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Comparison of Leaf Area Index from Four Plant Species on Vertical Greenery System in Pasir Gudang, Malaysia

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ABSTRACT

Vertical greenery system (VGS) is a subset of urban green infrastructure that ameliorates thermal performance, potential energy savings, and urban heat island. Plants provide shadow effects through the absorption or filtration of the heat radiant, which respond to these issues. The frequent variable used to indicate the leaf mass of a plant is the leaf area index (LAI). There are two methods to measure LAI: direct and indirect methods. However, little attention was given to calculating the LAI using direct measurement in VGS. This study was undertaken to distinguish the LAI value from four plant species, i.e., *Philodendron burle-marxii, Phyllanthus cochinchinensis, Nephrolepis exaltata,* and *Cordyline fructicosa 'Miniature'* in the industrial city of Pasir Gudang. An image analysis tool was used to facilitate the measurement. The results showed the LAI values are highly dependent on the number of leaves. It also found plants that keep growing have the highest LAI value. Importantly, the characteristics of a plant need to be considered before planting in a shrub bed.

Keywords: Experimental study, leaf area index (LAI), plant species, vertical greenery system (VGS)

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INTRODUCTION

The two major vertical greenery systems (VGS) are green façade system and living wall system (Azkorra et al., 2015; Abd-Ghafar et al., 2018; Bustami et al., 2019). These two systems have different

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fundamentals and use different planting materials. Green façades are climbing plants that directly or indirectly grow on an additional structure attached to the wall, while living walls are plants that are planted in modular pots or felt-pocket systems. Notably, VGS provides benefits in thermal performance on building façades. It provides shade to reduce the temperature of the façades and cool the environment through the process of evapotranspiration (Tan et al., 2014). As the temperature of the building decreases, the energy consumption of the building also reduces.

As studied by Jaafar et al. (2013) and Safikhani and Baharvand (2017), in the tropical climate of Malaysia, the living wall system has a better thermal performance compared to the green façade system. In line with Charoenkit and Yiemwattana (2017), plant selection is influential in maximising the performance of a living wall in reducing the temperature. From another study, Pérez et al., (2017) demonstrated leaf area index (LAI) had a direct influence on foliage density, which was related to the estimated amount of thermal reduction in VGS.

In Malaysia, the study on plant species of living walls is still limited. Only a few studies explored the comparison of the LAI value of each plant species. Apart from benefitting thermal reduction, VGS also improves human health (Ghazalli et al., 2018), and enhances aesthetics for visual pleasing (Razzaghmanesh & Razzaghmanesh, 2017) to increase the property values (Timur & Karaca, 2013). Many empirical studies have shown that leaf area index has affected thermal performances (Taib et al., 2019; Charoenkit & Yiemwattana, 2016). It also has great potential for removing particulate matter pollutants from the atmosphere (Dzierżanowski et al., 2011; Song et al., 2015). Previous studies have revealed vegetation has a strong relationship between shadow effect and particulate trap with the foliage thickness. Hence, the most popular method used to characterise foliage thickness is through the measurement of LAI.

Leaf area index (LAI) was defined by Pérez et al., (2017) as the total leaf area of all leaves of a plant per unit ground surface area. However, for shrubs, LAI is divided over the planted area of the shrub bed (Tan & Sia, 2010). LAI is an important parameter in plant ecology and plant physiology because it shows how much leaves there are in one tree. In the context of this study, it shows the growth of a plant in a pot. LAI also measures the photosynthetically active area, and the area subjected to transpiration. It becomes an indicator of how much light is passing through the canopy. For example, in the case of a multi-layer canopy, the LAI of an upper layer is important to determine the light received by the lower layer.

There are two methods to measure LAI: direct and indirect methods (Jonckheere et al., 2004). The direct LAI method has been widely used for crops and adapted for vegetation in small-scale studies (Bréda, 2003; Pérez et al., 2017). This method is useful in agriculture and ecological studies by harvesting the plant (Klingberg et al., 2017) to get the leaf area.

However, recent researchers collected only ten samples of leaves instead of harvesting all leaves from potted plants. Plant Canopy Analyser LAI-2200 (LI-COR Biosciences, Lincoln, USA) is an example of indirect method of LAI. It is a practical and expensive tool. Due to that, the direct LAI method was emphasised in this study. According to Weerakkody et al. (2018), the ImageJ software measures the individual leaf area as it is a part of the variable in the LAI equation. This process is elaborated in the section “Analyse the Measurement of Leaf Area”. Image analysis is a technique used to facilitate the LAI measurement. The development of image analysis has been practiced in many research disciplines, including in Sciences of Total Environment and also Urban Forestry and Urban Greening. The National Institutes of Health has introduced ImageJ as one of the tools of scientific multidimensional images (Schneider et al., 2017). It is made accessible for public programming software, and is a free operational tool for non-commercial purposes (Drienovsky et al., 2017; Stawarczyk et al., 2015).

