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Effect of mechanical ventilation and natural ventilation on indoor climates in Urumqi residential buildings

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ABSTRACT

Residential buildings are ventilated naturally and mechanically. Both ventilation methods provide a healthier indoor environment by introducing external fresh air into the indoor air. The fresh air that enters a room can affect the indoor climate, for example, by reducing the indoor temperature and humidity in the winter. The objective of this study was to research the effects of mechanical ventilation and natural ventilation on indoor climates. Nine homes were selected for a one-year test in Urumqi, China, where the winter weather is severely cold. Four of the residences had natural ventilation, four of the residences had mechanical ventilation with heat recovery, and one residence had mechanical ventilation without heat recovery. The results showed that the indoor climate in Urumqi was dry in the winter and comfortable during the other seasons. Operating a mechanical ventilation system in winter reduced the indoor temperature by 1.6 K and humidity by 3% on average. It also greatly reduced the rate of indoor carbon dioxide, exceeding the standard and making it easier for residents to sense dryness and more likely to humidify their space. Natural ventilation in a room resulted in a little better relative humidity but poorer ventilation. Humidification is necessary for both mechanical and natural ventilation.

1. Introduction

Indoor air quality (IAQ) is important for people's quality of life because they spend almost 90% of their time in an indoor environment [1]. Good thermal comfort and air quality are associated with productivity and performance [2,3]. In mechanically and naturally ventilated buildings, IAQ mainly depends on outdoor air [4].

To maintain thermal comfort in a room, about 30%–60% of China's building energy consumption is used to improve indoor thermal environments [5]. Balancing the demand between energy consumption conservation and thermal comfort improvement is a great challenge in building environments in China. Chinese standard GB50736 recommends using 18 °C–24 °C as a winter design temperature in cold (C) and severe cold (SC) zones [6]. A recent study on indoor thermal environments in five climate zones in China has revealed that a large regional discrepancy exists in indoor thermal environments. Also, occupants who live in thermal environments in hot summer and cold winter (HSCW) and hot summer and warm winter (HSWW) zones are more adaptive and tolerant to poor indoor conditions than those living in Northern China where central heating systems are used [7,8]. A study conducted in the city of Harbin, China, showed that the mean indoor air temperatures were 23.6 °C in the early-heating period, 24.3 °C in the mid-heating period, and 25.0 °C in the late-heating period, which were higher than or close to the upper limit recommended by thermal comfort standards [9].

The relative humidity (RH) of indoor air is another indicator of IAQ [10]. People's concerns about the humidity of residential environments are often concentrated on the relationship between a high RH and the adverse health consequences of mold proliferation [11–13]. Concerns about dry environments are much less than humid environments. In C and SC zones, low outdoor humidity and overheating in winter can reduce indoor RH to an unacceptably low level and can make people feel uncomfortable or even sick. In general, low RH can cause dry skin, throats, and nasal mucous membranes, in addition to a decrease in mean skin temperature [14]. If the RH is lower than 20%–30%, special attention should be paid to managing electrostatic discharge. Even when the electric conductivity of clothes, soil, carpet, and so on is reduced, a low RH can affect electrostatic shock [15]. In addition, a dry environment can promote the survival and spread of viral respiratory infections such as the flu [16]. A study conducted in the United States (US) showed that the onset of increased influenza-related mortality in the winter might be related to abnormally low, absolute humidity levels

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during that period [17]. Because lower humidity can affect the comfort and health of humans, humidification might be required in these dry areas to reduce air dryness, electrostatic shock, and airway symptoms [18].

Poor IAQ can be harmful to vulnerable groups, such as children, the elderly, and patients with chronic respiratory or cardiovascular diseases [19]. Carbon dioxide (CO_2) is often used as a proxy of IAQ, because the reduction of indoor CO_2 concentration usually means lower concentrations of interior pollutants. This assessment is an important standard for IAQ. The Ventilation for Acceptable Indoor Air Quality standards [20] recommend a stable indoor concentration level of CO_2 when the difference between indoor and outdoor CO_2 concentration levels is less than 700 ppm. The limit of this standard in China is 1000 ppm [6]. Emenius pointed out in his research that high indoor moisture levels usually indicate poor ventilation [21].

The city of Urumqi is in an SC area of Northwest China and has a temperate continental climate. The winter in Urumqi is long and cold. The coldest month is January, with an average temperature of about −15.2 °C. Urumqi is surrounded by mountains on three sides, low in the northwest and high in the southeast, and has a high frequency of static wind during the heating season that results in poor pollutant diffusion conditions. Fig. 1 shows the monthly average concentration of outdoor fine particulate matter (PM2.5) in Urumqi during the past few years (2014–2017). A high concentration of PM2.5 is found during the months of January, February, March, November, and December, all of which are central heating months. As the year progresses, PM2.5 pollution becomes even worse during the heating period. However, from April to September, the outdoor PM2.5 concentration is below 35 μg/m^3 in the months without heating.

