International Journal of Integrated Engineering, Vol. 10 No. 8 (2018) p. 43-55
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DOI: https://doi.org/10.30880/ijie.2018.10.08.006

Classification of Potential Risk Factors through HIRARC Method in Assessing Indoor Environment of Museums

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Received 12 April 2018; accepted 19 November 2018, available online 29 December 2018

Abstract: Museums were established in Malaysia more than a hundred years ago. Since the year 2005, Malaysian government has discouraged constructing new purposely built museums in favour of refurbishing historic and old buildings to function as adaptive reused museums. Commonly due to insufficient ventilation, fully mechanically ventilated museums can pose critical indoor environmental issues that may lead to health hazards and risks among employees and visitors. Thus, the purpose of this study is to determine the potential risk factors within the museums based on indoor environmental criteria. This potential risk factors are resulted from the 'Potential Risk Categories', which have been developed by adopting the established Hazard Identification, Risks Assessment and Risk Control (HIRARC) Method. Based on the assessment of four main indoor environmental criteria in the Potential Risk Categories, it was discovered that 8 out of 24 museums are in the range of medium potential risk, while the rest of them are in the range of low potential risk. The 'Potential Risk Categories' is important for assessing indoor environment at the museums whereby the most critical risk could be assessed, and then suggestion could be provided to minimize the potential risk within the spaces inside the museums.

Keywords: Indoor environment, Museum, Adaptive reused museum, HIRARC method

1. Introduction

Indoor air quality issues are not new in Malaysia. Nevertheless, the lack of study, data and local regulation becomes one of the major contributions towards this problem especially with the non-industrial sector [1]. Air pollution is a particular problem in historical buildings such as adaptive-reused museums, because they were not originally built to exhibit and protect art objects in a sustainable way [2]. Due to insufficient ventilation within these environments particularly in tropical regions, people are exposed not only to humid and hotter indoor spaces [3, 4] causing occupants' discomfort but also to pollutants emanating from a wide array of sources that creates indoor environmental problems which could affect their health [5, 6].

The museums were established in Malaysia more than a hundred years ago. Since the founding of the first museum (i.e. The Perak Museum) in Taiping in 1883, more than 100 museums have been set up in this country [7]. They are managed by various government agencies from federal to the state levels [8]. The museums in Malaysia are constantly challenged by poor public perception as being a dull repository and being queried from financial providers based on the museum's performance in generating profit for the nation [9]. Thus, improvements are necessary to attract more visitors and provide a healthy environment inside the museum.

Since the year 2005, Malaysia has encouraged refurbishing historic and old buildings to serve as adaptive reused museums instead of constructing new purposely built museums due to several reasons such as the economic crisis, land limitation and sustainable issues [10]. Furthermore, there are about 56 historical adaptive reused museums which were not originally built for the purpose of being a museum, where few studies have been conducted on the quality of their indoor environment in Malaysia [11]. These museums can be divided into two types, namely a purposely built museum, and an adaptive-reused museum where the building was originally built for other functions such as residential, office, institution, etc. For adaptive-reused museums in particular, balancing the requirements of the building fabric, the occupants and the contents, while meeting desired environmental criteria can be extremely difficult. Thus, it is even more crucial for museums that require a specialized and strict building control systems where thorough investigation of indoor thermal and air flow conditions using either field study or computer modelling and simulation are necessary [12, 13].

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There are numerous techniques, methodologies and tools that can be employed in managing hazards and risks in museums. An effective approach to indoor health and safety needs a suitable risk assessment phase. However, little attention has been paid to this phase of practice due to the lack of appropriate tools and methodologies [14]. Hence, there is an urgent need to develop appropriate techniques or tools that can be used to manage indoor hazards and risks. A study conducted by Hariri *et al.* has developed an index that serves as a ranking tool in comparing industrial environmental condition at different location such as for Small and Medium Enterprises (SMEs) [15] and welding workplace [16].

Nevertheless, for this study, the established Hazard Identification, Risks Assessment and Risk Control (HIRARC) method was selected as a base format for indoor environment assessment to develop the Potential Risk Categories, which was used to determine the potential risk factors inside museums based on indoor environment criteria. According to the guidelines for HIRARC provided by Department of Occupational Safety and Health (DOSH), the purpose of this HIRARC is to provide a systematic and objective approach to assess the hazards and their associated risks, and such risks will also provide an objective measurement of an identified hazard and a method to control the risk [17]. Table 1 demonstrates that the risk can be calculated by using Probability multiplying Consequences, whereas Table 2 presents the risks prioritization of HIRARC's semi–quantitative matrix along with their associated actions needed.

The primary aim of this study is to determine potential risk factors of museums in Melaka, under the management of Perbadanan Muzium Melaka (PERZIM). The potential risk factors are resulted from the Potential Risk Categories developed earlier by adopting the established HIRARC Method of DOSH Malaysia. Apparently, the Potential Risk Categories represent the process of walkthrough inspection for indoor environment assessment, which is utilized as a tool to determine the potential risk factors within the museums based on indoor environment criteria, especially the Indoor Air Quality (IAQ).

