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The influence of occupant activities and behaviour on indoor humidity of Chinese residential buildings

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Abstract: Both high and low humidity problems are widely happening in China. With the goal of investigating the influence of occupant activities and behaviour on indoor humidity of Chinese residential buildings, a questionnaire survey was designed and applied for the collection of household activities and behaviour linked to moisture and its related consequences. Based on a household moisture calculator developed by UKCMB, the indoor moisture production was calculated. Through statistical analysis and discussion, it can be concluded that a large amount of moisture is caused by occupancy, cooking, baths and showers, and washing and drying clothes indoor Chinese houses. Furthermore, mould and condensation are most common in bathrooms and kitchens. In consideration of the actual window opening behaviour and the heating and cooling system control in the participants' dwellings, inhabitants should increase natural ventilation when or after washing clothes, taking showers and cooking.

Keywords: occupant activities and behaviour, moisture production, indoor humidity, Chinese residential buildings.

1. Introduction

Since December 2005, an increasing number of residents living in the north of China, severe cold area, have reported dampness, dew condensation, mould, frosting and freezing around windows (Fan, 2012). Gao and Wei (2005) indicated that the climate in northern China is dry with people reporting dry mouth and cracked ski. In this area, indoor heating is mainly used in winter, which helps reduce internal humidity. In summer, the use of air conditioning (refrigeration with no air exchange), also creates a very dry indoor air and makes people feel uncomfortable. However, in the south of China or subtropical areas, due to high relative humidity, the humid indoor environment has become a public health problem (Liu, 2013). It also has been studied by Li et al. (1991) that the high humidity in the south of China supports the development of mould growth, which has been linked to 21% of total asthma patients. Furthermore, through analyzing the indoor humidity environment of residential houses in 9 representative cities of China, Zhang and Yoshino (2010) found that there are humidity problems widely existing in Chinese residential buildings.

In recent years, a considerable amount of literature has focused on the effects of humidity. EmpowHER (2017) determined 7 common health problems associated with high levels of humidity. They investigated the effect of expending a long time in conditions above 60% of relative humidity. The exposure mould spores may irritate eyes and nose or even cause lung diseases, and allergens like fungi and dust mites can fester and lead to allergies (Bornehag et al., 2001). On the other hand, Reinikainen and Jaakkola (2010) stated that dry air dehydrates the epidermis cells, reduces the secretion of sebaceous glands, and causes rough, wrinkled and even cracked skin. By monitoring the physical condition of office workers in 12 buildings for four weeks, Bornehag et al. (2001) indicated that low relative humidity has a strong correlation with symptoms of lower respiratory tract and sick building syndrome (SBS) such as headache, dizziness, fatigue, chest tightness and shortness of breath, sinus obstruction, respiratory disorders and cough.

Moreover, it has been reviewed by Zemitis et al. (2016) that the indoor relative humidity has huge influences not only on occupant health but also on construction materials in buildings. Moyer et al. (2001) stated that dampness could bend floors, deform wallboards, support the development of mould, the decay of wood materials and the corrosion of metal building components. Wood building materials are easy to expand, rot and warp in wet conditions. Moisture can cause the moisture expansion of the protective layer of the external wall insulation system, and the moisture expansion deformation may result in cracking (Foster, 2015).

Klepeis et al. (2001) pointed out that most people spend almost 90% of their time in the indoor environment. Therefore, indoor humidity in the Chinese residential buildings should be taken seriously, mitigated and improved. There are a number moisture sources inside buildings, which include human being, plants, cooking, washing dishes, taking showers and baths, washing and drying clothes and cleaning rooms (Christian et al., 2009). On the other hand, according to Rolloos (1993), both natural ventilation (such as opening windows) and mechanical ventilation (such as heating, ventilation and air conditioning system) can impact indoor humidity. Haldi (2015) demonstrated that ventilation related behaviour of occupants has a major impact on mould or condensation. Also, heating, ventilation and air conditioning system is used for maintaining a satisfactory thermal environment and indoor air quality (Rolloos, 1993). In this paper, the role that people's activities and behaviour play on indoor humidity in Chinese residential buildings was investigated in order to define measures to help improve the internal conditions and reduce indoor humidity in China.

