Surface Temperature Performance of Green Façade Wall

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***Abstract*— An application of green facade on external wall is a passive solution to improve outdoor microclimate, indoor thermal condition and later reduce the energy usage for cooling. The shading effect from the green façade decreases the surface temperature of behind wall and lessen heat to be transferred from outside toward inside. Thus, the objective of this study is to investigate surface temperatures performance on exterior and interior of wall attached with green façade. Two test cells were used in this study, which one of the test cells was attached with green façade and one left bare as control. Maximum temperature of exterior surface of wall with green façade was reduced of 28.3 % compared to control bare wall. While, for indoor wall surface temperature was reduced at maximum of 10.6 %. For this type of vertical greenery system, the selection on climbers to be used on green façade should be well considered for the optimum temperature reduction performance.**

Keywords*— *Green façade, Surface temperature, Thermal performance

I. Introduction

An optimum indoor thermal comfort condition of one building is an ultimate requirement for every end-user. Therefore, there are various approaches have been introduced in achieving the desirable indoor thermal conditions. Such example, an application of green façade on exterior surface of the building as a passive solution can improve the indoor thermal condition [1-5]. Cooling effect performance from green façade is capable to regulate and modify the external microclimate closed to the building setting [6-10]. Simultaneously, the application can also contribute to the cooling energy saving [11]. The cooling effect performance of green façade can be detected from the differences in environmental setting such as air temperature, surface temperature, and relative humidity.

Surface temperature is the most widely used to denote the cooling effect performance of green façade. Koyama et al. [12] investigated plant percentage coverage and plant morphology on shading cooling effect performance on free standing wall with five different species of climbing plants in Nagoya, Japan during summer time. The external surface temperature reduction ranges of five species were 3.7–11.3 K. Perez et al. [9] and Perini et al. [10] also found external surface temperature reductions behind green facade were 5.5 and 2.7 K, respectively. Meanwhile, the investigation on the exterior surface temperature of small-scale experimental and existing observational green facade, Sandifer and Givoni [13] found that similar temperature decrement between both conducted measurements. The range of reduction was 8-21 K.

Nevertheless, the results and findings from the full-scale setup experiment are more appreciated due to the actual building materials and climatic conditions. Coma et al. [8] studied an external surface temperature reduction of a one-room building or test cell wall with green façade at the south orientation during summer in Lleida, Spain. The walls were constructed of gypsum, alveolar brick (30 × 19 × 29 cm), and cement mortar finishes. Maximum reduction obtained was 14 K. The study also investigated on the differences of internal surface temperature of the test cell. The maximum result was 2 K. Using the same research tool, Price [4] conducted an experiment using one-room building to explore the potentials of green facade on cooling effect performance in Clarksville, USA. He attached green facade at the south and west facing aspects of the test cell. One test cell was treated as control room. The external surface temperatures of western and southern aspect of wood framed walls with green facade were decreased at a maximum of 11.3 K and 6.4 K, respectively. Another full-scale setup experiment by Koyama et al. [1] was conducted in Japan, to investigate cooling effect on identical test cells which the external walls were built from metal siding (15 mm thick), and the interior walls made of plywood (4 mm thick). One was left as a control unit. The maximum difference for external surface temperature was 9.5 K. The internal surface temperature of the wall with green facade was 1.2 K lower than a control test cell.

In the reference of tropical climate, Sunakorn and Yimprayoon [3] steered a full-scale building on empirical investigation of green facade in Thailand. The experiment was run on the existing identical rooms. However, the study was designed to explore the use of green facade with the influences of natural ventilation. Without natural ventilation, the indoor air temperature for room attached with green façade was 0.53 K lower than the non-covered room. With natural ventilation allowed to go through the room, the indoor temperature was 0.89 K lower. A small-scale experiment, Laopanitchakul et al. [4] used three identical small-scale chambers (0.73 m^3) to study the effect of coverage percentage of tropical climbing plants on external and internal surface temperatures. Plants with greater coverage percentage performed significantly on external and internal surface temperatures. The differences of external and internal surface temperatures of higher percentage were 5 and 3.5 K, respectively. Wong et al. [14] studied the green facade cooling performance with various vertical greenery systems available in the market using free standing walls. The walls were erected in a public park in Singapore. The performance of green facade was good and it was able to reduce the external surface temperature at a maximum of 4.4 K compared to the bare wall.

