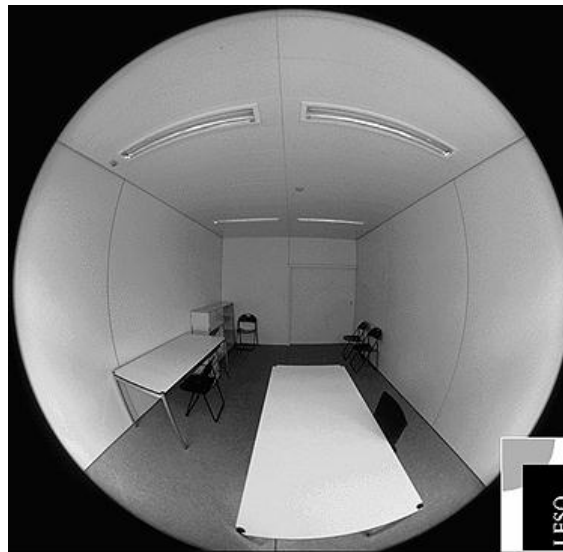
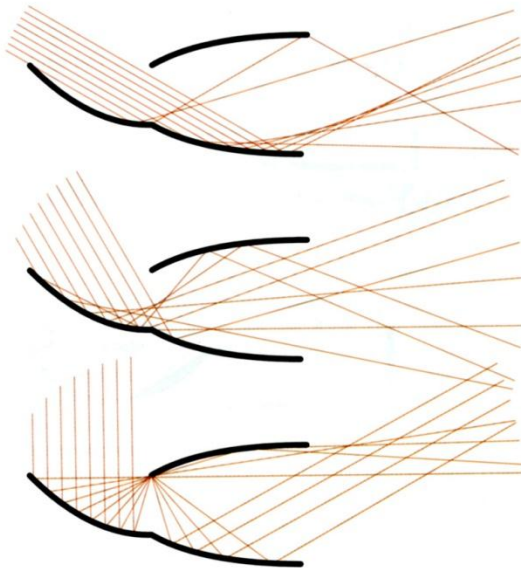
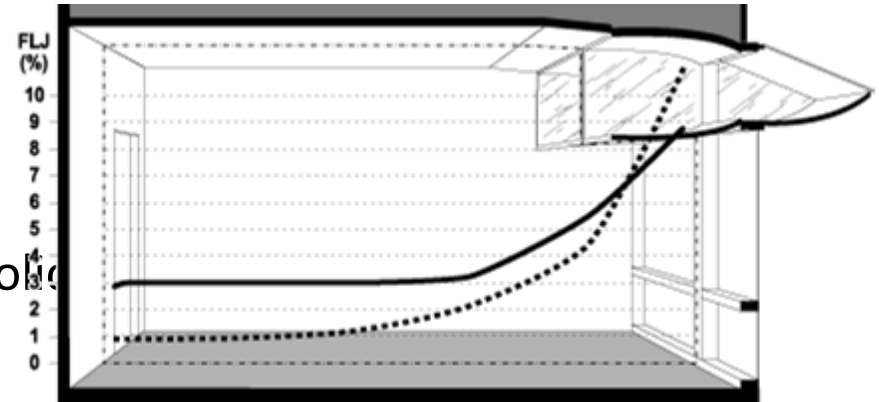


Use of Solar Energy

- Acceptable Interior Lighting Level :
1/10 to 1/100 of exterior level
- Associated thermal load of solar less than that for artificial lighting
- How to control it?
- How to bring it deeper into interior?

Enhancing daylight deeper in rooms

- Anidolics (based on non-imaging optics: research made at LESO-PB/EPFL)
 - Photos show 2 identical rooms at the same time, one equipped with an anidolic system, the other without



Full Scale Test in Tokyo of Window Unit



Building Condition Monitoring

Broken Buildings Waste Energy

- HVAC \approx 50% of **Total** building energy use
- Faulty HVAC \approx 5-30% of **Total** building energy use
- Simultaneous heating and cooling, extraneous HVAC operation, imbalanced flows \approx 80% of “faults”
- Detecting, evaluating and diagnosing broken buildings is central to scalable energy efficiency

Fixing Buildings Is Very Hard

- Culture of fixing buildings is re-active, not pro-active
- Performance data is rarely collected, reviewed, or used for decisions; data is expensive ~ \$1k per point
- Building documentation is usually poor; collecting system and equipment details is time consuming
- Risk-aversion and up-front labor costs control activities (~70% of data point cost is labor)

Thesis Focus on Automated Fault Detection and Evaluation

- Create a low-cost, easy-to-use tool to help fix lots of buildings, everywhere, quickly and consistently
- Help buildings save money, reduce CO₂ emissions, improve comfort conditions and create jobs
- Combine theory and practice into a web-based, automated FDD&E software system

