International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:5, No:4, 2011

The Building Thermal Performance and Carbon Sequestration Evaluation for *Psophocarpus tetrogonobulus* on Biofaçade Wall in the Tropical Environment

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***Abstract*—**Plants are commonly known for its positive correlation in reducing temperature. Since it can benefit buildings by modifying the microclimate, it's also believed capable of reducing the internal temperature. Various experiments have been done in Universiti Sains Malaysia, Penang to investigate the comparison in thermal benefits between two rooms, one being a typical control room (exposed wall) and the other a biofacade room (plant shaded wall). The investigations were conducted during non-rainy season for approximately a month. Climbing plant *Psophocarpus tetrogonobulus* from legume species was selected as insulation for the biofacade wall. Conclusions were made on whether the biofacade can be used to tackle the energy efficiency, based on the parameters taken into consideration.

***Keywords*—**biofacade, thermal benefits, carbon sequestration, *Psophocarpus tetrogonobulus.*

I. INTRODUCTION

BIOFACADE wall can be categorized as support system or commonly termed as "green facades" in various German green facades study. Biofacade term had once been used by Sunakorn [9], as a biological building skin whereas a combination between natural environment and build environment appeared. Lots of similar phrases have been used in academic research such as vines on wall [2], bio-shader [3], living wall [4], green facades (Kohler, 2008), vertical greenery [6], green wall (Alexandri, 2006) and vertical garden (Blanc, 2008). However, according to [6], these terms can be differentiated into two categories whether as support system and carrier system. Support system refer to plants which were guided to climb up through the structures like wires or cables, whereas carrier system are plants which were put into boxes and contain the media for planting on the vertical surfaces, attached directly to the wall. This paper is focused on support systems, with the media of planting placed on the ground.

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The study was conducted in Penang Island, Malaysia (5°21'20.39"N, 100°17'30.03"E), where the land are limited and pricey. The climate of Penang is humid tropical throughout the year. With the competitions on development, greenery often gives way to buildings. Appearances on large hard surfaces are one of the factors of global warming and unstable climate. Temperature as well as carbon emission in urban setting was higher compared to rural settings due to the urban heat island effect. One of the solutions towards reducing the urban temperature is to plant as many vegetation as possible. Various researches showed the thermal benefits when plants were grown on the wall.

According to Laopanitchakul [9], in a research conducted in Bangkok, the wall temperature of climbing plants can be reduced with the maximum average of 7.03 ^{o}C (daylight) compared with walls without climbing plants. During night time, the heat emitted from the insides of the wall is about the same for both walls. However, there are many factors which influenced the result such as the species selected for measurement, leaves coverage or leaf area index, leaves layer and the distance of climber planting next to the building envelope. For tropical climate, Laopanitchakul suggested that to increase the heat transfer from the inside to the outside of a building, the climbing plant should be planted with the distance of 15 cm offset the building wall.

Besides Thailand, Singapore also investigated the benefits of growing plants on walls. According to Wong (2009), from an experiment conducted in Singapore, the maximum reduction of wall temperature was recorded at 11.58 ^{o}C with the specific use of carrier system or living wall. However, the temperature reduction was affected by soil substrate attached to the wall surfaces.

Various investigations were made by Sandifer [2] from the University of California back in Sept 2001. The observations were on plant growth with vines thickness of approximately 30-35 cm. The analysis explained that, a temperature difference of approximately 20 ^{o}C was recorded when comparing the surface temperature between exposed brick surfaces and shaded surfaces with vines. Sandifer also concluded that the factor affecting the temperature difference was due to evapotranspiration from plants. Another experiment during the hot summer on daytime in July 2001, a pergola with Wisteria species in a family residence in Encino Ca., Los Angeles, was monitored for approximately one year. According to Sandifer [2], the difference in surfaces temperature reduction of 30 °C was recorded between bare wall and shaded climbing plant wall (distance total shaded of wall was 12 feet). However, a pergola receives shades mostly from the entwining and growth of plants along the crossbeams at the top and only partially from the vertical pillars.

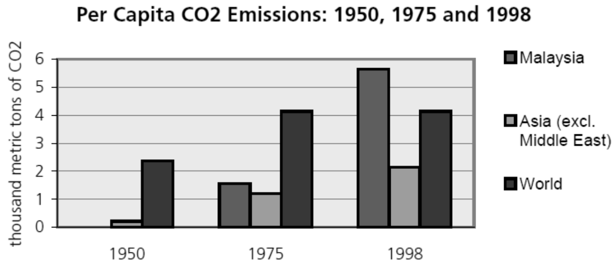
Sandifer [2] also experimented on the shrubs grown as espalier against stucco wall, which were painted light gray, in August 2001 in Encino Ca. The surface wall temperature also experienced a reduction up to 25 °C, when comparing between the bare wall and the plant shaded (a mixture of *Grewia caffra* and *Pyrus kawakami,* leaves thickness 8 to 14 inches) stucco wall. He also concluded that vines with 30-35 cm thickness can eliminate the surface color effect. From three different experiment made by Sandifer, it can be concluded that the distance of the plants to the building wall surfaces did effect the comparative temperature reduction. The leaves coverage and leaves thickness was also the main influence affecting the study.

