



**EVALUATION OF INHALABLE AND RESPIRABLE  
PARTICULATE MATTER IN A MUSEUM GALLERY**

**BY**

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**A thesis submitted in fulfilment of the requirement for the  
Master of Science (Built Environment)**

**Kulliyyah of Architecture and Environmental Design  
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## ABSTRACT

The primary idea of this research is to evaluate the inhalable and respirable particulate matter in the museum gallery of the National Museum Malaysia. Present study was conducted in Gallery A and Gallery B of the National Museum, Kuala Lumpur during January 2017. Temperature, Relative Humidity, Total Inhalable particulates and Respirable particulates were measured inside the galleries, stone, metal and ceramic artefact display cases at every 60 minutes interval for 8 hours between 9:00 AM to 5:00 PM. The average particulate matter concentration at the museum entrance ( $243 \mu\text{g}/\text{m}^3$ ) and lobby ( $382 \mu\text{g}/\text{m}^3$ ) was recorded much higher than the standard proposed by the Department of Environment ( $50 \mu\text{g}/\text{m}^3$ ) and Department of Occupational Safety and Health ( $150 \mu\text{g}/\text{m}^3$ ). Studies shown that, the concentration of inhalable and respirable particulates in Gallery A during weekday exposure was higher than the weekend exposure. The inhalable particulates mass concentration recorded was  $127 \mu\text{g}/\text{m}^3$  and  $92 \mu\text{g}/\text{m}^3$  for weekday and weekend exposure respectively. Meanwhile for respirable particulates mass concentration, the value recorded in weekday was  $210 \mu\text{g}/\text{m}^3$  and weekend was  $74 \mu\text{g}/\text{m}^3$ . High number of tourists and heavy traffic near *Jalan Damansara* and construction of *Muzium Negara* MRT Station could be attributed to significantly higher concentration of  $\text{PM}_{10}$  in the museum building. However, there was significant variation in the mass concentration inside artefact display cases of Gallery A and Gallery B. The average temperature recorded in the museum gallery was  $23^\circ\text{C}$  to  $28^\circ\text{C}$ , and average relative humidity measured was 44 % to 60 %. Both temperature and relative humidity value are close to the limit of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) class A's which means no mechanical risk to the most of artefact in the museum gallery. This study is beneficial towards *Jabatan Muzium Malaysia* by emphasizing that maintenance of Heating, Ventilation and Air Conditioning (HVAC) and regular monitoring of temperature and relative humidity inside museum are significantly influence the mass concentration. Hence, measures should be taken in minimizing the long term effect of particulate matter towards deterioration of artefact exhibited inside the National Museum and also to improve a better indoor air quality of the museum.

