Journal of Mechanical Engineering *Vol SI 2 (1), 185-196, 2017*

Simulation of Vertical Greenery System in Reducing Energy Cooling Loads for High Rise Residential Building

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ABSTRACT

The Vertical Greenery System (VGS) is considered an alternative solution of passive shading that implements green wall to various type of building facades. The main contributions of this paper are that by installing the VGS, it will minimize the energy used to cool the indoor space and eventually save the energy cooling load by 7.6 percent for low rise condition and 18.27 percent for high rise. This is due to capability of VGS to reduce heat transfer to and from building envelope. The VGS used in this paper consisted of an edible legume plant which is 'Psophocarpus Tetrogonobulus' (Winged Bean Plant). This paper presents a series of recent simulation findings that uses Integrated Environmental Solutions Software (IESVE). The measured data were taken from the use of simulation models that comprised of Test Cell Unit (low rise) and Condo Unit (high rise). From the data, the VGS also managed to reduce the indoor air temperature by an average of 0.47°C for low rise unit and 1.53°C drop for high rise. These promising results indicated that the software was able to give an indication and prediction of annual energy savings through the benefits of shading. This effective strategy may improve the ambient temperature conditions in urban cities that experience excessive urban heat island due to overgrowth development and overpopulation.

Keywords: *Vertical Greenery System, Multi-storey Building, Temperature Reduction, Energy Cooling Load.*

ISSN 1823-5514, eISSN 2550-164X

Received for review: 2016-05-29
Accepted for publication: 2017-02-01
Published: 2017-05-15

