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Thermal Performance of Edible Vertical Greenery System In High-rise Residential Balcony

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Abstract: The vertical greenery system (VGS) is a passive solution for urban greening in multi-storey buildings. This system could prove to be beneficial towards the building occupants. It is designed to provide urban greening for the benefits of environmental, economic and social aspects. As cities are experiencing urban heat island due to excessive development and overpopulation, the vertical greenery system is introduced to counter this issue. This paper presents a series of measured data from the use of balcony space at Putra Place Condominium, Penang. Apart from that, this paper also uses Psophocarpus Tetrogonobulus (Winged Bean Plant) as the core plant for VGS. It is chosen based on the ability to provide vegetable pod, have longer lifespan and withstand heat gain from long sun exposure at high-rise condition. The VGS that has been installed managed to reduce the indoor dry bulb temperature (DBT) and mean radiant temperature (MRT) by an average of 0.94°C and 1.25°C. The overall finding from this experiment confirms that when exposed to higher outdoor temperatures facing the west orientation, the indoor DBT and MRT behind the VGS managed to be stabilised and maintained at a constant 30.6°C. Thus, reducing the needs for future building energy cooling load.

Keywords: Cooling load, energy, high-rise, temperature reduction, vertical greenery system

1. Introduction

Since 1700s, the industrial revolution has started burning fossil fuels that increased the carbon dioxide emission [1]. As stated by Shakun et al. [2] with the release of this primary greenhouse gas, it causes a rapid growth of global ambient temperature leading to drastic climate changes. According to National Research Council 2010 [1] indicates that natural causes of temperature alteration alone are unlikely explain most of the global warming. But rather human activities that tend to use more energy to cool the indoor environment especially in urban areas can very likely causes the global warming issues. Recently urban dwellers are keen to use air conditioning system to cool the indoor temperature as the outdoor temperature is relatively high. When this mechanical cooling system is on, it increases heat gain built up that contributes to the urban heat island (UHI) phenomenon [3]. According to Zain-Ahmed [4], mechanical cooling method such as the air conditioning unit could consume at least 50 percent of overall building electricity energy consumption. This excessive usage of cooling meth-od may eventually causes global warming in larger scale [5].

Apart from that, by the year 2020 at least 70 percent or a total of 40.6 million Malaysians would consist of urban dwellers [6]. As landed property has become scarce, multi-storey buildings have been constructed to allocate space for increasing urban dwellers. In Malaysia, multi-storey buildings ranging from office towers and residential apartments are increasingly becoming a necessity to cope with the surge of population growth mainly due to shortage of land.

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Therefore, improving the thermal performance of multi-storey buildings is far more challenging than low-rise buildings as multi-storey building facades are more exposed to climatic elements such as the sun, wind and rain compared with low-rise buildings. Low-rise buildings are often surrounded by features such as trees and adjacent buildings that help to buffer from excessive climatic conditions [7]. However, in urban areas, many high-density buildings have overlooked the basic requirements of vegetation. Hard surfaces such as concrete pavements have been wide-ly used replacing trees that contributed to heat gain built up. To address the issues, the vertical greenery system (VGS) functions to lower the ambient temperature using plants as an additional layer on the external facades. This system consists of vertical planters to shade desired space of multi-storey building from sun exposure. By doing so, the VGS can reduce the surface and indoor air temperature which enables the reduction of energy consumption from air conditioning system cooling load. In time, issues related to climate changes can soon be diminished.

2. Aim and Objectives

The aim of this paper is to investigate the optimum temperature reduction using vertical greenery system (VGS) installed with Psophocarpus Tetrogonobulus (winged bean plant) on a high-rise residential balcony.

3. Literature Review

The term vertical greenery system (VGS) has been widely used to describe biological building envelope that helps to create equilibrium between artificial and natural environment. There are many phrases or similar keywords to describe vertical greenery system namely Bio-shader [8], Living wall [9] Bio-facade [10], Vertical Garden [11], Green Facades [12], Green Wall [13] and the most recent term Vertical Greenery System (VGS) [14]. According to Yu and Hien [15], the vertical greenery system is divided into four categories. Although the names are different in research perspectives, their performances and functionality are the same. The four categories are; tree-against-wall types, wall-climbing type, hanging-down type and module type (Fig.1). Similar to these four categories, the most common categories are divided into two big groups (Fig. 2) which are called "support system" and "carrier system" [16].

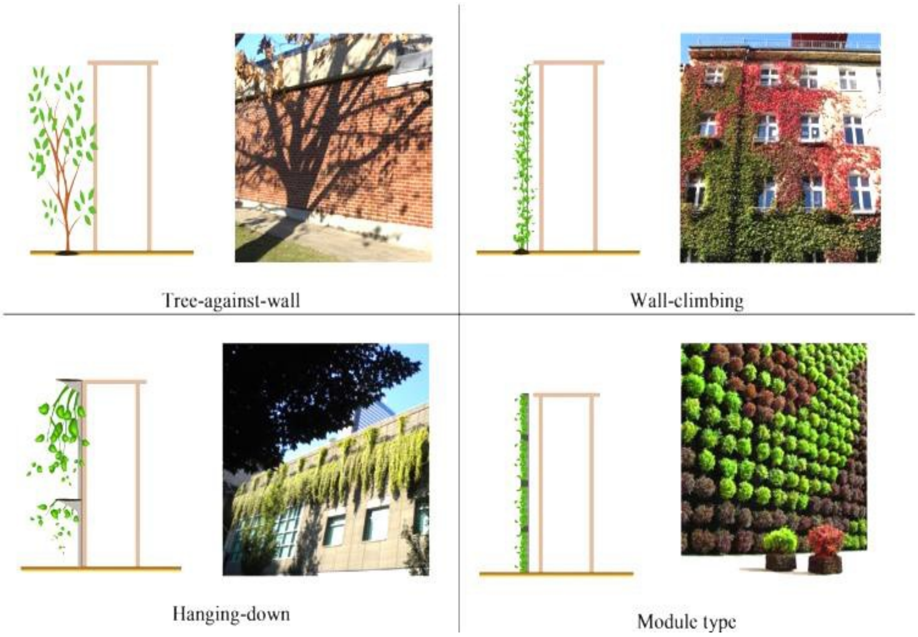

Fig. 1 - Vertical greenery system; tree against wall, wall-climbing, hanging-down and module type [15]

