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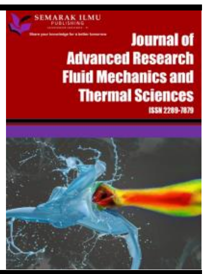

Optimization of Indoor Thermal Performance Through Orientation and Vertical Greenery Percentage Analysis in High-Rise Residential, Malaysia

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ABSTRACT

Vertical Greenery System (VGS) is one of the passive solutions for urban greening that emphasizes application of building envelope. It can improve both indoor thermal performance and energy efficiency in the longer run. To realize this effort, proper orientations are identified as the main key factors. As high-rise buildings are being develop throughout urban cities in Malaysia, indoor spaces received high amount of solar radiation due to improper orientation and site constraint exposure that mainly comes from East and West. To overcome this issues, orientation study and vertical percentage analysis were conducted in this paper. Investigation on the importance of having proper façade orientation and greenery percentage in urban cities are the main purpose of this research. Several methods that involved empirical studies and simulation using IESVE software were conducted to fulfil this investigation. Based on the findings, the highest reduction in both temperature and cooling load energy using vertical greenery system can be tabulated in the following order: East > West > South > North. It is suggested, that both the East and West orientations to be the best façades to implement the VGS. Both facades received direct sunlight in the morning and evening sessions, enabling the VGS envelope to reduce the indoor dry bulb temperature and building cooling load energy more efficiently at higher altitude. For vertical greenery percentage analysis, higher percentage of vegetation will result in a more positive effect towards the reduction of indoor dry bulb temperature. In conclusion, the incorporation of a 100% VGS window wall ratio coverage is shown to have a reduction of 1.42°C and it was estimated at least 16.9% for building cooling load energy saving.

1. Introduction

This paper describes an investigation on the use of a vertical greenery system (VGS) at different orientations in view of its effect on the indoor thermal performance and cooling load energy. According to Syed Fadzil and Sia, Moghaddam *et al.,* and Shuhaimi *et al.,* [1-3], selecting the most optimal building orientation is one of the critical energy efficient design decisions that could have an impact on a building's energy performance. The researchers added that the study of orientation

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would most affect fully glazed buildings. Glazing areas on the façades need protection against overheating and sun glare especially if facing east, southeast, and west orientations. As mentioned by *Al-Tamimi et al.,* [4], the east and west façades are exposed to direct sun radiation in the morning and evening, the north façade faces radiation during the month of May to August, and the south façade faces radiation between November and February. This shows that a building's orientation should be considered at the design stage as it may affect the outcome of indoor thermal performance and cooling load energy. The implementation of climate responsive building designs will not only provide thermal comfort for building occupants and energy saving implications, but also help preserve our planet's valuable resources [3, 4]. An orientation study by Al-Tamimi *et al.,* [4] stated that the east façade has a more obvious effect in increasing the indoor dry bulb temperature (DBT) than the west façade. The researchers highlighted that the east rooms are always hotter than those with a west orientation. Even by applying natural ventilation and changing the percentage of window wall ratio (WWR), the average difference between the indoor and outdoor air temperature is higher for the east orientation compared to the west orientation. However, some study results indicated otherwise, such as a previous study conducted by Syed Fadzil & Sia [1] in Georgetown, Penang with a latitude of 05◦28′ North and longitude of 100◦20′. They highlighted that the worst exposure to solar radiation and sunlight penetration is the façade facing the southwest by west orientation (240◦), followed by northeast by north (30◦), south (180◦), northwest by north (330◦), northeast by east (60◦), east (90◦), northwest by west (300◦), southeast by south (150◦), southeast by east (120◦), southwest by south (210◦) and west (270◦) orientations. The orientation with the least solar radiation and sunlight penetration is the north orientation (0◦).

