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Assessment of Indoor Air Quality in Maritime Museum Malacca

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Abstract: Indoor Air Quality (IAQ) problems are not new in Malaysia, and an imbalance of IAQ in museums might pose risks to both people and collection objects by causing indoor gaseous pollution within the museum structure. Therefore, the objectives of this study are to measure the IAQ and gaseous parameters, to compare the value for each parameters with standards and past studies, and proposing recommendations for improvement. The average results of the measurement sampling for 3 were compared to the indoor air quality levels in compliance with ASHRAE 55, ASHRAE 62.1, and ICOP standards. The methodology used for this research employ real-time monitoring using a 4-in-1 meter kit, IAQ meter KINOMAX, and VT 11-/ VT115 Hotwire thermo-anemometer. The data taken are compared. The average temperature in the Maritime Museum Malacca was measured to be 22.98°C, while the relative humidity was recorded at 59.19%. The air velocity inside the museum was found to be 0.35 m/s. Carbon monoxide levels were measured at 0.89 ppm, and carbon dioxide levels were observed at 850.50 ppm. It can be concluded that all the parameters measured are within the standard range. The significance of this study is to provide benefits to the occupants, including visitors and employees, enabling frequent visits for knowledge acquisition and improved work productivity without affecting their health during their time inside the building. Furthermore, the study will benefit visitors, the government, and the private sector in sustaining their buildings. The outcomes of this study have the potential to positively impact the indoor environment and the well-being of occupants in the Maritime Museum, setting a precedent for sustainable and healthy indoor spaces in heritage buildings. Findings will be used as a basis guide PERZIM management, particularly in identifying problems related to environmental air quality in the museum to improve indoor quality and achieving sustainability in a museum.

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Keywords: Indoor Air Quality, Museum Building, Refurbished

1. Introduction

Air is a crucial component for maintaining human existence on earth. Inhaling oxygen, especially air, is essential for proper breathing and a better quality of life. However, the negative impacts of urban outdoor and interior air pollution have led to more than two million avoidable deaths worldwide (Abdou, 2006). With people spending approximately 90% of their time indoors, indoor air quality (IAQ) problems are emerging as a significant health concern.

Museums play a vital role in preserving historical items and collections of immense value. To ensure the preservation of artwork and historical artifacts, maintaining clean and impurity-free indoor air quality is crucial. The Maritime Museum in Malacca, Malaysia, which showcases the region's maritime history, is one such museum where IAQ assessment is necessary.

Air pollution poses a particular challenge in historical structures like museums, as they were not originally designed to display and maintain artifacts sustainably. The Maritime Museum Malacca is not only an important tourist attraction but also a key cultural heritage site in Malaysia. Therefore, maintaining appropriate temperature and humidity levels within the museum is crucial for artifact preservation (Ambrose & Paine, 2006).

The museum is one of the most famous tourist places in Malaysia. The museum is one of the Malaysian cultural heritage tourism attractions that may impact the expansion of the country's tourism sector (Shuang et al., 2014). According to Ambrose, the museum should be maintained at a comfortable temperature of 18°C all year long with constant humidity that doesn't fall below 40% or increase over 60%. (Ambrose & Paine, 2006), (Muhammad Ilmam Tharazi, 2012). He also mentioned that 45% to 50% relative humidity for museums in older buildings, is a good balance, with temperatures ranging from 15°C to 25°C. In tropical climates such as Malaysia, relative humidity ranges from 67% to 96%, with an average value of roughly 80% (S.N et al., 2011), (Dzulkifli et al., 2016).One of the primary sources of this problem, particularly in the non-industrial sector, is a lack of analysis, data, and municipal ordinances (Deros, Ismail, & Leman, 2010). To provide a decent interior environment, inhabitants must feel more comfortable and safe. (Mazroei, et al., 2016).

As a result, this study is being conducted to assess the interior air quality at the Maritime Museum Malacca. The findings are based on selected characteristics such as temperature, relative humidity, air velocity, carbon monoxide (CO), and carbon dioxide (CO_2). Data from each reading point is gathered and compared to typical indoor air quality to understand this issue better. To achieve the goals of this study, the following objectives have been established which is to identify IAQ improvement in the Maritime Museum after renovation, measure the IAQ and gaseous parameters and Propose recommendations for improvement based on ASHRAE 55, ASHRAE 62.1, and ICOP standards.