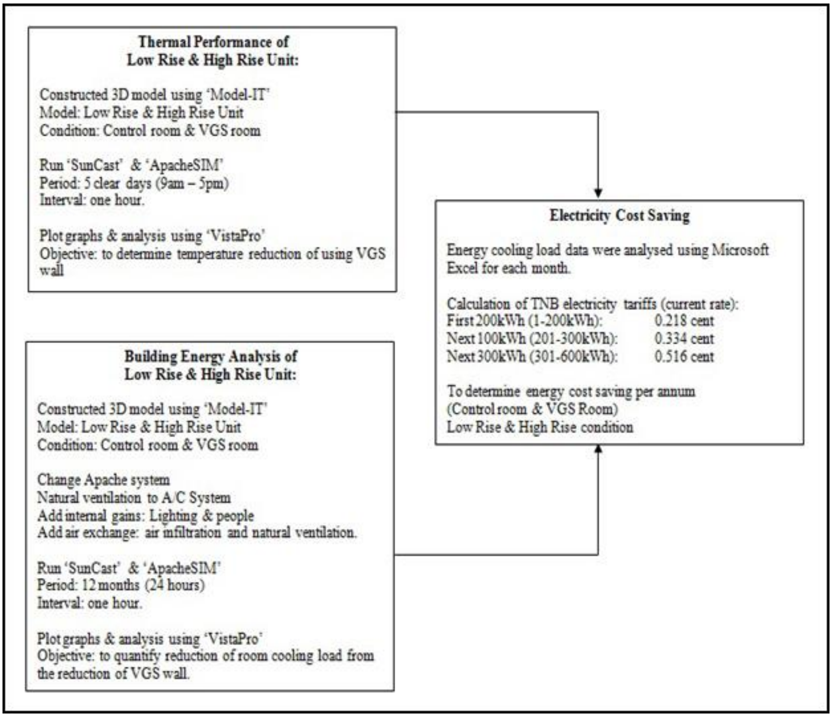
Introduction

The rising trend of constructing high density structures has overlooked the need of having basic vegetation in urban cities. In Malaysia, landed property has become scarce and developers have concentrated on developing multi-storey buildings to suit the needs for urban dwellers. Hence, urban heat island (UHI) effect rises and elevates the global ambient temperature. This issue has led to the use of mechanical cooling device such as air conditioning system that is not just able to cool the indoor air environment but also contributes to the rising of energy consumption. According to the Energy Commission [1], statistic has confirmed that about 21% of the total energy consumption is derived from residential electricity. Electricity consumption in residential building is mainly from the use of air conditioning and lighting purposes [2]. Majority household relentlessly uses electricity especially for mechanical cooling to remedy thermal discomfort [3]. When this mechanical system operates, it increases heat gain towards surrounding outdoor temperature. If not properly controlled, the mechanical cooling system would consume at least 50 percent of overall building electricity [4]. The effectiveness of building to consume energy depends primarily on the design stage. Key features such as passive design from proper plan layout and configuration of building at early stage may contribute to lesser use of energy. In this paper, simulation of using VGS wall is chosen as an alternative to predict and to counter these issues. Normally, building facades received solar radiation directly from the atmosphere and reflected from the ground. The building facades that made up the wall materials can absorb solar radiation energy and transfer it into indoor space through conduction. Moreover, the radiation is also emitted back to outdoor environment through convection that contributes heat built up and leads to urban heat island (UHI). With the use of VGS plant, it can reduce the heat transfer to and from the building envelope by absorbing solar radiation for photosynthesis and ‘evapotranspiration’, reduce solar reflection and re-radiation to atmosphere [5]. By doing so, it will eventually cool down the indoor space.

Greenery in urban settings can be used as a tool for mitigating urban heat island effect (UHI). As stated by the US EPA [6], an estimated of 1 million people or more could increase the annual mean air temperature in urban city by 1 to 3°C. By properly greening the façade of low rise and high rise building through the usage of VGS, it will mitigate the UHI effect through the benefits of shading, heat absorbance and ‘evapotranspiration’ cooling [7]. The ‘evapotranspiration’ is the process by which water is transferred from the land to the atmosphere and transpiration from plants in order to cool the environment [7,8]. Though it may not fully diminish air conditioning system usage, it has the potential to contribute building energy saving in a longer run.

Research Methods

The building energy simulation program has been developed throughout the last 50 years. The main core of this tool is the building energy simulation program which provides users with key building indicators such as energy demand, energy usage, temperature and humidity [9,10]. There are many applications of simulation tools in the market such as ECOTECT, Energy-10, Energy Plus, DOE, IESVE, TAS and so on. To simulate multiple data modules that allow integration between data input and output, the IESVE software is chosen. This program allows the user to construct 3D model using 'Model-IT'. The data input is then transferred to modules such as 'SunCast' for solar shading analysis and 'ApacheSIM' for thermal simulation. The simulation result is visualized by a graphical interface using 'VistaPro' suited for data analysis and interpretation [11]. This software has been validated to be in accordance with ANSI/ASHRAE 140 standard as it is internationally recognized in terms of diagnostic test [11,12]. In this paper, the simulation steps are briefly illustrated and explained in Figure 1.



Thermal Performance of Low Rise & High Rise Unit:

Constructed 3D model using 'Model-IT'
Model: Low Rise & High Rise Unit
Condition: Control room & VGS room

Run 'SunCast' & 'ApacheSIM'
Period: 5 clear days (9am – 5pm)
Interval: one hour.

Plot graphs & analysis using 'VistaPro'
Objective: to determine temperature reduction of using VGS wall

Electricity Cost Saving

Energy cooling load data were analysed using Microsoft Excel for each month.

Calculation of TNB electricity tariffs (current rate):

First 200kWh (1-200kWh):	0.218 cent
Next 100kWh (201-300kWh):	0.334 cent
Next 300kWh (301-600kWh):	0.516 cent

To determine energy cost saving per annum
(Control room & VGS Room)
Low Rise & High Rise condition

Building Energy Analysis of Low Rise & High Rise Unit:

Constructed 3D model using 'Model-IT'
Model: Low Rise & High Rise Unit
Condition: Control room & VGS room

Change Apache system
Natural ventilation to A/C System
Add internal gains: Lighting & people
Add air exchange: air infiltration and natural ventilation.

Run 'SunCast' & 'ApacheSIM'
Period: 12 months (24 hours)
Interval: one hour.

Plot graphs & analysis using 'VistaPro'
Objective: to quantify reduction of room cooling load from the reduction of VGS wall.

