Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 88 (2016) 761 – 767

Energy Procedia

CUE2015-Applied Energy Symposium and Summit 2015: Low carbon cities and urban energy systems

Improper window use in office buildings: findings from a longitudinal study in Beijing, China

Song Pan[a], Chuanqi Xu[a], Shen Wei[b,*], Tarek M Hassan[c], Lang Xie[a], Yingzi Xiong[a], Steven Firth[c], David Greenwood[b], Pieter de Wilde[d]

[a] College of Architecture and Civil Engineering, Beijing University of Technology, Beijing, 100022, China
[b] Faculty of Engineering and Environment, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK
[c] School of Civil and Building Engineering, Loughborough University, Loughborough, LE11 3TU, UK
[d] Chair of Building Performance Analysis, Plymouth University, Plymouth, PL4 8AA, UK

Abstract

Occupants' window opening behavior influences the performance of buildings significantly. Good window use can provide a comfortable indoor environment with a minimum energy use, while improper window use may result in bad indoor environment and may also waste great energy. This paper identifies improper window uses in an existing building in Beijing, China, based on a year-long longitudinal monitoring of occupants' window opening behavior, together with important indoor and outdoor environmental variables. The findings from this study provide evidence that occupants' window opening behavior in real buildings is required to be improved to promote the energy efficiency of the building.

Peer-review under responsibility of the organizing committee of CUE 2015

Keywords: Window opening behavior, Office building, China, Energy waste

1. Introduction

The importance of occupant behavior on the building performance has been well proven by a number of existing studies [1,2,3], and therefore making occupants use the building in an energy efficient way is crucial for minimizing the buildings' energy consumption [4,5]. Occupant behavior is a complex process,

* Corresponding author. Tel.: +44 (0)191 3495374.
E-mail address: shen.wei@northumbria.ac.uk.

Peer-review under responsibility of the organizing committee of CUE 2015
doi:10.1016/j.egypro.2016.06.104

as 1) it is influenced by a number of factors [6, 7] and 2) it appears in various modes, i.e. time related, environmentally related and random [8]. Many studies based on dynamic building performance simulation have been carried out to quantify the impact of changing behavior on the building performance [9-12], so that the optimization of occupants' use of the building can be paid more attention. These studies, however, were based on assumed behavioral patterns, not actual ones, so there is a lack of confidence in the predicted potential for energy saving by changing behavior. To overcome this issue, a longitudinal study monitoring occupants' window opening behavior was carried out in an office building in Beijing, China, for three different periods of the year, namely, winter, transitional and summer periods. The monitored data have been used to identify occupants' improper window uses in a real building, with respect to both energy waste and indoor environment. These improper window uses can be used to guide future studies on changing behavior for low carbon buildings.

2. Material and methods

The study was conducted in a mixed-mode office building located at the southeast of Beijing (39° 54' 27'' N, 116° 23' 17'' E, alt. 44m). The building has two floors, containing laboratories on the ground floor and offices with similar floor plan on the first floor. Each office can be occupied by two occupants simultaneously but during the survey period all monitored offices were occupied by one specific occupant only. In each office, there are two sliding windows facing south, for both daylighting and ventilation purposes. The building is built with bricks. In winter, all offices are continuously heated by a local hot-water radiator heating system, and in summer they are cooled using split air-conditioners. During the transitional season, the offices were cooled specifically using natural ventilation through the opening of windows by the occupants.

The monitoring of occupants' window usage and relevant influential parameters was carried out in three main seasons of the year, i.e. winter season (16.11.2014 to 15.03.2015), summer season (from 16.05.2015 to 07.07.2015) and transitional season (15.03.2014 to 15.05.2014 and 08.10.2014 to 15.11.2014). During the survey, five offices on the first floor were monitored, accounting for 70% offices in the building. The monitoring included room occupancy (at 1 minute intervals), window state (at 1 minute intervals), indoor temperature (at 5 minute intervals; accuracy: ±0.35°C) and outdoor temperature (at 5 minute intervals; accuracy: ±0.5°C).

