The Effects of Foliage Plants on Human Physiological and Psychological Responses and Productivity

July, 2015

Doctor of Engineering

Desto Jumeno

Toyohashi University of Technology

ABSTRACT

People spend a large amount of time in the workplace. In order to make their workplace more pleasant people put plants such as flowers or foliage plants in their rooms. It is believed that the presence of plants makes the room more attractive and fresh, is restorative to human spirit, and affects to human attitudes, behavior and physiological responses.

The main objective of this study is to investigate the effects of indoor foliage plants on human physiological and psychological responses and productivity. This objective is further divided into some sub-objectives such as; 1) to investigate the characteristics of tasks in researches of the effects of foliage plants on human; 2) to investigate the effects of the number of indoor foliage plants on productivity, stress and attention; 3) to investigate effects of the quantity of indoor foliage plants on mood, productivity, and perceived air quality; 4) to investigate the effects of foliage plants, illuminances and task types on human impressions, stress and performance.; 5) to investigate effects of foliage plants on human physiological and psychological responses at different temperatures; 6) to investigate the effects of foliage plants and lighting on human physiological and psychological responses and productivity.

In Chapter 2, general factors that reside in the tasks used in researches of indoor foliage plants were identified. Common characters of the task that foliage plants have affected in experimental researches were task complexity, attention requirement, time pressure, difficulty, duration, creativity, and feedback. Complexity of the task should not be so low or not too simple, which requires certain amount of logical thinking, information recognition, comprehension, storing and recalling from memory. A moderate amount of attention to the task is required for gaining the effect of foliage plants on the task. The difficulty of task should be moderate. If the task is too easy, it will be less challenging. Therefore, it will be not attractive or not interesting. If the task is too difficult, the subject may be given up, so that the performance cannot be measured. Moreover, moderate duration of task is necessary while conducting experiment for studying the effect of foliage plants on human performance. From this chapter, it is also found that foliage plants apparently have more effects on creative task such as association, memory and addition, than on a short and repetitive work such as sorting or letter identification task.

In Chapter 3, results of the study on the effects of the number of indoor foliage plants on productivity, stress and attention were presented. From the experiment, it is found that the

effects of the number of plants on the subjects' perceptions of friendliness, comfort, freshness, and the cleanliness of the room were statistically significant. The best number of plants that should be placed in a room sized 9.53 m^2 was seven. As it is not easy to determine whether these differences are due to the number of plants or simply the chance, a further confirmatory study with larger sample size is required. On the other hand, the effects of the number of indoor foliage plants on productivity, stress and attention were not statistically significant. Results also show that the effects of the number of plants on subject's perception of temperature, humidity, thermal satisfaction, and air quality among conditions were also not significantly different.

In Chapter 4, the effects of the number and the size of indoor foliage plants on mood, productivity, and perceived air quality were addressed. From the results presented in Chapter 4, several conclusions have been derived. The presence of plants indoors improves the mood, attention, productivity and the perception of air quality of the occupants. However, some factors need to be carefully considered. Firstly, it was found that the increase in the number of plants could trigger an improvement of the occupant's mood. Secondly, the interaction between the number and the size of foliage plants has an influence on perceived air quality and reaction time. Increase of perceived air quality is related to the increase in the quantity of greenery up to a certain number and size of the plants. In this chapter, it is found that room with three large-sized plants constitutes the best condition or mood, attention, productivity and perceived air quality (PAQ).

The effect of foliage plants on human is related to the perception. Human gathers most information by using visual sense. Visual sense is related to perception of colours and lighting. The amount of leafs colour of foliage plants is measured by using green coverage ratio, whether the amount of lighting is measured by using illuminance level. Therefore, it is important to study the effect of green coverage ratio and lighting on human physiological and psychological responses. In Chapter 5, the effect of green coverage ratio from the foliage plants, illuminance and task types on human perception, impressions, stress and relaxation were addressed. Several conclusions were derived from the results presented in Chapter 5. Firstly, it can be inferred that the impressions of the subject on room conditions are increase with the green coverage ratio. Secondly, higher levels of illuminance produce better pleasure, brightness, breeziness and quality impression on the participants. Thirdly, the increase of the green coverage ratio may decrease the level of stress and increase the level of relaxation.

Moreover, the performance of subjects on Sudoku test and word creation test was increased when the green coverage ratio was increasing, but the addition test and typing test did not show any significant pattern.

Temperature has important role to the comfort and performance of human. It is vital to understand the effect of plants and temperature on human physiological and psychological responses. In Chapter 6, we have investigated the effect of foliage plants on human physiological and psychological responses at different temperatures. We have obtained satisfactory results proving that the presence of foliage plants at an appropriate temperature can induce better attention and meditation, which is useful for increasing work performance and stress reduction. In this study, we have investigated three levels of temperatures within the range of comfort, 22^{o}C, 25^{o}C, and 28^{o}C in summer. Consequently, we still need to study further the effect of smaller range of temperatures in various seasons.

Human safety, performance, productivity and quality of production are greatly affected by attention. In Chapter 7, the effects of foliage plants and illuminace on human attention, stress and fatigue have been investigated. From the results in Chapter 7, several conclusion were derived. Firstly, it can be inferred that there is a significant effect of the interaction of the number and the size of plants on attention. One small sized foliage plant on a desk or workplace is as good as three medium sized or large sized foliage plant in producing better fascination to maintain attention. Secondly, the results show that the higher number of foliage plants placed indoor produce better quality impression, better perception of air freshness and less boringness than smaller number of plants, and provide evidence that the higher number of plants can maintain subject's alertness and attention. Moreover, it can be inferred that the presence of plants at a higher illuminance lighting reduces the work of the heart, thus reduces stress and fatigue.

To sum up conclusion from Chapter 1 to Chapter 7, recommended room condition that would give optimal human responses as well as high productivity in a working room which area is 9.5 m^2, are as follows: a room should be provisioned with 6 potted foliage plants, which height are between 25-50 cm. All plants should be positioned in the front of the room occupant, at his/her visual area. The potted plants can be placed on the desk or on the floor, depends on its height. The working room temperature should be 25^{o}C, and should be illuminated using 800 lx LED or fluorescent lamp.

Benefits for a company that can be obtained from the present of foliage plants by applying the above recommended condition would be substantial. These include economical benefits through the increase in employees' productivity, product defective reduction and customer satisfaction. The second benefit is the increase in employees health, by stress reduction, thus reducing the company's spending. The third benefit is energy saving, thus reducing the cost for energy. The fourth benefit is the increase in the company's "green" image. Moreover, another important benefit is the increase in company's share value.

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ABBREVIATION

DV = Dependent Variable

EEG = Electroencephalography

GCR = Green Coverage Ratio

IV = Independent Variable

PAQ = Perceived Air Quality

STRT = Secondary Task Reaction Time

LIST OF PUBLICATIONS

Journals

1. Jumeno, D., Matsumoto, H. (2015). Effects of foliage plants on human physiological and Psychological Responses at Different Temperatures. AIP Conf. Proc. Vol. 1649, 32-40.
2. Jumeno, D., Matsumoto, H. (2016). The Effects of Indoor Foliage Plants on Perceived Air Quality, Mood, Attention and Productivity. Journal of Civil Engineering and Architecture Research, Vol. 3 No. 4.

International Conferences

1. Jumeno, D. & Matsumoto, H. (2012). Characteristics of Tasks in Researches of the Effects of Foliage Plants on Attention and Human Performance. In Proceedings of The 9th ISAIA 2012, p A-3-4, Gwangju, South Korea.
2. Jumeno, D. & Matsumoto, H. (2013). The Effects of the Number of Indoor Foliage Plants on Productivity, Stress and Attention. In Proceedings of CLIMA 2013. Prague, Czech Republic.
3. Jumeno, D., Matsumoto, H., Susanti, L. (2014). Utilization of Foliage Plants on the Design of Eco-Ergonomic Office. In Proceedings of Indoor Air 2014. Hong Kong, China.

Chapter 1 GENERAL INTRODUCTION

1.1 Background

People spend a large amount of time in their workplace. In order to make their workplace more pleasant people put plant such as flowers or foliage plant inside their rooms, on the floor, on the desk, hanging on the wall and so on. Indoor plant in working environment has been introduced several decades ago. It was only in the late of 1950’s that indoor plants were introduced in Germany. The availability of plants in a room not only makes the room more visually attractive, but also makes the air in the room fresher by lowering the level of pollutants, such as formaldehyde, benzene and toluene. Contact with plants is believed to be restorative to the human spirit. Therefore, human attitudes, behaviors and physiological responses were affected by interaction with plants.

Number of researches on the benefits of indoor plants to improve indoor air quality and its effect on humans has been increased. However, the results were varied. Some positive results were found, such as an increase in productivity, reduction in stress of the employee, improvement of employee morale, reduction in health complaint, reduction in sick leave, increase in satisfaction, and improvement on quality of working life. On the other hand, some negative results were also found such as decrease in productivity and increase in the level of perceived stress. The differences in results might be caused by differences in the type of task, differences in acclimatization time, variations in work duration, variations in the number of plants, in the size of plants, and also variations in the arrangement of plants.

1.2 Objective of research

The main objective of this study is to investigate the effects of indoor foliage plants on human physiological and psychological responses and productivity. This objective is further divided into some sub-objectives as follows:

a. To investigate the characteristics of tasks in researches of the effects of foliage plants on human.
b. To investigate the effects of the number of indoor foliage plants on productivity, stress and attention.
c. To investigate effects of the quantity of indoor foliage plants on mood, productivity, and perceived air quality.
d. To investigate the effects of foliage plants with different illuminance and task types on human impressions, stress and performance.
e. To investigate effects of foliage plants on human physiological and psychological responses at different temperatures.
f. To investige the effects of foliage plants and lighting on human physiological and psychological responses and productivity.

1.3 Literature survey of related research

A study in history of office landscape by (Pearson-Mims & Lohr, 2000) indicated that indoor plant use in office landscape planning approach was developed in West Germany during late 1950s and began to appear in United States in early of 1960s. From several research that have been conducted in the area, it was reported that by putting indoor plant in the work environment can improve employee morale (Chang & Chen, 2005; Dravigne, Marcos, & Waliczek, 2008), reduce stress (Coleman & Mattson, 1995; Lohr, Pearson-Mims, & Goodwin, 1996), reduce health complaints (Fjeld, 2000), reduce sick leave (Bringslimark, Hartig, & Patil, 2007), increase work performance (Doi, Matsumoto, & Nakao, 2010; Shibata & Suzuki, 2002, 2004), increase productivity

(Bringslimark et al., 2007; Lohr et al., 1996), increase employee satisfaction of the job (Dravigne et al., 2008), and also increase quality of working life (Dravigne et al., 2008).

In contrast with above, several studies yield in different favor. Larsen, Adams, Deal, Kweon, & Tyler (1998) reported the decrease on performance when the number of plants increased. Bringslimark et al. (2007) also found that the greater the number of plants placed within 1 m from the desk the higher the level of perceived stress. In addition to this, adding plants indoor also has no significant effect on behavior, attitudes and satisfaction (Shoemaker, Randall, & Relf, 1992), concentration and number of error (Lohr et al., 1996), blood pressures and skin temperatures (Lohr & Pearson-Mims, 2000), subject's mood and preference (Adachi, Rohde, & Kendle, 2000; Shibata & Suzuki, 2002), and attention capacity while taking a break (Raanaas, Evensen, Rich, Sjøstrøm, & Patil, 2011).

The difference in the results of the studies were caused by several factors, such as population and sample selection was not clear (Fjeld, 2000; Shoemaker et al., 1992), no task was conducted by the subjects so that need for a recovery is questionable (Coleman & Mattson, 1995; Lohr & Pearson-Mims, 2000), duration of exposure to plant is too short (Larsen et al., 1998; Lohr et al., 1996; Shibata & Suzuki, 2002), and visual stimulation was not strong enough to simulate real condition (Chang & Chen, 2005; Hartig & Staats, 2006).

1.4 Outline of this thesis

This thesis is organized into eight chapters. It is started with General Introduction in Chapter 1 that explains the background and the objectives of this study and also some literature surveys of related researches. Chapter 2 explains the tasks characteristics that were used in researches of the effect of foliage plants on human. Chapter 2 provides background study for the subsequent chapters. Chapter 3 explains the effects of the number of foliage plants on productivity, stress and attention. Chapter 4 explains the effects of the quantity of foliage plants on perceived air quality, mood, and productivity.

The first four chapters provide background knowledge for undergoing studies in Chapter 5 to Chapter 7. Chapter 5 explains the effects of foliage plants with different illuminance and task types on human impressions, stress and performance. Chapter 6 explains the effects of foliage plants on human physiological and psychological responses at different temperatures. Chapter 7 explains the effects of foliage plants and lighting on human physiological and psychological responses and productivity.

Chapter 8 presents the main findings and overall conclusions of this doctorate research study.

Chapter 2 CHARACTERISTICS OF TASKS IN RESEARCHES OF THE EFFECTS OF FOLIAGE PLANTS ON ATTENTION AND HUMAN PERFORMANCE

2.1 Introduction

Plants have been used as indoor decoration for centuries. It was in the late 1950's that people also started to use plants in the office environment in order to make the environment more pleasant. Plants are one means of visual stimulus that is necessary for individuals to perform their tasks (Stone & English, 1998). Visual stimuli can also be used for restorative function, especially for individuals working on high attention demand tasks (Kaplan, 1983). Therefore, foliage plants can also be used as a means of restoration.

Research on the benefit of plant in workplace has been increased in the last 30 years. In some researches plants are beneficial such as reducing sick building syndrome by removing indoor air pollutants such as formaldehyde (B. C. Wolverton, McDonald, & Watkins, 1984), benzene (Orwell, Wood, Tarran, Torpy, & Burchett, 2004), and toluene (Matsumoto & Yamaguchi, 2007), raising the relative humidity without contributing to excessive humidity to interiors that may damage building materials (Lohr et al., 1996), reducing feeling of job pressure and increasing job satisfaction (Dravigne et al., 2008), increasing productivity and reducing stress (Lohr et al., 1996), and reducing health complaint by workers (Fjeld, 2000). In other research the benefit of plants on the task was not significant to the attention and satisfaction (Shoemaker et al., 1992), concentration and number of errors (Lohr et al., 1996), blood pressures and skin temperatures (Lohr & Pearson-Mims, 2000), mood and preference (Adachi et al., 2000;

Shibata & Suzuki, 2002) and attention capacity (Raanaas et al., 2011). Moreover, in the other research plant also gave negative effects on the task carried by human such as a reduction in performance (Larsen et al., 1998), and a decrease in stress perception (Bringslimark et al., 2007).

To understand the effects of foliage plants on human performance by subjective experiments, one needs a task to simulate the real condition. In each research task carried out were different such as test of tasking reaction time (Lohr et al., 1996), sorting task of fonts and letter identification productivity task (Larsen et al., 1998), association and sorting task (Shibata & Suzuki, 2002, 2004), addition, typing and memory task (Doi et al., 2010), and proofreading (Raanaas et al., 2011). The effects of foliage plants on these tasks were varied. These variations of effects made the judgment and generalization of the effects of foliage plant on human attention, mood and performance become difficult. Therefore, to understand better the effect of foliage plant on various human tasks, it is required to identify what the general factors are owned by the tasks, which used in researches where human is affected by foliage plants. With better understanding of these factors, studies on the effects of various foliage plants factors should be conducted in a more effective way.

To understand which tasks are significantly affected by the foliage plants and which tasks are not affected, it is required to analyze factors that differentiate one class and the other class, and how these factors are affected by foliage plants. Using this understanding, a framework for task design using plants as a source of visual stimulation environment can be proposed.

2.2 Theoretical background

2.2.1 Foliage plants

2.2.1.1 Definition of foliage plants

Foliage plants means "those plants, normally without flowers, primarily produced in pots or similar containers, that are primarily used for interior decorations, whether grown under cover or in field operations". (7 U.S.C. Section 4302, 2006)

The term "foliage plants" is necessary to defer it to flowering plants. Another term that sometimes used by people is "leafy plant". There are several classes on how people may bring foliage plants indoor that were used in researches of this field:

- Live plants (Adachi et al., 2000; Bringslimark et al., 2007; Coleman & Mattson, 1995; Doi et al., 2010; Fjeld, 2000; Larsen et al., 1998; Lohr et al., 1996; Park & Mattson, 2008; Raanaas et al., 2011; Shibata & Suzuki, 2002, 2004; A. J. Smith, Tucker, & Pitt, 2011),
- Artificial plants, (Doi et al., 2010)
- Picture/photo of plants (Coleman & Mattson, 1995; Hartig & Staats, 2006),
- Video of plants,
- Window (Chang & Chen, 2005; Dravigne et al., 2008)

2.2.1.2 Ability of foliage plants on removing indoor air contaminants

Foliage plants are capable of reducing indoor air contaminants such as toluene, benzene, formaldehyde and airborne microbes. Several foliage plants such as *benjamin*, *spathiphyllum*, *areca* palm and *concinna* is capable of reducing toluene from air (Matsumoto & Yamaguchi, 2007). Matsumoto & Yamaguchi (2007) also suggest that type lighting also has the effect on toluene removal rate by foliage plants.

Several foliage plants such as golden photos (*scindapsus aureus*), nephthytis (*syngonium podophyllum*), and spider plant (*chlorophytum alatum*) is capable to remove formaldehyde from contaminated air (B. C. Wolverton et al., 1984).

Houseplants such as weeping fig (*ficus benjamina*), peace lily (*spathiphyllum*), lady palm (*rhapis excels*) and so on are capable of removing airborne microbes inside energy efficient buildings (B. Wolverton & Wolverton, 1996).

Three top selling species, *Howea forsteriana* (kentia palm), *spathiphyllum walisii* (peace lily), and *dracaena deremensis*, are capable of removing benzene (a carcinogen) and n-hexane (a neurotoxin) from indoor air (Orwell et al., 2004; Wood, Orwell, Tarran, & Burchett, 2001).

2.2.1.3 Theories of the benefit of plants

There are theories that explain the benefits of plants (Paula Diane Relf & Lohr, 2003):

- The overload and arousal theories

  Modern world is full of noise, movement and visual complexity that overwhelm our senses that lead to decrease our level of psychological and physiological excitement. On the other hand, environment dominated plants, are less complex that reduce level of arousal, and therefore reduce our stress.
- The learning experiences theory

  This theory maintains that people's responses to plants are a result of their early learning experiences or the cultures in which they were raised. However, this theory does not take into account the similarities in responses to nature found among people from different geographical and cultural backgrounds, or people from different historical periods.
- Evolution theory

  This theory maintains that our responses to plants are a result of evolution. Since we evolved in environments comprised primarily of plants, we have a psychological and physiological response to them.
- Psycho-evolutionary theory

  Several studies on the effect of foliage plants on humans started from (Ulrich, 1986) theory about environmental influences on psychophysiological stress reduction. This theory posits that an environment with particular qualities, including moderate complexity, moderate depth, the presence of focal point, gross structural qualities, and natural contents such as vegetation and water, can evoke positive emotions, sustain non-vigilant attention, restrict negative thoughts, and reduce physiological arousal.

2.2.2 Physiological responses

A number of human physiological responses have been used by researchers for detecting the impact of indoor foliage plants on human. Physiological responses that were used in the studies of the impact of indoor foliage plants on human are as follow:

- Heart rate (Doi et al., 2010; Lohr et al., 1996; Park & Mattson, 2008)
- Blood pressure (Chang & Chen, 2005; Lohr et al., 1996; Park & Mattson, 2008),
- Brain measures, EEG (Chang & Chen, 2005)

  Brainwaves were recorded by placing electrodes on the scalp. Brainwaves produced by cerebral cortex were amplified and recorded by the electroencephalograph.
- Analgesic intake (Park & Mattson, 2008)
- Skin temperature (Coleman & Mattson, 1995)
- Amylase score (Doi et al., 2010)
- Muscle, EMG (Chang & Chen, 2005)

2.2.3 Psychological responses

There are a wide variations of psychological responses used in the studies of the impact of indoor foliage plants on human.

- Attitude (Hartig & Staats, 2006; Shoemaker et al., 1992)
- Attention recovery (Hartig & Staats, 2006)
- Attention capacity (Raanaas et al., 2011)

- Reflection (Hartig & Staats, 2006)
- Social stimulation (Hartig & Staats, 2006)
- Pain intensity (Park & Mattson, 2008)
- Pain distress (Park & Mattson, 2008)
- Fatigue (Park & Mattson, 2008)
- Satisfaction (Park & Mattson, 2008)
- Cleanness (Park & Mattson, 2008)
- Relaxing-stressing (Park & Mattson, 2008)
- Comfortable-uncomfortable (Larsen et al., 1998; Park & Mattson, 2008)
- Colorful-drab (Park & Mattson, 2008)
- Happy-sad (Park & Mattson, 2008)
- Pleasant smell-unpleasant smell (Park & Mattson, 2008)
- Bright-dull (Park & Mattson, 2008)
- Spacious-crowded (Park & Mattson, 2008)
- Calming-Irritating (Park & Mattson, 2008)
- Warm-Cool (Park & Mattson, 2008)
- Attractive-unattractive (Park & Mattson, 2008)
- Quiet-noisy (Park & Mattson, 2008)
- Mood (Adachi et al., 2000; Larsen et al., 1998; Shibata & Suzuki, 2002, 2004)
- Feeling (Adachi et al., 2000)
- Job satisfaction (Dravigne et al., 2008; Shoemaker et al., 1992)
- Behavior (Shoemaker et al., 1992)
- Perceived stress (Bringslimark et al., 2007)
- State anxiety (Chang & Chen, 2005)

2.2.4 The other responses

Besides physiological and psychological responses, there are other responses that used to measure the effect of indoor foliage plants on human. The other responses are as follow:

- Performance, productivity (Bringslimark et al., 2007; Doi et al., 2010; Larsen et al., 1998; Lohr et al., 1996; Shibata & Suzuki, 2002, 2004)
- Speed
- Accuracy
- Indoor air quality (Doi et al., 2010)
- Perceived odor (Doi et al., 2010)
- Vitality change rate (Doi et al., 2010)
- Sick leave (Bringslimark et al., 2007)

2.2.5 Subject of study

Different subjects of study were employed in the research of the impact of indoor foliage plants on human. However, among those studies, the use of elderly subjects on the study was not found in the literature.

- Adult, working age (Bringslimark et al., 2007; Dravigne et al., 2008; Fjeld, 2000; Larsen et al., 1998; Shoemaker et al., 1992; A. J. Smith et al., 2011)
- Adult, university students (Adachi et al., 2000; Chang & Chen, 2005; Coleman & Mattson, 1995; Larsen et al., 1998; Lohr et al., 1996; Raanaas et al., 2011; Shibata & Suzuki, 2002, 2004)
- Elderly
- Adolescent (Fjeld, 2000)
- Patients (Park & Mattson, 2008)

2.2.6 Place of study

Study of the effect of indoor foliage plants on human take place in various settings. Most study use office as its setting. Maybe because most of time people were in office. Little or no study that use home as a place of study was found in the literature.

- School classroom (Coleman & Mattson, 1995; Fjeld, 2000)
- Office (Bringslimark et al., 2007; Dravigne et al., 2008; Fjeld, 2000; Larsen et al., 1998; Raanaas et al., 2011; Shoemaker et al., 1992; A. J. Smith et al., 2011)

- Laboratory (Chang & Chen, 2005; Lohr et al., 1996; Shibata & Suzuki, 2002, 2004)
- Hospital (Fjeld, 2000; Park & Mattson, 2008)

2.2.7 Human performance

The effectiveness of a person conducting a task is measured by his or her performance. Human performance may be expressed as speed of work as well as output per unit of time and also the quality of the outputs. As human performance measured by output per unit of time, it also expresses productivity at the task. Human performance is affected by personal factor, job characteristics, and working conditions (Kahya, 2007).

Personal factors that affected human performances are age, gender, experience, anthropometry, physiological and psychological conditions, and so on. Job characteristics that impact on human performance are physical effort, job grade. Working conditions that affected human performance are environmental conditions such as thermal, noise, lighting, vibration and hazards (Hyge & Knez, 2001; Knez & Kers, 2000). Performance also affected by environmental color or view (Stone, 2003).

2.2.8 Ergonomics

"Ergonomics can be defined as the application of knowledge of human characteristics to the design of systems." (Parsons, 2000)

The goal of ergonomics is to design a system that is effective, efficient, safe and comfortable to the people. Environmental ergonomics is concerned with how people interact with the environment so that people can live and work safely, comfortably and achieve a high performance.

2.2.9 Attention

Attention comprises three major functions: orienting to sensory events, detecting signals for focal or conscious processing, and maintaining a vigilant or alert state (Posner & Petersen, 1990).

There are several ways of measuring attention:

1. EEG (electro encephalograph)

   EEG methodology to measure attention is based on the β activity, which are electromagnetic waves ranging between 14 and 30 Hz in frequency and between 5 and 20 mV in amplitude. When people are conscious and alert β activity occurs in the forehead (Liu, Chiang, & Chu, 2013). This activity is detected and measured using wireless sensors attached to the forehead of the subject and then transmitted to the monitor.
2. Secondary task reaction time (STRT)

   STRT methodology is based on limited capacity models of attention that assume people are information processors and that information processing requires mental resources (Lang, Bradley, Park, Shin, & Chung, 2006). Attention occurs when people allocate mental resource to a task. In the STRT paradigm, participants perform two tasks, a primary and a secondary task. They are instructed to pay most attention to the primary task. Participants are also given a secondary task (e.g. push a button as soon as you can when you hear a signal). The elapsed time between the signal and when the participants pushes the button is called the STRT (Lang et al., 2006).
3. The Necker Cube

   This is an alternative measure of direct attention that is more portable, time efficient and easy to administer (Hurlbut, 2011). The Necker Cube is conducted by drawing lines of a cube that naturally varies of reverses between two orientations. The frequency of fluctuation is predicted to be a measure of attention.

4. Digit span test

   Digit span test requires a person to respond effectively to and encode the digit and then accurately recall, sequence, and vocalize the information (Groth-Marnath & Baker, 2003). There are two types of digit span test, forward digit span test and backward digit span test. In backward digit span test a person perform more difficult functions of holding the number longer and transforming them to a different sequence prior to restating them.

5. Extensive proof reading

   Proof reading task is a task that highly demanding in directed attention. Hartig, Mang, & Evans, (1991) used this test to measure attention of subjects after they had vacation in the wilderness, urban place, and no vacation. The advantage of this test lies in its simplicity. However, this test might only applicable to those subjects with high skills in language grammar.

6. The attention network task

   The attention network task (ANT) is a test for attention networks that include alerting, orienting and executive control (Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, 2002). The ANT is combination of the Posner cueing paradigm and the Eriksen flanker test. Subjects complete the task on a computer by clicking right and left mouse buttons to respond to visual stimuli. A row of 5 visually presented white lines with arrowheads is shown pointing to the left or to the right. The target is a leftward or rightward pointing arrowhead at the center. The target is flanked on either side by two congruent or incongruent arrows (same or opposite direction), or by neutral lines. The task of the participant is to indicate the direction of the central target by pressing the right or left mouse button as quickly as possible. Each block of the task lasts approximately 5 minutes with the overall task taking about 30 minutes to complete (Gooding, Braun, & Studer, 2006).

2.2.10 Stress

2.2.10.1 Definition of stress

Stress is difficult to define, because it is different from one person to another. The term "stress", as it is currently used was coined by Hans Selye in 1936, who defined it as "the non-specific response of the body to any demand for change" (AIS, 2015). There are several definitions of stress as follow:

Stress is a state of mental or emotional strain or tension resulting from adverse or demanding circumstances. (Google translations, 2015).

Stress is the body's reaction to a change that requires a physical, mental or emotional adjustment or response. (Morrow, 2014)

2.2.10.2 The physiology of stress

When human brain interprets a situation of being stressful, it triggers the activation of hypothalamic pituitary adrenal (HPA) axis or neuroendocrine axis. Then, hypothalamus or master gland, releases a hormone called corticotrophin-releasing hormone (CRH). The release of CRH triggers the secretion of another hormone called adrenocorticotrophin (ACTH) from the pituitary gland. These glands are located in the brain. ACTH hormone then travels in the blood and reaches the adrenal glands, which are located above the kidneys, and triggers secretion of the so-called stress hormones. There are two main stress hormones, the glucocorticoids (called corticosterone in animals, and cortisol in humans), and the catecholamines (epinephrine and norepinephrine). When these two hormones are secreted in response to stress one would experience an increase in heart rate and blood pressure (Stress, 2007).

2.2.10.3 Measure of stress

Stress can be measured by psychological and physiological responses. There are a few methods available for measuring stress:

1. Psychological questionnaires

   There are a wide variety of questionnaires that have been developed to assess the psychological factors that are associated with stress in humans.

2. Blood Pressure

   Blood pressure is a measure of the force that blood exerts on the walls of blood vessels. Blood pressure can be easily measured using a simple vital signs monitor. When blood pressure is measured, two numbers appear, e.g. 120/80 mmHg. The first number, 120, represents the systolic pressure, which occurs when the heart pushes blood out of the arteries. The second number, 80, represents the diastolic pressure, which is the pressure of the heart at rest.

3. Vagal tone

   Vagal tone represents the parasympathetic impulse that would apply a brake to decrease heart rate during both resting and reactive conditions. This measure requires the use of more advanced electronic devices and the installation of leads.

4. Salivary Alpha Amylase

   It is only recently that people are using salivary alpha amylase to measure stress. The level of salivary α-amylase increases with the increase in physiological stress such as exercise. Salivary α-amylase is produced by salivary glands (Granger, Kivlighan, El-Sheikh, Gordis, & Stroud, 2007). Salivary α-amylase is used as biomarker, as it's level is increase in response to stressful conditions including exercise, heat and cold stress as well as psychological stress (Granger et al., 2007). Salivary α-amylase is easy to measure using a portable hand-held device and a disposable test strip. There is a positive correlation between salivary α-amylase and catecholamine level (Stress, 2007).

