



The 8th International Conference on Applied Energy – ICAE2016

Energy waste in buildings due to occupant behaviour

Song Pan¹, Xingru Wang¹, Shen Wei^{2,*}, Chuanqi Xu¹, Xingxing Zhang³,
Jingchao Xie¹, Jess Tindall², Pieter de Wilde⁴

1 College of Architecture and Civil Engineering, Beijing University of Technology, 100022, China

2 Faculty of Engineering and Environment, Northumbria University, Newcastle upon Tyne NE1 8ST, UK

3 College of science and Engineering, The University of Nottingham Ningbo China, 315100, China

4 Chair of Building Performance Analysis, Plymouth University, PL4 8AA, UK

Abstract

Occupants' behaviour has a significant impact on the energy performance of buildings. A good understanding of how occupants use a building provides a possibility of promoting the building's energy efficiency through changing occupant behaviour. Building simulation has been adopted as a useful method by building engineers for quantifying the effects of changing occupant behaviour on the building's energy consumption and indoor environment. However, due to the lack of real measured data with respect to how occupants use the building, such simulation work has relied on assumed behavioural patterns, which significantly reduces the reliability of the predicted results. This paper describes a longitudinal study monitoring occupants' heating, window opening and cooling behaviour in an office building throughout summer, transitional and winter periods. These behavioural data were then used to drive dynamic building performance simulation to predict the energy saving potential of changing behaviour. Comparison with predicted results by assumed behavioural patterns reflected that improperly assumed behavioural patterns may either overestimate or underestimate the energy saving potential of changing behaviour, especially for unextreme behaviours.

Keywords: Energy waste, Occupant behaviour, Office building, Building simulation

1. Introduction

Buildings are big energy consumers in current society [1] and reducing their energy consumption is essential for sustainable development. In a number of studies carried out in the past several decades, the high importance of the occupants' role, defined as occupant behaviour [2], in the energy performance of buildings has been shown to be critical through both field measured data in actual buildings [3,4] and predictive results from building simulations [5,6]. Energy efficient buildings require adequate consideration of occupant behaviour: firstly, since improper building use may result in a waste of energy [7,8]; secondly, because an occupant-involved building control system can significantly reduce the

* shen.wei@northumbria.ac.uk; T: +44 (0)191 3495374

building's energy demand [9,10]; and thirdly, as insufficient consideration of occupant behaviour when retrofitting/refurbishing buildings may cause inappropriate selection of energy efficient measures [11,12].

Over the past 20 years, many studies have been carried out to better understand occupants' energy behaviour in buildings [13,14], with the aim of producing more energy efficient buildings through changing occupants' of the systems within the building [15]. In order to help building occupants decide how to change their behaviour to have a more energy efficient behavior, tailored advice was often required [16,17]. To help prepare this 'tailored' advice, building engineers have used building simulation to quantify the impact of changing occupant behaviour on the performance of the building [18]. However, due to the lack of data with respect to occupants' actual behaviour in buildings, building engineers have had to use assumed extreme behavioural patterns to drive the simulation, e.g. heating always on [19] or windows/doors always open [19,20], resulting in a lack of confidence in the predicted impact.

In order to capture occupants' actual behaviour in buildings and identify energy wasteful behaviour based on field data, a longitudinal study was carried out in an office building located in Beijing, China, with field monitoring of occupants' use of window, heating and cooling systems. Using the field data, some behavioural patterns have been developed and introduced in a paper published earlier this year [21]. Following this paper, these patterns have been used to drive dynamic building performance simulation to predict the energy saving potential of behaviour changes, and the results are mainly introduced in the following sections. Additionally, in order to demonstrate the importance of realistic behavioural patterns in accurate prediction of energy saving potential of behaviour changes by simulation, the predicted results were compared with those predicted based on assumed behavioural patterns in existing studies.