In this paper, improper window uses in the three monitored seasons were captured and analyzed. Improper window use scenarios are listed in Table 1, for different seasons of the year, with a consideration of both energy conservation and indoor air quality. To conserve energy, occupants are expected to keep windows closed when the heating is on in winter. During the summer time, they are expected to open the window when the outdoor temperature is lower than the indoor temperature (even when the air-conditioner is on) so cooler air outdoors can come into the room to replace the warmer air indoors, hence reducing the cooling demand of the air-conditioning system. For the transitional season, the building is cooled by natural ventilation so windows should be opened for cooling the building based on two main strategies: 1) night cooling during the unoccupied night time and 2) natural ventilation during the occupied time. Additionally, whether the room is occupied and how long the room is unoccupied are also considered in the analysis as ventilation requirements may be a reason of opening windows even when heating/air-conditioning is on.

Table 1. Definitions of improper window uses

Seasons	Improper window use scenarios
Winter	1. The window is left open with heating on when the office is unoccupied for longer time periods (≥ 30 minutes); 2. The window is left open with heating on when the office is unoccupied for a short-time (< 30 minutes); 3. The window is kept open with heating on when the office is occupied.
Transitional	1. Over-heating (> 20% occupied time with indoor temperature above 26°C) happens on the day but night cooling was not used on the previous night; 2. During occupied time, when indoor temperature is higher than 26°C but outdoor temperature is lower than indoor temperature, the window is still kept closed.
Summer	1. The window is left closed when outdoor temperature is lower than indoor temperature for longer unoccupied periods (≥ 30 minutes); 2. The window is left closed when outdoor temperature is lower than indoor temperature for short unoccupied periods (< 30 minutes); 3. The window is left closed when outdoor temperature is lower than indoor temperature for occupied periods.

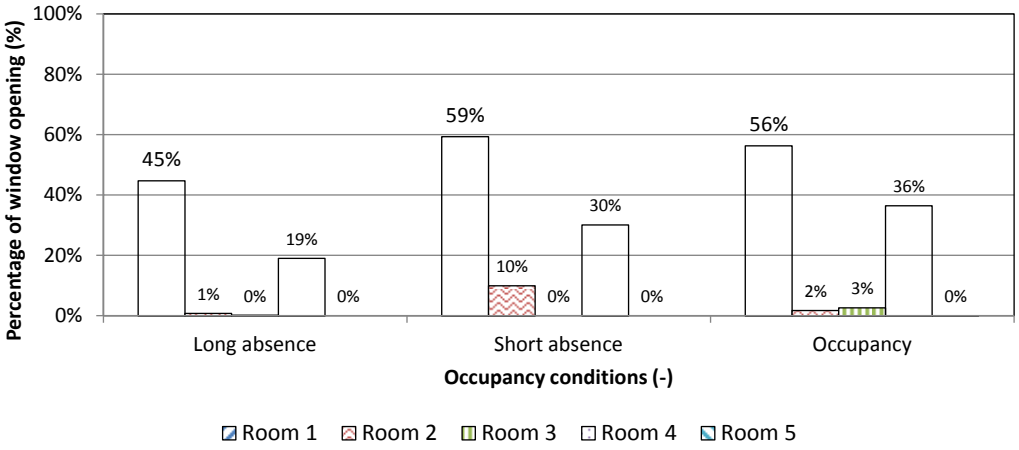

Fig. 1. Improper window use for the winter time

3. Results

3.1 Winter time

This section analyses occupants' improper window uses in the winter time, according to the definitions in Table 1. Figure 1 presents the percentage of opening windows when the heating is on, for long absence, short absence and occupancy conditions, and for each room, respectively. Figure 1 reflects that people use windows differently in the winter time (Room 1's and Room 4's windows were kept open longer than those in the other rooms), which is consistent with findings from previous studies [13,14]. For all occupants, there is no significant change of window states between short absence and occupancy conditions, meaning that occupants did not tend to close their windows when leaving the offices for a

short period of time. However, occupants of Room 1 and Room 4, who opened windows for a much longer time than the other occupants, seem to close their windows sometimes when leaving the offices for a long time, as the percentages for long absence is less than the other two occupancy conditions. This may because of a consideration of energy conservation. However, for those two offices there was still a long period with opened windows and the heating on, during which times there was the potential for a great waste of energy.

3.2 Transitional time

This section analyses occupants' improper window uses in transitional time, when the building is specifically cooled by natural ventilation through opening windows. Two types of improper window uses have been investigated here: one is about night cooling usage and another is about natural ventilation usage. Table 2 provides statistics regarding to the overheating and night cooling. Colum 2 lists the total number of overheating days for each office during the survey period, and Colum 3 lists the number of these overheating days without using night cooling last night. Additionally, the percentages in Colum 3 present the proportion of overheating days without using night cooling to the total number of overheating days. The data listed in Table 2 reflect the fact that most surveyed occupants do not use night cooling actively in summer to reduce the overheating issue during the daytime. The occupant of Room 4, however, seems to be more active in using night cooling than the others.