From the literature, LAI is an important factor in representing green features. Therefore, this study aimed to investigate the potential of selected tropical shrubs in establishing foliage density through direct LAI method on a living wall system. This is an initiative to establish fundamental information of the tropical plants used. Four plant species are included: *Philodendron burle-marxii, Phyllanthus cochinchinensis, Nephrolepis exaltata,* and *Cordyline fructicosa ‘Miniature’*.

MATERIAL AND METHODS

Pasir Gudang is an industrial city in Southern Johor, Malysia. High temperature, high humidity, and abundance of airborne particles are among the climatic attributes of the city. A living wall system has been installed at a 10km radius within the industrial zone. It was modular typed at the outdoor building of the Urban Transformation Centre (UTC) Pasir Gudang, Johor, Malaysia. The LAI measurement was conducted for each month from January to March 2019. Pasir Gudang experiences tropical climate with two seasons, a wet season and a dry season. Pasir Gudang is further categorised as an industrial town occupied by heavy industries, such as petrochemical, transportation and logistics, shipbuilding, and oil palm storage and distribution (Iskandar Regional Development Authority, 2013). The experimentation was constructed in size of 4-meter x 1-meter. This study has adapted the experimental scale of $1m^2$ for each plant species. The small-scale experimentation was also used by Sulaiman et al. (2018) and Charoenkit and Yiemwattana (2017) in the tropical climate of Malaysia and Thailand, and in Japan (Koyama et al., 2013). This type of modular living wall called the Advance Hook-on Green Module System, as shown in Figure 1, was suitable for low height installation. These modular living walls were hooked onto the wire-mesh base to allow for easy installation and maintenance.

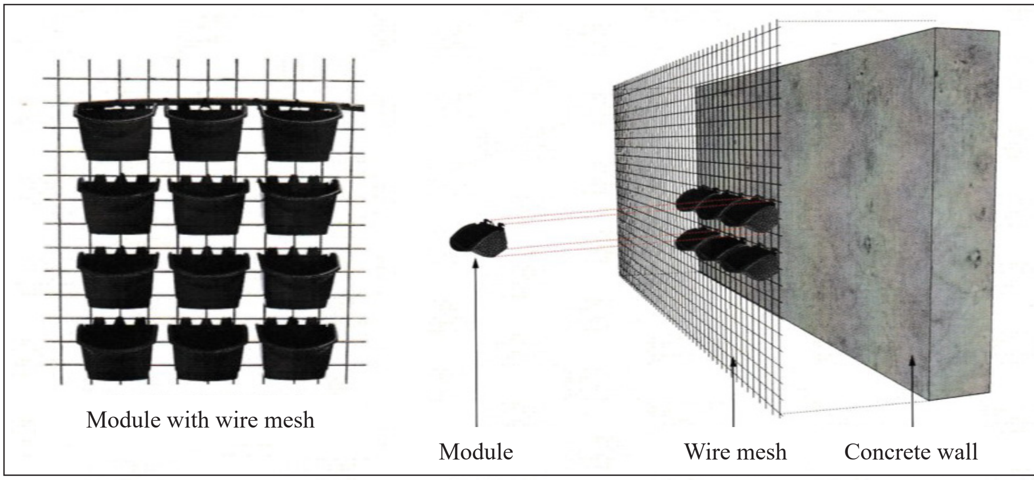


Figure 1. Construction of the modular living wall system (GWS Living Art, 2018)

Plant Selection

The plants were purchased from Chop Ching Hin Nursery, Johor Bahru, Malaysia, that pre-grows vertical plants with a minimum 85% maturity. Plant selection for this field study was made according to these three criteria: availability of plant species in local supplier's nursery, and suitability to tropical conditions (Charoenkit & Yiemwattana, 2017). These plant species were also chosen based on the common species of VGS used in Malaysia. All the species planted in the field study had a high demand from the market. *Phyllanthus cochinchinensis,* and *Cordyline fructicosa 'Miniature'* were both full sun and hardy plants. The other two, *Philodendron burle-marxii* and *Nephrolepis exaltata,* were semi-shade plants that needed more water. This study took three times of watering per day through the auto-irrigation system. This is because plants in small pots need regular watering (Bustami et al., 2019) due to the pots providing a limited area for root growth. In this case, an automatic irrigation system was installed to ensure good plant growth (Kmieć, 2015)

