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Modular Living Wall System Response to Relative Humidity and Air Temperature in Malaysia

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Abstract

The relative humidity is an essential environmental factor that affects thermal comfort. The influence of relative humidity on thermal comfort was studied in various mediums of green infrastructure. This environmental concern related to climate change pertains to the Sustainable Development Goals (SDGs) 13. A modular living wall system can be used as a climate mitigation measure to improve temperature at an outdoor building. Plants are the essential components of the system. The assessment of these experimental studies on modular living wall system, relative humidity, and air temperature is still scarce, especially from different plant species in tropical countries. As such, this study aimed to investigate the relationship between relative humidity and air temperature from the modular living wall system. This experimentation was undertaken in the industrial city of Pasir Gudang, Malaysia. Four plant species, *Philodendron burle-marxii, Phyllanthus cochinchinensis, Nephrolepis exaltata,* and *Cordyline fructicosa 'Miniature,'* were evaluated in 4-meter (width) x 1-meter (height). The study was conducted from January 1, 2019, to February 1, 2019. These results were evaluated by statistical analyses, which indicate that relative humidity significantly affects the thermal performance of the modular living wall system.

Keywords: Relative Humidity, Thermal Performance, Modular Living Wall System

Introduction

Most of the developed countries, including Malaysia, are having rapid development and many challenges because of the increasing population lives in the urban areas (Mohd-Fauzi and Abd-Ghafar, 2020). Human activities notably drive climate change which causes human discomfort. Vertical planting is an emerging technology from green infrastructure that be used successfully to promote outdoor living, mitigate urban heat island naturally (Zheng *et al.*, 2023) and city walkability. The trend for vertical planting increased in the 2000s, and it then experienced tremendous growth in the 2010s. The system's evolution showed the integration of greenery and the building provided multiple benefits to city spaces. It was then popularized in various formats, whether at the outdoor building, indoors, or on the street.

The value of the research lies in the fact that the often arbitrary and confusing use of the term to refer to green façades or living walls will be clarified. Vertical greenery system have two main approaches: the green façade system and the living wall system (Jaafar *et al.*, 2013; Bustami *et al.*, 2019). Generally, the green facade system is known as a ground-based system, while the LWS is recognized as a wall-based system (Abd Ghafar *et al.*, 2018). Many empirical studies have proven that the living wall system provides more beneficial ways of dealing with environmental problems than the green façade system. It also offers a noticeable appeal to the aesthetic values due to the planting characteristics and the color of the leaves.

From past studies, plants play an important role in providing a quality living environment (Pataky, 2016; Cameron *et al.*, 2014). This is due to the plant's benefit of lowering the temperature for air cooling and humidity control (Chaipong, 2020). Many researchers have compared the thermal impact from a different system (Jaafar, 2015) and different distances of the system's air gap (Safikhani and Baharvand, 2017) and related it to a control variable. Unfortunately, only two studies investigated temperature differences among the plant species using the modular living wall system. These studies were conducted in Thailand and Sri Lanka by Charoenkit and Yiemwattana (2017) and Rupasinghe and Halwatura (2020), respectively. Reviews have yet to attempt to discover the different thermal effects of plant species with modular living wall system in Malaysia. Hence, this study focuses on the role of plant species concerning the changes in outdoor thermal performance, which it is in line with high temperature and low relative humidity of the industrial city of Pasir Gudang, Malaysia (Department of Environment, 2016).

Materials and Methods

Pasir Gudang is an industrial city in Southern Johor, Malaysia. The modular living wall system was installed facing the industrial area in a radius of 10 km. This study adapted the experimental scale of $1m^2$ for each plant species. The small-scale experimentation was also used in the tropical climate of Malaysia (Abd Ghafar *et al.*, 2020; Sulaiman *et al.,* 2018) and Thailand (Charoenkit and Yiemwattana, 2017). This type of modular living wall system, called the Advance Hook-on Green Module System, was suitable for low-height installation. The modular living wall system were hooked onto the wire-mesh base to allow easy installation and maintenance.

Four plant species were selected: *Philodendron burle-marxii, Phyllanthus cochinchinensis, Nephrolepis exaltata* and *Cordyline fructicosa 'Miniature'*, to be explored in this study, as illustrated in Figure 1. These plants were selected as common species that grow well in Malaysia's tropical climate but have not been assessed in previous research. For instance, local researchers, such as Jaafar *et al* (2015); Safikhani and Baharvand (2017) have evaluated different plant species from those used in this study. However, the studies were not compared between the plant species. In this research, two of the plant species, *Phyllanthus cochinchinensis* and *Cordyline fructicosa 'Miniature',* are popular in the tropics due to their durability under full sun and their low maintenance. The other two plant species *Philodendron burle-marxii* and *Nephrolepis exaltata,* prefer semi-shade and require moderate maintenance, as they need more water.