Testing M16 and M56 AHUs

Pinpoint - [MIT\M16_CX14\M16_AH2_1\M16_AH2_2*]

File View Window Help

Outside Air Temp	41.7	Name	M16 AH2 1
Outside Air Humidity	49.2%	Location	Basement (North Center)

Serves floors B - 4

OutsdAirInlet_Te	
Temperature	44.8

ChWRet_Te	
Temperature	53.1

HtgDisch_Te	
Temperature	71.7

FrzStat_A1	
Off	

Smoke_A1	
Off	

SupAirFlow2A	
Flow	24009.3

SupAirFlow2B	
Flow	29141.8

SupAir_Te	
Temperature	55.0
Set Point	55.0

SupAir_SP	
Static	2.003
Set Point	2.000

FilterPr_A1	
Off	

FaceBypDmp	
Damper	0.0%
Enabled	
	1/1/1989

HtgStnVlv	
	37.8%
Enabled	
	1/1/1989

ClngVlv	
	68.5%
Enabled	
	1/1/1989

SupFanA	
Fan	On
Status	41.2
Enabled	
	1/1/1989

SupFanB	
Fan	On
Status	47.3
Enabled	
	1/1/1989

SupFanVanessA	
Speed	41.0%
Enabled	
	1/1/1989

SupFanVanessB	
Speed	41.0%
Enabled	
	1/1/1989

OA → SA

LO PRES HI PRES

AH1 60.0 CHW 43.6 DMP

M16 AH2 2 Zoom : 100 % Run Updating...

Wednesday, March 24, 2010 12:04:26 PM MIT\M46_CX76\M46_Rm7082A_1\Room_DP 0.0000 Alarm 40 Expr

Start Main - Continuum Continuum Explorer - MI... Pinpoint - [MIT\M16 ...]

Equipment View

Equipment Information:

Equipment Name: M16-AHU-02

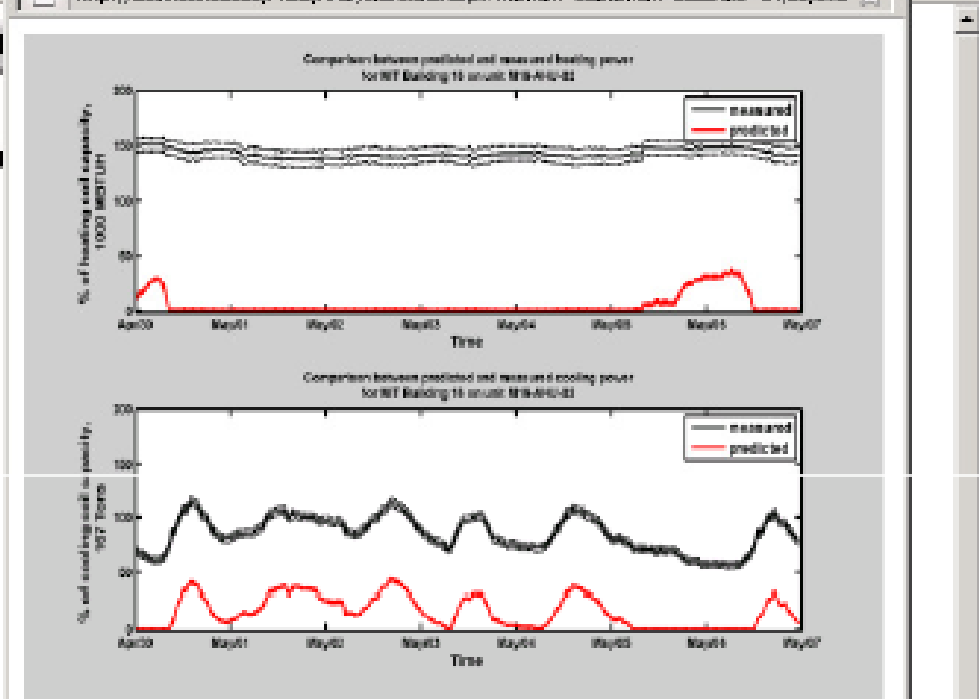
Equipment Type: DOA2coil Dual Fan

Observe a timeframe, scroll or change dates, and click "Get New Data".

- Single Day
- Seven Day
- Calendar Month

Analysis Report for M16-AHU-02, 9			
Analysis	Open Date	Close Date	No
DOASDualFan2Coil	04/30/09	05/07/09	The average chance of simult 100.00%. There is a 20% ch 5993.89 or more.
DOASDualFan2Coil	05/07/09	05/12/09	The average chance of simult 100.00%. There is a 20% ch 4228.75 or more.

