Assessing the impact of indoor plants towards physical indoor office building environment in hot and humid climates

Norhayati Mahyuddin[1,2*], Nurul Malina Jamaludin[2], Aseel Hussien[3], Farid Wajdi Akashah[1,2], Nur Farhana Binti Azmi[1,2], Alison Cotgrave[4], Mike Riley[4]

[1]Department of Building Surveying, Faculty of Built Environment, University of Malaya, 50603 Kuala Lumpur, Malaysia
[2]Center for Building, Construction & Tropical Architecture (BuCTA), Faculty of Built Environment, University of Malaya, 50603 Kuala Lumpur, Malaysia
[3]Department of Architectural Engineering, University of Sarjah, Sharjah, U.A.E
[4]Department of the Built Environment, Faculty of Engineering and Technology, Liverpool John Moores University.

Corresponding author: hayati@um.edu.my

Published: 30 April 2022

Abstract

Several studies have shown that plants with a variety of performance categories can improve indoor air quality (IAQ). In addition, it has positive impacts on occupants' concentration ability, work efficiency, job satisfaction, mental health, stress reduction, and sense of well-being. However, there is few research that have focused on the impact of indoor plants towards physical indoor environment. Therefore, this study performs several experiments to examine the impacts of indoor plants on physical indoor environment in Malaysia. This study further observes the use of five different species of potted plants and its effects on the IAQ concerning the physical parameters of air temperature and relative humidity in a classroom and an office room setting environment. Moreover, this paper explores the function of plants as a natural air purifying agent and temperature regulation, as it helps to cool down the internal temperature of a building while providing areas of the building with an aesthetic element. This study involves the assessment of plant and indoor space benefit studies, as well as the description of plant varieties and characteristics. Finally, the overall findings from several experiments show significant differences in relative humidity and total target volatile organic compound (TVOC) in the room. With intervention, it can be concluded that the inclusion of potted plants in a room have improved all parameters measured compared with that in normal condition. For future works, it is proposed that further study is done on the form of species, including the importance of understanding the need for positioning the potted plants in indoor environments.

Keywords: *Indoor environment; indoor environmental quality; potted plants; plant species; relative humidity.*

1.0 INTRODUCTION

Numerous studies have found that plants in a variety of performance categories have a positive impact on people. For example, the appearance of attractive foliage has been found to improve the general impression of building environments, value, and quality. NASA's pioneering experiments in the 1980s have successfully shown that plants can eliminate the ambient concentration of numerous total volatile organic compounds (TVOCs); however, these results are based on a simplified experimental approach by Wolverton B.C., Mcdonald R.C. [1]. Typically, indoor plants are selected based on their aesthetic and attractive characteristics rather than functional criteria, which reflect their ability to remove air pollutants [2]. Moreover, indoor plants also oxygenate the atmosphere [3, 4], thus increasing the attractiveness of the environment [5].

Over several decades, the impacts of indoor plants on humans have been thoroughly studied. The results are mostly similar, where plants are observed to be useful in terms of task- or performance-related indicators (e.g., concentration ability, work efficiency, job satisfaction), health (e.g., mental/happiness or stress reduction), and sense of well-being. With regard to job- and performance-related indicators, Lohr, Pearson-Mims [6] conducted an experiment involving reaction-time measurement, in which it was found that the reaction times were 12% quicker when participants were introduced to indoor plants, suggesting that indoor plants could improve the efficiency of office workers in a windowless environment. In a more recent study on windowless underground environment, indoor plants were found to improve perceptions along the semantic differential scales “Artificial–Natural”, “Unsuitable for a task–Suitable for a task” and “Monotonous–Diverse”; hence, it is deemed to be able to reduce the response time in the task given [7].

Additionally, when a cross-sectional study of 385 Norwegian office workers was conducted by Bringslimark, Hartig [8], the numbers of plants placed close to each worker were found to be negatively correlated with sick leaves and positively associated with increased productivity. In a controlled laboratory experiment, the focus ability of the participants with respect to the plant condition is seen to increase, showing a positive relationship between indoor plants and job-related measures [9], as well as level of job satisfaction [10].

In relation to health, Dijkstra, Pieterse [5] conducted an experiment involving indoor plants portraying a picture of an outdoor landscape in an artificial window, and found the indoor plants managed to lower the stress level. In another hospital setting, Park and Mattson [11] observed that both flowering and foliage plants improved pain tolerance for patients following treatment, suggesting that plants could be a cost-effective and efficient in healing process. In addition, Whear, Coon [12] did a study on dementia-related behaviours in response to time in a garden or engaged in horticultural activities from at least 17 research findings. It was found that rehabilitation services in parks with walking trails, non-toxic trees and shrubs, grass fields, raised beds, gazebos, fish ponds, and benches could reduce anxiety. Dementia, fall reduction, and functional ability with elderly populations were also reported to improve after greenspace interventions were carried out [13]. Apart from research in hospital settings, numerous experiments of office environments have been performed with regard to indoor plants. For example, in the reduction of neuropsychological and mucous membrane symptoms, Fjeld T. [14] found that foliage plants in the office environment help in increasing the health of employees.

The ability to function physically is a key indicator of any person to perform daily activities, not only of elderly population [15, 16], but also with the younger generation [17, 18]. The relationship between physical activity levels and executive control functioning (i.e., those processes involving working memory, inhibition, and mental flexibility) was seen to be highly significant [17], leading to productivity and comfort in an indoor environment. Research on the direct and indirect effects of indoor performance on the productivity of its occupants can be traced back to the 1930s when Vernon and Bedford [19] and Maslow [20] published their work on the environment and needs of the workplace. To date, there are still many researches highlighting on the influence of the physical indoor environment on the productivity of its occupants in the workplace environment. Various methods were established to enhance productivity [21], happiness [22], health and well-being [23, 24], thermal comfort [25, 26], visual comfort [27, 28], energy savings [29, 30], and indoor air quality [31, 32], among others. However, studies on the effect of indoor plants towards the physical indoor environment are still very limited.

2.0 BACKGROUND

Plants can improve indoor air quality (IAQ) by continuously removing carbon dioxide (CO_2) and releasing oxygen (O_2) via light-dependant photosynthesis and by increasing air humidity by water vapour from the leaves through microscopic pores of the leaf called stomata. [33]. A more reliable experiments by Fares, Paoletti [34] simulating long-term foliage exposure to typical indoor air pollutant concentrations have shown that stomatal (dependent) absorption is 30–100 times higher than that passively adsorbed through non-stomatal deposition. Plants are highly recommended for indoor workplace emissions control for refreshments, aesthetic enhancement, and emotional assistance for indoor users. The selection of pollution sensitive plants is recommended as the early warning system to indicate indoor air pollutions with the purpose of keeping the user safe from Sick Building Syndrome (SBS).

Potted plants are able to reduce dust levels [35], stabilise humidity and temperature, and lower noise levels [36]. There is also a growing body of evidence that show the direct measured benefits to the health and well-being of building occupants, which seemed to be the result of the capacity of pot-plants to produce cleaner air [37, 38], as well as their ability to provide feelings of pleasure, calm, and relief from attention fatigue [39]. Most of the reviewed studies found that the presence of plant in the building had a positive effect on the occupant. Conducted a one-week room test to measure the signs of well-being and discomfort among 120 junior high school students with three interventions in three standard classrooms [40]. The study result found a lower mean score of 21% for health symptoms in plant-based classrooms, while a more positive evaluation describing it as more beautiful, brighter, and more comfortable. In addition, Shibata and Suzuki [41] performed a randomised study with repeated tests on a total of 70 students under a simulated office environment without windows and found that there is a higher response rate with plants and no major mood or fatigue effects were detected in a room with plants.

Another study by Khan, Younis [4] adopted and measured a method using quasi-experiment with a single post-test on a total of 222 Master's and graduate students, as well as 28 teachers at a college, by introducing potted plants in the classrooms of the college. Based on the findings, majority reported that the plants had helped to improve air quality, increase pleasantness, and enhance their performance. Other than that, a study conducted by Burchett et al. (2011) demonstrated potential contributions of several indoor plant species to lower CO_2 indoor levels. The results found that this situation normally occurred in workplace with low light intensity. This low efficiency in CO_2 removal resulted in the breathing of non-green plant tissues and the potting mix of microorganisms producing CO_2 emissions that counterbalanced leaf uptake in order to achieve no net CO_2 reduction. The light intensity was suggested to be increased together with the reduction of potting mix microorganisms for potted plants to be a viable instrument in reducing indoor CO_2 loads. In addition to reducing potting mix microorganisms for potted plants, it was recommended that the light frequency be increased as a feasible method for reducing indoor CO_2 loads. Furthermore, indoor plants with Taiwanese junior high school students have been shown to be effective in terms of hours of sick leave and misbehaviour (e.g., punishment record) [42]. In this study, six plants were placed at the back of the classroom, and the finding shows immediate, significant, and stronger feelings of preference, comfort, and friendliness, compared with that of the control group.

