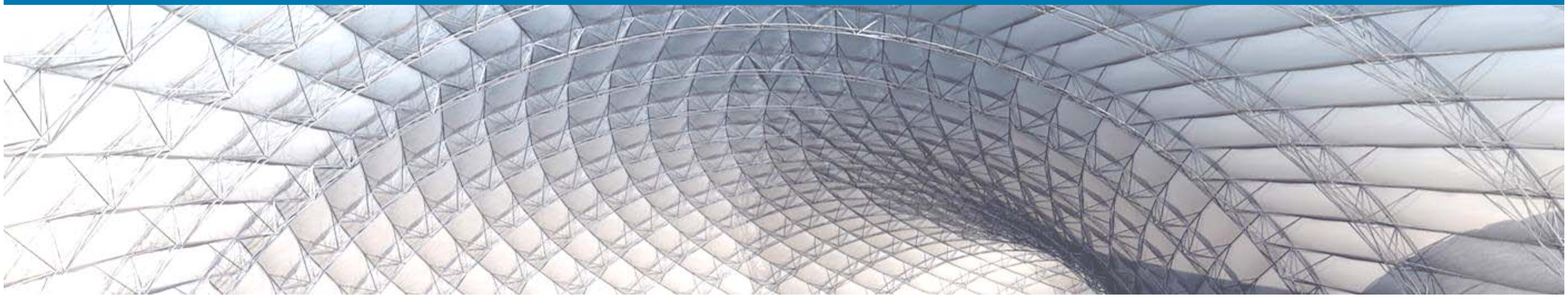
Innovative Use of Aerogel in Passive and Active Solar Storage Walls

Mark Dowson - CIBSE Building Simulation Group – 2nd June 2011

Buro Happold



Presentation outline:

- My background
- Research focus
- Two modelling case studies
  - Passive solar storage wall (i.e. a Trombe wall)
  - Active solar-air collector
- Questions

My background:

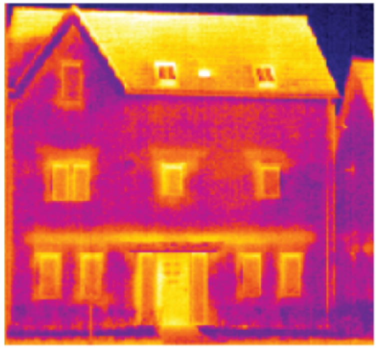
- Research engineer based in industry
- Currently undertaking an Engineering Doctorate (EngD) in Environmental Technology
- Industrial project sponsored by Brunel University and Buro Happold Ltd

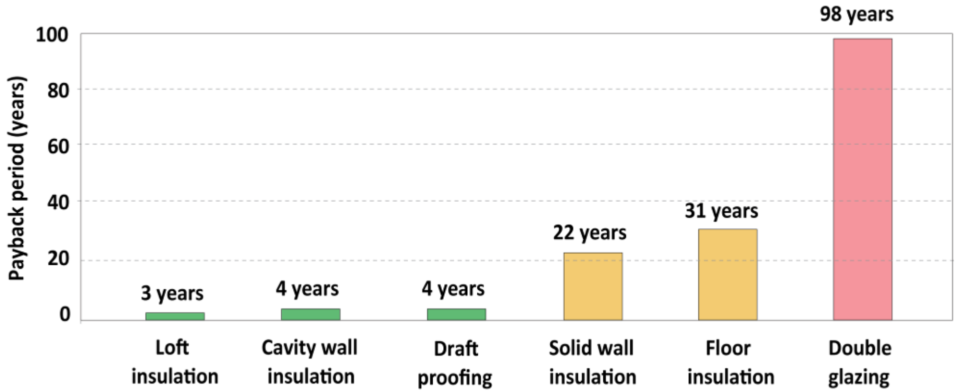
Buro Happold:

- Global engineering consultancy for the built environment
- Sustainability and Building Physics team (London)

Focus of my research:

- Developing and testing new building fabric technologies incorporating high performance ***silica aerogel insulation*** to reduce demand for heating and artificial lighting in buildings

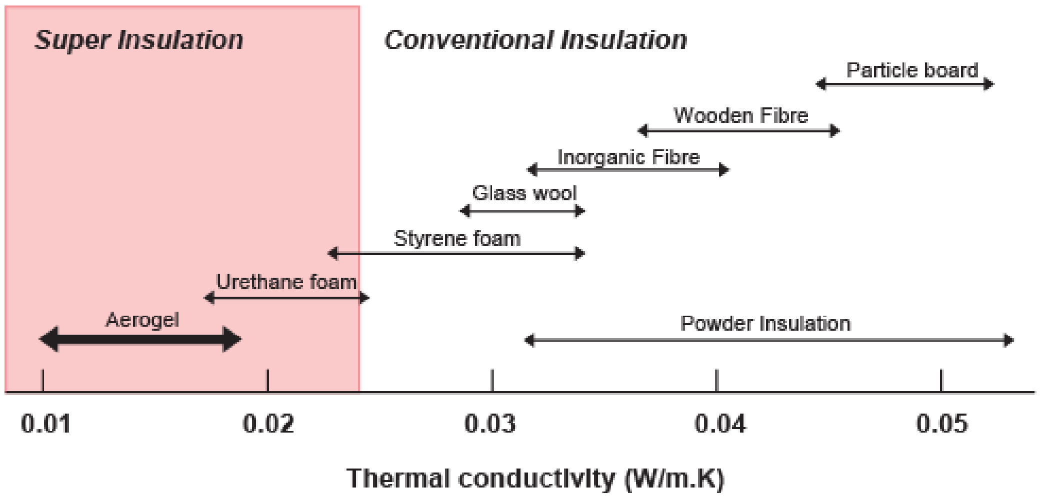




- Millions of homes in the UK are poorly insulated and expensive to heat
- Some conventional solutions to improve these homes are not cost effective

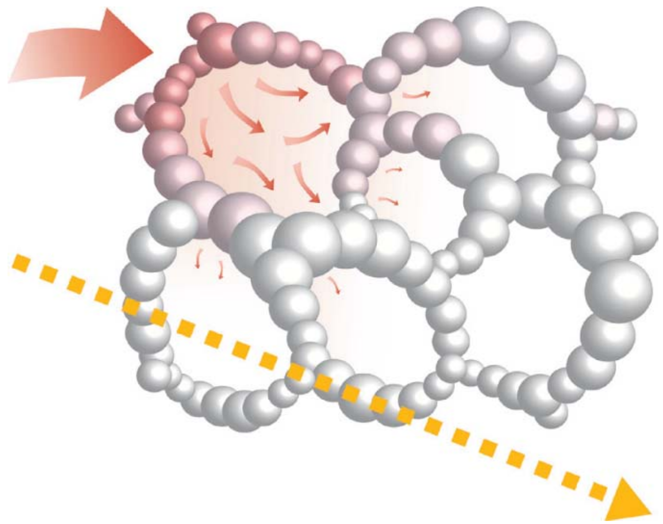
What is aerogel?

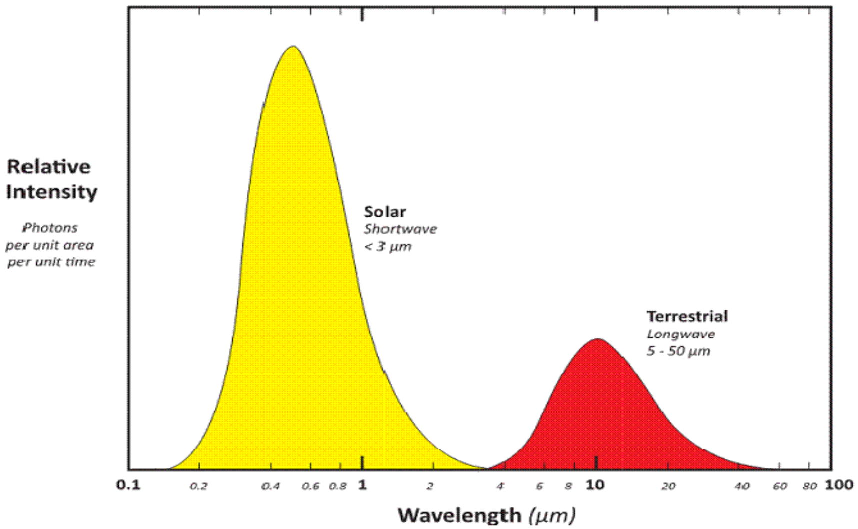
- Transparent “super-insulation” material
- Invented in the 1930s; only now emerging in the construction market
- Translucent granules are mass produced
- Solid tiles can be produced, but they are fragile and expensive, thus are not commercially available



How does it work?

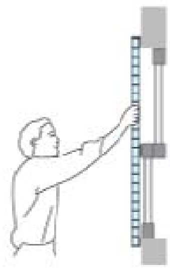
- Material contains a nanoporous structure – up to 99% air (1% silica)
- Nanosized pores block heat transfer by ***convection***, ***conduction*** and ***long-wave thermal radiation***
- Silica structure is highly transparent to ***light*** and ***short-wave solar radiation***

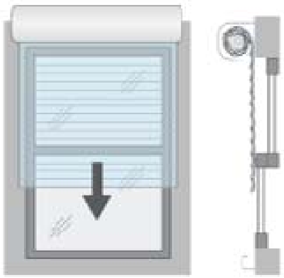




How can it be used?

