

# Vertical Greenery System as the Passive Design Strategy for Mitigating Urban Heat Island in Tropical Area: A Comparative Field Measurement Between Green Facade and Green Wall

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## Vertical Greenery System as the Passive Design Strategy for Mitigating Urban Heat Island in Tropical Area: A Comparative Field Measurement Between Green Facade and Green Wall

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**Abstract.** During the last decade, greenery aspect in the building envelope starts to increase their presence in the building design. Vertical greenery system became the one of alternatives that potential to energy-saving in the building. However, in tropical area, researches related to vertical greenery system are enigmatic since reducing heat in tropical area are crucial for maintaining space in comfort condition. In this study, a comparative thermal analysis between green facade and green wall will present. A model called house miniature set up with climbing plans as model of green facade. While for green wall, data measurement was conducted in the office building with green wall as building envelope. The results showed a high potential for energy savings during peak time in the afternoon for green wall (1.5%) and green facade (1.3%) in comparison to the bare wall. While for interior facade are 2.6% for green wall and 2.2% for green facade. Effect of vertical greenery also found in the outdoor air temperature around greenery system. Results show at the hottest time of the day, the green wall and green facade reduced outdoor temperatures by 3.0°C and 1.2°C, respectively. Based on the analysis, compared to green facade, the cooling effect produced by green wall is faster. Possibility, the substrate properties in the green wall also help to decrease temperature. The reduction can be due to the foliage density as the leaves of green wall is denser than leaves in green facade.

**Keywords :** building envelope, green facade, green wall, vertical greenery system

### 1. Introduction

Over the past decade, due to population growth, energy consumption has dramatically increased. More than half of human life is spent in building and cause the increasing demand for building functions and indoor environmental quality. This increases the energy consumption and becomes the factor of global warming.

Based on data from European Commission, buildings are responsible for approximately 40% of energy consumption and 36% of CO<sup>2</sup> emissions in the EU [1]. While according to Energy Information Administration (EIA) [2], the global totals of primary energy consumption and CO<sup>2</sup> emissions have grown by 85% and 75% from 1980 to 2012, with average annual increases of 2% and 1.7%. In this case, heating and cooling loads become the largest energy use. On the other hand, significant energy



saving can be achieved in building if they are properly designed, constructed and operated. This condition then encourages building planners to create sustainable design in the building.

Among other innovative technologies to improve energy saving in the building, vertical greenery systems are considered as design trends in the field of architecture and construction that increase building thermal performance. Many building planners used vertical greenery systems to enhance the quality of urban landscapes around buildings. Within this concept can provide multiple eco-system services in the building and urban scale and in the end resulting in mitigating urban heat island.

Research conducted by Perini et al., [3] divided vertical greenery system in the two terms :

- First, green façade, when the systems use climber plant as greenery element. The plants root directly in the wall or using wire or terallis as supporting element.
- Second, green wall, when the systems use small shrubs such as mosses and grass as greenery element. For applying in the building envelope, this system uses planter element and also needs special treatment for watering. Building planners can make special pattern by arranging the vegetations based on the colour.

Basically, vertical greenery systems have four key factors that influence the system as passive cooling design for energy saving : the shadow produced by vegetation; the insulation provided by vegetations and substrats; the evaporative cooling through evapotranspiration and barrier effect to wind [4]. From the previous studies, shadow effect produced by vertical greenery system has the highest impact in the reduction of building wall temperature and resulting in saving energy consumption [5]. Especially when the vegetation has higher percentage of leaves densities [5][6][7].

To arrange and summarize all the key factors, **Table 1** and **Table 2** showed the previous studies related to vertical greenery system in tropical area. There are nine studies were found, six related to green facade and three for green wall.

This research relates specifically to the comparison between thermal performance of green facade and green wall. In this regard, it must be taken into account that the each of study objects clearly has different design and different vegetation. Results from this study are expected can help architect and building planners to make more appropriate decisions in the building design.