Figure 1: Experimentation Steps of Simulation Study

Simulation by IESVE

This paper investigated the optimum indoor air temperature reduction using the IESVE software. The VGS wall was replicated as a topographical shade feature in front of the Test Cell unit (Low rise) and Condo Unit (High Rise). The application of the simulation models was carefully tested and the objective was to make sure that the IES model gave an indication of temperature drop and at the same time predict reduction of energy cooling load. The research was carried out using a low rise and high rise simulation model constructed in ‘Model-IT’ (inside the IES programme). Both test units were based on ASHRAE weather location located at Bayan Lepas, Penang Malaysia. This study adopts the Bayan Lepas Penang weather data from the IES library due to its prevailing urban local climatic condition. As referred to the Meteorological Department Penang [13], the Penang island is currently experiencing rapid urbanisation especially towards high rise residential and mix development buildings. To insure the validity of using this software, the output produced from this study lies in the accuracy of the weather data [14]. The ‘ApacheSIM’ and ‘SunCast’ programs run on exact full weather data set that contains hourly data on specific region under the user test unit location. The low rise and high rise models were constructed to represent units that have been used for field measurement purposes. It is situated on ground level and then compared with high rise model (8th floor). Simulation comparison between control condition (without VGS) and application of VGS (with VGS) was investigated (Figure 2 and Figure 3). The size of the low rise model unit is approximately 4.8m (l) x 4.2m (w) x 3.3m (h), whereas the high rise unit is smaller with a dimension of 5.0m (l) x 3.0m (w) x 3.1m (h). Each model unit was exposed to west orientation in order to simulate worst case scenario as the wall received higher outdoor temperature from sunlight radiation [14,15]. The simulations in each session were compared simultaneously between models to achieve better results.

Input and output parameters

This simulation modelling evaluated the reduction of energy cooling load by analysing indoor air temperature reduction. The output parameters generated from this simulation model consist of outdoor temperature (T), indoor air temperature (Ta), and energy room cooling load (kWh). Before running the simulation program, a selection of building input is required for the IES thermal performance and building energy analysis. Although in real building condition the input values were mostly suggested by the Malaysian Standard MS1525 [16], the author has to make a slight adjustment and decision to execute this program successfully. In this paper, both simulation models used generic thermal characteristic and construction composition that was referred inside the IES library (Table 1 and Table 2).

Data collections were simulated and logged for 5 clear days as the weekdays and weekends profile were set from 9.00am to 5.00pm with one hour interval. In the building energy session, the weekday and weekend profiles of air conditioning system run 24hours for one year period (12 months) with the cooling set point at 25°C. Both control and VGS conditions were simulated using this profile. For casual gain, the equipment inside the test cell unit and condo unit was set to 50 W/m^2 with people of 1 person/m2 (Table 2). Apart from that, the air exchange was set to 0.25ach for infiltration and 1.00ach for natural ventilation.

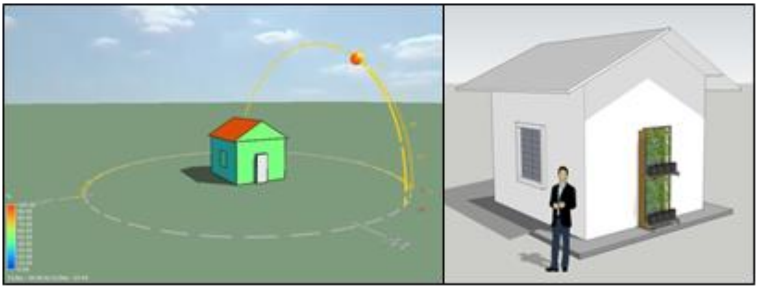


Figure 2: Test Cell on Ground Level (Low Rise Model)

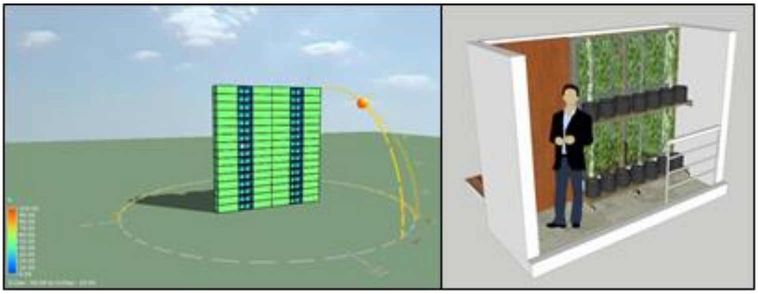


Figure 3: Condo unit on 8th Floor (High Rise Model)

