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EXPERIMENTAL AND NUMERICAL VERIFICATION OF VERTICAL GREEN WALL FOR THERMAL INSULATION AND HEAT PRESERVATION ON BUILDING

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Abstract. *Shading facilities for blocking the sunshine and insulation facilities for keeping suitable temperature need to be designed for buildings in many countries. Roles of plants are used as the growth medium for vertical greening wall to create the excellent shading and good outdoor microclimate for buildings. To create outdoor thermal comfort environment for residents, vertical green wall with hanging plants is established along path of dog go to increase façade and wind channel for building. Outdoor thermal comfort, semi-outdoor thermal comfort instruments and micro-scale weather station are applied to collecting real test data from two full-scale experimental houses, with and without vertical green wall in central Taiwan respectively to compare the real insulation and heat preservation efficacy of this proposed green wall. Then, Computational Fluid Dynamics (CFD) is applied to analyzing the thermal insulation and heat preservation efficacy in various weather conditions. Test and numerical results show that indoor temperature keeps warmly 5°C in winter and drops down 3°C in summer. Otherwise, the space between building and dog go causes wind channel to increase outdoor thermal comfort environment.*
Keywords: Hanging plants, Computational Fluid Dynamics (CFD), The efficacy of thermal insulation and heat preservation, Outdoor and semi outdoor comfort instrument

1. **Introduction.** According to the research achievements of Cheng et al. [1], there are four effects by greening façade. First, greening walls are visual focal points. These walls enrich dull artificial walls in garden or public spaces and also create beautiful landscape. Second, greening walls build excellent survival spaces and foods resources for animals. Evergreen climbing plants provide warm spaces for small animals in winter. Third, greening façade has cooling effect in summer. These walls provide with shading effect and evaporation to cool down outdoor environment, drop down the indoor temperature, decrease sun glare, reflect heat and adjust micro-weather environment. Forth, air temperature around green wall can be dropped because thick plants layer becomes an insulation layer as a calm wind zone [2-10]. Presently, green walls are divided as climbing wall type, hanging wall type and front wall type by *Neo Green Space Design Japan II* [11,12].

Construction methods of greening wall for climbing plants method or potted plants method are divided into contracture and indirect erection of the components respectively.

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Figure 1. Osaka University greening wall [11,12]

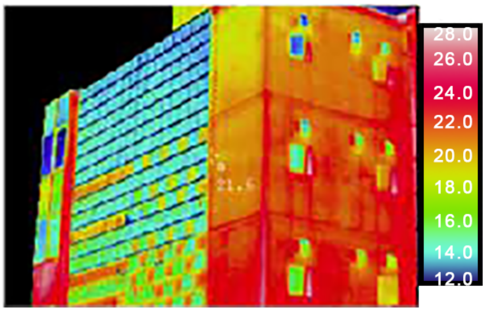


Figure 2. Image of infrared thermal image

The basic types of plants are natural ground, artificial ground, pot type, panel, greening bricks and mounting wall. The façade on an Osaka University building [11,12], seen as Figure 1, plants Bermuda grass, Ivy, Shortleaf Lilyturf and Chinese Juniper with peat, coconut fiber and other organic mediums. The water demand is 1.5 ml/m^2 in spring and fall, 3 ml/m^2 in summer and 0.6 ml/m^2 in winter. The plants need to be cropped and fertilized once or twice per year. The highest temperature is 40-45°C before making the greening wall by the temperature monitoring data. It dropped down to 30-35°C after making the greening wall. The difference is very obvious between the walls with and without greening, shown in Figure 2, captured by infrared thermal image. In this study, the vertical greenery wall with hanging type is constructed with one meter from external western wall of building to create a wind channel to increase outdoor thermal comfort environment, thermal insulation and heat preservation for building. Outdoor thermal comfort environment, thermal insulation and heat preservation effects for indoor temperature are tested and simulated to compare the practical benefits of this proposed type to verify the real effects of this proposed type in various seasons by real test and CFD simulation.

