Simulation of energy and water consumption in Australian housing

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Outline

1. Introduction
   Available tools for residential building energy simulation in CSIRO
2. Methodology for prediction housing energy and water consumption
3. Case study and validation
4. Future work
Building simulation tools

AccuRate

AccuRate Sustainability

AusZEH Design
Chenath engine

Chenath engine +GUI (AccuRate) - Benchmark software of housing energy star rating used in Australia;

BERS Professional and FirstRate

Developed by coupling a frequency response building thermal model (Wash and Delsante, 1983) with a multi-zone air flow model (Ren and Chen, 2010);

Heating and cooling thermostat setting based on the Protocol for House Energy Rating Software published by ABCB;

Using Typical Meteorological Year (TMY) weather data of 80 (69) climate zones;

Calculate hourly space heating and cooling loads over period of one year;

Assigns 0 to 10 stars based the annual total H/C energy loads in terms of Nationwide House Energy Rating Scheme (NatHERS).
Methodology

**Inputs**
- Building description, location, etc
- HVAC systems
  - Occupant number and occupancy profiles
- Water, hot water and lighting systems, plug-in appliances

**Data**
- Energy consumption for space heating and cooling
- Energy consumption for water heating, lighting and plug-in appliances. Indoor and outdoor Water consumption

**Chenath Engine**
- Energy consumption for space heating and cooling

**AusZEH Design tool Simulation Manager**
- Energy consumption for water heating, lighting and plug-in appliances.

**Modules for HW, lighting, appliances**
- Data

**System Output Manager**
- Data

**Outputs for a range of options**
- Hourly (half-half) end-use energy and water consumption over 12-month period
- End-use energy and water consumption for single modules and a whole household
- CO₂ emissions
Space heating and cooling

Modifying Chenath Engine for space heating and cooling energy consumption

1. Thermostat setting according to occupancy scenarios
2. HVAC system performance

\[
E_d = \sum_{i=1}^{24} \sum_{j=1}^{M} \frac{e_{ji} + q_{ji}}{cop_j}
\]
Hot water

Energy demand for water heating

\[ E_w = 4.186 \times [Q_s \times (T_s - T_o) + Q_o \times (T_{ou} - T_o)] - E_{solar} \]

Total energy consumption

\[ E = (E_w + E_{loss}) / \text{Eff}_w \]
Lighting

\[ E = \left( \frac{I_{\text{mean}}}{L_{\text{eff}}} \right) \times h \times A_{\text{floor}} \times \left( \frac{N_p}{N_r} \right) \]

Where

- \( E \) - daily electric lighting energy-consumption (kWh/day)
- \( I_{\text{mean}} \) - average luminance level, domestic building is 150 lux
- \( h \) - the hours of artificial lighting on
- \( L_{\text{eff}} \) - the luminance efficacy in workplace (lum/W)
- \( A_{\text{floor}} \) - the house floor area (m\(^2\))
- \( N_p \) - the number of occupants
- \( N_r \) - the number of rooms in the house
Appliances

- IT equipment (PCs, laptops, monitors, etc.)
- Home entertainment (games, set-top boxes, televisions, VCRs, etc.)
- Cooking (electronic ovens, electric hobs, microwaves, kettles, etc.)
- Cold appliances (refrigerators, freezers, and combined fridge-freezer)
- Wet appliances (washing machines, clothes dryers, and dishwashers)
- Miscellaneous appliances (vacuum cleaners, irons, electric tools, etc.)

\[ E = (h_a \times W_a + h_{sby} \times W_{sby} + h_{off} \times W_{off}) / 1000 \]
Water consumption

\[ V = \text{Flow rate} \times \text{Duration} \times \text{Frequency} \]

\[ V = \text{Volume} \times \text{Frequency} \]
Occupancy

• The way occupants use thermostats
  • Hours/weekday house is occupied
    • Unoccupied period is from 9:00 to 13:00. One of the occupants in this type of household may have a part-time job in the morning session.
    • Unoccupied period is from 13:00 to 17:00. One of the occupants in this type of household may have a part-time job in the afternoon session.
    • Unoccupied period is from 9:00 to 17:00. The occupants in the house all have full-time job.
    • Unoccupied period is from 9:00 to 16:00. The family of this type of household may have a child to look after when school closed.
    • The house is occupied all the time. The family of this type of household may have a minor child to look after or is of retired couples and single.
    • The house is unoccupied from 17:00 to 21:00. Weekend day.
## Appliance model vs monitoring studies in Australia and New Zealand

