INDOOR OUTDOOR RELATIONSHIP OF FINE PARTICLES ($PM_{2.5}$) IN SCHOOL CLASSROOM

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UNIVERSITI SAINS MALAYSIA
2017

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By

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This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfilment of requirement for the degree of

BACHELOR OF ENGINEERING (HONS.)
(CIVIL ENGINEERING)

School of Civil Engineering,
Universiti Sains Malaysia

JUNE 2017

ACKNOWLEDGEMENT

I would like to express my deepest praise to Allah S.W.T, who has given me strength and faith to complete this study. Alhamdulillah.

The writing of this dissertation has been one of the most significant academic challenges I have ever had to face. Without the support, patience and guidance of a few significant persons in my life, this study would not have been completed.

It is difficult to overstate my gratitude and appreciation to my supervisor, Dr Noor Faizah Fitri Binti Md Yusof. Throughout my dissertation, if not without her inspiration and her great efforts to explain things clearly and simply, I would have been lost.

Moreover, I would like to express my appreciation to all teachers and staff of Sekolah Kebangsaan Sungai Kechil and Sekolah Kebangsaan Khir Johari. Millions thanks to the Ministry of Education Malaysia and Penang Education Department on the authorization granted to complete the study.

I owe my deepest gratitude to my parents, Kamaruddin bin Shaari and Nahariah Binti Mohd Yazi, without them this effort would have been worth nothing. Their pray, love, support and constant patience have taught me so much about sacrifice and compromise.

Special thanks go to all administrative and environmental technical staff for their help during the period of research, PhD student, my friends and colleagues, who inspired my final effort despite the huge work pressures we were facing together.

ABSTRAK

Manusia menghabiskan 90% kehidupan mereka di dalam bangunan dan pencemaran udara dalaman adalah salah satu punca persekitaran yang paling berbahaya terhadap kesihatan manusia. Kajian-kajian telah menunjukkan terdapat hubungan yang signifikan di antara status kualiti udara dalaman (KUD) dengan aktiviti-aktiviti persekitaran.Di dalam kajian ini, kepekatan bahan terampai kurang daripada 2.5 mikron diameter ($PM_{2.5}$) telah dikaji semasa sesi pembelajaran dan pengajaran iaitu daripada 8.00 pagi ke 2.00 pagi di dua sekolah yang berbeza berdasarkan dua perbezaan sumber seperti kawasan industri (Sekolah Kebangsaan Sungai Kechil) dan ketinggian kepadatan trafik (Sekolah Kebangsaan Khir Johari). Selain itu, kajian ini juga dijalankan untuk menentukan kesan reka bentuk bangunan ke arah pencerobohan $PM_{2.5}$ luar ke dalam kualiti udara dalaman di dalam kelas. Di setiap sekolah, dua jenis bilik telah dipilih berdasarkan kepada jenis tingkap yang dipasang di dalam bilik seperti bilik yang menggunakan tingkap majmuk dan bilik yang menggunakan tingkap melingsir. Purata kepekatan $PM_{2.5}$ di dalam kelas dengan tingkap majmuk dan bilik darjah dengan tingkap melingsir yang diperolehi bagi SK Sungai Kechil adalah 13 µg/m³ dan 35 µg/m³ manakala bagi SK Khir Johari adalah 27 µg/m³ dan 37 µg/m³. Hasil dapatan menunjukkan terdapat perbezaan yang signifikan (nilai $P < 0.05$) pada parameter antara kedua-dua sekolah tersebut. Kesimpulannya, pengaruh dari aktiviti-aktiviti sekitar dan sumber-sumber dalaman penting dalam menyumbang kepada kepekatan dalaman bahan pencemar di dalam kelas bagi sesebuah sekolah.