Study on performance of cooling effect in the tropical climate is still in infancy stage. Thus crucial efforts need to be taken in order to provide knowledge of cooling effect performance of green facade on common construction wall materials especially in Malaysian context. Therefore, the objective of this study is to investigate wall surface temperature performance of common construction wall materials attached with green façade.

II. Methodology

Fig. 1 shows the setup for the experiment which involved test cells, green façade and instrumentations.

Fig. 1. Experiment setup of test cells; control test cell (right) and green façade test cell (left) and weather station (white arrow).

A. Test cell

The test cells were located at Faculty of Design and Architecture, Universiti Putra Malaysia, Serdang, Selangor (2.99°N, 101.71°E). Two units of test cell were used in this experiment. However, only one was attached with green façade at eastern and western orientation walls. The other test cell was left bare as control unit. The size of the test cells was 3.05 m (length) × 3.00 m (width) × 3.60 m (height). The test cells were built using sand brick and cement mortar with plastering on both sides of the walls. This is a common construction wall that is widely used in conventional building in Malaysia nowadays. East and west facing walls were no opening, however at south and north aspects, the openings were closed and sealed throughout the experiments to eliminate thermal infiltration.

Before green façades were attached on test cell walls, and before any measurements were taken, both of the identical test cells were investigated on the differences of indoor environment. The result from one way ANOVA test had confirmed that both of the test cells showed no significant difference in fluctuation and performance of indoor air temperature (df: 1487, F: 0.26, p: 0.87) as shown in Table 1. Therefore, the result for the comparison experiment to be undertaken is valid.

TABLE I. Variation study by one way ANOVA on performance of indoor air temperature

Test Cell	Mean	Std. Error	*F*	Sig.
Test Cell A (Control)	28.08	0.083	0.26	0.873
Test Cell B (Green Façade)	28.06	0.081	-	-

An important precautions need to be emphasised for this study is to minimise the thermal impact from the roof. The roof is a critical part of the building envelopes that was highly susceptible to solar radiation. In tropical climate region, the path of the sun generally goes through high altitudes during the daytime, exposing horizontal and inclined surfaces such as roof to intense direct solar radiation. Unlike vertical surfaces such as walls, the roof was exposed to the sun throughout the daytime all year round, significantly contributing to heat gain [15]. Therefore, this study had retrofitted the double roofs system on both test cells with the second roof was attached on top of the existing roof structure (Fig. 1). This technique is similar to ventilated roof passive cooling technique.

B. Green facade

Green façade for this study was custom-made to be specifically fitted onto the bare opaque wall of the test cell. The modular design of trellis corresponding to the shape of the eastern and western bare wall including the upper part was tailored with the pitch roof. It was also made to be covered on the overall surface of the bare wall at east and west aspects. The size of the structure was 3.00 m (width) × 3.10 m (height)/3.60 m (pitch height). The main structures of the trellis were made from 2 in. × 2 in. square hollow steel and the diagonal wire meshes on the trellis were common chain-link fences. All of the structures were coated with white paint to reduce heat absorption.

At the bottom of the green facade, nine boxes of polystyrene were used as planting pots. The size of each box was 62 cm (length) × 48 cm (width) × 37 cm (height). The white polystyrene boxes were used in this study due to its heat resistance and reflectance ability. In every planting pot, one climbing plant was planted. This was to encourage the healthy growth of the specimen. The substrate growing media used in every planting pot was mixed with topsoil, sand, and compost. The substrates were fertilised periodically. Watering was consistently occurred in the morning and late afternoon every day.