5. Salivary cortisol

   Cortisol measured in saliva reflects the fraction of cortisol that is "free" or "unbound" (to carrier proteins), the portion that crosses the blood-brain-barrier to affect different brain structures. The level of cortisol increase with the increase in stress as interpreted in brain.

2.2.11 Task characteristics

Human performance is influenced not only by his or her ability alone but also affected by many factors such as task, machine or tool, material, and indoor environment. The nature of the task, which influences human performance, is called task characteristics. In the model of *job characteristics* (Hackman & Oldham, 1976), skill variety, task identity, task significance, autonomy and feedback have an effect on the work performance. Poor job characteristics result in decreasing employee performance (Kahya, 2007).

Other factors that may affect performance are motivation, perceived role, and skills (Weitz, B. A., Sujan, & Sujan, 1986), motivation, knowledge and skills (Sonnentag & Frese, 2002), task demand and task complexity (Jimmieson & Terry, 1999), task demand and workload (Tiwari, Singh, & Singh, 2009), task duration and sleep loss (Heslegrave & Angus, 1985).

2.3 Characteristics of tasks in the foliage plant experiment setting

Among the characteristics mentioned in the literatures, not every characteristic is appropriate for the experiment setting. For example, it is difficult to give a supervisory feedback to the subject and to expect any improvement in performance. Without any feedback, it is difficult for the subject to know whether his or her performance is wrong or right, and below standard or above standard. However, other feedback can be acquired directly from a visual display unit, and this can be applied to task simulation using computer or electronics devices.

2.4 Effect of foliage plant on simple productivity task

Several studies has been conducted on the effect of foliage plants on simple task (Larsen et al., 1998; Lohr et al., 1996; Shibata & Suzuki, 2002). Lohr et al. (1996) was conducting an experiment of the effect of foliage plants on the simple reaction time. In this study Lohr et al. (1996) compared responses of subjects in the presence and absence of plants in a windowless working environment. Participants in the study were assigned tests of reaction time. Participants were asked to press a key associated with shape displayed on a computer screen. Measure of reaction time was used to measure performance under stressed or fatigue conditions. Lohr et al. (1996) reported that during the works in the room with plant participants felt more attentive or concentrating, the rise in blood pressure was less, and the reaction time was faster than in a room without plant.

Larsen et al. (1998) conducted a research to examine the effects of indoor plants on the individual's attitude, mood and productivity in the workplace environment. In this experiment, participants were asked to identify the occurrence of the letters *t* and *f* in passages of text within 60 seconds. Experimental conditions were based on the number of plants in the room: medium number of plants, high number of plants, and no plant condition. They found that the mean productivity values in the office with a high number of plants had the lowest productivity scores and the participants in the office without plants had the highest productivity scores. However, offices with high number of plants were rated as more attractive and more comfortable than offices with no plant. Larsen et al. (1998) argued that the presence of the plant might have distracted subject's attention.

Shibata and Suzuki (2002) investigated the effect of foliage plants on task performance and mood. In the experiment, subjects were asked to perform a sorting task, which was taking one card from a pile and place it into a box in Japanese syllabary order. Three conditions were tested during the experiment: a plant was placed in the front of the subject, side of the subject, and no plant condition. 10 minutes were given to the subject to perform the task. From the experiment, it was found that there was no difference in the effect of plant on female subject's performance, while on male subject although plant placed in the front and side of the subject condition were better than without plant condition, the effect was weak. In Table 1, task characteristics of reaction time (Lohr et al., 1996), letter identification (Larsen et al., 1998), and sorting (Shibata and Suzuki, 2002) were presented.

In each research reported in Table 1 the tasks were very simple and were conducted in very short duration. Compared to the real work situation, people were working 8 hours a day normally. Within these 8 hours, the tasks are varied and also relatively more complicated.

If the task conducted in the experiment was too simple and the duration was too short, there was a tendency for the participants to work faster than in the real work situation. As a result of this experiment, the experiment models might not be valid enough to represent the real work system. Therefore, in order to arrive at better conclusion, one need to design a task for the experiment that is representing the real work system better and to set a more suitable duration that is applicable for research.

Table 1. Characteristics of test of reaction time and letter identification, and sorting

No.	Task Characteristics	Reaction time (Lohr et al., 1996)	Letter identification (Larsen et al., 1998)	Sorting (Shibata & Suzuki, 2002)
1	Skill variety	Low	Low	Low
2	Task significance	Low	Low	Low
3	Autonomy	Moderate	Low	Low
4	Motivation	No report on motivating the subject.	No report on motivating the subject.	The subjects get extra credit on their study.
5	Knowledge	Novel knowledge of regular shapes.	Novel knowledge of alphabet.	Knowledge of Japanese syllabary was required.
6	Task complexity	Low. Only a small amount use of resources of attention, memory and reasoning was required.	Low. The subject was required to find letter t and f in the text and then to circle or cross it out.	Task structure was simple: read the card, then, sort it according to the Japanese syllabary.
7	Task demand	A small amount of knowledge, skill, and effort was required for the task. There was also a temporal demand.	Only very little amount of knowledge, skill and effort was required. Temporal demand might be existed.	Physical, mental and temporal demand was low.
8	Task Duration	The duration of the task was less than 10 minutes.	Total duration was three minutes.	10 minutes
9	Workload	Workload was small.	There was a time load.	Physical, mental and time load was small.
10	Sleep loss	No report	No report	No report
11	Learning	No learning effect.	There might be some learning effect.	No learning effect, the procedure was simple.

2.5 Effect of foliage plant on more complex tasks

Complex task is characterized by high requirement attention, memory, reasoning, and other information processing demands. Six complex tasks were used for studying the effect of foliage plants on human performance such as association task (Shibata & Suzuki, 2002; 2004), addition, typing, memory (Doi et al., 2010), reading span and proofreading (Raanaas et al., 2011).

2.5.1 Association task

In association task experiment conducted by Shibata and Suzuki (2002) the subject was asked to generate up to 30 words associated with each of the listed adjectives. The time for the subject to complete the task was 10 minutes. It was found that female subject was performing better in the room without plant, but male subject was performing better in a room with plants placed in the front of the subject

2.5.2 Addition, typing, and memory task

Doi et al. (2010) studied the effect of foliage plants on human physiological/psychological responses by using a series of addition task, typing, and memory task. Three experimental room conditions were tested in a room with living plants, *Benjamin* and *Areca-palms*, a room with artificial plants, and a room without plant. The characteristics of task simulated in the experiment are presented in Table 2. Results of Doi et al. (2010) showed that the performance of the subject in addition and typing task while living plants were present were significantly higher than the other conditions.

2.5.3 Reading span task and proofreading task

Raanaas et al. (2011) examined the effects of plant on attention capacity. In their research, Raanaas et al. (2011) also tested the effects of plant on performance during a short break between attention demanding tasks. Proofreading and RST (Reading Span Task) were being conducted during the experiment. In this task, the subject must read aloud, store information in the memory and recall the stored information several minutes later.

The results of Raanaas et al. (2011) showed that attention capacity while works in a workplace with plants was better than the workplace without plant. But, attention capacity while taking a break between attention demanding tasks was not different. However, Raanaas et al. (2011) also showed that there was a drawback in their experiment, as the performance was improved from the beginning until the last test. There are two processes that might be operated in this condition, practice and fatigueless effects. The practice effect might happen when the subject does not reach the steady state phase on his/her performance learning curve. A fatigueless effect might happen if the task was not demanding enough to cause fatigue to the subject. Characteristics of association, addition, typing, memory, reading span, and proofreading task are presented in Table 2.

Table 2. Task characteristics of association task , addition task, typing and memory task, reading span and proofreading task

No.	Task Characteristics	Association task	Addition, typing, and memory task	Reading span and proofreading task
1	Skill variety	Moderate	Moderate	Reading span task: moderate Proofreading: low
2	Task significance	Low	Low	Low
3	Autonomy	High	Low	Low
4	Motivation	The subjects get an extra credit on their study	No effort to induce motivation was reported.	Two tokens at the local bookstore being worth NOK 500
5	Knowledge	Knowledge of Japanese words	Knowledge of basic addition process, alphabets and characters.	Knowledge of vocabulary and structures.
6	Task complexity	High	High	High
7	Task demand	Physical demand was low. Mental and temporal demand was high.	Addition and memory task: high mental demand. Typing task: high mental and moderate physical demand.	Reading span task and proofreading task has high mental demand.
8	Task Duration	10 minutes	30 minutes for each task, 170 minutes in total	10 minutes for each test, 60 minutes in total.
9	Workload	Physical load was low. But, mental load and time load might be high.	Moderate mental workload	Moderate mental workload
10	Sleep loss	Not reported	Sleeping time was reported. No significant difference was found between conditions.	Not reported
11	Learning	Not reported.	The subjects were trained to perform the test.	The subjects were trained to perform the test.

It can be seen that the tasks in Table 2 have more skill variety than those presented in Table 1. The task with more skill variety is better for testing the effect of foliage plants on performance. A more homogenous task may induce boredom and sleepy feelings. Among researches mentioned above, Doi et al. (2010) and Raanaas et al. (2011) used tasks with more variety of skills. However, the significance of the tasks used among researches was different.

It is better to experiment using task that has high significance. A task with higher task significance induced more motivation to the subject. Grant (2008) also suggested that higher task significance would increase job performance and employee`s dedication to the job. The task was significant if the result was identifiable and important. The feeling of importance of a task could also be given to the employee by the management or the trainer. In laboratory experimental setting, the researcher or experimenter can explain the importance of the task to the subject before the experiment is conducted.

Motivation of the worker in a workplace can be addressed by many ways. For example, Shibata and Suzuki (2002) gave subjects (students) extra credit for their participation in the experiment. Raanaas et al. (2011) gave the participants coupons for a drawing of a gift at a bookstore.

Another way to increase participant's motivation is to give a degree of autonomy on the task. Autonomy may foster continuous motivation (Garcia & Pintrich, 1996). Autonomy may be given by allowing subjects to control his/her course of action, by giving a number of alternatives to choose to make a decision, or letting the subject to search for an answer. Among researches presented in Table 1 and Table 2, only association task (Shibata & Suzuki, 2002, 2004) which had given a degree of autonomy to the subject, where the subject was asked to find a number of words associated with 20 adjectives.

Performance of some tasks may also be determined by subject's knowledge. In some task, knowledge is critical for its accomplishment. The more knowledge we have, the chance for us to anticipate and predetermine the task performance is greater (Vakkari, 1999). Tasks presented in Table 2 generally require more knowledge than tasks presented in Table 1. Among tasks presented in Table 2, proofreading was the task that used most of knowledge.

Knowledge is associated with the complexity of the task. If the task is more complex, more knowledge is required. In complex task, the subject needs to retrieve information, to relate and to integrate it with another kind of information. Information retrieval of a task is associated with attention, memory and reasoning resources used in the task. Tasks listed in Table 2 generally are more complex than tasks listed in Table 1.

Attention of the participants is affected by visual stimulus features and by task demands (Einhäuser, Rutishauser, & Koch, 2008). Task demands of tasks listed in Table 2 are high, whereas in Table 1 are lower. There are three kinds of task demand: mental demand, physical demand and temporal demand. Among the three kinds of task demands, mental demand is the most common task demand of tasks listed in Table 2. Temporal demand was found in association task in Shibata and Suzuki (2002, 2004). Physical demand was found in the typing task in Doi et al. (2010). As task demand in each task is different, the attention level required for the task is different. It might be difficult for subjects to pay attention to indoor plants if they spend a large amount of attention to the task.

Attention is a limited resource, so that after paying direct attention to task over a long duration, task performance may be decreased. According to the model of Attention Reservation Theory by Kaplan (1992), the performance can be restored by looking into a natural visual stimulus such as indoor plants, window, or pictures of natural scenery. On the other hand, if task duration is too short, the decrease in performance cannot be observed. Therefore, to understand the effect of an indoor plant on performance of a task, the duration of the task should not be too short, so that the dynamic of performance can be observed. Duration of tasks conducted in indoor plant researches was varied between 1 minute and 30 minutes. The task that is conducted in 1 minute or less is considered as short duration and task conducted in 10 minutes or more is considered as long duration (Heslegrave & Angus, 1985).

Performance of subjects in the experiment is not only affected by the characteristics of the task, but also affected by the condition of the subject prior to the experiment such as condition of sleep of the subject a night before experiment and learning process. If the subject has lack of sleep, his/her performance can be impaired. Most research in the effect of foliage plants on human performance was not taken into account sleep loss. Sleeping time of the day before experiment was reported in Doi et al. (2010). However, the quality of sleep was not reported.

2.6 Conclusion

Common characters of the task that foliage plants have affected in experimental researches were task complexity, attention requirement, time pressure, difficulty, duration, creativity, and feedback. Complexity of the task should not be so low or not too simple, which requires certain amount of logical thinking, information recognition, comprehension, storing and recalling from memory. A moderate amount of attention to the task (directed attention) is required for gaining the effect of foliage plants on the task. If the task is too easy, it will be less challenging. Therefore, it will be not so attractive or not so interesting. If the task is too difficult, the subject may be given up, so that the performance cannot be measured. Moderate duration of task is necessary while conducting experiment for studying the effect of foliage plants on human performance.

Foliage plants apparently have more effect on creative work such as association (Shibata & Suzuki, 2002, 2004), memory and addition, than on a short and repetitive work such as sorting (Shibata & Suzuki, 2002) or letter identification task. Creative task employs a more divergent process in mind, while repetitive task employs a more convergent process. Divergent process frees one from directed attention to other sources of attention. This source of attention is not necessarily related to the task.

These results can be used as a framework for task design in experimental research using plant as source of visual stimulation environment. Experimenter must take a lot of care of these factors. Failure in taking these factors carefully, may lead to unsatisfactory experimental results.

Chapter 3 THE EFFECTS OF THE NUMBER OF INDOOR FOLIAGE PLANTS ON PRODUCTIVITY, STRESS AND ATTENTION

3.1 Introduction

People spend a large amount of time in their workplace. In order to make their workplace more pleasant, people put plants, such as flowers or foliage plants in rooms. The availability of plants in a room not only makes the room more visually attractive, but also makes the air in the room fresher by lowering the level of pollutants, such as formaldehyde (B. C. Wolverton et al., 1984), benzene (Orwell et al., 2004) and toluene (Matsumoto & Yamaguchi, 2007). Contact with plants is believed to be restorative to the human spirit (Lohr et al., 1996). Therefore, human attitudes, behaviors and physiological responses were affected by interaction with plants (P Diane Relf, 1990).

Number of researches on the benefits of indoor plants to improve indoor air quality and its effect on humans has been increased. However, the results were varied. Some positive results were found, such as an increase in productivity (Lohr et al., 1996), reduction in stress of the employee (Coleman & Mattson, 1995; Lohr et al., 1996; Ulrich et al., 1991), improvement of employee morale (Chang & Chen, 2005), reduction in health complaint (Fjeld, 2000), reduction in sick leave (Bringslimark et al., 2007), increase in satisfaction (Dravigne et al., 2008), and improvement on quality of working life (Dravigne et al., 2008). On the other hand, some negative results were also found in several studies such as decrease in productivity (Larsen et al., 1998) and increase in the level of perceived stress (Bringslimark et al., 2007). Larsen et al. (1998) showed that subjects working in a room with no plants had higher productivity than working in a room with 10 plants and a room with 22 plants. Therefore, there might be an optimal number between two extreme numbers of plants to be placed in a room. Moreover, Bringslimark et al. (2007) showed that an increase in the number of plants placed 1 meter from the subject would increase the level of perceived stress.

These differences in results might be caused by differences in the method adopted by each researcher, such as differences in the task, in acclimatization time, in work duration, in the number of plants, in the size of plants and also the arrangement of plants. A study on task design, acclimatization time and work duration of indoor plant research has been conducted by Jumeno & Matsumoto (2012).

The objective of the present study is to investigate the effects of the number of plants on human productivity, attention, and level of stress. In the present study, a laboratory experiment was conducted where subjects were instructed to conduct a word search task in a climatic room with different numbers of plants in each condition. To measure productivity, the number of forms and the number of words found were used as the dependent variable. To measure attention, a secondary task reaction time (STRT) was applied. Lang, Bradley, Park, Shin, & Chung (2006) suggest that STRT can be used to measure attention. To measure the level of stress, heart rate change between heart rate before the task and heart rate after the task was used. To understand further the effect of the number of plants on productivity, attention and stress, a questionnaire was given to the subjects.

3.2 Methods

3.2.1 Materials

Seven plants were used in the experiment. The seven plants were *aglaonema commutatum*, *spathyphyllum*, *epiremnum aureum*, *benjamin*, *schefflera arboricola*, and *neoregeria* as shown in Figures 1 - 6. All plants were potted and were placed on the table and on the floor. The plant heights were varied from 20 to 120 cm.

Numerous papers containing numerous alphabet characters were used for the word-search task. The objective of the task was to finish as many papers as the subject could do.

Figure 1. *Aglaonema Commutatum*

Figure 2. *Spathiphyllum*

Figure 3. *Epipremnum aureum*

Figure 4. *Benjamin*

Figure 5. *Scheflera arboricola*

Figure 6. *Neoregeria*

3.2.2 Facility

The experiment was conducted in Toyohashi University of Technology, in the climatic chamber of the Building Environment Laboratory, from 09:00 until 20:00, from June 6 to July 14, 2012. The space of the chamber was 3.57 meters in length, 2.67 meters wide, and 2.44 meters high. The illuminance on the desk was 408 lx, from two fluorescent lamps and without daylight.

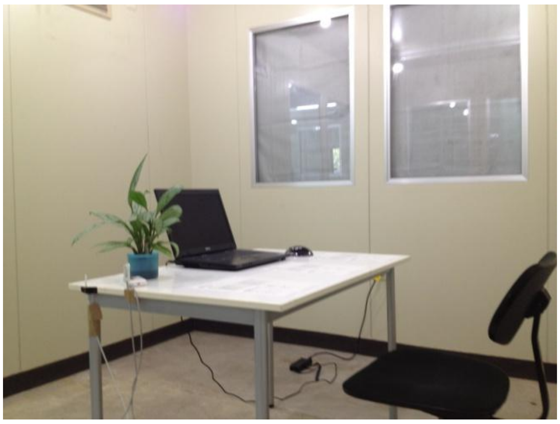
3.2.3 Subjects

18 subjects participated in the study, with volunteer or unpaid basis. Among the 18 subjects, 10 were male and 8 were female, with age ranged from 22-30 years old with average 23.5 years old. All participants were university students from various departments. Average height of the subjects was 169 cm. Average weight of the subjects was 60 kg.

3.2.4 Experimental conditions

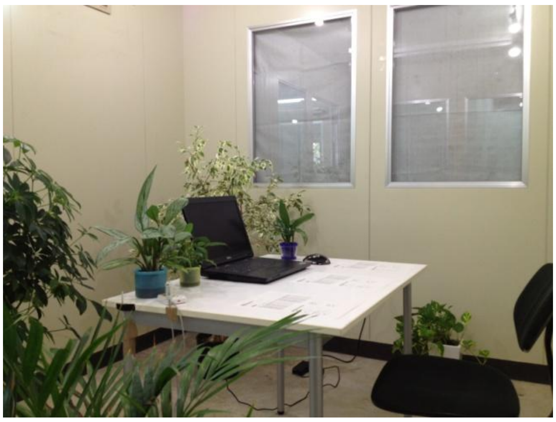
Four conditions were tested during the experiment. The four conditions were a room with no plant, one pot of plant, 3 pots of plant, and 7 pots of plant in the room. The four conditions were depicted in Figure 7.

a) No plant condition



b) 1 plant condition

c) 3 plants condition



d) 7 plants condition

Figure 7. Conditions of the experiment

3.2.5 Measurements

Heart rate before and after performing the primary task, secondary task reaction time (STRT), and productivity (number of forms and number of words) were measured during the experiment. Air temperature, air humidity, CO_2 compound, and lighting conditions were measured during the experiment. Air temperature and air humidity were measured and monitored using Espec RS 212 as shown in Figures 8 and 9. CO_2 levels were measured using Custom CO2-M1 as shown in Figure 10.

Figure 8. Espec RS-212 for air temperature monitoring

Figure 9. Espec RS-212 for air humidity monitoring

Figure 10. Custom CO2-M1

3.2.6 Experimental procedure

A within subject design was selected as the experimental design due to the limited number of participants, in which all 18 subjects participated in all conditions. A within-subjects design is an experiment in which the same group of subjects serves in more than one treatment. A within subject design is also called as a repeated measures design in some literature. However, to overcome learning bias, the sequence of conditions that followed by the subjects was randomized.

Before performing the task, the subject was given 10 minutes for acclimatization with room condition. After 10 minutes, the heart rate of the subject was measured. Then, the subject performed a word search on a form. Words on the form were in English. When a word was found, the subject then highlighted the word. The subject was instructed to find as many words as he/she could within 10 minutes. During the experiment, the subject was presented with a sound signal from a laptop. When the subject heard the signal, the subject was instructed to react to the signal by pressing the “Enter” key. The time between the signal was launched and the “enter” key was pressed was measured. After the task had been finished, the subject was instructed to fill in the questionnaire for 5 minutes. Schedule of the experiment is shown in Figure 11.

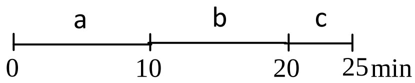


Figure 11. Schedule of the experiment

3.2.7 Statistical analysis

Data for subjects tested in all conditions were compared. A repeated measures test of the general linear model was performed to compare means of heart rate, secondary task reaction time, and productivity for all conditions. On the other hand, a nonparametric test of related samples Friedman's Two Ways Analysis of Variance by Ranks was performed to compare data of subjects' perception of the conditions. Statistical tests were performed using IBM SPSS Statistics Release 20.0.0.

3.3 Results

Physical measures of indoor environment were presented in Table 3.

Table 3. Physical measures of indoor environment

	No plant	1 plant	3 plants	7 plants	Test of ANOVA
Temp., $\bar{X}$:	24.3	24.3	24.2	24.1	F = 0.41
SD:	0.6	0.6	0.6	0.8	p = 0.70
Humid., $\bar{X}$:	82.9	83.4	82.1	83.3	F = 0.22
SD:	6.5	6.5	7.5	6.4	p = 0.86
CO_2, $\bar{X}$:	973.3	856.4	1017.4	933.8	F = 2.96
SD:	189.4	148.0	228.0	251.9	p = 0.06

$\bar{X}$: average SD: standard deviation

Table 3 shows the average ($\bar{X}$) and standard deviation (SD) of temperature (Temp.), Humidity (Humid.) and CO_2 concentration of each treatment (column 2-5). A two way analysis of variance (ANOVA) was conducted to examine the difference among conditions. The results of ANOVA test are presented in 6th column in Table 3. In Table 3, F is the value of test statistic, and p is the probability of obtaining result of test hypothesis that the means of each treatment are equal. If p value is smaller than 0.05 we can reject the null hypothesis, and conclude that treatments are significantly different.

From Table 3, it can be observed that there was no significant difference in the temperature and humidity. A significant difference was found on the CO_2 level, with p value < 0.1, which means that the probability of treatments are equal is lower than 10%. The lowest CO_2 was the room with 1 plant condition. However, the relationship between the number of plants and CO_2 level was unclear. From Table 3, it also can be seen that rooms with 1 plant and 7 plants have lower amount of CO_2 than rooms with no plants and rooms with 3 plants. CO_2 sensor was located on the desk, 40-50cm in the front of the subject.

Dependent variables measured in the experiment were presented in Table 4. Averages of condition 1, 2, 3, and 4 were presented in 2nd, 3rd, 4th, and 5th columns respectively. The 7th column contained the results of the ANOVA test, which is used for examining the averages among the 4 conditions.

Table 4. Physiological and productivity measures

	No plant	1 plant	3 plants	7 plants	Test of ANOVA
Heart rate change, $\bar{X}$:	2.0	3.3	3.9	2.9	F = 0.51
SD:	3.7	6.4	5.3	5.3	P = 0.67
Average of STRT, $\bar{X}$:	1.5	1.7	1.5	1.4	F = 1.94
SD:	0.2	0.6	0.2	0.2	P = 0.18
STRT change, $\bar{X}$:	0.0	-0.4	0.2	0.2	F = 0.94
SD:	0.3	2.0	0.3	0.5	P = 0.36
Number of papers, $\bar{X}$:	4.9	5.0	4.8	5.3	F = 0.44
SD:	1.6	2.7	1.7	2.2	P = 0.67
Number of words, $\bar{X}$:	42.0	45.7	42.7	44.4	F = 0.36
SD:	14.8	26.34	17.3	20.8	P = 0.72

During the experiment, STRT was measured 4 times, randomly. From these measurements, the average value of STRT can be obtained. The change of the STRT variable was used to detect any change of reaction time during the experiment, which was obtained by subtracting the 4th measurement by the 1st STRT measurement. Most of the averages of STRT changes were positive, except for conditions with 1 plant. It means that the average of the 4th STRT change was smaller than the average of the 1st STRT change.

From Table 4, it can be seen that there was no significant difference in the average of heart rate change, the average of STRT, the average of STRT change, average number of paper and average number of words among conditions, as the *p* values were larger than 0.05 or 0.1. Although the room with 7 plants was better on several variables than the other conditions, it was difficult to draw any conclusion based on the data on each condition due to the large standard deviation.

3.3.1 Questionnaire results

Perceptions of the participant on their physical condition, motivation and subjective feeling of the room are shown in Figure 12.

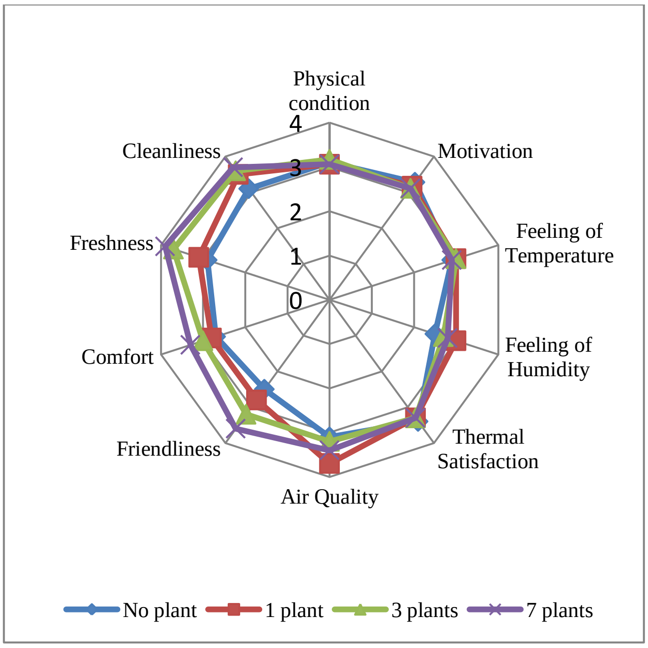


Figure 12. Subject's Perceptions of the Room

From Figure 12, it can be seen that physical condition, motivation, feeling of temperature, humidity, thermal satisfaction and air quality among conditions were not significantly different (*p* values were larger than 0.05). It can also be seen from this figure that significant differences were found in the perception of the subjects on friendliness, comfort, freshness, and cleanliness of the conditions ($p < 0.05$). From Figure 12, it can be seen that rooms with plants were perceived better than no plant condition. It also can be seen that the room with seven pots of plant has the largest area than the other experimental conditions. It suggests that the participants perceived the room with seven pots of plants best.

3.4 Discussion

3.4.1 Productivity

The result showed that there was no significant difference in the number of paper and the number of words among conditions. However, from Table 4, it can be observed that the room with 7 indoor plants had higher number of paper finished than no plant, 1 plant, and 3 plants condition. It seems that 7 was the optimal value for the number of plants, as decreasing or increasing the value into 10 plants would reduce the productivity. Larsen et al. (1998) suggested that the room with 10 plants and 22 plants had lower productivity than the room without any plant. However, further study with 8 and 9 plants is required to confirm this result.

3.4.2 Stress

The result showed that there was no significant difference in heart rate change among conditions. The insignificance might be caused by the high standard deviation of data. However, it is difficult to understand the cause of the high standard deviation of data of heart rate change. The high variability in heart rate change data might be due to the fact that for some participants the task was not so difficult, not fatiguing, and not stressful, although the duration was appropriate. Some of the subjects said that the task was interesting and challenging, therefore some of them wouldn't look stressed by the task. This finding confirms that plants had rather weak effects on stress measures and not always statistically significant as suggested by (Bringslimark et al., 2007; Chang & Chen, 2005; Coleman & Mattson, 1995; Lohr et al., 1996).

3.4.3 Attention

The result showed that although the room with seven plants condition was better in the average of secondary task reaction time than the other conditions (Table 4), this was not significant enough (p = 0.18). The result suggested that this might be that the subject still had enough resources to pay attention at the secondary task without being tied up to the primary task. The small value of STRT change (from -0.4 to 0.2 second) suggests that attention of the subject was not changed significantly during 10 minutes of the experiment. Therefore, a further study with a longer working time is required, so that attention change and fatigue can be observed.

Although not statistically significant, it can be seen from the mean value in Table 4 that the room with seven plants was superior to the other conditions. The room with seven plants condition has the lowest average of secondary task reaction time, the highest number of forms finished, and the second highest number of words found. Therefore, the room with seven plants was best for participants' productivity and attention. This also was supported by the fact that the room with seven plants condition was perceived as the most friendly, the most comfort, the most fresh, and also the most clean among the other conditions, as shown in Figure 12. Compared to the results of Larsen et al. (1998) and Lohr et al. (1996), our findings support the idea that the presence of plants may increase worker productivity and worker attention in tasks requiring moderate concentration, and improve the feeling on the environmental quality.

However, due to relatively small sample size, determining whether these differences in perception are as a result of the number of the plants or random variation is difficult. The differences found in this study were from hypothesis generating study. Therefore, a study with larger sample size is required. Moreover, as the subjects in this study were mainly students, a further study with more variations in the demography of the subjects is also considered.