The support system also shares the terminology with the wall-climbing type and green façade. This system is designed to guide plants up on the vertical building surface that can be emphasised on direct and indirect approach depending on purpose of installation, climate condition and budget. The direct green façade uses climbing plants that grow from ground or any substrate container and attached to the building wall surface. Meanwhile, the indirect green façade focuses on the use of support structure such as diamond fencing, trellis, and cables. These support systems perpetuate cheap façade greening and can support only a few plants ranging from climbers to creepers. In contrast with the support system, the carrier system can host greater diversity of plants ranging from evergreen (small shrubs), groundcovers and even grasses (Fig. 2). The carrier system consists of modular units on frame structure attached to various wall surfaces. The other terminology for this modular type is also known as living wall system (LWS). The carrier system contains its growing medium, fertilizers, and water irrigation. The living wall system is based on hydroponic culture stacked vertically [9]. The advantage of this system is that it enables the user to replace spoiled and withered plants by changing the module without taking down the whole green covers. To produce this carrier system with multiple growing media usually requires higher cost in production and maintenance [16], [17].

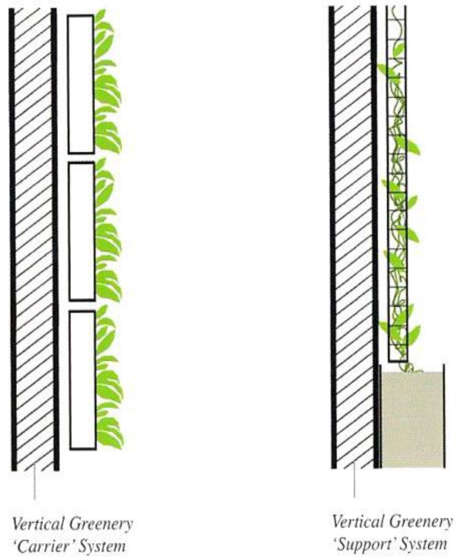

Fig. 2 - Support system and carrier system [16]

3.1 Benefits of Vertical Greenery System (VGS)

The vertical greenery system has many benefits towards the building occupants from economic, social to environmental perspectives. According to Cheng et al. [19] and Jim & He [20] this system has the potential to benefit dwellers in dense inner cities. In these dense areas, the walls of multi-storey buildings cover large proportion of the total surface while ground area for planting with shade trees is limited. The most important benefit gained from using the vertical greenery system is temperature reduction [21]. From economic perspective, temperature reduction eventually reduces the electricity demand for cooling and heating for indoor space [22], hence will reduce operative cost and energy, in the long run. For social benefits, the effect of using vertical greenery system has positive psychological impact towards the building occupants. The VGS system has been proven to reduce stress and enhance building occupants' productivity [23]-[25]. Apart from that, a survey conducted by Taib et al. [7] towards the human perception of having greenery in a multi-storey office building showed that the majority of respondents agreed that greenery are aesthetically pleasing. In terms of environmental benefits, the vertical greenery system on multi-storey building can reduce urban heat island effects [26]. In addition, this system can also lead to the reduction of carbon dioxide emission. In time, more surface areas could reduce the carbon dioxide level through the plants' photosynthesis process. As mentioned by Lemon [27], plants growth increased with the fluctuation of carbon dioxide at the ratio of 9:1.Therefore, it can be said that the plants can grow faster in urban spaces where there is an abundance of carbon dioxide.

3.2 VGS Plant Selection

Careful selection of suitable plants for vertical greenery system is important to ensure the efficiency of the system especially in designated areas exposed to direct sunlight. For support system, the selection of plants comes from climbers or vine family due to its ability to cover wall surface with lush green facade. When selecting plants for vertical greenery system, previous researchers have determined the quality of green facades by percentages of plants covered with trellises and number of leaf layers. Others such as Perini et al. [28] measured the plants for their thicknesses, substrates, density and even shadow factors. The measurement of quality upon choosing suitable plants for vertical greenery system may vary from one test to another. Hence, additional study is needed especially in to study the plant lifespan and thermal resistance towards environmental climates. Sunakorn and Yimprayoon [29] found that the Blue Trumpet Vine is a suitable plant for green façade in Thailand as it grew very fast and had consistent foliage density with minimum pruning. The Thunbergia grandiflora (Blue trumpet vine) was compared with Coccinia grandis (Ivy Gourd) and Antigonon leptopus (Mexican Creeper). The results indicated that the physical property of leaves gave different effects in air velocity and room temperature. In this case, the Blue Trumpet Vine with big round soft leaves that can move easily by wind flow provided no more than 4-5 leaves layers. According to Sunakorn and Yimprayoon [29], it is recommended to use plants with smaller and denser leaves that may provide better thermal effect and increase surface evapo-transpiration.

For direct green façade, some studies in temperate climate have used the Hedera Helix (English Ivy) and Parthenocissus tricuspidata (Boston Ivy) and Parthenocissus quinquefolia (Virginia Creeper) as part of the research. These species are commonly used in Europe and North America. These plant species can cover large areas rapidly and can even climb to 20-25 metres in height. Perini et al. [30] investigated several types of vertical greenery system using one of these plants. From the study, these temperate climate plants can attach itself directly to a wall surface without any support system. Moreover, these types of species are also termed traditional green facades that can last for decades [31]. Taraba [32] also studied on the traditional green façade, which is normally used as building green envelope in Europe. Apart from using basic ornamental vines, the author focused on the use of grapevine as an indirect approach. This plant enhances the building thermal performance and produced edible fruits for building occupants.

