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A Study of Indoor Air Quality in Refurbished Museum Building

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Abstract

Problem related with indoor air quality (IAQ), is rapidly becoming a major health issue as people spend almost 90% of their time indoors. Museums were established in Malaysia more than hundred years ago. Since the year 2005, Malaysia has been moving away from constructing new buildings in favour of refurbishing historic and old ones. A healthy environment at the museum building has been identified as one of the important element that must been considered, but it is not sure either IAQ in the museum building provide a good air quality or not. The purpose of this study is to determine the actual indoor environment of the museum building in Melaka. In this study, the IAQ measurement were conduct for six days at the Melaka Sultanate Palace Museum and at the History and Ethnography Museum. During the measurement, IAQ parameters of gaseous pollutant of nitrogen dioxide, sulfur dioxide and carbon dioxide, and particulate matter of fine particles were recorded by using specific IAQ equipment. The finding of this study indicates that the distance of buildings from roadways appears to have an impact on indoor environmental levels, especially for nitrogen dioxide, sulfur dioxide and particulate matter. Based on the results, only gaseous pollutant of sulfur dioxide had not exceeding the acceptable TLV compared to the other IAQ pollutants.

Keywords: Indoor Air Quality; Museum Building; Refurbished.

1. Introduction

Air is the most important element that supports human life on earth [1]. For an example, in breathing people need to inhale air, especially clean air in order to live a better life. However, more than two million premature deaths are attributed to the effects of urban outdoor and indoor air pollution [2, 3]. Problem related with indoor air quality (IAQ) is rapidly becoming a major health issue as people spend almost 90% of their time indoors, which they might be exposed to hazardous and unhealthy concentrations of pollutants due to the improper air circulation turnover within and outside the building [4]. Normally, aged, ill people and youngsters who spend longer time inside the buildings have a tendency exposure of indoor hazardous pollution. These indoor environments are including homes, offices, stores, restaurants, warehouses, factories, public buildings and vehicles. In these environments, people are exposed to pollutants emanating from a wide array of sources that creates indoor environmental problems which could affect their health.

IAQ issues are not new in Malaysia. Nevertheless, the lack of study, data and local regulation become one of the major contributions towards this problem especially with the non-industrial sector [5]. Nowadays, people are being exposed to a variety of health risks from the surrounding indoor pollution which can affect one's health. Some risks are unavoidable. The effects of particulates matter and gaseous pollutants, such as nitrogen dioxide (NO_2), sulfur dioxide

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(SO_2) and ozone (O_3) gaseous, in the museum under tropical and subtropical climates and with different economic realities are still unclear [6] despite many museums have been widely investigated in Europe. Thus, there is still a lack of study on the particulate matter contaminants in the museum, especially in Malaysia scenario. When discussing about particulate matter aspect, this knowledge seems to be new in Malaysia compared to Singapore, as they are focusing deeper on fine particulates effects and its contribution while Malaysia is still focusing on total suspended particulates [7]. Particulates pollution, especially fine particulates, contains microscopic solids or liquid droplets that are small enough to get deep into the lungs and cause serious health problems [8]. The human health study involved people who stayed in the museum buildings such as the visitors and staff. In order to make sure people comfortable with the current environment, a study on IAQ must be done. It is due to the fact that IAQ has become an important factor in providing a healthy environment in the museum building. In this study, the IAQ pollutants mainly focused on the gaseous pollutant and particulate matter as they are much reasonable and suitable for research to conduct the IAQ assessment in the museum environment.

2. Health Effect due to Indoor Air Quality

According to Air and Water Inc., air pollution is one of the most serious problems in the world [9]. It occurs when harmful substances including particulate and biological molecules are introduced into Earth's atmosphere and may cause diseases, allergies or death to humans [10]. In 2008, Blacksmith Institute mentioned that the World's Worst Polluted Problems Report stated the two worst pollution problems in the world are urban air quality and indoor air pollution [11]. For instance, in 2012, the air pollution caused the deaths of around 7 million people worldwide [10]. Apart from that, it was discovered that 65% of the deaths in Asia and 25% of deaths in India were due to air pollution [12].