2. Methodology.

2.1. **Test method and experimental equipments.** Micro-weather station, shown in Figure 3(a), is established in National Chin-Yi University of Technology, Taichung, Taiwan to collect temperature, humidity, amount of insolation wind speed, air volume, wind direction, and rainfall in this area. A full-scale experimental house with hanging potted pothos as greening wall is shown in Figure 3(b). Outdoor thermal and semi-outdoor thermal comfort equipments are installed at dog go and test point of building, shown in Figure 4(a) and Figure 4(b), to detect temperature, humidity, amount of insolation, wind speed, air volume and wind direction for surveying efficacy of thermal insulation, heat

(a) Micro-weather station

(b) Full-scale experimental house

FIGURE 3. Test equipments and full-scale test and control houses

(a) Vertical greening with semi-outdoor thermal comfort equipment

(b) Outdoor thermal comfort instrument

FIGURE 4. Test equipments for semi-outdoor and outdoor thermal comfort instruments

preservation and energy saving from outdoor vertical greening. Three-dimensional model is applied to simulating thermal insulation and heat preservation effect of sunshine angle to experimental house in four seasons. Then, thermal insulation and heat preservation effects of experimental house are compared with those of compared house by test and simulated data.

Figure 5 shows the location of the surface temperature patches to detect the temperature variance of this test in four seasons. Figure 6 displays the three-dimensional model for Computational Fluid Dynamics (CFD) to analyze the thermal insulation and heat preservation effects of green wall with various sunshine angles in different seasons. Airflow state is resolved from the micro meteorological data from micro-weather station, outdoor thermal comfort and semi-outdoor thermal comfort instruments. The influence

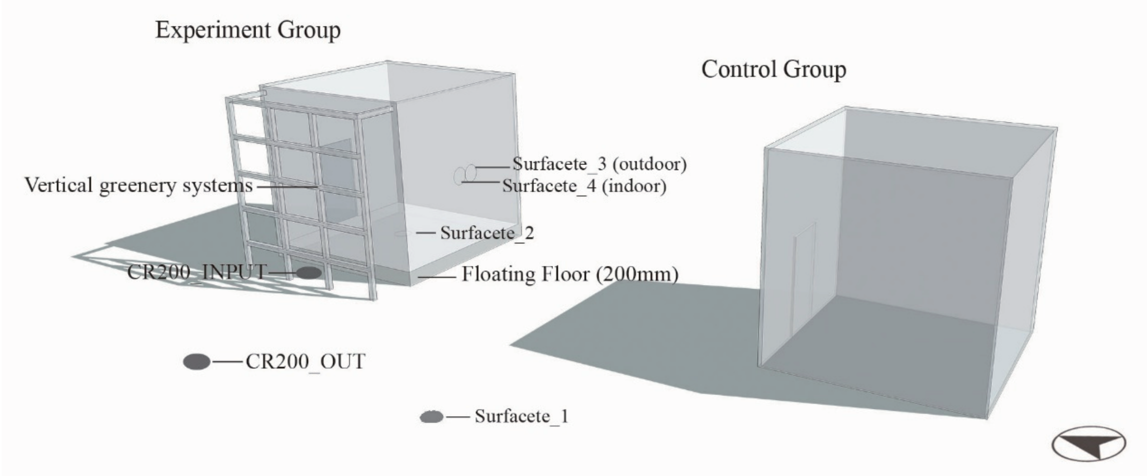
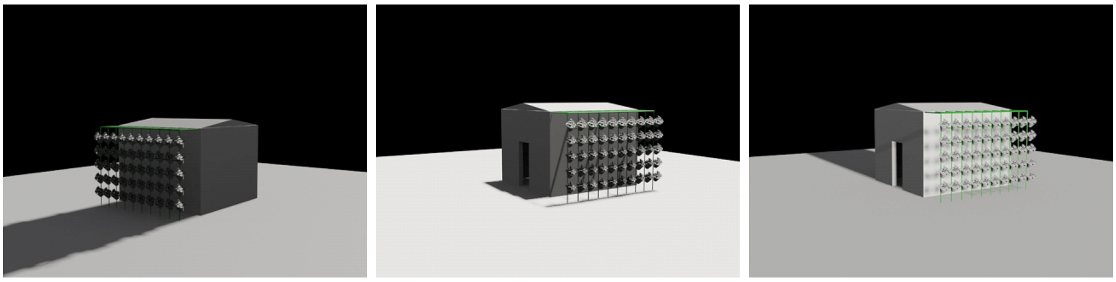