In terms of the effect of the Vertical Greenery System (VGS) on orientations, many researchers indicated that the VGS would perform well when facing the west orientation. Many researchers have tested the effectiveness of the VGS, especially when exposed to the west side orientation [4–9]. This section simulating several tests of the VGS at four orientations namely north (0◦), south (180◦), east (270◦) and west (90◦). The purpose of this simulation is to determine the effectiveness of the VGS placement depending on which orientation gives the best results in terms of indoor thermal performance and building energy efficiency. The simulations cover high-rise conditions at the Putra Place condo, Penang. The readings are based on the IES<VE> simulations which are extracted from the Sun path tool library programme. The building thermal performance and cooling load energy are assessed by considering the orientation and proportion of VGS wall layer to the total wall area. For the examined orientations which correspond to each main compass point, the percentage of VGS wall covering vary between 0% and 100% and situated 150mm gap act as ventilated cavity [10] in front of the glazing material.

2. Methodology

2.1 Computer Simulation Method

This paper uses a building energy simulation program that has been developed throughout the last 50 years. The main research method tool is the building energy simulation program which provides users with key building indicators such as energy demand, energy usage, temperature, and humidity [11, 12]. There are several applications of simulation tools in the market such as ECOTECT, Energy-10, Energy Plus, DOE, IESVE, TAS and so on. However, to ensure accurate results and able to project building energy cooling load from the thermal performance IES<VE> software was chosen. This program allows the user to replicate and construct a 3D model to exact specific dimension using the 'Model-IT' tab. Then it is transferred to the 'SunCast' program for solar shading analysis. For thermal performance the data from shading analysis are then opt to the 'ApacheSIM' program. The overall results will be tabulated and visualized in a graphical interface called 'VistaPro' which also part of the IES<VE> program tab. This software has been validated to be in accordance with ANSI/ASHRAE 140 standard as it is internationally recognized in terms of diagnostic test [13,14].

This paper investigated the optimization of indoor air temperature reduction using the IESVE software. In the software, VGS wall was replicated as a 'topographical shade' feature in front of the Condo Test Unit (High Rise). The 'topographical shade' act as 'insulation material' that can equivalently simulate layers of vegetation by setting thermal properties of vegetated wall [15,16].

The simulation model was carefully tested several times in line with the existing empirical data obtained from the field measurement studies [17,18]. The simulation model gave an indication of temperature drop and simultaneously predict reduction of energy cooling load. It was able to project readings if the test model was facing certain orientations and can simulate VGS coverage analysis. The simulation model test unit was based on ASHRAE weather location located specifically at Bayan Lepas, Penang Malaysia. The weather data for this location was obtained from the IES library due to its prevailing urban local climatic condition. The validity and accuracy of the output data lies in the concurrent weather data in line with the meteorological department [19]. Next, the 'ApacheSIM' and 'SunCast' app programs was run on exact full weather data set that contains hourly data on specific region under the user test unit location. The high-rise test unit model was constructed to represent the exact unit with correct dimension referred to the field measurement studies [18] . It is situated on the 8th floor facing West orientation as the main base case study. The simulation compares between control condition (without VGS) and application of VGS. The dimension of the high-rise unit is approximately 5.0m (l) x 3.0m (w) x 3.1m (h) (Figure 1 and Figure 2).

Fig. 1. VGS Orientation Study (High-rise)