**Table 1.** Most significant previous studies on the use of green facade as passive design cooling in building in tropical countries.

Authors	Publication year	Location	Method	Period of observation	Plants species	Building storey and material	Control treatment	Surface temperature reduction (°C)	
								Interior	Exterior
Laopanitchakul et al. [6]	2008	Thailand	Experimental	Summer	<i>Mann bali</i> (local name)	One storey concrete	Bare wall	Depending on the systems	Depending on the systems
Wong et al. [7]	2010	Singapore	Experimental	February; April; June	Climber plants	One storey concrete	Bare wall	-	4.36
Rashid et al. [8]	2010	Bangladesh	Observation	-	-	Six storey	-	-	-
Sunakorn and Yinprayoon [9]	2011	Thailand	Experimental	Summer	<i>Thunbergia grandiflora</i>	One storey concrete	Bare wall	-	-
Rahman et al. [10]	2011	Malaysia	Experimental	Summer	<i>Psophocarpus tetragonobulus</i>	Multiple storey brick.	Bare wall	0.38-1.28	3.97-10.7
Safikhani et al. [11]	2014	Malaysia	Experimental	April; Mei; June	<i>Thunbergia grandiflora</i>	One storey plywood	Bare wall	4.5	-

**Table 2.** Most significant previous studies on the use of green wall as passive design cooling in building in tropical countries.

Authors	Publication year	Location	Method	Period of observation	Plants species	Building storey and material	Control treatment	Surface temperature reduction	
								Interior	Exterior
Wong et al. [7]	2010	Singapore	Experimental	February; April; June	M3: <i>Hemigraphis repanda</i> ; M6: <i>Phyllanthusmyrtifolius</i> ; <i>Tradescantia spathacea</i> ; M7: Mosses	One storey concrete	Bare wall	-	Depending on the systems
Widiastuti et al. [12]	2016	Indonesia	Observation	October	<i>Phalaenopsis</i> sp., <i>Dracaena warneckii</i> and local climber plants	Three storey brick	Bare wall	2.1	-
Safikhani et al. [11]	2014	Malaysia	Experimental	April; Mei; June	<i>Thunbergia grandiflora</i>	One storey plywood	Bare wall	6.5	-

Note : M Model

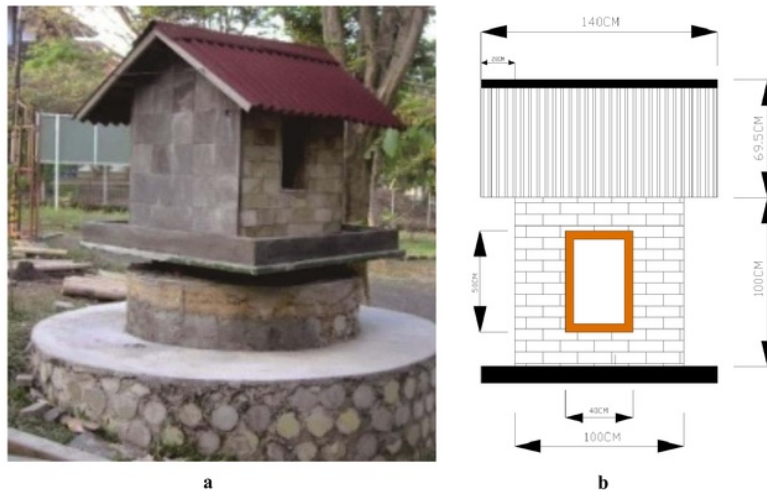
## 2. Methodology and Materials

### 2.1. Climatic condition

The location of experimental site is in Semarang City, Indonesia, can be seen in **Figure 1.**, at south latitude 6°58'0.0012" and east longitude 110°24'59.9904" under tropical monsoon climatic condition defined according to Koppen-Geiger climate classification [13] as the climate that has a driest month which nearly always occurs at or soon after the "winter" solstice for that side of the equator with rainfall less than 60 mm, but more than 1/25 the total annual precipitation.