In Malaysia, in accordance with the enforcement of the law, it comes under the jurisdiction of Department of Safety and Health (DOSH). DOSH has introduced the practice on IAQ assessment through the Industry Code of Practice on IAQ, which been approved by the Minister on 30 August 2010. The purpose of Industry Code of Practice on IAQ is to ensure the employees and occupants are protected from poor IAQ, which could adversely affect their health and wellbeing [13, 14]. Table 1 indicated the regulations on IAQ in Malaysia, based on the Industry Code of Practice on IAQ [15].

Table 1. Regulations on IAQ in Malaysia

Indoor Air Contaminants	Malaysia
	8- hour time weighted average concentration
Carbon dioxide (CO_2)	C1000 ppm
Carbon monoxide (CO)	10 ppm
Formaldehyde (HCHO)	0.1 ppm
Total volatile organic compound (TVOC)	3 ppm
Respirable particulate	0.15 mg/m^3
Ozone (O_3)	0.05 ppm
Total bacteria counts	500 cfu/m^3
Total fungal counts	1000 cfu/m^3

Air pollution has constantly been an overwhelming issue in Malaysia, especially for legislators, the aviation industry and the citizens [12]. According to the Institute for Health Metrics and Evaluation, from the year 2005 until 2016, there were 11 risk factors that drive the most death and disability in Malaysia, showing that the air pollution and occupational risks were identified as the listed risk factors that contribute to the death and disability [16]. Apart from that, it was discovered that the high percentage of death is due to the air pollution, particularly the outdoor air pollution caused 6,251 deaths in Malaysia in 2012 [17]. Other deaths were caused by the heart disease (3,630), stroke (1,773), lung cancer (670), pulmonary disease (148) and lower respiratory disease (29). Nevertheless, this death statistics did not include indoor air pollution, which may have harmed many more people. Thus, the total deaths caused by air pollution would be higher than 6,251 deaths, if the death from the indoor air pollution was known and added [17].

3. Museum Environment

Air pollution is a particular problem in historical buildings such as museums, because they were not originally built to exhibit and protect art objects in a sustainable way [18]. Systematic air quality assessment is a requirement in most heritage conservation plans. Temperature and humidity are identified as one of important factors that contribute either the air quality inside the building is good or poor. It was discovered that museum should have a constant humidity all year round and that humidity should not rise above 60% or fall below 40% while temperature of 18°C is an acceptable for the museum, while for museum in older building, 45% to 50% of relative humidity is an effective compromise with the temperature between 15 to 25°C [19]. In tropical climate like Malaysia, they experiences high relative humidity,

varying from 67% to 96 % with an average value of around 80%, whereas the outdoor air temperature varies from 24°C to a maximum of 33°C [20].

Air quality is an important factor in the preservation of cultural heritage, especially in museum environment. In museum, imbalance of temperature and humidity could bring potential risk towards people and collection materials because it could produce indoor gaseous pollution inside the museum building [21]. However, apart from temperature and humidity, air quality, which is another air pollution factor, is less often monitored [22]. It is true that most pollutants are dangerous to human health, such as particulate matter, gaseous pollutant and traffic-generated pollutants, but they are also harmful to heritage materials. The World Health Organization (WHO) has long identified particulates matter as one of the pollutants most dangerous to human health. For this reason, particulates matter is the most widely monitored pollutant worldwide [23]. Other outdoor pollutants such as NO_2 and SO_2 are also commonly monitored by local air quality monitoring networks.

3.1. Museum in Malaysia

In Malaysia, museum is one of the popular tourist destinations. Museums were established in Malaysia more than hundred years ago, started with the opening of Perak Museum, Taiping in 1883 by the British colonial and was followed by the establishment of the Sarawak Museum, Kuching in 1888 and Selangor Museum in 1907 [24]. Malaysia has been moved away from constructing new buildings in favor of refurbishing historic and old building since year of 2005 [25]. Malaysia now has about 150 historical museum buildings [26] and there are about 56 historical museum buildings which was originally built not for the purpose of being a museum, where few studies has been done on the quality of their indoor environment [27]. The usage of refurbishment building will change building demand in future as the building profession may shift its focus from new construction to maintenance and refurbishment of existing buildings which include historic buildings [28]. In tropical countries like Malaysia, which are hot and humid throughout the year with the average rainfall of 250 centimeters a year and the average temperature of 27 ºC which can contribute to the fluctuations of indoor climate and affect the building fabric from the passive design approach to refurbished active building design [20].