As the task carried out by the subject in the experiment is a visual search, lighting factor is also important. Also, plants need light to grow and for photosynthesis, so that they can absorb CO_2 and release O_2. In this experiment, however, the level of light is almost the same throughout the experiment days, as no daylight is used in the experiment, and the source of light was only two fluorescent lamps, the same for every treatment. Therefore, the results of the present study are not affected by lighting condition.

3.4.4 Perception of room condition

Results of the study show that subject' perceptions of comfort, cleanliness, freshness and friendliness of conditions were significantly different. Subjects perceived that room with more plants is more comfort, cleaner, fresher and friendlier than room with less or no plant. This is in line with the notion that humans prefer a more natural environment, which has more greenery. This also supports the notion that bringing natural aspects indoor will provide comfort, fresh and friendly to its occupants.

However, there are several limitations of the study such as the number of subjects, the characteristics of the subjects, and the age and type of plants. Moreover, a future study also is required to measure the distribution of CO_2 in the room where the subject participated in the experiment.

3.5 Conclusion

In the present experimental study, the following question was addressed: what is the effect of the number of the indoor foliage plants on productivity, stress and attention? After carefully controlling other physical factors and designing tasks appropriate for the study, we found that the effects of the number of plants on subjects' perceptions in the friendliness, comfort, freshness, and the cleanliness of the room were statistically significant. The best number of plants that should be placed in a room sized 9.53 meters squared was seven. However, as it is not easy to determine whether these differences are due to the number of plants or simply the chance, a further confirmatory study with larger sample size is required. On the other hand, the effects of the number of indoor foliage plants on productivity, stress and attention were not statistically significant.

Subject's perception in temperature, humidity, thermal satisfaction and air quality among conditions was also not significantly different.

Chapter 4 EFFECTS OF THE QUANTITY OF INDOOR FOLIAGE PLANTS ON MOOD, PRODUCTIVITY, AND PERCEIVED AIR QUALITY

4.1 Introduction

Nowadays, people mostly spend their time indoors. By working indoors, work performance no longer depends on the weather, the time of day, or the time of year (Wyon, 2004). It was reported that 90% of Americans' time was spent indoors and more importantly, indoor pollutant levels were two to five times higher than outdoor levels (U.S. Environmental Protection Agency (U.S. EPA), 2005). Therefore, indoor air quality is important not only for occupants' comfort but also for their health.

People place plants indoors to create a pleasant interior space and to make the indoor air fresher. Since the 3rd century BC, people have used plants as indoor decorations (Bringslimark, Hartig, & Patil, 2009). However, it has only been since the late 1950's that plants started being used in office landscape planning (Pearson-Mims & Lohr, 2000). The presence of plants can make the indoor air fresher because plants release O_2 and absorb CO_2 (Tarran, Torpy, & Burchett, 2007; Wood et al., 2006) and other indoor pollutants such as formaldehyde (H.-H. Kim et al., 2014; K. J. Kim et al., 2008; B. C. Wolverton et al., 1984), benzene (Orwell et al., 2004; Torpy, Irga, Moldovan, Tarran, & Burchett, 2013), toluene (Matsumoto & Yamaguchi, 2007; Wood et al., 2006), and airborne microbes (Kobayashi, Kaufman, Griffis, & Mcconnell, 2007; B. Wolverton & Wolverton, 1996). Indoor plants improve the air quality and make the office a more desirable place to work (Shoemaker et al., 1992). Having plants in the office can increase worker productivity and attentiveness, reduce work stress (Bringslimark et al., 2007; Chang & Chen, 2005; Grinde & Patil, 2009; Lee, Lee, Park, & Miyazaki, 2015; Lohr et al., 1996), increase positive feelings about the environment and increase the level of pain tolerance (Lohr & Pearson-Mims, 2000). They reduce worker's health complaints (Fjeld, 2000; Largo-Wight, Chen, Dodd, & Weiler, 2011), and feelings of job pressure, while increasing job satisfaction (Dravigne et al., 2008).

Although there are some evidences that the presence of plants benefits the occupants, the placement of plants indoors is generally more instinctive or artistic than it is rational. Some previous works showed that plants have no significant effects on humans (Adachi et al., 2000; Lohr & Pearson-Mims, 2000; Raanaas et al., 2011; Shibata & Suzuki, 2002, 2004; Shoemaker et al., 1992). In a survey study conducted in an office in Virginia, there was no evidence that plantscaping affected behavior, attitudes or work satisfaction (Shoemaker et al., 1992). There was no difference in the attitudes of the workers before and after the plants have been introduced. In the examination of pain tolerance, there was no significant difference in the participants' blood pressure and skin temperatures among treatments (Lohr & Pearson-Mims, 2000). Moreover, another study also suggested that the presence of plants did not affect the mood of the participants (Shibata & Suzuki, 2002).

On the other hand, there are some works that show negative effects of plants (Bringslimark et al., 2007; Larsen et al., 1998; Yang, Son, & Kays, 2009). In an investigation of the effects of indoor plants on a letter identification task, it was found that people who worked in a room with 10 - 22 plants performed lower productivities than those who worked in a room without any plants (Larsen et al., 1998). Moreover, another study also found that an increase in the number of plants placed indoors increased the level of perceived stress (Bringslimark et al., 2007). Therefore, there is a need to look for a more systematic method for placing plants indoors to gain positive results, such as questioning how many plants are best for humans, as studies in this area indicated that putting plants indoors was good, but putting too many plants was worse than putting no plants inside of a room. It is also important to add that some VOCs also released by some ornamental plants (Yang et al., 2009).

Therefore, how many plants should be placed in a room is still unclear. However, it seems that it is not only the number of plants that affected human productivity and stress, but also the size of the plants. The bigger the plant, the more leaves it has and the more pollutants it can absorb, so it has been hypothesized that the bigger the plant, the better the air quality.

The behavior of humans is influenced by mood. Mood is defined as a conscious state of mind or predominant emotion (Merriam-Webster.com, 2014). People always seek satisfaction by maintaining positive moods and avoiding or repairing negative moods (Gendolla, 2000). Moods are naturally influenced by the pleasantness of the environment (Schwarz, Strack, Kommer, & Wagner, 1987). As humans are more interested in a natural setting rather than an urban setting, it is hypothesized that the more plants there are and the bigger the size, the better the mood and productivity of the occupants.

Perceived air quality is the perception of a subject toward complex stimulation from the environment. It depends on various sensory processes such as vision and olfactory. Humans largely rely on their sense of vision. Therefore, visual perception might play an important role in the perceived air quality. Moreover, visual stimuli can also be used for restorative functions, especially for individuals working on tasks that demand a high amount of attention. In the present study, how the appearance of foliage plants affected subjects' subconscious perceived air quality will be investigated. Perception is a quick process. Because of the sensory adaptation process, the longer the subjects receive stimulation, the less the intensity of their judgment. However, the success of the detection of a pollutant or odour also depends on the ratio of the stimulation and the background activity of the nerves (Hedge, 1996). Other factors that might affect sensitivity to air quality are personal, occupational, and psychological factors (Hedge, 1996). In addition, the sensitivity to perceived air quality is affected by air temperature (Iwashita, 1992).

The aim of the present study is to investigate the effects of the number and size of plants on mood, attention, productivity and perceived air quality (PAQ). No previous work on the effects of the size plants or the combination of the number and size of plants on mood, attention, productivity and perceived air quality was found in the literature. In the previous study, we investigated the characteristics of tasks conducted in the study on the effect of foliage plants on human performance (Jumeno & Matsumoto, 2012).

Furthermore, in the previous study we also compared the effects of differing numbers of foliage plants on productivity and stress (Jumeno & Matsumoto, 2013).

4.2 Methods

A factorial design experiment containing two factors was adopted to study the effect of the number and the size of plants on perceived air quality, mood and productivity. The first factor was the number of plants, and the second was the size of the plants. The first factor had two variations, and the second factor consisted of three variations. The dependent variables were perceived air quality, mood and productivity. Because humans are largely reliant on our sense of vision, the appearance of foliage plants may affect our perception of air quality as well as our perception of air freshness. However, the effects of foliage plants on perceived air quality may also be affected by the amount of fresh air compared to the amount of pollutant, such as CO_2 and VOC. In this study the air pollution source was the breathing of the subject. The experiment was conducted in a laboratory that was designed to mimic the conditions of a working room. Room temperature, humidity and air velocity of the experimental room were kept constant by an air conditioner and a ventilator.

Besides plant factors, the other cause of differences in the research results on the effects of foliage plants on human performance and stress was the task design performed in the previous studies. Task designs that might cause differences in results were the task type, task demand, work duration, and acclimatization time (Jumeno & Matsumoto, 2012). In the experiment, each subject was asked to do a word search task, so that subject's moods and attention at work and productivity can be measured. A word search is a simple productivity task in which the objective is to locate and highlight the words hidden within a grid of letters. Teachers use word searches as an educational tools, especially in language and foreign language classes. In our experiment, the word search task was used for the purpose of measuring productivity and attention. Some studies also used word search tasks to measure attention and cognitive search abilities (Hills, Todd, & Goldstone, 2008; van den Berg, Manstead, van der Pligt, & Wigboldus, 2006). This task can provide subjects with significance and autonomy, require certain levels of knowledge as well as a moderate level of task demands, and its results can be easily calculated. The word search task is significant, as it involves text editing and also requires skills similar to visual checking for quality control. For the participants, word search tasks can provide many benefits, such as increasing the subject's vocabulary, spelling skills, pattern recognition skills, memory, flexibility and speed. The above characteristics and benefits constitute the meaningfulness of this task.

The word search task was paper based. The subject was asked to search for words listed at the bottom of the paper and to highlight the words in the puzzle. There were 8-10 words in each paper, and the subjects were asked to finish as many words or papers as he/she could within the given time duration of 10 minutes. Before the task was commenced, subjects entered the room and spent 10 minutes to acclimatize with the room condition. Each subject's heart rate was measured just before the task was started and just after the task was finished. The schedule of the experiment is shown in Figure 13.

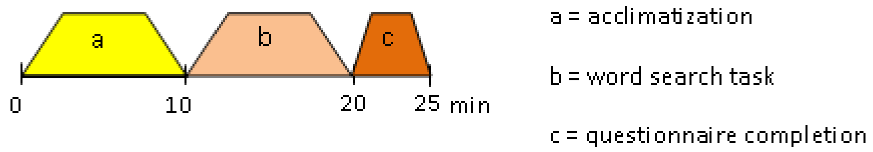


Figure 13. The schedule of experiment

4.2.1 Subjects

Eighteen subjects, 10 females and 8 males, voluntarily participated in the study. The ages of the subjects ranged from 22-30 years old with an average age of 23.5 years. All participants were university students from various departments. Average height of the subjects was 169 cm. Average weight of the subjects was 60 kg. All subjects participated in all treatments. Therefore, a crossover design was applied in the experiment. With a crossover design, the same confidence interval for the treatment effect could be obtained by using one quarter of the number of subjects as in a fully-controlled design would have required (Hopkins, 2000). The main benefit of applying a repeated measures design is the reduction of variability between people. Therefore, it will be less difficult to detect the real differences between treatments by applying a repeated measures design. Moreover, an experimental study needs only one-tenth of a sample size than a descriptive study on the same level of confidence interval (Hopkins, 2000). Sequence of treatments in repeated measures design is allocated by a randomized blinded process (Wang, Lorch, & Bakhai, 2006). Before taking part in the experiment the experimenter read the procedure to all subjects, and then all subjects signed consent form fro the ethical committee of the Toyohashi University of Technology.

4.2.2 Experimental conditions

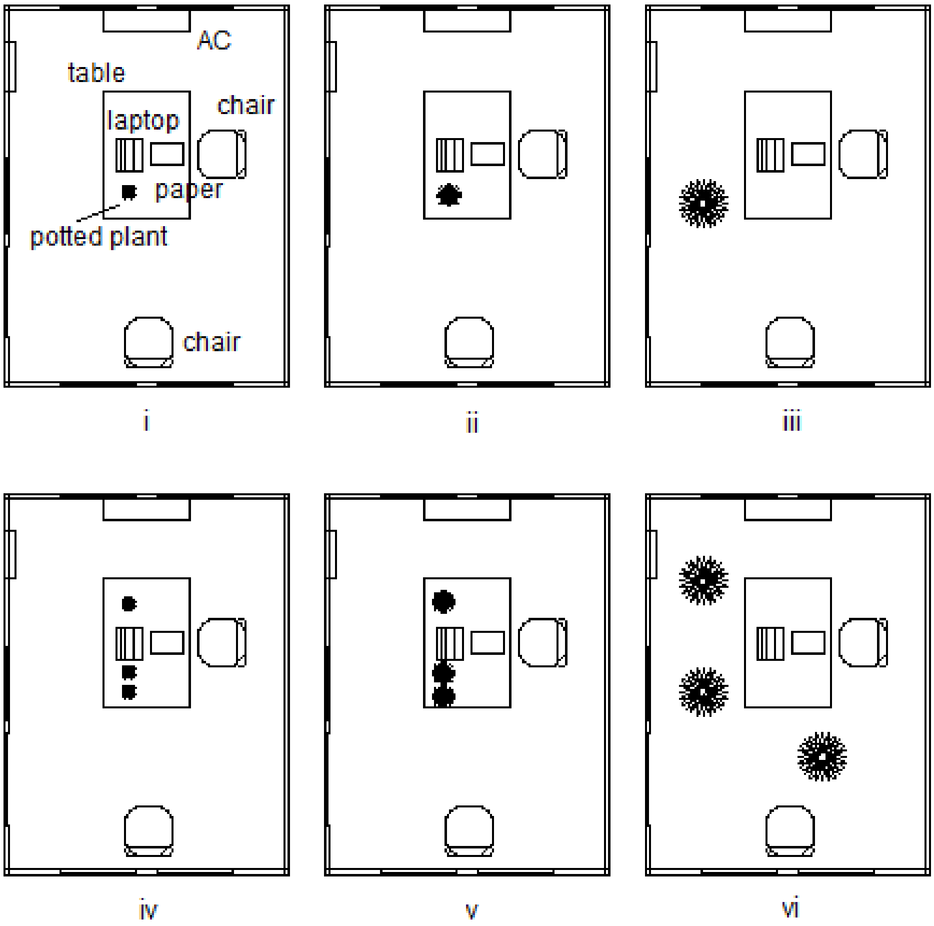
There were six experimental conditions, with different number and size of plants as presented in Table 5. All plants in the experiment were potted. Small-sized plants and medium-sized plants were placed on a desk and large plants were placed on the floor. The plants used in this experiment were *spathyphyllum, epiremnum aureum,* and *schefflera arboricola*. These plants were selected from among many kinds of plants because of their commonness and because they were available in three different sizes. Other plants may have only been suitable to be presented in one size. The small plants' were 20-30 cm height, the medium-sized plants' were 50-60 cm height, and the large-sized plants' were 90-100 cm height. All plants' color was green. The plants shapes were varied. *Spathiphyllum*, commonly known as peace lily, has lance-shaped leaves. *Epipremnum aureum*, commonly known as golden photos, has heart-shaped leaves. *Schefflera arboricola*, commonly known as umbrella tree, has hand-shaped leaves.

Plants were placed in the front of the subject, at the working height. The small-sized plants and medium-sized plans were placed on the table, whereas large-sized plants were placed on the floor. The experimental conditions are illustrated in Figure 14.

All subjects are participated in all experimental conditions or treatments. Randomization of the sequence of treatments for each subject is conducted to reduce a bias of learning. In some cases a single subject may have two consecutive treatments. When this is the case, the subject needs a washout or re-stabilization period between the treatments. Although this was not always the case, the minimum time given for re-stabilization period was 20 minutes. The experimenter also used this time to prepare the room for the next treatment.

Table 5. Experimental condition

No.	Number of plants	Size of plants
1	1	Small
2	1	Medium
3	1	Large
4	3	Small
5	3	Medium
6	3	Large



i. One small-sized plant, ii. One medium-sized plant, iii. One large-sized plant,
iv. Three small-sized plants, v. Three medium-sized plants, vi. Three large-sized plants

Figure 14. The experimental conditions' layout

4.2.3 Outcome

From the experiment, several variables such as mood of the subjects and the perceptions of the subjects on the air quality were measured using a questionnaire. The questionnaire was given after the end of the task. Productivity and attention were also measured during the experiment.

The questionnaire contained several items relating to the subject's impressions of plants and perceptions on thermal conditions and air quality. Subject impressions on plants consisted of five items: mood, friendliness, freshness, comfort, and cleanliness. The subject's perception of the thermal and air condition consists of feelings of three items: the subject's feeling of humidity, thermal satisfaction and PAQ. Each test item used a 5-level scale question. The scale of the questionnaire items is presented in Table 6.

Table 6. Questionnaire items scale

Items	Item's Scale
Impressions of plants	
Mood	1 (boring), 2, 3, 4, 5 (fun)
Friendliness	1 (friendly), 2, 3, 4, 5 (unfriendly)
Freshness	1 (fresh), 2, 3, 4, 5 (heavy)
Comfort	1 (uncomfortable), 2, 3, 4, 5 (cozy)
Cleanliness	1 (beautiful), 2, 3, 4, 5 (dirty)
Perception of thermal and air quality	
Feel of humidity	1 (dry), 2, 3, 4, 5 (humid)
Thermal satisfaction	1 (dissatisfied), 2, 3, 4, 5 (satisfied)
Perceived air quality	1 (dissatisfied), 2, 3, 4, 5 (satisfied)

To measure productivity during the word search task, the number of papers finished by the subject was counted. There were 10 words on each piece of paper that had to be found and highlighted by the subject. When the subject found all 10 words, the subject could proceed to the next paper. To measure attention, the reaction time of a secondary task is used. The subjects pressed the “enter” button on a laptop when a sound from the laptop was heard, while continuing to work on the primary task until end of the task’s duration.

4.2.4 Data analysis method

A number of data analysis methods were used in the study, as there were numerous parametric data and also non-parametric data. Data were analyzed using the general linear model (GLM) of repeated measures for comparing variances among treatments. Before the data were analyzed, they were restructured. In SPSS, data need to be restructured or rearranged from groups of related cases (treatment) so that data from each group are represented as a single case in a new data set. Means were compared using paired samples of t-tests. Bivariate correlation tests were conducted to measure correlations among variables. All statistical procedures were conducted using IBM SPSS Statistics 20.0.0.

4.3 Results and Discussion

Table 7 shows the parameters of the room condition during the experiment. The experiment was conducted in the summer season 2012 in Japan.

Table 7. Room condition measurements

Variables	Measurement
Temperature (inside chamber)	24.2 ± 0.6 ^{o}C
Temperature (outside)	26 ^{o}C
Humidity (inside chamber)	82.6 ± 6.4 %
Humidity (outside)	73%
Air speed (of air conditioner)	2.5 m/s
Air speed (of air ventilator)	0.8 m/s
Air speed (at working height)	0.01 m/s
CO_2 concentration (inside chamber)	942 ± 80 ppm
CO_2 concentration (outside)	512 ppm
Illuminance (at working height)	408 lux
Clothing insulation index	0.54 clo

Results of the measurements are shown in Table 8. The mean and standard deviation of the dependent variables of each treatment can be seen in Table 8. Moreover, Table 8 also shows the significant effects of the independent variables on the dependent variables.

Table 8. Means and standard deviation of dependent variables of each treatments

Size of plants	Mean (SD)						*F* value (*P* value)		
	Number of plants						Number of plants	Size of plants	Number & Size of plants
	1			3					
	S	M	L	S	M	L			
Thermal satisfaction	3.33 (0.97)	3.33 (0.84)	3.61 (0.85)	3.5 (1.01)	3.28 (0.83)	3.56 (0.86)	0.02 (0.90)	1.34 (0.29)	0.75 (0.49)
Feeling of Humidity	3.5 (0.71)	3.0 (0.97)	3.5 (0.62)	3.44 (0.70)	3.28 (0.46)	3.28 (0.58)	0.08 (0.93)	2.41 (0.12)	1.54 (0.25)
PAQ	3.11 (1.23)	3.67 (0.77)	3.67 (0.84)	3.78 (0.88)	3.22 (1.00)	3.56 (0.98)	0.23 (0.64)	1.01 (0.39)	7.61 (0.00)**
Friendliness	3.11 (1.08)	3.22 (1.00)	2.83 (1.04)	2.72 (1.02)	2.83 (1.10)	2.89 (1.13)	3.55 (0.08)	0.24 (0.79)	2.76 (0.09)
Freshness	2.83 (0.92)	2.89 (0.83)	2.83 (0.86)	2.67 (0.77)	2.28 (0.83)	2.5 (0.71)	5.86 (0.03)*	0.75 (0.49)	0.84 (0.45)
Comfort	3.06 (0.87)	2.78 (0.94)	3.06 (0.87)	3.39 (0.85)	3.00 (0.91)	3.33 (0.97)	2.93 (0.11)	1.11 (0.36)	0.10 (0.91)
Mood	2.56 (0.92)	2.28 (0.9)	2.44 (1.1)	2.83 (1.1)	2.83 (1.15)	2.72 (1.13)	5.04 (0.04)*	0.53 (0.60)	1.33 (0.29)
Productivity	5.11 (1.64)	5.0 (2.66)	4.67 (1.68)	4.67 (2.38)	4.83 (1.69)	5.06 (1.86)	0.25 (0.62)	0.08 (0.92)	0.94 (0.41)
Reaction time	1.46 (0.18)	1.66 (0.63)	1.49 (0.22)	1.51 (0.19)	1.46 (0.20)	1.46 (0.20)	1.07 (0.32)	0.97 (0.40)	4.48 (0.03)*

* Significant at $p < 0.05$

** Significant at $p < 0.01$

4.3.1 Mood

From Table 8, it can be seen that the highest mood is in Treatments 4 and 5, room with 3 small plants and room with 3 medium sized plants, which mean and standard deviation is 2.83 and 1.1 respectively. Figure 15 shows the average mood of the participants taken after the experiment.

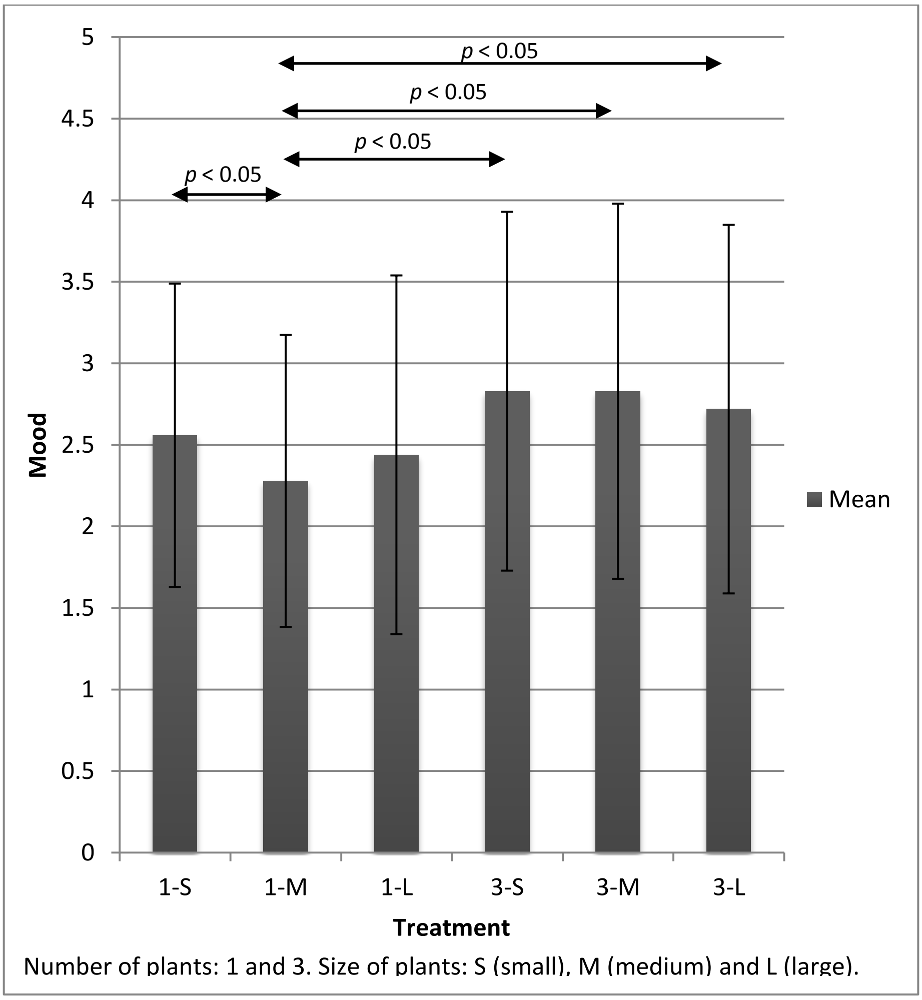


Figure 15. Mood of participants

Table 8 shows the effects of the number and size of plants on the mood of the participants. It can be observed that the effect of the number of plants on the mood of the participants is significant, F (1, 17) = 5.04, $p < 0.05$.

These results showed that the number of plants affects the mood of the subject, and that rooms with three plants were better than rooms with one plant. Also, an increase in the number of plants reduced the feeling of boredom in participants. These facts suggest that plants can be a source of fascination. Plants as a part of the natural setting can act as tools for a soft fascination by providing an opportunity for reflection and recovery from directed attention fatigue (Kaplan, 1995). Involuntary attention to plants, induced by indoor plants in a work setting, can provide recovery from attention fatigue. However, if the subject is too fascinated with the plants, this can lower productivity, as suggested by the results of this study, which show that the mood was negatively correlated with productivity. However, in a longer time setting, when the worker becomes accustomed with the plant, the fascination with the plant dwindles. If this happens, the occupant should change the plant with a new type frequently so that the fascination can be maintained. The results of our study were similar to the result of (Larsen et al., 1998). In their study on the effect of plant density, Larsen et al. (1998) found that the mood of subjects was more positive when the density of plants increased. However, in that study, the subject's performances were contrary to their mood. The subjects' performance decreased when the density of the plants increased. In another study, it was found that the presence and position of a plant had no effect on the mood of the participants (Shibata & Suzuki, 2002). Shibata & Suzuki (2002) presumed that the insignificant effect of a plant on the moods of the subjects was due to the short period of the task duration in the experiment.

4.3.2 Attention

The subjects' attention was measured in this experiment by using secondary task reaction time. Test statistics were obtained using SPSS and the results are presented in Table 8. In Table 8, it can be seen that there is an effect of the interaction of the number and the size of foliage plants on the secondary task reaction time, F (2,17) = 4.48, $p <$ 0.05. The secondary task reaction time of the subject can be seen in Figure 16. There is a significant difference between one medium-sized plant (1-M) and three medium-sized plants (3-M) treatment, where the 3-M has smaller reaction time than the 1-M treatment. Mean and SD of reaction time for 3-M as well as for 3-L are 1.46 seconds and 0.20 respectively.

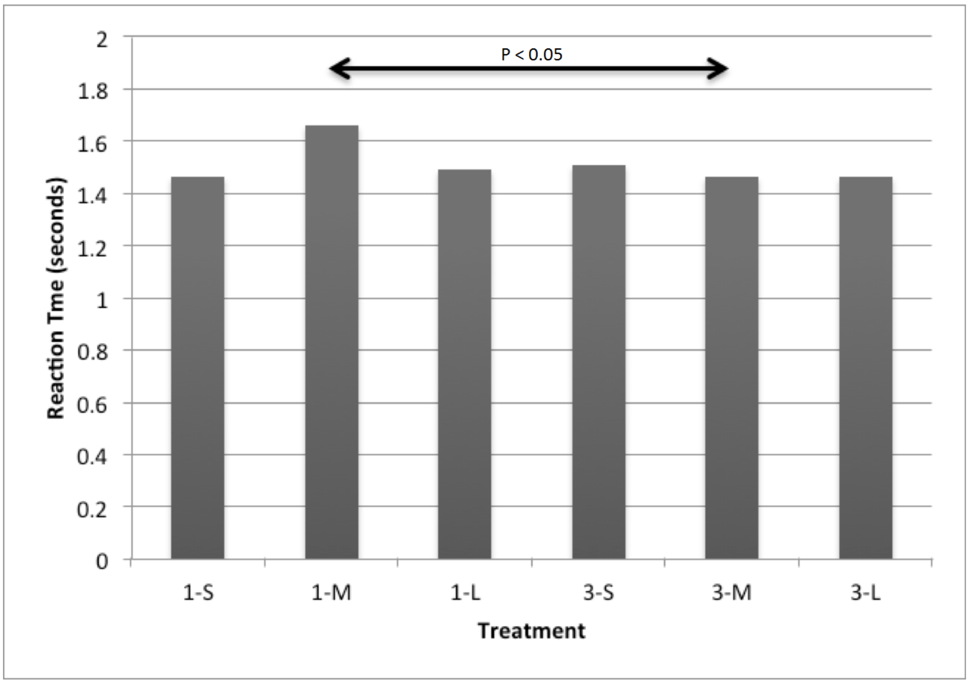


Figure 16. Secondary task reaction time

These results showed that there is an interaction effect between the number and the size of the foliage plants on attention. Based on reaction time, our results show that the best workplaces that produce the smallest reaction times are workplaces with 1-S foliage plant, workplaces with 3-M plants and workplaces with 3-L foliage plants. Faster reaction or smaller reaction times for the secondary task can be interpreted as the subject paying a sufficient amount of attention to the primary task. This means that 1-S plant, or 3-M or 3-L plants can be better sources of fascination. In attention restoration theory (Kaplan, 1995), when fascination is stimulated, directed attention is recovered, and fatigue is reduced or delayed. Our results support the idea that involuntary attention or fascination affects reaction time (A. Smith & Pitt, 2008). Foliage plants in this study act as sources of involuntary attention, whereas secondary task reaction time (STRT) has been used as a measure of attention.