Direct Method of Leaf Area Index

This study carried out a repeated measurement of four plant species. These four plant species were *Philodendron burle-marxii, Phyllanthus cochinchinensis, Nephrolepis exaltata* and *Cordyline fructicosa 'Miniature'* (Figure 2). Consequently, this research explained the direct measurement thoroughly to obtain LAI, where direct measurement is the estimated measurement of leaf area from harvested leaves. This sampling method can be time-consuming; however, a variety of computerised image analysis software is available and accurate in a short time. Direct measurement and the application of ImageJ software in this study are suitable only for small plants. This study gave an example of the measurement of the *Nephrolepis exaltata* (Boston Fern). However, the results of LAI values for all species were calculated and shown in the section "Results and Discussion". This field study had applied the standard equation in a small structure (Blanco & Folegatti, 2003) to calculate the estimated value of LAI. Hence, Figure 3 illustrates the flowchart to measure LAI from the harvesting process until the LAI value was obtained.

(a) (b) (c) (d)

Figure 2. (a) *Philodendron burle-marxii*; (b) *Phyllanthus cochinchinensis*; (c) *Nephrolepis exaltata*; and (d) *Cordyline fructicosa 'Miniature'* were used at the field study of Pasir Gudang

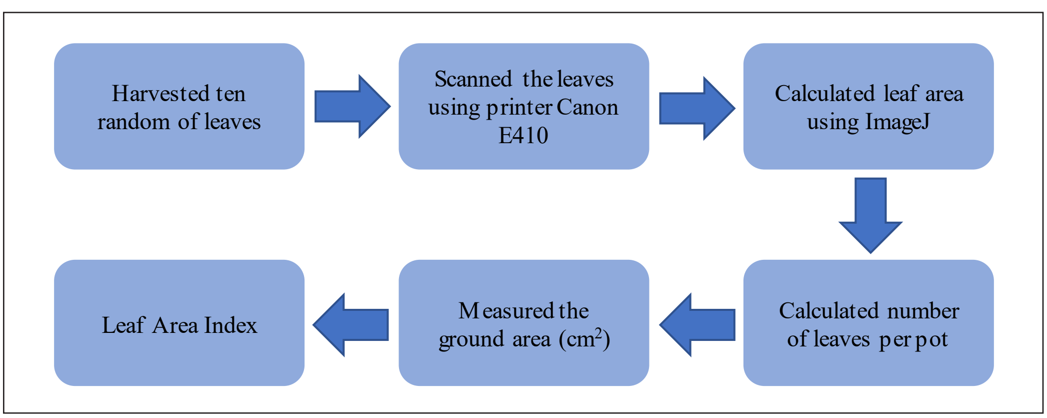


Figure 3. Flowchart of measurement of leaf area index in a modular living wall

Harvested Leaves. The leaves were collected in the early month of the monitoring study. Samples similar in height and size were randomly harvested. The sampled plants were in good condition with no wilted leaves and disease. This direct method involves physical calculation. Therefore, it is necessary for the individual leaves that were picked from a plant to be wet and green (Ong, 2003) to get an accurate reading of leaf area (cm^2). In accordance with Weerakkody et al. (2018), ten random leaves per species were used to calculate the mean leaf size. Individual leaf sizes were then measured using the ImageJ software.

Flat Image - Using Scanner. Figure 4 illustrates ten random leaf images scanned using the A4 flat scanner (Stawarczyk et al., 2015) Canon E410. These prepared samples were attached into a drawing block with double-sided adhesive tape to ensure proper images are produced. The Adobe Photoshop CS6 functioned to combine all the leaves in one file. This accommodates the user when importing the leaf file in the ImageJ software afterward. The imported file uploaded has to be in the same quality to assure all leaves are of a similar pixel. A scale ruler was placed next to the leaves during the scanning process to help draw a linear segment in the scale calibration process.

Figure 4. Ten random leaves harvested from the study site

ImageJ. The common instruments to measure leaf area are leaf area meter and Delta-T Image Analysis System (DIAS) (Pérez et al., 2017) . Hence, this study analysed the leaf area using an image analyser, the ImageJ (Weerakkody et al., 2017), after the scanning procedure. Although the scanning process was not stated in detail, a flat image is required to apply the ImageJ software. Therefore, the leaves need to be scanned before being imported into the software. ImageJ is a public domain Java image processing programme inspired by NIH Image.

