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MOISTURE-RELATED BUILDING DEFECTS IN HERITAGE BUILDING: A REFURBISHMENT-BASED ASSESSMENT

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ABSTRACT

Moisture-related building defects in Penang's heritage buildings persist despite refurbishment efforts, posing threats to structural integrity, aesthetics, and occupant comfort. This problem is exacerbated by tropical coastal conditions, stringent conservation guidelines mandating original materials (e.g., lime), and the inherent vulnerability of aged structures. This study employed a mixed-methods approach, combining field surveys (thermal imaging, humidity tests) and user questionnaires across three refurbished heritage buildings (hotel): 23 Love Lane (strict WHS compliance), Jawi Peranakan Mansion (moderate), and USM Guesthouse (weak compliance). Quantitative data were analyzed via SPSS (descriptive statistics, chi-square tests). Key results revealed: (1) Moisture-driven defects (dampness, fungi, peeling paint) recurred in all buildings, with severity highest under strict compliance (27 defects at 23 Love Lane); (2) Weak-compliance USM Guesthouse used cement, reducing moisture ingress but violating authenticity; (3) User surveys identified peeling paint discomfort as significant concerns ($P<0.05$). The implications underscore a critical dilemma: strict material preservation perpetuates moisture susceptibility, while modern substitutions compromise heritage values. Effective refurbishment guidelines must integrate moisture-mitigation strategies compatible with historical materials and tropical environments.

Keywords: heritage building, moisture-related building defect, refurbishment, WHS guidelines

INTRODUCTION

As one of the important areas in the Strait of Malacca, Penang became one of the places that are rich in values of art and culture that is able to co-exist alongside modern development (Hussin, 2013). Heritage building is one of the most important wealth. In order for these values to be maintained, the presence of a refurbishment project in Penang at the moment is a form to promote the reuse of heritage building that is not lost due to both extensive economic and tourism expansion (Farahani et al., 2012; Siew, 2002). One of the actions to improve this heritage building is refurbishment activities according to the World Heritage Site (WHS) guidelines (Yacub & Salleh, 2022).

Refurbishment is one way to upgrade buildings that have decayed due to age (Watt, 2015). Heritage buildings are one of the type of buildings that need refurbishments. These heritage buildings conditions are as follow: first, the decaying stage because of the old bulding age (non-durable buildings); second, buildings have undergone function change; third, these buildings were changed to enhance the local economy; fourth, he unilateral decision of the owner or authorized party; and fifth, changes in ambient conditions (Aikivuori, 1996). The main goal of the refurbishment work is to improve the reusability of the heritage buildings, so that it can provide benefits and contribution towards a better environment.

Reyers and Mansfield (2001) argued that refurbishment is not an easy work. Refurbishment also requires number of experts who need to be involved. Furthermore, this work also involves many techniques and the use of different materials to achieve the appropriate improvements to existing functionality and usability. In other words, the desired expectation is heritage buildings can remain preserve and comfortable to use despite the risks and uncertainty.

Regarding to the condition of heritage buildings, building defect would be a serious matter that needs to be investigated. Building defects very commonly occur on heritage buildings. One of common possible cause of building defects on heritage buildings in Penang is humidity. It can be seen on several part of building, such as the increase in dampness, termite attack, loose plaster, peeling paint and also fungus (Khalid & Mydin, 2012; Talib et al., 2014). The influences of humidity are also accompanied by the high level of salt which increases the dampness (Ahmad & Rahman, 2010).

Building defect is a natural effect that occurs in every building that will essentially reduce the function, performance, statutory or user requirement of building. It is often referred to as a failing or shortcoming (Watt, 2009).

Furthermore, Gurnstein (Gurnstein, 1985) explained that building defect involved into two categories, which are structural defect and non-structural defect. Structural defect are defect which appear in the structure of the building such as: columns, beams, wall, roofs, floor and foundations. The defects are due to building settlement, deformation, cracking and bowing of the buildings.

While, non–structural defect are defect which appear in the non-structural elements of the buildings such as: façade, floor finishes, doors, windows, rain-water down pipe and gutter. The defects are usually caused by chemical and biological condensation process and small cracks.

