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The Use of Plants to Improve Indoor Air Quality in Small Office Space

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ABSTRACT

Exposure to volatile organic compounds (VOC) can cause a series of effects towards human health. VOC is also associated with Sick Building Syndrome and other building related illnesses. Common materials found in every home and place of business may cause elevated exposure to toxic chemicals. The aim of this study was to examine the best indoor plants that could be used to improve indoor air quality in a small office space. In this study, the concentration of VOC inside a room was monitored before and after the test, using Aeroquol Model S500 VOC Gas Detector and by using oil-based paint painted on a panel measuring 0.05 x 0.05 m in order to create a minimum of 3ppm of VOC. Three types of tropical indoor plants were used in this study; *Nephrolepis exaltata*, *Rhapis excelsa* and *Dracaena fragrans*. Data were monitored for eight hours at 10 minutes interval. The results showed no significant differences between the number of pots and the type of plants used in reducing VOC content in the real room environment. This was probably due to several factors, such as the interference of outside air and the condition of the experimental room. This experiment suggests that further experiments should be carried out in a controlled environment to improve our knowledge of how indoor plants can improve indoor air quality, and thus improve human health and well-being.

Keywords: Human health, indoor air quality, tropical indoor plants, volatile organic compounds (VOC)

INTRODUCTION

Media reports regarding air pollution have long been realized by the public. Awareness towards the quality of air that we breathe is important as people spend more than 80% of their daily life indoors (e.g. home, office, shopping malls and vehicles). Everyday, people are exposed to a certain level of toxic gases, both indoor and outdoor. However, outdoor air pollution has always been seen as the main problem regarding air quality; but due to changes of lifestyle, the indoor

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air quality (IAQ) is also seen as a problem as well.

Acceptable temperature and relative humidity, controlled airborne contaminants and adequate distribution of ventilated air are some elements that promote good IAQ. Some examples of common indoor air pollutants include radon, carbon monoxide and ozone. One of the pollutions that is widely found indoors is VOCs. VOCs are organic chemical compounds that have high enough vapour pressures under normal conditions to significantly vaporize and enter the atmosphere. Many VOCs are human-made chemicals and used as industrial solvents. Some of VOC sources are formaldehyde and methane. Formaldehyde is found in many building materials, such as paints, adhesives and wall boards. Many VOCs are neurotoxic, nephrotoxic or hepatotoxic, or carcinogenic and many can damage the blood components and the cardiovascular system and cause gastrointestinal disturbances (Leslie, 2000). Indoor air pollution can even increase the chance of long-term and short-term health problems for indoor occupants, reduce in productivity and degrade students' learning environment and comfort (Lee & Chang, 2000).

VOCs are emitted by various types of products that can be found indoors, such as paints and lacquers, cleaning agents, building materials and furnishings, office equipment like copiers and printers, correction fluids and carbonless copy paper, permanent markers, and photographic solutions. Table 1 shows some common emissions and their sources (Wolverton, 1997). However, VOCs did not only originate from internal sources but are influenced by outdoor sources as well (Ekberg, 1994).

People now build well-sealed homes and install insulation and other materials to conserve energy. This reduces movement of air through a building and increases the concentration of many indoor pollutants. Dependencies on air-conditioning and bad ventilation system worsen the condition and quality of the indoor air. There are several

TABLE 1
Some common emissions and their sources (Wolverton, 1997)

	Sources of Chemical Emissions				
	Formaldehyde	Xylene	Benzene	Alcohols	Acetone
Adhesives	√	√	√	√	
Carpeting				√	
Computer VDU screens		√			
Draperies	√				
Fabrics	√				
Office correction fluid					√
Paints	√	√	√	√	
Plywood	√				
Upholstery	√				

effects caused by poor indoor air quality and a common symptom associated with poor indoor air quality is the Sick Building Syndrome (SBS).

SBS is defined as a set of sub-clinical symptoms with no specifically identified cause. It is a collection of symptoms experienced when a person is exposed to high concentrations of certain gasses, specifically those living or working inside a building. The SBS symptoms include irritation in the eyes, blocked nose and throat, complaints in upper airways, headache, dizziness, sensory discomfort from odours, dry skin, fatigue, lethargy, wheezing, sinus, congestion, skin rash, irritation, nausea, difficulty in concentrating, fatigue and can even cause the occupants to be sensitive to odours (Gupta *et al.*, 2007).