Table 1: HIRARC's Semi-Quantitative Matrix (Probability vs. Consequences)

Cons. / Prob.	Extreme (4)	Major (3)	Moderate (2)	Minor (1)
Very Likely (4)	**Extreme (16)**	**High (12)**	**High (8)**	**Medium (4)**
Likely (3)	**High (12)**	**High (9)**	**Medium (6)**	**Medium (3)**
Unlikely (2)	**High (8)**	**Medium (6)**	**Medium (4)**	**Low (2)**
Very Unlikely (1)	**Medium (4)**	**Medium (3)**	**Low (2)**	**Low (1)**

Table 2: Risks Prioritization (Probability vs. Consequences)

Risk	Description	Action
16	Extreme	Requires an immediate action to control the hazard as detailed in the hierarchy of the control.
8 - 12	High	
3 - 6	Medium	Required a planned approach to control the hazard and apply temporary measurement if required
1 - 2	Low	Considered as acceptable and future reduction may not be necessary. However, if the risk can be resolved quickly and efficiently, control measurement should be implemented and recorded

2. Methodology

Walkthrough inspections were carried out to assess and determine the potential risk factors of indoor environment criteria within the museums by using Potential Risk Categories as shown in details in Fig. 1. These Potential Risk Categories are the risk assessment tool developed from the established risk assessments known as the HIRARC Method and is used for analyzing and selecting the suitable museums as case studies by categorizing them based on several indoor environment assessment criteria.

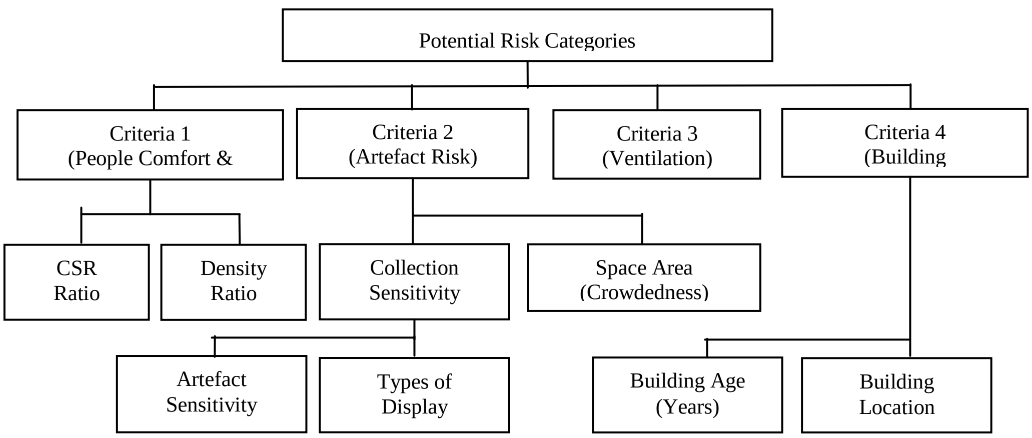

Fig. 1: Method in Assessing Potential Risk Categories

Thus, the case studies were conducted around the vicinity of Bandar Hilir, located in the district of Kota Melaka, in the state of Melaka, Malaysia. Bandar Hilir was selected as this town consists of a number of museums (where several of them are adaptive reused from historical buildings), and the city also has been officially declared as World Heritage Site by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 2008. Kota Melaka district is well-known internationally for its various tourist's attraction sites comprising most historical and interesting places as compared to other cities in Malaysia.

3. Results and Discussion

The selection of museums for case studies are made according to their possible risk factors using the Potential Risk Categories and classified into three main categories namely high potential risk, medium potential risk, and low potential risk. The Potential Risk Categories are based on the four main criteria related to the indoor environment assessment, which include Criterion 1 (People Comfort & Safety), Criterion 2 (Artefact Risk), Criterion 3 (Ventilation) and Criterion 4 (Building Characteristic).

3.1 People Comfort and Safety Risk

Criterion 1 basically concerns with the comfort level within the museums, focusing on the people's comfort and safety. Crowd Safety and Risk (CSR) ratio and Density ratio are the two main sub-criteria related to people's comfort and safety that have been considered. For CSR, this method was developed by Still in 2013 to comprehend the crowd (people) safety for a standing crowd and a moving crowd, and to analyze the impact of crowd density by considering the number of people per area (people per m^2) of the selected location [18]. Annual Visitor Report of 2015 was referred to estimate the number of people, while the area and volume of the room were derived from the building characteristics. Based on the factors related to the number of people present and the room's size in terms of its area, for overall CSR analysis, Still [18] has recommended the CSR ratio of 5.0 persons/m^2 as the threshold safety limit for visitors to have a comfortable and safe environment within any space inside the museums, as shown in Table 3.

As for the Density ratio, the data were collected based on the number of people visited the museum daily and the volume (m^3) of the selected room inside the museums during the walkthrough inspections as well as referring to the PERZIM's Annual Visitor Report of 2015. By adopting the HIRARC Method, the semi-quantitative matrix was employed in Criteria 1 to analyze the data collected for CSR ratio (person/daily/m^2) and Density ratio (person/daily/m^3) of all the selected museums. Final results of Criterion 1 (People Comfort & Safety) risk assessment for the 24 selected museums under PERZIM's management are shown in Table 4.

Table 3: CSR ratio and Density ratio in museum's exhibition area.