In line with the current trend of façade greening, the selection of plant for vertical greenery system has progressed from ornamentals to edible plants that can produce multiple benefits. In 2011, a team of researchers in Malaysia, Abdul Rahman et al. [33] and Fukaihah et al. [34] introduced the most effective legume plants as part of vertical greenery system for wall application, not just for the benefit of improving thermal performance but also providing food supply for residents. In this study, edible legume plant such as Pisum sativum (Sweet Pea), Vigna unguiculata sesquipedalis (Long Bean), Psophocarpus tetrogonobulus (Winged Bean) and Phaseolus vulgaris (Kidney Bean) were compared. After due consideration of suitable wall application, [34] indicated that the most effective legume plant to be used as part of vertical greenery system is the Psophocarpus tetrogonobulus (Winged Bean) as the plant can absorb heat from solar radiation more than other climbing plants due to its darker leaf features. Apart from that, this plant has longer life span compared with other climbers due to its tuberous root that can store sufficient nutrients over a two-year period.

With the recent inclination to produce food and mitigate urban heat island, one study showed results of growing of Pisum Sativum (snow peas) in dry yard balcony of a multi-storey residential building in Tokyo Japan [35]. The snow pea plant originated from the legume family, and it is considered fast growing. In Japan, the snow pea plant is among the favourite winter plants that can be home grown using a support structure such as balcony railings. Apart from reducing surface temperature and produce food, the snow peas plant can also be turned into biodegradable thermoplastics [36].

According to Koyama et al. [37], a study of key plant traits that contributed to the cooling effects of green façade have been conducted during the summer in Chikusa Japan. In this experiment, six freestanding walls made out of plywood were compared facing south orientation. Five of the walls were covered with vine plants and one was used for the blank control test. Only three were identified as edible plants, which are Momordica charantia (Bitter melon), Canavalia gladiate (Sword bean) and Apios American medikus (American groundnut) while others are Ipomoea tricolour (Morning Glory) and Pueraria lobata (Kudzu). From this experiment, the most suitable plant used for green façades is the Kudzu plant as this deciduous vine grows faster compared to other evergreen vines. Koyama et al. [37] suggested that Kudzu would be appropriate for long-term green coverage of building as the development of vine length statistically determined the percentage coverage. Therefore, the results also indicated that vine length could be the main criterion for selecting suitable plants for green facades. Though the Kudzu plant was determined the most suitable, investigation using edible plants such as the bitter melon should not be neglected as the result showed that it was the highest in terms of percentage coverage.

In summer of 1988, a study of using Luffa Aegyptiaca (Dishcloth Gourd) as part of the vertical greenery system was conducted in Kyushu Japan campus building [38]. In this research, the veranda space on the fourth floor was chosen. During the investigation, the Dishcloth Gourd plants leaves covered the front of the glass windows with approximately 55% facing South-west. The investigation compared the indoor air temperature adjacent to the green wall, with and without the use of vertical greenery system using Dishcloth Gourd plants on clear days. Both of the experimented rooms were air-conditioned to maintain the same room temperature. The results indicated that the plant was able to reduce 2- 4°C of the indoor air temperature during the daytime. This plant has proven to be beneficial in terms of thermal performance and produce a food source in a transitional space.

As stated by Šuklje et al. [39] a microclimatic layer of green façade is proven to have specific temperature and flow conditions on the building envelope. In this research, a bionic façade, which comprised of PV panels were compared with Anellino Verde plant green façade. The researchers focused on the positive effects of the bionic façade, which eliminated the disadvantages of using current green facades. From the experiment, the edible plant known as Anelino Verde (French green beans), are considered fast growing climbing plant. It was planted in a container structure. The results indicated that the French green bean plant was able to reduce the temperatures of the microclimatic layer when compared with the bionic façade. Still, the reading was only 0.1K lower than those of the bionic façade. Although edible plant was used in this investigation, the thermal property of plant selection was not explained in detail.

3.3 Thermal Performance of Existing VGS

The function of the vertical greenery system is to reduce air temperature through shading properties and even provide cooling solution from various types of plants and configurations. Each of the vertical greenery systems that comprises of green façade and living wall system has their specific effect on thermal performance. Chen et al. [40]; Jaafar et al.[17]; Perini et al.[28], mentioned that green facades affect thermal performance towards ventilation that flows through the vegetation foliage. While living wall system is based on insulation from substrate cover that act as shading properties [14]. By doing so, these configurations are able to reduce the cost of energy consumption thus contributing to building energy saving. This section reviews several studies that applied the vertical greenery system from ground level to multi-storey building with several configurations with the aim of reducing internal temperature and energy cooling load.

In the tropical climate of Singapore, Wong et al. [14] compared eight vertical greenery systems with different configurations of substrate and plants. The location of the experiment was situated in Hot Park Singapore and these eight configurations of vertical greenery system were compared with a controlled bare concrete wall as a benchmark located side by side. During the experiment, important parameters such as ambient temperature, surface temperature and substrate temperature were recorded. The results indicated that the living wall system with modular panels and inorganic substrate showed promising results in terms of thermal performance. With a maximum temperature reduction of 11.58°C, this system has the potential thermal benefits for building facades especially in tropical climate conditions. However, the living wall system should be analysed further in order to reveal more insight as the temperature reduction may have been caused by other factors such as the substrate composition and impact of irrigation moisture content. There was only one climber used as green façade. Throughout the research, the green façade showed insufficient plant growth as most of the vegetation density is focused towards the upper region compared to the lower areas. Safikhani et al. [16] suggested that this experiment should be repeated by comparing proper selection of climbers as green façade so as appropriate comparison of thermal performance between green façade and living wall system can be achieved.

