Effects of Indoor Air Quality on the Occupant's Health and Productivity in an Office Building

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DEDICATION

For my beloved mother, father, sister, telly oktowianti and family…

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ABSTRACT

Indoor Air Quality (IAQ) is an important parameter in deciding the status of Sick Bulding Syndrome (SBS). Poor IAQ which leads to SBS can result in adverse effect on the health of the occupant which causing lower productivity. This study was conducted to establish correlation between IAQ and employee's productivity. Five parameters of IAQ which include air velocity, air temperature, relative humidity, particulate matters ≥ 0.3 µm and CO_2 were considered in this study. The values of these parameters were measured using *Davis Anemometer, Particle Counter GT 521* and *YES Plus LGA Meter*. The measured data were then used as an input data for simulation model of the room using *Comsol Multiphysics software*. The simulation generated the indoor air velocity of the room and particle distribution. For validation purpose, only the predicted velocity was compared with the measured value, and found that the percentage difference were in the range of 1.5% to 8.45% (below than 10%). Once the model had been validated, the parametric study of air supply inlet position was conducted on the model and found that the position of air supply inlet with x = 2.5 ft, y = 10 ft and H = 6.5 ft give the most efficient air distribution model for diluting the impurities due to the particulate. The questionnaire survey distributed amongst the occupants of the room showed that the occupants were less satisfied (75%) with the IAQ which can lead to SBS problem. The analysis of correlation between IAQ and occupant's productivity depicted that both of the factors were correlated with Rank-Spearman value of 0.648. This study serves as a good platform in assessing IAQ based on the modelling and simulation approach.

ABSTRAK

Kualiti udara dalaman merupakan parameter penting dalam menentukan status Sindrom Bangunan Sakit (SBS). IAQ yang rendah boleh memberi kesan yang buruk pada kesihatan penghuni dan juga menyebabkan produktiviti rendah. Kajian ini dijalankan untuk menentukan tahap SBS bilik pejabat yang dipilih dan kesannya terhadap produktiviti penghuni. Parameter SBS yang dipertimbangkan dalam kajian ini adalah IAQ dan tahap kepuasan penghuni. Lima parameter IAQ yang terlibat dalam kajian ini adalah halaju udara, suhu udara, kelembapan relatif, zarah ≥ 0.3 µm dan CO_2. Nilai parameter tersebut diukur menggunakan *Davis Anemometer*, *Particle Counter GT521* dan *YES Plus LGA Meter*. Data diukur digunakan sebagai input bagi model simulasi bilik dengan menggunakan perisian *Comsol Multiphysics*. Simulasi yang dihasilkan adalah halaju udara dalaman dan pengedaran zarah. Untuk pengesahan, hanya halaju udara sahaja divalidasikan dengan nilai yang diukur. Hasil validasi mendapati peratus perbezaan adalah 1.5% kepada 8.45% (iaitu kurang dari 10%). Apabila model telah disahkan, kajian parametrik dijalankan ke atas model dan mendapati bahawa kedudukan masuk dengan x = 2.5 ft, y = 10 ft dan H = 6.5 ft memberikan model pengedaran udara yang paling berkesan untuk mencairkan kekotoran zarah . Kaji selidik soal selidik yang diedarkan di kalangan penghuni bilik itu mendapati bahawa penghuninya kurang berpuas hati (75%) dengan IAQ dan ini boleh membawa kepada terjadinya SBS. Analisis korelasi antara IAQ dan produktiviti penghuni menunjukkan bahawa kedua-dua faktor ini berkait rapat dengan nilai Rank-Spearman 0.648. Kajian ini bertindak sebagai platform yang baik dalam menilai IAQ berdasarkan pendekatan model.