The toxicity level of certain VOCs can be carcinogenic. Among other, formaldehyde has been long considered as a probable human carcinogen (Group 2A chemical) based on experimental animal studies and limited evidence of human carcinogenicity. However, the International Agency for Research on Cancer (IARC) reclassified formaldehyde as a human carcinogen (Group 1) in June 2004 based on the ‘‘sufficient epidemiological evidence that formaldehyde causes nasopharyngeal cancer in humans’’ (Zhang *et al.*, 2008). The chemical characteristic of VOCs indicates that these chemicals decline with time. Newer materials emit higher concentration of VOC. It was concluded that common materials found in every home and place of business may cause elevated exposures to toxic chemicals (Wallace *et al.*, 1987).

There are three common ways to improve indoor air quality; these include source control, good ventilation systems to exhaust contaminated air, and air cleaning. Other methods include phytoremediation, photocatalytic oxidation, adsorption and by using plants. Recently, using plants as a biofiltering system is widely advised. Plants not only serve as an ornament but they can also promote a better indoor air condition. This does not apply only to indoor environment but also the outdoor (Jim & Chen, 2008). Most plants transpire through their stomata. During the process, plants absorb indoor air pollution (Song *et al.*, 2007). Gaseous pollutants could be absorbed into plant tissues through the stomata, together with CO2 in the process of photosynthesis, and with O2 in respiration. After entering the plant, transfer and assimilation could fix the pollutants in the tissues (Jim & Chen, 2008).

Plants also have psychological effects on humans. A review suggests that indoor plants can and provide psychological benefits such as stress-reduction and increased pain tolerance (Bringslimark *et al.*, 2009). Despite the fact that many research has been carried out in this area (Oyabu, 2003; Raza, 1991; Song *et al.*, 2007), little emphasizes on the effectiveness of indoor plants in reducing indoor pollution in the tropical, as well as work done in real room or office environment. Therefore, this study was conducted to investigate the effectiveness of three different species and treatments of indoor plants in reducing indoor pollutants in real working or office environment.

MATERIALS AND METHODS

Characteristics of the Plants

The plants chosen for this study were divided into three categories of characteristics; palms, herbaceous and ferns. The selected plants were *Rhapis excelsa*, *Dracaena fragrans* and *Nephrolepis exaltata*. These plants were chosen to represent leaf characteristic groups. *Rhapis excelsa* represents the palm group, *Dracaena fragrans* represents the herbaceous group and *Nephrolepis exaltata* represents the fern group. The characteristics of the plants are shown in Fig.1 to Fig.3. All the three plants are known to have the ability to purify the air in a previous study (Wolverton, 1997) and are therefore suitable to be used as indoor plants. All plants were planted in a standard clay pot and the soil mixture used was the John Innes 3:2:1 compost. The soil mixture consisted of three parts of loam, 2 parts of peat and 1 part of sand. This soil mixture is widely used and it is known as a standard soil mixture for plants in Malaysia. Plants were randomly selected from a total of 10 plants from each group and divided into three different treatments (one, three and six pots). No plants were used for the control.

The Experimental Room

The experiment was conducted at the Landscape Research Laboratory, Faculty of Design and Architecture, Universiti Putra Malaysia. The room measures 0.3m width x 0.5m length x 0.3m height, with four window panes, a door and a personal air-conditioning unit. In order to imitate a real small office condition, the air-conditioning was set at 21^{o}C, with a medium speed fan and lights were turned on during the experiment.

Measurement of VOC

The source of VOC came from a panel painted with oil paint. Oil-based paint was chosen because the emission rate

Fig.1: *Dracaena fragrans* (herbaceous plant group)

Fig.2: *Rhapis excelsa* (palm group)

Fig.3: *Nephrolepis exaltata* (fern group)

is slower as compared to water based spray paint. A few guidelines suggested a minimum of four hours to collect air sample (Environmental Protection Agency, 2007). For this experiment, however, the data were measured for a duration of eight hours, from 9.30 a.m. to 5.30 p.m., which are the standard working hours (Ministry of Human Resources, 2005).

Measurement of VOC was carried out using a hand-held data logging device Aeroqual 500 Series, with a maximum measurement limit of 25ppm. The relative humidity and temperature was recorded using the MC-83 Relative Humidity-Temperature meter. The recorded data will show if the temperature and humidity levels are within human comfort level. The devices were placed in the middle of the room. Some previous experiments (*see* Wallace *et al*., 1987; Chan *et al.*, 2009; Sohn *et al.*, 2007) indicated that the experimental device should be put between 1 meter to 1.5 meter above the floor level. However, according to the manufacturer of the device used in this experiment, the Aeroqual 500 Series, can be placed anywhere in the experimental room. Fig.5 shows the layout of the experiment.

Statistical Analysis

The one-way analysis of variance (ANOVA) and Fisher least significant difference (LSD) tests were used to determine the differences between the group of plants and the treatment used in reducing VOC concentration.