2. Methodology

Methodology is defined as a specific method or procedure to achieve a research objective. Figure 1 depicts the flowchart of the research methodology that has been employed to provide a clearer overview and understanding of the sequential research processes.

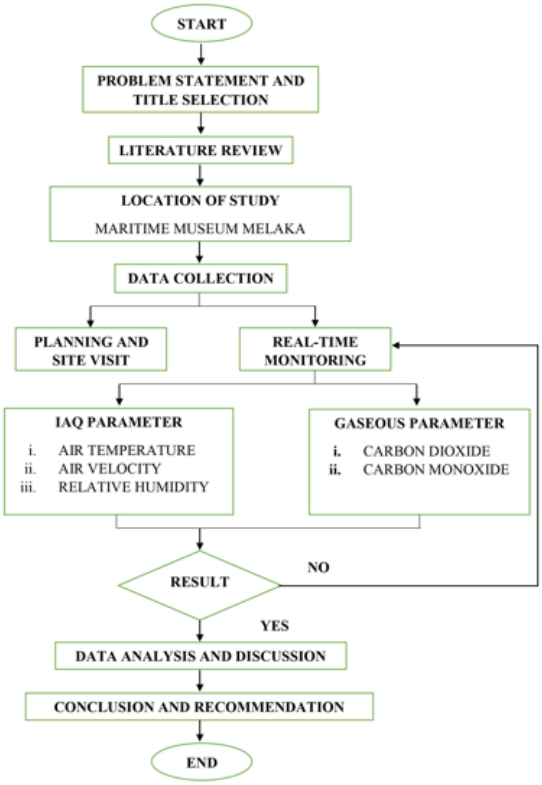


Figure 1: Methodology Flow Chart

2.1 Location of Study

This study was conducted at the state of Johor which is at Maritime Museum Malacca. This study's location was chosen because it collaborated with the Perbadanan Muzium Malacca (PERZIM) to examine the museum's IAQ. Figure 2 shows the location plan of the study and Figure 3 shows the Maritime Museum Malacca.

Figure 2: Location Plan

Figure 3: Maritime Museum Malacca

2.2 Data Collection

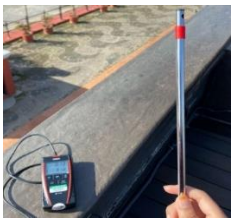
To launch the findings of this study, extensive planning and discussions were conducted with PERZIM, aimed at obtaining relevant information. The discussions encompassed various aspects, including the history of the building, the building plan of the Maritime Museum Malacca, the application process for permits and access to the building, identification of the IAQ data parameters to be collected, as well as the identification of any issues and problems within the building.

Moreover, a site visit was conducted to establish a connection with the staff or the designated personnel who would provide assistance throughout the research process. During the visit, data collection focused on gathering information about the construction materials used in the building. This included details regarding the types and quantities of air conditioners, as well as information on wall, floor, and roof materials. Additionally, information regarding the building's equipment and the minimum and maximum visitor capacity at any given time was also recorded.

2.3 Real time-Monitoring

The real time monitoring of IAQ is a scientific measurement performed using specific equipment for the IAQ parameter. The equipment shows in Table 1.

Table 1: Equipment used for real-time monitoring.

No	Equipment and Parameter		
1.	4 in 1 Meter Kit 	VT 110/ VT115 Hotwire thermo-anemometer 	Indoor Air Quality Meter, KINOMAX 
	• Air temperature (°C) • Air Velocity (m/s) • Relative Humidity (%)	• Air Velocity (m/s)	• Carbon dioxide CO_2 (ppm) • Carbon Monoxide (ppm)

The real-time monitoring as shown in Figure 4 are carried out for 3 days which is Friday, Saturday, and Sunday. The time interval used for the research is 15 minutes between each reading. The data is collected in the morning, afternoon, and evening to get average data. The overall amount of time taken is 8 hours, from 9 am to 5 pm. This is to ensure that the data obtained does not have a lot of errors. Each parameter's average is calculated, recorded, and the data are then processed for analysis. The average reading outcome used to determine the level of air quality in the museum.