ABSTRACT

People spend about 90 % of their lifetime indoors and indoor air pollution is one of the most harmful environmental factors for human health. Studies have shown that there is significant relationship between indoor air quality (IAQ) status with surrounding activities. In this study, $PM_{2.5}$ concentration was monitored during teaching and learning session from 8.00 a.m. to 2.00 p.m. at two primary schools exposed to different major expected sources that are industry (Sekolah Kebangsaan Sungai Kechil) and mobile (Sekolah Kebangsaan Khir Johari) sources. The effect of building design towards the intrusion of outdoor $PM_{2.5}$ into the indoor air quality in classroom was investigated. In each school, two rooms have been selected based on the type of window that is installed in a room with a window that uses a louvre and sliding window. The average of $PM_{2.5}$ concentration in classroom with louvre window (CLW) and classroom with sliding window (CSW) were obtained which for SK Sungai Kechil (value for CLW and CSW) were 13 µg/m³ and 35 µg/m³ while for SK Khir Johari (value for CLS and CSW) were 27 µg/m³ and 37 µg/m³. Results shows that there exist statistically significant differences (p-value <0.05) of parameter indoor and outdoor $PM_{2.5}$ concentration between these two schools. As a conclusion, the influence from the surrounding activities and indoor sources are important in contributing on indoor concentrations of pollutants in school classroom.

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LIST OF ABBREVIATIONS

ASHRAE	American Society for Heating, Refrigerating & Air Conditioning Engineer
CSW	Classroom with Sliding Window
CLW	Classroom with Louvre Window
DOSH	Department of Safety and Health
HVAC	Heating, Ventilating and Air-Conditioning
ICOP	Industry Code Of Practice
IAQ	Indoor Air Quality
MAAQS	Malaysian Ambient Air Quality Standard
NV	Natural Ventilation
$PM_{2.5}$	Particulate Matter less than 2.5 micrometers in diameter
RSP	Respirable Suspended Particulate Matter
USEPA	Environmental Protection Agency (US)
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

1.1 Background

Air pollution is one of the environmental challenges facing the world today. Air pollution is contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere. From day to day the impact of air pollution is more severe in developing countries, leading to ill health, death and disabilities of millions of people annually. Clean air is a very important element that need to be taken care of as it is a need of human health and well-being. Unfortunately, the clean air nowadays had been interrupted by air pollutants which majority come from anthropogenic sources. This condition is quite alarming due to the facts that contaminated air could be one of a major threat towards human health specifically respiratory system. An assessment on the burden of disease due to air pollution had been conducted by World Health Organization (2006) and they found that more than two million premature deaths each year can be attributed to the effects of urban outdoor air pollution and indoor air pollution (caused by the burning of solid fuels). Based on report (World Health Organization, 2016), ambient (outdoor) air pollution alone kills around three million people each year, mainly from no communicable diseases. Only one person in ten lives in a city that complies with the WHO air quality guidelines.

Malaysia has been a successful developing country and is looking forward to become a developed nation. Since twenty years ago, the air pollution issues that associated with development activities and economic sectors occurred in this country had been of concern (Mohamad and Mazdi, 2006). Additionally, the contribution of

particulate matter to the air are caused by the industrial activities and traffic emission from the automobiles (Blondeau *et al.*, 2005).

Most of the people are aware that outdoor air pollution can affect their health, but they do not realised that indoor air pollution can also contribute to the health problems. People spend most of their time indoors either in home, school, office or other types of building (Mentese *et al.*, 2015). Bad indoor air quality can cause serious health effects such as fatigue, respiratory problem, headaches, cough, carbon monoxide poisoning and asthma, especially for children (Yang *et al.*, 2009). Clean air can prevent many environmental health hazards. According to US Environmental Protection Agency (USEPA, 2017), the definition of good indoor air quality (IAQ) management includes control of airborne pollutants; introduction and distribution of outdoor air; and maintenance of acceptable temperature and relative humidity.

Air pollution become a main contributor to the increment of a health problems (He *et al.*, 2017). Breathing with good air quality especially indoor air is very crucial for good respiratory health especially to the sensitive group i.e. children, old adults, pregnant woman and respiratory illness patients. During the school time, children and teenagers spend much of their time in indoor classrooms, where the indoor air pollution concentrations can be different from outdoor air pollution (Mohammadyan *et al.*, 2016). A good air quality is highly needed as continuity of productivity of life especially to children as they will be a leader in future. Poor indoor air quality had been recognized to give negative effects on school children (Lee *et al.*, 2008). This is supported by many epidemiological studies conducted which found that air pollution in schools had given impact on their behavioural and emotional, also respiratory problems (Tippayawong *et al.*, 2009). Indoor air quality in workplace and schools become a major concern among the people because it is a very important aspect in providing a

healthy and conducive learning and teaching environment as it has an effect on health, productivity, performance and comfort for students and teachers in a variety of ways.