### 2.2. Experimental set-up

In order to get green facade data, a building miniature called house miniature has been built in Architecture Department of Universitas Diponegoro to carry out the experiment, can be seen in **Figure 1.** The dimension is 1m x 1m x 1m, and can be considered as one real scale building, illustrated one storey building. The comparison scale between model and real building is 1:4. The foundation is made from reinforced concrete slab and in the base of building is equipped with rail from steel that the model can be spin 360°. The roof construction is gable roof with asbestos as roof covering material. The length of overhang is 50 cm, possibility can create shadow in the building walls. While for the walls are constructed from brick and have inlet outlet with porosity 30%.



**Figure 1.** Study object. a). House miniature; b). Detail of house miniature

A green facade is installed on the east facade. Climber plant attached directly in the facade used mesh trallis, while the plant roots was planted in the planter boxes, can be seen in **Figure. 2.** The facade covered by green facade orientated to face the east according to sunlight direction. *Passiflora flavicarva* and *Pseudocalymma alliaceum* are selected as greenery element because it is ease to climb and presents well adaptation to micro climatic condition, can be seen in **Figure. 3.** As data comparison for green facade is the existing model without green facade.



**Figure 2.** Model of green facade



**Figure 3.** Climbing plants for green facade application. a). *Pseudocalymma alliaceum*; b). *Passiflora flavicarva*

On the other hand, an *in situ* measurement was done in the office building of PT. Pertamina to get thermal data of green wall. This green wall previously was used as study object in the previous research [12]. The green wall was using geotextile system that consists of an aluminium structure, a PVC panel and felt layers. The plants are growing in the plant pockets with automatic watering system from irrigation pipes in the top and side of green wall.

The green wall is installed on the external non insulated wall. While the wall construction is brick and the thickness is 15 cm including internal and external plasters. The green wall is using various types of plants as greenery element such as *Phalaenopsis sp.*, *Dracaena warneckii* and some of local climber plants, can be seen in **Figure 4**. Bare wall for data comparison of green wall is a wall above the green wall.



**Figure 4.** Model of green wall

### 2.3. Data measurement

Both of green facade and green wall are using bare wall as control treatment. Each of data measurement from vertical greenery system will compare with data measurement from bare wall and analyze the difference of thermal profile.

The experiment consisted of three data measurements :

- Measurement of surface temperature on the interior and exterior facade.
- Measurement of outdoor air temperature near vertical greenery system.
- Measurement of outdoor air humidity near vertical greenery system.

Data measurement was done in October from 05.00 AM to 06.00 PM. The interval of data collecting are every 1 hour. For data measurement of surfaces temperature, the surface of measured wall divided into 9 point. They are three in the middle, three in the bottom and three in top. The analysis was based on the average of hourly data measurement from each measured points.

## 3. Discussion

Because there are limited of test room with bare wall, present of data measurement between green facade and green wall are separately. Both vertical greenery systems has different models size, with the result that, it is invalid to compare humidity and air temperature inside test room. The analysis only restricted in comparison of surface temperature and outdoor humidity and air temperature near the vertical greenery systems.

### 3.1. Surface temperature

#### 3.1.1. Green wall

According to data measurement, surface temperature of green wall is lower than surface temperature bare wall. Respectively, the difference between the average of surface temperature are 3.17°C for exterior facade and 5.38°C for interior facade. In fact, exterior surface temperature of green wall is lower than exterior and interior of bare wall.

