The Importance of Thermal Mass: Lightweight or Heavyweight

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Max Fordham LLP

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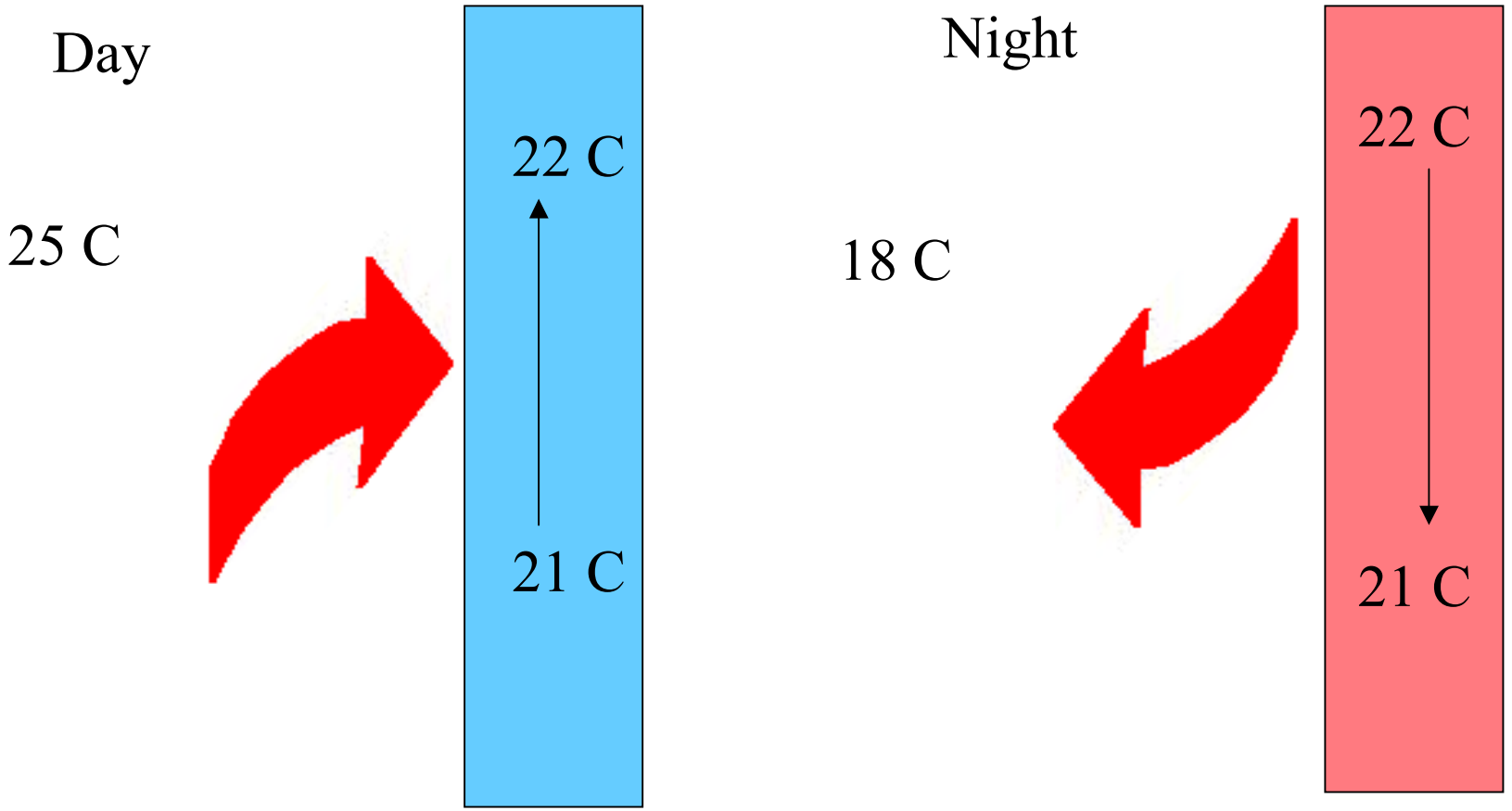
MaxFordham has been awarded the Queen's Award for Enterprise, in the category of Sustainable Development

Thermal Mass



What is Thermal Mass?

The Energy required to heat up a material is its heat capacity

Material	Specific Heat Capacity (J/kgK)	Density (Kg/m3)	Heat Capacity (MJ/m3)
Water	4180	1000	4.18
Air	1000	1.29	0.0013
Plasterboard	840	950	0.80
Brick	840	1000	0.84
Concrete	840	2240	1.88

What is Thermal Mass

This heat energy also needs to enter the fabric: admittance

	Lightweight	Heavyweight
Material	Waterproof covering	Waterproof covering
	100mm polyurethane insulation	100mm polyurethane insulation
	vapour control layer	vapour control layer
	19mm timber decking	75mm screed
	airspace	150mm cast concrete
	12mm plasterboard	13mm dense plasterboard
	U-value = 0.22	0.22
	Admittance = 1.55	5.13

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What is the benefit?

Store the excess heat during the day

Avoid overheating on a warm summer day:

Store During the day

(Must) Release at Night by Ventilation

Avoid heating on a winter morning

Store excess heat during the day

Release heat at night to offset heat losses

BUT

Must have a way of cooling the building

- Night time ventilation has security issues
- Ground Coupling
- Active Cooling Systems

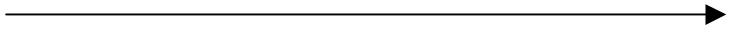
AND

Poorly insulated buildings and Intermittent use (e.g. Primary Schools) require higher heat energy due to heating up the mass.

Materials

Lightweight **Heavyweight**

Fabric Wood Plasterboard Brick Concrete

Embedded Energy 

Cost: Variable and needs to be considered along with other costs

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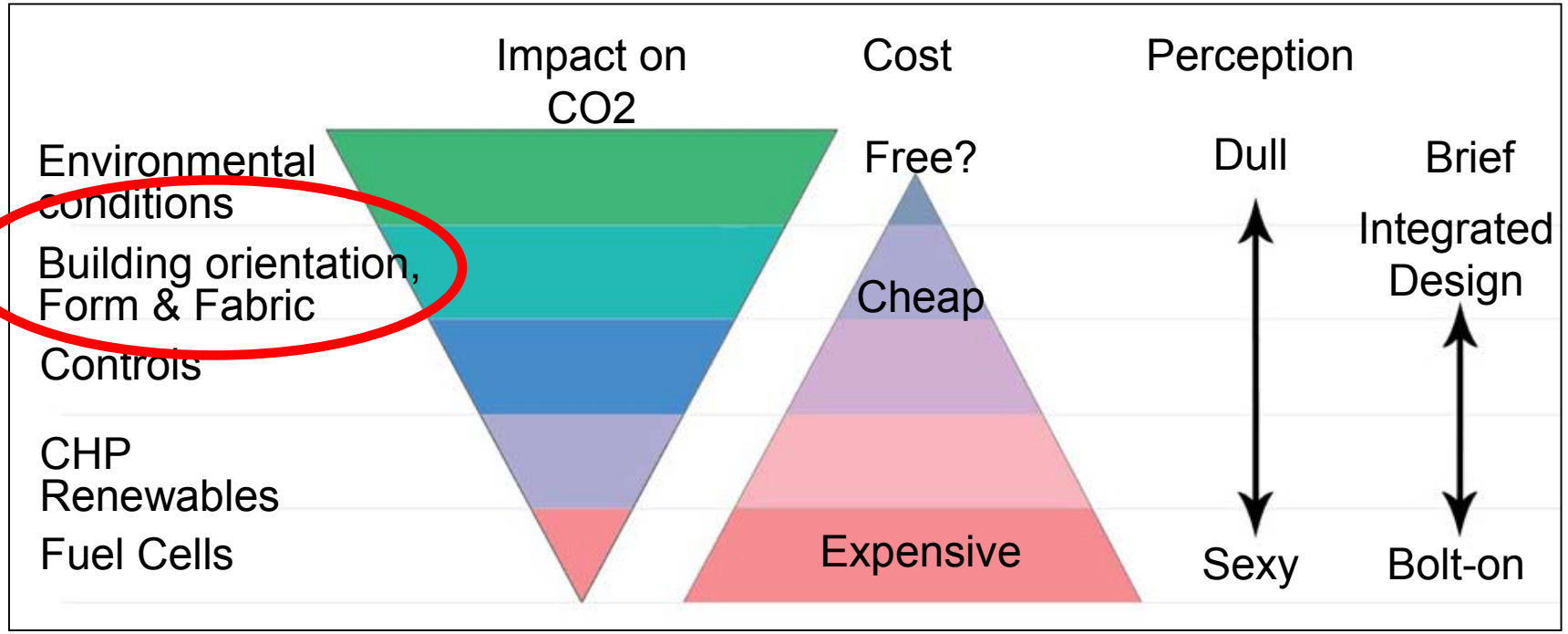
Impact on CO2
Cost
Perception
Environmental conditions
Building orientation, Form & Fabric
Controls
CHP
Renewables
Fuel Cells
Free?
Cheap
Expensive
Dull
Sexy
Brief
Integrated Design
Bolt-on

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Does Thermal Mass Cool Buildings?

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No, is simply stores it

Materials that are thermally heavy are able to store a greater amount of heat energy.

It can reduce the cooling load if the night cooling is cheaper:

Night Ventilation is not free – security problems or additional building cost.

Does Thermal Mass Reduce the Energy Demand?

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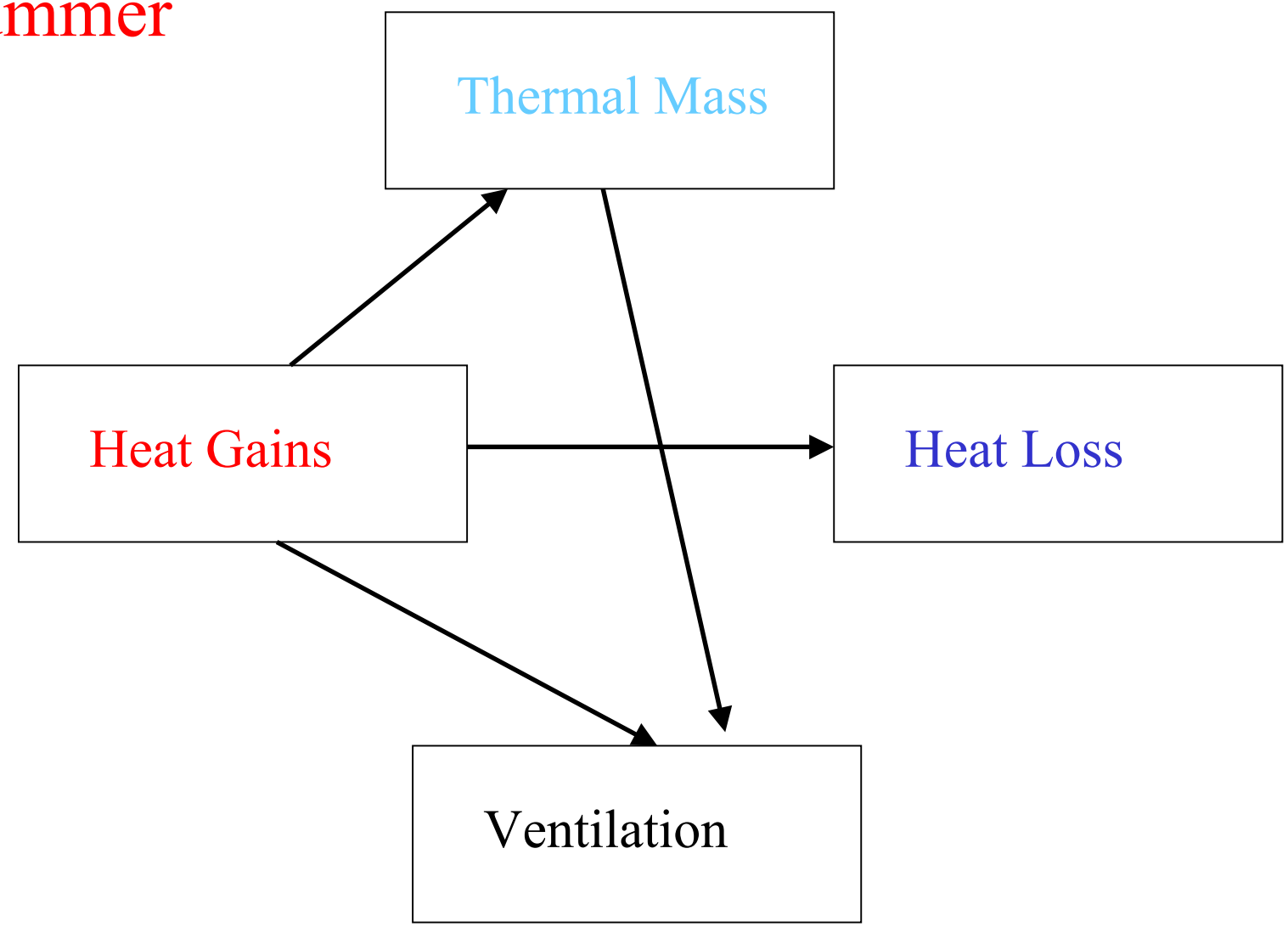
Working week / Type of construction	
7 day / Light weight	1
7 day / Medium weight	1
7 day / Heavy weight	1
5 day / Light weight	0.75
5 day / Medium weight	0.8
5 day / Heavy weight	0.85