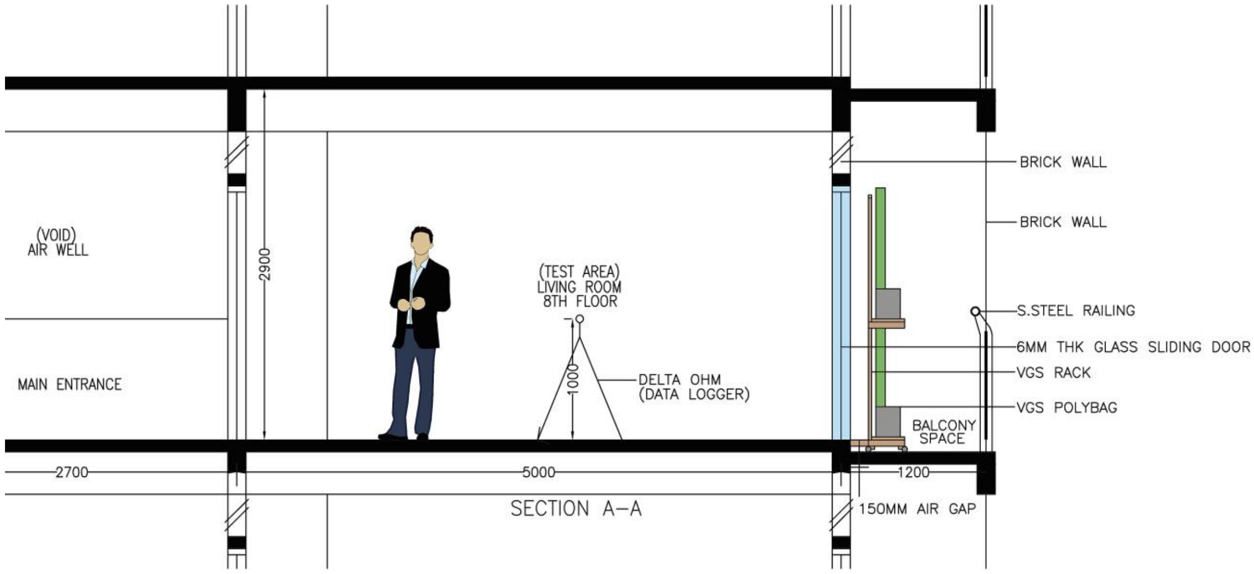


Fig. 2. VGS Orientation Study (High-rise)

3. Results

3.1 VGS Orientation Study Results

The 12-month readings of control and VGS were simulated facing west orientation as the main base case study. It indicated that the application of the VGS wall at high-rise conditions was able to reduce the temperature at least 1.35°C (Table 1). During this simulation, the mean reading for control indoor DBT was 32.81°C, while the mean DBT reading for the VGS room was 31.46°C. According to Figure 3, the hottest indoor DBT had occurred in the month of April as the reading had spiked to almost 38.54°C. When the VGS wall was applied, the highest reading ever achieved was 34.99°C (Figure 4). The trend slowly began to descend after the month of June. The high-rise results indicate that increasing the size of the VGS wall and exposing it towards more sunlight and solar radiation may trigger the VGS to perform better. Apart from that, the increasing size of glazing material and window wall ratio (WWR) percentage may also contribute to the high indoor temperature reduction. A study on the VGS coverage's performance will be included in a subsequent section for further analysis.

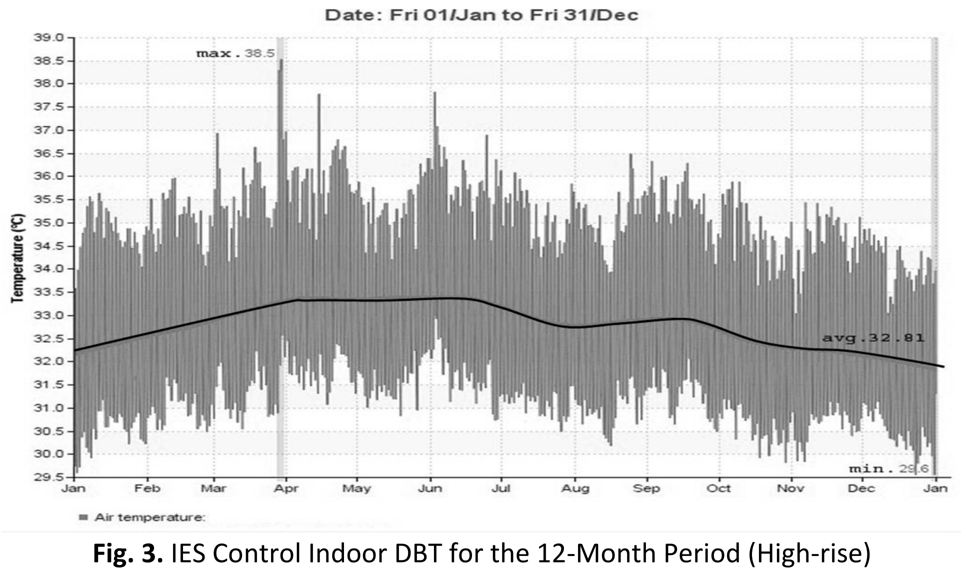


Fig. 3. IES Control Indoor DBT for the 12-Month Period (High-rise)