Particulate matter (PM) is one of the most important pollutants in the air that can give adverse effects to health. PM is the mixture of all solid and liquid particles suspended in the air. PM is often divided into two main groups based on size which is $PM_{2.5}$ and PM_{10}. $PM_{2.5}$ is a fine particulate matter with the aerodynamic diameter equal to less than 2.5 microns and it generated by various sources such as fuel combustion process in vehicles, open burning by the local people, smoking, cooking, cleaning and industrial combustion process (Martuzevicius *et al.*, 2008; Massey *et al.*, 2012). All this sources contribute primarily to the $PM_{2.5}$ level and traffic related fine particles are recognized as an important contributor to outdoor $PM_{2.5}$ concentrations.

Good ventilation in classroom is necessary to maintain a comfortable, healthy, and productive indoor environment. There are two types of ventilation systems which are known as natural and mechanical. Most of the schools in Malaysia are mechanically ventilated which allow the particles from outside to freely penetrate into the classroom by passing through the windows and doors with the support of ceiling fans. Therefore, this research could help to be a guideline and reference for Ministry of Education (MOE) Malaysia and developer to construct and provide a conducive classroom design with a good ventilation system. Thus, it contribute to reduction of indoor air pollutants and provide healthy environment in class so that many health problem issues can be prevented.

1.2 Problem Statement

In Malaysia, the research about indoor air quality in school classroom are still limited and many people are focusing in the school's facilities rather than IAQ in classroom. The condition of school itself give an important role to the air quality. Schools that are located near to the industrial area and high traffic densities commonly reported to have bad indoor air quality. The gas and smoke production from industry will contribute to the increasing of outdoor and indoor air pollution. Thus, it will give effect to the children during the learning and teaching lesson. Furthermore, type of ventilation system in classroom is also the main component that need to be considered. The variety on type and size of windows and doors need to be measured. The number of ceiling fans and size of class also need to be identified too (Ramli *et al.*, 2012; Gordon and Aia, 2012).

The air inside the classroom could be more polluted than outside if there is bad ventilation system (Kim *et al.*, 2015). For example, usually the windows located at the top are not fully open and it block the air inside to pass through to outside. Other than that, the windows are not having any maintenance like cleaning so the pollutants inside the classroom cannot move out and the pollutants accumulate inside the classroom.

There are some effects that will be experienced if the failure to act promptly and effectively to a lack of air quality in the classroom. There are effect of short-term and long-term to health, increasing to the budgetary maintenance, thus bringing to greater risk of closing schools. Therefore, it is important that for this research was conducted to determine the status of air quality especially in school because children are the future generation of leaders.

1.3 Aim and Objectives

The aim of this study is to identify influence of outdoor $PM_{2.5}$ towards indoor based on building design. The specific objectives of this study are:

i) To determine the level of $PM_{2.5}$ concentration in the classroom at school located near industrial source and mobile source.

ii) To investigate the indoor and outdoor relationship of $PM_{2.5}$ concentration.

iii) To determine the effect of building design toward intrusion of outdoor $PM_{2.5}$ into the indoor air quality in classroom.

1.4 Scope and Limitation

Monitoring and data collection were collected in Sekolah Kebangsaan Sg. Kechil, Nibong Tebal and Sekolah Kebangsaan Khir Johari, Perai, Penang. Both of this school were selected based on their criteria which is Sekolah Kebangsaan Sungai Kechil is near to industrial area while Sekolah Kebangsaan Khir Johari is near to mobile sources. All the parameter such as particulate matter $PM_{2.5}$, temperature, relative humidity, wind speed, wind direction and flow data were collected. $PM_{2.5}$ was collected to know the level of $PM_{2.5}$ in school classroom and to identify whether the $PM_{2.5}$ level is under the limit or not. The details of the selected room such as number of fans, number of windows and doors, size and type of window, the dimension of the selected rooms were collected. The statistical analysis was used to analyze data related to the measured parameters of the two schools.