The selection of plants in a building to mitigate air pollution depends not only on their ability to clean the air, but also on their growth habit, their ease of growing and maintaining, and their light requirements. Plants are thought to have a profound influence on the psychological well-being and serenity of the people in the building. In addition, it has been shown that plants have a measurable beneficial effect on individuals in living and working spaces. The presence of plants in the workplace has documented numerous benefits, including improved employee morale, increased productivity, and reduced absenteeism. Research has found that, in addition to plants bringing charm to a room and making it an attractive place to live or work, people tend to feel relaxed and calm when they are close to the plants. For indoor elimination of air pollution, many foliage plants have been shown to reduce volatile organic compounds (TVOCs) [37, 43-45], particulate matter [46, 47], ozone [48], carbon dioxide [49, 50], carbon monoxide, and nitrogen dioxide [51]. On the contrary, Priyamvada, Priyanka [52] found that human occupancy and potted plants are the main contributors to the high concentrations of indoor bacteria (> 800 CFU m^{-3}). Fine-to-coarse bioaerosol fractions implied the abundant presence of coarse mode bacteria and fungi representing more than 80% of the total cultivable bioaerosol load across all sites. *Bacilli* and *Gammaproteobacteria* dominated the bacterial aerosols, while *Cladosporium* and *Aspergillus* dominated the fungal aerosols.

Hence, not all plant species have been proven to be equally effective and it cannot be concluded that all indoor plants can remove harmful pollutants. The table below summarises the characteristics used in previous studies on the selection of indoor plants. According to the information provided in Table 1.0, two family plant species known as Araceae and Asparagaceae are mostly used and justified.

Table 1.0 List of family plant species.

Species of plants	A	B	C	D	E	F	TVOC Removal	Reference
Acanthaceae	√	√	√				Benzene, octane, α pinene, toluene, trichloroethylene	Kim, Yoo [53], Kim, Cha [7], Yang, Pennisi [54], Yoo, Kwon [55]
Apocynaceae		√	√				Formaldehyde, Toluene, Trichloroethylene, Tetrachloroethylene, Benzene, octane, α-pinene	Kim Kwang Jin. and Kim Hyoung Deug. [56], Kim, Kil [57] Kim K., Jeong M. [58], Kim, Yoo [53], Kondo, Hasegawa [59] Yang, Pennisi [54]
Aquifoliaceae		√	√			√	Toluene	Kim, Yoo [53], Sriprapat, Suksabye [45]
Araceae	√	√	√	√	√	√	Formaldehyde, acetone, xylene, benzene, toluene	Aydogan and Montoya [60], Baosheng, Shibata [61], Kim Kwang Jin. and Kim Hyoung Deug. [56], Kim, Kil [57] Orwell, Wood [43], Oyabu, Onodera [62], Oyabu, Sawada [38], Sawada, Yoshida [63], Sawada and Oyabu [64], Tani and Hewitt [65], Tani, Kato [66], Treesubsuntorn and Thiravetyan [44], Xu, Wang [67], Yang, Pennisi [54], Chun, Yoo [68], Wolverton B.C., Mcdonald R.C. [1], Wolverton B. C. and Wolverton J. D. [69], Zhou, Qin [70], Orwell Ralph L, Wood Ronald A [71],
Araliaceae	√	√	√				Formaldehyde, toluene, xylene	Aydogan and Montoya [60], Wolverton B. C. and Wolverton J. D. [69], Wolverton B.C., Mcdonald R.C. [1]

Asparagaceae	√	√	√	√	√	√	Formaldehyde, benzene, xylene, Toluene, m-xylene,	Kim Kwang Jin. and Kim Hyoung Deug. [56], Oyabu, Sawada [38], Themanson, Pontifex [18], Wolverton B.C., Mcdonald R.C. [1], Wolverton B. C. and Wolverton J. D. [69], Yang, Pennisi [54], Zhou, Qin [70], Orwell, Wood [43], Orwell Ralph L, Wood Ronald A [71], Godish and Guindon [72]
Asphodelaceae	√	√	√		√	√	Formaldehyde, xylene, Benzene, trichloroethylene	Wolverton B. C. and Wolverton J. D. [69], Wolverton B.C., Mcdonald R.C. [1], Xu, Wang [67]
Asteraceae	√	√	√		√		Formaldehyde, benzene, trichloroethylene, toluene, xylene	Aydogan and Montoya [60], Liu, Mu [73], Wolverton B. C. and Wolverton J. D. [69], Wolverton B.C., Mcdonald R.C. [1], Kim, Yoo [53], Wood, Orwell [74]
Begoniaceae	√	√	√		√	√	Toluene	Kim, Yoo [53], Kim and de Dear [75]
Bromeliaceae			√			√	Formaldehyde, xylene, Benzene, octane, α-pinene, toluene, trichloroethylene	Wolverton B. C. and Wolverton J. D. [69], Yang, Pennisi [54],
Commelinaceae	√	√			√	√	Benzene, pentane, toluene	Yang, Pennisi [54], Yoo, Kwon [55]
Convolvulaceae	√	√	√			√	Formaldehyde	Wolverton B.C., Mcdonald R.C. [1],
Crassulaceae		√		√	√	√	Benzene, pentane, toluene	Cornejo, Muñoz [76]
Davalliaceae	√		√			√	Toluene	Kim, Yoo [53]
Ericaceae	√	√	√		√	√	Toluene, Formaldehyde, xylene	De Kempeneer, Sercu [77], Wolverton B. C. and Wolverton J. D. [69], Kim, Yoo [53]
Euphorbiaceae	√	√	√			√	Formaldehyde, xylene, Benzene, octane, α-pinene, toluene, trichloroethylene	Wolverton B. C. and Wolverton J. D. [69], Yang, Pennisi [54],
Fern	√		√	√		√	Formaldehyde, benzene, xylene	Oyabu, Sawada [38], Wolverton B. C. and Wolverton J. D. [69], Liu, Mu [73], Barboni, Leonelli [78]
Geraniaceae	√	√	√		√	√	Benzene, pentane, toluene, octane, α-pinene, toluene, trichloroethylene	Kim, Yoo [53], Cornejo, Muñoz [76] Yang, Pennisi [54]
Herbaceous	√	√	√		√		Formaldehyde, xylene, benzene, toluene	Wolverton B. C. and Wolverton J. D. [69], Yang, Pennisi [54], Zhou, Qin [70],
Hydrangeaceae	√	√	√		√		Benzene	Liu, Mu [73]
Lamiaceae	√	√	√		√		Formaldehyde, Toluene	Kim, Yoo [53]
Lauraceae		√	√				Toluene	Kim, Yoo [53]
Liliaceae		√	√		√		Formaldehyde, xylene	Wolverton B. C. and Wolverton J. D. [69], Zhou, Qin [70],
Malvaceae		√	√		√		Benzene, toluene, m/p-xylene, o-xylene	Chun, Yoo [68]
Marantaceae	√	√	√				Benzene, octane, α-pinene, toluene, trichloroethylene	Yang, Pennisi [54]

Moracae			√				Formaldehyde, xylene, benzene	Kim, Kil [79], Wolverton B. C. and Wolverton J. D. [69], Wolverton B.C., Mcdonald R.C. [1], Yang, Pennisi [54]
Musaceae			√				Benzene, formaldehyde, trichloroethylene	Wolverton B.C., Mcdonald R.C. [1],
Oleaceae		√	√				Toluene	Kim, Yoo [53]
Orchidaceae	√	√	√		√		Formaldehyde, Benzene, xylene	Kim Kwang Jin. and Kim Hyoung Deug. [56]. Liu, Mu [73], Wolverton B. C. and Wolverton J. D. [69]
Pentaphylacaceae			√				Toluene	Kim, Yoo [53]
Pinaceae		√					Toluene	Kim, Yoo [53]
Piperaceae			√	√			Benzene, octane, α-pinene, toluene, trichloroethylene	Yang, Pennisi [54]
Pittosporaceae		√	√				Toluene	Kim, Yoo [53]
Primulaceae	√	√	√				Benzene,pentane,toluene, formaldehyde, xylene	Cornejo, Muñoz [76], Kim Kwang Jin. and Kim Hyoung Deug. [56], Kim, Yoo [53], Wolverton B. C. and Wolverton J. D. [69]
Rubiaceae		√	√		√		Formaldehyde, Benzene	Treesubsuntorn and Thiravetyan [44], Kim, Kil [57]
Ruscaceae		√	√	√	√		Formaldehyde, Benzene	Treesubsuntorn and Thiravetyan [44], Zhou, Qin [70],
Rutaceae		√	√		√		Benzene	Liu, Mu [73]
Saxifragaceae	√	√	√		√		Benzene, pentane, toluene	Cornejo, Muñoz [76]
Solanaceae		√	√		√		Benzene, chloroform, perchloroethylene, toluene, trichloroethylene, vinyl chloride, Formaldehyde, styrene, xylene	Sawada and Oyabu [64]
Urticaceae	√	√	√				Toluene	Kim, Yoo [53]
Verbenaceae	√	√	√		√		Toluene	Kim, Yoo [53]
Vitaceae	√		√				Formaldehyde, xylene, Benzene	Yoo, Kwon [55], Wolverton B. C. and Wolverton J. D. [69]

Note: A: Non-woody foliage stem; B: Aesthetic effect: conspicuous and attractive flower; C: Climatic suitability (especially suitable in tropic climate); D: Minimum care: Low water and sun requirement; E: Growth pattern: household plants, not climbing; F: Height and spread: (prefer plants that are not too big and tall); G: TVOC removal.

