VERTICAL GREENERY SYSTEMS AND ITS EFFECT ON CAMPUS: A META-ANALYSIS

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ABSTRACT

The studies on vertical greenery systems are increasing due to its presence in technology and research that are composed with sustainable approaches. The remarkable functions of vertical greenery systems comprise of facilitating urban adaptation to a warm climate, reducing internal wall temperatures, and mitigating building energy consumption. Apart from it's benefits for the environment, it is also visually appealing and promotes healthier air quality. There are two major methods in constructing vertical greenery systems; ground-based system and wall-based system of vegetation. This paper disseminates plants with a passive cooling character as it helps cool the air and buildings on which it is installed, naturally. Approximately 46 articles were reviewed from multidisciplinary fields such as that of renewable and sustainable energy, plant physiology, ecological engineering, and built environment. This paper focuses on experimentations, simulations and case studies, which were conducted in a few university campuses to investigate thermal regulation feature of vertical greenery systems. Building effects were evaluated time-dependently for different cases and the results were thoroughly compared according to researchers' observations on the methodologies. Regions and climate conditions of tropical, Mediterranean, and oceanic were also considered within the scope of this research as independent variables. As a result of the meta-analysis, thermal reduction was achieved based on several factors including physiology of plants and vertical greenery system's classifications. Hence, this paper suggests VGS has capability to enhance strategies of the urban heat island mitigation in order to improve thermal performances in campus building.

Keywords: Vertical Greenery Systems; Campus Building; Thermal Performance; Plant Physiology; Sustainability

1.0 INTRODUCTION

This paper presents an overview of comprehensive approaches used for institutionalizing greening of campuses (Koester, Eflin and Vann, 2006). Sustainable development has been proposed as one of the environmental literacies with which a 21st century citizen should be equipped. Since the early 1970s, the awareness of environmental impact and sustainability has grown within the institutions of higher education (Finlay and Massey, 2012). Particularly, their contribution to climate change, including the implementation of formal or informal environmental management systems (Atherton and Giurco, 2011) were able to mitigate urban heat island. Urban heat island is the phenomenon of urban area that are significantly warmer than its surrounding (Wang, Er and Abdul-Rahman, 2016). According to Tan et al. (2014), vegetation can reduce the impact of urban heat island by shading heat-absorbing surfaces and cooling the air through the process of evapotranspiration. In many respects, university campuses are microcosms of the broader complexities, environmental issues, concerns and challenges in towns and cities.

In response, nature can be used to provide important services for communities by protecting them against flooding or excessive heat, or helping to improve soil air, and water quality (Tzoulas et al., 2007). When nature is harnessed by people and used as an infrastructural system, it is called green infrastructure. The largely driven concerns over climate changes and urban expansions can be addressed with the application of green infrastructure as it helps in city cooling, reducing energy loads on buildings and improve human thermal comfort. Different forms of green infrastructure have been studied, including urban forests, turf-grass, street trees parks, green roofs, gardens and green walls although their relative contributions and inter-relationships are perhaps arduous (Cameron et al., 2014).

As studies broadens, green wall and green façade were found to be the major types of vertical greenery systems which are planted in vertical structures using either support systems or carrier systems. Vertical greenery systems are usually used for aesthetic purposes as to cover up building flaws and encourages visually pleasing facades. Apart from that, since this system acts as passive cooling agent, it is able to protect the facade against direct solar radiation and reduce the temperature of the buildings (Safikhani and Baharvand, 2017).

2.0 CLASSIFICATION OF VERTICAL GREENERY SYSTEMS

According to Perini and Rosasco (2014) and Pérez et al., (2011), vertical greenery systems had two main systems which are green façade and living wall system (Azkorra et al., 2015). These two systems have different fundamentals in the types of plants and planting systems.

2.1 Green Façade— Ground Based Systems

Green facades system uses climbers to cover the building surface. This system managed to plant at different height of the façade either directly at the ground area, or in the hanging pots (Sari, 2017). From the previous studies, green façade systems are divided into four types: traditional green façade, double- skin green façade, double- skin green façade with planter boxes (Perini et al., 2011; Jaafar, 2015) and perimeter flowerpots (Pérez et al., 2011).

