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A field study on occupants’ ventilation behaviour through balcony doors in university students’ apartments during transitional seasons in Beijing

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Abstract

Occupant behaviour has an important role in both the environmental performance and energy performance of buildings, which has been thoroughly demonstrated in the past several decades. Based on a review work, some research gaps have been identified in the area of occupants’ ventilation behaviour and to answer those gaps a field study was carried out in a student dormitory building in Beijing, China, over the period of one transitional season in 2015. The study monitored students’ ventilation behaviour dynamically with concurrent measurement of relevant influential factors that have been identified in existing studies carried out in conventional buildings. The analysis carried out in the study aimed to demonstrate the influence of those previously-identified factors in the case study building. The factors examined in the study included outdoor air temperature, indoor air temperature, occupant presence, and certain aspects relating to personal preferences. From the analysis, it was found that all these factors can influence students’ ventilation behaviour in dormitories. However, the influence of occupant presence seems to be different from the findings in conventional buildings which focused mainly on the use of external windows, and not balcony doors, which are included in this study.

Keywords: Environmental Performance, Residential buildings, Ventilation behaviour, China.

1. Introduction

In the past several decades, occupants’ adaptive behaviour, for example, opening/closing windows and adjusting thermostatic settings (Brager and de Dear 1998) has been critically demonstrated to have significant impact on the energy performance of buildings, using both real measured data (Haas, Auer et al. 1998, Steemers and Yun 2009, Gill, Tierney et al. 2010) and building performance simulation (de Meester, Marique et al. 2013, Fabi, Andersen et al. 2013, Wei 2014). Additionally, providing occupants with more adaptive opportunities may also help them respond better to their local thermal environment (de Dear and Brager 2002, Luo, Cao et al. 2014), hence reduce building energy demands. When performing energy retrofitting for existing buildings, a good understanding of occupant behaviour and its
influence on the retrofitting measures is also essential for selecting the most suitable measure(s) (Ben and Steemers 2014, Wei, Hassan et al. 2016).

Occupant behaviour is complicated. It is influenced by a number of factors (Fabi, Andersen et al. 2012, O'Brien and Gunay 2014, Wei, Jones et al. 2014) and may also performs in various modes, i.e. time-related, environment-related and random (Peng, Yan et al. 2012). In dynamic building performance simulation, occupant behaviour has been acknowledged as one of the most important factors that cause the performance gap: that is, the difference between the simulated performance of buildings and the actually measured one (de Wilde 2014). In order to achieve energy efficient buildings, the so-called ‘golden rule’ for occupant behaviour is ‘If you don’t need it, don’t use it’ (Masoso and Grobler 2010). Thus, many studies have been carried out with an aim of making occupants use their building more energy-efficiently (Staats, van Leeuwen et al. 2000, Abrahamse, Steg et al. 2005, Jian, Li et al. 2015, Wei, Goodhew et al. 2015).

Ventilation behaviour, usually referring to window opening behaviour, has a key influence on the buildings’ indoor thermal environment (Yun, Tuohy et al. 2009, Porritt, Cropper et al. 2012), the air quality (Offermann 2009, Bekö, Lund et al. 2010) and energy consumption (Wei, Wang et al. 2014, Wang and Greenberg 2015). In order to obtain a good understanding of occupants’ ventilation behaviour in buildings, field studies have been carried out in both domestic and commercial buildings, and Wei (2014) and Fabi et al. (2012) have both carried out a thorough review of related studies and collected influential factors of ventilation behaviour that have been identified in existing studies. Combining the results introduced in these two publications, a number of factors have been listed in Table 1. Additionally, Wei et al. (2013) have pointed out the influence of ‘personal preference’ on the various behavioural patterns among occupants and have demonstrated its importance for achieving a more accurate modelling of occupant ventilation behaviour (Wei, Buswell et al. 2014).

Table 1: Influential factors of ventilation behaviour in buildings

<table>
<thead>
<tr>
<th>Building level factors</th>
<th>Sub-group level factors</th>
<th>Personal level factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor climate (dominated by outdoor air temperature)</td>
<td>Window type</td>
<td>Personal preference</td>
</tr>
<tr>
<td>Indoor climate (dominated by indoor air temperature)</td>
<td>Window orientation</td>
<td></td>
</tr>
<tr>
<td>Season</td>
<td>Floor level</td>
<td></td>
</tr>
<tr>
<td>Time of day</td>
<td>Shared offices/rooms</td>
<td></td>
</tr>
<tr>
<td>Previous window state</td>
<td>Building type</td>
<td></td>
</tr>
<tr>
<td>Presence</td>
<td>Room type</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heating system type</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Occupant age</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Occupant gender</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Property ownership</td>
<td></td>
</tr>
</tbody>
</table>
The above classification method has been introduced in detail in a PhD thesis by one of the author’s (Wei 2014).