Therefore, the usage of old buildings has changed from the time they were built when the new mechanical ventilation system being applied and installed to provide a comfort and better indoor environment inside the buildings. However, these modern services cannot be installed without considering the risk in altering the performance of the historical museum buildings, especially towards people health. A healthy environment at the museum building has been identified as one of the important element that must been considered. In this study, IAQ has become an important factor to provide a healthy environment in the museum building, but it is not sure either IAQ in the museum building provide a good air quality or not. So, the purpose of this study is to determine the actual indoor environment of the museum building in Melaka, under the Perbadanan Muzium Melaka (PERZIM) management.

4. Research Methodology

The IAQ measurement (physical measurement), were conducted at the Throne Room (Balairong Seri) of Melaka Sultanate Palace Museum (Case Study 1) and at the Dutch Governor Room of History and Ethnography Museum (Case Study 2). In this study, the Throne Room is located on the first floor of Case Study 1, whereas the Dutch Governor Room is located on the ground floor of Case Study 2. Both rooms were installed with a mechanical ventilation system, which is a split unit air conditioning. The physical measurement were took place during the museum's operating hour, starting from 9.00 am and finish on 5.00 pm, for six days (Day 1: Friday, Day 2: Saturday, Day 3: Sunday, Day 4: Monday, Day 5: Tuesday and Day 6: Wednesday). During the measurement, IAQ parameters of gaseous pollutant of nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and carbon dioxide (CO_2) and fine particulate matter ($PM_{2.5}$) were recorded by using specific IAQ equipment, using the YES Plus LGA IAQ Monitor for gaseous pollutant while for particulate matter are using the GT-321 Hand Held Particle Counter. These IAQ equipment were set-up properly based on the guidelines [15] and the sampling period for indoor monitoring was 8 hours for real time measurement. The sampling point will depend on the size or total floor area of the room in the museum building. The IAQ measurement were conducted after received complaints related to the IAQ at the refurbished museum buildings, based on the IAQ investigation process provided by DOSH, as shown in Figure 1.

