Simulations on non-healthy indoor humidity by ventilation rates in nearly zero energy residential buildings in China

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Abstract. Indoor humidity can be easily overlooked when discussing building ventilation. However, evidences have shown that moisture-related consequences on health are increasingly common both in China and worldwide. In addition, there is an ongoing debate on what the adequate ventilation rates (VRs) should be for nearly zero energy buildings (NZEBs). Therefore, the effects of VRs for NZEBs in China, on moist environment, are investigated using EnergyPlus in this paper. More than 1100 residential settings have been analysed with different VRs in five major cities, representing all climate zones, in China. Three generally-agreed humidity levels have been adopted as the thresholds to reduce habitability of microbes. The results indicate that, first, humidity risk decrease with higher VRs in all zones except for some southern regions, and most cities would be free of moisture issues under current VR requirements (~8 L/s). Second, indoor spaces feature, 1) small per capita area; 2) the ground or top floor; 3) small window-wall ratio and 4) north-orientation, are more prone to risk of high humidity.

1. Introduction
Ventilation is the most common method to dilute indoor air pollutants in buildings. In practice, what the adequate ventilation rate (VR) 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 (VRs) written in ventilation guidelines, standards are determined mostly based on bio-effluents (e.g., CO₂, etc.) 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 VR per person that prevent occupants from suffering unacceptable health consequences.

Moisture, or indoor humidity level, is often less prioritized when determining VRs. However, issues caused by humidity are commonly found in residences, such as moulds 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 VRs for residential buildings in China, it is necessary to discuss potential non-healthy humidity levels that can pose on occupants by setting constant VRs without dehumidification.

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

2. Methods
The overall approach are as follows. First, indoor humidity levels corresponding to various VRs are simulated using EnergyPlus (version 8.8). A simplified structure of a three-person family was set. Building characteristics that may cause humidity change were considered, including dimensions (i.e.,
6m×6m×3m, 10m×10m×3m and 14m×14m×3m), areas and orientations of exterior wall(s), levels (from 1st to 6th floor) and window-wall ratios (i.e., 0.2, 0.4, 0.6 and 0.8), as shown in Table 1. Meteorological data from five typical cities, i.e., Harbin, Beijing, Shanghai, Guangzhou and Kunming, each from a different climate zone, were selected for demonstration. Other simulation settings were summarized in Table 2. Then, three generally-agreed non-healthy humidity levels, i.e., 50%, 60% and 80%, are adopted as thresholds, respectively, to, 1) prevent or reduce house mite infestation; 2) prevent mould growth (3). Finally, ranges of ventilation rates are determined and discussed to reduce non-healthy humidity levels.

### Table 1. Residential building models used in EnergyPlus simulations.

| Room area | Building characteristics (floor, orientation, window-wall ratio) |
|-----------|---------------------------------------------------------------|
|           | Window-wall ratio                                             |
|           | 0.2  0.4  0.6  0.8  0.2  0.4  0.6  0.8                     |
| 6m×6m     | 0.2  0.4  0.6  0.8                                          |
| 10m×10m   | 0.2  0.4  0.6  0.8                                          |
| 14m×14m   | 0.2  0.4  0.6  0.8                                          |

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

| Parameters           | Setting values                      | References |
|----------------------|-------------------------------------|------------|
| Timestep             | 10 min                              | -          |
| Run period           | 1 year                              | -          |
| Envelope [W/(m²·K)]  | Harbin: Roof: 0.198, Floor: 0.297  | (4, 5)     |
|                      | Exterior wall: 0.148, Window: 0.932 |            |
|                      | Beijing: Roof: 0.224, Floor: 0.376 | (4, 5)     |
|                      | Exterior wall: 0.200, Window: 1.200 |            |
|                      | Shanghai: Roof: 0.336, Floor: 0.389| (4, 6)     |
|                      | Exterior wall: 0.390, Window: 1.986 |            |
|                      | Guangzhou: Roof: 0.393, Floor: 0.385| (4, 7)     |
|                      | Exterior wall: 0.706, Window: 2.484 |            |
|                      | Kunming: Roof: 0.393, Floor: 0.385 | (4, 8)     |
|                      | Exterior wall: 0.598, Window: 1.994 |            |
| Internal heat gains  | People (sensible): 70 W/p           | (9-11)     |
|                      | Lights: 6 W/m²                       |            |
|                      | Equipment: 10 W/m²                   |            |
Moisture Generation rate: 1.0×10^{-4} \text{ kg/s} \tag{12}

