Experimental Investigation on the Effect of Vertical Greening Facade on the Indoor Thermal Environment: A Case Study of Dujiangyan City, Sichuan Province

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Abstract. The vertical greening system is more and more widely used in architectural design and it is one of the sustainable development trends of new buildings. The green vertical façade can alleviate the urban heat island effect and improve the indoor thermal environment. To study the effect of vertical greening on indoor temperature and humidity and wall surface temperature, this study carried out a comparative experiment between two rooms that have completely identical structures and functions with or without vertical greening in Dujiangyan. According to the research, when vertical greening is adopted, the room temperature is reduced by 2.2°C on average and the surface temperature of the exterior walls is lowered by 13.9°C. Vertical greening can effectively reduce the temperature of the interior and exterior surfaces of the wall, improve the indoor thermal environment and better achieve building energy efficiency.

1. Introduction

In recent years, with the rapid advancement of urbanization in China, the area of green land has been decreasing and a large number of natural vegetation has been replaced by reinforced concrete buildings. It has caused many environmental problems, such as urban heat island effect, greenhouse gas emissions and building energy consumption high. Vertical greening façade is an exterior wall that is planted with plants mainly used for aesthetic and ecological purpose [1]. Vertical greening of buildings can effectively alleviate the deterioration of urban ecological environment.

According to data issued by the United Nations Environment Deployment Department, building energy consumption accounts for 40% of total energy consumption [2]. Therefore, reducing building energy consumption is an effective way to solve urban heat island effect and greenhouse gas emissions. Scholars at home and abroad have carried out different degrees of research from the perspective of green building. Liu Baohua combined with meteorological data to analyze the temperature changes of non-greening and green roof rooms in summer during natural operation and air conditioning and conducted systematic analyses of roof greening and cooling qualitatively and quantitatively [3]. He Yongzhong[4]carried out a comparative analyses of the energy consumption of a villa building when it was under the condition of vertical greening and non-vertical greening, and proposed countermeasures for the maintenance of greening on this basis. Liu Yanfeng[5]tested the influence of exterior wall greening on the indoor thermal environment in the hot summer and warm winter zone and found that vertical greening could effectively console the west wall temperature. Peng Nanjing discovered installed living wall could relieve the overheating phenomenon of wall surface in summer to achieve
energy saving and cool down [6]. Giuliano Vox[7] studied temperature variation about the exterior wall surface covered with pandorea jasminoides variegated and Rhyncospermum jasminoides in the Mediterranean climate.

Till now, most of researches on vertical greening focus on the application and promotion of vertical greening technology and analyses of different plant species in vertical greening. Hence, this study fills a gap in related research in Sichuan. The study selects two rooms with and without vertical green facades as experimental test objects. It combines the climatic characteristics of the experimental area to analyse the improvement of indoor thermal environment and building temperature with vertical green facade, which provides a foundation for the relevant research.

2. Research process

2.1. Research objects
To study the effects of vertical green facade on indoor thermal environments and building facades, Yangcha Village in Dujiangyan is selected as the experimental site in this study, which belongs to subtropical monsoon climate with high air humidity, abundant rainfall and less sunshine in the year.

The experimental building orientation is 29 degrees from north to east, which is two-layer brick-concrete structure. The experiment uses plastic sheeting to seal the door and window openings and there are no high-rise buildings around. The building structure is shown in Figure 1. The room size is 15.42 square meters with 20 centimeters thickness climbing plants and the layer height is 3.60 meters. Otherwise, the area of the door is 3.1 square meters and room window area is 1.5 meters wide and 2.3 meters high. The room diagram is shown in Figure 2.

2.2. Research methodology
In order to explore the effects of vertical greening on indoor temperature and interior and exterior wall temperature, this study measures the temperature of the interior and exterior and the indoor temperature and humidity where there are climbing plants and no climbing plants.

Interior and exterior wall temperature measuring instruments are multi-channel temperature and heat flow tester which can achieve recording continuously. The outdoor air temperature and humidity are measured by air temperature and humidity tester every 5 minutes.