Based on several experiences, building defects that common occur on the heritage building is caused by humidity. Some of building defects that often occur on the heritage buildings are dampness, paint peeling, cracking/leaning of wall, timber decayed, fungi/mould and termite attack (Watt, 2009; Young, 2008). The presence of moisture became a serious problem in both heritage buildings in situation before and after the refurbishment.

However, several literature review reveal no established fundamental principles for refurbishment guidelines compliant with WHS requirements. This gap poses serious operational and maintenance challenges. Many heritage building owners who committed to preserving authenticity face dilemmas, as building defect (particularly moisture presence) persists recurrently. This inevitably strains finances and compromises user comfort.

The main objective of this research is to explain how the effect of systematic refurbishment procedures on the presence of building defects. The next objective is to present the importance of repair guidelines which will enable precise specifications to be given for the required restoration work.

METHODS

This research was conducted using qualitative and quantitative research methods to obtain information and data. The methodology used consists of two data collection methods – primary data and secondary data. There are two important variables used in this research. The first variable is the refurbishment approach as an independent variable, while the second variable is building defects as the dependent variable. The building defect analysis followed the literature review and the guidelines of George Town World Heritage Incorporated (GTWHI) which is a member of UNESCO and the Penang Island City Council (MBPP) as the local authority.

Data analysis which derived from the questionnaire is important in interpreting the quantitative phase of research findings. In order to achieve the objective for the study, the Data were analyzed by using Statistic Package for the Social Science (SPSS) software, version 25. The techniques used for the data analysis in this study were descriptive statistics: frequency distribution and chi-squared tests.

As for qualitative analysis, the method used is to investigate directly the buildings by observing the state of the associated heritage value and defect. The use of specialized equipment (such as a thermal imager) and humidity tests helps measure how ambient temperature affects the moisture content of the object

The research was conducted at heritage buildings (hotel) in Penang, the heritage buildings which are the focus of this research are: 23 Love Lane Hotel; Jawi Peranakan Mansion; and USM Guesthouse. 23 Love Lane is located at 23 Love Lane (World Heritage Site core zone), Jawi Peranakan Mansion is located at 153 Hutton Street (Area adjacent to the buffer zone), and USM Guesthouse is located on the USM main campus (Outside of World Heritage Site zone).

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RESULT AND DISCUSSION

Based on previous literature review, the appearance of defects in the heritage building largely due to moisture content (Ahmad & Rahman, 2010). This triggers the emergence of various types of building defects. As is known, refurbishment becomes a way to improve the standards of a building (Bullen & Love, 2011; Power, 2008). However, based on the results of investigations on some heritage buildings (hotels), refurbishment is not necessarily able to restore the expected standards.

The Possible Causes of Building Defect on Heritage Buildings

As established in previous literature, moisture content in building environments is a key factor contributing to defects in heritage buildings. Relating to this case, some of possible causes of building defects that often occur are rain, condensation, raising damp and water leakage. Richardson (2002) argued that moisture can influence structural and non-structural of building as illustrated in Figure 1.

Furthermore, moisture infiltration in heritage buildings exacerbates salt attack and rising damp, accelerating material deterioration. This is a serious problem, especially in buildings that undergo refurbishment. This issue leads to visible deterioration in the buildings' condition, significantly diminishing their aesthetic value (Ahmad & Rahman, 2010).

