Improving the thermal performance of the buildings using a green façade system: an experimental study in a tropical climate

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Abstract. The green façade systems can be considered as an effective way to create sustainable building design through improving building thermal performance. The significant temperature decrease can significantly decrease the building temperature and enhancing energy efficiency for cooling load. An experimental study of the vertical greenery system was conducted at the Faculty of Integrated Technologies, Universiti Brunei Darussalam, Brunei Darussalam to evaluate the thermal impact of a green façade on the building by varying the wall surface and room temperature. Two identical rooms were identified as green façade rooms (GF-Room) and bare wall room (BW-Room). The temperature variation shows that the GF-Room consistently had lower temperatures than BW-Room. The notable drop in temperature is due to the shading effect of the green façade, as shown by the ambient air temperature in the cavity between the green façade system and the GF-Room. The mean and maximum temperature reduction is observed to be 2.2°C and 19.8°C, respectively. While the indoor thermal parameters showed a smaller temperature reduction by an average of 1.0°C. The findings of the current study led to the conclusion that using a vertical greenery system as a passive cooling design can significantly contribute to the temperature reduction of the buildings.

1 Introduction

The large portion of energy in cities is consumed by buildings and causing climate changes. On the other hand, conventional planting is hard to realize since most of the lands were converted into housing and business areas lead to Urban Heat Island (UHI). One widely acknowledged approach to mitigate the negative impacts of climate change in urban areas is the utilisation of ecosystem services (ESS) provided by Urban Green Infrastructure (UGI) [1]. Speaking about the Urban Green Infrastructure (UGI), the greenery concept on the building envelopes such as green roof and green façade recently become popular in urban areas to restore the green space in cities. Designing green facades by combining living plants

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and building facades materials can be seen as the idea of using ’nature’ to help cities reduce the impact on global challenges such as climate change, in the context of nature-based solutions [2].

The environmental benefits provided by green façades can represent a sustainable solution for constructing new buildings and retrofitting existing buildings [3]. Among other benefits, the implementation of these systems contributes to reducing the energy demands [4], mitigating the Urban Heat Island (UHI) and cooling down public spaces [5], acoustic improvements [6], and other intangible benefits as human health and social and cultural benefits [7].

To date, the widespread use of green façades has led to the development of new systems and technological solutions which can improve the quality of urban environments. A study conducted by Perini et al. [8] presented that a green layer can enhance the thermal properties of the façade and provide protection from heavy winds. Alexandri and Jones mentioned that the effect of shading and evapotranspiration by vertical greenery systems can reduce cooling energy consumption [9]. An experimental study conducted by Coma et al. [10] found that high potential for energy savings between green wall (58.9%) and double skin green façade (33.8%) during cold season compared to reference wall. Through the numerical simulation, Zhang et al. [11] discovered the green façade can reduce the room cooling load by 11.7 % - 18.4 %. However, despite their current proliferation, there are significant challenges that still face the use of green façades, especially in the tropical regions. Only few studies conducted to observe the benefits of green façades. Therefore, through this study, the findings have opportunity to deal with this issue.

2 Material and methods

2.1 Experimental location

This study was conducted at the Faculty of Integrated Technologies, Universiti Brunei Darussalam. The experimental setup is located at 4°58'27"N and 114°53'33"E (**Fig. 1**). This area is characterized as the tropical rainforest climate (Af) according to Köppen-Geiger climate classification [12][13].