Figure 4: The data collection was being conducted

3. Data analysis and Discussion

The data analysis and discussion section of the study provides a detailed overview of the findings obtained from field studies conducted at Samudera Malacca. The data collection process occurred during the summer season in March, which coincided with the school holiday period, ensuring a suitable time for data gathering due to the increased visitor activity at the museum. The collection spanned three

days, primarily on weekends when the museum operates from 9:00 am to 5:00 pm. Measurements were taken at 15-minute intervals, following recommended guidelines. The study aimed for consistency and accuracy by conducting measurements during hot weather conditions typical of equatorial regions. The collected data was organized using Microsoft Excel, allowing for easy analysis and presentation through tables and graphs, facilitating a clear representation of the environmental air quality analysis.3.1 Air Temperature

Figure 5 and 6 presents the findings of the temperature measurements conducted over three days. On Day 1, a temporary power outage resulted in a lack of air conditioning, leading to an elevated average temperature of 24.08°C. Day 2 recorded a lower average temperature of 22.18°C, indicating the proper functioning of the air conditioning system. On Day 3, the average temperature slightly increased to 22.68°C due to higher visitor occupancy and increased human activities. These variations in temperature were influenced by factors such as technical issues, air conditioning functionality, and visitor presence. The results emphasize the importance of maintaining a controlled indoor climate and highlight how external factors can impact temperature conditions within the museum.

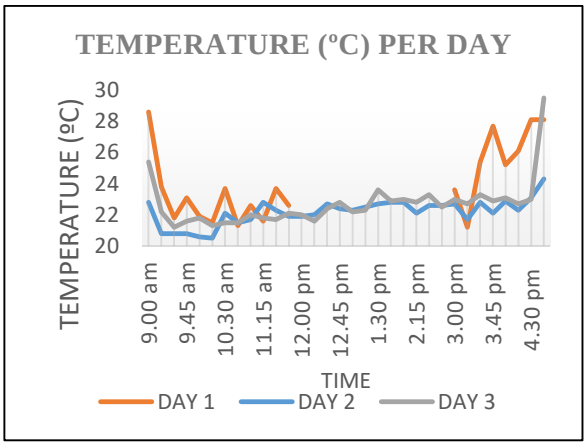


Figure 5: Temperature Readings Per Day

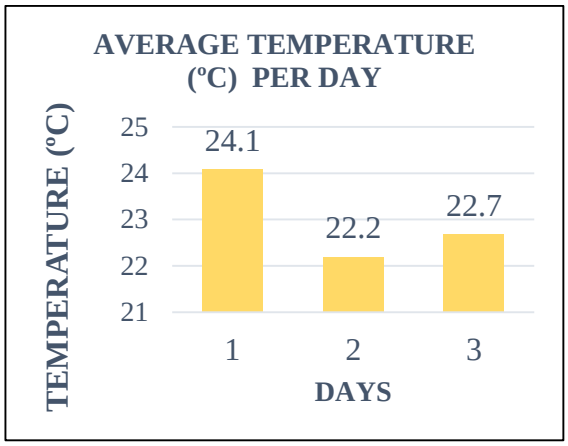


Figure 6: Average Temperature Per Day

3.2 Relative Humidity

Monitoring relative humidity is essential for preserving artifacts and maintaining optimal indoor air quality in museums. It helps identify moisture-related issues and safeguards the structural integrity of the museum building. Figure 7 and 8 displays the data collected for relative humidity over three days, with average values of 63.07% on Day 1, 56.32% on Day 2, and 58.29% on Day 3. These values fall within the acceptable range defined by ICOP (2010) standards, which recommend a relative humidity range of 40% to 70%. The ASHRAE-55 (2017) standard allows for a broader range of 25% to 95%. However, it is important to note that an electricity outage occurred on Day 1, potentially affecting the accuracy of the humidity readings during that timeframe. The interruption in power could have disrupted the functioning of the air conditioning system, which plays a critical role in regulating humidity and temperature.