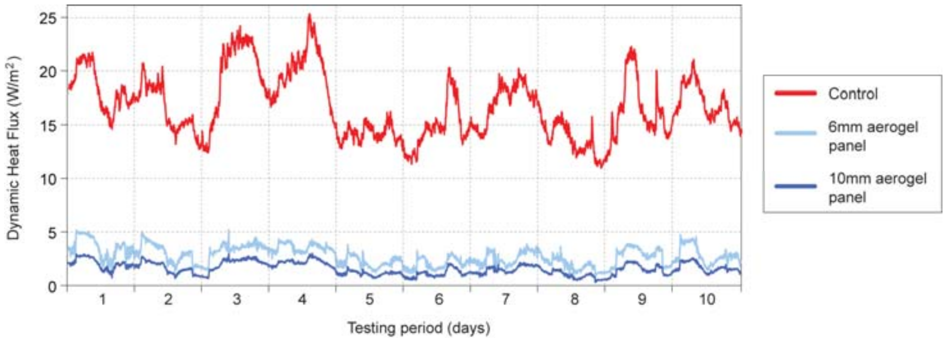
Concepts to insulate existing windows:


'Pop-in' magnetic secondary glazing


Internal/external airtight roller shutters


Sliding shutters integrated into external wall insulation

Measurements show an 80% reduction in heat loss!

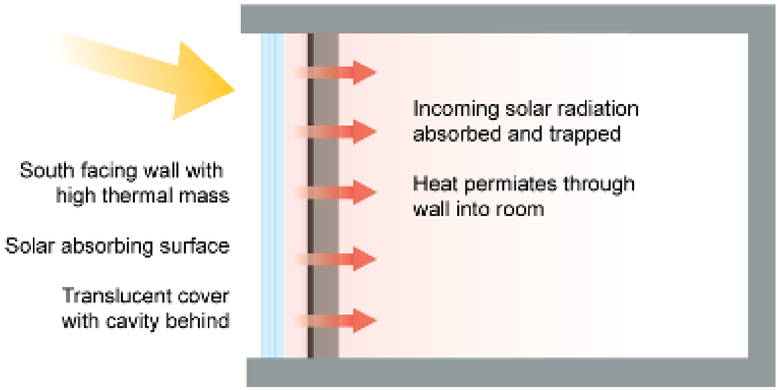


Concepts for passive solar storage:

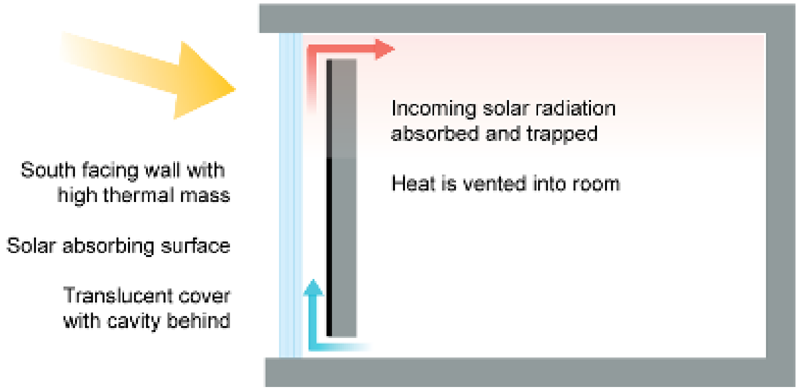
- High performance cover in south facing solar storage walls
- Aerogel has a lower solar transmission to standard single glazing but significantly reduces heat losses

Let solar energy in.
Trap it.
Let it accumulate.
Use it

Unventilated trombe wall:



Ventilated trombe wall:

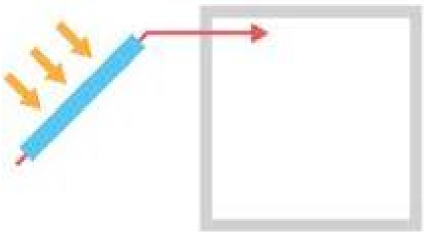


Concepts for active solar collection:

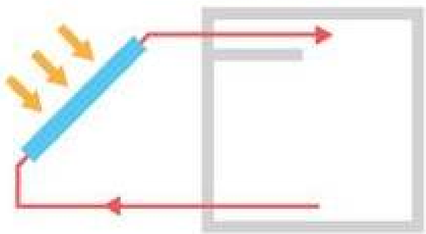
- Supply free solar heated warm air to a space instantaneously
- Storage can be introduced through PCM in collector or ductwork
- Air-water heat exchangers can avoid wasting heat in summer

Let solar energy in.
Trap it.
Let it accumulate.
Use it

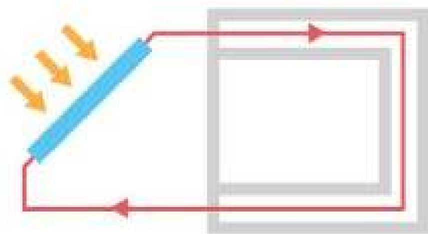
Solar heating of outside air supplied directly to space



Solar heating of room air returned via thermal storage in roof



Solar heated air circulated through cavity in the building envelope



CASE STUDY 1: Aerogel Trombe wall

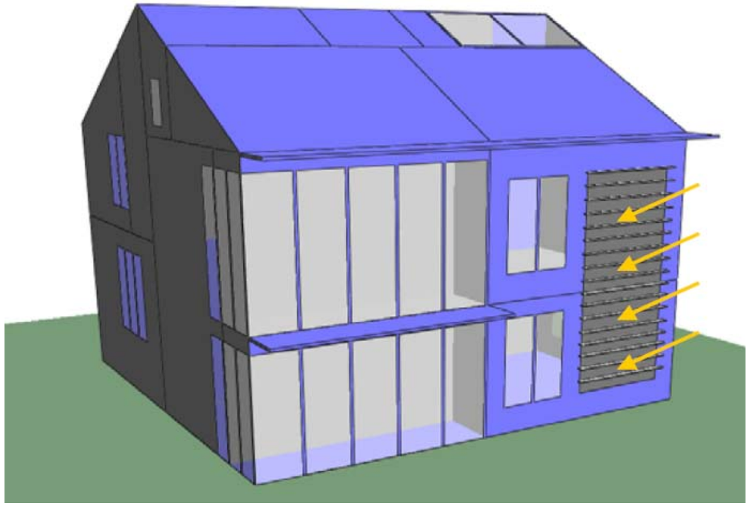
Riches Hawley Mikhail Architects

Robinson Associates Engineers

- Concept currently planned for a new eco-home in the UK
- Property will be highly insulated and have high thermal mass
- Aerogel Trombe wall is anticipated to reduce need for heating during cold-mild sunny days

Approach used:

- Parametric calculator built in Excel
- Model combines building parameters obtained through IES Virtual Environment software with average solar radiation and degree-day data for the site.
- Max allowable area = **7.5m²**

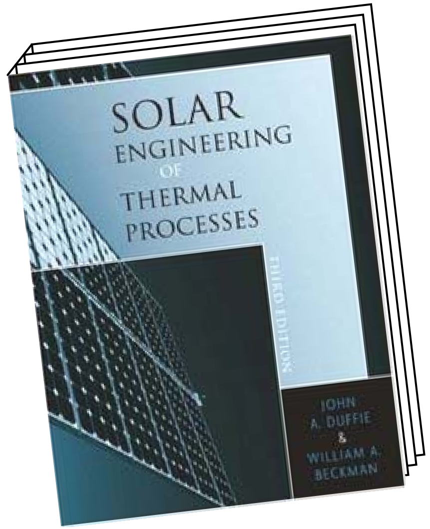


Calculation methodology:

Duffie and Beckman (2006), Solar Engineering of Thermal Processes

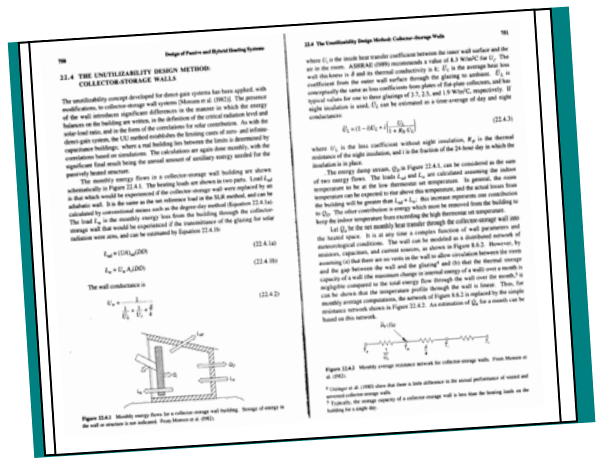
Third Edition, John Wiley & Sons Inc, New York, USA

- Widely cited book to predict the performance of solar technologies
- Calculations validated through TRYNSYS simulations + measurements
- Educational software available from www.fchart.com



Contents include:

- Solar radiation calculations
- Transmission properties of materials
- Passive, active and hybrid solar technologies
- Energy storage systems
- Financial modelling

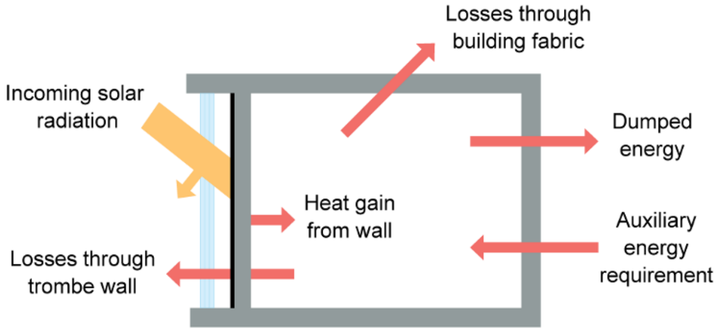


Overview of method:

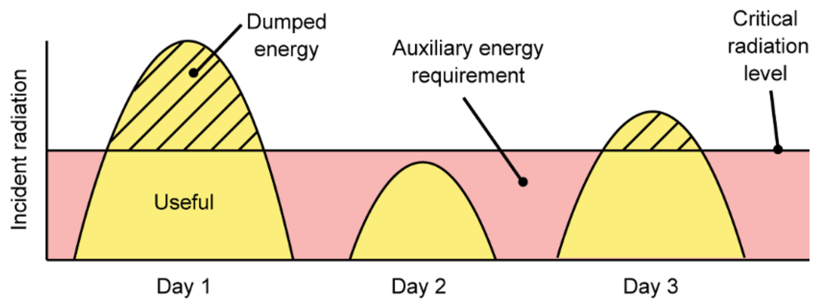
Chapter 22: Un-utilizability design method for collector-storage walls

- Method assumes system is unvented and heat transfer though the wall is linear
- Calculates a buildings monthly-average heat load with + without a Trombe wall, based upon:
  - Absolute upper and lower limits of the building and walls thermal capacity
  - Storage-dump ratio, defined by the systems actual thermal capacity

Trombe wall energy balance:



Storage-dump concept
(for zero capacitance system):



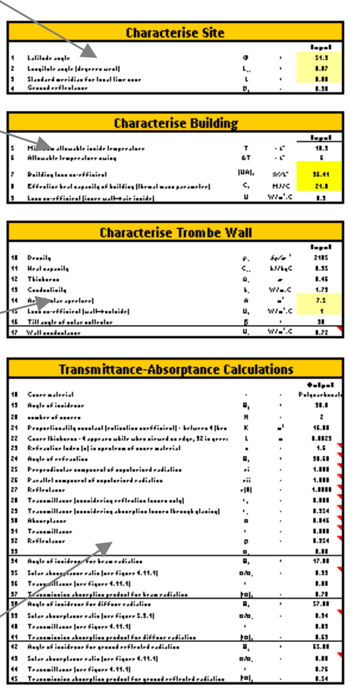
Parametric calculator

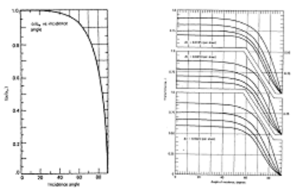
Characterise site
- latitude
- longitude
- ground reflectance

Characterise building
- Heat loss parameter
- Thermal capacity
- Stat set points
- Allowable temp swing

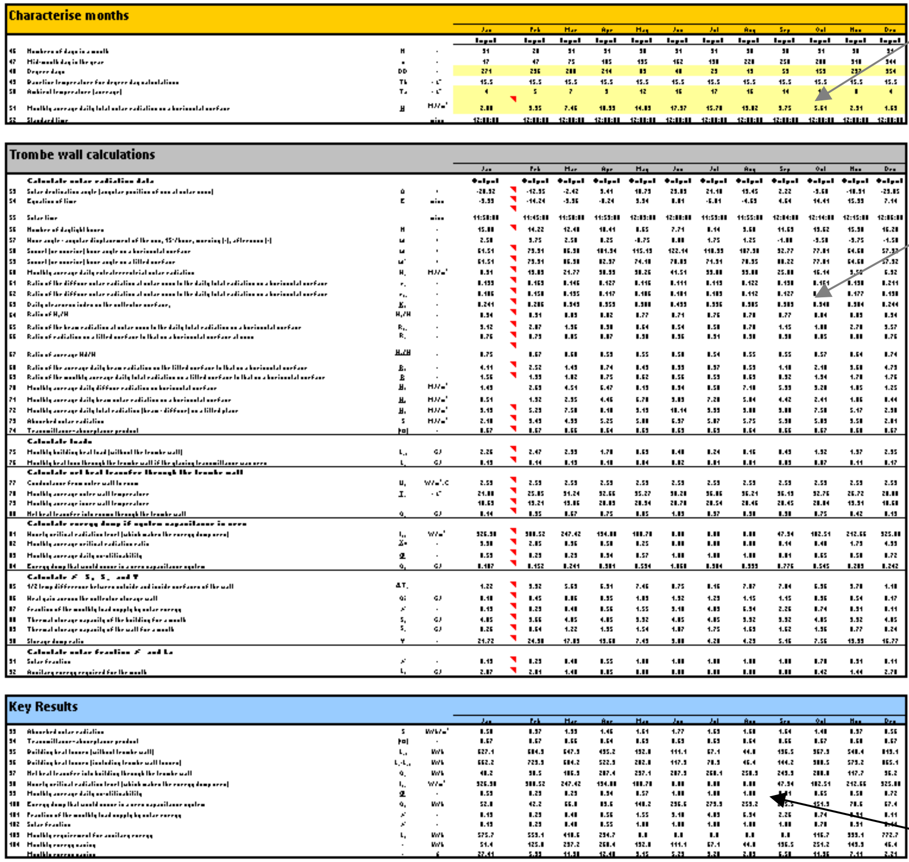
Characterise wall
- Area
- Thickness
- Heat capacity
- Density
- Conductivity
- Loss co-efficient

Characterise cover transmission
- Solar transmission
- Solar absorptance
- Solar reflectance
- Overall product in terms of beam, diffuse and ground reflected radiation