Sunakorn and Yimprayoon [29] investigated the thermal performance of bio facade with natural ventilation on the rooftop residence of the Faculty of Architecture during summer of 2011 in Bangkok, Thailand. During the investigations, two cases were investigated which are no ventilation and with ventilation using back door opening. Blue Trumpet vine is selected as bio facade feature. This plant was chosen as it grew very fast and gave a consistent density and full leaves coverage. The room with bio facade and typical room were compared each day by dividing it into two sections that were daytime (09:00 to 20:30) and overnight (21:00 to 08:30). Both rooms were 4m x 6m and facing west orientation. The results showed that with 90% of green façade coverage, it was able to reduce at least maximum of 4.71°C when compared to test room and typical room. The difference of outdoor and indoor air temperature reading reached a maximum of 9.93°C. Unlike tropical climate, temperate climate configurations may perform like insulation during winter as the foliage layer blocked and trapped the ambient air from getting into the internal space. However, this case performed otherwise as by the ventilation enhances thermal performance of climbing plant for daytime. The ventilation recorded was more than 0.5m/s. It can be achieved surprisingly by allowing a back door opening to the tested room with bio facade. On the contrary, at night time the bio facade did not help much in decreasing air temperature, as the plants may obstruct heat dissipation. It is recommended to study the air gap between the foliage and the building wall so that the bio facade could improve daytime thermal performance due to its shading and 'evapotranspiration' while night time through its heat dissipation.

Another study related with green facades and living wall system was compared to the tropical climate of Malaysia [18]. In this study, the comparison was made at the corridor space of a five-storey office building. Through this comparison, it is a study that investigated thermal performance of both configurations (with and without VGS) at different floor levels and heights. The maximum temperature reduction is 12.9°C when the control temperature of 46.7°C and first-floor temperature of 33.7°C are compared. However, it is recommended to compare the vertical greenery system temperature and control temperature side by side as practiced by Wong et al. [14]and Chen et al. [40].This is to achieve fair results as control temperature recorded was located at rooftop level that may have been affected by excessive sun exposure and re-radiated solar energy of the concrete rooftop.

In line with the thermal performance of vertical greenery system for multi-storey buildings, a research compared three different greenery systems at a 21-storey office building in Penang, Malaysia [7]. There are three levels of ornamental plant greenery systems located on the eastern facade of the building. The first is sky courtyard located on the 10th floor; the second is balcony garden located on the 13th floor and the third is roof top garden located on the upper roof level. From this experiment, the thermal performance parameters such as air temperature, solar radiation and wind velocity were compared. Based on the results in Table 3, the sky court garden had the lowest average temperature of 29.0°C and mean radiant temperature of 29.9°C. The result was affected by the wind tunnelling effect which produced the highest rate of air velocity at 0.67 m/s. In addition, the introduction of water cascade and fish pond on that level may also contribute to the lower air temperature. The balcony garden recorded an average temperature of 30.4°C and mean radiant temperature of 32.7°C. It can be said that the balcony garden had the lowest air velocity of 0.16 m/s. For rooftop garden, the average temperature was 33.4°C and mean radiant temperature was 43.2°C, making it the highest average and mean radiant temperature recorded. Although it received more wind velocity (0.58 m/s) compared to balcony garden, the rooftop garden was exposed to direct sunlight that elevated the air temperature and surroundings.

In Netherlands, a similar experiment was performed to investigate the effects of ventilation on the different types of vertical greenery system. This experiment was conducted in the summer [30]. During investigations, the direct green façade, indirect green façade, and living wall system were compared with identical bare wall without plants as a control experiment. The results showed that the living wall system had better temperature reduction than both green facades configurations. The living wall system was able to reduce 5.0°C respectively while the direct and indirect green facades recorded temperature reductions of 1.2°C and 2.7°C. In this maritime climate condition, the air velocity for living wall system showed reduction of 0.56-10.0 m/s when it reached the surface of the plant. This reading is considered good for temperate climate as it has the capability to become insulation for maintaining warm weather inside the buildings. In contrast to this trend, the indirect green façade proved to be a viable configuration for tropical climate rather than temperate condition as it was able to increase the wind velocity to 0.29 m/s at the 20 cm air cavity layer. Although the living wall system showed promising results in temperate condition, Perini et al. [30] stated that it demands a more complex design that must consider major variables. These are supporting structure, control of water and on top of that, this configuration is often expensive and energy consuming.

In Penang, Malaysia, a study of green façade using indirect greening was investigated in real case condition. The experiment was conducted using *Psophocarpus Tetrogonobulus* (Winged Bean Plant) on ground level of multistorey dormitory at 'Universiti Sains Malaysia' (Fig. 11). This system used indirect greening approach that relied on diamond fencing with PVC coated as a support structure. Unlike previous support structure that emphasised on thermal conductivities such as steel cables and trellis, this PVC support structure ensured insulation that subsequently reduced plants stress. During investigation, four categories of configurations were measured which were typical room, bio-facade room, typical room with opening and bio-façade room with opening. All of the configurations were facing west orientation. The results in Table 4 indicated that the average outdoor surface temperature of bio-façade wall showed reduction of 11.0°C when compared with typical wall outdoor surface. However, the indoor temperature of bio-façade showed in contrast with the result as it recorded 1.5°C higher than a typical room. According to Rahman et al. [33]; Fukaihah et al. [34], the winged bean plants should absorb a significant amount of heat by acting as shading device to the building wall, making the surface temperature and inside temperature lower than the typical room. However, this research showed otherwise as the bio facade wall does not affect much on the indoor temperatures. The typical bare wall shows lower indoor temperature than the bio-façade wall. The author admitted that the bio-façade room should be compared side by side with the typical room, as it was located further away. In addition, sun orientation that penetrated the typical wall was blocked by staircase structure that may have caused different results.

Generally, the thermal performance experimental based research has showed that the vertical greenery system (VGS) has become an architectural feature for a long period of time. Applications are more focused towards building facades, fenestration and green roofs. Recently, the VGS are also applied to commercial transitional spaces such as multi-storey car parks, corridors and vertical greenery fencing. In Malaysia, the use of VGS is at an early stage. It is considered a relatively new approach and more research is still ongoing all around the globe. Based on the comprehensive studies on the thermal performance of VGS, it is evident that there are limited studies that have been conducted on edible VGS installed on high-rise balcony spaces. Many studies, especially experimental or field measurements have shown that the installation of VGS is focused towards using ornamental or aesthetic plants on building facades, fenestration, free standing structures and so on.