Based on a review of more than 30 relevant studies, the following research gaps have been identified:

1. Existing studies focused mainly on conventional residential buildings (i.e. houses and apartments) and student dormitories were usually ignored. However, student dormitories often have a much higher energy demand than conventional residential buildings as in most case the energy bills are included in the rent. Therefore, a good understanding of students’ energy behaviour is also essential. Schweiker et al. (2011) have made some initial exploration on students ventilation behaviour in dormitories in Japan, but their study did not considered the second research gap;

2. Many apartment/dormitory buildings have balconies for the rooms and occupants’ ventilation behaviour for this special condition (i.e. the ventilation of the living space is dependent on the state of both external windows and the balcony door) has not been investigated;

3. Most studies in this area were carried out in European countries, such as the UK, Denmark and Germany, and high resolution data on occupants’ ventilation behaviour in China are still needed.

To answer the above gaps, this paper introduces a case study carried out in a student dormitory in Beijing, China, during a transitional season in 2015, when no mechanical cooling and heating are available. In the study, students’ ventilation behaviour (mainly their use of the balcony door in each room) was monitored dynamically, with concurrent measurement of the relevant influential factors listed in Table 1. This study provided evidence about the similarity of ventilation behaviour in student dormitories with balconies and conventional buildings, with respect to factors influencing their ventilation behaviour.

2. Research Method

2.1 Case study building

The case study building is located in the southeast of Beijing, China, with a climatic condition of hot & wet summer and cold & dry winter. It is a dormitory building of a university. The building has 17 floors, with a total number of students around 1200 (see Figure 1, left). Six dormitories were selected for the study. A small number of samples is a weakness of many field studies with respect to occupant behaviour in buildings, mainly because of the cost intensive nature of using electronic devices to achieve dynamic monitoring (as described following). To tackle this issue, the researchers in the current study tried to diminish the uncertainties caused by some factors through a careful selection of monitored rooms: all selected dormitories (Figure 1 right: 3m X 6m) were all occupied by male students, located on the 10th floor (with no shading effect from their surroundings) and on the east facade of the building. Therefore, the influence of occupant gender, floor level and window orientation can be ignored in the analysis. Each room may be occupied by a maximum
number of four students, all between 18-23 years, and this selection eliminated the influence of occupant age.

Each room has a balcony with some external windows and the balcony is linked to the living space through a sliding door, as shown in Figure 1 (right). During the transitional seasons in Beijing (i.e. from the middle of March to the end of April and from the beginning of October to the middle of November) (Wei, Xu et al. 2015), all windows would typically be always left open in order to increase the ventilation of the building. Therefore, additional ventilation for the indoor thermal environment was mainly dependent on the opening of the balcony door. Because of this, the later analysis will be mainly based on occupants’ behaviour with respect to the use of the balcony door.
2.2 Data collection
The case study was carried out during the first transitional season in 2015, which was between 16th March and the 30th April. During this period, no mechanical cooling and heating was available and the whole building was naturally ventilated through opening the balcony door and external windows. Figure 2 shows some electronic devices that were used in the study to capture indoor air temperature (Figure 2a: Accuracy: ±0.35°C; Monitoring interval: 10min), room occupancy (Figure 2b: Detection range: 5m; Monitoring interval: 1min), window state (Figure 2c: Monitoring interval: 0.5s) and outdoor air temperature (Figure 2d: Accuracy: ±0.5°C; Monitoring interval: 10min). All indoor measurement devices were placed on a book shelf situated away from local heat gains (such as human bodies and computers) and solar gains. The exception was the window state sensor which was placed on the frame of the balcony door. The outdoor air temperature sensor was placed within the main campus of the university, which was about 800m away from the case study site. Before the tests, all indoor temperature sensors were calibrated against a Testo 650 thermometer.

3. Data analysis
Using the field data collected in this study, the influence of outdoor air temperature, indoor air temperature, the time of day, occupant presence and personal preference on the state of the balcony door was analysed using a systematic approach used by Wei et al. (2013).