3.0 MATERIALS AND METHODS

3.1. Study area

Malaysia is located between latitude 1°N and 7°N and longitude 0° and 119°E in the equatorial region of Southeast Asia. The climate is described as hot and humid with minor temperature fluctuations throughout the year. The Köppen-Geiger climate classification of this region is an Af, Tropical Rainforest climate. The region is also characterised by heavy rains during monsoon seasons. A study of the Malaysian climate by Mahmud, M [80] shows the average wind speed is less than 1.5 m/s throughout the year. This confirms that light winds and calm conditions occur across all states in the region, including Kuala Lumpur, for approximately 40% of the time in a year.

Although Malaysia does not experience extreme temperatures, the temperature is relatively high all year round. This is mainly due to its insularity and moderate relief. All parts of the country are within 80 miles of the sea and the entire country is permanently bathed in the warm moist tropical maritime air. In general, the temperature seldom rises above 36°C or falls below 20°C. The annual mean temperature varies between 1°C–3°C of the mean shade air temperature of 27°C. Another specification of the Malaysian climate is the high relative humidity rate throughout the day and night with an average annual mean relative humidity of 85%. However, the trend of humidity change is reversed when compared to the trend of temperature change, as the relative humidity during the day is lower than that at night. During the day, the relative humidity varies between 55% and 70%, whereas at night, it rises above 95%, which often leads to evaporation and makes sleeping difficult.

Daghigh R. , Adam [81] investigated the thermal comfort range of eleven air-conditioned offices in Malaysia. The results showed that the comfort range for these building types ranged from 20.8°C to 28.6°C. An overview of the research on thermal comfort range in office buildings in tropical climates reveals that the upper limit of the comfort range fluctuates between 27.5°C and 28.6°C for air-conditioned offices in Malaysia [82], and 30.5°C for naturally ventilated and air-conditioned office spaces in Bangkok [83]. The unsatisfactory of thermal comfort proportionately linked to the condition of the IAQ in Malaysian's indoor environment. Air Movement, Ventilation, and Freshness were seen to be of poor quality due to the high occupancy density in classrooms [84]. Relative humidity in Malaysia generally decreases with higher air temperature. This means that the relative humidity is low when the air temperature is high, but the thermal sensation of the occupants increases because the air temperature has more effect on the thermal sensation of the occupant rather than the effect of relative humidity. The IAQ in classrooms is also often seen to be inadequate and often much worse than in office buildings. One of the main reasons for this difference is that occupancy in classrooms is generally denser.

3.2 Initial study on indoor environment intervention with potted plants

A classroom setting with an intervention was carried out with four small potted plants placed at each four corners of the classroom. Prior to this intervention, measurement on the physical parameters, i.e., indoor and outdoor air temperature, relative humidity and air velocity were taken. Total Volatile Organic Compound (TVOC) and CO_2 were also monitored. Three poles holding devices for the physical parameter's measurement were located in the middle (Pole C) and at the back (Poles A and B) of the classroom at the height of 1.1 m. A device measuring both TVOC and CO_2 was located in the middle of the class at the same height devices at Pole C. Based on the experimental setup in this classroom carried out by Jamaludin, Mahyuddin [85], several parameters were seen to be improved significantly when the intervention was introduced.

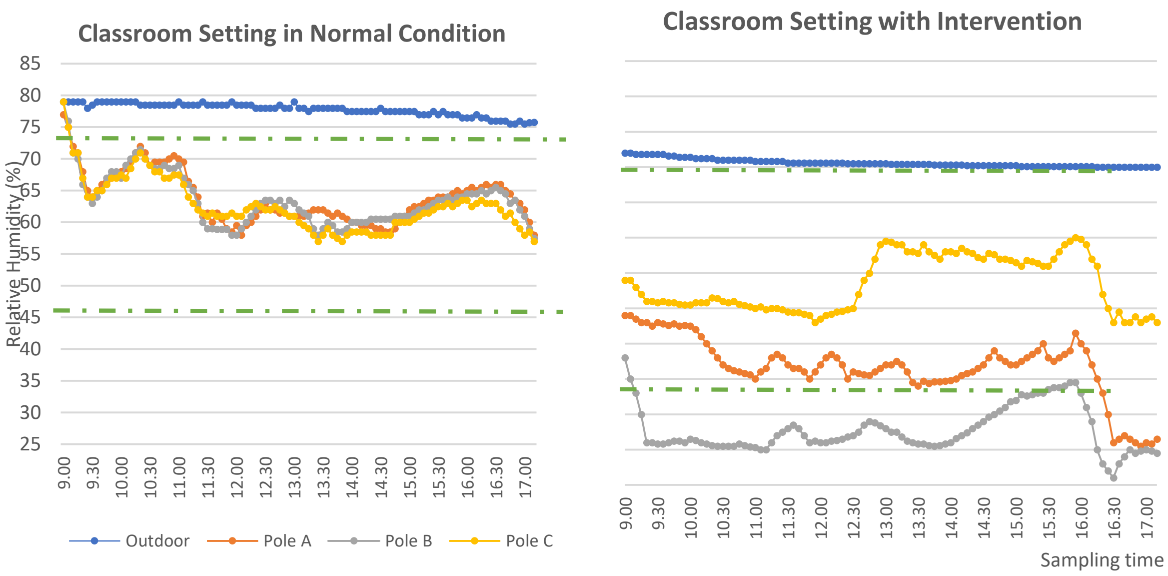

Figure 1.0. Comparison of relative humidity in a classroom in a normal classroom and that with intervention.

The comparison of relative humidity between normal condition and the intervention in Figure 1.0 shows that the relative humidity level has dropped quite substantially when plants were placed in the classroom. It can be noted that the level of RH measured at Pole C (middle of the classroom) has similar pattern of distribution in both situations. However, readings in both Poles A and B, which are located near to the potted plants, were seen to be declining throughout the measuring period. The level of relative humidity at Pole B appears to be below the recommended threshold limit value set by DOSH and Malaysian Standard, as listed in Table 1.0. The US EPA recommends maintaining indoor relative humidity between 30% and 60% [86], while ASHRAE Standard 62.1-2016 [87] recommends that relative humidity in occupied spaces be controlled to less than 65% to reduce the likelihood of conditions that can lead to microbial growth. High humidity environment can also affect the perceptibility of air quality [88] and induce mould growth, leading to breathing discomfort and allergies [89, 90]. Low humidity environment below 30% RH, on the other hand, is associated with skin and throat dryness, mucous membrane, sensory irritation of eyes [91-93], as well as static electricity [94].

Table 1.0: Recommended relative humidity parameter in an air-conditioned space for comfort cooling.

Standard	ASHRAE standard [87]	DOSH (ICOP IAQ) - 2010 [95]	Malaysia Standard (MS 1525) - 2014 [96]
Relative Humidity (RH)	40%–60%	40%–70%	50%–70%

The overall findings from this experiment demonstrate significant differences in the relative humidity and the TVOC in the classroom with intervention, as recorded in Table 2.0. It can be concluded that the presence of potted plants in the classroom has improved all parameters measured, compared with normal condition i.e., with no potted plants. Although the outdoor environment could not be controlled, but in relation to the indoor-outdoor ratio, the intervention classroom is of better quality. Owing to the significant decline in the relative humidity readings, it is observed that the number of potted plants placed in an enclosed environment could possibly be the main cause. In addition to this, another possible argument is that the temperature during the test day with intervention was higher than the normal condition test day with approximately 2°C and 4°C temperature differences indoor and outdoor, respectively. For a classroom with high temperature, i.e., hot, there is a possibility that vapour is absorbed by the soil from the potted plants. Moreover, air movement was also found to be almost stagnant within the classroom [85], which reduces the level of relative humidity significantly. Hence, further investigation was carried out to further justify the results of fluctuations in RH when potted plant was used this study.