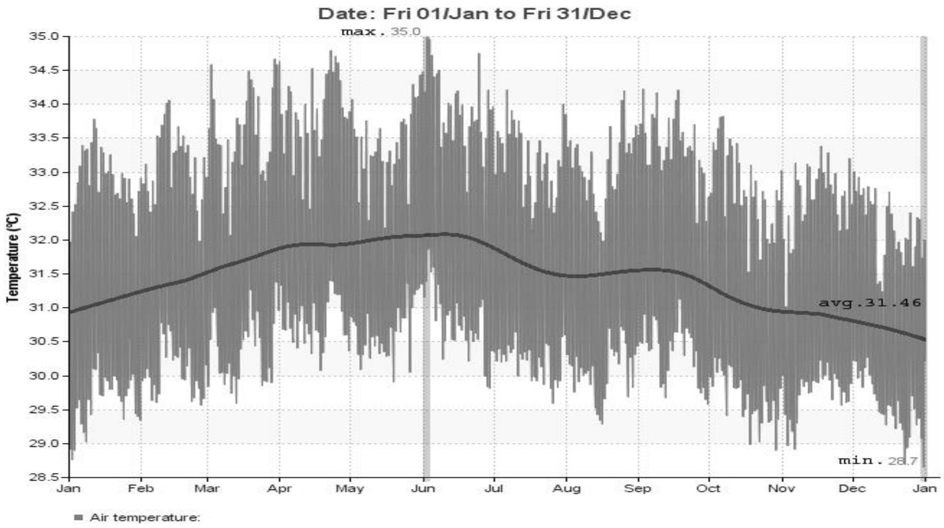


Fig. 4. IES VGS Indoor DBT for the 12-Month Period (High-rise)

The high-rise level orientation study shared similar simulation parameters with the ground level in terms of test cell conditions and VGS coverage. The simulation results in this section involve both control (without VGS) and 'with VGS wall' conditions at four orientations which were used on the 8^{th} floor high-rise unit and balcony of the Putra Place Condominium Penang. Table 1 below indicates that the west facing orientation managed to reduce the indoor DBT by 1.35°C. At this point, the indoor DBT dropped from 32.81°C to 31.46°C.

Table 1
VGS Orientation Study Results (Putra Place Condo, High-rise)

Orientation	Control Wall	VGS wall	Variation/Reduction
North wall (0◦)	32.54°C	31.41°C	1.13°C
Average indoor DBT:	2488kWh	2141kWh	347kWh
Building cooling load energy:	-	-	13.9%
Energy saving:			
South wall (180◦)	32.60°C	31.42°C	1.18°C
Average indoor DBT:	2500kWh	2141kWh	359kWh
Building cooling load energy:	-	-	14.3%
Energy saving:			
West wall (90◦)	32.81°C	31.46°C	1.35°C
Average indoor DBT:	2551kWh	2140kWh	411kWh
Building cooling load energy:	-	-	16.1%
Energy saving:			
East wall (270◦)	32.91°C	31.48°C	1.43°C
Average indoor DBT:	2582kWh	2139kWh	443kWh
Building cooling load energy:	-	-	17.1%
Energy saving:			

During this simulation (Figure 5), the west wall façade was self-shaded in the morning and afternoon between 09:00 and 14:00. The west façade with the VGS wall received direct sunlight only after 15:00 onwards with solar altitudes recorded at 55.18° (15:00), 44.28° (16:00) and 31.71° (17:00) (Figure 6). The solar radiation exposure was at least 412w/m² and began to diminish at 134w/m². In terms of building cooling load energy, the west wall orientation managed to save at least 16.1% of energy with a reduction of 411 kWh.