2. Methods

Questionnaire design

A questionnaire was designed and applied in this research for the collection of quantitative information with respect to human activities in dwellings. Occupant behaviour regarding building devices control and the perceptions and perspectives of inhabitants on indoor humidity was also gathered. Concerning the sources of moisture generation questions were designed in relation to the number of habitants, daily sleeping hours and time at home, fuel used, length and number of times per day cooking, frequency of showers and baths, laundry activities, and cleaning habits (washing of dishes and floors). From the perspective of occupant behaviour, information was gathered concerning the habit and preferences on window opening (frequency, duration, opening periods, reasons and habits during winter and summer). Information on the types of heating system and the period of time using heating and/or cooling equipment was also gathered. In addition, the perceptions of residents concerning the indoor humidity, mould and condensation were also collected. Finally, the city in which people live was also asked in the survey to analyse if the climate may have an effect on occupant activities and behaviour. A total of 45 questions were designed and the questionnaire randomly assigned to Chinese households.

Method of analysis

The data in connection with occupant activities was put into a spreadsheet called the household moisture calculator which was designed by the UK Centre for Moisture in Buildings (UKCMB) in order to calculate the moisture production of each property surveyed. The minimum, maximum, average values and standard deviation of parameters linked with seven categories of household activities were calculated to obtain a primary overview and determine which kind of occupant activities causes the most moisture generation. Through this quantitative analysis, the calculated data was used to compare with the moisture production rate provided in published research in order to evaluate whether the amount of moisture produced in Chinese dwellings could be considered normal or reasonable. Pie charts and box plots were applied to show the distribution of these values. Then, classifying the results by combining the consideration of five disparate climate regions in China: cold-temperate, mid-temperature zone, subtropical zone, warm-temperature zone and tropical zone. The distribution of household moisture production within each climate zone was also compared and presented via box plots and pie charts. Using statistical analysis, the occupant window opening behaviour, the use of heaters and air conditioners and the perception of the indoor humidity environment of these participants was determined. The link between generated moisture and participants behaviour was also investigated.

3. Results

A total of 120 participants responded an online version of the questionnaire through a professional online platform for questionnaire survey, evaluation and voting called the questionnaire star (WJX). Also, the questionnaire was translated to Chinese. Thirty-four respondents live in the cold-temperate zone (severe cold zone) with an extremely cold and dry winter like cities in northern China. Thirty-three participants reside in the mid-temperature zone, also named the cold climate zone, such as the capital Beijing. The largest number up to 41 people live in subtropical cities, which has high outdoor humidity like Shanghai. Eight participants live in cities belonging to the warm-temperature zone (temperature zone), which have no severe cold in winter and no intense heat in summer, and then have a minimum variation in outside temperature and humidity. In addition, only four live in Chinese tropical cities in the hot summer and warm winter zone accompanied with the humid, hot and thunderstorm weather throughout the year; Shenzhen, Guangdong Province and Sanya, Hainan Province in the southern part of China.

Moisture production due to occupant activities

From the view of literature, the most integrated data summarising average moisture generation was found in the IEA Annex XIV (IEA, 1991). For one or two adults, the mean moisture production rate is about 8.2 L/day. The averages of daily residential moisture release are about 11.9 kg for an ordinary household with an additional child, 13.3 kg for adding two children and 14.4 kg for adding three children (Tenwolde and Iain, 2001). Therefore, 11.9 kg of daily moisture was considered as a comparable value for evaluating the level of indoor moisture production among the 120 samples. Sixty-four families have a daily moisture generation lower than the target value for one or two adults with a child. This is mainly because the criterion is based on a household occupied by two adults and one child. Seventy-seven participants indicated to live in families with three or more adults. After calculation, Figure 1 presents the distribution of moisture arisen from seven household activities.