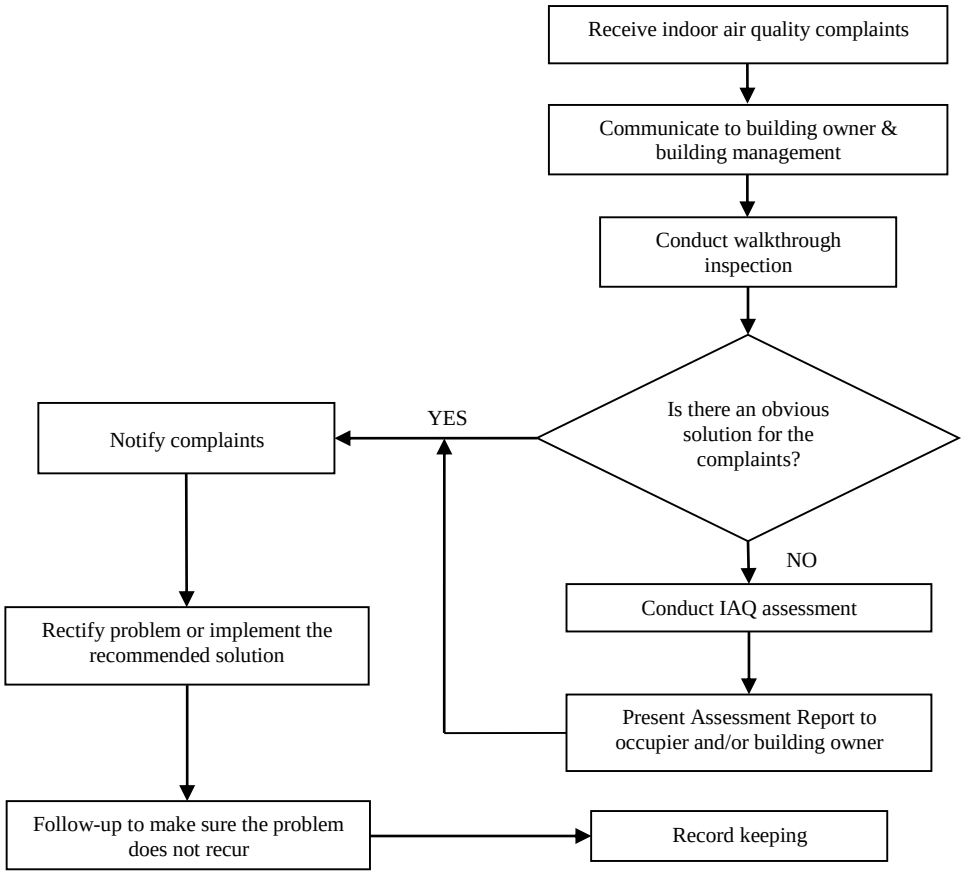

Figure 1. IAQ Complaints and Investigation Process

4.1. Case Study 1

Melaka Sultanate Palace Museum which represents as Case Study 1 (Figure 2), is located at district of Kota Melaka (Melaka City), which is at Jalan Kota in Bandar Hilir and it is opened for public since July 17, 1986. This three-storey museum has an area of about 1,243.2 m^2, which comprises of six chambers and three galleries. The Melaka Sultanate Palace is a replica of a Sultan's palace during the era of the Melaka Sultanate. According to PERZIM [29], this replica was built from records obtained from the *'Malay Annals'* depicting the unique architecture of a palace during the ruling era of Sultan Mansur Shah.

Figure 2. Melaka Sultanate Palace Museum

Melaka Sultanate Palace Museum have showcase of some 1,350 items collection related with the history and culture of Melaka Sultanate as well as various communities that settled in Melaka during the sultanate period. Most of the displays are weaponry, decorative art and gifts. Apart from the unique building design and ornate wood carvings, visitors are also able to obtain insights on the institution of the Melaka Malay Sultanate and opportunity to experience a true palace atmosphere via dioramas of a Throne Room, a visiting trade delegation and diorama of the feud between Hang Tuah and Hang Jebat, which are located at Malay Historical Gallery (Gallery 1) as shown in Figure 3. According to PERZIM [30], in 2015, there was about 130,000 visitors that visit this museum building. Thus, most visitors usually spend almost an hour to complete their touring here.

Figure 3. Melaka Sultanate Palace Museum (Malay Historical Gallery)

This museum building applies a mixed mode ventilation system, by using an air-conditioning (split unit) system with an opening of door for natural ventilation on the first floor (Gallery 1). As for the second floor (Gallery 2) and third floor (Gallery 3), fans are used as the mechanical ventilation system with an opening of windows for natural ventilation. The physical measurement is set-up at the Throne Room (Balairong Seri), which is located at the Gallery 1 on the first floor to provide IAQ data of the current indoor environment conditions based on establish IAQ guidelines.

4.2. Case Study 2

History and Ethnography Museum which represents as Case Study 2 (Figure 4), is also located at district of Kota Melaka (Melaka City), which is at the junction of Jalan Kota and Jalan Gereja in Bandar Hilir and it was opened for public since December 17, 1982. However, this museum is located inside of the Stadthuys main building complex, a three-storey building that covers 49,000 square feet (4,552.2 m^2). The Stadthuys building complex was built during the colonial era by Dutch in 1650s, which makes it the oldest and biggest Dutch colonial building in SEA region.

Figure 4. History and Ethnography Museum

Nowadays, this building complex houses two museums which is the Literature Museum and History and Ethnography Museum. The History Museum exhibits is about the founding of Melaka, followed with the colonization by the Portuguese, Dutch and British, and the invasion of Japanese, before eventually leading to the independence of the nation in 1957. The Ethnography Museum, which is located at the lower floor of the building complex, emphasizes the lifestyles of the multi-racial local communities. Amongst the exhibits is the wedding customs and practices, daily living lifestyles, agricultural diorama and tools used by the Malaccans including artefacts like porcelains, weapons, and various old currencies. According to PERZIM [30], in 2015, there was about 95,000 visitors that visit this museum building. Mostly visitors will spend almost an hour to complete their touring here.

This museum building installed a mix ventilation system by using an air-conditioning (split unit) system with an opening of door for natural ventilation on ground floor. The first floor and second floor use an air-conditioning (split unit) system as a mechanical ventilation system and combined with an opening of windows for natural ventilation. The physical measurement is set-up at the Dutch Governor Room (Figure 5), which is located on the ground floor with an area of 76.44 m^2 and volume of 321.05 m^3.

