Indoor Environment & Soiling Defects from Airborne Particulates towards Artefacts, Tourists, Visitors and Staff at the National Museum Kuala Lumpur.

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Abstract. Museums are essential facilities as they represent the history and culture of every nation, this research aims to evaluate the indoor air environment conditions in the Malaysian national museum, providing the temperature, relative humidity, and air pollutants evaluation readings, the method of conducting the research was done by 6 HOBO data loggers were used to provide the readings of the indoor air environment, that the average temperature and relative humidity, within the standard limits ranging between 23.5^{0}C to 25.1^{0}C and 52.5% to 64.9% except for HOBO 5 giving reading of 11.7^{0}C and the lowest RH reading of 34%. The results provide an insight of the current conditions in the museum and it is effect on the artefacts, visitors, tourist and staffs, and give the management indicators on the issues that can be improved through recommendations on the scheduled museum maintenance specifically air conditioning and HVAC, and also Acute monitoring and control of temperature, relative humidity and indoor air quality (IAQ) of their in the future.

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1 Introduction

A museum is a public, non-profit, lifelong facility that collects, preserves, shares, and displays the physical and intangible legacy of humanity and its world for the cause of education, study, and enjoyment, also they are a primary link between the past, present, and future, which are regarded as the history repositories for the countries, museums are a trustworthy source of data for scholars and can be a fun way to teach kids about history and many other subjects (Askari & Altan, 2014). Sulaiman, Kamaruzzaman, Salleh, and Mahbob (2011), stated that Malaysian museums are faced with a generally negative public impression of them. The Department of Museums Malaysia states there are 20 museums under their department. Malaysia's weather is tropical. Therefore, museum buildings require air conditioning equipment to run continuously the entire year, 24 hours a day, leading to the possibility to disregard the control methods for cooling, heating, and humidification, it is challenging to achieve harmony between maintaining the indoor environmental requirements needed to conserve the artifacts and give the visitors thermal comfort (Yau, Chew, & Saifullah, 2013). The paper will study the Muzium Negara, which is the National Museum of Malaysia. The museum has four main galleries, and the paper will study only two galleries that is the gallery A and B. This research aims to evaluate the indoor air environment in the Malaysian national museum, providing the temperature, relative humidity, and air pollutants evaluation, as it is very important to guarantee the safety of the indoor environment of the museum.

2 Literature Review

Indoor environment quality is a crucial factor to consider when designing buildings like museums, as it not only affects the visitors and their comfort but also impacts the preservation of numerous objects (Efthymiou et al., 2021). Due to the artifacts that need certain climatic conditions to be preserved, museum environments differ from other architectural environments, the indoor environment quality is divided into three parts, thermal conditions, lighting, and air pollution (Sharif-

Askari & Abu-Hijleh, 2018). To prevent deterioration, artifacts in museums should be kept in a controlled environment with the appropriate temperatures, relative humidity, and illumination level (Yu, Zhang, Zhao, & Zhang, 2019).

2.1 Relative Humidity and Temperature

Relative Humidity (RH) and Temperature (T) set points may be rigorously regulated or they may change according to the seasons and times, based on the state and local climatic circumstances and the standards followed by various museums, the durability, and longevity of the exhibits are enhanced by providing uniform climatic conditions with little variations when configured properly (Sharif-Askari & Abu-Hijleh, 2018). The purpose of temperature and climate management in a museum is, first and foremost, to avoid and minimize the deterioration process of the artifacts while also guaranteeing a comfortable environment for visitors. The indoor microclimatic parameters in museums are greatly influenced by thermal-hygrometric factors and the efficiency of air ventilation, for accurate regulation of temperature, humidity, and air velocity, suitable heating, ventilation, and air-conditioning (HVAC) system is required, to create a safe and adequate environment needed for the exhibits and the visitors, as the HVAC system minimizes these parameters (Yau et al., 2013). According to ASHRAE (2011), the ideal current standard set point is 50% RH and Temperature of 20°C, however, when determining the thermal conditions there must be a consideration of the type of artifacts, and location of the building and not just have a standard value, as the value must consider the biological damage, mechanical damage, and chemical damage.