2. Material and methods

2.1 Case study building

The study was conducted in a mixed-mode office building (39° 54' 27'' N, 116° 23' 17'' E, alt. 44m), which contains a number of offices that can be occupied by 1-2 persons. The building is located in the southeast of Beijing, China, which has a climatic condition with hot summer and cold winter. During the survey period all monitored offices were occupied by one person only. In each office, there are two sliding windows facing south, for both daylighting and ventilation purposes. This is a typical layout of offices not only in China, but also in other countries such as the USA and the UK. In winter, all offices were continuously heated by a local hot-water radiator system, and in summer they were cooled using a fan-coil unit system. Individual control of both heating and cooling systems for each room was available so the room occupants could decide whether the system was on or off, according to their preference. The valve/controller used in the case study building was in old-fashion but this style is still very popular in old office buildings in China. During the transitional season, natural ventilation, through the opening of windows by the occupants, was the only cooling strategy. In this study, all monitored offices have similar physical conditions, for example, window orientation and room size, and outdoor environmental conditions, such as outdoor air temperature and solar gains.

2.2 Data collection

The monitoring of occupants' behaviour was carried out in three main seasons of the year, i.e. the winter season (16.11.2014 to 15.03.2015), the summer season (from 16.05.2015 to 07.07.2015) and the transitional seasons (08.10.2014 to 15.11.2014 and 16.03.2015 to 15.05.2015). There was concurrent recording of potential influencing factors, such as indoor and outdoor air temperatures. During the survey, five offices on the first floor were monitored, accounting for 70% offices in the building. In the study,

real-time monitored parameters included room occupancy, indoor air temperature, outdoor air temperature, window operation (open/close) and fan-coil unit system operation (on/off). The heating system operation (on/off) was recorded by asking occupants to fill out logs when they turn on or turn off the heating system. Detailed information can be found in Pan et al. [21].

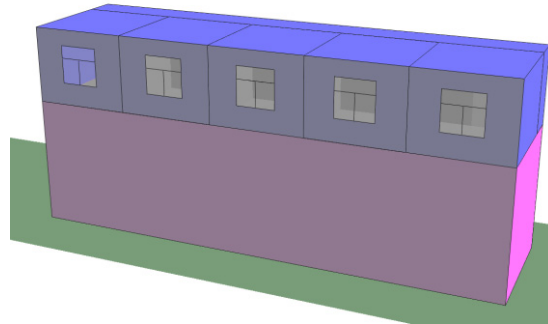


Figure 1: Simulation model in IES VE

2.3 Building simulation

For the purposes of this study, ‘energy-wasteful behaviour’ has been defined differently for winter, summer and transitional periods, based on the following rationales. Detailed definitions could be found in the paper published already [21].

1. The window should be closed when the mechanical cooling/heating system is on;
2. When the indoor temperature becomes too cool in summer (too warm in winter), the mechanical cooling (heating) system should be turned off; and,
3. Outdoor air should be used whenever possible to heat (cool) the building in winter (summer).

The implementation of the developed behavioural patterns above was carried out in IES VE, aiming to predict the energy saving potential of each behavioural type examined in the study. To do this, a model for the case study building was developed, as shown in Figure 1, and the developed behavioural patterns were used to define the base case model. Then, changes of behaviour were introduced into the base case model through modification of relevant parameters (e.g. changing the heating set point to represent a change of heating behaviour) and the newly-predicted building performance was compared with the one predicted by the base case model. This provided quantified evidence about how much changing occupant behaviour would affect the energy performance of a building. The implementation was focused on the winter time.

The occupancy of the offices was assumed to be typical working hours, i.e. 9am to 5pm on Monday to Friday. This was not generated from the field data as occupancy was not a main topic considered in this study. The operation of the systems (occupant behaviour), namely the heating system and the ventilation system is defined in Table 1, based on the real data collected from the field study. The simulation was carried out between 16th November and 15th March, which was the ‘heating season’ for the case study building [21], and used weather data stored in the ASHRAE design weather database for Beijing, China, which is available in the IES VE software.

Table 1: Building operation information

Systems	Operations
Heating system	Always on with a setting temperature of 21°C (mean indoor air temperature monitored during the winter survey period). There is no difference for occupied and unoccupied time because the heating was found to be always on in the case study building.
Window operation[21]	Occupied time: Open in 25% of occupied time; Unoccupied time: Open in 12% of unoccupied time.