Figure 5. History and Ethnography Museum (Dutch Governor Office Room)

5. Results and Discussion

In urban areas, man-made contribution are greatest concern which contribute to environmental levels of NO_2, SO_2 and PM, and according to WHO, indoor environmental levels are a function of indoor and outdoor sources [31]. For CO_2 pollutant, combustion and human respiration are common sources of CO_2 and this pollutant is present in all buildings. Trends of gaseous pollutant for NO_2, SO_2 and CO_2, and fine particle of $PM_{2.5}$ for Case Study 1 and Case Study 2, over a period of 8 hours for six days are discussed in the next section.

5.1. Nitrogen Dioxide

Based on Figure 6, according to WHO, for a short term NO_2 exposure within one hour, the acceptable Threshold Limit Value (TLV) for NO_2 concentration is 200 µg/m^3 [31]. It is found that both case studies had exceeded the acceptable TLV for the NO_2 concentration in the evening daily. Case Study 1 and Case Study 2 are located at urban area and based on Figure 6, it shown that NO_2 concentration for Case Study 2 are higher and more pollute compared to indoor levels of NO_2 for Case Study 1, because there was heavy traffic occurred, especially on weekends (Day 1, Day 2 and Day 3). It was discovered thatm, the distance of building from roadway can influence the indoor levels of NO_2 [32, 33]. And based on this fact, Case Study 2 recorded higher NO_2 concentration compared to Case Study 1 because Case Study 2 are much closer to the roadway with a distance of 60 meter while Case Study 1 are located 500 meter from the roadway.

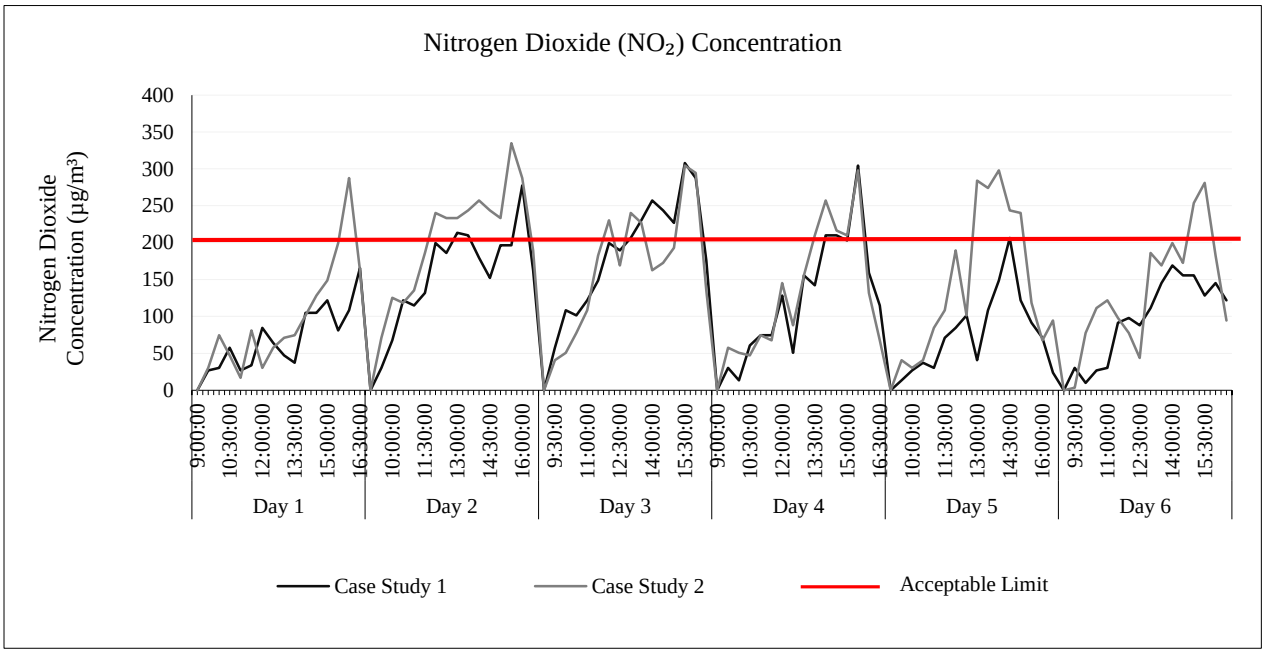

Figure 6. Nitrogen dioxide concentration for Case Study 1 and Case Study 2

5.2. Sulfur Dioxide

Based on Figure 7, according to WHO, for a short term SO_2 exposure within 10 minutes, the acceptable TLV for SO_2 concentration is 500 µg/m^3 [31]. It is found that both case studies are still safe and provide a healthy indoor environment because SO_2 concentration for both case studies had not exceeding the acceptable TLV. It is because, even though Case