Criterion 1				Matrix Score
Score	Description	CSR Ratio (Persons/m²)	Density Ratio (Persons/m³)	
1	Low Risk	≤ 2.0	≤ 0.25	1 - 2
2	Medium Risk	2.0 < x ≤ 4.0	0.25 < x ≤ 0.50	3 - 6
3	High Risk	4.0 < x ≤ 5.0	0.50 < x ≤ 0.75	8 - 12
4	Extreme Risk	> 5.0	> 0.75	16

Table 4: Total Score for Criteria 1 (People Comfort and Safety)

Museum		Annual Visitor (2015)	Building		Density (Persons/m³)	Crowd Safety and Risk (CSR) (Persons/m²)	Matrix Score		
			Area (m²)	Volume (m³)			CSR Ratio	Density Ratio	Criterion 1 Score
1	Melaka Sultanate Palace Museum	134,777	132.26	495.97	0.745	2.8	2	3	2
2	History & Ethnography Museum	91,963	76.44	321.05	0.785	3.3	3	3	3
3	Democratic Government Museum	26,275	136.00	571.20	0.126	0.5	1	1	2
4	Education Museum	26,275	76.44	267.54	0.269	0.9	1	2	1
5	Governor Museum	26,275	286.00	1001.00	0.072	0.3	1	1	1
6	Literature Museum	26,275	153.00	535.50	0.134	0.5	1	1	1
7	Flor de la Mar Museum	279,855	176.80	477.36	1.606	4.3	3	4	3
8	Royal Malaysian Navy Museum	79,958	778.64	4866.47	0.045	0.3	1	1	1
9	Submarine Museum	110,062	21.96	61.49	4.904	13.7	4	4	4
10	People Museum	29,404	340.60	1192.10	0.068	0.2	1	1	1
11	Kite Museum	29,404	549.90	1924.65	0.042	0.1	1	1	1
12	Beauty Museum	29,404	549.90	1924.65	0.042	0.1	1	1	1

Table 4 (continued): Total Score for Criterion 1 (People Comfort & Safety)

Museum		Annual Visitor (2015)	Building		Density (Persons/m³)	Crowd Safety and Risk (CSR) (Persons/m²)	Matrix Score		
			Area (m²)	Volume (m³)			CSR Ratio	Density Ratio	Criteria 1 Score
13	Hang Tuah Centre Museum	21,701	286.00	1787.50	0.033	0.2	1	1	1
14	Melaka Islamic Museum	11,165	90.00	315.00	0.097	0.3	1	1	1
15	Malaysia Youth Museum	5,674	90.00	315.00	0.049	0.2	1	1	1
16	Stamp Museum	5,594	72.00	252.00	0.061	0.2	1	1	1
17	Chitty Museum	2,462	64.00	224.00	0.030	0.1	1	1	1
18	Pulau Besar Museum	1,958	26.00	91.00	0.059	0.2	1	1	1
19	Traditional Custom Museum	1,926	95.00	332.50	0.016	0.1	1	1	1
20	Demang Abdul Ghani Gallery Museum	1,410	26.00	91.00	0.042	0.1	1	1	1
21	Orang Asli Museum	1,015	97.50	341.25	0.008	0.0	1	1	1
22	Melaka Al-Quran Museum	702	166.25	581.88	0.003	0.0	1	1	1
23	Agriculture Museum	800	45.50	159.25	0.014	0.0	1	1	1
24	Malay & Islamic World Museum	11,152	78.40	329.28	0.093	0.4	1	1	1

3.2 Artefact Risk

Criterion 2 basically concerns with the visitors' comfort level inside the museums, focusing only on the risks due to the displayed artefacts. In this study, there were two main sub-criteria related to artefacts or collection of materials which have been considered namely the Space Area (Crowdedness) and Collection Sensitivity. Assessment of artefact risks of Criterion 2 generally involves two processes of semi-quantitative matrix of HIRARC method. The first process of semi-quantitative matrix (i.e. Matrix 1) was initially carried out to determine the Collections' Sensitivity, coded as "C". Whereas the second process of semi-quantitative matrix (i.e. Matrix 2) was then conducted to provide results for matrix score of Criterion 2. Lord and Lord [19] stressed on the importance of materials' (or artefacts') sensitivity and types of material displayed within the museums in determining the overall collection sensitivity when relating the criteria of Collection Sensitivity to visitors and its surrounding indoor environment.

The initial process of the semi-quantitative matrix or Matrix 1 focuses on determining the Collection Sensitivity by considering both Artefact Sensitivity (artefact originality) coded as "A" and Types of Display coded as "B", as shown in Table 5. In this study, the Artefact Sensitivity was determined based on the artefact originality and condition of the artefact itself since artefact of a high quality material (such as bones or biological natural specimen) requires special treatment by using a chemical product in order to preserve for its rehabilitation procedure. Apart from that, a high sensitivity artefact, such as biological natural specimen, might also generate or produce hazardous pollutants to the surrounding environment, by exposing the biological agent and particulate matter agent, which may affect human health.

Table 5: Artefact Sensitivity & Types of Display criteria.