2.1.1 Traditional Green Façade

In the traditional green façade, plants directly grow without any additional structure on building surfaces (Soon and Kim, 2016; Stav, 2016) such in Figure 1 (a) and (b). The system appears to be more practical because it does not require any supporting structure. However, the weakness of this system lies in its’ potential to damage the building façade due to humidity and roots distributed by plants (Medl et al., 2017); thus, up the cost of wall maintenance.

Figure 1(a): Traditional green façade in Kluang housing area

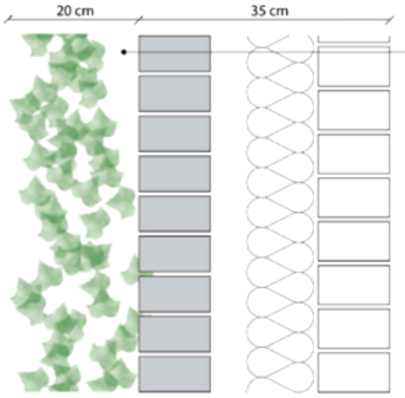

Figure 1(b): Section of traditional green façade (Source: Ottelé and Perini, 2017)

2.1.2 Double Skin Green Façade

The double-skin green façade has its system positioned to be indirectly attached to the wall. Based on Pérez et al. (2014), the system used additional structure such as wired, modular trellises, or mesh structures to reduce moisture distribution from damaging building façade. The air cavity between green screen and the building surface (intermediate space) are also important to control excessive moisture from climbers. It gives a good thickness of vegetation with the minimum possible cost of materials and minimum subsequent maintenance (Pérez et al. 2017). Hence, this method offers more selection of plant species.

Figure 2(a): Double skin green façade in Spain (Source: Coma et al., 2017)

Figure 2(b): Section of double skin green façade (Source: Ottelé and Perini, 2017)

2.1.3 Double Skin Green Facade with Planter Boxes

Indirect green system with planter boxes is another type of green façade, planted at different heights of the building. The system shown in Figure 3 is most probably similar as that in Figure 2 whereby the only difference is the added planting boxes that acts as the growing medium. Adequate growing medium is important for rooting spaces to achieve a lush and growth greenery planting.

Figure 3(a): Double skin green façade with planter boxes in Spain
(Source: Jaafar, 2015; Pérez et al., 2011)

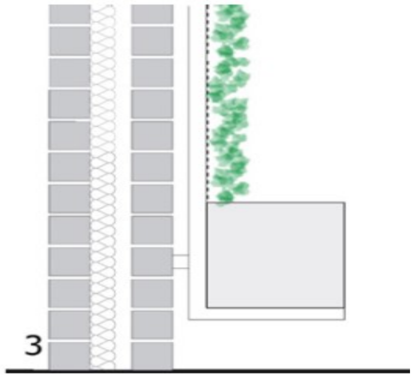

Figure 3(b): Section of double skin green façade with planter boxes (Source: Perini and Rosasco, 2014)

2.1.4 Perimeter Flowerpots

The hanging-down type shown in Figure 4 is another standard method applied around building to form green facades (Wang, Er, et al., 2016; Pérez et al., 2011) and encourages the creation of extensive green curtains. This hanging pot shrubs known as perimeter flowerpots can easily form a complete vertical green belt on a multi-story building through planting (Wilmers, 1990; Sadeghian, 2016).

Figure 4: Spa Center Design in Vietnam (Oki, 2015)

2.2 Living Walls— Wall Based Systems

Wall based systems normally consist of pre-vegetated panels that are mounted to the wall structure (Jaafar, Said and Rasidi, 2011). This system, also called as living walls, are able to exercise planting of greater range of species from groundcovers, grasses, ferns, mosses, and sedges (Wang, Wood and Teo, 2016). It gives different aesthetic values and thermal benefits based on planting characteristics and colour of leaves. The living wall system can be in the form of geotextile felts, panels or modular system (Vosloo, 2016). The planting media that is integrated with the system makes living wall systems becomes more complex compared to green façade systems. The commonly used systems are: modular living walls;

vegetated mat walls; and landscape walls (Timur and Karaca, 2013; Haggag and Hassan, 2015).

