Architecture and Energy: *Occupants and implications for design*

Koen Steemers
The Martin Centre for Architectural & Urban Studies
Department of Architecture
University of Cambridge

Contents:

- History
- Climate change
- UK energy use
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- Offices
- Case studies
- Conclusions

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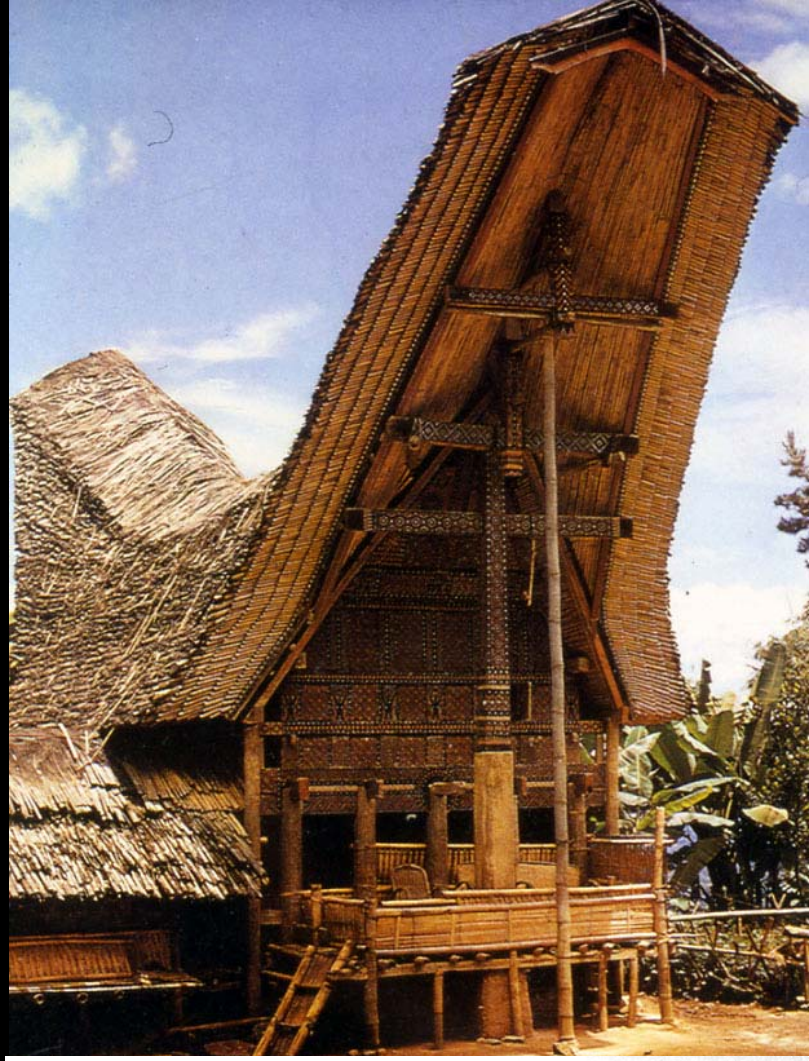
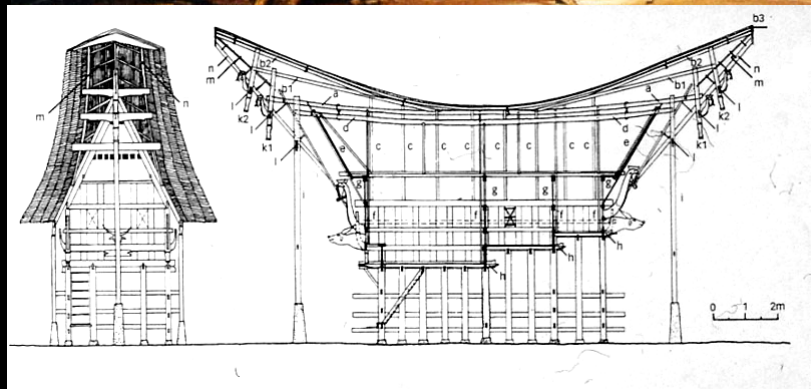
History

The success of human adaptive ability is remarkable. If we include the human skill of the provision of shelter... then it has resulted in the human species occupying climatic extremes wider than almost any other species. This has been achieved by sustainable technologies using little or no fossil energy.

Nick Baker, “We are all outdoor animals”





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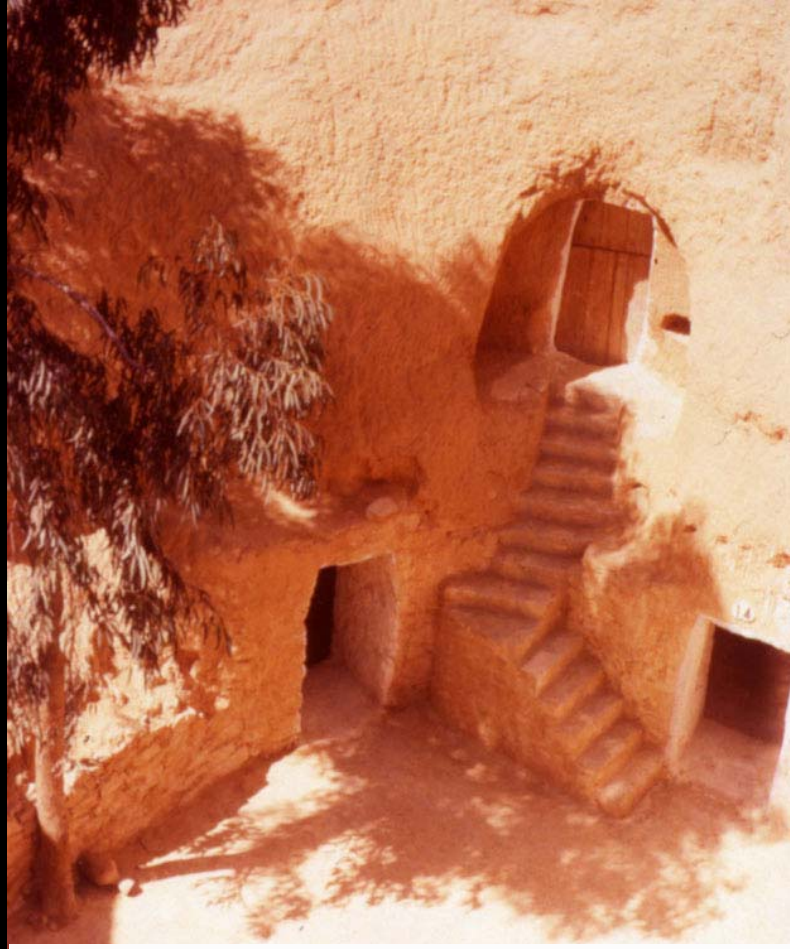

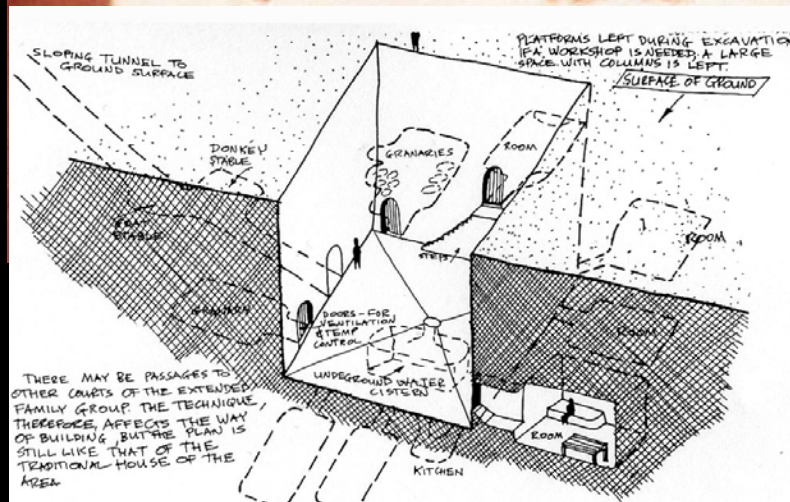

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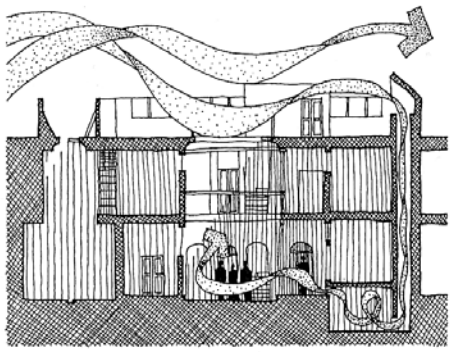
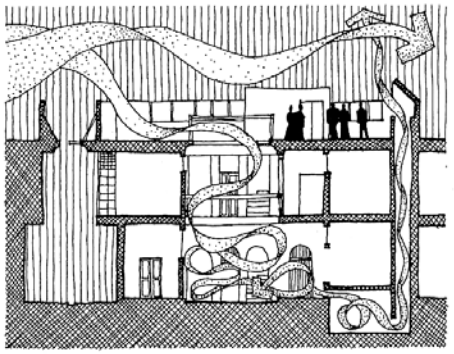


Iraq House, Summer Day



Iraq House, Summer Night

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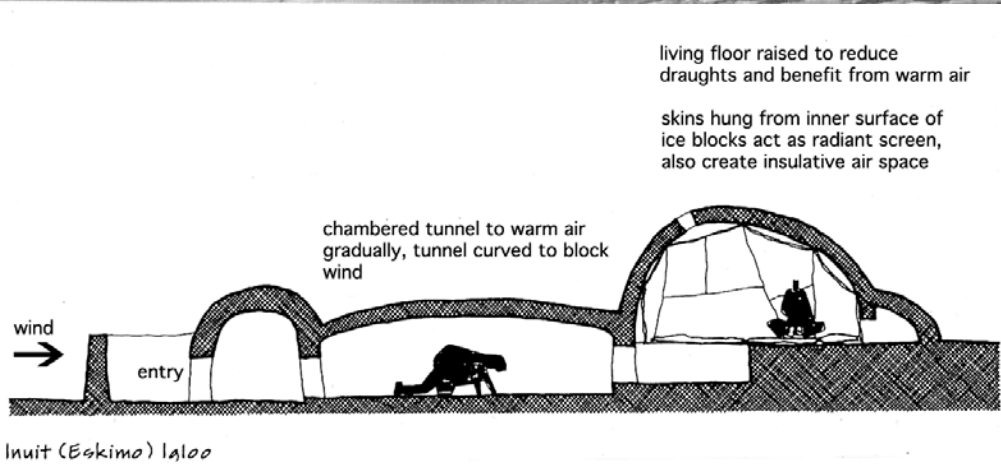
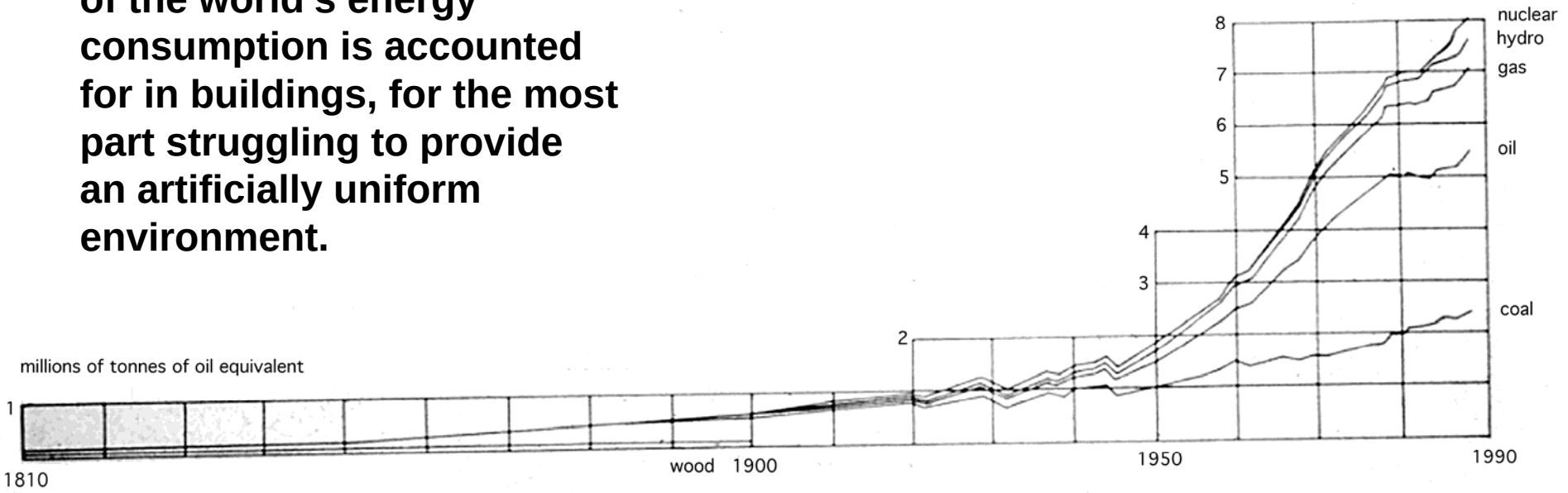


Inuit (Eskimo) Igloo

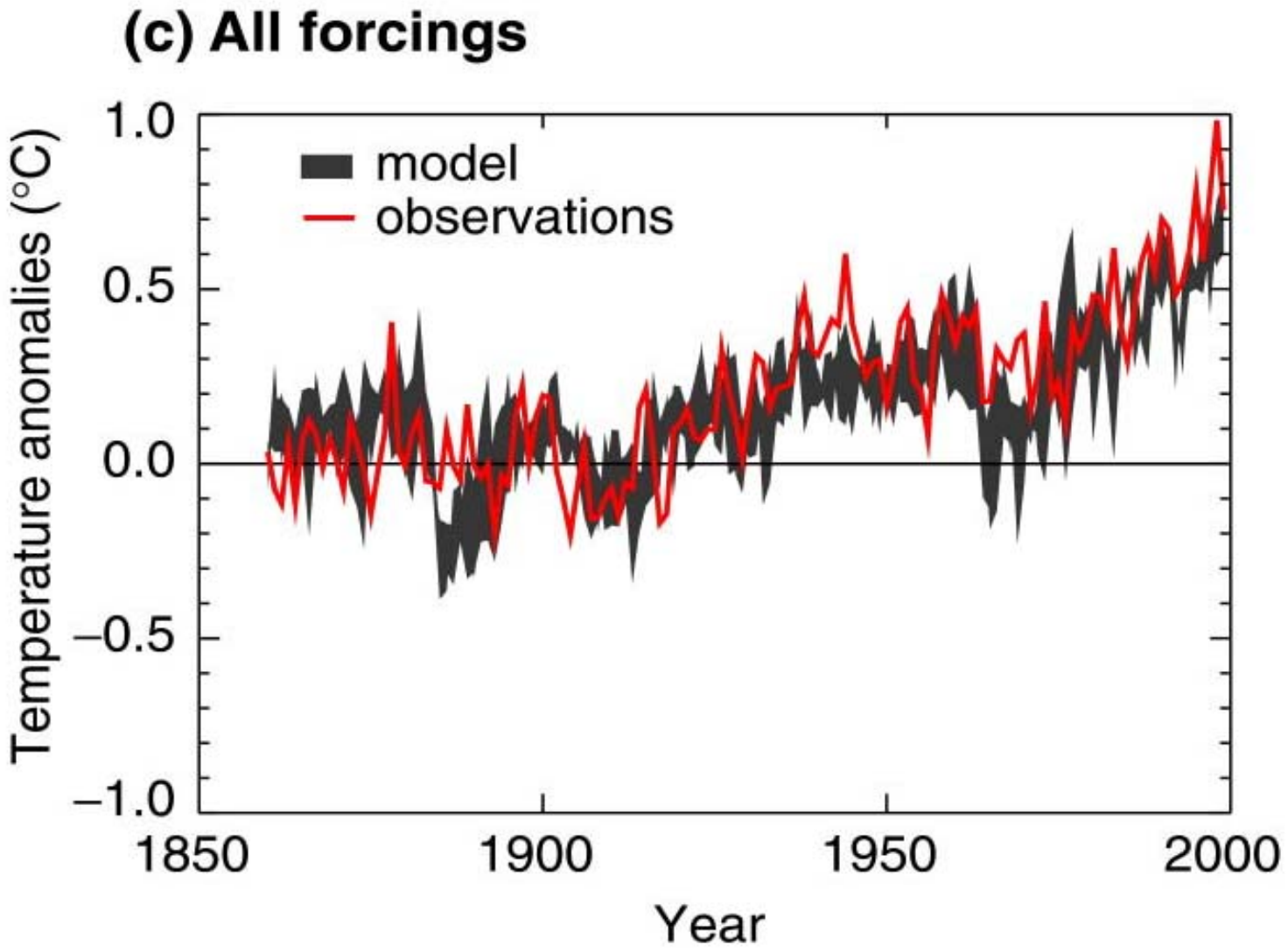
History

…This is in contrast with the present situation where 40% of the world's energy consumption is accounted for in buildings, for the most part struggling to provide an artificially uniform environment.