Table 2.0 Summary of measurement results in both normal and intervened classrooms

Parameters	Average value (9.00 a.m. to 5.00 p.m.)					
	Temperature (°C)		Relative Humidity (%)		Carbon Dioxide (ppm)	TVOC (ppm)
	Outdoor	Indoor	Outdoor	Indoor	9.00 a.m. to 5.00 p.m.	
Normal Classroom	28.3	27.9	76.4	61.6	1084	11.7
Intervention Setting	33.3	29.7	71.5	43.8	781.89	1.5

3.3 Case study

This study aims to investigate the indoor air quality of an office room with potted plants. The quantity and the selection of indoor plants species will be carried to elaborate further on the suitability of having potted plants in an indoor environment with regard to the reduction of TVOC, as well as the air temperature and relative humidity. In this study, an air freshener is used as the intermediate material (sources of TVOC) for an intervention setting (simulated office setting). The office selected for the purpose of this study is located in Kuala Lumpur, and the area of the room is 4.5 × 4.03 m, as shown in Figure 2.0. The room mainly consisted of wooden furniture, which included desks cabinets and chairs. The room was ventilated by a single unit air-conditioning and glazing window along one side of the walls. For the purpose of this study, the room was unoccupied throughout the experiment in order to monitor the decay of the air freshener that was sprayed at constant interval rate.

Fieldwork measurement method is adopted in this research using several devices for the purpose of data collection. The indoor air quality (IAQ) device, YESAIR and YESDUST is used to measure carbon dioxide (CO_2), Total Volatile Organic Compounds (TVOC), and Particulate Matters (PM_{10}). YESAIR is an equipment used to measure the indoor air quality, as well as the temperature. It functions as a portable information recording device, which is designed for the purpose of intermittent or continuous operation.

Consequently, HOBO data logger is used to monitor the air temperature, relative humidity (RH), and air velocity with an interval of 5 minutes from 9.00 a.m. to 5.00 p.m. to ascertain the indoor thermal performance and ventilation effectiveness. Meanwhile, the measurements of the outdoor environmental condition will be based at the Kuala Lumpur meteorological weather data station. Table 3.0 illustrates the specification of all devices used.

Table 3.0: Measured variables and equipment

Instrument	Variable	Measurement range	Accuracy
YESAIR AND YESDUST	Temperature	–5°C–55°C	0.1°C @ 25°C
	Relative Humidity	0%–100%	2%RH
	Carbon Dioxide (CO_2)	0–5000 ppm	+2% full scale @ 20°C (68°F), 1 bar pressure, applied gas, 2.5% volume CO_2
	Total Volatile Organic Compound (TVOC)	0–30 ppm	0.02 ppm
	PM_{10}	1–10 microns	250 particulate/ cubic foot
Hobo Data Logger	Temperature	Range: –20° to 70°C (–4° to 158°F) Resolution: 0.03°C at 25°C (0.05°F at 77°F)	± 0.35°C from 0° to 50°C (± 0.63°F from 32° to 122°F)
	Relative Humidity	Range: 5% to 95% RH Resolution: 0.05% RH	± 2.5% from 10% to 90% RH
HOBO air velocity	Air velocity	Range: 0.15–5 m/s	Greater of 10% of reading or +/– 0.05 m/s or 1% full-scale

3.4 Selection of indoor plants

Table 4.0 shows the 9-month old specimens of the selected indoor plants that were used in a standard potting mix, which consisted of composed earth, composed coarse river sand, and fertiliser. Five selected plants with the same condition, i.e., similar type of pot, soil, and fertiliser, were used to avoid unstable figure in order to carry out precise measurement. Table 4.0 below shows the comparison of each selected plant with respect to their characteristics. The five types of indoor plants were selected based on the most cited family species of Araceae and Asparagaceae, as mentioned earlier in this paper. Figure 2.0 illustrates the picture of each plant.

Table 4.0: Characteristics of the selected indoor plants

NAME OF PLANT	Characteristics			
	Family	Type	Height (m)	Spread (m)
GOLDEN PHOTOS (***Epipremnum Aureum***)	Araceae	Vine	0.29	0.26
PEACE LILY ***(Syngonium podophyllum)***	Araceae	Vine	0.33	0.24
SWEET CHICO ***(Spathiphyllum)***	Araceae	Herbaceous Perennial	0.38	0.24
SPIDER PLANT (***Chlorophytum comosum***)	Asparagaceae	Herbaceous Perennial	0.25	0.30
JANET CRAIG (***Dracaena eremensis***)	Asparagaceae	Shrub	0.27	0.22

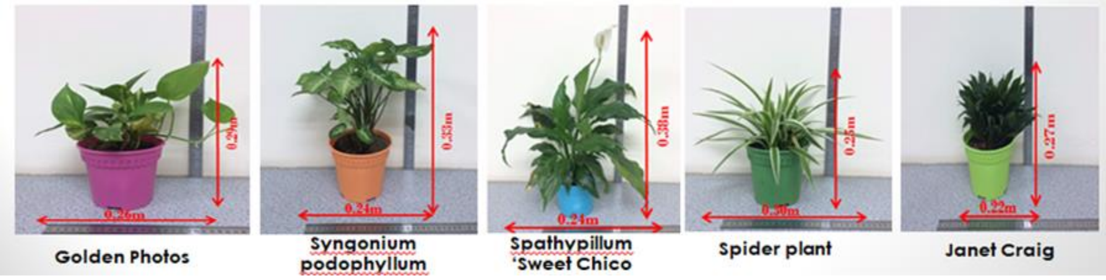

Figure 2.0. Different types of plant characteristics

3.5 Experimental design

Continuous fieldwork monitoring will be carried out in a controlled environment with several cases applied. The first case is normal condition without any plants, named as C1; the remaining cases are with the intervention of potted plants in the room. With the intervention cases, there will be two phases, where Phase 1 involves the selection of indoor plants and Phase 2 further investigates on the quantifying of number of potted plants suitable for a space. Table 5.0 demonstrates a list of cases carried out in this study (Table 5.0). In order to monitor the decay of TVOCs in the room, an air freshener (chemical solvent of ethanol 99.99% purity of phenol, benzene, and hexanediol) packed in a non-pressurised finger operated spray bottle was used to elevate the level of TVOCs before decay measurements were taken. A number of 60 shots were injected into the room continuously to produce approximately 4.0 ppm concentration of TVOCs.

Table 5.0. List of cases for experimental design.

<table>
<tr><td colspan="7">Phase 1</td></tr>
<tr><td>Indoor setting</td><td colspan="6">Normal condition of an office room without air-conditioning with 60 shots of TVOCs</td></tr>
<tr><td>Cases (C)</td><td>Control</td><td>C1</td><td>C2</td><td>C3</td><td>C4</td><td>C5</td></tr>
<tr><td>Plant species</td><td>No plant</td><td>Golden Photos</td><td>Syngonium podophyllum</td><td>Peace Lily/Sweet Chico</td><td>Spider Plant</td><td>Janet Craig</td></tr>
<tr><td colspan="7">Phase 2</td></tr>
<tr><td>Indoor setting</td><td colspan="6">Normal condition of an office room without air-conditioning</td></tr>
<tr><td rowspan="2">Number of potted plants identified from Phase 1</td><td colspan="2">Pot 1</td><td colspan="2">Pot 2</td><td>Pot 3</td><td>Pot 4</td></tr>
<tr><td colspan="2">1 pot</td><td colspan="2">2 pots</td><td>3 pots</td><td>4 pots</td></tr>
</table>

In Phase 1, two pots of each species will be placed in the centre of the office on each of the test day, as illustrated in Figure 3.0. Instruments (YESAIR and YESDUST) and Graywolf probe sensors were placed at a height of 1.1 m from the ground for the purpose of simulating the working height of an occupant seated on a chair. In Phase 2, the quantity of the potted plant will be changed each test day from 1 pot to 4 pots, as illustrated in Figure 4.0. At this point, the levels of TVOCs and relative humidity were monitored to evaluate the effectiveness of TVOC decay and to prevent any excessive moisture content in the air.