Scale Calibration. A reference size like a scale ruler image is necessary for the scale calibration process, to optimise the accuracy of the calibration. Then, the scale ruler image was imported beside the leaf images (Figure 2). In sum, the scale ruler image was enlarged via the magnifying glass tool to acquire the exact measurement. After that, the straight-line tool was used to draw a line between two points on the ruler image. For example, a line was drawn over a 4-cm section of the ruler, then the Analyse button was clicked and a set scale was selected. After that, the four-digit number is keyed into the Known Distance box, the unit of measurement was changed to cm, and the Global function was selected. A standard metric measurement in ImageJ is cm, however, a user can manually change this unit of measurement . The scale must be reset each time the software reboots.

Analyse the Measurement of Leaf Area. As researchers, a variety of image analysis is used to acquire and analyse data. The image analysis is also called leaf measurement. Additionally, this study had imported ten replicates of the Boston fern in the ImageJ software to analyse the mean of leaf area. However, the area of measurement process requires an 8-bit colour or grey image to form a binary image.

As shown in Figure 5, the leaves' colour has changed from green to grayscale. This software suggested using a white background for the sampling to facilitate the leaf area calculation. The threshold process turned the dark parts into a black image, while the light parts converted into a white image, resulting in a binary image (Figure 6). This image only produced two colours, black and white, or other preferable two colours to distinguish the measurement area. The accuracy of the calculation area depended on the photograph pixels. To arrive at this stage, the wand (tracing) tool from the ImageJ software was selected, and the leaf shape is selected to produce the yellow outline around the leaf. It was automatically highlighted as demonstrated in Figure 7.

The automatic selection sometimes uncovered the entire leaf calculation. However, ImageJ provided modes to adjust the perimeter of the leaf that influenced the value of leaf area. This tool allowed the modification of the shape area through a circular brush. The circle boundary in Figure 7 (a) was the image before the adjustment was made which shows the irregularities of the yellow outlines formed. The step involved selecting the inside of the leaf image and dragging the yellow line along the border of the leaf to expand the area. Inversely, this step was repeated from the outside of the boundary to minimise the image. The differences could be seen in Figure 7 (b) that shows after the alteration process, the yellow line had formed the toothed leaf.

The results tabulated in Table 1 show the ten Boston Fern leaves (Figure 4) and the mean leaf area (cm^2)**.** This table contains only one-month measurement, calculated repeatedly for three months. The last column depicts the mean leaf area from ten leaves.

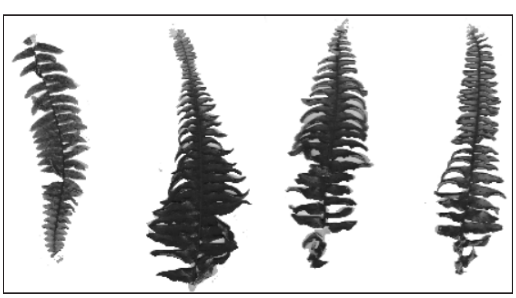
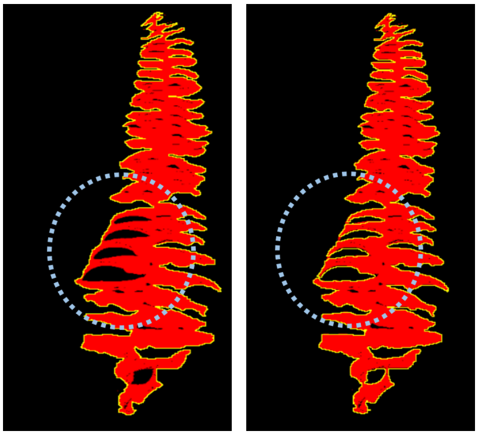


Figure 5. Grayscale image of the Boston Fern

Figure 6. Binary image of the Boston Fern



(a) (b)

Figure 7. Adjustment of the calculation area: (a) before; and (b) after

Table 1
Results of the leaves area from ImageJ measurement

	Label	Area (cm^2)
1	Leave 1	73.78
2	Leave 2	83.40
3	Leave 3	64.19
4	Leave 4	103.09
5	Leave 5	91.07
6	Leave 6	76.12
7	Leave 7	58.76
8	Leave 8	89.25
9	Leave 9	49.32
10	Leave 10	52.94
11	**Mean**	**74.19**

Number of Leaves and Ground Area. The number of leaves (N) represents the leaves in one potted plant. This study took three potted plants to procure an average of N. In vertical planting, the concept of the ground area referred to the area according to the modular size (Charoenkit & Yiemwattana, 2017). This measurement was taken manually using a scale ruler. The concept is that light absorption is based on the density of the leaves covering the ground area where the plant grows (Burstall & Harris, 1983).