4. Materials and Method

In this study, the experiments with the VGS are located at Putra Place Condominium, 'Persiaran Bandar Indah', Penang (Fig.3 and Fig.4) the location was selected based on accessibility to the premise and exposure to west wall orientation for worst orientation case scenario. For the site selection, a preliminary study on medium cost and low cost high-rise residential unit was conducted to identify several criteria before the field measurement was carried out. The study on high-rise residential building focused on transitional exterior space such as balcony that has accessibility and safety circulation for measurement purposes. At first, the size of the testing area had to be considered. The VGS that is stacked onto a rack structure requires certain amount of space and circulation for maintenance. The site must be positioned in front of wall at least 3 metres long or in front of a sliding door depending on the balcony design. The exterior wall of balcony outside the indoor living space was chosen to represent both controlled and VGS wall. Due to space constraint and limitation of access to a second unit for field measurement purposes, the data collection was taken before the installation of VGS and when installed with VGS. The rack system is exposed to the sunlight on the west orientation as it received higher solar radiation for worst-case scenario. This is to investigate possible plant stress and address any difficulties that occurred on site.

4.1 Experiment Description

The study was conducted at Block 5 Putra Place Condominium (5°20'27.0"N 100°18'34.4"E), which is located 1.62 km from the University Science Malaysia (USM), Penang. The investigation was conducted on the 8th floor balcony space (Fig.5). The balcony size is approximately 1m x 3m while the living room area covers at least 15 metre square. With only 6mm thick glass sliding door existed on site, the field measurement on this condition focused towards the glass wall (without VGS) and glass wall behind the VGS (with VGS). The edible VGS was planted and positioned facing the sun on the west orientation (247.5 degree). The VGS rack structure is placed on the balcony in front of the sliding glass door with a gap space of at least 150mm between the VGS and the glass wall. The Putra Place condominium was chosen for the field measurement study as the features met the criterias of the building selection which are located 5 storeys and above, exposed to the west orientation and has a transitional space (balcony) for application of VGS. This building is a medium cost high-rise residential which has a total of 13 storeys. It is located in 'Persiaran Bayan Indah' and the building is surrounded by urban high-rise skyline that may contribute to urban heat island (UHI). The condition of living room is unoccupied and the wall feature consisted of sliding door that leads to a sufficient balcony space for VGS application. The balcony space is facing west orientation. During the field measurement, there was no opening from the inside of the room that could affect thermal performance such as air infiltration that could influence the indoor temperatures.

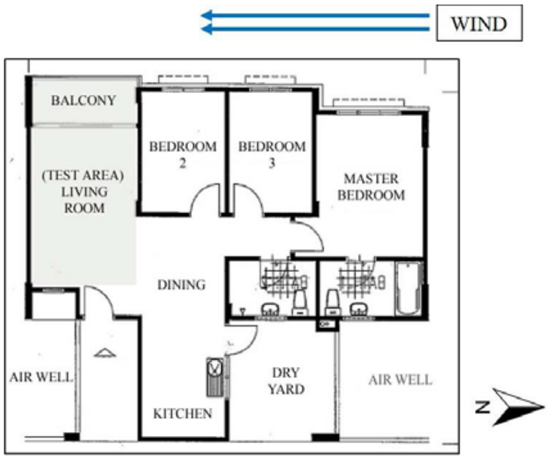

Fig. 3 - Putra Place Condo typical floor plant (experimental test area)

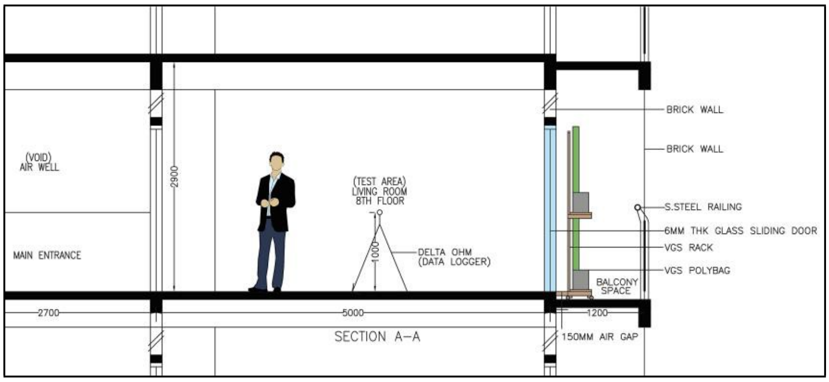

Fig. 4 - Section façade of the test area

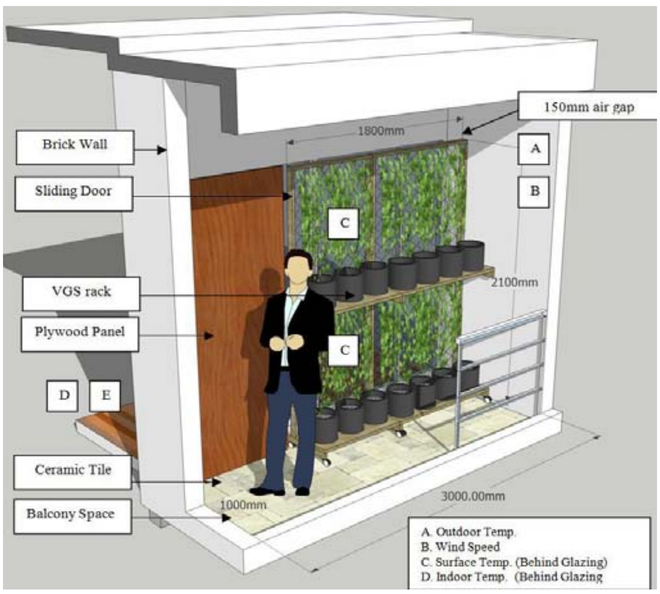

Fig. 5 - VGS test area (balcony space)