Thermostat

- Heating setpoint: 18^\circ\text{C} (16^\circ\text{C} for Guangzhou)
- Cooling setpoint: 26^\circ\text{C} \tag{5-8}

Ventilation

- Ventilation rate: 2, 4, 6, …., 18, 20 \text{ L/(s \cdot p)} \tag{-}

Schedule

- People: 19:00-7:30, Ventilation: 19:00-7:30
- Lights, equipment: 6:30-7:30 & 19:00-23:00 \tag{13, 14}

A simplified moist-balance-based equation to predict indoor humidity was embedded in EnergyPlus as shown in Eq. (1):

$$\rho_{air} V_z \frac{dW_z}{dt} = k_{mass} (W_\infty - W_z^f)$$  \tag{1}

where $\rho_{air}$ is zone air density, $V_z$ is volume of zone, $W_z$ is zone humidity ratio, $k_{mass}$ is sum of the internal moisture gains, $m_{vent} (W_\infty - W_z^f)$ is moisture transfer due to ventilation of outside air.

Moisture buffering in buildings was modelled with the effective moisture penetration depth model to ensure the accuracy with relatively less solution time (15).

3. Results and discussions

3.1. Annual risk estimation for different cities

Figure 1 shows the results of annual risk estimation based on assumed non-healthy humidity in five cities. The boxplots consider all data from varied set of models.
Simulation results show considerable spatial variability. The overall results agree with those obtained in other field researches on residential buildings (1, 16) that reported indoor humidity levels were low in some northern cities and could be really high in some southern cities.

3.3. Effects of ventilation rate on indoor humidity

The change in VR leads to either an increase or a decrease of indoor humidity, depending on the outdoor humidity level. According to Figure 1, increased ventilation (> 4 L/s) can easily remove indoor generated moisture in cold cities like Harbin and Beijing, while the more humid outdoor condition in Guangzhou results in different conclusion. Although increased VR reduces the humidity in Guangzhou winter, it increases moisture risk for the year.

Despite the increasing attention to the health-based ventilation (3), the VR requirements in current ventilation standards (14, 17, 18) are based largely on researches into the perception of unpleasant odours. Thus, VR of 8 to 10 L/(s·p) from most guidelines may fail to meet the humidity requirements. The results indicate that when the minimum VR is ensured, cities from cold zones and mild zone are free of humidity risk, while dehumidification is needed in cities from hot summer and warm winter zone. For the healthy indoor humidity alone, VR of 4 L/s in Harbin and Beijing, of 10 L/s in Shanghai and of 6 L/s in Kunming were recommended.

3.4. Effects of building characteristics on indoor humidity

House characteristics were also associated with humidity levels, mainly because these parameters affect indoor temperature. For example, the orientation of house could impact the indoor high-humidity risk as shown in Figure 2(a). It was clear that north oriented buildings were more likely to under the risk of high humidity, with median annual moisture risk up to around 3800 hours in Guangzhou within a year. Figure 2(b) provides another example. The ground or top floor reaches the higher humidity risk comparing to other floors, mainly because of more exterior envelopes. Figure 2(c) illustrates that window-wall ratio larger than 0.2 is suggested for better indoor moisture environment.
Figure 2. Annual moisture risk for different house characteristics

Figure 2(d) 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. In general, small sized house was more likely to suffer dampness. In Guangzhou, houses of 12 m² per capita hit the median humidity risk hours up to 4300 hours a year, which was nearly 4 times the house with 65 m² per capita.

4. Conclusions and limitations

4.1. Conclusions
Indoor humidity levels caused by VRs for residential NZEBs in five major climate zones of China were studied using EnergyPlus. Assumed non-healthy humidity levels (50%, 60% and 80%) were adopted. The results show that, first, risk of non-healthy humidity was sensitive to VR, raising ventilation could lower the high-humidity risk in two cold zones and mild zone, however, it might cause dampness in wet regions like hot summer zone. Second, under the current ventilation standards (~8 L/s), buildings in two cold zones and mild zone are free of moisture risk, while buildings in hot summer zones need dehumidification. Finally, north orientation, ground or top floor, small window-wall ratio (0.2) and small sized house (12 m² per capita) could increase indoor high-humidity risk.

4.2. Limitations
The limitation of this study is that VRs in this study are total outdoor air flowrate. So, the recommend VRs also include window ventilation rate (if any).

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