Field Measurements of Bedroom Environment in Winter and Summer on Qinghai-Tibet Plateau

Haodong Zhang[1], *Li* Lan[1*], *Yan* Yan[1], and *Mengyuan* Kang[1]

[1]Department of Architecture, School of Design, Shanghai Jiao Tong University, China

Abstract. Field measurements of the bedroom environment on Qinghai-Tibet Plateau was conducted by continuously measuring the air temperature, relative humidity, and CO2 concentration in the bedrooms of 197 residents (100 in winter and 97 in summer) for 7 days. And the daily environmental controls of residents were recorded. The results showed that the night-time thermal environment in bedrooms on the Qinghai-Tibet Plateau was more warmer and wetter in summer than in winter, but the CO2 concentration was lower in winter. On both winter and summer nights, drops in air temperature, relative humidity and CO2 concentration in the bedrooms were found when doors or windows were opened, increases in relative humidity and CO2 concentration in bedrooms were found when there were more occupants in the bedrooms. This study also found there was a greater reduction of CO2 concentrations when doors or windows were opened in the bedrooms of multiple occupants compared to the bedrooms of a single occupant. And on winter nights, the humidity increase in the bedrooms caused by the action of the humidifier was not affected by the status of doors and windows.

1 Introduction

The Qinghai-Tibet Plateau, located at the world's highest elevation, is known as "the Third Pole of the Earth". It is the only polar region where there is abundant human activity [1], covering over one-fourth of China's land area and home to more than 10 million people.

The climate of the Qinghai-Tibet Plateau is mainly characterized by hypobaric hypoxia, low average temperature, low rainfall, high solar radiation and air speed [2, 3, 4, 9]. To adapt to the harsh climate, unique passive designs were implemented to local building for the protection from the cold, the utilization of solar radiation and heat storage [5].

The indoor environment on the Qinghai-Tibet Plateau and the thermal comfort of residents have been concerned by some scholars. Yang [6] found that the indoor temperature in residential buildings in Lhasa varied from 2 °C to 20 °C in winter and from 17 °C to 27 °C in summer. Cheng [7] found that the indoor thermal neutral temperature was lower than the predicted thermal neutral temperature calculated based on the PMV model in winter. The thermal comfort range may shift towards the lower temperature compared to the thermal comfort range recommended by ASHRAE, ISO7730 and China's Evaluation Standard for indoor thermal environment (GB/T 50785-2012) [8-9].

However, among the indoor environment studies on the Qinghai-Tibet Plateau, none of the them focused on the bedroom environment where people sleep at night. Many evidences suggest that the thermal environment in the bedroom is important for human sleep [10]. Controlling the bedroom environment can improve the sleep [11], which is particularly important in high-altitude areas where sleep problems are widespread. Therefore, this study focused on bedroom environment on Qinghai-Tibet Plateau and the impact of environmental controls on it.

2 Methods

2.1 Subjects

Staff dormitories at four sites on the Qinghai-Tibet Plateau were selected as the research objects for this study. The 4 sites were Gyaca County in Shannan (3255 m above sea level), Sangri County in Shannan (3574 m above sea level), and Liuwu New Area in Lhasa (3650 m above sea level), Chengguan District in Lhasa (3650 m above sea level).

One hundred residents living in site 1 and 2 were recruited during the winter survey period from December 2020 to January 2021, and ninety-seven residents living in site 1, 3, and 4 were recruited during the summer survey period from July 2021 to August 2021. Among them, 154 residents were male and 43 residents were female; 61 residents were 20-29 years old, 59 residents were 30-39 years old, 55 residents were 40-49 years old, and 22 residents were 50-60 years old.

2.2 Measurements

In this study, TR-76Ui devices (T&D, Inc.) were chosen to measure and record the air temperature, humidity and

* Corresponding author: lanli2006@sjtu.edu.cn

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CO_2 concentration in the bedrooms simultaneously. They were placed at the bedside of residents for seven consecutive days to record environmental parameters at 2-minute intervals. And subjective questionnaires were used to record residents' environmental controls every night.

Additionally, the outdoor average daily air temperature, average daily relative humidity and average daily air velocity during survey period were provided by local weather stations.