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LIST OF SYMBOLS AND ABBREVIATIONS

%RH	-	Percentage of Relative Humidity
ρ	-	Air Density
A	-	Cross Section Area of the Opening
A_O	-	Terrain of The Area
Al	-	Aluminium
ASHRAE	-	American Society of Heating, Refrigerating, and Air-Conditioning for Engineer
°C	-	Degree Celcius
$CaCO_3$	-	Calcium Carbonate
Cd	-	Cadmium
C_D	-	Coefficient of Discharge
CFM	-	cubic feet per minute
CH_4	-	Methane
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
COHb	-	CarboxyHemoglobin
Cu	-	Cuprum
ETS	-	Environmental Tobacco Smoke
Fe	-	Ferrum
H^+	-	Hydrogen
HVAC	-	Heating, Ventilation, and Air-Conditioning
IAP	-	Indoor Air Pollutants
IAQ	-	Indoor Air Quality
IPCC	-	Intergovernmental Panel on Climate Change
kg/m^3	-	kilogram per meter cubic

Mn	-	Mangan
NO_3^-	-	Nitrate
NH_4^+	-	Ammonium
NaCl	-	Natrium Chloride
Ni	-	Nickel
NO	-	Nitrogen Oxide
NO_2	-	Nitrogen Dioxide
O_3	-	Ozone
OHb	-	OxyHemoglobin
Pb	-	Plumbum
PDE	-	Partial Differential Equations
PM	-	Particulate Matter
PM_{10}	-	Particulate Matter smaller than 10 μm in diameter
$PM_{2.5}$	-	Particulate Matter smaller than 2.5 μm in diameter
PM_1	-	Particulate Matter smaller than 1 μm in diameter
ppm	-	parts per million
Q	-	Volumetric Flow Rate
RSP	-	Respirable Suspended Particle
RH	-	Relative Humidity
Si	-	Silicon
SO_2	-	Sulphur Dioxide
SO_4^{2-}	-	Sulfate
SPM	-	Suspended Particulate Matter
SBS	-	Sick Building Syndrome
THI	-	Temperature Humidity Index
Ti	-	Titanium
TLV	-	Threshold Limit Value
U_{REF}	-	Reference Wind Velocity
U_{MET}	-	Wind Velocity Measured at The Weather Station Nearest to The Building Location
U.S. EPA	-	United States Environmental Protection Agency
TVOC	-	Total Volatile Organic Compounds
U	-	Air Velocity Leaving the Opening

UTHM	-	University Tun Hussein Onn Malaysia
V	-	Vanadium
VOC_s	-	Volatile Organic Compounds
WHO	-	World Health Organization
Zn	-	Zincum

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CHAPTER 1

INTRODUCTION

1.1 Background

In Malaysia, air quality becomes an interesting issue to be investigated since the rapid growth of industrial area which is not only contribute to the economic growth but also at the same time is affecting air quality as in Figures 1.1 and 1.2 respectively.