The climbing plant used in this experiment is *Argyreia nervosa* (AN). The distinguish trait of AN is the leaf size, which AN has an extra-large size (±25 cm). AN leaf shape is cordate (heart-shaped) with entire edges (smoothed). The pubescent surface of AN has soft white hair on the leaf surface. The climbing plants were left and trained for foliage establishment and covered at least 75 % of overall trellis surface of green facade before transferred to the test cell. The coverage establishment was needed in order to provide good results. The establishment took approximately one to three months depending on the species.

C. Instrumentation

Eight sets of single channel Onset Hobo U12 type K thermocouple with individual data logger were attached at the internal and external surface of eastern and western orientation walls to measure surface temperature (T_s) for both test cells. An Onset Hobo U30-NRC weather station was set up nearby to collect background meteorological parameters which included ambient air temperature, relative humidity, global solar radiation, wind speed, wind direction, and rainfall as shown in Figure 1 (white arrow). In addition, other climatic conditions also been measured for both test cells. Nevertheless, the measurements were carried out for ongoing interrelated research. The test cells were installed with Onset Hobo S-THB-M002 dry bulb temperature (T) and relative humidity (RH) with radiation shield in front of east and west orientation opaque walls. All measurements were recorded using U30-NRC Onset Hobo data logger. Two sets of Delta Ohm HD32.3 PMV data logger were placed indoor, at the middle of both test cells. They were equipped to measure and record indoor ambient temperature (T), indoor relative humidity (RH), air velocity (v), and globe temperature for both rooms. Globe temperature (T_g) is required in calculating radiant temperature (T_r) of indoor environment together with air velocity (v). This instrument automatically computed radiant temperature. All of the instruments were calibrated beforehand.

D. Measurement time and procedures

The experiment was executed on 26 June – 25 July 2013. Duration for experiment was one month (30 days). Before any measurements, the green facades were already transferred to the east and west aspects walls of test cells. Foliage coverage on both of green facade of same species was at least 75 % established before attached to the wall. Both rooms were left with no activity and occupant. All instruments were calibrated. Data collections were logged at every 10-minute interval for 24 hours. This was applicable to all instruments including the nearby weather station that recorded climatic parameters at the height of 3.5 m from the ground. Data were collected from data loggers after the experiment completed. Data collected were analysed for selected five sunny days. The sunny day was referred to high solar radiation throughout the day with the minimum average of 350 W/m² of global solar radiation. Comparative analyses were incorporated to investigate the performance of parameters of both test cells.

III. Results and Discussion

The assessment of the performance of cooling effect was carried out by comparative study on the thermal behaviour of two identical one-room buildings. The presented results are average of 10-minute data of five selected sunny days (i.e. 28 and 29 June, 10, 21, and 23, July 2013). Temperature difference in the figures indicates the cooling effect performance from the green façade. The negative (-) sign in the figures attached indicates the cooling effect performance of green facade, whereas the positive (+) shows the downside of the system.

A. External surface temperature

Both of the aspects performed significantly. At eastern aspect, external surface temperature (EST) of wall attached with green façade, average of 24 hours, is 28.8 °C and control was is 31.8 °C. The difference of average EST is 3.0 K which signified cooling effect performance of green facade. Meanwhile, at western aspect, the difference is smaller, only registered of 1.2 K difference. The average of green façade wall and control wall are 29.2 °C and 30.4 °C, respectively.

It can be seen in Fig. 2, the maximum reduction of external surface temperature (EST) at the eastern aspect is 15.2 K (0940) and at the western aspect, maximum reduction is 5.5 K (1510). The highest EST is recorded on eastern control wall with 44.2 °C (1040), whereas the green façade wall only registered at 31.7 °C (1320) for the same wall orientation. At western orientation, the maximum EST for green façade wall is 35.6 °C (1600) and 39.8 °C (1720) for control wall.