Artefact Sensitivity (A)	Types of Display (B)		Collection Sensitivity (C)	
			Description	Matrix Score
Low	Inorganic	Ceramic, glass	Low	1
Medium	Organic	Wood, paper, textile, plastic	Medium	2
High	Inorganic	Metal, mineral	High	3
Extreme	Organic	Bones, natural specimen	Extreme	4

Therefore, by conducting walkthrough inspections inside the 24 selected museums around Kota Melaka, the risks due to displayed artefact can be estimated by multiplying the Artefact Sensitivity with Types of Display to obtain the total matrix score for the initial process of the semi-quantitative matrix, Matrix 1 (Collection Sensitivity), as detailed in Table 6.

Table 6: Semi-Quantitative Matrix for Collection Sensitivity (Artefact Sensitivity vs. Types of Display)

(A) \ (B)	Extreme (4)	High (3)	Medium (2)	Low (1)
Extreme (4)	Extreme (16)	High (12)	High (8)	Medium (4)
High (3)	High (12)	High (9)	Medium (6)	Medium (3)
Medium (2)	High (8)	Medium (6)	Medium (4)	Low (2)
Low (1)	Medium (4)	Medium (3)	Low (2)	Low (1)

After obtaining the total matrix score for Matrix 1 (Collection Sensitivity), it is essential to find the total matrix score for overall criteria of indoor environment assessment related to the exhibited artefact inside the selected museums, which is Criterion 2 (Artefact Risk) by conducting the process of Matrix 2. The second process of semi-quantitative matrix (i.e. Matrix 2) focuses on the overall artefact risk that might occur inside the museums. Information on Space Area (Crowdedness) and Collection Sensitivity were gathered, and the total matrix score for Collection Sensitivity should be referred to the previous semi-quantitative matrix process of Matrix 1. The details of space area and collection sensitivity criteria are shown in Table 7. Space Area (Crowdedness) is determined by applying the same method employed earlier to obtain the CSR Ratio. Determining the space Area (crowdedness) within spaces inside the museums is important in order to have a clearer picture of the impact and crowdedness of objects or materials that were set-up within the museums. Thus, using the data gathered during the walkthrough inspections, the total matrix score for second process of the semi-quantitative matrix, Matrix 2 (i.e. Artefact Risk) can be estimated by multiplying the Collection Sensitivity with Space Area (Crowdedness), as shown in Table 8. Final results of Criterion 2 (Artefact Risk) risk assessment for all the 24 selected museums under PERZIM's management are outlined in details in Table 9.

Table 7: Collection Sensitivity and Space Area (Crowdedness) criteria

Criterion 2				Matrix Score
Score	**Description**	**Collection Sensitivity (C)**	**Space Area (Crowdedness)**	
1	Low Risk	1 - 2	2.0/m²	1 – 2
2	Medium Risk	3 - 6	3.0/m²	3 – 6
3	High Risk	8 - 12	4.0/m²	8 – 12
4	Extreme Risk	16	5.0/m²	16

Table 8: Semi-Quantitative Matrix for Criterion 2 (Collection Sensitivity vs. Space Area)

(C) \ Space Area	Extreme (4)	High (3)	Medium (2)	Low (1)
Extreme (4)	Extreme (16)	High (12)	High (8)	Medium (4)
High (3)	High (12)	High (9)	Medium (6)	Medium (3)
Medium (2)	High (8)	Medium (6)	Medium (4)	Low (2)
Low (1)	Medium (4)	Medium (3)	Low (2)	Low (1)

Table 9: Total Score for Criterion 2 (Artefact Risk)

	Museum	**Gallery**						**Matrix Score**		
		Space Area (Crowdedness)		**Collection Sensitivity (Original) (A)**	**Types of Display (B)**	**Collection Sensitivity**		**Collection Sensitivity (C)**	**Space Area**	**Criterion 2 Score**
		Percentage (%)	**Space Occupied Ratio (Object/m²)**			**(A)**	**(B)**			
1	Melaka Sultanate Palace Museum	55	4.0	Low	Textile/ Photographic/ Wood	1	2	1	3	2
2	History & Ethnography Museum	60	4.0	Medium	Art/Paper/ Wood	2	2	2	3	2
3	Democratic Government Museum	55	4.0	Medium	Photographic/ Textile/ Silverware	2	2	2	3	2
4	Education Museum	30	3.0	Low	Paper/ Photographic	1	2	1	2	1
5	Governor Museum	65	4.0	Medium	Photographic/ Wood/ Silverware	2	2	2	3	2
6	Literature Museum	35	3.0	Low	Paper/ Photographic	1	2	1	2	1
7	Flor de la Mar Museum	70	4.0	High	Metal/ Photographic/ Silverware	3	3	3	3	3
8	Royal Malaysian Navy Museum	45	3.0	High	Metal/ Photographic/ Textile/ Silverware	3	3	3	2	2
9	Submarine Museum	90	5.0	Extreme	Metal	4	3	3	4	3
10	People Museum	30	3.0	Low	Photographic	1	2	1	2	1
11	Kite Museum	40	3.0	Low	Paper/ Photographic	1	2	1	2	1

Table 9 (continued): Total Score for Criterion 2 (Artefact Risk)