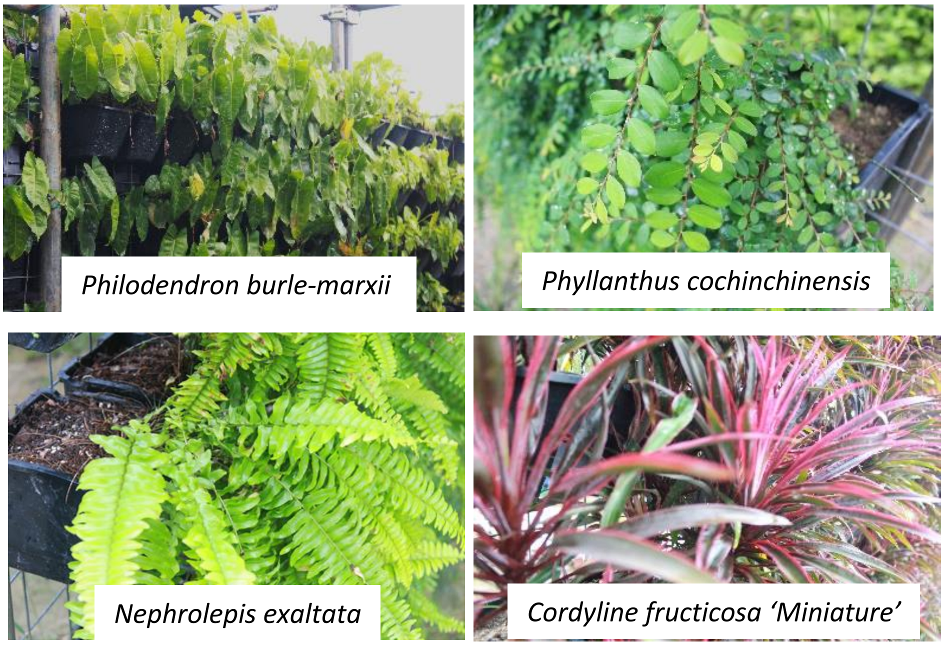

Figure 1. Four plant species were used in the modular living wall system

Forty-two plants of every species were planted in a modular living wall system measuring 1 m^2. The plants of each species were arranged in six horizontal and seven vertical lines. The plant materials had already had three months of growth with a minimum 85% growth rate at Chop Ching Hin Nursery, Johor Bahru.

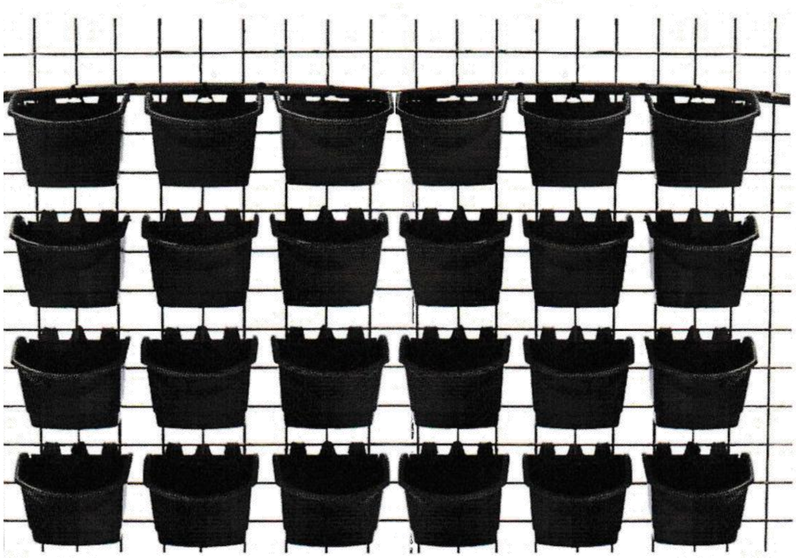

Figure 2. Forty-two plant species were used each species

Data Collection and Analysis

The experimentation was carried out from January 1, 2019, until February 1, 2019, daytime for a month at 30-minute intervals. The greenery of each plant species was recorded for air temperature and relative humidity by HOBO UX 100-011 Temp\RH Data Logger, which only has a single channel, as tabulated in Table 1. The data logger of installed at distance of 30 cm from the concrete wall (Wong et al., 2010). This means that study collected each species the two variables, air temperature and relative humidity. All the data transferred from

HOBOware Pro software were then exported into an MS Excel spreadsheet (Onset Computer, 2012). The analysis of this study involves comparing the data by using a one-way analysis of variance (ANOVA).

