

Study on window-opening habit of urban residential buildings in Liaoning province

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Abstract. Residents' window-opening behavior is the most basic method to obtain fresh air and improve the indoor environment, and is also an important factor affecting building energy consumption. The behavior of opening and closing windows of urban residents will be different due to regional differences. However, there are less of the thorough enough research on the time and seasonal habit of residents' window-opening behavior in Liaoning. This paper investigated the window-opening behavior and its influencing factors of 28 typical urban households in natural ventilation and mechanical ventilation houses in Liaoning province by questionnaire survey and on-site testing. The opening and closing behavior of residents' windows were continuously monitored online for one year by using magnetic sensors of XIAOMI brand. The long-term monitoring results showed that the window-opening behavior of residents in Liaoning has strong seasonality. In summer, the window-opening time is relatively longer, and often more than 24 hours. What's more, most local residents have the habit of opening windows for ventilation when they get up in the morning, even in the cold winter. The understanding of the window-opening behavior of residents in this area can provide strong support for architectural design or renovation strategy.

1 Introduction

In today's social background and working environment, about 90% of the time in a person's life is spent indoors. Poor indoor air quality can lead to serious diseases such as sick building Syndrome (SBS), which has become an increasingly global problem [1-3]. At present, Chinese residents are facing serious "internal troubles and external troubles", so the study of indoor air quality and ventilation strategy has not only important theoretical significance, but also far-reaching practical significance.

At present, the main solution to indoor air pollution in residential buildings is ventilation. Indoor ventilation can be divided into natural ventilation, mechanical ventilation and mixed ventilation according to the different ventilation volume [4]. Different countries adopt different ventilation methods. Most western developed countries generally adopt mechanical ventilation in the form of indoor and outdoor air exchange through fans to achieve the purpose of reducing indoor pollutant concentration. And Chinese residence uses natural ventilation more, household decides switch window time according to indoor temperature and humidity circumstance by oneself [5]. Natural ventilation, as an ancient ventilation method that has existed for thousands of years, is more in line with people's living habits than mechanical ventilation. Moreover, it has the advantages of comfort, energy

saving and no economic pressure on residents [6]. However, the controllability of natural ventilation is poor. In Liaoning, the outdoor environment and pollution are very bad in winter. Opening windows will lower indoor temperature and introduce PM2.5 in severe outdoor pollution [7,8], which leads to the habit of residents in Liaoning seldom opening windows for ventilation in winter. At present, there are relatively few researches on the long-term indoor pollution and window ventilation strategy of residential buildings in Liaoning province.

In this paper, the present situation of indoor window-opening behavior and the trend of indoor temperature and humidity of residential buildings in Liaoning region were obtained through 15 months of continuous online monitoring. And through the questionnaire supplement residents' window-opening habits to develop appropriate window-opening ventilation strategies for residential buildings in the Liaoning region. This test and survey aim to recommend reasonable window ventilation methods for residents, ensure the health of residents' living environment, reduce unnecessary energy consumption caused by window ventilation, and provide data support and strategy guidance for building a good indoor environment. The research data are scientific and reliable, and the data analysis results can be used to guide the indoor air quality strategy and advice for the entire province of Liaoning.

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2 Methods

2.1 Information

In order to study the behavior of opening and closing windows of residential buildings in Liaoning province, In this paper, three cities, Shenyang (41° 48'n, 123° 25'e), Fushun (41° 52'n, 123° 55'e) and Yingkou (40° 56'n, 123° 02'e), which are the capital of Liaoning Province, are studied. A total of 30 houses with natural ventilation and mechanical ventilation were selected to conduct long-term indoor air quality monitoring for 15 months. The climate of the selected region is characterized by a cold and dry winter (November-March), a short transition season (April-May, September-October) and a hot and rainy summer (June-August). In this paper, different test objects are selected according to the decoration time, floor, house type, floor area, decoration method and the location of the house (whether it faces the street, whether there are gas stations, thermal power plants, etc.). The decoration time of about half of all households is 1~2 years from the beginning of the test. The housing types are diverse, including single room, two-bedroom, three-bedroom, four-bedroom, loft and villa. The floors of the households basically cover low, middle and high positions, and the highest is 32 floors. Most of the window types are push-pull windows and a few are casement windows. The window frame types include broken bridge aluminum and plastic steel window frames, and the glass is mainly double-layer glass.