Study 1 and Case Study 2 are located at urban area, there was no power stations and industries are located nearby to both case studies, which according to WHO [3], the use of sulfur-containing fossil fuels for domestic heating, stationary power generation and motor vehicles contribute to environmental levels of SO_2. However, there still has a presence of SO_2 pollutant in indoor environment due to the motor vehicles factor as reported by Clean Air Initiative Asia [34], showing that although the power sector and industries accounted for the majority of SO_2 emissions, with 60% and 20% respectively, motor vehicles or transport sector still contribute to indoor levels of SO_2 pollutant, represent with 8%. Due to this factor, with also consider the distance of building from roadway, it shown that SO_2 concentration at Case Study 2 are higher and more pollute compared to indoor levels of SO_2 at Case Study 1, because there was heavy traffic occurred, especially on weekends (Day 1, Day 2 and Day 3).

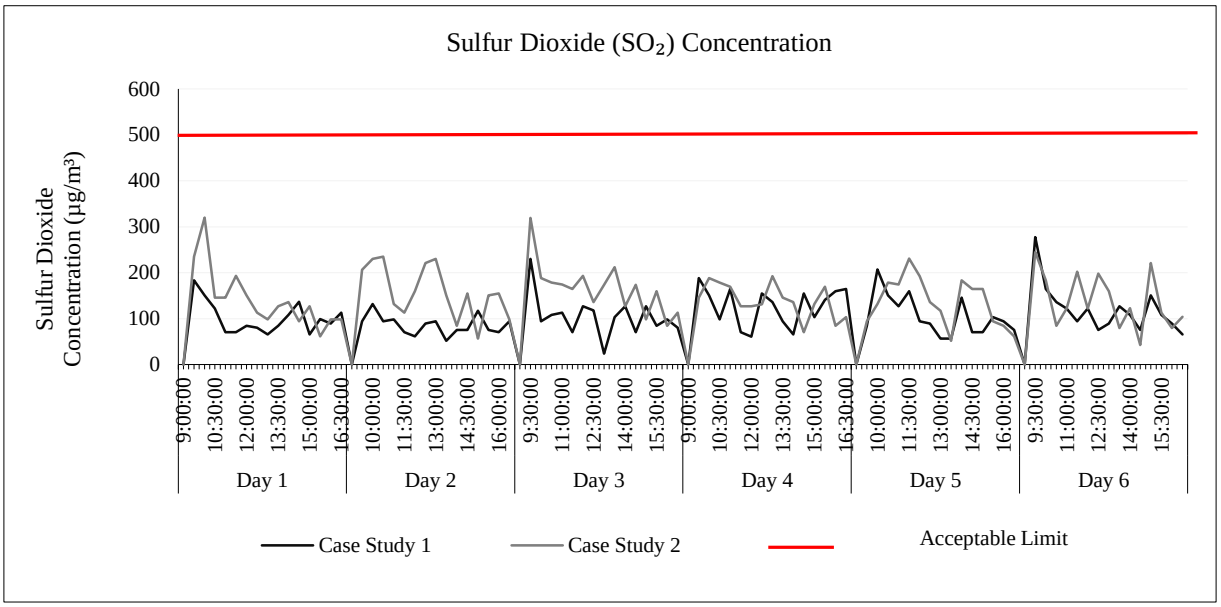

Figure 7. Sulfur dioxide concentration for Case Study 1 and Case Study 2

5.3. Carbon Dioxide

Based on Figure 8, according to DOSH, for a short term CO_2 exposure, the acceptable TLV for CO_2 concentration is 1,000 ppm [15]. It was discovered that on weekends (Day 1, Day 2 and Day 3), both case studies were constantly exceeding the acceptable TLV from morning until the end of the museum's operating hour. However on weekdays (Day 4, 5 and 6), the CO_2 concentration for Case Study 1 have constantly exceeded the acceptable TLV starting from morning (mostly after 10 am) until the end of the museum's operation hour, while for Case Study 2, there have a mixed trends of CO_2 concentration profile that exceeds the acceptable TLV, except on Monday (Day 4) showing that the CO_2 concentration are constantly exceeding the acceptable TLV starting from afternoon (12.00 pm) until evening (4.00 pm).

