Research on the Influence of Vertical Green of Envelope Structure on Indoor Thermal Environment ——A study of Zhengzhou city

Jinxia Du1, Wentao Hu2, Luxu liang1, Wanying Zhang1, Jianye Tian1*, Kangjie Li1, and Jiacheng Kang 1

1Department, School of Architecture, North China University of Water Resources and Electric Power, Zhengzhou 450045, China

2Department, College of Architecture and Urban-Rural Planning, Sichuan Agricultural University, Chengdu 610065, P.R. China

*Corresponding author’s e-mail: Z201811442600@stu.ncwu.edu.cn

Abstract. In this paper, control variable comparative test was employed to study the effect of the vertical greening of the envelope structure on the indoor thermal environment of Zhengzhou city. Two rooms with exactly the same structure except for the vertical greening were used as the experimental group and the reference group. The experimental results found that when vertical greening was adopted, the average temperature of the outer surface of the wall was decreased by 7.6 ℃ and 0.4 ℃ during the day and night, while the average indoor air temperature was decreased by 1.8 ℃ and 0.1 ℃ respectively. Therefore, we also found out that the average indoor air relative humidity of green vertical room was increased by 3.9% and 0.2% during the day and night with respect to the reference room. It shows out that vertical greening can effectively alleviate overheating, stabilize indoor environmental humidity, and improve the indoor thermal environment significantly.

1. Introduction
The external maintenance structure of the building can not only beautify the facade of the building, but also assume the protective role of various unfavorable factors in the environment. The quality of the indoor thermal environment directly affects the comfort of human living. Considering that the outdoor climate is often quite different from the suitable living environment for humans, the building envelope plays an important role to create an independent indoor thermal environment to improve the indoor living environment. However, the heat insulation performance of common building materials such as reinforced concrete is poor. In the hot summer, the temperature of the inner surface of the external maintenance structure will be higher, thus, people will feel thermal discomfort[1]. The existing solution is to install a thermal insulation layer in the building envelope, or adopt intermittent ventilation and air conditioning methods to reduce the indoor temperature. However, it will bring about problems such as increased construction costs, Sick Building Syndrome (SBS), and sharp increase in energy consumption. As an organic combination of plants and buildings, vertical greening can not only increase the green area without occupying land resources, and provide a more comfortable living environment; it can also cool down and increase humidity and beautify the environment[2, 3]. Vegetation leaves can reflect and absorb sunlight, and the natural air cavity formed between the vegetation and the wall can reduce heat transfer and the absorption of solar radiation on
the wall surface[4]. Therefore, the transpiration and evaporative of plants water further reduce the heat absorbed by the wall. In this way, the vegetation wall not only reduces the environmental temperature, but also affects the change of the indoor thermal environment.

Some researches have been conducted to study the cooling effect of vertical greening. Peck et al. found out that in the hot summer, the plant layer of the vertical green building can block most of the solar radiation from directly irradiating the surface of the external wall, thereby reducing the surface temperature of the building envelope[5]. In a study of a concrete building covered with ivy in Tokyo, Hoyano et al. found that vertical greening can reduce the temperature of the outer surface of the wall by 18%, thereby reducing the cooling load of the room[6]. Liu et al. studied the impact of vertical greening on the building's air conditioning load through Computational Fluid Dynamics (CFD) software simulation and found that after the building adopts wall greening, the summer air conditioning cooling load can be reduced by more than 10%[7]. Eumorfopoulou et al. found that climbing plants can reduce the surface temperature of indoor and outdoor walls, keeping the average indoor temperature 2°C lower than the reference room[8]. Alexandri et al. conducted separate researches on roof greening and wall greening, and pointed out that the combination of roof and wall greening can reduce building air conditioning and cooling energy consumption by about 32% to 100%, which is more conducive to creating comfortable indoor and outdoor heating environment[9]. Zhang et al. found that wall greening can reduce the indoor temperature by 3.61°C and the outdoor wet bulb temperature by 2.71°C[10]. Zhou et al. found that the effect of vertical greening on the surface temperature of the external wall is related to the intensity of solar radiation. The cooling effect of east and west is better than that of the north and south, by decreasing 7.0°C, 6.8°C, 6.4°C, and 4.8°C respectively[11].

Zhengzhou is a typical area with hot summer and cold winter. The vertical greening of the building external maintenance structure has great potential application value to the indoor thermal environment in this area. However, there are few related researches in this area, so this article has carried out a real measurement study on the influence of the vertical greening of the external maintenance structure of Zhengzhou buildings on the indoor thermal environment in the area.