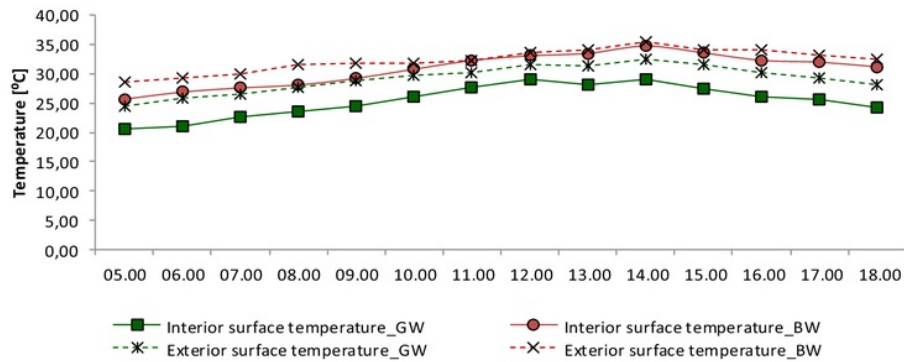


Figure 5. Surface temperature profile of green wall

### 3.1.2. Green facade <sup>5</sup>

It is noticeable that surface temperature in the bare wall model <sup>14</sup> considerably higher than surface temperature in green facade. In general, the average of surface temperature difference between bare wall and green facade are 4.4°C for exterior facade and 2.9°C for interior facade. The lowest difference between interior surface temperatures and exterior surface temperatures, respectively are 1.3°C at 1:00 PM and 1.5°C at 10:00 AM.

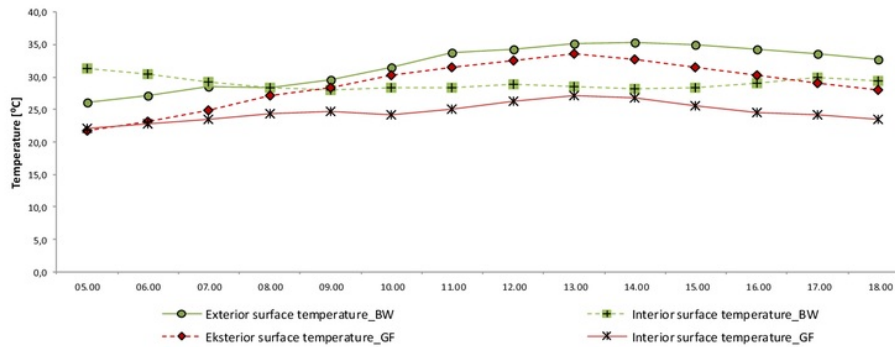


Figure 6. Surface temperature profile of green facade

### 3.2. Analysis surface temperature

In the analysis the difference on the thermal performance between VGS and bare wall were not analyzed <sup>1</sup>.

The results showed that both the green facade and green wall reduced the temperatures especially in the afternoon. During the morning, direct solar radiation fell on the east part of the facade. Plants reduced temperatures using natural evapotranspiration and cooling effects.

In the afternoon when outside temperatures are at their highest, vertical greenery systems have a significant effect on temperature reduction. During the afternoon when direct solar radiation hits the plants on the west side, cooling effect and the shade provided by the vertical greenery systems effectively reduce temperature.

The results showed a high potential for energy savings during peak time in the afternoon are 1.5% for green wall and 1.3% for green facade in comparison exterior facade to the bare wall. While for interior facade are 2.6% for green wall and 2.2% for green facade.

At that time, green wall can reduce temperature better than the green facade, especially in the afternoon until evening. The reduction can be due to the foliage density as the leaves of green wall is denser than leaves in green facade. In addition, the substrate properties also help to decrease temperature. In green facade, the cooling effect is directly due to the shading effect and evapotranspiration from the leaves of the climbing plants. There is no substrate to contribute to the cooling effect due to evaporation of moisture from the substrate as in the green wall.

### 3.3. Air temperature

From Figure 7. of data measurement on the trends of the ambient temperature, the aim is to observe the potential of vertical greenery system in producing a cooling effect on the immediate external environment.