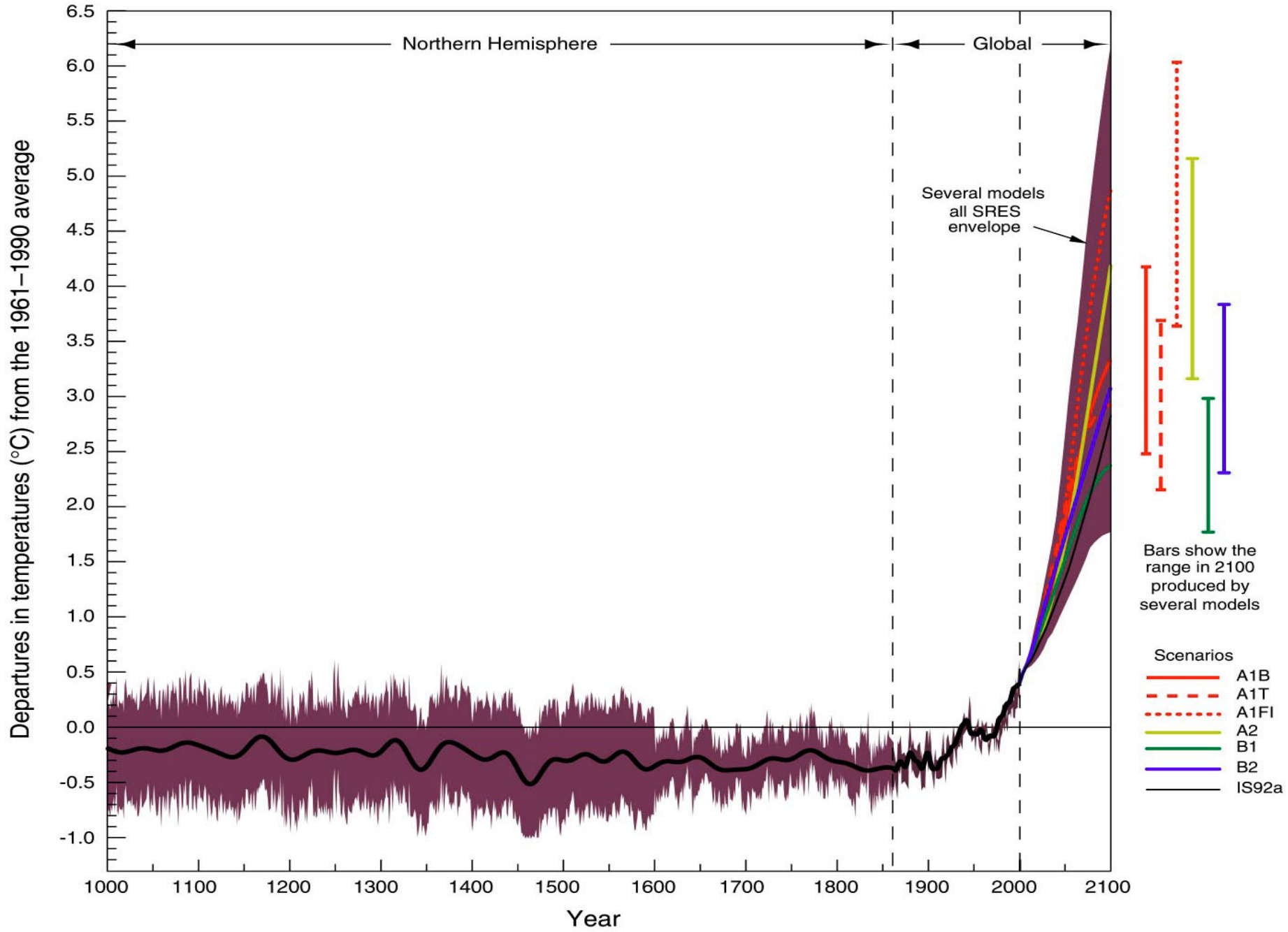


growth in world primary energy demand

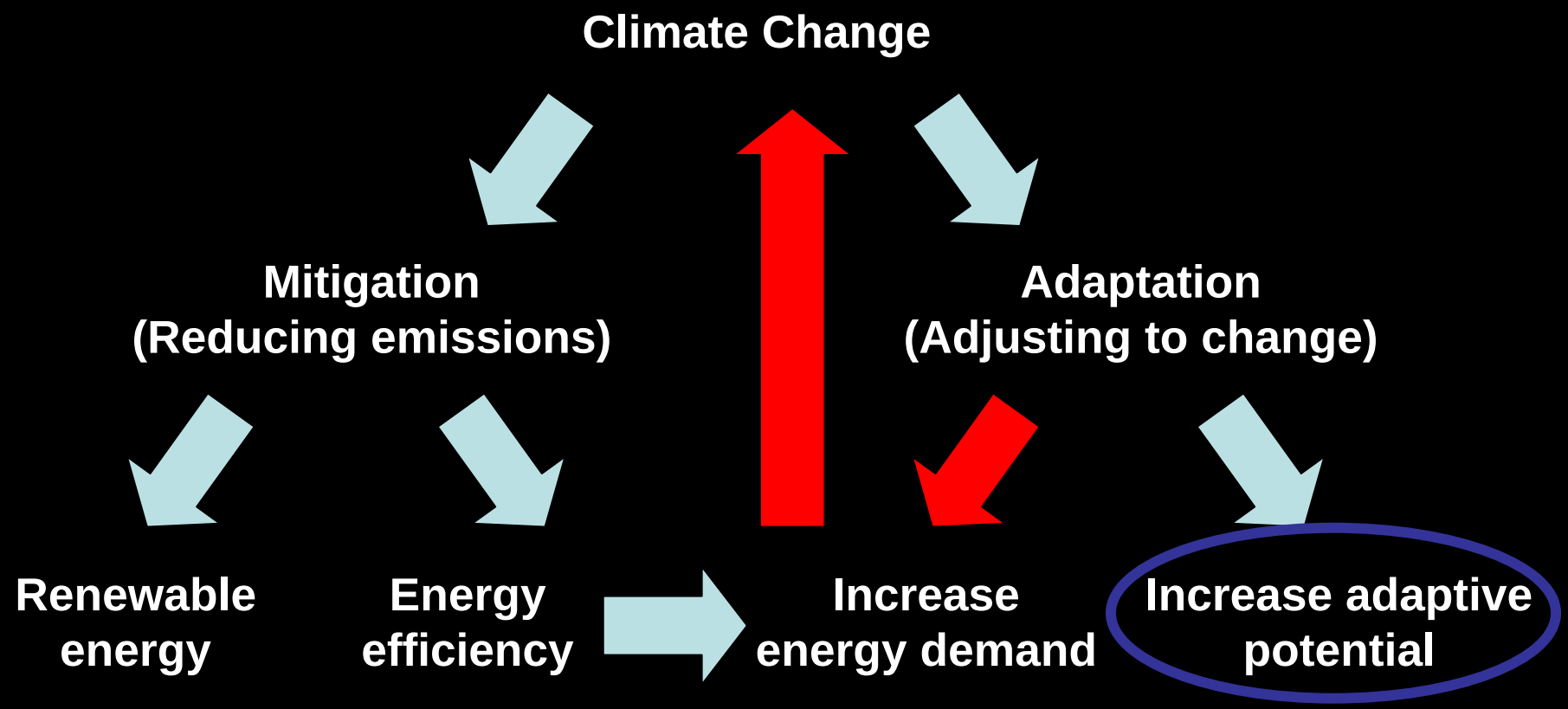
Climate Change



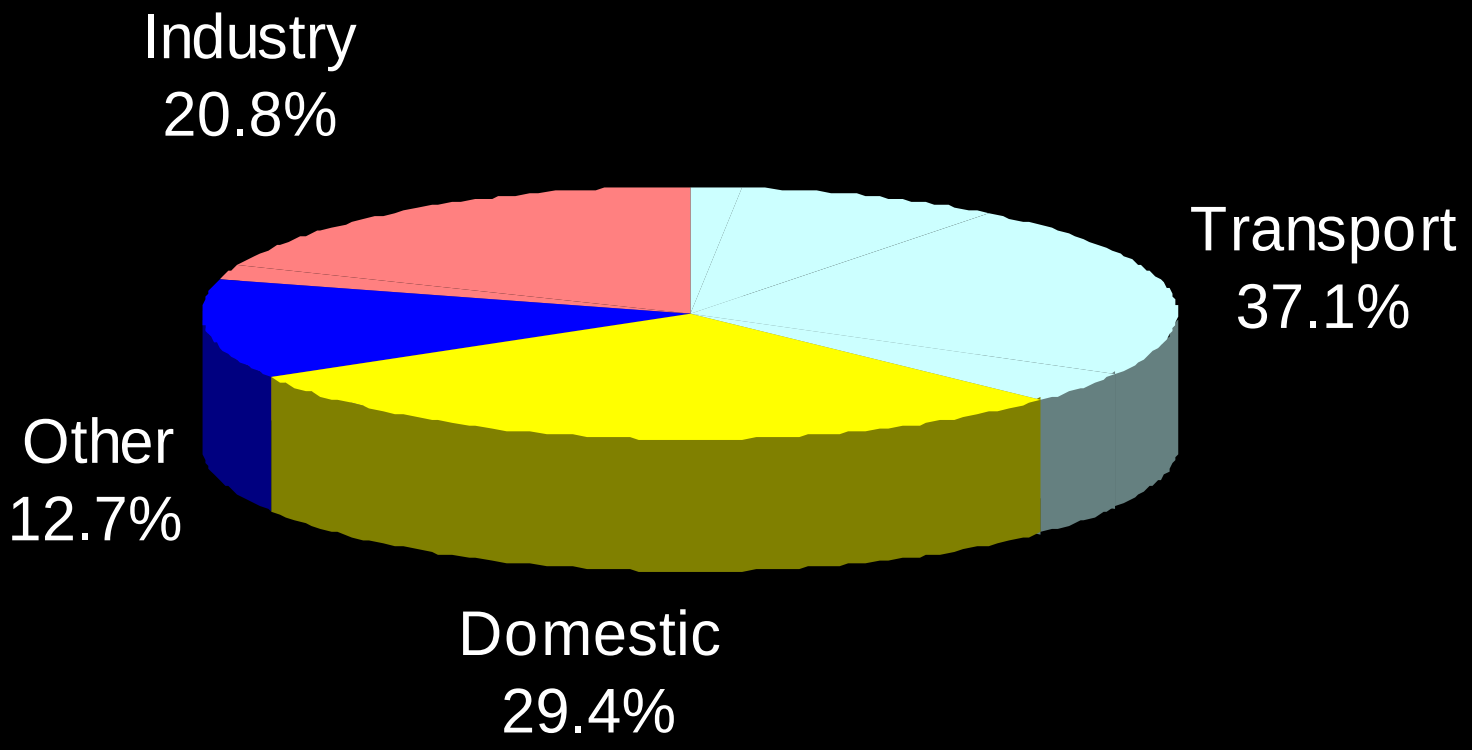
IPCC, 2006


1000 to 1861, N.Hemisphere, proxy data; 1861 to 2000 Global, instrumental; 2000 to 2100, SRES projections
Northern Hemisphere
Global
Several models
all SRES
envelope
Departures in temperatures (°C) from the 1961–1990 average
Year
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
Bars show the
range in 2100
produced by
several models
Scenarios
A1B
A1T
A1FI
A2
B1
B2
IS92a

The building design challenge:

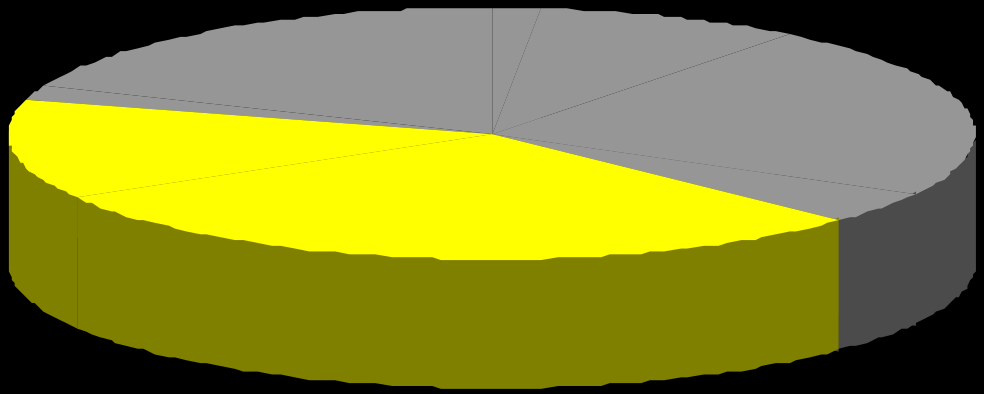


UK Energy Use



Digest of UK Energy Statistics, 2006

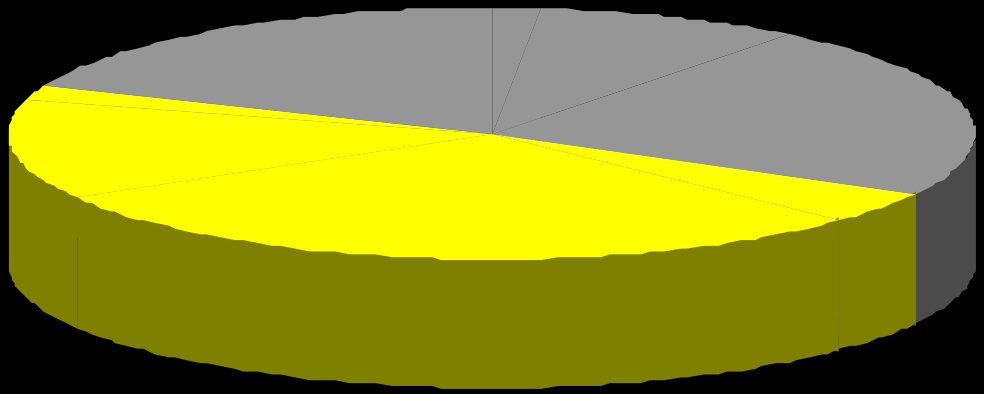
UK Energy Use



Buildings
42.3%

Digest of UK Energy Statistics, 2006

CO_2 Emissions

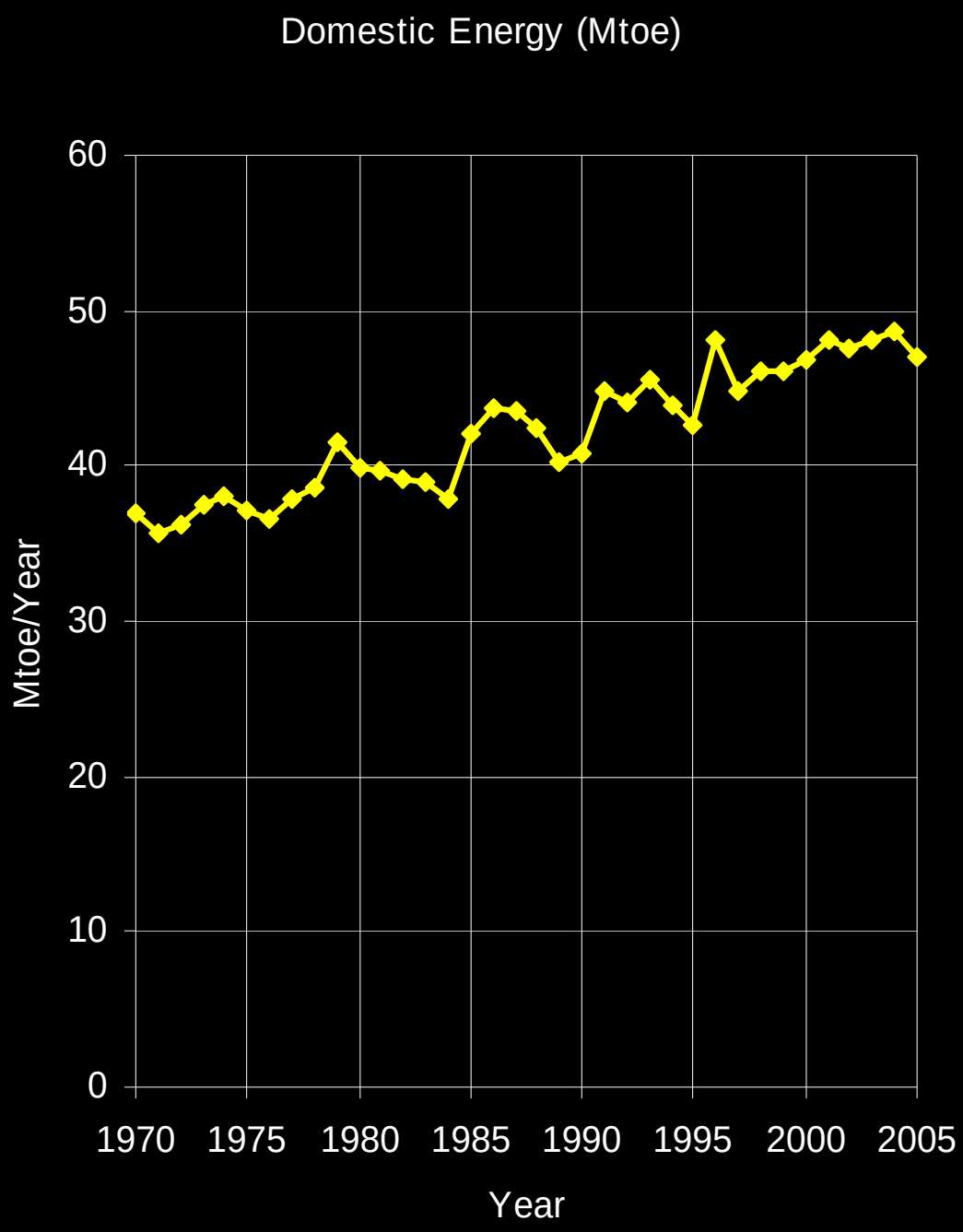


Buildings
47%

D. Vincent, Carbon Trust, 2007

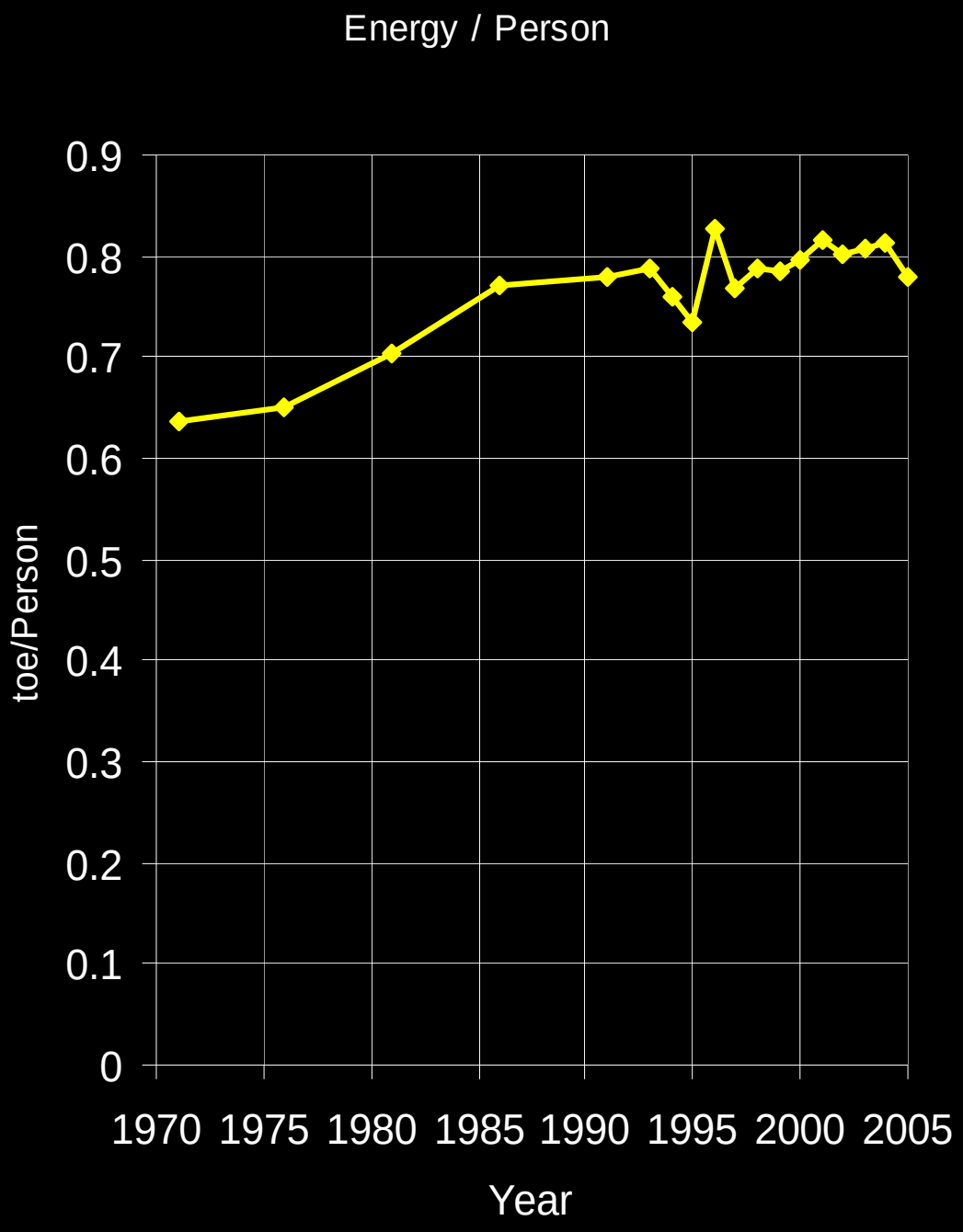
Domestic buildings

House for the future, Cardiff (Jestico + Whiles) – appropriate sustainable materials within affordable contemporary design, using local materials



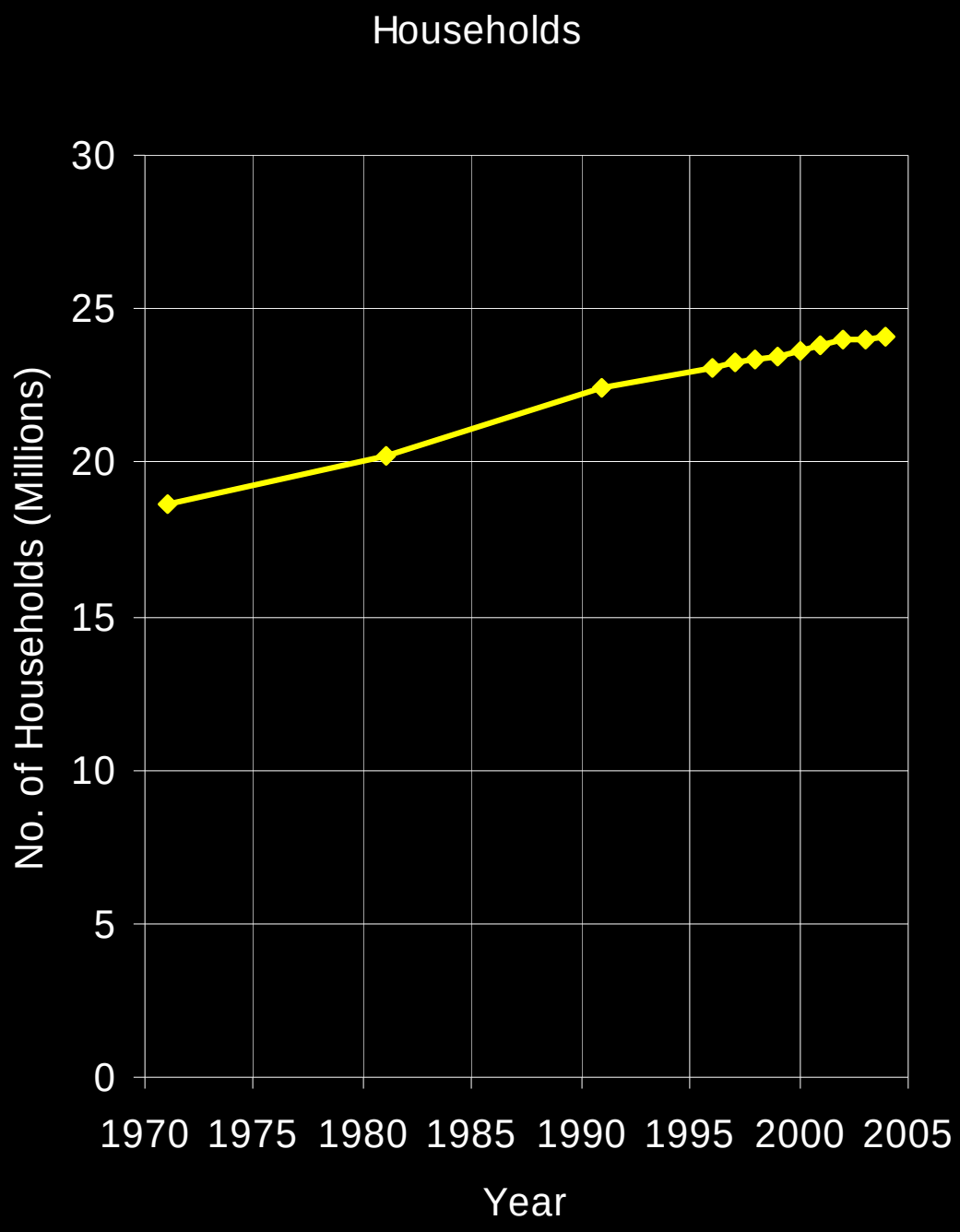
Domestic energy demand continues to increase, although the 'dash for gas' has limited the CO_2 emissions.

Digest of UK Energy Statistics, 2006



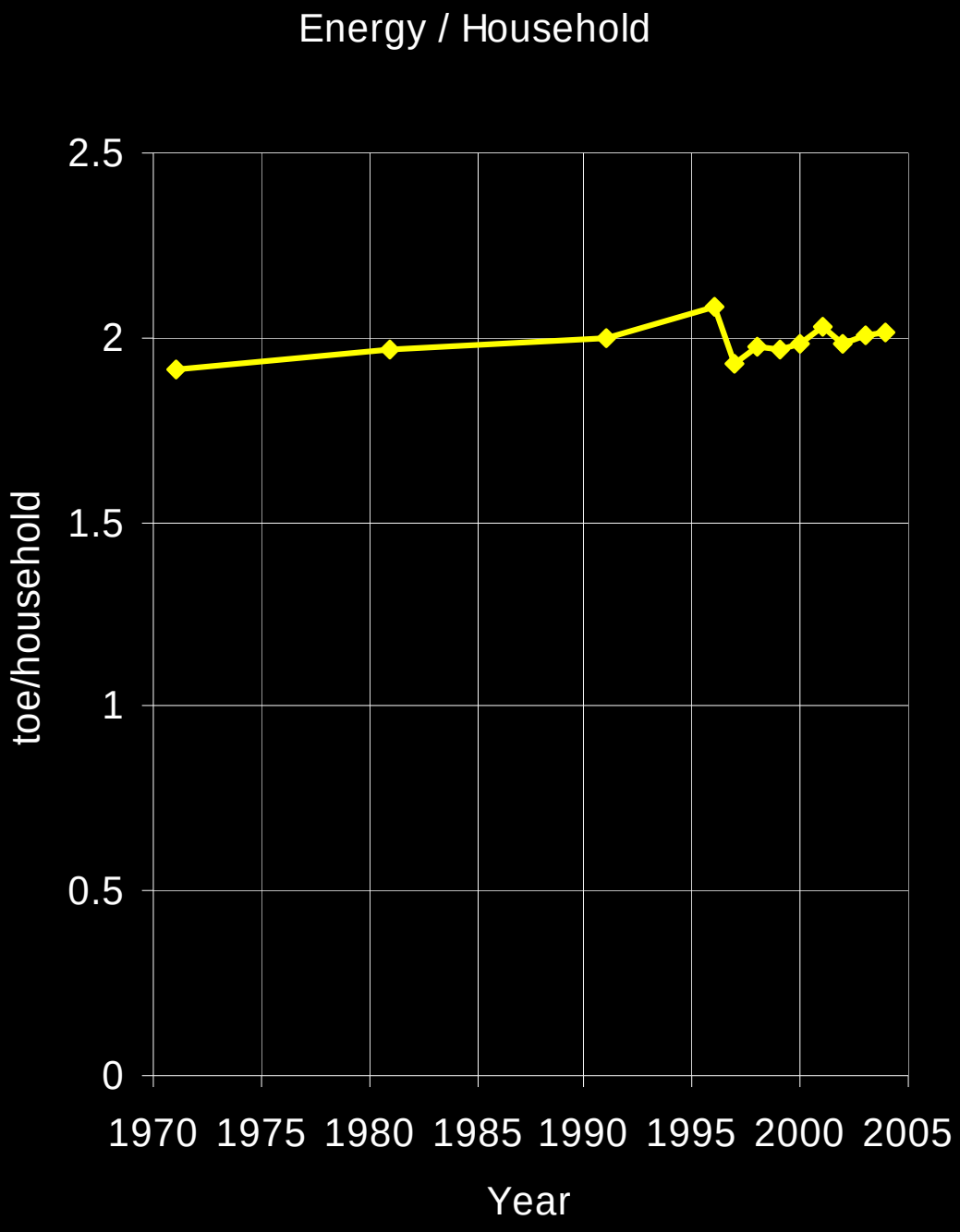
Energy demand per person also continues to increase (so energy increase is not attributable to population increase).