2. Study area & method

2.1. Description of the experimental site
The experimental site is located in No. 58 Longhai East Road, Guancheng Hui District, Zhengzhou City. The test rooms are with the same structure and function and located in multi-storey buildings. The area of room is about 18 square meters, and the outer wall is an ordinary brick-concrete structure. The room covered by green plants is the experimental group, and the room without green plants is the reference group. There are ordinary glass windows on the outer walls of the two rooms, and the window area is about 3.6 square meters. As shown in Figure 1, Boston Ivy with an average thickness of about 15 cm was attached to the room of the experimental group.
2.2. Layout of experimental instruments and measuring points

The placement points of the experimental instrument are marked in Figure 2. Points T1 and T4 are located indoors, points T2 and T5 are located on the inner surface of the room wall, and T3 and T6 are located on the outer surface of the room wall. Thermocouple temperature sensor and air temperature and humidity sensor were employed to measurement the temperature and humidity of the target, and there performance parameters are shown in Table 1.

Table 1. Instrument performance parameters.

| Measurement content       | Sensor type              | Sampling interval | Accuracy              |
|---------------------------|--------------------------|-------------------|-----------------------|
| Surface/air temperature   | Φ0.2 mm T-type thermocouple | 5 min             | ± 0.1°C               |
| Air relative humidity     | HOBO Pro V2              | 5 min             | ±2.5% (10–90% RH)     |

Figure 1. The red frame represents the test room, where (a) and (b) are experimental rooms with vertical green, (c) and (d) are reference rooms without vertical green.
Figure 2. Layout of measuring points. (a) Measurement room with vertical green, (b) Measurement room without vertical green.

3. Results and discussion

3.1. Comparison of indoor and outdoor temperature

In this paper, on May 23rd, the outer surface, inner surface and indoor temperature of the experimental group and reference group rooms were continuously measured at 5 minute intervals. For reference, we also simultaneously measured the outdoor ambient temperature.

According to statistical analysis, the outdoor environment has an average temperature of 30°C during the day (8:00-18:00) and of 25.6°C at night (0:00-8:00, 18:00-0:00); the average temperature of the outer surface of the wall without vertical green is 33.4°C during the day and 25.8°C at night, while the average temperature of the wall with vertical green is 25.8°C during the day and 25.4°C at night; the average temperature of the inner surface of the wall without vertical green is 25.2°C during the day and 25.5°C at night, while the average temperature of the wall with vertical green is 23.8°C during the day and 25.3°C at night; the average temperature indoor without vertical green is 25.6°C during the day and 25.4°C at night, while the average temperature indoor with vertical green is 23.8°C during the day and 25.3°C at night. Thus, it can be concluded that the influence of vertical greening on room temperature is greater during the day with respect to that at night. While there is about 2°C difference between two rooms, it means that vertical green can be effective to reduce the indoor temperature during the day.

In addition, this paper also draws Figure 3 based on the measurement data. Figure 3a is the comparison of indoor temperature with or without vertical greening, while Figure 3b and 3c are the comparison of external/internal surface temperature of the envelope structure with or without vertical greening respectively. Generally speaking, the outer surface, inner surface and indoor temperature of the room with vertical greening are lower than those without vertical greening, and the temperature of the room with vertical greening is more stable than that without vertical greening, which will have better thermal comfort. Therefore, it can be seen from Figure 3b that the temperature of the external surface of the wall with vertical greening is significantly lower than that of the wall without vertical greening, and the temperature of the external surface of the room without vertical green is even higher than the outdoor temperature, which indicates that green plants have a positive effect on reflect/absorb solar radiation.
3.2. Comparison of indoor and outdoor humidity

As shown in Figure 4, the average relative humidity of the outdoor environment is 44.6% during the day (8:00-18:00) and 46.9% at night (0:00-8:00, 18:00-0:00); The indoor average relative humidity without vertical greening is 62.5% during the day and 48.3% at night, while it is 66.4% during the day and 48.1% at night with vertical green. It means that vertical green can be effective to increase the indoor humidity during the day, and the humidity in a room with vertical green is more stable than that without vertical green.
4. Conclusion
This paper analyzes the temperature and humidity of rooms with and without vertical green, and it can be concluded that vertical green can significantly improve the comfort of indoor environment.

(1) The average temperature of the outer surface of the wall with vertical green is 7.6°C lower than that of the wall without vertical green. This shows that vertical green can reduce the surface temperature of the wall.

(2) The average indoor temperature of a room with vertical green is 1.8°C lower than that of a room without vertical green. It shows that vertical green can increase the thermal inertia of the outer envelope structure and avoid large changes in indoor air temperature.

(3) The relative humidity of a room with vertical green is 3.9% lower than that of a room without vertical green. In addition, the humidity of the room with vertical green is relatively stable, which has a good effect on improving the indoor thermal environment in summer.

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