2.2.1 Modular Living Walls

Modular living walls consist of several modules in the form of panels and pocket-typed planters as shown in Figure 5. The planter boxes designed were fixed to a structural frame (Charoenkit and Yiemwattana, 2016) either attached to an exterior wall or free-standing system. Pre-grow plants are used as planting method. According to Medl et al. (2017), plants are able to grow directly in organic media (soil) or inorganic media (granular material such as perlite, felt, foam, mineral wool) or natural fiber. It provides a complex design with vertical, angled or horizontal planting interface (Soon and Kim, 2016) based on the technological innovations and trend.

Figure 5: Example of modular living wall in Malaysia (Source: Hydro Solution)

2.2.2 Vegetated Mat Walls

Vegetated mat walls is a unique form of a living wall known as 'Mur Vegetal' (Figure 6) which was pioneered by Patrick Blanc. He is a French researcher and also a botanist who popularized the approach to grow vertical planting (Bakar, Mansor and Harun, 2014). It has two layers of synthetic fabric which support growing media and plants (Elgizawy, 2016). Due to high humidity, the fabric wall is supported by waterproof membrane wall to reduce the moisture content. Generally, nutrients are distributed from the top down system through the irrigation water cycle.

Figure 6: Quai Branly Museum in Paris (Source: Vertical Garden Patrick Blanc, 2004)

2.2.3 Landscape Walls

Landscape walls are the only effective greening method of vertical greenery system, fitted with ecological engineering principles (Ottelé, van Bohemen and Fraaij, 2010; Medl et al., 2017). These walls are an evolution of landscape berms and apart of strategic approach for living wall system. In landscape design, berms are recognized for its ability to capture runoff and are usually constructed perpendicular to steep slope. It is typically built in a crescent shape and compacted to keep them for slope stabilization (Jang et al., 2016) as shown in Figure 7. Some examples of the application of green walls can be seen on highway bridges, shotcrete walls or tunnel portals. The greening of shotcrete walls corresponds two major challenge; technical implementation to set up a sustainable vegetation layer and environmental conditions for growth of plant.

Figure 7: The shotcrete wall along a highway exit (Source: Medl, Mayr, et al., 2017)

3.0 BENEFITS FROM SUSTAINABLE UNIVERSITIES

3.1 Greening effect on university campus

University campus can be regarded as a small city due to its large coverage, population size, and complex activities, which have serious direct and indirect impacts on the environment. Campus sustainability has become a global concern for university policy makers and planners as they realize the impacts of university activities and operations on the environment (Koester, Eflin and Vann, 2006). Thus, according to Srivanit and Hokao (2013) greening programs which collaborate with nature provides comfort and privacy for both indoor and outdoor areas. It also promotes a healthy student-environment as well as encourages community integration (Chew and Conejos, 2016). With the application of vertical greenery systems, thermal performance on campus building can be monitored leading to climate adaptation.

Other benefits of vertical greenery systems are improvements from air filtration and air quality to storm water management. Acoustic insulation is also provided with the presence of substrates and greenery systems in sound-absorbing effects (Wang, Er and Abdul-Rahman, 2016). Vegetation patterns gives visual screening and enhances the aesthetical values of student's life. In relation to the theory of environmental literacy, the exposure of student to natural elements can increase their ability to focus and reduce volatility (Lugg, 2009; Stav, 2016). There were also discussions that the view of greenery restores, calm and reduces stress on campus life. It is known as active interaction-nature which students are to interact directly with growing plants (McFarland, Waliczek and Zajicek, 2008).

3.2 Greening Effect on Campus Economy

Due to the diversity and density of plant, living walls require more intensive maintenance than that of green facades especially in the supply of nutrients to plants. The selection of plants must take into consideration the climate characteristics including rainy and dry seasons. Cooling effects on campus building can be achieved through vegetation effectiveness by selecting appropriate plant species. Additionally, these systems significantly contribute in reducing wall surface temperature and indoor surface temperature as well as lowering the energy saving. It also acts as eco-retrofitting of buildings which increases and protects the lifetime of building structure as well as property values (Chew and Conejos, 2016). Whereas in the environmental and economic perspectives, researchers should play an important role in initiating practices for sustainable approaches. For example, by using a plastic mesh for green façade, installation and maintenance cost of vertical greenery systems can be reduced. This can clearly be seen in Spain, as they run the test of utilizing organic substrates that eventually leads to low environmental impact (López-Rodríguez et al., 2016).

