Determining Moist-Based Ventilation Rates for Residential Buildings with Low-Infiltration in China: A Preliminary Discussion

Shengyi Tang, Wei Ye, Xing Su and Xu Zhang

Abstract There is a growing concern over whether ventilation rates (VRs) for building are health-based. For example, moisture-related problems, e.g., molds and mites, can pose adverse health effects on occupants. However, ventilation-induced moist indoors is an overlooked issue in China. In this paper, the effects of VRs, as well as typical building characteristics, on indoor humidity levels were investigated using EnergyPlus. 1008 residential models (with low infiltration, and various ventilation and climate scenarios) were simulated. Generally-agreed non-healthy humidity levels were used to analyze health risks. The results showed that, first, buildings in two hot summer zones were at risk of high indoor humidity, while buildings in two cold zones might experience higher risks of low humidity. Second, higher the VRs, higher the risk of low humidity in cold zones, and higher the risk of dampness in hot summer zones. Third, it can be easier to be more humid indoors for small-size, top-floor, or north orientation residences in China.

Keywords Indoor environment · Humidity · Infiltration · Climate zone · Ventilation requirement

1 Introduction

Ventilation is the most common method to dilute indoor air pollutants in buildings. In practice, what the adequate ventilation rate for a specific building space should be is often of interest to many and applicable to debates. During the last ~200 years, the recommended ventilation rates that are written in ventilation guidelines, standards are determined mostly based on bio-effluents (e.g., CO_2, etc.)

S. Tang · W. Ye · X. Su · X. Zhang
School of Mechanical Engineering, Tongji University, Shanghai 200092, China

W. Ye (✉) · X. Su
Key Laboratory of Performance Evolution and Control for Engineering Structures of Ministry of Education, Tongji University, Shanghai 200092, China
e-mail: weiye@tongji.edu.cn

Z. Wang et al. (eds.), *Proceedings of the 11th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC 2019)*, Environmental Science and Engineering, https://doi.org/10.1007/978-981-13-9520-8_11

that may cause discomfort or odour, rather than concrete health-based evidences. At present, health requirements have raised more attention. In Europe, 4 L/s has been proposed to be the minimum ventilation rate per person that prevents occupants from suffering unaccepted health consequences.

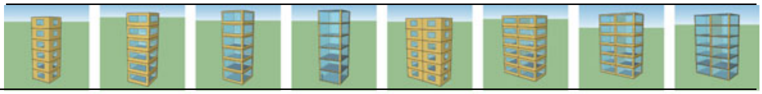
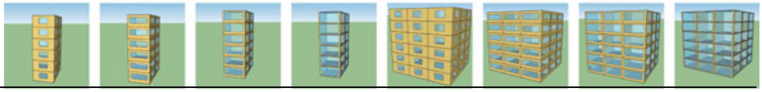
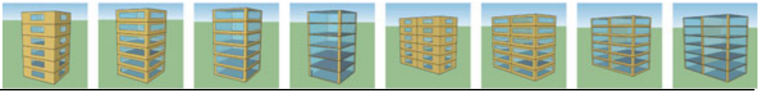
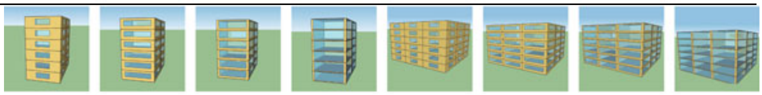
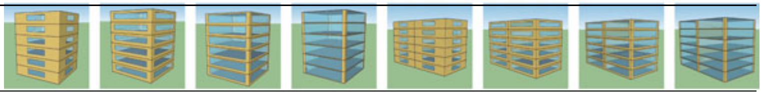
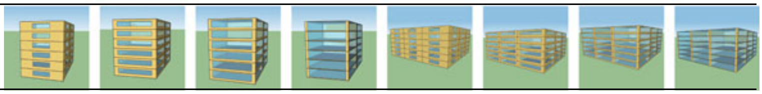
Moisture, or indoor humidity level, is often less prioritized when determining ventilation rates. However, issues caused by humidity are commonly found in residences, such as molds and mites [1], widely resulting in health effects on occupants, especially for infants and young children [2]. Although it is still not mandatory to regulate ventilation rates for residential buildings in China, it is necessary to discuss potential non-healthy humidity levels that can pose on occupants by setting constant ventilation rates without humidification or dehumidification.