Type of heating / Type of construction	
Intermittent - responsive plant / Light weight	0.55
Intermittent - responsive plant / Medium weight	0.7
Intermittent - responsive plant / Heavy weight	0.85
Intermittent - plant with long lag / Light weight	0.55
Intermittent - plant with long lag / Medium weight	0.7
Intermittent - plant with long lag / Heavy weight	0.85
Continuous / Light weight	1
Continuous / Medium weight	1
Continuous / Heavy weight	1

Occupied period (hours) / Type of construction	
4 / Light weight	0.68
4 / Medium weight	0.82
4 / Heavy weight	0.96
7.5 / Light weight	0.96
7.5 / Medium weight	0.98
7.5 / Heavy weight	0.99
8 / Light weight	1
8 / Medium weight	1
8 / Heavy weight	1
12 / Light weight	1.25
12 / Medium weight	1.14
12 / Heavy weight	1.03

Summer



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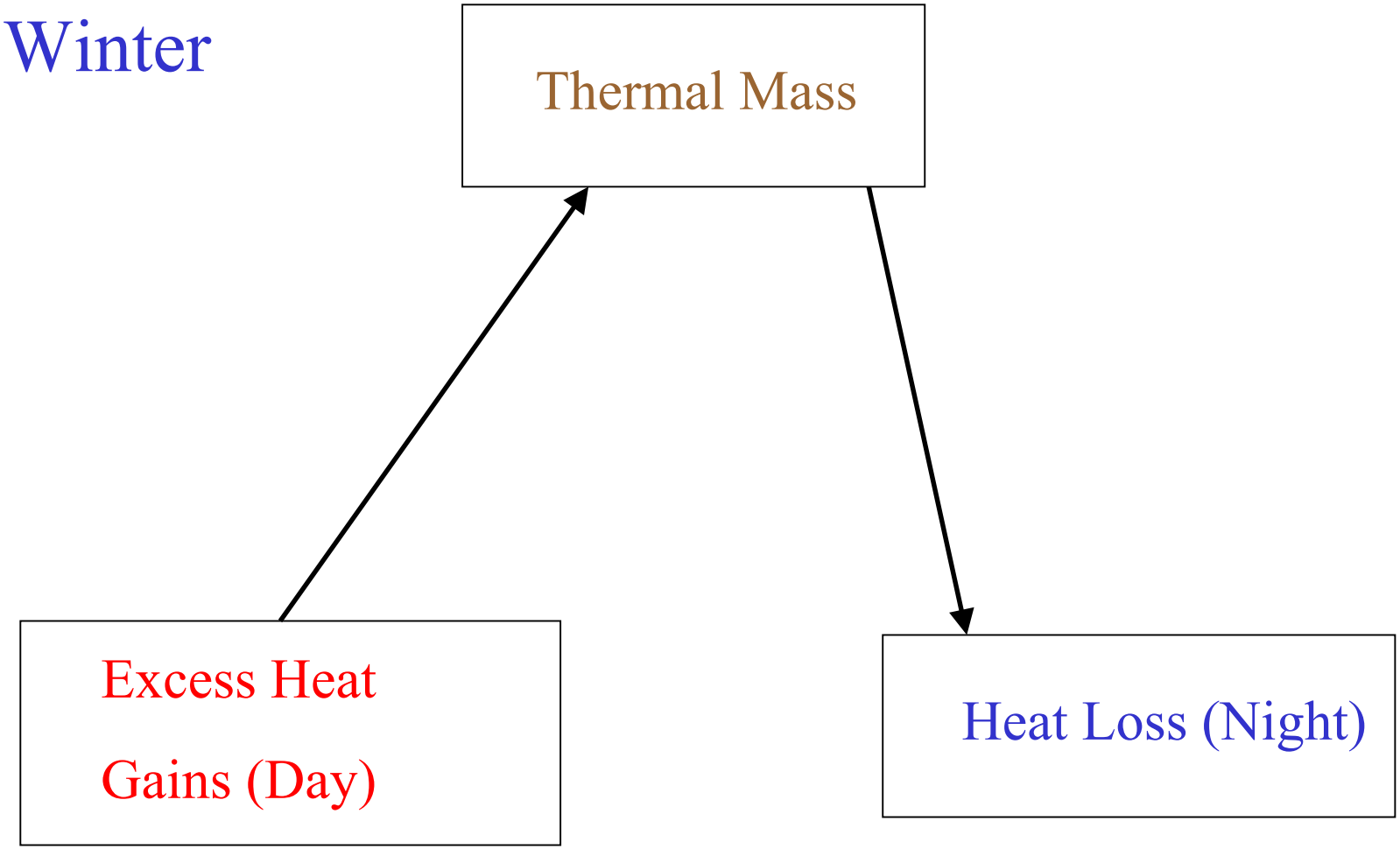
Winter



Simple Rules of Thumb

If:

limited heat losses and gains, a standard construction will suffice

high summer heat gains, thermal mass helps

high winter heat loss, thermal mass is not a benefit

Classrooms

Thermal Modelling of a Proposed School

High Thermal Mass (exposed Concrete Ceiling, Brick Internal Walls) with constant 24 hour Ventilation rate (10 air changes per hour)

Low Thermal Mass (Plasterboard Internal walls, false ceiling), day Ventilation of 10 ach

High Thermal Mass without night Ventilation. 10 ach in the day

Each model was assessed with 4 orientations

Site Orientation

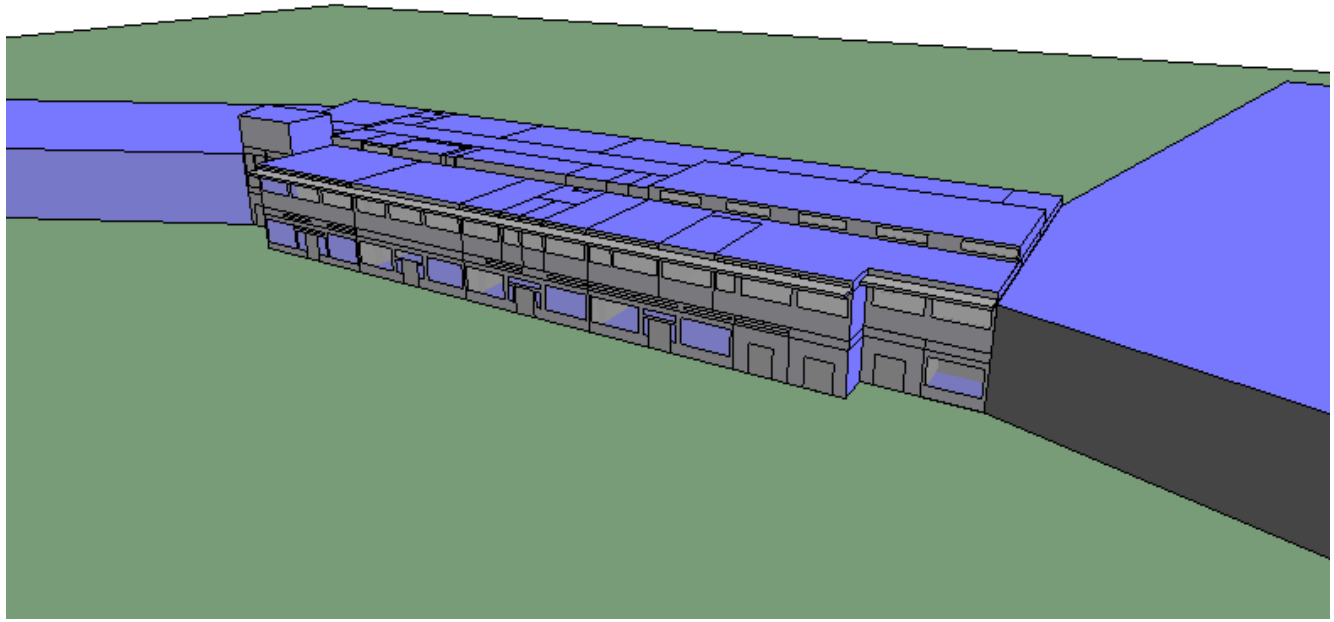
The solar gain is dependent on the area of glazing, the type of glazing, the placement of any shading and the direction the glazing faces.

Unshaded mean July solar gain over 8hrs for various orientations (W/m^2 glazing):