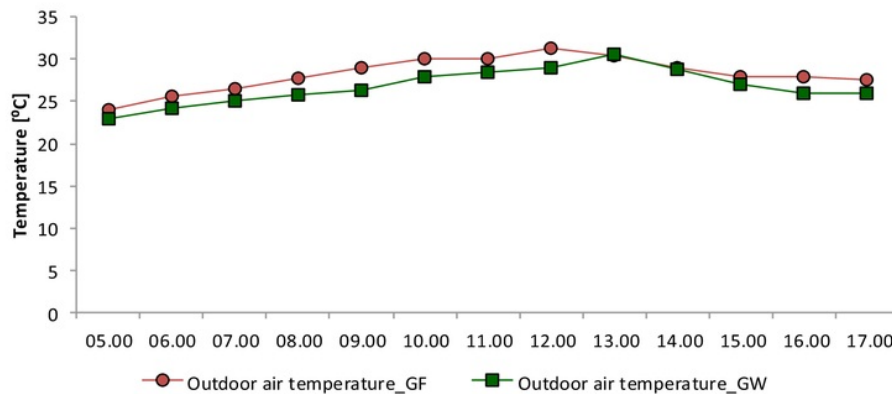
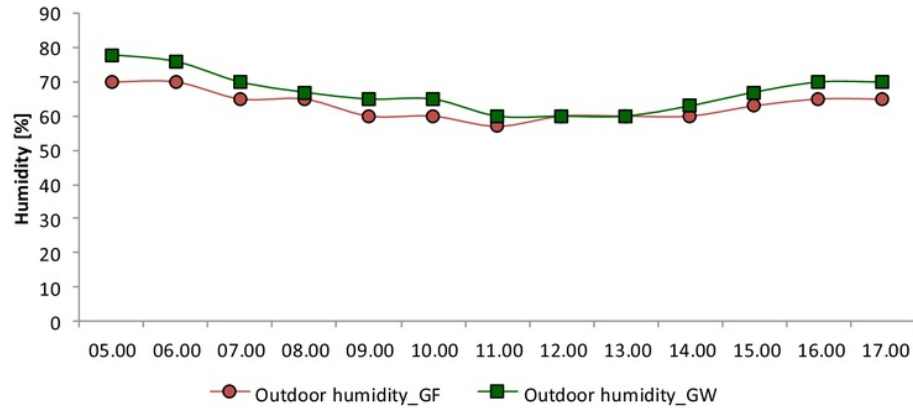


Figure 7. Profile of outdoor air temperatures near green facade and green wall

At the hottest time of the day, the green wall and green facade reduced outdoor temperatures by 3.0°C and 1.2°C, respectively. Possibility, the ambient temperature may be affected by air circulation, yet the factor not always occurred during data measurement. Though green facade and green wall are covered by well-distributed greenery, green wall has thicker greenery near that may block the air circulation and trap heat. The substrate surface of the green wall also had a significant effect on temperature reduction around greenery application.

### 4. Air humidity

Although installing vertical greenery systems have a positive effect on indoor temperatures in hot and humid climates, they have a negative effect on humidity control.



**Figure 8.** Profile of outdoor humidities near green facade and green wall

The green wall increased humidity around facade more than the green facade because the leaves densities and substrat in the green wall interfere with evaporation resulting the increase of humidity. Calculation on the average of humidity around the greenery systems are 67.2% for green wall and 63.% for green facade.

#### 4. Conclusion

As continuation of a long term research in order to study the potential of vertical greenery systems as a passive cooling design for energy saving in the buildings in tropical countries, two in situ observation have been down to collect the data of vertical greenery system.

The effects of vertical greenery system on the building thermal profiles are depend on the specific parameters of vertical greenery system. From the results obtained in the data measurement, it is found that green wall can produce cooling effect better than green facade. The reduction can be due to the foliage density as the leaves of green wall is denser than leaves in green facade. Substrate in the green wall also contribute in the cooling effect. In the green facade, the cooling effect is directly due to the shading effect and evapotranspiration from the leaves of the climbing plants.

The temperature reduction is most prominent around noon when it is the hottest weather. This is a significant reduction in surface and outdoor air temperature that will lead to a corresponding reduction in the energy cooling load. A cooler ambient temperature means that the air intakes of air-conditioning are at a lower temperature, translating into saving in energy cooling load.

#### 5. Acknowledgement

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