2.3 Data analysis

In this study, there were a total of 7*197 samples, and one sample means the data of one resident for one night. The data was screened as samples from Monday night to Thursday night, and samples with missing data and abnormal data were eliminated, resulting in 690 samples. For each sample, the mean value of the environmental parameters over the resident's actual sleep period was taken as a representation of the entire night.

Linear Mixed-effects Model (LMM) was chosen for the analysis of the bedroom environment data, and Student's t-test was chosen for the analysis of outdoor environment data.

Since the marginal mean is the mean response for each category of a factor obtained by controlling for the effects of other variables in the statistical model, it was presented in this paper rather than the mean of the original data.

3 Results

3.1 Outdoor and bedroom environments in winter and summer

As shown in Fig. 1, the average outdoor air temperature (TA), relative humidity (RH), and air speed during the winter survey period were 2.7°C, 30%, and 1.92 m/s, respectively. And during the summer survey period, they were 17.0°C, 62%, and 1.19m/s, respectively. Significant differences were found in outdoor air temperature, relative humidity, and air speed between winter and summer.

As shown in Fig. 2, the average air temperature, relative humidity, and CO_2 concentration in the bedrooms on winter nights were 20.9°C, 21%, 766ppm, respectively. On summer nights, they were 21.7°C, 53%, 909ppm, respectively. The air temperature, relative humidity and CO_2 concentration were significantly different between winter and summer nights, which were higher on summer nights.

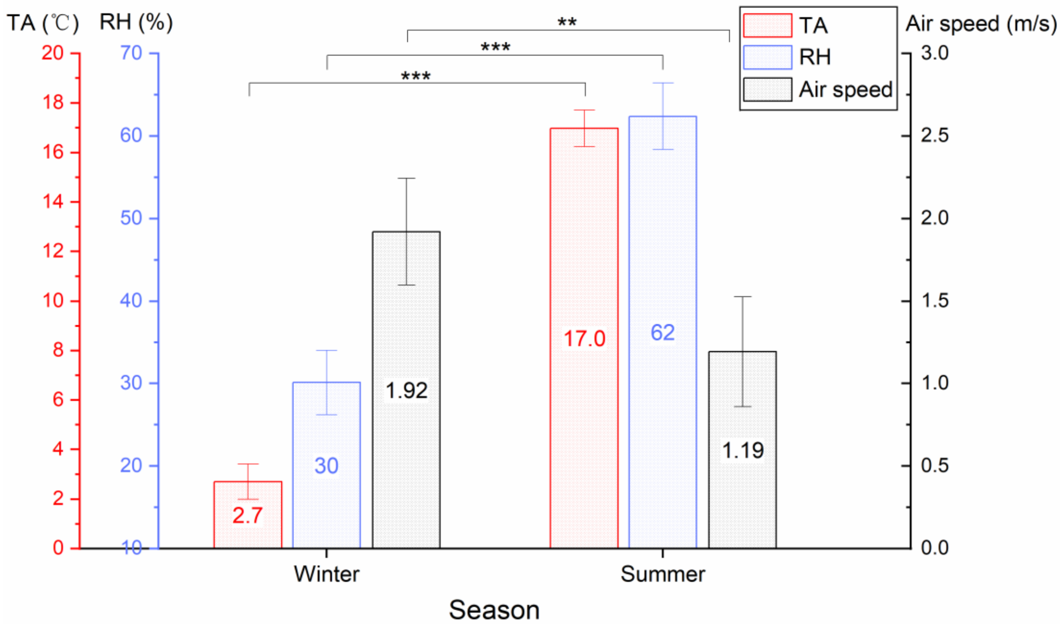

Fig. 1. The Outdoor air temperature, relative humidity and air speed in winter and summer during survey period (Winter: December 5-19, 2020, January 11-25, 2021; Summer: July 26-August 24, 2021. Significance of difference: *, P<0.05; **, P<0.01; ***, P<0.001).