## خلاصة البحث

كانت الفكرة الأساسية لهذا البحث هي تقييم المادة الجسيمية المستنشقة والقابلة للتنفس في معرض المتحف الوطني في ماليزيا. لقد أجريت الدراسة الحالية في المعرض A والمعرض B للمتحف الوطني في كوالا لامبور خلال شهر يناير 2017. وتم قياس درجة الحرارة والرطوبة النسبية (RH) والجسيمات المستنشقة (IP) والجسيمات القابلة للاستنشاق (RP) داخل المعارض والحجر والمعادن وحافظات العرض المصنوعة من السيراميك في كل 60 دقيقة فاصل لمدة 8 ساعات بين 9:00 ص إلى 5:00 م. وسجل متوسط تركيز المادة الجسيمية عند مدخل المتحف (243 ميكروغرام / م<sup>3</sup>) واللوبي (382 ميكروغرام / م<sup>3</sup>) أعلى بكثير من معيار وزارة الطاقة (50 ميكروغرام / م<sup>3</sup>) ومعيار (DOSH 150) ميكروغرام / م<sup>3</sup>). لقد أظهرت الدراسات أن تركيز الغبار المستنشق والقابل للتنفس في المعرض A خلال التعرض لأسبوع الأسبوع كان أعلى من التعرض لعطلة نهاية الأسبوع. كان تركيز كتلة الغبار المستنشق المسجل 127 ميكروغرام / م<sup>3</sup> و 92 ميكروغرام / م<sup>3</sup> للتعرض خلال أيام الأسبوع وعطلة نهاية الأسبوع على التوالي. وفي الوقت نفسه، بالنسبة لتركيز كتلة الغبار القابلة للتنفس، كانت القيمة المسجلة في أيام الأسبوع هي 210 ميكروغرام / م<sup>3</sup> وكانت نهاية الأسبوع 74 ميكروغرام / م<sup>3</sup>. يمكن أن تعزى السياحة الجماعية وحركة المرور الكثيفة بالقرب من شارع دامانسارا وبناء محطة مترو وأنفاق موزيوم نيجارا إلى زيادة كبيرة في تركيز في مبنى المتحف. ومع ذلك، كان هناك تباين كبير في تركيز PM10 داخل حالات عرض القطع الأثرية في المعرض A و Gallery B. كان متوسط درجة الحرارة المسجلة في معرض المتحف من 23 إلى 28 درجة مئوية، وكان متوسط الرطوبة النسبية المقاسة 44 ٪ إلى 60 ٪ لكل من درجة الحرارة وقيمة الصحة الإنجابية القريبة من الحد الأقصى لفئة ASHRAE ، مما يعني عدم وجود مخاطر ميكانيكية لمعظم القطع الأثرية في معرض المتحف. هذه الدراسة مفيدة لقسم المتحف الماليزي من خلال التأكيد على أن صيانة HVAC والمراقبة المنتظمة لدرجة الحرارة و RH داخل المتحف تؤثر بشكل كبير على تركيز PM10. وبالتالي، ينبغي اتخاذ تدابير للتقليل إلى أدنى حد من التأثير طويل الأجل للمواد الجسيمية نحو تدهور القطع الأثرية المعروضة داخل المتحف الوطني وكذلك لتحسين نوعية الهواء داخل المتحف أفضل

## APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the Master of Science (Built Environment).

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## DECLARATION

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# CHAPTER ONE

## INTRODUCTION

### 1.1 BACKGROUND OF STUDY

This research explains the defect of airborne particulates matter towards deterioration of museum artefact, especially on soiling. The aim of this study is to evaluate the characterisation of airborne particulates matter affecting the soiling of museum artefact. The characterisation of airborne particulates matter is divided into two categories which are physical and chemical characteristics.

This research focuses on the airborne particulates matter which deposited on the surface of artefact. Airborne particulates matter includes the particles that can be found from atmospheric pollution. The airborne particulates matter deposition can cause soiling of the artefact surfaces which can also be considered as the blackening of the artefact (Horemans et al, 2012 & Anaf et al, 2015). In addition, airborne particulates matter encompasses both chemically and physically diverse substances and they comprise of solid and liquid particles which suspended in the air. The measurement for particulate mass concentrations, size distribution and particle number represent the physical parameters of airborne particulate matters.

The ‘bulk chemical composition’ is the term associated by the relative abundance of the major chemical components. Meanwhile, Lee and Park (2010) and Latif et al., (2014) described chemical components as the elemental carbon, organic carbon, secondary sulphate, nitrate and ammonium particles, sea salt, mineral dust, biological materials (pollens, spores, bacteria, viruses) and heavy metals (Al, Fe, Cu, Zn, Pb).

Artefacts are known to be exposed to various sources of airborne particulates matter inside museums and galleries. For instance, the usage of heater, ventilator and air conditioning (HVAC) system, cleaning services, vacuuming process, displayed artefact or storage room, openings, outdoor environment as well as the mass tourism (Group, 1998; Fu & Li, 2006; Hanapi & Mohd Din, 2012). Either museums, galleries, libraries and archives, or other historical palaces, most of the sites are situated in urban centres, which are surrounded by complex and unstable urban atmosphere. Hence, a large number of substances accumulated and left in unhealthy museum environments, which later cause permanent damage to each artefacts.