The majority of museums demand RH of 40 - 55% and temperatures of 18 - 24 °C, with daily swings of ±3% RH and ±3°C, respectively, to be comfortable and healthy, a filtration system must remove at least 50% of particles and pollutants (Yau et al., 2013). The relative humidity in the space must be regulated at a detailed value for preservation purposes. Normally, the relative humidity in museum spaces is kept at a fixed value between 40 and 60%. (RH) (Bøhm & Ryhl-Svendsen, 2011). According to Van Schijndel, Schellen, Wijffelaars, and Van Zundert (2008), a researcher found that a relative humidity (RH) range of 40 to 50% is advised, for paper the LCM Foundation stated an RH of between 48 and 55% with a variation of under 3% per day and a temperature of 16 and 18 °C with a variation under 2°C /h. Kramer, van Schijndel, and Schellen (2017), researched the museum building, Hermitage Amsterdam, using ASHRAE standards, the set point of 21°C and 50% RH, using the ASHRAE classes AA, As, Ad, and B. according to Ilieș et al. (2021), summarized the standards for the RH and T as follows in table 1.

Table 1. Standards for the Relative Humidity (RH) and Temperature (T) (Ilieș et al., 2021).

Recommendations		Temperature °C	RH %
Conditions in museums in general		20 (±1–2) 21(±2) 15–25	50 (±3) 45 (±8) 40 – 65
Individual recommendations depending on the nature of the exhibits	Wood	19–24 14–18	40–65 55 (±5)
	Paper	19–24 14–18	50–60 50–65
	Ethnographic materials	19–24	40–60
	Iron armour	N/A	<40
	Leather	N/A	50–60
	Fur and leather	15–21	45–60
	Ceramics	N/A	20–6

According to Nakielska and Pawłowski (2020), temperature under 10°C, relative humidity, and poor air ventilation cause moistness and microbial issues, the temperature and relative humidity that must the museum obtain vary depending on the artifacts, table 2 show the values.

Table 2. The relative humidity and temperature standard values for different museum artifacts (Nakielska and Pawłowski, 2020).

Item / Material	Air relative humidity	Air temperature
Iron armour, weapon	< 40	
Bones, ivory	45–65	19–24
Bronze	< 55	
Paper	50–60	19–24

Anatomic collection	40–60	19–24
Minerals collection, stone, marble	45–60	< 30
Leather, hide, parchment	50–60	
Botanical collection (including herbs)	40–60	
Oriental lacquer	50–60	19–24
Wood	40–65	19–24
Painting on wood, polychrome wood	45–65	19–24
Books, manuscripts	50–60	19–24
Ethnographic materials	40–60	19–24
Organic materials (generally)	50–65	19–24
Plastics	30–50	
Polished metals and alloy, brass, silver, tin, lead, copper	< 45	
Gold	< 45	
Papyrus	35–40	19–24
Fur and leather	45–60	15–21
Paintings on canvas	35–50	19–24
China, ceramics* , stoneware, earthen goods	20–60	

* types of ceramic made at a low temperature, the relative humidity is < 45%

According to ASHRAE. (2019), classifies the museum depending on the type of control into six types AA, A1, A2, B, C, and D, table will present the Temperature and Relative Humidity Specifications for Collections in Buildings or Special Rooms.

Table 3. The Relative Humidity and Temperature standard for artifacts (ASHRAE, 2019).

