Experimental research on the indoor thermal environment of the office buildings with solar energy heating in Xinjiang, China

Xin Xu1, Jie Li1,3, Shuguang Jiang1, Mengyun Wu1, Jin Dai1 and Dianwei Qi2
1 Collage of Water Conservancy and Architecture Engineering, Shihezi University, Shihezi, Xinjiang, China;
2 Institute of Building Engineering, Xinjiang University, Urumqi, Xinjiang, China
3 Email: 18245526@qq.com

Abstract. In order to study the indoor thermal environment of solar heating of office buildings in Xinjiang, A rural office building in Shihezi was selected in this paper as the research object. Indoor temperature and relative humidity were monitored in field testing during the winter heating period. 4363 sets of effective data were collected in the experimental research. PMV-PDD was calculated to analyse its indoor thermal comfort by a program. The results show that the indoor thermal comfort of the room without a heat source was always not satisfied. Furthermore, the average indoor PMV of the room with coal-fired heating was -1.6 and that with solar heating was -0.5. At the same time, the room with solar energy heating can control the fluctuation margin of indoor temperature within a certain range, especially to the temperature fluctuations during the working time. Therefore, the technology of solar heating was certified as a suitable method to maintain indoor comfort in Xinjiang.

1. Introduction
Fossil fuels consumed by heating in winter have become the main cause of air quality deterioration and environmental degradation in major cities in northern China [1]. Accordingly, heating should be prevented to a source of pollution in a rural area in Xinjiang. In 2015, Hu Lili adopted a new type of kang to reduce coal consumption and damage to the environment on the loess hilly region in western China, while improving indoor thermal comfort [2]. From the perspective of expanding the use of renewable energy and reducing the energy consumption of building envelopes, Li Jinping compared a new type of rural dwelling house, which combines solar hot water system with a coal-fired boiler, with a traditional small coal-fired boiler [3]. Rural areas in Xinjiang are much larger than urban areas. Rural office buildings are characterized by low floors, small size, large shape coefficient, and scattered layout. Besides, most of the rural office buildings are heated by coal, which consumes high amounts of fuel [4-5]. With the development of economy, some technologies of clean heating have come into people's vision, but the adaptability of local buildings to these technologies is still a problem for the designer [6]. Therefore, on the basis of using new heating technology to ensure the reduction of energy consumption, how to determine the impact of the new heating method on the thermal comfort of the building is worth studying.

In this study, a typical office building with new solar heating in Shihezi City, Xinjiang, China was used as a research object, and experimental research of the heating period was carried out. The purpose of this study is to explore the thermal comfort and adaptability of office buildings with new...
solar heating. By comparing the thermal environment test data under the conditions of the room with solar heating and the room without heating and the room with coal-fired heating, the indoor thermal comfort of solar heating is analyzed, which provides data support for the application of solar heating technology in Xinjiang.

2. Experiments

2.1. The Experimental building
A rural office building in Shihezi, a typical cold climate city, was chosen in the paper as the research object. The building is a single layer frame structure. Three rooms with different heating modes were tested, as shown in Figure 1. Among three rooms, the south-facing conference room was transformed into a floor radiation heating room with solar energy, which was automatically heated by the automatic control system according to the indoor temperature during the working hours of 8:00-19:00. The west-facing office was heated by traditional coal-fired and turned on by staff at work. The north-facing room is a sundry room, which was a room without heating.

Figure 1. Lay out of the testing office building.

2.2. The measuring system
The main parameters related to the indoor thermal environment in this experimental research include air temperature, globe temperature, and relative humidity. According to test instruments and parameter accuracy in Table 1, the horizontal distance of the test instrument from the wall was more than 0.5m, and the vertical distance from the ground was 1.5m. From December 5, 2018, to January 15, 2019, the indoor and outdoor temperature and relative humidity were continuously monitored. The field test time was from 8:00 to 19:00.

| Parameters                | The versions of instruments | Measuring range | Measuring accuracy |
|---------------------------|------------------------------|-----------------|-------------------|
| Indoor temperature        | JTR08B                       | -40~80℃        | ±0.3℃             |
| Relative humidity         | JTR08B                       | 0~100%          | ±1.5%             |
| Globe temperature         | JTR04                        | -20~125℃       | ±0.5℃             |
| Environment temperature   | Vantage Pro2                 | -40~65℃        | ±0.5℃             |
3. Results
Xinjiang is a typical temperate continental climate, with annual natural precipitation of more than 100 mm. Xinjiang has less rainfall, dry climate, long sunshine time and a large difference in temperature between day and night [7]. During the survey period, the mean ambient temperature and the average relative humidity were -14.6°C and 71.9%.