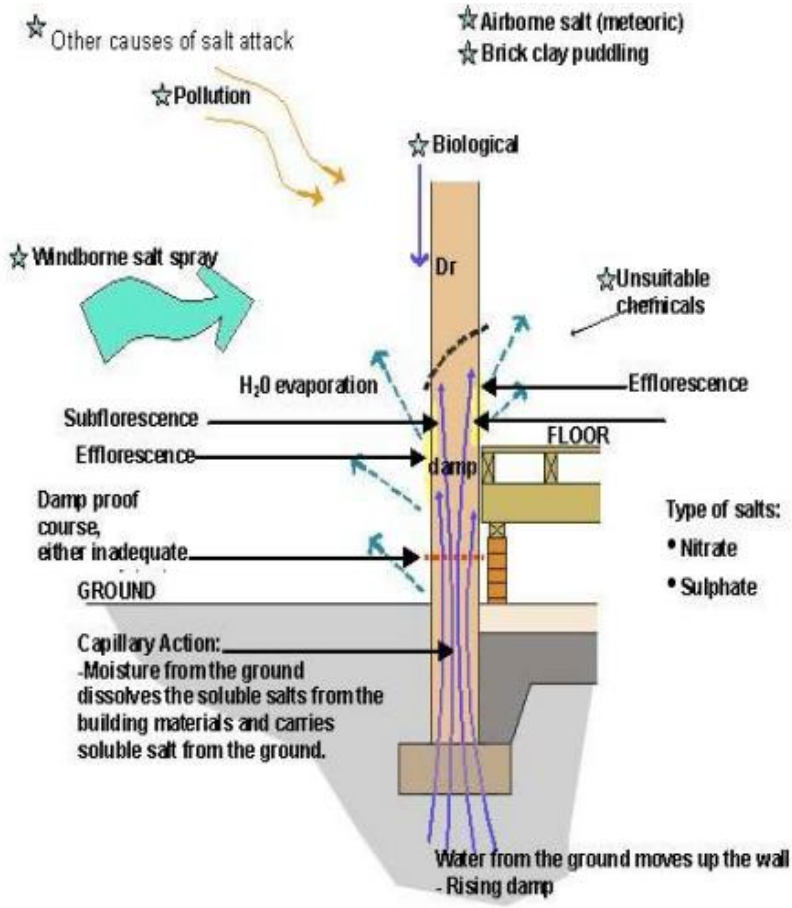

Figure 1. Moisture content that causes salt attack and raising damp
Source: Ahmad & Rahman, (2010).

Understanding the geography and the site of heritage building becomes an important factor to see how the major causes building defect occurs (Ahmad & Rahman, 2010). As known, Penang is a small island surrounded by sea and has a high rainfall intensity (tropics) causes a lot of heritage building being exposed to humidity. Additionally, the geographical location of heritage buildings in low-lying areas contributes to higher moisture retention, exacerbating deterioration issues.

Defects of Building on 23 Love Lane Hotel

Based on observation, the condition of 23 Love Lane Hotel is undergoing some defect in some parts of the building as shown in Figure 2. This condition started to look after a period of 3 years of hotel operations after refurbishment process finished by the end of 2011. Some of the defects seen in buildings are cracking (non-structural), dampness, fungi/mould, timber decayed, peeling paint and leaking (roof) as shown in Table 1.