4.2 Experimental Equipment

The Rack system functions to guide the edible VGS to grow upwards in order to emphasise the benefits of shading (Fig. 6). Normally, the climber plant should be able to grow at least to a 3 metres height equivalent of a single storey building. In this case, a rack system was designed and made out of plywood material to house the edible VGS plants. The rack system uses steel mesh to assist and guide the plants growth upwards in order to reach the desired foliage density. Eight poly bags of winged bean plant are sufficient to cover the entire wall with foliage within a maximum of four month of growing period. The size of the rack system matches the size of the glass sliding door that is 2.1m (h) x 1.8m(l) x 0.15 (air gap). It has a 4 roller wheels for easy mobility. The rack system is divided into two different intervals, which are upper interval and low interval. The plant was stacked at 1-metre intervals so that the leave density could be controlled (Fig. 7). Apart from that, the rack system was being offset at least 150mm (0.15m) from the building wall so that its function as an air gap to improve air circulation and avoid any damage to the wall surface [34].

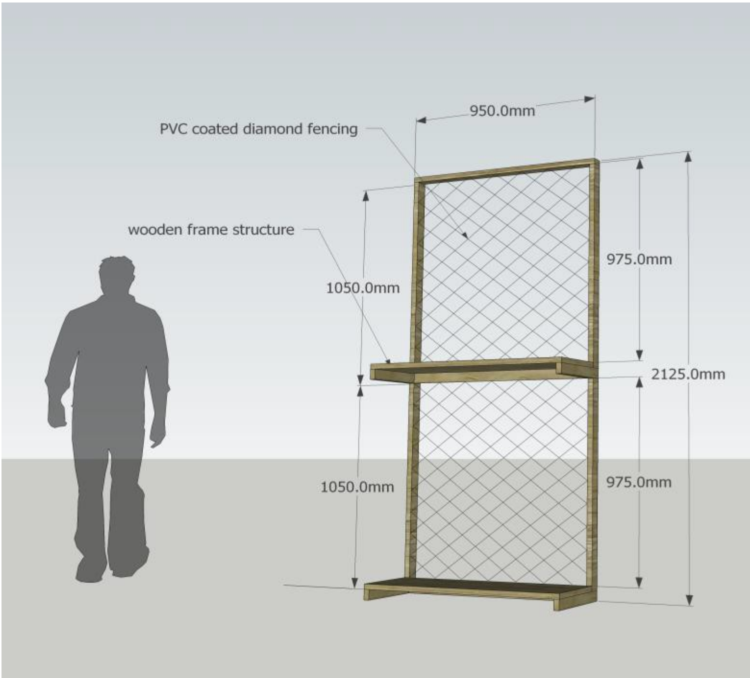

Fig. 6 - VGS rack system

Fig. 7 - Vertical greenery system using winged bean plant

The data collection for field measurement was conducted during the dry season. According to Malaysian Meteorological Department (2009) [41], the months that represent dry season are between January to April. While for the wet season between August to November. The field measurement results were taken from the data collected between 15th Jan 2016 and 24th Jan 2016. The data logger recorded readings between 09:00 and 17:00 daily and the thermal performance sensors were logged at every five-minute interval during day time. Due to time constraint and rental security purposes, the equipment was not made available for night-time usage. The instrumentation were placed at least 1.0m heights from the floor level in compliance with ISO 7726 (1998).

According to Table 1, the Delta Ohm data logger measures and monitors the data through acquisition and memorisation inside the instrument. This model is connected with four sensor probes. For this paper, the probes involved are the indoor dry bulb temperature (DBT) (model TP3207) and Mean Radiant Temperature (MRT) (globe thermometer model TP3275). The Delta Ohm data logger can detect simultaneous and instantaneous data following quantities of these parameters. The selected measurement unit was set to °C. Besides that, The Hobo micro station was also used to measure and log the ambient temperature parameter (balcony space). This micro station data logger is mounted on a 2-meter tripod tower with mast. The logging interval for this device is dependent on the user specification. In the field measurement study, the data logging was set to 5 minutes interval similar to the Delta Ohm data logger (Fig. 8).

Table 1 - Experimental instrumentation

Instrumentation	Probe Sensors / Location/ Parameters
Delta Ohm Data Logger	To measure and monitor indoor parameters: Indoor Temperature (°C) Mean Radiant Temperature (MRT) (°C)(internal)
HOBO Micro Station	To measure and monitor outdoor parameters: Outdoor/ambient Temperature (°C)(external)