Table 1
Equipment used in the modular living wall system's experimental study

Variables	Name of equipment	Number
Air temperature Relative Humidity	HOBO UX 100-011 UX 100 Temp\RH Data Logger (Onset, USA)	4
	Hoboware Pro Software	1

Results and Discussion

The mean values for air temperature were examined from the ANOVA and post-hoc tests to show the air temperature pattern. The significant *p*-value was 0.000, which is below 0.05; therefore, there was a statistically significant difference in the overall analysis of the mean air temperature effect between four plant species, including a bare wall. The value was $F (4, 2935) = 38.585$, $p=0.000$ ($p< 0.05$). It shows that temperature reduced consistently for all four species in January. The results showed *Philodendron burle-marxii* had the highest average temperature reduction with a difference of 2.50 ^{o}C. The average air temperature was then followed by *Phyllanthus cochinchinensis* and *Nephrolepis exaltata,* with differences of 2.33 ^{o}C and 1.56 ^{o}C, respectively. However, *Cordyline fructicosa 'Miniature'* revealed the minimum reduction in average air temperature of 1.06 ^{o}C.

The four plant species showed increases in relative humidity compared to the bare wall and this was due to the presence of plants. The data were analyzed using ANOVA and post-hoc multiple comparisons to measure the validity of the data. The January value of the ANOVA analysis was $F (4, 2935) =27.84$, $p=0.00$ ($p< 0.05$). Therefore, there was a statistically significant difference in the humidity effect between the four plant species compared with a bare wall, in which the p-value is below 0.05. The percentage of relative recorded in January was for *Philodendron burle-marxii* with differences of 6.64%, followed by *Phyllanthus cochinchinensis* at 6.34% and *Nephrolepis exaltata at* 4.23%. Meanwhile, the minimum relative humidity rate was for *Cordyline fructicosa 'Miniature'* at 2.19%.

Table 2
Relationship of air temperature and relative humidity in the experimental study in Pasir Gudang

Plant species	Mean difference	
	Air temperature (^{o}C)	Relative humidity (%)
Philodendron burle-marxii	2.50	6.64
Phyllanthus cochinchinensis	2.33	6.34
Nephrolepis exaltata	1.56	4.23
Cordyline fructicosa 'Miniature'	1.06	2.19

The average air temperature from one-way ANOVA and post-hoc test has revealed that *Philodendron burle-marxii* was the best performer of air temperature. This was followed by *Phyllanthus cochinchinensis*, *Nephrolepis exaltata* and *Cordyline fructicosa 'Miniature'* as shown in Table 2. *Cordyline fructicosa 'Miniature'* was the least air temperature reduction among the four plant species experimented with. A similar performer of *Philodendron burle-marxii* also presented this study's maximum mean relative humidity. The level had increased by 6.64% from a bare wall. This showed that this species was the best performer for air temperature reduction, with a reduction of 2.50 ^{o}C, and has the highest percentage of relative humidity, 6.64%. This study demonstrated a strong relationship between these two variables. It is parallel to Jaafar's (2015) tropical climate study in which air temperature and relative humidity were closely connected. This is because an increase in air temperature of surrounding improves the capacity to hold water vapors (Wong and Baldwin, 2016; Raji *et al.*, 2015; Chen *et al.*, 2013; Wong *et al.*, 2010) by the presence of plants; thus, increasing the percentage of relative humidity.

Plants naturally increase relative humidity levels through transpiration, which releases moisture into the air. The plant species in the LWS prevented the temperature from rising by increasing the environment's humidity, especially on hot days (Shafiee *et al.*, 2020). This means that the presence of the plants from the living wall system influenced the relative humidity level, as tabulated in Table 2. These findings showed each plant species has a different ability in thermal reduction. This illustrates that the heat radiation was absorbed by moisture and produced cooling effects on the surrounding environment. It is parallel to two studies from a tropical climate, namely, Taib *et al* (2019) and Charoenkit and Yiemwattana (2017), in which different plant species filtered different amounts of radiation due to their plant characteristics. Those studies identified the best plant species resulting in a greater reduction. Thus, in this study, *Philodendron burle-marxii* showed the best performer in reducing air temperature and relative humidity at the outdoor building of the industrial city of Pasir Gudang, Malaysia.

Conclusion

In summary, this study showed a strong relationship between air temperature and relative humidity from the modular living wall system at the outdoor building of Pasir Gudang. The best performer for air temperature reduction was *Philodendron burle-marxii,* with a decrease of 2.50 °C and contributing the highest relative humidity, 6.64%. The second-best performer was *Phyllanthus cochinchinensis,* with a decrease of 2.33 °C and it contributed relative humidity from the plant by as much as 6.72%. Meanwhile, *Nephrolepis exaltata* was the third-best performer in reducing air temperature, 1.56 °C. This means that the plant's lushness helped increase the relative humidity level to 4.23%. Lastly, *Cordyline fructicosa 'Miniature* was the plant species that achieved the lowest air temperature reduction with a 1.06 °C. This species also had the lowest relative humidity level of 2.19%. Therefore, air temperature reduction and relative humidity have a strong relationship to enhance the cooling effect at the outdoor building in Pasir Gudang.

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