4.3.3 Productivity

The mean and standard deviation of productivity of six treatments of the experiment are also shown in Table 8. The number of papers completed in the word search task measured productivity in the experiment. The highest total productivity is attained from Treatment 1 (1-S), and the second highest is attained from Treatment 6 (3-L). Mean ± SD of productivity for 1-S and 3-L are 5.11 ± 1.64 and 5.06 ± 1.86 respectively.

The results of this experimental study were similar to the result of (Lohr et al., 1996), but in contrast with the results of (Larsen et al., 1998; Shibata & Suzuki, 2002). Lohr et al. (1996), when comparing the presence of plants and the absence of plants, suggested that the presence of plants can increase worker productivity. On the other hand, Larsen et al. (1998) suggested that the presence of many indoor plants decreased worker productivity. In contrast to the above studies, Shibata & Suzuki (2002) yielded different results, as the productivity of the subjects was not significantly affected by the presence of plants. Comparing the productivity of subjects while performing a sorting task and an association task in the presence and absence of plants, Suzuki and Shibata (2002) found that the plant's effect is task-dependent. The effect of the plant is more significant in the association task than in the sorting task.

4.3.4 Perceived Air Quality (PAQ)

Figure 17 shows the subjective perceptions of temperature, humidity, thermal satisfaction and perceived air quality over the six treatments. It can be seen that Treatment 4 (3-S), has the highest PAQ among all treatments. Overall, the PAQ in a room with plants was better than in a room without any plants. Moreover, there was an increasing trend in the PAQ with an increase in green amenity.

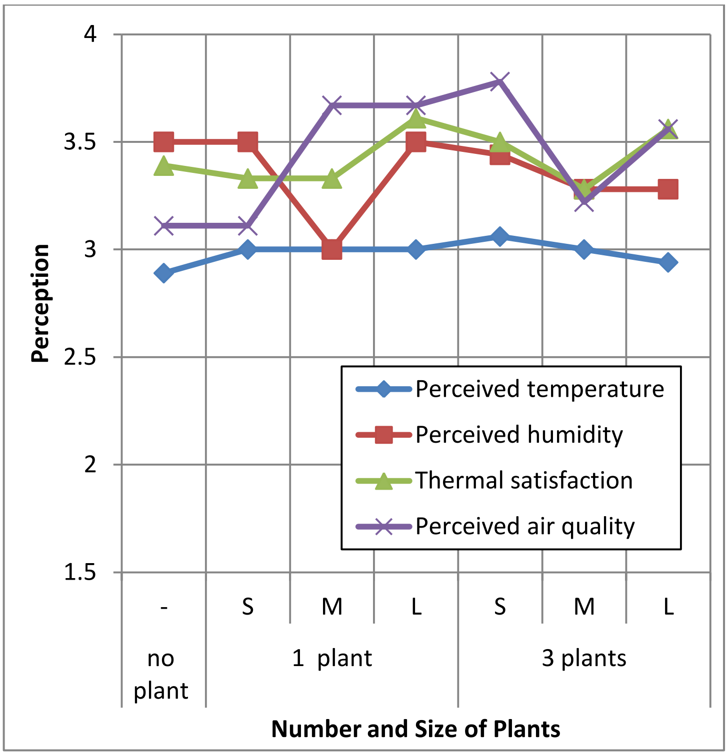


Figure 17. The effect of the number and size pf plants on perceived temperature, perceived humidity, thermal satisfaction and perceived air quality

The *p* values of the ANOVA test for repeated measures of the effects of the number of plants, the size of plants, and the interaction of these variables on PAQ are also presented in Table 8. It can be seen from Table 8 that there is a significant interaction effect between the number of plants and the size of plants on the PAQ, $F(2,17) = 7.61$, $p < 0.01$. From Figure 18, it can be seen that the room with 3-S has a better PAQ than the room with 3-M or 1-S. Also, the room with 1-M- or 1-L has a better PAQ than 1-S. The mean and SD for room with 3-S is 3.78 and 0.88 respectively.

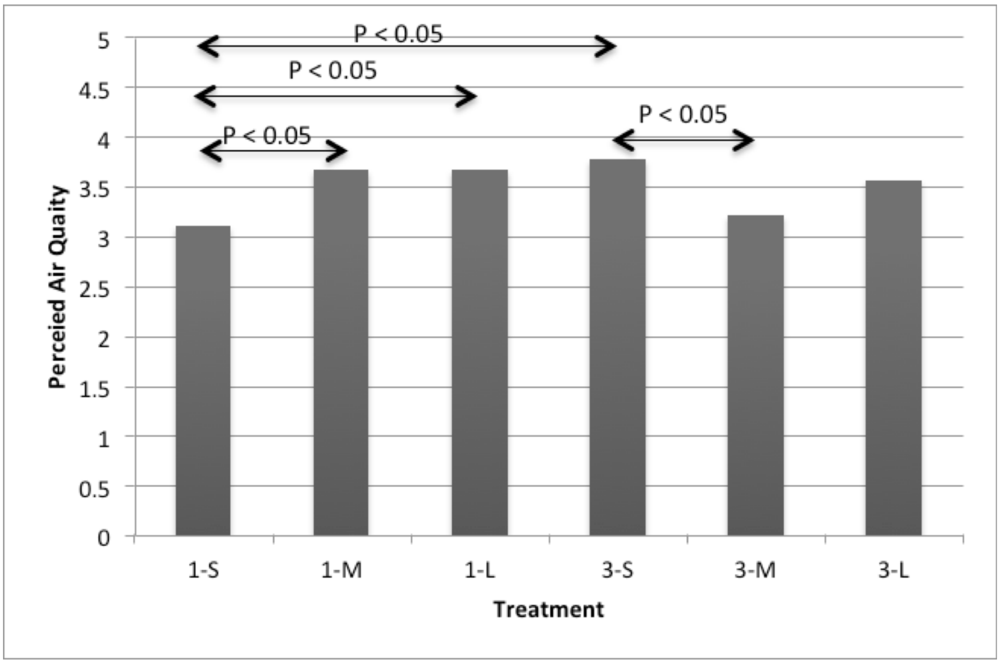


Figure 18. Perceived air quality

The results of this experimental study indicated that physical air quality in all treatments were acceptable, given that mean CO_2 concentration remained below 1000 ppm. Moreover, based on subjects' opinions, PAQ was measured by asking his/her degree of satisfaction, which shows the degree of acceptability of the perceived air quality. The results of this study show that the interaction between the number and the size of plants affects the perceived air quality. In smaller-sized plants, air quality was perceived to be better when there were three plants, but in medium- and large-sized plants, air quality was perceived to be better when there was only one. Small plants have a smaller number of leaves than medium-sized and large-sized plants. Therefore, it may be interpreted that there is an optimum value or range of the quantity of leaves that is perceived best by the occupants. This finding suggests that there is an optimal value or range of greenery brought by plants that is required by the occupants. The occupant's level of satisfaction concerning the air quality is the highest within this optimal quantity of foliage plants. This finding further suggests that the visual existence of plants is more important to the subject than its actual adsorption effect. The results of this study confirmed the findings of Smith & Pitt (2008), who suggested that 61% of participants preferred using plants to manage air quality over using mechanical methods, and of Doi et al. (2010), who found the difference in the latitude of PAQ between a room with plants and without plants. Despite the significant effect of this interaction, the influence of only the number and size of plants on the PAQ is still challenging to understand.

Further data analysis showed that the perceived air quality was positively correlated with freshness, friendliness, and comfort. These positive feelings of the occupants towards the room with plants were consistent with the results of other researchers (Fjeld, 2000, 2002; Larsen et al., 1998; Lohr et al., 1996; Shoemaker et al., 1992). Human comfort in the presence of foliage plants is mainly related to visual comfort. However, visual comfort during the experiment might be less than optimal due to the presence of a laptop. The existence of the laptop in front of the subject may be a problem for some people, but for other people may not be because they are already used to working at a PC or laptop for their daily activities. In the current experiment, the laptop functioned as an input device for measuring the subject's reaction time. To overcome the problem of visual comfort reduction, the functions of the laptop can be substituted with other devices such as a push button attached to the corner of the table and connected to a microcontroller and PC.

4.3.5 Correlation among variables

Table 9 shows the correlation between variables, where it can be seen that the number of plants is positively correlated with friendliness, freshness and comfor, $p < 0.05$. Friendliness, freshness and comfort were also positively correlated with thermal satisfaction and PAQ, $p < 0.05$. Furthermore, friendliness, freshness and comfort were positively correlated to each other, $p < 0.01$.

It can be seen that the PAQ is significantly correlated with thermal satisfaction ($p < 0.01$), the correlation between PAQ and thermal satisfaction is positive, and the magnitude of association is moderate. According to SPSS tutorial given by Kent University, $0.3 < |r| < 0.5$ is moderate. A significant correlation also found between productivity and mood ($p < 0.05$).

Table 9. Correlation among variables

Variable	Variable								
	1	2	3	4	5	6	7	8	9
1. Number of plants	1								
2. Size of plant	-	1							
3. Thermal satisfaction	-0.051	0.076	1						
4. PAQ	0.048	0.07	0.326**	1					
5. Friendliness	0.356**	0.022	0.414**	0.206*	1				
6. Freshness	0.445**	0.041	0.292**	0.301**	0.562**	1			
7. Comfort	0.243*	-0.013	0.473**	0.324**	0.698**	0.575**	1		
8. Mood	0.177	-0.043	-0.007	-0.092	-0.082	0.021	0.052	1	
9. Productivity	0.046	-0.006	-0.025	-0.087	0.135	0.108	-0.056	-0.201*	1

* Significant at $p < 0.05$

** Significant at $p < 0.01$

However, the findings of this study do not imply that these can be implemented in all places in the world at all times, as they are limited by the places and subjects of study, seasons, and characteristics of treatments. For a generalization, another study should be conducted under different circumstances, such as in a tropical region that has different climatic conditions and involving participants from different regions during different seasons. For future study, it is important to consider temperature differentiation, larger numbers of plants, different time durations, and different levels of task difficulties to gain more general results on the effect of plants on the perception and performance of occupants.

4.4 Conclusion

The effects of the number and size of indoor foliage plants on mood, attention, productivity, and perceived air quality were investigated through an experimental study. From the results of the experiment, several conclusions can be derived. The presence of plants indoors improves the mood, attention, productivity and the perception of air quality of the occupants. However, some factors need to be carefully considered. Firstly, it was found that the increase in the number of plants could trigger an improvement of the occupant's mood. Secondly, the interaction between the number and the size of foliage plants has an influence on perceived air quality and reaction time. Increase of perceived air quality is related to the increase in the quantity of greenery up to a certain number as well as the size of the plants. Overall, room with three large-sized plants constitutes the best condition for mood, attention, productivity and PAQ. Further study is required to determine the effect of plants on mood and productivity over longer durations.

Chapter 5 EFFECTS OF FOLIAGE PLANTS WITH DIFFERENT ILLUMINANCE AND TASK TYPES ON HUMAN IMPRESSIONS, STRESS AND PERFORMANCE

5.1 Introduction

People have put plants as indoor decorations since the 3rd century BC. However, only since the late of 1950s, plants have been included in office landscape planning. Plants have brought indoors, as people like to bring nature into their homes and believe that nature may give them more relax and peaceful. The presence of plants indoor has been reported to bring many benefits such as absorbing pollutant substances, increasing occupant's work performance, reducing occupant's stress and improving occupant's attention. Wolverton et al. (1984) reported that plants can absorb formaldehyde, make the room fresher. Moreover, the presence of plants indoors can reduce the concentration of benzene (Orwell et al., 2004) and toluene (Matsumoto & Yamaguchi, 2007). Results of Shoemaker et al. (1992) also suggest that the presence of plants improves the air quality of the office and makes the office a more pleasant place to work. Moreover, Lohr et al. (1996) suggests that indoor plants can increase worker productivity and attentiveness and reduce work stress. However, bringing too many plants indoors can lower productivity (Larsen et al., 1998) and increase the level of perceived stress (Bringslimark et al., 2007). Further study by the authors suggests that there is an optimal number of plants that can be brought into an office (Jumeno & Matsumoto, 2013).

The effect of indoor plant is also determined by the lighting condition. In general, plant requires considerable amount of light for photosynthesis to occur, so that CO_2 is absorbed by the plant and O_2 is produced, resulting fresher indoor air. However, there are several plants that can live in low light conditions such as photos (*epipremnum aureum*), philodendron, snake plant (*sanseviera trifasciata*), chinese evergreen (*aglaonema commutatum*), and peace lily (*spathiphyllum*). These plants are popular foliage plants that commonly used indoors.

On the other hand, human need a moderate level of lighting for working, especially for conducting a task that requires the use of vision. Knez & Kers (2000) pointed out that lighting affected the performance of cognitive task. Generally speaking, the performance of human is affected by environmental color or view (Stone, 2003). Nowadays, with the increase of the cost of energy, use of LED as a light source is becoming common. Moreover, LED also has been used as the major energy efficient light source for growing plants, because it consumes lower power, and capable of cutting out unnecessary spectrum and turning off the light periodically (Yeh & Chung, 2009). The aim of the current research is to study the effects of foliage plants with different illuminance and task types on human impressions, stress and performance.

5.2 Methods

An office room for two persons was designed by incorporating indoor foliage plants, energy efficient lighting, and personal ventilation. Foliage plants were located on the desk or on the floor. Measurements of the indoor climatic conditions, occupant productivity, level of stress, and attention level have been conducted to evaluate the eco-ergonomic office and have been compared to the typical office with the same size and conditions. To measure the level of stress, a CES-D scale (Centre of Epidemiologic Studies, (Radloff, 1977)), a subjective symptom complaint, and relax have been used. To simulate the working situation, an experiment was conducted using multiple crossover design experiment (Hopkins, 2000). 10 subjects participated in the experiment. During the experiment, the subject was instructed to perform four kinds of task. Temperature and air flow speed inside the room for both conditions were controlled. Conditions of the experiment are presented in Table 10. Room condition with and without plants are presented in Figure 19. The green coverage ratio was determined using Equations (1) and (2):

$$V_r = \frac{p_g}{T_p} \quad (1)$$

$$T_p = T - A_b \quad (2)$$

Where V_r is green coverage ratio, p_g is number of green pixel, T_p is total number of pixel of eyesight, T is total area, and A_b is black area. The total area presented in Figure 20, was captured by using fish-eye lens.

Table 10. Conditions of testing experiment

Condition	Number of plants	Lighting	Illuminance level [lx]	Green Coverage Ratio [%]
Case 1	0	LED	400	0
Case 2	0	Fluorescent	400	0
Case 3	1	LED	400	8.1
Case 4	1	Fluorescent	400	8.1
Case 5	4	LED	400	9.2
Case 6	4	Fluorescent	400	9.2
Case 7	6	LED	400	11.7
Case 8	6	Fluorescent	400	11.7
Case 9	6	LED	400	18.7
Case 10	4	LED + Fluorescent	1000	10.0
Case 11	4	LED	200	8.4

Types of plants used in this experiment were *fiscus benjamina*, *schefflera arboricola*, *aglaonema commutatum*, parlour palm, peace lily (*spatiphyllum*) and golden photos (*epipremnum aureum*). *Aglaonema commutatum*, peace lily and *epipremnum aureum* are unique indoor plants that can live in low light conditions.

Figure 19. Room condition. (Left) Without-plant and (right) With-plants

Figure 20. Area of eyesight, captured using a fish eye lens.

5.2.1 Subjects

10 people participated in the experiment, consisted of 5 males and 5 females. The range subjects' age was 22-24 years old. Average age of the participants was 22.1±1.1 years old. Average clothing index worn by the participants was 0.7±0.1.

5.2.2 Task

Participants were asked to do a word search task, typing, addition test, and Sudoku test, with duration of 10 minutes for each task and 10 minutes rest break between tasks. Total duration of each subject was 90 minutes. Before starting the task, the subjects were given 10 minutes for acclimatization with the room condition. After finishing each task, the subjects were given 5 minutes for filling the questionnaire about their stress condition.

5.3 Results and Discussion

Measures of thermal environment are shown in Table 11. Table 11 shows the average of temperature, average of relative humidity, average of mean radiant temperature (MRT), average of predicted mean vote (PMV) and average of predicted percentage of dissatisfied (PPD). The experiment was carried out in a climatic chamber, where the thermal condition was controlled. Therefore, there was no significant difference or pattern in thermal measures and comfort.

Table 11. Thermal environment measurement

Green Coverage Ratio	Temperature (°C)	Relative Humidity (%)	MRT (°C)	PMV	PPD (%)
0	25.3 ± 0.6	41.6 ± 0.9	26.1 ± 0.8	0.28	6.95
8.1	25.4 ± 0.5	52.6 ± 1.1	25.9 ± 0.6	0.32	7.18
9.2	25.6 ± 0.6	50.4 ± 1.5	26.2 ± 0.7	0.34	7.66
11.7	25.5 ± 0.5	45.2 ± 0.7	26.0 ± 0.4	0.36	7.76
18.7	25.0 ± 0.2	38.9 ± 1.0	26.5 ± 0.7	0.21	5.95

Subject impression of the room conditions is shown in Figure 21 and Table 12. It can be seen that as the green coverage ratio (GCR) increases, the subject's room impression also increases. The differences in room impressions between 0% GCR and other higher levels of GCR are significant. This suggests that the presence of foliage plants induces better impressions of the participants. From Table 12, it also can be seen that significant differences among 8.1%, 9.2%, 11.7% and 18.7% GCR conditions are only on pleasure and softness impression. Participants' impression of brightness and cosiness among the GCR conditions of 9.2% and above are not significantly different. There is also no significant difference in impressions between 9.2% and 11.7%, and also between 11.7% and 18.7% GCRs.

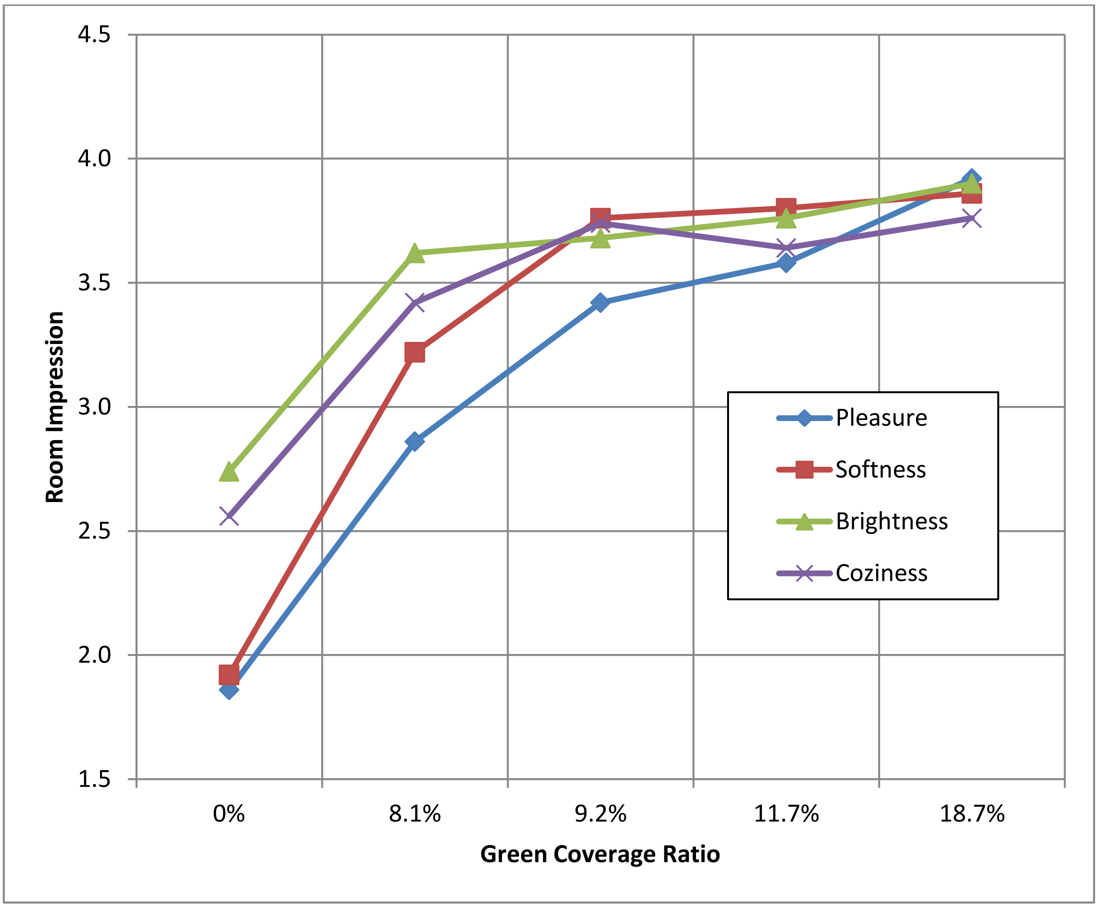


Figure 21. Green coverage ratio and Subject's room impression

Table 12. Subject's impressions differences between GCR conditions

GCR		Pleasure	Softness	Brightness	Coziness
GCR 0%	GCR 8.1%	**	**	**	**
GCR 0%	GCR 9.2%	**	**	**	**
GCR 0%	GCR 11.7%	**	**	**	**
GCR 0%	GCR 18.7%	**	**	**	**
GCR 8.1%	GCR 9.2%	*	**		
GCR 8.1%	GCR 11.7%	**	**		
GCR 8.1%	GCR 18.7%	**	**		
GCR 9.2%	GCR 11.7%				
GCR 9.2%	GCR 18.7%	*			
GCR 11.7%	GCR 18.7%				

In Figure 22, participants' impressions of different illuminance levels are shown. In general, higher levels of illuminance produce a better impression on the participants. From Figure 22 and Table 13, it can be observed that there were significant differences of the impression of pleasure, brightness, breeziness and quality between the illuminances 200, 400, and 1000 lx. However, there are no significant differences of pleasure, breeziness and quality between 400 and 1000 lx. This may be caused by the nature of the task, which is not requiring a high level of visual discrimination such as detail engineering drawing or assembling watches. For the tasks given in the experiment, like general task in office environment, 400 lx is adequate.

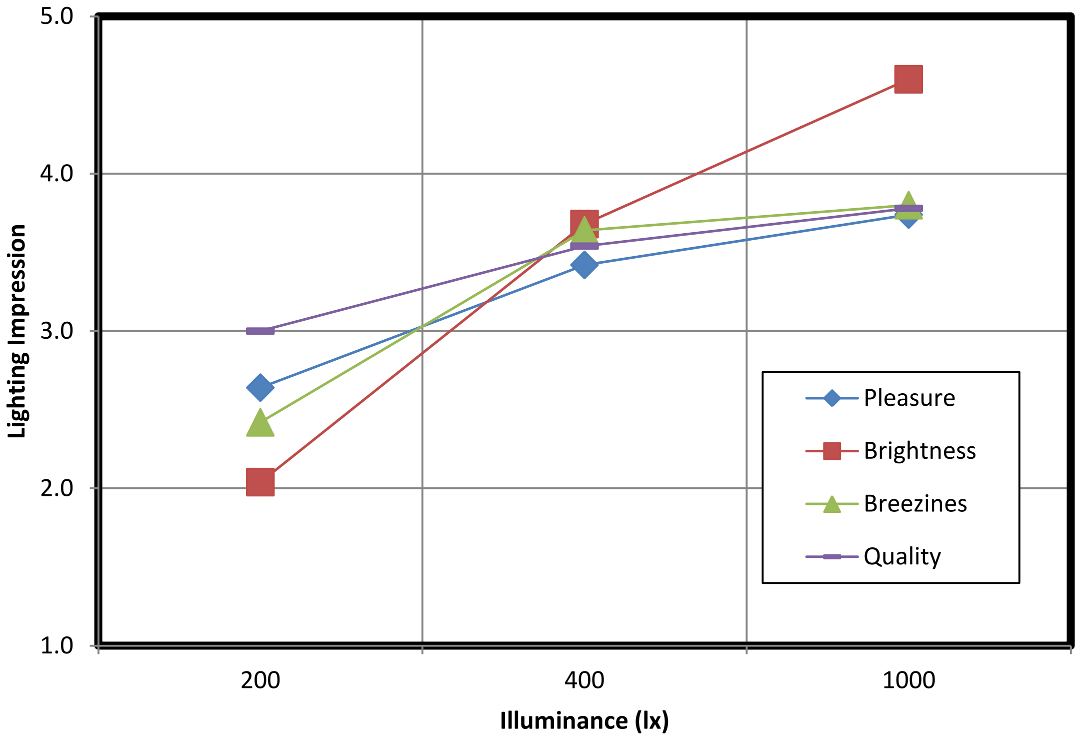


Figure 22. Illuminance and lighting impression

Table 13. Illuminance and lighting impression difference

Illuminance		Pleasure	Brightness	Breeziness	Quality
200 lx	400 lx	**	**	**	**
200 lx	1000 lx	**	**	**	**
400 lx	1000 lx		**		

Subject's measures of stress are presented in Figure 23. Three measures were used to measure stress, CES-D, symptom complaint, and relax. CES-D is a scale for measuring self-reported depression symptoms (Radloff, 1977). From Figure 23, it can be seen that with the increase of green coverage ratio, generally CES-D is decreasing, although there is an exception case with the 8.1% green coverage ratio. From Figure 23, it also can be seen that for subjective symptom complaint, a substantial decrease can be seen between 0% and the other green coverage ratios. However, among these nonzero green coverage ratios, a slight increase is found in 11.7% GCR, in both CES-D and symptom complaint. From our point of view, it might be that the optimum value for GCR is around 9-10%, so that increasing the GCR from that value will increase the index of CES-D or symptom complaint. Furthermore, it also can be seen from Figure 23 that there is an increase in level of relaxes with the increase in the green coverage ratio. In general, the presence of foliage plant decreases the level of stress of the participants, and on the other hand increases the level of relaxation of the participants.

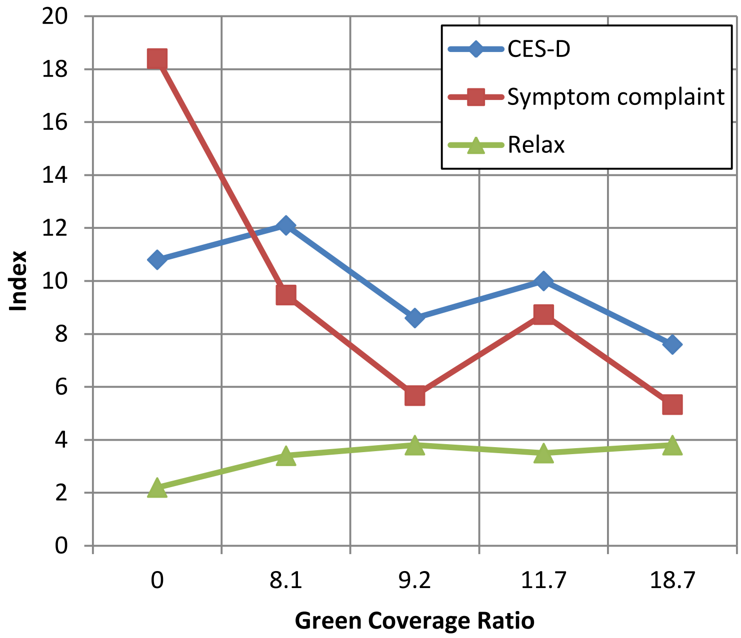


Figure 23. Stress index on 5 conditions with different green coverage ratio

In Figure 24 we can see the plot of the subject performance on the addition task on 5 green coverage ratio conditions. From Figure 24, it can be seen that the performance of the addition task and typing are scattered and does not show a significant pattern.

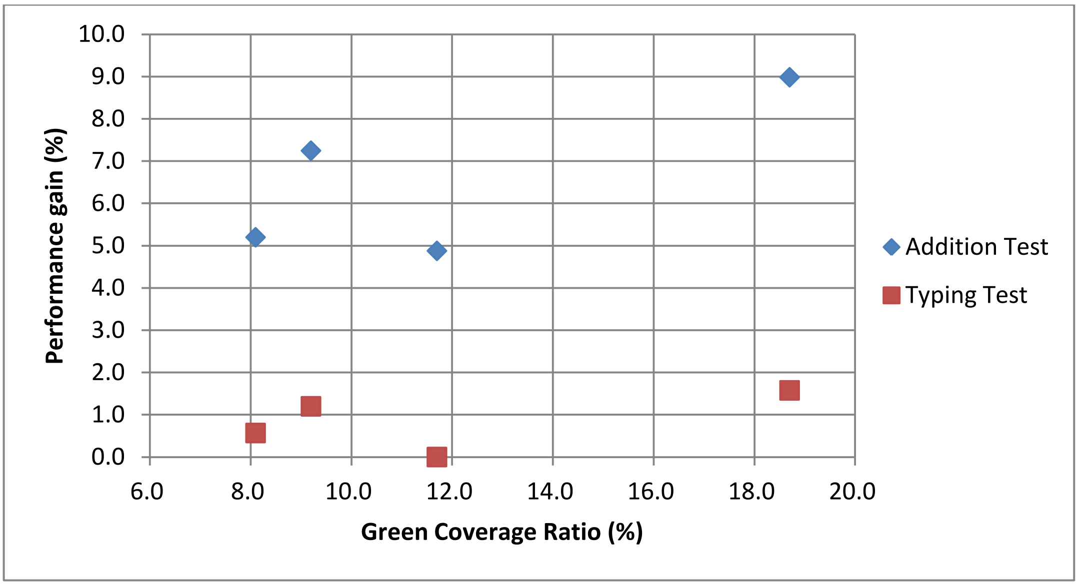


Figure 24. Performance of subjects with different green coverage ratio conditions in addition test and typing test

The performance of subjects on word creation task and Sudoku task are presented in Figure 25. From this figure, it can be seen that there is a significant correlation between performance of Sudoku task and green coverage ratio (R^2 = 0.9987). It also can be seen that as the green coverage ratio increases, the performance of Sudoku test also increases sharply. The correlation between performance of the word creation task and the green coverage ratio is also significant (R^2 = 0.7449). Although there is a positive correlation between performance of the word creation task and green coverage ratio, the rate of increase of performance is lower than that of the rate of increase of performance in Sudoku task. This result suggests that the presence of plants give more benefit on a task with a higher level of thinking.