Table 1: Thermal characteristic and construction composition [17]

Building/Element	Materials	Description	U-value (W/m^2K)
Ground Floor	100mm concrete 20mm Chipboard finished. Insulation	2013 Exposed Floor	0.223

External Wall	125mm brickwork with plasterboard 12mm thk cement bonded (solar absorptance 0.7)	2013 External Wall IES	0.259
External Glazing	6mm thk. Glass window	2013 External Window IES	1.565
Door	6mm thk. Glass door	2013 Glass Door IES	1.565
Roof	Alum. Sheet insulation Concrete roof tiles 50mm air cavity (solar absorptance 0.7)	2013 Roof	0.179
Topographical Shade/VGS wall	100% vegetation 40% moisture content	-	0.25

Table 2: Thermal characteristic and construction composition [17]

Input	**Description**	**Details**
Working hours profile	Monday – Sunday	(on continuously)
Internal gain	Fluorescent lighting People	50 w 90 w/person
Air exchange	Infiltration Natural ventilation	0.25 ach (on continuously) 1.00 ach (on continuously)

VGS wall material

Vertical greenery system (VGS) is a green building envelope that emphasizes building thermal performance using ornamental plants. In this study, the term edible VGS was opted to improve not just the indoor air quality and energy but also to provide food supply. '*Psophocarpus tetrogonobulus*' (winged bean plant) was first used as edible VGS in Malaysia to investigate the indoor air temperature drop and provide food supply for the building occupants. It was introduced by Fukaihah *et al*. [18,19] who indicated that the winged bean plant is probably the most effective legume plant to be used as VGS feature. The winged bean plant with dark coloured leaf features could absorb the most energy from sunlight including heat from solar radiation more effectively when compared to other edible legume plant such as *Pisum sativum* (Sweet

Pea), *Vigna unguiculata sesquipedalis* (Long Bean) and *Phaseolus vulgaris* (Kidney Bean). Apart from that, it also has a longer lifespan due to its tuberous root that can store sufficient nutrients over a two-year period. The hypothesis indicated that with the reduction of thermal performance using the edible VGS, it is believed that the energy cooling load will also follow the similar trend [20]. Studies concerning the VGS rarely addressed the indoor thermal performance and instead focused on transitional space such as corridors, walkways, rooftops, balconies and so on. Yet most research is keen towards improving low rise condition rather than high rise. In this study, comparison between low rise and high rise condition will be investigated simultaneously using data weather location of urban context. Therefore, this paper will bridge the gap in order to fully understand the capability of using VGS to lower the indoor air temperature and cultivate energy savings towards multi-storey building.

Based on real building condition, the VGS is mounted onto a rack system that functions to guide the plants upward in order to achieve the desired foliage density. However, in this simulation program, the rack system and VGS material were represented using a 'topographical shade' which was a single wall mostly affected by 'Suncast' analysis from the 'Model-IT' library (Figure 2 and Figure 3) with u-value of 0.25 W/m^{2}K. This 'topographical shade' matches the size of glazing doors (0.9m x 2.1m and 1.8m x 2.1m) used in both conditions. The VGS wall was placed in front of the test unit by offsetting 0.15 metre gap. Since IES library was unable to provide vegetation thermal characteristic to the current VGS wall and simulate the data based on shading and 'evapotranspiration' process, the temperature reduction relies mostly on the benefits of 'Suncast' solar shading analysis and 'ApacheSIM' thermal simulation modules.

Results & Discussion

In the following, the IES thermal performance and energy cooling load results are presented.

IES thermal performance (low rise)

During the investigation of thermal performance, the test cell unit (low rise) was simulated for 5 days. The VGS wall was used as a shading component in front of the control wall. From the simulation modeling, the VGS managed to reduce the indoor air temperature by an average of 0.47°C. When exposed to the outdoor temperature of 32.0°C, the control room indicated an average reading of 31.12°C, whereas the VGS room recorded 30.65°C respectively. The maximum reading ever achieved in this trend was in the control condition and it peaked at 32.7°C. Figure 4 indicates that the low rise unit performed steadily as the VGS material showed frequent fluctuation in both control and VGS room. This trend shows that the lower the indoor air temperature was achieved, the more energy savings could be made in terms of reducing room sensible cooling load.