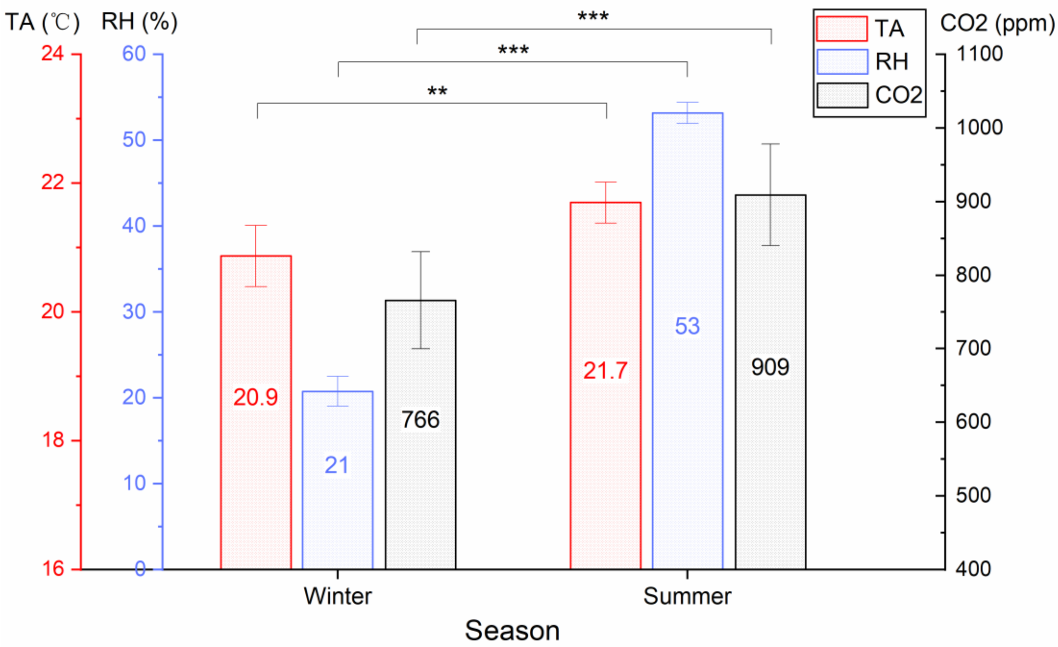

Fig. 2. Night-time air temperature, relative humidity and CO2 concentration in bedrooms in winter and summer. (Sample size: Winter, 335; Summer, 302).

3.2 The effect of environmental controls of residents on the bedroom environment on winter nights

In winter, residents controlled the night-time environment in the bedrooms by controlling heaters, humidifiers, doors and windows, etc. Among them, all samples turned on the heater, 47.2% of the samples turned on the humidifier, and 56.4% opened the doors or windows. Additionally, 27.8% of the samples were multi-occupancy (2 or 3 occupants).

This study found that the bedroom environment on winter nights was significantly affected by the status of the doors and windows, the number of occupants in the bedroom, and the status of humidifiers.

As shown in Fig. 3, significant decreases in air temperature (21.7°C vs. 19.9°C), relative humidity (24% vs. 20%) and CO2 concentration (989 ppm vs. 566 ppm) were observed when doors or windows were opened, compared to when doors and windows were closed. And both relative humidity and CO2 concentration were significantly increased due to the increase in the number of occupants in the bedroom.