Table 2. Overheating vs. Night cooling

Room no.	Total no. of overheating days	no. of overheating days without using night cooling
1	11	11 (100%)
2	17	15 (88%)
3	7	7 (100%)
4	27	7 (26%)
5	16	10 (63%)

Figure 2 depicts the percentage of opening windows during the occupancy time, when the indoor temperature is higher than 26°C and outdoor temperature is lower than indoor temperature. It reflects how occupants apply natural ventilation for cooling the building when overheating occurs. From the figure, it can be seen that not all occupants use natural ventilation actively in summer to cool their offices (e.g. the occupants of Room 1, 2 and 3). Occupants of Room 4 and 5 demonstrated good behavior by using natural ventilation to keep their offices thermally comfortable.

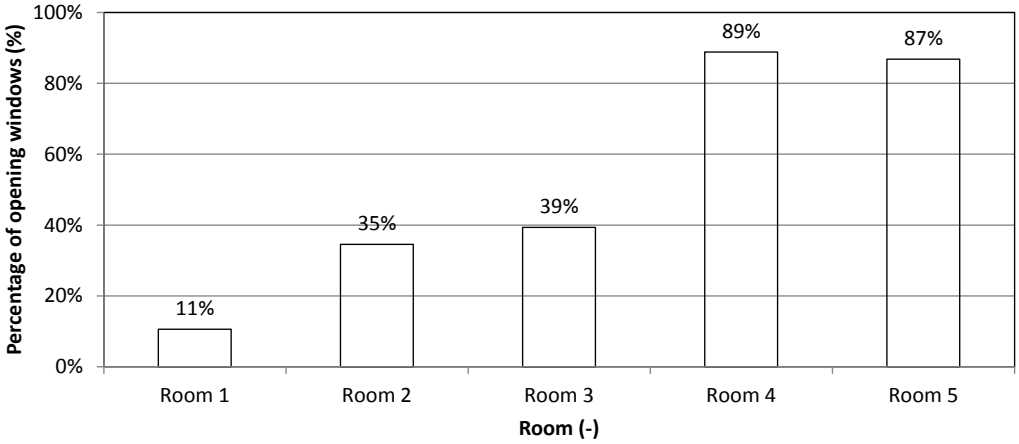

Fig. 2. Use of natural ventilation in transitional seasons when the office is overheated

3.3 Summer time

The core mechanism of natural ventilation is to use the cooler outdoor air to replace the warmer indoor air, and a proper use of natural ventilation can be helpful to reduce the use of air conditioners in summer. In this paper, it is proposed that occupants should open the window when the outdoor temperature is lower than indoor temperature, so cooling energy can go inside the room by natural ventilation. Figure 3 compares window uses of the five monitored occupants when the outdoor temperature is lower than the indoor temperature in summer, for different occupancy conditions. Figure 3 shows that occupants of Room 4 and 5 made better use of their windows than occupants of other rooms, as they captured more cooling energy from outdoors during the summer time. However, it is obvious that for all occupants there is still a considerable untapped potential for using natural ventilation to cool down their offices, rather than using air conditioners.