North	92.5	East	111.2
South East	126.8	South	138.9
South West	144.7	West	133.9

Source: CIBSE example weather year for Kew

Secondary School



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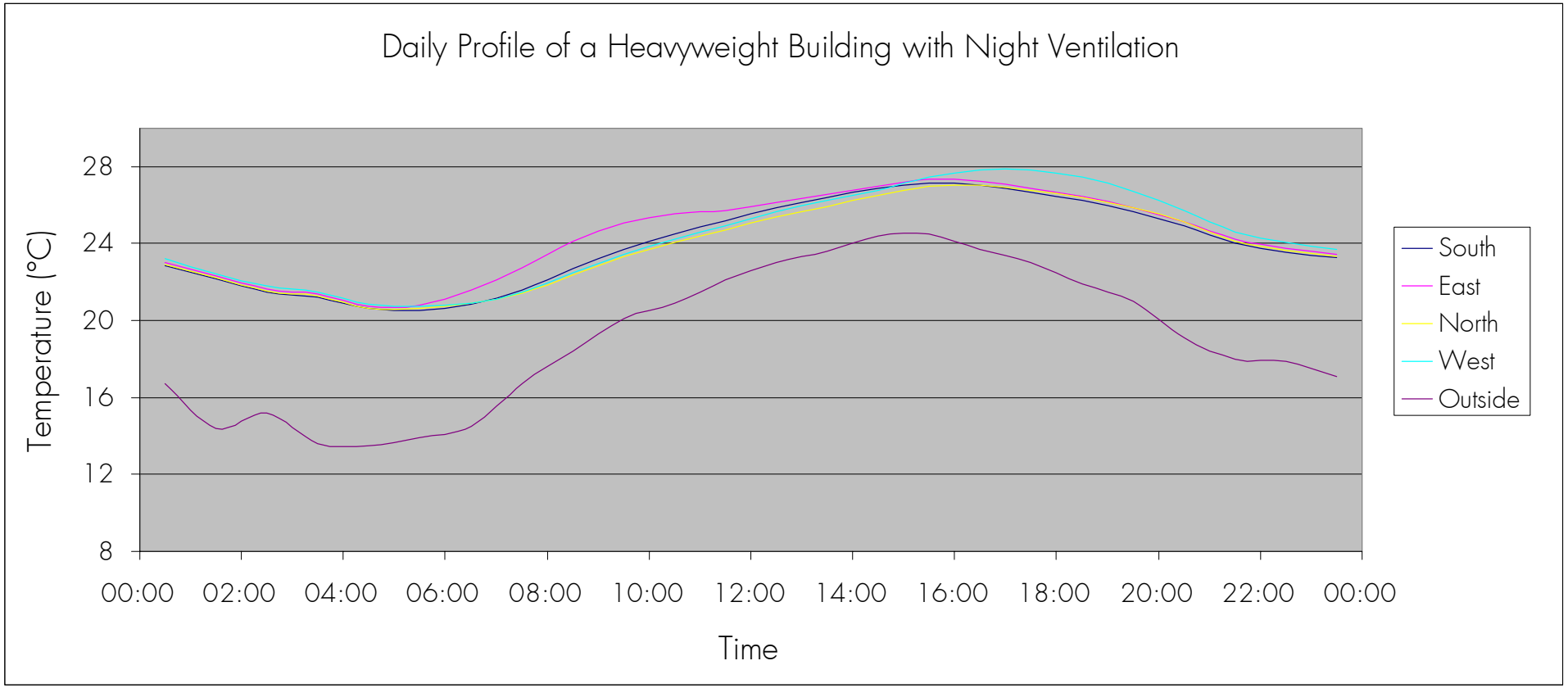
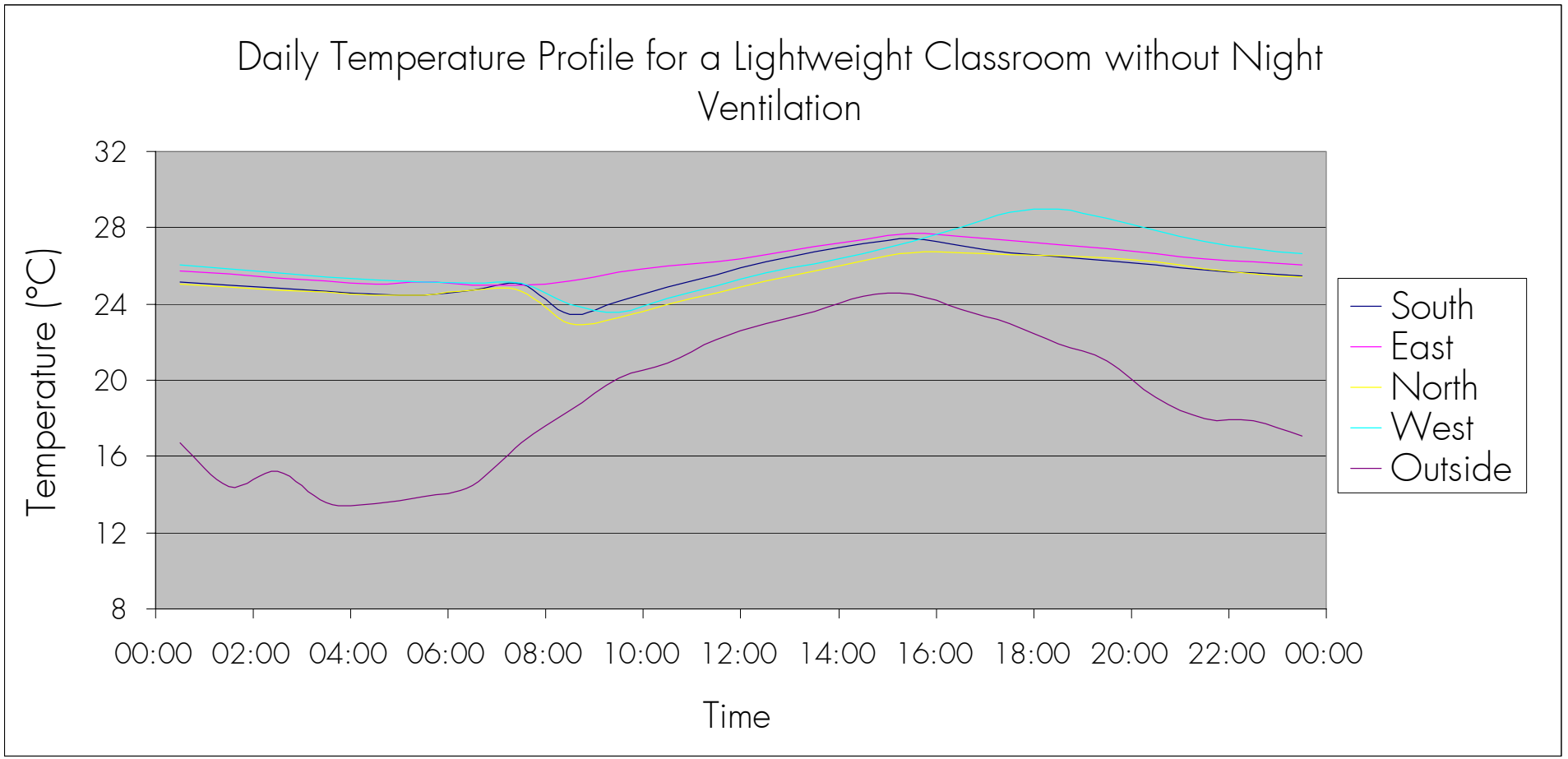
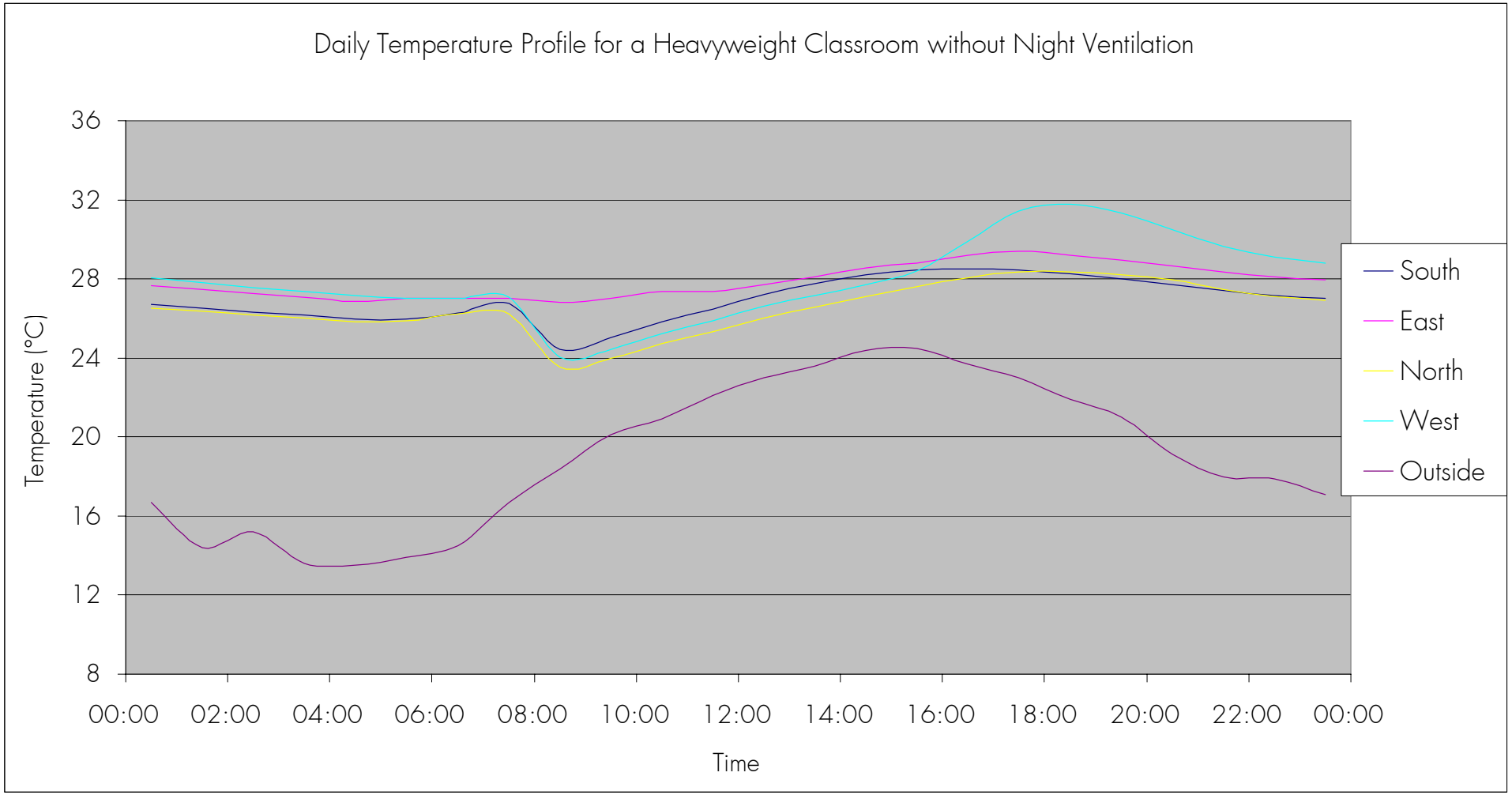

Daily Profile of a Heavyweight Building with Night Ventilation
Temperature (°C)
28
24
20
16
12
8
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Time
South
East
North
West
Outside


Daily Temperature Profile for a Lightweight Classroom without Night Ventilation
Temperature (°C)
32
28
24
20
16
12
8
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Time
South
East
North
West
Outside


Daily Temperature Profile for a Heavyweight Classroom without Night Ventilation
Temperature (°C)
36
32
28
24
20
16
12
8
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Time
South
East
North
West
Outside

How to use Thermal Mass?

50% Convective through air movement

50% Radiant – line of sight

Decoupling the thermal mass: having a lightweight and heavyweight structure

Daily, Weekly and Seasonal Temperature Fluctuations

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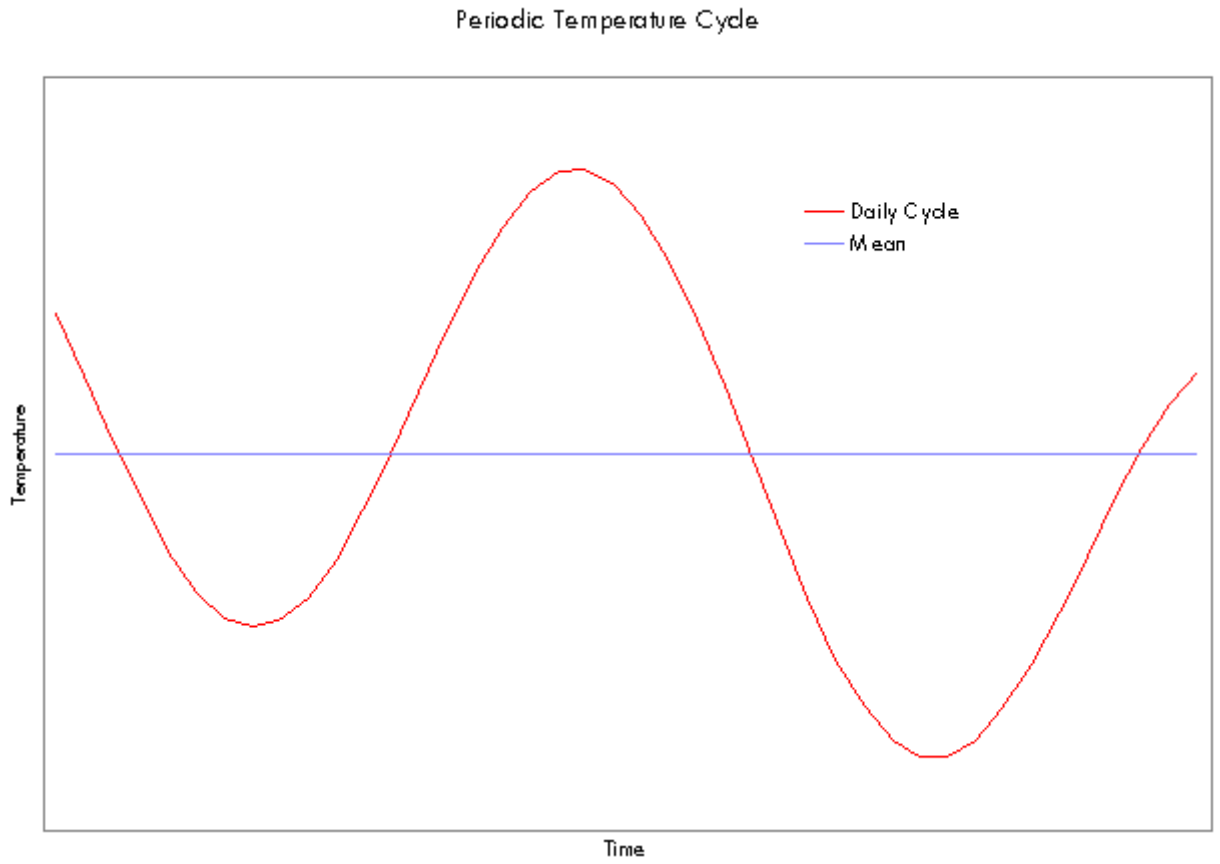
Thermal storage: daily cycle



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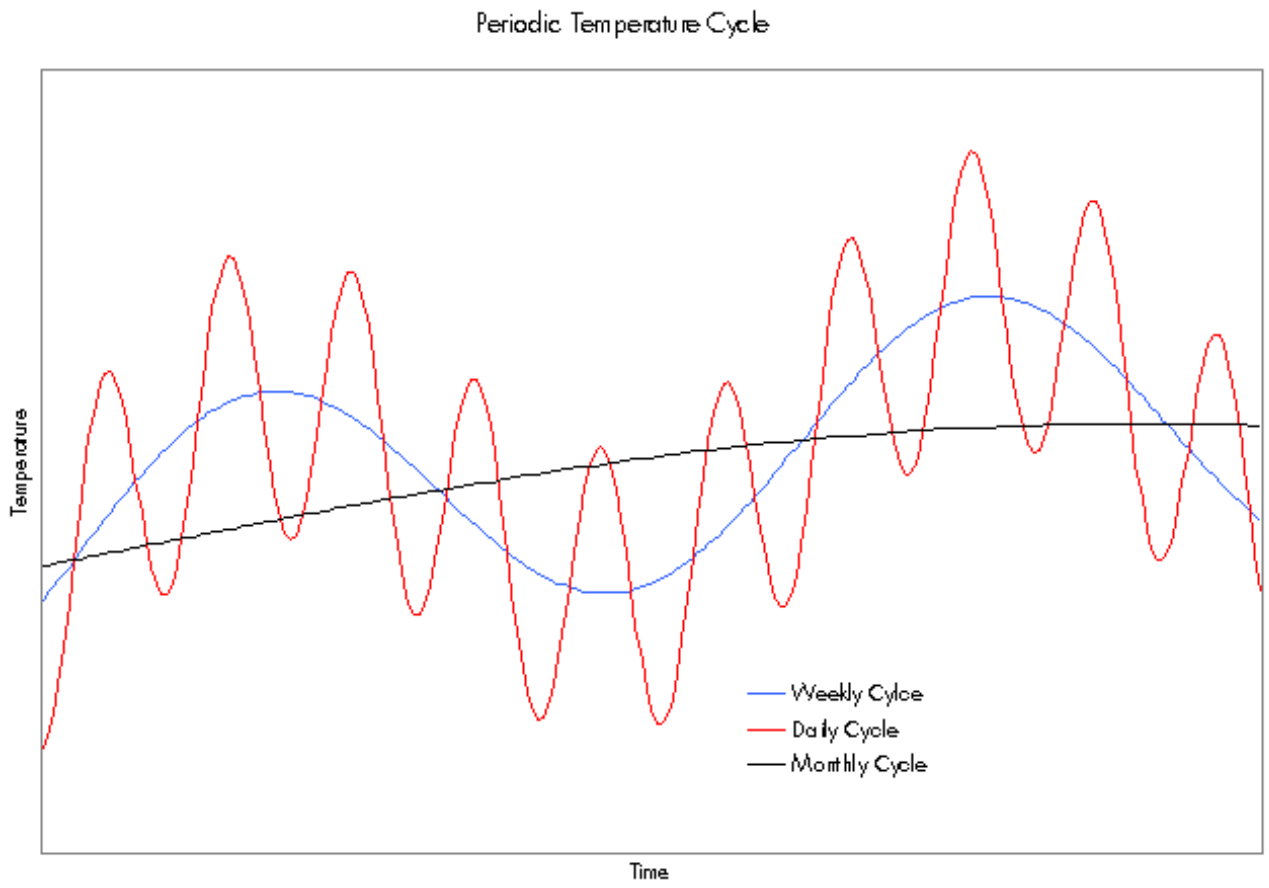
Thermal storage: weekly cycle