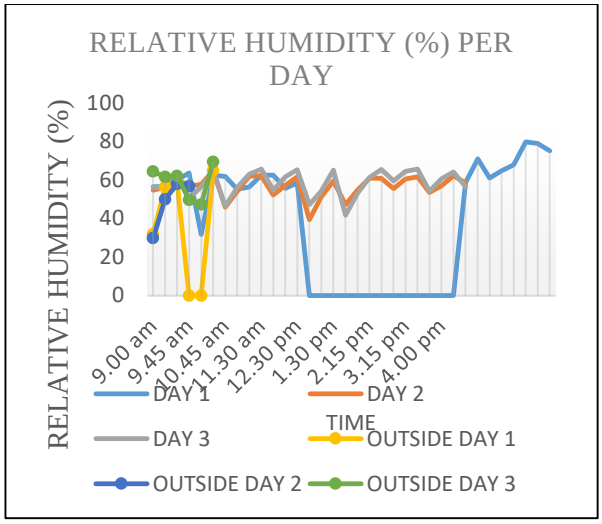


Figure 7: Relative Humidity Readings Per Day

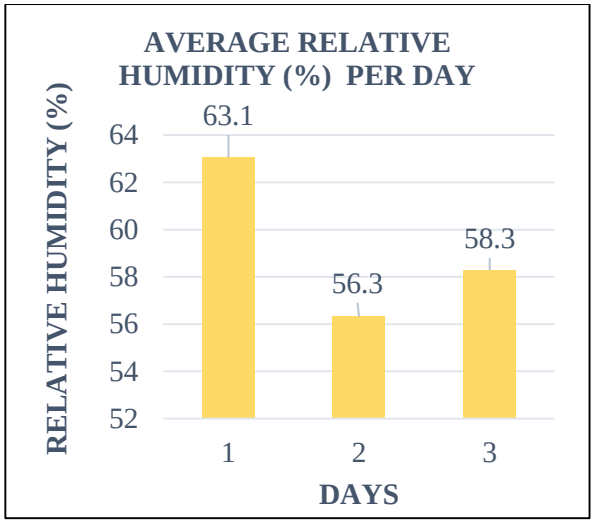


Figure 8: Average Relative Humidity (%)

3.3 Air Velocity

Figure 9 and 10 presents the data on air velocity for three days. On Day 1, the average air velocity was 0.28 m/s, within the range specified by ICOP (2010). Despite a power outage that disrupted air conditioning, the air velocity remained relatively consistent. Day 2 recorded a higher average air velocity of 0.51 m/s, surpassing the ICOP (2010) standard and falling within the range recommended by ASHRAE-55 (2017). This can be attributed to increased foot traffic on the weekend. On Day 3, the average air velocity slightly decreased to 0.27 m/s, still within the ICOP (2010) standard but at the lower end of the range. Overall, the museum generally meets the ICOP (2010) criteria, with Day 2 showing improved air movement and potentially better indoor air quality, aligning closely with ASHRAE-55 (2017) guidelines.

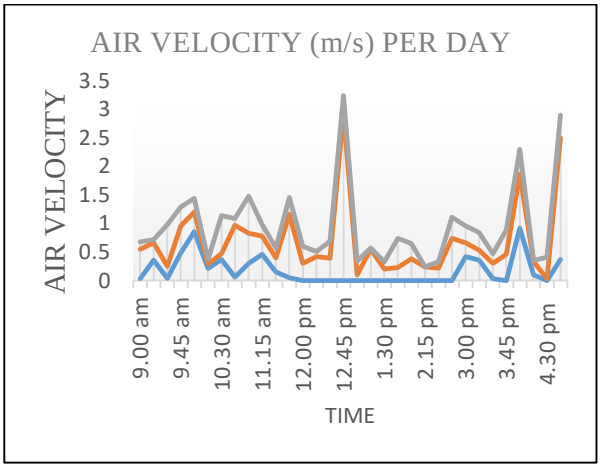


Figure 9: Air Velocity Readings Per Day

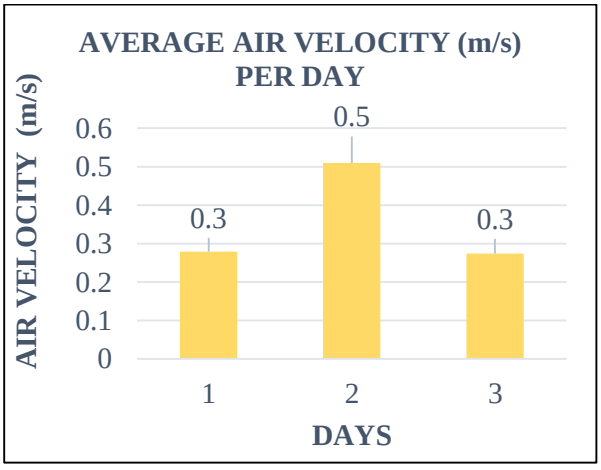


Figure 10: Average Air Velocity Per Day

3.4 CO

Figure 11 and Figure 12 shows the analysis of carbon monoxide (CO) data at Samudera Malacca Museum reveals that the measured CO levels remain well below the standards set by ASHRAE 62.1 and ICOP 2010. The average CO levels recorded for each day were 0.54 ppm, 0.98 ppm, and 0.93 ppm, respectively. These values are significantly lower than the recommended limits, indicating that the indoor air quality in terms of CO concentration at the museum is within acceptable ranges. Despite a