In this paper, a preliminary discussion on determining ventilation rates based on one aspect of the health requirements, i.e., humidity environment and habitability of microbes, is presented. Residential settings are employed and the ranges of ventilation rates to reduce health-related issues caused by indoor humidity levels are determined for cities in different climate zones.

2 Methods

The overall approach is as follows. First, indoor relative humidity levels corresponding to various constant ventilation rates are simulated using EnergyPlus (version 8.8). A simplified structure of a three-person family was used for simulation, as shown in Table 1. Meteorological data from five typical Chinese cities, i.e. Harbin, Beijing, Shanghai, Guangzhou and Kunming, each from a different climate zone, were selected for demonstration. Then, non-healthy humidity levels are identified and analyzed. Two generally-agreed relative humidity levels, i.e., (1) 30%; and (2) 60% are adopted as the low and high thresholds, respectively, to, (1) reduce health symptoms, such as dry eye and irritation [3]; (2) reduce the proliferation of house dust mites, as well as the emergence and development of molds [4]. It should be noted that these moisture-related agents are also affected by indoor temperature, so relative humidity, instead of humidity ratio, is chosen as thresholds. The following variables, as shown in Table 1, that may cause indoor humidity change, were considered, including dimensions (i.e., 6 m × 6 m × 3 m, 10 m × 10 m × 3 m and 14 m × 14 m × 3 m, respectively), areas and orientations of exterior wall(s), levels(from first to sixth floor, respectively), window-wall ratios (i.e., 0.2, 0.4, 0.6 and 0.8, respectively) and floor areas (i.e., 12 m^2, 33 m^2 and 65 m^2, respectively), etc. Rest of the settings were summarized in Table 2. Finally, ranges of ventilation rates are discussed for reducing non-healthy humidity levels.

Table 1 Residential building models used in EnergyPlus simulations

House area	Building characteristics (floor, orientation, window-wall ratio)							
	Window-wall ratio				Window-wall ratio			
6 m × 6 m (12 m²/p)	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8
								
	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8
								
10 m × 10 m (33 m²/p)	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8
								
	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8
								
14 m × 14 m (65 m²/p)	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8
								
	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8
								

A simplified moist-balance-based equation to predict indoor humidity was embedded in EnergyPlus as shown in Eq. (1). This equation, seemed as moisture predictor approach, together with zone heat balance equation, has formulated energy and moisture balances for the zone air.

$$\rho_{\text{air}} V_z \frac{\mathrm{d}W_z}{\mathrm{d}_t} = kg_{\text{mass}} + m_{\text{vent}}\left(\dot{W}_\infty - W_z^t\right) \tag{1}$$

where ρ_{air} is zone air density, V_z is volume of zone, W_z is zone humidity ratio, kg_{mass} is sum of the internal moisture gains, $m_{\text{vent}}\left(\dot{W}_\infty - W_z^t\right)$ is moisture transfer due to ventilation of outside air.

Moisture buffering of interior walls in buildings was modelled with the effective moisture penetration depth model to ensure the accuracy with relatively less solution time [16]. However, moisture buffering in furniture and furnishing was neglected for its complexity and further work was required.

Table 2 Simulation settings for residential buildings in five different climate zones

Parameters	Setting values		References
Timestep	10 min		–
Run period	1 year		–
Envelope	Harbin	Roof: 0.198 W/(m^2 K) Exterior wall: 0.148 W/(m^2 K) Floor: 0.297 W/(m^2 K) Window: 0.932 W/(m^2 K)	[5, 6]
	Beijing	Roof: 0.224 W/(m^2 K) Exterior wall: 0.200 W/(m^2 K) Floor: 0.376 W/(m^2 K) Window: 1.200 W/(m^2 K)	[5, 6]
	Shanghai	Roof: 0.336 W/(m^2 K) Exterior wall: 0.390 W/(m^2 K) Floor: 0.389 W/(m^2 K) Window: 1.986 W/(m^2 K)	[5, 7]
	Guangzhou	Roof: 0.393 W/(m^2 K) Exterior wall: 0.706 W/(m^2 K) Floor: 0.385 W/(m^2 K) Window: 2.484 W/(m^2 K)	[5, 8]
	Kunming	Roof: 0.393 W/(m^2 K) Exterior wall: 0.598 W/(m^2 K) Floor: 0.385 W/(m^2 K) Window: 1.994 W/(m^2 K)	[5, 9]
Internal heat gains	People (sensible): 70 W/p		[10–12]
	Lights: 6 W/m^2		
	Equipment: 10 W/m^2		
Moisture	Generation rate: 1.0×10^{-4} kg/s		[13]
Thermostat	Heating setpoint: 18 °C (16 °C for Guangzhou) Cooling setpoint: 26 °C		[6–9]
Ventilation	Ventilation rate: 2, 4, 6, …, 18, 20 L/(s p)		–
Schedule	People: 19:00–7:30, Ventilation: 19:00–7:30 Lights, equipment: 6:30–7:30 and 19:00–23:00		[14, 15]