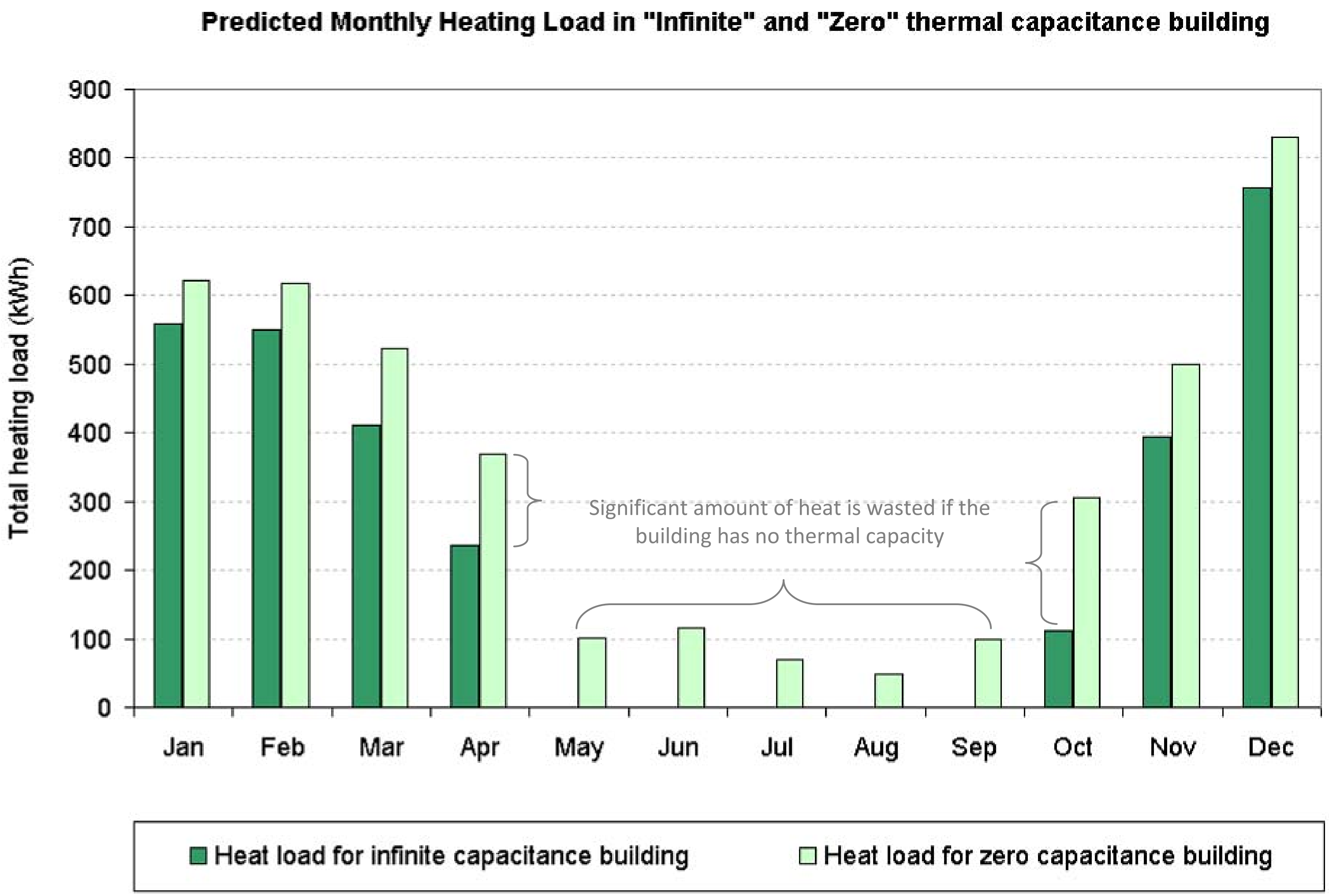
Monthly-average values

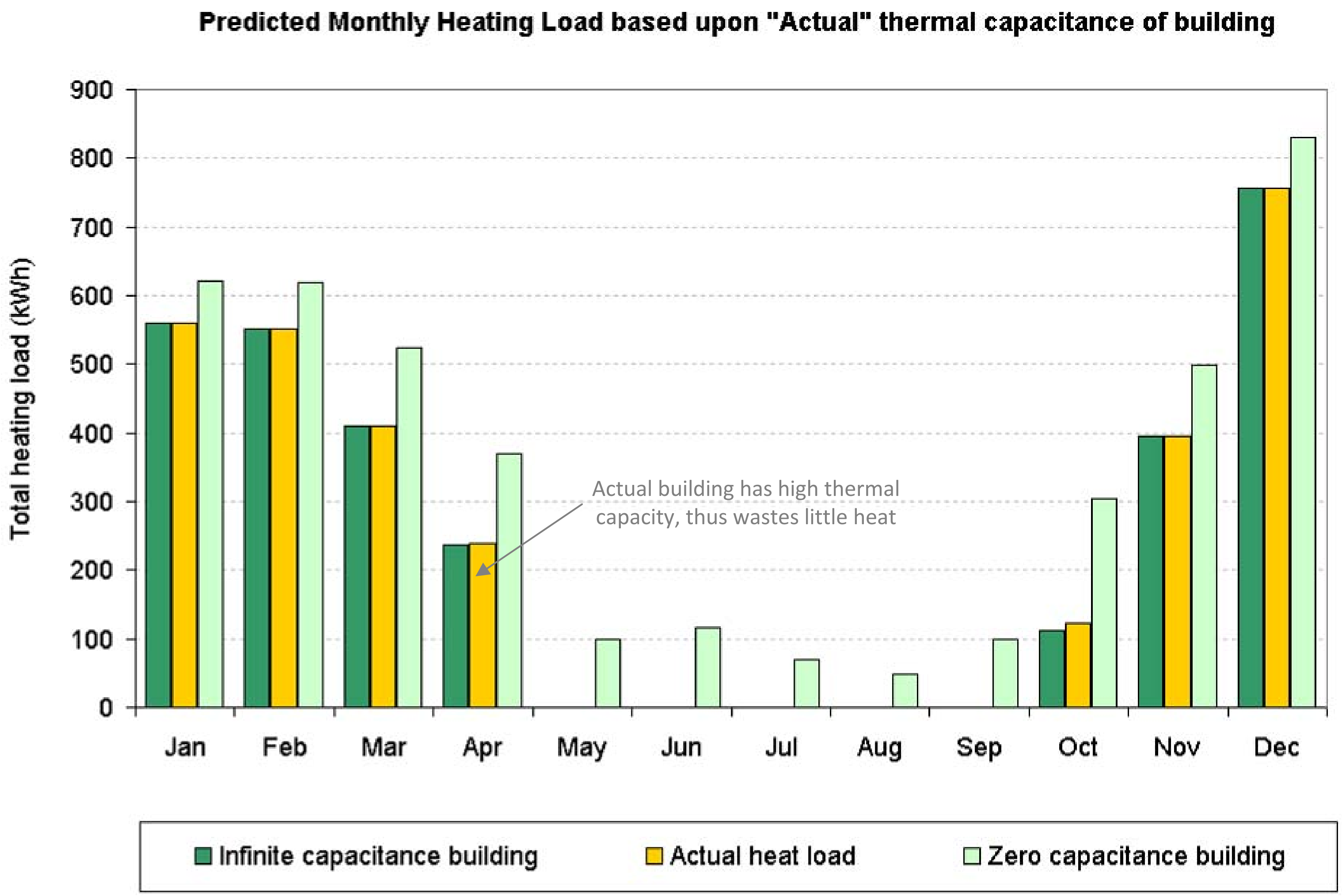


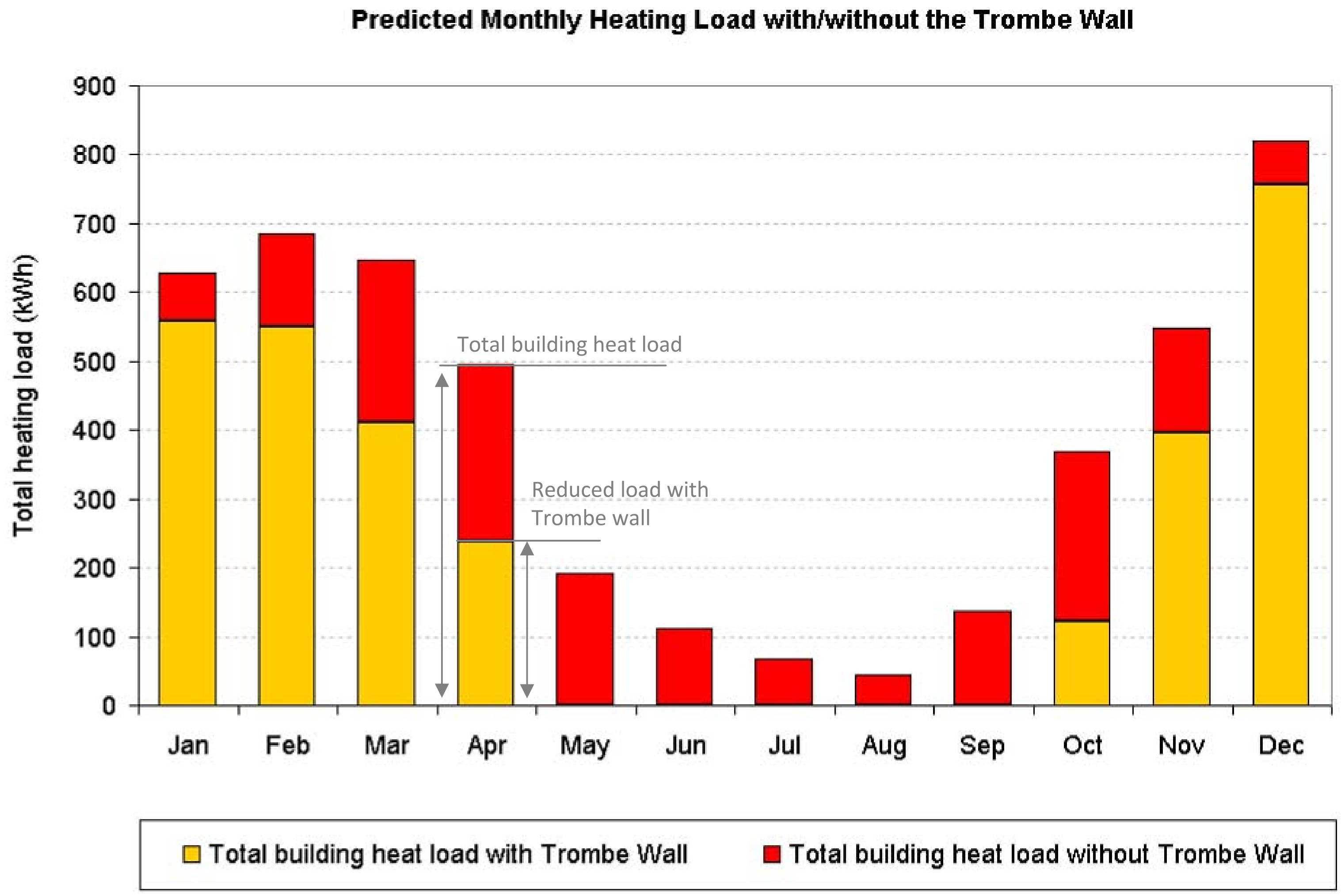
Characterise months
- Degree days
- Ambient temp
- Days in month
- Average total solar radiation

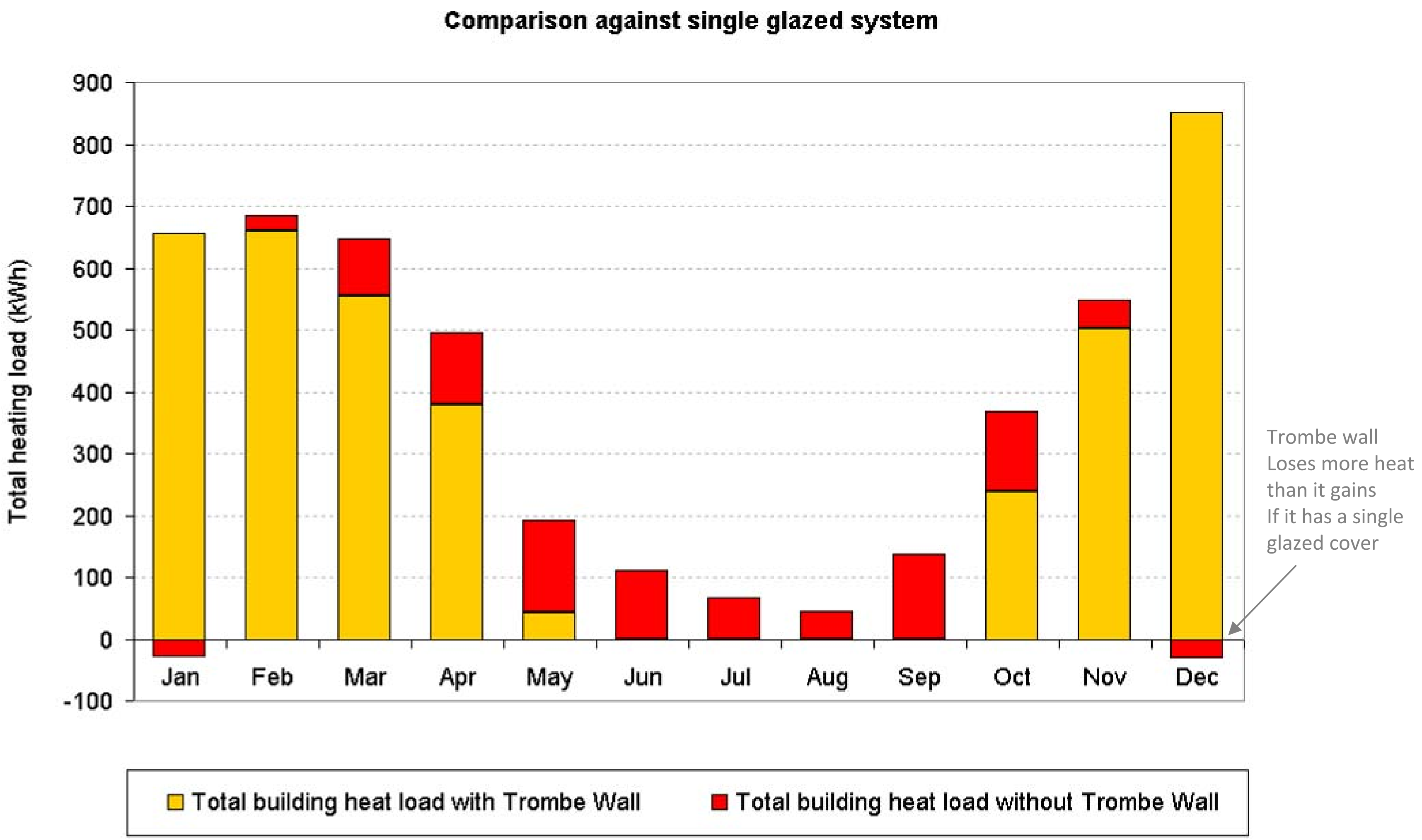
Performance Calculations
- Daylight hours
- Solar radiation absorption calcs
- Building loads
- Wall temperature
- Critical radiation & energy dump calcs
- Storage capacity of wall & building
- Solar fraction & Net energy gain

