INDOOR ENVIRONMENTAL QUALITY FOR HUMAN COMFORT FACTORS STUDY IN OFFICE BUILDINGS

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Construction Management)

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FEBRUARY 2021

DEDICATION

This project report is dedicated to my parents, who always love and support me, who taught me about the power of inspiration and courage.

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians and practitioners who have contributed towards this study. I would like to express my most sincere gratitude and appreciation to my Master's Project supervisor, Dr. Ain Naadia Mazlan, for her passionate guidance, encouragement and support.

I also would like to thank my beloved family and friends who support me during the research period.

ABSTRACT

Poor indoor environmental quality (IEQ) can cause Sick Building Syndrome (SBS), different people have different tolerance level of indoor environment condition that could result in various kinds of subjective responses. Previous study demonstrate that current building user are dissatisfied with the indoor environmental conditions even though the technical measurement results show that the present standards are fulfilled. This research aims to study the indoor environmental quality (IEQ) for human comfort in office buildings. Data was collected by means of questionnaire, in-situ measurement and document review. The questionnaire survey was analysed using SPSS version 27.0. Four equipment were used to measure the IEQ condition which are humidity/temperature data recorder (Model MHT-381SD), lux meter (Model LX-1128SD), sound level meter (Model SoundPro SE/DL) and anemometer (Model AM-4307SD). As a result, overall respondents were more comfortable and satisfied with the IEQ in Eco Botanic. The measured IEQ average value ranges were 25.3 °C to 28.8 °C (temperature), 105 lux to 489 lux (illuminance), 46.4 dB(A) to 57.3 dB(A) (sound level), 0.10 m/s to 0.27 m/s (air movement) and 53.3 % to 75.8 % (relative humidity). From the document review, most measured IEQ values did not fulfil the requirement of MS 1525:2014 and BS EN 15251:2007. In conclusion, it is very important to ensure good IEQ in order to achieve human comfort and health.

ABSTRAK

Kualiti persekitaran dalaman (IEQ) yang tidak baik dapat menyebabkan Sindrom Bangunan Sakit (SBS), setiap individu mempunyai tahap toleransi keadaan persekitaran dalaman yang berbeza, yang boleh mengakibatkan pelbagai jenis respons subjektif. Kajian sebelumnya menunjukkan bahawa pengguna bangunan semasa tidak berpuas hati dengan keadaan persekitaran dalaman itu walaupun hasil pengukuran teknikal menunjukkan bahawa standard masa kini dipenuhi. Tujuan kajian ini adalah untuk mengkaji kualiti persekitaran dalaman (IEQ) untuk keselesaan manusia di bangunan pejabat. Data dikumpulkan dengan menggunakan soal selidik, pengukuran in-situ dan semakan dokumen. Soal selidik dianalisis dengan menggunakan SPSS versi 27.0. Empat peralatan yang digunakan untuk mengukur keadaan IEQ adalah perakam data kelembapan/suhu (Model MHT-381SD), meter lux (Model LX-1128SD), meter tahap bunyi (Model SoundPro SE/DL) dan anemometer (Model AM-4307SD). Akibatnya, secara keseluruhan responden berasa lebih selesa dan berpuas hati dengan keadaan IEQ di Eko Botani. Julat nilai purata kualiti persekitaran dalaman (IEQ) yang diukur adalah 25.3 °C hingga 28.8 °C (suhu), 105 lux hingga 489 lux (pencahayaan), 46.4 dB(A) hingga 57.3 dB(A) (tahap bunyi), 0.10 m/s hingga 0.27 m/s (pergerakan udara) dan 53.3 % hingga 75.8 % (kelembapan relatif). Bagi semakan document, kebanyakan nilai IEQ yang diukur tidak memenuhi syarat-syarat dalam MS 1525:2014 dan BS EN 15251:2007. Kesimpulannya, ia adalah sangat penting untuk memastikan kualiti persekitaran dalaman (IEQ) yang baik untuk mencapai keselesaan dan kesihatan manusia.

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HVAC	-	Heating, Ventilation, and Air Conditioning
IAQ	-	Indoor Air Quality
IEQ	-	Indoor Environmental Quality
SBS	-	Sick Building Syndrome
SPSS	-	Statistical Package for the Social Sciences
UTM	-	Universiti Teknologi Malaysia

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Previous researches have been carried out in indoor environmental quality (IEQ) in order to study the human perception of thermal, acoustic, visual and indoor air quality conditions (Yang and Moon, 2019; Wu *et al.*, 2019a). Indoor environmental comfort can be used to indicate the overall comfort (Chiang and Lai, 2002). A study has found that the interactions among the indoor environmental parameters will influence the overall comfort (Yang and Moon, 2019). Among the four main indoor environmental parameters, thermal comfort has greater influence upon overall workplace satisfaction (Frontczak and Wargocki, 2011; Paul and Taylor, 2008).