1.5 Thesis Layout

This thesis contains five main chapters where every chapter explains different parts of this study. Chapter 1 elaborates on introduction, background and problem statement, research objectives and scope and limitation.

Chapter 2 is a literature review, which emphasizes on collection of published information and data that is relevant to this research. This chapter has also reviewed the effect of indoor air pollutant toward the human health and the effect of ventilation system toward the indoor air pollutant.

Chapter 3 is methodology, equipment used, material used, details of monitoring locations to collect and evaluate data, software to analyse data. E-BAM and E-Sampler were used to collect the data. The maps and the arrangement of table in classroom and intensive class were represented in the drawing. The location of the equipment were shown in the figure.

Chapter 4 shows the results and discussions obtained from the monitoring and sampling including the tables, graphs and figures. All the data was analysed by using SPSS and Microsoft Excel software. WR PLOT software was used to analyse wind direction.

Chapter 5 is the final conclusion of the study, findings and recommendation for improvement of this study in future.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter defines particulate matter and provides an explanation of the terms and concepts. Moreover, this chapter provides an overview of the health concerns that is related to the poor indoor air quality and further to identify the ventilation system in school buildings and sources that contribute to the outdoor indoor air pollution

2.2 Particulate Matter

Particulate matter (PM) is a particle pollution. It is a combination of fine solids particles and aerosols (liquid droplets) that are suspended in the air (Breysse *et al.*, 2010). Particulate matter are made up of different things. “A mixture of mixtures” is how EPA describes them. This complex mixture includes both organic and inorganic particles, such as dust, pollen, soot, smoke, and liquid droplets (Gieré and Querol, 2010). These particles vary greatly in size, composition, and origin. According to World Health Organization, particulate matter have given the public health impact and it is consistently showing adverse health effects to the peoples in both developed and developing countries. The range of health effects is vast especially to the respiratory and cardiovascular systems World Health Organization (2006). The chemical composition of PM besides particle size distributions is the most significant factor affecting air quality and human health, although less investigate. Calcium (Ca) become an abundant element in the classroom as its high concentrations is associated to chalk dusts compare to other elements such as iron (Fe), aluminium (Al), titanium (Ti) and strontium (Sr) are mostly come from the outdoor sources (Maruthi *et al.*, 2017).

2.3 Types of particulate matter

Types of particulate matter can be describe by their size, physical and chemical properties. Not all particles are spherical in size but it typically is classified by their diameter (d) (Gieré and Querol, 2010). PM are commonly divided into two principal groups, which is coarse particles and fine particles. Based on US Environmental Protection Agency (USEPA, 2017), PM can be classified in three size classes: $PM_{2.5}$, PM_{10} and $PM_{1.0}$ fractions.

PM_{10} is the coarse particles that have aerodynamic diameter less than or equal to 10 µm while $PM_{2.5}$ is fine particulate matter with the aerodynamic diameter less than 2.5 microns meter and it is generated by various sources (Martuzevicius *et al.,* 2008). $PM_{2.5}$ is a major indicator of risk to health from particulate pollution, and might also be a better indicator than PM_{10} for anthropogenic suspended particles in many areas.

The concentrations of $PM_{2.5}$ depend on the type of source, distance from the source and wind speed. $PM_{2.5}$ is a made up by the mixture of chemical species like organic compound, soot, ionic compound, trace metal and smoke and mainly come from the combustion and the reaction of gases in air which emitted from the industry and automobiles (Lodgejr, 1996).