Digest of UK Energy Statistics, 2006 and Office of National Statistics, 2006



The number of households is growing due to demographics: Household size has reduced (i.e. number of people per household has reduced).

Office of National Statistics, 2006



Domestic energy demand per household remains flat, despite large increase in energy efficiency.

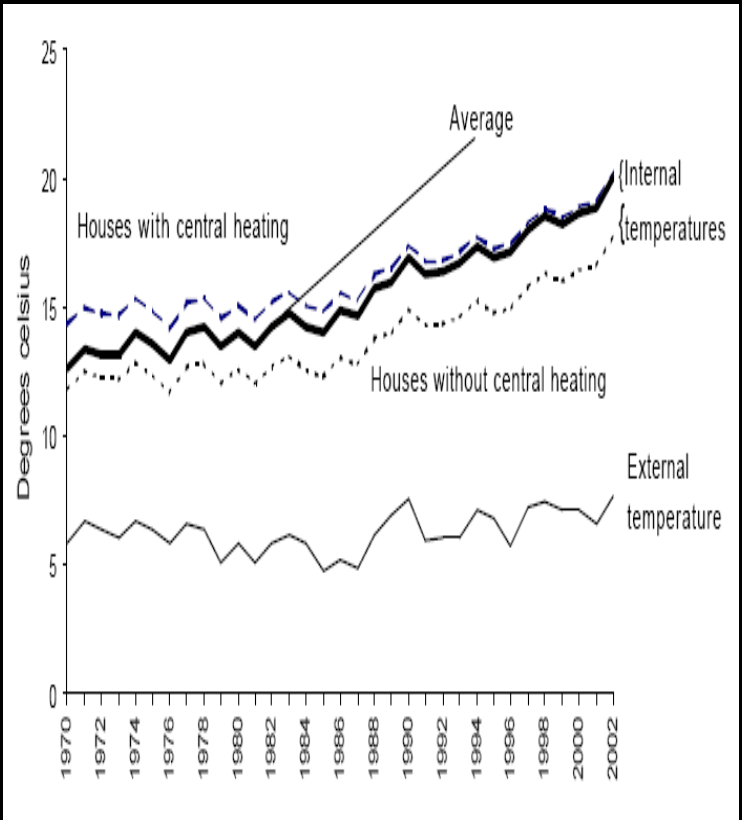
Wall insulation:
- 2% in 1974
- 37% in 2004

Double glazing:
- 8% in 1974
- 83% in 2004

Digest of UK Energy Statistics, 2006 and Office of National Statistics, 2006

Explanations:

1. Increased comfort expectations (average household temperatures have increased from 12 ^{o}C in 1970 to 18 ^{o}C now)



This internal temperature increase of 6 ^{o}C equates to more than a doubling of heating energy use

(communication with Lowe, 2007 / SAP, 2005)

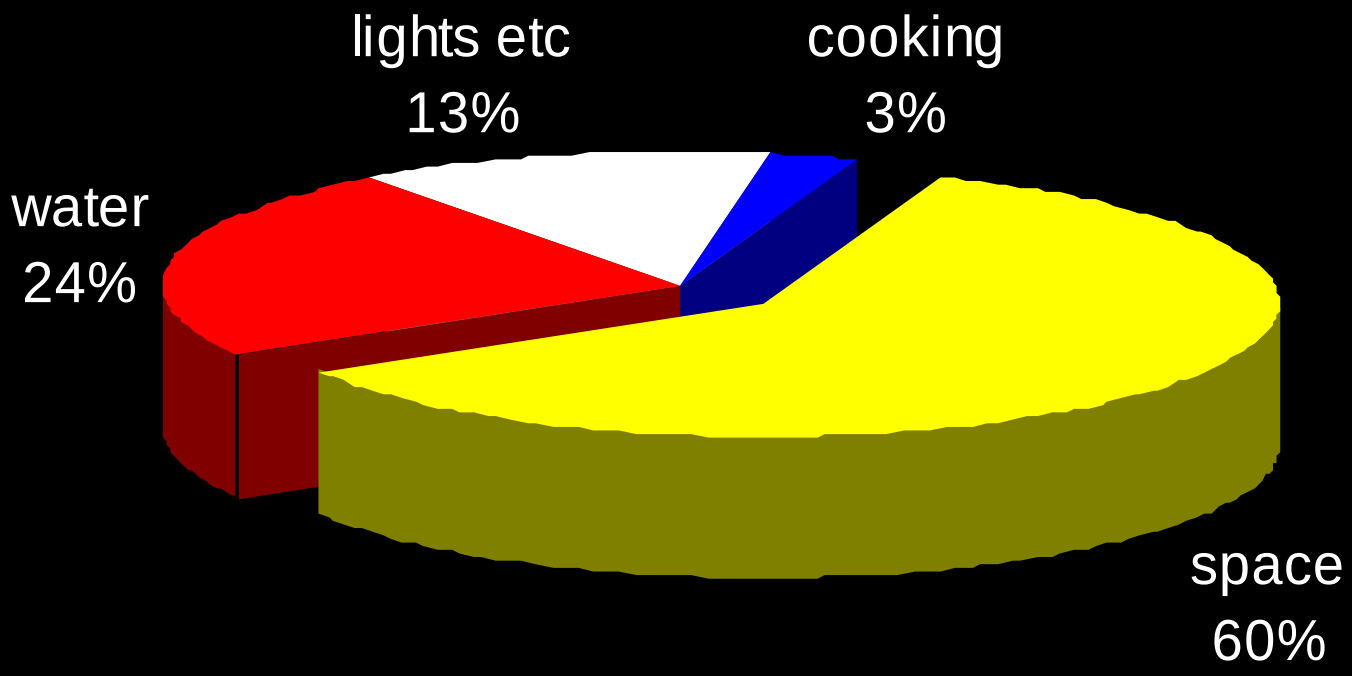
BRE, Domestic Energy Fact File, 2006

Explanations (cont.):

2. Household size and numbers (i.e. increased sqm / person)

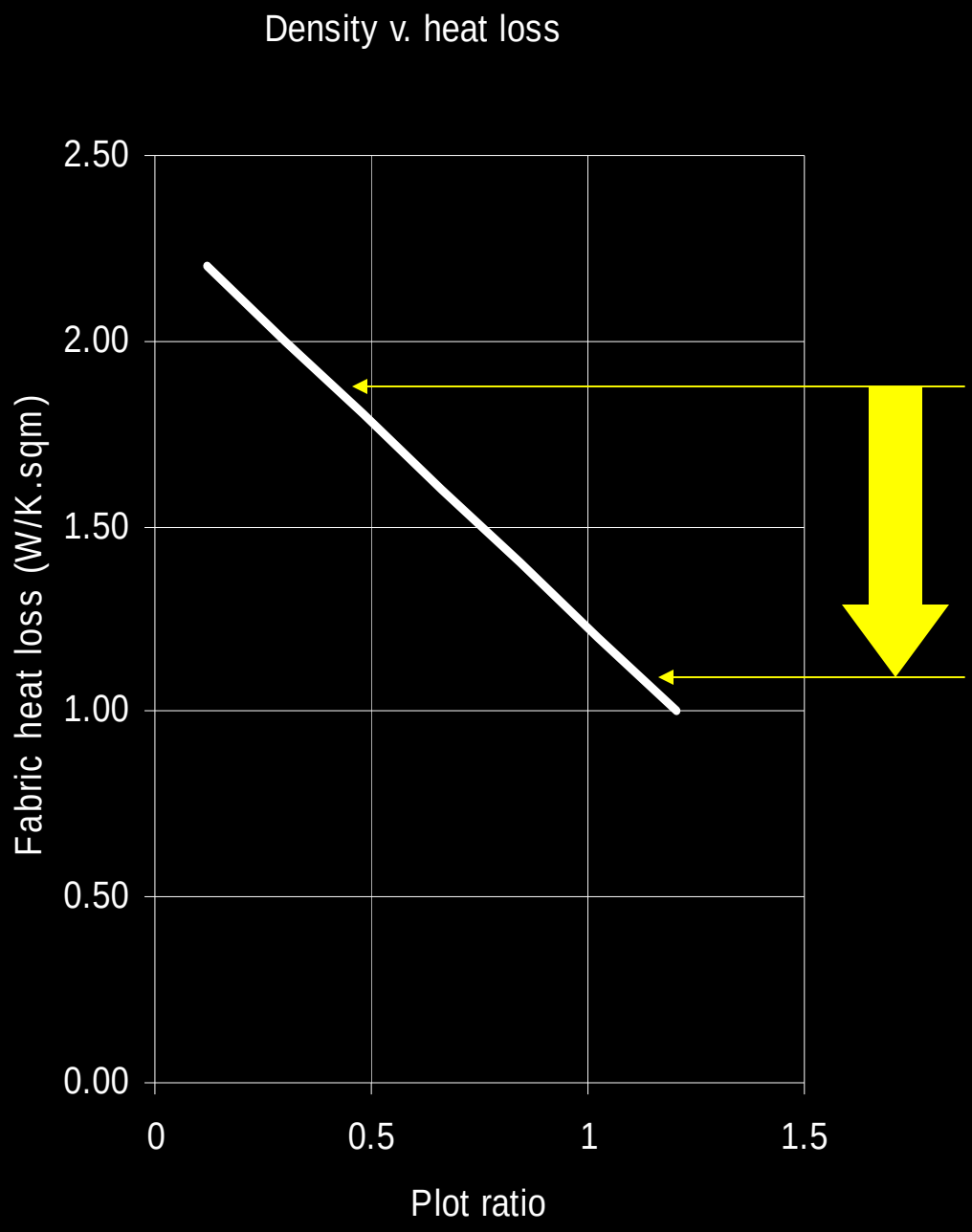
3. Household type (e.g. 52% increase in detached houses since 1971, with greater surface to volume ratio)

4. Disposable income (e.g. 40% increase since 1990) which results in more appliances



BRE, Domestic Energy Fact File, 2006

1. More compact design



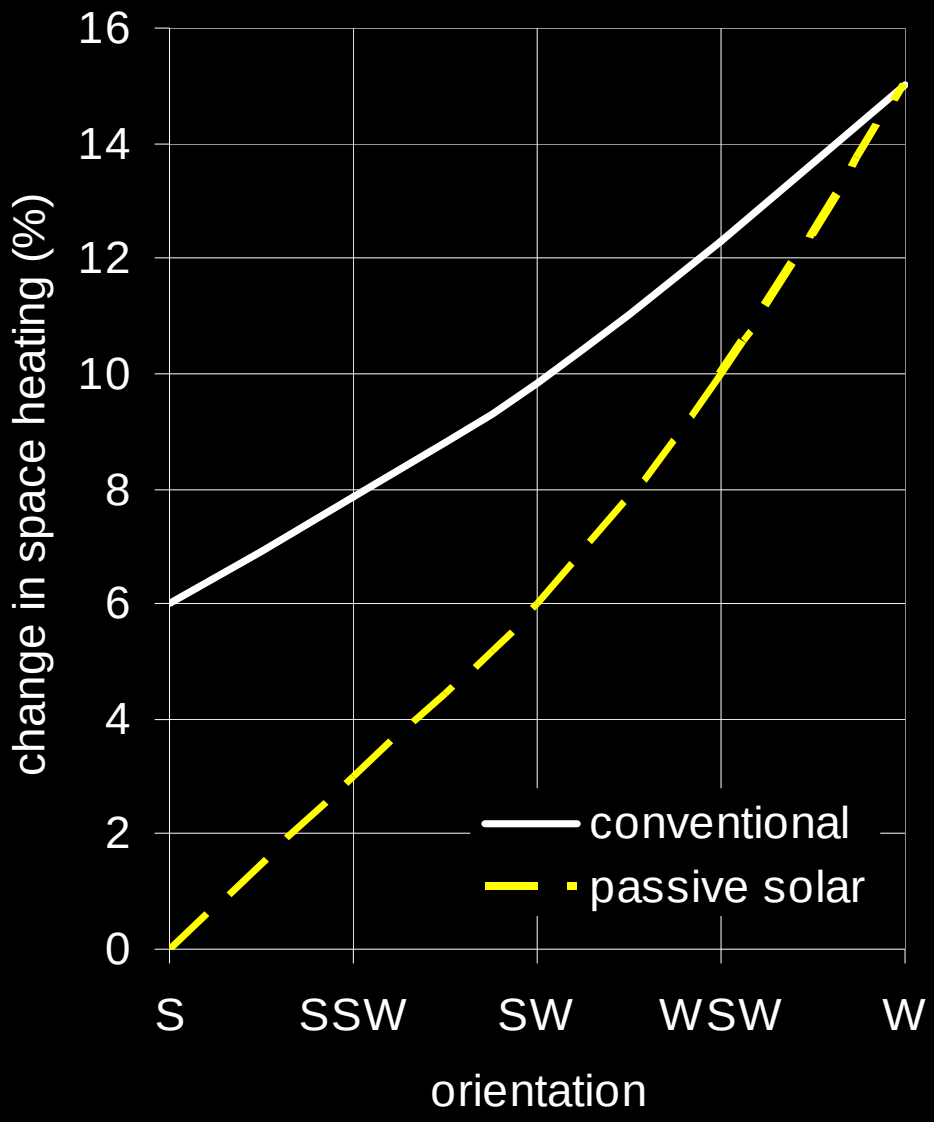
e.g. Detached house

40% reduction

e.g. Apartment

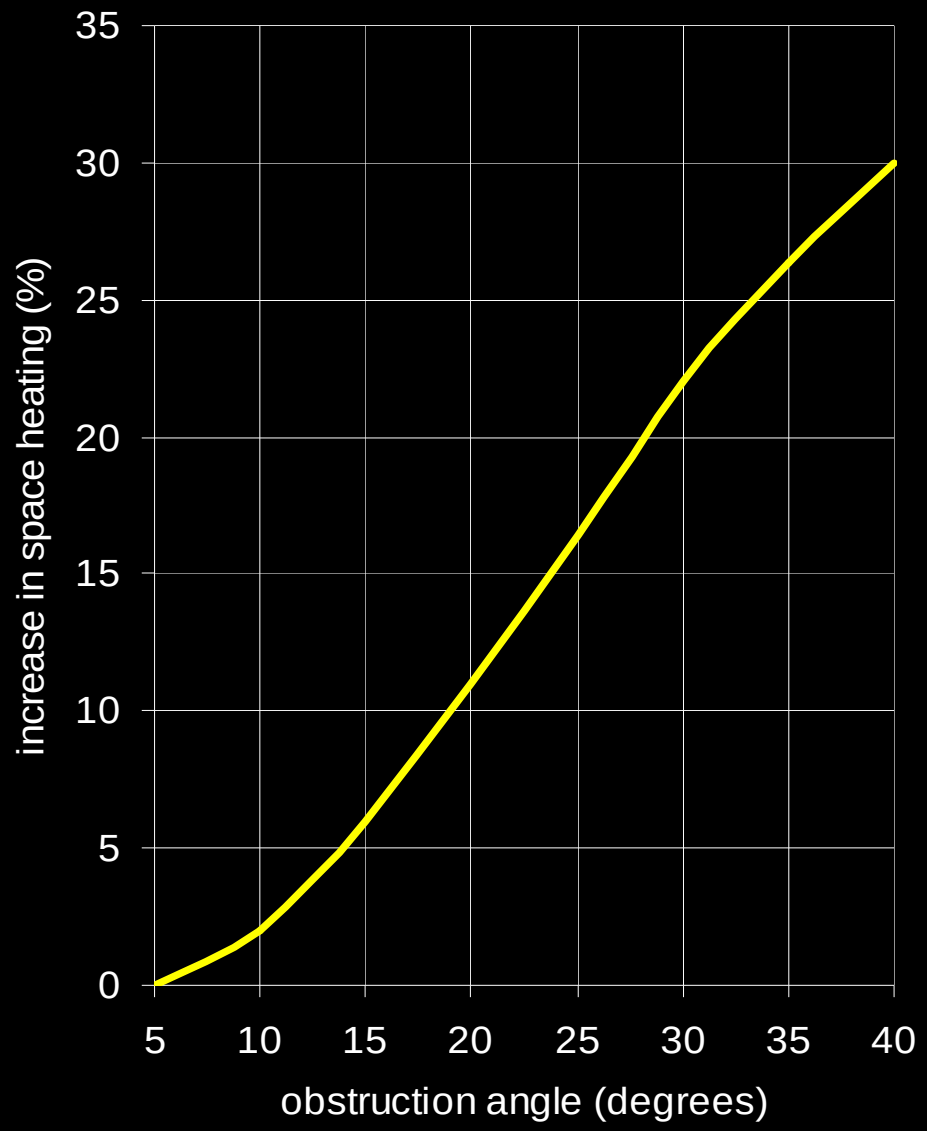
‘Compact’ housing can save energy (although this difference becomes less significant as insulation levels rise).
Compact city = energy efficient city?

2. Design for solar gain



Solar orientation reduces energy, but this option is reduced in an urban environment.

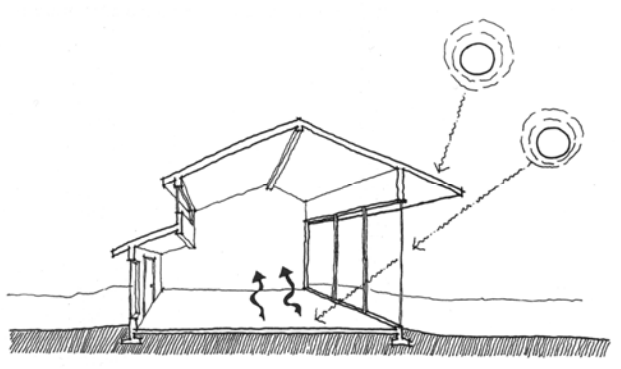
3. Increase access to sun and light



Obstructions increase energy demand (due to reduced sunlight and daylight). Urban density increases obstructions.

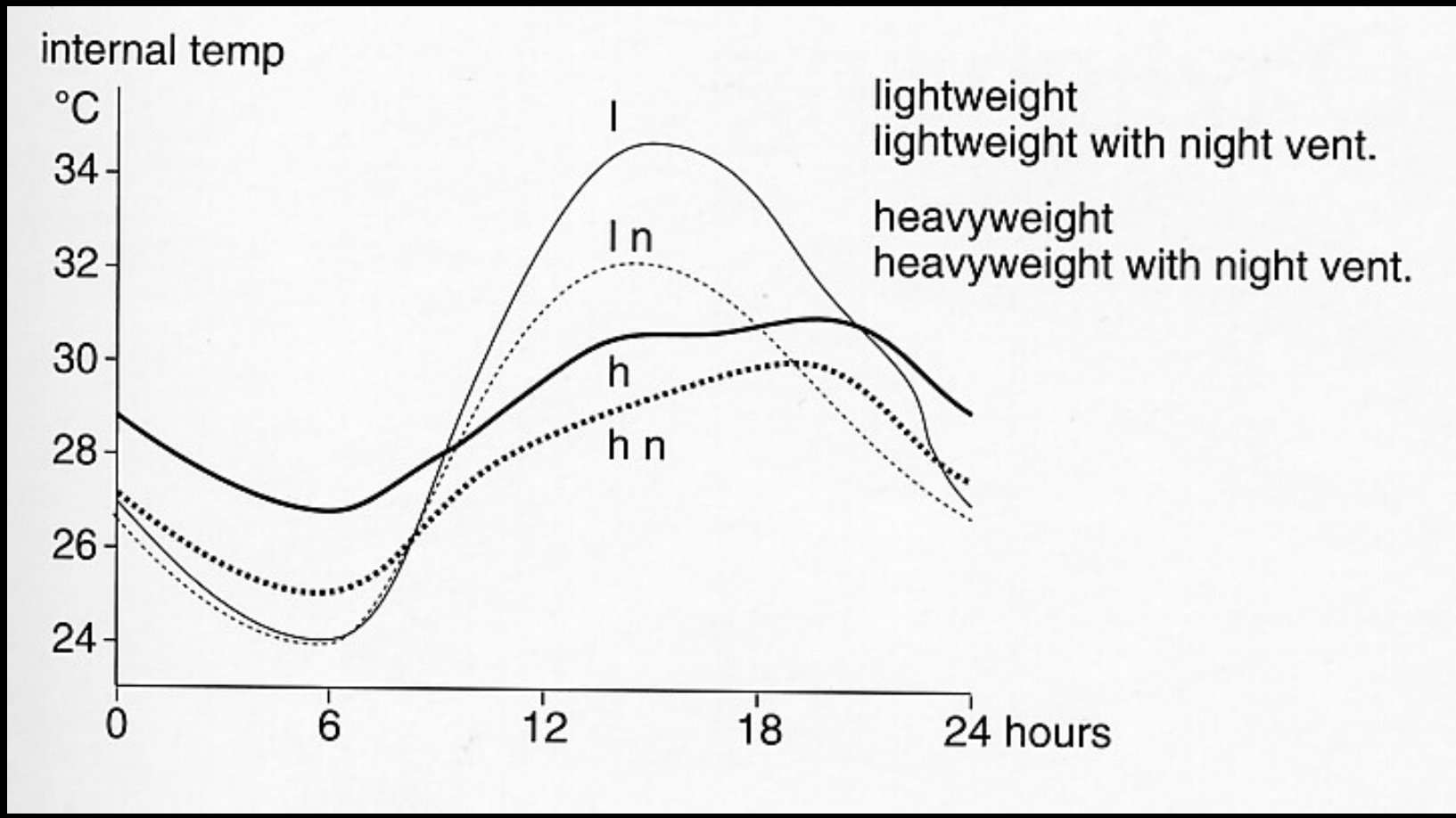
The thermal advantages of urban compaction can be offset by the disadvantages.

