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
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
**CASE STUDY 1: Aerogel Trombe wall**

- 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

- Widely cited book to predict the performance of solar technologies
- Calculations validated through TRYSYS 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
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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 absorbance
- Solar reflectance
- Overall product in terms of beam, diffuse and ground reflected radiation

### Table: Characterise Site

<table>
<thead>
<tr>
<th>Characterise Site</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude</td>
<td></td>
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<tr>
<td>Longitude</td>
<td></td>
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<tr>
<td>Ground reflectance</td>
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</tbody>
</table>

### Table: Characterise Building

<table>
<thead>
<tr>
<th>Characterise Building</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Heat loss parameter</td>
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<tr>
<td>Thermal capacity</td>
<td></td>
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<tr>
<td>Stat set points</td>
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<tr>
<td>Allowable temp swing</td>
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</tr>
</tbody>
</table>

### Table: Characterise Trans Wall

<table>
<thead>
<tr>
<th>Characterise Trans Wall</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td></td>
</tr>
<tr>
<td>Thickness</td>
<td></td>
</tr>
<tr>
<td>Heat capacity</td>
<td></td>
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<tr>
<td>Density</td>
<td></td>
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<tr>
<td>Conductivity</td>
<td></td>
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<tr>
<td>Loss co-efficient</td>
<td></td>
</tr>
</tbody>
</table>

### Table: Trans/Rice Absorption Calculations

<table>
<thead>
<tr>
<th>Trans/Rice Absorption Calculations</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
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<tr>
<td>Thickness</td>
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<tr>
<td>Heat capacity</td>
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<tr>
<td>Density</td>
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<tr>
<td>Conductivity</td>
<td></td>
</tr>
<tr>
<td>Loss co-efficient</td>
<td></td>
</tr>
</tbody>
</table>

### Table: Monthly-average values

<table>
<thead>
<tr>
<th>Monthly-average values</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree days</td>
<td></td>
</tr>
<tr>
<td>Ambien ec temp</td>
<td></td>
</tr>
<tr>
<td>Days in month</td>
<td></td>
</tr>
<tr>
<td>Average total solar radiation</td>
<td></td>
</tr>
</tbody>
</table>

### Table: Parameteric calculator

<table>
<thead>
<tr>
<th>Parameteric calculator</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daylight hours</td>
<td></td>
</tr>
<tr>
<td>Solar radiation absor</td>
<td></td>
</tr>
<tr>
<td>Building loads</td>
<td></td>
</tr>
<tr>
<td>Wall temperature</td>
<td></td>
</tr>
<tr>
<td>Critical radiation &amp; energy dump calc</td>
<td></td>
</tr>
<tr>
<td>Storage capacity of wall &amp; building</td>
<td></td>
</tr>
<tr>
<td>Solar fraction &amp; Net energy gain</td>
<td></td>
</tr>
</tbody>
</table>

### Summary table of key results

<table>
<thead>
<tr>
<th>Key Results</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar fraction</td>
<td></td>
</tr>
<tr>
<td>Net energy gain</td>
<td></td>
</tr>
<tr>
<td>Beam, diffuse and ground reflected radiation</td>
<td></td>
</tr>
</tbody>
</table>
Significant amount of heat is wasted if the building has no thermal capacity.
Actual building has high thermal capacity, thus wastes little heat.
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Predicted Monthly Heating Load with/without the Trombe Wall

- Total building heat load
- Reduced load with Trombe wall

Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec

| Total building heat load with Trombe Wall | Total building heat load without Trombe Wall |
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Comparison against single glazed system

Trombe wall
Loses more heat than it gains
If it has a single glazed cover

<table>
<thead>
<tr>
<th>Month</th>
<th>Total building heat load with Trombe Wall (kWh)</th>
<th>Total building heat load without Trombe Wall (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feb</td>
<td></td>
<td></td>
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<tr>
<td>Mar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apr</td>
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<tr>
<td>May</td>
<td></td>
<td></td>
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<tr>
<td>Jun</td>
<td></td>
<td></td>
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<tr>
<td>Jul</td>
<td></td>
<td></td>
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<tr>
<td>Aug</td>
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<td></td>
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<tr>
<td>Sep</td>
<td></td>
<td></td>
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<tr>
<td>Oct</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nov</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dec</td>
<td></td>
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</tr>
</tbody>
</table>
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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)

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:

1m³ with glazed south façade (g-value = 1)

Shading grill cutting 45° solar angle

Annual solar gain (beam + diffuse)

Direct solar radiation blocked mid April - September
Key results:

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy requirement (no trombe wall) kWh</td>
<td>627</td>
<td>685</td>
<td>648</td>
<td>495</td>
<td>192</td>
<td>111</td>
<td>67</td>
<td>44</td>
<td>137</td>
<td>368</td>
<td>548</td>
<td>819</td>
<td>4741 kWh/year</td>
</tr>
<tr>
<td>Energy requirement (with trombe wall) kWh</td>
<td>589</td>
<td>551</td>
<td>411</td>
<td>238</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>122</td>
<td>395</td>
<td>756</td>
<td>3033 kWh/year</td>
</tr>
<tr>
<td>Solar fraction</td>
<td>-</td>
<td>0.14</td>
<td>0.22</td>
<td>0.39</td>
<td>0.54</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.68</td>
<td>0.90</td>
<td>0.11</td>
</tr>
<tr>
<td>Energy savings (84% efficient boiler) kWh</td>
<td>81</td>
<td>159</td>
<td>282</td>
<td>306</td>
<td>229</td>
<td>132</td>
<td>80</td>
<td>52</td>
<td>163</td>
<td>293</td>
<td>182</td>
<td>75</td>
<td>2034 kWh/year</td>
</tr>
<tr>
<td>Fuel bill savings (0.04p/kWh gas) £</td>
<td>3.2</td>
<td>5.4</td>
<td>11.3</td>
<td>12.2</td>
<td>9.1</td>
<td>5.3</td>
<td>3.2</td>
<td>2.1</td>
<td>6.5</td>
<td>11.7</td>
<td>7.3</td>
<td>3.0</td>
<td>81 £/year</td>
</tr>
</tbody>
</table>

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 CO₂ 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
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
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System placement:

South facing top floor suitable for solar collector
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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
### Innovative Use of Aerogel in Passive and Active Solar Storage Walls

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#### Summary table of key results

<table>
<thead>
<tr>
<th>Character</th>
<th>Weather (snapshot)</th>
<th>Character</th>
<th>Heat loss co-efficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air flow properties</td>
<td>Characterise weather</td>
<td>Ductwork losses</td>
<td>Efficiency factors</td>
</tr>
<tr>
<td>Characterise Collector</td>
<td>Characterise Heat Transfer-Mile</td>
<td>Characterise MVHR</td>
<td>Summary table of key results</td>
</tr>
<tr>
<td>Characterise House</td>
<td>Characterise Ductwork</td>
<td>Characterise Air properties</td>
<td>Performance calculations</td>
</tr>
<tr>
<td>Characterise resistance network (construction layers)</td>
<td>Characterise MVHR</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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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   Mobile: (+44) 07706 260523

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