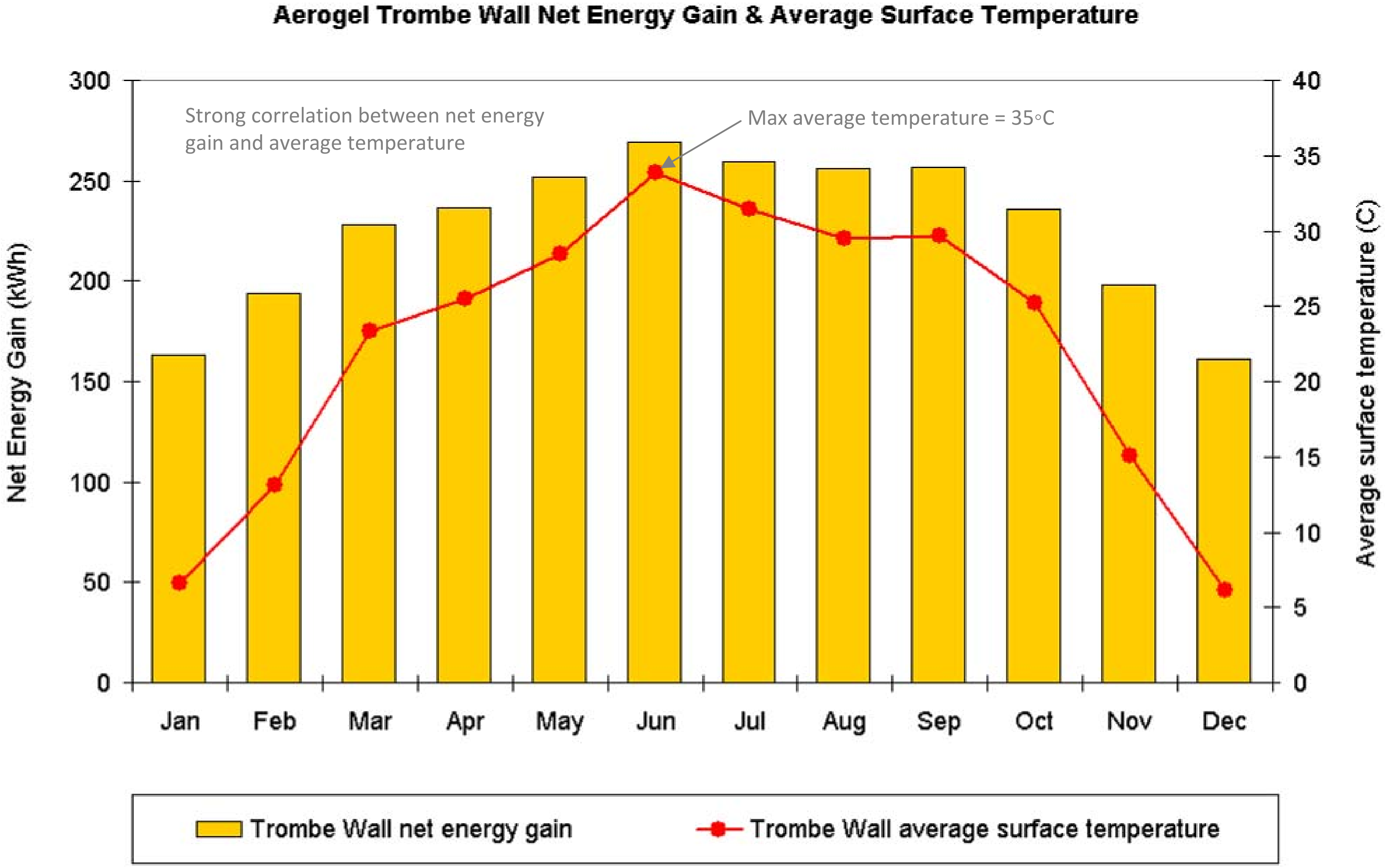
Summary table of key results


Predicted Monthly Heating Load in "Infinite" and "Zero" thermal capacitance building
Total heating load (kWh)
0
100
200
300
400
500
600
700
800
900
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Significant amount of heat is wasted if the building has no thermal capacity
Heat load for infinite capacitance building
Heat load for zero capacitance building


Predicted Monthly Heating Load based upon "Actual" thermal capacitance of building
Total heating load (kWh)
900
800
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Actual building has high thermal capacity, thus wastes little heat
Infinite capacitance building
Actual heat load
Zero capacitance building

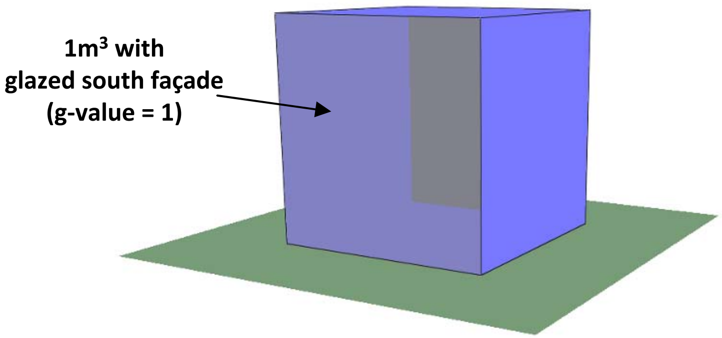

Predicted Monthly Heating Load with/without the Trombe Wall
Total heating load (kWh)
900
800
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Total building heat load
Reduced load with
Trombe wall
Total building heat load with Trombe Wall
Total building heat load without Trombe Wall

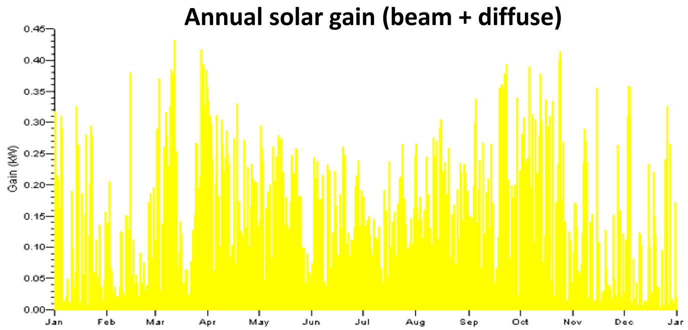

Comparison against single glazed system
Total heating load (kWh)
900
800
700
600
500
400
300
200
100
0
-100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Trombe wall
Loses more heat
than it gains
If it has a single
glazed cover
Total building heat load with Trombe Wall
Total building heat load without Trombe Wall

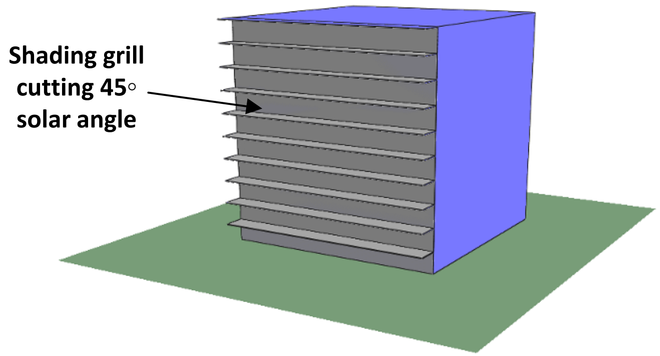

Aerogel Trombe Wall Net Energy Gain & Average Surface Temperature
Strong correlation between net energy gain and average temperature
Max average temperature = 35◦C
Net Energy Gain (kWh)
Average surface temperature (C)
300
250
200
150
100
50
0
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Trombe Wall net energy gain
Trombe Wall average surface temperature

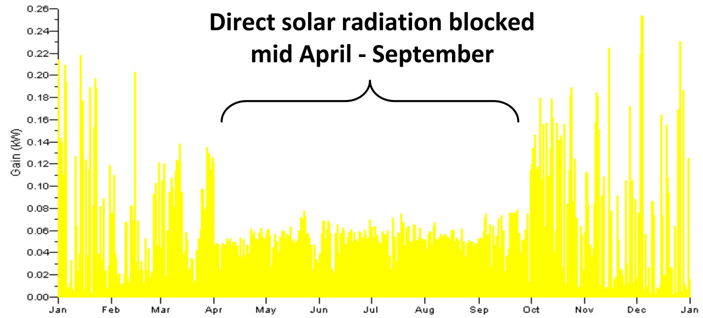
Summertime overheating mitigation

- Calculator assumes wall is un-shaded, but basic modelling can demonstrate benefit of shading grill:





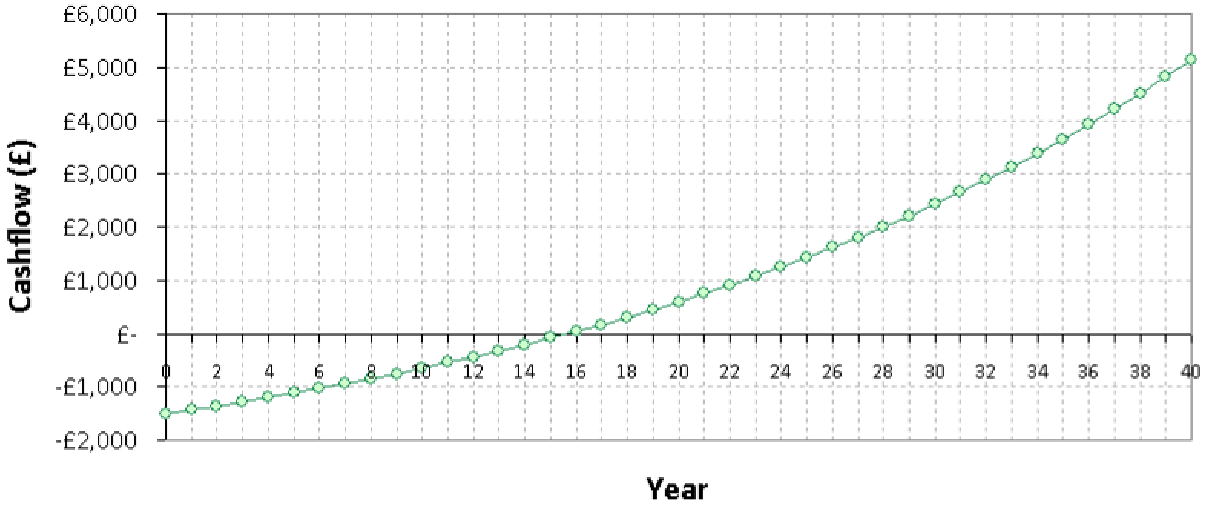




Key results:

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total
Energy requirement (no trombe wall)	kWh	627	685	648	495	192	111	67	44	137	368	548	819	**4741 kWh/year**
Energy requirement (with trombe wall)	kWh	559	551	411	238	0	0	0	0	0	122	395	756	**3033 kWh/year**
Solar fraction	-	0.14	0.22	0.39	0.54	1.00	1.00	1.00	1.00	1.00	0.68	0.30	0.11	**61 %**
Energy savings (84% efficient bolier)	kWh	81	159	282	306	229	132	80	52	163	293	182	75	**2034 kWh/year**
Fuel bill savings (0.04p/kWh gas)	£	3.2	6.4	11.3	12.2	9.1	5.3	3.2	2.1	6.5	11.7	7.3	3.0	**81 £/year**

Preliminary payback graph:



Assumptions

Capital cost	£ 1,500
Fuel price increase rate	6% per year
Interest rate	2% per year

Net present value

Year 5	-£ 1,116
Year 10	-£ 650
Year 15	-£ 86
Year 20	£ 598
Year 25	£ 1,427
Year 30	£ 2,433
Year 35	£ 3,651
Year 40	£ 5,127

CASE STUDY 2: Aerogel Solar Collector

- Concept currently being constructed as part of the *'**Retrofit for the Future**'* competition
- Property is a 3 storey 1960's end-terrace in Thamesmead, South East London
- Refurbishment strategy must achieve deep CO_2 reductions in order of 80%

Refurbishment strategy

- Aspiring towards Passivhaus certification
- Externally insulating building
- Triple glazing throughout
- Air-tight tapes on all junctions
- Mechanical ventilation with heat recovery
- DHW from boiler + solar thermal panels
- Electricity from roof mounted PVs

Gallions Housing Association

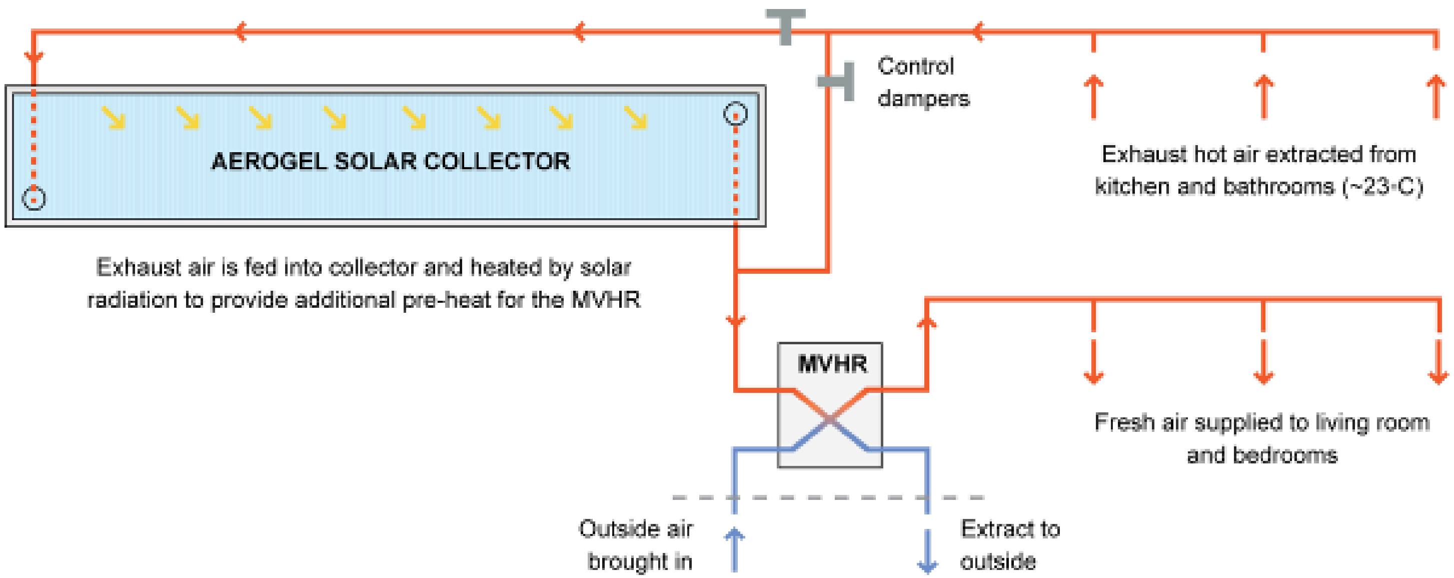
axis

FraserBrownMacKennaArchitects

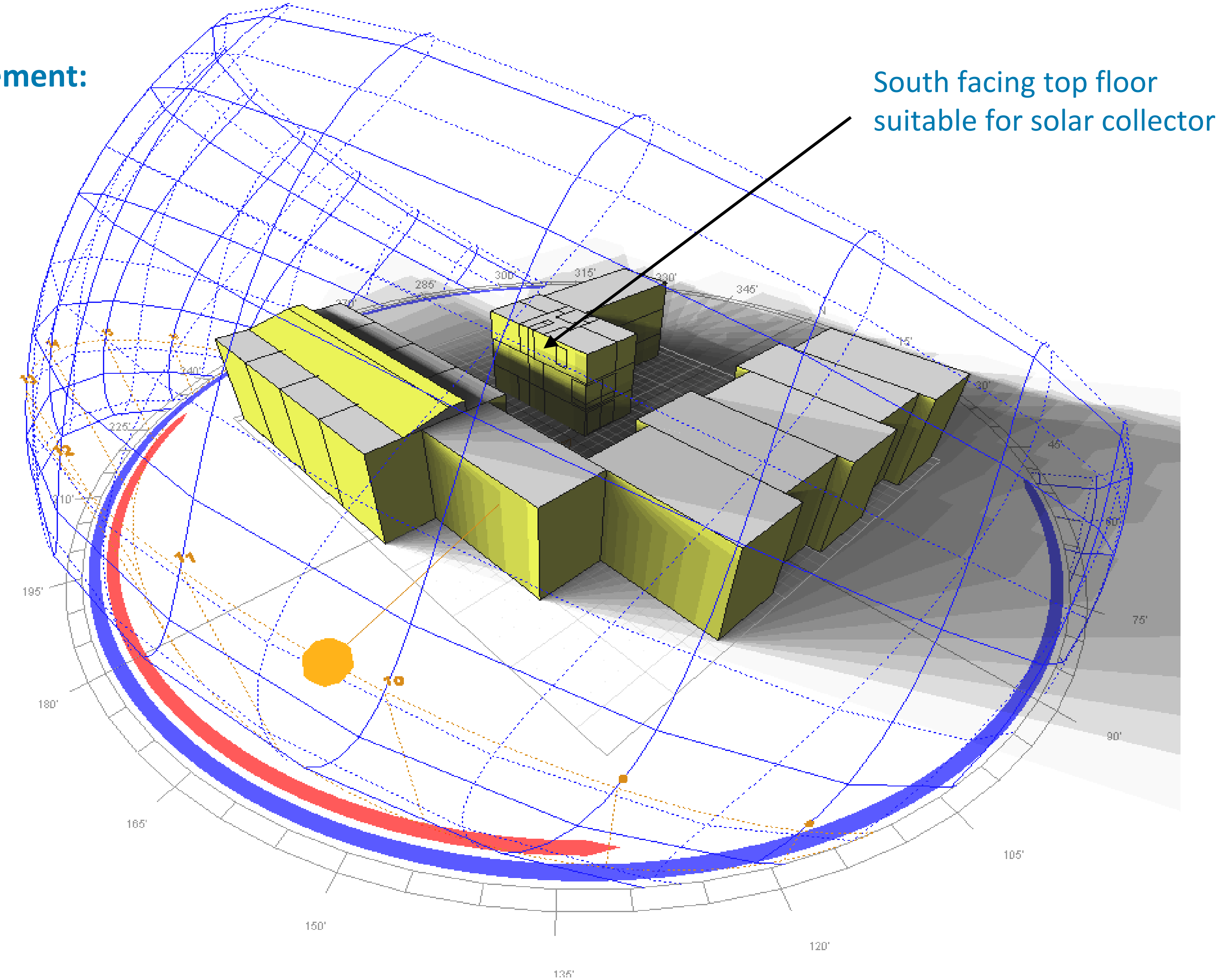
MARTIN ASSOCIATES
CHARTERED SURVEYORS

Aerogel solar collector

- Active solar-air system anticipated to increase the efficiency of the MVHR
- Normally an MVHR uses extracted heat from the kitchen/bathrooms to indirectly pre-heat incoming air
- Aerogel solar collector will be used to elevate this extracted air to higher temperatures