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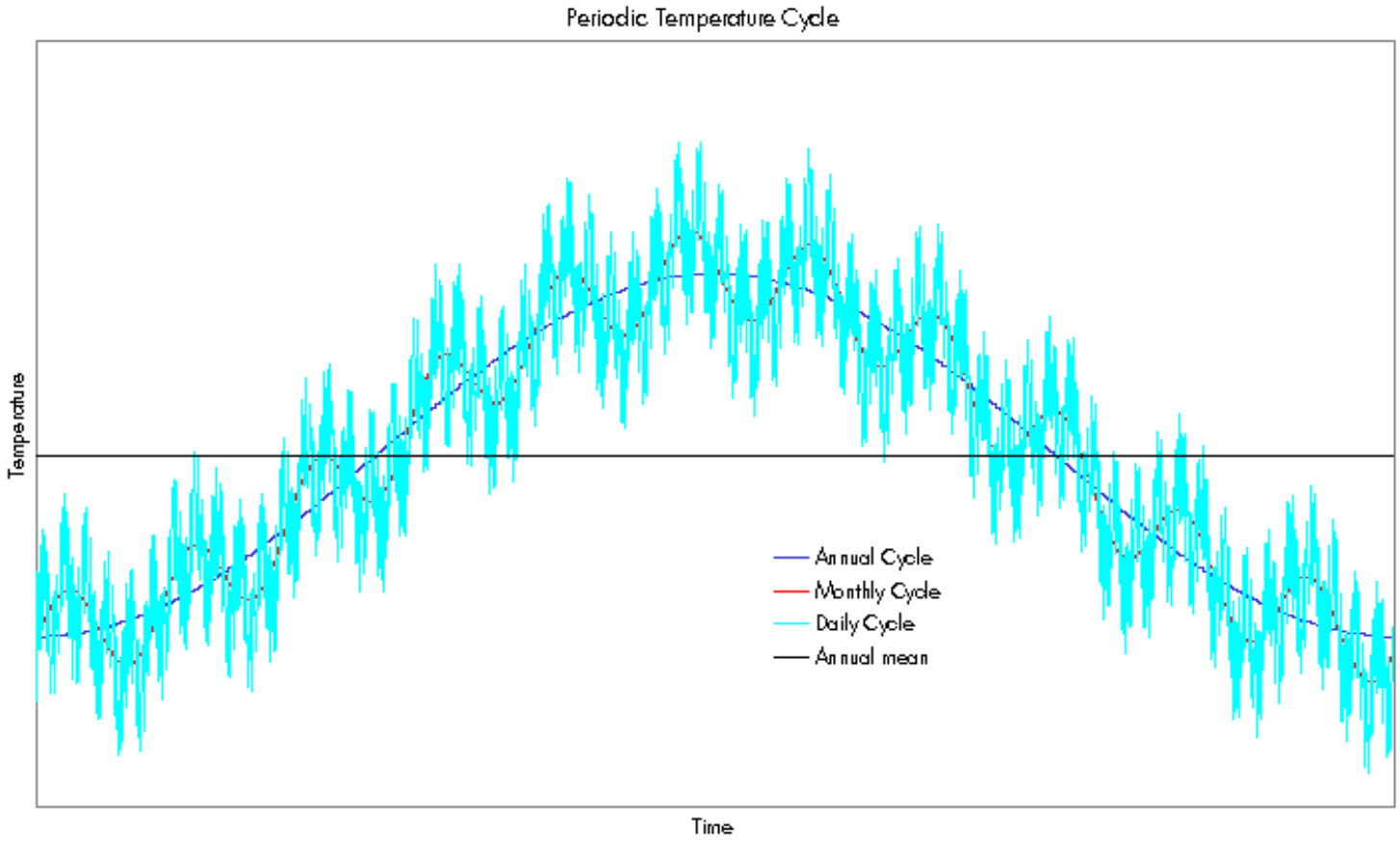
Thermal storage: annual cycle



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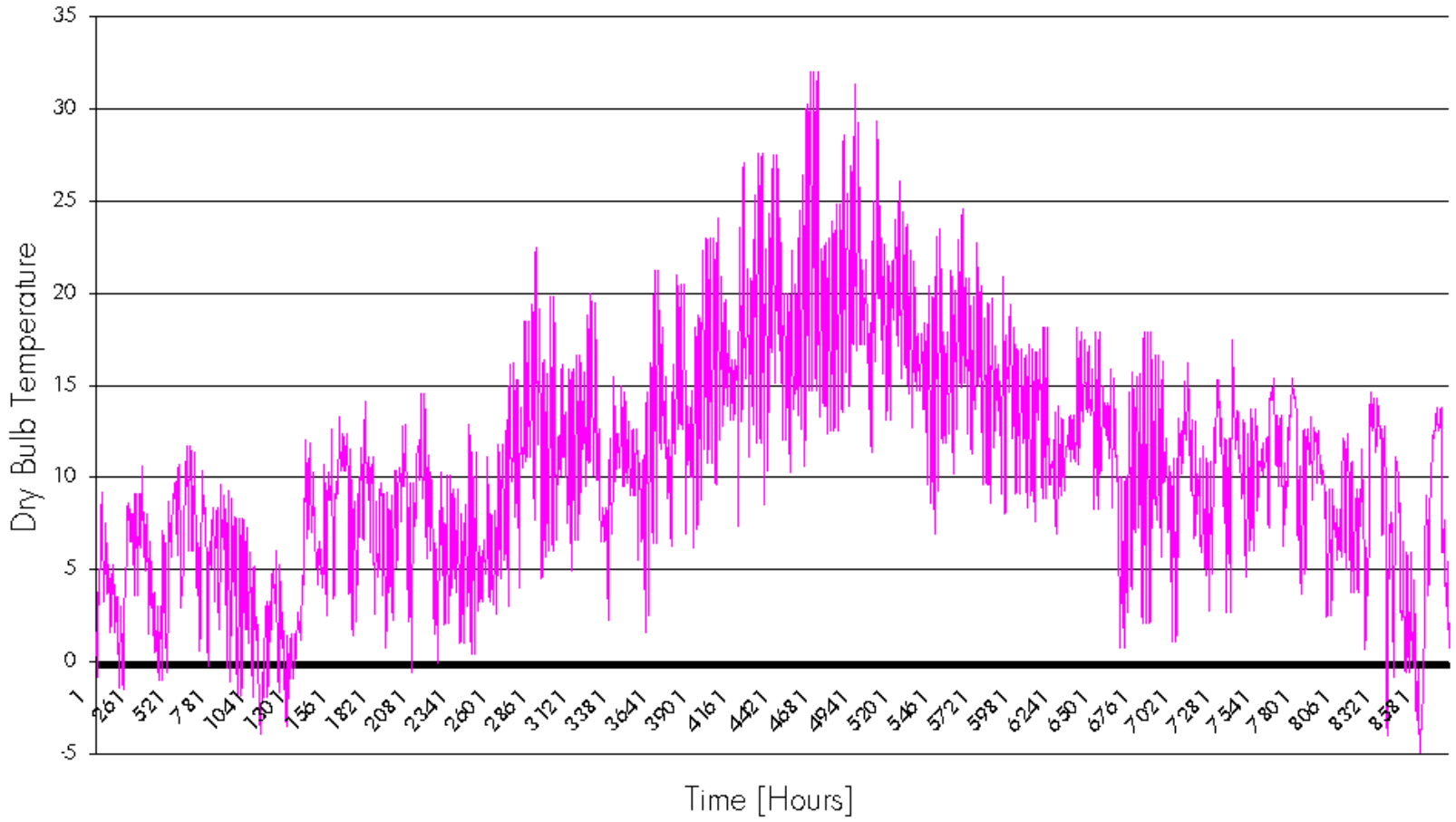
Climatic Variables



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Penetration of heat into slab