Leaf Area Index (LAI). In this study, LAI was directly evaluated from harvested leaves at the field study of Pasir Gudang. According to Sonnentag et al. (2007), this method is more accurate for short-stature ecosystems. Leaf Area Index (LAI) for shrubs is different from other plant categories in which it measures the ratio of the total leaf area to the planted area of the shrub bed (Tan & Sia, 2010). LAI is considered as the main factor in determining the shading effect of VGS due to its cooling ability in buildings and the environment, as reviewed by Charoenkit and Yiemwattana (2016). Thus, the Leaf Area Index (LAI) is measured by dividing the total leaf area of a plant pot by the plant pot area (Blanco & Folegatti, 2003). All steps were mentioned in detail in the previous section.

$$LAI = \frac{Leaf\ area\ (cm^2) \times N}{Ground\ area\ (cm^2)}$$

The equation shows the leaf area portrays the average of ten random leaf area. Afterward, it was analysed using the ImageJ software, where N represents the number of leaves per plant. The mean LAI of three measurements were extrapolated to $1m^2$ as the LAI of each plant species (Charoenkit & Yiemwattana, 2017). Commonly the LAI value ranges from 3.5 to 4.5 based on the generic values (Tan & Sia, 2010) for shrubs. Of late, the monthly measurement of the LAI value keeps changing due to the growth rate of each species.

RESULTS AND DISCUSSION

The LAI values of four plant species at UTC Pasir Gudang are tabulated in Table 2. *Phyllanthus cochinchinensis* recorded the highest LAI in January (LAI 5.02) followed by *Philodendron burle-marxii* (LAI 4.45), *Cordyline fructicosa 'Miniature'* (LAI 3.94), and *Nephrolepis exaltata* (LAI 3.75). A study by Tan et al. (2015) found the LAI value of a similar plant species, *Phyllanthus cochinchinensis,* measured in a horizontal, green roof medium was 2.78, making the results parallel. From the observation, this study has a smaller ground area compared to the study by Tan et al. (2015). The smaller ground area of shrub bed produces a larger LAI value. It contradicts Ong (2003), who showed *Phyllanthus cochinchinensis* had the average LAI value of up to 7. Shrubs provide higher LAI value than palm and tree species. It reveals shrubs have denser leaves due to lack of lighting that penetrates behind the shrubs. It means that different plant species have a varied cooling capacity based on the evapotranspiration of each plant. The maturity of plants was also influenced by the shading effect through the heat absorption of plants (Taib et al., 2019). Thus, the selection of plants must consider the plant character to maximise the cooling effect of VGS.

In February, the LAI value of each species increased except for *Cordyline fructicosa 'Miniature'* with the lowest LAI value of 3.58. The value decreased as much as 0.4 compared the value from January. It statistically demonstrated the mean leaf area and the number of leaves per pot have reduced. However, the the LAI value of the plant species *Nephrolepis exaltata* drastically increased (LAI 5.82). This is followed by *Philodendron burle-marxii* (LAI 5.20) and *Phyllanthus cochinchinensis* (LAI 5.04). The LAI values steadily increased in March; *Nephrolepis exaltata* (LAI 6.55), *Philodendron burle-marxi* (LAI 5.84), *Phyllanthus cochinchinensis* (LAI 5.48), and *Cordyline fructicosa 'Miniature'* (LAI 3.61).

This is due to the increase in the number of leave per pot for each species. Figure 4 illustrates the changes in LAI values according to monthly reading from January until March 2019. In a similar vein with Wong et al. (2009), the plant used in VGS was *Nephrolepis exaltata* with an LAI of 6.76. The result of the simulated study from Singapore was consistent with this study, where the Boston fern had an LAI of 6.55. It was found that *Nephrolepis exaltata* has the highest leaf area index due to the dense canopy, allowing for multiple layers of shading. Previous studies did not have the LAI for *Cordyline fructicosa 'Miniature'* and *Philodendron burle-marxii* in any of the landscape settings.

