Thermal Performance of Prefabricated Modular Buildings in Australia: A Baseline Study

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Prefabricated Buildings Offer

- benefits to construction industry with reduction in time, cost and waste management.
- Improvements in environmental performance and building overall quality

<table>
<thead>
<tr>
<th>Cost</th>
<th>Quality</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓Time saving</td>
<td>✓Higher level of control</td>
<td>✓Waste management</td>
</tr>
</tbody>
</table>

Life cycle costs?  IEQ?
Knowledge Gaps

• There is lack of knowledge on current baseline performance of prefabricated buildings.

• Thermal performance of modular houses is not well documented in the literature.

• The effects of building size and envelope on thermal performance of modular houses is not well documented.
Aim

• To investigate the thermal performance of four prefabricated modular buildings in Melbourne, Australia

Objectives

• To investigate the effects of building size on thermal performance
• To investigate the effects of envelope parameters on thermal performance
Method

• OpenStudio plugins in Sketchup environment were applied.
• EnergyPlus engine was used for the simulations.
• Effects of window to wall ratio and floor area on cooling and heating loads were investigated.
Buildings Investigated

Outback
- Living Room and Kitchen: 20 m²
- Bedroom: 12 m²
- Bath: 3 m²
- Study Room: 9 m²
- Room: 7 m²
- Bedroom: 10 m²
- Bedroom: 10 m²
- Bedroom: 9 m²
- Laundry: 4 m²
- Store: 1 m²
- WC: 2 m²
- Bedroom: 20 m²

Wattle
- Living Room and Kitchen: 56 m²
- Ensuite: 5 m²
- Room: 7 m²
- Bedroom: 10 m²
- Bedroom: 10 m²
- Bedroom: 9 m²

Banksia
- Living Room and Kitchen: 40 m²
- Laundry: 4 m²
- WC: 4 m²
- Room: 9 m²
- Room: 5 m²
- Bedroom: 10 m²
- Bedroom: 9 m²
- Bedroom: 19 m²

Study Room: 7 m²
Bathroom: 6 m²
Living Room: 33 m²
Bedroom: 9 m²
Bedroom: 9 m²
## Fixed Parameters

<table>
<thead>
<tr>
<th>Category</th>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location, Melbourne, Australia</strong></td>
<td>Latitude [deg]</td>
<td>-37.817</td>
</tr>
<tr>
<td></td>
<td>Longitude [deg]</td>
<td>144.967</td>
</tr>
<tr>
<td></td>
<td>Time Zone [h]</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Elevation above sea level [m]</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Site ground temperature [°C]</td>
<td>18</td>
</tr>
<tr>
<td><strong>Window glazing</strong></td>
<td>U-Factor [W m(^{-2}) K(^{-1})]</td>
<td>2.10</td>
</tr>
<tr>
<td></td>
<td>Solar transmittance [-]</td>
<td>0.237</td>
</tr>
<tr>
<td><strong>Thermostat settings</strong></td>
<td>Heating set point</td>
<td>Day:21°C, Night:18°C</td>
</tr>
<tr>
<td></td>
<td>Cooling set point</td>
<td>24°C</td>
</tr>
<tr>
<td><strong>Space infiltration rate</strong></td>
<td>Flow per space floor area [ms(^{-1})]</td>
<td>0.0007</td>
</tr>
<tr>
<td><strong>Design ventilation rate</strong></td>
<td>Outdoor Air flow per floor area [ms(^{-1})]</td>
<td>0.0003</td>
</tr>
</tbody>
</table>
Wall Components

- Steel wall panel: 1.6 mm
- OSB Board: 25 mm
- Insulation: 90 mm
- OSB Board: 25 mm
- Plasterboard: 10 mm
- Air space: 20 mm
- OSB Board: 25 mm
- Plasterboard: 10 mm

OSB = Oriented Strand Board
Building Areas

While 92% of the spaces in the Wattle building are conditioned, this percentage decreases to 85% in the Outback.

<table>
<thead>
<tr>
<th></th>
<th>Unconditioned</th>
<th>Conditioned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wattle</td>
<td>3.35</td>
<td>36.89</td>
</tr>
<tr>
<td>Banksia</td>
<td>6.6</td>
<td>61.84</td>
</tr>
<tr>
<td>Territory</td>
<td>15.36</td>
<td>94.37</td>
</tr>
<tr>
<td>Outback</td>
<td>20.84</td>
<td>114.86</td>
</tr>
</tbody>
</table>

Building area (m²)
Regarding the fact that Wattle is the smallest building, the high value of window to wall ratio can be justified.
Heating and Cooling load per unit floor area

- **Heating load per unit floor area (MJ m$^{-2}$)**
  - **Wattle**: 325
  - **Banksia**: 308
  - **Territory**: 238
  - **Outback**: 244

- **Cooling load per unit floor area (MJ m$^{-2}$)**
  - **Wattle**: 10.69
  - **Banksia**: 2.63
  - **Territory**: 1.55
  - **Outback**: 1.40
### Annual Electricity Consumption

#### Energy Consumption (kWh m⁻²)

<table>
<thead>
<tr>
<th>Building</th>
<th>Heat pump model</th>
<th>Heating (kW)</th>
<th>Heating COP</th>
<th>Cooling (kW)</th>
<th>Cooling COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wattle</td>
<td>Daikin FFQ25C2 / RXS25K3</td>
<td>3.2</td>
<td>4.00</td>
<td>2.5</td>
<td>4.46</td>
</tr>
<tr>
<td>Banksia</td>
<td>Daikin FTXM50P / RXM50P</td>
<td>6.0</td>
<td>4.23</td>
<td>5.0</td>
<td>4.24</td>
</tr>
<tr>
<td>Territory</td>
<td>Daikin FTXM60P / RXM60P</td>
<td>7.0</td>
<td>4.07</td>
<td>6.0</td>
<td>3.87</td>
</tr>
<tr>
<td>Outback</td>
<td>Daikin FTXS71L / RXS71L</td>
<td>8.0</td>
<td>3.67</td>
<td>7.1</td>
<td>3.41</td>
</tr>
</tbody>
</table>

![Bar chart showing annual electricity consumption per building.](chart)
Conclusions

• In this paper energy performance simulations of four prefabricated modular houses have been carried out using EnergyPlus interface with OpenStudio.

• The results reveal that heating and cooling load of the buildings highly depend on both floor area and window to wall ratio.

• While the energy required for heating showed increase in buildings with larger floor area, the cooling load followed a different pattern that indicated the impact of envelope parameters.

• The heating and cooling energy per floor area show a decreasing trend with increase of floor area.

• Results also indicate that window to wall ratio has higher impact on cooling load compared to heating load.
Thank you