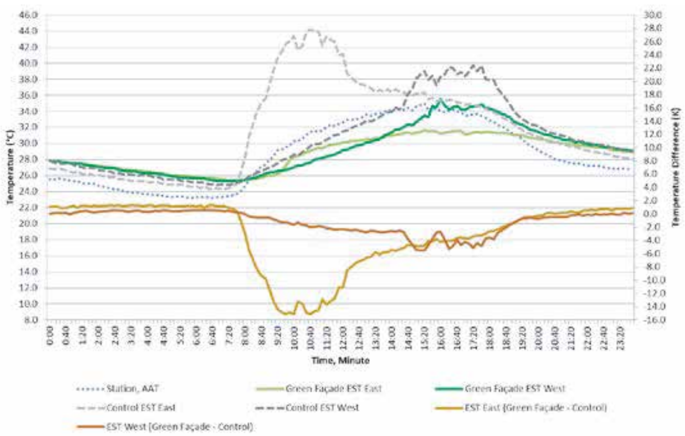

Fig. 2. External surface temperature (EST) for control and green façade walls for eastern and western orientations. Temperature difference shown the cooling effect performance of the green façade.

The plant parameters of higher percentage coverage and leaf area index encourage the green facade to perform efficiently. The percentage of the overall coverage of plant foliage on green facade has potentially improved the performance of green facade on the reduction of EST at the front of the opaque wall. The highest percentage of coverage intercepts more global solar radiation before penetrating to the behind wall. However, the loose arrangement of the plant foliage is conceivably encouraged the sun fleck to penetrate into behind wall. The loose arrangement hypothetically provides an ample and open gap area for the sunlit area.

Eventually, the air flanked by the green facade and the wall is heated, and then EST is increased.

The fluctuation of wall attached with green facade also considered small compared to the bare wall for both experiments. As shown in Table 2, the maximum and minimum amplitudes of green façade are significantly lower and produced a small gradient of fluctuation. The reduction of EST fluctuation implies to lengthening material (wall) lifespan which minimises crack and weathering cause of thermal expansion [16, 17].

TABLE II. MINIMUM, MAXIMUM AND GRADIENT OF FLUCTUATION FOR EXTERNAL SURFACE TEMPERATURE (EST) OF GREEN FACADE ON MEAN OF 10 MINUTES INTERVAL FROM FIVE SUNNY DAYS

Test Cell (°C)	**East**			**West**		
	Max	*Min*	*Gradient*	*Max*	*Min*	*Gradient*
Control	44.2	24.3	19.9	39.8	24.8	15.0
Green Façade	31.7	25.4	6.3	35.6	25.3	10.3

B. *Internal Surface Temperature*

The impact of shading from the plant foliage of green facade on the exterior surface of the wall can be seen on internal surface temperature (IST) fluctuation pattern. The pattern of both aspects is almost identical as shown in Fig. 3. Fig. 3 also shows cooling effect performance of IST. At eastern orientation, experiment reveals significant performances with a maximum reduction of 4.0 K at 1230. At western orientation, the maximum reduction is 2.3 K (1810). The possible reason for the low performance at western orientation is due to the small foliage coverage and density establishment of climber plants at this orientation. Table 3 summarises the overall thermal performance of IST. The average cooling effect performance of green façade on IST contributed 1.1 K and 0.8 K for eastern and western orientations, respectively. Maximum reduction IST are 4.0 K (1230) and 2.3 K (1810) for east and west aspects, respectively.

The performance indicates that green facade is able to stabilise the interior surface performance compared to control test cell. At most of the time, IST of green façade is even lower than the indoor air temperature (IAT) as shown in Fig. 4. The IST is lower than IAT during the daytime, slightly after sunrise (0800) and before sunrise (1700). From the figure also, it can be noticed that eastern wall of control test cell produces immediate impact towards the indoor thermal environment, which is only delayed for two hours after sunrise (at 0900). At western aspect, the bare wall of control test is delayed for two hours (at 1500).