3.1. Analysis of indoor thermal environment
As shown in Figure 2, the average indoor temperature of the room without heating was 2.6°C, the maximum temperature was 8.7°C, and the minimum temperature was -2.5°C. The temperature fluctuation in this room was mainly affected by the outdoor temperature, which fluctuated greatly during the whole test period. However, the fluctuation of indoor temperature was stable in the daytime, only about 0.63°C. Without the heat source, the relative humidity of the room also reflected the change of the outdoor humidity. The average indoor relative humidity was 59.9%. Because of the extremely low outdoor temperature, indoor air condensation occurred in the windows and walls, which made the indoor relative humidity of the room without heating the highest in the test room during the test period. The maximum and minimum indoor relative humidity were 82% and 32%, respectively.

Figure 2. Indoor thermal environment of the room without hot source.

Figure 3 was the indoor thermal environment with a mean indoor temperature of 16.8°C in a room with coal-fired. The highest temperature could reach 25.9°C and the lowest temperature was only 5.5°C. The heating rates and cooling rates of coal-fired heating were very high and directly affected the indoor air temperature, which had little effect on the thermal storage of building envelope structure, resulting in the indoor temperature difference as high as 20.4°C during the heating period, and the temperature variation range was very large. The variation range of indoor relative humidity was stable, fluctuates between 20% and 44%, and the average humidity was 32.2%. However, the fluctuation frequency of indoor relative humidity was relatively high, and the indoor relative humidity was in a low state due to the high temperature when coal was burned for heating.

As shown in Figure 4, obvious regularity was presented in the indoor temperature of the room heated by solar floor radiation. The average indoor temperature was 18.0°C and the highest temperature was 21.1°C which occurred around 18:00 and the lowest temperature was 13.9°C which occurred around 8:00. Floor radiation heating controlled by an automatic control system first heated the building's envelope structure, and then raised the indoor air temperature. Therefore, the indoor temperature was relatively stable, the highest difference in temperature was only 4.1°C. Considering the working hours of office buildings, the difference in indoor temperature during working hours was...
lower than that in the whole day. The average indoor relative humidity was 50.5%. The highest and lowest values of humidity were 56% and 43%. The fluctuation of humidity was stable. Relative humidity also has certain regularity, especially in the latter half of the test period, relative humidity fluctuates of temperature, and the lowest humidity usually occurred at the highest indoor temperature.

![Figure 4](image)

**Figure 4.** The indoor thermal environment of the room with solar energy heating.

To summarize, Xinjiang is cold in winter, and the difference in temperate between indoor and outdoor is large. The room without heating was obviously affected by the outdoor temperature, and the indoor temperature was extremely low, which could not meet the requirements of human thermal comfort. The temperature fluctuation of the coal-fired heating room was too large and the air was relatively dry. Differently, the room with solar energy as a heat source for floor radiation heating had a small fluctuation in temperature, and the relative humidity value was between the former two.

3.2. The indoor comfort

PMV-PDD, a thermal comfort model, describes the votes of a large group of persons on thermal sensation scale and the quantitative prediction of the percentage of thermally dissatisfied [8-9]. It combines metabolic rate, Clothing insulation, air temperature, radiant temperature, air speed, and humidity [10]. For testing the heating demand time of office buildings, 4363 valid data of testing room in working hours were selected. On the premise of 1.2metabolic rate and 1.0clo clothing thermal resistance, a Python program was used to analyze the tested objects.