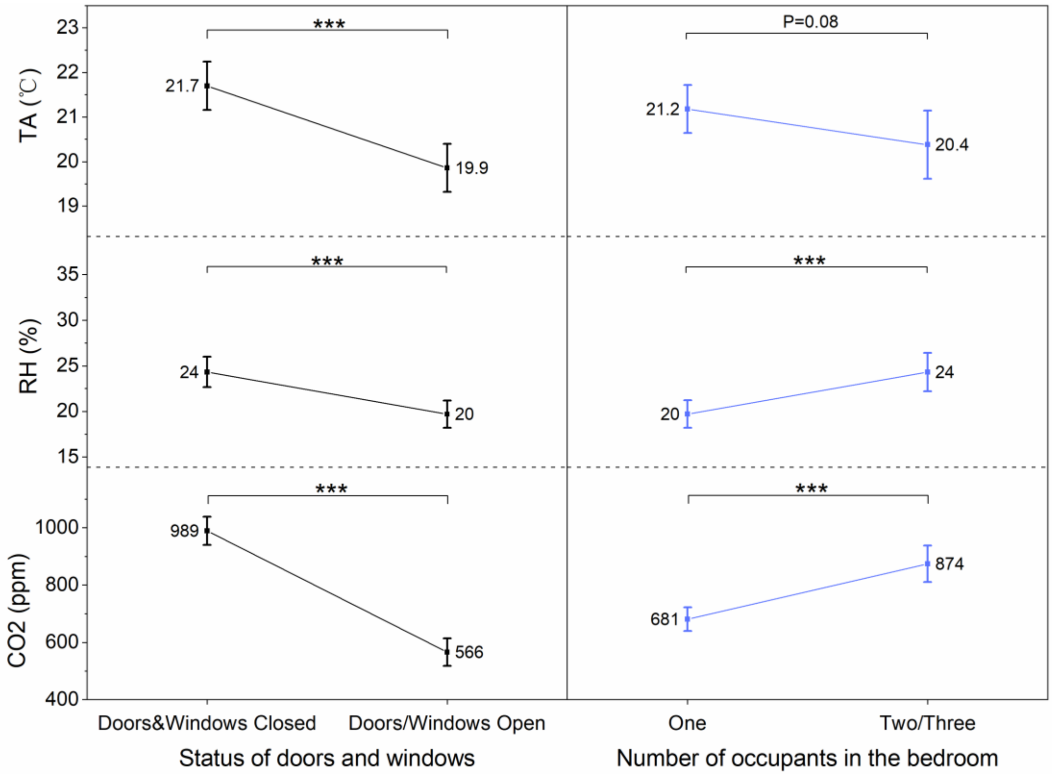

Fig. 3. Effects of the status of doors and windows and the number of occupants on air temperature, relative humidity and CO2 concentration in bedrooms on winter nights.

In addition, the interaction effects of doors and windows status and number of occupants on CO2 concentration were found to be significant (Fig. 4). A greater reduction of CO2 concentrations was observed when doors or windows were opened in the bedrooms of multiple occupants compared to the bedrooms of a single occupant.

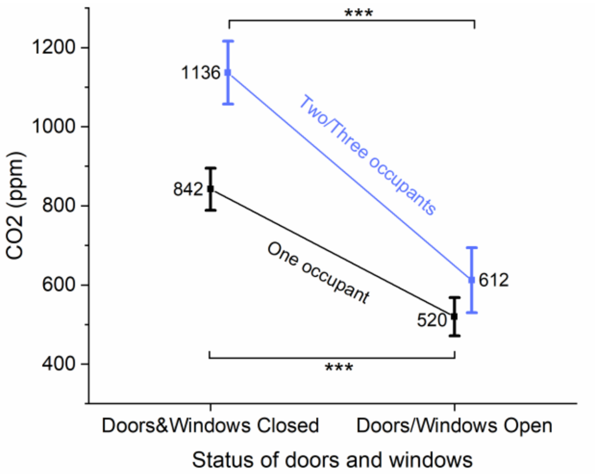

Fig. 4. Interactive effects of the status of doors and windows and the number of occupants on CO2 concentration in bedrooms on winter nights.

The relative humidity in bedrooms was also significantly affected by the status of the humidifier, as shown in Fig. 5. Turning on the humidifier increased the relative humidity in bedrooms in both "doors and windows closed" and "doors or windows open" conditions. Besides, there was no interactive effect of the status of doors and windows and the status of humidifier on relative humidity.

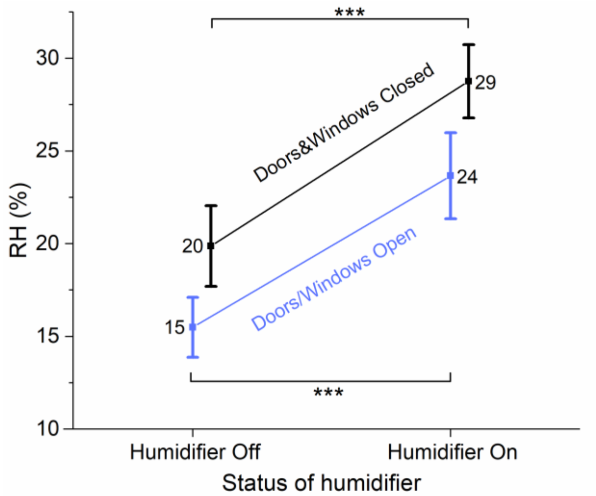

Fig. 5. Effects of the status of doors and windows and the status of humidifier on relative humidity in bedrooms on winter nights.