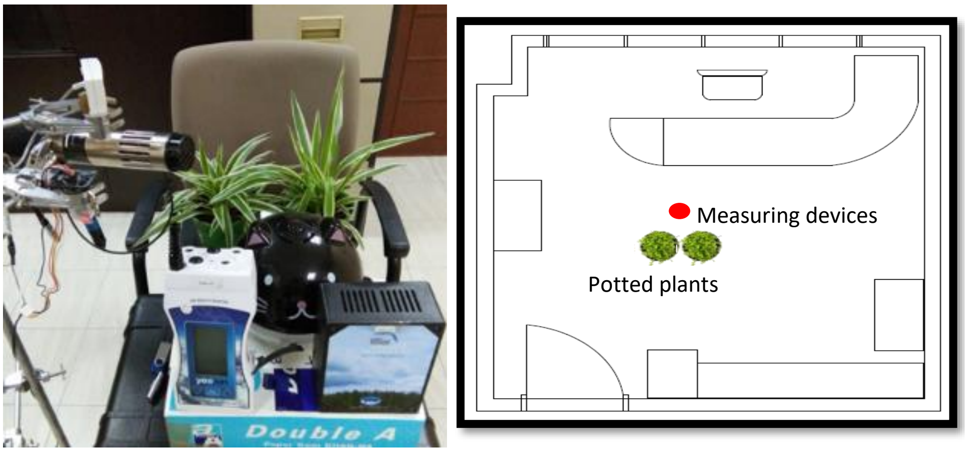

Figure 3.0. Experimental setup in an office with two potted plants and measuring device.

(a)

(b)

Figure 4.0. Example of: (a) two potted plants; and (b) three potted plants in Phase 2 experimental setup.

4.0 RESULTS AND DISCUSSION

4.1 Phase 1 – Selecting indoor plant species

In Phase 1, five species of potted plants were monitored to study on its effect on the indoor environment. Concerning the physical parameters of air temperature and relative humidity, the indoor and outdoor (I/O) ratios were monitored. Since Malaysia is a hot and humid country, the external environment is always higher than the indoor environment at most of the time especially during the day. Therefore, the differences will be calculated using outdoor-to-indoor (O/I) ratio, leading to lower air temperature and relative humidity in the indoor environment if it is a positive value. Figure 5.0 illustrates the comparative studies on the O/I ratio of temperatures in different cases (i.e., different potted plant species).

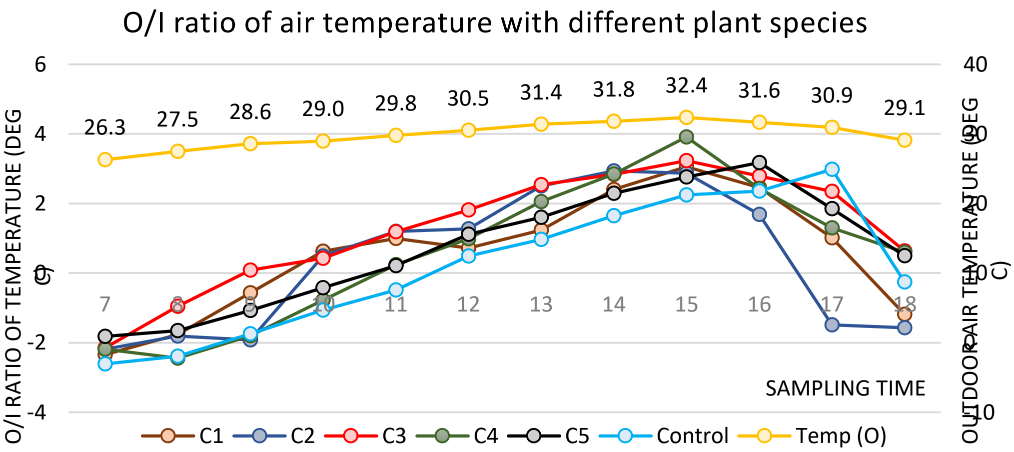

Figure 5.0. Comparison of air temperature differences among different types of plant species.

Based on the Figure 5.0, C3 Sweet Chico or better known as Peace Lily consistently improved the indoor thermal condition, as compared with other species. This can be observed in the red line that demonstrates higher ratio value, indicating high temperature differences based on an indoor-outdoor environment. The O/I ratio pattern in C5 (Janet Craig plant) was be observed to be similar with that in C3 but with slightly lower differences. On the other hand, both C1 (Golden Photos) and C2 (*Syngonium podophyllum*) appeared to have similar fluctuation pattern with temperature differences throughout the day. The highest indoor-outdoor difference can be seen in C4 (Spider plant) at 15.00 due to the increase of outdoor temperature (32.9°C), while the rest of the results in this case were at the lower range. Based on Figure 5.0, most of the results shows a decline after 14:00, where the outdoor temperature decreased and three cases (C1, C2, and Control) were observed to experience higher indoor temperature (negative results in the ratio).

The insert of outdoor temperature (data taken from one of the test days) illustrates the trend of typical outdoor temperature (with no rainfall) throughout the day. Therefore, if the indoor environment setting could maintain or is able to have a substantial difference between indoor and outdoor, extensive energy consumption in terms of cooling the indoor space further may not be needed. This can be seen in the test day during normal condition (control-chart line in brown), the difference of O/I ratio is minimal compared with the rest of the cases, indicating that the indoor and outdoor temperatures are almost similar.

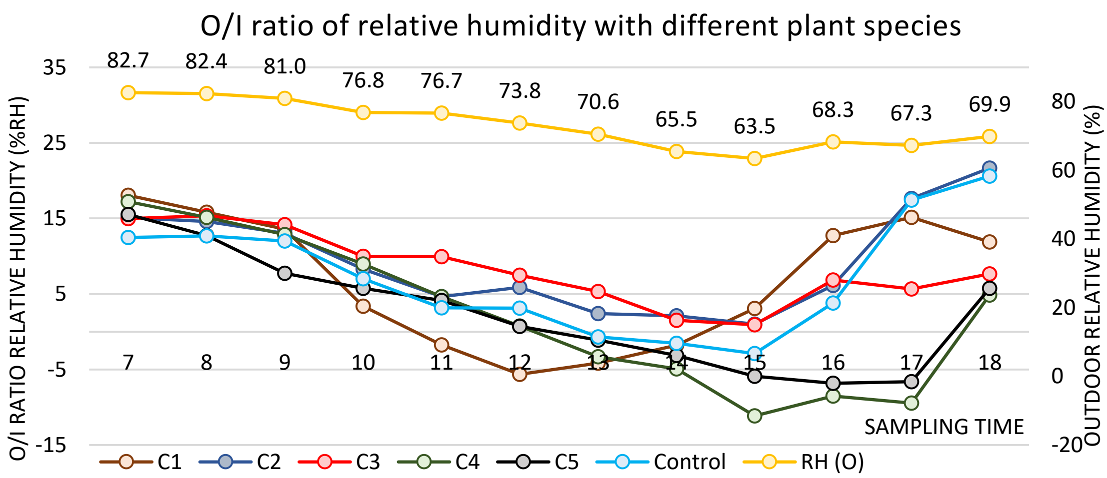

Figure 6.0. Comparison of air temperature differences among different types of plant species.

Corresponding to the findings in Figure 5.0, C3 (Peace Lily plant) consistently marked higher O/I ratio of relative humidity, preserving lower indoor relative humidity level throughout the day (see Figure 6.0). The control environment without any plants showed lower O/I ratio result throughout the day, except at the end of the day when the temperature drops and outdoor relative humidity rise similar to C2. Most cases have low ratio during midday and afternoon between 13:00 and 14:00 when the temperature is increasing, causing marginal ratio of indoor-outdoor relative humidity. In all cases except for C3 and C2, the indoor relative humidity is observed to be higher than that of the outdoor. When the temperature increases, the plant itself tends to cool the surrounding by releasing vapour through the opening of the stomata. Similar trend lines of O/I ratio can be seen in C2, C3, and C4, with bigger margin throughout the day, as compared with other species (Figure 4.0). The O/I pattern (brown line) in the control setting appeared to be in line with that of C2, C3, and C4 but with low difference in the ratio.

Conversely, the O/I ratio was observed to have low variation of indoor-outdoor relative humidity. The insert of outdoor relative humidity (yellow line) measurement throughout the day shows the inversed pattern to that of outdoor air temperature in Figure 3.0, which supported the earlier statement by [15] that higher temperature will lead to a stronger cooling effect. However, at this juncture, the role of plants in indoor environment remains unclear. It is a fact that water will continuously evaporating from the surface of leaf cells exposed to air, which gives a cooling effect to the indoor environment when the surrounding temperature increases, but the number of plants needed to be determined so that the indoor relative humidity will not go beyond the recommended threshold value.

Table 6.0. Rate of TVOC decay in different plant species.