![Figure 5](image)

**Figure 5.** Indoor PMV of the room with coal-fired heating.

![Figure 6](image)

**Figure 6.** Indoor PMV of the room with solar energy heating.
As shown in Figure 5, the average indoor PMV of the room with coal-fired heating was -1.6. Most of the time, the corresponding thermal sensation was from cool to cold, and the thermal comfort of the room is always not ideal. Although the PMV distribution frequency is concentrated, there were also very low values which make people feel severely cold. As shown in Figure 6, the average PMV of the room with solar heating was -0.5. The corresponding thermal sensation is often between slightly cool and slightly warm. The overall indoor thermal comfort in this room was better than that in the room with coal-fired heating. The PMV was affected by the start and stop of the automatic control system. The numerical frequency distribution was concentrated, and the numerical distribution follows a Poisson distribution.

As shown in Figure 7, the distribution frequency of PDD in the room with coal-fired heating was polarized, and percentage of thermally dissatisfied was high. The proportion of times when the percentage of thermally dissatisfied was more than 80% had been as high as 39.4%. As shown in Figure 8, the indoor uncomfortable index in the room with solar energy heating was low, the number of times less than 20% accounted for more than 45%, and the comfortable period of time was about 20.2% longer than that of the room with coal-fired heating.

4. Conclusions

The experimental research of this work allowed us to meet the Conclusions: The average indoor temperature of the room without heating in winter is 2.6°C, and the fluctuation range was -2.5°C to 8.7°C, so the indoor temperature was extremely low, which could not meet the requirements of human thermal comfort. The indoor relative humidity was the highest in the test rooms due to the indoor air condensation occurred in the windows and walls. The indoor temperature and relative humidity of the room with solar energy heating shown obvious regularity, and the temperature and humidity fluctuation showed an inverse relationship. Therefore, in the process of solar heating operation, in addition to conventional temperature control, indoor humidity should also be considered to ensure good indoor thermal comfort. The average indoor PMV of the room of coal-fired heating was -1.6, the average PMV of the room with solar energy heating was -0.5. The indoor comfort of the room with solar energy heating was relatively satisfied. The solar heating not only consumed much less than coal-fired heating but also given the room better comfort than coal-fired heating.

Acknowledgement

This paper is support by Xinjiang Production and Construction Corps’ industrial high-tech science and technology project research project “Research on key technologies of solar energy-air source heat pump energy saving heating” and Xinjiang graduate research and innovation project “Application research on automatic control system of solar combined air source heat pump compound heating in severe cold region of Xinjiang”.

Figure 7. Indoor PDD of the room with coal-fired heating.
Figure 8. Indoor PDD of the room with solar energy heating.
References

[1] Wang Z, Xue Q, Ji Y, et al. 2018 Indoor environment quality in a low-energy residential building in winter in Harbin[J] Building and Environment 135 194-201

[2] Lili H, Shuwen N 2015 Analysis on environmental and economic benefits of suspended kang of rural households in loess hilly region[J] Transactions of the Chinese Society of Agricultural Engineering 31(15) 208-215

[3] Li J, Li X, Wang N, et al. 2016 Experimental research on indoor thermal environment of new rural residence with active solar water heating system and external wall insulation[J] Applied Thermal Engineering 95 35-41

[4] Luo X L, Chen H S, Chen B, et al. 2012 Experimental Study of Greenhouse Solar Energy Combined with Coal-Fired Boiler Heating System[J] Applied Mechanics and Materials 178-181 197-203

[5] Yuan X, Wang X, Zuo J 2013 Renewable energy in buildings in China--A review[J] Renewable and Sustainable Energy Reviews 24(Complete) 1-8

[6] Yuan L, Ruan Y, Yang G, et al. 2016 Analysis of Factors Influencing the Energy Consumption of Government Office Buildings in Qingdao[J] Energy Procedia 104 263-268

[7] Yan R, Gao J, Li L 2016 Streamflow response to future climate and land use changes in Xinjiang basin, China[J] Environmental Earth Sciences 75(14) 1108

[8] Wang Z, Zhang L, Zhao J, et al. 2010 Thermal comfort for naturally ventilated residential buildings in Harbin[J] Energy and Buildings 42(12) 2406-2415

[9] Wang Z, Xue Q, Ji Y, et al. 2018 Indoor environment quality in a low-energy residential building in winter in Harbin[J] Building and Environment 135 194-201

[10] Enescu D 2017 A review of thermal comfort models and indicators for indoor environments[J] Renewable and Sustainable Energy Reviews 1353-1379