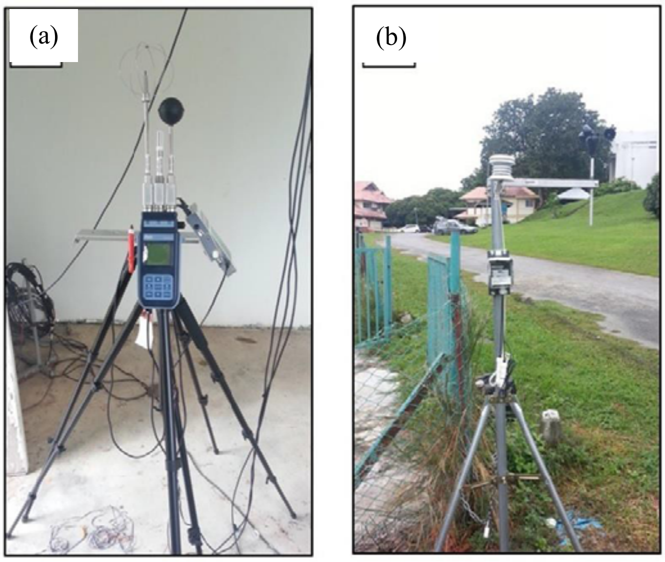

Fig. 8 - (a) Delta Ohm data logger; (b) Hobo micro station

5. Results and Discussion

The field measurement study was conducted to examine the reduction of indoor dry bulb temperature (DBT) when edible VGS was placed in front of a glazing component at high-rise condition. The temperature reduction was quite high when compared to the results from the previous studies conducted at low-rise level. This is probably due to less exposure of solar heat gain penetrating the room due to large leaf covers from the edible VGS. Moreover, the high-rise unit only received solar radiation from the façade angle rather than from the conduction of roof or other exposed wall at low-rise setting. This showed that the VGS indicated higher thermal lag as it slowed the rate solar heat gain into the internal space more efficiently. Thermal lag is the delay of heat transmitted through a material surface. When a material has high heat capacity and low conductivity, it will have a high thermal lag. The experiment results at the high-rise balcony showed that the edible VGS was able to reduce the indoor DBT and MRT by 0.94°C and 1.25°C (Fig. 9 and Fig. 10). When exposed to higher outdoor temperatures facing the west wall orientation, the indoor DBT and MRT behind the VGS managed to be stabilised and maintained at a constant 30.6°C (Fig.10). Although the results were 2.0°C higher than the standard thermal comfort upper level for building occupants (28.6°C) with a thermal neutrality at T_n 26.1°C [42], the results proved that the VGS is able to enhance indoor thermal performance and may possibly reduce the building energy cooling load.

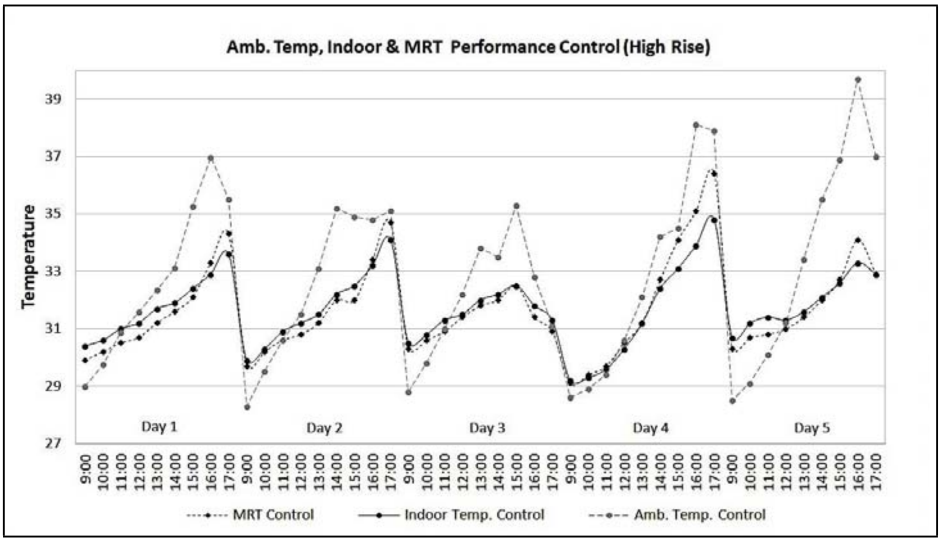

Fig. 9 - Control indoor thermal performance (without VGS)

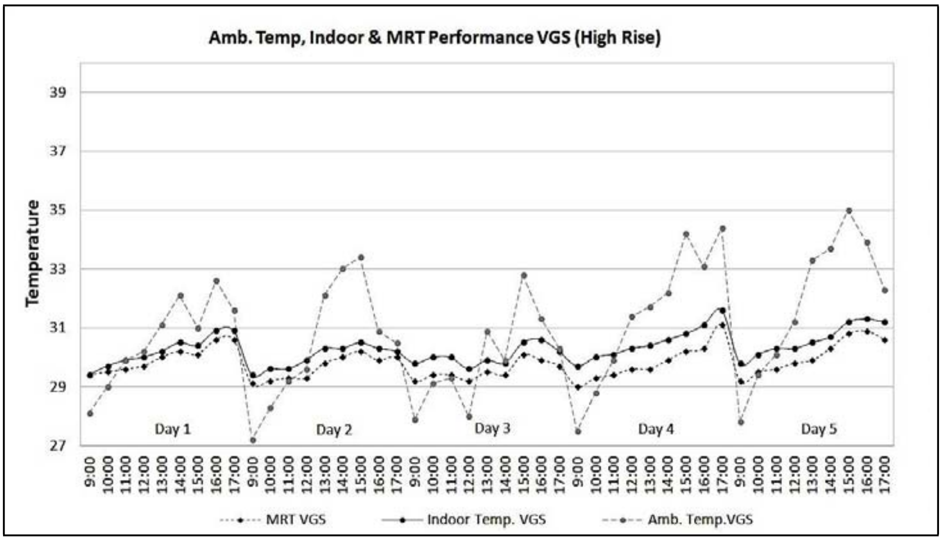

Fig. 10 - VGS indoor thermal performance (with VGS)

Apart from improving indoor thermal performance, the application of VGS in the high-rise balcony had also managed to reduce sun glare and heat gain. Fig. 11 and Fig. 12 revealed that the application of VGS in the high-rise balcony created a sense of comfort in the living room space.

When the VGS application was brought to the high-rise setting which was to the 8th floor balcony space, the edible VGS with a WWR of 45% or wall surface area of 2.1m (l) x 1.8m (h) x 0.15m (w) had managed to reduce the indoor DBT by 0.94°C. According to this assessment, there are many variables that may have influenced the outcome. One of the reasons could be that the session was carried out on different days and the comparisons were made using a similar outdoor temperature relatively index due to limitations of space and time. Therefore, the experiment had to be done during two seasons (the dry and wet seasons). Despite this limitation, the high-rise condition was similar based on the fact that the investigations were carried out on significantly on clear days and the recessed balcony used faces the west orientation.