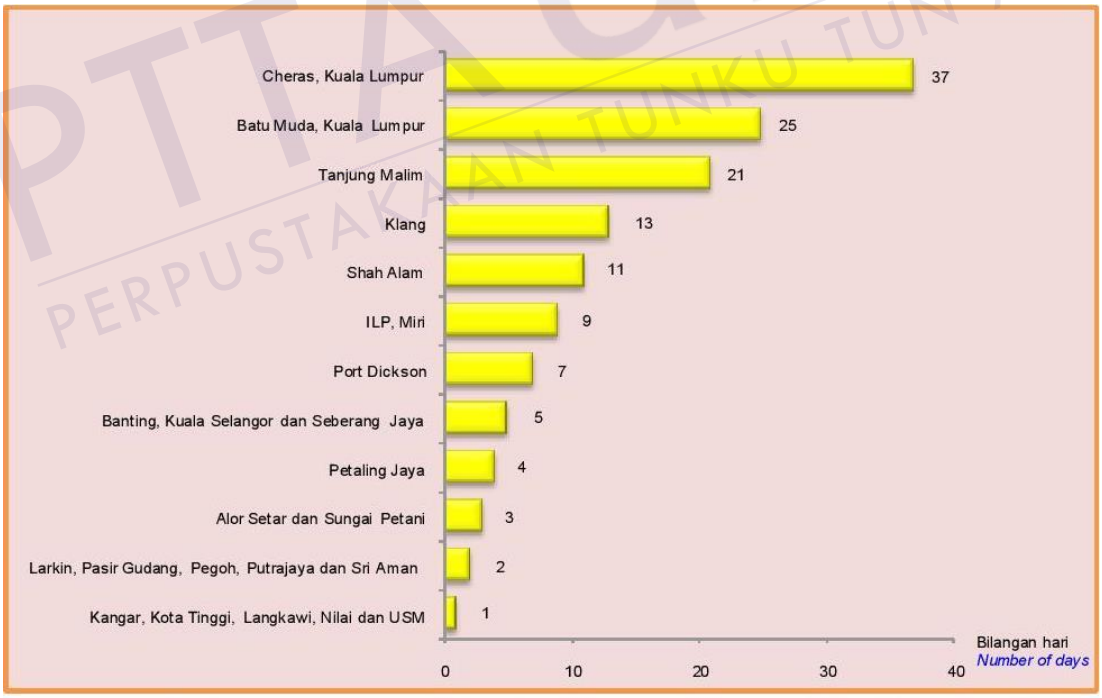

Figure 1.1: Number of days for unhealthy air quality status by station, Malaysia 2012 (Department of Statistic Malaysia, 2013).

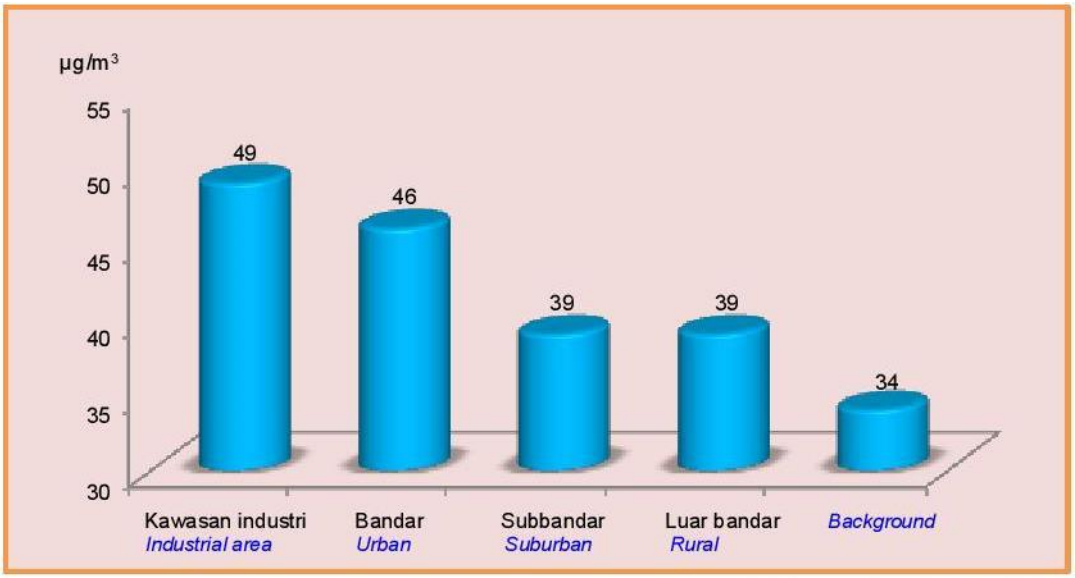

Figure 1.2: Average annual concentration of Particulate Matter by land use, Malaysia 2012 (Department of Statistic Malaysia, 2013).

According to study conducted by WHO (2005), more than 2 million premature deaths each year are attributed to the effects of urban outdoor air pollution and indoor air pollution. For controlling indoor air quality, ventilation is a commonly way to provide the healthy air for breathing (Zhang, 2005) by both diluting the pollutants originating in the building and removing the pollutants from building (Etheridge and Sandberg, 1996a; Awbi, 2003). Additionally, Sick Building Syndrome (SBS) is one of the indicators which can be used for assessing the capability of ventilation in providing healthy air within building (Finnegan *et al*., 1984; William, 2009; Guo *et al*., 2013; Norhidayah *et al*., 2013).

According to Israeli and Pardo (2011), SBS is defined as a term coined for a set of several clinically recognizable symptoms and ailments without a clear cause reported by occupants of a building. The symptoms usually resolve soon after occupants leaving the building (Environmental Protection Agency, 1991; Norhidayah *et al*., 2013). In addition, these symptoms can reduce working performance of employee's due to sick leave and it must be noted that SBS is not only a health hazard for employees but it is an adverse impact to the company. Thus, these motivates to study on the effect of indoor air quality on the occupant's health and productivity in an office building.