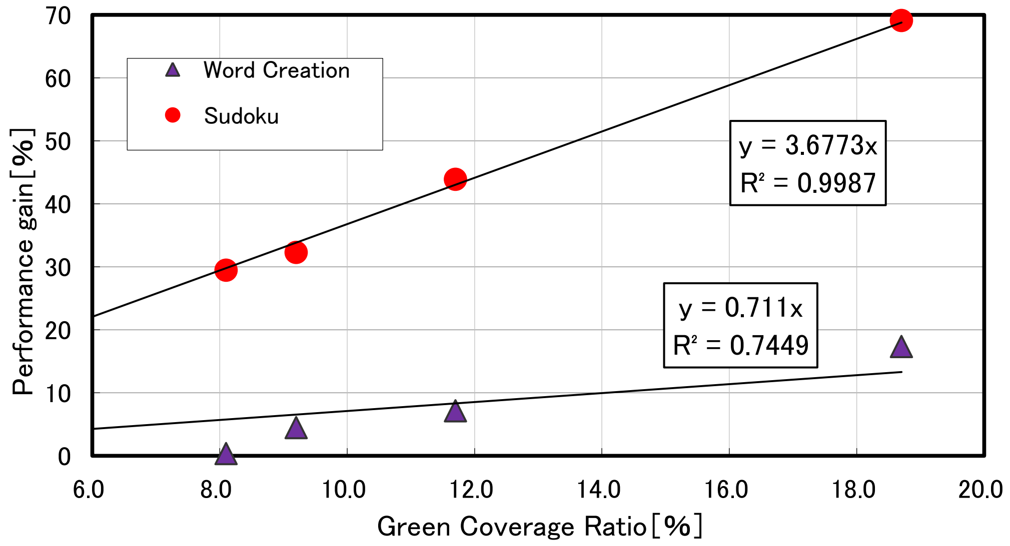


Figure 25. Performance of the subjects in room with different green coverage ratio on word creation and Sudoku test

However, the increase in performance for green coverage ratio above 20% is questionable, whether it will be continually increasing, or whether it will achieve a top performance and start to decrease at a certain point. Future study with more plants to get higher green coverage ratios can be conducted for this purpose.

5.4 Conclusions

Effects of foliage plants with different levels of illuminance and task types have been investigated by using a series of experiments. Several conclusions can be derived from the study. Firstly, it can be inferred that the impressions of the subject on room conditions are increase with the green coverage ratio. Secondly, higher levels of illuminance produce better pleasure, brightness, breeziness and quality impression on the participants. Thirdly, the increase of the green coverage ratio may decrease the level of stress and increase the level of relaxation. Moreover, the performance of subjects on Sudoku test and word creation test were increased when the green coverage ratio increasing, but the addition test and typing test did not show any significant pattern.

Chapter 6 EFFECTS OF FOLIAGE PLANTS ON HUMAN PHYSIOLOGICAL AND PSYCHOLOGICAL RESPONSES AT DIFFERENT TEMPERATURES

6.1 Introduction

Strong competition in business necessitates companies to streamline their operation which in turn producing an increase in task demand. At the same time companies are also required to react to customer's demand as fast as possible, producing time pressures to workers. Escalation of task demands and time pressures tends to make a worker run into work stress, which leads to mental fatigue and depression. The mental fatigue can be reduced when attention capacity is restored. Nature can serve as a source of fascination which can restore the attention capacity (Kaplan, 1995). For psychological restoration people are more favored to natural environment rather than urban environment (Hartig & Staats, 2006). People bring plants indoors so they can experience nature in their workplace. The increase in the number of indoor plants may increase the impressions of the employees on their environment (Jumeno, Matsumoto, & Susanti, 2014). Furthermore, other previous studies also reveal that the presence of plants can reduce stress of the employee, health complaint, and increase employee's satisfaction and quality of working life (Coleman & Mattson, 1995; Dravigne et al., 2008; Lohr et al., 1996; Paula Diane Relf & Lohr, 2003; Ulrich et al., 1991). Therefore, the interaction of human with plants affects human attitudes, behaviors and physiological responses.

Another means to cure depression and anxiety is by meditation. Meditation promotes relaxation, both for mind relaxation and muscle relaxation, compassion and patience. Meditation also prevents one from being stressed or cures one from a depression.

People have long been studying meditation using electroencephalography/EEG (Cahn & Polich, 2006). Meditation is generally characterized by increasing alpha waves and theta waves and accompanied by a decrease in the other waves. However, the way these waves occur at work, is still in question. There is a possibility that meditation waves are not only occurring while one is not doing or thinking something, but also occur at work.

EEG also can be used for measuring attention (Busch & VanRullen, 2010). Attention can be determined using beta wave (14-30 Hz). Not alike with meditation, when a person is attentive there is a greater beta wave (Liu et al., 2013). Moreover, attention also can be measured using secondary task reaction time or STRT (Lang et al., 2006) and accuracy (Prinzmetal, McCool, & Park, 2005).

The stress and fatigue are also affected by air temperatures. A specified range of air temperature together with humidity and air movement constitutes a comfort zone. According to ASHRAE 55-2010, the acceptable operating temperatures are 20 – 25.5 ^{o}C in winter and 23 – 28 ^{o}C in the summer. The increase or decrease of temperatures from the comfort zone may induce the stress and fatigue and may affect performance and safety. In Japan, the most common comfort temperature is around 25^{o}C. To maintain indoor temperature at this level, people use an air conditioner in the summer and a heater in the winter. However, the use of an air conditioner and a heater requires considerable amount of energy. The presence of indoor plants may affect the perception comfort of the occupant at different temperatures. Thus, the presence of indoor plants may reduce the amount of energy required to maintain the room stays in the comfort condition. However, most studies on the effect of foliage plants on human physiological and psychological responses have been conducted in the prescribed temperature. No study on the effect of plants on human physiological and psychological responses at different temperatures was found.

The objective of this study is to investigate the intervention of using indoors foliage plants on attention and meditation at different air temperature levels. The study also investigated the effect of plants at several types of tasks. Three types of tasks were investigated, namely typing, math and logics. Characteristics of tasks in the studies on the effect of foliage plants on human physiological and psychological responses has been investigated in the previous study (Jumeno & Matsumoto, 2012).

In this study, the effect of plant on attention is measured using EEG and STRT (secondary task reaction time). The study hypothesized that the presence of plants at different temperature levels has no effect on physiological and psychological responses as well as the performance and accuracy of the subject.

6.2 Methods

In this study, an experiment was conducted using a within subject design or a repeated measures design. The independent variables (IV) of the experiment are plant and temperature. There were 2 levels of plant and no plant conditions, and 3 levels of temperature, which is 22^{o}C, 25^{o}C, and 28^{o}C. The dependent variables (DV) of the study were human physiological responses such as heart rate, amylase level, electroencephalography (EEG), the secondary task-reaction time (STRT), and task performance. As we use human subjects, duration of experiment is important issue, because subject will be reluctant to participate if the duration of experiment is too long. Therefore, we use an incomplete factorial design to reduce the number of experiment for each participant. There were 4 conditions tested in the experiment:

1. No plant condition, at temperature of 25^{o}C
2. 6 foliage plants at temperature of 22^{o}C
3. 6 foliage plants at temperature of 25^{o}C
4. 6 foliage plants at temperature of 28^{o}C

No plant condition at temperature 22^{o}C and 28^{o}C were omitted from the design, because we were less focused to the no plant condition, and more focus to the temperature variations. The condition of no plant and with the presence of plants is presented in Figure 26. The experiment took place in the Natural Energy Building at Toyohashi University of Technology. The space of the climatic chamber is 3.57 meters long, 2.67 meter wide and 2.44 meter high. The illuminance of the room was 408 lx, by two fluorescent lamps without any daylight, measured at desk level.

Plants used in the experiment were *aglaonema commutatum*, *calathea concinna*, *spathyphillum*, *epiremnum aureum*, *benjamin*, and *scheflera arboricola*. Plant heights were varied between 25 cm and 50 cm. All plant leaves are green. Foliage plants are located on the desk, 80 cm – 120 cm from the subject position.

Fifteen subjects, with the age ranged from 22 to 38 years old participated in the study. All participants were postgraduate students from various departments. All participants have lived in Japan for at least 2 years, so they all have been acclimatized to the subtropical weather. All subjects participated in all conditions.

(a) (b)

Figure 26. Room condition (a) without plant, (b) with the presence of plants

A subject only participated in the experiment two times maximum in a day during the experiment. To overcome learning bias, randomization was carried out so that the sequence of conditions was different for one subject to the other. Several different tasks, namely typing, math and logical sequences are included in the investigation of these studies. The sequence of tasks also was randomized for each trial.

Before performing the first task, the subject was given 10 minutes for acclimatization with room condition, because the temperature and humidity in the experiment room may be different with the outdoor temperature and humidity. Each task lasted for 10 minutes, followed by taking rest for 5 minutes. The total time required for each subject in each experimental session is 60 minutes.

Heart rate and body temperature were measured before and after each task. Body temperature was measured inside the ear. Heart rate was measured near the chess using Polar S610i as shown in Figure 27. Body temperature measured using Jintan thermometer as shown in Figure 28.

Figure 27. Heart rate monitor Polar S610i

Figure 28. Jintan Body Thermometer

EEG was measured by using Brainwave Visualizer from NeuroSky, Inc. EEG data were taken 5 times when the subject is conducting the prescribed task from a monitor located outside the chamber. The EEG sensor and the monitor are wireless. The EEG sensor (as can be seen in Figure 29) sends signals through bluetooth to an android apps monitor called Brainwave Visualizer. The outputs from Brainwave Visualizer apps (as can be seen in Figure 30) are attention wave's rating and meditation wave's rating. Attention rating measure the degree of attentiveness and meditation rating measure the degree of relaxed of mind. Attention rating is related to beta wave. Meditation rating is related to alpha and gamma waves. The scale of attention rating and meditation rating is from 0 (not attentive or not relaxed) to 100 (highly attentive or highly relaxed).

Fatigue and stress were measured by using NIPRO amylase monitor (as can be seen in Figure 31), before and after the experiment. A disposable stick for measuring amylase score was placed in the mouth, under the tongue, for 30 seconds.

Figure 29. Mindwave EEG sensor

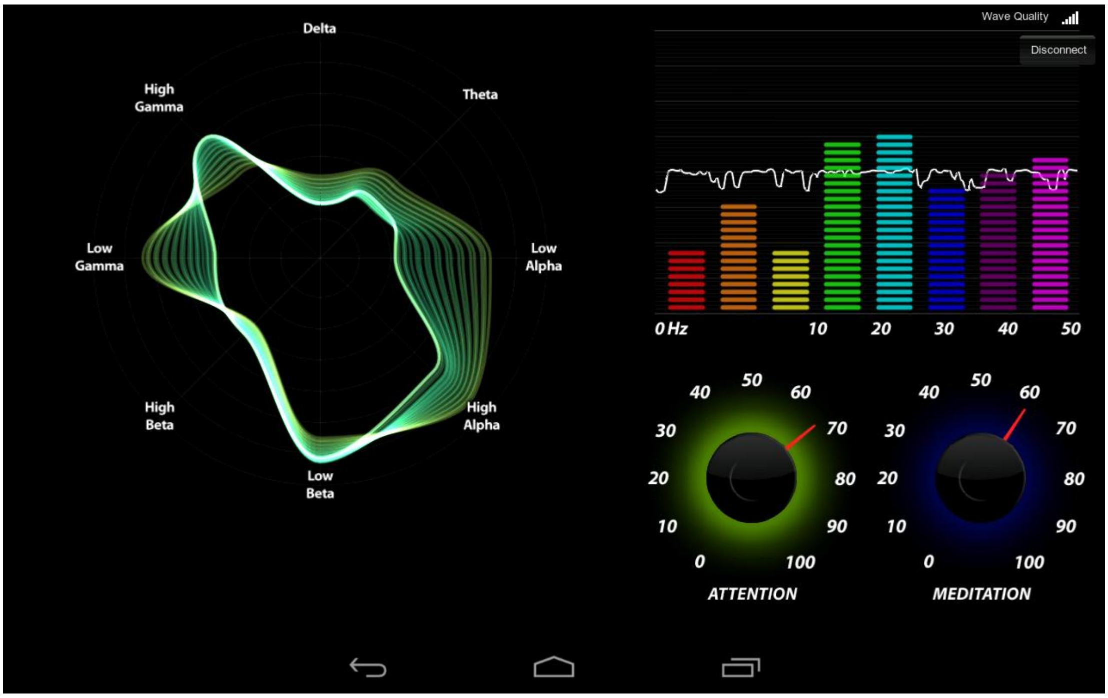


Figure 30. Brainwave Visualizer

Figure 31. NIPRO amylase monitor

Secondary task reaction time (STRT) is conducted during the primary task. During the primary task, there would be sound signals generated from a computer that can be heard by the subjects using an earphone. When the subject hears the sound signal (secondary signal), he or she was instructed to react to the signal by pressing the “enter” key on the keyboard. STRT data were taken 4 times when the subject is conducting the prescribed task. After all tasks has been finished, the subject then fills out the questionnaire.

Schedule of the experiment is presented in Figure 32. The experiment was conducted in the summer (from July to September 2014). Each experiment lasted for about 60 minutes.

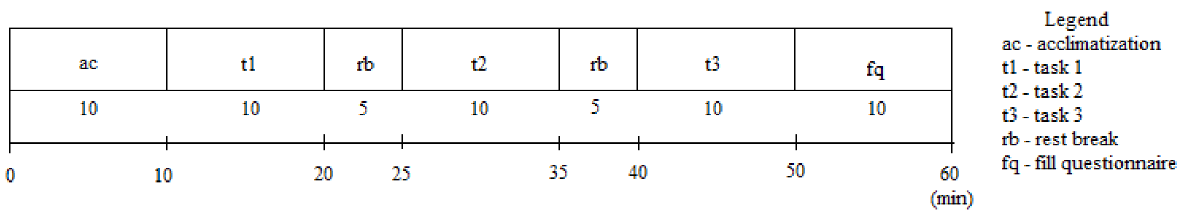


Figure 32. Schedule of experiment

6.3 Results

The experiment was conducted during the summer, with outside temperature from 20^{o}C to 33^{o}C. Climatic conditions of the experiment are presented in Table 14.

Table 14. Conditions during the experiment

Variables	**Measurement**
Temperature (inside chamber)	22, 25 and 28^{o}C
Temperature (outside)	20-33^{o}C
Humidity (inside chamber)	50 - 60%
Humidity (outside)	73 – 88 %
Air speed (at air conditioner)	2.5 m/s
Air speed (at air ventilator)	0.8 m/s
Air speed (at working height)	0.01 m/s
Illuminance (at working height)	400 lx
Clothing insulation index	0.54 clo
Green coverage ratio	9.55%

In Table 15, the effects of plants on physiological responses and performances were presented. From Table 15, it can be seen that there is a significant effect of task type on the secondary task reaction time ($p < 0.05$). A significant effect of the interaction of plant and task type on the secondary task reaction time ($p < 0.005$) is also found in this study. As illustrated in Figure 33, reaction time in typing task is increasing with the presence of plants, whether in math task and logic task, the reaction time is decreasing with the presence of plants.

Table 15. The effect of plants on physiological responses and performances

Independent Variable	**Dependent Variable**	**F value**	**Degree of freedom**	**Significance**
Plant	Heart rate	1.377	1	0.260
Task		1.970	2	0.179
Plant & Task		0.527	2	0.602
Plant	Attention	1.528	1	0.237
Task		1.124	2	0.355
Plant & Task		3.146	2	0.077
Plant	Meditation	0.839	1	0.375
Task		0.618	2	0.554
Plant & Task		0.291	2	0.752
Plant	Average body	1.147	1	0.302
Task	temperature	1.966	2	0.179
Plant & Task		2.123	2	0.159
Plant	Amylase	0.022	1	0.884
Plant	Reaction Time	0.310	1	0.587
Task		4.321	2	0.036*
Plant & Task		9.598	2	0.003*
Plant	Typing accuracy	0.454	1	0.512
Plant	Typing speed	1.154	1	0.301
Plant	Math productivity	0.075	1	0.788
Plant	Math accuracy	0.984	1	0.338
Plant	Logic productivity	0.035	1	0.853
Plant	Logic accuracy	0.012	1	0.916

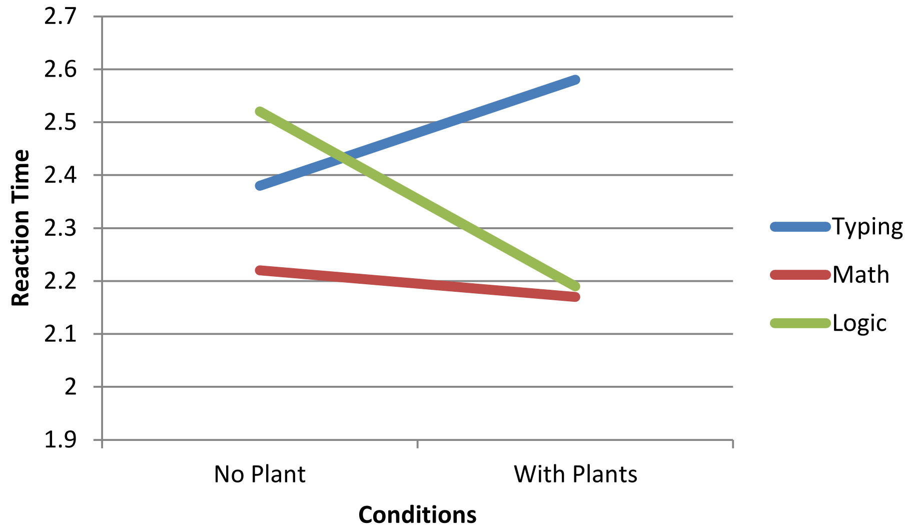


Figure 33. The effects of plants and task types on reaction time

The effect of room air temperatures on physiological responses and performances is presented in Table 16. From Table 16, it can be seen that variable temperature has a significant effect on meditation. Figure 34 depicts further the relationship between temperature, meditation waves' rating and tasks. From Figure 34, it can be seen that the meditation waves' rating at 25°C temperature is higher than the waves' strength in the other temperatures. It can be seen also that the pattern of meditation waves' rating for every task is the same, suggesting that 25°C is the optimal temperatures for the brainwaves to feel relax.

It also can be seen from Table 16 that variable task has a significant effect on attention. Figure 35 depicts further how the attention waves' rating for each task has a different level. From Figure 35, it can be seen that attention waves' rating in math has a higher level than the attention wave's rating on the other tasks. Also, the attention waves' rating in the typing task has a lower level than attention waves' rating on the other tasks. It can be observed from Figure 35 that significant differences in attention rate are between typing test and math test in temperature 22°C ($p < 0.05$) and between typing test and math test in temperature 25°C ($p < 0.01$).

From the experiment, a significant effect of room air temperature on average body temperature is shown in Table 16. The relationship between the room air temperature and the average body temperature is shown in Figure 36. From Figure 36, it can be seen that the average body temperature is increased as the room air temperature increased, and the pattern of the three tasks is almost similar. It seems obvious that the body reacts to the change of temperature of environment by adapting the skin temperature.

As can be seen from Table 16, a significant effect of temperature on reaction time was found. Reaction time measured in this experiment is secondary task reaction time (STRT) which is a measure of attention. Figure 37 shows the effect of temperature on the average reaction time. From Figure 37, it can be seen that reaction time was lower in 25^{o}C then in the other temperatures. From Figure 37, it also can be seen that reaction time in typing task is significantly higher than math ($p < 0.01$) and also significantly higher than logic task ($p < 0.05$) in every temperature conditions. No significant effect of temperature has been detected on the reaction time. It probably because the difference of reaction time between each temperature is less than 0.2 second.

Moreover, it also can be seen from Table 16 that temperature has a significant effect on typing accuracy. Figure 38 shows further the relationship between typing accuracy and air temperature. From Figure 38, it can be seen that the typing accuracy increases with the air temperature. However, for the female, the optimum temperature is 25^{o}C.

In the comparison of temperature levels shown in Figure 34 – Figure 38, 22^{o}C temperature is worse than the other temperature levels almost in all dependent variables, except for attention wave strength and secondary task reaction task on the math task. Temperature of 25^{o}C was the best in meditation wave rating, and also in secondary task reaction time for logic sequence and typing tasks. Temperature of 28^{o}C was the best for attention wave rating on the logic sequence and typing tasks, and also the typing accuracy.

Table 16. The effect of temperatures on physiological responses and performances

Independent Variable	Dependent Variable	F value	Degree of freedom	Significance
Temperature	Heart rate	0.533	2	0.600
Task		0.005	2	0.995
Temperature & Task		0.303	4	0.869
Temperature	Attention	1.15	2	0.348
Task		3.78	2	0.050*
Temperature & Task		0.36	4	0.829
Temperature	Meditation	3.92	2	0.032*
Task		0.83	2	0.448
Temperature & Task		0.361	4	0.835
Temperature	Average body	32.19	2	0.00**
Task	temperature	1.00	2	0.394
Temperature & Task		3.357	4	0.050*
Temperature	Reaction Time	0.166	2	0.849
Task		11.132	2	0.002**
Temperature & Task		0.794	4	0.553
Temperature	Typing accuracy	3.34	2	0.050*
Temperature	Typing speed	1.40	2	0.283
Temperature	Math Productivity	1.13	2	0.356
	Math accuracy	0.554	2	0.589
Temperature	Logics productivity	0.492	2	0.623
	Logics accuracy	1.31	2	0.287

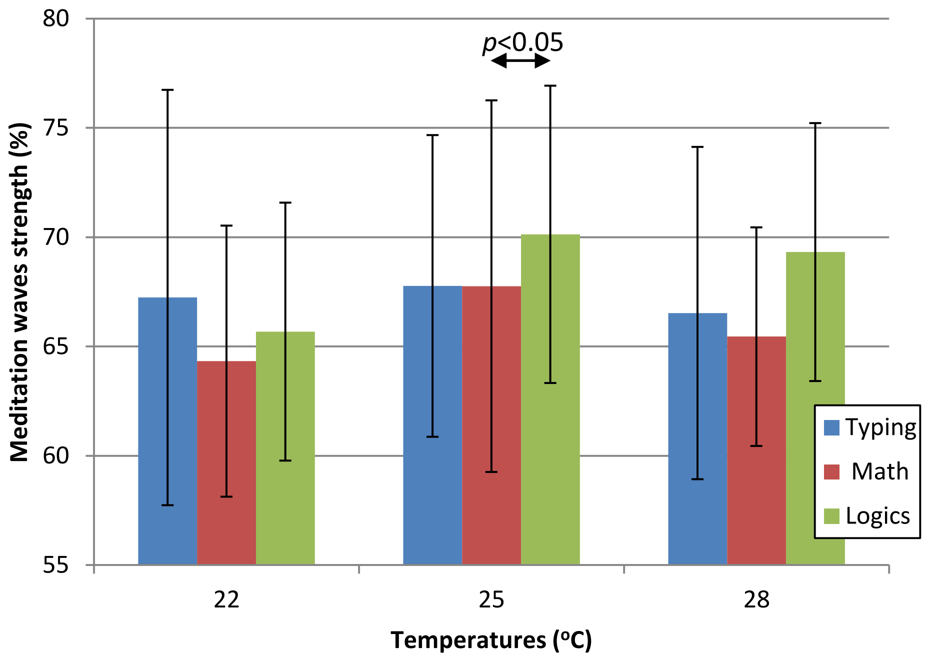


Figure 34. The effect of temperature on meditation

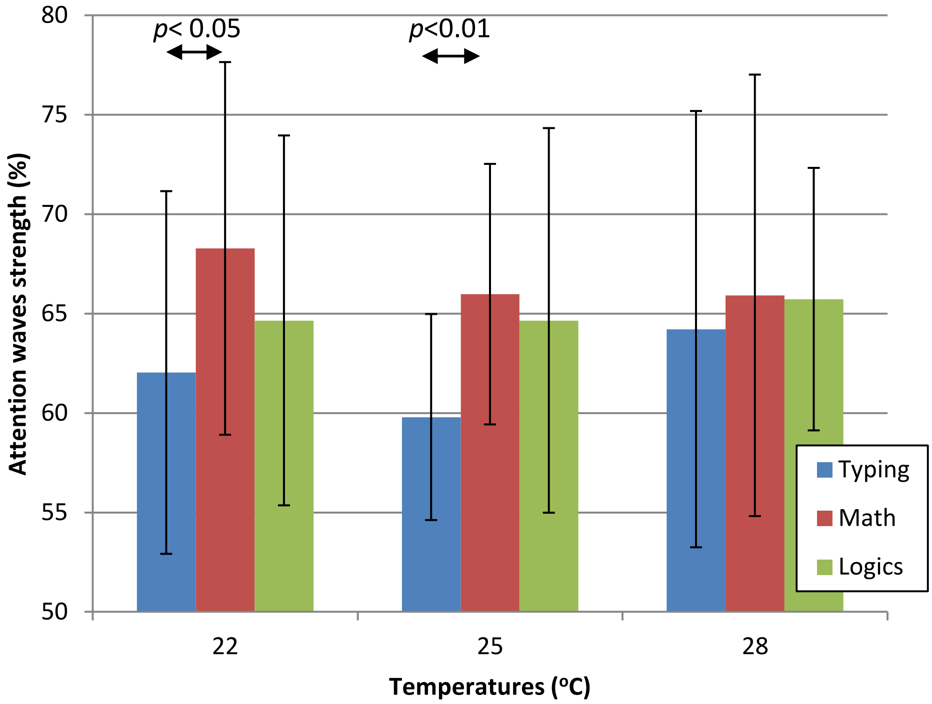


Figure 35. The effect of temperature on attention

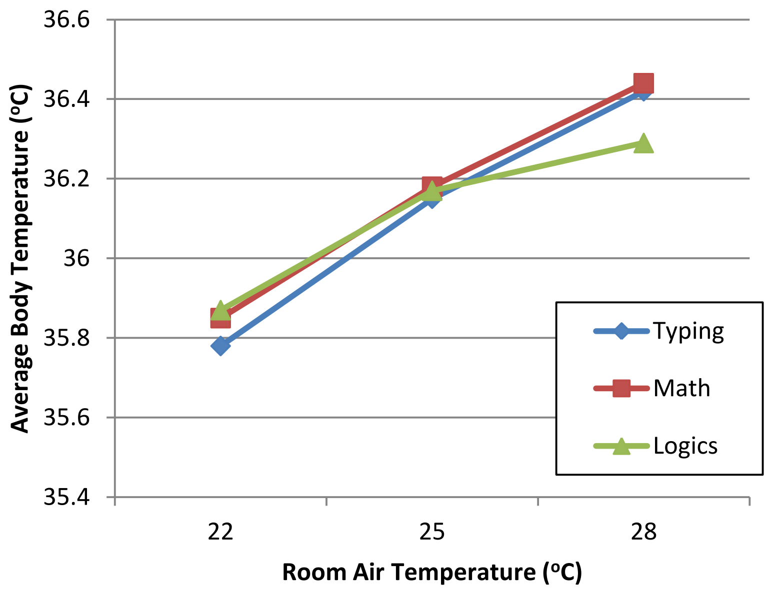


Figure 36. The effect of air temperature on body temperature

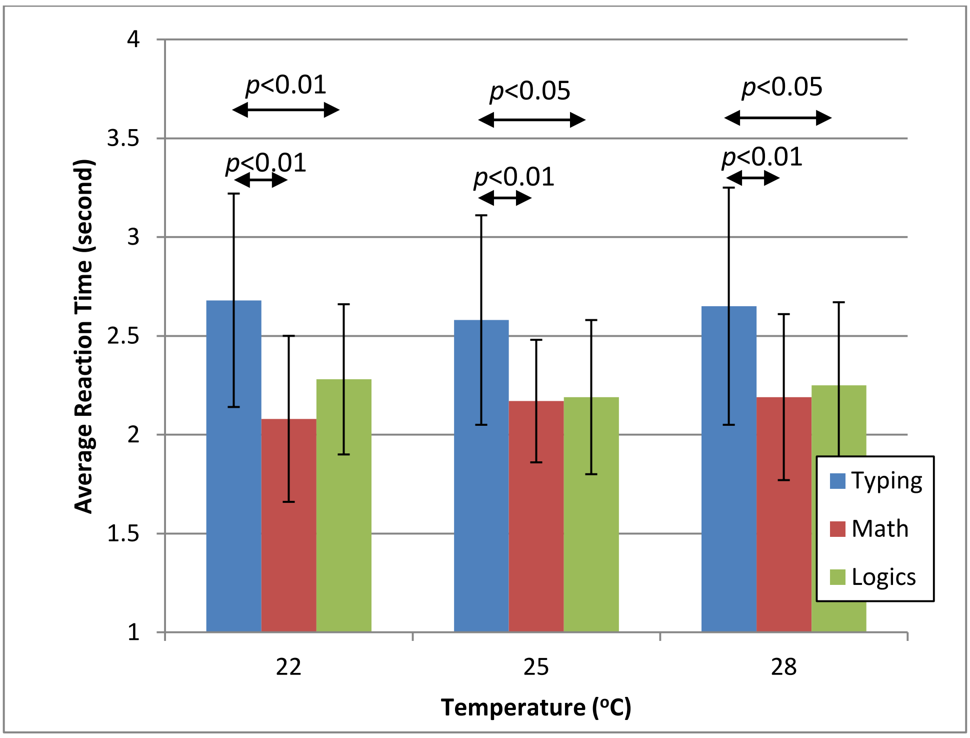


Figure 37. The effect of temperature on reaction time

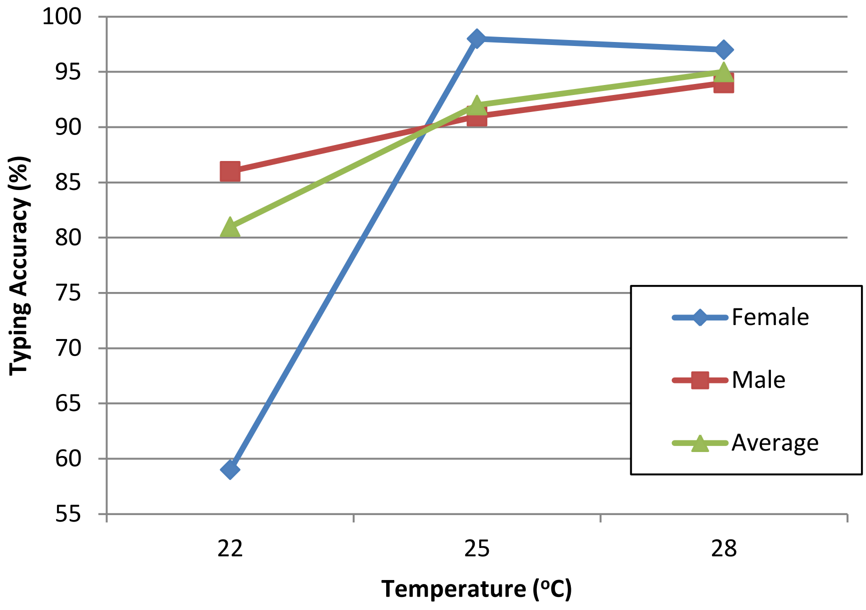


Figure 38. The effect of temperature on typing accuracy

6.4 Discussion

From the EEG analysis, it is revealed that the type of task has a significant effect on attention, whereas meditation is significantly affected by temperatures. In this study, the subject paid more attention in math task than that in the logic task and in the typing task. Solving math problem requires attentiveness and concentration, which associated with beta brainwave (14 to 30 Hz). The difference in height of beta waves between solving math problems, logic sequence, and typing task, shows that brain cells and neuron are working harder in solving math problems task than logic sequence and typing tasks. Higher level of attentiveness and concentration is required for solving math problems because this kind of thinking uses only the left side of the brain continuously and work only with numbers and then recall solution from the long term memory. It differs from solving logic task which uses also the other side of the brain to find solution, which is not only work on numbers but also pictures, positions and nonstandard figures. It also differs from typing task, which use less portion of the load in the brain, but also distributing the load to both hands and eyes. The results of this study on the effect of task types on attention are consistent with the results of Shibata & Suzuki (2002), which compared association task and sorting task. In their results, the subject paid more attention in the association task than that in the sorting task. It also shows that the association task requires more thinking than the sorting task.