FIGURE 5. Locations of data captured



(a) Morning (b) Noon (c) Nightfall

FIGURE 6. 3D model simulation for various sunshine angles with vertical greening wall

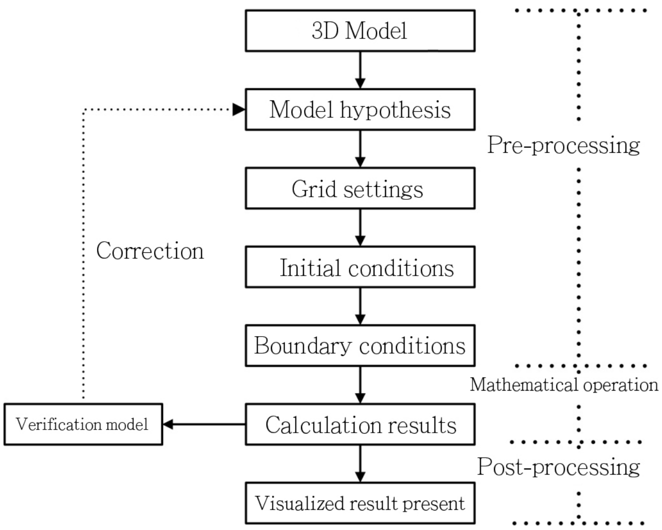


FIGURE 7. Research flow chart of this study

of airflow around experimental house is investigated and also analyzed to obtain analysis parameters for CFD simulation. Then, the real thermal insulation and heat preservation effects of green wall of test house are verified and compared with those of compared houses. Simulation diagram of CFD process is shown in Figure 7.

2.2. **Mathematical modeling.** The energy equation is applied as external heat source to a building, detected by real test data. Considering the heat phenomenon, includes convection in fluid, conduction in solids, thermal (solar) radiation, and external heat gains.

$$\rho\frac{\partial\vec{V}}{\partial t} + \rho(\vec{V}\cdot\nabla)\vec{V} = -\nabla P + \rho\vec{g} + \mu\nabla^2\vec{V} \tag{1}$$

$$\rho C_p\frac{\partial T}{\partial t} + (\vec{V}\cdot\nabla)\rho C_p T = \nabla\cdot(k\nabla T) + \mu\Phi + \dot{q} \tag{2}$$

$$\rho = \frac{p_{op} + p}{\frac{R}{M_w}T} \tag{3}$$

where T: Temperature; ρ: Density; C_p: Specific heat; q: Heat source (mean solar radiation); R: Gas constant; M_w: Molecular weight of gas; $-\nabla P$ is the pressure force; $\rho\vec{g}$ is the gravity force; $\mu\nabla^2\vec{V}$ is the shearing force; $\nabla\cdot(k\nabla T)$ is the conduction dissipation; $\mu\Phi$ is the viscous dissipation; and $\dot{q}$ is the heat generation.

Operating temperature is as follows:

$$T_{op} = \begin{cases} \left(M.R.T + T_a\sqrt{10v}\right)/\left(1+\sqrt{10v}\right) & (v \geq 0.1\text{m/s}) \\ \left(M.R.T + T_a\right)/2 & (v < 0.1\text{m/s}) \end{cases} \tag{4}$$

$$M.R.T = \left(\frac{I_{rad}\cdot\pi}{\sigma}\right)^{0.25} \tag{5}$$

where $M.R.T$: Means radiation temperature (T_a); T_a: Ambient air temperature (°C); T_{op}: Operative temperature (°C); v: Velocity (m/s); σ: Stefan Boltzmann constant (kg/(s^3·K^4)); I_{rad}: Radiation intensity (W/(m^2·sr)).