SAMPLING DURATION	0	100	200	300	400	500	AVG. REMOVAL RATE OF TVOC PER MINUTE
CONTROL CONDITION (PPM)	4.04	2.32	1.8	1.46	1.25	1.1	0.009
C1 (PPM)	4.28	2.49	1.93	1.30	0.94	0.67	0.0128
C2 (PPM)	4.05	1.94	1.44	1.06	0.8	0.65	0.0116
C3 (PPM)	4.28	1.92	1.32	0.96	0.68	0.59	**0.0132**
C4 (PPM)	4.24	1.9	1.3	0.96	0.75	0.60	0.0129
C5 (PPM)	4.19	1.84	1.36	1.00	0.81	0.69	0.0127

In Phase 1, TVOCs, which acts as the source of pollutant in the office, were sprayed constantly and the decay throughout the day were monitored in each case. Table 6.0 shows the distribution of TVOC in a room for 500 minutes. The decay in each case can be seen instantly at 100 minutes and gradually decreases at different rate for each case. The highest average of TVOC removal rate per minute was C3 with Peace Lily plant, followed by C4, C1, C5, and C2. The TVOC decay in the control room was the lowest, which further verifies the effectiveness of plants in removing TVOC although not extensively.

4.2 Phase 2 – Quantifying number of potted plants

Following the findings in Phase 1, Sweet Chico or better known as Peace Lily species that was placed in an office (Case C3) was found to be the most effective plant in improving the indoor environment of the office. Hence, this plant is used to further investigate on the number of potted plants required in a room to obtain better air quality. Similar method of analysis used in Phase 1 was used in this phase. Table 7.0 shows the variation of indoor-outdoor relative humidity with different quantity of potted plants.

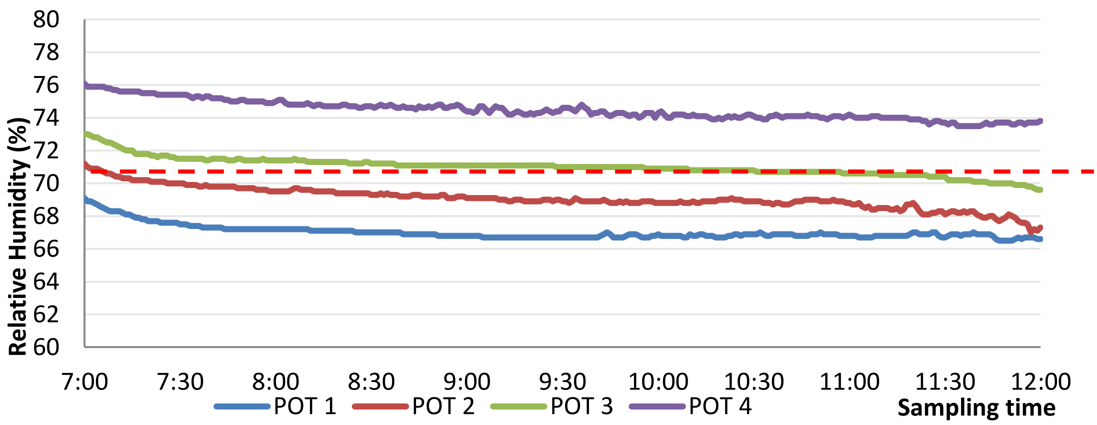

Figure 7.0. Relative humidity in the office with varying quantity of potted plants.

As illustrated in Figure 7.0, the distribution of relative humidity throughout the sampling duration shows a correlation between the value of relative humidity with the number of potted plants in the office. More plants in a room increases the level of humidity. Pot 3 and Pot 4 were observed to upraise the level of relative humidity in the room reaching to a level above recommended threshold value. Corresponding to the size of the test room area of 18 m^2, it is recommended that not more than two pots can be in a room at one time to prevent further inclination of humidity, which could create discomfort to the user, thus leading to the formation of mould and fungus. However, this result contradicts the results obtained in the initial study, where relative humidity dropped significantly when the plants were placed in a classroom.

Consequently, it can be concluded that the low relative humidity in the classroom at that point of study could be attributable to the supply of dry air into the classroom via the air-conditioning system. It was also noted that although there were 2 air-conditioning system operated in the classroom, the air temperature was still very high (29.7°C), in addition to the very low air movement (< 0.14 m/s) creating the room even more dryer. Hence, the assumption that the low relative humidity may be due to the existence of potted plants is erroneous. Nevertheless, if the number of plants in that classroom were to increase, the relative humidity could possibly affect the indoor environment. The justification to this statement is that the potted plants used in the classroom were one size smaller than the potted plants used in this study. Furthermore, as recommended in the results of this study, two potted plants were proposed for a room size of < 20 m^2. Therefore, for a classroom sized approximately 50 m^2, it is projected that four medium-sized potted plants or more are needed to improve the indoor environment in the said space.

5. CONCLUSION

This paper presents the technique to assessing the effects of the indoor plants on occupant in an office setup in Malaysia via several experimental methods. Different types of plants were used, and results were compared to establish their best impacts in a physical indoor environment. Since Malaysia is a hot and humid country, the external environment is always higher than the indoor environment most of the time, especially during the day. Therefore, the differences were calculated using outdoor-to-indoor (O/I) ratio, leading to lower air temperature and relative humidity in the indoor environment in the case of positive value.

A two-phase experiment was conducted; Phase 1 involved the selection of indoor plants, while Phase 2 further examined the quantifying number of potted planets needed for the classroom or an office. During both phases, the level of TVOCs and humidity were monitored. The results show that if the number of plants in the classroom were increased, the relative humidity could possibly affect the indoor environment. This is because as the number of potted plants increases, the high relative humidity that surpassed ASHRAE's normal standards (60%–70%) is subsequently induced. Increased number of potted plants has a positive effect on TVOC reading, as TVOC reading begins to decline. It is recommended that two potted plants are used for a room size of smaller than 20 m^2. Hence, it is evident that indoor plants have a positive impact on the IAQ, resulting in positive effects on the health and well-being of occupants.

Acknowledgement

This work was supported by the Universiti Malaya Living Lab Grant Programme [Grant number: LL006-15 SUS].

6.0 REFERENCE

1) 1. Wolverton B.C., Mcdonald R.C., and Watkins E.A., *Foliage plants for removing indoor air pollutants from energy-efficient homes.* Economic Botany, 1984. **38**(2): p. 224-228.

2) 2. Brilli, F., et al., *Plants for Sustainable Improvement of Indoor Air Quality.* Trends in Plant Science, 2018. **23**(6): p. 507-512.

3) 3. Zompanti, A., et al., *Innovative IAQ Organic Sensor.* Procedia Engineering, 2014. **87**: p. 1326-1329.

4) 4. Khan, A.R., et al., *Effect of interior plantscaping on indoor academic environment.* Journal of Agriculture Research, 2005. **43**: p. 235-242.

5) 5. Dijkstra, K., M.E. Pieterse, and A. Pruyn, *Stress-reducing effects of indoor plants in the built healthcare environment: The mediating role of perceived attractiveness.* Preventive Medicine, 2008. **47**(3): p. 279-283.

6) 6. Lohr, V.I., Pearson-Mims, and G. C.H., G.K., *Interior plants may improve worker productivity and reduce stress in a windowless environment.* Journal of Environmental Horticulture, 1996. **14**(2): p. 97-100.

7) 7. Kim, J., et al., *The effects of indoor plants and artificial windows in an underground environment.* Building and Environment, 2018. **138**: p. 53-62.

8) 8. Bringslimark, T., T. Hartig, and G.G. Patil, *Psychological Benefits of Indoor Plants in Workplaces: Putting Experimental Results into Context.* 2007. **42**(3): p. 581.

9) 9. Raanaas, R.K., et al., *Benefits of indoor plants on attention capacity in an office setting.* Journal of Environmental Psychology, 2011. **31**(1): p. 99-105.

10) 10. Dravigne, A., et al., *The Effect of Live Plants and Window Views of Green Spaces on Employee Perceptions of Job Satisfaction.* 2008. **43**(1): p. 183.

11) 11. Park, S.-H. and R.H. Mattson, *Effects of Flowering and Foliage Plants in Hospital Rooms on Patients Recovering from Abdominal Surgery.* 2008. **18**(4): p. 563.

12) 12. Whear, R., et al., *What Is the Impact of Using Outdoor Spaces Such as Gardens on the Physical and Mental Well-Being of Those With Dementia? A Systematic Review of Quantitative and Qualitative Evidence.* Journal of the American Medical Directors Association, 2014. **15**(10): p. 697-705.

13) 13. de Keijzer, C., et al., *Green and blue spaces and physical functioning in older adults: Longitudinal analyses of the Whitehall II study.* Environment International, 2019. **122**: p. 346-356.

14) 14. Fjeld T., V.B., Sandvik L., Riise G., Levy F., *The effect of indoor foliage plants on health and discomfort symptoms among office workers.* Indoor and Built Environment, 1998. **7**(4): p. 204-209.