Alexandri (2006) studied the green wall thermal effect on nine different cities with a diverse climate from Athens, Beijing, Brasilia, Hong Kong, London, Montreal, Moscow, Mumbai and Riyadh, comparing the temperature decrease on outdoor thermal comfort and energy savings. Hong Kong, which has similar climate to Malaysia (tropics and high humidity), can achieve up to a maximum of 8.4 °C in temperature decrease if both the walls and roofs are covered with vegetations. Alexandri sum it up by stating that when the surfaces receive higher amount of solar radiation, the larger the temperature would decreases when it is covered with vegetation. For a tropical hot climate like Malaysia, which receives high amount of solar radiation, it is possible to increase the temperature reduction.

According to Alexandri (2006), apart from increasing the temperature reduction for outdoor thermal conditions, green walls can also cause temperature reduction inside the building by decreasing the cooling load demands. For the green wall study in humid-subtropical climate like Hong Kong, the temperature levels and achieve energy saving for cooling load can be reduce up to 66 % falls into second place when comparing with all nine cities.

Part of the research by Bass [11] on energy consumption also showed, the shading from vertical garden reduces energy usage for cooling by about 23 % whereas energy used for fans is about 20 %. The results made the shading effect of plants towards building walls even more promising. Parallel with the studies, Chan (2008) in Green Building Index, a study of household energy used by Center for Environment, Technology & Development Malaysia (CETDEM), reported that the electricity consumption for cooling of average home in the year 2006 was the highest, reaching up to 45 % from the total utilization. Energy consumption for cooling loads depends very much on the air temperature within the building. Chan stated that the comfortable temperature is about 24 ^{0}C and average outdoor air temperature in Malaysia is approximately 4 ^{0}C above the comfort range.

Malaysia's contribution of carbon dioxide emission in the environment is rapidly increasing. Statistic from Earth Trends Country Profiles (2003) gives evidence of the increase from approximately 1.5 thousand metric tons to 5.5 thousand metric tons in year 1975 and 1998, respectively. More comparison on carbon dioxide emission trends in figure 1.



Source: Earth Trends Country Profiles (2003)

Fig. 1 Trends of carbon dioxide emission through time

According to Yok (2009), trees act as a natural sinks through carbon dioxide fixation from the photosynthesis process and store it as biomass in its tissue. Tropics climate like Malaysia have the potential for reducing the carbon emission. It is strengthen by the statement from Loh (2008), that Malaysia was reported as one of the highest biomass production in the world.

The other issue by Yu (2004), on how a higher thermal reduction could be achieved when plants with large leaf area index value is planted. Moreover, Sunakorn [17] also observed on experiments scenario that plants with larger leaves were absorbing efficiently compared to the smaller ones on the ambient carbon dioxide. To sum up, this paper should include the leaf area size for thermal benefits and carbon sequestration evaluation to broaden the perspective view. Thus, the objective of the research is:

A. To provide food and medicinal produce through biofacade

Plants give benefits to human being. For example *P. tetrogonobulus* (winged bean) provides food supply from the legume pods. The flower part can be used as food colouring and tuber part are beneficial for women after giving birth. Meshed shoots, young leaves and flower buds can be used as a tonic for hair growth. Biofacade can be beneficial for apartment residential and office blocks during harvesting time. It can bring people together and increase social activity among the neighbourhood. Moreover, it is beneficial for urban areas agriculture where the price of land is higher.

B. To reduce indoor temperature through biofacade

Building surfaces that faces the sun's orientation both in the morning and afternoon usually experience higher daily temperature. Biofacade act as insulation from the heat outside. Plants are beneficial for its shade and cool the area, especially those with broad leaves. Reducing the temperature inside the building is hypothesized to placate the occupants and would actually lower the energy usage for cooling the space thus, would reduce the electrical consumption. Moreover, biofacade can reduce the urban heat island effect if we plant it covering the hard surfaces of buildings.

C. To reduce carbon dioxide emission in urban areas through biofacade

Carbon exposures from power plants, cars and buildings are the causes of the rising temperature level in urban spaces. Biofacade grows vertically up the side of the building and it actually provides more surface area to sink down the carbon dioxide level by photosynthesis of the plants. On an average in laboratory experiments, plant growth increases when carbon dioxide was increased at the ratio of 9:1 (Lemon 1983). Thus, plants can actually grow faster in urban spaces where the carbon dioxide can act as plant fertilizer.

II. Materials and Method

Legume species of *Psophocarpus tetrogonobulus* (Figure 2) was selected to study the carbon sequestration and thermal benefits of biofacade wall. Certified seeds of *P. tetrogonobulus* were purchased locally. The duration of the study was approximately six months of observation starting in August 2010 until February 2011. Ten pots of *P. tetrogonobulus* were grown on diamond fences (with 15 inches gap from wall) attached to the wall of approximately 3 meter height. A mix of soil and compost was used as media of growth. Identical treatment was applied evenly to all pots with regular watering depending on the soil moisture. Chemical control pesticide (Furadon 3G) and water based aerosol was used and fertilizer N: P: K (at the ratio of 20: 6: 40) was applied when the plants' growth appeared to have slowed down five month after it was cultivated.

Fig. 2 *Psophocarpus tetrogonobulus* (winged bean) fruits when it reaches 2-3 months of plantation.