Type of Collection and Building	Type of Control	Long-Term Outer Limits	Seasonal Adjustments from Annual Average	Short-Term Fluctuations plus Space Gradients

Museums, Galleries, Archives, and Libraries in new buildings or special rooms (Temperature achieving human comfort)	AA Precision control, no seasonal changes to relative humidity	≥35% RH ≤65% RH ≥10°C ≤25°C	No change in relative humidity Increase by 5 K Decrease by 5 K	±5% RH, ±2 K
	A1 Precision control, seasonal changes in temperature and relative humidity	≥35% RH ≤65% RH ≥10°C ≤25°C	Increase by 10% RH. Decrease by 10% RH. Increase by 5 K; Decrease by 10 K	±5% RH, ±2 K
	A2 Precision control, seasonal changes in temperature only	≥35% RH ≤65% RH ≥10°C ≤25°C	No change in relative humidity. Increase by 5 K; Decrease by 10 K	±10% RH, ±2 K
Museums, galleries, archives, and libraries need to reduce stress on their building (e.g., historic house museums), depending on the climate zone	B Limited control, seasonal changes in relative humidity, and large seasonal changes in temperature.	≥30% RH ≤70% RH ≤30°C	Increase by 10% RH Decrease by 10% RH	±10% RH, ±2 K
	C Prevent relative humidity extremes (damp or desiccation) and prevent high-temperature extremes.	≥25% RH ≤75% RH ≤40°Cg		Not continually above 65% RH for longer than X days. (Temperature rarely over 30°C)
Collections in open structured buildings, historic houses	D Prevent very high relative humidity (dampness)	≤75% RH		Not continually above 65% RH for longer than X days.

The galleries for the museum will be classified as AA type of control as the current museum achieve the required condition for the classification, with 35% - 65% RH and Temperature range between 10°C - 25°C.

2.2 Air pollution

Both maintaining proper air conditions, such as temperature and humidity, and protecting exhibits from risks related to air quality are crucial, acceptable pollution values that depend on the material are required since going above the limits of some gases that pollute the air causes permanent alterations in collections (Nakielska & Pawłowski, 2020). Poor air quality within museums has the potential to harm people's health while affecting the exhibits' integrity, In general, carbon dioxide caused by users, particulate and dust, total volatile organic compounds (HCHO) and formaldehyde (TVOC), and pollutants related to light and illuminance are the most significant indoor inspected pollution factors effected by air pressure and air velocity (Ilieș et al., 2021), table 4 show the air pollution factor standards. The particulate matter PM sampling method depends on the aerodynamic response of the air-suspended particles, particles are classified into three size classifications PM_1 (AD b 1 µm), $PM_{2.5}$ (AD b 2.5 µm), and PM_{10} (AD b 10 µm) (Krupińska, Van Grieken, & De Wael, 2013).

Table 4. Standards of air pollutants limits for human health and artifacts (Ilieș et al., 2021).

Recommendations	CO_2 ppm	PM (µg/m^3)	TVOC (mg/m^3)	HCHO (mg/m^3)
Human health	<1000	< 15 < 10 PM2.5 < 20 PM10	<1	<0.004

According to ASHRAE. (2019), there are many sources of air pollution, the artifacts can be a source, visitors, and outside air, and the damage and defects occurring to the artifacts are irreversible, ASHRAE lists the gases and what they affect. Table 5 below illustrates the airborne pollutants.

Table 5. Airborne Pollutants (ASHRAE, 2019).

Gaseous Pollutants	
Important Inorganic Pollutants	
	Sulfur dioxide (SO,)
	Nitrogen oxides (NO,)
	Reduced sulfur compounds

Strong Oxidizing Pollutants	
	Ozone (0,)
	Peroxyacetyl Nitrate (PAN)
	Peroxides
Organic Carbonyl Pollutants: Aldehydes and Organic Acids	
	Organic carbonyl pollutants
	Organic acids
	Aldehydes
	Formaldehyde
Other Potentially Damaging Pollutants	
	Ammonia (NH,)
	Ammonium ion (+NH,)
	Amines (R-NH,)
	Fatty acids
	Hydrochloric acid (HCl)
	Water vapor (H, O)
	Particles (fine and coarse)

For this research, the study will be on Dust Particulates (PM), Carbon Dioxide (CO_2), Nitrogen Dioxide (NO_2), VOCs, Ozone (O_3), Carbon Monoxide (CO), and Air Pressure. According to the dosh, the standard values for the air pollutants values are shown in the table.