Museum		Gallery						Matrix Score		
		Space Area (Crowdedness)		Collection Sensitivity (Original) (A)	Types of Display (B)	Collection Sensitivity		Collection Sensitivity (C)	Space Area	Criterion 2 Score
		Percentage (%)	Space Occupied Ratio (Object/m²)			(A)	(B)			
12	Beauty Museum	20	2.0	Low	Photographic/ Textile	1	2	1	1	1
13	Hang Tuah Centre Museum	20	2.0	Low	Photographic/ Textile	1	2	1	1	1
14	Melaka Islamic Museum	35	3.0	Medium	Metal/Art/ Paper/ Ceramic	2	3	2	2	2
15	Malaysia Youth Museum	20	2.0	Low	Paper/ Photographic/ Textile	1	2	1	1	1
16	Stamp Museum	30	3.0	Medium	Paper/Textile	2	2	2	2	2
17	Chitty Museum	60	4.0	Low	Photographic/ Silverware	1	1	1	3	2
18	Pulau Besar Museum	30	3.0	Medium	Metal/ Photographic/ Silverware	2	1	1	2	1
19	Traditional Custom Museum	30	3.0	Low	Textile/ Silverware	1	2	1	2	1
20	Demang Abdul Ghani Gallery Museum	20	2.0	Low	Textile/ Wood/ Silverware	1	2	1	1	1
21	Orang Asli Museum	30	3.0	Medium	Photographic/ Textile/ Wood/ Silverware	2	2	2	2	2
22	Melaka Al-Quran Museum	20	2.0	Low	Art/Paper/ Photographic	1	2	1	1	1
23	Agriculture Museum	55	4.0	Low	Photographic/ Textile/Wood	1	2	1	3	2
24	Malay & Islamic World Museum	30	3.0	Medium	Photographic/ Textile/ Silverware	2	2	2	2	2

3.3 Ventilation

The provision of proper ventilation system is significant in order to ensure a good and healthy indoor air flow and comfortable thermal environment inside the museums. In this study, the indoor/outdoor pollutant ratio is considered in conducting the ventilation system assessment in Criterion 3 without implementing the semi-quantitative matrix of HIRARC method. The indoor/outdoor pollutant ratio is estimated using a mathematical model of mass balance equation developed by Wescler *et al.* in 1989 [20], as expressed in Equation (1). It can be seen from the equation that three factors are involved in determining the indoor/outdoor pollutant ratio (I/O) which include air change rates (ACH), deposition velocity of pollutant (V_{deep}) and room characteristics (surface area, S and interior volume, V).

$$I/O = ACH / (V_{deep}(S/V) + ACH) \quad (1)$$

The air change rates or air changes per hour (ACH) is determined based on the types of ventilation system installed at the museums. There are three main types of ventilation system namely mechanical ventilation system, natural ventilation system and mixed-mode ventilation system. The required air change rates for museums with regards to the different types of ventilation system are based on the common values as recommended by The Engineering Toolbox [21] and The Chartered Institution of Building Services Engineers Guide B [22], as shown in Table 10.

Table 10: Air change rates for museums

Ventilation System	Air Change Rates (ACH)		
	Common Value (ACH)	Assumption of ACH in Museum's Gallery (hr^{-1})	
Natural	10	Natural	10
Mechanical	12 – 15	Split Unit	15
		Fans	12
Mixed - Mode	Depends	Depends on mechanical usage	

During the walkthrough inspections, it was discovered that 19 out of the 24 selected museums were installed with fully mechanical ventilation system. It was also observed that 17 out of the 19 museums that have been installed with fully mechanical ventilation system were equipped with split air conditioning units, while the other two museums were equipped with ceiling and wall fans. Moreover, 4 out of 24 museums have been installed with mixed-mode ventilation system. It was also noticed that three of the four museums were equipped with split air conditioning units with windows and door wide open, while another museum was equipped with ceiling and wall fans with windows and door wide open. Demang Abdul Ghani Gallery Museum is the only selected museum that was found to be fully naturally ventilated where its windows and door were kept open widely throughout the visiting hours. Based on the types of ventilation system for all the selected museums as described earlier, the assumptions of air change rates were made as outlined in Table 10.

After determining the estimated air change rates for all the museums, the next step was to find the indoor/outdoor pollutant ratio by identifying the deposition velocity of pollutant, V_{deep} (m/hr). Deposition velocity is a property of the gas pollutant and its interaction with surface materials surrounding a room. According to Blades *et al.* [23], the design of a building and materials used in construction, and finishing for rooms and galleries inside the museums can greatly affect the indoor concentrations of both externally and internally generated pollutants, as the materials and finishes can add to the pollutants. Nevertheless, the interior surface can remove pollutants. Pollutant removal by surface deposition (interior surface) is an important mechanism which the indoor concentrations of outdoor pollutants can be reduced [20, 24-30]. When discussing on indoor environment, especially in terms of IAQ, the most common pollutants discovered in buildings can be categorize into four categories which include chemical contaminants, biological contaminants, gaseous pollutant and particulate matter. In this study, gaseous pollutant and particulate matter are considered as IAQ parameters, whereas nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and carbon dioxide (CO_2) represent gaseous pollutant while fine particles ($PM_{2.5}$) are regarded as particulate matter. Thus, gaseous pollutant of NO_2 and SO_2, as well as fine particles have been selected to determine the estimated values of deposition velocity of pollutants particulate matter inside the museums, as shown in Table 11. The values of deposition velocity for NO_2, SO_2 and fine particles were estimated to be 1.8 m/hr, 2.0 m/hr, and 0.7 cm/s (0.42 m/hr) respectively.