A. Temperature evaluation

Observations were conducted on biofacade shaded surface temperatures and exposed surface temperatures in two different setting in Universiti Sains Malaysia. The duration of the study was for about a month beginning from Jan 5, 2011 to Feb 5, 2011. Four measurements were divided in a month. Measurements were taken on the alternate rooms (Figure 3).

Both walls were chosen based on a shared characteristic which is because both are facing west towards direct, harsh sunlight orientation and consist of two identical rooms (11 feet long x 11 feet width x 7.5 feet height). The tests were conducted with five month's old grown *P. tetrogonobulus* (winged bean) as insulation for biofacade wall (Figure 4). The species was chosen based on preliminary experiments for the highest photosynthetic assimilation rate for legumes in tropics climate. The tests were conducted in two different rooms,

TABLE I
MONITORING EQUIPMENT USED IN THE EXPERIMENT
(TABLE MODIFICATION [21])

No	Equipment	Description
1	Pyranometer	Above climbing plant. Measures solar radiation
2	Outdoor temperature	Measures the ambient temperature
3	Indoor air velocity	Center of the room
4	Indoor humidity	Center of the room
5	Indoor temperature	Center of the room
6	Lux meter	Center of the room
7	Indoor surface temperature	Inside room, on wall surface 1800mm from floor area
8	Outdoor surface temperature	Outside room, on wall surface 1800mm from floor area

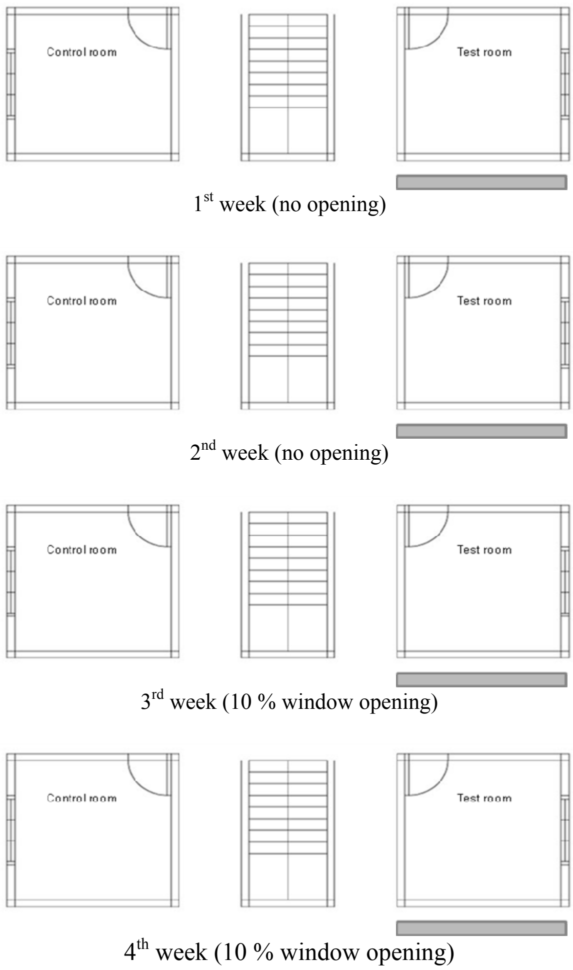


Fig. 3 A set of pyranometer and outdoor temperature were placed on the upper part of wall external surface. A set of indoor wind speed, indoor humidity, indoor temperature and lux-meter were placed on the center of the room. Two surfaces temperature were placed on the indoor and outdoor building wall, 1800 mm from the floor base.

namely the typical room (exposed wall) and the biofacade room (plant shaded wall). Both rooms' wall consisted of 115 cm thick brick with plaster and light peach painted on the external surfaces.

Babuc/M instrument includes two sensors of temperature for measurement of indoor temperature, for the biofacade room and typical room, before and after the application. The system was logged at every 10 minutes for three straight days and counts as one measurement. Only two measurements were carried out for this study. Babuc/M instrument with one sensor of wind velocity was used to measure the range of wind rate flowing towards both rooms. The system was logged at every five minutes for two straight days. This measurement was to allocate for thermal comfort inside two different habitable rooms.

The ADAM-4000 series developed by Advantech Co., Ltd was used to measure solar radiation, temperature, relative humidity, lux and air velocity (ADAM-4000, 2002). A set of Data Acquisition System (DAQ) with eight sensors (table 1) were connected directly to the computer. The system was logged on to every 5 minutes and this is continued for six days counts as a single measurement. Pyranometer sensor, which measures the solar radiation, was the key to guide the research. The analyses of temperatures were initiated with every 1000 W/m^2 and above of solar radiation. To sum up, four measurements were carried out for this study.

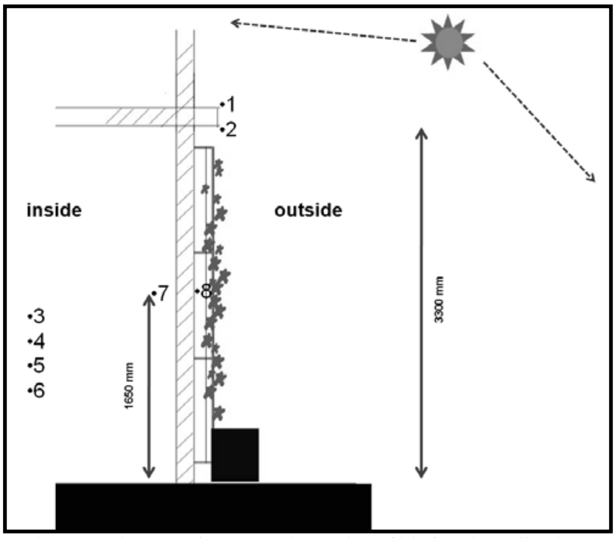


Fig. 4 Section part for measuring point of biofacade wall. The external wall was facing west orientation.