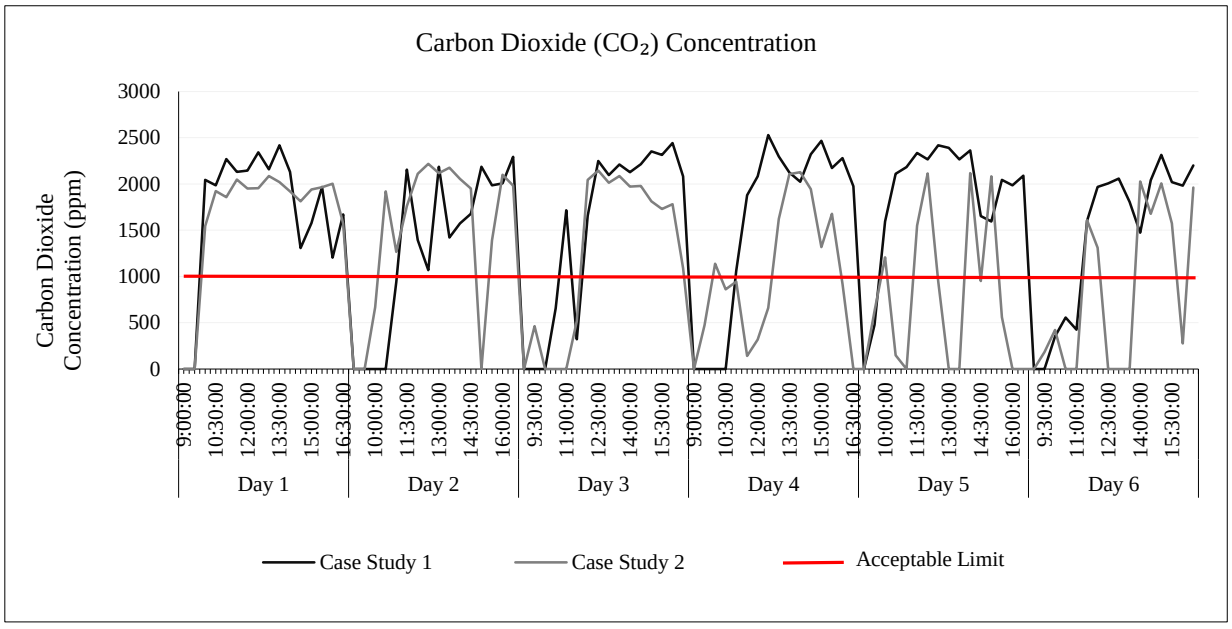

Figure 8. Carbon dioxide concentration for Case Study 1 and Case Study 2

For CO_2 pollutant, combustion and human respiration are common sources of CO_2 levels. In Melaka, tourism is a popular destination among tourist and as a state which is associated with history, museum such as the Melaka Sultanate Palace Museum and the History and Ethnography Museum are among the most popular museums that received quite a huge number of visitors annually [35]. Due to this factor, it shown that CO_2 concentration for Case Study 1 are higher and more pollute compared to indoor levels of CO_2 for Case Study 2, because Case Study 1 received higher visitors compared to Case Study 2.

5.4. Fine Particle

Based on Figure 9, according to WHO, for a short term $PM_{2.5}$ exposure within 24 hours, the acceptable TLV for $PM_{2.5}$ concentration is 25 µg/m^3 [31]. It is shown that the $PM_{2.5}$ concentration profile for both case studies are constantly exceeding the acceptable TLV starting from the opening of the museum's operation hour until the end of the museum's operation hour. According to WHO [3], there are numerous sources of particles related to natural sources as well as human activities, such as source obtain from infrastructure, manufacturing, landfills, construction sites, agricultural fields and vehicle use. WHO stated that indoor levels of environmental pollutant are a function of indoor and outdoor sources, where high outdoor levels originating from local traffic or other combustion sources influence indoor levels [31]. Due to this factor, with also consider the distance of building from roadway, it shown that $PM_{2.5}$ concentration for Case Study 2 are higher and more pollute compared to indoor levels of $PM_{2.5}$ for Case Study 1, because there was heavy traffic occurred, especially on weekends.