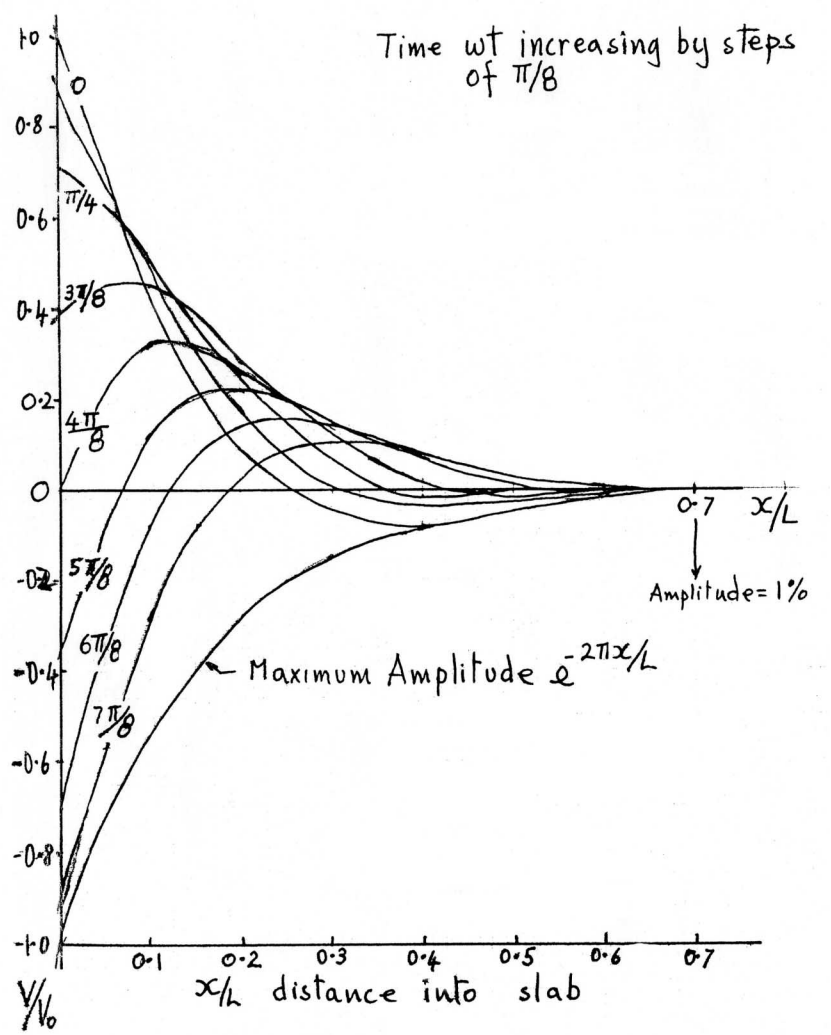

Fig 1. Graph of $V = V_0 \exp\{-2\pi x/L\} \cos\{\omega t - 2\pi x/L\}$

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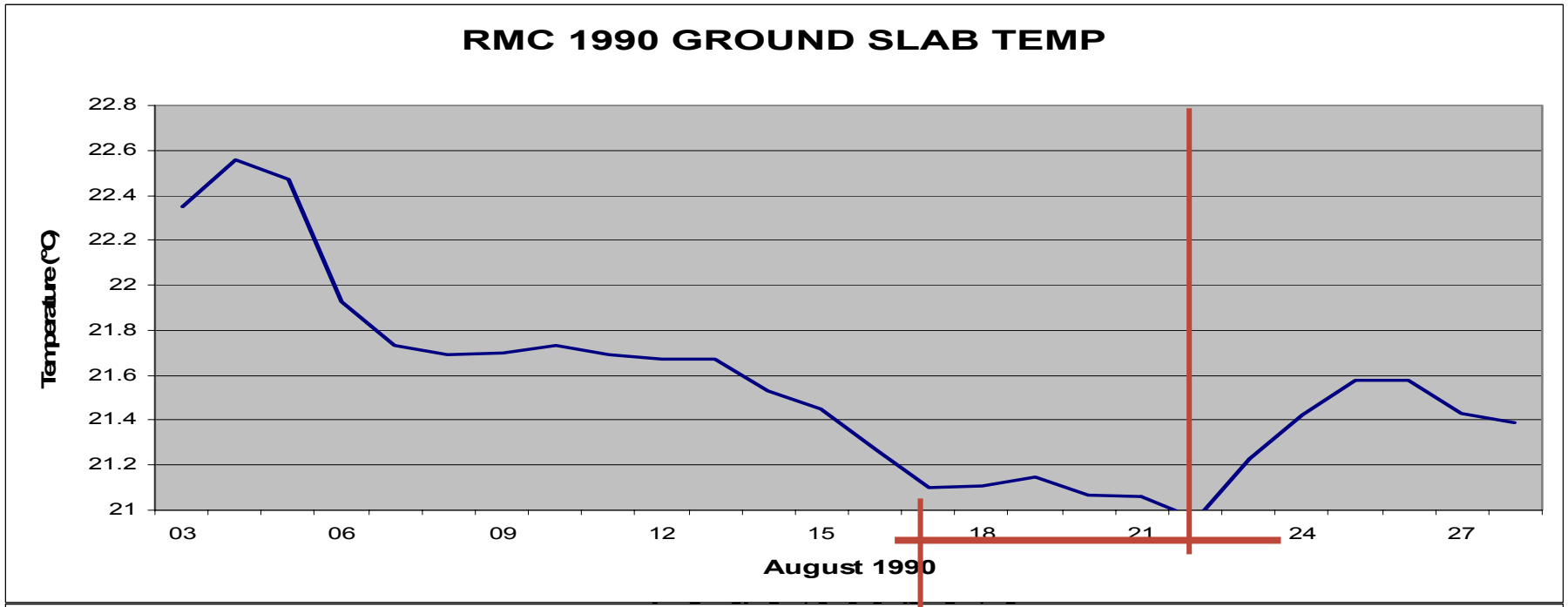
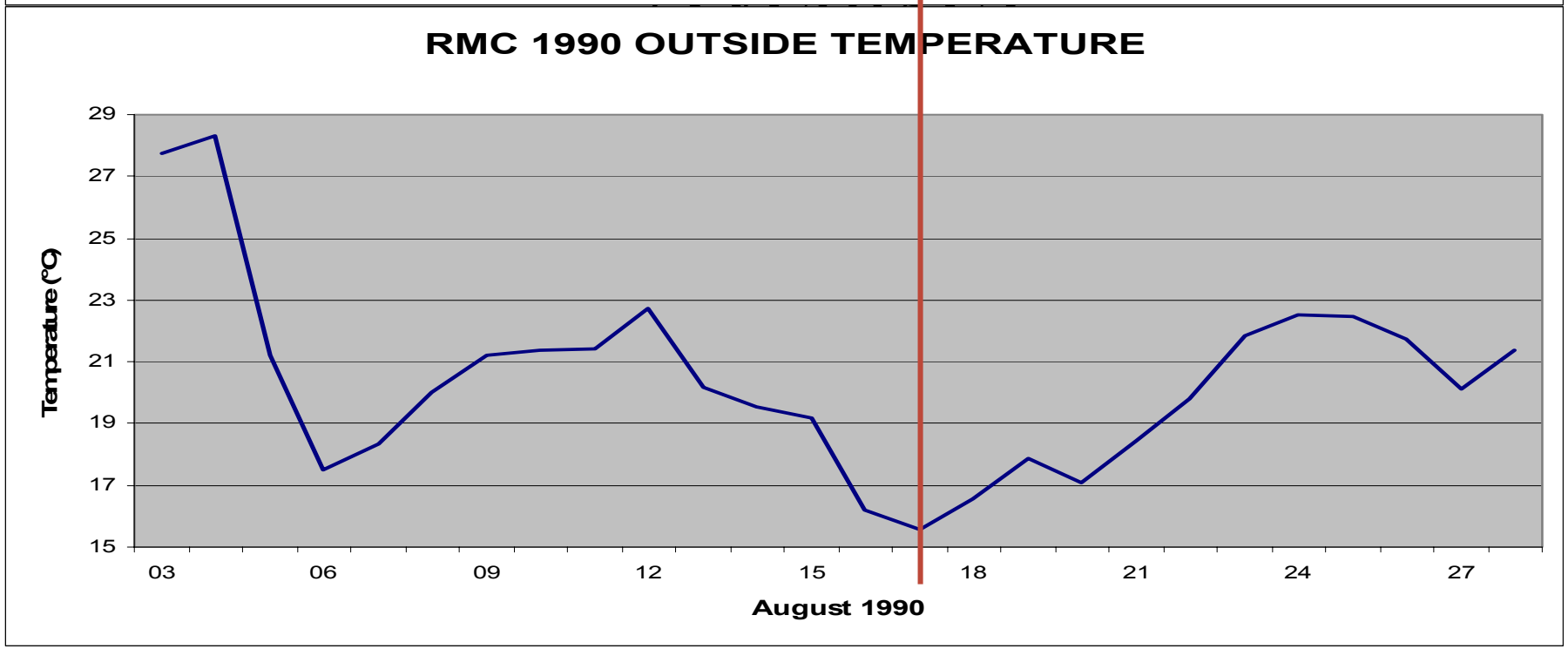

RMC 1990 GROUND SLAB TEMP
Temperature (°C)
22.8
22.6
22.4
22.2
22
21.8
21.6
21.4
21.2
21
03
06
09
12
15
18
21
24
27
August 1990


RMC 1990 OUTSIDE TEMPERATURE
Temperature (°C)
29
27
25
23
21
19
17
15
03
06
09
12
15
18
21
24
27
August 1990

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Examples

BRE: Heavyweight Building

Termodeck

Ground Pipes

Rockstore

Phase Change Materials

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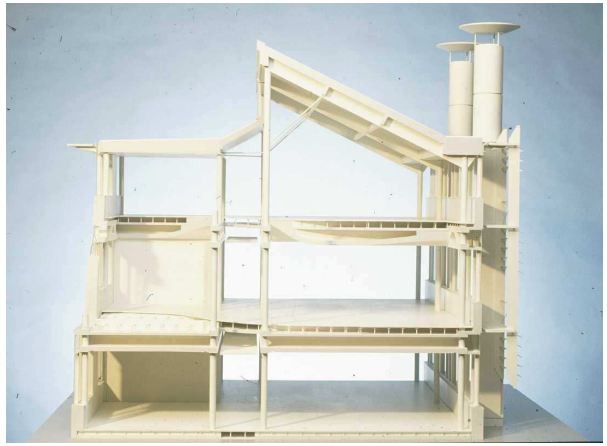
Environmental Building - Garston

- Very Heavyweight
- Natural ventilation with stack chimneys
- Generous windows for natural light
- Louvres to control heat gain
- Water from borehole wells circulates through pipes in the concrete structure
- Individual control for lights and ventilation



BRE Building
Architects: Fielden Clegg Architects

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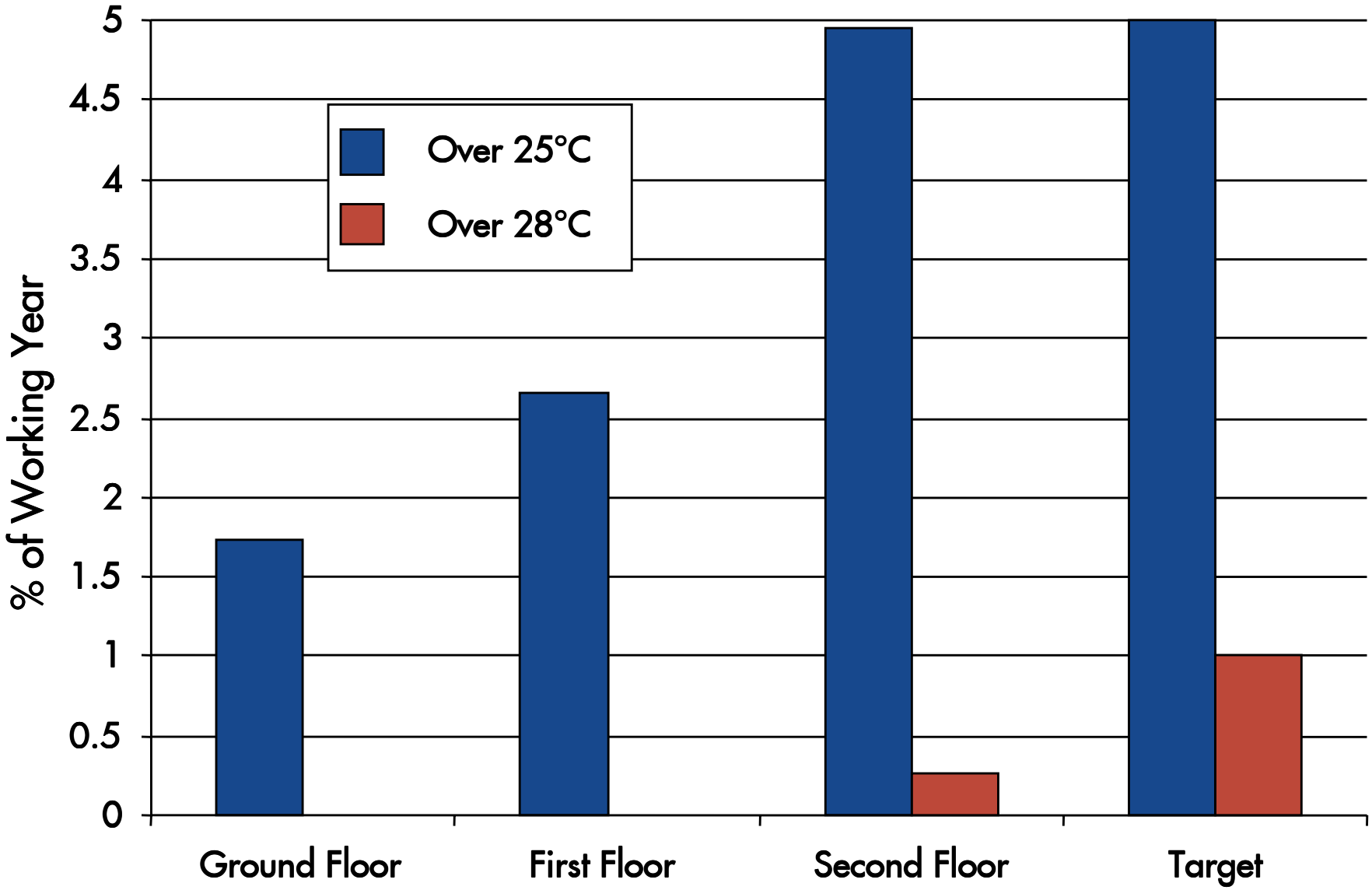
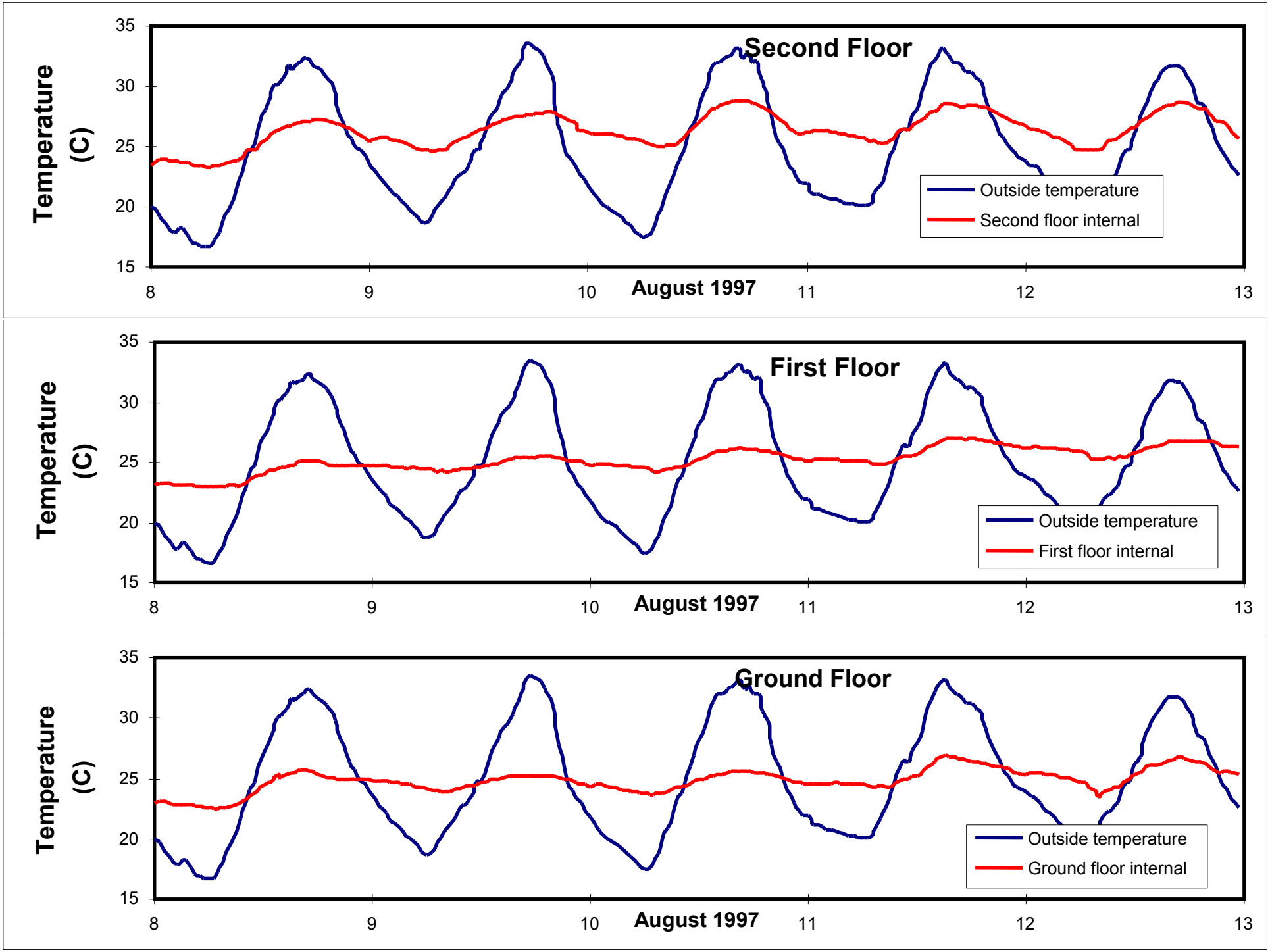
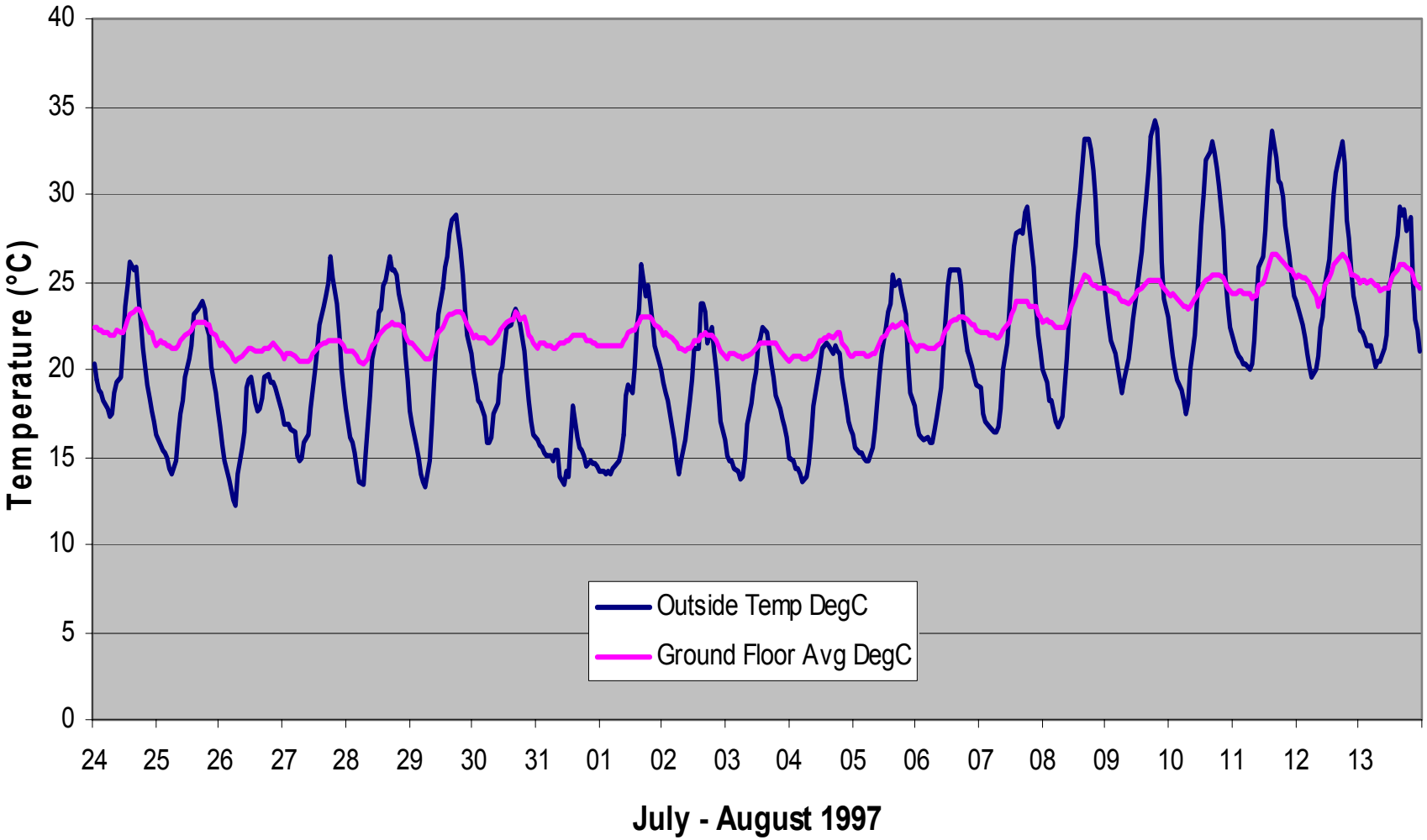
Slide 17