B. Photosynthesis evaluation

Carbon dioxide uptake measurement was done using LICOR 6400 with 2 cm x 3 cm leaf chamber standard size (Figure 6). Two clear weathered, hot days were chosen randomly in January where the plant seems covered the entire wall. The measurements were taken from Jan 17, 2011 to Jan 19, 2010. Plant species *P. tetrogonobulus* were identified as a legume tropical plant that can absorb the highest carbon dioxide constantly. It was based on the preliminary experiment on 26 April 2010. Combined, these two times of experiment, form a complete year-long calculation of carbon dioxide uptake. Carbon dioxide is not constant, thus by doing the experiments in two separate parts; it gave a more specific reading of carbon dioxide uptake.

During the experiment, 20 leaves were tagged. Basically, we chose mature leaves that have broad leaf size with a minimum of 2 x 3 cm with dark green hue. The selected leaves are then clamped in the LICOR 4600's leaf chamber. Three readings were logged every time the machine clamped on a leaf. Photosynthesis rate will be measured when the leaves are stabilized from environmental carbon dioxide concentration after about 2 minutes.

Fig. 5 Typical room (exposed wall) on the left and biofacade room (plant shaded wall) on the right. The walls were painted with light peach. The picture was taken when *P. tetrogonobulus* at 3-4 months old.

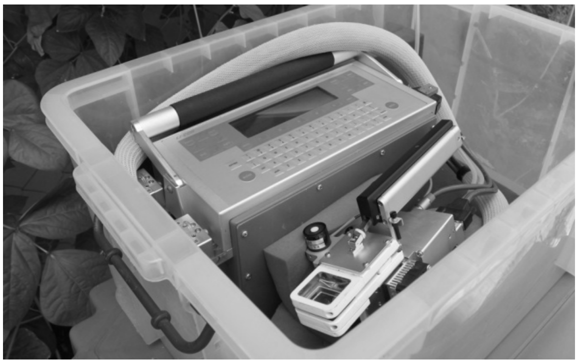


Fig. 6 LICOR 6400 while experiment

III. Results

A. Temperature evaluations

Temperature evaluations were conducted within two sub-phases which are:

1) Determining the indoor temperature before and after the application of biofacade and comparing it with standard room temperature. The objective is to measure the difference between the two. This method was done using Babuc/M and two temperature sensors.

This experiment was conducted on the 5-8 January 2011. The outdoor temperature recorded was between 25-37 ^oC, and the highest reading of solar radiation was 1209 W/m^2. With a plant applied to the biofacade room, the average temperature was 27.2 ^oC, whereas the typical room was at 26.0 ^oC. The minimum and maximum reading of biofacade room was 25.9 ^oC and 29.2 ^oC, respectively. However, the typical room reading was much lower for both minimum and maximum temperatures which were 25.0 °C and 27.3 °C. To sum up, typical room indoor temperature was always lower than biofacade room by the factor of 1.2 °C (Figure 8).

The experiment continued to February 2011, whereupon the plants (biofacade wall) were removed. The outdoor temperature was ranging between 24-41 °C. The highest reading of solar radiation was 1234 W/m^2. Without a plant applied to the biofacade room, the average temperature was 29.6 °C whereas the typical room was at 27.8 °C. The minimum and maximum reading of biofacade room was 28.1 °C and 30.9 °C, respectively. However, the typical room reading was much lower for both minimum and maximum temperatures which were 26.7 °C and 29.0 °C. The difference temperature between these two rooms was 1.8 °C (Figure 9). To sum up, the indoor temperature before and after application of biofacade was 0.6 °C reduction. It can be consider that there was not much difference for indoor temperature when biofacade was applied.

Graph plotted on figure 8 showed a smooth parallel sinusoidal, whereas graph in figure 9 showed a little bit distract on the morning until late afternoon, between 7:30 hours until 14:00 hours.

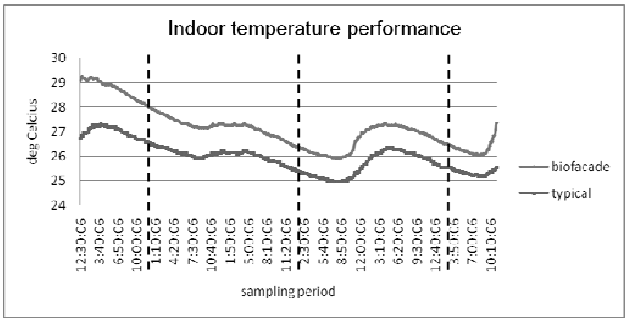


Fig. 8 Temperature difference of biofacade room (plant shaded wall) and typical room on 5-8 Jan 2011 (without opening evaluation) using Babuc/M equipment.