<table>
<thead>
<tr>
<th>Appliance</th>
<th>(Isaacs et al., 2006)</th>
<th>(Pacific Power, 1994)</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fridge/freezer</td>
<td>1119 ± 72</td>
<td>944</td>
<td>827</td>
</tr>
<tr>
<td>Cooking</td>
<td>549± 50</td>
<td>783</td>
<td>525</td>
</tr>
<tr>
<td>Clothing washing and dryer</td>
<td>182±35</td>
<td>178</td>
<td>275</td>
</tr>
<tr>
<td>Dishwasher</td>
<td>107±18</td>
<td>227</td>
<td>306</td>
</tr>
<tr>
<td>Microwave</td>
<td>62±6</td>
<td>67</td>
<td>89</td>
</tr>
<tr>
<td>Computer/games</td>
<td>227±43</td>
<td>-</td>
<td>170</td>
</tr>
<tr>
<td>Entertainment (TV + DVD, etc.)</td>
<td>364 ± 57</td>
<td>157 (TV/Video only)</td>
<td>432</td>
</tr>
<tr>
<td>Total</td>
<td>2610</td>
<td>2356</td>
<td>2624</td>
</tr>
</tbody>
</table>
Demonstration house

![Graph showing energy consumption (kWh) over 24 hours. The graph compares monitored data with modelled data. The monitored data is represented by a red line, and the modelled data is represented by a black line.](image)
Electricity usage patterns of five-people family in SEQ During May 2012-April 2013
Comparison between actual and modelled electricity consumption (kWh)

- HVAC
- Lighting
- Water heating
- Oven
- Refrigerator
- Dishwasher
- Kitchen
- Living
- Theatre
- Master bedroom
- Bedrooms

Actual
Model
Monitored vs modelled

Energy consumption for period Dec 2010-Nov 2011

- Monitoring: 10000 kWh
- Model: 5000 kWh
2006 NSW and VIC electricity consumption
Impact of thermostat setting on cooling load

![Graph showing the impact of various thermostat settings on cooling load over a 24-hour period on 13 Dec. 2011. The x-axis represents the hour of the day, and the y-axis represents the cooling load in kW. Different thermostat settings (23.5C to 29.5C) are indicated with distinct line colors and markers. The graph highlights the peak cooling load at different times for each setting, showing how higher thermostat settings lead to lower peak loads.](image-url)
Water consumption of three people family in Melbourne

- Model
- Metered
- Theory

<table>
<thead>
<tr>
<th>Year</th>
<th>Shower</th>
<th>Toilet</th>
<th>Clothes washer</th>
<th>Tap</th>
<th>Dishwasher</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td></td>
<td></td>
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<td></td>
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<td>2010</td>
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<tr>
<td>2012</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Water consumption of four people family in SEQ

- **Model**
- **Metered**
- **Theory**

<table>
<thead>
<tr>
<th>Location</th>
<th>Shower</th>
<th>Toilet</th>
<th>Clothes washer</th>
<th>Tap</th>
<th>Dishwasher</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brisbane</td>
<td></td>
<td></td>
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<tr>
<td>Gold Coast</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Ipswich</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Sunshine Coast</td>
<td></td>
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</tr>
</tbody>
</table>

Water consumption (L/day)
Predicted water consumption patterns (weekday)
Predicted water consumption patterns (weekend day)

Water consumption (L/P/day)

- Toilet
- Tap
- Dishwasher
- Shower
- Clotheswasher

Hour

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
## Water saving through upgrading water appliances and behaviour change