TEMPERATURES EXCEEDED IN 1997




Second Floor
Temperature (C)
35
30
25
20
15
8
9
10
August 1997
11
12
13
Outside temperature
Second floor internal
First Floor
Temperature (C)
35
30
25
20
15
8
9
10
August 1997
11
12
13
Outside temperature
First floor internal
Ground Floor
Temperature (C)
35
30
25
20
15
8
9
10
August 1997
11
12
13
Outside temperature
Ground floor internal

BRE GROUND FLOOR OFFICES 1997



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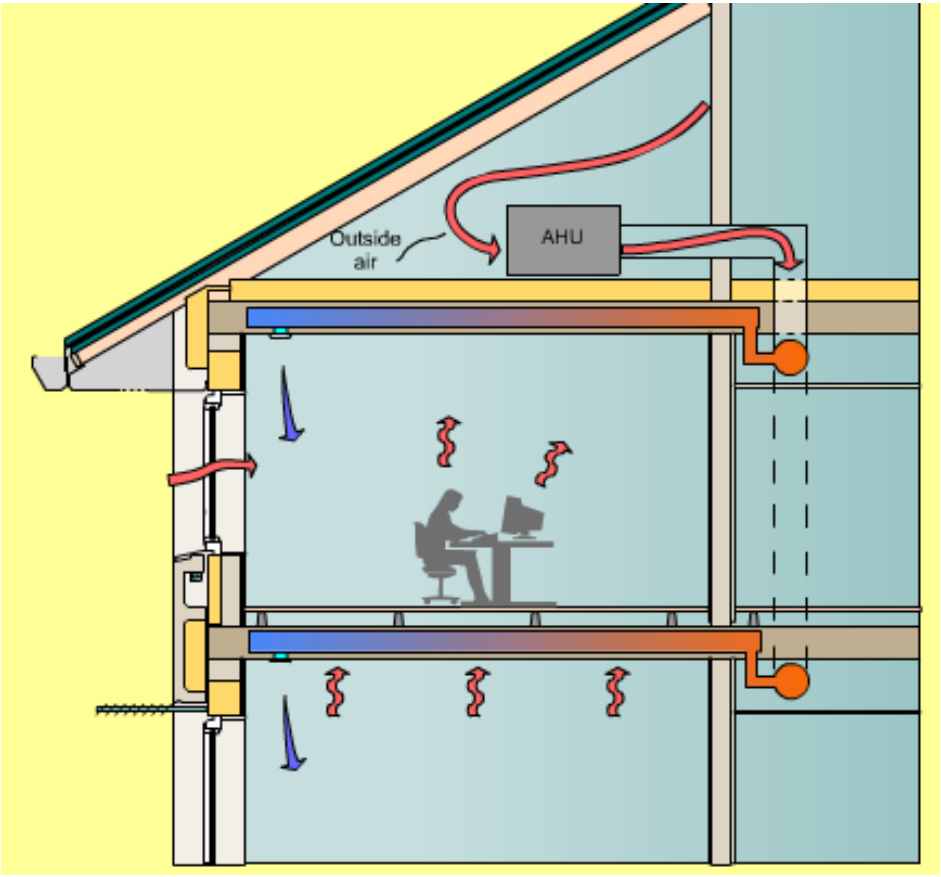
Termodeck



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Ground pipes

Use (25m) lengths of buried pipes to lower the temperature of ventilation air

Lightweight extension to existing office

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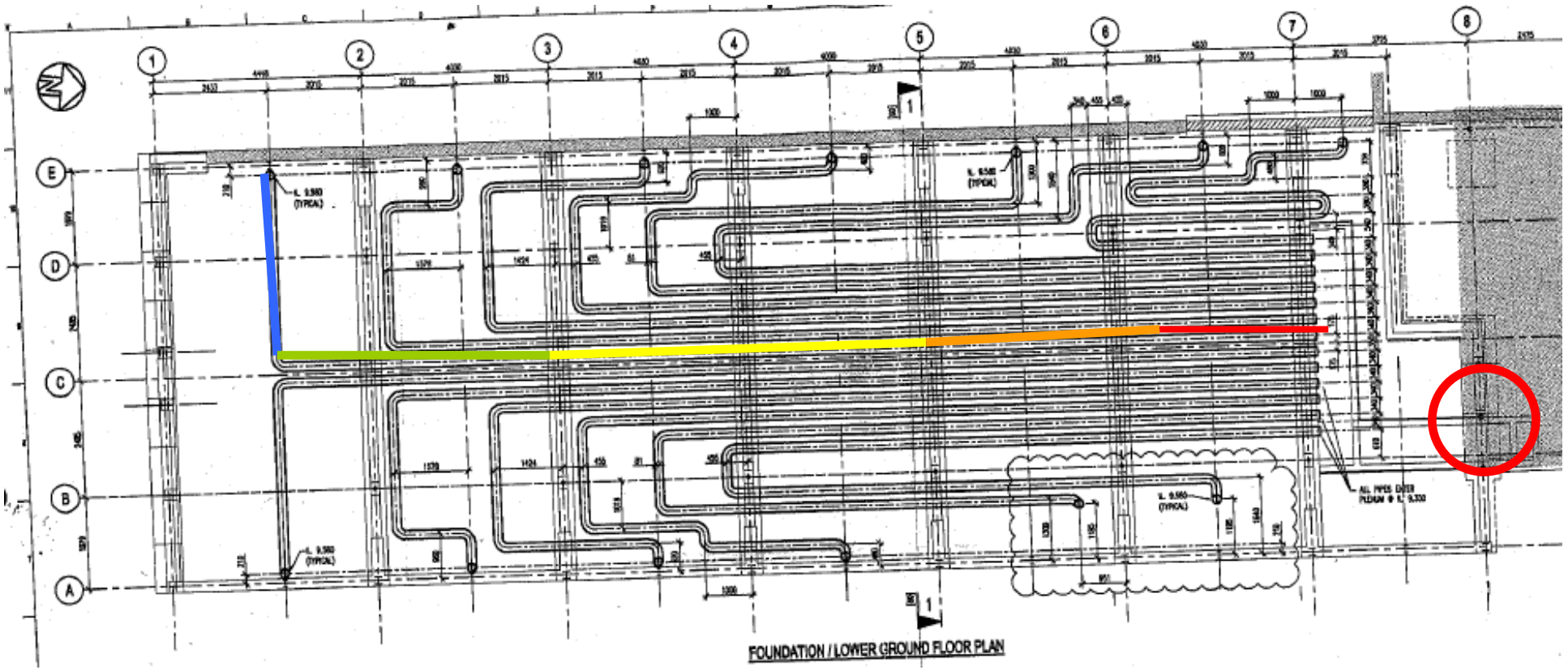
1
2
3
4
5
6
7
8
A
B
C
D
E
FOUNDATION / LOWER GROUND FLOOR PLAN