3.3 The effect of environmental controls of residents on the bedroom environment on summer nights

In summer, residents mainly controlled the night-time environment in the bedrooms by opening or closing the doors and windows, with 55.6% of the samples opening doors or windows at night. Besides, 40.1% of the samples were oxygen-enriched, and none of the samples adopted air-conditioning, heaters and humidifiers. Additionally, 25.5% of the samples were multi-occupancy (2 or 3 occupants).

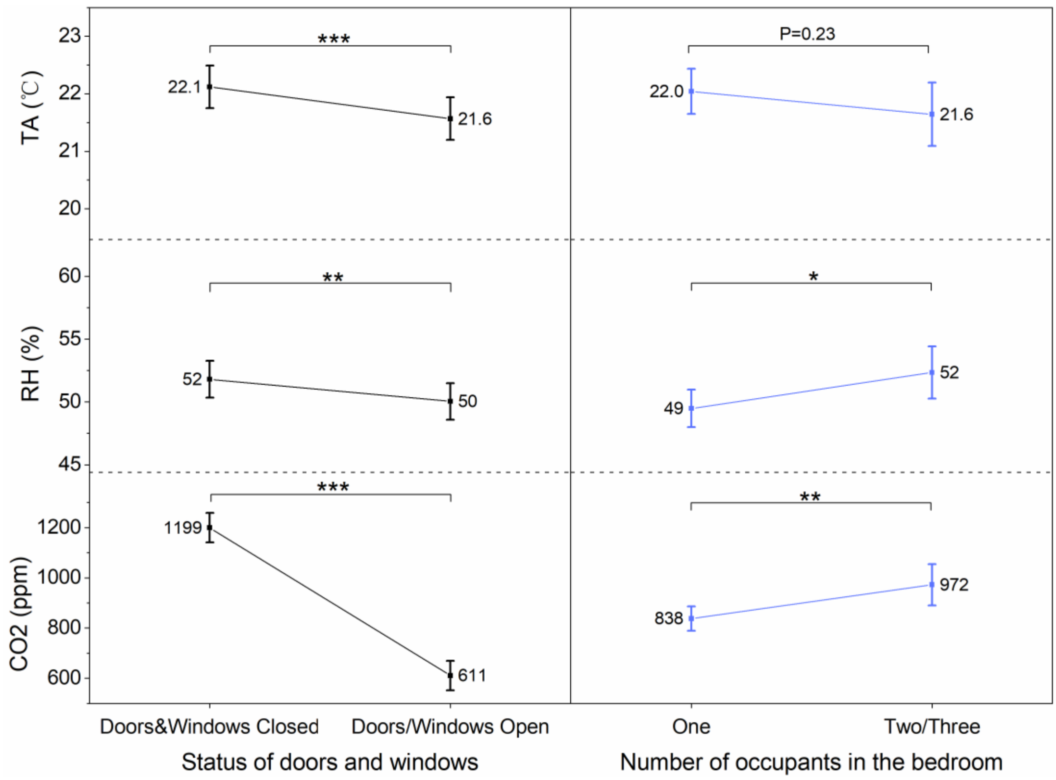

Fig. 6. Effects of the status of doors and windows and the number of occupants on air temperature, relative humidity and CO2 concentration in bedrooms on summer nights.

This study found that the bedroom environment on summer nights was significantly affected by the status of the doors and windows, the number of occupants in the bedroom, and the oxygen supply.

As shown in Fig. 6, significant decreases in air temperature (22.1°C vs. 21.6°C), relative humidity (52% vs. 50%) and CO2 concentration (1199 ppm vs. 611 ppm) were observed when doors or windows were opened, compared to when doors and windows were closed. And due to the increase in the number of occupants in the bedroom, the relative humidity (49% vs. 52%) and CO2 concentration (838 ppm vs. 972 ppm) were both significantly increased.