slight increase in CO levels on Day 2 compared to Day 1, the measured values consistently remained below the established standards throughout the observed period. This suggests that effective measures are in place to minimize CO emissions and ensure a safe and healthy indoor environment at the museum.

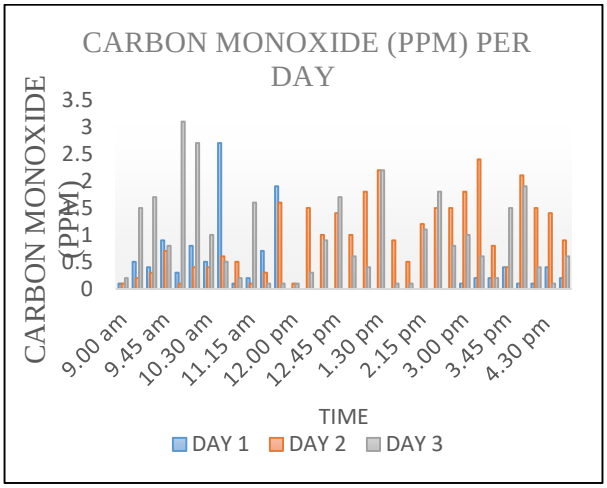


Figure 11: Carbon Monoxide Readings Per Day

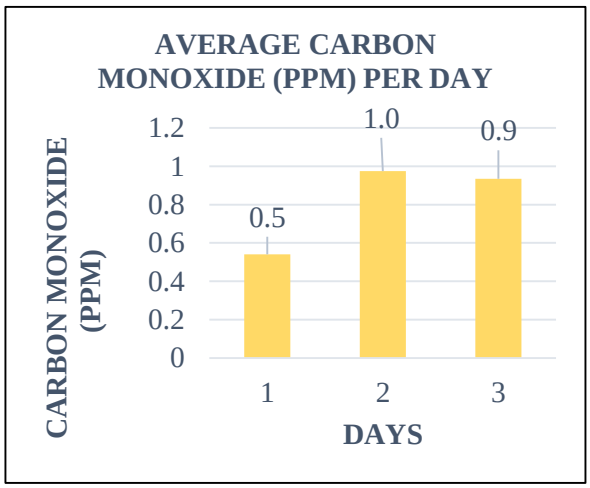


Figure 12: Average Carbon Monoxide Per Day

3.5 CO_2

Figure 13 and 14 provides an analysis of carbon dioxide levels over three days. On Day 1, the average carbon dioxide level was 699.1 ppm, indicating effective ventilation and satisfactory indoor air quality, even on a public holiday with a high number of visitors. On Day 2, the average carbon dioxide level increased to 883.97 ppm, likely due to increased occupancy during the weekend. However, the readings remained below the acceptable limit of 1000 ppm. Day 3 recorded an average carbon dioxide level of 862.72 ppm, again within an acceptable range despite increased weekend occupancy. Overall, the museum's ventilation system effectively managed indoor air quality, ensuring carbon dioxide levels remained within acceptable limits.