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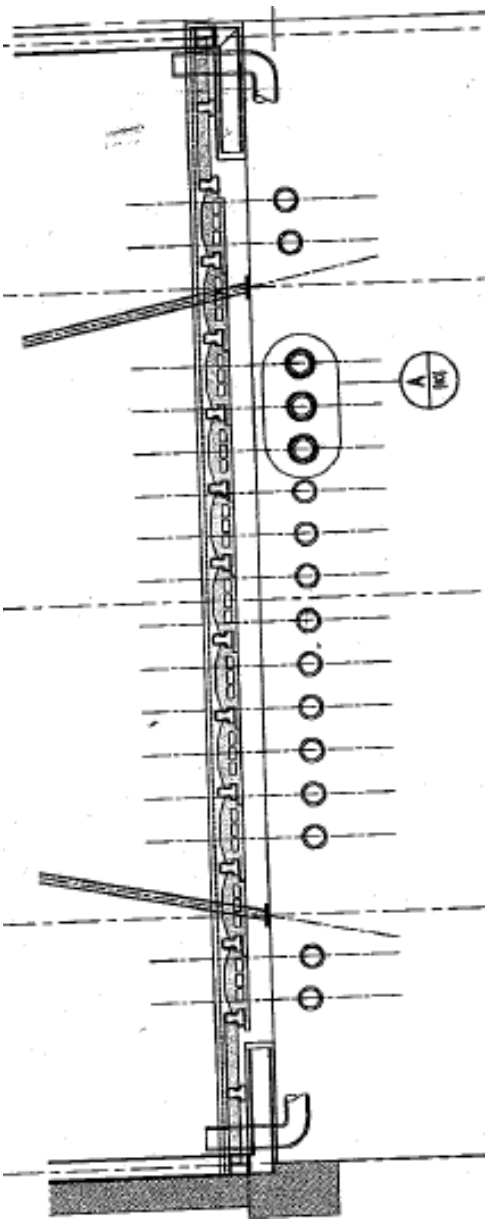
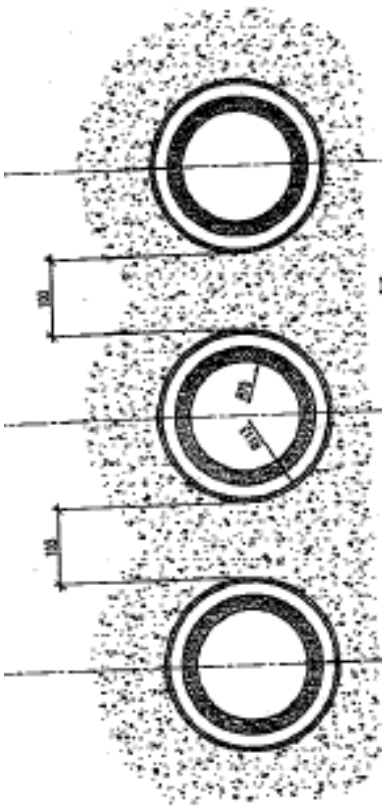
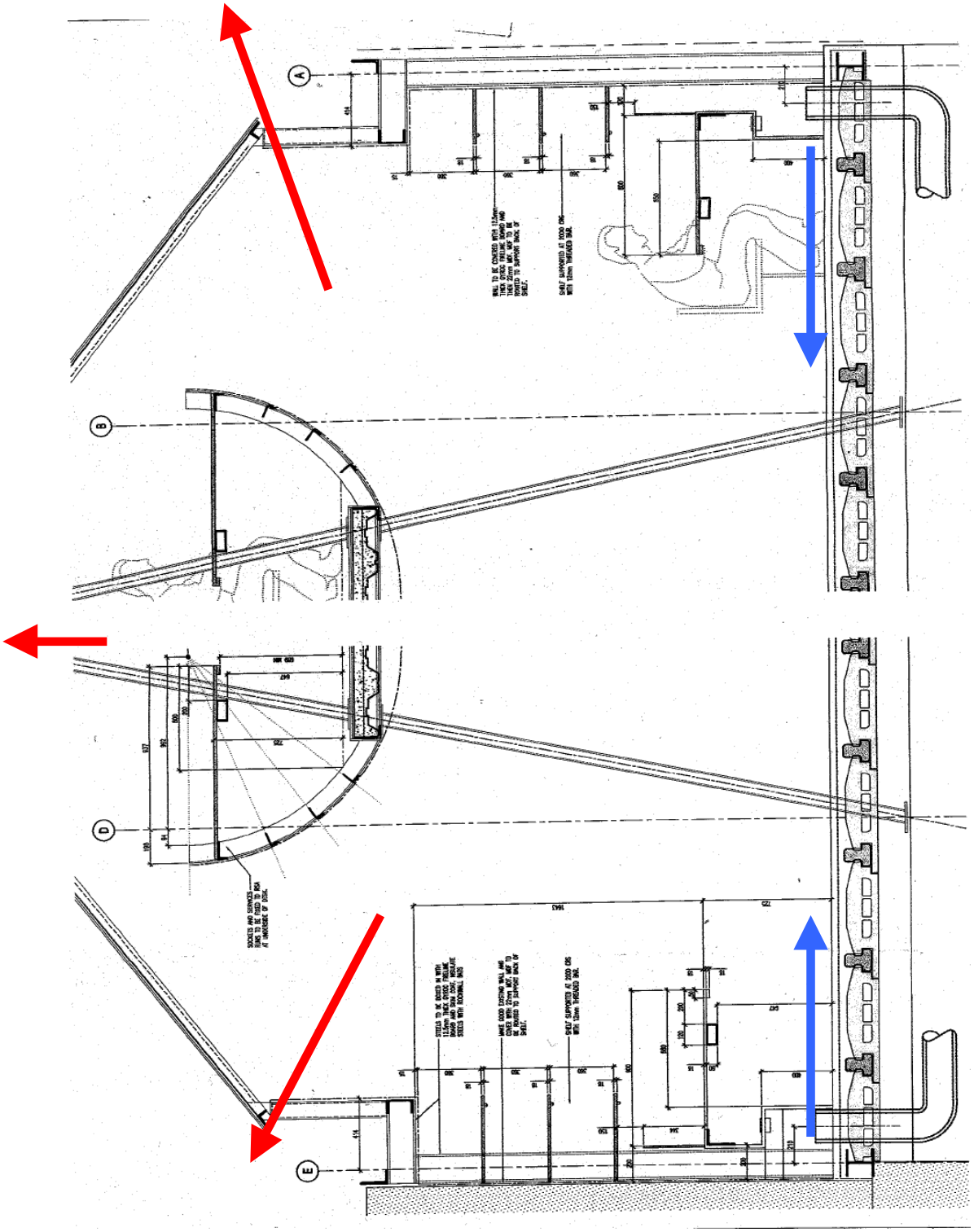
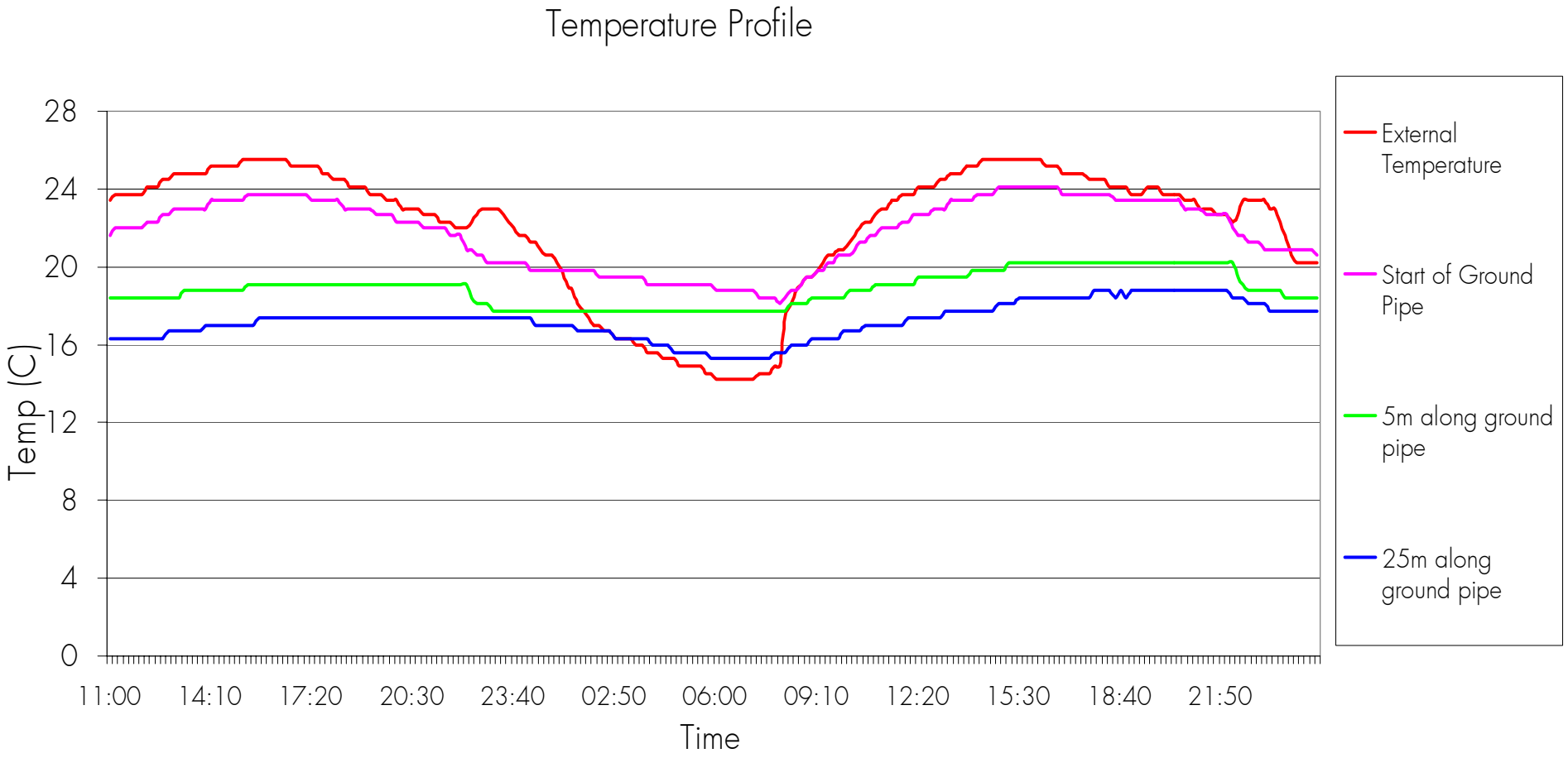




MAX FORDHAM




Temperature Profile
28
24
20
16
12
8
4
0
Temp (C)
11:00
14:10
17:20
20:30
23:40
02:50
06:00
09:10
12:20
15:30
18:40
21:50
Time
External Temperature
Start of Ground Pipe
5m along ground pipe
25m along ground pipe

2 St James

- Gerrards Cross, Buckinghamshire
- Provide Low energy ventilation by driving warm external summertime air through underground rocks
- Post air-mixing to obtain desired ventilation temperature
- Control issues: need for temperature sensors to control fan speeds and dampers

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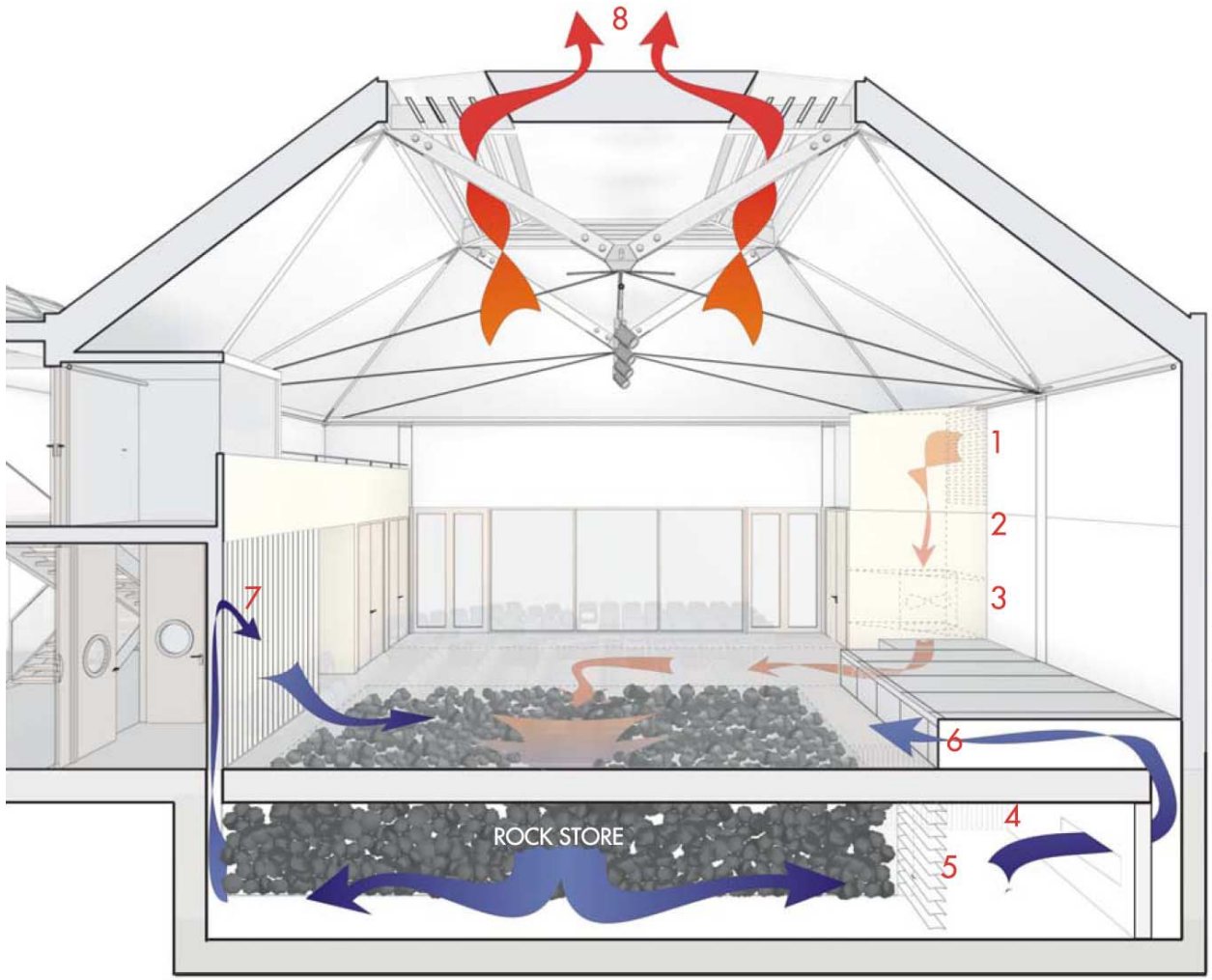

1. Inlet louvre
2. Attenuated inlet duct
3. Fan
4. Heater battery bypass for winter operation
5. Control damper
6. Supply air diffuser
7. Supply air diffuser
8. Acoustic outlet plenum