Human comfort is defined as the state of the mind that indicates satisfaction with the overall surrounding environment in terms of physical, physiological, psychological, and social aspects to be suitable for the task performed (Elzeyadi, 2002). Study has shown that human is highly affected to the variation of temperature compared to relative humidity (Hussein *et al.*, 2009) and have significant effect on its occupancy (Al Obaidi *et al.*, 2014). In general, the four main indoor environmental parameters consists of indoor air quality (IAQ), thermal, acoustic, and visual comfort (Frontczak and Wargocki, 2011).

There are a number of sources of human discomfort including excessive level of temperature, lighting and noise, insufficient space and lack of control (Leaman and Bordass, 2007). A study by Kim and de Dear (2012) found that some factors such as temperature, noise level, space amount are classified as 'Basic Factors' of dissatisfaction that are minimum requirements which negative effects are much greater than positive effects. 'Proportional Factors' such as lighting level, air quality, visual comfort, etc. are the factors to which the overall satisfaction of occupants increases or decreases proportionally (Kim and de Dear, 2012).

Most of the people, especially in industrialised countries, spend over 90% of their time indoors (Frontczak *et al.*, 2012; Frontczak and Wargocki, 2011; Höppe, 2002). Recently, public concern regarding the influence of indoor environment on human comfort has been increasing (Wu *et al.*, 2019a; Huang *et al.*, 2012) as indoor condition can possess influence over the occupants' well-being and performance (Frontczak *et al.*, 2012; Frontczak and Wargocki, 2011). Poor IEQ, such as unsuitable temperature, improper lighting, disturbing noise and poor indoor air quality, will cause Sick Building Syndrome (SBS) (Fisk, 2000), including headaches, malaise, throat dryness, cough and so on (Jafari *et al.*, 2015) that will affect the productivity of the occupants (Arif *et al.*, 2016). Occupants may take sick leave or long break, complain, and make mistake at work due to the poor indoor environment (Azuma *et al.*, 2018; Mahbob *et al.*, 2011).

In addition, SBS will greatly affect job satisfaction, job stress and performance (Norhidayah *et al.*, 2013). Such symptoms become more apparent when people stay in the buildings for longer time and start to disappear when people leave the buildings (Norhidayah *et al.*, 2013; Wong *et al.*, 2009). Lack of immediate mitigation for the issues of poor IEQ can lead to adverse problems to human health (Norhidayah *et al.*, 2013). Moreover, the negative stress could potentially cause both physical and mental health issues in short-term and long-term (Bluyssen *et al.*, 2011). Thus, a comfortable indoor environmental condition is needed as a support to occupants' activities (van der Linden *et al.*, 2002).

Poor indoor environment will also cause human discomfort which results in decrease in productivity (Huang *et al.*, 2012). According to World Green Building Council (2016), productivity will decrease by 6 % in hot condition and 4 % in cold condition. Moreover, employees will tend to have additional 46 minutes of sleep when they are near windows. Furthermore, productivity will decrease by 66 % if disturbing noise exists. A study by Soewardi *et al.* (2016) measured the temperature, lighting and noise in office buildings, which found that the temperature is 31.2 °C, lighting level is

111 lux and noise level is 89.3 dB. In addition to that, by reducing temperature to 25.4 °C, noise level to 85.6 dB and enhancing lighting level to 210.5 lux, overall productivity can be improved by 14 %.

70-80 % of occupants are uncomfortable in lowest-rated buildings, in some cases it can reach 100 %. There are even 5-10 % occupants who feel uncomfortable in the highest-rated buildings (Leaman and Bordass, 2007). In addition, it is not surprising to have 30-40 % of occupants who are dissatisfied with the indoor environment (Leaman and Bordass, 2007). There is even limited evidence which proves that occupants' comforts are well addressed in environmentally-concerned buildings (Zhang and Altan, 2011; Paul and Taylor, 2008). There is even a number of employees who are uncomfortable in modern buildings (Abdou *et al.*, 2006).

1.2 Problem Statement

According to United Nations (2020), the current population is about 7.7 billion and it is estimated to increase by 2 billion in 2050. At present, there are 55 % of the population living in cities and it is estimated that there will be 68 % of population living in cities by 2050. The increasing growth in world's population results in increasing urban density of buildings, therefore, the features of indoor environments are more and more depending on artificial systems to satisfy the building occupants (Rupp *et al.*, 2015).

Previous researches have proven the relationship between the occupants' individual control over the indoor environmental conditions and productivity (Park *et al.*, 2018; Roelofsen, 2002; Menzies *et al.*, 1997). Yet, in fact, these kinds of rooms tend to disappear at present due to the increasing popularity of open space workplaces, where the occupants are unable to adjust the comfort level to their preference (Leaman and Bordass, 2007).

