Investigation on the Thermal Performance of Green Facade in Tropical Climate Based on the Modelling Experiment

Ratih Widiastuti1,∗, Eddy Prianto2 and Wahyu Setia Budi3

1Department of Architectural Design, Vocational School, Universitas Diponegoro, Semarang, Indonesia
2Department of Architecture, Faculty of Engineering, Universitas Diponegoro, Semarang, Indonesia
3Department of Physics, Faculty of Mathematics and Sciences, Universitas Diponegoro, Semarang, Indonesia

Abstract: This study presents an in situ experimental study of buildings covered by green facades in the tropical country of Indonesia. A scaled model called house miniature was used as measurement object. The aim of this study is to examine the influence of green facades on the thermal performance of buildings. Data measurement is recorded during rainy season where the average of humidity is 69.35% and the average of ambience temperature is 24.48°C. Considering overall thermal performance, model with green facade has lower surface temperature and indoor air temperature than model without green facade. On the surface temperature, the differences with model without green facade are 6°C for exterior facade and 6.3°C for interior facade. Compared to model without green facade, in the morning, indoor air temperature of model with green facade tends to increase up to 25.6°C. Meanwhile, in the afternoon until evening, indoor air temperature tends to decrease up to 25.6°C. Thus, it is beneficial to create indoor thermal comfort. However, green facade will produce higher humidity in the model and becomes a disadvantage. Based on the data measurement, indoor air humidity of model with green facade is 42.93% higher than model without green facade. This condition can be a reason of discomfort for building occupants.

Keywords: Green facade, modelling experiment, building thermal performance

DOI: http://dx.doi.org/10.7492/IJAEC.2018.004

1 INTRODUCTION

One of the negative effects of city development is the decrease of greenery area (Wong et al. 2010; Chen et al. 2013). Human tend to use each part of the city as building area and cause higher temperature of surrounding ambient. Due to limited area, conventional parks are difficult to realize in the cities. The present of vertical greenery system then become one of solutions to encounter this problem (Francis and Lorimer 2011). Even though trend of using vertical greenery system can not play as water catchment, as building envelope it become more common.

Some of major cities in Indonesia, such as Jakarta, Surabaya, Bandung and Semarang have been using vertical greenery system as one of building’s element. However, based on the observation, it seems just to increase building aesthetic rather than build thermal performance and lack of maintenance causes some of plants to die and ruins facade appereance.

In the building science research, vertical greenery system not only as building aesthetic but also as part of passive cooling design beneficial to increase energy saving. In the dense urban areas where the walls of high rise building are the largest part of the building that has potential benefits for green facade as building envelope (Cheng et al. 2010; Jim and He 2011). Probably, an even greater potential is for low and medium residential, industrial and commercial buildings to create green facade.

Plant in the building envelope will reduce solar radiation and produce humidity through evapotranspiration (Scudo and Ochoa De La Torre 2003). These effects are beneficial especially during summer months when plant shading can reduce heat flow and decrease temperature on the building surface (Wong et al. 2010).

Another study conducted by Peck et al. (1999), said that walls and windows shaded by vertical greenery system can reduce the amount of energy needed for air-conditioning by 50% to 70%. Result of study conducted by Bass and Baskaran (2003), also said that the shading effect of vertical greenery systems can reduces 8% annual energy consumption. It means when all building facades covered by vertical garden, potential for energy saving also improve (Dunnett and Kingsbury 2004; Alexandri and Jones 2008; Köhler 2008).

A number of studies in vertical greener system were published. First, using eight types of vertical greener system,
a study conducted by Wong et al. (2010) said that vertical greenery system potentially can reduce surface temperature on the building facade and ambient temperature in the tropical climate. Another result from this study is the effect of temperature reduction depend on the various types of vertical greenery system. However, this research did not answered the effect of vertical greenery system in the indoor.

Second, Mazzali et al. (2013), has been extended a study of three living wall field tests to heat flux calculated on the building facade. This study conducted in the Mediterranean temperate climate in the different location. Even thought the living wall applied in the outside of building facade, but there is no calculation in the indoor temperature. Furthermore, there is difference in building materials. It would be better if the study used one kind of building material.

Third, a study conducted by Widiastuti et al. (2016), explained that facade with vertical garden has longer thermal lag than bare facade. This result has explained that vertical garden beneficial to reduce cooling load during peak hours. However, the short period of data measurement did not answered the behaviour of vertical garden in the night. Moreover, the position of bare facade and vertical garden are in different elevation, possibility influenced in thermal condition, both outdoor and indoor.