Table 11: Estimated values of Deposition Velocity for gaseous pollutant and particulate matter

Gaseous Pollutant	**Deposition Velocity, V_{deep}**	
	Estimated Value (m/hr)	**Notes**
Sulfur Dioxide (SO_2)	57.6 – 90.0	On various cement
	25.2	On activated carbon
	6.1 – 14.8	On various wallpapers
	4.7	On emulsion paint
	1.2	On gloss paint
	1.8	Typical interior value
Nitrogen Dioxide (NO_2)	0.01 – 4.3	On various indoor surface materials
Particulate Matter	0.004 cm/s – 0.005 cm/s	0.05 µm to 0.5µm
	0.7 cm/s	2.5 µm to 15µm

Lastly, the museum's characteristics (i.e. particularly gallery's characteristics) have been used to determine the values of surface area, S (m^2) and interior volume, V (m^3). Typical values of surface area to volume ratio (S/V) for a small store room are in the range of 1 to 10, while for a large open plan galleries, the value of S/V are less than 1. However, the added surface area due to room furnishings may also be significant [14]. With all of this information, the value of indoor/outdoor pollutant ratio can be calculated and the matrix score for Criterion 3 can be recorded. The details of indoor/outdoor pollutant ratio criteria are shown in Table 12. Table 13 presents the final results for Criteria 3 (Ventilation) risk assessment for all the 24 selected museums around Kota Melaka under PERZIM's management.

Table 12: Indoor/outdoor pollutant ratio criteria

Criterion 3		
Score	**Description**	**I/O Ratio**
1	Low Risk	x < 0.05
2	Medium Risk	0.3 < x < 1
3	High Risk	x = 1
4	Extreme Risk	x > 1

Table 13: Total Score for Criterion 3 (Ventilation)

Museum		**Ventilation System (Source)**			**Building Detail**		**Indoor/outdoor Pollutant Ratio (I/O)**				**Matrix Score**
		Mechanical	**Natural**	**Assumption Air Change Rate (hr^{-1})**	**Area (m^2)**	**Volume (m^3)**	**SO_2**	**NO_2**	**$PM_{2.5}$**	**Average**	**Criteria 3 Score**
1	Melaka Sultanate Palace Museum	Split Unit	Yes	25	132.26	495.97	0.98	0.98	1.00	0.99	2
2	History & Ethnography Museum	Split Unit	Yes	25	76.44	321.05	0.98	0.98	1.00	0.99	2

Table 13 (continued): Total Score for Criterion 3 (Ventilation)

Museum		Ventilation System (Source)			Building Detail		Indoor/outdoor Pollutant Ratio (I/O)				Matrix Score
		Mechanical	Natural	Assumption Air Change Rates (ACH)	Area (m^2)	Volume (m^3)	SO_2	NO_2	$PM_{2.5}$	Average	Criterion 3 Score
3	Democratic Government Museum	Split Unit	No	15	136.00	571.20	0.97	0.97	0.99	0.98	2
4	Education Museum	Split Unit	No	15	76.44	267.54	0.97	0.96	0.99	0.97	2
5	Governor Museum	Split Unit	No	15	286.00	1001.00	0.97	0.96	0.99	0.97	2
6	Literature Museum	Split Unit	No	15	153.00	535.50	0.97	0.96	0.99	0.97	2
7	Flor de la Mar Museum	Split Unit	No	15	176.80	477.36	0.96	0.95	0.99	0.97	2
8	Royal Malaysian Navy Museum	Split Unit	No	15	778.64	4866.47	0.98	0.98	1.00	0.99	2
9	Submarine Museum	Split Unit	No	15	21.96	61.49	0.96	0.95	0.99	0.97	2
10	People Museum	Split Unit	No	15	340.60	1192.10	0.97	0.96	0.99	0.97	2
11	Kite Museum	Split Unit	No	15	549.90	1924.65	0.97	0.96	0.99	0.97	2
12	Beauty Museum	Split Unit	No	15	549.90	1924.65	0.97	0.96	0.99	0.97	2
13	Hang Tuah Centre Museum	Split Unit	No	15	286.00	1787.50	0.98	0.98	1.00	0.99	2
14	Melaka Islamic Museum	Split Unit	Yes	25	90.00	315.00	0.98	0.98	1.00	0.98	2
15	Malaysia Youth Museum	Split Unit	No	15	90.00	315.00	0.97	0.96	0.99	0.97	2
16	Stamp Museum	Split Unit	No	15	72.00	252.00	0.97	0.96	0.99	0.97	2
17	Chitty Museum	Fan	Yes	22	64.00	224.00	0.98	0.97	0.99	0.98	2
18	Pulau Besar Museum	Split Unit	No	15	26.00	91.00	0.97	0.96	0.99	0.97	2
19	Traditional Custom Museum	Split Unit	No	15	95.00	332.50	0.97	0.96	0.99	0.97	2
20	Demang Abdul Ghani Gallery Museum	No	Yes	10	26.00	91.00	0.95	0.95	0.99	0.96	2
21	Orang Asli Museum	Split Unit	No	15	97.50	341.25	0.97	0.96	0.99	0.97	2
22	Melaka Al-Quran Museum	Fan	No	12	166.25	581.88	0.96	0.95	0.99	0.97	2
23	Agriculture Museum	Fan	No	12	45.50	159.25	0.96	0.95	0.99	0.97	2
24	Malay & Islamic World Museum	Split Unit	No	15	78.40	329.28	0.97	0.97	0.99	0.98	2