RESULTS AND DISCUSSION

From the analysis, no significant difference was found between the plants species and even the number of pots. Nonetheless, there were still decrements in the concentration of VOC. The results derived from the analysis are as follows:

TABLE 2
ANOVA test results for *Nephrolepis exaltata*

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	.016	3	.005	.322	.809
Within Groups	.333	20	.017		
Total	.349	23			

TABLE 3
ANOVA test results for *Rhapis excelsa*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.009	3	.003	.087	.966
Within Groups	.719	20	.036		
Total	.729	23			

TABLE 4
ANOVA test results for *Dracaena fragrans*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.024	3	.008	.440	.727
Within Groups	.362	20	.018		
Total	.386	23			

In general, however, a decrease in VOC was found in the number of plants, ranging from 70% to 77% in *Nephrolepis exaltata*, 63% to 72% in *Dracaena fragrans* and 75% to 81% in *Rhapis excelsa*, with the highest value recorded in 6 plants. From Table 5, and by disregarding the control treatment, *Rhapis excelsa* (3 pots) has the highest value (0.8078), while the lowest is *Dracaena fragrans* (1 pot), with a value of 0.6320. The decrement in the percentage of *Rhapis excelsa* (3 pots) is the highest (81%) as compared to other species and the numbers of pots. The lowest percentage is *Dracaena fragrans* (1 pot) with 63%.

When the results of the experiments with the plants and no plants (control) in the room were compared, the VOC concentration still seemed to decrease. This could be due to the interference of air

Fig.4: The experimental room

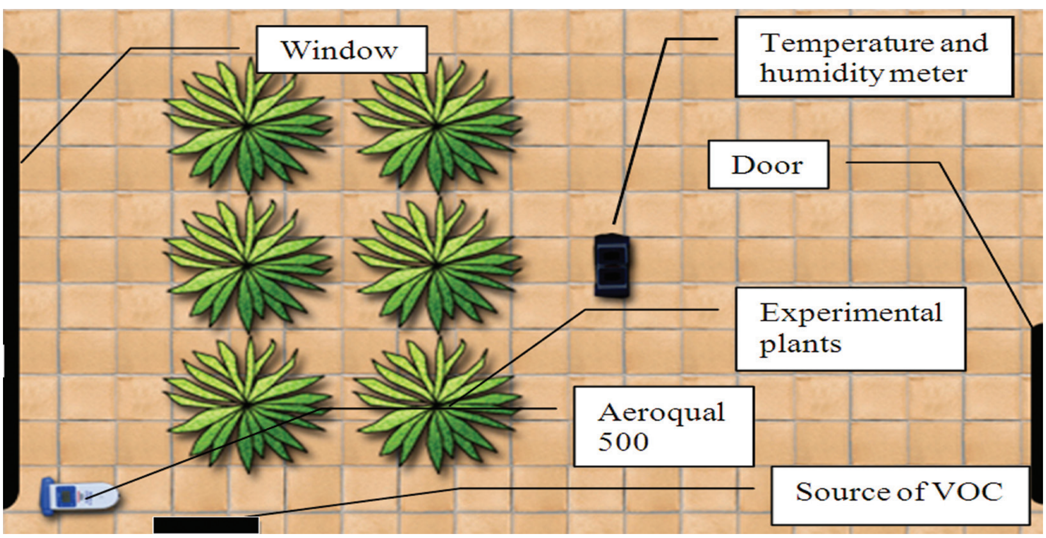

Fig.5: The layout of the experiment

Fig.6: The experimental devices

TABLE 5
Decrement value of VOC by plant species and treatment (data are means ± standard error)

Species	Treatment			
	1 pot	3 pots	6 pots	Control
Nephrolepis exaltata	0.70 ± 0.05	0.74 ± 0.07	0.77 ± 0.05	0.75 ± 0.04
Dracaena fragrans	0.63 ± 0.06	0.69 ± 0.07	0.72 ± 0.04	0.67 ± 0.05
Rhapis excelsa	0.75 ± 0.07	0.81 ± 0.07	0.77 ± 0.08	0.72 ± 0.09

which entered the room from outside (i.e. from beneath the door, windows and air-conditioning). VOC is not mainly reduced by plants but by dilution of air. According to Wallace *et al*. (1987), the concentrations of several VOCs (ethylbenzene, 1,1,1-trichloroethane, xylenes) declined sharply over time, indicating that building materials or finishings (paints, carpets, adhesives, etc.) were likely the sources. Assuming a decline in emissions with age, the newer materials used in the chamber should lead to higher concentrations than in the building.

