Innovative low carbon steel building envelopes

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OXFORD BROOKES UNIVERSITY

• Top new University with one of the most highly rated Schools of Architecture

• Architectural Engineering Research Group jointly based in the School of Architecture and Department of Mechanical Engineering, specialising in ‘Close to Industry’ activities.

• One of the largest building physics and sustainability portfolios in the UK

Newly constructed award winning John Henry Brookes Building
FACILITIES

- Dedicated building envelope and light steel structures laboratory
- World class computational analysis capabilities for structures and building physics
CORE ACTIVITIES

• Offsite and modular construction
• Physical element testing
• Accreditation and CE marking
• Construction and life cycle costing
• Construction design guidance and regulation
• Regulatory compliance including energy and structural
• Building physics analysis including: thermal, acoustic, structural and air-tightness testing and analysis
• Building envelope systems
• Low carbon building systems
• Product and systems development
• CAD and computer modelling
• Long span solutions
• Building Performance Evaluation (POE)
PRIORITY DEVELOPMENT THEMES

• Low carbon and sustainable design
• Efficiency
• Performance
• Cost
UK markets

Highly developed metal building envelope market
UK markets

High proportion of buildings with steel structures
UK markets

- Commitment to low and zero carbon buildings
- Focus on renewable energy solutions
- Fabric first approaches generally favoured
UK markets

Good quality design culture
Sectors

Manufacturing
Sectors

Distribution
Sectors

Industrial
Sectors

Offices and commercial
Sectors

Housing
Systems

Composite and built-up
Systems

Rainscreen
Developments

Wide ranging areas of technical development
1. Modelling and simulation
Thermal modelling: simulation

Whole buildings can be modelled using dynamic thermal simulation software to predict thermal comfort, shading, ventilation, and energy use for heating and cooling.

A geometric model of the building is created, and construction elements are defined (with appropriate thermo-physical properties – density, thermal capacity, thermal conductivity etc)

Internal heat loads from people, lighting and equipment are added to schedules that reflect usage. Real or standard hourly weather data is then applied.
Thermal modelling: simulation

Outputs include zone air, radiant and operative (resultant) temperatures, humidity, bulk air flow, and heating/cooling energy use on an hourly basis.
Thermal modelling: conduction

Building details such as interfaces and framing can be modelled in two or three dimensions as necessary to determine the effect on U-value, linear or point thermal bridging, and surface temperatures (to establish condensation risk).

The results are presented as both graphical outputs (e.g. temperature distributions) and as numerical data (such as energy flows) which enable the required thermal bridging characteristics to be calculated.
2. Physical Testing
Airtightness testing

Airtightness of building components can be measured using a bespoke rig. This is a pressurised box, one side of which is closed by the component under test, for example a cladding panel joint. It can be pressurised to 50Pa and the resulting airflow is measured. The difference between the airflow with the joint taped up and the air flow with the joint un-taped is the leakage at that pressure.
Airtightness testing
Airtightness testing
3. Effective energy balances
Industrial Roofing in Europe

In-plane rooflights, sloping roof

Separate rooflights on flat roof
Results: Daylighting

Daylight factor:

‘the ratio of interior illuminance on a horizontal surface to the exterior illuminance on a horizontal surface from an overcast sky.’
Results: Daylighting

Flat roof (5% rooflights)
Average daylight factor 1.8%

Sloping roof (12% rooflights)
Average daylight factor 5%
Results: Energy

**Annual energy for heating**

- London: ≈ 10 kWh/m²
- Naples: ≈ 20 kWh/m²
- Strasbourg: ≈ 50 kWh/m²
- Warsaw: ≈ 60 kWh/m²

**Total CO2 emissions from heating and lighting**

- London: ≈ 10 kg/m²
- Naples: ≈ 20 kg/m²
- Strasbourg: ≈ 50 kg/m²
- Warsaw: ≈ 60 kg/m²

Legend:
- Blue: Flat roof 5%
- Red: Pitched roof 12%
4. High performance finishes
High reflectivity liner sheets

These preserve light within buildings allowing designers to reduce roof light areas so increasing the levels of thermal insulation in the building envelope and reduce the levels of electric lighting needed. They are proving a low cost and effective energy efficiency improvement.