Ultrafine particles are usually formed by nucleation, which is the initial stage of the process by which gas becomes a particle. These particles are a few nanometres in size but can grow up to 1 µm, either through condensation (when additional gas condenses onto the particles) or through coagulation (when two or more particles combine to form a larger particle) (WHO, 2006)

Table 2.1 List of indoor air $PM_{2.5}$ concentration maximum limit

Pollutants	**WHO (2006)**	**USEPA (2014c)**	**Malaysia (DOSH, 2010)**
$PM_{2.5}$	25 µg/m³ (24 hr average)	150 µg/m³ (24 hr average)	150 µg/m³ (8 hr average)

2.4 Sources of Particulate Matter

Particulate matter are generated by various type of sources. There is two type of sources that contribute to the air pollution: anthropogenic emission sources and natural sources. Anthropogenic emission sources consist of industrial energy production, transport, agriculture, waste management, biomass burning and etc. (Mayer, 1999) . Natural sources of air pollution also cause poor air quality. The most common natural sources of particulate matter are desert dust, volcanoes, biological decay, forest and grassland fires, and salt from sea spray (European Environment Agency, 2012).

2.4.1 Stationary Sources

In utility and industrial use, coal and, to a lesser extent, oil combustion contribute most of the particulate (and sulphur oxides) emissions. Coal combustion particles consist primarily of carbon, silica, alumina and iron oxide. In contrast to coal, oil is a fast-burning, low-ash fuel. The low ash content results in formation of less particulate matter, but the sizes of particles formed in oil combustion are generally smaller than those of particles from coal combustion. Oil combustion particulate matter contains cadmium, cobalt, copper, nickel, and vanadium.

For indoor air pollution like classroom, the contribution of pollutants are not just coming from the outside but it also tend to be generated in indoor space. According to Lee and Chang (2000) the effect of combination of physical, chemical and biological factors contribute to the indoor air pollution.

Sofian and Ismail, (2012) studied about indoor and outdoor relationships of respirable suspended particulate matter at primary schools in Kuala Terengganu, Malaysia. The study was done in seven schools which were selected based on the different activities on-going adjacent to each school. The study found that areas with high ambient respirable suspended particulate matter (RSP) concentrations were found in coastal area (sea-spray) and industrial area. Based on the research, the second strongest (RSP) concentration was in the industrial area where the cement factory and house construction across the road had contributed to the RSP concentrations.

The adequacy of ventilation in the environment also play main role to reduce the air pollutants. The human activities, heating, ventilation and air conditioning (HVAC), building equipment and furnishings are the sources that generate the pollutant.

2.4.2 Mobile sources

The rise in traffic volumes in developing countries such as Malaysia may lead to exposure to poor air quality both outdoors and indoors (Zainal Abidin *et al.*, 2014). The increasing of mobile transport give a major impact to the environment mainly air pollution. According to Afroz *et al.*,(2003) Kuala Lumpur has the highest number of registered vehicles in Malaysia, and in 2009, there were over 4.3 million vehicles registered in the city. In Klang Valley, the most urbanised region in Malaysia,

emissions from traffic-related sources are estimated to contribute between 70 % and 89 % of the particulate matter and NO_2 measured in outdoor sampling positions.

The contribution of traffic sources to urban air quality nowadays are in serious condition, relatively few studies have been conducted and evaluated the effects of traffic-related air pollution on health, such as its influence on the development of asthma and other childhood respiratory diseases (Brauer *et al.*, 2002). In studies of Brauer *et al.* (2002) also stated that significant variability in exposure to traffic-related pollutants have indicated that indoor concentrations and exposure to particulate matter from traffic sources, such as soot, is highly correlated with ambient levels.

Han *et al.* (2017) monitored the source apportionment of $PM_{2.5}$ in Baton Rouge, Louisiana during 2009-2014. The results showed that traffic emissions from both gasoline vehicles and diesel engines are the main contributor to $PM_{2.5}$. Ca is arising from the combustion of lubricating oil additives while Zn is an additive in motor oil, also being used in tyre manufacturing and brake lining. Fe could also be emitted from muffler and brake ablation. Diesel vehicles tend to have higher NO_2 emission.

According to Sawyer *et al.* (2000), mobile sources contribute to the atmospheric burden of particulate matter (PM) through three mechanisms, primary PM emissions, secondary PM formation, and fugitive emissions. Primary particles are those that are directly emitted by vehicles. They are emitted in the vehicle exhaust, and also are emitted via brake and tire wear. Secondary PM formation comes via emissions of HC, NOx, and SO_2 which then react in the atmosphere to give organic, nitrate and sulphate.