3 Results and Discussion

3.1 Annual Risk Estimation for Different Cities

Figure 1 shows some of the results of annual risk estimation of the assumed non-healthy humidity in five different cities, with both high-humidity threshold on the upper half and low-humidity threshold on the lower half of the figures for each city. The boxplots consider all data from varied set of models.

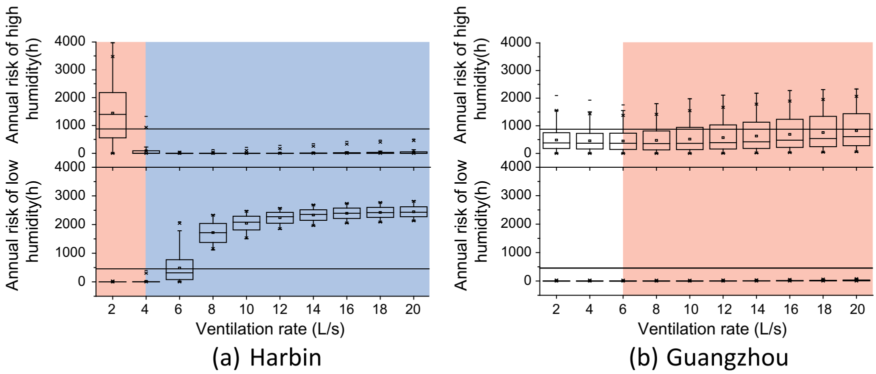


Fig. 1 Annual risk estimation of non-healthy humidity in cities from different climate zones

3.2 Validation

Simulation results demonstrate that outdoor climate can play a key role in determining indoor humidity levels. Therefore, it is necessary to estimate indoor environment using different meteorological data, as we did in previous sections. The overall results are in agreement with those obtained in other field researches on residential buildings [1, 17] that reported the indoor humidity levels were too low over the winter in some northern cities and could be really high in some southern cities like Shanghai.

3.3 Effects of Ventilation Rate on Indoor Humidity

The change in ventilation rate leads to either an increase or a decrease of indoor humidity, depending on the outdoor humidity level. According to results, increased ventilation (>2 L/s) can easily remove indoor generated moisture in cold and dry cities like Harbin and Beijing, but in the meanwhile can keep the indoor humidity down even to an unhealthy level, while the more humid outdoor conditions in Guangzhou and Shanghai result in different conclusion. Although increased ventilation rate slightly reduces the humidity in winter in these two cities as well, the annual high-humidity risk boxplots show the trend of decrease to increase, making a best rate of ventilation for indoor moisture control. This is because the low humidity indoor is basically caused by dry ventilation air, whereas the high humidity indoor results from the interaction between both indoor moisture sources and ventilation rates.

Despite the increasing attention to the health-based ventilation [4], the ventilation rate requirements in current ventilation standards [15, 18, 19] are based largely on researches into the perception of unpleasant odours. Thus, ventilation rate of

8–10 L/(s p) from most guidelines may fail to meet the humidity requirements. The results from this study indicate that when the minimum ventilation rate is ensured, humidification is needed in cities from severe cold and cold zones, while in hot summer and warm winter zone like Guangzhou, dehumidification measures are generally needed. Further, it is worth to mention that ventilation is a good option to expel moisture for hot summer and cold winter climate zone. For the healthy indoor humidity alone, ventilation rate of 4 L/s in Harbin and Beijing, of 8 L/s or higher in Shanghai, of 6 L/s or lower in Guangzhou and of 12 L/s or lower in Kunming were recommended.