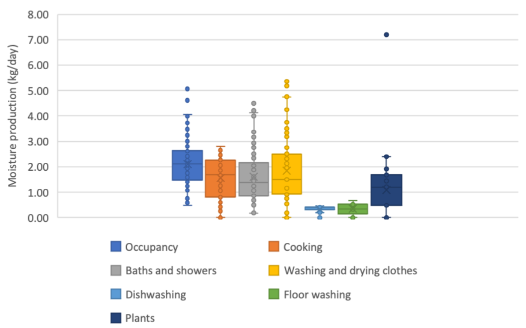

Figure 1: Box plot of moisture production due to seven activities

The calculated moisture production was assessed according to the five climate zones in China. The box plot of Figure 2 displays the distribution of household moisture production per zone and clearly show that in the tropical zone, the moisture generation due to family activities is overall higher than that of other regions.

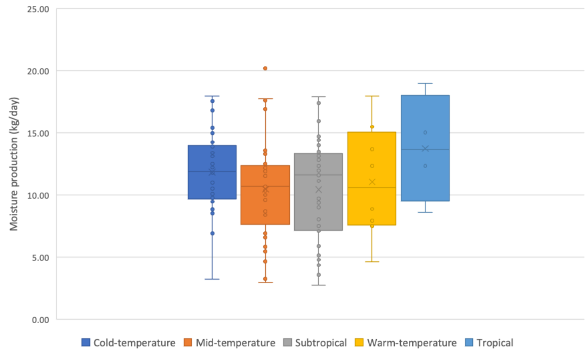

Figure 2: Box plot of moisture production in five climatic zones

For further study on occupant activities in different regions leading to the discrepancy of moisture production in more detail, the pie charts below show the ratio of moisture production due to occupant activities in the five climatic zones. Through comparison, occupancy and washing and drying clothes are two main sources of indoor moisture in the relatively cold areas. This may be explained as in these areas the outdoor environment is not suitable for drying clothes; residents prefer to dry clothes inside and increasing indoor moisture. However, in the other three regions, the moisture due to occupancy, baths and showers accounts for the largest proportion with all over 20%. It can also be inferred and concluded that with the change of the outdoor environment, the frequency of bathing would also vary. The higher the outside temperature and humidity in the district are, the more showers people take, and the more indoor moisture people produce.