- ≥ 85% reflectance, reducing the amount of energy required to achieve the same level of lighting.
- Significantly reduces CO2 emissions by 2-3% per year, helping to achieve compliance with tightening regulations.
- Can improve daylight factor by 10%
- Possible energy savings of up to 12% per annum
High reflectivity liner sheets

Typical enhancement levels:

<table>
<thead>
<tr>
<th>50m x 80m x 5m warehouse (4000m²) 10% rooflights</th>
<th>Average Daylight factor %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard liner, standard 140mm purlins</td>
<td>3.56</td>
</tr>
<tr>
<td>Standard liner, reflective 140mm purlins</td>
<td>3.68</td>
</tr>
<tr>
<td>Reflective liner, standard 140mm purlins</td>
<td>3.84</td>
</tr>
<tr>
<td>Reflective liner, reflective 140mm purlins</td>
<td>3.95</td>
</tr>
<tr>
<td>Standard liner, standard 240mm purlins</td>
<td>3.22</td>
</tr>
<tr>
<td>Standard liner, reflective 240mm purlins</td>
<td>3.42</td>
</tr>
<tr>
<td>Reflective liner, standard 240mm purlins</td>
<td>3.42</td>
</tr>
<tr>
<td>Reflective liner, reflective 240mm purlins</td>
<td>3.66</td>
</tr>
</tbody>
</table>
5. Transpired solar
Operation

Ambient air warmed by sun and drawn in through perforations

Fan unit

The warm air is circulated using mechanical ventilation

Warm air flows to top

Airspace

Perforated exterior sheet

Insulated wall
Performance

Transpired Solar Collectors can capture around 50% of the energy falling on the surface of a building, equating to approximately 500wp/m2 of collector surface area.

Systems can deliver around 250 KWH/M2 per year or up to 50% of space heating requirements depending on building configuration and usage but good availability of useful heat at the times required necessitates careful design.
Optimisation

Complex CFD capability to optimise performance recognising a range of complex factors including:

- **Variable flow regimes**
- **Flow non-uniformities**
- **Jet flow through perforations**
- **Multi-scale modelling geometries**
- **Complex boundary layer conditions**
- **Varied forms of heat transfer**

World leading sophistication of models now exceeds that used for most automotive applications.
Advanced systems

Development of system engineered solutions.
6. Life Cycle Assessment
Embodyed Energy

Energy used to manufacture a product, from extraction of raw materials, to transport, manufacture, assembly, installation, disassembly, recycling or disposal.

Linear relationship between embodied carbon and insulation thickness based on PUR insulation for a medium size distribution warehouse.
Embodied and Operational Energy

CO$_2$ emissions (kgCO$_2$/m$^2$.yr) vs U-value (W/m$^2$.K), Insulation thickness (mm)

- 25 years ECO2
- Operational CO2
Combined Operational and Embodied Energy

Point of minimum combined carbon.
Impact of Insulation Materials

Mineral wool insulation achieves its minimum carbon performance at 330mm thickness. This will result in 1 kgCO$_2$/m$^2$ additional saving compared to PUR insulation for a similar scenario.
7. Improved structural solutions
Optimised structural design of metal building envelope buildings

- At least 80% reduction of greenhouse gas emissions by 2050 compared to 1990 levels.
- Buildings responsible for 36% of CO$_2$ emissions in the EU (50% in UK).
- Insulation thicknesses increasing. Current thickness typically: Walls 70-120mm, Roofs 80-120mm.
- Accounts for around 60% of building envelope market.
- Structural capability of deeper composite envelope panels not yet fully exploited.
- Potential significant implications for optimising building structure.