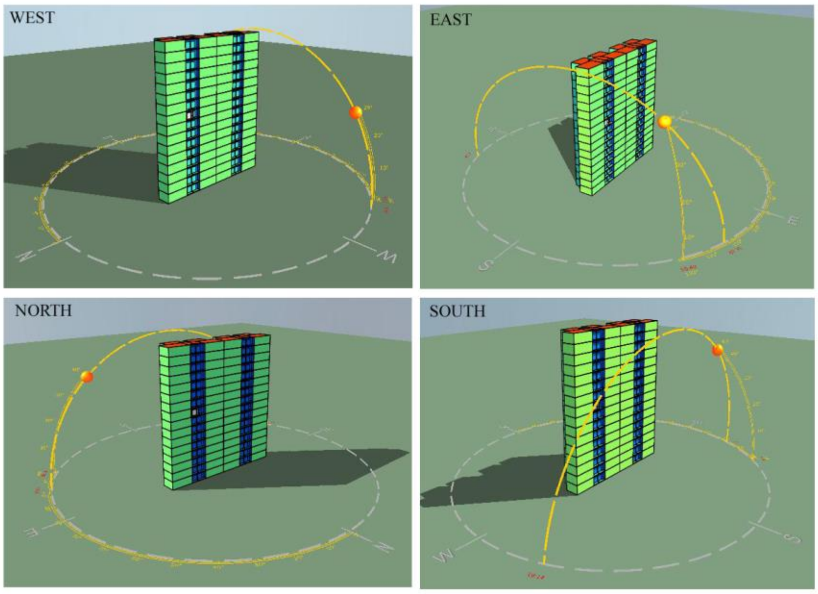


Fig. 5. VGS Orientation Study (High-rise)

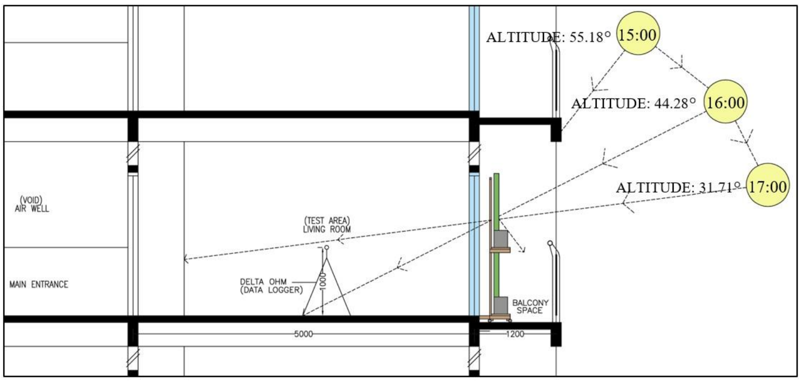


Fig. 6. High-rise Sun Path Facing the West Orientation (8th Floor)

However, when compared with the east facing orientation, the results of east wall simulations dominated in terms of reductions in indoor DBT and cooling load energy. The temperature reduction recorded was 1.43°C, and a total savings of 17.1% of building cooling load energy was also observed. This reduction is considered the highest among the orientations with its cooling load energy efficiency increased by 1% when compared with the current west wall orientation. Without the VGS coverage, the reading at the east orientation climbed up to 32.91°C which is considered the highest average control indoor DBT reading. During the morning session, the balcony with VGS received 2 hours of direct sunlight between 10:00 and 12:00. The solar altitudes were at least 32.49° (10:00), 44.99° (11:00) and 55.74° (12:00) (Figure 7).