3.4 Building Characteristic

Finally, for Criterion 4 (Building Characteristic), the general information of building characteristics which comprise building's age and location are considered for the final indoor environment assessment criteria. The reason for considering building's location as one of the indoor environment assessment criteria is due to the possibilities of pollutant sources that could generate from the surrounding area of the building, especially when taking into account the indoor/outdoor pollutant ratio. Generally, buildings located in the urban area are contributing more hazardous pollutants as compared to that of the rural area. Urban area refers to a city, living in a city and is having characteristics of being in the city. On the other hand, suburban area refers to an area on the outskirts of a city, life in an area on the outskirts of a city and is having characteristics of being in an area on the outskirts of a city. Furthermore, rural area refers to the countryside, living in the countryside and is having characteristics of being in the countryside. The population in the urban area is approximately over 100,000 people, whereas the population can vary from 10,000 to 100,000 people for suburban area, and population in rural area is usually under 10,000 people. Previous studies conducted by several researchers stressed that building's age [27-29] and location [34-44] are important to be considered when assessing building characteristics. The summary of the matrix score criteria (Criteria 4) classifying the museum's characteristics into different risk possibilities namely low potential risk, medium potential risk, high potential risk, or extreme potential risk, as shown in Table 14.

Table 14: Details of museum's characteristics

Criterion 4				Matrix Score
Score	Description	Building Age (Years)	Building Location	
1	Low Risk	< 30	Rural Area	1 - 2

Table 14 (continued): Details of museum's characteristics

Criterion 4				Matrix Score
Score	Description	Building Age (Years)	Building Location	
2	Medium Risk	31 - 60	Sub-urban Area	3 - 6
3	High Risk	61 - 90	Urban Area	8 - 12
4	Extreme Risk	> 91	Urban Area (Nearby Industry)	16

Hence, by adopting the HIRARC method, the semi-quantitative matrix was applied in Criterion 4 to analyze the data collected for the museums' age and location. Relevant information related to the museum's age and location were obtained through a discussion with an officer from PERZIM and observation during the walkthrough inspections at all the selected museums. Table 15 presents the detailed results of Criterion 4 risk assessment for all the 24 selected museums around Kota Melaka under PERZIM's management.

Table 15: Total Score for Criterion 4 (Building Characteristics)

Museum		Building Characteristics		Matrix Score		
		Age (Years)	Building Location	Age (Years)	Building Location	Criterion 4 Score
1	Melaka Sultanate Palace Museum	33	Urban	2	3	2
2	History & Ethnography Museum	367	Urban	4	3	3
3	Democratic Government Museum	56	Urban	2	3	2
4	Education Museum	133	Urban	4	3	3
5	Governor Museum	21	Urban	1	3	2
6	Literature Museum	127	Urban	4	3	3
7	Flor de la Mar Museum	23	Urban	1	3	2
8	Royal Malaysian Navy Museum	22	Urban	1	3	2
9	Submarine Museum	39	Rural	2	1	1
10	People Museum	57	Urban	2	3	2
11	Kite Museum	57	Urban	2	3	2
12	Beauty Museum	57	Urban	2	3	2
13	Hang Tuah Centre Museum	3	Sub-urban	1	2	1
14	Melaka Islamic Museum	167	Urban	4	3	3
15	Malaysia Youth Museum	357	Urban	4	3	3
16	Stamp Museum	357	Urban	4	3	3
17	Chitty Museum	14	Sub-urban	1	2	1
18	Pulau Besar Museum	7	Rural	1	1	1
19	Traditional Custom Museum	28	Urban	1	3	2
20	Demang Abdul Ghani Gallery Museum	123	Sub-urban	4	2	3
21	Orang Asli Museum	20	Sub-urban	1	2	1
22	Melaka Al-Quran Museum	9	Urban	1	3	2
23	Agriculture Museum	27	Urban	1	3	2
24	Malay & Islamic World Museum	107	Urban	4	3	3

4. Potential Risk Categories

Based on the findings obtained from the four main assessment criteria comprising Criterion 1 (People Comfort & Safety), Criterion 2 (Artefact Risk), Criterion 3 (Ventilation) and Criterion 4 (Building Characteristic), total of matrix's scores from each assessment criterion will be added (+) between each other to obtain an average value. This was done using the mathematical arithmetic mean equation [48], as expressed in Equation (2), where "A" is a Total Matrix Score for each criterion, "N" is the number of elements or criteria and "*x*" is the value of each individual score in the list of numbers being averaged (*n*).

$$A = \frac{1}{N} * \sum_{i=1}^{n} x_i \quad (2)$$

Finally, the overall matrix score can be produced and categorized based on its potential risk categories whether it is considered as high potential risk, medium potential risk or low potential risk, by referring to Table 16 as a basic decision making for determining the Potential Risk Categories. The overall matrix score for each of the selected PERZIM's museums was analyzed based on Potential Risk Categories, and results are presented in Table 17. After conducting walkthrough inspections at the 24 selected museums around Kota Melaka, it was discovered that 18 out of the 24 selected museums are of refurbished old buildings to function as adaptive reused museums. Four buildings were purposely built to serve as museums and the other two are vehicle's museums.