Currently, two potential models can improve IAQ in residential buildings in China: natural ventilation (NV) with an air cleaner and mechanical ventilation (MV) with an air filtration unit [22]. NV is low maintenance and requires zero energy. It improves thermal comfort levels and provides a healthier indoor environment by supplying external fresh air in the indoor air space [23]. However, bringing outdoor air inside can increase the concentration of outdoor pollutants in a room, such as the pollution from outdoor PM during the winter in China [24]. Residents are recommended to use an air purifier in their homes because it can reduce particle exposure indoors, even if the concentration of indoor particles is high [25,26]. An MV system, which is commonly equipped with filters, can remove particles from outdoor air and recirculated indoor air. Many previous studies have shown that an MV system that contains an air filter can effectively control the concentration of PM that enters a room [27–29]. A study at the Tuskegee Healthy House in the Southeastern US in summer shows that MV will increase the indoor temperature of 0.55–0.88 °C and 7% humidity [30]. However, the impact of different ventilation types on indoor climates and people's lifestyles during an entire year is rarely reported. This article explores the effects of NV and MV on indoor climates.

2. Method

2.1. Questionnaires

Local building information, indoor air, and the living habits of some residents were collected through a questionnaire. The questionnaire was distributed to citizens through local schools in Urumqi. Teachers received training about the study and were then given the questionnaire to distribute to their students. The students delivered the questionnaire to their parents to complete it. In total, 258 parents responded to the survey.

This article uses information in the questionnaire, such as building age, number of occupants, number of bedrooms, heating method, and main air quality problems in a room. According to the collected building information, we found nine households as representative households who were willing to help us conduct further study. Through the questionnaire, we learned that most of the people who filled out the questionnaire were 30–50 years old (73%), and thus the questionnaires are convincing because of good psychological maturity. The questionnaires showed that 99% of the residential units are with 2–3 bedrooms, 67% of the households have 3 people. Among the residential homes we studied, 8/9 families had 2 people, 1/9 families had 3 people, 3/9 families had 2 bedrooms (3/9), and 6/9 families had 3 bedrooms. The type of apartment (and the number of bedrooms) that we chose can represent the mainstream of Urumqi. The reason why the number of people in the study is smaller than the number of mainstream households in the questionnaire is that, the number of long time monitored households refers to the number of people who were living at home all year long (or people who traveled frequently or stayed at school were not included), while the questionnaire counts the total number of people in the family. Since traveling or going to school may result in one or two fewer people living in a family, this number is generally

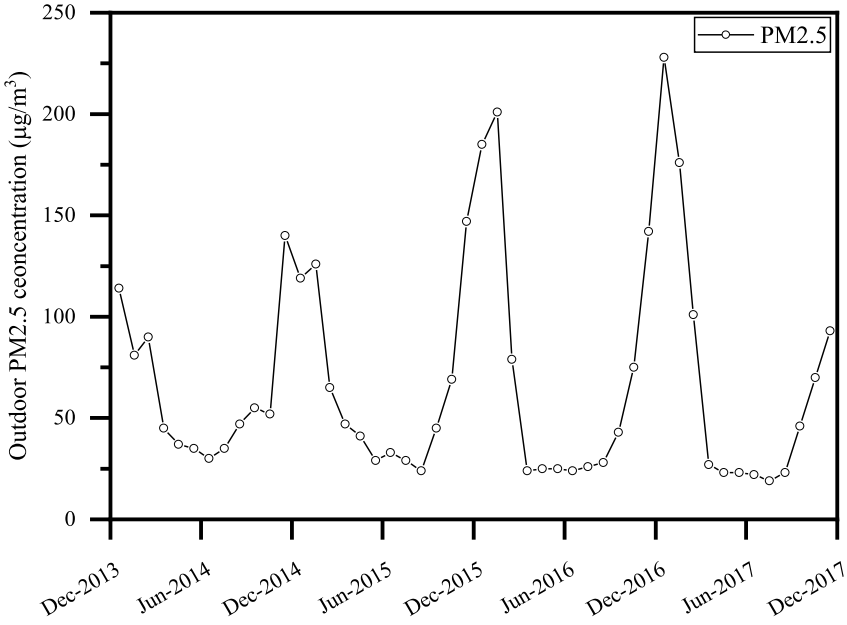

Fig. 1. Monthly average outdoor PM2.5 concentration in Urumqi from 2014 to 2017.