System placement:

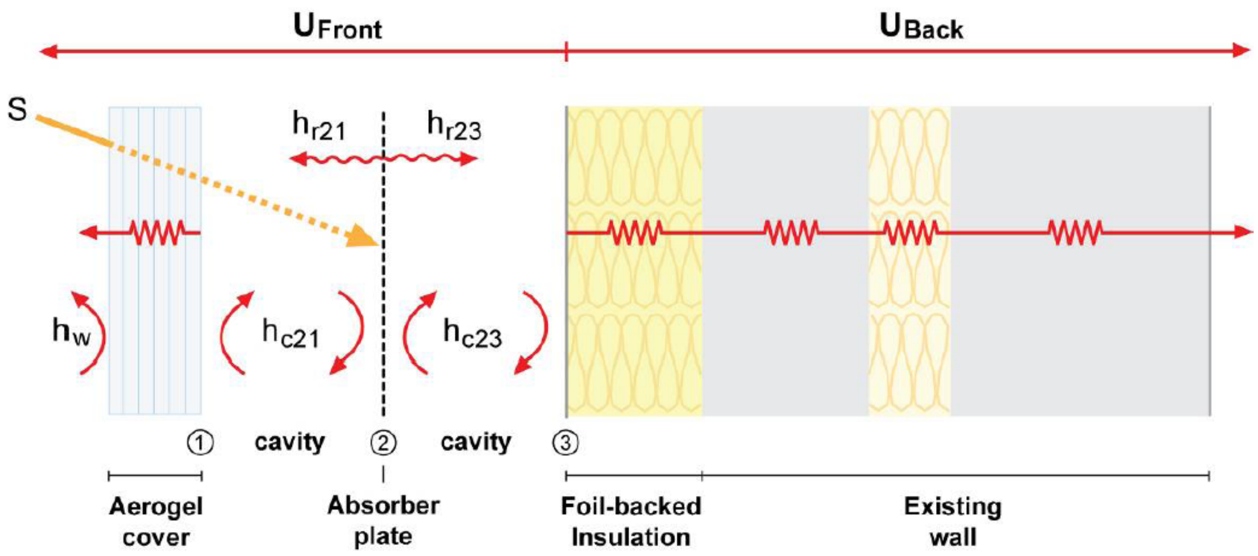


Modelling Validation:

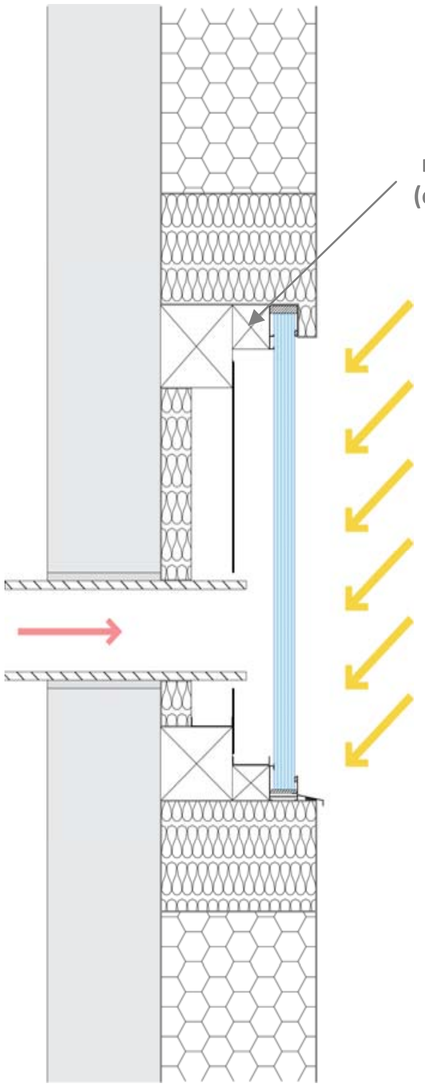
Calculation methodology:

Duffie and Beckman (2006) - Chapter 6: Flat plate solar air heater

- Parametric Excel tool combining design constants from steady state modelling with dynamic annual-hourly climate data generated using IES Virtual Environment software
- Model calculates outlet temperatures and energy generation before/after the ductwork leading to MVHR



Parametric calculator



Characterise resistance network (construction layers)

				Nanogel panel	Air gap (Front)	Aluminium sheet	Air gap (Back)	Rockwool insulation	Concrete inner-leaf	EPS insulation	Concrete outer-leaf	Inner surface
1	Thickness	x	m	0.040	0.080	0.001	0.080	0.060	0.080	0.035	0.105	-
2	Conductivity	k	W/m/K	0.022	-	250	-	0.035	1.701	0.040	1.701	-
3	Resistance	R	m^2/K/W	1.85	-	0	-	1.71	0.05	0.88	0.06	0.13
4	Transmittance	U	W/m^2.K	0.54	-	250000	-	0.58	21.26	1.14	16.20	7.69
5	Emissivity	ε	-	0.85	-	0.88	-	0.10	-	-	-	-

Characterise weather (snapshot)

Characterise Weather (snapshot)				Input
1	Ambient temperature	Ta	°C	5
2	Incident radiation	G_T	W/m^2	500
3	Wind velocity	v	m/s	4

Characterise Collector

Characterise Flat Plate Collector				Input
4	Width	W	m	6
5	Height	H	m	0.9
6	Tilt	β	°	90
7	Cover transmittance	τ	-	0.46
8	Plate absorptance	α	-	0.72
9	Mean absorber temperature	T_{pm}	°C	46.31
10	Mean fluid temperature	T_{fm}	°C	44.80

Characterise Air properties

Characterise Heat Transfer Fluid				Input
11	Mass flow rate	ṁ	kg/s	0.033
12	Inlet air temperature	T_i	°C	23
13	Density	ρ	kg/m^3	1.127
14	Specific heat	Cp	J.kg.K	1007
15	Thermal conductivity	k	W.m.K	0.0272
16	Dynamic viscosity	μ	m^2.s	1.90E-05
17	Prantl number	Pr	-	0.7

Characterise House

Characterise House				Input
18	Total volume	V	m^3	400
19	Internal temperature	Ta	°C	21

Characterise Ductwork

Characterise duct leaving colletor				Input
20	Duct diameter	D	m	0.15
21	Duct length	L	m	10
22	Insulation thickness	Δx	m	0.03
23	Insulation conductivity	k	W/m.K	0.035

Characterise MVHR

Characterise MVHR				Input
24	Heat exchange efficiency	η_{MVHR}	m	85%

Performance calculations

Calculations				Output
1	Stephan boltzman constant	σ	-	5.67E-08
2	Hydraulic diameter	Dh	m	0.16
3	Reynolds number	Re	-	3823
4	Flow regime?			Transition
5	Nusselt number	Nu	-	
6	Laminar			10.26
7	Turbulent			11.60
8		Selection:		11.60
9	Wind co-efficient	h_w	W/m^2.K	8.89
10	Convection co-efficient	h_{c12}	W/m^2.K	1.97
11	Convection co-efficient	h_{c23}	W/m^2.K	1.97
12	Radiation co-efficient	h_{r12}	W/m^2.K	5.55
13	Radiation co-efficient	h_{r23}	W/m^2.K	0.72
14	Back losses	U_b	W/m^2.K	0.35
15	Front losses	U_f	W/m^2.K	0.46
16	Overall losses	U_L	W/m^2.K	0.77
17	Collector efficiency factor	F'	-	0.94
18	Capacitance rate	-	-	8.51
19	Collector flow factor	F''	-	0.94
20	Heat removal factor	F_R	-	0.88
21	Area of outlet ducting	Ao	m^2	4.71
22	Loss co-efficient of ducts	U_d	W/m^2.K	1.17
23	Temperature drop from ducts	T_d	°C	4.01

Air flow properties (rows 1–8)

Heat loss co-efficients (rows 9–16)

Efficiency factors (rows 17–20)