In order to examine the effect of energy conservation approaches, the current behaviour (base case behaviour) of occupants, as listed in Table 1, was replaced by some energy efficient behaviours (Table 2) in the building simulation, for both heating and window operations. To quantify the impact of changing behaviour on the building heating demand, Equation 1 was used to calculate the saved energy on heating usage.

$$E_{pre-change} - E_{post-change} = E_{saving} \quad (1)$$

where $E_{pre-change}$ is the building's heating demand before the behavioural change, $E_{post-change}$ is that after the behavioural change and E_{saving} is the energy saving potential by this behavioural change.

Table 2: Energy efficient behaviours

Energy efficient behaviour	Behavioural profiles
Heating 01	Turn off the heating system when the offices are unoccupied
Heating 02	Turn down the temperature setting to 19°C
Window 01	Always keep windows closed during the occupied time
Window 02	Always keep windows closed during the unoccupied time

Figure 2 shows the predicted energy saving potential of each behavioural change option listed in Table 2. It quantifies the heating energy that can be saved by changing occupants' use of the building, and turning off the heating system when the offices are unoccupied has shown the biggest energy saving potential for the case study building.

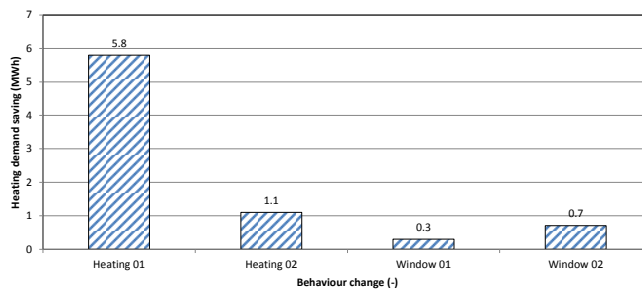


Figure 2: Predicted energy saving potential of each behavioural change option listed in Table 2

Figure 3 compares the predicted energy saving potential for the ‘Heating 01’ when various base case models were used. Model 01 was the base case model used in Figure 2, which was developed based on field measured data. Model 02 to 05 adopted popular assumptions in existing studies: Model 02 assumed the heating was always on; Model 03 assumed the heating set point was 22°C; Model 4 assumed all openable windows were kept open during the occupied time; Model 5 assumed all openable windows were kept open during unoccupied time.

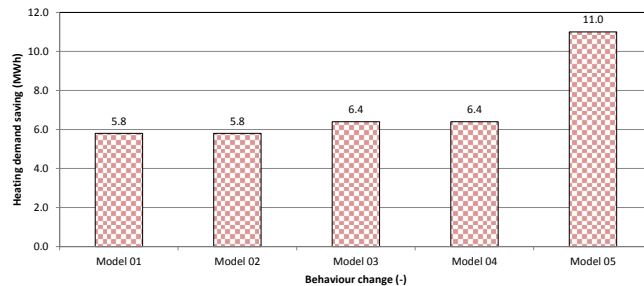


Figure 3: Predicted energy saving potential for behavioural change option 1 based on various base case models

Figure 3 reflects to what degree assumed behavioural patterns will influence the predicted results. Model 02 provided the same predictions as the model used previously because the heating in the case study was found to be always on (extreme behaviour) so the assumed pattern was the same as what was happening in the real building. However, occupants did not control the heating operation due to the old style of the control valves, and a modern control method may change their behaviour for energy conservation. Overestimations on the impact of changing behaviour have been identified for Model 03, 04 and 05, while this overestimation can be more than two times higher as caused by Model 05.

3. Conclusions

Occupant behaviour can greatly influence the performance of a building, with respect to both energy consumption and indoor environment. Changing occupant behaviour for building energy conservation is an urgent task for sustainable development. Due to the lack of realistic behavioural patterns to drive simulation, demonstrating the impact of behavioural changes was usually based on assumed patterns and this may overestimate/underestimate the energy saving potential. This study has used behavioural patterns generated from real-monitored behavioural data to drive dynamic building performance simulation, and critically demonstrated the reliability of existing methodology that is based on assumed patterns. Main findings from this study are:

- (1) Change occupants' use of the building may have a great impact on the building energy efficiency and should be paid more attention in the future; and
- (2) Assumed behavioural patterns in existing studies may either overestimate or underestimate the predicted energy saving potential, especially for those unextreme behaviours.

