Temperature and humidity characteristics of residential buildings in northern China

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Abstract. Buildings are one of the typical underlying surfaces of cities, but the study of hydrological effects of buildings is a weak link in urban hydrological research. Indoor temperature and humidity are important embodiments of the hydrological effect of building water activity. Beijing, as the capital of China, is selected as the representative research area in north China. The variation characteristics of temperature and humidity of residential buildings, as well as their relationship with each other, are analyzed through experimental monitoring. The results show that human water use activities in buildings will increase indoor humidity. The indoor humidity is higher than the outdoor humidity in sunny days of spring, summer, and winter, while it is lower than the outdoor humidity through rainy days and the whole autumn. Both indoor and outdoor humidity reach peak and nearly the same at night, but the difference between the indoor and outdoor humidity is obvious during the daytime. Based on the results we can draw the conclusion that (1) indoor water use activities can produce obvious water vapor diffusion; (2) in northern China, the indoor humidity of the residential buildings is higher than the outdoor humidity, and will flow to outdoors during most sunny days; (3) among all the types of the rooms in the residential building, bathroom is the largest contributor to water vapor dissipation. We suggest that water vapor dissipation in buildings should be taken into account in the study of evaporation in urban areas since it may profoundly affect the urban hydrological cycle.

1. Introduction
Since 2007, the proportion of the urban population in the world has exceeded the rural areas, and the cities have become the main residential areas in the world[1]. As a necessary place for the urban population to live in, urban residential buildings are one of the typical underlying surfaces of the city. Most of the domestic water use activities of urban residents occur in the interior of buildings[2], among which residential buildings are the most important type of buildings[3]. Therefore, from the point of water quantity, the internal water use of buildings or the internal water use of residential buildings is an important part of the urban hydrological cycle[4].

As the most important buildings, urban residential buildings are not only the main places of activity for urban residents[5] but also the main place for residents to use domestic water[6]. The types of water used in residential buildings cover all the types of the daily life of residents[7], so it is of great significance to choose residential buildings to carry out research[8]. The distribution characteristics of indoor temperature and humidity have an important influence on the arrangement of household electrical appliances and electrical connections[9]. More importantly, indoor humidity is closely related to human health. The monitoring data showed that the temperature variation inside residential
buildings in summer is about 4.3 ℃ in southern China[10]. The humidity of on the upper floors, was relatively higher compared to that of the lower floors because of the airflow from the outdoor to the lower floors. It means that the indoor humidity of the low-rise residential building will be replenished to the outside[11]. Water vapor is not only allowed to flow from the room to the outside through a door, a window, or other ventilation[12], or even migrate through walls[13]. In humid areas, the humidity is usually high, more than 80%, which need to be adjusted by ventilation[14].

There are some related studies on the temperature and humidity in the building, few systematic studies the characteristics of the temperature and humidity in the residential building, especially based on the long series of monitoring, compared with the outdoor temperature and humidity. Here, we take the temperature and humidity characteristics of residential buildings in north China as the research object. The relationship between indoor and outdoor temperature and humidity, are compared, as well as the variation law with different time scales through analyzing a long series of monitor data. This study aims to provide reference and basis for the study of water cycle process in urban buildings and the study of urban water vapor change process.

2. Methods and materials
Experimental monitoring is the main research method. A residential building in Chaoyang District of Beijing was selected as the main monitoring object, and the monitoring time lasted from July 2018 to July 2019. The main monitoring elements were air temperature and relative humidity, and the data of meteorological elements such as rainfall were also monitored.

2.1. Experimental monitoring instruments and methods
The instruments used for experimental monitoring are temperature and humidity loggers, which are high-precision instruments for monitoring the temperature and relative humidity of the recording air. The product model selected is WSZY-1, which was produced by Tianjianhuayi Company. The temperature that the instrument can monitor ranges from -40 ℃ to 100 ℃, and the relative humidity ranges from 0 % to 100%. The monitoring resolution of the temperature is ±0.5 ℃. The monitoring resolution of humidity in cabinet is 0.1%, and the error range is ±3%. The time step of experimental monitoring can be set from 1 second to 1 day. The instrument can store up to 15000 sets of data. The WSZY-1 has a rechargeable built-in battery, charging and data transmission via the USB interface. Its size is very small so that it can be easily installed anywhere.