Detecting data for sun effects are applied for the sunshine tracking algorithm, including sun direction vector, sunshine quantity, direct and diffuse reflection solar radiation. The formulas of solar thermal radiation effect are listed as follows:

$$E_{total} = E_{direct} + E_{diffuse,solar} + E_{reflect,ground} \tag{6}$$

$$E_{d,solar} = CE_{direct}\frac{1+\cos\varepsilon}{2} \tag{7}$$

$$E_{r,ground} = E_{direct}(C+\sin\beta)\rho_g\frac{1-\cos\varepsilon}{2} \tag{8}$$

where E_{total} is the total solar radiation; E_{direct} is the normal direct solar irradiation; $E_{diffuse}$ is the total diffuse irradiation; $E_{d,solar}$ is the diffuse solar irradiation; and $E_{r,ground}$ is the ground reflected solar irradiation.

All parameters for simulation analysis are determined by real test results. Then, these parameters are applied to simulating all situations of various seasons.

3. **Results and Discussion.** In this study, an overload cold weather affected Taiwan in the end of January, 2016. Average temperature dropped down the lowest point for 10 days in 44 years. Test results are listed in Figures 8 and 9. Atmospheric temperature chart is shown in Figure 8. Temperature chart from black balls of outdoor and semi-outdoor thermal comfort equipments is displayed in Figure 9. Figures 10 and 11 are temperature variation of external and internal western wall and outdoor and indoor floor of building respectively.

Test results in summer are that the average temperature of summer is around 27 to 29°C in central Taiwan. This study detected weather data from 20 to 24 June, 2016. Atmospheric temperature variation in this time period is shown in Figure 12. Then, temperature chart from black balls of outdoor and semi-outdoor thermal comfort equipments is shown in Figure 13. Figure 14 displays temperature variation and comparisons of green wall, western external wall of test house and western external wall of control house respectively.