4. Design thermally robust passive buildings



4.125 Classic example of solar apertures, solar control, and thermal mass in the Shaw residence in Taos, New Mexico.

4. Design thermally robust passive buildings



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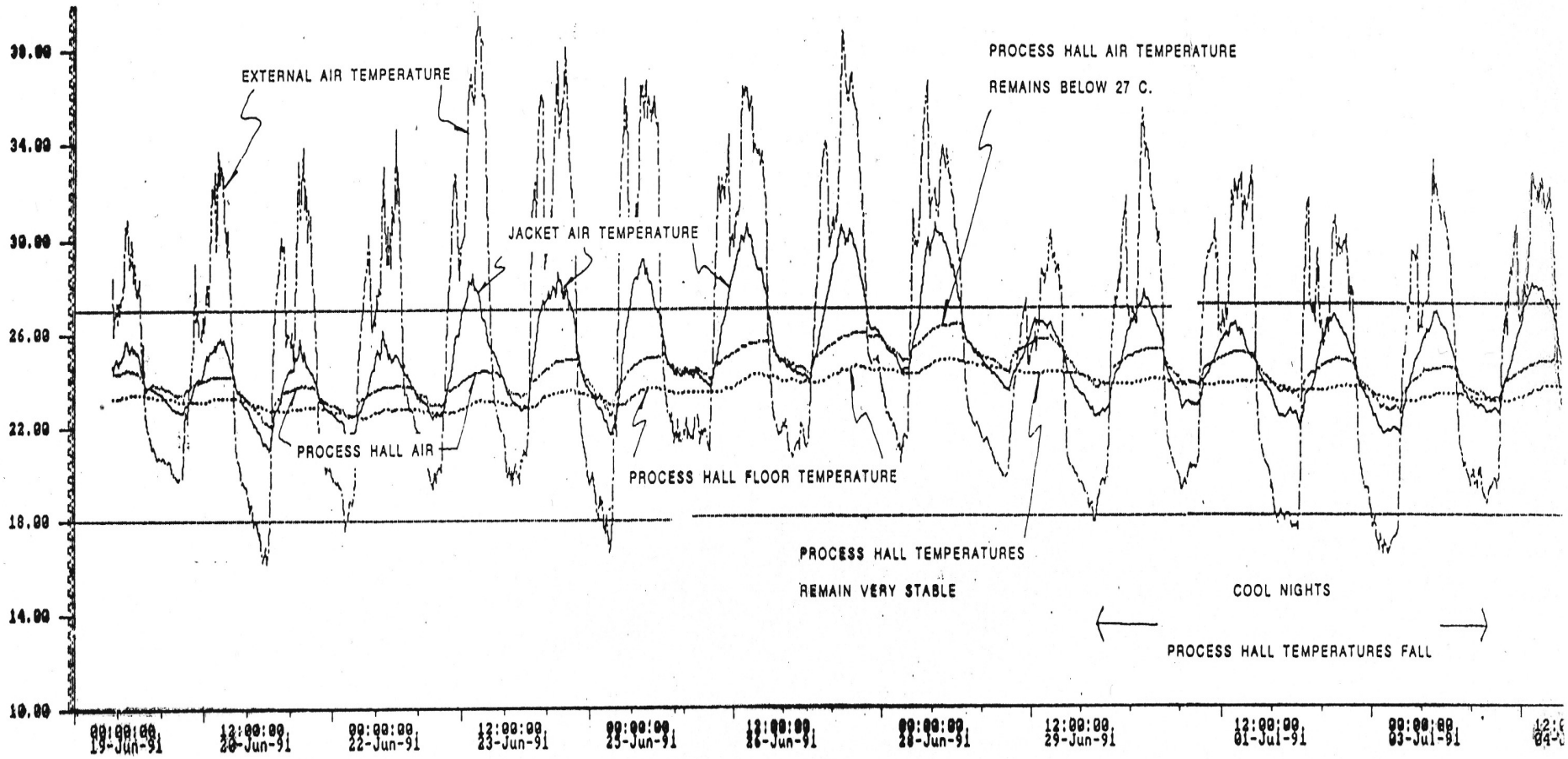
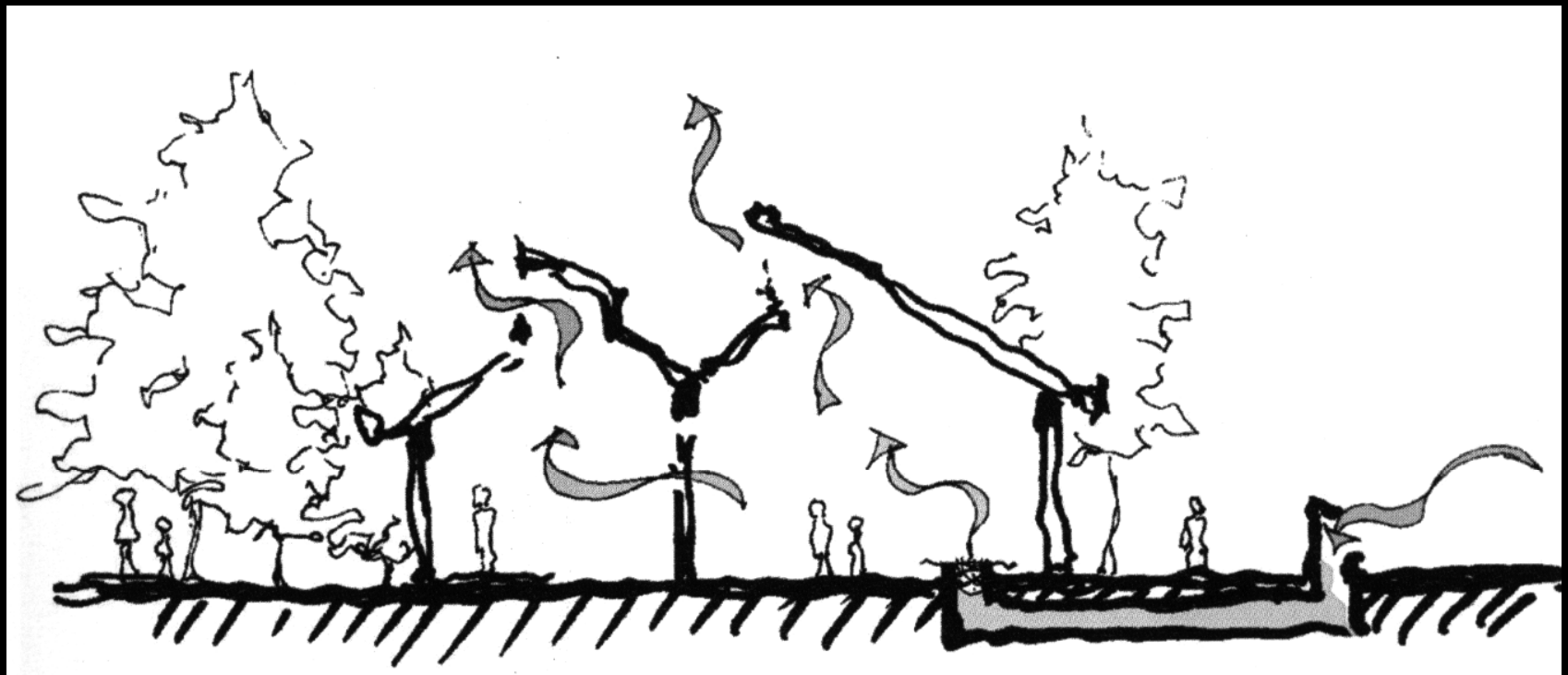


Fig. 3 RECORDED TEMPERATURES 19 JUNE - 11 JULY PROCESS BUILDING SFC BREWERY MALTA

4. Design thermally robust passive buildings – earth ducts



4.186 Schematic diagram showing an open loop cooling tube configuration, assisted by stack effect ventilation. The length of the cooling tube is greatly understated in this sketch.

KATE BECKLEY

4. Design thermally robust passive buildings – PCM

e.g. **Dupont (UK) Ltd**
“A thermal mass panel with energy saving and temperature control properties has been launched by DuPont Building Innovations. Energain is a lightweight panel of 5mm thickness, composed of a 'phase change material' made from paraffin in a DuPont copolymer at a 60-40% ratio and laminated on either side in an aluminium sheet. Panels are supplied in 1.2m by 1.2m dimensions. An aluminium tape is required to seal joins between panels and repair abrasions.

It works by employing the capability of the phase change material to absorb and release heat. The compound has a melt point of 22?C, at which stage it begins to absorb heat from the room and to store it. When the internal temperature drops back to 18?C, it re-solidifies and releases heat back into the room.

It has been designed to be installed behind the plasterboard lining on the interior walls and ceilings of lightweight structures such as timber, steel or aluminium framed buildings. ”

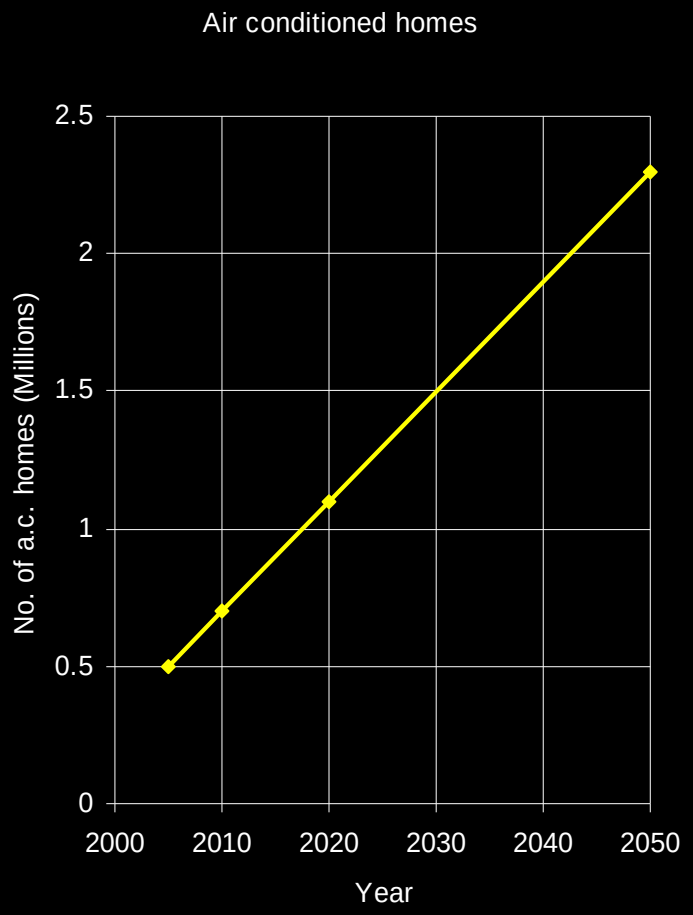
4. Design thermally robust passive buildings – advantages v disadvantages

	Advantages	Disadvantages
Heavy weight	Stable and more comfortable temperatures	Slow response – reacts slowly to heating input
	Potential to increase useful solar gain to reduce energy demand	Potential increase in embodied and running energy
	Robust – thermally, acoustically, physically	Slower to build and less adaptable – cost implications?
Light weight	Quick response - energy used only when occupied	Risk of overheating increased (increase in a.c.)
	Potential for low embodied energy	Less robust (physically, to CC effects, shorter life?)
	Rapid, flexible, offsite construction	Fast–response heating required

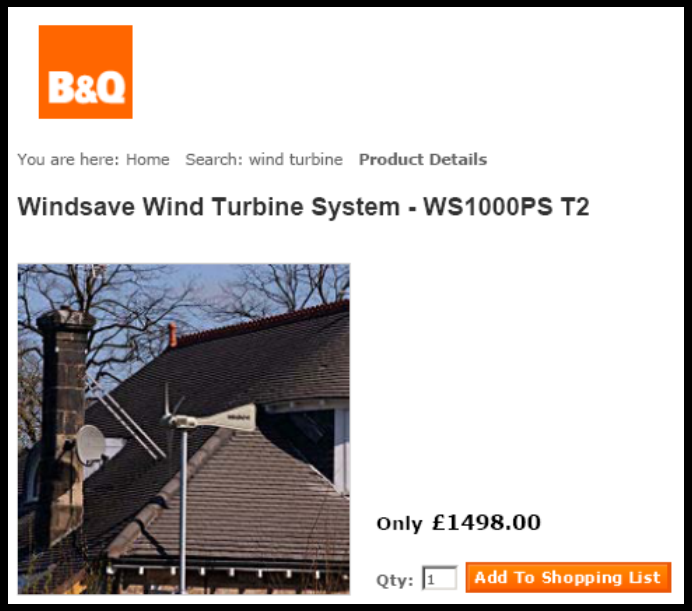
5. Avoid or limit air conditioning

Domestic air conditioning is expected to increase, and can double the electricity consumption, due to:

- Hot periods as climate change affects UK
- Heat island effect in urban areas
- Noise and pollution in urban areas
- Rising expectations (air conditioned cars (50%), offices and hotels)
- More advertising and lower prices of air conditioning units



Morley, House of Commons Hansard, 7 June, 2005



"The favourable weather conditions during the summer of 2003 boosted air conditioning sales in the lower end of the market" (Alvaro, Modern Building Services, 2004)

"We need to start removing our industry's obsession with domestic air conditioning and act responsibly by looking at what is needed rather than simply trying to drive up sales" (Daw, MBS, 2007)

Domestic a.c. won’t happen in the UK?

In the USA in 1951, virtually no homes had air conditioning

In the USA in 2001, 76% of homes had some form of air conditioning

In the UK in 1951, virtually no homes had central heating

In the UK in 2001, 85% of homes had some form of central heating

In 2005 the percentage of homes in the UK with air conditioning is thought to be around 2%...

Waide, House of Commons Hansard, 7 June 2005

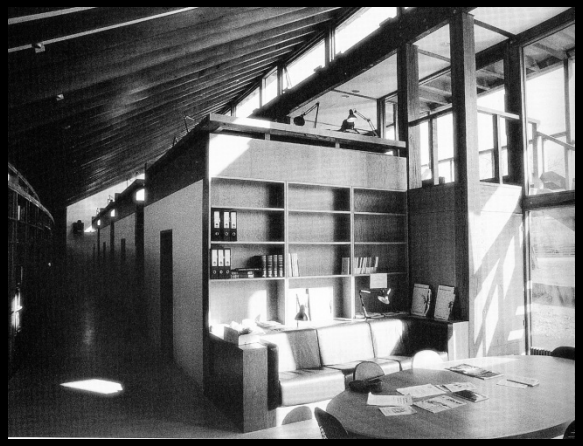
Adaptable design

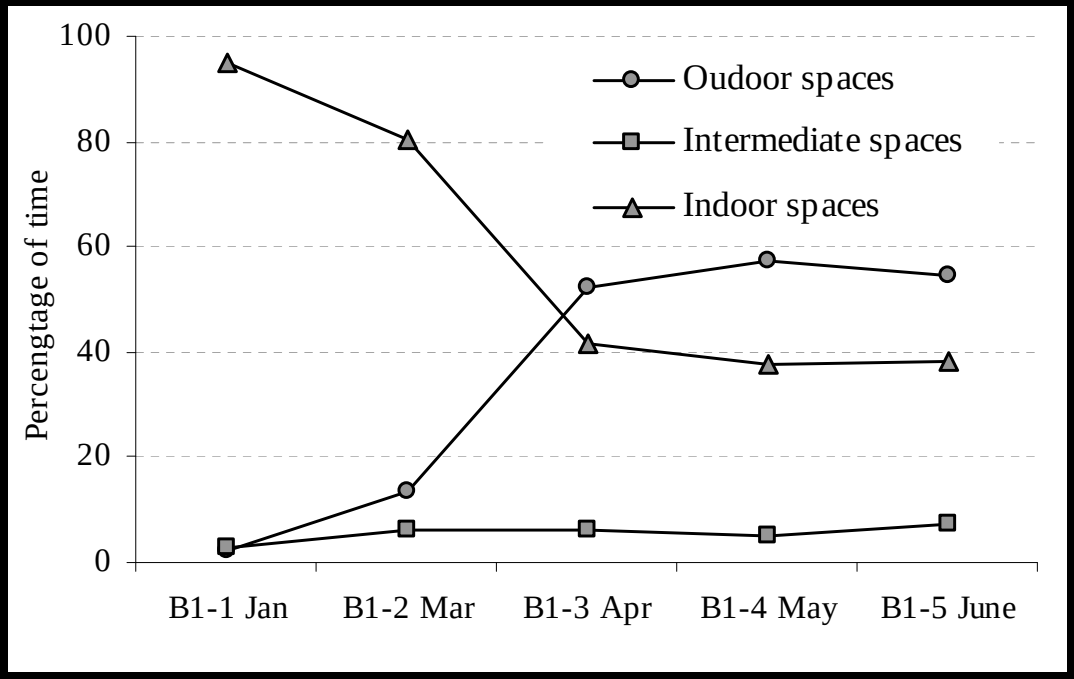
“Most higher organisms engage in an active process of seeking variability if not found in the immediate surrounding” *Parr*

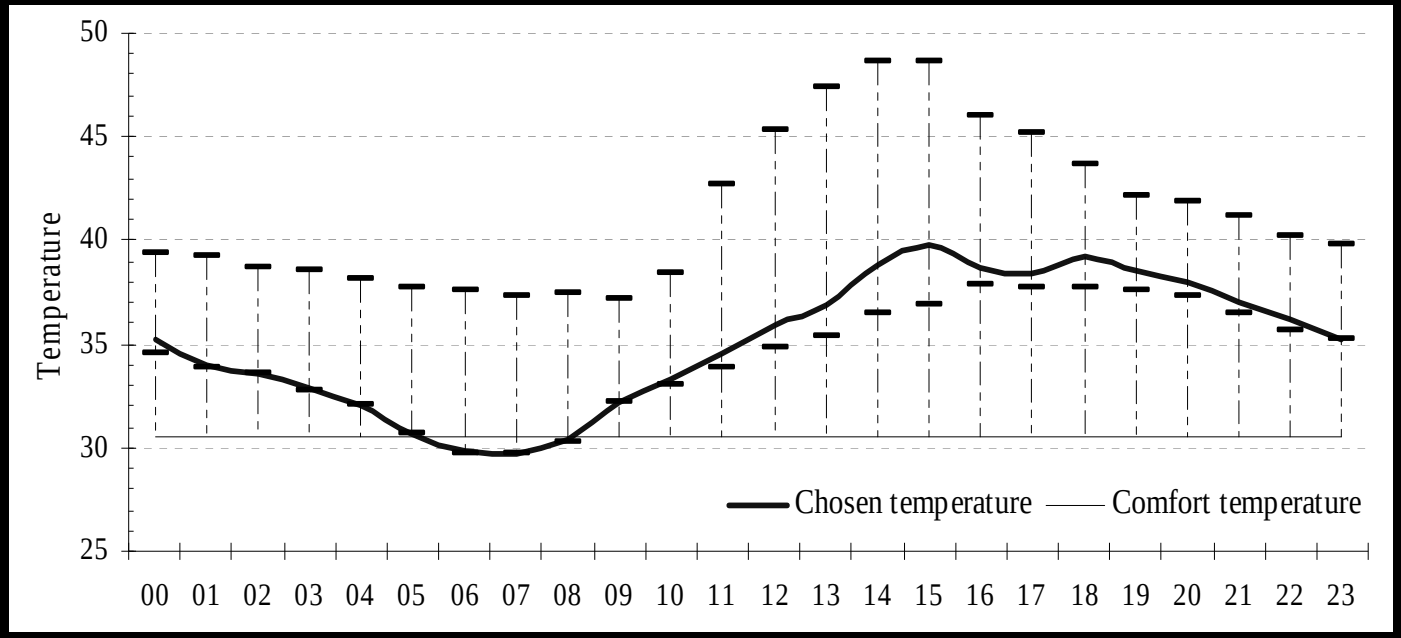
“In any situational context, the individual attempts to organise his physical environment so that it maximises his freedom of choice” *Proshansky, Ittelson and Rivlin*

Gabriel Poole’s House

Spatial adaptation







Adaptive comfort

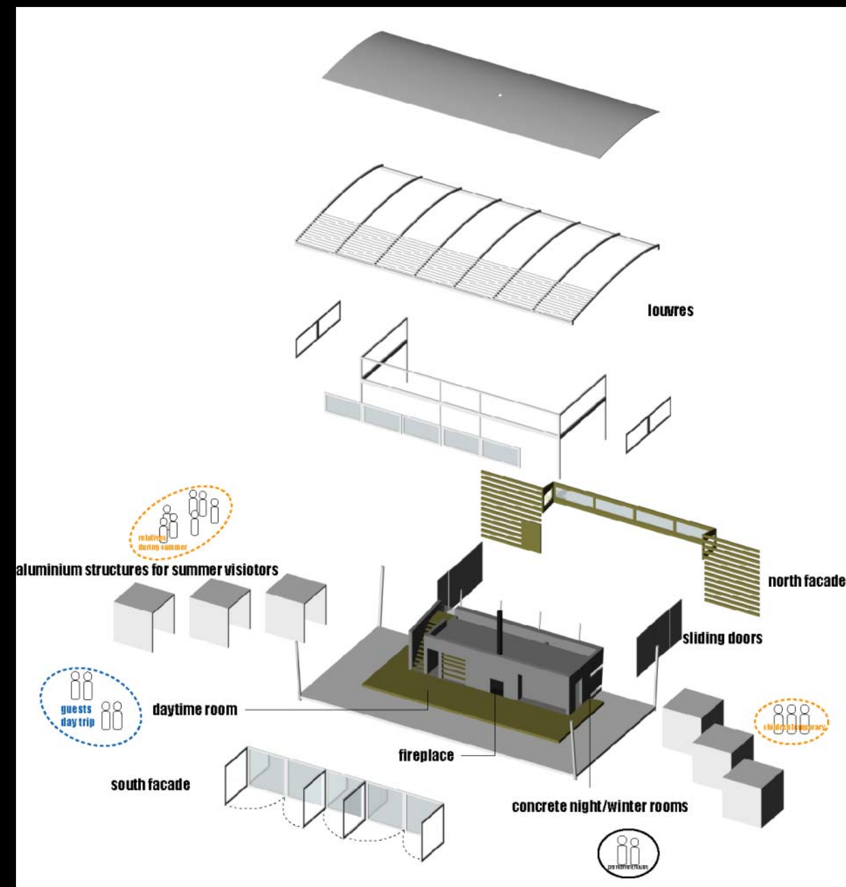
The range and accumulation of adaptive opportunities available significantly improves physiological comfort.

	base case	adapted case
air temp	30.5	28.0
rad temp	30.5	28.0
air speed	0.1	0.2
clo	0.5	0.4
met	1.2	1.1
Discomfort (PPD)	**68.4%**	**17.5%**