Decay and deterioration are on-going problems for artefacts. Henry et al., (2013) defined artefact as a complex phenomenon, consisting of a collected material things, its specific documentation, and the stories and theories that give it a history. Therefore, curators are very careful in storing the items that they are responsible for. There are 2 categories of artefact which are organic and inorganic artefacts. The organic artefacts are those that are made from animal products (fur, leather, wool, silk, bone, feather) and another one is made from plant products (wood, paper, cotton natural fibres). The inorganic artefacts consist of non-living materials such as metal, stone and ceramic glass (Basic Guidelines for the Preservation of Historic Artifacts, 2013).

Artefact soiling is generally assumed to be directly proportional to loss of reflectance and lightness (or increase in haze) of a material. Outdoor soiling is popularly associated with black stains on facades. However, indoor soiling is mostly associated with the deposition of household dust (Brimblecombe et al., 2009 and Chianese et al., 2012). Hence, it is vital for researchers and museum organisation to preserve and conserve the artefacts. In addition, artefacts are valued specially for their

visual qualities, the works themselves are unique and the values of some pieces are extraordinarily large. So, rates of soiling should be decreased because it can lead to unacceptable cumulative damage over centuries.

## **1.2 PROBLEM STATEMENT**

The conservation of cultural heritage and its protection against possible damage from air pollution is a great concern in today's world. Indoor air pollution can cause soiling due to particle deposition on the surface of artefact (Hu et al., 2011). Over long periods of time, dark deposits build up on the surface of painting, sculptures, and stone building necessitating cleaning procedures that are expensive and that may pose some risks to the works themselves. Hu et al., (2011) also mentioned that after more than 30 years of exposure, it was found that grey dust depositions have covered some details of the warriors in Pit 1 of Terra-Cotta Museum. However, it has been reported that the cleaning procedures of the dark deposits will bring additional risk to the statues of Terra-Cotta.

Literature studies on outdoor air pollutant measurement showed that airborne particles cluster into a distinctly different range of sizes and different chemical properties. Nazaroff et al., (1993) reported that coarse particles with a diameter of  $2\mu\text{m}$  and larger consist largely of soil dust, road dust, and sea salt while fine particles smaller than  $2\mu\text{m}$  in diameter consisting of vehicle exhaust material, soot, ammonium sulphate, ammonium nitrate, and sulphuric acid. Larger dust particles such as fibres visually contribute most to soiling (Yoon & Brimblecombe, 2001), but small particles such as soot can cause noticeable blackening (R. Van Grieken et al., 2000). If soiling is to be prevented, control of both fine and coarse particles must be considered.

The accumulation mode for particulate matter (0.1 -1 $\mu$ m), due to its size, displays low deposition rates, low re-suspension rates, and a high penetration efficiency through cracks and filters. There are different implications to the low deposition rates, such as the deposition will be a slow process, but it will occur eventually if particles are not removed. The particles will distribute evenly around the space, depositing far from the source, and will reach areas that are difficult to access such as walls and ceiling. Low re-suspension rates, in combination with a small size that favours penetration into porous surfaces, will lead to difficulties with cleaning and irreversible soiling (Grau-Bove & Strlic, 2013).

Air filtration devices may remove coarse particles efficiently but often leave the fine soot-containing fraction uncollected. Yocom et al., (1971) as cited by Nazaroff et al., (1993) examined indoor and outdoor soiling index ratios in air-conditioned versus non-air-conditioned buildings. They found that the soiling index ratios did not appear significantly different, indicating that soiling particles were not effectively removed by the air-conditioning systems. Moreover, Grau-Bove and Strlic (2013) clarify that the use of windows for ventilation can quickly increase the particles concentration indoor to match the outdoor levels for all particle sizes. When that situation happens in a museum, the possibility of damage to the collection over long periods should be seriously considered. Hence, the primary idea of this research is evaluate the inhalable and respirable particulate matter in the display cases of stone, metal and ceramic artefact at the National Museum of Malaysia