From the result of this study, it is also important to see the phenomenon that when the subject solving math problems, meditation waves (alpha and theta) exceeds attention wave (beta). It is against the general premise that beta waves are identical with thinking aloud, while the alpha and theta waves synonymous with rest and tranquility. This is not to say that the beta wave is equal to zero when the subject solving math problems. This fact shows that the brain of human generates several brainwaves at different frequencies and rating simultaneously. As brain constructed in several parts and different parts account for different kind of thinking, it may be seen that at the same time, different parts of the brain generating different brainwave. For example, when the front left is active it produces beta waves, but at the same time the other side of the brain is at rest and it produces alpha and theta waves.

The results of this study also revealed that temperatures have a significant effect on meditation. Subject working in a chamber with foliage plants at 25^{o}C *temperature* has a higher rating of meditation waves (alpha and theta) than working in a chamber with foliage plants at 22^{o}C and 28^{o}C. With relative humidity of 49%-59%, temperature of 25^{o}C is the most comfortable temperature condition for an office. Therefore, at this temperature the brain is more easily to produce slower brain waves frequency like alpha and theta (4-13 Hz). This result also shows that the effect of temperature on meditation waves is stronger than the effect of plants. If the effect of plants is stronger than the effect of temperature, it can be expected that the meditation waves at 28^{o}C are higher or the same with the meditation waves at 25^{o}C.

Furthermore, a significant effect of temperatures on subject's secondary task-reaction time was found in the study. The results of this study show that reaction time on 25^{o}C is shorter than reaction time on 22^{o}c and 28^{o}C. The reaction is a secondary task in the experiment and is used to measure attention. Shorter reaction time means that the subject has more resource for attention, thus has a better attention or is less stressful. This result also implied that the effect of temperature on attention is stronger than the effect of plants. If the effect of plants is stronger than the temperature, it can be expected that the reaction time at 28^{o}C is shorter than that at 25^{o}C.

The results of this study also show that temperature has a significant effect on typing accuracy. The accuracy of typing increased with the temperature. However, there was no such difference in accuracy between 25^{o}C and 28^{o}C. It might be expected that difference in accuracy might be caused by plants rather than by temperature. As, it is suggested that 25^{o}C is a desirable comfort temperature compared to 28^{o}C, so the accuracy in 25^{o}C should not be lower than the accuracy at 28^{o}C, if the temperature is expected to have a larger effect of the typing accuracy. Higher accuracy in typing task may mean better concentration and attentiveness, because the subject got less number of errors. It means that attentiveness in typing at temperature 25^{o}C and 28^{o}C is better than at temperature 22^{o}C.

For typing accuracy and reaction time (STRT), both are affected by temperatures, whereas reaction time also affected by the task and interaction of plants and task. Prinzmetal, McCool and Park (2005) also showed that reaction time and accuracy reveal different mechanisms. Temperature and the presence of plants are noninformative cues which form involuntary attention, whereas the task is informative cues which form voluntary attention.

The results of this study also show that the most suitable temperature for various tasks and variable is different. Temperature of 22^{o}C is best for achieving attention on the math task. Temperature of 25^{o}C is best for meditation and attention, or is least stressful at all tasks, especially in logic sequence task and typing tasks. Temperature of 28^{o}C is best for attention on the logic sequence task and typing tasks, and also for typing accuracy.

The limitation exists in the levels of temperature in this study. Three different temperatures within the range of comfort were examined in this study. A further study can be conducted in the other level of temperatures, such as outside the range of comfort, or at temperatures closer to the desirable temperature of 25^{o}C. Also, this study only measure brainwave while the subject is working. Further study can be conducted to measure brainwave during the rest period so that the effect of plants on recovery can be investigated. Other limitations in the study include the number of participants, characteristics of the participants, and also age of plants.

6.5 Conclusion

In conclusion, this study has investigated the effect of foliage plants on human physiological and psychological responses at different temperatures. We have obtained satisfactory results proving that the presence of foliage plants at an appropriate temperature can induce better attention and meditation, which are useful for increasing work performance and stress reduction. Therefore, we recommend the best room condition is room with the presence of plants with room temperature of 25^{o}C.

The present study has only investigated three levels of temperatures within the range of comfort, 22^{o}C, 25^{o}C, and 28^{o}C in summer. Consequently, we still need to study further the effect of smaller range of temperatures in various seasons. Such research will sharpen the knowledge in this area and provide the best foundation for designing work and its environment.

Chapter 7 PRESERVING ATTENTION THROUGH THE APPLICATION OF INDOOR FOLIAGE PLANTS

7.1 Introduction

With increasingly competitive business and tight deadlines, work stress is increasing from time to time. Work stress can lead people to illness or depression. People are finding ways to overcome work stress, such as designing work contents or designing a more pleasant workplace. Previous studies have shown that the well being of people, their psychological as well as physiological level of stress is influenced by the environment. Stress at work is caused by an imbalance condition between the demand for work or the environment and the resources of the person to cope with.

Stress can trigger mental fatigue. A prolonged mental effort may also lead to attentional fatigue. Attentional fatigue usually occurred resulting from directed attention, which plays a central role in achieving focus and controls distraction (Kaplan, 1995). Fatigue can cause lack of mental clarity, difficulty in concentrating, memory loss, and a decrease in performance. There are several signs of fatigue such as feeling of lack of energy, feelings of muscle weakness, and slowed movements or central nervous system reactions. A landscape dominated by vegetation may give relief from stress (Hartig & Staats, 2006; Ulrich, 1986; Ulrich et al., 1991). Moreover, natural environments can give a restorative experience, which is important to reduce mental fatigue (Felsten, 2009; Fjeld, 2000; Kaplan, 1992). Fjeld (2000) reported that fatigue, as a neuropsychological symptom, was reduced between 9%-32% as plants are presented in an office, hospital, and class.

Fatigue is reduced when directed attention capacity restored. While a person awake, directed attention is restored when fascination, another form of attentional mechanism, is activated. Fascination is involuntary, requires no effort, and is likely to be resistant to fatigue. Fascination can be obtained from natural settings such as a view of the beach, view of mountain, flowers, parks, and so on.

This paper is focused on fascination from the indoor environment, because indoor natural setting is becoming more important nowadays. Almost 90% of modern human activities are indoors. There are a growing number of researches on the indoor natural settings, such as putting plants indoors, putting windows with view to nature, or viewing simulated nature through images in paintings, slides, or videos. Several researchers have studied the effect of indoor plants on cognitive performance, such as (Larsen et al., 1998; Lohr et al., 1996; Raanaas et al., 2011; Shibata & Suzuki, 2002), Shibata & Suzuki (2001 and 2004). The effect of plants on cognitive performance might be moderated by perception of air quality and comfort. Shoemaker, Randall, & Relf (1992) suggest that the presence of plant can improve air quality and comfort. The quality of the environment determines the motivation, performance and productivity (Leblebici, 2012).

Lohr et al. (1996), examined the presence of 11 species of indoor plants, suggested that people working with plant were feeling more attentive or more concentrating and have lower blood pressure increase. Shibata and Suzuki (2002), investigated the relative position of photos (*epiremnum aureum)* to the subject, suggested that the presence of the plant affects the cognitive performance of the subject, but it does not affect mood of the subject. Raanaas et al. (2011), using 4 indoor plants, found that the cognitive performance is better with the presence of plants than without plant condition, but the presence of plants does not improve attention capacity after a five minute break. Larsen et al. (1998), on the study of the density of plants in an office setting, suggested that the presence of plants affects negatively on the productivity of the work which need a focused attention. These differences in results suggest that there are still many questions on how to put plants indoors so that the cognitive performance or the attention capacity improved, such as on types of plants, on the number of plants, on the size of plants, on the position of plants relative to the occupants, and so on.

Most studies on the effect of foliage plants on humans involve visual tasks such as sorting task (Larsen et al., 1998 and Shibata & Suzuki, 2002), letter identification task (Larsen et al, 1998), test of reaction time using a computer (Lohr et al., 1996), video viewing (Adachi et al., 2000), office tasks and study classes (Fjeld, 2000) and so on. To perform these visual tasks, humans require light. Human perception is largely dependent on his vision system. Most of human tasks are visually dependent. Therefore, most of human activities require lighting. The amount of lighting required for a task is varied and dependent on the type of the task and the object.

The perception of color of an object is affected by lighting. Therefore, the perception of green leaves of the foliage plants may also be affected by the lighting. The illuminance level, the color of lights are factors that may affect the perception of the subject on the foliage plants. It is possible that the effect of plants on human physical and physiological responses depends on the lighting that illuminate the plants. Several studies on the effect of lighting on cognitive performance has been conducted such as (Knez & Kers, 2000), (Gabel et al., 2013), and (Lehrl et al., 2007). However, no study on the effect of lighting and foliage plants has been found in the literature.

The other factor that may contribute to the variation of results of the study in this field is task in the experiment that simulates the real world task. Jumeno & Matsumoto (2012) suggested a framework on how to design a task in the indoor plant experiment after classifying and analyzing tasks and task factors. An experimental study also has been conducted to answer above question on how to put plants indoors by studying the effect of the number of plants on productivity, stress and attention (Jumeno & Matsumoto, 2013). Previous efforts on the study in this field also have been conducted in our laboratory such as the effect of foliage plants on removing toluene (Matsumoto & Yamaguchi, 2007) and the effects of foliage plants on physiological and psychological responses (Doi et al., 2010).

As a continuation of previous studies, the present study’s aim is to investigate the effects of the number of plants and the size of plants and the illuminance level of lighting on attention capacity during a number of simulated visual tasks. It is assumed that fatigue develops during the working process, making the attention capacity scarce, slower reaction and longer reaction time. Moreover, it is assumed that in the presence of plants, fascination is activated through vision. It is hypothesized that the more plants in the vision area, the better is fascination, so that the directed attention is restored and fatigue is reduced. Furthermore, in the present study it is hypothesized that the effects of the number of plants and the size of plants on attention capacity are moderated by perception of air quality, impression of the quality of the room, perception of freshness, and boringness. Moreover, it is also hypothesized that the higher illuminance over the plants and working area, the lower the heart rate and the higher the attention capacity restored.

7.2 Methods

In the present research, two experimental studies were conducted with a repeated measures design. The experiments were carried out in a simulated office (L x W x H = 3.57 x 2.67 x 2.44 m). The temperature and humidity during experiment were controlled.

7.2.1 Study 1: Effect of the number and the size of plants on attention and impression of the participant

There were two factors that being studied, namely the number of plants and the size of plants. The dependent variables in the study were attention, impression of the room, boringness and freshness of the room condition. The secondary task reaction time (STRT) was used to measure attention capacity during work. The use of secondary task reaction time in measuring attention was also found in Lang, Bradley, Park, Shin, & Chung (2006). The smaller is the reaction time means that the attention capacity of the occupant is higher. To be able to measure the effect of plant on cognitive performance, a mental demand dominated task is required. In this experiment, the subject was conducting the word search task. The word search task that was used to simulate a mental demand dominated task also were found in some papers such as van den Berg, Manstead, van der Pligt, & Wigboldus (2006) and Hills, Todd, & Goldstone (2008). The word search task used in this experiment was paper based. There was 9 and 10 words scattered on each paper, and the subjects were instructed to finish as many papers as he/she could within a designated time. Impression of the room, boringness and freshness of the room condition were measured using a 5 scale questionnaire.

Eighteen subjects participated in the study. Their age varied between 22 years old to 30 years old. Among 18 participants, 10 are male and 8 are female. All participants were students. All of them have working experience, some as full time workers and the other as part time workers in various areas. All participants are from Asian countries but they have lived in Japan for at least 2 years, so they all have been acclimatized to the subtropical weather. All participants worked on the experiment as a volunteer, although a souvenir was given at the end of the experiment. A within subject or crossover design was applied in this study. Therefore, all subjects followed all experimental conditions. With a crossover design the need of high number of subjects can be reduced. A crossover design only required one quarter the number of subjects required by full controlled design experiment in obtaining the same confidence interval (Hopkins, 2000). Experimental conditions of this study are presented in Table 17.

Table 17. Experimental conditions

Condition	Number of plants	Size of plants	Height of plants
Case 1	No plant	-	-
Case 2	One	Small	20-30 cm
Case 3	One	Medium	50-60 cm
Case 4	One	Large	90-100 cm
Case 5	Three	Small	20-30 cm
Case 6	Three	Medium	50-60 cm
Case 7	Three	Large	90-100 cm

Plants used in this experiment were *spathiphyllum*, *epiremnum aureum,* and *schefflera arboricola*. All plants were potted with soil. Small size plant and medium size plants were placed on the desk, large plants were placed on the floor.

All conditions were followed by each of the participants. However, the order of the experimental conditions for each participant was randomized to prevent learning bias or the effect of learning during the experiment. This randomization was done manually by drawing pieces of cards from a box.

7.2.2 Study 2: The effect of plants and lighting on human physical and psychological responses

The 2nd experiment took place in the same room as the 1st experiment, but in the subsequence time. Three conditions were tested in the experiment: no plant with 400 lx, 6 plants with illuminance of 400 lx, and 6 plants with illuminance of 800 lx. The dependent variables (DV) of the study were human physiological responses such as heart rate, amylase level, electroencephalography (EEG), the secondary task-reaction time (STRT), and task performance.

Six plants were used in the experiment, namely chinese evergreen (*aglaonema commutatum*), prayer plant (*calathea concinna*), peace lily (*spathiphyllum*), photos (*epiremnum aureum*), weeping fig (*ficus benjamina*), and dwarf umbrella tree (*schefflera arboricola*). Plant heights were varied between 25 cm and 50 cm. All plant leaves were green. Foliage plants were located on the desk, at horizontal distance 80 cm – 120 cm from the subject position.

Fifteen postgraduate students participate in the study. Their ages range from 21 to 38 years old. All subjects participated in all conditions, but a subject should not participate in the experiment for more than two times in a day during the experiment, as regulated by Toyohashi University of Technology. A randomization was carried out to overcome learning bias of the subject toward the sequence of trials. In this study several different tasks, namely typing, math and logical sequences were included in each trial. The sequence of tasks also was randomized for each trial.

Acclimatization with room condition was given for each subject before performing the first task for 10 minutes. The duration of each task was 10 minutes, followed with rest break for 5 minutes. The total time spent by each subject in each experimental session is 60 minutes. The schedule for an experiment is presented in Figure 39.

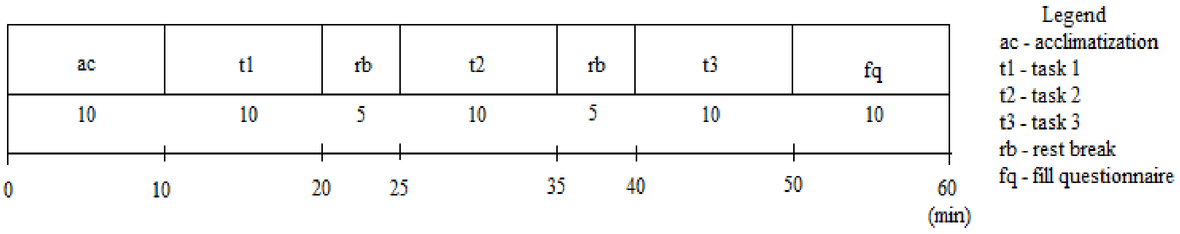


Figure 39. Schedule of experiment

Before starting each task and after finishing it, heart rate and body temperature measurement data were collected from the subject. Heart rate was measured near the chess using Polar S610i. Body temperature was measured inside the ear. EEG measured by using Brainwave Visualizer from NeuroSky, Inc. The EEG sensor and the monitor are wireless. The EEG sensor sends signals through bluetooth to an android apps monitor called Brainwave Visualizer. The outputs from Brainwave Visualizer apps are meditation wave's rating and attention wave's rating. The scale of rating is from 0 to 100. Fatigue and stress were measured by using NIPRO amylase monitor, before and after the experiment. A disposable stick for measuring amylase score was placed in the mouth, under the tongue, for 30 seconds.

Secondary task reaction time (STRT) measurement is also conducted in the course of the primary tasks. During the primary task, there were several sound signals generated from a computer that can be heard by the subjects using an earphone. When the subject hears the sound signal, he or she was instructed to react to the signal by pressing the "enter" key on the keyboard. STRT data were taken 4 times during the primary task.

7.2.3 Statistical methods

Data were analyzed using general linear model of repeated measures for comparing variances among conditions. The aim of comparing variances is to test the effect of one or more factors and interaction of factors on a dependent variable. Factors in this study are the number of plants, the size of plants, and gender of the subject. Dependent variables in this study are perceived air quality, perception of friendliness, perception of freshness, perception of comfort, attention, attention change, and heart rate. A repeated measure method was used for the analysis, because a within subject design was applied in this study. To analyze means of 7 groups/conditions with a within subject design, ANOVA for repeated measures was used. SPSS 20.0 was used for the analysis of the data. The mean of each group was compared to each other using paired sample of T test method. The aim of comparing means is in order to understand which condition is the best and how significant it different than the other condition. Bivariate correlation tests were conducted to measure correlation among variables. The aim of measuring correlation is to measure the strength or the degree of relationship between two variables. Two types of correlation coefficient were used in the analysis, the Pearson's and the Spearman's. The Pearson's coefficient was used for parametric variable and the Spearman's coefficient for non-parametric variable.

7.3 Results

7.3.1 Room condition

The chamber condition where the experiment was conducted is controlled. Table 18 shows the condition of the chamber during the experiment.

Table 18. Room condition

Variables	Measurement
Temperature (inside chamber)	$25.0 \pm 0.6^{o}C$
Temperature (outside)	$26.0 \pm 3.5^{o}C$
Humidity (inside chamber)	55.6 ± 6.4%
Humidity (outside)	73.0 ± 8.3%
Air speed (at air conditioner)	2.45 m/s
Air speed (at air ventilator)	0.8 m/s
Air speed (at working height)	0.01 m/s
Clothing insulation index	0.54 clo

7.3.2 Study 1: Number and size of plants

Figure 40 shows the average of secondary task reaction time (STRT), which was conducted to measure attention. During the experiment, STRT was measured 4 times in random times. The lowest average STRT was 1.46 seconds (Case 2, 6 and 7) and the highest was 1.66 seconds (Case 3). Moreover, it seems that female reaction times were smaller than male reaction times. It also can be observed that there is a big difference of reaction time between female and male in Case 1. It is probably that male is more affected by plants treatment than female, as female generally more like plants than male. However, there are no similar results from other researcher. Lohr et al. (1996) suggested that reaction time was smaller in condition with plant than in condition without plant, but they did not differentiate the reaction time of male and female subjects. Shibata and Suzuki (2002) suggested the same pattern in productivity of male and female in no plant and with plant condition, but did not measure the reaction time of the subjects.

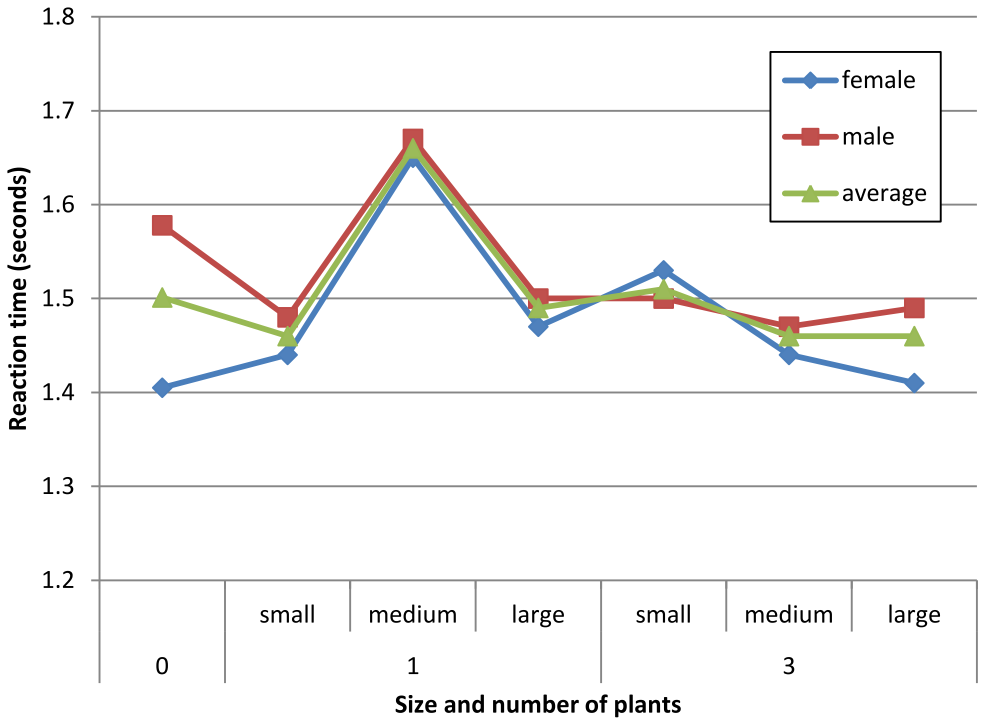


Figure 40. Average of STRT

The trend of the average reaction time is shown in Figure 41. From this figure, it can be seen that there is a slight down trend on reaction time toward the increase in the level of green coverage. It means that with the increase in the quantity of plants the attention of the subject is better.

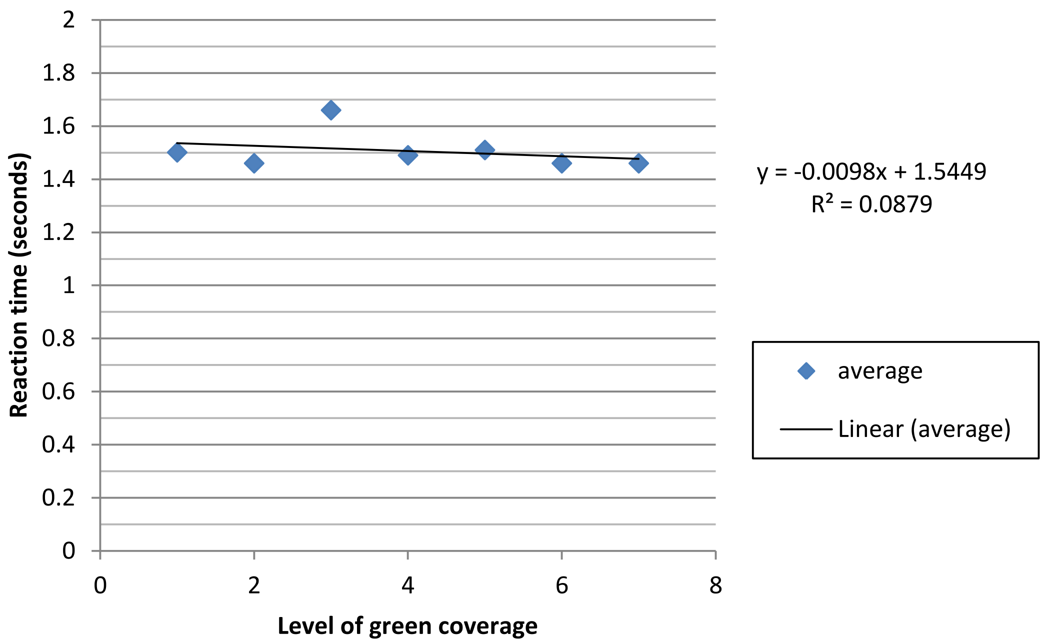


Figure 41. Trend of STRT

Further analysis using ANOVA on the effect of the number of plants and size of plants on attention is shown in Table 19. It can be seen that the effect of interaction of the number and the size of plants on attention was significant ($p < 0.05$). However, the effect of each individual variable, the number of plants and the size of plant on attention still need further investigation.

Table 19. The effect of number of plants and size of plants on attention

Effect	Degree of freedom	*F*	*p*
Number	1	1.07	0.32
Number & Gender	1	0.00	1.00
Size	2	0.97	0.40
Size & Gender	2	0.34	0.72
Number & Size	2	4.48	0.03*
Number, Size & Gender	2	0.44	0.65

* Significant at $p < 0.05$

Figure 42 shows the effect of interaction of the number and the size of the plants on attention. It can be seen that the most observable difference in attention between 1 plant condition and 3 plants condition is in the medium size plant/plants. Reaction time is lower when the number of plants is 3 and the size are medium and large. When the size of plants is small, 3 plants condition has higher reaction time than 1 plant condition. From Table 18, valid contrasts between the levels is derived from the correlation value of the residual sscp matrix. From Table 20, valid contrasts exist between 1 plant – small size with 1 plant medium and between 1 plant medium and 3 plants medium.

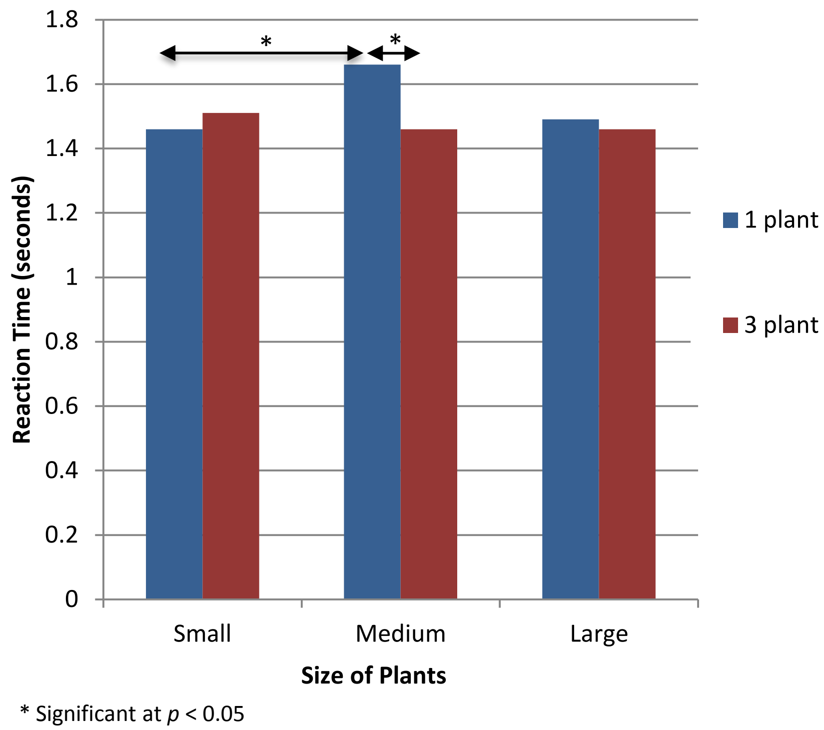


Figure 42. The effect of interaction of the number and the size of plants on the average STRT

Table 20. Residual SSCP matrix – correlation among experiment conditions

	1 plant - Small	1 plant - Medium	1 plant - Large	3 plants - Small	3 plants - Medium	3 plants - Large
1 plant - Small	1	0.751*	0.647	0.149	0.617	0.225
1 plant - Medium		1	0.618	0.058	0.838*	0.659
1 plant - Large			1	0.359	0.563	0.383
3 plant3 - Small				1	0.253	0.211
3 plants - Medium					1	0.703
3 plants - Large						1

* Significant at $p < 0.05$

7.3.2.1 Impression of the room

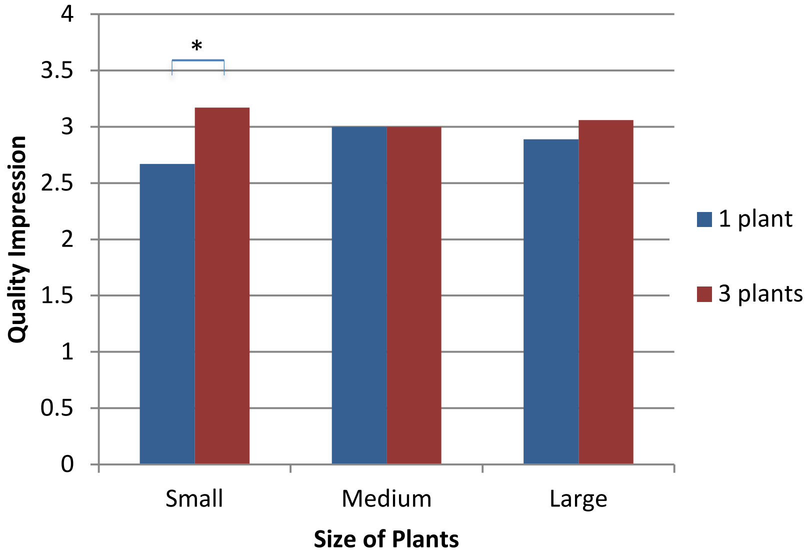
The effect of plants on the impression of the room is shown in Table 21. There are significant effects on the number of plants on quality and boringness ($p < 0.05$). From Table 21, it can be seen also the effect of interaction of the number of plants and the size of plants on friendliness ($p < 0.1$), and the interaction effect of the size of the plant and gender on boringness ($p < 0.1$).