3.4 Effects of Building Characteristics on Indoor Humidity

House characteristics were also associated with relative humidity levels, mainly because these parameters affect indoor temperature. For example, the orientation of house could impact the indoor high-humidity or low-humidity risk as shown in Fig. 2. It was clear that north-east or north-west oriented buildings were more likely to under the risk of high humidity, with annual moisture risk up to around 1800 h in Shanghai within a year for ventilation rate of 8 L/(s p). While facing south-east or south-west could cause low humidity conditions in some cities, with annual low-humidity risk up to around 2300 h in Harbin of total 4563 h indoor time a year. Figure 3 provides another example. The top floor which was the sixth floor in this study, reaching the highest high-humidity risk in Shanghai at the ventilation rate of 8 L/(s p), much larger than the risk in 1st to 5th floors, mainly because of more exterior envelopes. Nevertheless, the top floor tended to slightly reduce risk of low humidity in Harbin (down by ~20%) and Beijing (down by ~36%), comparing to other floors.

Figure 4 shows the effect of building characteristics on indoor humidity for reasons other than temperature, house sizing small, medium or large could have a significant impact on humidity levels, primarily due to the mediation of change in air change rate and indoor moisture generation. In general, small-sized house, with

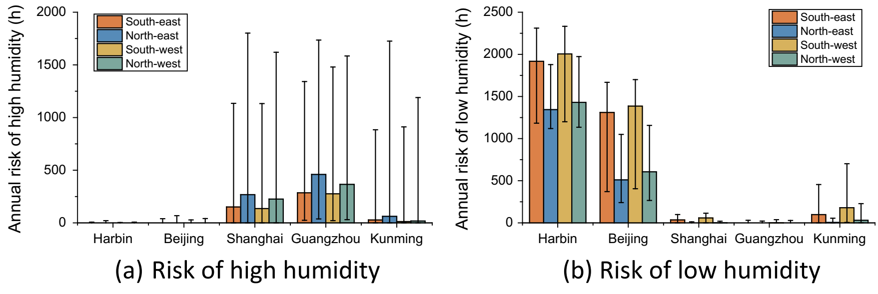


Fig. 2 Annual moisture risk for different house orientations at ventilation rate of 8 L/s

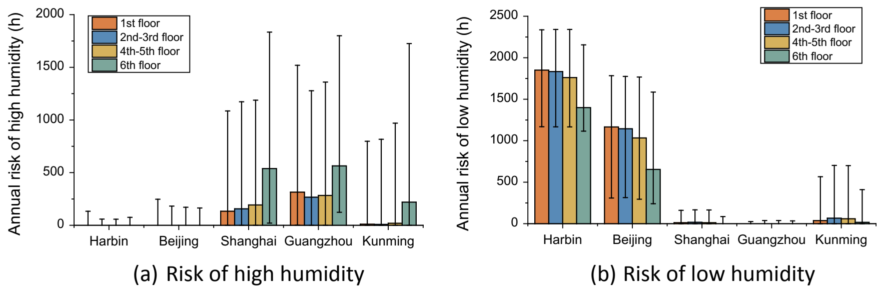


Fig. 3 Annual moisture risk for different floor located at ventilation rate of 8 L/s

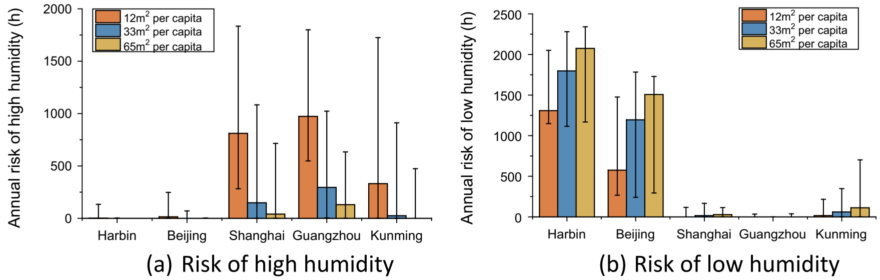


Fig. 4 Annual moisture risk for different house size at ventilation rate of 8 L/s

small area per capita was more likely to suffer dampness. In shanghai, house of 12 m^2 per capita hit the highest high-humidity risk hours up to 1800 h a year for ventilation rate of 8 L/(s p), which was more than 2.5 times than house with 65 m^2 per capita. However, when considering the low-humidity risk, small-sized house appeared to take less risk than medium- or large-sized house. And medium-sized house generally had less risk of low humidity than large-sized house.

3.5 Limitation

The limitation of this study is that the residential buildings here are high-performance buildings with high air tightness and hence infiltration can be neglected. Thus, the ventilation rate presented in this paper should be viewed as actual ventilation rate for normal buildings. Further research is required to understand the relationship between design ventilation rate and indoor humidity level in different real buildings. Last but not least, more detailed house types, e.g., models with bathrooms and kitchens, and more accepted occupant-related moisture generation schedule are required for indoor humidity level predicting, especially for local moisture risk, e.g. mold risk predicting.