Table 2
LAI values of four plant species in Urban Transformation Centre (UTC) Pasir Gudang

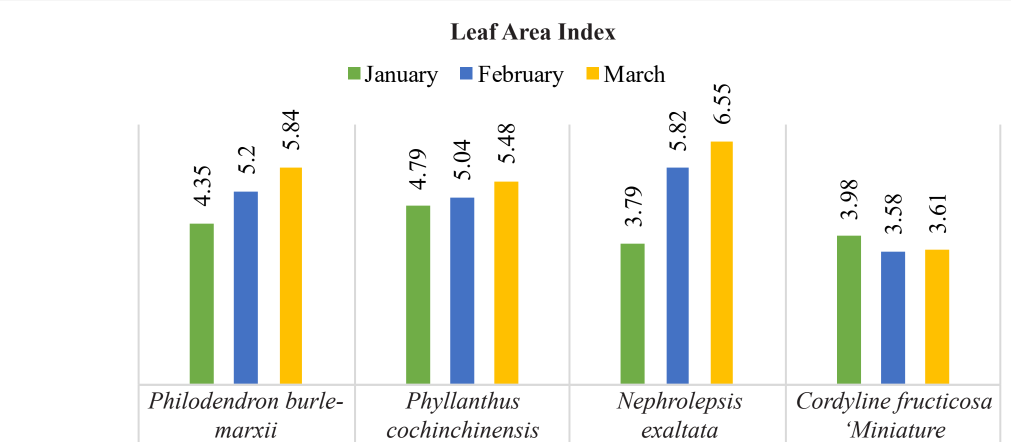
Type of plants used/ Months	January				February				March			
	Mean Leaf Area (cm^2)	Number of leaves per pot	LAI	Mean LAI	Mean Leaf Area (cm^2)	Number of leaves per pot	LAI	Mean LAI	Mean Leaf Area (cm^2)	Number of leaves per pot	LAI	**Mean LAI**
Philodendron burle-marxii	88.12	11	4.22	4.35	87.40	13	4.95	5.20	87.30	15	5.71	**5.84**
		13	4.99			14	5.33			16	6.09	
		10	3.84			14	5.33			15	5.71	
Phyllanthus cochinchinensis	1.99 34 .10 (stem)	31	4.61	**4.79**	1.97 32 .13 (stem)	35	4.90	5.04	1.96 32 .08 (stem)	38	5.31	**5.48**
		35	5.20			37	5.18			39	5.45	
		32	4.76			36	5.04			41	5.73	
Nephrolepis exaltata	65.31	13	3.69	3.79	74.19	17	5.49	**5.82**	75.21	20	6.55	**6.55**
		13	3.69			19	6.14			21	6.88	
		14	3.98			18	5.82			21	6.23	
Cordyline fructicosa 'Miniature'	19.13	50	4.17	3.98	18.51	38	3.87	3.58	18.03	47	3.69	**3.61**
		47	3.92			41	3.31			46	3.61	
		46	3.4			44	3.55			45	3.54	

*Pot size 17cm x13.5cm = 229.5 cm^2

The *Philodendron burle-marxii'* is an epiphytic, herbaceous vine. It climbs through its roots. It also needs frequent maintenance due to its semi-shade plant type, with moderate watering needs. The mean leaf area of this plant was about 87.3-88.3 cm^2. The leaves often grow as they dry. Therefore, this plant is considered to have a good growth rate, as the LAI values have increased every month (Figure 8). *Cordyline fructicosa 'Miniature'* is hardy, which only preferred moderate water. The mean leaf area measured around 18.03-19.13 cm^2. More importantly, the LAI value decreased because the plant's leaves grew inconsistently as the plant withered to an unappealing brown. The trunk height then increased, and the plant lost its density compared to the first month of measurement.

Phyllanthus cochinchinensis is a woody shrub. It is a drought-tolerant plant that prefers dry soil conditions, and survive under full sunlight. It is able to grow up to 3 m tall (NParks, 2013b); nonetheless, it has a slow height growth. The mean leaf area measured in this study was approximately 1.96-1.99 cm^2. The leaves were spirally aligned on short branches, however, the multiple layers of its leaves increased and the branches were longer. Good plant growth increases the value of LAI from January to March, as shown in Table 2. The *Nephrolepis exaltata* or Boston fern is a semi-shade plant but the most tolerant to drought among the common cultivated ferns. The plant needs only moderate water but requires moist soil. The leaves have slightly toothed dagger-shaped fronds (NParks, 2013a) with a mean leaf area of about 65.3-75.2 cm^2.

The number of leaves in this study represents the density of leaves. On this note, the number of leaves from three species, namely *Philodendron burle-marxii, Phyllanthus cochinchinensis,* and *Nephrolepis exaltata* have increased. A study by Taib et al. (2019)



	Philodendron burle-marxii	*Phyllanthus cochinchinensis*	*Nephrolepsis exaltata*	*Cordyline fructicosa 'Miniature*
January	4.35	4.79	3.79	3.98
February	5.2	5.04	5.82	3.58
March	5.84	5.48	6.55	3.61

Figure 8. Specific mean LAI from January to March

proved trees that had multiple layers of leaves were more effective at absorbing solar radiation. The multiple layers of leaves of the *Cordyline fructicosa 'Miniature'* had fluctuated according to monthly measurement, thus providing a low density of leaves. Figure 8 shows the LAI values of four different plant species from January until March. It shows that multiple layers of leaves, the density of leaves, and the average leaf area contributed to a higher mean value of the leaf area index.