Table 21. The effect of plants on the impression of the room

	Quality Impression		Friendliness		Boringness	
	F	p	F	p	F	p
Number	6.25	0.02*	3.55	0.08	5.04	0.04*
Size	0.35	0.71	0.24	0.79	0.53	0.6
Number vs size	1.31	0.3	2.76	0.09	1.33	0.29
Number vs gender	0.02	0.89	0.73	0.4	1.21	0.29
Size vs gender	1.18	0.33	1.49	0.26	2.7	0.099
Number vs size vs gender	1.16	0.34	0.89	0.43	1.97	0.17

* Significant at $p < 0.05$

The effect of the number of plants on quality impression is further depicted in Figure 43. From Figure 43, it can be seen that 3 plants condition gives better quality impression than 1 plant condition. A significant contrast of quality impression between trials is found between 1 plant-small and 3 plant-small. Furthermore, it also shows that the highest quality impression is given by 3 small sized plant's condition.

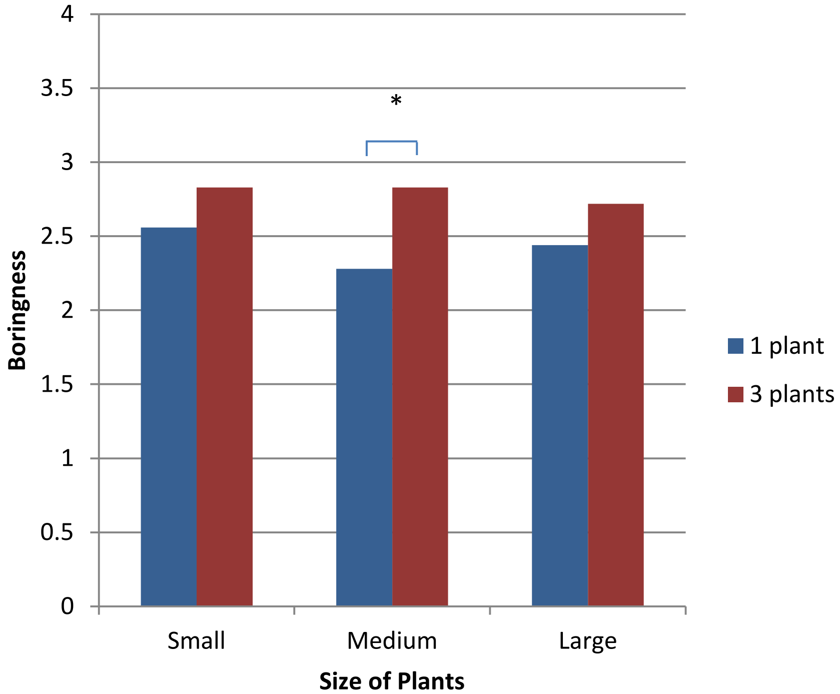


* Significant at $p < 0.05$

Figure 43. The Effect of the number of plants on quality impression

1 = poor, 2 = somewhat poor quality, 3 = neutral, 4 = somewhat of good quality, 5 = good quality

Figure 44 further depicted the effect of indoor foliage plants on boringness impression. From Figure 44, it can be seen that 3 plants condition gives less boringness (or more fun) impression than 1 plant condition. A significant contrast of boringness between trials is found between 1 plant-medium and 3 plants-medium.



* Significant at $p < 0.05$

Figure 44. The effect of the number of plants on boringness

1 = boring, 2 = somewhat boring, 3 = neutral , 4 = somewhat fun, 5 = Fun

Table 22 and Figure 45 show the effect of the number and the size of plants on perception of air freshness. From Table 22, it can be seen that there is a significant effect of the number of plants on freshness ($p < 0.05$). On the other hand, the effects of other variable and interactions were not significant. From Figure 45, it can be seen that the perception of air freshness is better in the room with 3 plants (average = 2.48) than the room with one plant (average = 2.85). Significant contrasts between 1 plant and 3 plants are found on medium and large size plants.

Table 22. The effect of number of plants and size of plants on perception of air freshness

Effect	Degree of freedom	*F*	*p*
Number	1	5.86	0.03*
Number & Gender	1	0.26	0.62
Size	2	0.75	0.49
Size & Gender	2	1.12	0.35
Number & Size	2	0.84	0.45
Number, Size & Gender	2	0.25	0.78

*Significant at $p < 0.05$

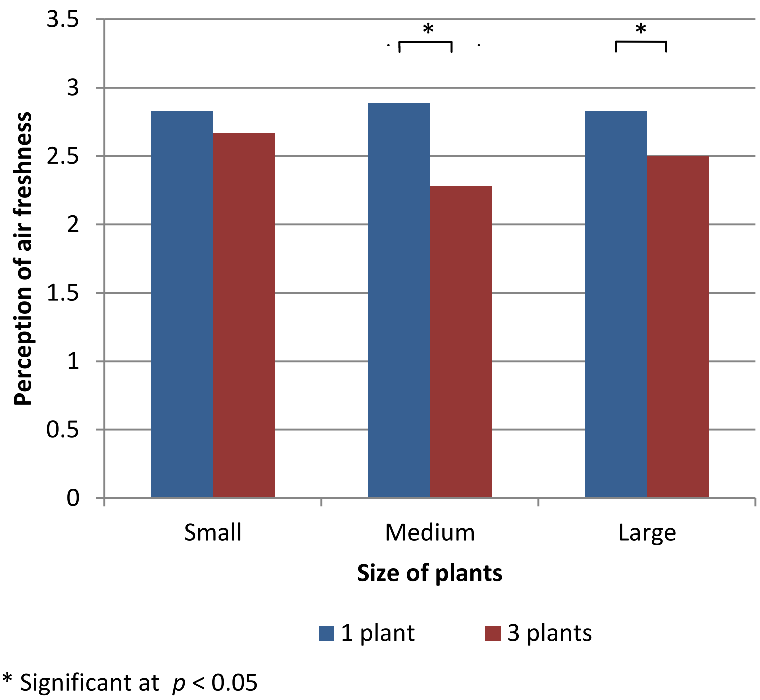


Figure 45. The effect of number of plants on perception of air freshness

1= fresh, 2 = somewhat fresh, 3 = neutral, 4 = somewhat heavy, 5=heavy

Table 23 shows correlations between variables in the experiment. There is a significant positive correlation between the number of plants and freshness. Significant positive correlations also can be seen between quality impression with friendliness and freshness.

Table 23. Correlations

	Number of plants	Size of plants	STRT	Quality Impression	Friendli-ness	Boring-ness	Fresh-ness
Number of plants	1						
Size of plants	0	1					
STRT	-0.096	-0.056	1				
Quality Impression	0.161	0.022	0	1			
Friendliness	0.122	0.008	0.141	0.475**	1		
Boringness	0.168	-0.086	0.094	-0.03	-0.129	1	
Freshness	0.235*	0.053	-0.051	0.51**	0.55**	-0.008	1

* Significant at $p < 0.05$

** Significant at $p < 0.01$

7.3.3 Study 2: Plants and Lighting Experiment

Plants and lighting condition can be measured using the green coverage ratio (GCR). The amount of pixel and the green coverage ratio on both illuminance level is illustrated in Figure 46. As illustrated in Figure 46, the amount of green pixel and green coverage ratio of 800 lx lighting is higher than 400 lx lighting.

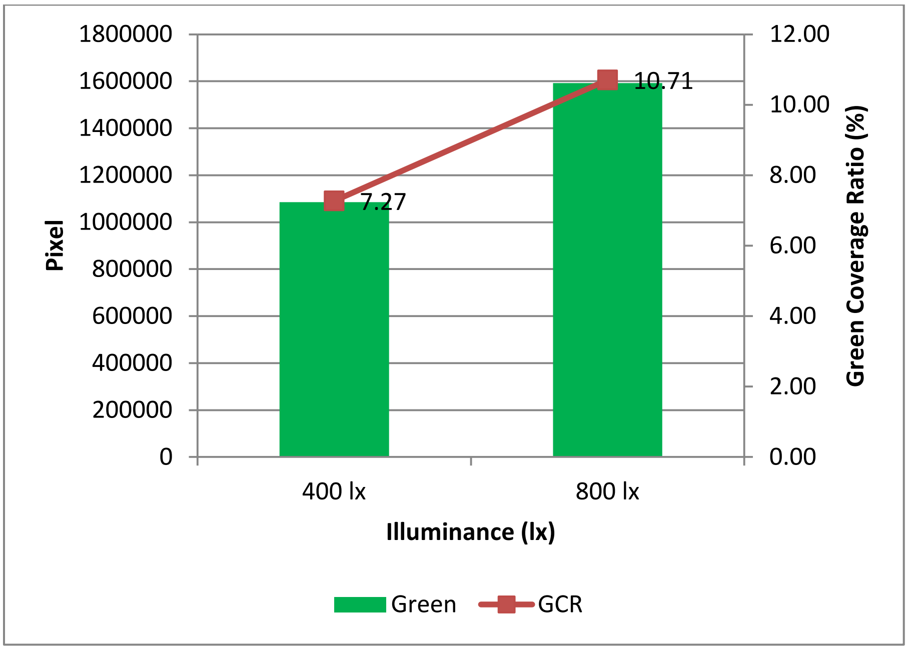


Figure 46. The amount of pixel and green coverage ratio on 400 lx and 800 lx lighting

The effect of illuminance and task types on the subject's heart rate difference between post task and pre-task is presented in Table 24 and Figure 47. Table 24 contains results of ANOVA test for repeated measures using SPSS, such as F value, degree of freedom and significance value. The experiment used 2 independent variables, light and task. F value is calculated by dividing mean square treatment ($MS_{treatment}$) with mean square error (MS_{error}). $MS_{treatment}$ is calculated by dividing sum square treatment ($SS_{treatment}$) with its degree of freedom (df). For interaction effect of light and task, mean square interaction ($MS_{interaction}$) is calculated by dividing sum square interaction ($SS_{interaction}$) with its df. $SS_{interaction}$ is calculated by subtracting sum square total (SS_{total}) with sum square treatment of light (SS_{light}), sum square treatment of task (SS_{task}) and sum square error (SS_{error}).

From Table 24 it can be observed that there is a significant effect of tasks on heart rate differences ($p < 0.05$). From Figure 47 it can be seen that the heart rate difference in logic task in 400 lx illuminance is higher than any other tasks. Increase in heart rate is used as a measure of stress. Increase in heart rate is a sign that the heart is working harder than the starting condition. However, from a post hoc analysis of ANOVA test, using Residual SSCP Matrix and also Paired-Samples T Test, no significance different was found among pairs. This result suggests that, although there is a significant different result from the ANOVA test, it is not adequate to conclude that the higher levels of illuminance decrease the heart rate difference.

Table 24. Effect of lighting with the presence of plant on physiological and psychophysical responses

Independent Variable	Dependent Variable	F value	Degree of freedom	Significance
Light	Heart rate	3.108	1	0.067
Task		3.518	2	0.045*
Light & Task		0.307	2	0.918
Light	Attention	2.179	1	0.162
Task		3.540	2	0.043*
Light & Task		0.075	2	0.928
Light	Meditation	2.780	1	0.118
Task		0.638	2	0.536
Light & Task		0.265	2	0.769
Light	Amylase Saliva	0.130	1	0.723
Light	Body Temperature	3.784	1	0.072
Task		0.210	2	0.812
Light & Task		0.366	2	0.697
Light	Reaction Time	0.071	1	0.794
Task		12.207	2	0.000*
Light & Task		0.411	2	0.667

* Significant at $p < 0.05$

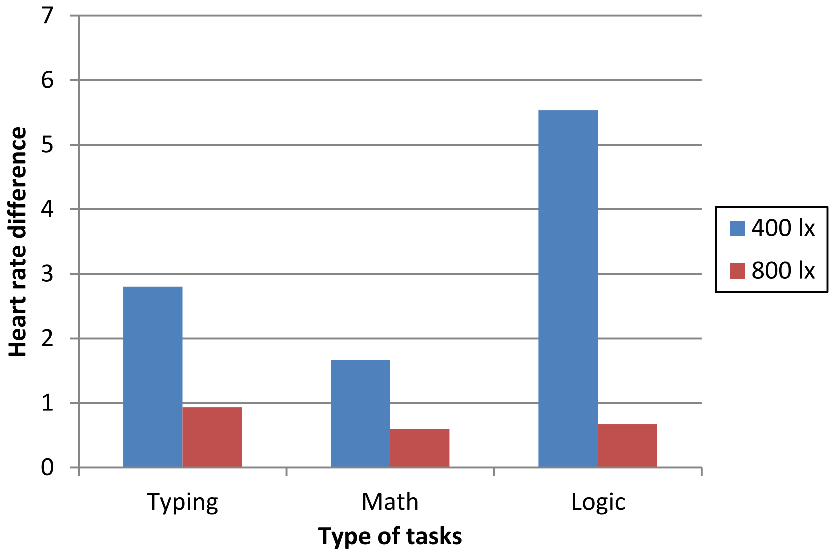


Figure 47. The effect of task types and illuminance on the subject's heart rate differences

Table 24 also highlights that there is a significant effect of task types on attention waves rating ($p < 0.05$). The effect of task types on attention is depicted in Figure 48. Figure 48 illustrates that attention waves rating among task types were different. As highlighted in Figure 48, attention waves rating at logic task and math task were higher than that of typing task.

Another important result from Study 2 is the effect of task type on the secondary task reaction time (STRT). It can be seen from Table 24, that there is a significant effect of task types on the average reaction time ($p < 0.05$). The effect of task type on reaction time is depicted in Figure 49. From Figure 49 it can be seen that reaction time on typing task is higher than and significantly contrast with reaction time on math task and logic task.

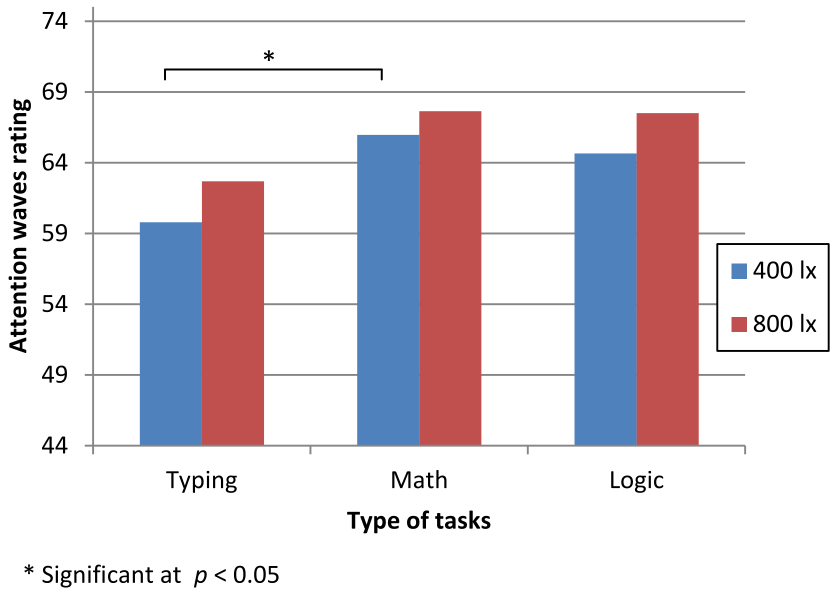


Figure 48. The effect of task types and illuminances on the subject's attention waves rating

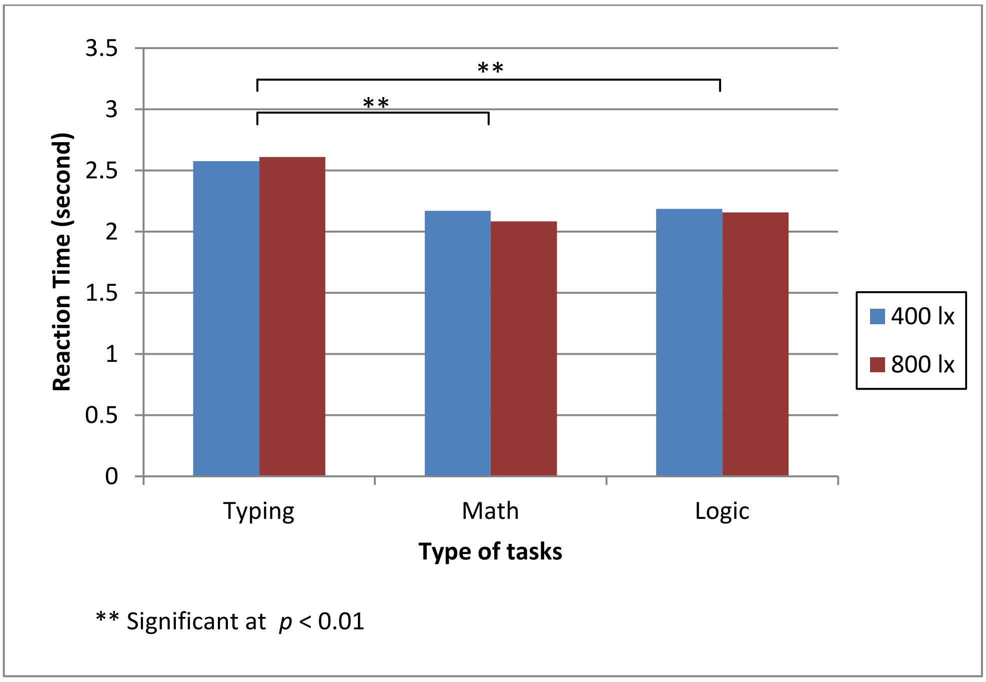


Figure 49. The effects of task types and illuminances on reaction time

7.4 Discussion

7.4.1 Attention response

The results of this study reveal that the interaction of the number of plants and the size of the plants has a significant effect on attention, although the individual variable has no significant effect. From this study it is shown that the best workplace conditions are workplace with one small sized foliage plant, workplace with three medium sized plants and workplace with three large sized foliage plants, because they produce the smallest reaction time. Faster reaction or smaller reaction time on the secondary task can be interpreted as sufficient amount of attention is paid to the primary task by the subject. Room with plants that can produce smaller reaction time is better at preserving subject's attention than the other room conditions. This can be explained using the attention restoration theory (ART). According to the attention restoration theory (Kaplan, 1992), when the fascination is activated, the directed attention is recovered, and the fatigue is reduced or delayed. This means that room with one small sized plant, or room with three medium sized or room with large sized plants are the best source of fascination. Furthermore, our results show that with the increase of level of green coverage, the trend of the reaction time is decreasing. This suggests that with the increase of the quantity of plants in the room, the subject has more attention capacity recovered and is less fatigue. These results also support the idea that involuntary attention or fascination affects reaction time (Prinzmetal et al., 2005). Foliage plants in this study act as a source of involuntary attention, whereas reaction time has been used as a measure of attention. Other explanations that might also true, the brief visual contact with plants in these conditions, can restore one's mind from stress, as also pointed out by Shoemaker et al. (1992).

The interaction between the number and the size of plants suggests that one factor cannot be separated with the other when designing a workplace with foliage plants. If we have only one plant it is better to have a smaller plant than medium or large sized plant. But if we can afford 3 plants, medium or large sized plants are better because the reaction time is smaller. However, these quantities of plants might only apply to a room that has a similar space in the room in this study. For larger or smaller room, the quantity of foliage plants might be different.

7.4.2 Impression on the room responses

Significant effects of the number of plants on quality impression and boringness were found in the present study. Room with higher number of plants produced better quality impression and less boringness. These results also show that the number of plants has a significant effect on perception of air freshness. Room with more plants is perceived to have the higher air freshness. These results show that room with higher number of plants give better impressions to the participants. On the other work by Larsen et al. (1998), they also found that room with higher number of plants is more attractive to the participants. These findings substantiate the work of Lohr & Pearson-Mims (2000), which pointed out that the presence of plants improved people's impressions of a room and their mental well being. Other study such as Smith, Tucker, & Pitt (2011) also found that with the presence of plant people are feeling greater comfort, although they only considered with-plants and no-plant conditions.

Recognizing the positive impressions of plants in the room is important for understanding the effect of plants on the attention. The impressions of the plants proving that plants are sources of fascination. The fact that the higher number of plants induces less boringness than smaller number of plants reveal that the presence of plants can maintain subject's alertness and attention.

7.4.3 Heart rate response to plant and lighting

The result of this study suggests that the presence of plant in a room with a higher level of illuminance decreases the heart rate differences between pre-task and post-task. It means that the presence of plants at a higher illuminance lighting reduces the work of the heart, thus reduce stress and fatigue. The explanation is that with the increase in illuminance, the green coverage area captured by our eyes is larger. The increase in the green coverage area means that our eyes see the green color more than that of at the lower level of illuminance. This results in better restoration of attention.

Another explanation is with the stress reduction effect of the natural environment (Ulrich et al., 1991). With the increase in the green coverage area seen by human eyes, the sense of nature received by human increased and stress is reduced. This stress reduction is marked by the decrease in the heart rate difference.

Also, it might be caused by the notion that the increase in illuminance affects visual comfort. This notion supported by (Jumeno et al., 2014), who suggested that higher levels of illuminance produce better pleasure, brightness, breeziness and quality impression on the participants. On the other hand, this is different with Flynn (1977), who indicated that people prefer more warm and dim (lower illuminance) than cool (more bluish type of lamp) and bright (higher illuminance) white lighting, although differences in the level of illuminance required by type of task also should be taken into account.

Explanation about the effect of illuminance on stress and attention also can be related to the diurnal rhythm of the hormone secretion of melatonin and cortisol. Melatonin, a hormone secreted by the pineal gland in the brain that helps regulate other hormones and maintains the body's circadian rhythm within 24 hours, produced more in a dark condition, and produced less in a bright condition. Light decreases melatonin production and signals the body to stay awake, and therefore, induces better attention. If the light is too bright, however, the melatonin level is very low, inducing disturbance on the regulation of cortisol hormone, which modulates many changes that occur in the body in response to stress.

7.4.4 Task and attention

The results of this study show that the type of tasks also affect the attention waves rating and secondary task reaction time (STRT). Typing has lower attention waves rating and higher STRT than math task and logic task. It is may be caused by the amount of physical effort exerted by typing task. Compared to math and logic task, typing is requiring more physical efforts. With the high requirement of physical effort as well as work of brain and eyes, typing also requires more coordination between fingers, eyes, and brain than the other tasks. These efforts of fingers, eyes and brain require considerable use of attention.

Limitations of the study are the duration of tasks and the duration of rest break. Longer task duration and rest break durations will allow the subject to have more interaction with the plants, for both active interaction or passive interaction. Other limitations of the study were the number of participants, characteristics of the participants, and age of plants. Further study also required to examine the effect of indoor plants on people's attention that are in work groups and their work performance.

7.5 Conclusion

This study supports the notion that the presence of indoor foliage plant gives benefits to human occupants. These results provide further guidance on how to put foliage plants in a workplace such as how many plants, in what size should be the plants, and how much illuminance should be given in the room in order to maximize the benefit to the occupants. It can be concluded that:

- The interaction of the number and the size of plants has a significant effect on attention. One small sized foliage plant on a desk or workplace is as good as three medium sized or large sized foliage plant in producing better fascination to maintain attention.
- The higher number of foliage plants placed indoor produce better quality impression, better perception of air freshness and less boringness than smaller number of plants, and provide evidence that the higher number of plants can maintain subject's alertness and attention.
- The presence of plants at a higher illuminance lighting reduces the work of the heart, thus reduces stress and fatigue.

Therefore, our results recommend to provide a room with 6 medium sized plants, with 800 lx illuminance, so that we can maintain employees alertness and attention and reduces their stress and fatigue.

By maintaining employees alertness and attention, it can reduce the number of defective products or processes, thus it may increase customer satisfaction, and it may bring economical benefit to the company. By reducing stress and fatigue to the employees, it can increase employees health, reduce the number of absenteism, thus reduce company spending. By applying foliage plants in office, it also can increase the companys's "green" image. Those above facts in its turn can increase the company's share value.

Chapter 8 CONCLUSIVE SUMMARY

People spend a large amount of time in the workplace. In order to make their workplace more pleasant people put plants such as flowers or foliage plants in their rooms. The presence of plants is believed not only make the room more attractive and fresh, but also is restorative to human spirit, and affect to human attitudes, behavior and physiological responses. However, the effects of foliage plants on each study were varied. There are studies that show positive effects, negative effects or neutral. There may be some source of differences such as, the setting of study, the subject of study and the task that is used for simulating the real condition. In literature, tasks carried out in each research were greatly varied such as test of tasking reaction time, sorting task of fonts and letter identification task, association task, sorting task, addition, typing, memory task, and proofreading. The effects of foliage plants on these tasks were also varied. These variations of effects made the judgment and generalization of the effects of foliage plant on human attention, mood and performance become difficult. Therefore, to understand better the effect of foliage plant on various human tasks, it is required to identify what are general factors owned by the tasks affected by foliage plants.

In Chapter 2, general factors that reside in the tasks that are used in research of indoor foliage plants were identified. Common characters of the task that foliage plants have affected in experimental researches were task complexity, attention requirement, time pressure, difficulty, duration, creativity, and feedback. Complexity of the task should not be so low or not too simple, which requires certain amount of logical thinking, information recognition, comprehension, storing and recalling from memory. A moderate amount of attention to the task is required for gaining the effect of foliage plants on the task. If the task is too easy, it will be less challenging. Therefore, it will be not so attractive or not so interesting. If the task is too difficult, the subject may be given up, so that the performance cannot be measured. Moderate duration of task is necessary while conducting experiment for studying the effect of foliage plants on human performance.

Foliage plants apparently have more effect on creative work such as association, memory and addition, than on a short and repetitive work such as sorting or letter identification task. Creative task employs a more divergent process in mind, while repetitive task employs a more convergent process. Divergent process frees one from directed attention to other sources of attention. This source of attention is not necessarily related to the task.

In studying the effect of foliage plants on human it is important to understand how is the effect of the number of the indoor foliage plants on productivity, stress and attention. In Chapter 3, the effects of the number of indoor foliage plants on productivity, stress and attention were presented. After carefully controlling other physical factors and designing tasks appropriate for the study, we found that the effects of the number of plants on the subjects' perceptions of friendliness, comfort, freshness, and the cleanliness of the room were statistically significant. The best number of plants that should be placed in a room sized 9.53 meters squared was seven. However, as it is not easy to determine whether these differences are due to the number of plants or simply the chance, a further confirmatory study with larger sample size is required. On the other hand, the effects of the number of indoor foliage plants on productivity, stress and attention were not statistically significant. Results presented in Chapter 3 also show that the effects of the number of plants on subject's perception of temperature, humidity, thermal satisfaction, and air quality among conditions were also not significantly different.

Another factor of foliage plant that is important to be addressed is the size of the plants. In Chapter 4, the effects of the number and the size of indoor foliage plants on mood, productivity, and perceived air quality were addressed. From the results presented in Chapter 4, several conclusions can be derived. The presence of plants indoors improves the mood, attention, productivity and the perception of air quality of the occupants. However, some factors need to be carefully considered. Firstly, it was found that the increase in the number of plants could trigger an improvement of the occupant's mood. Secondly, the interaction between the number and the size of foliage plants has an influence on perceived air quality and reaction time. Increase of perceived air quality is related to the increase in the quantity of greenery up to a certain number and size of the plants. In this chapter, it is found that room with three large-sized plants constitutes the best condition or mood, attention, productivity and PAQ.

The effect of foliage plants on human is related to the perception. Human gathers most information using visual sense. Visual sense is related to perception of colours and lighting. The amount of leafs colour of foliage plants is measured by using green coverage ratio, whether the amount of lighting is measured by using illuminance level. In Chapter 5, the effect of green coverage ratio from the foliage plants, illuminance and task types on human perception, impressions, stress and relaxation were addressed. Several conclusions can be derived from the results presented in Chapter 5. Firstly, it can be inferred that the impressions of the subject on room conditions are increase with the green coverage ratio. Secondly, higher levels of illuminance produce better pleasure, brightness, breeziness and quality impression on the participants. Thirdly, the increase of the green coverage ratio may decrease the level of stress and increase the level of relaxation. Moreover, the performance of subjects on Sudoku test and word creation test were increased when the green coverage ratio increasing, but the addition test and typing test did not show any significant pattern.