Table 6. Standard values for the air pollutants limits (ICOP IAQ, 2010).

Indoor Air Contaminants	Acceptable limits	
	ppm	mg/m^3
Chemical contaminants		
(a) Carbon monoxide	10	
(b) Formaldehyde	0.1	
(c) Ozone	0.05	
(d) Respirable particulates		0.15
(e) Total volatile organic compounds (TVOC)	3	
Ventilation performance indicator		
(a) Carbon dioxide	C1000	

NOTE: for chemical contaminants, the limits are eight-hour time-weighted average airborne concentrations

3 Methodology

The temperature, relative humidity, and air pollutants for the period of the study, at various locations in the Museum, were computed and evaluated according to the ASHRAE standards, and the Malaysian Department of Occupational Safety and Health, 6 HOBO data loggers were placed in the museum to obtain the temperature, and relative humidity. The HOBO data loggers device gave the readings for temperature and relative humidity. The study of this research is only been conducted on the 2 exhibitions area in the museum that is the gallery A and B.

3.1 Site Measurement

This research is conducted in galleries A and B in the national museum of Malaysia, the dimensions of the galleries were measured to have proper plans. Gallery B contains an unglazed ceramic exhibition, a glazed exhibition, and a metal exhibition, and Gallery A has a ceramic exhibition box, all Galleries have tiled floor finishes and a painted block wall.

3.2 Data Collection

For collecting the data of the parameters, 6 HOBO data loggers devices were used to obtain readings for two weeks, three devices in each gallery were distributed in different places in the gallery, HOBO loggers 1, 2, and 3 were installed in gallery A, and HOBO data logger 4, 5, and 6 were installed in gallery B, the readings were done from 12:00 pm Jan 9th, 2023 till 11:00 am Jan 25th, 2023 with an interval of 30 minutes of reading. The recommended minimum number of sampling points for indoor air quality is 1 per 500m^2 if the area is <3000 m^2. The figure 1 and 2 below shown the layout of the National Museum Gallery A & B and the location of the sampling stations.

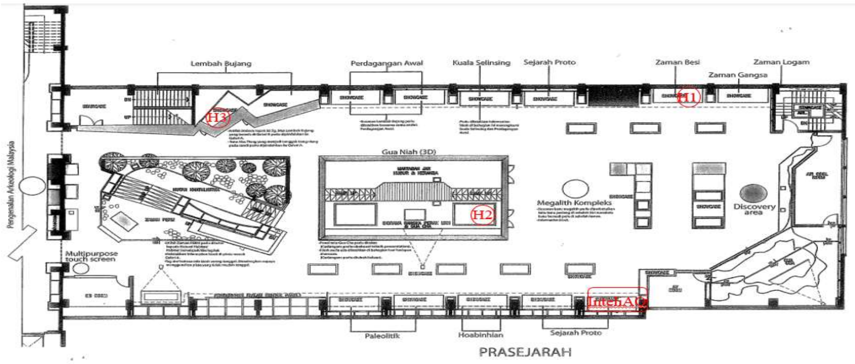

Fig. 1. The location of the sampling stations at the National Museum Gallery A.

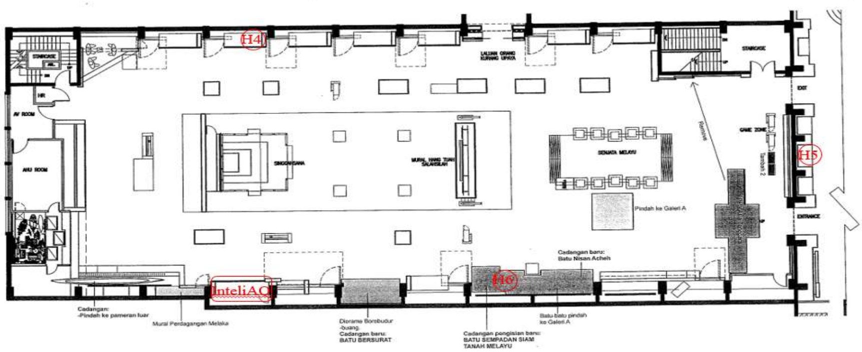

Fig. 2. The Location of the sampling stations at the National Museum Gallery B.