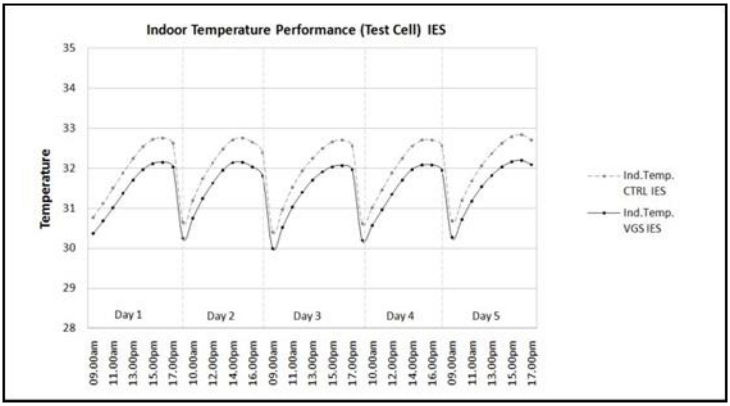


Figure 4: Room Cooling Loads (Low Rise Unit)

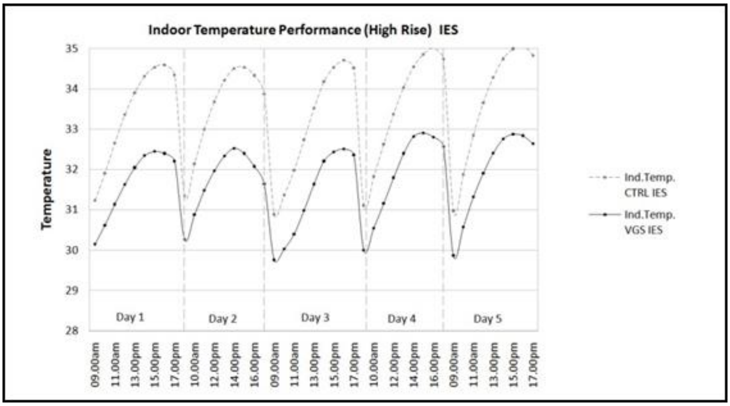


Figure 5: Room Cooling Loads (High Rise Unit)

IES thermal performance (High rise)

For the high rise unit, the thermal performance revealed that the VGS room performed better than the low rise simulation with temperature differential of 1.53°C (figure 5). At this condition, the outdoor temperature recorded was similar to the low rise trend with a reading of 32.0°C. During the simulation, the control room was relatively higher than the low rise with an average reading of 33.05°C. The VGS room managed to maintain an average reading of 31.52°C towards the 5 days simulation. The highest reading ever recorded peaked at 35.0°C in the control room condition. As for the VGS room, the reading peaked slightly below the 33.0°C. The increase of indoor air temperature captured in the control room was possibly due to the usage of glazing material which doubled in size when compared to low-rise model. In addition, since the high rise unit was simulated on the 8th storey similar to the current field measurement study, 'SunCast' analysis elevated most readings triggered from the 'ApacheSIM' thermal simulation. It is due to high exposure of west orientation sunlight radiation. Through the observation of this simulation modelling, other findings indicated that by increasing the size of VGS material and higher exposure towards sunlight may probably enhance the VGS room to accomplish better results.

IES energy cooling loads

This simulation was derived from one year (12 months) thermal performance reduction in the previous session. At this level, it generated annual energy cooling load or annual electricity consumption in kWh. The values were then analyzed into Microsoft Excel and calculated with Malaysian energy provider 'Tenaga Nasional Berhad' (TNB) [21] electricity tariffs to determine annual cost saving of using VGS wall. The low rise simulation results using the IES software stated that with the use of 0.9m (w) x 2.1m (l) VGS wall in front of the low rise test unit, it managed to save energy cooling load at least 7.6%. During this session, the annual energy cooling load for control unit (without VGS) was calculated to be approximately 3437 kWh whereas the VGS unit (with VGS) was 3176 kWh. The reduction was at least by 261 kWh (figure 6). Moreover, the reduction of this energy cooling load was able to save electricity cost of RM 95.77 (USD 23.45) per annum when referred to the electricity tariffs calculation (Figure 1).

