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An experimental evaluation of the living wall system in hot and humid climate

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ABSTRACT

This research aims to identify the microclimate of the living wall system (LWS) in a hot and humid climate and to examine how ventilation and different wall-vegetation distances (w-v-d) affect the thermal performance of the LWS. Two identical thermal labs are constructed with adjustable LWS installed on their west-facing walls in Wuhan, China. Three series of experiments were carried out. Results show that the LWS has a notable cooling effect to the wall surface and the indoor space. The microclimate created by the LWS features in a cool layer of air with identical mean relative humidity as the ambient air. Instead of gaining heat, the exterior wall surface is losing heat to the microclimate all day, where the LWS is the cooling instrument that removes heat by radiative heat exchange. The LWS with a sealed air layer performs better in cooling the wall surface than the LWS with a naturally ventilated air layer. Lastly, three comparison experiments tested the LWS with different w-v-d: 30 mm, 200 mm, 400 mm, and 600 mm. Results show that the smaller distance has better cooling effect but higher relative humidity in the air layer.

1. Introduction

With the rapid development featuring urbanization in China, cities are expanding and towns are becoming cities. More and more land with vegetation cover is converted into urban environment and most cities have less than 10% of their total land area remaining as green spaces. In order to improve the urban ecological environment, green spaces need to be preserved and to be implemented inside the urban area extensively. Francis and Lorimer [1] state that living walls (as well as living roofs) represent ecological engineering techniques with notable potential for reconciliation ecology, either by replicating urban or non-urban natural and semi-natural ecosystems; or preferably by allowing spontaneous urban assemblages to form.

There are three terminologies relating to living walls: green façades, living walls, and biowall. Green façades refer to the establishment of climbing vegetation which is rooted in the ground or planters, and which is then trained to grow directly on wall surfaces or on an overlying wire or trellis framework (Francis and Lorimer [1], Dunnett and Kingsbury [2]). Living walls support vegetation that is either rooted on the walls or in substrate attached with the wall itself, rather than being rooted at the base of the wall (Francis and Lorimer [1], Dunnett and Kingsbury [2]). A biowall is a living wall or green façade that is constructed on indoors walls (Francis and Lorimer [1], Dunnett and Kingsbury [2]). The research subject of this paper is the living wall system (LWS).

Summer in Wuhan, China is hot and humid. During the hottest months (July–September), the peak day temperature can reach up to 40 °C with an average relative humidity more than 70% which makes the heat intolerable. That the night temperature remains no less than 30 °C with little natural ventilation worsens the situation. Wuhan is a typical big industrial city that has expanded twice its size in the last twenty years. The Urban Heat Island effect has a strong influence on Wuhan's climate, causing high temperatures inside the city and allowing little natural ventilation. In summer, reduced heat and humidity is crucial for maintaining spaces in comfortable conditions. When designing LWS with buildings, the ideal implementation is to reduce the heat load without increasing the air humidity substantially.

2. Literature review

Green façades have historically been used in buildings and more researches have been found on green façade than the LWS. Since they do share some similar features, researches on green façade are also useful for understanding the LWS. Thus a review on both fields is performed.

2.1. Green façade

Prez et al. [3] verified that a microclimate between the wall of the building and the green façade is created, and it is characterized by slightly lower temperatures and higher relative humidity.

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Kontoleon and Eumorfopoulou [4] found that the influence of a green layer on the wall surface is more pronounced for east or west oriented surfaces. Wong et al. [5] performed a simulation research and found that green façade is able to lower the mean radiant temperature values and that 50% greenery coverage and a shading coefficient of 0.041 can reduce the envelope thermal transfer value of a glass facade building by 40.68%. Sunakorn and Yimprayoon [6] studied climbing plants as vertical shading devices for naturally ventilated building in terms of influencing air temperature and wind velocity. The indoor air temperature of the biofaçade room remains lower than the control room during daytime. The biofaçade also improves ventilation for a naturally ventilated room. Perini et al. [7] studied the difference between the green façade attached directly to the wall and the green façade attached indirectly to the wall (with an air gap). A small temperature reduction of 1.2 °C was found on the surface of the wall behind the direct green façade compared to the surface of the bare wall, and a reduction of 2.7 °C was found for the indirect greenery system.