3.1 Influence from outdoor air temperature
The influence of outdoor air temperature on the state of dormitory balcony doors is presented by the correlation between the proportion of opening time and the ‘binned’ outdoor air temperature (the following proportions were calculated based on data within each 3°C range). Figure 3 shows the results based on data collected during the occupied time. It reflects that the opening of balcony doors was generally proportional to the outdoor air temperature, i.e. with the increase of outdoor air temperature, the opening of doors increased.
This phenomenon has been identified in existing studies (Herkel, Knapp et al. 2008, Haldi and Robinson 2009, Zhang and Barrett 2012, Wei, Buswell et al. 2013). There was, however, a significant drop when outdoor air temperature exceeded 32°C. This may be caused by two reasons. Firstly, occupants prefer to shut off the ventilation at high outdoor temperature conditions in order to stop hot air outdoors coming into the living space; and this has been observed by other researchers (Haldi and Robinson 2008). Secondly, this analysis method was based on the proportion so the number of samples used in each bin may also influence the results (Haldi and Robinson 2009, Wei, Buswell et al. 2013). Therefore, more data are required in future studies to examine the validity of the first reason. However, for other temperature bins, a clear proportional relationship has been observed from this study.

3.2 Influence from indoor air temperature

Figure 4 shows the relationship between the proportion of opening balcony doors and indoor air temperature, also based on data collected during occupied time. Due to the smaller changing range of indoor air temperature, 2°C was used to bin the data. From Figure 4, a general proportional relationship between the proportion of door opening and the indoor air temperature can be observed, although not as good as for outdoor air temperature.
3.3 Influence from occupant presence

Figure 5 reflects that occupants’ door opening/closing actions mostly happened during the occupied period (78%), rather than entering (15%) or leaving the room (6%). This finding is not consistent with what has been observed in office buildings (Herkel, Knapp et al. 2008, Haldi and Robinson 2009, Pan, Xu et al. 2015), where more ventilation-related actions happened when arriving at the office or leaving it. This may be because the various situations between office buildings and residential buildings. For example, in residential buildings, occupants generally have more adaptive opportunities to adjust the indoor thermal environment and their thermal sensation than in office buildings. Another reason may because doors have one more function than windows which is linking the balcony and the living space. Therefore, occupants may need to use them to enter the balcony or come back to the room, which may also trigger the change of the door state. Further studies are still needed to confirm this finding.
Figure 5: Relationship between the occupant presence and the percentage of open-balcony-door actions

Figure 6: Relationship between the occupant presence and the percentage of opening the balcony door

Figure 5 illustrates occupants’ ventilation actions, i.e. opening/closing the balcony door. Figure 6 compares the proportion of keeping balcony doors open for occupied time and unoccupied time, so it is based on the state of the balcony door. The data used here do not include those taken when subjects arrived or left the room. The comparison reflects the fact that students preferred to leave the balcony door open when not in the room and close them when staying in the room. This also contradicts what has been suggested for window use in office buildings. This may be because the monitored rooms are located on the 10th floor so security issues can be ignored. Further studies are still needed to further demonstrate this conclusion.

3.4 Influence from personal preference

Many studies have suggested that occupants’ ventilation behaviour differs significantly between individuals; some used windows actively whereas other used passively (McCartney and Fergus Nicol 2002, Haldi and Robinson 2009, Yun, Tuohy et al. 2009). Wei et al. (2013) have defined this as ‘personal preference’. To investigate the influence of this factor on the observed dormitories, each room’s door-use pattern during occupied time was drawn and compared in Figure 7, based on outdoor air temperature (this parameter performed better than indoor air temperature in the previous analysis). The comparison reflects that occupants in various rooms used the balcony differently but with a similar correlation to the outdoor air temperature.
4. Conclusions

Occupant behaviour has a significant influence on both the environmental performance and energy performance of buildings, especially their ventilation behaviour. This paper used field data collected from a student dormitory building in Beijing, China, and analysed the influence of previously acknowledged factors on the use of ventilation in six monitored dormitories, mainly focused on students’ use of balcony doors. These factors include outdoor air temperature, indoor air temperature, occupant presence and personal preference. The results reflect that all these factors can significantly influence students’ ventilation behaviour in Beijing, China and can be used to further analyse when those students use natural ventilation, i.e. through statistical modelling of occupant ventilation behaviour (Herkel, Knapp et al. 2008, Yun and Steemers 2008, Haldi and Robinson 2009, Yun and Steemers 2010, Andersen, Fabi et al. 2013). Additionally, an inconsistent finding was found for the influence from occupant presence between student dormitories and conventional buildings, as more ventilation behaviour happened when occupants are using the room, not when they arriving at or leaving the room. Additionally, students preferred to use more natural ventilation when they were not in the room which also contradicts the findings from conventional buildings. This may be because the difference between the use of windows and balcony doors, and further studies are still needed to confirm this conclusion.

Due to the small number of samples, the monitored rooms were carefully selected so the influence of other factors (shown in Table 1) cannot be examined in this study. Future studies also need to expand the samples and test the influence of the remaining factors.
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Reference


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