4 Result

Results gathered from the measurement equipment for the specified period of the study were evaluated according to the ASHRAE standards for Museums, Libraries, and Archives, and the Malaysian Department of Occupational Safety and Health. ASHRAE requirement for AA type of control for Museums, Libraries, and Archives is (35% - 65% RH) and (10°C - 25°C). The HOBO logger reading result for the specified period are shown in the figure 3 to 8 below.

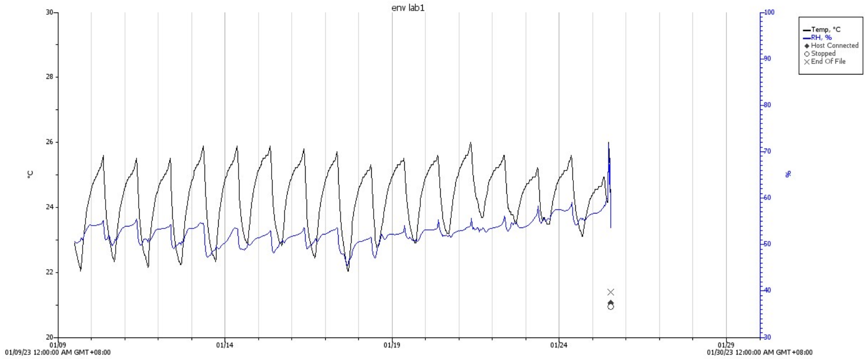

Fig. 3. HOBO 1 logger reading

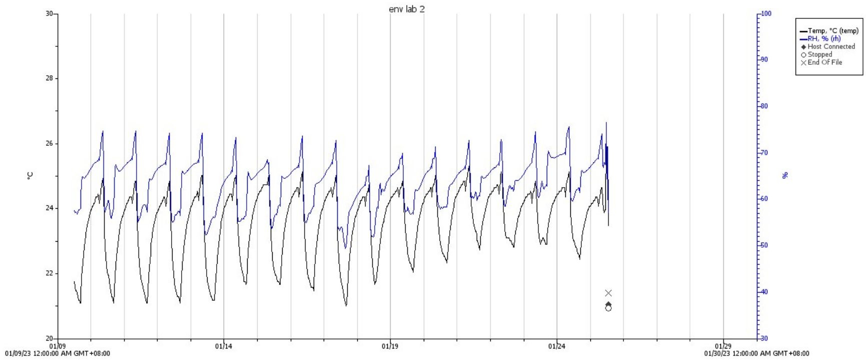

Fig. 4. HOBO 2 logger reading

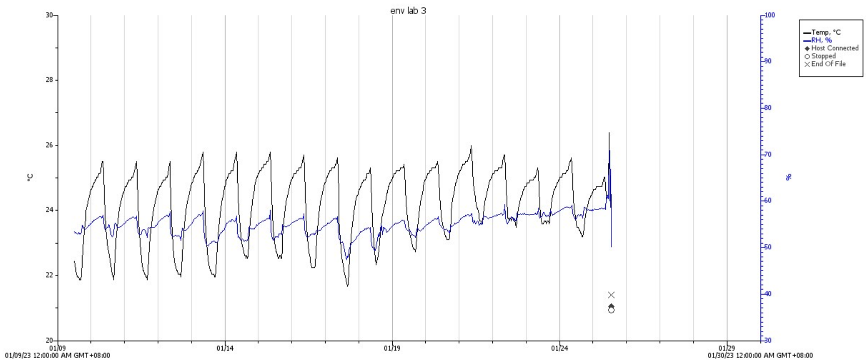

Fig. 5. HOBO 3 logger reading

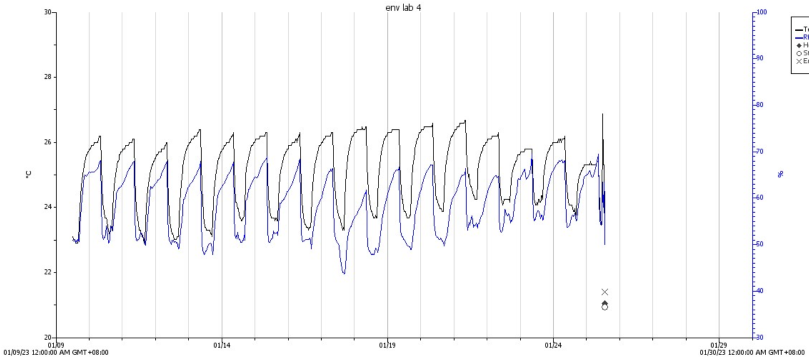