Based on the literatures review, remain of studies in vertical greenery system are enigmatic. It means, possibility to develop this research is promising, especially in tropical countries like Indonesia.

This study observe the effects of green facade on the building thermal performance. The observation includes profile of indoor air temperature and indoor air humidity. Different with previous studies, the experiments use scaled model with the materials and the condition same as a real building. Data measurement was done for 24 hours to find out the building thermal profile on the night.

2 METHODOLOGY
2.1 Description of Study Object

In this study, an experiment in situ was conducted to create a situation that was same as real building using vertical greenery system. Study object is a model like house called house miniature. It illustrates a single story building, as seen in Figure 1.

Figure 1. House miniature as study object

Details of the building materials on the model explains in Table 1. While, the comparison scale between model and real building is 1:4, seen in Figure 2.

Table 1. Details of model

<table>
<thead>
<tr>
<th>No</th>
<th>Details of model</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Model size</td>
<td>1m x 1m x 1m</td>
</tr>
<tr>
<td>2</td>
<td>Roof material</td>
<td>Asbestos</td>
</tr>
<tr>
<td>3</td>
<td>Roof shape</td>
<td>Gable roof</td>
</tr>
<tr>
<td>4</td>
<td>Wall material</td>
<td>Brick</td>
</tr>
<tr>
<td>5</td>
<td>Inlet outlet</td>
<td>Porosity 30 %</td>
</tr>
<tr>
<td>6</td>
<td>Floor material</td>
<td>White ceramic</td>
</tr>
<tr>
<td>7</td>
<td>Ceiling material</td>
<td>Asbestos</td>
</tr>
<tr>
<td>8</td>
<td>Position of opening</td>
<td>Inlet in the front and outlet in the back</td>
</tr>
</tbody>
</table>

Figure 2. Detail of house miniature

On the December 2013, the study began to collect data for model without vertical greenery system. After that, on the same week, the data measurement for model with vertical greenery system was conducted.

2.2 Description of Vertical Greenery System

There are two kinds of green facade:

2.2.1 Direct Green Facade

As seen in Figure 3, direct green facades is climber plants that self-clinging on the building exterior using its roots. This technique also can using wire or cable as supporting material. Even though building that covered by green facade can reduce wall temperature, but self-climber plant may damage building construction especially on the wall surfaces (Sternberg et al. 2011; Perini et al. 2013). Planting climber plants in the soil at the base of a wall is cheap and highly effective for greenery facade (Dunnett and Kingsbury 2004; Hopkins and Goodwin 2011).
2.2.2 Green Facade with Double-Skin System

Double skin system in green facade rely on the supporting material such as modular trellises, stainless steel cable, or stainless steel/HDPE mesh to assist the upward growth of a wider variety of climbing plants. This technique will create small cavity between green facade and building wall, as seen in Figure 4, different from direct green facade that attached in the building wall. In addition, double-skin green facades create an insulating layer of air between the foliage and building wall (Köhler 2008; Ottelé et al. 2011; Perez et al. 2011a; Perez et al. 2011b).

Based on the theory, in this study we used direct green facade as vertical greenery system (Sternberg et al. 2011; Perini et al. 2013). Climber plant attached directly in the facade used mesh trellis, while the plant roots was planted in the planter boxes. The facade covered by green facade orientated to face the east according to sunlight direction. In the following are detail of green facade:

1. Step one, plants choice. Passiflora flavicarva and Pseudocalymma alliaceum are kinds of climbing plan used as green facade, as seen in Figure 5. Mesh trellis used to support the plants in order can be climbed on the facade.

2. Step two, planting the climbing plants. The roots of climbing plans were planted in the boxes filled with soil to simulate the ground. The plan grew quickly during the first months, as seen in Figure 6. Once the plant high reached 2-3 m, it would be moved on the house miniature as green facade.

3. Step three, green facade installation. The green facade was installed in December 2013. Using mesh trellis that entwined to support plant to climb on the wall. The mesh trallis attached on the ones of building facades for plant to climb. The leaves and stems furled around the trellis mesh, covered facade, filled the area and provided dense foliage for the green facade. The facade area covered by green facade is 1 m$^2$, as seen in Figure 7.
2.3 Experiment Description

The experiment was conducted in Architecture Department, Universitas Diponegoro, Semarang City (6°58′0.0012″S and 110°24′59.9904″E), as seen in Figure 8. The site is an open area surrounded by trees and buildings. Condition at that moment, the trees have been cut and the sunlight is not blocked by trees.