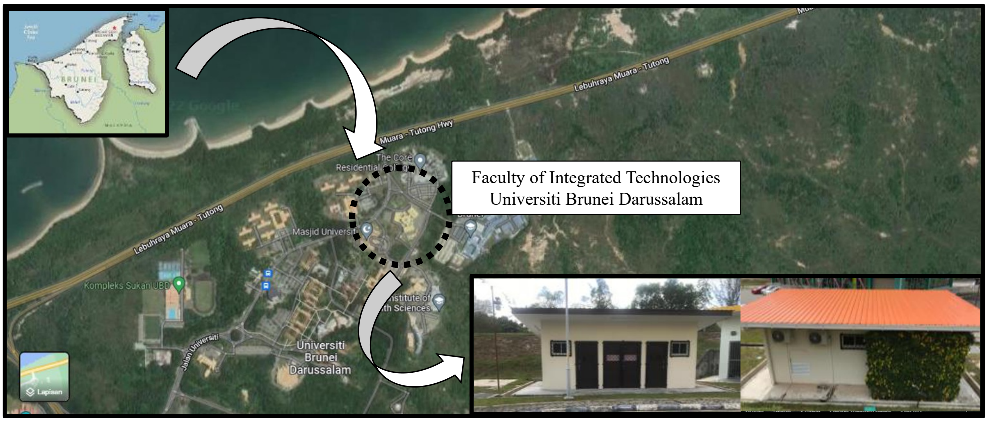


Fig. 1. Experimental setup at the Faculty of Integrated Technologies, Universiti Brunei Darussalam

2.2 Experimental setup of the green façade system

The measurement campaigns were conducted in January 2022. Model of the vertical greenery system in this study is green façade as shown in (**Fig. 1**). It was installed on the east façade to provide the shading effect as it attracts more solar radiation during daytime. [14]. *Dolichandra unguis-cati* or the common name is cat's clow trumpet was considered to be the selected vegetation since it has better characteristics such as, faster growth ability, greater leaf coverage area, stand with hot weather, and easy maintenance.

The detail construction of the green façade was used modular trellis and wire mesh made from stainless steel. An automatic watering system was installed to water the plants periodically once a week. There was a gap of 50 cm between the green façade layer and the wall to provide maintenance space and air circulation.

In term of Life Cycle Assessment (LCA), the green façade system is more sustainable since used less supporting material. The modular trellis and the wire mesh also can be recycled. The reduction of building temperature due to the greenery layer was the significant factor in reducing the buildings life cycle environmental impacts by 1% [2].

(a) **(b)**

Fig. 1. Green façade experiment **(a)** Details of the green façade **(b)** Model of green façade

2.3 Weather station

Internet of Things (IoT) technologies are adopted to provide an efficiency measurement campaign of local climatic conditions. An integrated sensor suite of the weather station was installed around the site to daily monitor the local climatic data. The continuous monitoring of the local climatic conditions was sent to cloud data analytic via internet connection.

Since the characteristics of daytime and nighttime surface temperature was different, the temperature data were divided in two sessions accordingly to avoid the influence the daytime condition on the nighttime data and vice versa. Daytime was specified as the period from sunrise to sunset (6:00 a.m.-5:59 p.m.). While time marked between sunset to sunrise was defined as nighttime (6:00 p.m.-5.59 a.m.).

Vantage Pro2 Integrated Sensor Suite manufactured by Davis Instruments was selected as the weather station. It can measure various weather conditions such as air temperature, relative humidity, rain rate, wind speed, and wind direction. **Fig. 2** gives a general illustration process of the data collection and data transfer.

Fig. 2. General illustration of the data collection and data transfer in Vantage Pro2

The integrated sensor suite was used to measure the weather conditions. It utilized anemometer, UV sensor, solar radiation sensor, rain collector, and temperature-humidity sensor. Type and technical specifications of the sensors is presented in **Table 1**.

Table 1. The type and technical specifications of sensors

Sensors	Type	Specifications		
		Resolution	**Range**	**Accuracy**
Anemometer (6410)	Wind speed: solid state magnetic sensor	1 km/h; 0.1 m/s; 1 knot	1-200 mph; 1-173 knots; 0.5-89 m/s; 1-322 km/h	±2 mph or ±5%
	Wind direction: wind vane and potentiometer	1°	0°-360°	±3°
UV sensor (6490)	Semiconductor photodiode	0.1 Index	0 to 16 Index	±5%
Solar radiation sensor (6450)	Silicon photodiode	1 W/m^2	0-1800 W/m^2	±5%
Rain collector (6463)	Tipping bucket with magnetic switch	0.2 mm	1000 mm/hr	4"/hr (100 mm/hr): ±4% of total or ± 1 tip of the bucket (0.01"/0.2 mm)
Temperature-humidity sensor (6830)	Temperature sensor: PN junction silicone diode	0.1°C	-40°C to +65°C	±0.3°C
	Humidity sensor: Film capacitor element	1.00%	1%-100%	±2%