CONCLUSION

The significance of this study demonstrates the direct measurement of LAI in VGS. Step by step measurement was successfully shown in this study. The current phenomenon is the application of the ImageJ software to help accelerate the calculation of leaf area. In summary, the field measurement in this study showed the observation of growth for each plant species. It revealed the rate of plant growth and its physical characteristics affected the calculation process of LAI. Plant growth can be represented by the increase in the number of leaves upon monthly measurement. This method can be applied for shrubs in vertical planting. Appropriate plant selection has a better tolerance of environmental issues such as thermal performance and air pollution. This due to each of plant species has different ability in producing shade and trapping particulate through VGS. Therefore, other plant species and their characteristics are also vital to be studied.

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REFERENCES

Abd-Ghafar, A., Abdulkarim, K. H., Said, I., & Jasmani, Z. (2018). Vertical greenery systems and its effect on campus: A meta-analysis. *Journal of BIMP-EAGA Regional Development*, *4*(1), 42-56.

Azkorra, Z., Pérez, G., Coma, J., Cabeza, L. F., Bures, S., Álvaro, J. E., … & Urrestarazu, M. (2015). Evaluation of green walls as a passive acoustic insulation system for buildings. *Applied Acoustics*, *89*, 46-56.

Blanco, F. F., & Folegatti, M. V. (2003). A new method for estimating the leaf area index of cucumber and tomato plants. *Horticultura Brasileira*, *21*(4), 666-669.

Bréda, N. J. J. (2003). Ground-based measurements of leaf area index: A review of methods, instruments and current controversies. *Journal of Experimental Botany*, *54*(392), 2403-2417.

Burstall, L., & Harris, P. M. (1983). The estimation of percentage light interception from leaf area index and percentage ground cover in potatoes. *The Journal of Agricultural Science*, *100*(1), 241-244.

Bustami, R. A., Brien, C., Ward, J., Beecham, S., & Rawlings, R. (2019). A statistically rigorous approach to experimental design of vertical living walls for green buildings. *Urban Science*, *3*(3), 1-15.

Charoenkit, S., & Yiemwattana, S. (2016). Living walls and their contribution to improved thermal comfort and carbon emission reduction: A review. *Building and Environment*, *105*, 82-94.

Charoenkit, S., & Yiemwattana, S. (2017). Role of specific plant characteristics on thermal and carbon sequestration properties of living walls in tropical climate. *Building and Environment*, *115*, 67-79.

Drienovsky, R., Nicolin, A. L., Rujescu, C., & Sala, F. (2017). Scan leaf area-a software application used in the determination of the foliar surface of plants. *Research Journal of Agricultural Science*, *49*(4), 215-224.

Dzierżanowski, K., Popek, R., & Gawro, H. (2011). Deposition of particulate matter of different size fractions on leaf surfaces and in waxes of urban forest species. *International Journal of Phytoremediation*, *13*(10), 1037-1046.

Ghazalli, A. J., Brack, C., Bai, X., & Said, I. (2018). Alterations in use of space, air quality, temperature and humidity by the presence of vertical greenery system in a building corridor. *Urban Forestry and Urban Greening*, *32*(April), 177-184.

GWS Living Art. (2018). *Advance hook-on green module system* [Brochure]. Singapore: Author.

Iskandar Regional Development Authority. (2013). *Road to Completion*. Retrieved June 17, 2019, from https://www.irda.com.my

Jaafar, B., Said, I., Reba, M. N. M., & Rasidi, M. H. (2013). Impact of vertical greenery system on internal building corridors in the tropic. *Procedia - Social and Behavioral Sciences*, *105*, 558-568.

Jonckheere, I., Fleck, S., Nackaerts, K., Muys, B., Coppin, P., Weiss, M., & Baret, F. (2004). Review of methods for in situ leaf area index determination: Part I. Theories, sensors and hemispherical photography. *Agricultural and Forest Meteorology*, *121*(1), 19-35.

Klingberg, J., Konarska, J., Lindberg, F., Johansson, L., & Thorsson, S. (2017). Mapping leaf area of urban greenery using aerial LiDAR and ground-based measurements in Gothenburg, Sweden. *Urban Forestry and Urban Greening*, *26*, 31-40.