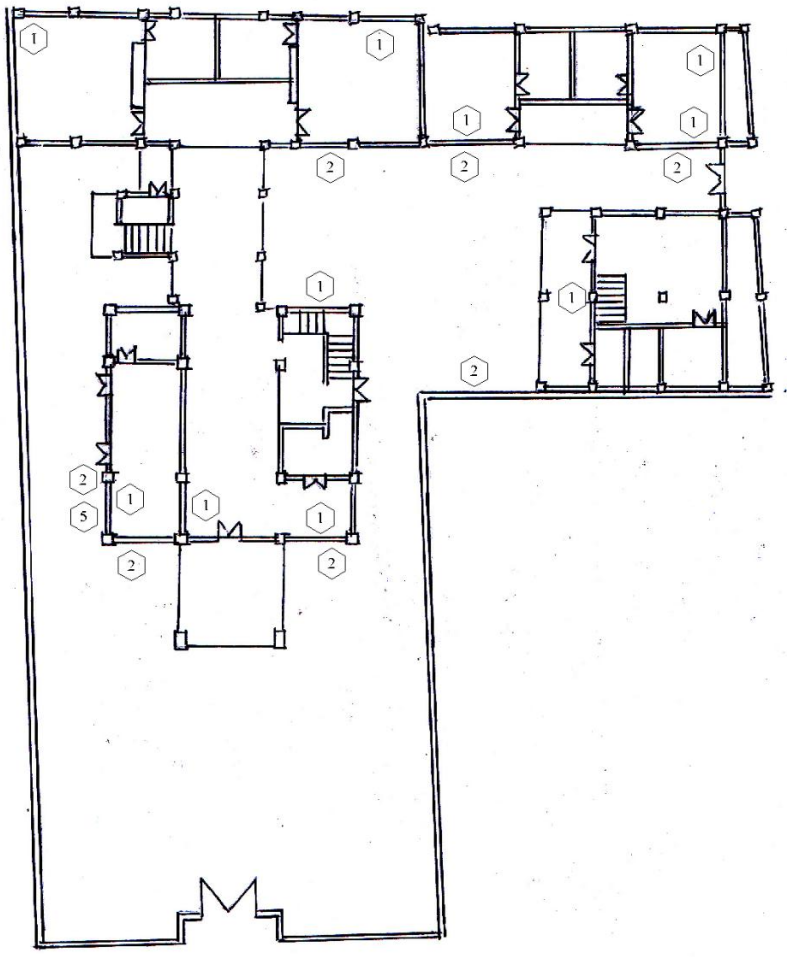

Figure 2. The spread of building defect on the ground floor plan
Source: Individual Analysis, (2025).

Table 1. Code of building defects on 23 Love Lane Hotel

Number Code	Building Defect	Unit(s)
1	Dampness	10
2	Fungi/Mold	10
3	Cracking	3
4	Timber Decayed	2
5	Peeling Paint	1
6	Leaking (Roof)	1
	Total	**27**

Source: Individual Analysis, (2025).

(a) **(b)**

Figure 3. Fungi/mold visible on outside of building:(a) near Indian Shophouse and (b) part of Jack annex roof
Source: Individual Analysis, (2025).

Growth of fungi/mold at 23 Love Lane Hotel is located on the outside of the building. Its presence can be found in some parts of the building, such as Anglo-Indian Bungalow; Straits eclectic annex; Indian Shophouse; and Jack annex roof as shown in Figure 3.

Defects of Building on Jawi Peranakan Mansion

The condition of Jawi Peranakan Mansion is undergoing some defect in some parts of the building. Based on observational data, these deterioration signs first appeared just two months after the building resumed operations following its January 2016 refurbishment. Some of the defects seen in buildings are dampness, fungi/mould, timber decayed, and peeling paint.

Dampness manifestations are visible at multiple locations throughout the building. Dampness occurring in Buildings - A (front building in Figure 4) is caused by the retention and structural formations of the old building. The building's proximity to a water source (within 3 feet/0.9 meters) creates favorable geographical conditions for moisture infiltration, particularly affecting vulnerable structural elements.

Two spots of fungi/mold growth at Jawi Peranakan Mansion is located on the facade of Building – A (front building). Based on observation in Table 2, the emergence of fungi/mold is caused by higher moisture content, less of sunlight and higher humidity. The growth of fungi/mold in Jawi Peranakan Mansion is not alarming, yet preventive action is needed to keep the building appearance and occupants healthy as shown in Figure 5.