Done



Analysis	DOASDualFan2Coil
Open Date	04/30/09
Close Date	05/07/09
Notes	The average chance of simultaneous heating and cooling is 100.00%. There is a 20% chance that you wasted \$ 5993.89 or more.
Energy Priority	10.00
Comfort/Health Priority	Not Specified
Maintenance Priority	10.00

China

~ 10 M new residence units/year!







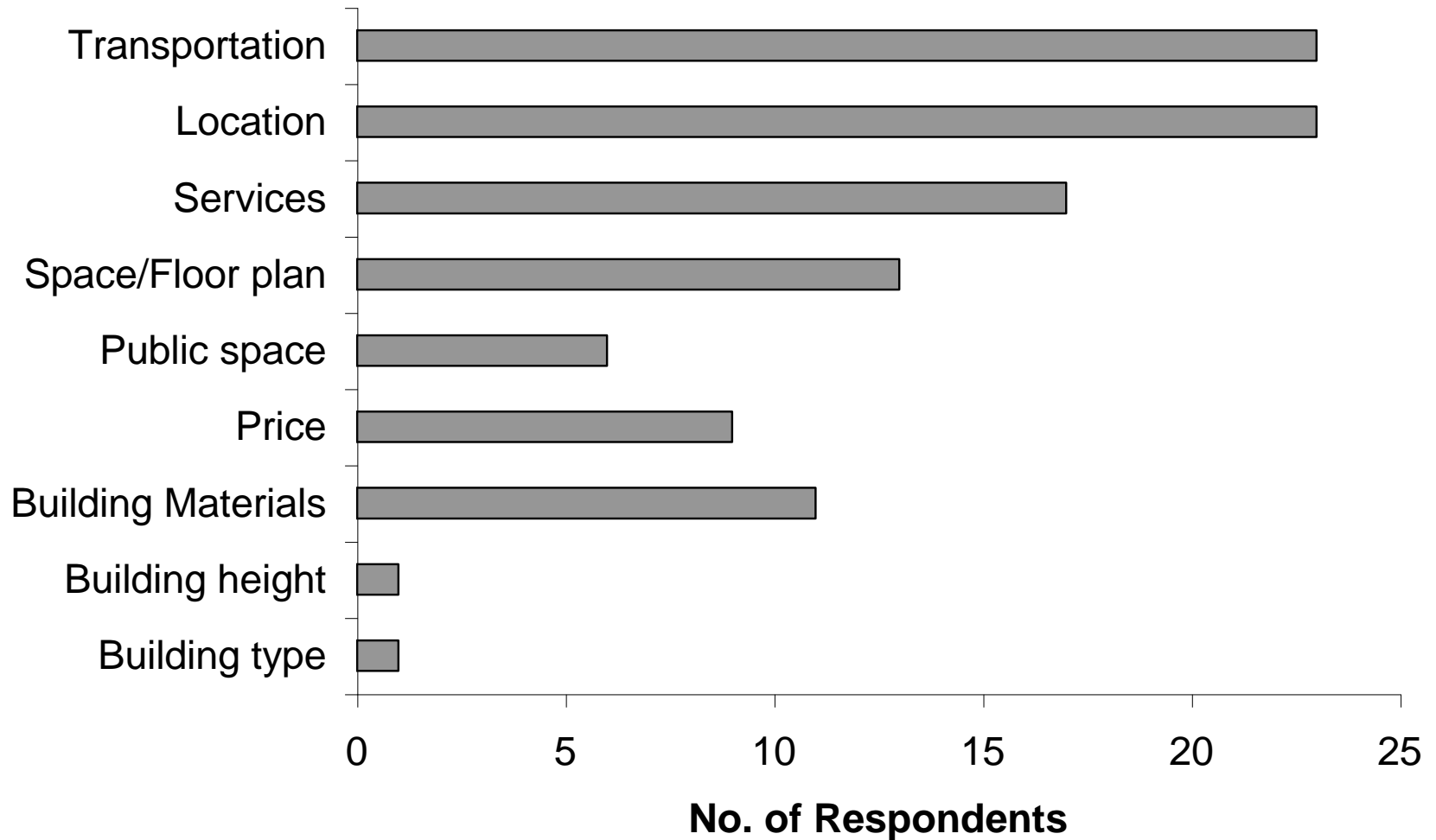
We conducted surveys with three groups of Chinese consumers:

1. Visitors to the *Tian Hong* sales office in Beijing,
2. Other potential home-buyers in Beijing, and
3. Chinese nationals at MIT.

Tian Hong is a new “affordable” housing development in Beijing priced at 2600 RMB (\$313) per sq. m.



Survey: Three Most Important Features of Home



Published Fall 2006

SUSTAINABLE URBAN HOUSING IN CHINA

Principles and Case Studies for Low-Energy Design

Leon Glicksman and Juintow Lin

Editors