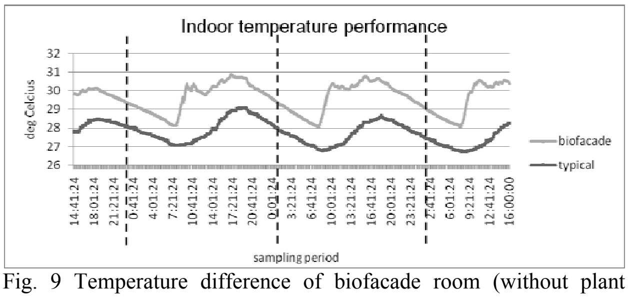


Fig. 9 Temperature difference of biofacade room (without plant shaded) and typical room on 16-19 Feb 2011 (without opening evaluation) using Babuc/M equipment.

2) Determining the effectiveness of plants as shading devices by comparing the wall surface temperature using ADAM 4000 equipment with DAQ system and seven sensors as listed in table 1.

a)Evaluation of biofacade room

This study was conducted on the 8-13 January 2011 and documented as sub-phase 1. The evaluations of all the parameters are as listed in table 2. The solar radiation level (1000 W/m^2 and above) was used as an indicator for temperature analysis. There were 50 sets of data gathered by 9 and 12 Jan 2011. These measurements were taken at the level with highest density of leaves, at approximately 2300 mm from the floor level. The minimum and maximum reading of the indoor surface temperature, outdoor surface temperature, indoor room temperature and outdoor temperature were 30.47-32.95 °C (mean: 31.73 °C), 33.06-38.6 °C (mean: 35.98 °C), 31.46-32.52 °C (mean: 31.91 °C), and 32.77-36.66 °C (mean: 34.86 °C), respectively. In conclusion, when the solar radiation reaches 1000 W/m^2, the outdoor surface temperature is always higher by 1 °C from the outdoor temperature at the level with the highest leaf density. The indoor surface temperature and indoor temperature are about the same and are always lower than outdoor surface temperature by 4 °C (Figure 10).

The experiment continued on the 14-17 January 2011. These measurements were taken on the level with lowest leaf density, at the height of approximately 1500 mm from the floor level. There were 46 sets of data gathered. The minimum and maximum reading of the indoor surface temperature, outdoor surface temperature, indoor room temperature and

TABLE II
BIOFACADE ROOM EVALUATION

No	Parameters	Description
	9, 12, 14-17 Jan 2011	
1	Lux	137-401 lx
2	Solar radiation	1003-1209 W/m^2
3	Indoor surface temperature	30.47-33.46 °C
4	Outdoor surface temperature	33.06-38.87 °C
5	Indoor temperature	31.46-33.14 °C
6	Outdoor temperature	31.61-36.66 °C
7	Relative humidity	57.4-63.9 %
	25, 28 January 2011	
1	Lux	260-506 lx
2	Solar radiation	1006-1225 W/m^2
3	Indoor surface temperature	29.03-31.88 °C
4	Outdoor surface temperature	32.2-39.29 °C
5	Indoor temperature	30.26-31.86 °C
6	Outdoor temperature	30.33-34.55 °C
7	Relative humidity	58.1-67.7 %

TABLE III
TYPICAL ROOM EVALUATION

No	Parameters	Description
	18-23 January 2011	
1	Lux	412-1302.4 lx
2	Solar radiation	1006-1253 W/m^2
3	Indoor surface temperature	28.70-35.16 °C
4	Outdoor surface temperature	39.06-59.08 °C
5	Indoor temperature	29.53-31.24 °C
6	Outdoor temperature	31.33-38.50 °C
7	Relative humidity	37.7-67.7 %
	2,3,5 February 2011	
1	Lux	494-1449 lx
2	Solar radiation	1003-1265 W/m^2
3	Indoor surface temperature	29.41-33.16 °C
4	Outdoor surface temperature	36.17-50.00 °C
5	Indoor temperature	30.17-32.28 °C
6	Outdoor temperature	31.72-36.83 °C
7	Relative humidity	60.6-65.5 %

outdoor temperature were 32.16-33.46 °C (mean: 32.75 °C), 35.14-38.87 °C (mean: 36.49 °C), 32.61-33.14 °C (mean: 32.83 °C), 31.61-34.27 °C (mean: 32.70 °C) respectively. To sum up, when the solar radiation reaches 1000 W/m^2 and without air ventilation through the room, the outdoor surface temperature is always higher by 3 °C from the outdoor temperature at the level of the lowest leaf density, a 1 °C temperature difference compared to the level with the highest leaf density. This shows that the dense leaves areas are more effective sparse ones in order to insulate the buildings on sunny days. The indoor surface temperature and indoor temperature is mostly the same and is always lower than outdoor surface temperature by 3 °C (Figure 11). The maximum reading of solar radiation and lux of biofacade room were 1209 W/m^2 and 635 lx, respectively (Figure 13).

b)Evaluation of typical room

This experiment was conducted on the 18-22 January 2011 and documented as sub-phase 2. Solar radiation (above 1000 W/m^2) was used as an indicator for when to measure the temperature. The evaluation of all parameters is as listed in table 3. There were 84 sets of data gathered. These measurements were taken at the height of approximately 2300 mm from the ground. The minimum and maximum reading of the indoor surface temperature, outdoor surface temperature, indoor room temperature and outdoor temperature were 28.70-35.16 °C (mean: 31.22 °C), 39.06-59.08 °C (mean: 49.15 °C), 29.53-31.24 °C (mean: 30.26 °C), 31.33-38.50 °C (mean: 35.94 °C), respectively (Figure 14). In summary, when the solar radiation reaches at 1000 W/m^2, the outdoor surface temperature is in average higher by 13 °C from the outdoor temperature. The indoor surface temperature is always higher by 1 °C from indoor temperature.