The Vantage Pro2 used UBIQ-IoT LoRaWAN (Long Range Wireless Access Network) WS-100LRW/LW gateway as the transmitter and integrated with the sensors. The LoRaWAN gateway received the data from sensors through LoRaWAN network and stored the data onto the WeatherLink CLOUD. Console was equipped with WeatherLink data logger as receiver, transmitted the weather data via internet to the Weatherlink software on to the computer. The weather data can also be accessed through mobile phone from account in the WartherLink.com. **Fig. 3** illustrates the process of the data transfer from integrated sensor suite to the user in Vantage Pro2.

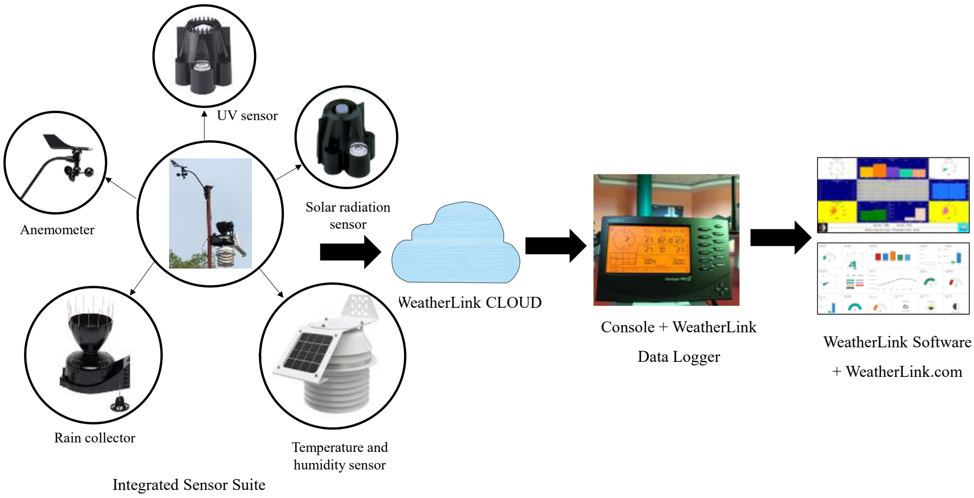


Fig. 3. Sensor and IoT framework of Vantage Pro2 for continuous monitoring of the local climatic conditions

3 Result and discussion

3.1 Local climatic conditions

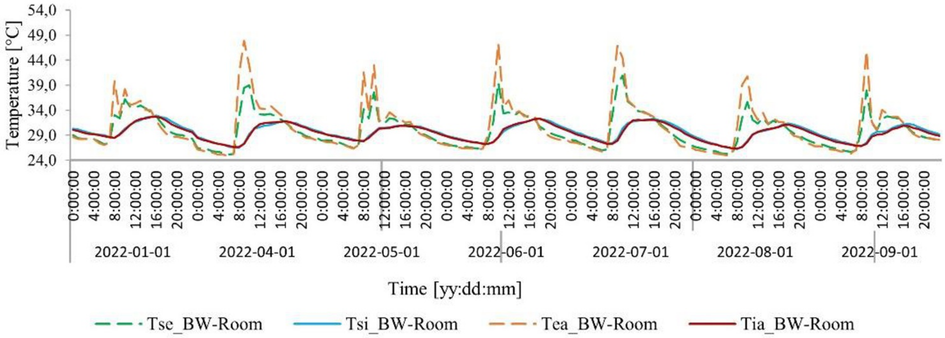
During the measurement campaign, the range of outdoor air temperature was from 24.4°C to 31.7°C with daily temperature average of 28.0°C. The average of humidity was 82.6% with minimum and maximum values of70% and 95%, respectively. The intensity of solar radiation was up to 1097 W/m^2 with an average of499.8 W/m^2. The average rain rate was observed as 5.27 mm with maximum rain rate of 52.3 mm. Most of the time the data were collected for the sunny period. As the wind velocity was varied from 0 m/s to 3.6 m/s. **Table 2** presents the local climatic data around site during measurement campaign.