2.2 Test methods

For the monitoring of window-opening behavior and habits, Xiaomi door and window sensors (as shown in Figure 1-1) and intelligent gateway (as shown in Figure 1-2) are selected for long-term online monitoring. Xiaomi door and window sensors are composed of a sensor body and magnet. The sensor body adopted a built-in replaceable CR1632 battery. There is a status indicator light on the sensor body. The two components of millet door and window sensor are respectively installed on the window frame and window sash. Through the opening and closing of the window, the open/close signal issued by the magnetic sensitive element in the component is triggered. The mi gateway connects to the wireless network, and automatically records the state of "open" and "close" of the window and the time when the action occurs. When the door and window sensor in the window-opening gap exceeds 22mm, the sensor sends an "open" signal.

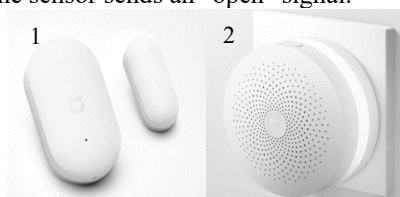


Fig. 1. Door and window sensors & intelligent gateway.

2.3 Questionnaire

In order to better understand and count the living environment and habits of the residents in Liaoning, this paper designed a subjective questionnaire from four aspects: family background, basic characteristics of housing, subjective feelings of residents and daily behavior habits. More than 300 questionnaires were distributed through mobile phone online filling, paper offline filling and on-site interview, and 285 valid answers were collected in total.

2.4 The error analysis

As networked electronic products, integrated sensors and door and window sensors often produce errors or failures due to various reasons or interference by other factors. In order to ensure the data accuracy of the whole database, it is necessary to first understand the parts prone to problems of the whole monitoring system, which can be roughly divided into the following aspects:(1) Interference from indoor personnel behavior or background environment. For example, when the window-opening angle is small, it will be affected by outdoor airflow disturbance, resulting in repeated small amplitude window-opening and data oscillation. (2) The sensor itself fails. Integrated sensor due to low cost, its own WIFI module or other sensor module in use after a period of time prone to failure, door and window sensors because by foam double-sided tape to stick on the window, often appear tape clay-free falls off phenomenon, if the tenants are not found in time, or when the window falls off phenomenon will cause the loss of the sensor, the impact data. (3) Network faults. Due to various reasons at home, such as power failure on business trips, power failure in the community, change of WIFI password, change of router, etc., the sensor cannot upload data to the data platform, and the sensor terminal itself has no storage function, resulting in the loss of data. In addition, as the cloud server is a rented server, it cannot guarantee that it will not fail at any time, and sometimes the website will crash. Later, due to the large amount of data, the phenomenon of insufficient server memory has also appeared.

3 Results and Discussion

The behavioural habits of opening and closing windows of 20 natural households and 8 mechanical households were used to conduct continuous online monitoring for 15 months with XIAOMI brand gateway combined with door and window sensor.

3.1 Window-opening duration

The duration of the window-opening can be obtained by subtracting the time corresponding to the opening and closing state of the window returned by the sensor. Figure 2 shows the natural ventilation for 15 consecutive months of Liaoning residents daily average window length and the change trend of outdoor temperature. The trend line of window-opening time and outdoor

temperature is the smooth curve obtained after processing the original data by using the smoothing function of Origin software, which can more clearly reflect the overall trend of the curve. In previous studies, the influence of outdoor temperature on window-opening behavior has been repeatedly emphasized [9,10]. In Beijing, which belongs to cold area, outdoor temperature is the most influential factor [11].