<table>
<thead>
<tr>
<th>Room/place</th>
<th>Options for reducing water consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garden</td>
<td>Replacing sprinklers with micro-spray irrigation systems for watering garden and lawn</td>
</tr>
<tr>
<td>Shower</td>
<td>Upgrading 2 star showerheads to 3 star and reducing shower time from 7 mins to 5 mins</td>
</tr>
<tr>
<td>Clothes washer</td>
<td>Upgrading 1 star clothes washer to 6 star</td>
</tr>
<tr>
<td>Tap and sink</td>
<td>Upgrading 3 star taps and sinks to 6 star</td>
</tr>
<tr>
<td>Toilet</td>
<td>Upgrading 3 star toilets to 6 star</td>
</tr>
<tr>
<td>Dishwasher</td>
<td>Upgrading 3 star dishwasher to 6 star</td>
</tr>
</tbody>
</table>
Indoor water saving (L/day), 38% (1200 kWh/year) electricity saving

- **Toilets**: 97.3 L/day
- **Dishwashers**: 7.2 L/day
- **Clothes washer**: 139.3 L/day
- **Taps and Sinks**: 128 L/day
- **Toilets**: 81.8 kWh/year
- **Dishwasher**: 23.2 kWh/year
- **Clothes washer**: 23.2 kWh/year
- **Taps and Sinks**: 72 kWh/year
- **Shower**: 102.9 kWh/year
- **Shower**: 288 L/day

[Pie charts showing the breakdown of water and electricity savings by household appliances]
Outdoor water saving (L/day)

- Garden: 74.5 L/day
- Lawn: 167.1 L/day
- Swimming pool: 74.3 L/day
- Car wash: 3.3 L/day

- Garden: 61.9 L/day
- Lawn: 139.3 L/day
- Swimming pool: 74.5 L/day
- Car wash: 3.3 L/day

Legend:
- Garden
- Lawn
- Swimming pool
- Car wash
PV battery system for grid-free housing (without non-electric resources)

<table>
<thead>
<tr>
<th>Item</th>
<th>City</th>
<th>House 1</th>
<th>House 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Solar PV size (kW)</td>
<td>Solar PV size (kW)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Battery size (kWh)</td>
<td>Townsville</td>
<td>350</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td></td>
<td>42</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>28.5</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Sydney</td>
<td>1467</td>
<td>278</td>
</tr>
<tr>
<td></td>
<td></td>
<td>506</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>165</td>
<td>65</td>
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<tr>
<td></td>
<td>Melbourne</td>
<td>6067</td>
<td>2926</td>
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<tr>
<td></td>
<td></td>
<td>4391</td>
<td>1750</td>
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<td></td>
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<td>3100</td>
<td>1032</td>
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</table>
## PV battery system for grid-free housing (with non-electric resources)

<table>
<thead>
<tr>
<th>Item</th>
<th>City</th>
<th>House 1</th>
<th>House 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar PV size (kW)</td>
<td></td>
<td>5</td>
<td>10</td>
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<tr>
<td>Battery size (kWh)</td>
<td></td>
<td>1231</td>
<td>53</td>
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<tr>
<td>Sydney</td>
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<td>55</td>
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<tr>
<td>Melbourne</td>
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<td>235</td>
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</tr>
<tr>
<td>Townsville</td>
<td></td>
<td>524</td>
<td>36</td>
</tr>
<tr>
<td>Melbourne</td>
<td></td>
<td>281</td>
<td>16.5</td>
</tr>
</tbody>
</table>
Grid – free city case study: Townsville FY2010-11

71,300 Households (57,233 detached, 80.3%), population: 167,847
9.4% families installed PV

- <2KW: 36%
- 2-3.5KW: 24%
- >3.5 KW: 40%
Measures to reduce electricity consumption from grid

- Appliances: 45.2%
- Cooling: 28.3%
- Hot water: 19.8%
- Lighting: 6.3%
- Heating: 0.4%
Annual electricity consumption (10%)
Solar PV + 1C thermostat

267.6 GWh (56% actual electricity consumption) generated by detached and semi detached houses (86%)

4.6 KW solar PV (detached +semi detached) + 1C increase thermostat setting for cooling to achieve off-grid for Townsville 2010-11
Future work

1. Infiltration model
2. Heat loss through ground
3. Occupant behaviour
4. Other environment modules
5. New technologies
References


Thank you!
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