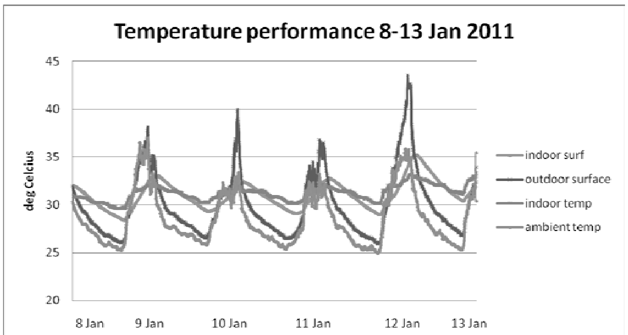


Fig. 10 Temperature performance of biofacade room on the crowded leaves level, without opening (sub-phase 1).

Solar radiation level of 1000 W/m^2 is considered as the worst case condition in measuring the effectiveness of plant as shading device for building performance. In conclusion, it is determined that using plant as a shading device was more effective than bare wall. From data observation, the average temperature of a biofacade wall's outer surface is 36 °C (when the outdoor temperature was about 34 °C), whereas a typical wall's outer surfaces is 49 °C (when outdoor temperature was 36 °C). Taken the average of 35 °C for outdoor temperature, the external wall surface of biofacade can reduce up to 13 °C, comparing with typical wall. Therein lies the evidence that biofacade wall is more effective than a typical bare wall for tropical climate even in the scorching sunlight.

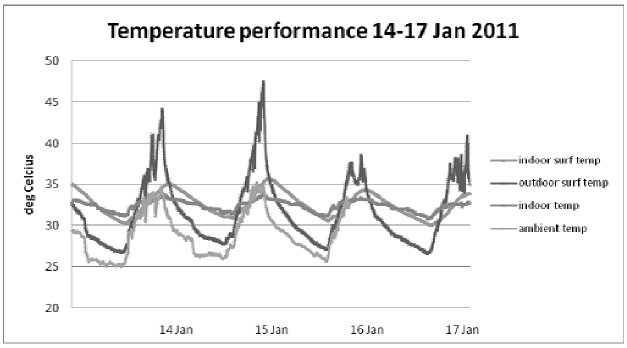


Fig. 11 Temperature performance of biofacade room on the sparse leaves level, without opening (sub-phase 1).

c)Evaluation of biofacade room and typical room.

All the measurement divided into four categories. Sub-phase 1 was considered in biofacade room, sub-phase 2 was considered in typical room, sub-phase 3 on biofacade room again but with opening, and sub-phase 4 on typical room with opening as diagramed in Figure 3. Comparison has been made in average to determining the temperature reduction of two rooms, biofacade and typical. On average, biofacade room showed the indoor surface temperature, outdoor surface temperature, indoor temperature and outdoor temperature were 31.5 °C, 36 °C, 32 °C and 33 °C, respectively. However, typical room showed the the indoor surface temperature, outdoor surface temperature, indoor temperature and outdoor temperature were 31 °C, 47 °C, 30.5 °C and 35.5 °C, respectively. At the range of 33-35.5 °C, the outdoor surface temperature of biofacade wall was better than typical wall, which were can reduce on average 11 °C. The indoor surface temperature was about the same for both rooms. However, indoor temperature showed, the typical room was cooler than biofacade room by the factor of 1.5 °C. We continue the study with BABUC/m application which with the removal of the plants at biofacade wall.

3) Considering the Universal Building by Law (UBBL) 1984 for ventilation and lighting in habitable rooms. The habitable room should be 10 % of the floor area to provide natural lighting, and 5 % of the floor area to provide natural ventilation (MDC Legal Advisers, 2006). Babuc/M with wind velocity sensor was used together with DAQ system in analysis.

a)Evaluation of biofacade room for thermal comfort

This experiment was conducted on 25-28 January 2011 and documented as sub-phase 3 (with 10 % of opening). There were 12 sets of data gathered by 25 and 28 January 2011. The sensor was put in the middle of the room. The minimum and maximum reading of the indoor surface temperature, outdoor surface temperature, indoor room temperature and outdoor temperature were 29.03-31.88 °C (mean: 31 °C), 32.2-39.29 °C (mean: 36 °C), 30.26-31.86 °C (mean: 32 °C), 30.33-34.55 °C (mean: 32 °C), respectively. From the observations, there is no wind inside the room, if only one-sided of window was open. Moreover, the indoor temperature was increased 1 ^oC when comparing with the room with no opening. There is a possibility for only a heat that passes through the room when there is opening.