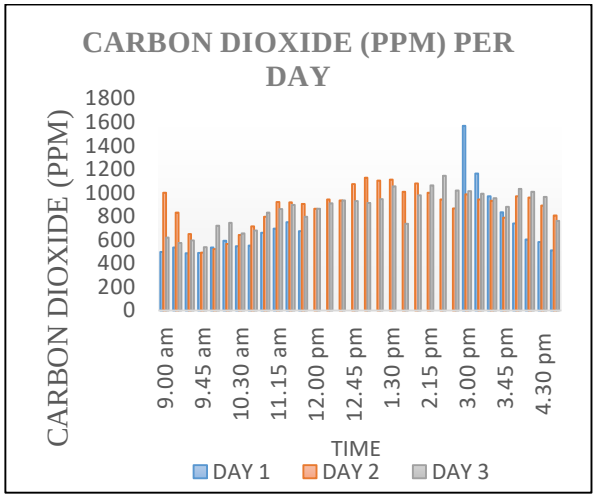


Figure 13: Carbon Dioxide Readings Per Day

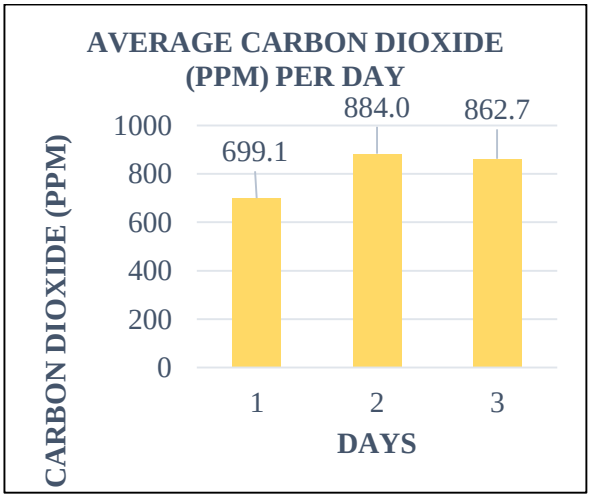


Figure 14: Average Carbon Dioxide Per Day

4. Relationship Between Environmental & Gaseous Parameter

The relationship between environmental parameters (temperature, relative humidity, and air velocity) and gaseous parameters (carbon dioxide and carbon monoxide) was examined in this study. The environmental parameters play a crucial role in determining the indoor air quality and comfort level within the museum. Temperature affects the perception of comfort, while relative humidity influences

moisture levels and potential for mold growth. Air velocity contributes to air circulation and the dispersion of pollutants. On the other hand, gaseous parameters like carbon dioxide and carbon monoxide are indicators of air pollution and can impact human health. Analyzing the relationship between these environmental and gaseous parameters provides valuable insights into the overall indoor air quality and helps in identifying areas that require improvement or mitigation strategies to ensure a safe and healthy environment within the museum.

4.1 Environmental Parameters

The combination of air temperature, relative humidity, and air velocity is crucial in creating a comfortable and healthy indoor environment. The combination of air temperature, relative humidity, and air velocity is crucial in creating a comfortable and healthy indoor environment. The average air temperature in the museum was 22.98 °C, falling within the acceptable range set by ICOP (2010) and ASHRAE-55 (2017) standards. This suggests that the temperature was maintained at an appropriate level to promote comfort for visitors.

Regarding relative humidity, the average value of 59.22% indicates that the museum's indoor environment was within the acceptable range specified by both ICOP (2010) and ASHRAE-55 (2017) standards. Maintaining an optimal level of moisture in the air contributes to a comfortable atmosphere and supports healthy breathing conditions.

The average air velocity of 0.35 m/s indicates that there was sufficient air movement within the museum. This falls within the recommended range set by ICOP (2010) standards, ensuring adequate circulation and preventing stagnant air. Proper air velocity helps in distributing temperature evenly and enhances thermal comfort for occupants.

Based on Figure 15, the relationship between these parameters is essential, as they collectively contribute to the overall comfort and indoor air quality within the museum. By maintaining appropriate air temperature, relative humidity, and air velocity, the museum ensures a pleasant environment for visitors to enjoy their experience.