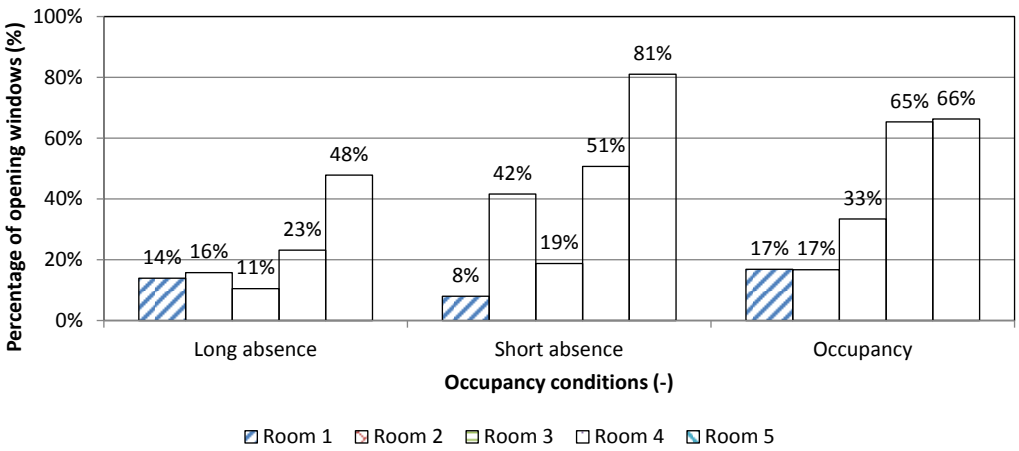

Fig. 3. Use of natural ventilation in summer

Conclusions

Occupants' window opening behavior significantly influence on the performance of buildings. Proper use of windows can greatly help to reduce the building energy consumption and improve the indoor air quality. In order to analyze occupants' actual window use in buildings and identify improper window uses, a longitudinal study with respect to occupants' window opening behavior was carried out in an office building located in Beijing, in three different seasons of a year, namely, winter, transitional and summer seasons. The main findings from the analysis are that:

(1) Occupants' use of their office windows varies significantly among each other in all seasons of the year;
(2) Occupants' use of their office windows needs to be optimized with respect to building energy efficiency, and there is a high potential of reducing building energy consumption and improving indoor air quality through changing their window opening windows;
(3) Occupants' window use may change when occupants vacate their offices for a long time.

After identifying occupants' improper window uses, future studies are needed to explore how to reduce their influence on the building performance. One research direction could be educating occupants on how to properly use their buildings and another could be developing an occupant-centered window control system, with consideration for both occupants' ventilation requirements and energy saving.

Acknowledgement

The work reported in this paper is funded by the National Science Foundation of China (NSFC), no. 51578011, 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), and the European Commission, Information Society and Media Directorate-General, under the Seventh Framework Programme (FP7), Grant Agreement no. 609380.

References

[1] Steemers K, Yun GY. Household energy consumption: a study of the role of occupants. Building Research & Information 2009; 37 (5-6): 625-637.

[2] Gill ZM, Tierney MJ, Pegg IM, Allan N. Low-energy dwellings: the contribution of behaviours to actual performance, Building Research & Information 2010; 38 (5): 491-508.

[3] Wei S, Jones R and de Wilde P. Extending the UK's green deal with the consideration of occupant behaviour. Conference of BSO 2014. 2014. UCL, London, UK. 23-24 June.

[4] Kashif A, Ploix S, Dugdale J, Le XHB. Simulating the dynamics of occupant behaviour for power management in residential buildings. Energy and Buildings 2013; 56 (0): 85-93.

[5] Jian Y, Li Y, Wei S, Zhang Y, Bai Z. A case study on household electricity uses and their variations due to occupant behavior in Chinese apartments in Beijing; Journal of Asian Architecture and Building Engineering 2015; 14(3): 679-686.

[6] Wei S, Jones R, de Wilde P. Driving factors for occupant-controlled space heating in residential buildings. Energy and Buildings 2014; 70 (0): 36-44.

[7] Fabi V, et al. Occupants' window opening behaviour: A literature review of factors influencing occupant behaviour and models. Building and Environment 2012; 58(0): 188-198.

[8] Peng C, et al. Quantitative description and simulation of human behavior in residential buildings. Building Simulation 2012; 5(2): 85-94.

[9] Porritt SM, Cropper PC, Shao L, Goodier CI. Ranking of interventions to reduce dwelling overheating during heat waves. Energy and Buildings 2012; 55: 16-27.

[10] Wei S, Wang X, Jones R, de Wilde P. Using building performance simulation to save residential space heating energy: A pilot testing. Windsor Conference 2014, Cumberland Lodge, Windsor, UK, 10-13 April.

[11] Kim YK and Altan H. Using dynamic simulation for demonstrating the impact of energy consumption by retrofit and behavioural change. Building Simulation Conference 2013, Chambery, France. 26-28 August.

[12] de Wilde P, Pahl S, Hamza N, Wei S, Jones R, AboHela I (2013). Using building simulation to drive changes in occupant behaviour: A pilot study. Building Simulation 2013 Conference. Chambery, France. 26-28 August.

[13] Wei S, Buswell R, Loveday D. Factors affecting 'end-of-day' window position in a non-air-conditioned office building. Energy and Buildings 2013; 62 (0): 87-96.

[14] Yun GY, Tuohy P, Steemers K. Thermal performance of a naturally ventilated building using a combined algorithm of probabilistic occupant behaviour and deterministic heat and mass balance models. Energy and Buildings 2009; 41 (5): 489–499.