Baker and Standeven, 1996

Denmark

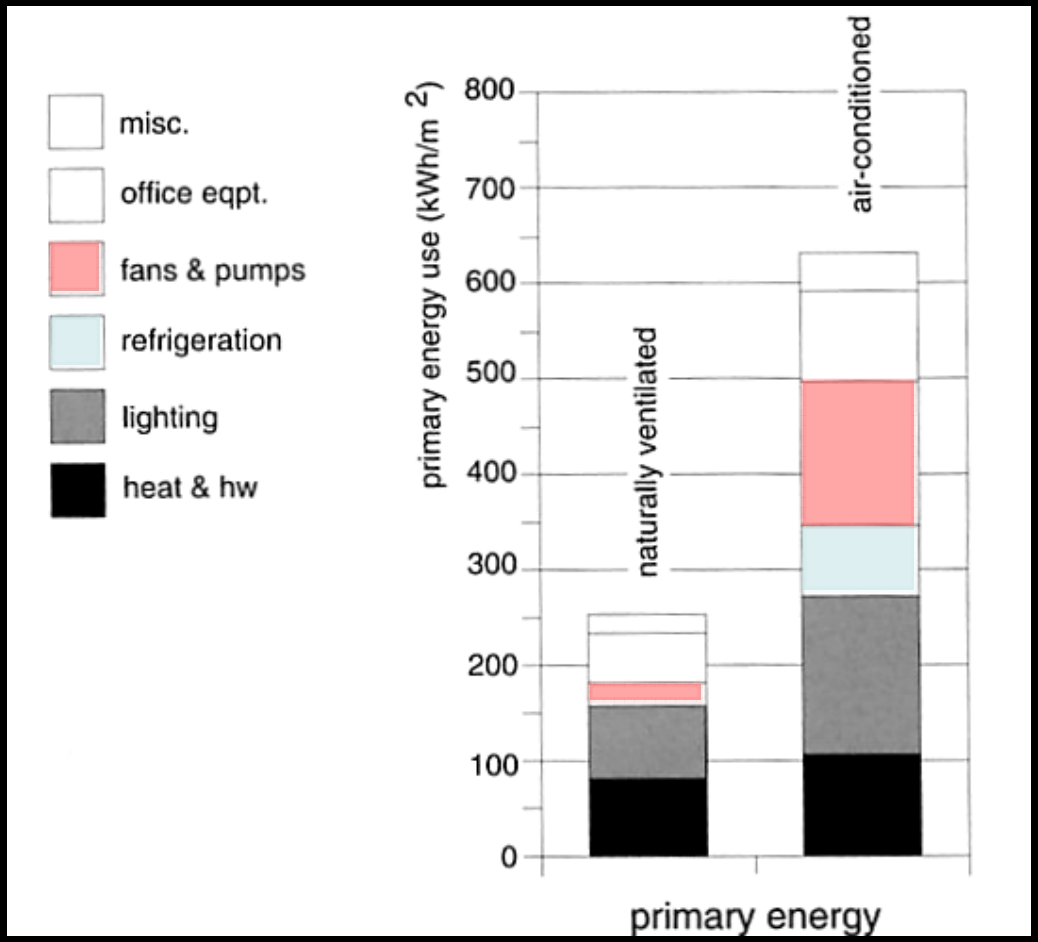
Japan




STOP

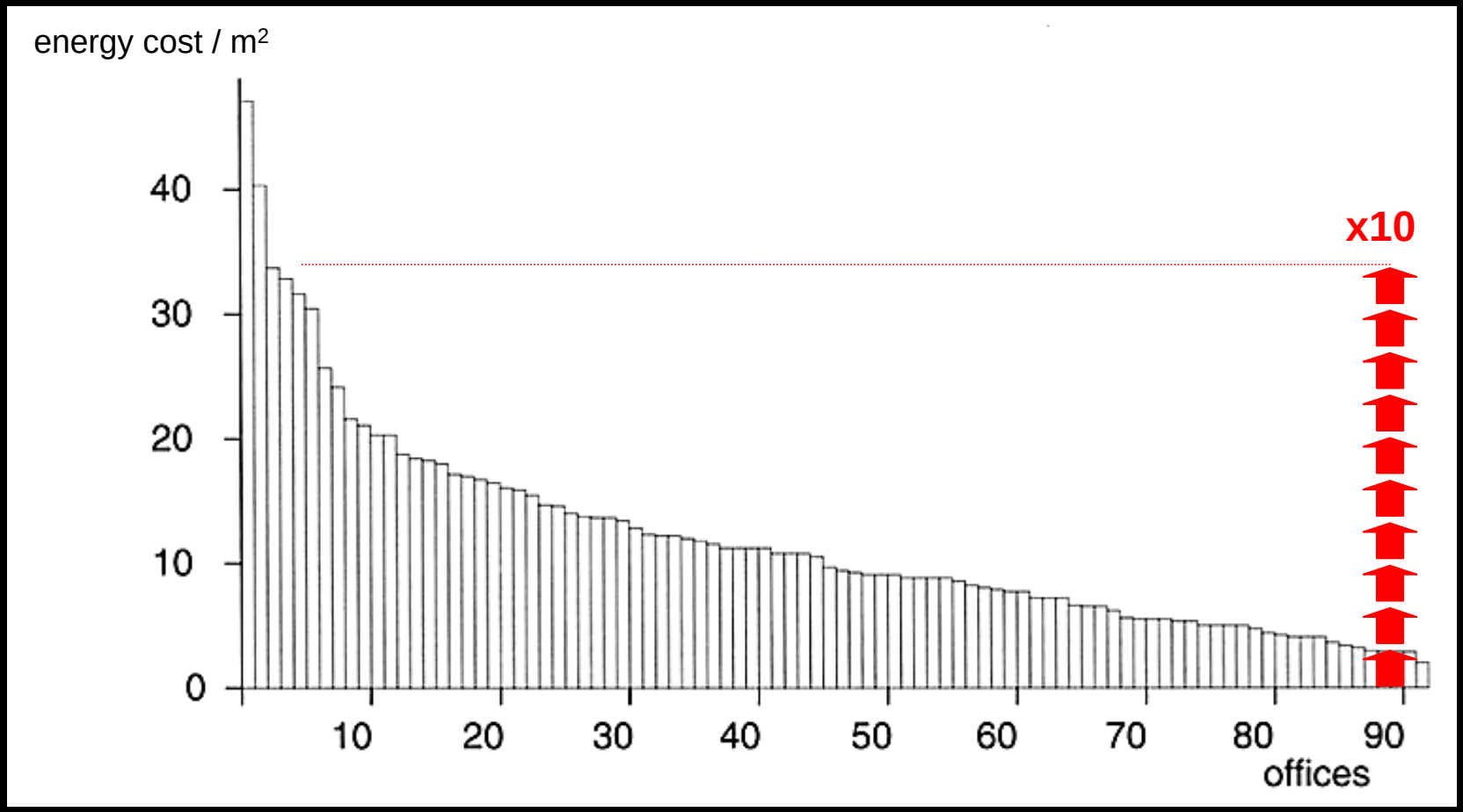
Office buildings

Non-Domestic Energy Use



Baker and Steemers, 2000

Non-Domestic Energy Use



Action Energy, 2003 (1993)

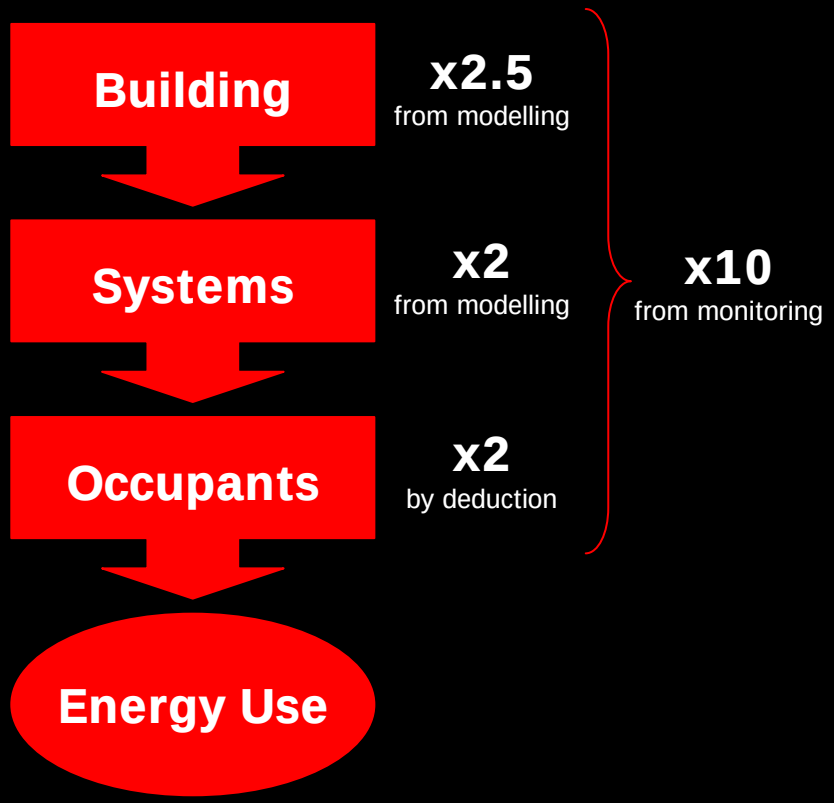
Key energy factors

Factors affecting energy use:

Building design
(long term: 30-60 yrs)

Services and systems
(med. term: 7-25 yrs)

Occupants / commissioning / building managers
(short term: 1-10 yrs)



Baker and Steemers, 2000

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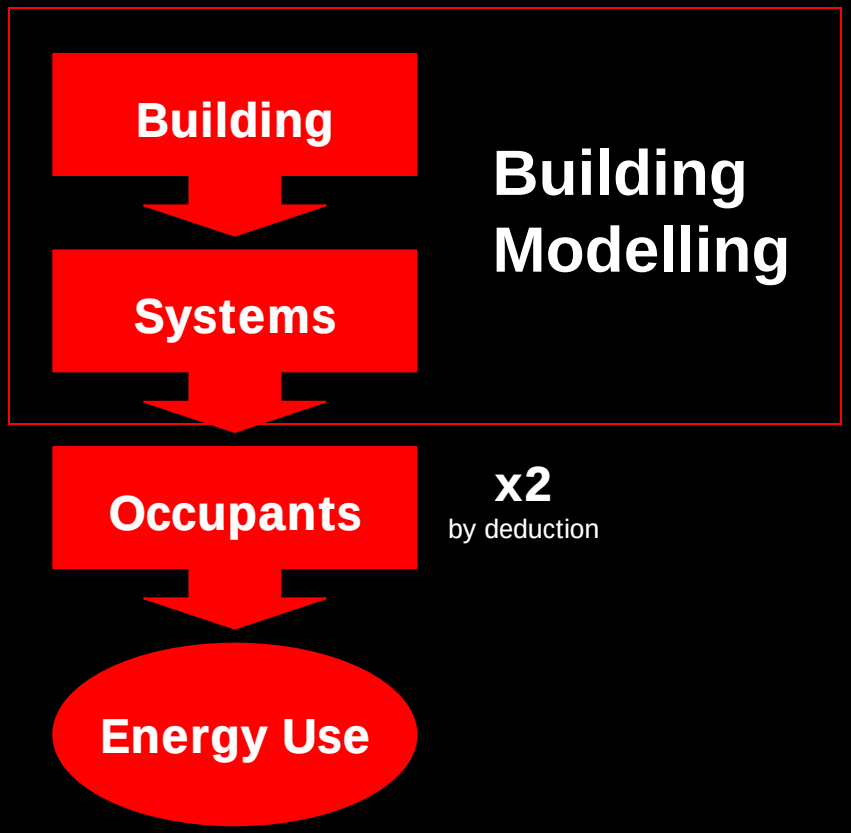


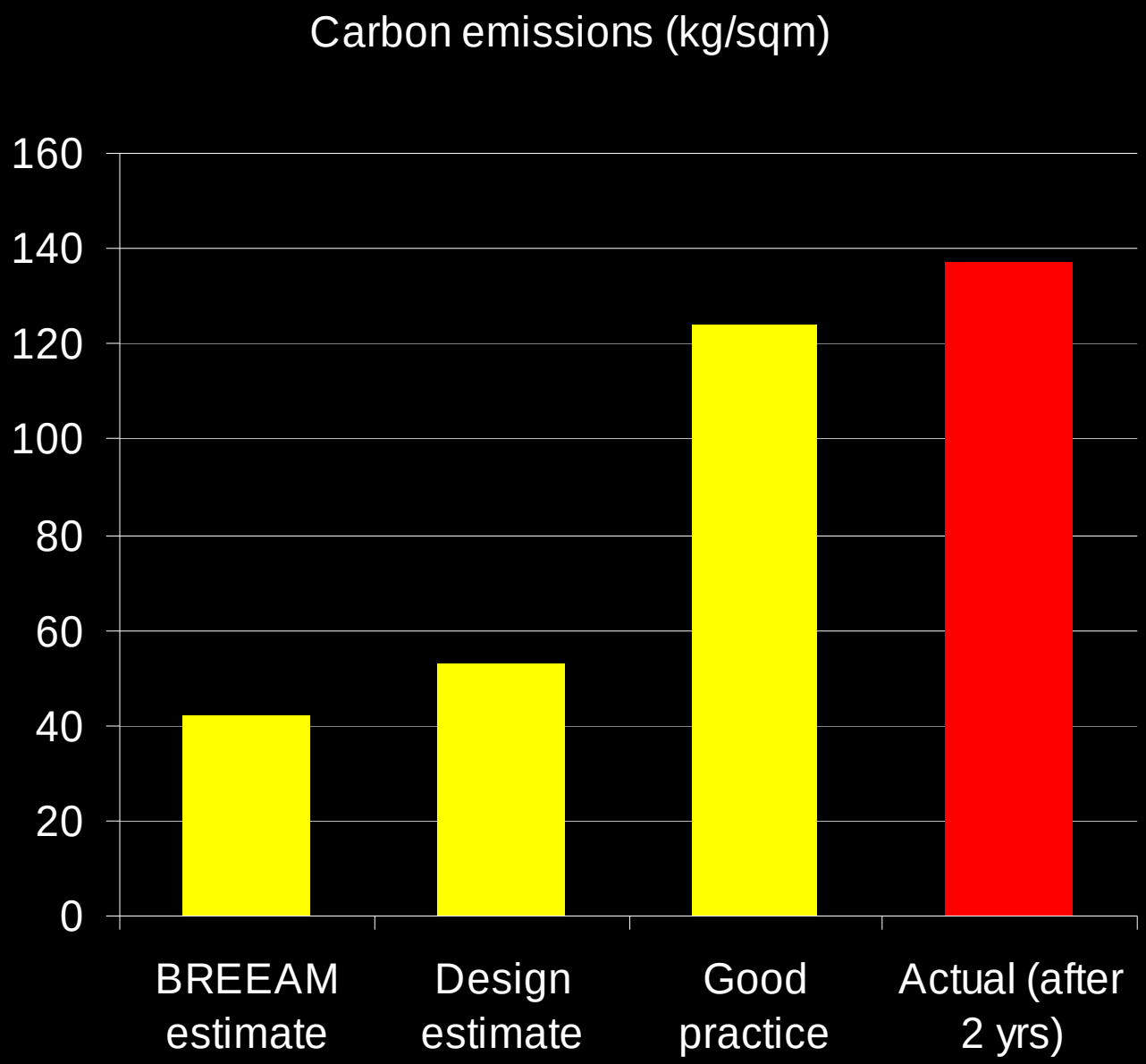
Baker and Steemers, 2002

“Two-to-one discrepancy between measured and predicted performance of a low energy office” – Norford et al., 1994

(unanticipated tenant energy consumption contributes the largest proportion of the two-fold energy increase)

“Energy performance of non-domestic buildings: Closing the credibility gap” – Bordass et al., 2004

(a widespread problem is incorrect assumptions about use and poor control systems with poor user interface)



Emissions from an environmental award winning office

Curwell et al., 1999

Design principles

Exclusive

Selective

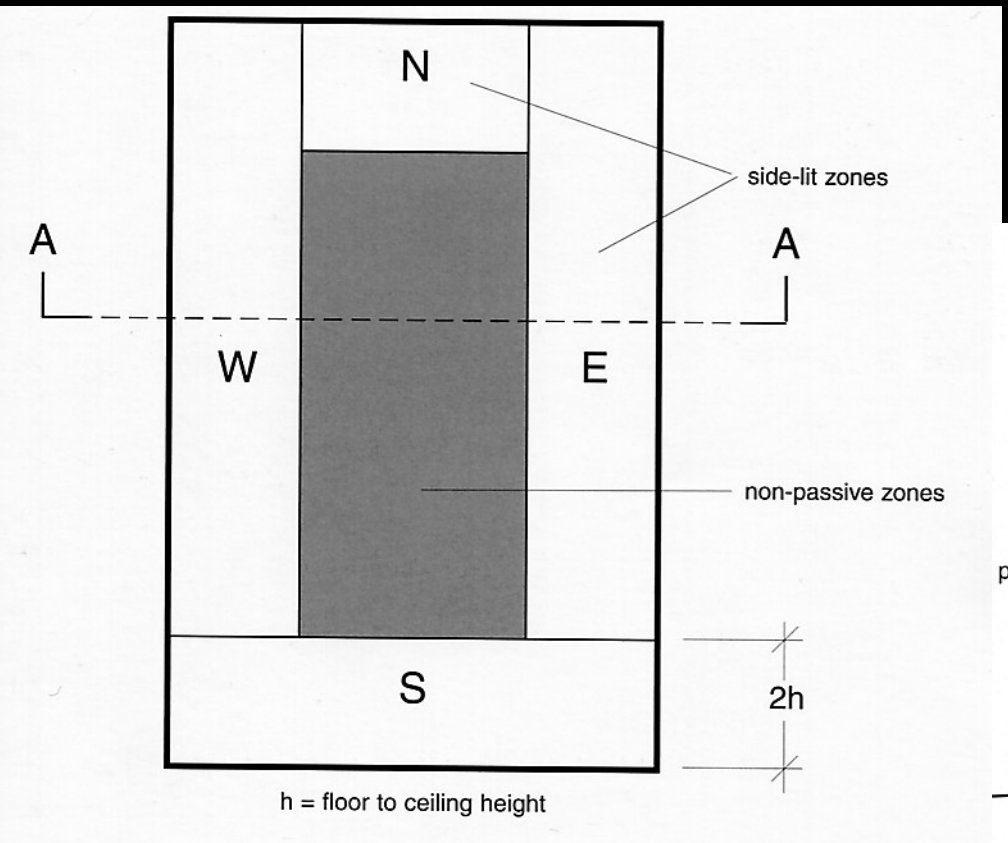
Exploit benefits from adaptive occupant interaction with the climate (selective design).

Limit negative effects of interaction with climate (exclusive design).