Acknowledgements

The work reported in this paper is funded by the National Science Foundation of China (NSFC), no. 51578011, and the Engineering and Physics Sciences Research Council (EPSRC, UK) under the ‘Transforming Energy Demand in Building through Digital Innovation’ (TEDDI) eViz project (grant reference EP/K002465/1).

References

- [1] EC, Report from the commission to the European parliament and the council. 2013, European Commission: Brussels.
- [2] IEA. IEA ANNEX 66: Definition and Simulation of Occupant Behavior in Buildings. 2013 [cited 2015 December]; Available from: <http://www.annex66.org/>.
- [3] Yun, G.Y. and K. Steemers, Behavioural, physical and socio-economic factors in household cooling energy consumption. *Applied Energy*, 2011. 88(6): p. 2191-2200.
- [4] Huebner, G.M., et al., Explaining domestic energy consumption – The comparative contribution of building factors, socio-demographics, behaviours and attitudes. *Applied Energy*, 2015. 159: p. 589-600.
- [5] Mavrogianni, A., et al., The impact of occupancy patterns, occupant-controlled ventilation and shading on indoor overheating risk in domestic environments. *Building and Environment*, 2014. 78: p. 183-198.
- [6] Chen, J., R.K. Jain, and J.E. Taylor, Block Configuration Modeling: A novel simulation model to emulate building occupant peer networks and their impact on building energy consumption. *Applied Energy*, 2013. 105: p. 358-368.
- [7] Mohamed, A.M.A., et al., Towards exporting renewable energy from MENA region to Europe: An investigation into domestic energy use and householders’ energy behaviour in Libya. *Applied Energy*, 2015. 146: p. 247-262.
- [8] Guerra Santin, O., Occupant behaviour in energy efficient dwellings: evidence of a rebound effect. *Journal of Housing and the Built Environment*, 2013. 28(2): p. 311-327.
- [9] Yang, R. and L. Wang, Development of multi-agent system for building energy and comfort management based on occupant behaviors. *Energy and Buildings*, 2013. 56: p. 1-7.
- [10] Gulbinas, R., R.K. Jain, and J.E. Taylor, BizWatts: A modular socio-technical energy management system for empowering commercial building occupants to conserve energy. *Applied Energy*, 2014. 136: p. 1076-1084.
- [11] Ben, H. and K. Steemers, Energy retrofit and occupant behaviour in protected housing: A case study of the Brunswick Centre in London. *Energy and Buildings*, 2014. 80: p. 120-130.
- [12] Wei, S., et al., Impact of occupant behavior on the energy saving potential of retrofit measures for a public building in the UK, in *The 7th International Conference of SuDBE2015*. 2015: Reading, UK.
- [13] Gunay, H.B., W. O'Brien, and I. Beausoleil-Morrison, A critical review of observation studies, modeling, and simulation of adaptive occupant behaviors in offices. *Building and Environment*, 2013. 70: p. 31-47.
- [14] Wei, S., R. Jones, and P. de Wilde, Driving factors for occupant-controlled space heating in residential buildings. *Energy and Buildings*, 2014. 70: p. 36-44.
- [15] Abrahamse, W., et al., A review of intervention studies aimed at household energy conservation. *Journal of Environmental Psychology*, 2005. 25(3): p. 273-291.
- [16] Guy, S. and E. Shove, *The Sociology of Energy, Buildings and the Environment: Constructing Knowledge, Designing Practice*. 2000: Routledge 176.
- [17] Gifford, R., *Environmental Psychology Matters*. *Annual Review of Psychology*, 2014. 65(1): p. 541-579.
- [18] Wei, S., et al. Using building performance simulation to save residential space heating energy: A pilot testing. in *Windsor Conference 2014*. 2014. Cumberland Lodge, Windsor, UK.
- [19] Wei, S., R. Jones, and P. de Wilde, Extending the UK's green deal with the consideration of occupant behaviour, in *Conference of Building Simulation and Optimization 2014*. 2014: UCL, London, UK.
- [20] de Wilde, P., et al., Using building simulation to drive changes in occupant behaviour: A pilot study, in *Building Simulation 2013 Conference*. 2013: Chambéry, France.
- [21] Pan, S., et al., Improper window use in office buildings: findings from a longitudinal study in Beijing, China. *Energy Procedia*, 2016.