The procedure of experimental monitoring is to select the monitoring target first, and then to determine the specific monitoring position according to the actual situation of the target, which is usually located in the geometric center of the monitoring space, which can better reflect the temperature and humidity of the target space. The parameters of the instrument, including the start time of monitoring and the time step of recording, are set according to the target elements and research requirements of monitoring.

2.2. Data Acquisition Processing
After the monitoring is completed, the instrument is then connected to the computer through the data line and USB interface. The monitoring data is read through the corresponding software, and the data can be exported and saved as the formats of .CSV or .XLS. To ensure the reliability of the monitoring data, each WSZY-1 was detected by advanced instrument before leaving the factory. The temperature was checked by thermostat (XMT-152) with ±0.2 ℃. The relative humidity value was tested by humidity sounder with range of ±2%.

2.3. Experimental monitoring schemes
Three experimental monitoring groups were set up, with the purpose of (1) comparing the difference of temperature and humidity inside and outside the residential building under the condition of living or empty; (2) studying the variation characteristics of temperature and humidity inside and outside
residential buildings in different seasons; (3) monitoring the temperature and humidity of different rooms in residential buildings in 24 hours under rainfall and sunny weather condition.

2.3.1. Living or empty. In this monitoring scheme, we selected a household of a residential building in Chaoyang District of Beijing as the research object and arranged four monitoring sites in the households. Figure 1 shows the room pattern of the household and the layout of the observation point, in which the pentagram represents the monitoring point. The monitoring time range is July-August 2018, and the monitoring time step is 30 minutes. The building is used during most of the monitoring time except the duration from 6:00 a.m. on July 20 to 5:00 p.m. on July 28.

![Figure 1. Layouts of rooms and monitoring points](image)

2.3.2. Different seasons. The purpose of this monitoring is to explore the temperature and humidity differences between indoor and outdoor in a long series of cases. The monitoring time is from July 2018 to July 2019, and the monitoring time step is 30 minutes. Because the experimental site is in Beijing, which is located in northern China with four distinct seasons, we select the most typical month of each season as the representative of the season to analyze the results. The typical months of the four seasons are April (spring), July (summer), October (autumn) and January (winter).

2.3.3. Diurnal variation process. The monitoring diurnal changes include the temperature and humidity changes in different rooms (bathroom, kitchen, bedroom, living room) in residential apartments and outdoor (hardened ground surface). The monitoring time step is 10 minutes. Monitoring is divided into two situations, one is sunny weather, and the other is rainy weather. So rainfall data for open-air environment need to be monitored at the same time.

3. Results and discussions

Because of the large amount of data, the data for seven consecutive days in a typical month are selected to display the results to better reflect the monitoring results. Of these seven-day choices, rainy weather is required for seven days in summer and autumn. For inhabited and uninhabited situations, we set up four monitoring points, namely, bedroom and living room, kitchen, bathroom, and outdoor, the results are shown in figure 2.

In the case of uninhabited, the temperature and humidity of different rooms are very similar, and their change processes are very similar too. Although the doors and windows are closed, due to the limited sealing conditions, indoor temperature and humidity changes are affected by outdoor temperature and humidity in the absence of human habitation. Because of the rooms’ layout features, the temperature and humidity of the bathroom change more smoothly, and the changes in the living room and bedroom are more obvious and have certain fluctuation.

In the case of living, the temperature and humidity characteristics of bedroom and living room, kitchen, bathroom are very different. To ensure indoor comfort, air conditioning is often operated in the living room and bedroom during noon or evening, and the air conditioning set temperature is 27 °C or 28 °C, as the weather temperature is high during the experimental monitoring period. Under the influence of air conditioning, the indoor temperature will reduce from 30 °C to 27 °C or 28 °C, and the
corresponding relative humidity will reduce from about 75% to about 55%. Unlike the temperature drop caused by air conditioning in the bedroom and living room, the kitchen temperature will rise rapidly during cooking, and the relative humidity will also rise due to the steam produced. The temperature will rise from 30 °C to about 40 °C, and the relative humidity will rise from about 55% to 80% or even higher. Compared with the normal temperature of other rooms, the temperature of bathroom is 1~2 °C lower than that of other rooms. The humidity of the bathroom shows a more regular peak and valley value changes in the case of habitation. Households usually take a shower and wash at 21:00 ~ 23:00, and the relative humidity increases more than 90% during this period.