↑ Insulation depth
↑ stiffness
↑ strength
Possible optimisations

Include:

1. Long span envelope systems
2. Better use of diaphragm action
3. Frameless construction

Of these long span solutions are attracting particular interest as a means of reducing steel weights, embodied carbon and growing the market for panel systems with high levels of thermal insulation.
Long span: systems

- Duo-pitch portal frame with purlins *(base case)*
- Duo-pitch portal frame without purlins
- Re-oriented portal frames
- Trussed roof frames with north lights
## Long span: Potential weight savings

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Steelwork reduction</th>
<th>Optimal frame spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong> Duo-pitch portal frame with purlins</td>
<td>N/A (base case)</td>
<td>Small: 6.67m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium (1-bay): 10.00m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium (2-bay): 8.00m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large: 8.33m</td>
</tr>
<tr>
<td><strong>2</strong> Duo-pitch portal frame without purlins</td>
<td>Small: 6%</td>
<td>Small: 6.67m</td>
</tr>
<tr>
<td></td>
<td>Medium (1-bay): 1%-13%</td>
<td>Medium (1-bay): 8.00m-13.34m (negligible difference)</td>
</tr>
<tr>
<td></td>
<td>Medium (2-bay): 6%-16%</td>
<td>Medium (2-bay): 8.00m</td>
</tr>
<tr>
<td></td>
<td>Large: 4%-19%</td>
<td>Large: 10.00m-13.33m (negligible difference)</td>
</tr>
<tr>
<td><strong>3</strong> Flat-pitch multi-bay re-oriented portal frames</td>
<td>Small: 13%</td>
<td>Small: 6.25m</td>
</tr>
<tr>
<td></td>
<td>Medium: 51%-53%</td>
<td>Medium: 8.33m / 6.25m (negligible difference)</td>
</tr>
<tr>
<td></td>
<td>Large: 34%-42%</td>
<td>Large: 10.00m-13.33m (negligible difference)</td>
</tr>
<tr>
<td><strong>4</strong> Trussed roof frames with north lights</td>
<td>Small: 20%-38%</td>
<td>Small: 6.67m</td>
</tr>
<tr>
<td></td>
<td>Medium (1-bay): 46%-53%</td>
<td>Medium (1-bay): 6.67m-10.00m (negligible difference)</td>
</tr>
<tr>
<td></td>
<td>Medium (2-bay): 53%-60%</td>
<td>Medium (2-bay): 8.00m</td>
</tr>
<tr>
<td></td>
<td>Large: 49%-55%</td>
<td>Large: 8.00m</td>
</tr>
</tbody>
</table>
8. Structural Testing
Structural testing

Dedicated laboratory equipped for structural testing of:

- Building envelope components
- Light gauge and composite structures
- Full assembly testing eg. building modules
- Support of innovative systems and materials.

Composite panel testing.
Compliance

Comprehensive testing capabilities for:

• Proof of concept
• Product development
• Span and load tables
• Compliance, e.g. CE marking, BBA certification

Sway testing of spacer brackets. Deeper brackets for lower U values.
9. Advanced insulation systems
Benefits of metal roofs

• Pitched roofs enable better day lighting and less use of artificial light.
• Whilst there can occasionally be some increase in heating demands this is offset by reductions electric lighting.
• Overall CO₂ emissions are reduced.
• Peak internal temperatures can increase due to solar gain so correct design is essential.
• Optimal rooflight area must be found for location.
Vacuum and advanced insulation
## K value of insulation materials

<table>
<thead>
<tr>
<th>Insulation material</th>
<th>$k_{\text{core}}$ (mW/mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass fibres</td>
<td>35</td>
</tr>
<tr>
<td>EPS, PUR</td>
<td>30-25</td>
</tr>
<tr>
<td>Fumed silica</td>
<td>20</td>
</tr>
<tr>
<td>VIP</td>
<td>4</td>
</tr>
</tbody>
</table>
Effect of Gas pressure

- Gas pressure within panels influences thermal conductivity.
- Core materials respond differently to pressure variations.

Thermal conductivity plotted against gas pressure inside VIP (three types of core materials compared: glass fibres, foams and fumed/precipitated silica)
Systems Development
Systems Development