4.0 COMPARISON OF SELECTED STUDIES

This study has reviewed 46 sources discussing the emerging field of vertical greening systems, and 8 studies were measured within campus background. The reviews are referred in Table 1 and includes 4 studies focusing on green façade systems and another 4 dealing with green wall systems. Majority from recent studies revealed a large number of results concerning the benefits of thermal performance. The following paragraph highlights the studies based on four climate zones includes mediterranian, tropical, oceanic and temperate. Surface and indoor cooling potential as well as energy saving potential are closely linked to environmental (counterbalance urban heat island), social (reducing heat stress) and reduction of energy costs. The classification of thermal performance categories into three benefits which are surface cooling potential, indoor cooling potential and energy saving potential (Medl, Stangl, et al., 2017).

Safikhani and Baharvand (2017) analyzed surface temperature reduction of building envelope by living wall systems. Design Builder (version 3.0.0.105) as building simulation program was utilized due to its capabilities in modelling surface temperature, air temperature and natural ventilation. The experiment located in Universiti Teknologi Malaysia was installed in small-scale model due to economical expect. Both experimental studies used Thunbergia grandiflora, a plant species that is adaptable to the hot and humid climate of Malaysia. Comparison of the air cavity (30 cm and 15 cm) between wall surface and greenery wall were measured to record the differences of thermal performance. Based on the study, 30 cm distance had a high effectiveness on temperature reduction in the hot and humid climate of Malaysia. The orientation of living wall was also considered in measuring thermal response, as there is variance of temperature at different orientation. Thus, greenery on West in 30 cm distance of air cavity had better performance on temperature reduction.

According to Razzaghmanesh and Razzaghmanesh (2017), an experiment investigating the contribution of living wall systems in energy performance and building environments were carried out. This study was conducted in University of South Australia, Mawson Lake campus in a hot Mediterranean climate. Nine plant species were planted to modular based system. The experiment was compared to a bare wall during cold days and warm day's scenario. The recorded temperatures within the surface of the bare wall was up to 25oC warmer than that of the living wall. Furthermore, surface of the system was cooler than the bare wall in both scenarios. However, the living wall did not record a significant effect on microclimate study but was effective in reducing the back-wall temperature.

Pérez et al. (2017) carried out an investigation to study the effect of the proportion of plant-covered wall layer and orientation on the thermal performance of a building zone. This experiment took place at University of Lleida located in the village of Puigverd de Lleida (Spain). From this study, indirect method was an easy way to measure Leaf Area Index (LAI) to save energy. The energy savings were achieved up to 34% for Boston Ivy plant species with LAI of 3.5–4, under Mediterranean continental climate during summer period. Hence, the influence on facade orientation was confirmed with the presence in contribution of whole energy savings from West and East orientation.

According to Djedjig et al. (2017) who studied the thermal impacts of living walls on buildings located in La Rochelle city under the oceanic climate, there were six different species of vegetation planted on the living wall. Measurements of temperature, humidity and heat fluxes through facades with and without greening provide valuable data. The results showed the cooling effect of living walls in summer and underlined moderate reduction of heat losses in winter. During summer, living wall indicated that the heat gained from the building were reduced by 97% while heat losses were decreased by 30%. During winter, the energy balance of building with living wall is still 20% higher than bare wall. This confirmed the effect of insulation provided by living walls during winter and emphasized the cooling effect during summer days. Hence, this experiment concludes that living wall could lower indoor building temperature up to 5oC.

An experiment described by Charoenkit and Yiemwattana (2017) was conducted in the Architecture Building of Naresuan University, Thailand. The climate was characterized as tropical climate that is very hot and humid. The study was undertaken for six months covering both hot and cold seasons. It investigated the cooling effect and carbon sequestration potential of vegetation in different physical characteristics. Three herbaceous plants were selected based on leaf sizes, Excoecaria cochinchinensis, Cuphea hyssopifola H.B.K and Tibouchina urvilleana. These results demonstrated the temperature reduction from living walls compared to the reference wall up to 7.2oC and 3.3oC (daytime). Hence, Cuphea hyssopifola H.B.K, the plant with smallest leaf size, densest foliage, and woody branches had the best performance in both aspects.