The use of VGS also affects the indoor and outdoor humidity level due to evaporative cooling or 'evapo-transpiration' process which allows the water from the plant transferred from soil medium to atmospheric level together with transpiration from the plants. This process helps the cooling of both indoor and outdoor environment. The important highlight obtained from the field measurements to fulfil the objective is that the edible VGS wall installed on the high-rise balcony was able to stabilise the indoor DBT to be at 30.6°C, regardless of the high exposure to solar radiation and the ambient temperature in the test room. This shows how effective the edible VGS can be, depending on the orientation of the building and distance from the ground level.

Apart from that, when compared to other typical shading device the edible VGS relies mostly on the benefits of shading and the evaporative cooling effects which contribute to the reduction of indoor DBT. Most of the solar radiation absorbed by any shading material may reradiated back to external space as sensible heat [43]. According to Asan [44], some shading strategies may store heat depending on the material. In some cases, this makes the indoor space appear to be hotter during night time. In order to resolve this issue, growing plants on buildings' external wall surfaces could intercept the radiation process at early stage. This will also reduce solar reflection effectively in day time [34],[45].Thus, makes the VGS an advantage to other strategies in the market in order to alter the outdoor temperature to a cooler state. Eventually, this strategy of using VGS could mitigate the urban heat island in future cities.

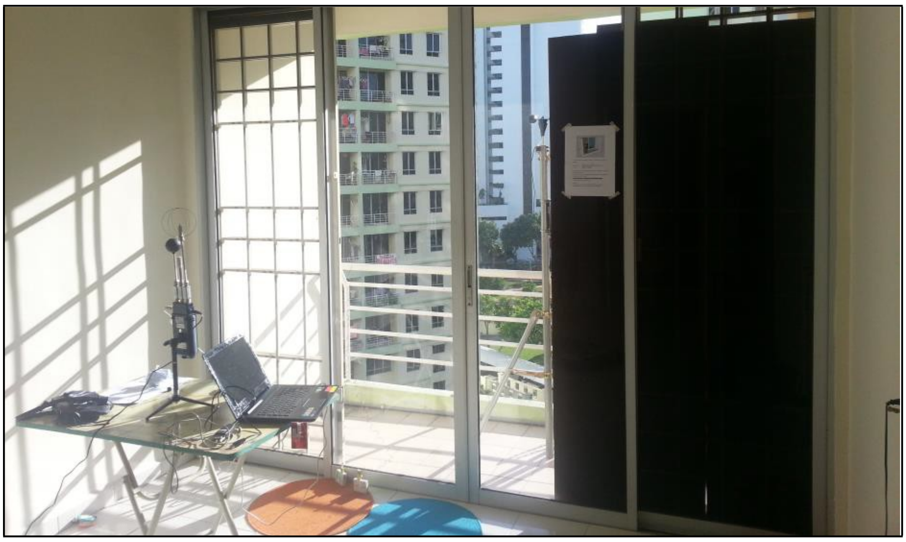

Fig. 11 - Control condition (without VGS) of Putra Place Condo, living room

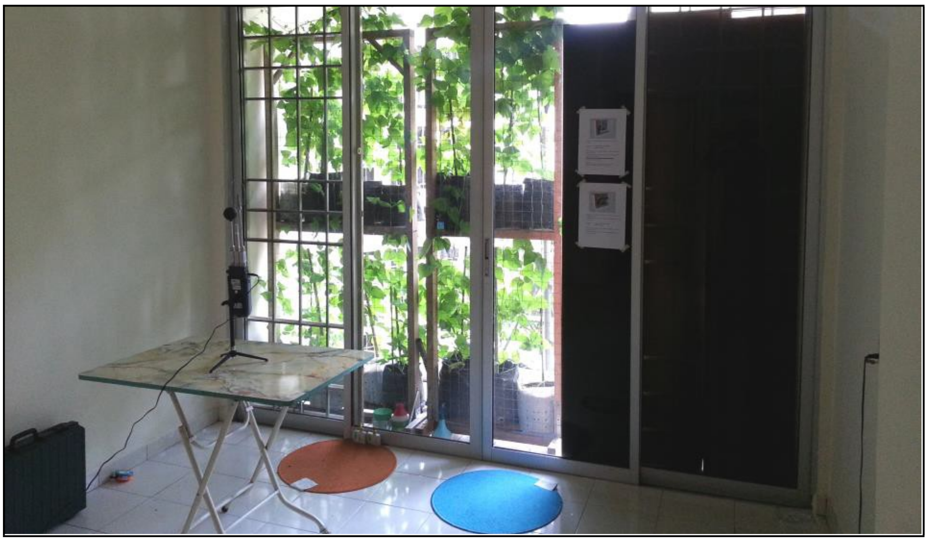

Fig. 12 - VGS condition of Putra Place Condo, living room

6. Conclusion

Vertical greenery system is proven to reduce temperature and diminish the cooling energy demand. This system has a greater impact towards the occupants especially in multi-storey buildings and high-density cities. Different configurations of vertical greenery system may lead to different results. From this paper, the following conclusions are highlighted:

- Selecting suitable plants can only improve the sense of wellbeing towards building occupants. Using edible plants could improve both thermal performance and food source simultaneously that will lead to energy savings, in the long run. Therefore, further studies regarding the use of edible plants are essential.
- When applying the vertical greenery system to improve a building thermal performance, it is recommended to identify appropriate orientation and location of control wall so that the outcome results could achieve maximum efficiency. Besides that, effective time may also contribute to the efficiency of VGS. Improvement can be made for application of VGS during night-time heat dissipation study.

- Improvement should be made on green façade system, as most of the climber foliages are concentrated on the upper level, leaving the bottom space exposed to excessive solar radiation. Occasionally, the green facades foliage will decrease at the lowest level as the plants grow upwards. By stacking the plant at different intervals may cover the whole system with consistent foliage.
- According to Taib et al. [7], balcony level is considered to be the worst case scenario when compared to other levels in multi-storey buildings. Therefore, by solving this issues related with sun exposure in high-rise level, the demand of building energy cooling load can be reduced. In time, this will eventually lower the urban heat island effect.

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