The measurements was conducted to validate the thermal profile of the model and consisted of three data measurements. Both for model with and without green facade, can be seen in Figure 9. In the following are detail of data measurement:

1. Measurement of surface temperature on the interior and exterior facade.

There are nine measured points on the facade surface, three on the bottom, three on the middle and three on the top. The data of surface temperature are the average from the nine measured points. Whereas for indoor air temperature and indoor air humidity, the measurement tools placed in the middle of house miniature.

This research used some of measuring instruments:

1. Hygrothermometer used to measure air temperature and air humidity in exterior and interior of house miniature.
2. Infrared surface thermometer used to measure surface temperature, both exterior and interior of facade.
3. 4 in 1 environment tester LM-8000 used to measure wind speed.

2.4 Local Climate Condition

Data collecting was done in three days in December 2013. Beginning on 16th December 2013 at 6:00 am until 19th December 2013 at 5:00 am. These three days were cloudy and sunny. There is no solar radiation measurement. However, we used solar illuminances as indication as solar radiation.

Generally, during data measurement of model with green facade, the weather is hot and humid, and the average of humidity is 69.35%, varying from 64.00% to 76.00%. The average of ambience temperature is 24.48°C, varying from 23.00°C
Figure 9. (A). Exterior side of field measurement with green facade; (B). Data collected of model without green facade; (C). Data collected of model with green facade

Figure 10. Profile of local climate condition during data measurement

Table 2. The weather conditions during the experiment

<table>
<thead>
<tr>
<th>No.</th>
<th>Values of weather condition</th>
<th>Outdoor air temperature (°C)</th>
<th>Relative humidity (%)</th>
<th>Wind speed (m/s)</th>
<th>Intensity of solar illuminances (*10 lux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Highest values</td>
<td>26</td>
<td>78</td>
<td>1</td>
<td>155.6</td>
</tr>
<tr>
<td>2</td>
<td>Average values</td>
<td>24.48</td>
<td>69.35</td>
<td>0.26</td>
<td>45.65</td>
</tr>
<tr>
<td>3</td>
<td>Lowest values</td>
<td>23</td>
<td>64</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Extreme thermal condition frequently recorded when heavy rain happened, especially in the day time. To achieve the accurate results, data were collected every an hour. Data measurement was only used in the sunny condition. It was indicated by higher illuminances that means higher incident solar radiation.

In order to carry out a more detailed study on the climatic conditions during the data measurement. The data of local climate condition were grouped by four categories: morning, day time, afternoon and night.

2.4.1 Day Time-Afternoon

During the day time, intensities of solar illuminances decreased 14.32% between 12:00 pm-4:00 pm, caused by cloudy. However, between 1:00 pm-4:00 pm, the average of humidity increased 2.51% and the average of air temperature decreased 0.79%, from 26.00°C to 25.00°C. At that moment, the average of air movement was 0.5m/s. The highest solar illuminances recorded at 12:00 am and became the lowest humidity during the day time. While the highest of humidity was 76% recorded at 5:00 pm–6:00 pm.

2.4.2 Night

During the night, air temperature decreased from 24.00°C to 23.00°C, because of air movement and the decreased of solar radiation. The humidity also decreased from 72.00% to 64.00% recorded around 6:00 pm-2:00 am. However, around 3:00 am to 5:00 am, the humidity increased up to 68.00%.

3 RESULTS AND DISCUSSION

Because the weather was in sunny and cloudy condition, data from rainy and full cloudy days were excluded and only used the averages data from full sunny days. The average of thermal profile for 24 hours period for the model without green facade and with green facade are compared.
3.1 Comparison between Surface Temperatures

As shown in Figure 11, it is noticeable that surface temperature in the model without green facade is considerably higher than surface temperature in the model with green facade. In general, the average of surface temperature difference between model without and with green facade are 6.00°C for exterior facade and 6.30°C for interior facade. A reduction in surface temperature will reduce thermal stress on the building materials, especially in the regions with higher solar radiation.

Nevertheless, during the night with lower solar radiations, both exterior surfaces temperature recorded were cooler than interior surface. It was from heat accumulation during the day, made interior surface temperature was higher than exterior surface temperature. The effect of this condition is interior temperature will warmer than ambient temperature.

The first balanced condition between exterior and interior surface temperature of model without green facade occurred at 6:15 am (28.35°C) and the second balanced condition occurred at 6.30 pm (31.60°C). However, in the model with green facade, the first balanced condition between exterior and interior surface temperature occurred at 5:30 am (22.43°C) and the second balanced condition occurred in the evening at 4:30 pm (24.10°C). Through the result, model with green facade tend to faster in the cooling its surface temperature.