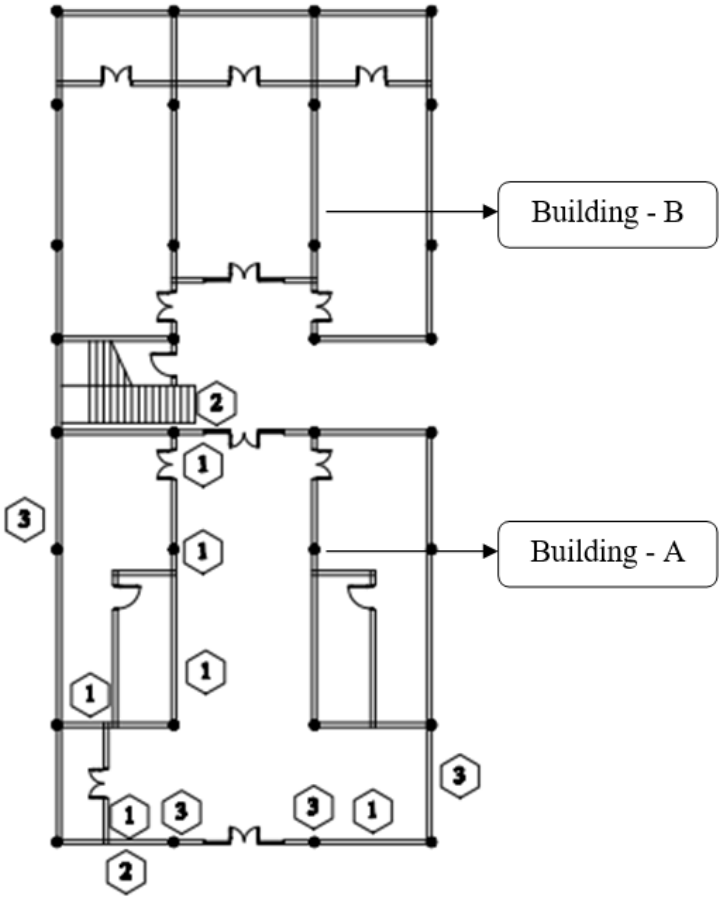

Figure 4. Building defect layout plan on Jawi Peranakan Mansion
Source: Individual Analysis, (2025).

Table 2. Code of building defects on Jawi Peranakan Mansion

Number Code	Building Defect	Unit(s)
1	Dampness	6
2	Fungi/Mold	2
3	Peeling Paint	4
	Total	**12**

Source: Individual Analysis, (2025).

(a) **(b)**

Figure 5. Conditions of dampness after repaired: (a) receptionist room and (b) main hall
Source: Individual Analysis, (2025).

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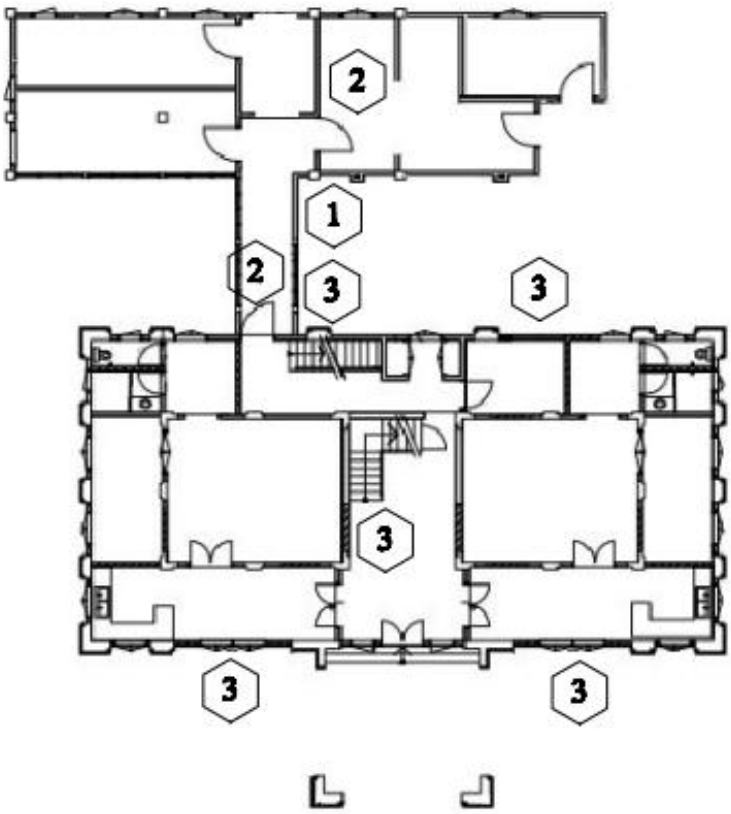

Figure 6. Building defect layout plan on USM Guesthouse
Source: Individual Analysis, (2025).

Defects of Building on USM Guesthouse

Based on observation, the condition of USM Guesthouse (Figure 6) is undergoing some defect in some parts of the building. This condition is found at some point. Some of the defects seen in buildings are fungi/mould, timber decayed, peeling paint, leaking and termite attack as illustrated in Table 3.

The presence of peeling paint on the USM Guesthouse occurs on the inside and outside of the building. As known, paint peeling occurs on building façade. In this building, peeling paint occurs on doors and windows (Figure 7). While on the walls, paint peeling occurs inside and outside of building, but the intensity is very low.