We also monitored the temperature and humidity process outside the balcony during the period. The results show that in the case of people living, the indoor temperature and humidity are more affected and interfered by the activities in the room, and the interference from the outside is weaker. During the uninhabited period, the indoor temperature changes slowly and lagged with the outdoor temperature. Compared with indoor temperature and humidity, outdoor temperature and humidity change more obviously. In the absence of rainfall, at noon, the outdoor relative humidity reaches the valley value, while the temperature reaches the peak. At midnight, the relative humidity reaches the peak but the temperature reaches the valley.

Figure 2. Temperature and relative humidity characteristics of indoor and outdoor in the period of occupied and unoccupied

To compare the indoor and outdoor characteristics of the temperature and humidity, a long series of monitoring has been carried out for one year. The indoor monitoring point is the living room, and the outdoor monitoring point is the surface of permeable hardened ground. The permeable hardened ground here is permeable concrete, and the choice is to verify the hydrological effect of permeable hardened ground. The monitoring results show that in the sunny days, the indoor humidity will be significantly higher than the outdoor humidity at noon during the day, and the outdoor humidity will be higher than the indoor humidity when there is rainfall. In spring, summer and winter, the relative humidity of indoor and outdoor at midnight are nearly the same. But in autumn, the relative humidity
outside at night is significantly higher than the indoor humidity. In the spring, summer, autumn, and winter, the indoor temperature varies very little, while the outdoor temperature varies greatly, except some days in the spring. In summer and autumn, when rainfall occurs, outdoor temperatures will fall, relative humidity will rise, and indoor humidity will also be affected and increased.

The daily variation can reflect the change of temperature and humidity at different times of the day, which can be related to the water activity of the occupants. At the same time, the effect of rainfall is taken into account, and the monitoring and result display carried out in both sunny and rainy days. In sunny weather, indoor and outdoor relative humidity peaks at night and falls into the valley at noon. Between 8:00 and 20:00, the relative humidity of indoor is higher than that of outdoor. When the window is open, it can be considered that the indoor water vapor flows to outdoors and supplies the outdoor water vapor during this period. The relative humidity of the bathroom is almost always higher than that of other rooms and outdoors. The variation range of temperature and humidity in each room is much smaller than that in outdoor. On rainy days, the outdoor relative humidity will rise to 99% rapidly when rainfall occurs, which will be significantly higher than the indoor relative humidity, including the bathroom. At the same time, the temperature will drop obviously, which is lower than the indoor temperature.
4. Conclusions
This study focuses on the temperature and humidity characteristics of residential buildings, mainly through experimental monitoring methods. Three scenarios were set up to monitor (1) the variation characteristics of temperature and humidity in different rooms in residential buildings, (2) the variation characteristics and correlation between indoor and outdoor temperature and humidity in different seasons, and (3) the diurnal variation characteristics of temperature and humidity in sunny and rainy days.

Through the analysis of experimental monitoring data and results, we can draw the following conclusions: (1) Indoor human activities and water using processes will produce water vapor dissipation and increase indoor humidity, because the indoor humidity of each room in the occupied period was significantly higher than that in the unoccupied time. (2) In the year, the relative humidity indoors is higher than that outside at noon when there is no rain. The relative humidity of autumn night will be significantly higher than that of indoor. (3) The bathroom is the main contributor to indoor water vapor, because the humidity of the bathroom is significantly higher than that of other rooms and outdoors. Indoor water vapor flows to the outdoor on sunny days, while outdoor moisture flows to indoors on rainy days.

The monitoring data show that the indoor temperature is relatively stable in a short period, while the humidity will show obvious peak and valley changes in a day. In the case of human habitation, the indoor humidity is mainly the water vapor dissipation caused by all kinds of human water use activities. These vapors enter the outdoor air through doors, windows, or other ventilation equipment to participate in the atmospheric hydrological cycle. Although the water vapor dissipation of a single room is very small, because most of the residential buildings are multi-storey or high-rise buildings with high building density, so for the whole living area, the indoor water vapour dissipation should not be ignored, which is also the amount of water neglected in the current urban hydrological cycle research.

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