Fig. 6. HOBO 4 logger reading

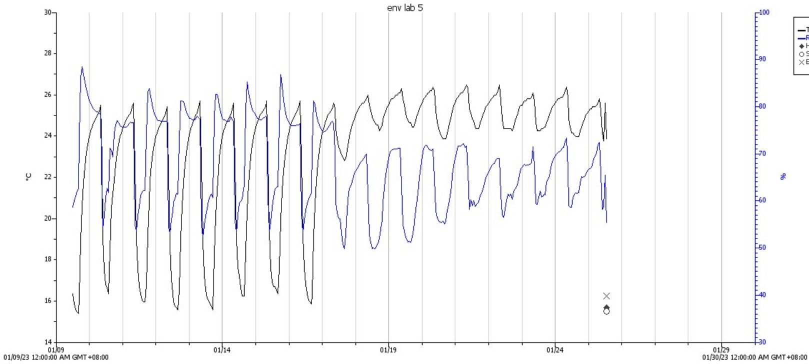

Fig. 7. HOBO 5 logger reading

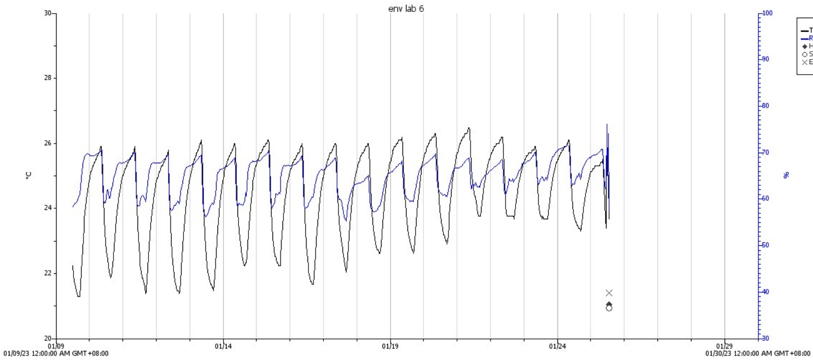

Fig. 8. HOBO 6 logger reading

Table 7 shows the resulting average value for the different HOBO data loggers at both gallery A and B. From the data, it shows that the average temperature and relative humidity, within the standard limits ranging between 23.5^{0}C to 25.1^{0}C and 52.5% to 64.9% except for HOBO 5 giving reading of 11.7^{0}C and the lowest RH reading of 34%. It is anticipated that the reading was affected by the position of the data logger close to the air conditioning flow for the gallery B. However, all the readings are still within the limits.