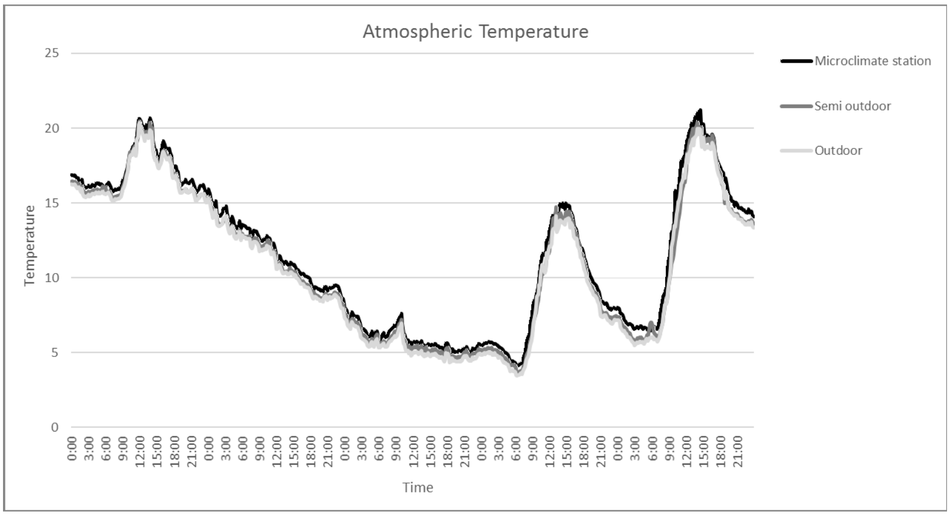


FIGURE 8. Atmospheric temperature variation

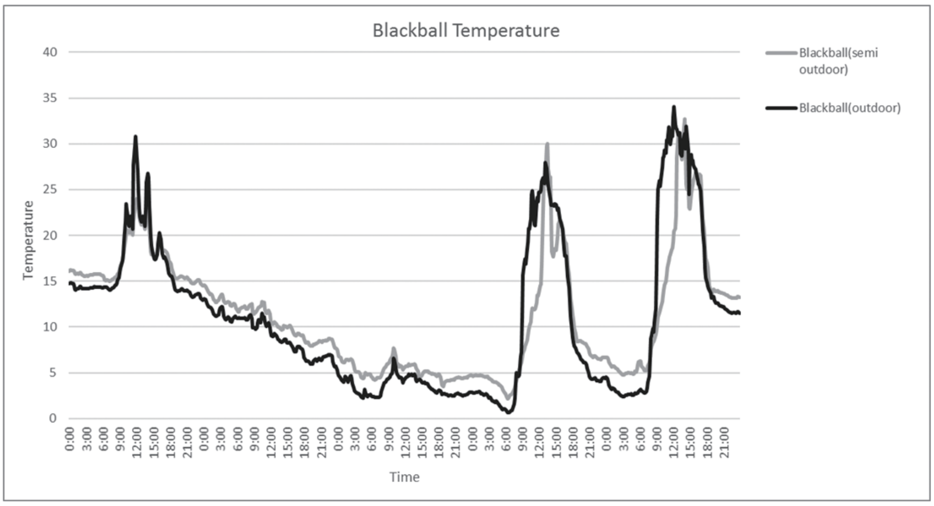


FIGURE 9. Temperature chart from black balls of outdoor and semi-outdoor thermal comfort equipments

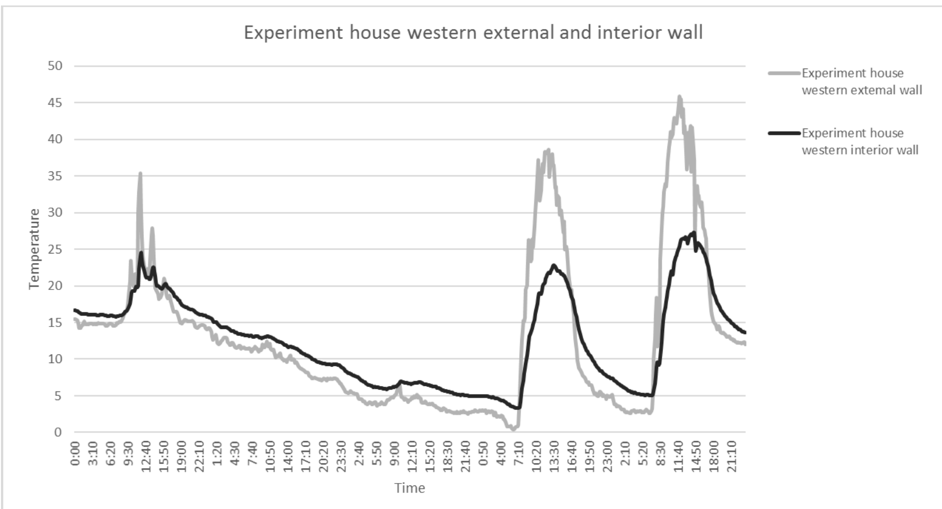


FIGURE 10. Temperature variation of west external wall and interior wall of test house