15) 15. Zhang, Y., et al., *Exercise interventions for improving physical function, daily living activities and quality of life in community-dwelling frail older adults: A systematic review and meta-analysis of randomized controlled trials.* Geriatric Nursing, 2019.

16) 16. Chou, C.-H., C.-L. Hwang, and Y.-T. Wu, *Effect of Exercise on Physical Function, Daily Living Activities, and Quality of Life in the Frail Older Adults: A Meta-Analysis.* Archives of Physical Medicine and Rehabilitation, 2012. **93**(2): p. 237-244.

17) 17. Kamijo, K. and Y. Takeda, *Regular physical activity improves*

executive function during task switching in young adults. International Journal of Psychophysiology, 2010. **75**(3): p. 304-311.

18) 18. Themanson, J.R., M.B. Pontifex, and C.H. Hillman, *Fitness and action monitoring: Evidence for improved cognitive flexibility in young adults.* Neuroscience, 2008. **157**(2): p. 319-328.

19) 19. Vernon, H.M. and T. Bedford, *A Study of Heating and Ventilation in Schools*. 1930, London : H.M.S.O. p. 72 pp.

20) 20. Maslow, A.H., *A theory of human motivation.* Psychological Review, 1943. **50**(4): p. 370–396.

21) 21. Mujan, I., et al., *Influence of indoor environmental quality on human health and productivity - A review.* Journal of Cleaner Production, 2019. **217**: p. 646-657.

22) 22. Korpela, K., et al., *Nature at home and at work: Naturally good? Links between window views, indoor plants, outdoor activities and employee well-being over one year.* Landscape and Urban Planning, 2017. **160**: p. 38-47.

23) 23. Al Horr, Y., et al., *Occupant productivity and office indoor environment quality: A review of the literature.* Building and Environment, 2016. **105**: p. 369-389.

24) 24. Norbäck, D., et al., *Respiratory symptoms, perceived air quality and physiological signs in elementary school pupils in relation to displacement and mixing ventilation system: an intervention study.* Indoor Air, 2011. **21**(5): p. 427-437.

25) 25. Yeom, D., J.-H. Choi, and Y. Zhu, *Investigation of physiological differences between immersive virtual environment and indoor environment in a building.* Indoor and Built Environment, 2019. **28**(1): p. 46-62.

26) 26. Marino, C., A. Nucara, and M. Pietrafesa, *Thermal comfort in indoor environment: Effect of the solar radiation on the radiant temperature asymmetry.* Solar Energy, 2017. **144**: p. 295-309.

27) 27. Li, D.H.W., *A review of daylight illuminance determinations and energy implications.* Applied Energy, 2010. **87**(7): p. 2109-2118.

28) 28. Hemphälä, H. and J. Eklund, *A visual ergonomics intervention in mail sorting facilities: Effects on eyes, muscles and productivity.* Applied Ergonomics, 2012. **43**(1): p. 217-229.

29) 29. Dong, B., et al., *A review of smart building sensing system for better indoor environment control.* Energy and Buildings, 2019. **199**: p. 29-46.

30) 30. Che, W.W., et al., *Energy consumption, indoor thermal comfort and air quality in a commercial office with retrofitted heat, ventilation and air conditioning (HVAC) system.* Energy and Buildings, 2019. **201**: p. 202-215.

31) 31. Montazami, A., M. Wilson, and F. Nicol, *Aircraft noise, overheating and poor air quality in London primary schools' classrooms.* Building and Environment, 2012. **52**: p. 129–141.

32) 32. Heiselberg, P. and M. Perino, *Short-term airing by natural ventilation – implication on IAQ and thermal comfort.* Indoor Air, 2010. **20**(2): p. 126-140.

33) 33. Smith, A. and M. Pitt, *Healthy workplaces: Plantscaping for indoor environmental quality.* Facilities, 2011. **29**(3): p. 169-187.

34) 34. Fares, S., et al., *Bidirectional Flux of Methyl Vinyl Ketone and Methacrolein in Trees with Different Isoprenoid Emission under Realistic Ambient Concentrations.* Environmental Science &

Technology, 2015. **49**(13): p. 7735-7742.

35) 35. Lohr V. I. and C.H. Pearson-Mims, *Particulate matter accumulation on horizontal surfaces in interiors: Inluence of foliage plants.* Atmospheric Environment, 2000. **30**(14): p. 2565-2568.

36) 36. Costa, P.R. and R.W. James. *Air conditioning and noise control using vegetation*. in *Proceedings of the 8th International Conference on Indoor Air Quality and Climate*. 1999.

37) 37. Wang, Z., J. Pei, and J.S. Zhang, *Experimental investigation of the formaldehyde removal mechanisms in a dynamic botanical filtration system for indoor air purification.* Journal of Hazardous Materials, 2014. **280**: p. 235-243.

38) 38. Oyabu, T., et al., *Characteristics of potted plants for removing offensive odors.* Sensors and Actuators B: Chemical, 2003. **89**(1): p. 131-136.

39) 39. Shibata, S. and N. Suzuki, *EFFECTS OF THE FOLIAGE PLANT ON TASK PERFORMANCE AND MOOD.* Journal of Environmental Psychology, 2002. **22**(3): p. 265-272.

40) 40. Fjeld, T., *The Effect of Interior Planting on Health and Discomfort among Workers and School Children.* 2000. **10**(1): p. 46.

41) 41. Shibata, S. and N. Suzuki, *Effects of indoor foliage plants on subjects' recovery from mental fatigue.* North American Journal of Psychology, 2001. **3**(3): p. 385-396.

42) 42. Han, K.-T., *Influence of Limitedly Visible Leafy Indoor Plants on the Psychology, Behavior, and Health of Students at a Junior High School in Taiwan.* Environment and Behavior, 2009. **41**(5): p. 658-692.

43) 43. Orwell, R., et al., *Removal of Benzene by the Indoor Plant/Substrate Microcosm and Implications for Air Quality.* Water Air and Soil Pollution, 2004. **157**: p. 193-207.

44) 44. Treesubsuntorn, C. and P. Thiravetyan, *Removal of benzene from indoor air by Dracaena sanderiana: Effect of wax and stomata.* Atmospheric Environment, 2012. **57**: p. 317–321.

45) 45. Sriprapat, W., et al., *Uptake of toluene and ethylbenzene by plants: removal of volatile indoor air contaminants.* Ecotoxicol Environ Saf, 2014. **102**: p. 147-51.

46) 46. Panyametheekul, S., T. Rattanapun, and M. Ongwandee, *Ability of artificial and live houseplants to capture indoor particulate matter.* Indoor and Built Environment, 2016. **27**(1): p. 121-128.

47) 47. Ghazalli, A.J., et al., *Alterations in use of space, air quality, temperature and humidity by the presence of vertical greenery system in a building corridor.* Urban Forestry & Urban Greening, 2018. **32**: p. 177-184.

48) 48. Abbass, O.A., D.J. Sailor, and E.T. Gall, *Effectiveness of indoor plants for passive removal of indoor ozone.* Building and Environment, 2017. **119**: p. 62-70.

49) 49. Raza, S.H., *Plant Life Forms in Thermal Regulation and Self Purification of Urban Housing Environments.* Indoor Environment, 1995. **4**(1): p. 58-61.

50) 50. Torpy, F.R., P.J. Irga, and M.D. Burchett, *Profiling indoor plants for the amelioration of high CO2 concentrations.* Urban Forestry & Urban Greening, 2014. **13**(2): p. 227-233.

51) 51. Woverton, B.C., R.C. MaDonald, and M. H.H., *Foliage plants for indoor removal of the primary combustion gasses carbon monoxide and nitrogen dioxide.* Journal of the Mississippi Academic of Sciences, 1985. **30**: p. 1-8.

52) 52. Priyamvada, H., et al., *Assessment of PM and bioaerosols at diverse indoor environments in a southern tropical Indian region.* Building and Environment, 2018. **137**: p. 215-225.

53) 53. Kim, K., et al., *Changes in the phytoremediation potential of indoor plants with exposure to toluene.* HortScience, 2011. **46**(12): p. 1646-1649.

54) 54. Yang, D.S., et al., *Screening Indoor Plants for Volatile Organic Pollutant Removal Efficiency.* 2009. **44**(5): p. 1377.

55) 55. Yoo, M.H., et al., *Efficacy of indoor plants for the removal of single and mixed volatile organic pollutants and physiological effects of the volatiles on the plants.* Journal of the American Society for Horticultural Science, 2006. **131**(4): p. 452-458.

56) 56. Kim Kwang Jin. and Kim Hyoung Deug., *Development of model and calculating equation for rate of volatile formaldehyde removal of indoor plants.* Horticulture, Environment and Biotechnology, 2008. **49**(3): p. 155-161.