Cuce (2017) conducted a case study in the Jubilee Campus of University of Nottingham, United Kingdom in temperate climate. Indoor temperatures of traditional green façades were measured on both sunny and cloudy days to identify the impact of ambient conditions on the thermal insulation performance. The results were compared between bare wall and greened wall and were carried out using Ecotect numerical models. The results revealed an average of 4oC decrease in wall temperature and 2.5oC reduction in indoor temperature can be achieved from 10 cm thick climber vegetation, Hedera helix. The author proved that thermal regulation feature of vertical greenery systems depends on plants species, plant intensity and orientation.

Poddar et al. (2017) recorded data on temperature reduction of living wall and energy saving potential. Simulations were generated in Design Builder based on three different building activities at KAIST campus, South Korea under temperate climate. Authors evaluated the role of Hedera helix in reducing building temperature and energy cost by using plant coverage area. The parameters were measured based on occupancy schedule, operational pattern and physical characteristics of buildings throughout the year. From the results, direct green façade managed to reduce energy consumption for residential (60%) compared to research (7%) and administrative (3%) building. Whereas during winter, green facade reduced the heat consumption by 44%, 4.5% and 0.5% for residential, research and administrative building respectively. Therefore, thermal performances of campus building were achieved in residential context; heating (60%), cooling (10%), and energy savings (31%) due to the maximum occupancy level at night.

Hoelscher et al. (2016) experimented on cooling effects of direct green façade for building and street canyon. The study distinguished between shading and transpiration impacts as well as discussed on insulation effects. Case study were conducted during summer periods on three building facades in Berlin, Germany under oceanic climate. The transpiration rates and surface temperatures between greened and bare walls were determined. Leaf temperature of three climber plants, Parthenocissus tricuspidata, Hedera helix and Fallopia baldschuanica were also measured. No cooling effect was detectable for the street canyon. Surface temperatures of greened walls were up to 15.5oC lower than the bare walls data, whereas indoor wall temperature was up to 1.7oC during night-time measurement.

Table 1: Summary of thermal performance on vertical greenery system.

Sources	Types of VGS	Method	Climate/ location	Plant types	Period	Factor	Findings
Safikhani and Baharvand (2017)	Living wall	Simulation Experiment	Tropical (Johor, Malaysia)	*Thunbergia grandiflora*	April- June	Air cavity (15cm, 30cm)	30 cm distance between greenery and wall surface had higher effectiveness on thermal reduction.
Razzaghmanesh & Razzaghmanesh (2017)	Living wall	Modelling/ experiment	Mediterranean (Adelaide, Australia)	Nine of Australian native plants	December- July	Air cavity (50cm, 100cm)	15 ^oC until 25 ^oC on reducing the indoor temperature.
Pérez et al. (2017)	Double-skin GF (steel mesh)	Experiment	Mediterranean (Spain)	*Partenocissus Tricuspidata*	Not stated	LAI Orientation	Energy savings were obtained (up to 34% with a LAI of 3.5-4, during summer period. The dependence on façade orientation was proved.
Djedjig et al., (2017)	Living wall (continuous)	Experiment	Oceanic (French city)	Six of different species	August- December	With/ without greenery	The experimental living wall lowered the indoor temperature up to 5 ^oC.
Charoenkit & Yiemwattana (2017)	Living wall	Experiment	Tropical (Thailand)	*Cuphea hyssopifola, Tibouchina urvilleana, Excoecaria cochinchinensis*	Winter: (Jan- February) Summer: (March-May)	Plant species	The cooling capacity from surface temperature and indoor temperatures up to 7.2 ^oC and 3.3 ^oC compared to bare wall.
Cuce (2017)	Direct GF	Case study	Temperate (UK)	*Hedera helix*	3 weeks	With/ without greenery	4 ^oC decrease in wall temperatures and 2.5 ^oC in indoor temperature using a direct green façade.
Poddar et al. (2017)	Direct GF	Simulation	Temperate (Korea)	*Hedera helix*	The whole year	LAI	Living wall reduced the heating consumption 60%, 7% and 3% for the residential, research and administrative building due to ivy coverage of the building.
Hoelscher et al. (2016)	Direct GF	Case study	Oceanic (Berlin, Germany)	*Parthenocissus tricuspidata, Hedera helix, Fallopia baldschuanica.*	July- August	Plant species	Surface temperatures from greenery up to 15.5 ^oC compared to bare wall and 1.7 ^oC reduction for the interior wall.