### **1.3 RESEARCH AIM AND OBJECTIVES**

The study aimed to evaluate the inhalable and respirable particulate matter at the National Museum of Malaysia. This study is expected to achieve the following objectives:

1. To measure and evaluate the mass concentration of airborne particulates matter in the National Museum Malaysia.
2. To survey the sources of airborne particulate matter in the National Museum Malaysia.
3. To provide recommendation towards a healthy indoor environment and reducing artefact deterioration.

### **1.4 RESEARCH QUESTIONS**

1. What are the mass concentrations of the airborne particulate matter found in the museum?
2. How does museum microclimate parameter relate to the mass concentration of inhalable and respirable particulate matter?
3. What is the comparison between outdoor mass concentration and the indoor mass concentration?
4. What can be done to maintain a good indoor air quality and preserve the artefact from deteriorate?

## **1.5 SIGNIFICANCE OF THE STUDY**

The findings from this research will increase the knowledge regarding the influence of particle pollution to the inhalable and respirable mass concentration inside museum galleries. Besides, the survey to determine the sources of pollution associated with the particulate mass concentration is significance towards Jabatan Muzium Negara because reducing air pollution will give positive impacts towards reducing artefact deterioration as well as protect tourist health. Hence, if artefact deterioration can be reduced, future generation can gain benefit in learning about the historical heritage of Malaysia embodied inside galleries of the National Museum.

## **1.6 RESEARCH METHODOLOGY**

This research is carried out based on the Quantitative Methodology which specifically incorporates the Experimental research which measured and quantified the physical and chemical characterisations of airborne particulates matter which exposed artefacts towards soiling defect. Laboratory experiment would be conducted to measure the mass concentration of the inhalable and respirable particulates matter.

The general approach for this study was first through the selection of the sampling sites. The National Museum of Malaysia was selected as the case study site due to its location. The museum is located at the city centre, in front of busy traffic conjunction of Jalan Damansara as illustrated in Figure 1.1 below. The surrounding environment of the museum is always busy with vehicles. So, the museum is always exposed to haze and construction pollutants. This is because, there is an undergoing construction of Mass Rapid Transit (MRT) at the front entrance of the museum as shown in Figure 1.2.

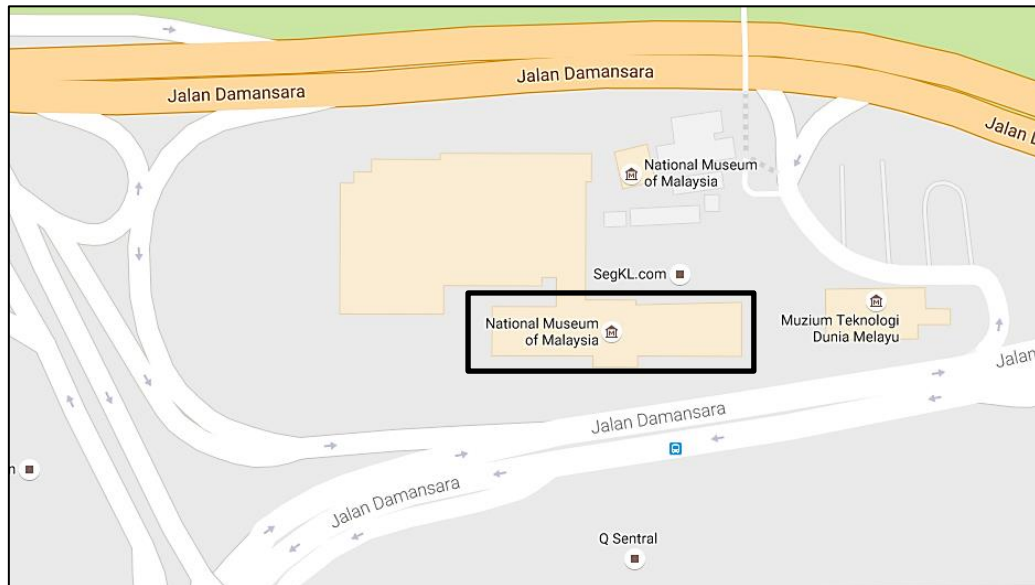


Figure 1.1. The Location of The National Museum of Malaysia, Kuala Lumpur  
(Source: Google Maps)