Table 2. Local climatic data of the experimental site during measurement campaign

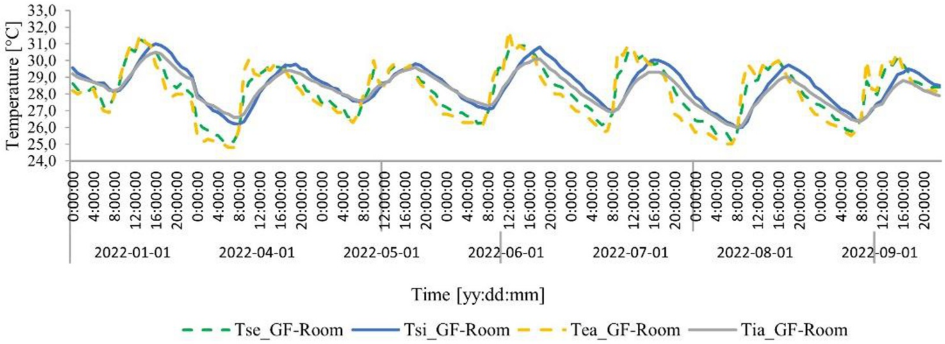
Local climatic condition	**Criteria**		
	Mean	**Minimum**	**Maximum**
Air temperature [°C]	30.0	24.4	33.7
Humidity [%]	82.6	70	95
Wind speed [m/s]	0.72	0	3.6
Solar radiation [W/m^2]	499.8	0	1097
Rain rate [mm]	5.27	0	52.3

3.2 Temperature variations

Fig. 4 presents the temperature variation per hour for each measured room. The clearest temperature reduction is due to the shading effect of green façade as shown by the ambient air temperature (T_{ea}) in the cavity between the green façade system and the GF-Room. The mean and maximum temperature reduction in this section was 2.2°C and 19.8°C, respectively. It was higher by 1.8°C-2.0°C (mean temperature reduction) and 14.3°C-16.5°C (maximum temperature reduction) than the previous study conducted by Yang et al. [15] with southern and northern orientation of green façade system. As in tropical region, the solar inclination angle is from east, south, and west, the results indicated that installing the green façade on the east reduces the heat for the most critical orientation. However, further observation is needed to compare the results from south and west orientations.



(a)



(b)

Fig. 4. Temperature variation per hour **(a)** BW-Room **(b)** GF-Room
Note: T_{ea}: External air temperature; T_{se}: Exterior wall surface temperature; T_{si}: Interior wall surface temperature; T_{ia}: Internal air temperature

Fig. 5 shows the temperature variation during the highest solar radiation. The exterior wall surface (T_{se}) of BW-Room reached the maximum difference with outdoor ambient temperature (T_{ea}) by 9.8°C. on the other hand, the maximum difference between the exterior wall surface temperature (T_{se}) and the outdoor ambient temperature (T_{ea}) of GF-Room during the highest temperature variation was never exceed 1.0°C due to the heat storage in the wall. The similar results are also presented by Zhang et al. [16]. Furthermore, the peak exterior wall surface temperature of GF-Room was slower by 4 hours 29 minutes than BW-Room with temperature difference between the peak exterior wall surface temperature by 10.5°C. The air flow inside the cavity between the green façade and the wall provide a significant effect in reducing the convective heat transfer between the wall and the air.

As the promising green infrastructure, green façade system has potential to improve the air quality. Deeper observation found the average air temperatures behind the green façades were always lower than ambient air. Compared to the air temperature near the reference wall, air temperature behind the green façade was 2°C cooler. Evapotranspiration from the green façade played a significant role in the humidification of the air behind the green layer, which contributed to cooler the air temperatures between the greenery layer and the wall. In the large scale, the thermal benefits provided by the green façade could contribute effectively in reducing Urban Heat Island.