More and more complaints regarding the health issues due to staying in artificially ventilated buildings, especially in work environment, for a long time have been recorded (Li *et al.*, 2020; de Magalhães Rios *et al.*, 2009). The reason might be the physical and chemical exposures in workplace (de Magalhães Rios *et al.*, 2009). In addition, conventional studies were conducted to address the IEQ separately (Mahdavi *et al.*, 2020; Wong *et al.*, 2008). Until now, designers still address the IEQ separately for the design in many offices (Mahdavi *et al.*, 2020; Wong *et al.*, 2008).

Since different people have different tolerance level of indoor environment condition, same indoor environment condition could result in various kinds of subjective responses (Tsang *et al.*, 2020; Bluyssen *et al.*, 2011; Frontczak and Wargocki, 2011). Although standards have been developed to define the acceptable range of IEQ (Frontczak and Wargocki, 2011), it is common situation that building occupants are still not satisfied with the indoor environmental conditions even though the technical measurement results show that the present standards are fulfilled (Kang *et al.*, 2017; Abdou *et al.*, 2006).

Compared to other countries, study with respect of IEQ in working environment in Malaysia is limited (Mahbob *et al.*, 2011). More research is required for the optimisation of standards (Kamaruzzaman *et al.*, 2011). It is necessary to ensure IEQ conditions are in desired condition in order to create a healthy environment that improves performances and well-being of building occupants (Al Horr *et al.*, 2016; Oral *et al.*, 2004). From previous studies, it can be inferred that indoor environment is essential to human comfort. However, what is unknown is whether building users feel comfortable with the indoor environmental conditions. Therefore, it is necessary to carry out reassessment for measurement and standards (Park *et al.*, 2018; Abdou *et al.*, 2006).

1.3 Research Questions

The research seeks to answer the following questions:

(a) Are the building users comfortable and satisfied with the IEQ conditions in the office buildings?

(b) What are the IEQ conditions in the office buildings?

(c) Does the IEQ conditions meet the IEQ standard guidelines in the office buildings?

1.4 Aim of Research

The aim of the research is to study the indoor environmental quality (IEQ) for human comfort in office buildings. This is very important as many previous researches revealed that a lot of people are dissatisfied with the indoor environmental conditions of buildings even though the conditions meet the required IEQ standard guidelines.

1.5 Objectives of Research

In order to achieve the aim of the research, the research intends to attain the following objectives:

(a) To investigate the building users' human comfort perception of IEQ in terms of thermal comfort, visual comfort, acoustic comfort and indoor air quality in two office buildings.

(b) To conduct IEQ in-situ measurement in terms of thermal, visual, acoustic and indoor air quality conditions in two office buildings.

(c) To analyse the IEQ condition with IEQ standard guidelines.

1.6 Scope of the Study

This study focused on thermal comfort, visual comfort, acoustic comfort and indoor air quality. The two office buildings which were selected as case studies are located in Eco Botanic and Bandar Putra Kulai, Johor respectively. The respondents in this study were the building users in the two selected office buildings. In addition, the personal factors of the respondents are not considered in the analysis of comfort level and satisfaction level. Furthermore, this study reviewed two IEQ standard guidelines which are Malaysia Standard MS 1525:2014 and British/European Standard BS EN 15251:2007.

1.7 Significance of the Study

The research is highly significant as the IEQ, which consists of thermal, visual and acoustic comfort as well as indoor air quality, directly influences the human comfort and health (Al Horr *et al.*, 2016; De Giuli *et al.*, 2012). Indoor contaminants are more hazardous to human well-being compared to outdoor contaminants (Jones, 1999). High IEQ is needed to ensure the healthiest environment possible (Jones, 1999). Previous studies have proven the relation between illness and IEQ, which revealed that some of the illness may not appear in the short-term but could result in severe issues in the long-term, for instance, musculoskeletal and mental health problems, cardiovascular disease, coronary heart diseases, asthma-related issues and obesity (Abdulaali *et al.*, 2020; Azuma *et al.*, 2018; Jaakkola *et al.*, 2013; Houtman *et al.*, 2008).

Apart from that, studies have shown that the productivity of occupants can be maximised when their satisfactions with the comfort are the highest (Humphreys and Nicol, 2007; Leaman and Bordass, 2007). Roelofsen (2002) pointed out that improvement of the indoor environment can generally lead to an increase of productivity by 10 %. Evidence has shown that there is less chance for requesting higher salary when they feel comfortable in working environment and the employees are more likely to decline job offers with higher salary when they notice the less comfort in new workplaces (Abdou *et al.*, 2006).

Investigation of human discomfort is highly needed (Leaman and Bordass, 2007) and high protection against the adverse health problems as a result of poor IEQ must be done (Kosonen and Tan, 2004). It is highly significant to ensure the desired thermal, visual, acoustic and indoor air quality conditions (Al Horr *et al.*, 2016; Oral *et al.*, 2004). Therefore, there is a necessity to carry out reassessment for measurement and standards (Abdou *et al.*, 2006).

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