1.2 Problem Statement

In Malaysia, research that related with indoor air quality in work place is restrictive as compared to other country (Mahbob *et al*., 2011) and people mostly spend 90% of their times at indoor for working, living, etc (Frontczak and Wargocki, 2011). According to U.S. EPA (2000), pollutants on indoor air are two to five times and occasionally more than 100 times higher than outdoor air. In order to overcome that problem, mechanical ventilation system is one of ventilation types widely used in indoor space like office building. However, the utilization of mechanical ventilation could be also responsible with the problems regarding with IAQ like high level of air contaminants due to the insufficient of airflow (Anderson, 1998) cited by Posner and Buchanan (2003) that will lead to SBS (Dutton *et al*., 2013). Thus, the risks to health which will lead to the decrease of employee productivity through exposure to indoor air pollution maybe greater than those posed by outdoor air pollution. Clearly, the quality of indoor air should be as high as possible. Since Universiti Tun Hussein Onn Malaysia (UTHM) located near to the factories that emit pollutants, it is interesting to know the effects of outdoor air quality towards the indoor air quality. Thus, this study investigates an indoor air quality of The Office of Research, Innovation, Commercialisation, and Consultancy (ORICC) rooms in UTHM. Besides that, it also simulates the performance of ventilation system in controlling the indoor air quality. Finally, this study correlates the indoor air quality of the rooms with employees' productivity.

Figure 1.3: Location of ORRIC office with Evergreen factory in 200 m distance.

1.3 Aim and Objectives

The primary purpose of this research is to study the effects of IAQ on the occupant's health and working performance. This aim can be achieved by carrying-out the following objectives as below:

i. To determine the level of IAQ parameters in the selected rooms.
ii. To establish correlation between IAQ and working performance.
iii. To determine the optimum position of inlet air supply for improving IAQ.

The determination of IAQs' level is to check whether its level exceed the Threshold Limit Value (TLV). Then, the correlation between IAQ and working performance is established to assess their relationship. Finally, the determination of optimum position of inlet air supply for improving IAQ is carried out by perturbing its location as a strategy to enhance the working performance of occupants.

1.4 Significance of Research

The significances of this research include :

i. The outcomes of this research as an input to the authority in improving the quality of IAQ of the office building in ensuring the heatlh of occupant.

ii. An alternative approach to improve IAQ in a particular room is generated in this research by optimizing the location of inlet air supply in order to dilute the pollutants.

1.5 Scope of the Research

This study was conducted on ORICC office at ground floor. The office is located in UTHM area and has a total area about 244.238 m^2. However, for simulation works it involves only one (1) of the selected room which is the most critical in terms of measured IAQ. The selected rooms are ventilated by air-conditioning systems (split unit). Employee's productivity is measured based on the questionnaire survey on the occupants of the rooms. For IAQ, the parameters measured are confined to air velocity, number of particles (PM $\geq$ 0.3 µm), CO_2, temperature and humidity.

1.6 Thesis Layout/Organization

The organization of this thesis consists of 6 chapters and divided as followings :

Chapter 1: this chapter discusses on the fundamental and basic framework for this thesis. It contains background of the study, problem statement, aim and objectives, significance of research and scope of the research.

Chapter 2: this chapter discusses the literature review of published research work on Indoor Air Quality (IAQ) and types of ventilation both experimentally and modelling. Besides, the adverse effect which occurs regarding with poor IAQ such as Sick Building Syndrome that will decrease productivity of occupant's also described.

At the last an introductory review of the latest available modelling tools are presented here, which can simulate the IAQ in ventilated room.

Chapter 3: presents the framework idea of this whole research, how the research designed and the methodology used. This chapter is also contains detailed of research procedures and the selected analysis method.

Chapter 4: reports how the measurement was conducted, which contains of analysis of IAQ measurement while questionnaire survey was conducted based on occupant's perception .

Chapter 5: this chapter presents the modelling and simulation of IAQ in the selected rooms using COMSOL Multiphysics.

Chapter 6: this chapter discusses the conclusion achieved from this study by keeping in view the core principles, and objectives of this study. Then, the recommendations for future study are highlighted.

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