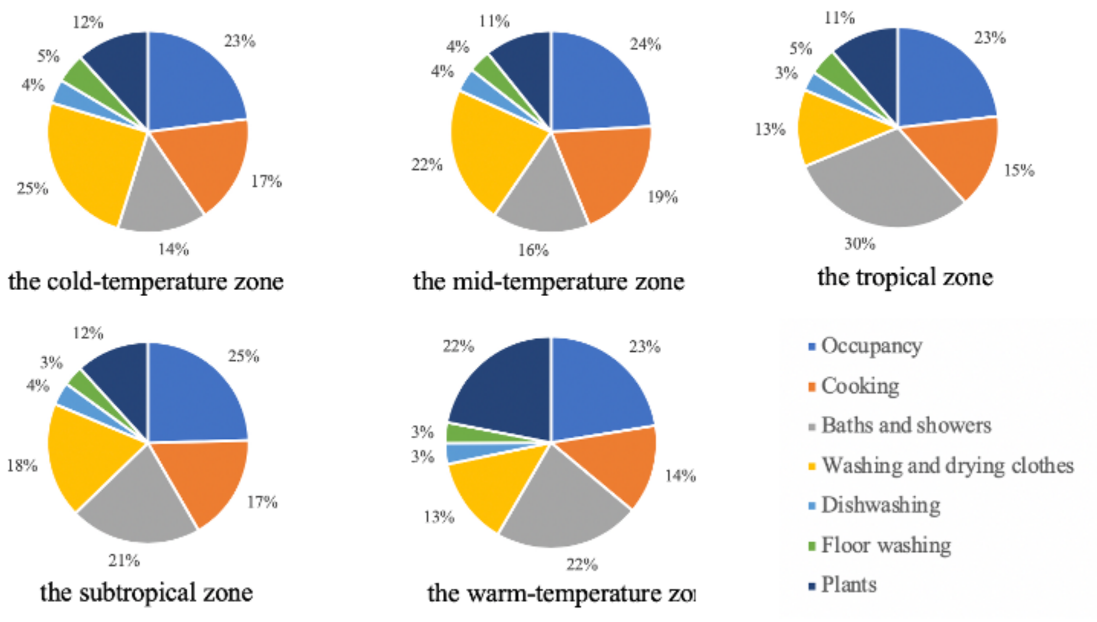

Figure 3: Percentage of household moisture production in five zones

Occupant behaviour

The frequency of opening windows during both cold and hot months is shown in Figure 4a. Windows are generally opened more frequently in summer. Besides, it can be seen from Figure 4b that the duration of windows opening in winter is significantly shorter than in summer. Similarly, the times when residents open windows can be seen in Figure 5. The main time being in the morning or after returning home (e.g. from work). The main reason for opening windows seems to be the removal of odours or to improve the quality of the indoor air, and closing windows in winter due to cold outside temperatures and bad weather such as strong wind and heavy rain (Figure 6).

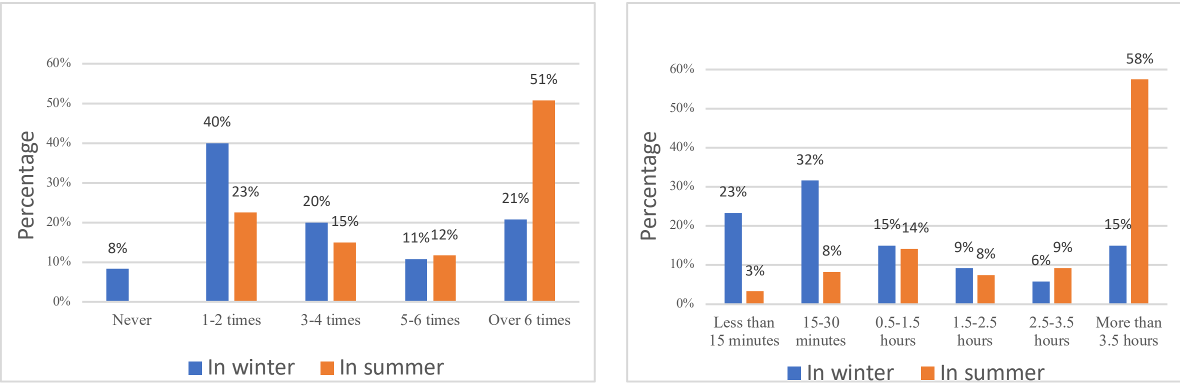

Figure 4: a) Percentage of frequency of opening windows and b) Percentage of duration of opening windows