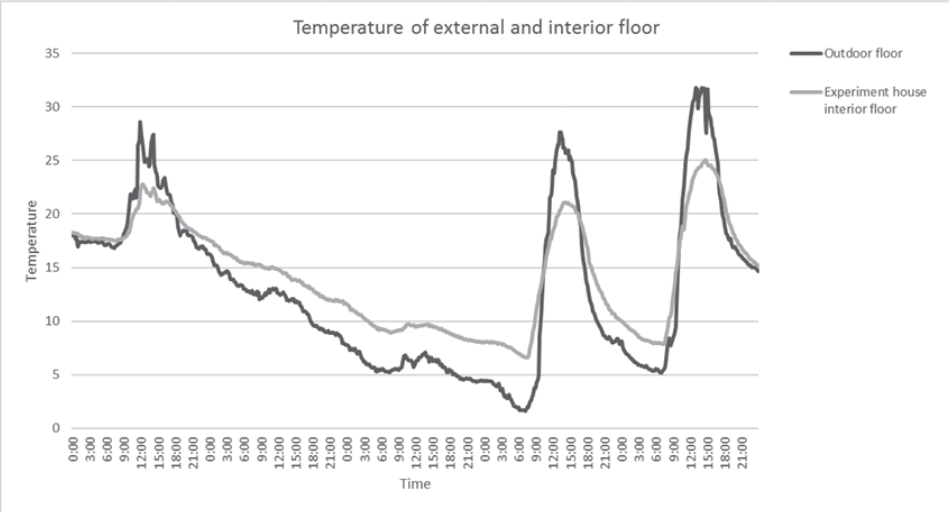


Figure 11. Temperature variation of outdoor floor and indoor floor

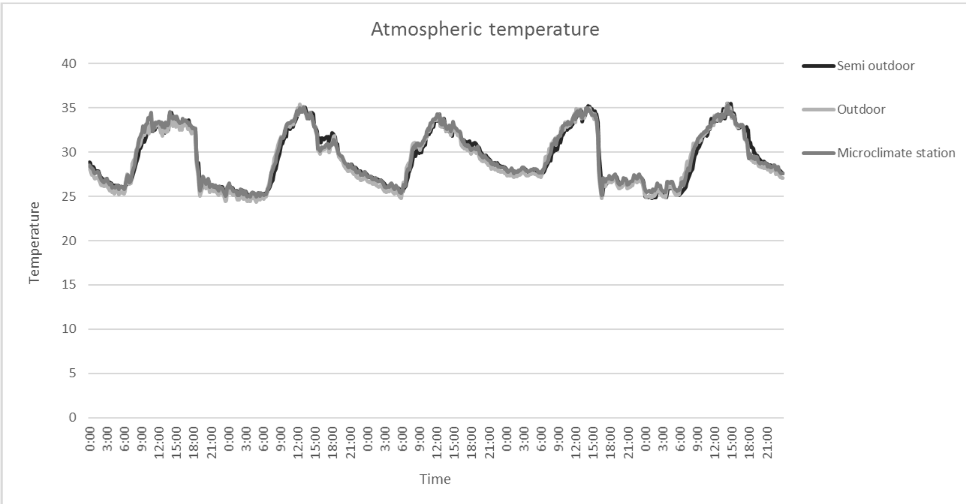


Figure 12. Atmospheric temperature variation

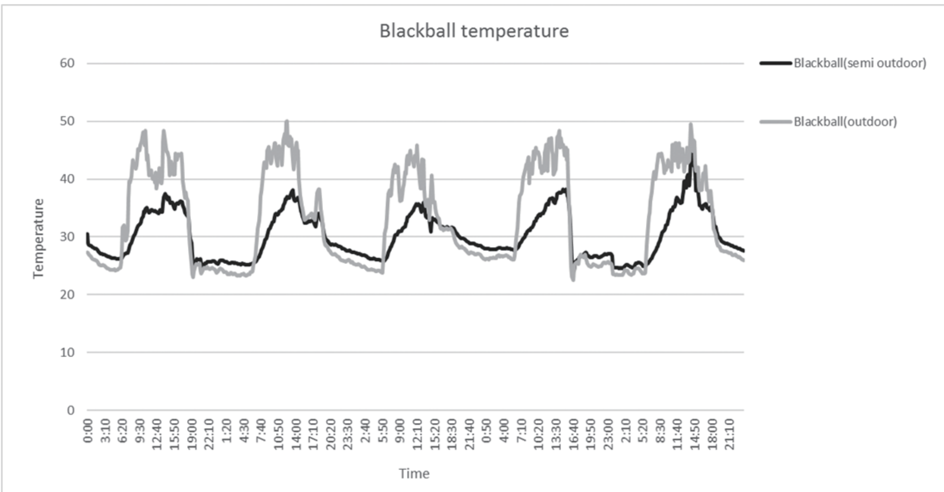


Figure 13. Temperature chart from black balls of outdoor and semi-outdoor thermal comfort equipments