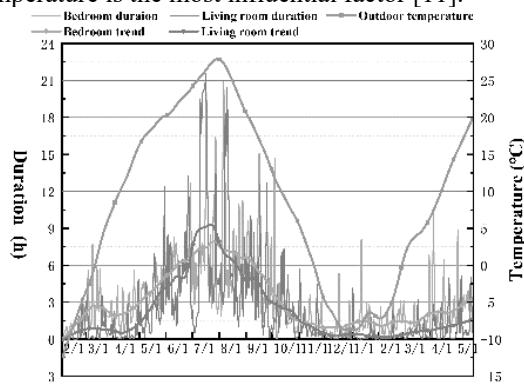


Fig. 2. Average daily window-opening duration and average outdoor daily temperature

In Liaoning, the average daily outdoor temperature in winter is usually below zero. Moreover, the outdoor temperature in cold areas has a greater impact on window-opening behavior than in cold areas, which results in the habit of residents in Liaoning seldom opening windows in winter [9]. According to the calculated monitoring data, the average daily window opening time of the bedroom and the living room in Liaoning is 0.6 hours and 1.6 hours respectively in winter. Because the spring and autumn seasons in Liaoning are very short, and the climate is characterized by dry and strong winds, and the window opening habits of residents in these two seasons are similar, the two seasons are uniformly regarded as transition seasons. When the central heating is stopped at the end of winter, the duration of opening windows of households begins to increase. When the central heating is about to enter winter, people will reduce the duration of opening windows because there is no indoor heating and the outdoor temperature is low. In the transition season, the window-opening duration of the bedroom and living room of residents in Liaoning was 2.4 hours and 3.2 hours respectively. In Liaoning province since summer is not so hot, compared with other regions in Liaoning province and residential air tightness and thermal insulation performance is getting better and better, the descent of the high temperature to indoor outdoor effect is also slightly lower, rely on the fan and the natural ventilation can be solved in the basic work of family problem of indoor thermal comfort in the night, In summer, the residents in Liaoning are accustomed to opening windows and ventilating in order to achieve thermal comfort. As a result, residents in Liaoning often open their windows all day long when the weather is good. Through the calculation of monitoring data, it can be found that the average daily window-opening duration of the bedroom and living room of residents in Liaoning in summer is almost two to three times that of the transitional season, which is 6.7 hours and 6.9 hours respectively.

3.2 Window-opening time

The probability of window-opening habit in different periods of time of residents in Liaoning was obtained by statistical period monitoring of the window opening time. Figure 3 shows the window opening time of bedrooms and living rooms. It can be seen from the figure that the window opening frequency is highest in the morning due to getting up, followed by the time after dinner. Noon is also the time when the windows often opened. The low frequency of window-opening at noon is also related to the work of residents. As there is generally no one at home on weekdays, the window opening frequency of these time periods is less.

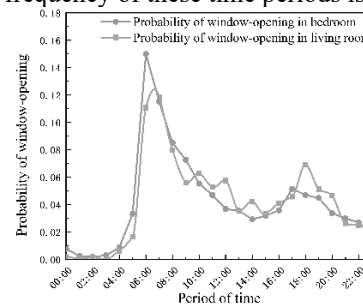


Fig. 3. Window-opening time

3.3 Questionnaire survey Results

3.3.1 Driving Force for window-opening in summer (multiple choice)

In this question, respondents are asked under what circumstances they generally choose to open windows in the summer. The statistical results are illustrated in Figure 4. In summer, the first driving force for residents in Liaoning to open windows is when they feel the indoor temperature is hot, and 48.42% of respondents prefer this option. The second is the feeling of indoor smell or stuffy, accounting for 47.02%. The following three choices have similar proportions, accounting for approximately one third of the total number. They open the window all the time, open it when there is no smog outside, and open it when you wake up.

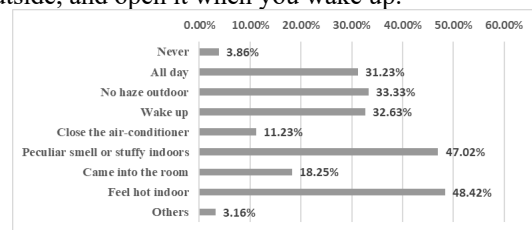


Fig.4. Driving Force for window-opening in summer

3.3.2 Driving Force for window-opening in winter (multiple choice)

In this question, respondents are asked under what circumstances they generally choose to open windows in winter. The statistical results are illustrated in figure 5. In winter, the primary driving force for residents in Liaoning to open windows has a peculiar smell or stuffy indoors, accounting for 55%. Secondly, they will open

the windows when they feel hot indoors. Since central heating is used in Liaoning, there is often an adjustment phenomenon. As a result, some households have high home temperatures and often have to open the windows to achieve thermal comfort. When there is no haze outdoors, roughly one-third of respondents will choose to open the window under such conditions; Even in winter, 22.8% of the respondents keep the habit of opening their windows when they wake. In winter, 15.8% of respondents never choose to open their windows.