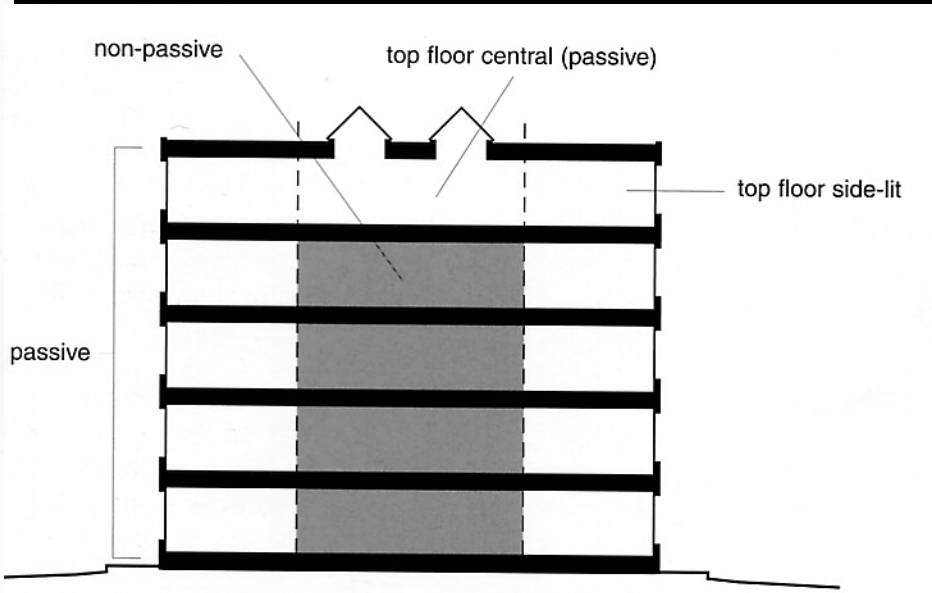
Building form

Potentially passive zones

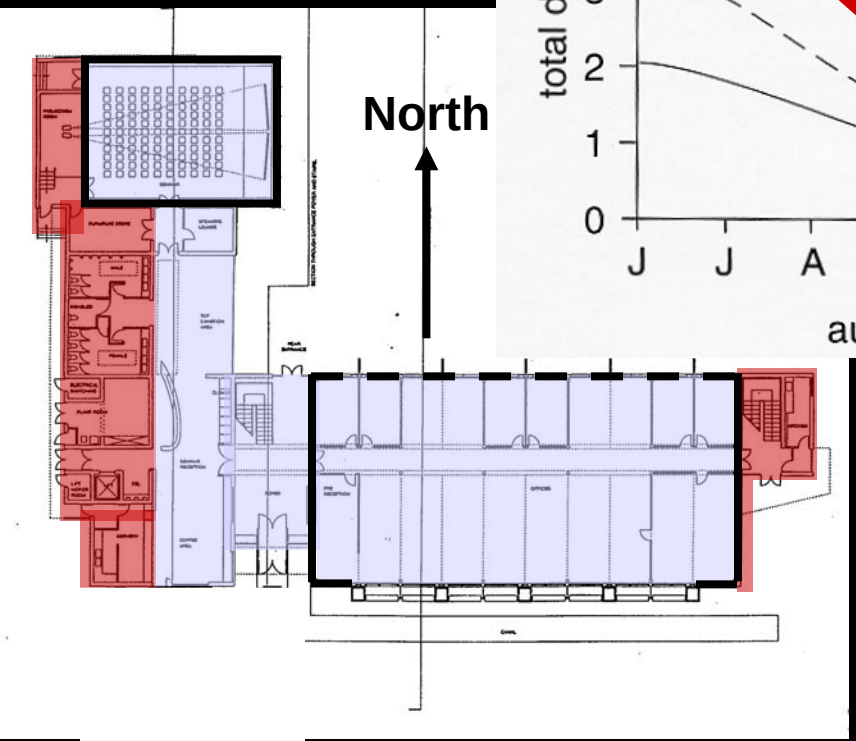
Plan

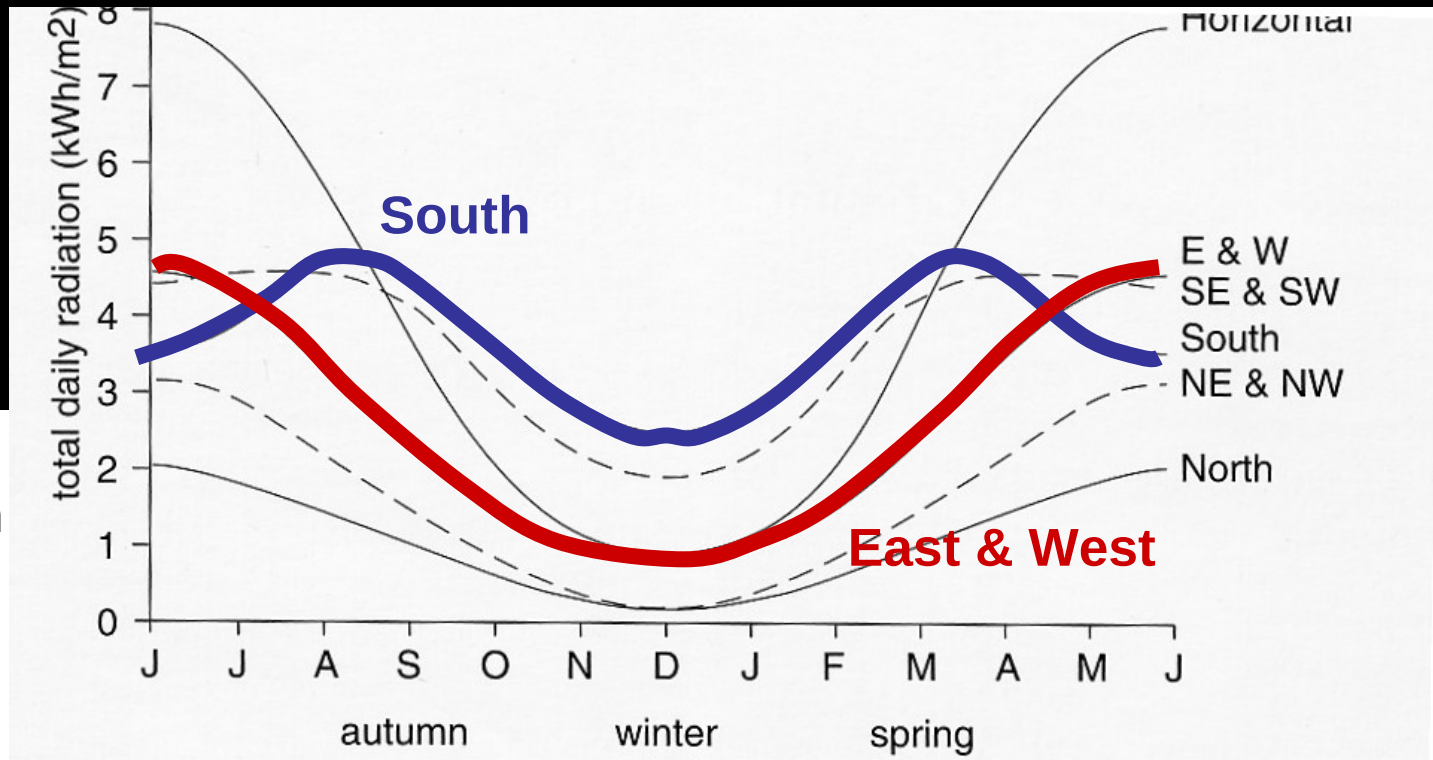


Section



Building form: orientation

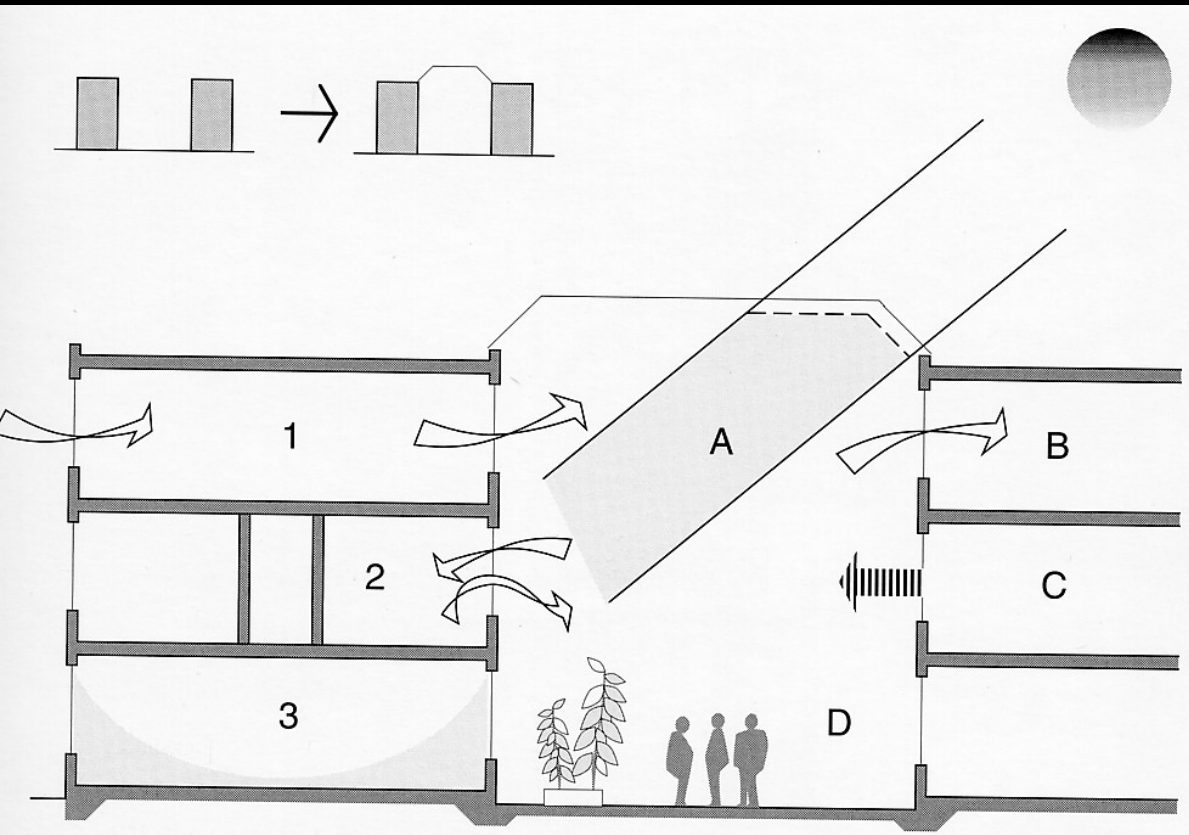




Building form: atria

Energy benefits of atria:

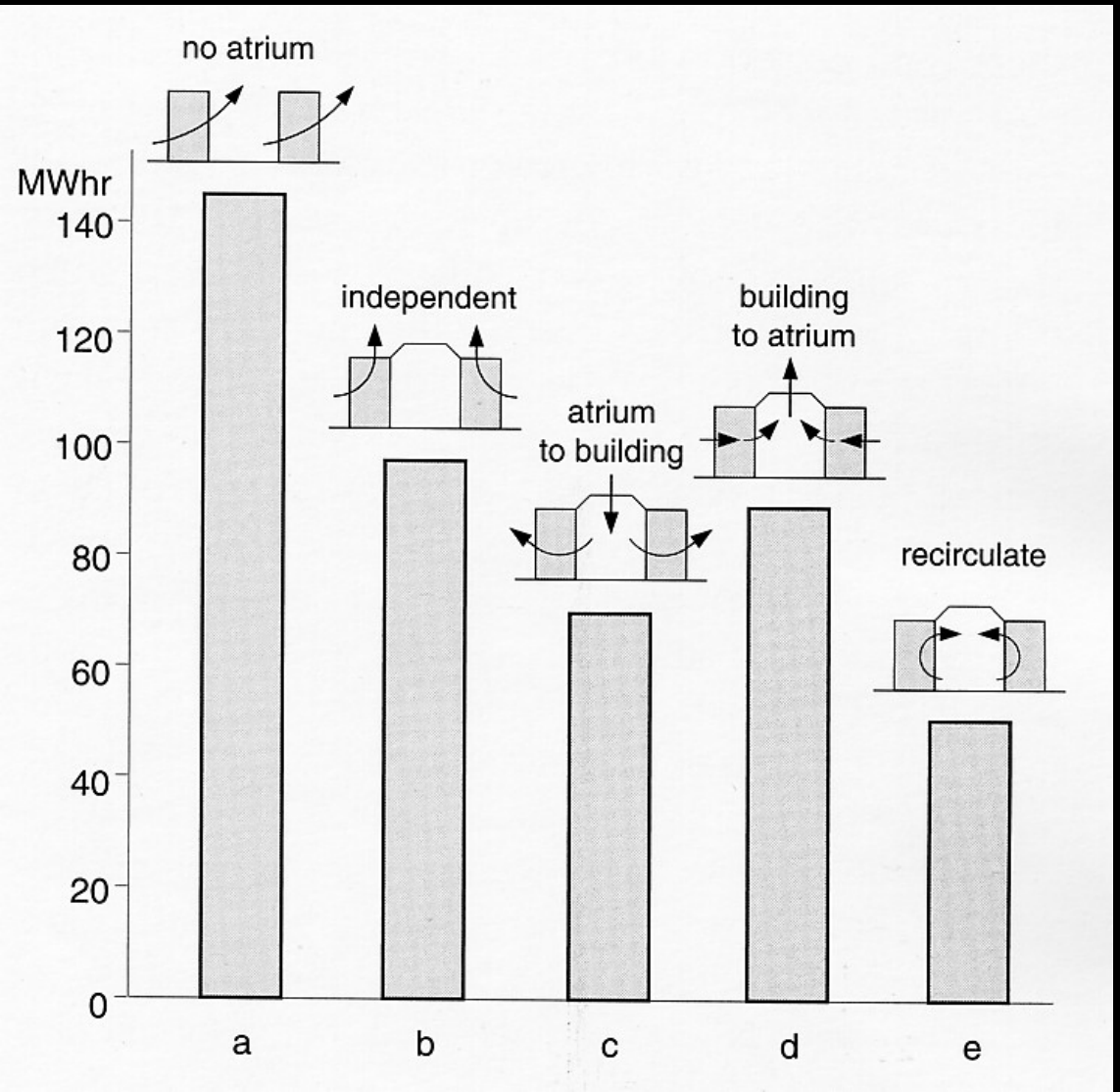
Thermal, lighting & ventilation potential



1 cross ventilation
2 single-sided ventilation
3 daylight

A sun in winter, shade in summer
B pre-heated ventilation
C reduced conduction loss
D useful space

Building form: atria

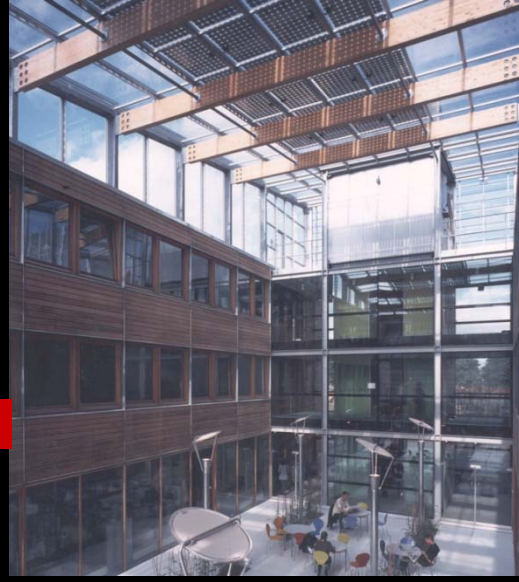


Thermal benefits from ventilation strategies

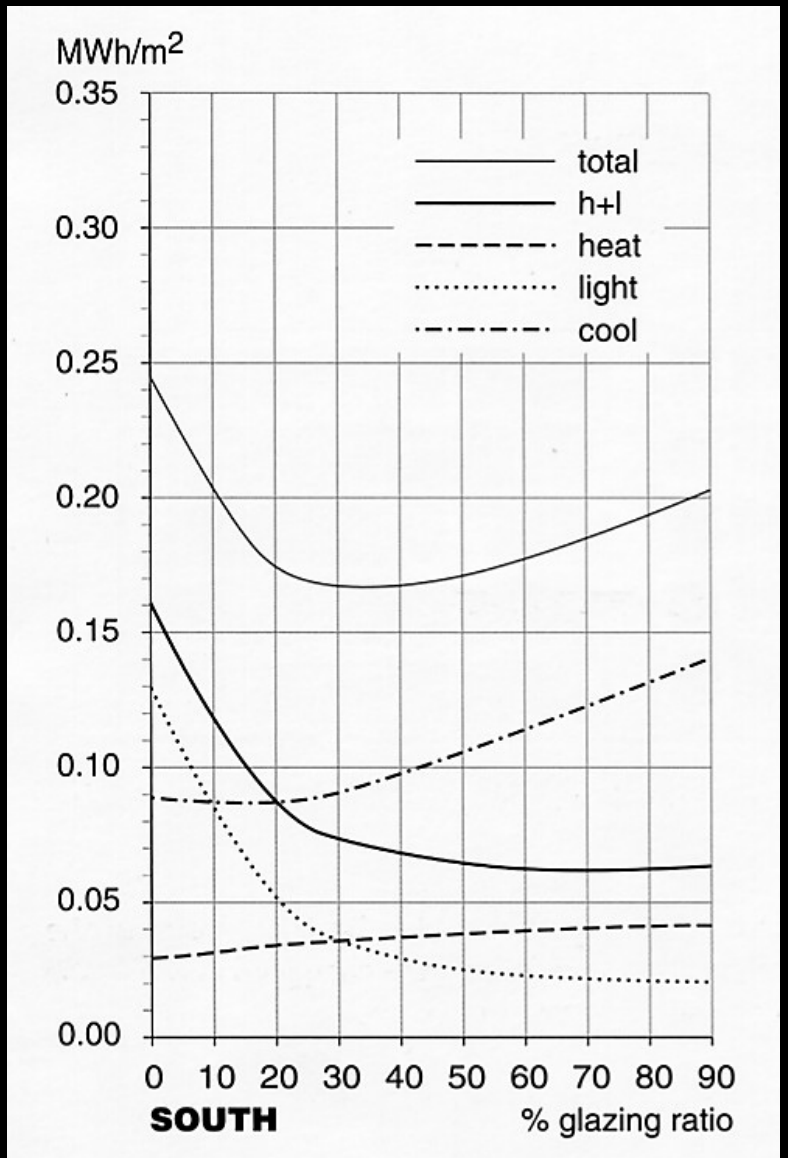
Building form: atria

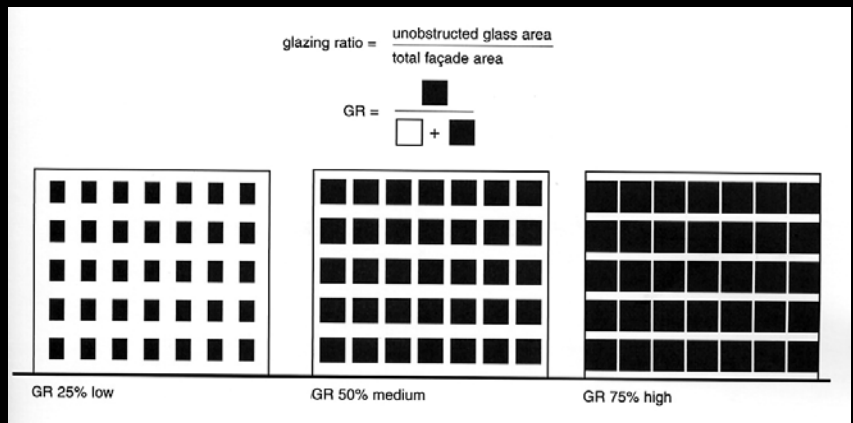
Thermal savings related to form and ventilation mode

config. type \ vent mode	a		b		c		d	
	x1	x2	x1	x2	x1	x2	x1	x2
1 N	0.52	0.60	0.58	0.63	0.54	0.57	1.02	1.12
2 N	0.55	0.71	0.70	0.84	0.59	0.71	1.02	1.24
3 N	0.41	0.53	0.51	0.62	0.48	0.58	0.83	1.02
4 N	0.36	0.49	0.53	0.69	0.42	0.53	0.84	1.10
5 N	0.35	0.46	0.46	0.64	0.38	0.50	0.56	0.80
6 N	0.57	0.83	0.75	1.03	0.61	0.85	0.93	1.30
7 N	0.47	0.63	0.58	0.74	0.54	0.70	0.83	1.03



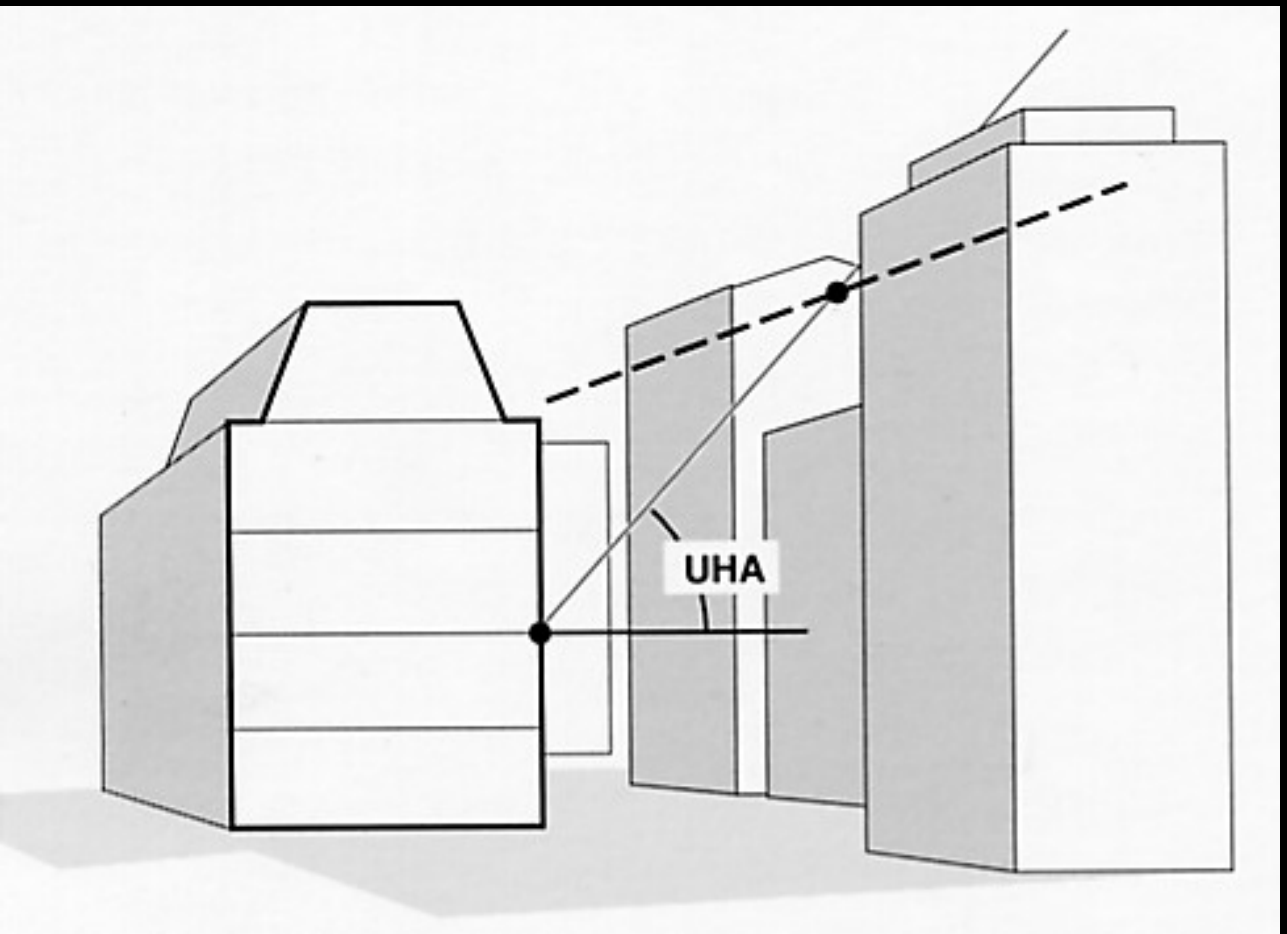
Façade design

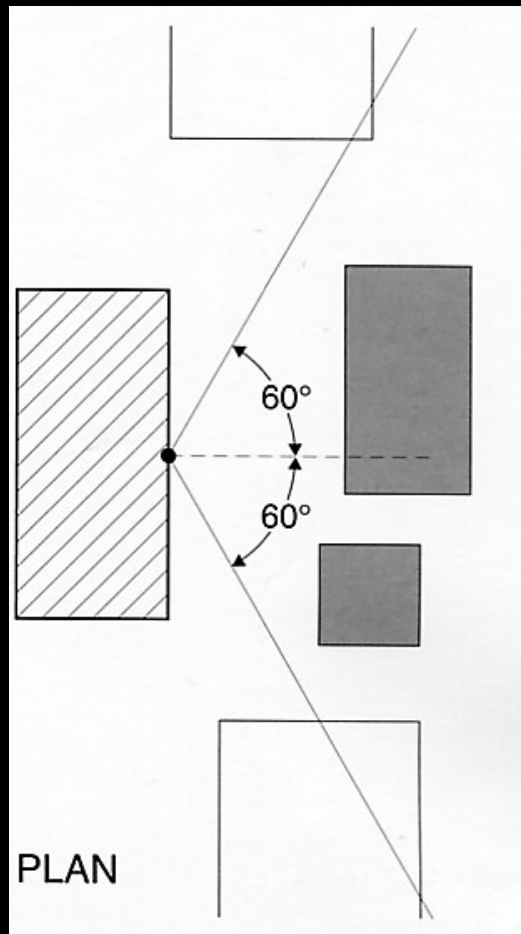




Façade design

Obstructions



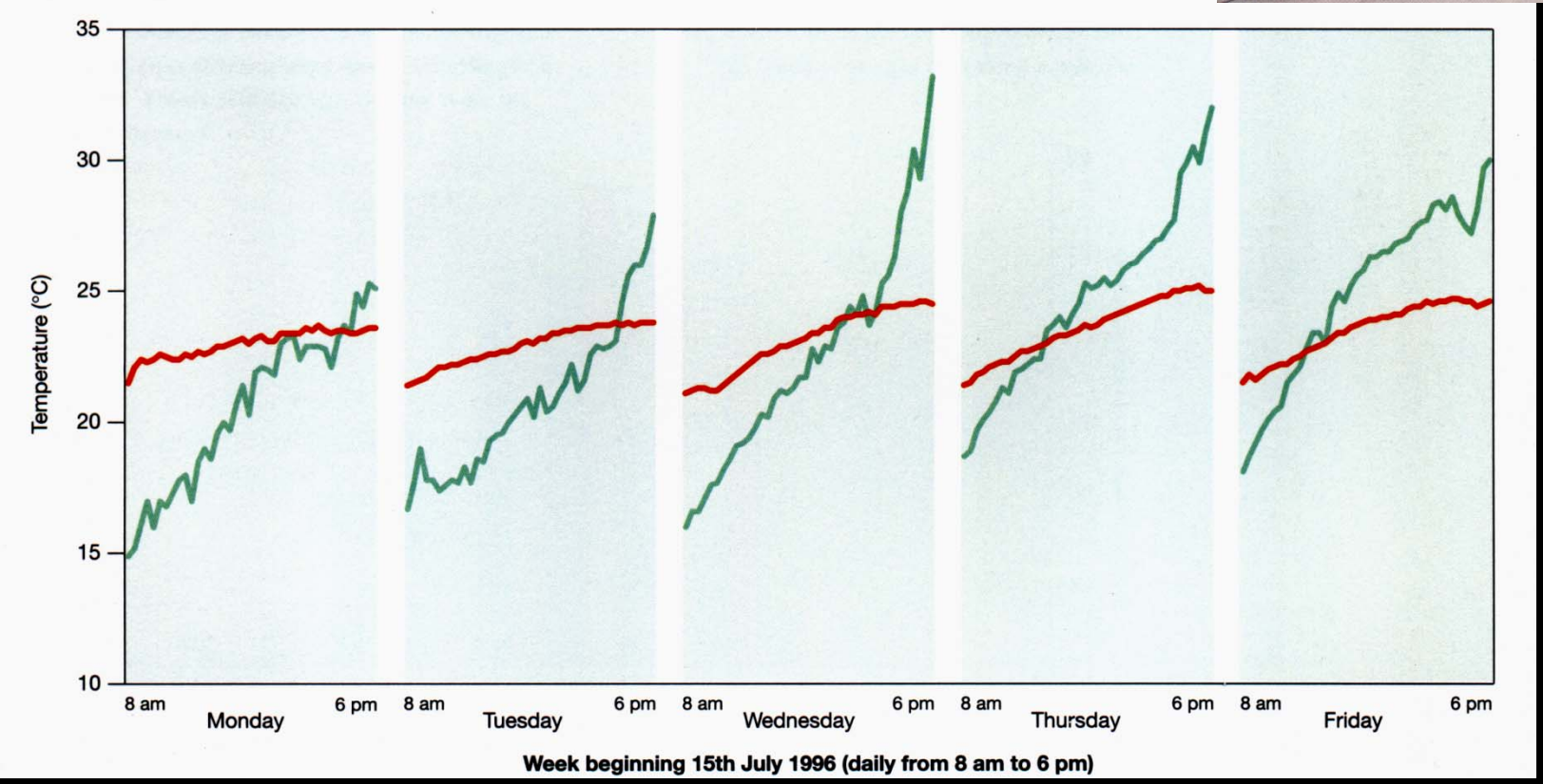


Façade design

orientation	UHA deg.	glazing ratio %	correction factors heating	cooling	lighting
south	15 - 45	20	1.4	1.01	1.5
		40	1.9	0.93	1.5
		60	2.0	0.89	1.7
		80	2.3	0.86	1.5
	> 45	20	1.3	0.99	2.1
		40	1.9	0.81	2.3
		60	2.2	0.70	2.6
		80	2.8	0.62	2.2
east / west	15 - 45	20	1.1	1.01	1.4
		40	1.1	0.93	1.5
		60	1.2	0.89	1.7
		80	1.2	0.86	1.6
	> 45	20	1.0	1.02	2.0
		40	1.0	0.88	2.5
		60	1.2	0.78	2.6
		80	1.3	0.71	2.3
north	15 - 45	20	0.9	1.04	1.4
		40	1.0	0.97	1.5
		60	1.0	0.94	1.5
		80	1.0	0.91	1.6
	> 45	20	0.9	1.09	2.0
		40	0.8	0.97	2.4
		60	1.0	0.89	2.4
		80	1.0	0.84	2.4