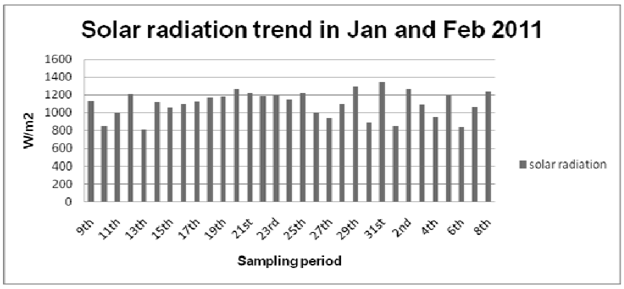


Fig. 13 Maximum reading of solar radiation and lux of biofacade room during 9-17 Jan 2011(sub-phase 1)

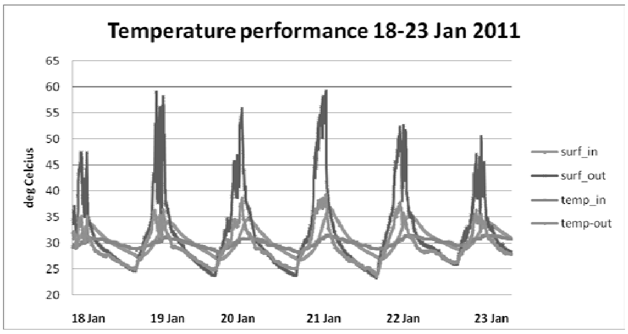


Fig. 14 Temperature performance of typical room, without opening (sub-phase 2).

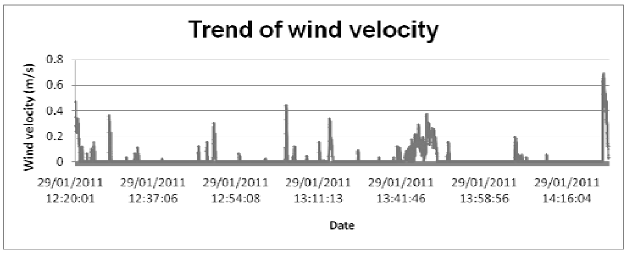


Fig 14 wind velocity every one second for two hours at the highest sun penetration on 29 Jan 2011. The average of air velocity in habitable room for thermal comfort is 0.25 m s^{-2} (Ibrahim, 2001)

We then continue the study with a different location of sensors. The air velocity, relative humidity, indoor temperature and lux meter was placed near the window. The objective was to evaluate the wind flow passes through the room for thermal comfort evaluation. The measurement was conducted on 29 and 31 Jan 2011. It happened to be non-rainy days on both durations. We logged every 5 minutes of wind velocity for two hours, 12:20 until 14:20 hours, which is the hardest time of sun penetration to the wall. The wind are multi direction and unexpected. So, there was no reading at all during 5 minutes logged. Therefore, the study was replaced and gathered on every 1 second measurement (Figure 14).

The measurement were conducted on 14 Jan 2011 for room condition without opening (N= 18), and 29 Jan 2011 for room condition with 10 % of opening of the floor area (N=16). These days were selected based on the average time that usually penetrate the wall, which was within two hours approximately from 12:40 until 14:40 hours. Secondly, data were gathered from 1000 W/m^2 solar radiation and above .

The room without opening showed the indoor surface temperature, outdoor surface temperature, indoor temperature, and outdoor temperature were 33 ^oC, 36 ^oC, 33 ^oC and 33 ^oC, respectively. The room with opening showed 30 ^oC, 34 ^oC, 32 ^oC and 32 ^oC, respectively. To sum up, from the observations, there was not much temperature different when comparing the room with or without 10 % of opening of the floor area. Both situation didn't achieved range as ASHRAE thermal comfort zone for summer, 22-27 ^oC. Therefore, it can be concluded, there was not enough data to support the hypothesis.

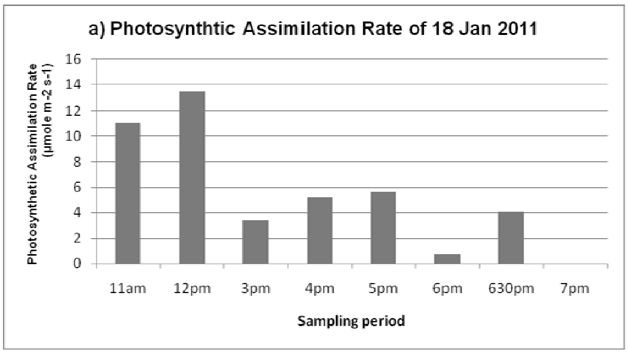
B. *Photosynthesis evaluation*

The measurement was taken on two non-raining days, which are January 18th and 19th of 2011.

On the 18th, the measurement was conducted from 11:00 till 19:00 hours. The relative humidity ranges from 30 % to 50% with air temperature between 32 ^oC to 39 ^oC and ambient CO_2 concentration from 400 to 400 mmol l^{-1} during our C sequestration study. The Photosynthetic Assimilation Rate, from the average of over three readings, stands at 7.4 µmole m^{-2} s^{-1} (max: 21.1 µmole m^{-2} s^{-1}).

On January 19th however, the measuring session lasted from 08:00 until 19:00 hours with relative humidity ranging from 26 % to 44%, air temperature between 30 ^oC to 39 ^oC and an ambient Carbon Dioxide concentration from 405 mmol l^{-1} to 556 mmol l^{-1} during our C sequestration study. The (PAR) Photosynthetically Active Radiation, averaging from over three readings, was 5.0 µmole m^{-2} s^{-1} (max: 19.3 µmole m^{-2} s^{-1}).