2.3. Experimental instruments and parameters
The main instruments used in this experiment and the test parameters are as follows:

2.3.1. Multi-channel temperature and heat flow tester
The multi-channel temperature heat flow tester consists of a host and a sensor that can not only simultaneously measure temperature and heat flux in real time, but also automatically store temperature and heat flux density according to storage time interval. This experiment mainly uses the instrument to test the surface temperature of the wall and its measurement precision can reach 0.2°C. The instrument is shown in Figure 3.

2.3.2. Air temperature and humidity tester
It is capable of continuously monitoring the temperature and relative humidity of the air for a long time. It can clearly and intuitively record the temperature and humidity of the indoor and outdoor air with a precision of 0.5 °C. The instrument is shown in Figure 4.
2.4. Arrangement of measuring point

2.4.1. Thermocouple probes
Each room is selected for 6 measuring points on the interior and exterior wall surfaces probed by thermocouple. Four thermocouples are placed on the walls of 1.4 m from the floor of the room. There is a thermocouple placing 0.9 metres above the floor center in the room, and the other is placed on the exterior surface of the wall.

2.4.2. The temperature and humidity tester
Use a temperature and humidity meter to measure the temperature and humidity inside and outside the room and each room is set up with two measuring points. The testers are placed 0.9m above the ground and walls covered with or without climbing plants. A Temperature and humidity tester can be placed outdoors in direct sunlight.

3. Data results and analyses

3.1. The effect about temperature and humidity
The experimental date is from May 10 to May 17 and the representative data of 8:00-18:00 on May 13 is selected for analyses. The indoor and outdoor temperature and humidity changes of the two rooms are shown in Figure 5 and Figure 6. According to the data, the average outdoor temperature is 29.95°C and the maximum is 39.2°C. The indoor temperature of the room with climbing plants ranges from 23.2°C to 24.1°C, with an average value of 23.75°C. However, the indoor average temperature and maximum temperature of the room without vertical greening are 25.59°C and 26.3°C, which are 1.84°C and 2.2°C higher than those with vertical greening. Due to the heat transformation, the temperature is transmitted to the indoor air through the wall so that the indoor temperature of the non-vertical greening room is higher than the indoor temperature of the vertical green room. The average humidity of the room with vertical greening is 86.36%RH and that of the room without vertical greening is 82.56% RH. Owing to the evaporation of moisture in the air caused by excessive temperature, the humidity of the room without vertical greening is lower than that of the room with vertical greening.

3.2. The effect about temperature of interior and exterior walls

The maximum temperature of interior and exterior wall surface temperature reflects the absorption degree of solar radiation by vertical greening. The temperature changes of the interior and exterior walls with or without vertical greening are shown in Figure 7 and Figure 8.

According to the analyses of Figure 7 and Figure 8, the temperatures of interior and exterior walls with vertical greening are obviously lower than that without vertical greening. The maximum differences of the interior and exterior walls are 1.5°C and 13.9°C respectively. The study shows that vertical greening of walls reduces the solar radiation to decrease exterior temperature of walls, while the surface temperature of walls without vertical greening increases gradually with the increase of the solar radiation.
4. Conclusions
This study explores the impact of vertical greening on the indoor thermal environment based on the climate characteristics of Dujiangyan City. According to the experimental data analyses, the temperature of the room with vertical greening is 1.84°C lower than that of the non-vertical greening room and the maximum difference is 2.2 °C. The vertical greening improves the temperature of the exterior surface of the wall by affecting the thermal environment around the building, thereby reducing the indoor temperature. At the same time, the higher the outdoor temperature is, the more obvious the improvement of the vertical surface greening on the wall surface and indoor temperature is. Therefore, vertical greening as a green energy-saving technology can achieve social and economic benefits. In view of the limitation of experimental conditions, there are still many shortcomings in this study. This study only tests the indoor and outdoor temperature and humidity as well as the surface temperature of interior and exterior wall. In the future, comprehensive analyses can be carried out in combination with factors such as solar radiation, greening rate and heat flow.

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