2.2. The LWS

Wong et al. [8] studied eight different LWS and green façades installed on free standing concrete walls. The LWS with modular panels showed better capacity in reducing the temperature of the wall surface and having the lowest diurnal range of average wall surface temperature fluctuation, comparing to the green façade. The maximum reduction of the wall surface temperatures by the cooling effect of the LWS is 11.58 °C. Olivieri et al. [9] studied a LWS in an experimental building and found that during diurnal hours, the indoor temperature of the LWS was 20% lower and had a smaller fluctuation than temperature in the space without vegetation. Perini et al. [7] showed the potential of the LWS on reducing the wind velocity around building façades: a decrease from 0.56 m/s to 0.10 m/s starting from 10 cm in front of the façade to the air cavity. Alexandri and Jones [10] simulated the thermal effects of green roof and green walls on the urban environment. Simulated results show that green walls have a stronger effect than green roofs inside the urban canyon. The combination of both green roofs and green walls could bring temperatures down to more comfortable levels and achieve energy saving for cooling buildings from 32% to 100%.

In sum, existing research about the green façade and the LWS shows that both the systems have great potential in reducing building surface temperatures, promoting energy saving, as well as mitigating Urban Island Effect. No existing research has studied the thermal environment of the microclimate between the LWS and the wall, nor explained the mechanism of its cooling effect.

This paper focuses on the thermal behavior of the microclimate between the LWS and the building wall. Detailed description of the heat exchange process, temperature shift, and relative humidity conditions of the microclimate are provided and analyzed to identify its thermal features. Then, two parameters of the microclimate are adjusted to examine how they alter the cooling effect of the LWS. One parameter is the ventilation status of the air layer; the other is the w-v-d. Both parameters are design concerns in the implementation of the LWS. To find out how these parameters would affect the LWS's cooling effect is helpful for making design decisions in LWS practices.

3. Methodology

3.1. Design of the thermal labs

An experimental approach is used in this research. First, two identical thermal labs are built on the roof of the 3-story Architecture department building in Wuhan, China (Fig. 1). The building

Fig. 1. Thermal labs with the LWS on the roof.

envelope is carefully designed to be well insulated. It has a heat transfer coefficient value of 0.25 w/m^{2}k and a Thermal Inertia index of 2.5, required by "Design Standard for Energy Efficiency of Residential Buildings in Wuhan City Zones" (DSEERB-WCZ, a local code for energy efficiency design of residential buildings in Wuhan. Code No: DB42/T 559-2009). The better the thermal labs are insulated, the slower they get heated during the day. The roof of the thermal lab is built with double plates with a naturally ventilated air layer in between to prevent overheating from direct solar radiation. The windows have low-e double glazing glass with shutters installed at a fixed angle (60° from horizontal plan) that can block all direct solar radiation and still allow ventilation when the windows are open. The west walls are attached with an adjustable steel structure that can be moved to and away from the wall. The allowable distance between the steel structure and the wall ranges from 30 mm to 600 mm. The gap between the steel structure and the wall is covered completely by horizontal and vertical shading devices from the top, the south, and the north side, so that the air layer does not get heated by direct solar radiation. Natural ventilation is still allowed in the air layer, shown in Fig. 2. Twenty-five vegetation boxes, 500 mm in square and 10 mm in depth, are arrayed and hung on the steel structure to cover the whole west wall area. The substrate is a mixture of light growth media. Six different plant species were transplanted randomly in the boxes two months before the experiment. The substrate is watered once a day thoroughly by electrically controlled irrigation system (Nelson SoloRainTM 8014 DuraLifeTM). Detail of the LWS is shown in Fig. 3.

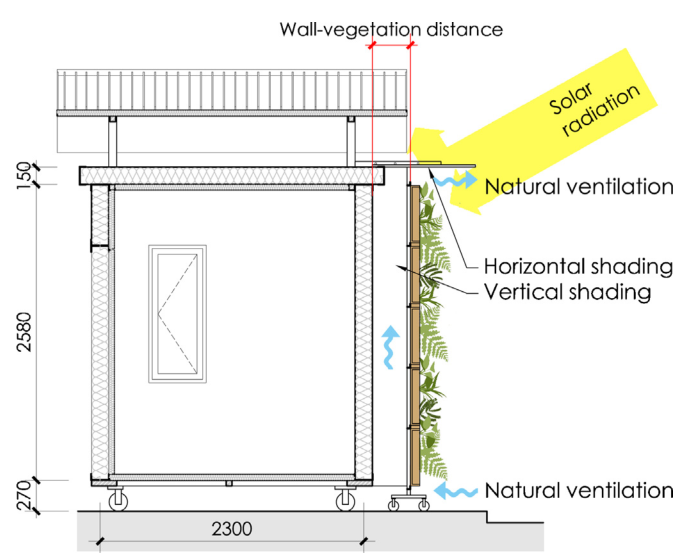

Fig. 2. Section of the thermal lab.