Further effect of this condition is peak of surface temperature on the model without green facade occurred faster, for exterior facade around 1:00pm, (35.40°C) and for interior facade around 6:00 pm (31.80°C). Meanwhile, on the model with green facade, peak of exterior surface temperature occurred around 11:00 am (33.40°C) and for interior surface temperature occurred around 6:00 pm (25.40°C). The position of peak temperatures will lead how long thermal lag on the model and how much cooling load can be reduced during peak hours. Based on the calculation, model with green facade has thermal lag 2 hours longer than model without green facade. It means green facade will reduce the amount of heat that received by facade.

3.2 Comparison between Indoor Air Temperature

Generally, indoor air temperature on the model with green facade was lower than model without green facade, as shown in Figure 12. Decrease on the surface temperature caused decrease in indoor air temperature. The mean difference reaches up to 1.27°C.

Based on the data measurement, at the morning indoor air temperature tend to increase up to 25.60°C (10:00 am). Meanwhile, at the afternoon until evening, after static period, indoor air temperature tend to decrease up to 25.60°C (6:00 pm) and decrease more in night time. This condition is different from model without green facade that tend to static until night time, at the range 26.50°C.

Possibility, it was from evapotranspiration that made the process of heat release on the model occurred more rapidly and reduce the amount of energy from solar radiation (Scudo and Ochoa De La Torre 2003; Mazzali et al. 2013). In the meantime, at night until morning green facade tend to isolat heat from facade. Thus, the room will be warmer. This effect is beneficial to create indoor thermal comfort.

The highest difference between indoor air temperature of both model recorded during the night, approximately 0.80°C to 1.70°C. The peak of indoor air temperature on the model without green facade occurred at 26.60°C for 9 hours, which was 5 hour longer and 26.00°C higher than model with green facade. It means in these hours, the model without green facade need more energy to cooling down the indoor air temperature. As a shadowing element, green facade can manage to reduce indoor air temperature, by preventing the overheating of exterior surface temperature.

3.3 Comparison between Indoor Air Humidity

Generally, as shown in Figure 13, model with green facade has higher indoor air humidity. Actually, during the data measurement, the indoor air humidity of model with green facade tend to be static and in several times, its record has 100% humidity. The average of its indoor air humidity is 98.33% and higher.
42.93% than model without green facade.

According to Scudo and Ochoa De La Torre (2003), this is due to evapotranspiration. Plant will prevent air containing water vapor moving. The result is high humidity in the room. In addition, possibility of high humidity can be caused by weather conditions and size of model. Data measurement done in the rainy season, when the ambience humidity was high and the size of model is small, giving possibility to produce high humidity in the room.

Even though air temperature on the model with green facade was cooler than model without green facade, nevertheless if indoor air humidity beyond of standard (30.00%-60.00%) (Balaras and et al. 2007; Wolkoff and Kjaergaard 2007), this condition can be a reason of discomfort for building occupant, especially for 24 hours daily use. Hence, for special building such as housing, applying green facade in the building must be taken into account.

4 CONCLUSION

This is a series of studies which aims to prove the influences of vertical greenery system regarding thermal conditions in the building. In this work, a model with green facade were conducted and the aim was to extend the result of previous works.

Based on data measurement, model with green facade has lower surface temperature and indoor air temperature than model without green facade. The mean differences of surface temperature between model without and with green facade are 6°C for exterior facade and 6.30°C for interior facade. However, in the night, both exterior surface temperature recorded cooler than interior surface. It was from heat accumulation during day time, made interior surface temperature was higher than exterior surface.

Possibility of green facade application to create indoor thermal comfort can be seen from the data measurement. In the morning, indoor air temperature of model with green facade tend to increase up to 25.60°C. Meanwhile, in the afternoon until evening, after static period, indoor air temperature tend to decrease up to 25.60°C. This condition is different from model without green facade that tend to static until night time, at the range 26.50°C.

Higher humidity in the model with green facade becomes a disadvantage of green facade application. Even though
air temperature on the model with green facade was cooler than model without green facade, if air humidity higher than 70.00%, this condition can be a reason of discomfort for building occupant.

ACKNOWLEDGEMENT

This research is fully supported by LPDP scholarship. The authors fully acknowledge Indonesian Ministry of Finance for the approved fund which makes this important research viable and effective.

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