Kmieć, M. (2015). Green wall technology. *Czasopismo Techniczne*, *10A*(23), 47-60.

Koyama, T., Yoshinaga, M., Hayashi, H., Maeda, K., & Yamauchi, A. (2013). Identification of key plant traits contributing to the cooling effects of green façades using freestanding walls. *Building and Environment*, *66*, 96-103.

NParks. (2013a). *Nephrolepis exaltata*. Retrieved July 17, 2019, from https://florafaunaweb.nparks.gov.sg

NParks. (2013b). *Phyllanthus cochinchinensis*. Retrieved July 17, 2019, from https://florafaunaweb.nparks.gov.sg

Ong, B. L. (2003). Green plot ratio: An ecological measure for architecture and urban planning. *Landscape and Urban Planning*, *63*(4), 197-211.

Pérez, G., Coma, J., Sol, S., & Cabeza, L. F. (2017). Green facade for energy savings in buildings: The influence of leaf area index and facade orientation on the shadow effect. *Applied Energy*, *187*, 424-437.

Razzaghmanesh, M., & Razzaghmanesh, M. (2017). Thermal performance investigation of a living wall in a dry climate of Australia. *Building and Environment*, *112*, 45-62.

Safikhani, T., & Baharvand, M. (2017). Evaluating the effective distance between living walls and wall surfaces. *Energy and Buildings*, *150*, 498-506.

Schneider, C. A., Rasband, W. S., & Eliceiri, K. W. (2017). NIH Image to ImageJ: 25 years of Image Analysis. *Nat Methods*, *9*(7), 671-675.

Song, Y., Maher, B. A., Li, F., Wang, X., Sun, X., & Zhang, H. (2015). Particulate matter deposited on leaf of five evergreen species in Beijing, China: Source identification and size distribution. *Atmospheric Environment*, *105*, 53-60.

Sonnentag, O., Talbot, J., Chen, J. M., & Roulet, N. T. (2007). Using direct and indirect measurements of leaf area index to characterize the shrub canopy in an ombrotrophic peatland. *Agricultural and Forest Meteorology*, *144*(3-4), 200-212.

Stawarczyk, K., Programu, Z., Do, I., Uszkodze, O., & Przez, L. I. N. (2015). Use of the ImageJ program to assess the damage of plants by snails. *Chemistry Didactics Ecology Metrology*, *20*, 67-73.

Sulaiman, M. K. A. M., Shahidan, M. F., Jamil, M., & Zain, M. F. M. (2018). Percentage coverage of tropical climbing plants of green facade. *IOP Conference Series: Materials Science and Engineering*, *401*(1), 1-6.

Taib, A. N., Ali, Z., & Abdullah, A. (2019). The performance of different ornamental plant species in transitional spaces in urban high-rise settings. *Urban Forestry and Urban Greening*, *43*(2019), 1-8.

Tan, C. L., Wong, N. H., & Jusuf, S. K. (2014). Effects of vertical greenery on mean radiant temperature in the tropical urban environment. *Landscape and Urban Planning*, *127*, 52-64.

Tan, C. L., Wong, N. H., Tan, P. Y., Jusuf, S. K., & Chiam, Z. Q. (2015). Impact of plant evapotranspiration rate and shrub albedo on temperature reduction in the tropical outdoor environment. *Building and Environment*, *94*, 206-217.

Tan, P. Y., & Sia, A. (2010). *Leaf area index of tropical plants a guidebook on its use in the calculation of green plot ratio*. Singapore: Centre of Urban Greenery and Ecology

Timur, Z. B., & Karaca, E. (2013). Vertical gardens BT - advances in landscape architecture. *Advances in Landscape Architecture*, (Chapter 22), 1-36.

Weerakkody, U., Dover, J. W., Mitchell, P., & Reiling, K. (2017). Particulate matter pollution capture by leaves of seventeen living wall species with special reference to rail-traffic at a metropolitan station. *Urban Forestry and Urban Greening*, *27*, 173-186.

Weerakkody, U., Dover, J. W., Mitchell, P., & Reiling, K. (2018). Quantification of the traffic-generated particulate matter capture by plant species in a living wall and evaluation of the important leaf characteristics. *Science of the Total Environment*, *635*, 1012-1024.

Wong, N. H., Tan, A. Y. K., Tan, P. Y., & Wong, N. C. (2009). Energy simulation of vertical greenery systems. *Energy and Buildings, 41*(12), 1401-1408.