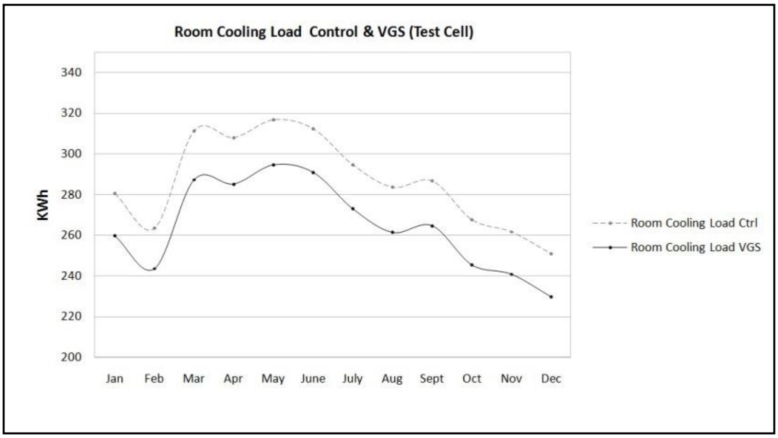


Figure 6: Room Cooling Loads (Low Rise Unit)

The high rise unit results indicated an energy saving of at least 18.27% or reduction of 497 kWh (figure 7). This session implies to VGS wall of 1.8m (w) x 2.1m (l). During the control unit simulation, the result was calculated to be approximately 2719kWh, which was 20% less than the low rise control unit. After the VGS was applied, the simulation calculated a significant drop which fell to 2222 kWh. During this session, the annual electricity cost saving predicted was at least RM 143.88 (USD 35.27).

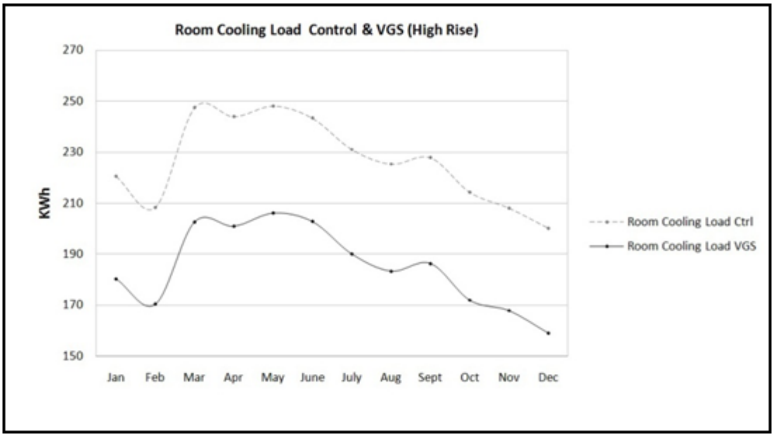


Figure 7: Room Cooling Loads (High Rise Unit)

Conclusion

This paper presented the potential of using vertical greenery system (VGS) as an alternative method to reduce energy cooling load in low rise and high rise residential building. It derived from a simple building thermal reduction simulation modelling and analysed using energy saving prediction tool. Thermal performance results were generated through IESVE ‘Model-IT’, ‘SunCast’, ‘ApacheSIM’ and ‘VistaPro’ simulation. It was then later used to simulate the annual energy cooling load from the benefits of shading. Although the simulation results are based on thermal simulation assumptions, it can only detect the basic shading analysis for temperature reduction purposes. Like other simplified energy design tools, the IESVE software used in this study is limited in its application especially in terms of VGS or plant thermal properties. The results generated from this paper are currently being explored in the field measurement conditions. In terms of application, it can be implemented and applicable for other building designs such as high rise offices and hotels. From this paper, it can be concluded that the VGS wall has proven to lower the indoor air temperature and saved building energy. By increasing the size of VGS wall, it will eventually improve temperature reduction and reduce greater annual energy cooling load. Apart from that, application of VGS wall in high rise settings may trigger the VGS to perform efficiently as the results indicated that it will become more stable with higher outdoor temperature exposure.

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