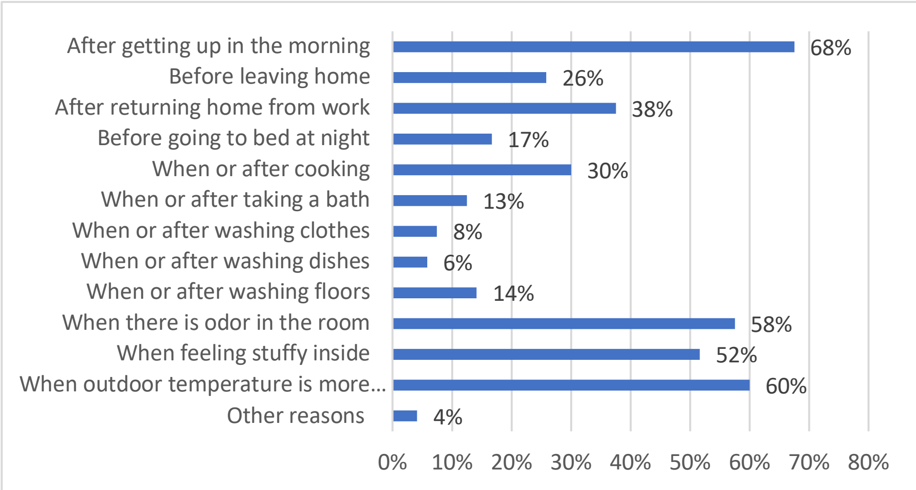

Figure 5: Percentage of period of opening windows

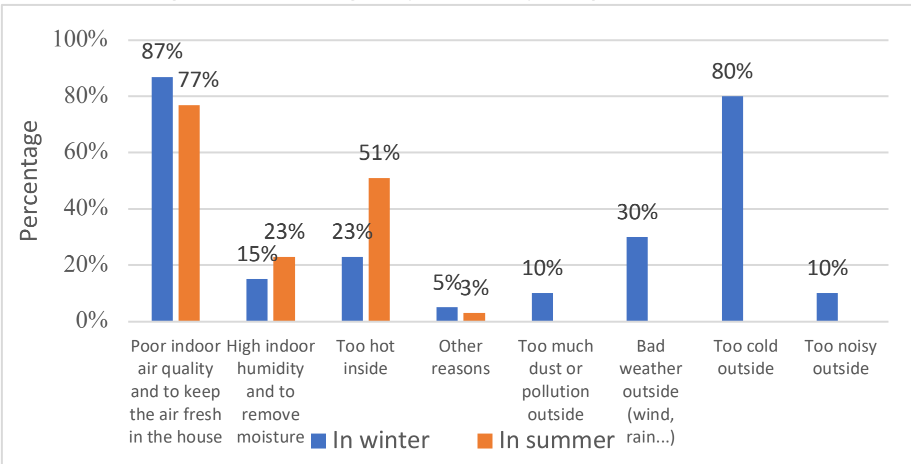

Figure 6: Percentage of reasons why residents open or close windows

Furthermore, people’s views on the humidity levels in their dwellings vary, however only 15 indicated that their homes are humid or very humid in both winter and summer. Most of them come from the subtropical area. This also supports the idea that indoor moisture production is closely linked with outdoor climatic.

4. Conclusion

This study investigated the influence of occupant activities and behaviour on indoor humidity of Chinese residential buildings via a questionnaire survey. The existing moisture problems and factors affecting indoor humidity were reviewed. The moisture production and relevant household activities and behaviour in dwellings were also studied for the design of the questionnaire. The survey was conducted among residents of different cities in China. It can be determined that occupancy, cooking, taking baths and showers, and washing and drying clothes are four main family activities producing moisture inside Chinese dwellings. Thereinto, washing and drying clothes is the dominant moisture source in the cold-temperature and mid-temperature zones. The habit of bathing frequently leads to high moisture in the south of China. Moreover, mould and condensation are most commonly found in bathrooms and kitchens. Therefore, examining the current behaviour of window opening and heating and cooling system control, some improvement measures can be proposed. Residents should increase natural ventilation through window openings during or after cooking, taking baths and washing clothes. Exhaust fan and air conditioner with dehumidification can also be applied for removing indoor moisture effectively. Besides, inhabitants can reduce moisture production by using vented dryer instead of drying clothes inside, using a washing machine instead of washing by hand. For achieving a healthy indoor humidity environment, the wall edges, window reveals, wooden furniture and the edge of the sink should be cleaned regularly as well. In future research, more samples from hot and humid areas of China can be studied through field measurement and monitoring.

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