Table 3. Code of building dafects on USM Guesthouse

Number Code	Building Defect	Unit(s)
1	Fungi/Mould	1
2	Timber Decayed	1
3	Peeling Paint	5
4	Leaking	2
5	Termite Attack	1

Source: Individual Analysis, (2025).

(a) **(b)**

Figure 7. Peeling paint condition on: (a) window and (b) door
Source: Individual Analysis, (2025).

Based on the findings in the field (Table 4), the results of building defects on heritage buildings that remain visible are: (1) 23 Love Lane Hotel has high defect value, because it is located in the World Heritage Area (WHS) which enforces strict regulations. This also confirms that the initial refurbisment work starting from the implementation stage to maintenance still strictly based on guidelines; (2) Rumah Jawi Peranakan has moderate defects value. The application of the same guidelines applies to the building. Related to the location of the building is in an area bordering the buffer zone. The preservation method used is by mixing original materials and new materials. The impression obtained is that the appearance of moisture content is still visible but still under control; and (3) Wisma USM has low defects value, especially the presence of moisture content that does not dominate. This is caused by several factors, namely: 1) its location is far from the WHS, 2) lack of supervision during the restoration efforts (based on guidelines) and 3.) the existence of several restoration approaches only as a basis for upgrading buildings using new materials.

Table 4. Condition of Refurbishment toward defects of heritage building

Building Defect	23 Love Lane Hotel (finish refurbishment 2011)	Jawi Peranakan Mansiaon (finish refurbishment 2015)	USM Guesthouse (finish refurbishment 2000)
	Strict Regulation	Moderate Regulation	Weak Regulation
• Dampness	10	6	-
• Fungi/Mould	10	2	1
• Cracking	3	4	-
• Timber Decayed	2	-	1
• Peeling Paint	1	-	5
• Leaking (Roof)	1	-	2
• Termite Attack	-	-	1
Total	**27**	**12**	**10**

Source: Individual Analysis, (2025).

Refurbishment Perception toward Building Defects

The result obtained for building defects by users/occupants on heritage building in Penang, Malaysia is illustrated in Table 5. Based on observation on heritage buildings, peeling paint and thermal problem are significant for building defect. This is because the result was P> 0.05. As an illustration of Table 5, on the thermal problem, there is exactly 0.036 of the chi-square area under the curve that lies to the right of X2 = 6.667. This means that if the null hypothesis is true, the chance that the chi-square value is as large as 6.667, or larger, is 0.036. Since this is a fairly small probability, the null hypothesis can be rejected. That is, at any level of significance as low as 0.036, the null hypothesis can be rejected. At any lower level of significance than 0.036, the null hypothesis cannot be rejected.

Table 5. Significant value of building defects

		case study				
		23 Love Lane	Jawi Peranakan Mansion	USM Guesthouse	X^2	P
Dampness Problem (%)	not satisfied	0.0%	0.0%	0.0%	4.787	0.091
	neutral	5.0%	20.0%	0.0%		
	satisfied	95.0%	80.0%	100.0%		
Peeling Paint Problem (%)	not satisfied	0.0%	20.0%	0.0%	14.884	**0.005***
	neutral	5.0%	30.0%	5.0%		
	satisfied	95.0%	50.0%	95.0%		
Cracking Problem (%)	not satisfied	0.0%	10.0%	5.0%	3.271	0.513
	neutral	5.0%	0.0%	0.0%		
	satisfied	95.0%	90.0%	95.0%		
Leaking Problem (%)	not satisfied	0.0%	0.0%	5.0%	5.573	0.233
	neutral	0.0%	10.0%	0.0%		
	satisfied	100.0%	90.0%	95.0%		
Structural Problem (%)	not satisfied	0.0%	0.0%	5.0%	5.573	0.233
	neutral	0.0%	10.0%	0.0%		
	satisfied	100.0%	90.0%	95.0%		
Thermal Problem (%)	not satisfied	0.0%	0.0%	0.0%	6.667	**0.036***
	neutral	0.0%	30.0%	10.0%		
	satisfied	100.0%	70.0%	90.0%		
Health and Safety Problem (%)	not satisfied	0.0%	10.0%	5.0%	6.037	0.196
	neutral	0.0%	10.0%	0.0%		
	satisfied	100.0%	80.0%	95.0%		

*significant at P<0.05 N=50

Furthermore, when examining the user perceptions of the three heritage buildings, it appears that the Peeling Paint problem related to moisture content remains the primary concern. This condition is highly correlated with the environmental setting of the building area, which is located around the coastal area (Ahmad & Rahman, 2010). Such an environment certainly facilitates the entry of water content into the structural and non-structural parts of the heritage buildings (Richardson, 2002).