Figure 1.2. The Construction of Mass Rapid Transit (MRT) at The National Museum, Kuala Lumpur.  
(Source: Google Image)

The second approach is developing the sampling protocol. A multi-point sampling system was designed and chosen inside Gallery A, Gallery B, the Lobby and near the main entrance of the museum. 7-holes sampler head and Cyclone sampler head were selected to collect the sufficient amount of airborne particulates for

subsequent analysis which represented the inhalable dust and respirable dust respectively. Sampling equipment and protocols were preliminarily tested at the Kulliyah of Architecture and Environment Design, International Islamic University Malaysia. Then, the researcher would perform the physical analyses. Filters with particles were weighed and then analysed in Environment Lab 1 and Herbarium Lab in Kulliyah of Architecture Environmental Design, International Islamic University Malaysia. The detail research design and fieldwork will be explained further in Chapter 3.

### **1.7 THESIS OUTLINE**

Chapter one provides the overview of the whole research. It explained on the background of research, problem statement, aim and objectives of research, research questions, research methodology and significance of research. Chapter two presents the literature studies covering the scope of air pollution, outdoor and indoor pollutants, air pollutant inside museums and the characteristics of the airborne particulates. Chapter three discusses the methodologies to be carried out to meet the research objectives. Chapter four will discuss thoroughly on the results collected throughout the research work. Analysis of the results collected from site survey and laboratory experiments will be presented in the forms of figures, tables and bar graphs. Lastly, chapter five represent the general conclusion achieved from the research conducted, limitation of study and recommendation for future studies.

## **CHAPTER TWO**

### **LITERATURE REVIEW**

#### **2.1 INTRODUCTION**

Air pollution are significantly affecting the global climate, human health, lives of flora and fauna as well as the distinctive materials. A new WHO air quality model confirms that 92% of the world's population lives in places where air quality levels exceed WHO limits. This includes museums, where it is a building that stores and conserves all types of national artefacts. The outdoor air pollutants will enter the museum building from different sorts of opening such as doors, windows, air ducts and visitors. Once they entered the museum, the pollutants which consists of carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), sulphur dioxide (SO<sub>2</sub>), volatile organic compound (VOCs), particulate matter (PM), soot particles and ozone (O<sub>3</sub>), will settle in the museum gallery horizontally and vertically either on the walls or floors.

The particulates matter deposition is significantly harmful towards museum artefact as it causes the materials to decay. The deterioration of artefacts includes metal corrosion, surface cracking, painting discolouration, fading of dyes and soiling defect. The airborne particulates matter that causes the soiling of artefact comprises several chemical components such as carbonaceous compounds (elemental carbon and organic carbon), sea salt, mineral dust, biological materials (pollens, spores, bacteria, viruses), heavy metals (Aluminium (Al), Iron (Fe), Copper (Cu), Zinc (Zn), Lead (Pb)) and secondary sulphate, nitrate and ammonium particles.

Previous studies have reported that soiling defect of inorganic artefact i.e. metal, stone and ceramic glass is influenced by the presence of heavy metal elements such as Iron (Fe), Manganese (Mn), Copper (Cu), Lead (Pb) and Zinc (Zn) which can catalyse the oxidation and hydrolysis of sulphur dioxide (SO<sub>2</sub>) to form sulphuric acid. When sulphuric acid reacted with stone, aqueous ions are formed and the mass from the stone is lost. The inorganic artefacts were selected for this research because the soiling rate of inorganic artefact is higher as the time taken for the particulate pollutants to react with the surface of artefact is faster than organic artefacts. Hence, the inorganic artefacts deteriorate faster. As mentioned above, the organic artefacts are the materials made from animal and plant products while inorganic artefacts are created from non-living materials.