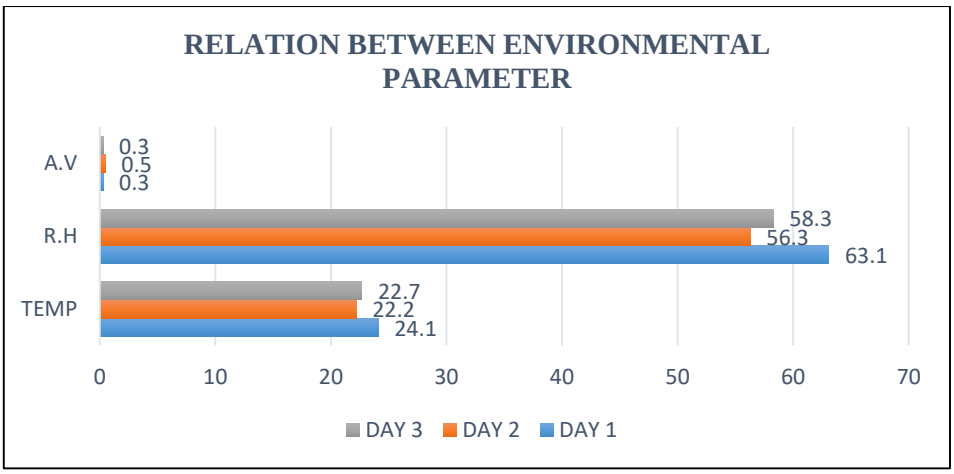


Figure 15: Relation Between Environmental Parameter

4.2 Combination of Carbon Dioxide and Carbon Monoxide

Figure 16 shows the combination of carbon dioxide (CO_2) and carbon monoxide (CO) levels in the indoor environment is crucial for assessing air quality and potential health risks. The average carbon dioxide level is 815.26 ppm, which falls below the standards set by ASHRAE-62.1 (2016) and ICOP (2010), which recommend a limit of 1000 ppm. This indicates that the museum's indoor air quality with

regards to CO_2 concentration is within acceptable ranges. However, it is important to note that the CO_2 levels are relatively elevated compared to outdoor atmospheric concentrations. Monitoring CO_2 levels is essential as it can serve as an indicator of ventilation effectiveness and occupancy patterns within the indoor space.

In terms of carbon monoxide, the average level recorded is 0.82 ppm, which is significantly lower than the acceptable limits of 10 ppm set by ICOP (2010) and 9 ppm by ASHRAE-62.1 (2017). This indicates that the museum maintains a safe environment in terms of carbon monoxide concentration. The low levels of CO suggest that there are no significant combustion processes or pollutant sources emitting carbon monoxide within the museum, which ensures the well-being of visitors and occupants.

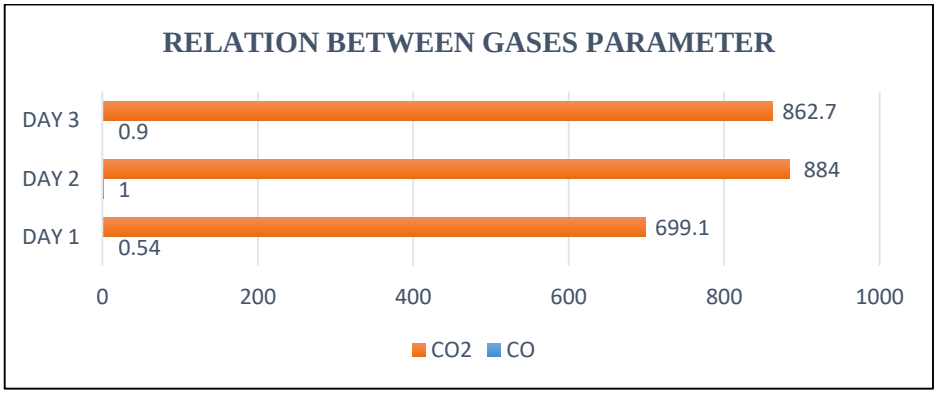


Figure 16: Relation Between Gases Parameter

4.3 Comparison of the IAQ parameter average data reading obtained with standards and previous studies.

Comparing data from different time periods helps track changes and evaluate the effectiveness of interventions, such as renovation. Table 2 shows the comparison of the IAQ parameter average data reading obtained with standards and past studies from year 2020 (Roy Hazlin,2020). The temperature showed a 19.5% improvement, decreasing from 28.56 °C to 22.98 °C. The relative humidity showed a 4.04% improvement, decreasing from 61.68% to 59.19%. The air velocity experienced a significant increase of approximately 8675%, rising from 0.004 m/s to 0.35 m/s. These improvements indicate efforts to create a more comfortable and well-ventilated environment within the museum.

Table 2 : Comparison of the IAQ parameter average data reading obtained with standards and past studies.

Parameter	2020	2023	ICOP (2010)	ASHRAE-55 (2017)
	Average Reading Value			
Temperature (°C)	28.56	22.98	23 – 26	10– 40
Relative Humidity (%)	61.68	59.19	40 - 70	25 - 95
Air Velocity (m/s)	0.004	0.35	0.15 – 0.50	0.05 – 2

In 2023, the average temperature at the museum was recorded as 22.98°C, which falls within the recommended range of 23°C to 26°C according to ICOP (2010). This indicates that the museum has successfully maintained suitable temperature levels. However, in 2020, a temperature reading of 28.56°C suggests a deviation from the recommended range during that year.