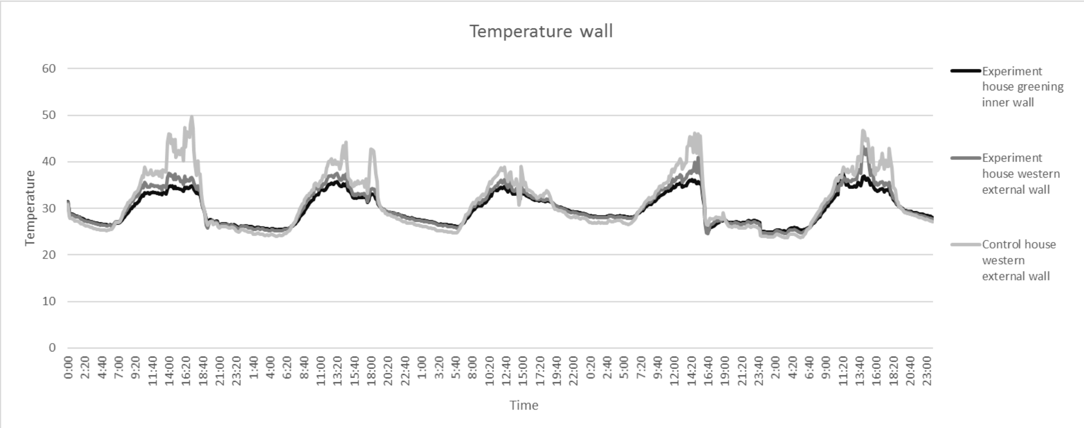
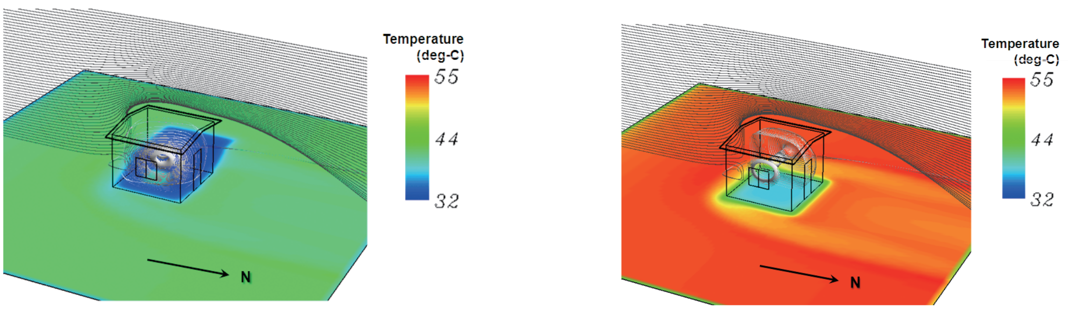


Figure 14. Temperature variation of green wall and western external wall of experimental house and western external wall of control house



(a) Indoor and outdoor temperature variation in winter

(b) Indoor and outdoor temperature variation in summer

Figure 15. The simulation results of CFD analysis of test house with different season

Then, analysis results of formula calculation and CFD simulation are visualized as Figure 15 based on all detected data. Figures 15(a) and 15(b) show the simulation results of indoor and outdoor temperature variation in winter and summer respectively. Otherwise, the wind speed along path of dog go with green wall is 3.5-4.5m/sec. Then, these results can be compared with the test results of test house installed with green wall to verify the thermal insulation and heat preservation effects of building with this proposed system.

In winter, when outdoor atmospheric temperature dropped down to 5°C, the surface temperature of floor kept warm around 10°C in experimental house on winter. Temperature difference between outdoor atmospheric temperature and surface temperature of indoor floor reaches about 5°C. When the temperature of external wall dropped down to 3-5°C, the interior wall still kept 6-8°C. Heat preservation effect of this proposed system is about 5°C.

In summer, when atmospheric temperature was 33-35°C, the black ball temperature of outdoor comfort instrument was dramatic changed as 37-39°C. The black ball temperature of semi-outdoor instrument minor changes as 35-37°C. The temperature of western external wall of control house has been changed violently as 37-49°C during the same time period. However, the temperature of western external wall of experiment house was changed slightly as 35-37°C. However, the temperature of greening wall of experimental house changes even more stably as 31-34°C. The thermal insulation effect of this proposed system is about 3°C.

4. **Conclusion.** This research carries out the real test and numerical simulation to confirm the thermal insulation and heat preservation effects of this proposed system. Some conclusions can be summarized as follows.

1) Vertical greening wall provides not only thermal insulation in summer, but also heat reservation in winter. It stabilizes the temperature of interior floor or wall changes in experimental house. The vertical greening wall keeps more 5°C in winter and drops down 3°C in summer. Otherwise, wind speed along green wall is about 3.5-4.0m/sec. This proposed green wall system can improve the indoor temperature and humidity and also provides a fine outdoor thermal comfort space.
2) The 3D model simulation analysis results of CFD program are coincided with test data of experimental house. The simulation accuracy with different scales or modeling can possess with a considerable degree of reference effect for designing this proposed system for building.

This proposed system can be combined with green roof and hot sunshade to find the overall benefits of thermal insulation and heat preservation effects of building in Subtropical region.

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