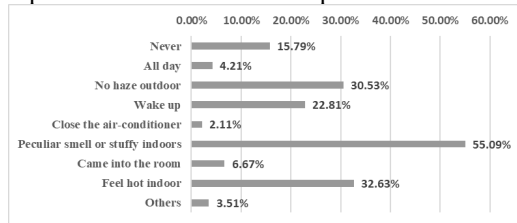


Fig.5. Driving Force for window-opening in winter

3.3.3 The form and the size of the window-opening in summer

In this question, the form and the size of window-opening in summer of respondents in Liaoning were statistically analyzed. The specific statistical results are illustrated in Fig. 6. It can be seen from the figure that three-quarters of respondents in Liaoning are accustomed to ventilation in summer by cross ventilation. Half of the respondents open their windows completely, and 22.45% of the households open windows with large area and half area occupy the same proportion.

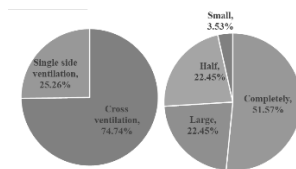


Fig 6. The form and the size of the window-opening in summer

3.3.4 The form and the size of the window-opening in transition season

Fig. 7 shows the statistical results of window-opening form and size of respondents in Liaoning during the transition season. It can be seen from the figure that, contrary to the result in summer, approximately three quarters of respondents in Liaoning are accustomed to utilizing a single side ventilation during the transition season. Half of the respondents only open the window half, 23.47% of the respondents used to open the window completely, and both large area and small area of window-opening accounted for 13%.

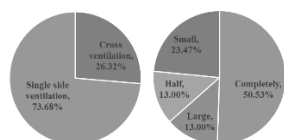


Fig 7. The form and the size of the window-opening in transition season

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4 Conclusion

This paper mainly introduces the current situation of window-opening behavior and habit of residents in residential buildings in Liaoning, respectively introduces the window opening duration, time period and the statistical results of 300 questionnaires about window-opening habit. The specific conclusions are as follows:

(1) The average window opening time of bedrooms and living rooms in Liaoning is 0.73 hours and 0.42 hours in winter, 5.8 hours and 4.2 hours in transition season, and 12.25 hours and 10.46 hours in summer.

(2) When residents in Liaoning area get up in the morning and after dinner, the window opening time is the highest. On non-working days, noon is also one of the most window opening time.

(3) The main driving force for residents in Liaoning to open windows in summer is indoor temperature and smell. In winter, the driving force for opening windows has a peculiar smell or stuffy, and the second is the high indoor heating temperature. Three-quarters of the interviewees used to ventilate in summer, half of them opened all the Windows when opening the window, and nearly three-quarters of them used to ventilate with a single opening in the transition season.

References

1. J. Sundell. Indoor Air,14:51-58. 2004
2. N. Klepeis, W. Nelson, W. Ott, et al. JESSEE, 11(3):231-52, 2001.
3. Z. Du, J. Mo, Y. Zhang. Environment International, 73:33-45, 2014.
4. Y. Fan. BUCEA,2021.
5. H. Fu, W. Liang, M. Qin. Building Science, 32(8):20-26, 2016.
6. M. Wilson, M. Schwarzman. EHP, 117(8):1202-1209, 2009.
7. Z. Ren, J. Yao. ESM,45(10):82-86,2020.
8. K. Huang, J. Wang, G. Feng. JoSJU,36(03):568-576,2020.
9. K. Huang, G. Feng, H. Li, et al. ENERGBUILDINGS, 84 :567-574, 2014.
10. M. Yao, B. Zhao. BUILD ENVIRON, 124, 2017.
11. Z. Shi, H. Qian, X. Zheng, et al. BUILD ENVIRON, 130:85-93, 2018.