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A study on influential factors of occupant window-opening behavior in an office building in China

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ABSTRACT

Occupants often perform many types of behavior in buildings to adjust the indoor thermal environment. In these types, opening/closing the windows, often regarded as window-opening behavior, is more commonly observed because of its convenience. It not only improves indoor air quality to satisfy occupants' requirement for indoor thermal comfort but also influences building energy consumption. To learn more about potential factors having effects on occupants' window-opening behavior, a field study was carried out in an office building within a university in Beijing. Window state (open/closed) for a total of 5 windows in 5 offices on the second floor in 285 days (9.5 months) were recorded daily. Potential factors, categorized as environmental and non-environmental ones, were subsequently identified with their impact on window-opening behavior through logistic regression and Pearson correlation approaches. The analytical results show that occupants' window-opening behavior is more strongly correlated to environmental factors, such as indoor and outdoor air temperatures, wind speed, relative humidity, outdoor $PM_{2.5}$ concentrations, solar radiation, sunshine hours, in which air temperatures dominate the influence. While the non-environmental factors, i.e. seasonal change, time of day and personal preference, also affects the patterns of window-opening probability. This paper provides solid field data on occupant window opening behavior in China, with high resolutions and demonstrates the way in analyzing and predicting the probability of window-opening behavior. Its discussion into the potential impact factors shall be useful for further investigation of the relationship between building energy consumption and window-opening behavior.

1. Introduction

Indoor environment regarding to both thermal condition and air quality, is important for building occupants' health and productivity. Owing to the fast development in both economy and urbanization, the demand on better indoor environment has increased. In many buildings, when people are dissatisfied with the indoor environment, they may often perform adaptive behaviors, such as opening/closing a window, adjusting clothing insulation level and changing cooling/heating setpoints, to adjust their surrounding environment [1–3]. In places with mild outdoor environment, opening windows can reduce indoor cooling demand and enhance indoor air quality simultaneously. Therefore, openable windows, have been widely selected for many buildings as a type of low-carbon solution. When the building is running in a free mode, opening windows can bring cool-and-fresh air from outdoors [4,5]. When the building is mechanically heated or cooled, opening windows will provide a better indoor air quality, but may increase the building's heating or cooling demand [6]. In many buildings, openable windows are controlled manually by the occupants. Thus, a comprehensive understanding in occupants' window-opening behaviors is important to ensure a healthy indoor environment and adjust energy supply systems in buildings at a reduced consumption level [7].

In the past 30 years, a number of studies have been carried out to explore occupants' window-opening behavior, especially within European countries, such as the UK [7–16], Switzerland [17–19], Denmark [1,20], Germany [21,22] and Italy [23]. Nevertheless, this is

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very limited contribution [24] from China by providing solid evidence on how people in China context operate their windows. A thorough review work on occupants' window-opening behavior studies is conducted as following Sections 1.1 and 1.2, which focus on influential factors of occupants' window-opening behavior.

1.1. Existing studies in the Europe

In Switzerland, Haldi and Robinson [2,17–19] carried out a detailed analysis of the influences from occupancy patterns, indoor air temperature and outdoor climate parameters (i.e. temperature, wind speed and direction, relative humidity and rainfall) on window-opening behavior in their experimental building, based on data collected over 7 years. From the analysis, they reported that indoor air temperature was a dominating factor influencing window-opening behavior because indoor air temperature has a direct link to occupants' decision of window operation. Yun et al. [14] conducted a field monitoring study in 4 offices and demonstrated close links between impact factors (CO_2 concentrations, prevailing internal and external temperature, occupancy schedules and window control patterns. From the study, they also revealed that there were statistically significant relationships between occupants' window uses and indoor environmental parameters, i.e. indoor thermal stimuli and CO_2 concentrations, and also the previous window state, i.e. whether it has been opened or closed, was a crucial factor in the relationship. Occupancy has been suggested as another important driver of window-opening behaviors, which has been classified as time of arrival, time of departure and time of day. In another study, Yun [25] further justified the strong link between window-opening behavior and time of day. He proposed that occupants attempted to restore their comfort in the easiest way possible, which, of course, were influenced by many contextual factors. Contextual drivers have been defined as those factors that have an indirect influence on window-opening behavior, and they were including many factors such as window orientation, window type, seasonal change, time of day and occupancy pattern. Additionally, it has been observed that there was an apparent difference in window positions during the night time among individual occupants, in both summer and winter times. Some windows were rigorously closed at the end of almost every day, whilst others were left open across a very large range of temperature conditions. Andersen et al. [26] did repeated surveys on occupant control of the indoor environment in Danish dwellings, and analyzed influences from a number of factors, i.e. outdoor air temperature, indoor air quality, thermal sensation, noise level, outdoor solar radiation, wind speed, sunshine hours, age, gender, house property ownership and type of heating systems. From the study, they concluded that the window-opening behavior was strongly correlated to outdoor air temperature and occupants' perception of the environment and factors concerning the dwelling also affected the window-opening behavior. Wei et al. [27] suggested that even if all common factors were the same, occupants may still perform different window operations in office buildings, and this difference could be explained by personal preference. And based on the frequency of opening windows, they classified survey objects into three categories: habitual closers, adjusters and leave openers. In studies carried out by Rijal et al. [12], Haldi and Robinson [19] and Yun et al. [28], window users have been termed as 'active', 'medium' and 'passive'. These results also reflect the various behavior for different users, which were caused by occupants personal preference. The potential factors that influence window-opening behavior are summarized from above studies, as shown in Table 1.

