The influence of occupant behaviour on indoor environment and energy use in buildings
October 12, 2017

Development towards Near Zero Energy Buildings

- Not possible to reach goals through 'traditional' technologies
  - Envelope insulation
  - Building airtightness
  - Ventilation heat recovery
- Other measures are needed
  - Demand controlled ventilation
  - Solar shading to control overheating and daylight
  - Lighting control
  - Window opening

The choice can affect energy use by up to 300%

Adjust to the environment
- clothing
- activity level
- posture
- hot/cold drinks
- etc.

Adjust the environment
- thermostat adjustments
- window openings
- electrical lights
- solar shading
- etc.

The adaptive principle

If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort

To restore comfort occupants can

Robust technologies
- No user interactions
- Works with and without people in the building

Sensitive technologies
- User interactions required
- Difficult to understand consequences
Investigation of heating used in 290 identical houses*

- Correction for differences in outer wall area
  - End houses vs. Middle houses
- Highest used up to 20 times higher than lowest
- Stable use distribution over time
- No measurements of indoor environment

Types of behaviour with impact on indoor environment and/or energy use

- Adjust to the environment
  - clothing
  - activity level
  - posture
  - hot/cold drinks
  - etc.
- Adjust the environment
  - thermostat adjustments
  - window openings
  - electrical lights
  - solar shading
  - etc.
- Activities with other aims than adjusting (to) the environment
  - cooking
  - electrical loads
  - Showering
  - etc.

Calculated and measured energy use in 135,311 houses*

*Data from: SØ: 2016 09, Forskellen mellem målt og beregnet energiforbrug til opvarmning af parcelhuse

Background

- OB has significant influence on building energy use

The cooling energy consumption data in different apartments of one residential building in Beijing, 2006
Occupant Behaviour

- ECB Annex 66 Definition and Simulation of Occupant Behaviour in Buildings
- ASHRAE has established a MTG (Multiple Task Group) on Occupant Behaviour
- Obama issues an Executive Order (EO)
  – *Behavioral Science Insights Policy Directive*

Sensitivity to changes in occupants’ behaviour (robustness)*

- Simulations of office building
- Stochastic modelling of occupants’
  – Window opening
  – Solar shading
- Variations to
  – window area
  – Thermal mass
  – Solar shading
  – Geographical location (climate)

RESULTS

- Sensitive
  – Low thermal mass
  – large glazing area
- Robust
  – high mass
  – low glazing area

Heating season 2013-2014*

**Interviews:**
- Individual billing
  – focus on heat savings
  – Accepted uncomfortable conditions to save money
- Collective billing
  – Focus on health, comfort and avoiding moisture problems

- Feedback created increased awareness of indoor environment
  – 5 residents found feedback useful
  – Daily routines changed in 2 apartments as result of feedback

Shared or individual heating cost*

**Collective billing**

- Measurements in 39 apartments

**Individual billing**

- Measurements in 17 apartments


How many of you have checked your...

- email within the last hour?
- Facebook/twitter account today?
- bank account this week?
- energy meter this month?
- energy meter this year?
  – Do you remember how much you pay?

Feedback

- Letters each week to 14 apartments including
  – Overall evaluation of indoor environment
  – Personal tips
  – Focus of the week
  – Comparison with average
- 3 apartments acted as reference

CO₂ Concentration before and during feedback

- Large differences between apartments
  – None of the apartments cover the entire temperature range
- Energy consumption follows residents, when they move
- Patterns can be modelled
  – and simulated

Behaviour – random or patterns?

<table>
<thead>
<tr>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
<th>Saturday</th>
<th>Sunday</th>
</tr>
</thead>
<tbody>
<tr>
<td>61</td>
<td>45</td>
<td>32</td>
<td>57</td>
<td>40</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>35</td>
<td>30</td>
<td>13</td>
<td>27</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>70</td>
<td>19</td>
<td>46</td>
<td>36</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>78</td>
<td>63</td>
<td>34</td>
<td>65</td>
<td>25</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>43</td>
<td>5</td>
<td>28</td>
<td>6</td>
<td>68</td>
<td></td>
</tr>
</tbody>
</table>
Ventilation in schools with or without feedback

Winter-heating season, windows opening and CO₂

Models of occupants’ window opening behaviour

- Many models
- Most, only rely on thermal environment
  - Is that enough?
  - Which one should I use?
- Lack of validation
- Lack of validation methods

A complex issue – Drivers reported in literature*

*from Fabi et al. ClimaMed 2011
Measurements in 16 dwellings*

- Behaviour
  - Window opening
  - Heating set-point

- Indoor environment
  - Temperature
  - Relative humidity
  - CO₂ concentration

- Weather
  - Temperature
  - Wind speed
  - Solar radiation
  - Relative humidity

*R. Andersen et al. Building and Environment 2013

How is behaviour modelled?

- Often based on designers own observations
  - representative?
  - Comparable?

Tendency to view occupants as rational controllers of IEQ and energy

Examples from praxis

- Thermal comfort
  - Temperature > 25 °C → Window open
  - Temperature < 21 °C → Window closed
  - Heating set-point = 20 °C

- Air quality
  - Constant ventilation rate

- Fixed schedule
  - Windows open from 8.00 to 8.15 every day

From deterministic to stochastic modelling

Models of occupant behaviour*

Stochastic models
- Window opening
- Heating set-points
- Cooling set-points
- Lighting

Deterministic model of physical aspects

Probability distribution of performance indicators

*R. Andersen et al. Building and Environment 2013

S. D’oca et al. HAVC&R 2013
Verification of behaviour models

- Measurements in five apartments
  - temperature
  - CO2 concentration
  - Relative humidity
- Simulations based on questionnaire and observations
- Stochastic models
  - Window opening
  - Thermostat adjustments
  - Inferred from detailed measurements in apartments

Measurements vs. simulation – in each time step *

- Measurements in 16 dwellings*
  - Behaviour
    - Window opening
    - Heating set-point
  - Indoor environment
    - Temperature
    - Relative humidity
    - CO2 concentration
  - Weather
    - Temperature
    - Wind speed
    - Solar radiation
    - Relative humidity

Measurements vs. simulation - overall *

- Stochastic simulations
  - temperature ranges rather than fixed figures
- Simulated temperatures in the same range as measurements

*R. Andersen et al. Building and Environment 2013


Measurements vs. simulation – in each time step *

\[
\begin{align*}
\text{y} & = 0.60 \times x + 7.57 \\
R^2 & = 0.21
\end{align*}
\]
Sensitivity to changes in occupants’ behaviour (robustness)*

- Simulations of office building
- Stochastic modelling of occupants’
  - Window opening
  - Solar shading
- Variations to
  - window area
  - Thermal mass
  - Solar shading
  - Geographical location (climate)

RESULTS
- Sensitive
  - Low thermal mass
  - large glazing area
- Robust
  - high mass
  - low glazing area

Effect of occupants’ behaviour on energy consumption

- Differences in occupants’ behaviour leads to
  - large differences in some buildings
  - smaller differences in other buildings
- Why?

Summary

- In simulations, behaviour is just as important as weather and physical properties of the building
- Models of occupants’ behaviour implemented in existing simulation software
- We need more qualitative studies to investigate drivers of behaviour
- We need large datasets including all major driving variables
- We need good validation methods
  - And data to validate models
- This work is performed in IEA-EBC annex 66