Table 7. The HOBO logger average reading result for the specified period.

location	AVG T°C	AVG RH%	limits T°C	limits RH%	T°C Result	RH% Result
Gallery A HOBO 1	24.2	52.5	10°C - 25°C	35% - 65%	Within Limits	Within Limits
Gallery A HOBO 2	23.5	63.6	10°C - 25°C	35% - 65%	Within Limits	Within Limits
Gallery A HOBO 3	24.2	54.9	10°C - 25°C	35% - 65%	Within Limits	Within Limits
Gallery B HOBO 4	25.1	58.6	10°C - 25°C	35% - 65%	0.1°C Above The Limit	Within Limits
Gallery B HOBO 5	11.7	34	10°C - 25°C	35% - 65%	Within Limits	Within Limits
Gallery B HOBO 6	24.4	64.9	10°C - 25°C	35% - 65%	Within Limits	Within Limits

5 Discussions

The evaluated result shows the climate data in the two Galleries, all of the HOBO loggers are above the ASHRAE temperature standard except the HOBO 2 logger, gallery A reading starting with HOBO 1 temperature is above the standard as it reaches 26°C and the relative humidity is within the standards, for HOBO 2 the temperature reaches 25°C on most days and the relative humidity reaches a value of 77% which is above the standard with more than 12%, for HOBO 3 the temperature is above the standard as it is close to 26°C and the and the relative humidity is within the standards. Moving to gallery B, HOBO 4 reading the temperature is above the standard as it reaches 26.7°C as it is above standard 1.7°C more than the standard, for the relative humidity reaches a value of 70% which is above the standard with more than 5%, HOBO 5 reading the temperature from the start of the reading till Jan 18th the temperature is between 15°C till close to 26°C, however, from Jan 19th till the end of the reading the temperature is between 24°C till 26°C, the result shows that there is a change affecting the HVAC system leading to this change also the temperature is above the standard with 1c, the relative humidity from the start of the reading till Jan 18th is between 50% - 85% and from Jan 19th till the end of the reading period is between 50% - 72%, for HOBO 6 reading the temperature is above the standard as it reaches 26.3°C as it is above standard with 1.3°C more than the standard, for the relative humidity reach a value of 72% which is above the standard with more than 7%. The HOBO logger average reading result for the specified period is shown in table 7. From table 7, the resulting average value for the different HOBO loggers shows that all the result is within the ASHRAE standard limit, except gallery B HOBO 4, which is above the temperature limits by only 0.1°C.

Ferdyn-Grygierek (2014), recorded the result through one year in a Polish museum by installing sensors in exhibition halls, the reading was from October–April 15.1°C – 25.3°C with RH 24%–57%, in Jan, the weather was colder, the temperature was recorded from 15°C to 21°C and RH 25% - 45%, however, from May–September the temperature was 15.5°C –28.4°C with RH 36%–76%, in June were the weather, in general, is warmer, the temperature was recorded from 18°C to 26°C and RH 60% - 65%. Marcelli, Sebastianelli, Conte, Lucci, and Della Ventura (2020), recorded temperature and RH for historical museum of Bersaglieri in Rome from start of March till the end of April of 2019, the temperature reading in march was weighted mean value of 18.4°±0.3 °C with RH of weighted mean value of 42.5 ± 2.3%, in April the temperature reading was of weighted mean value 20.2° ± 0.2 °C with RH of weighted mean value of 45.6 ± 0.7%, however, Marcelli et al. (2020), stated that due to the historical structure's architecture and the absence of a ventilation system to regulate the exhibition temperature and humidity, environmental conditions are extremely variable during day and night which is the same as this case study as The Malaysian National Museum was opened in 1963, figure 5, shows that in Jan 10th the temperature reading in 12:00 am was around 24°C and during the day at 12:00 pm it reaches close to 16 and then incline close to 25°C at 12:00 am the same cycle occurs from Jan 9th till Jan 18th and then the temperature variation limits between 24°C – 26°C till the end of the reading period, the RH from Jan 10th at 12:00 am reach 80% and then decline close to 55% and this condition occurs from the beginning of the reading till Jan 18th, then the RH reading is limited between 55% - 70% from Jan 19th till the end of the reading period, his shows that there is an issue with the HVAC system supply of air and that the difference of reading through short period of time. The results of this research have maximum values that considerably surpass the advised limits, the ideal parameters for the correct protection of various types of artifacts are listed in Table 2, and proper maintenance and observation of the current HVAC system must be done to prevent any defect to the artifacts inside the museum.