1.2. Existing studies in China

In China, Li et al. [24] carried out a 2-month field observation on occupant window-opening behavior in a naturally ventilated office building during the transition seasons. From the study, they found that outdoor air temperature significantly affected window-opening behavior among other factors such as outdoor relative humidity, indoor air temperature, indoor relative humidity, and indoor CO_2 concentrations, which have much less effect. The main trigger point for opening windows in transition seasons, revealed by them, is from occupants' desire to improve the indoor thermal and air quality environment. Weihuang Chen [29] analyzed the influence of thermal comfort due to window-opening behavior in hot summer and cold winter zone, in 2009. Jian Zhang [30] analyzed the influence of building orientation and height on window-opening behavior in 2011.

Table 1
The influential factors of occupants' window-opening behavior.

Environmental factors	Non-environmental factors		
Outdoor environment (dominated by outdoor air temperature and relative humidity)	Age	Time of day	Previous status of the window
	Gender	Heating modes	House Property ownership
	Season	Window type	Window orientation
Indoor environment (dominated by indoor air temperature and air quality)	Smoking	Building type	Occupancy pattern
	Presence	Room type	Personal preference
	Floor level		

Comparing to the related foreign research, there is a lack of in-depth research into occupants' window-opening behavior, especially aiming in China scenario since China has a very different background and condition from western countries in terms of its air pollution and speed of economic development. As a result, to handle this particularity, a real-time monitoring for a long period was carried out in this paper, aiming at finding out and quantifying the influence of environmental/non-environment factors on window-opening behavior in China context. Beyond that, this study developed a dedicated analytical model for window-opening behavior that can be applied further in energy consumption simulation in China context.

This paper aims to provide high-quality data resolution to the research of window-opening behavior in China, through development of statistic analytical models. This work is expected to fill in the research gap existing in occupant window-opening behavior of office buildings. In this paper, occupants' window-opening behavior and relevant influential factors were monitored in an office building in a University in Beijing with high resolutions (including window state, indoor and outdoor air temperatures, outdoor relative humidity, outdoor $PM_{2.5}$ concentrations, outdoor wind speed and direction, solar radiation, sunshine hours, seasonal change, time of day, personal preference). An integrated model, combined with logistic regression and Pearson correlation approaches, was then developed to analyze the recorded data. The potential influential factors on occupants' window-opening behavior were finally identified in the case study building, which shall be meaningful for the future integrated behavioral modeling in a whole building or cluster scale.

2. Method of study

2.1. Building description

The case office building was constructed of reinforced concrete and brick, which located at a university in Beijing. The building shape and office layout were very common for office buildings in China. Around the building, there were no tall buildings and trees blocking solar gains and external noise was ignorable. As shown in Fig. 1 (a), the building has two stories, where laboratories were based on the ground floor, and a total of 9 offices with same size of 10 m^2 were placed on the second floor. The typical internal layout of all offices is shown in Fig. 1 (b). The geometry information of the measured offices is shown in Table 2. In these 9 offices, 5 offices were applicable and selected for the