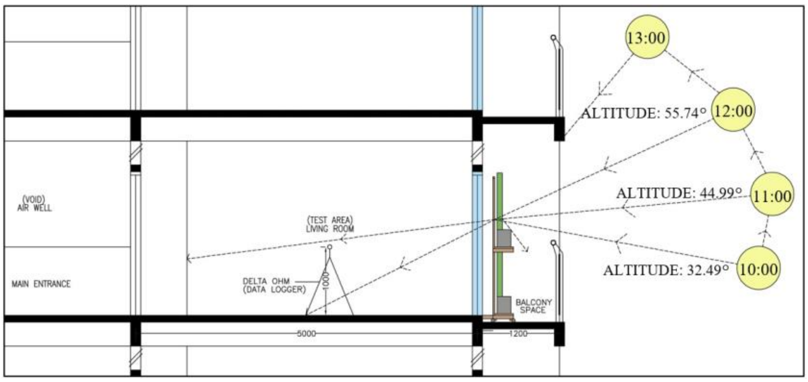
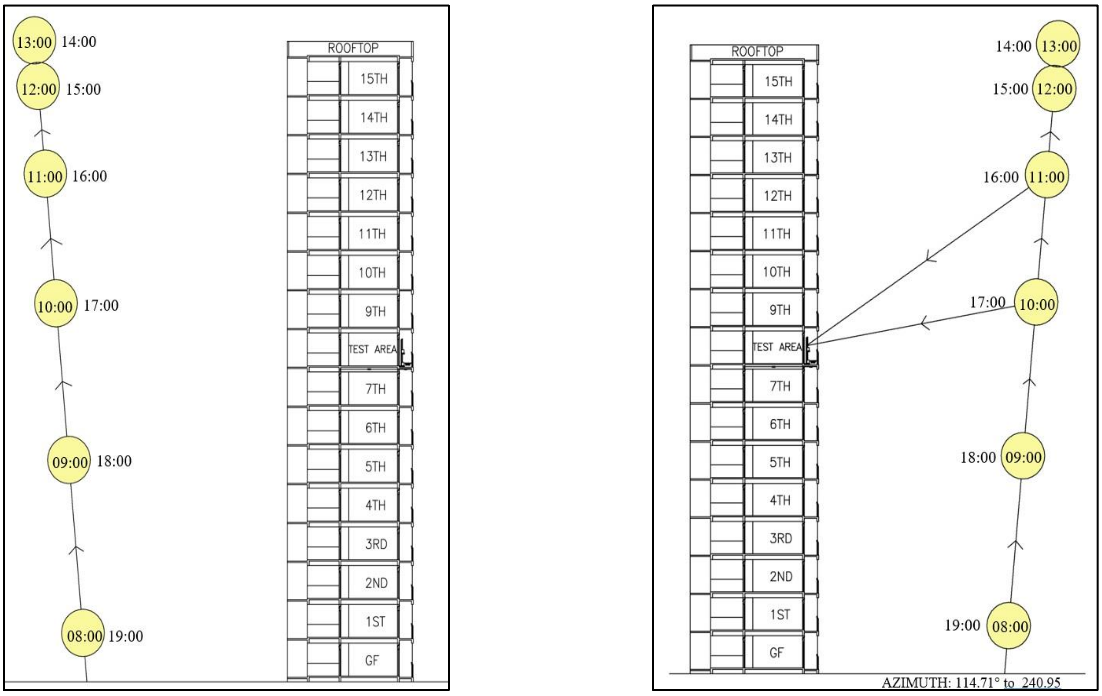


Fig. 7. High-rise Sun Path Facing the East Orientation (8th Floor)

The solar radiation at these hours ranged between 309 W/m² and 525 W/m². This shows that the sunlight and solar radiation exposure was greater on the east side when the simulation room is located at higher level. The balcony began to self-shade from 13:00 onwards. For the north orientation, it was found that the reading estimations were similar to the findings for the ground level studies. In line with the test cell readings, the balcony with VGS was self-shaded during the test hours between 09:00 and 17:00 as the sun path rises and sets in the rear (north) direction (Figure 8a). It was considered to have the least reduction in terms of indoor DBT and building cooling load energy. The indoor DBT dropped from 32.54°C to 31.41°C, giving a reduction of 1.13°C. As for the building cooling load energy, the north orientation managed to save electricity by only 13.9%. The second least reduction falls to the south wall orientation. The indoor DBT reduction was at least 1.18°C. Meanwhile, the cooling load energy for this orientation had managed to be lowered by 14.3%. During the simulation, the solar altitude angles which the balcony received indirect sunlight were between 32.49° (10:00) and 44.99° (11:00) for the morning session and between 44.28° (16:00) and 31.71° (17:00) for the evening session (Figure 8b). The solar azimuth angles ranged between 114.71° and 240. 95°.Although the north and the south facing orientations were considered less significant in terms of VGS application, however at high-rise conditions, the VGS coverage is essential as all orientations are exposed to higher global sunlight and solar radiation which might contribute to building occupants' discomfort.