57) 57. Kim, K.J., et al., *Determination of the efficiency of formaldehyde removal according to the percentage volume of pot plants occupying a room.* Kor. J. Hort. Sci. Technol., 2009. **27**: p. 305-311.

58) 58. Kim K., et al., *Variation in Formaldehyde Removal Efficiency among Indoor Plant Species.* HortScience, 2010. **45**(10): p. 1489-1495.

59) 59. Kondo, T., et al., *Absorption of atmospheric C2–C5 aldehydes by various tree species and their tolerance to C2–C5 aldehydes.* Science of The Total Environment, 1998. **224**(1): p. 121-132.

60) 60. Aydogan, A. and L. Montoya, *Formaldehyde removal by four indoor plant species.* 12th International Conference on Indoor Air Quality and Climate 2011, 2011. **4**: p. 3133-3134.

61) 61. Baosheng, K., et al., *Air Purification Capability of Potted Phoenix Roebelenii and Its Installation Effect in Indoor Space.* Sensors and Materials, 2009. **21**: p. 445-455.

62) 62. Oyabu, T., et al., *Purification Ability of Interior Plant for Removing of Indoor-Air Polluting Chemicals Using a Tin Oxide Gas Sensor.* Journal of Japan Society for Atmospheric Environment, 2001. **34**: p. 319-325.

63) 63. Sawada, A., et al., *PURIFICATION EFFECTS OF PLANTS FOR INDOOR AIR-POLLUTION IN A UNIVERSITY HOSPITAL.* Archives of Complex Environmental Studies (ACES), 2002. **14**: p. CDROM.

64) 64. Sawada, A. and T. Oyabu, *Purification characteristics of pothos for airborne chemicals in growing conditions and its evaluation.* Atmospheric Environment - ATMOS ENVIRON, 2008. **42**: p. 594-602.

65) 65. Tani, A. and C.N. Hewitt, *Uptake of Aldehydes and Ketones at Typical Indoor Concentrations by Houseplants.* Environmental Science & Technology, 2009. **43**(21): p. 8338-8343.

66) 66. Tani, A., et al., *A proton transfer reaction mass spectrometry based system for determining plant uptake of volatile organic compounds.* Atmospheric Environment, 2007. **41**(8): p. 1736-1746.

67) 67. Xu, Z., L. Wang, and H. Hou, *Formaldehyde removal by potted plant-soil systems.* J Hazard Mater, 2011. **192**(1): p. 314-8.

68) 68. Chun, S., et al., *Effect of Bacterial Population from Rhizosphere of Various Foliage Plants on Removal of Indoor Volatile Organic Compounds.* Korean Journal

of Horticultural Science and Technology, 2010. **28**.

69) 69. Wolverton B. C. and Wolverton J. D., *Plants and soil microorganisms: removal of formaldehyde, xylene, and ammonia from the indoor environment.* Journal of the Mississippi Academy of Sciences., 1993. **38**(2): p. 11-15.

70) 70. Zhou, J., et al., *Purification of formaldehyde-polluted air by indoor plants of Araceae, Agavaceae and Liliaceae.* Journal of Food Agriculture and Environment, 2011. **9**: p. 1012-1018.

71) 71. Orwell Ralph L, et al., *The Potted-Plant Microcosm Substantially Reduces Indoor Air VOC Pollution: II. Laboratory Study.* Water, Air, and Soil Pollution, 2006. **177**(1): p. 59-80.

72) 72. Godish, T. and C. Guindon, *An assessment of botanical air purification as a formaldehyde mitigation measure under dynamic laboratory chamber conditions.* Environ Pollut, 1989. **62**(1): p. 13-20.

73) 73. Liu, Y.-J., et al., *Which ornamental plant species effectively remove benzene from indoor air?* Atmospheric Environment, 2007. **41**(3): p. 650-654.

74) 74. Wood, R.A., et al., *Potted-plant/growth media interactions and capacities for removal of volatiles from indoor air.* Journal of Horticultural Science and Biotechnology, 2002. **77**: p. 120-129.

75) 75. Kim, J. and R. de Dear, *Nonlinear relationships between individual IEQ factors and overall workspace satisfaction.* Building and Environment, 2012. **49**: p. 33-40.

76) 76. Cornejo, J.J., et al., *Studies on the Decontamination of Air by Plants.* Ecotoxicology, 1999. **8**(4): p. 311-320.

77) 77. De Kempeneer, L., et al., *Bioaugmentation of the phyllosphere for the removal of toluene from indoor air.* Applied Microbiology and Biotechnology, 2004. **64**(2): p. 284-288.

78) 78. Barboni, T., et al., *Study of the burning of Pteridium aquilinum L. and risk for the personnel involved: Thermal properties and chemical risk.* Fire Safety Journal, 2019. **110**: p. 102904.

79) 79. Kim, K.J., et al., *Efficiency of volatile formaldehyde removal by indoor plants: Contribution of aerial plant parts versus the root zone.* J. Amer. Soc. Hort. Sci., 2008. **133**: p. 521-526.

80) 80. Mahmud, M., *The simulation of low-level equatorial local winds in Peninsular Malaysia during the haze episode of 1997 through the LADM.* Geografia, 2008. **5**(2): p. 26-39.

81) 81. Daghigh R. , N.M. Adam, and B.B. Sahari, *Ventilation Parameters and Thermal Comfort of Naturally and Mechanically Ventilated Offices.* Indoor and Built Environment, 2009. **18: 113**.

82) 82. Daghigh, R., K. Sopian, and J. Moshtagh, *Thermal comfort in naturally ventilated office under varied opening arrangements: objective and subjective approach.* European Journal of Scientific Research, 2009. **26**(2): p. 260-276.

83) 83. Busch, J.F., *A tale of two populations: thermal comfort in air-conditioned and naturally ventilated offices in Thailand.* Energy and buildings, 1992. **18**(3): p. 235-249.

84) 84. Salleh, N.M., et al., *A quantitative evaluation of indoor environmental quality in refurbished kindergarten buildings: A Malaysian case study.* Building and Environment, 2015. **94**: p. 723-733.

85) 85. Jamaludin, N.M., N. Mahyuddin, and F.W. Akashah, *Assessment On Indoor Environmental Quality (Ieq) With The Application Of Potted Plants In The Classroom: Case*

Of University Malaya. Journal of Design and Built Environment, 2017(2): p. 1-15%V 17.

86) 86. 2012. *A Brief Guide to Mold, Moisture and Your Home*. U.S.Environmental Protection Agency 15 November 2019]; Available from: https://www.epa.gov/sites/production/files/2016-10/documents/moldguide12.pdf.

87) 87. ASHRAE, *ASHRAE 62.1-2016, Ventilation for Acceptable Indoor Air Quality (ANSI Approved).* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, Ga, 2016.

88) 88. Fang, L., *Impact of temperature and humidity on the perception of indoor air quality.* Indoor Air, 1998. **8**(2): p. 80-90.

89) 89. Bornehag, C.G., *Dampness in buildings and health nordic interdisciplinary review of the scientific evidence on associations between exposure to "dampness" in buildings and health effects (NORDDAMP).* Indoor Air, 2001. **11**(2): p. 72-86.

90) 90. Bornehag, C.G., Sundell, J., Bonini, S., Custovic, A., Malmberg, P., Skerfving, S., Sigsgaard, T., Verhoeff, A. , *Dampness in buildings as a risk factor for health effects, EUROEXPO: a multidisciplinary review of the literature (1998–2000) on dampness and mite exposure in buildings and health effects.* Indoor Air, 2004. **14**(4): p. 243-257.

91) 91. Toftum, J., A.S. Jørgensen, and P.O. Fanger, *Upper limits of air humidity for preventing warm respiratory discomfort.* Energy and Buildings, 1998. **28**(1): p. 15-23.

92) 92. Reinikainen, L.M. and J.J. Jaakkola, *Significance of humidity and temperature on skin and upper airway symptoms.* Indoor Air, 2003. **13**(4): p. 344-352.

93) 93. Sato, M., S. Fukayo, and E. Yano, *Adverse environmental health effects of ultra-low relative humidity indoor air.* Journal of Occupational Health, 2003. **45**(2): p. 133-136.

94) 94. Paasi, J., et al., *Performance of ESD protective materials at low relative humidity.* Journal of Electrostatics, 2001. **51-52**: p. 429-434.

95) 95. DOSH, *Industry Code of Practice on Indoor Air Quality.* 2010: Department of Occupational Safety and Health Ministry of Human Resources.

96) 96. MS1525, *MS 1525:2014 - Energy efficiency and use of renewable energy for non-residential buildings - Code of practice (Second revision)*, D.O.S. MALAYSIA, Editor. 2014.