Koyama et al. [1] conducted a full-scale experiment on green facade to study the IST performance in Nagoya, Japan. The performance of interior surface was notable, where green façade was able to reduce to average value up to 8.55 K under the condition of global solar radiation (GSR) above 600 W/m2. The highest reduction of the current study is 4.0 K for a maximum of an hourly average of sunny days. The reduction of IST in the current study is lower due the high thermal effect of heavyweight building materials. The lightweight building in Reference [1] was constructed by metal siding and plywood. Therefore, the reduction performance was rather impressive. The material choices of the building and even the colour on the external surface can influence the interior thermal performance [16]. It can be speculated that combination of green façade and wall materials able to improve overall thermal transfer value (OTTV) and simultaneously enhance indoor thermal performance.

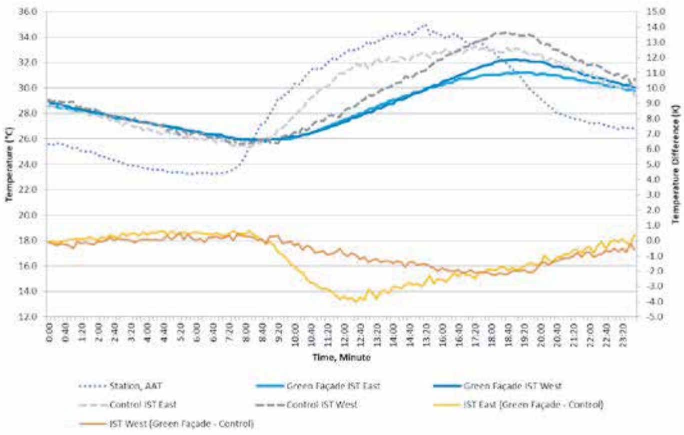

Fig. 3. Internal surface temperature (IST) for control and green façade walls for eastern and western orientations. Temperature difference shown the cooling effect performance of the green façade.

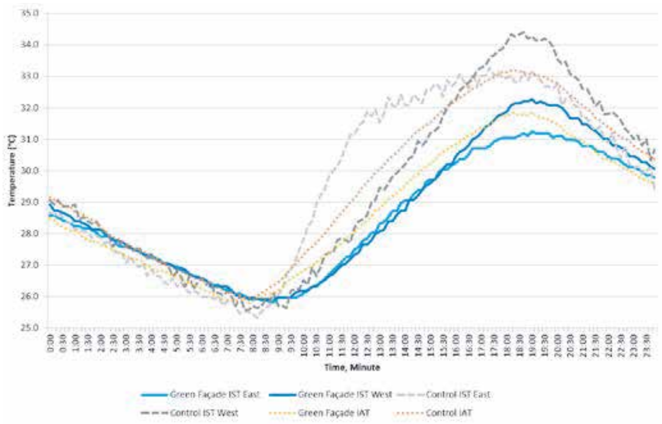

Fig. 4. Thermal performance of internal surface temperature (IST) and indoor air temperature (IAT).

TABLE III. MINIMUM, MAXIMUM AND AVERGE FOR INTERNAL SURFACE TEMPERATURE (IST) OF GREEN FACADE ON MEAN OF 10 MINUTES INTERVAL FROM FIVE SUNNY DAYS

Test Cell (°C)	**East**			**West**		
	Max	*Min*	*Average*	*Max*	*Min*	*Average*
Control	33.3	25.3	29.6	34.4	25.6	29.5
Green Façade	31.2	25.8	28.5	32.3	25.9	28.7

IV. CONCLUSION

Application of green façade is able to regulate and improve outdoor and indoor thermal condition. The significant reduction of external surface temperature on behind wall attached with green façade, up to 15.2 K is able to lessen the heat to be transferred towards indoor environment. It is proved by maximum reduction of 4.0 K on the indoor surface temperature. The contribution of green façade also can lead to energy saving.

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