The most critical orientation for the low-rise simulation study is the South façade. The South facade received indirect sunlight from 09:00 to 17:00, making it the highest control indoor DBT recorded without the application of the VGS. During this simulation study, the estimated reading was 31.17°C. Even though this façade did not receive direct sunlight, it managed to increase the indoor DBT most likely due to solar radiation and heat conduction through roof, glazing and exposed wall materials. As for the high-rise simulation study, the most critical orientation is the East façade. This orientation received direct sunlight in the morning for almost two hours between 10:00 and 12:00, with solar radiation built up ranging between 309w/m² and 525w/m². In line with the study conducted by Lam, Li, and Cheung [20,21], the high-rise simulation study facing this orientation is mostly dominated by solar heat gain through glazing material of the sliding door that separates the living room and balcony.

In terms of VGS application, it is suggested that both the East and West orientations to be the best façades to implement the VGS. This is because both facades received direct sunlight in the morning and evening sessions. Apart from that, these facades received higher solar radiation compared to the other façades, thus enabling the VGS to reduce the indoor DBT and building cooling load energy more efficiently. Overall, the VGS orientation study performed better at a higher level. From the results, it can be concluded that the highest reduction in both temperature and cooling load energy can be tabulated in the following order: East > West > South > North (Table 1). Both ground and high-rise levels share similar trends in terms of estimation of temperature and building cooling load energy reduction. However, the variation of thermal performance and building cooling load energy for the high-rise setting was most probably determined by the percentage of VGS coverage. Hence, the analysis of VGS coverage is explained in the next section.



(a) (b)

Fig. 8. High-rise Sun Path Facing the (a) North Orientation (8th Floor) (b) South Orientation (8th Floor)

3.2 VGS Percentage Analysis

The percentage of coverage study focuses on the analysis of a full VGS coverage when placed in front of the simulation model test unit. This section tests the potential of using 100% VGS coverage and its effect towards the reduction of indoor dry bulb temperature (DBT) and building cooling load energy. The results are presented and compared with previous normal VGS coverage which consisted of 0% (control or without VGS), 45% (VGS on high-rise unit) and finally 100% (VGS on high-rise unit). In line with the previous simulation techniques and parameters, this section only changes the size of VGS coverage that covers both glass doors and brick wall façade from 0% to 100%. The purpose of this analysis is to identify the potential and projection readings of full VGS coverage when placed on high-rise unit [22]. This simulation involved varying VGS coverage percentages from 0% (control or without VGS), 45% VGS, to 100% VGS. The VGS cover for the condominium unit measures 3.0m (l) x 2.8m (h). It covers the entire balcony façade from sun exposure and solar radiation. Table 2 indicates that the application of the 100% VGS at the high-rise condition had managed to reduce the indoor DBT by 1.42°C which is higher by 0.07°C compared to the reduction achieved using the 45% VGS coverage. Figure 9 shows the comparison between VGS coverage that affects the cooling load energy at the high-rise setting. From the graph, the indoor DBT which fell by almost 1.42°C was able to save the building cooling load energy by 16.9% or 432 kWh per annum (Table 3). In terms of energy efficiency, the full coverage (100% VGS) at this condition only saved an additional 0.8% compared to the 45% VGS coverage. This can be shown in the graph as the gap progression between the 45% VGS coverage and full coverage (100% VGS) is minor and almost similar. The trend in Figure 9 climbs sharply between February and March and maintains its value at a mean of 196 kWh until June.