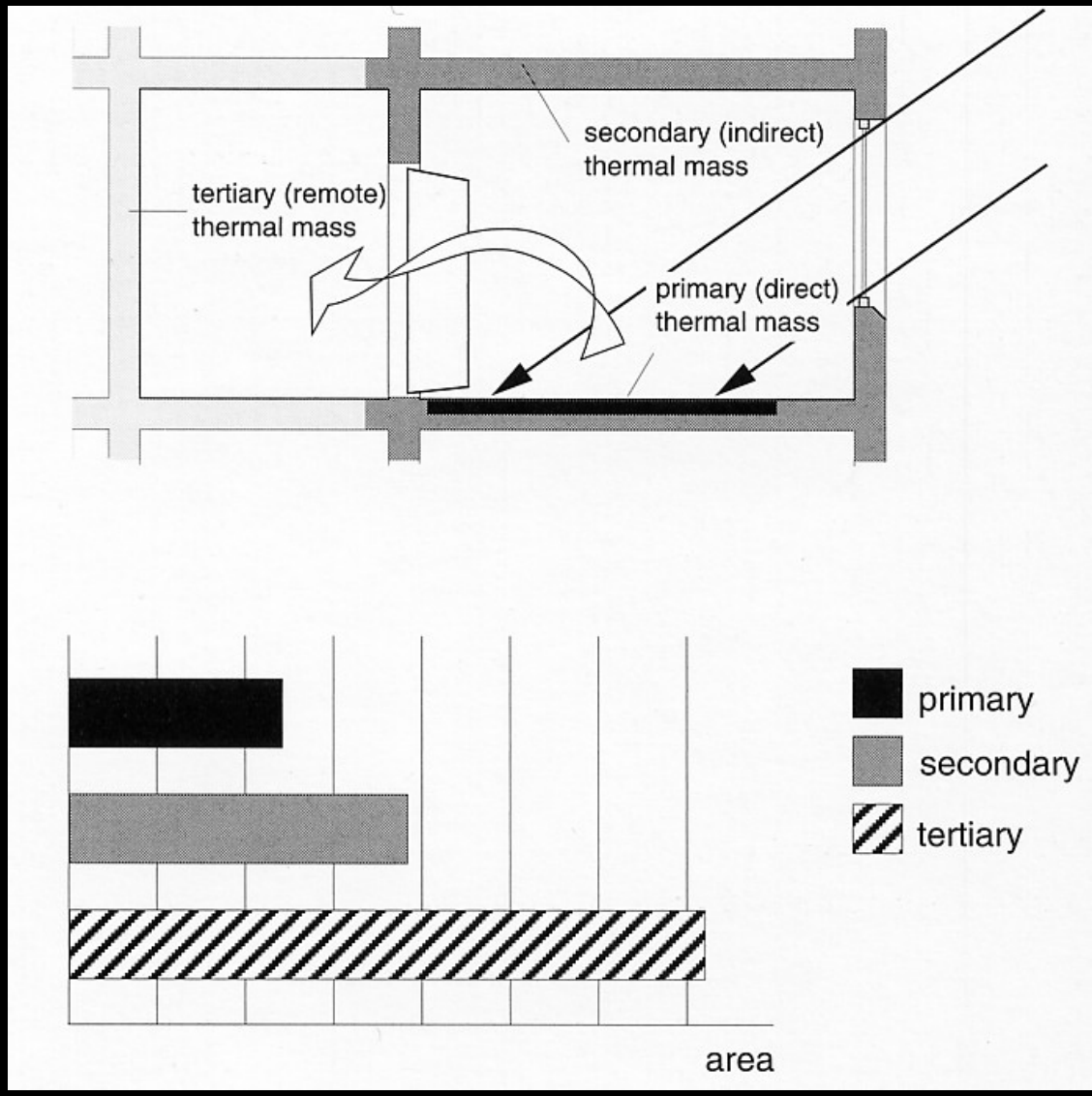
Thermal mass

Thermal mass as passive cooling



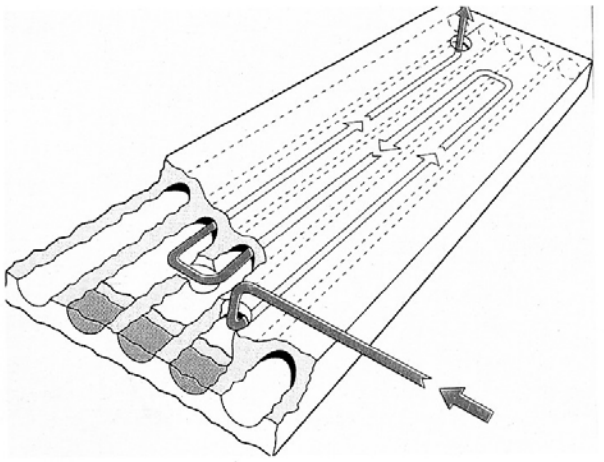
Thermal mass

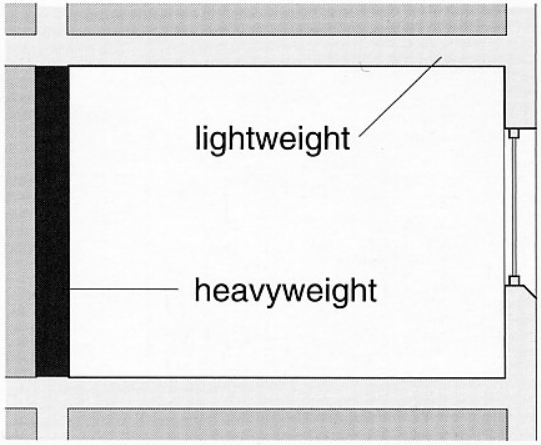
Location and relative effectiveness of thermal mass



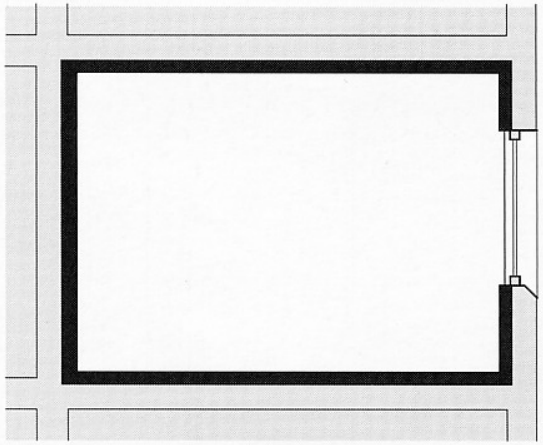
Thermal mass

Distribution and access to thermal mass

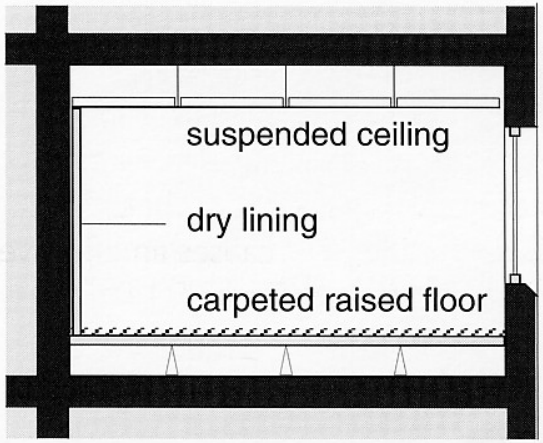




(a) *Concentrated thermal mass*



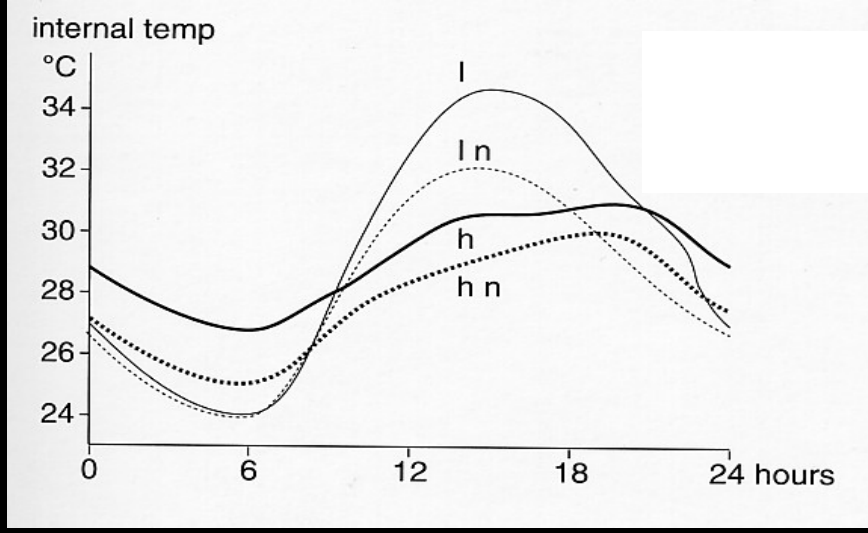
(b) *Most effective thermal mass*

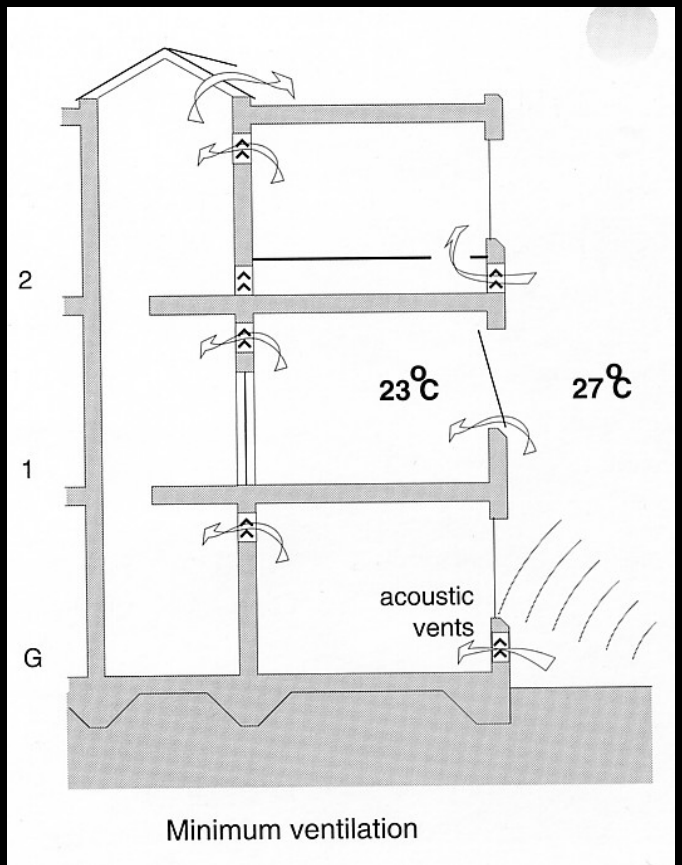


(c) *Least effective thermal mass*

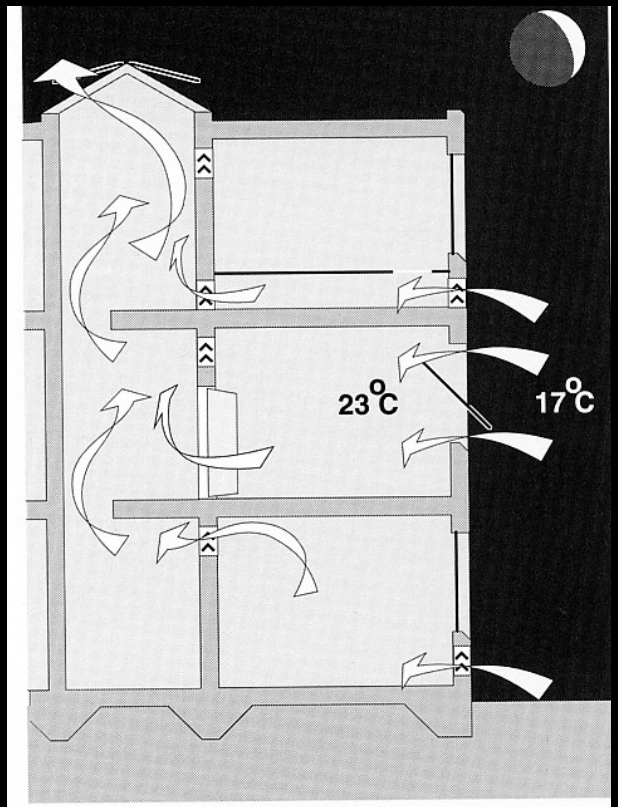
Thermal mass

Thermal mass and night purging ventilation strategy



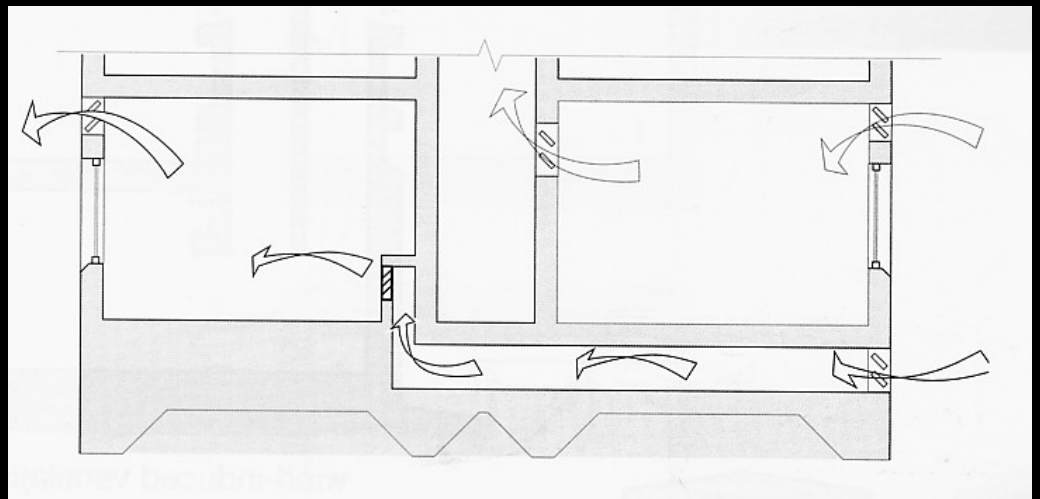


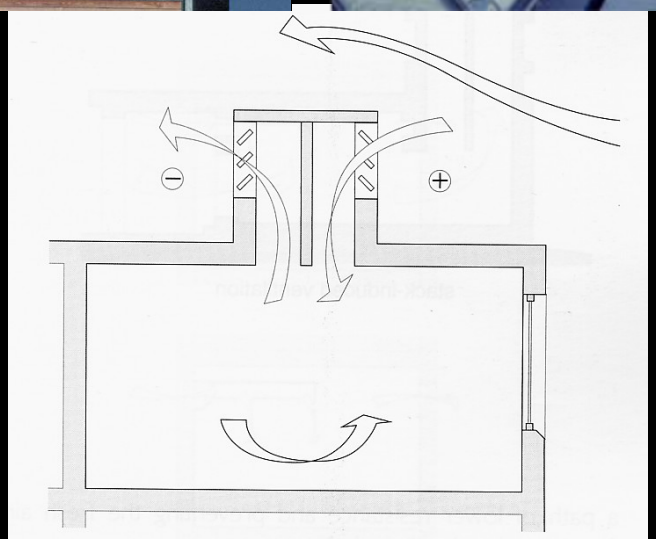
Minimum ventilation



Maximum ventilation

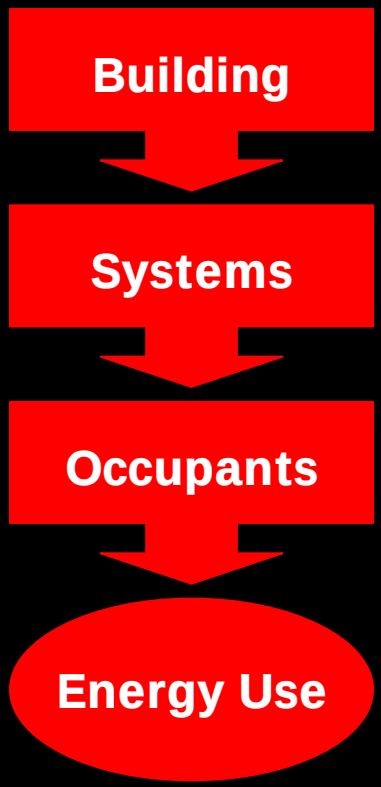
Natural ventilation





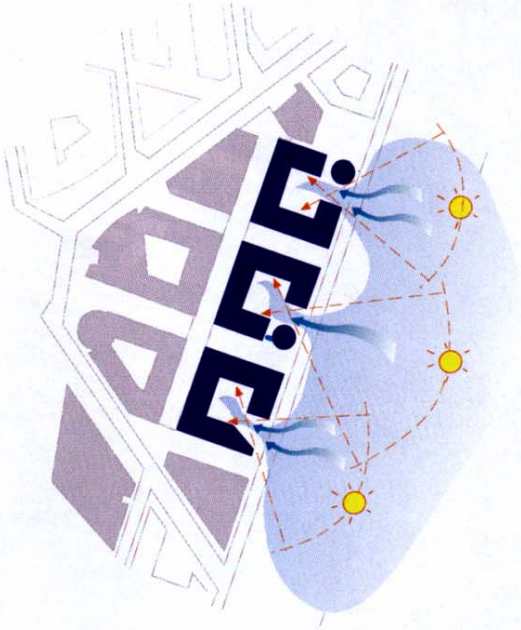
Interacting design parameters

Local climate
Building form
Orientation
Façade design
Obstructions
Ventilation strategies
Construction / mass
Occupancy
Controls
Systems
Renewables

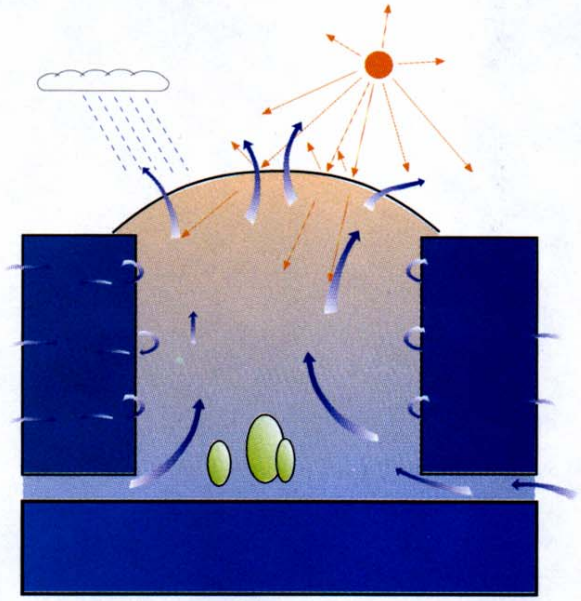


Case study examples

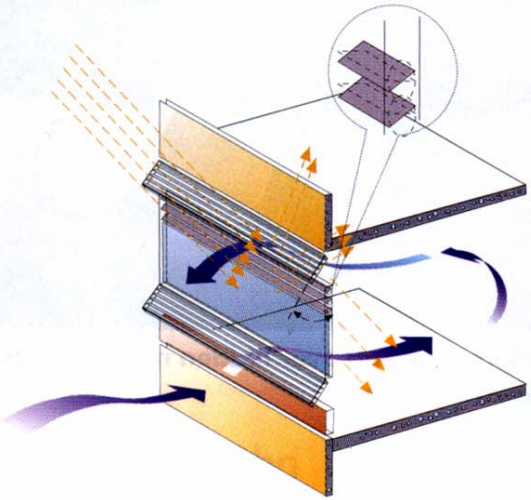
Potsdamer Platz, Berlin
Richard Rogers Partnership



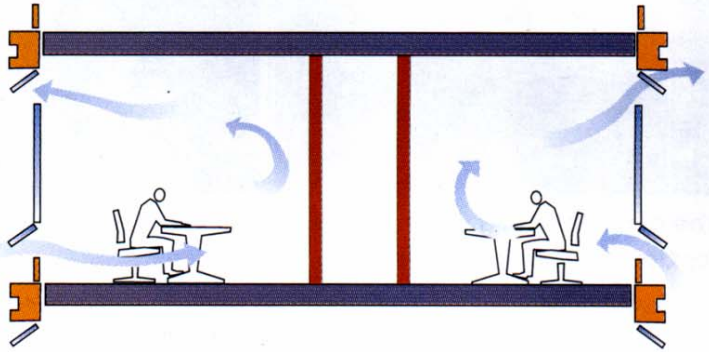
1) U-shaped courtyards catch the sun, and the buildings have been cut away to admit light.



