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Case study of window operating behavior patterns in an open-plan office in the summer

Xin Zhou*, Tiance Liu, Xing Shi, Xing Jin

School of Architecture, Southeast University, Nanjing, Jiangsu Province, 210096, China

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ABSTRACT

While previous studies have focused on window operation in residential buildings and small-scale offices, typical window operation behavior in an open-plan office is studied here. Unlike single offices, open-plan offices accommodate more people at once, which leads to more complex window operating behavior. An open-plan office located in Nanjing, Jiangsu Province was studied. Questionnaires and field measurements were adopted to determine factors influencing window operating behavior. Differences between subjective and objective feedback were detected in this study. Three typical window operating patterns were classified under the influence of outdoor temperature. The distribution of the "windows open state" with changes in outdoor temperature was polynomial. Through coupling analysis of environmental and non-environmental factors, it was found that window operating behavior in the open-plan office was influenced by the outdoor temperature, the daily work schedule of occupants, and the state of air conditioners.

1. Introduction

Energy consumption of buildings is a global area of concern. In 2009, global public building energy consumption exceeded 2 billion TCE, 11.4% of the total energy consumption [1]. In 2014, the total energy consumption of public buildings in China was approximately 260 million TCE, accounting for 30% of the total energy consumption of buildings in the country [2]. The energy consumption of office buildings constitutes almost 1/5 of total energy use by buildings [3]. Therefore, reducing office building energy consumption while continuing to satisfy the requirements for a suitable indoor environment for occupants is particularly important.

Researchers have studied the elements influencing office building energy consumption [4]. According to a study in IEA Annex 53 [5], factors influencing office building energy performance can be classified into four categories, including climate, building envelope, building equipment, and occupant behavior. Occupant behavior here refers to operation and maintenance, occupancy, and indoor environmental conditions. It has become increasingly clear recently that occupant behavior is one of the most important factors influencing the thermal load, energy consumption, and technical suitability of buildings [6–11]. Numerous models have been developed that account for occupant behavior, such as the occupant movement [12–18], occupants' behavioral diversity [19,20], window opening, and appliance usage models [21–25].

As an important occupant behavior that influences building energy consumption, window operating behavior has attracted global attention. Through studying an office building in Germany, Schakib-Ekbatan [26] elucidated that window operating behavior is closely related to indoor temperature during the winter, while it is more closely related to outdoor temperature during the summer. Herkel [27] presented the results of a year-long field study on manual window control in 21 individual offices within one building in Germany. He measured window states, occupancy, and indoor and outdoor climatic conditions every minute. The research revealed a strong correlation between the percentage of windows open and the time of year, outdoor temperature, and building occupancy patterns. D'Oca [28] analyzed a dataset with physical indoor and outdoor parameters and human interactions with operable windows in 16 individual offices, and concluded that temperature and occupancy are the main elements driving occupants to change window states. Rijal [29] found that the ratio of open windows in buildings with air conditioners (ACs) was lower than that of naturally ventilated buildings, and that window operating behavior is influenced by indoor and outdoor temperature, and the time of year and day. Based on long-term monitored data from an office area and its calibrated simulation model, Tahmasebi [30] conducted an external evaluation of a number of stochastic and non-stochastic window operation models.

* Corresponding author.
E-mail address: zhou-x06@seu.edu.cn (X. Zhou).

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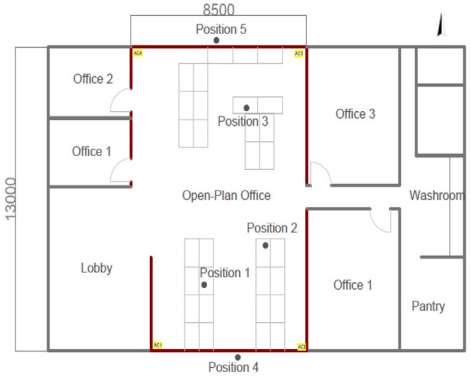
(a) Surroundings of the office

(b) Inside of the office



(c) Plane graph of the office

Fig. 1. Details of the test area.

While previous studies focused on window operation in residential buildings and small-scale offices, here, window operating behavior in an open-plan office is assessed. Unlike single offices, open-plan offices accommodate more people at once, which leads to more complex window operating behavior. Operating behavior is influenced by interrelationships between occupants; thus, behavior patterns in open-plan offices are more complex and need further study.

The main aims of this study are as follows:

1. To understand and identify the primary elements influencing window operating behavior in open-plan offices;
2. To understand and identify the combined relationships of different elements influencing window operating behavior in open-plan offices;
3. Determine the pattern of window operating behaviors.

2. Methodology

An open-plan office located in Nanjing, Jiangsu Province was studied here. Questionnaires and field measurements were conducted to determine factors influencing window operating behavior.

2.1. The open-plan office

An open-plan office in a small office building was studied during a hot summer and cold winter. The office building has three floors, and is surrounded by residential buildings and trees, as shown in Fig. 1(a). The open-plan office is located on the western first floor of the building. The whole space is open and clear, as shown in Fig. 1(b). The entire office area on this floor consists of four small offices and one central open-plan space. As this study focuses on window operating behavior, and the surrounding small offices have little impact on the activity of the central area, we only studied the area indicated in red in Fig. 1(c).

The survey area is approximately 110 m^2. The north and south walls have three groups of push-pull windows, which are double glazed and covered with sunshades. The open-plan office receives mixed ventilation, and the ACs are placed in the four corners. There are 25 office staff who perform various jobs, including graduate students, heating ventilation air conditioning (HVAC) engineers, electrical engineers, and architects.

2.2. Questionnaire

A total of 20 questionnaires were issued, and the valid response rate was 70% (14 of 20 returned). The questionnaire was divided into four parts:

a) basic information about the staff;
b) window operating behavior;
c) factors influencing window operating behavior;
d) assessment and expectations of the office environment;

Through statistical analysis of questionnaire data, the following aspects were analyzed: 1) the regular occupancy schedule, 2) typical window operating behavior, 3) the weight of each factor influencing window operating behavior, and 4) occupants' satisfaction with the indoor environment.

The part of the questionnaire about the staff includes questions about each occupant's gender, age, and occupancy schedule. Occupancy was recorded following the scale method to reflect the working and rest schedule of each person, which was then compared with measured data to verify and analyze the actual occupancy schedule.