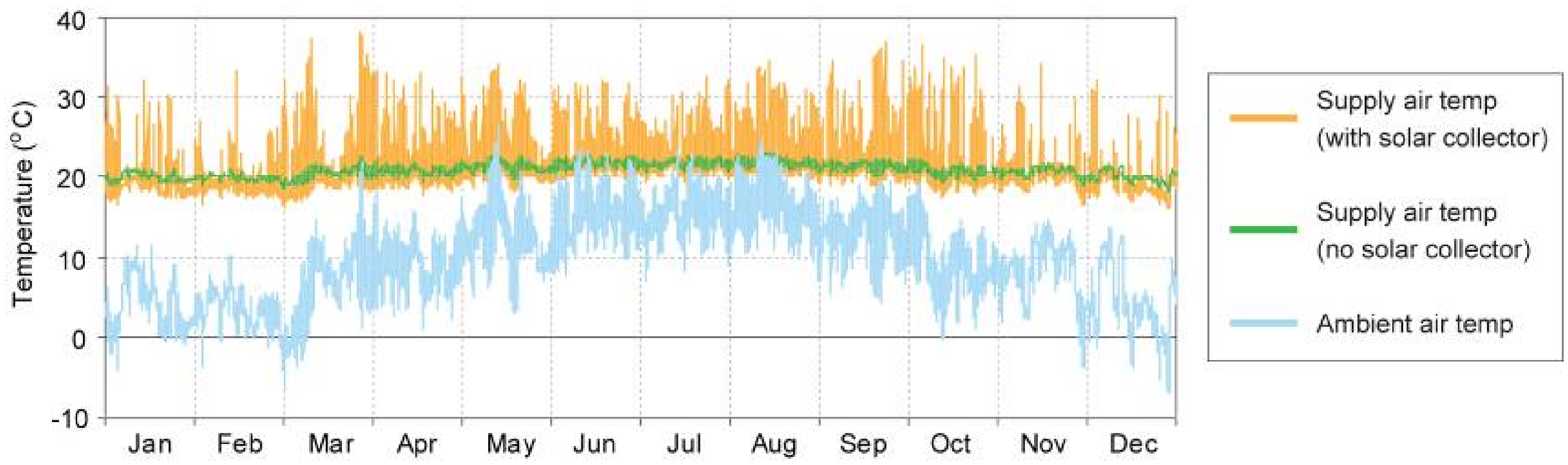
Ductwork losses (rows 21–23)

Summary table of key results

Key Results				Output
21	Useful energy	Q_u	W	723.38
22	Outlet temperature	T_o	°C	44.98
23	Mean plate temperature	T_{pm}	°C	46.31
24	Mean fluid temperature	T_{fm}	°C	44.80
25	Instantaneous efficiency	η_i	%	0.27
Effect of ductwork leaving collector				
26	Useful energy	Q_u	W	591.54
27	Outlet temperature	T_o	°C	40.97
Supply temperature to house				
28	Basecase (no solar collector)	T_s	°C	20.30
29	Supply temp with solar collector	T_s	°C	35.58

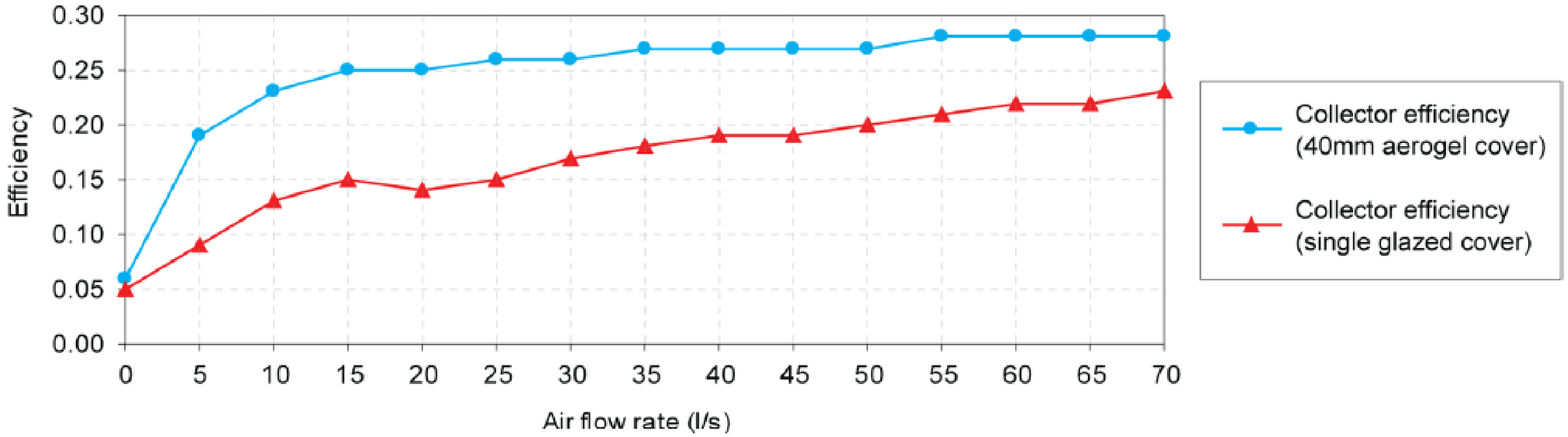
Predicted supply air temperatures:

- Predicted supply-air temperatures up to 30◦C on cold-mild sunny days
- Peak temperatures up to 40◦C in March & September indicating bypass controls required



- Note that supply air temperatures without solar collector are predicted between 18-21 ◦C
- However, this may not be accurate as model assumes constant flow rate & exhaust air temp of 23◦C

Efficiency compared to single glazed system:



Notes on efficiency:

- System located on vertical wall – not at 30◦ pitch
- System inlet temperature – higher efficiency occurs if system heats ambient air directly
- Absorber sheet is perforated – efficiency calculation assumes absorption area is reduced

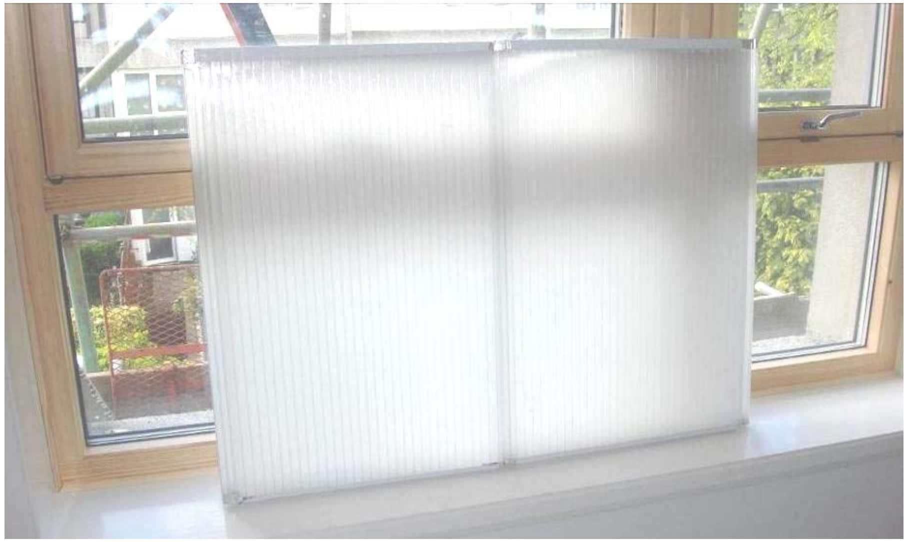
Next steps:

- Construction
- Monitoring
- Validation

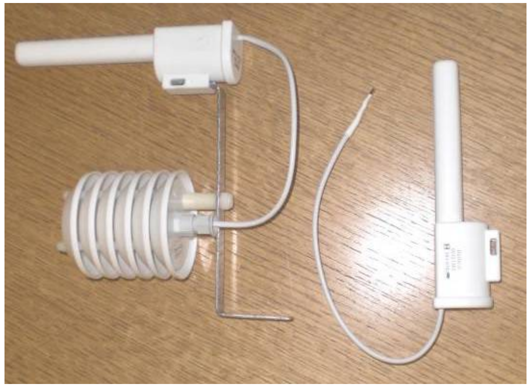
Installation of solar collector frame:

Installation of pre-fabricated ductwork:

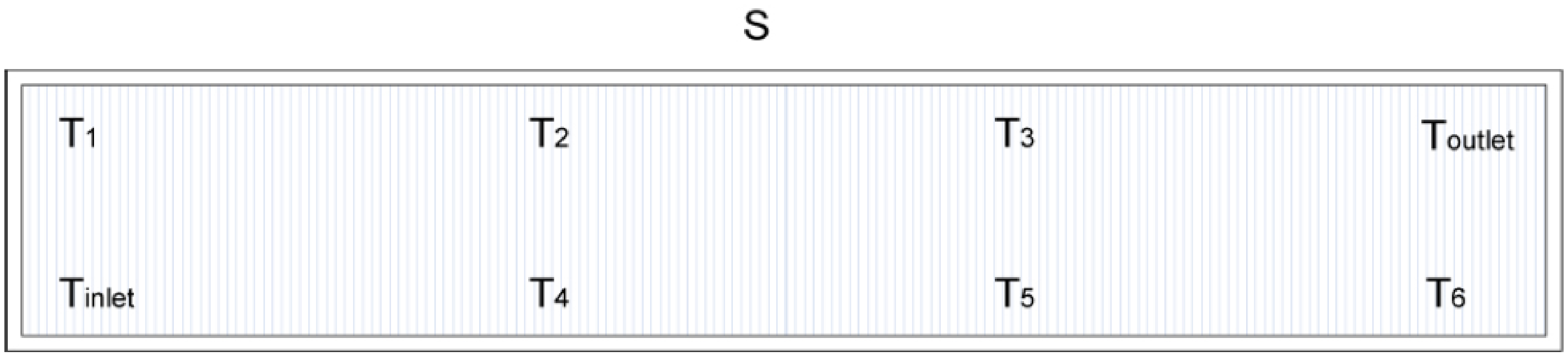
Aerogel panels, absorber sheet MVHR + flow control dampers:



Monitoring & Validation:



- Whole house
  - Gas, electricity + water consumption
  - Internal + external temperatures and humidity
  - Performance of renewable technologies
- Aerogel solar collector:



Thank you for listening

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Modelling Reference:

Duffie and Beckman (2006), Solar Engineering of Thermal Processes
Third Edition, John Wiley & Sons Inc, New York, USA