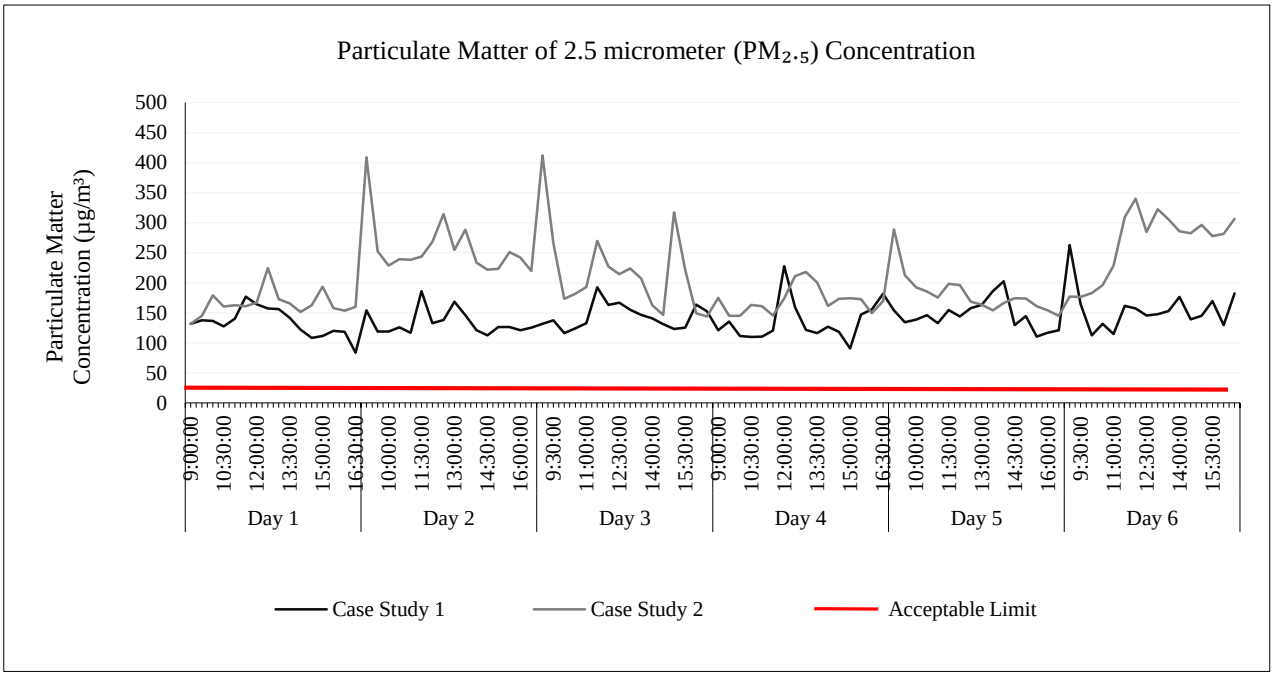

Figure 9. Fine particle concentration for Case Study 1 and Case Study 2

Nevertheless, there was a possibilities that indoor levels of PM pollutant could also originated from indoor sources, which generate source from visitors itself. There has a role of visitors' clothing as a source of fibres and dust which contributed to indoor levels of PM pollutant in museums [36]. During the field study measurement, it was discovered that Case Study 1 received a huge number of visitors with a total of 536 visitors whereas Case Study 2 received 508 visitors, recorded for six days.

6. Conclusion

The finding of this study indicates that the distance of buildings from roadways appears to have an impact on indoor environmental levels, especially for NO_2, SO_2 and PM. Based on the results, only gaseous pollutant of SO_2 had not exceeding the acceptable TLV compared to the other IAQ pollutants. It can be conclude that Case Study 2 are more pollute for IAQ parameters of NO_2, SO_2 and fine PM, compared to Case Study 1 because location of Case Study 2 are much closer to the roadway compare to Case Study 1. Due to this reason, it is found that emissions from mobile sources have been the major source of air pollution for this three IAQ parameters, while for CO_2, Case Study 1 record higher CO_2 concentration and more pollute compared to indoor levels of CO_2 for Case Study 2, because Case Study 1 received higher visitors compared to Case Study 2.

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8. Conflicts of Interest

The authors declare no conflict of interest.

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