Table 16: Basic decision making in Potential Risk Categories

Total Score	Consequences	Index	Descriptions
n = 4	Extreme	4	High Risk
3 ≤ n < 4	Major	3	
2 ≤ n < 3	Moderate	2	Medium Risk
1 ≤ n < 2	Minor	1	Low Risk

Table 17: Overall matrix score for the selected museums under PERZIM's management.

Museum		Elements				Overall Matrix Score	
		Criteria 1 Score	Criteria 2 Score	Criteria 3 Score	Criteria 4 Score	Total Score	Index
1	Melaka Sultanate Palace Museum	2	2	2	2	2.00	2
2	History and Ethnography Museum	3	2	2	3	2.50	2
3	Democratic Government Museum	2	2	2	2	2.00	2
4	Education Museum	1	1	2	3	1.75	1
5	Governor Museum	1	2	2	2	1.75	1
6	Literature Museum	1	1	2	3	1.75	1
7	Flor de la Mar Museum	3	3	2	2	2.50	2
8	Royal Malaysian Navy Museum	1	2	2	2	1.75	1
9	Submarine Museum	4	3	2	1	2.50	2
10	People Museum	1	1	2	2	1.50	1
11	Kite Museum	1	1	2	2	1.50	1
12	Beauty Museum	1	1	2	2	1.50	1
13	Hang Tuah Centre Museum	1	1	2	1	1.25	1
14	Melaka Islamic Museum	1	2	2	3	2.00	2
15	Malaysia Youth Museum	1	1	2	3	1.75	1
16	Stamp Museum	1	2	2	3	2.00	2
17	Chitty Museum	1	2	2	1	1.50	1
18	Pulau Besar Museum	1	1	2	1	1.25	1
19	Traditional Custom Museum	1	1	2	2	1.50	1
20	Demang Abdul Ghani Gallery Museum	1	1	2	3	1.75	1
21	Orang Asli Museum	1	2	2	1	1.50	1
22	Melaka Al-Quran Museum	1	1	2	2	1.50	1
23	Malay & Islamic World Museum	1	2	2	3	2.00	2
24	Agriculture Museum	1	2	2	2	1.75	1

It was discovered that 8 out of the 24 selected museums were found to have medium potential risks, while the rest of them are of low potential risks, as summarized in Table 18. Surprisingly, none of the selected museums had high potential risk. Based on these findings, it was proven that most of the current museums in Malaysia, particularly those around the vicinity of Kota Melaka, have been provided with reasonably sufficient ventilation since none of the investigated museums falls within the high potential risk category. Nevertheless, museums' management should always be concerned with the indoor environment issues as the pollutants are not only generated from indoor sources, which is common in museums, but also coming from outdoor environment especially those situated nearby the industrial areas.

Table 18: PERZIM's museums and their associated risk category based on the Overall Matrix Score

<table>
<tr><th colspan="3">Potential Risk Categories</th></tr>
<tr><th>Low Risk</th><th>Medium Risk</th><th>High Risk</th></tr>
<tr><td>Education Museum</td><td rowspan="2">Melaka Sultanate Palace Museum</td><td rowspan="16">nil</td></tr>
<tr><td>Governor Museum</td></tr>
<tr><td>Literature Museum</td><td rowspan="2">History & Ethnography Museum</td></tr>
<tr><td>Royal Malaysian Navy Museum</td></tr>
<tr><td>People Museum</td><td rowspan="2">Democratic Government Museum</td></tr>
<tr><td>Kite Museum</td></tr>
<tr><td>Beauty Museum</td><td rowspan="2">Flor de la Mar Museum</td></tr>
<tr><td>Hang Tuah Centre Museum</td></tr>
<tr><td>Malaysia Youth Museum</td><td rowspan="2">Submarine Museum</td></tr>
<tr><td>Chitty Museum</td></tr>
<tr><td>Pulau Besar Museum</td><td rowspan="2">Melaka Islamic Museum</td></tr>
<tr><td>Traditional Custom Museum</td></tr>
<tr><td>Demang Abdul Ghani Gallery Museum</td><td rowspan="2">Stamp Museum</td></tr>
<tr><td>Orang Asli Museum</td></tr>
<tr><td>Melaka Al-Quran Museum</td><td rowspan="2">Malay & Islamic World Museum</td></tr>
<tr><td>Agriculture Museum</td></tr>
</table>

5. Conclusion

In this study, the 'Potential Risk Categories' was used as a tool in conducting indoor environment assessment to determine the potential risk factors inside the investigated museums. This tool is adopted from an established HIRARC Method developed by DOSH Malaysia. The 'Potential Risk Categories' is important for the indoor environment assessment at the museums such that the most critical risk could be assessed and solutions could be recommended in order to minimize the impacts of the potential risk within the museum on the employees and visitors.

Acknowledgments

The authors would like to express our gratitude especially to the Universiti Tun Hussein Onn Malaysia (UTHM) for providing facilities and equipment, and also to our colleagues for their assistance during the data collection and walkthrough inspections throughout the studies. We also would like to acknowledge the PERZIM's management for providing support and cooperation during the process of collecting data and walkthrough inspections.

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