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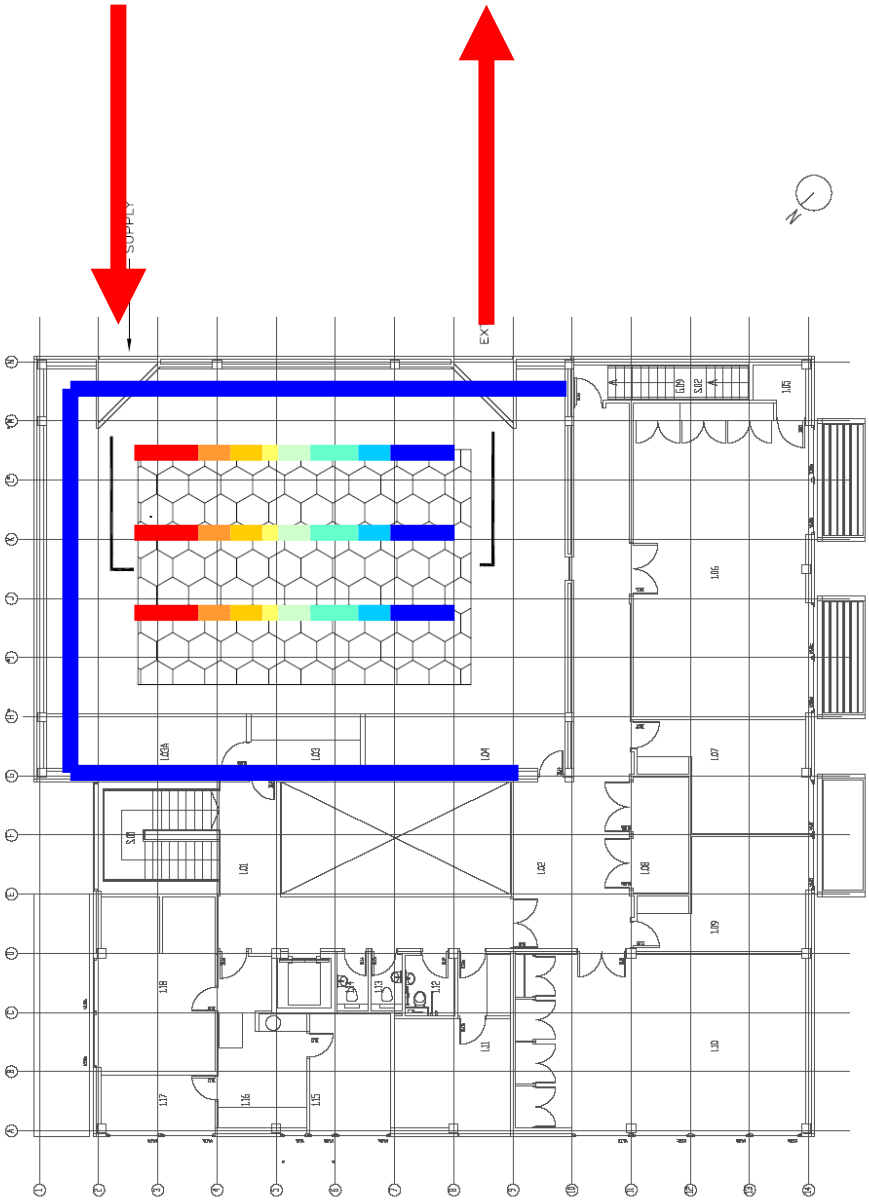
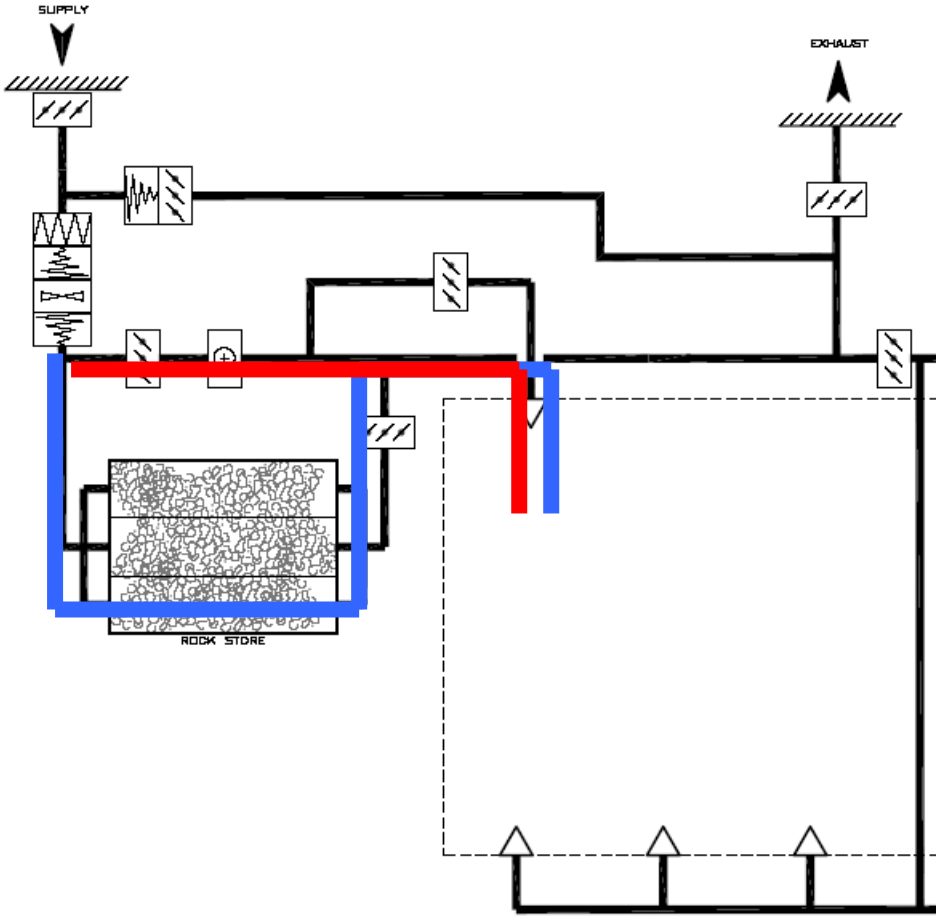


Rock Store Schematic



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The Rocks

Packed in steel cages

Washed by contractor – not planned and these rocks were eventually changed

Not happy on the rock packing!

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Access

Panels lift to provide access

Restricted space due to 1.5m height and damper positions

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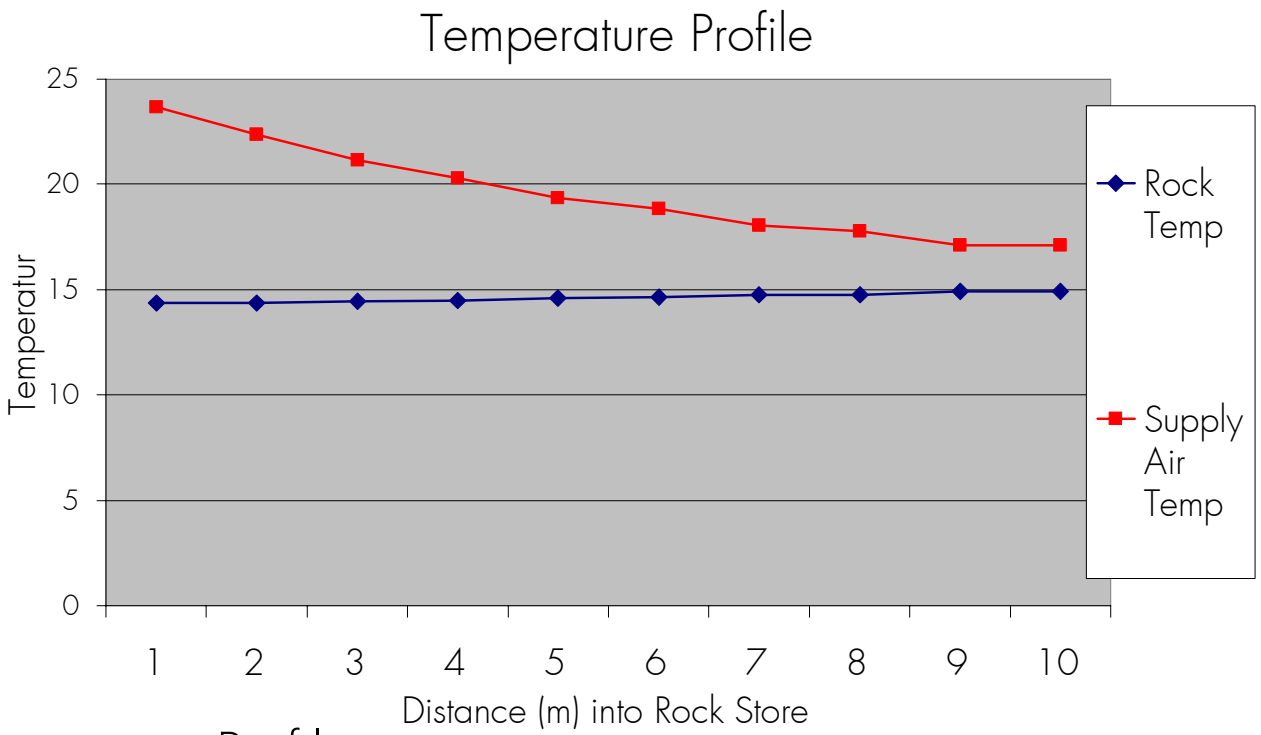
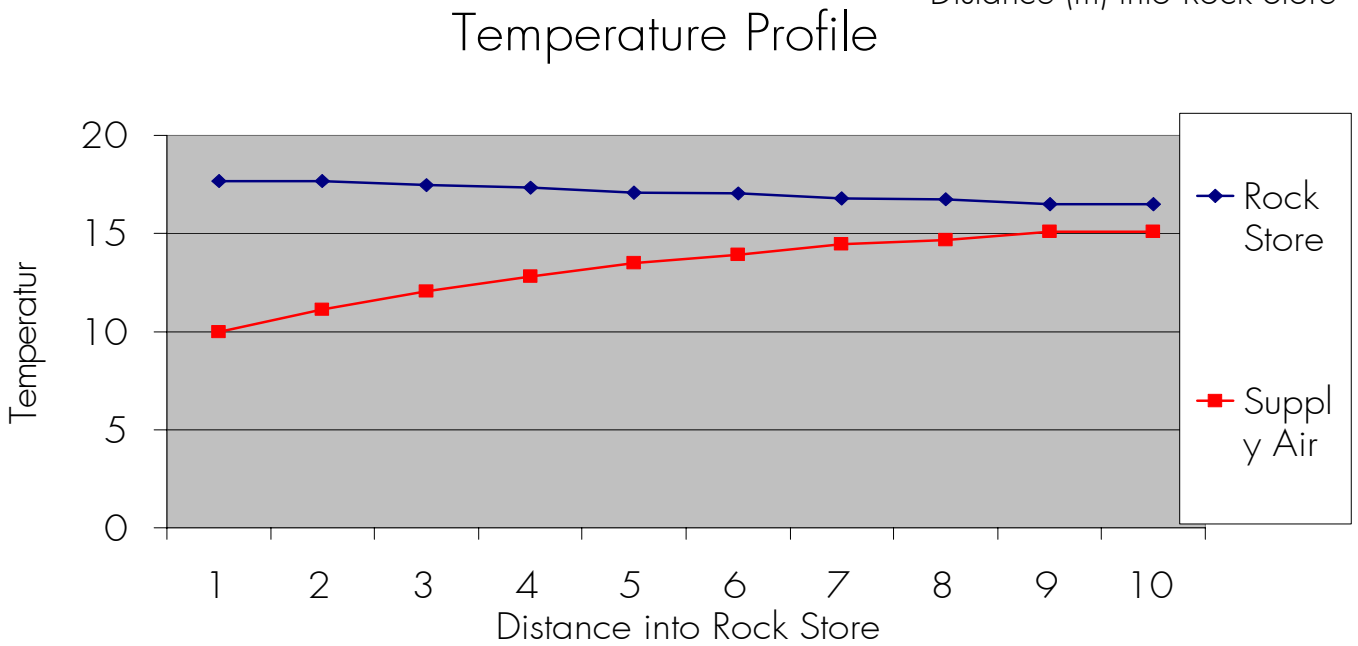
Snapshots

Day-to-day running: air-cooling

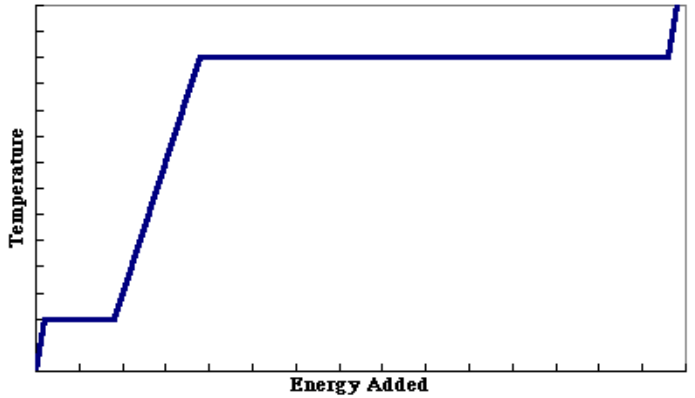




Night-Cooling/Preparation: cooling the rock store

Phase Change Materials

- Waxes
- Salts
- Compounds
- Encapsulation
  - Fibreboards, granules, plaster, concrete



Benefits of Lightweight and Heavyweight building materials

PCMs – Safe Building Materials?

- One problem of having a paraffin based building material is that it is commonly seen as a fuel
- Once encapsulated/packaged are they still a threat to building fire safety?
- University experimentation, BRE assessment and the patio test!

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Current Issues

- Resilience to Wear and Tear
- Gypsum plaster mixed with encapsulated PCM
- Solution: implementing some materials into lightweight schools

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Current Issues

- Phase Change
  - The way in which materials melt is not clearly understood: the properties of the material will vary with time and temperature
  - Solution: experimentation and consultation with manufacturers

Requirements for Long Term Storage

- Suitable heat sources and sinks
- Use low grade heat
- Excess heat needs to be rejected
- Lots of fine tuning once performance of the building is ascertained

Some quick calculations 1

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Daily Gains

People: 30 pupils x 80 W x 6 hours	14,400 Wh
Lights: 15W/m2 x 60m2 x 8 hours	7,200 Wh
Computers: 4 PCs x 120 W x 8 hours	3,840 Wh

Daily Losses

Ventilation : 5l/s x 1.29 x1 x15 x 30 pupils x 6 hours	17,415 Wh
Fabric : 30m2 x 0.75 x 15 x 24 hours	8,100 Wh

Daily Excess Heat 75 Wh

Some quick calculations 2

Day Time heat gains:	25,440 Wh
Day time heat losses (6 hours):	19,440 Wh
Excess Heat to be stored for the Night:	6,000 Wh

i.e 1000 W over 6 hours during the day

Available Area approx 200m2

Temperature Swing 2 C

Required Admittance 2.5 W/m2K

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Conclusion

This is a basic example and assumes the correct ventilation and an air-tight building

Indicative: the potential of thermal mass

It is not the placement of thermal mass,

but the utilisation of it