4 Conclusions

Indoor humidity levels caused by constant ventilation rates for residential buildings with low infiltrations are studied using EnergyPlus to analyze potential health-based ventilation rates in China. Assumed non-healthy humidity levels (<30% or >60%) were adopted to determine the annual total hours that indoor humidity falls outside this range in five cities in different climate zones. The results show that, first, healthy risk of non-healthy humidity was sensitive to ventilation rate, raising ventilation could lower the high-humidity risk and increase the low-humidity risk in two cold zones, however, it might cause dampness in wet regions like two hot summer zones. Second, buildings in two cold zones could be at risk of low indoor humidity, while buildings in two hot summer zones could be at risk of high indoor humidity under the current ventilation standards. Finally, other building factors, such as north orientation, top located floor and small-sized house could increase indoor high-humidity risk.

Acknowledgements This research has been supported by the China National Key R&D Program during the 13th Five-year Plan Period (Grant No. 2017YFC0702600).

References

1. Xueying, W., et al.: Associations of dwelling characteristics, home dampness, and lifestyle behaviors with indoor airborne culturable fungi: on-site inspection in 454 Shanghai residences. Build. Environ. **102**, 159–166 (2016)
2. Dan, N., et al.: Common cold among pre-school children in China—associations with ambient PM10 and dampness, mould, cats, dogs, rats and cockroaches in the home environment. Environ. Int. **103**, 13–22 (2017)
3. Peder, W., Søren K.: The dichotomy of relative humidity on indoor air quality. Environ. Int. **33**(6), 850–857 (2007)
4. Paolo, C., et al.: On the development of health-based ventilation guidelines: principles and framework. Int. J. Environ. Res. Public Health **15**(7), 1360 (2018)
5. MOHURD: Technical Standard for Nearly Zero Energy Building (Draft). China Architecture & Building Press, Beijing, China (2016)
6. MOHURD: JGJ 26-2010 Design Standard for Energy Efficiency of Residential Buildings in Severe Cold and Cold Zones. China Architecture & Building Press, Beijing, China (2010)
7. MOHURD: JGJ 134-2010 Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zones. China Architecture & Building Press, Beijing, China (2010)
8. MOHURD: JGJ 75-2012 Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Warm Winter Zones. China Architecture & Building Press, Beijing, China (2012)
9. MOHURD: Standard for Energy Efficiency of Residential Buildings Design in Moderate Climate Zone (Draft). China Architecture & Building Press, Beijing, China (2017)
10. Yaoqing, L.: Practical Design Manual of Heating and Air Conditioning. China Architecture & Building Press, Beijing, China (2008). (in Chinese)
11. Yu, J., Yang, C., Tian, L.: Low-energy envelope design of residential building in hot summer and cold winter zone in China. Energy Build. **40**(8), 1536–1546 (2008)

12. Yan, L., Xiaofeng, L.: Natural ventilation potential of high-rise residential buildings in northern China using coupling thermal and airflow simulations. Build. Simul. **8**(1), 51–64 (2014)
13. ASHRAE: Standard 160-2016 Criteria for Moisture-Control Design Analysis in Buildings. American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc., Atlanta, GA (2016)
14. Chuang, W.: Simulation Research on Occupant Energy-related Behaviors in Building. Tsinghua University (2014) (in Chinese)
15. MOHURD: GB 50736-2012 Code for Design of Heating Ventilation and Air Conditioning. China Architecture & Building Press, Beijing, China (2012)
16. Jason, W., Jon, W., Dane, C.: Moisture Penetration Depth Model for Estimating Moisture Buffering in Buildings—Report NREL/TP-5500-57441, USA (2013)
17. Huibo, Z., Hiroshi, Y.: Analysis of indoor humidity environment in Chinese residential buildings. Build. Environ. **45**(10), 2132–2140 (2010)
18. ASHRAE: ANSI/ASHRAE Standard 62.1-2016 Ventilation for Acceptable Indoor Air Quality. ASHRAE, Atlanta, GA, USA (2016)
19. CEN/TC: prEN:16798-1: Indoor Environmental Input Parameters for the Design and Assessment of Energy Performance of Buildings. European Committee for Standardization (2015)