*All sites is located at university campus

5.0 DISCUSSION

Most of the peer-reviewed literature on vertical greenery systems demonstrated thermal performance of building envelopes and energy savings. Methods of the studies were conducted in experimentations, simulations and case studies with chosen specific variables. The methods were then attached on a wall and placed on an appropriate site. The bare wall acts as the control variable whereby thermal performance were compared. The previous research underlined the systems with traditional green façade system and had temperature reduction from 1.7oC to a maximum of 15.5oC compared to the bare wall. For the double skin green façade system, the temperature reduction was from 1.5oC up to 16.4oC maximum compared to the bare wall. While the living wall systems had temperature reduction up to 25oC respectively when compared to the bare wall.

Additionally, the benefits of case studies method were implemented for simpler ways in recording data measurement since these processes existed in real scale projects. It differs with that of experimentation method as funds and duration in model making were required. Long periods are taken in conducting experiments as the length of time required for the growth of plant. Researchers also need to consider the measurement processes at varied times and seasons based on climate zones. Meanwhile, unexpected factors such as unhealthy growth of plants and unpredictable weather conditions were among the factors influencing the experiment. According to Poddar et al. (2017), simulation analysis is a beneficial method in investigating building energy consumption to represents real buildings.

The results on weather parameters such as temperature, air humidity, solar radiation and wind speed were affected according to Koppen climatic zones. These weather parameters mainly affect the thermal performances of vertical greenery systems. Djedjig et al. (2017) indicated reduction at 5oC upon surface temperatures behind green layered walls compared to bare walls which were influenced from reduction of wind velocity. From previous studies highlighted, thermal reduction of building envelope and energy savings were reviewed based on four different climate zones including tropical climate of Malaysia and Thailand. However, most studies conducted were in the temperate and Mediterranean climate, which had four seasons in a year.

The relation between plant physiology and these systems strongly influences thermal performances through shading and cooling effects. Nevertheless, plants were also able to reduce the amount of sunlight from entering a building as the amount of sunlight transmitting through the leaves are between 5% and 30% while majority of sunlight was reflected, absorbed, transformed into heat, and used for evaporation, transpiration and photosynthesis (Charoenkit and Yiemwattana, 2017). Foliage density, leaf area index (LAI), and the shadow effect were consequently important factors in estimating the amount of temperature reduction. According to Poddar et al. (2017) and Pérez et al. (2017), plants with higher evapotranspiration (evaporation and transpiration) rate were recommended for improvements of cooling effects. This process requires sunlight and water to ensure that the thermal performances had the optimal reduction in areas with higher solar radiation and rainfall intensity. Therefore, substrates also play an important role in providing humidity and fertility that affects the performances of plants.

Hypothesis from literature reviews indicate that combination of systems with good irrigation model will improve thermal performances during summer compared to during winter season. Thermal performances on west orientation were more effective rather than other orientations. These hypothesis were proven in research by Pérez et al. (2017), Cuce (2017) and Safikhani and Baharvand (2017) which were conducted in different climates. The studies in accordance underlined that best thermal performances were generated through systems facing west followed with east orientation. The studies were reviewed in terms of different climates, plants and vertical greenery system classifications. However, the reviews indicated that living wall systems had better thermal performances, followed by green façade systems, studied by Shafikhani and Baharvand (2017). Modular system-living wall was found to be more effective in lowering temperatures compared to cable system-green façade (Jaafar et al., 2013). Living wall systems had a more complex method due to plant substrates that must be directly installed to system. This benefitted plants in maintaining its nutrients and stability of water in retaining the substrate.

In conclusion, vertical greenery system is a well-functioned system in providing achievable thermal benefits and offers prior for campuses development. However, there are no studies available on water demand although such information is necessary for the systems to have sufficient watering upon plants. More ideas and implementations for these systems are required for future research.

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