In addition, the interaction effects of doors and windows status and number of occupants on CO2 concentration were also found to be significant (Fig. 7). A greater reduction of CO2 concentrations was observed when doors or windows were opened in the bedrooms of multiple occupants compared to the bedrooms of a single occupant.

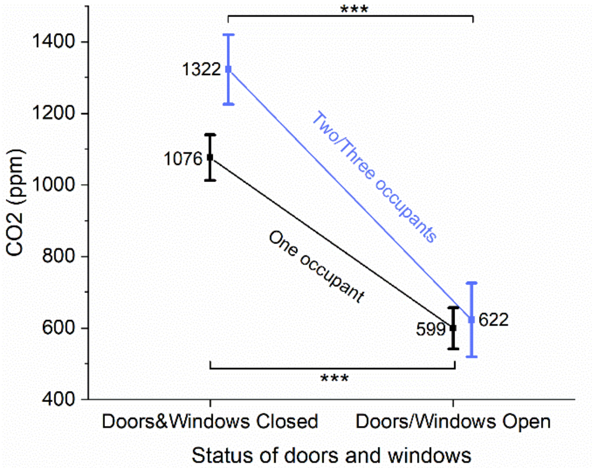

Fig. 7. Interactive effects of the status of doors and windows and the number of occupants on CO2 concentration in bedrooms on summer nights.

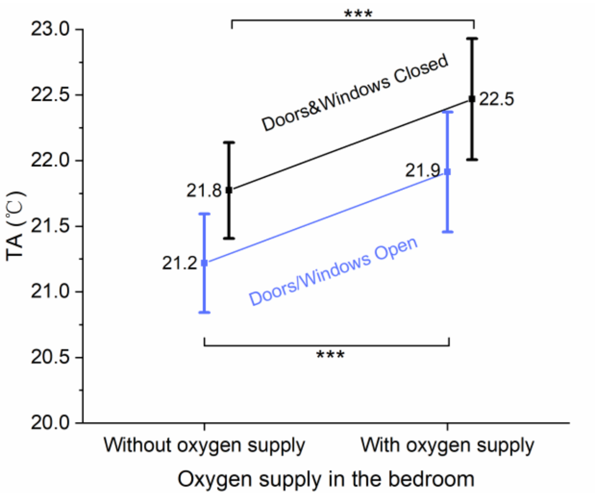

Fig. 8. Effects of the status of doors and windows and oxygen supply on air temperature in bedrooms on summer nights.

The air temperature in bedrooms was also significantly affected by the oxygen supploy, as shown in Fig. 8. Higher air temperatures were found in the oxygen-supplied samples for both "doors and windows closed" and "doors or windows open" conditions. Besides, there was no interactive effect of the status of doors and windows and the oxgen supply on relative humidity.

4 Discussion

Due to the higher outdoor air temperature and higher outdoor relative humidity in summer, the air temperature and relative humidity in bedrooms were higher on summer nights than on winter nights (Fig. 1, Fig. 2), although all samples adopted heaters and half samples adopted humidifiers on winter nights (the ratio of opening doors or windows on winter and summer nights was close).

The CO2 concentration in the bedrooms was higher on summer nights than on winter nights, and it had a significant positive correlation with the air temperature in the bedrooms (Fig. 9). Angelova et al. [12] also found that carbon dioxide emissions from the human body will increase when air temperature in the indoor environment increased. Therefore, the fact that the air temperature in the bedrooms on summer nights was higher than that on winter nights may explain why the CO2 concentration in the bedrooms was higher on summer nights. Outdoor air speed in summer was lower than that in winter, which may result in lower indoor ventilation rate in summer. And that would also lead to higher CO2 concentrations in bedrooms on summer nights.