Based on the findings presented in the tables above, there is no significant difference between the numbers of pots in all the three species of plants used in the experiment. Each species was tested with several numbers of pots. 1 pot, 3 pots, 6 pots and control treatment were used to compare the plants ability in improving indoor air quality. From the results, the plant with the best ability to purify the air was *Rhapis excelsa,* with 3 pots in one room. This finding indicates that different types of foliage can influence the reduction of VOC.

According to Lohr (1992), plants can increase indoor relative humidity by releasing moisture into the air. During photosynthesis, the final products are glucose ($C_6H_{12}O_6$), oxygen (O_2) and water (H_2O). Plants with large leaf surface area emit more water vapour during photosynthesis, and thus increase the humidity level in a space. Relative humidity can affect temperature. It gets warmer if the relative humidity increases (Swanson, 2006). According to Zhang *et al*. (2007), temperature is one of the environmental parameters that influences VOC emissions from building materials, together with air velocity and humidity (Wolkoff, 1998). Bremer *et al.* (1993), Cox *et al*. (2005) and Yang (1999) reported that the emitted substances were temperature dependant.

Meanwhile, the emission of formaldehyde from particle-board was also observed to be strongly dependent on relative humidity which has to be taken into account when examining these materials in climate chamber studies (Sollinger *et al.*, 1994). Therefore, the use of plants is not only to filter the air but can help maintain a good relative humidity and temperature in order to control airborne pollutants.

Previous research indicates that the plants, *Crassula portulacea*, *Cymbidium* Golden Elf, and *Hydrangea macrophylla*, have very high removal rates (60-80%) of the pollutant benzene (Liu *et al.*, 2007). On the contrary, no significant difference was found between all the three plant species used in the experiment in this study. This might e due to the use of a real room condition. The previous experiments were mainly done in sealed gas chambers to test the plants' capability to purify the air. The chamber's size ranges from $1m^3$ (Raza *et al.*, 1995) to a set of four interconnected, cylindrical Plexiglas chamber measuring 40cm in diameter x 60cm tall (Liu *et al.*, 2007) to 3.5 m x 3.5 m x 2.4m (Song, Kim, & Sohn, 2007). These chambers are air-tight, i.e. there is no outside air interference that can dilute the contaminated air.

This experiment was done in a real room environment. Even though the laboratory size used by Liu *et al*. (2007) is about the same as the experimental room used in this study, the reading of VOC may vary because the room used for the experiment is more airtight and has no ventilation system, whereas this study imitated the real personal office environment. Salthammer (1997, as cited in Guieysse *et al*., 2008), indoor VOC concentrations depend on the total space volume, the pollutant production and removal rates, the air exchange rate with the outside atmosphere, and the outdoor VOC concentrations. This also shows that different sizes of experimental room may give different VOC readings.

CONCLUSIONS

There have been a lot of changes in the world we live in today. The effects of global warming have caused people to spend more time indoors. Even outdoor activities have been brought indoors because of heat and polluted air. Technological advancements have caused people to be dependant to alternatives sources. Even though it positively improves the way of living, it can also negatively affect human health at the same time.

The issue regarding indoor air quality is of every field's concern. Architects, landscape architects and even interior designers must always put human health and comfort as priorities in their designs. Architects have been known to be the main persons in a building design process. Therefore, an architect must produce a good design, not only to beautify the building, but also to make it environmentally friendly for humans.

Similarly, ventilation system plays a big role as big offices depend on it to bring in fresh air. Natural aeration is always the best but issues, such as outdoor air pollution and safety in high buildings, often make it not possible. According to Wargocki *et al*. (2002), periodical air refreshing is often not efficient because many indoor air pollutants are constantly released. Hence, forced ventilation is still one the most common methods used for air treatment (Guieysse *et al*., 2008). A central air conditioning re-circulates air in order to save energy, but it also circulates airborne biological materials. There are numerous effects on health due to airborne biological materials. These include a range of infections and allergic diseases, such as extrinsic allergic alveoli, allergic rhinitis and asthma and perhaps even lung cancer (Leslie, 2000). A central air conditioning must be installed with some sort of device that can filter the air.

However, the filter system must be properly maintained because the filter is seen as the main pollution source (Bitter & Fitzner, 2002). At the same time, indoor air must be brought outside and fresh air from the outside be brought inside, provided that the outdoor environment allows a better outdoor air quality. In this study, the ventilation system is the main suspect for the null hypothesis.

Plants have always been seen as a good biological filter for both indoor and outdoor. They do not only serve as the green lung of the earth, but also bring physiological benefits to humans. The focus of this study was to identify which tropical indoor plant in Malaysia has better efficiency in improving indoor air quality. Nevertheless, only three plant species were experimented in this study. To provide further insights into how plants can reduce indoor pollution and improve our health and working environment, more plants need to be tested, and a more controlled environment is needed as well.

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