Through a period of time, the surface of the inorganic artefact will be darkened and it will be difficult and expensive to clean the surface. Thus, it is important to preserve and conserve the artefacts because their visual qualities are what being valued for. These works of arts are irreplaceable, and the values of some pieces are extraordinarily large. Even small rates of soiling may lead to unacceptable damage over centuries. Hence, the purpose of this paper is to review the sources and effects of air pollution and airborne particulates matter which give the significant impact towards soiling defect of museum artefacts.

## **2.2 AIR POLLUTION**

First and foremost, to study the sources of airborne particulates matter inside museum, Pollutants in the air come from multiple sources, including industrial, transportation and agricultural sectors. Every day, air pollution causes respiratory and cardiovascular diseases. It also damages vulnerable ecosystems and biodiversity and leads to a

decrease in agricultural crop and commercial forest yields. The World Health Organization (WHO) reported recently in news in September 2016 the effect of air pollution exposure that caused 3 million deaths each year. Moreover, about 6.5 million deaths which are 11.69% from the overall global death were associated with indoor and outdoor air pollution (WHO, 2016). This shows that air pollution is one of the major concerns in respect to the human health, environment and economy.

In order to further understand the characteristics of airborne particulates matter, Figure 2.1 presented by National Park Service, (2018) explains the flow of pollutants from their sources, transport, transformation, deposition and to the effects towards global ecosystem. Vehicles, industrial factories, agricultural area, cities, wildfires and volcanoes are all emit pollution into the air. Then, the pollution is transported through the air and reacts with chemical in the atmosphere to change pollutants before they are deposited. Pollutants in the air can create haze, making it harder to see, and pollutant deposition can have biological effects.

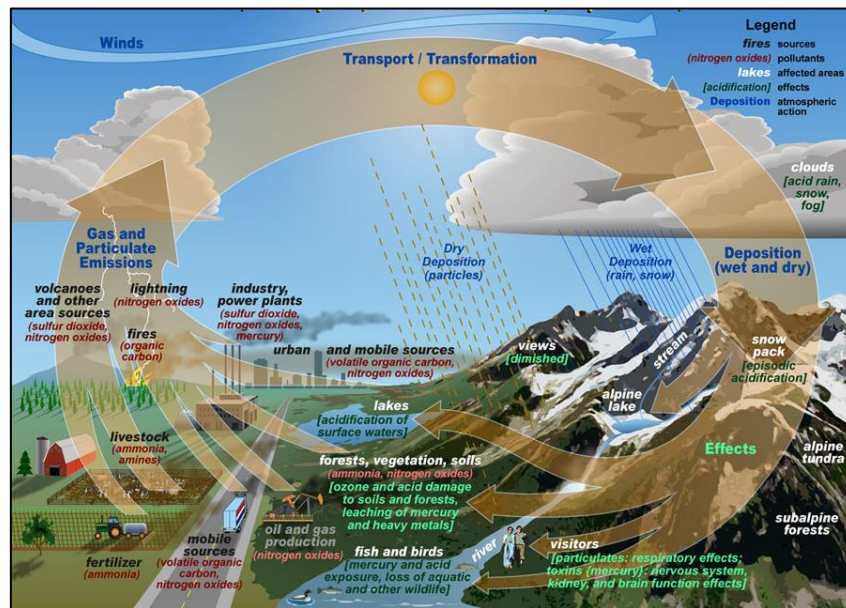


Figure 2.1. The Pollutant Sources, Transport, Transformation, Deposition and Effects to The Ecosystem.  
(Source: National Park Service, 2018)