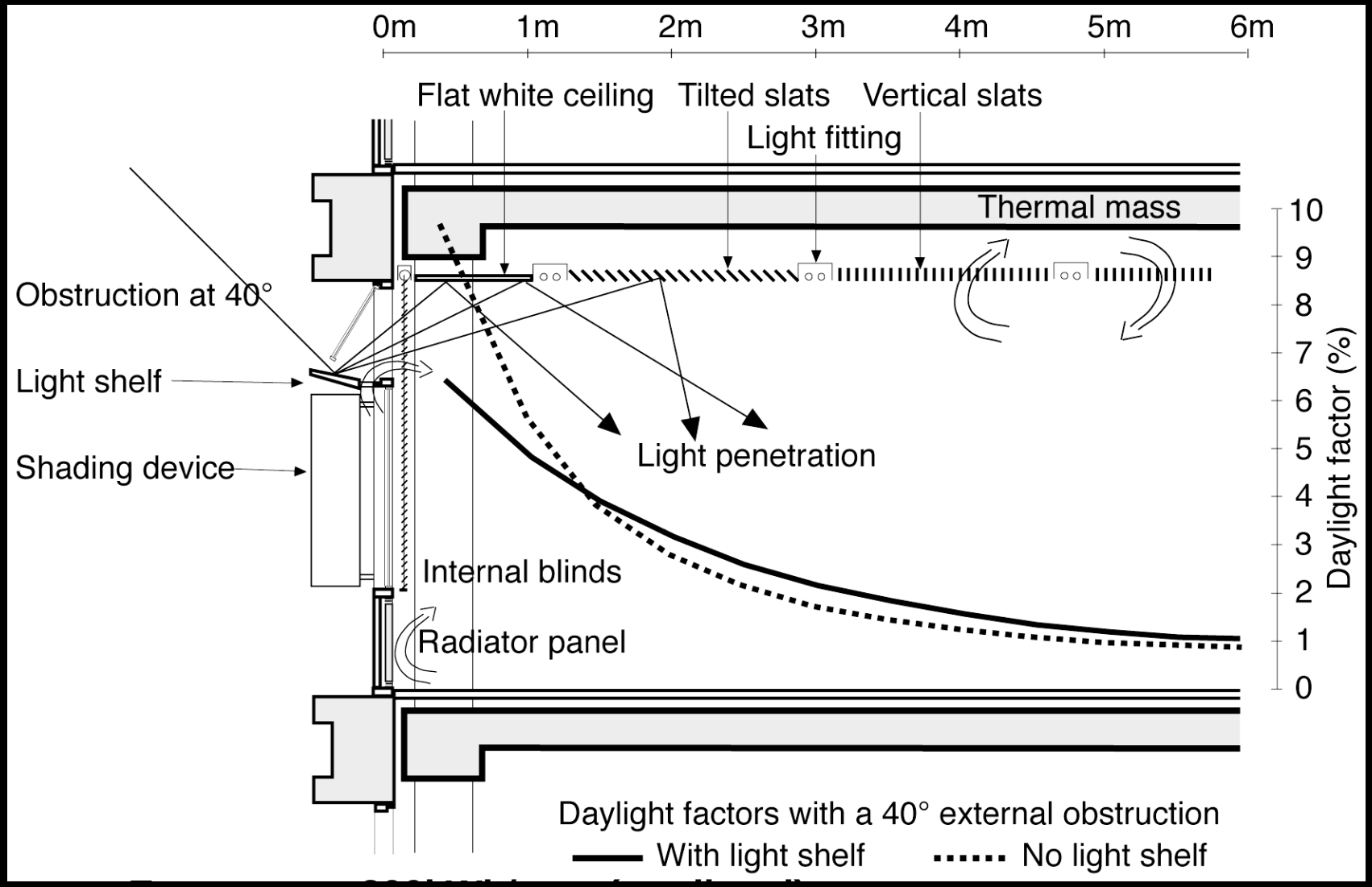
2) The enclosed atrium is naturally ventilated all year round and heated in winter.



3) Each facade bay in the high-performance building envelope is designed in response to its particular microclimate.

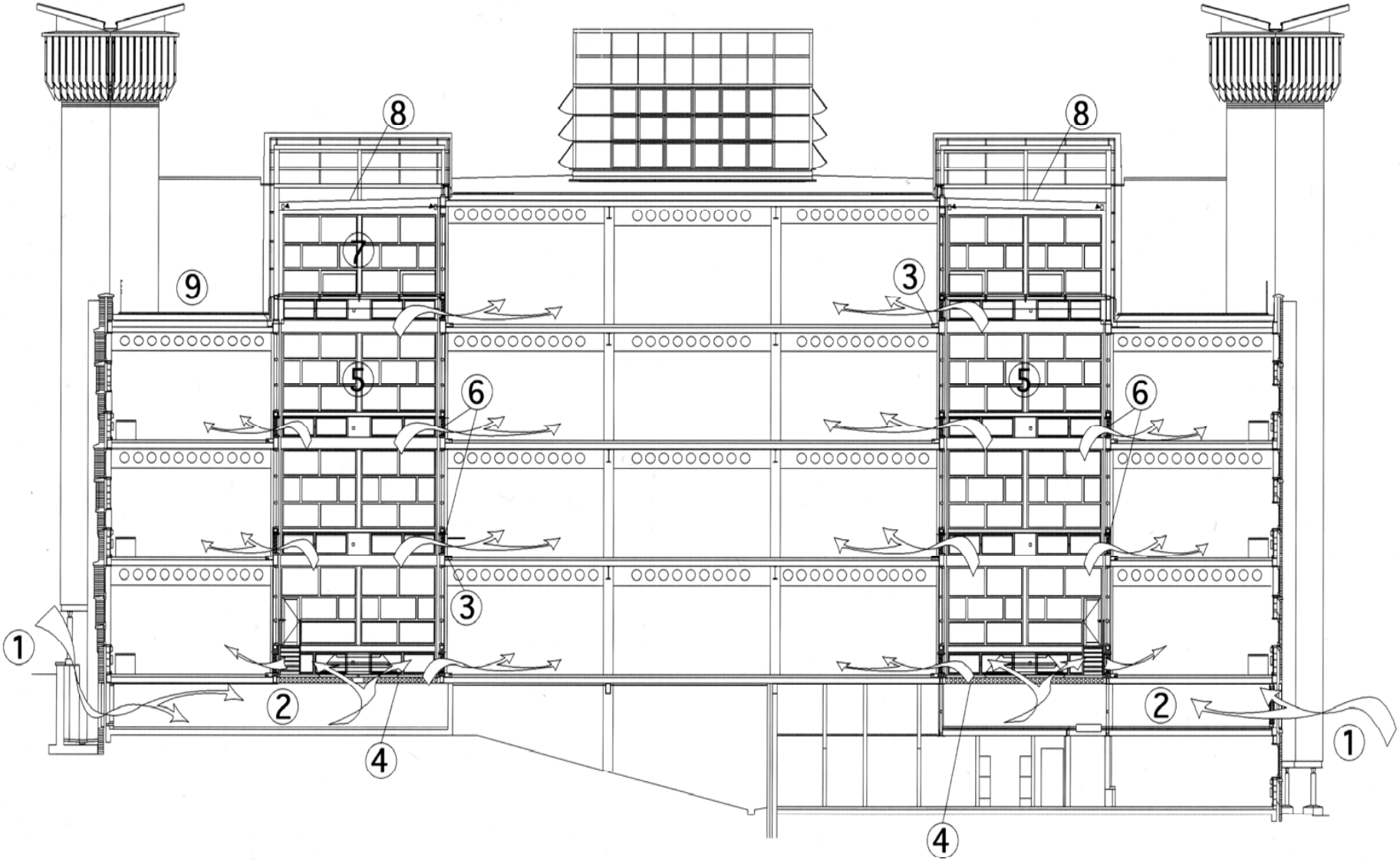


4) 100% naturally ventilated interiors are made possible by fresh air circulating naturally around the offices.



Potsdamer Platz, Berlin

Lancester Library, UK
Alan Short Associates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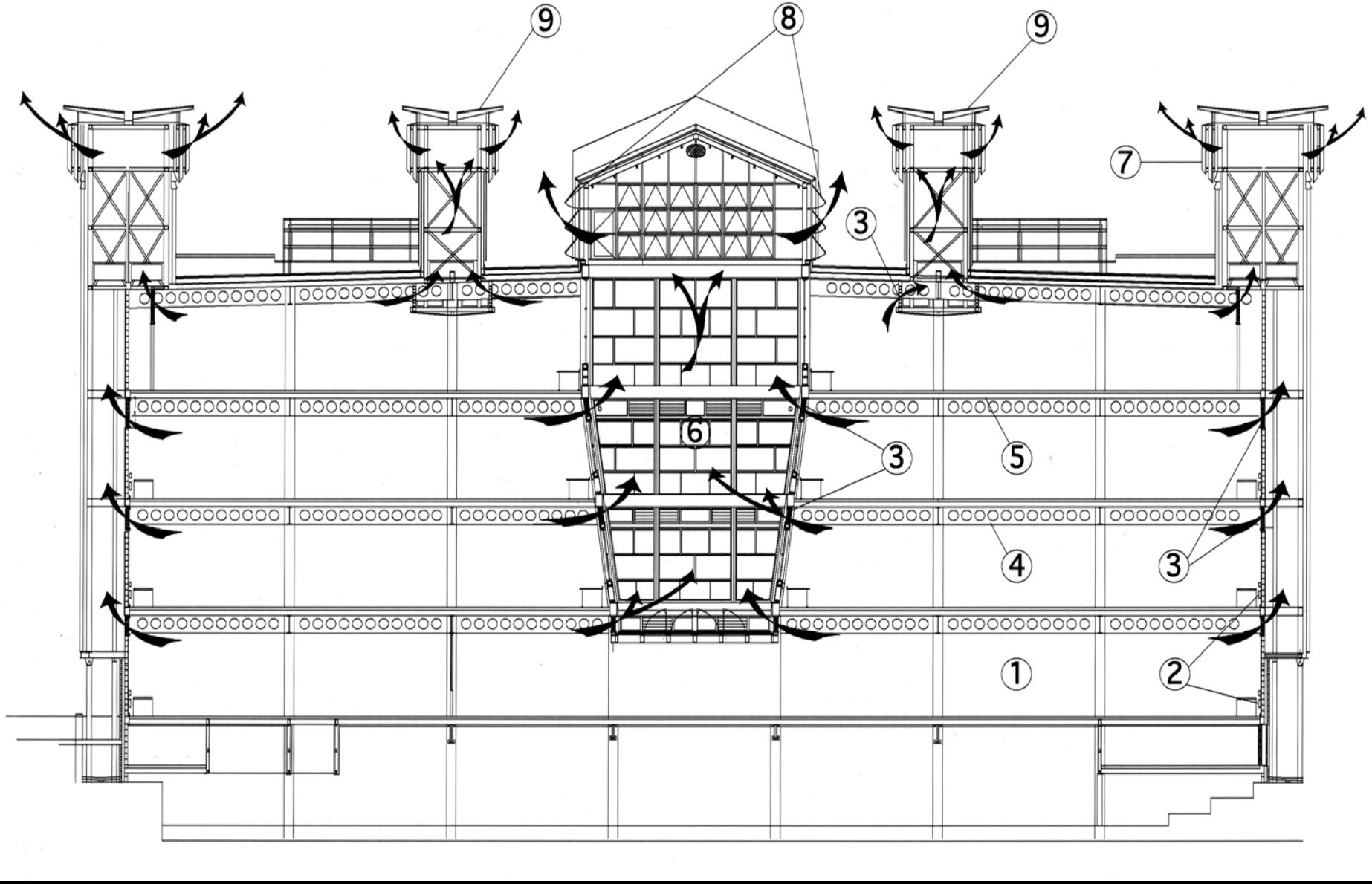
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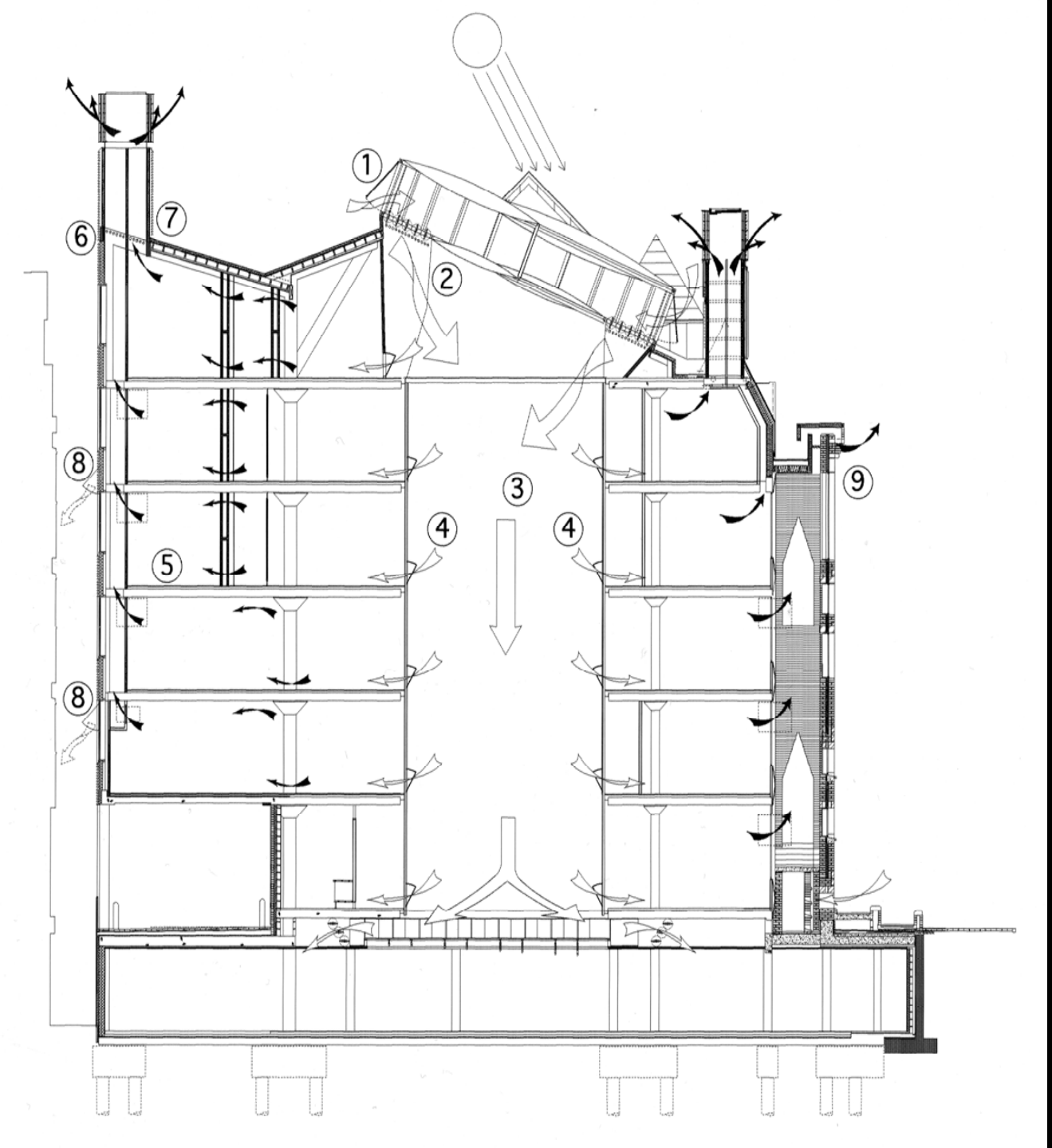
SSEES Building, London
Alan Short Associates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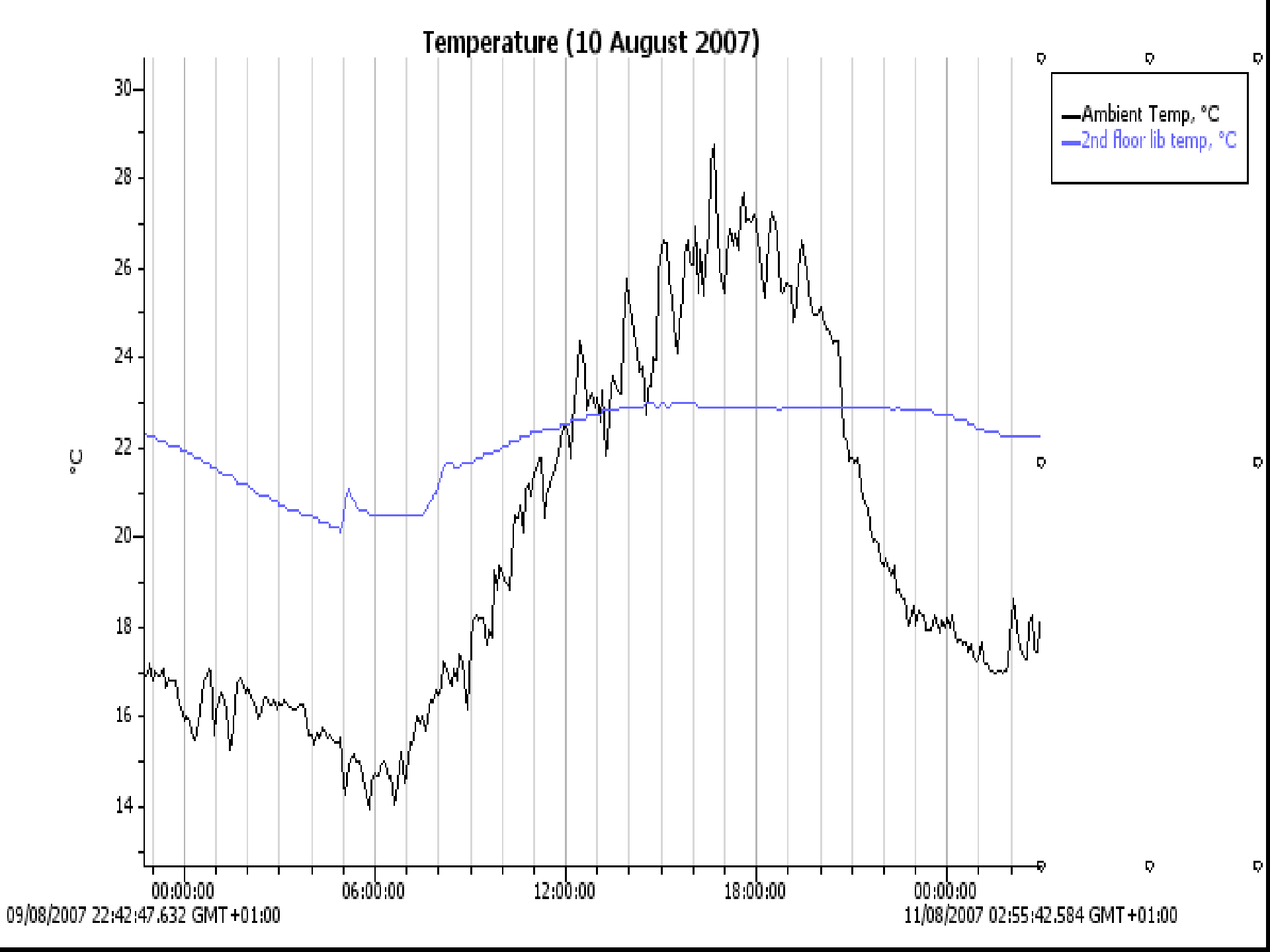
Temperature (10 August 2007)
Ambient Temp, °C
2nd floor lib temp, °C
°C
30
28
26
24
22
20
18
16
14
00:00:00
06:00:00
12:00:00
18:00:00
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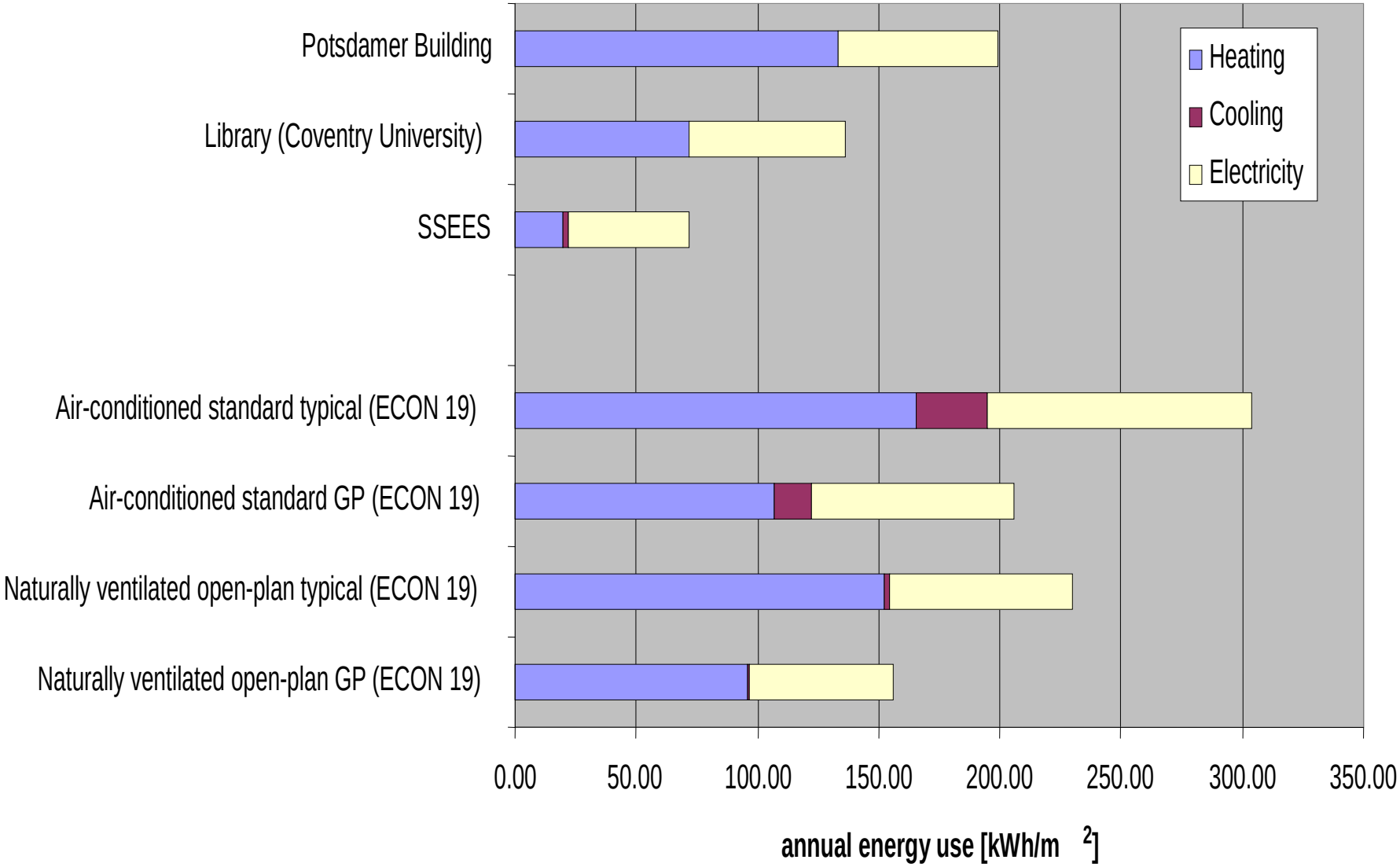
11/08/2007 02:55:42.584 GMT+01:00

2004


Potsdamer Building
Library (Coventry University)
SSEES
Air-conditioned standard typical (ECON 19)
Air-conditioned standard GP (ECON 19)
Naturally ventilated open-plan typical (ECON 19)
Naturally ventilated open-plan GP (ECON 19)
Heating
Cooling
Electricity
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
annual energy use [kWh/m 2]

Lessons from history, practice and research:

1.The technical principles are well understood.

2.Exemplar projects are available and have been studied.

3.Improvements are slow to have an impact due to the existing stock.

4.The technical potential will not be achieved if designs are not robust and do not anticipate human behaviour and expectations.