For relative humidity, both the 2020 and 2023 readings were within the ICOP (2010) range of 40% to 70%. This indicates successful preservation of artifacts, as the recommended range is being met. Furthermore, the broader range of 25% to 95% set by ASHRAE-55 (2017) was also met by the museum in both years. Regarding air velocity, the 2023 reading of 0.35 m/s falls within the recommended range of 0.15 m/s to 0.50 m/s as per ICOP (2010). This suggests adequate air movement and improved ventilation after the renovation. However, the 2020 reading of 0.004 m/s indicates significantly lower air velocity, highlighting the need for better ventilation during that period.

Table 3 : Comparison of the gas pollutant average data reading obtained with standards and past studies.

Gas Pollutant	2020	2023	ICOP (2010)	ASHRAE-55 (2017)
	Average Reading Value			
Carbon Monoxide (ppm)	0.17	0.89	10 ppm (Average 8 hour)	9 ppm (Average 8 hour)
Carbon Dioxide (ppm)	511.74	850.50	1000 ppm	1000 ppm

Table 3 shows the comparison of gas pollutant average data readings between 2020 and 2023 provides insights into the air quality at the museum. The carbon monoxide (CO) concentration increased by approximately 423.53%, rising from 0.17 ppm to 0.89 ppm. The carbon dioxide (CO2) concentration also experienced an increase of about 66.31%, going from 511.74 ppm to 850.50 ppm .In terms of carbon monoxide levels, the average reading in 2020 was 0.17 ppm, while in 2023, it increased to 0.89 ppm. Despite the increase, both readings remained significantly below the ICOP (2010) and ASHRAE-55 (2017) standards of 10 ppm (average 8-hour exposure) and 9 ppm (average 8-hour exposure), respectively. The high carbon monoxide levels observed in the Malacca Maritime museum can be attributed to a significant number of vehicles present on that particular day. The emissions from these vehicles release carbon monoxide (CO) gas, which contributes to the increased concentration of CO2 in the air.

Regarding carbon dioxide, the average reading in 2020 was 511.74 ppm, which increased to 850.50 ppm in 2023. However, both readings were below the recommended limit of 1000 ppm set by ICOP (2010) and ASHRAE-55 (2017) standards. While there was an increase in carbon dioxide levels in 2023, it still suggests that the air quality in terms of carbon dioxide remained within acceptable ranges in both years.

5. Conslusion

In conclusion, the objectives of this study, which aimed to identify Indoor Air Quality (IAQ) improvements in the Malacca Maritime Museum before and after the renovation, were successfully achieved. The analysis focused on various parameters to assess the changes in IAQ from 2020 to 2023.

The objective of evaluating the temperature was met, as a significant improvement of 19.5% was observed. The average temperature decreased from 28.56 °C in 2020 to 22.98 °C in 2023, indicating a more comfortable indoor environment. The objective of assessing relative humidity was also accomplished, with a 4.04% improvement observed. The relative humidity decreased from 61.68% in 2020 to 59.19% in 2023, indicating better moisture control within the museum. Furthermore, the objective of evaluating air velocity was successfully fulfilled. There was a substantial increase of

approximately 8675% in air velocity, with the average reading rising from 0.004 m/s in 2020 to 0.35 m/s in 2023. This indicates improved air circulation within the museum. Regarding gas pollutants, it was found that carbon monoxide (CO) levels increased by approximately 423.53% from 0.17 ppm in 2020 to 0.89 ppm in 2023. Similarly, carbon dioxide (CO2) levels increased by about 66.31%, rising from 511.74 ppm in 2020 to 850.50 ppm in 2023. Despite these increases, the concentrations of CO and CO2 remained within acceptable limits according to the ICOP (2010) and ASHRAE-55 (2017) standards.

In summary, the objectives of identifying IAQ improvements in the Malacca Maritime Museum before and after the renovation were successfully accomplished. The study revealed improvements in temperature, relative humidity, and air velocity, indicating a more comfortable indoor environment. While there were increases in carbon monoxide and carbon dioxide levels, they remained within acceptable limits. These findings highlight the positive impact of the renovation on IAQ in the museum.

Acknowledgment

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