CONCLUSIONS

The challenge of refurbishment in heritage buildings in Penang is the presence of WHS regulations that maintain original materials, as well as the influence of environmental conditions. The coastal location of these heritage buildings creates heightened exposure to moisture, which actively degrades their original construction materials. Without any replacement of the original materials, the emergence of defects (caused by moisture) in buildings continues. This condition is certainly causes a dilemma related to the sustainability of users/occupants comfort.

While building defects in heritage structures may theoretically justify refurbishment as a means of improving standards, in practice such interventions often fail to achieve their intended outcomes when applied to historic buildings. The inherent complexity of heritage conservation makes refurbishment significantly more challenging than comparable work on conventional structures. These challenges are further compounded by restrictive conservation policies and guidelines, which add layers of complexity to decision-making regarding appropriate rescue measures. (Zolkafli et al., 2012).

Based on the results of the investigation on the site, several of the defects seen in heritage buildings in Penang occur because of the presence of moisture content. This was confirmed by the previous literature review. Some building defects that arise are dampness, fungi/mold, cracking, decayed timber, peeling paint, leaking and termite attack.

The defect documentation result from three heritage building in Penang reveal varied post-refurbishment defect patterns. At 23 Love lane Hotel (finish refurbisment 2011), dampness and fungi/mold growth dominated with 10 occurrences each, followed by cracking (3 cases). Total defects reached 27 spots. Jawi Peranakan Mansion (finish refurbisment 2015) recorded 12 spots with dampness as the primary issue (6 cases), succeeded by cracking (4 cases) and fungi/mold (2 cases). Meanwhile, USM Guesthouse (finish refurbisment 2000) exhibited 10 spots dominated by peeling paint (5 cases) along with roof leaking and fungi/mold (2 cases each). This data reflects differing defect characteristics despite all three buildings having undergone refurbishment in different time periods. If it is associated with the completion of the refurbishment work, the presence of defect spots is greatly influenced by the presence of water content.

The results of the study literature review and field observations found that there are several common factors that cause building defect re-occur, namely: (1) Compliance with the guidelines (maintaining originality); (2) Materials and technology used; and (3) Factors of the environment and weather.

Based on the analysis, refurbishment that strictly followed the guideline easily exposed to different kinds of building defect (especially moisture content) as seen in 23 Love Lane Hotel and Jawi Peranakan Mansion. While at USM Guesthouse, the building is easier to survive from defects.

The original construction materials significantly influence the recurrence of defects in heritage buildings. As characteristic of 19th-century construction, these structures predominantly employ clay and lime-based materials. While historically appropriate, these materials exhibit particular vulnerability to post-refurbishment deterioration due to their incompatibility with modern interventions and inherent susceptibility to environmental stresses.

The inherent 'breathability' of lime-based materials facilitates moisture movement, often leading to visible dampness. This phenomenon is clearly demonstrated at 23 Love Lane Hotel and Jawi Peranakan Mansion. In contrast, at USM Guesthouse, moisture manifestations are less pronounced aesthetically, owing to the use of modern cement-based materials which effectively mitigate excessive moisture penetration in walls and ground-contact elements.

Differences in technology from time to time also played a crucial role for the sustainability of the building. The presence of cement instead of lime gives the advantage to make the building more sustainable. However, the use of cement in heritage building which uses lime as the basic material is strictly prohibited. This is because the use of both of these materials will lead to a more severe defect.

As with other factors, the effect from the environment and weather is a major factor that can not be denied in bringing the building defect. Based on geographic position, Penang is located in the tropical country and is also surrounded by ocean. from it, the reemergence of a building defect is caused by the raising damp and salt attack both of which are derivatives of the moisture content. All three of the heritage building (hotel) received the direct impact of these factors.

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