To sum up, the PAR for *P. tetrogonobulus* is 6.32 µmole m^{-2} s^{-1}. Its photosynthetic rates are at its highest between 11:00 and 12:00 hours due to the higher solar radiation. However, if the temperature is too high and it is getting too hot, the leaves stomata are closed in order to preserve the water content inside the plant from being hydrated or evaporated. The photosynthesis rates of leaves are at a low level when its stomata are closed (Figure 15 (a) (b)).



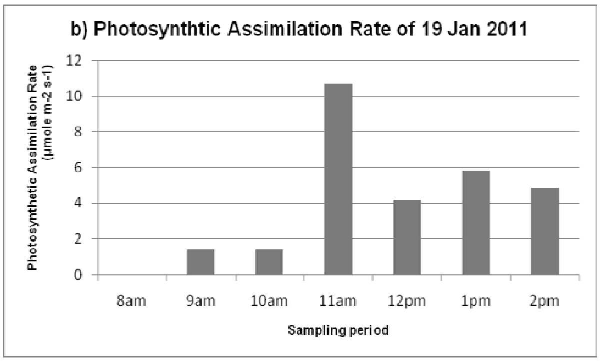


Fig. 15 (a) Relationship of Photosynthetic Assimilation Rate and sampling period of 18 Jan 2011 (b) Relationship of Photosynthetic Assimilation Rate and sampling period of 19 Jan 2011

IV. Discussion

A. Temperature evaluations

The outdoor wall surfaces on the biofacade wall experience on 11 ^{o}C temperature reduction when comparing with typical wall. It shows that plant can absorb a significant amount of heat, also act as a shading device to the building wall. The indoor temperature of biofacade room was always higher 1.2 ^{o}C than typical room, made the evaluation more puzzled. However, the temperature difference inside the room of biofacade after plants were removed shows 1.8 ^{o}C. It shows there was not much difference on indoor temperature whether the plants on the external wall were applied or not. However, from the observation, the study has lots of factor that affect the evaluation on both rooms which were building orientation, sun penetration and wind flow. Biofacade room receives more sunlight comparing with typical room. This was the main factor that influencing the indoor temperature (Figure 17). Therefore, therein lies the evidence of 0.6 ^{o}C temperature reduction in biofacade room eventhough biofacade room receives more sunlight than typical room. If both rooms were treated with same condition, the temperature on biofacade room was believed to be more reducing.

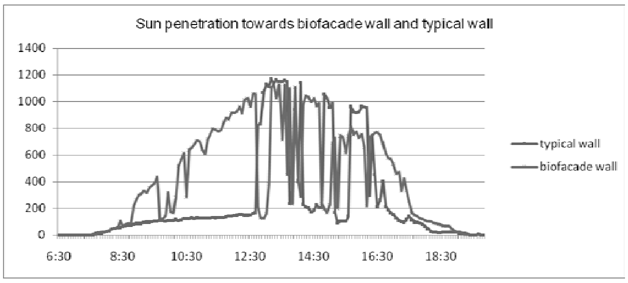


Fig. 17 Sun penetration towards biofacade wall on 14 Jan 2011, and typical wall on 19 Jan 2011. Both days were selected based on the same average of sampling period, and same rate of sun penetration to the wall using pyronometer sensor.

Time taken approximately 7:30 hours until 14:00 hours was the timing where the wall starts to receive harsh sunlight (Figure 9). It can be concluded, with the plants application on wall, the temperature was reduce during 7:30 hours until 14:00 hours and produce smooth parallel sinusoidal graph, showed a constant of temperature (figure 8).

B. Photosynthesis evaluations

Photosynthesis rates have its own factors, which influence the C sequestrates on leaves, which are light, water, temperature, wind turbulence and carbon dioxide concentration [20]. From analysis, Photosynthesis Assimilation Rates is found to have a strong positive correlation with solar radiation, leaves stomata conductance, temperature, relative humidity and carbon dioxide. However, due to technical constraints, we weren't able to measure the outdoor wind range and the soil's water content. These investigations only look into the carbon sequestration of one species, namely *P.tetrogonobulus*, for a period of two day. Different species might perform differently and longer period of study might yield more information.

V. Conclusion and Future works

Further investigation on various species has to be explored. This is to ensure a range of other plants with potentials for reducing the carbon emission into the air can be identified. Data was collected from two seasons to ensure precision in data collection. However, more persistent data has to be obtained on specific species for accurate reading. Difficulty with unstable cloud movement made the data more inconsistent. With additional cloud slot from LICOR 6400, it is believed that the data can be made more reliable.

It would be a better data collection if a sufficient number of sensors can connect to DAQ system. Limited sensors led the research to have to alternate the weeks in taking the measurement. The benefits of wall covered with the plants are important for investigations of thermal performance of the building envelope can be improved.

Acknowledgment

Acknowledgement is dedicated to Associate Prof. Ar. Dr. Abdul Malek Abdul Rahman for his assistance in idea contribution as well as his help in proof reading. Special regards to Dr. Foong Swee Yeok from the School of Biological Sciences for co-researching especially for her guidance in plant matters. Sincerest thanks to Mr Muhamad Fadli bin Mohd Tap for assisting with the ADAM 4000 and DAQ sensor, and Mr Kumaradevan a/l Samir from Centre for Marine & Coastal Studies (CEMACS) for his assistance in handling the LICOR 6400. This research is fully funded by grant RU-PGRS 1001/ PPBGN/ 843053, School of Housing, Building and Planning, Universiti Sains Malaysia (USM).

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