6 Recommendations

There are very clear relationships between airborne particulates with relative humidity and temperature inside the museum gallery A & B, and also the exhibition boxes. The hygrothermal microclimate of the indoor area of Gallery A has more effect on the mass concentration of dust when compared to that of Gallery B.

The anticipated airborne particulates comes from the traffic condition passing through around the National Museum as the National Museum located in between busy streets especially during the peak hours. As observed by the researcher, the high percentage of dust mass concentration values were due to reasons as exhibition boxes locations, the gap between glasses enclosing the artefacts, visitors population, construction activities nearby, infiltration, through the HVAC system and other openings.

In reducing the effects of airborne particulates inside the galleries in the National Museum, below are few recommendations to improve the indoor environment as follows :-

i. *Plant purifier* : Purifying plants are able to convert carbon dioxide to fresh oxygen and also able to remove indoor pollutants such as formaldehyde, Volatile organic compounds (VOCs), nitrogen dioxides, pesticides, roden and decrease dust level up to 20% (Maria, 2023). Good example plant to be used includes English Ivy (*Hedera Helix*), Gerbera Evergreen (*Aglaonema Modestum*), and Peace lily (*Spathiphyllum Mauna Loa*). Placement of plant purifiers at strategic location as walking area, lobby, and some specific exhibition box will limit the total dust concentrations, and thus improve the overall state of Indoor Air Quality (IAQ) in the museum.

ii. *Exhibition boxes* : Most exhibition boxes have leakages around their edges, which allows the passage of dust particles and extreme environmental conditions. Sealed cases usually require passive or unique conditioning system that is independent on normal air condition of the room. As sealed exhibition boxes are subject to a build-up of contaminants, they should be made of inert materials. Additionally, sealing of these gaps with an appropriate sealant, will reduce the infiltration of dust particles and hence, subsequently reduce the soiling defects of airborne particulates towards the artefacts.

iii. *Scheduled cleaning and vacuuming* : Both operation are part of museum maintenance management. The operation need to be conducted in a specific time as it will also reduce to a substantial amount, the possibility of any mechanical damage that may arise as a result of improving the condition of one artefact. Because some artefacts are vulnerable in a condition that will not affect another artefact. Some attempt to improve the state of the artefacts might be dangerous to others. Therefore, activities such as a well-organised cleaning and vacuuming process i.e. three times in a year or every six months will help to reduce these effects.

iv. *Cleaning and maintenance of HVAC* : It has been observed by numerous researchers that the HVAC system is a significant source of pollutants in the indoor area. For this reason, the management should maintain the HVAC system by cleaning of the ducting system and the filters. Similarly, best to be conducted every three months, as suggested by an experienced Building Services Engineer.

v. *Acute monitoring and control of temperature, relative humidity and indoor air quality (IAQ)* : The museum management should also alert to the microclimate condition of the museum. An easy practicing by placing HOBO data logger and also IAQ real time measurement equipment at some specific location to monitor and record the profile of temperature, relative humidity and also IAQ at the required interval. By having this, the climate condition of the museum can be controlled to avoid both mechanical, chemical and biological damages caused by adverse temperature.

7 Conclusion

As understandable, the museum is an important facility, it is indoor environment is vital as the museum is a place where many people are inside at the same time and it collects many precious artifacts. Therefore, the indoor environment analysis is vital to prevent harm to both visitors and artifacts, this research evaluated the indoor air condition in the National Museum of Malaysia. The value for temperature and relative humidity were found and evaluated regarding the standards, the temperature limits are 10°C - 25°C, and relative humidity are 35% - 65%, the average RH and temperature were found complying to the standards, this type of research is important for museum management and governments to be able to prevent any harm for visitors and artifacts. By following the recommendations, it is hope the microclimate condition inside the museum galleries and exhibition boxes will be well maintain and protecting the artefacts from the soiling defects of airborne particulates. Hence, this action will improve further and minimise the health impact towards the tourists, visitors, and staff in the long run.

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