At this point, the maximum value achieved was 198.6 kWh which happened in May. It began to show a downward progression between June and December with a minimum value of 152.4 kWh.

Table 2
Thermal Performance When Using 100% VGS Coverage (High-rise)

Criteria	Mean Min. °C	Mean Max. °C	Mean. /avg. °C	Avg. Temp. Reduction °C
Outdoor Temp. (Control)	20.90	35.80	27.16	-
Outdoor Temp. (VGS)	20.90	35.80	27.16	-
Indoor DBT (control)	29.56	38.54	32.81	-
Indoor DBT (VGS)	28.61	34.82	31.39	1.42

Table 3
Building Cooling Load Energy When Using 100% VGS Coverage (High-rise)

Orientation	Control Wall	VGS wall (100% coverage)	Variation /Reduction
West wall (90◦)	32.81°C	31.39°C	1.42°C
Average indoor DBT:	2551 kWh	2119 kWh	432kWh
Building cooling load energy saving:	-	-	16.9%

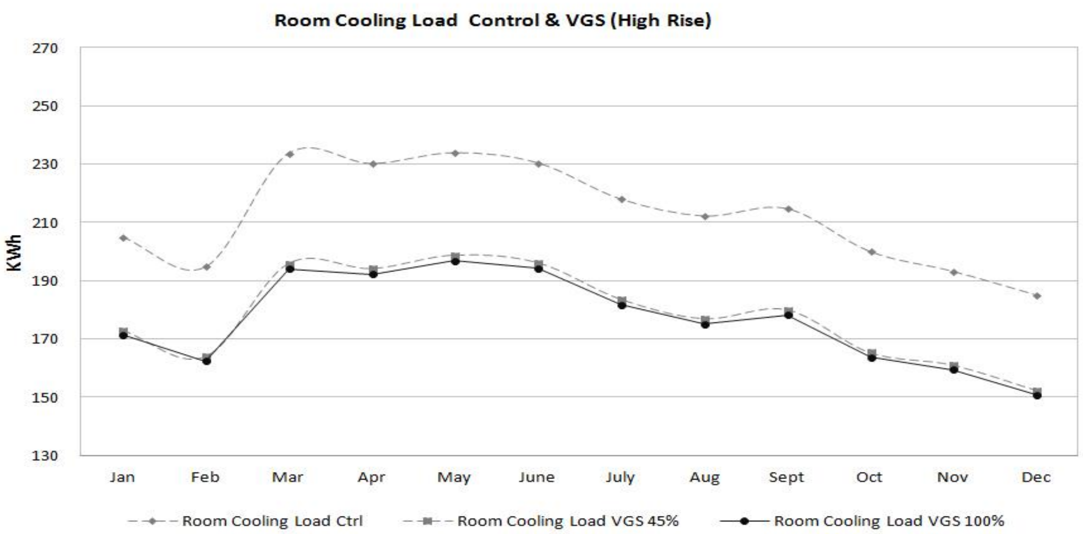


Fig. 9. Room Cooling Loads (Putra Place Condo, High-rise) West Orientation

4. Conclusions

Based on this study, a higher percentage of vegetation will result in a more positive effect towards the reduction of indoor dry bulb temperature (DBT). Moreover, the vegetation's influence on a wall or glazing surface is more pronounced for east and west oriented facades. From an architectural perspective and energy conservation point of view, the incorporation of a 100% VGS coverage wall is shown to be beneficial even though the energy percentages are slightly increased (Figure 9) However, it is proven that the VGS application plays an important role as it act as heat insulation which can filter, reduce, and delay the heat transfer from outdoor to indoor spaces [23]. Besides improving and regulating the microclimate that surrounds the building, the VGS wall is proven to stabilise and neutralise the solar heat gain into the indoor space depending on which orientation it is exposed to.

With full VGS coverage, it manages to reduce the indoor dry bulb temperature at 1.42°C and able to at least save the building energy cooling load by 16.9%.

Acknowledgement
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