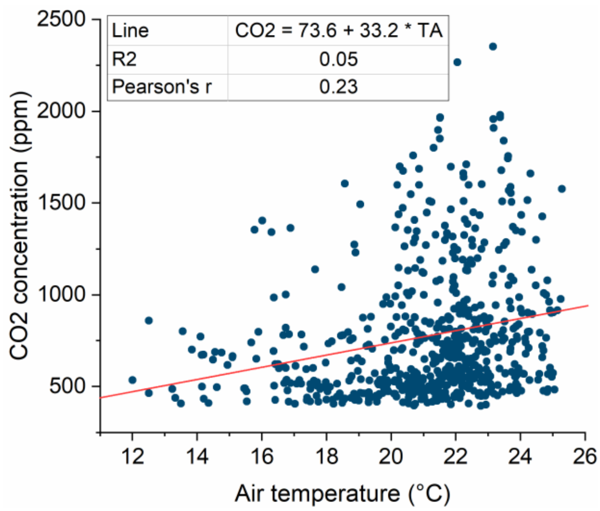

Fig. 9. The correlation between night-time air temperature and CO2 concentration in bedrooms.

The air temperature and relative humidity in the bedrooms were higher than those outside, no matter in winter or summer. As a result, when the doors or windows were opened, the heat and water vapor in the bedrooms would escape to the outside, and then the air temperature and relative humidity in the bedroom dropped. The same for CO2 concentration (Fig. 3, Fig. 6).

Under normal circumstances, the human body will lose water through breathing, sweating, etc., and emit carbon dioxide through breathing. Therefore, both relative humidity and CO2 concentration in bedrooms were found to increase significantly on both winter and summer nights when there were more occupants in the bedrooms. Furthermore, no significant effect was found on the effect of number of occupants in the bedroom on air temperature, but it was shown that the sample mean of air temperature in multi-occupancy bedrooms was lower than that in single-occupancy bedrooms (Fig. 3, Fig. 6). It was assumed that occupants in multiple bedrooms preferred cooler indoor environments than occupants in single bedrooms, and then regulated the air temperature in the bedrooms by controlling heaters or doors and windows.

On both winter and summer nights, it was found that opening doors or windows in the multi-occupancy bedrooms resulted in a greater reduction in CO_2 concentration than in the single-occupancy bedrooms (Fig. 4, Fig. 7). The reason may be that in multi-person bedrooms, the difference between indoor and outdoor CO_2 concentrations was larger, which facilitated the escape of CO_2 to the outdoors.

On winter nights, the use of humidifiers increasesd the relative humidity in the bedroom, and the increase in relative humidity was not affected by the status of doors and windows (Fig. 5).

The reason for the higher air temperature in the bedrooms with oxygen supply in summer was not clear. It may be that the oxygen input into the bedrooms brought heat, or oxygen inhalation will increase the heat loss of the human body in high-altitude environments. While the temperature at the oxygen outlet was not measured, the cause of this phenomenon cannot be determined at this time.

5 Conclusion

- The night-time environment in bedrooms on the Qinghai-Tibet Plateau was warmer and wetter in summer than in winter, but the CO_2 concentration was lower in winter. During summer survey period, the mean of air temperature, relative humidity and CO_2 concentration in bedrooms were 21.7°C, 53% and 909 ppm respectively, and in winter they were 20.9°C and 21% and 766 ppm respectively.
- On both winter and summer nights, the heat, water vapor and CO_2 in bedrooms would escape to the outside when doors or windows were opened. Drops in air temperature (1.8°C in winter, 0.5°C in summer), relative humidity (4% in winter, 2% in summer), CO_2 concentration (432 ppm in winter, 588 ppm in summer) in the bedrooms were observed when doors or windows were opened.
- The relative humidity and CO_2 concentration would increase when there were more occupants in the bedroom. Due to water loss and CO_2 emissions from human bodies, increases in relative humidity (4% in winter, 3% in summer) and CO_2 concentration (193 ppm in winter, 134 ppm in summer) were observed when there were more occupants in the bedroom.
- On both winter and summer nights, there was a greater reduction of CO_2 concentrations when doors or windows were opened in the bedrooms of multiple occupants compared to the bedrooms of a single occupant. On winter nights, when the doors or windows of multi-occupancy and single-occupancy bedrooms were opened, CO_2 concentrations in the two kinds of bedrooms dropped respectively by 524 ppm and 322 ppm. On summer nights, CO_2 concentrations dropped by 700 ppm and 477 ppm, respectively.
- The humidity increase in the bedroom caused by the action of the humidifier was stable on winter nights. Regardless of whether the doors and windows were open or not, turning on the humidifier in winter could increase the relative humidity in bedrooms by about 9% in this study.

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