In Chapter 6, we have investigated the effect of foliage plants on human physiological and psychological responses at different temperatures. We have obtained satisfactory results proving that the presence of foliage plants at an appropriate temperature can induce better attention and meditation, which are useful for increasing work performance and stress reduction. In this study, we have investigated three levels of temperatures within the range of comfort, $22^{o}C$, $25^{o}C$, and $28^{o}C$ in summer. Consequently, we still need to study further the effect of smaller range of temperatures in various seasons.

Human safety, performance, productivity and quality of production are greatly affected by attention. In Chapter 7, the effects of foliage plants and illuminace on human attention, stress and fatigue have been investigated. From the results in Chapter 7, several conclusion were derived. Firstly, it can be inferred that there is a significant effecy of the interaction of the number and the size of plants on attention. One small sized foliage plant on a desk or workplace is as good as three medium sized or large sized foliage plant in producing better fascination to maintain attention. Secondly, the results show that the higher number of foliage plants placed indoor produce better quality impression, better perception of air freshness and less boringness than smaller number of plants, and provide evidence that the higher number of plants can maintain subject's alertness and attention. Moreover, it can be inferred that the presence of plants at a higher illuminance lighting reduces the work of the heart, thus reduces stress and fatigue.

To sum up conclusion from Chapter 1 to Chapter 7, a recommended room conditions that would give an optimal human responses as well as high productivity of a working room which area is 9.5 m2, is as follows: room should be provisioned with 6 potted foliage plants, which height between 25-50 cm. All plants should be positioned in the front of the room occupant, at his/her visual area. The potted plants can be placed on the desk or on the floor, depends on its height. The working room temperature should be 25^{o}C, and should be illuminated using 800 lx fluorescent lamp.

Benefits for a company that can be obtained from the present of foliage plants by applying above recommended condition would be substantial. These include economical benefits through the increase in employees' productivity, product defective reduction and customer satisfaction. The second benefit is the increase in employees health, by stress reduction, thus reducing the company's spending. The third benefit is energy saving, thus reducing the cost for energy. The fourth benefit is the increase in the company's "green" image. Moreover, another important benefit is the increase in company's share value.

ACKNOWLEDGEMENT

This study was funded by the Directorate General of Higher Education, Ministry of National Education of Indonesia and was also supported in part by Grants in Aid for Scientific Research, Japan. All plants used in this study were provided by PLANET Co. Ltd. Japan. The author would like to acknowledge students and laboratory members of Toyohashi University of Technology for their participation in this study.

References

7 U.S.C. Section 4302. (2006). CHAPTER 74—FLORAL RESEARCH AND CONSUMER INFORMATION. In *United States Code, 2006 Edition, Supplement 4, Title 7 - AGRICULTURE, Section 4302* (pp. 1503–1504). U.S. Government Publishing Office. Retrieved from hhttp://www.gpo.gov/fdsys/granule/USCODE-2010-title7/USCODE-2010-title7-chap74-sec4302

Adachi, M., Rohde, C. L. E., & Kendle, A. D. (2000). Effects of floral and foliage displays on human emotions. *HortTechnology*, *10*(1), 59–63.

AIS. (2015). What is Stress? Retrieved from http://www.stress.org/what-is-stress/

Bringslimark, T., Hartig, T., & Patil, G. G. (2007). Psychological benefits of indoor plants in workplaces: putting experimental results into context. *HortScience*, *42*(3), 581–587.

Bringslimark, T., Hartig, T., & Patil, G. G. (2009). The psychological benefits of indoor plants: A critical review of the experimental literature. *J. Environ. Psychology*, *29*(4), 422–433.

Busch, N. a, & VanRullen, R. (2010). Spontaneous EEG oscillations reveal periodic sampling of visual attention. *Proceedings of the National Academy of Sciences of the United States of America*, *107*(37), 16048–53. doi:10.1073/pnas.1004801107

Cahn, B. R., & Polich, J. (2006). Meditation states and traits: EEG, ERP, and neuroimaging studies. *Psychological Bulletin*, *132*(2), 180–211. doi:10.1037/0033-2909.132.2.180

Chang, C., & Chen, P. (2005). Human response to window views and indoor plants in the workplace. *HortScience*, *40*(5), 1354–1359.

Coleman, C. K., & Mattson, R. H. (1995). Influences of Foliage Plants on Human Stress during Thermal Biofeedback Training. *HortTechnology*, *5*(2), 137–140.

Doi, K., Matsumoto, H., & Nakao, T. (2010). Effect of foliage plants on human physiological / psychological response and productivity. In *Proceedings of CLIMA 2010*. Antalya, Turkey.

Dravigne, A., Marcos, S., & Waliczek, T. M. (2008). The effect of live plants and window views of green spaces on employee perceptions of job satisfaction. *HortScience*, *43*(1), 183–187.

Einhäuser, W., Rutishauser, U., & Koch, C. (2008). Task-demands can immediately reverse the effects of sensory-driven saliency in complex visual stimuli. *Journal of Vision*, *8*(2), 1–19. doi:10.1167/8.2.2

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience*, *14*(3), 340–347. doi:10.1162/089892902317361886

Felsten, G. (2009). Where to take a study break on the college campus: An attention restoration theory perspective. *Journal of Environmental Psychology*, *29*(1), 160–167. doi:10.1016/j.jenvp.2008.11.006

Fjeld, T. (2000). The effect of interior planting on workers and school children. *HortTechnology*, *10*(1), 46–52.

Fjeld, T. (2002). The effect of plants and artificial day-light on the well being and health of office workers, school children and health care personnel. In *Int. Hort. Exhib.* (Vol. 0, pp. 1–10). Floriade, Australia.

Gabel, V., Maire, M., Reichert, C. F., Chellappa, S. L., Schmidt, C., Hommes, V., … Cajochen, C. (2013). Effects of artificial dawn and morning blue light on daytime cognitive performance, well-being, cortisol and melatonin levels. *Chronobiology International*, *30*(8), 988–97. doi:10.3109/07420528.2013.793196

Garcia, T., & Pintrich, P. R. (1996). The Effects of Autonomy on Motivation and Performance in the College Classroom. *Contemporary Educational Psychology*, *21*(4), 477–486.

Gendolla, G. H. E. (2000). On the impact of mood on behavior: An integrative theory and a review. *Review of General Psychology*, *4*(4), 378–408. doi:10.1037//1089-2680.4.4.378

Gooding, D., Braun, J., & Studer, J. (2006). Attentional network task performance in patients with schizophrenia-spectrum disorders: evidence of a specific deficit. *Schizophr Research*, *88*(1-3), 169–178.

Granger, D. A., Kivlighan, K. T., El-Sheikh, M., Gordis, E. B., & Stroud, L. R. (2007). Salivary Alpha-Amylase in Biobehavioral Research Recent Developments and Applications. *Annals of The New York Academy of Sciences*, *1098*, 122–144. doi:10.1196/annals.1384.008

Grinde, B., & Patil, G. G. (2009). Biophilia: does visual contact with nature impact on health and well-being? *Int J Environ Res Public Health*, *6*(9), 2332–2343. doi:10.3390/ijerph6092332

Groth-Marnath, G., & Baker, S. (2003). Digit span as a measure of everyday attention: a study of ecological validity. *Perceptual and Motor Skills*, *97*, 1209–1218.

Hackman, J. R., & Oldham, G. R. (1976). Motivation through the design of work: test of a theory. *Organizational Behavior and Human Performance*, *16*(2), 250–279. doi:10.1016/0030-5073(76)90016-7

Hartig, T., Mang, M., & Evans, G. W. (1991). Restorative Effects of Natural Environment Experiences. *Environment and Behavior*, *23*(1), 3–26. doi:10.1177/0013916591231001

Hartig, T., & Staats, H. (2006). The need for psychological restoration as a determinant of environmental preferences. *Journal of Environmental Psychology*, *26*(3), 215–226. doi:10.1016/j.jenvp.2006.07.007

Hedge, A. (1996). Addressing the psychological aspects of indoor air quality. In *The 1st Indoor Air Quality Seminar*. Urumqi, China. Retrieved from http://gse.cat.org.uk/downloads/addressing_the_psychological_aspects_of_indoor_air_quality.pdf

Heslegrave, R. J., & Angus, R. G. (1985). The effects of task duration and work-session location on performance degradation induced by sleep loss and sustained cognitive work. *Behavior Research Methods, Instruments, & Computers*, *17*(6), 592–603.

Hills, T. T., Todd, P. M., & Goldstone, R. L. (2008). Search in external and internal spaces: evidence for generalized cognitive search processes. *Psychological Science*, *19*(8), 802–8. doi:10.1111/j.1467-9280.2008.02160.x

Hopkins, W. G. (2000). Quantitative research design. *Sportscience*, *4*(1). Retrieved from http://www.sportsci.org/jour/0001/wghdesign.html

Hurlbut, J. (2011). The Necker Cube - An Alternative Measure of Direct Attention. In *Proceedings of The National Conference On Undergraduate Research (NCUR)*. New York.

Hyge, S., & Knez, I. (2001). Effects of Noise, Heat and Indoor Lighting on Cognitive Performance and Self-Reported Affect. *Journal of Environmental Psychology*, *21*(3), 291–299. doi:10.1006/jevp.2001.0222

Iwashita, G. (1992). *Assessment of indoor air quality based on human olfactory sensation*. Waseda University.

Jimmieson, N. L., & Terry, D. J. (1999). The moderating role of task characteristics in determining responses to a stressful work simulation. *Journal of Organizational Behavior*, *20*(5), 709–736. doi:10.1002/(SICI)1099-1379(199909)20:5<709::AID-JOB954>3.0.CO;2-7

Jumeno, D., & Matsumoto, H. (2012). Characteristics of tasks in researches of the effects of foliage plants on attention and human performance. In *Proceedings of The 9th ISAIA 2012* (p. pp. A–3–4). Gwangju, South Korea.

Jumeno, D., & Matsumoto, H. (2013). The effects of the number of indoor foliage plants on productivity, stress and attention. In *Proceedings of CLIMA 2013*. Prague, Czech Republic.

Jumeno, D., Matsumoto, H., & Susanti, L. (2014). Utilization of Foliage Plants on the Design of Eco-Ergonomic Office. In *the 13th International Conference on Indoor Air Quality and Climate. Vol. V* (pp. 920–926). Hong Kong.

Kahya, E. (2007). The effects of job characteristics and working conditions on job performance. *International Journal of Industrial Ergonomics*, *37*(6), 515–523. doi:10.1016/j.ergon.2007.02.006

Kaplan, S. (1983). A model of person- environment compatibility. *Environment and Behavior*, *15*(3), 311–332.

Kaplan, S. (1992). The Restorative Environment : Nature and Human Experience. In P. D. Relf (Ed.), *The Role of Horticulture in Human Well-Being and Social Development*. Portland: Timber Press.

Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology*, *15*(3), 169–182. doi:10.1016/0272-4944(95)90001-2

Kim, H.-H., Yang, J.-Y., Lee, J.-Y., Park, J.-W., Kim, K.-J., Lim, B.-S., … Lim, Y.-W. (2014). House-plant placement for indoor air purification and health benefits on asthmatics. *Environmental Health and Toxicology*, *29*. doi:10.5620/eht.e2014014

Kim, K. J., Kil, M. J., Song, J. S., Yoo, E. H., Son, K.-C., & Kays, S. J. (2008). Efficiency of volatile formaldehyde removal by indoor plants: contribution of aerial plant parts versus the root zone. *Journal of the American Society for Horticultural Science*, *133*(4), 521–526.

Knez, I., & Kers, C. (2000). Effects of Indoor Lighting, Gender, and Age on Mood and Cognitive Performance. *Environment and Behavior*, *32*(6), 817–831.

Kobayashi, K. D., Kaufman, A. J., Griffis, J., & Mcconnell, J. (2007). Using houseplants to clean indoor air. *Ornementals and Flowers*, *39*, 7.

Lang, A., Bradley, S. D., Park, B., Shin, M., & Chung, Y. (2006). Parsing the Resource Pie: Using STRTs to Measure Attention to Mediated Messages. *Media Psychology*, *8*(4), 369–394.

Largo-Wight, E., Chen, W. W., Dodd, V., & Weiler, R. (2011). Healthy workplaces: the effects of nature contact at work on employee stress and health. *Public Health Reports*, *126*(Suppl 1), 124–130. Retrieved from www.ncbi.nlm.nih.gov/pmc/articles/PMC3072911/

Larsen, L., Adams, J., Deal, B., Kweon, B. S., & Tyler, E. (1998). Plants in the workplace: The effects of plant density on productivity, attitudes, and perceptions. *Environment and Behavior*, *30*(3), 261–281.

Leblebici, D. (2012). Impact of Workplace Quality on Employee's Productivity: Case Study of a Bank in Turkey. *Journal of Business, Economics & Finance*, *1*(1), 38–49.

Lee, M., Lee, J., Park, B.-J., & Miyazaki, Y. (2015). Interaction with indoor plants may reduce psychological and physiological stress by supressing autnomic nervous system activity in young adults: a randomized crossover study. *Journal of Physiological Anthropology*, *34*(1), 21. doi:10.1186/s40101-015-0060-8

Lehrl, S., Gerstmeyer, K., Jacob, J. H., Frieling, H., Henkel, a W., Meyrer, R., … Bleich, S. (2007). Blue light improves cognitive performance. *Journal of Neural Transmission (Vienna, Austria : 1996)*, *114*(4), 457–60. doi:10.1007/s00702-006-0621-4

Liu, N.-H., Chiang, C.-Y., & Chu, H.-C. (2013). Recognizing the degree of human attention using EEG signals from mobile sensors. *Sensors*, *13*(8), 10273–86. doi:10.3390/s130810273

Lohr, V. I., & Pearson-Mims, C. H. (2000). Physical discomfort may be reduced in the presence of interior plants. *HortTechnology*, *10*(1), 53–58.

Lohr, V. I., Pearson-Mims, C. H., & Goodwin, G. K. (1996). Interior plants may improve worker productivity and reduce stress in a windowless environment. *J. Environ. Hort.*, *14*(2), 97–100.

Matsumoto, H., & Yamaguchi, M. (2007). Experimental study on the effect of foliage plants on removing indoor air contaminants. In *Proceedings of Clima 2007 Well Being Indoors*.

Merriam-Webster.com. (2014). Mood. *The Free Merriam Webster Dictionary*. Retrieved April 28, 2014, from http://www.merriam-webster.com/dictionary/mood

Morrow, A. R. (2014). Stress Definition. Retrieved May 14, 2015, from http://dying.about.com/od/glossary/g/stress.htm

Orwell, R. L., Wood, R. L., Tarran, J., Torpy, F., & Burchett, M. D. (2004). Removal of benzene by the indoor plant/substrate microcosm and implications for air quality. *Water, Air, & Soil Pollution*, *157*(1-4), 193–207.

Park, S. H., & Mattson, R. H. (2008). Effects of flowering and foliage plants in hospital rooms on patients recovering from abdominal surgery. *HortTechnology*, *18*(4), 563–568.

Parsons, K. . (2000). Environmental ergonomics: a review of principles, methods and models. *Applied Ergonomics*, *31*(6), 581–594. doi:10.1016/S0003-6870(00)00044-2

Pearson-Mims, C. H., & Lohr, V. I. (2000). Reported Impacts of Interior Plantscaping in Office Environments in the United States. *HortTechnology*, *10*(1), 82–86.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, *13*, 25–42. doi:10.1146/annurev.ne.13.030190.000325

Prinzmetal, W., McCool, C., & Park, S. (2005). Attention: reaction time and accuracy reveal different mechanisms. *Journal of Experimental Psychology : General*, *134*(1), 73–92. doi:10.1037/0096-3445.134.1.73

Raanaas, R. K., Evensen, K. H., Rich, D., Sjøstrøm, G., & Patil, G. (2011). Benefits of indoor plants on attention capacity in an office setting. *Journal of Environmental Psychology*, *31*(1), 99–105.

Radloff, L. S. (1977). The CES-D Scale: A Self-Report Depression Scale for Research in the General Population. *Applied Psychological Measurement*, *1*(3), 385–401. doi:10.1177/014662167700100306

Relf, P. D. (1990). Psychological and sociological response to plants: Implications for horticulture. *HortScience*, *25*(1), 11–13.

Relf, P. D., & Lohr, V. I. (2003). Human issues in horticulture. *HortScience*, *38*(5), 984–993.

Schwarz, N., Strack, F., Kommer, D., & Wagner, D. (1987). Soccer, rooms, and the quality of your life: Mood effects on judgments of satisfaction with life in general and with specific domains. *European Journal of Social Psychology*, *17*(1), 69–79.

Shibata, S., & Suzuki, N. (2002). Effects of the foliage plant on task performance and mood. *J. Environ. Psychology*, *22*, 265–272.

Shibata, S., & Suzuki, N. (2004). Effects of an indoor plant on creative task performance and mood. *Scandinavian Journal of Psychology*, *45*(5), 373–381. doi:10.1111/j.1467-9450.2004.00419.x

Shoemaker, C. A., Randall, K., & Relf, P. D. (1992). Relationships between plants, behavior, and attitudes in an office environment. *HortTechnology*, *2*(2), 205–206.

Smith, A. J., Tucker, M., & Pitt, M. (2011). Healthy, productive workplaces: Towards a case for interior plantscaping. *Facilities*, *29*(5/6), 209–223.

Smith, A., & Pitt, M. (2008). Preference for plants in an office environment. In *Healthy and Creative Facilities, Proceedings of the CIB W70 Conference in Facilities Management* (pp. 629–637). Edinburgh, UK.

Sonnentag, S., & Frese, M. (2002). Performance Concepts and Performance Theory. In S. Sonnentag (Ed.), *Psychological Management of Individual Performance* (pp. 3–25). Chichester: John Wiley & Sons.

Stone, N. J. (2003). Environmental view and color for a simulated telemarketing task. *Journal of Environmental Psychology*, *23*(1), 63–78. doi:10.1016/S0272-4944(02)00107-X

Stone, N. J., & English, A. J. (1998). Task Type, Posters, and Workspace Color on Mood, Satisfaction, and Performance. *J. Environ. Psychology*, *18*, 175–185. Retrieved from https://www.researchgate.net/publication/222720764_TASK_TYPE_POSTERS_AND_WORKSPACE_COLOR_ON_MOOD_SATISFACTION_AND_PERFORMANCE

Stress, C. for S. on H. (2007). Introduction. In *HOW TO MEASURE STRESS IN HUMANS?* (p. 39). Quebec, Canada: Fernand-Seguin Research Centre of Louis-H. Lafontaine Hospital.

Tarran, J., Torpy, F., & Burchett, M. (2007). Use of Living Pot-Plants to Cleanse Indoor Air - Research Review. In *Proceedings of Sixth International Conference on Indoor Air Quality, Ventilation & Energy Conservation in Buildings – Sustainable Built Environment* (Vol. III, pp. 249–256). Sendai, Japan.

Tiwari, T., Singh, A., & Singh, I. (2009). Task demand and workload: Effects on vigilance performance and stress. *Journal of the Indian Academy of Applied Psychology*, *35*(2), 265–275. Retrieved from http://medind.nic.in/jak/t09/i2/jakt09i2p265.pdf?origin=publication_detail

Torpy, F. R., Irga, P. J., Moldovan, D., Tarran, J., & Burchett, M. D. (2013). Characterization and biostimulation of benzene biodegradation in the potting-mix of indoor plants. *Journal of Applied Horticulture*, *15*(1), 10–15.

U.S. Environmental Protection Agency (U.S. EPA). (2005). *Program Needs for Indoor Environments Research (PNIER)*. Washington DC: Environmental Protection Agency.

Ulrich, R. S. (1986). Human responses to vegetation and landscapes. *Landscape and Urban Planning*, *13*, 29–44. doi:10.1016/0169-2046(86)90005-8

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. a., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology*, *11*(3), 201–230. doi:10.1016/S0272-4944(05)80184-7

Vakkari, P. (1999). Task complexity, problem structure and information actions, Integrating studies on information seeking and retrieval. *Information Processing and Management 35, 35*, 819–837.

Van den Berg, H., Manstead, A. S. R., van der Pligt, J., & Wigboldus, D. H. J. (2006). The impact of affective and cognitive focus on attitude formation. *Journal of Experimental Social Psychology, 42*(3), 373–379. doi:10.1016/j.jesp.2005.04.009

Wang, D., Lorch, U., & Bakhai, A. (2006). Crossover trials. In D. Wang & A. Bakhai (Eds.), *Clinical Trials, A Practical Guide to Design, Analysis, and Reporting* (pp. 91–100). London: Remedica. Retrieved from http://www.richmondpharmacology.com/downloads/Publications/Chapter10.pdf

Weitz, B. A., Sujan, H., & Sujan, M. (1986). Knowledge, Motivation, and Adaptive Behavior: A Framework for Improving Selling Effectiveness. *Journal of Marketing*, *50*(4), 174–191.

Wolverton, B. C., McDonald, R. C., & Watkins, E. A. (1984). Foliage plants for removing indoor air pollutants from energy-efficient homes. *Economic Botany*, *38*(2), 224–228.

Wolverton, B., & Wolverton, J. D. (1996). Interior plants: their influence on airborne microbes inside energy-efficient buildings. *Journal of the Mississippi Academy of Sciences*, *41*(2), 99–105. Retrieved from http://www.wolvertonenvironmental.com/MsAcad-96.pdf

Wood, R. a., Burchett, M. D., Alquezar, R., Orwell, R. L., Tarran, J., & Torpy, F. (2006). The potted-plant microcosm substantially reduces indoor air VOC pollution: I. office field-study. *Water, Air, and Soil Pollution*, *175*(1-4), 163–180. doi:10.1007/s11270-006-9124-z

Wood, R., Orwell, R., Tarran, J., & Burchett, M. (2001). Pot-plants really do clean indoor air. *The Nursery Papers*, *2001*(2), 1–4.

Wyon, D. P. (2004). The effects of indoor air quality on performance and productivity. *Indoor Air, 14 Suppl 7*(Suppl 7), 92–101.

Yang, D. S., Son, K. C., & Kays, S. J. (2009). Volatile organic compounds emanating from indoor ornamental plants. *HortScience*, *44*(2), 396–400.

Yeh, N., & Chung, J.-P. (2009). High-brightness LEDs—Energy efficient lighting sources and their potential in indoor plant cultivation. *Renewable and Sustainable Energy Reviews*, *13*(8), 2175–2180. doi:10.1016/j.rser.2009.01.027

Appendix A
Tests in the Experiment with Foliage Plants

Word Creation Test

A paper contains 144 letters, arranged in 12 lines and 12 columns, shaping the puzzle area. The paper also contains prescribed words in the bottom side of the paper that should be searched in the puzzle area. The arrangement of letters can be vertical, horizontal or diagonal. When a word is found, the subject then marked the puzzle using highlighter. Each puzzle contains 9 or 10 words. When all 10 words have been discovered and the time is still available, the subject can move to the other paper, which contains different set of words. A typical puzzle of the word creation test is presented in Figure 50.

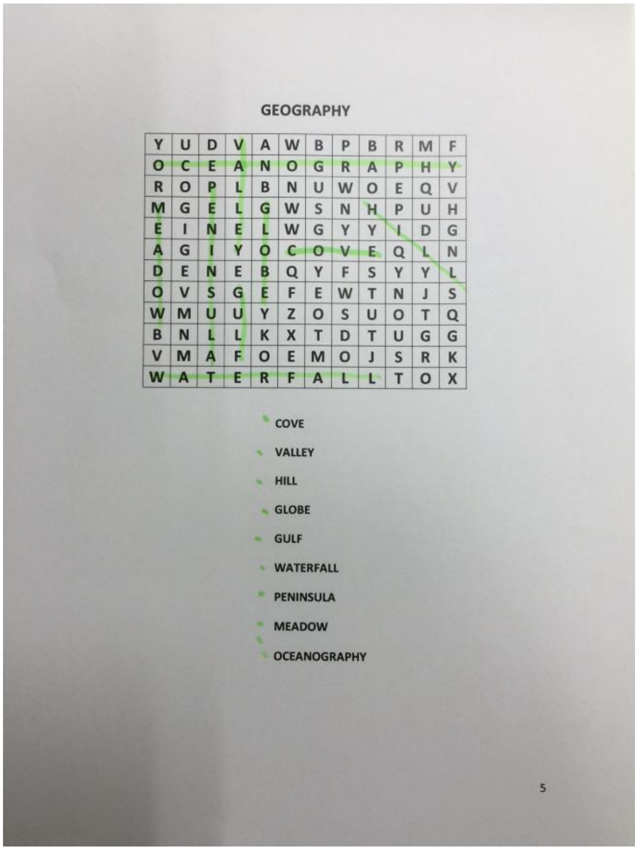


Figure 50. The Word Creation Test

Typing Test

The typing test from Giletech e.K measures subject typing speed and accuracy. The test is computer based. QWERTY keyboard on a TOSHIBA laptop was used. The outputs from the test are in words per minute (WPM) and percentage of accuracy. More than 150 sets of texts are available for the test. The window of typing test is presented in Figure 51.

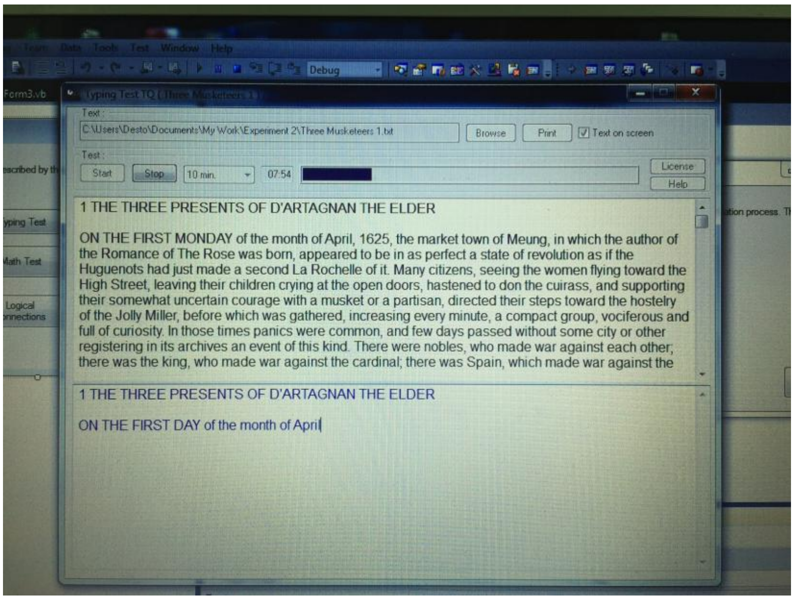


Figure 51. The typing test from Giletech e.K.

Math Test

Math test measures the subject ability of addition and subtraction of two digits numbers in a prescribed time. This is also a computer based test. The window of the math test is presented in Figure 52.

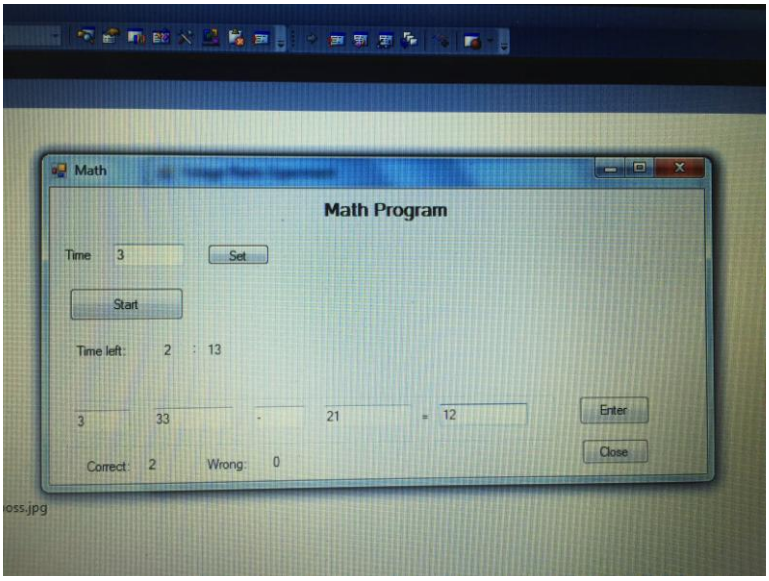


Figure 52. Math test

Logical Connection Test

Logical connections test measures the subject ability to discover a connection among numbers or shapes. The window of logical connection test is presented in Figure 53.

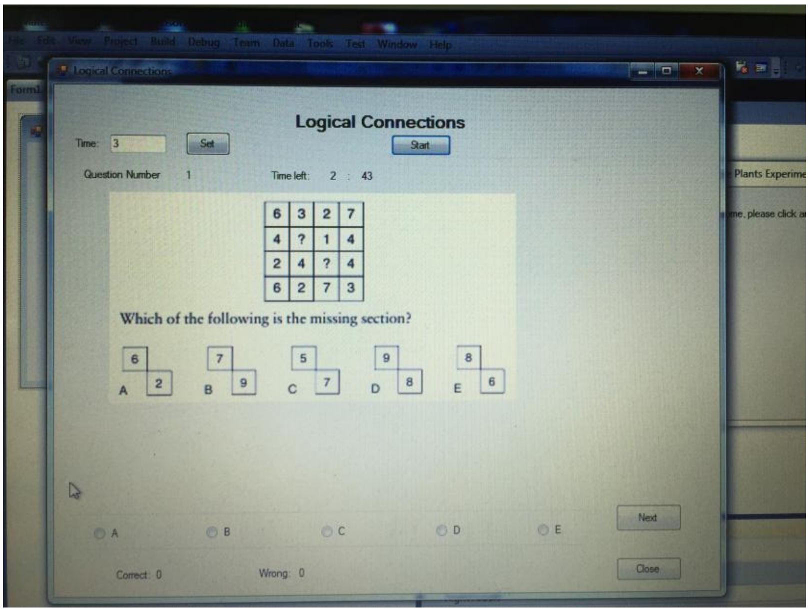


Figure 53. Logical connection test