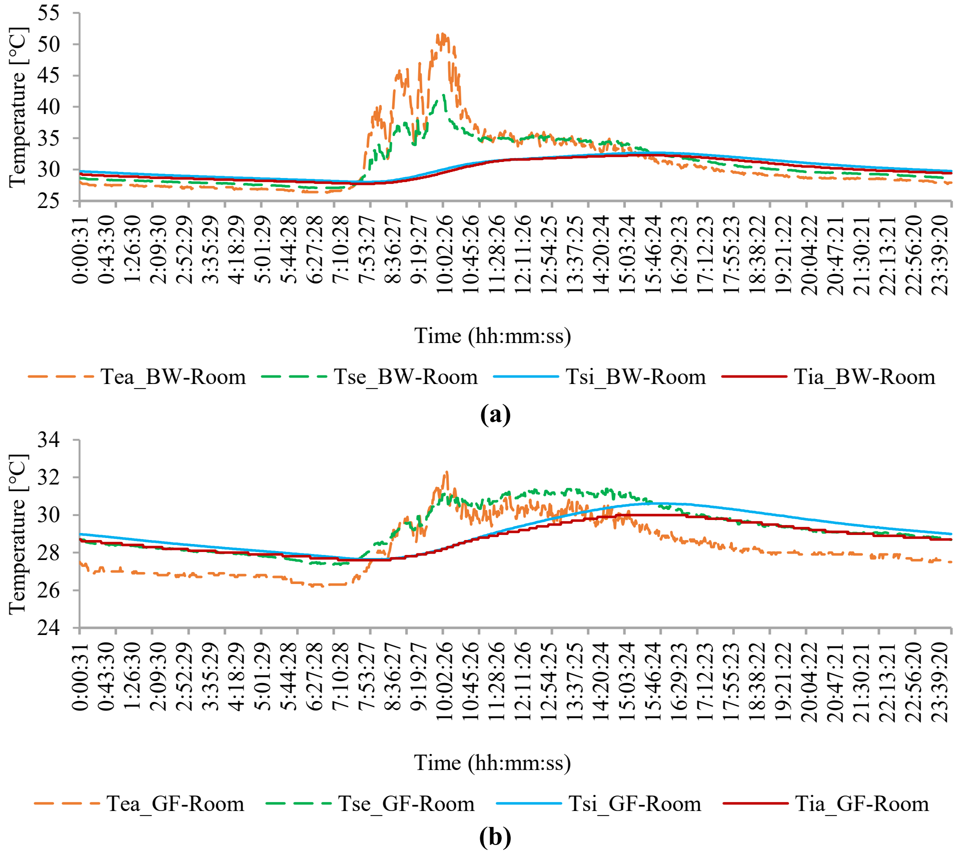


Fig. 5. The temperature variation at the highest profiles **(a)** BW-Room **(b)** GF-Room
Note: T_{ea}: External air temperature; T_{se}: Exterior wall surface temperature; T_{si}: Interior wall surface temperature; T_{ia}: Internal air temperature

4 Conclusions

The use of vertical greenery systems not only portrays a great potential in mitigating Urban Heat Island (UHI) but also gives a very good impact in transferring landscape in urban area. Since building walls are larger than roof, the opportunity to develop vertical greenery systems in the urban areas is promising. In this study, a vertical greenery system is developed at the Faculty of Integrated Technologies, Universiti Brunei Darussalam, Brunei Darussalam with the objective to evaluate the thermal impact of vertical greenery system on the buildings based on the wall surface and the room temperature.

General variation in temperature shows that the GF-Room consistently had a lower temperature than BW-Room. The most visible temperature reduction is due to the shading effect of the green façade as indicated by ambient air temperature in the cavity between the green façade system and the GF-Room. The mean and maximum temperature reduction was observed to be 2.2°C and 19.8°C, respectively. While the indoor thermal parameters showed a smaller temperature reduction of 1.0°C.

The findings of the current study led to the conclusion that using vertical greenery system as passive cooling design can significantly contribute to the temperature reduction of the buildings. The existence of climbing plants attenuated the maximum building temperature resulting less energy exchange between the external and the internal environment, consequently, reducing the energy required to maintain the cooling load.

From this study, if green façade systems are integrated into regional strategies and applied to the whole scale city, it can mitigate the urban temperature and enhancing sustainability, especially for tropical regions. However, exploring the integration of green façades with renewable energy technologies or smart building systems is needed in the future to maximize their environmental benefits.

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