INVESTIGATION OF RISING DAMP AND SALT ATTACK PROBLEMS OF HERITAGE BUILDINGS

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Abstract
Conservation is a new issue in Malaysia as compared to other countries. Conservation is a more challenging task which requires a deep understanding of the structure of the buildings and the problems of the buildings. A proper dilapidation is a must before conservation work takes action to ensure that appropriate action is being taken. Salt contamination and rising dampness, which are the interrelated problem, are the most common problem among the rest due to the geographic location of Penang Island as it surrounded by sea water. Moreover, salt contamination and rising dampness are also considered as the most challenging problem. In this paper, five inheritance buildings that have salt contamination and dampness problem are chosen as the case study. Dilapidation survey is done and salt contamination sample collected from the case studies is sent to laboratory for X-Ray Fluorescence (XRF) test to determine the salt content of the sample. The finding of this study can be used for reference before the conservation works take place and it could improve the effectiveness and outcome of the outcome of the building from the conservation works.

Keywords: *Conservation; rising dampness; water penetration; salt attack*

INTRODUCTION

In Penang, we have a lot of heritage buildings or buildings inherited from the past generations. Since the reorganisation by the UNESCO World Heritage in year 2008, conservation issue is highly concerned. However, building conservation practice is relatively new in Malaysia compared to some other countries. As such, the practice of conservation work in Penang is considered challenging. The practice of conservation or conserving normally contains two activities, to care and safeguard from being destroyed without careful planning. Furthermore, a well conserved heritage will boost up the tourism in the local (Ahmad, 2004). Conservation works doesn’t mean only to the architectural works or aesthetic value but the safety and health to the occupants or users in the building. While conservation, dilapidation survey is a must before any conservation works applied. This is due to it is important to understand the extent and nature of the building defects on the building. A precise and appropriate remedial and repairing works only can be carried out when the cause of the defects is known. There are many types of defects occurred in inheritance buildings such as dampness, salt crystallization, termite attack and other defects. However, rising dampness and salt contamination are the most common defects can be found in the buildings. This is due to the installation of Damp Proof Course (DPC) is not common during the construction work in nineteenth century (Brian, 2005). Generally, rising damp is caused by capillary action (or suction) drawing water from the ground through the network of pores in a permeable masonry material. Capillary suction become stronger as the pore size gets smaller, if the pore size is fine enough damp may rise many meters in a wall, until the upward suction is balanced by the downward pull of gravity (Burkinshaw and Parrett, 2004). This research is aiming to identify the extent and nature of salt contamination and rising damp problems in selected inheritance buildings in Penang. Moreover, this paper will be analysing the type of salt and possible cause of salt contamination occurred in the inheritance buildings based on the laboratory results. Thus, appropriate treatment and remedial action will be proposed based on the possible cause of defects occurred in the building.

REVIEW OF RELATED LITERATURES

Types of building defects

It is very natural that building has defects especially for those aged buildings. This is due to no building is maintenance free especially the building has been through ages. Defects can also be the result of improper construction, poor workmanship; building design is not accordance with the usage, lack of proper building practice, lack of or incorrect maintenance and other factors. Apart from the above stated factors, there are several factors contributed to building defects includes external factor, biological agent and building material itself. External factors such as air, sunlight, moisture, gaseous contamination, soil and so on. Biological agencies contributed are fungi, bacteria, termite, insect and other agencies. Some building material composition such as calcium chloride is one of the factors contributed to the defects especially salt crystallisation (Pourzeynali and Jooei, 2013).

Bird damage

The damages that bird fouling causes to historic buildings can be extensive as been shown in Figure 1. Apart from the obvious unsightliness, the main problem is the acids released from their excrement. Studies have shown that the corrosive effects of the bird droppings can continue for a long time once the building fabric has been contaminated, even the fouling is removed or being washed away. The droppings from nesting materials can severely deteriorate the quality of virtually any roof. As time passes by, the acid contained in bird droppings will eat away the tar-based roofing materials and thus leading to leaks in asphalt roofs.

Figure 1. Bird damage on historical building

For those buildings especially historical building which is constructed of limestone or calciferous sandstone are most susceptible to the effects of the acids released from the bird excrements. The excrement from birds or any organisms is majority acidic nature (David, 2008). The method to reduce the building damage is to identify the location of the bird problems, treat and clean the affected area if any fouling found. Deterrents can be installed in order to avoid the bird from fouling in the same place. Another alternatives is, installing anti-perching devices such as anti-perching wire on the roof or the places where bird most likely to be fouling on.

Insect damage

Timber has been used widely in the past. It can be found in most of the elements in a building including floors, walls, windows, doors and roofs. Thus, many of the historic buildings are facing insect damage included termite damage. However, insecticides are not the wisest choice to kill the insect from damaging the building. This is due to insecticides might be killing the insect natural predator – spider at the same time. Figure 2 shows the termite damage on building structure. All of the organisms that damage timber in buildings are part of the natural process that takes dead wood to the forest floor, decomposes it into humus and recycle the nutrients released back into trees (Ernesto, 1999).

Figure 2. Termite damage on building structure

Salt crystallisation

Salt crystallisation is used to describe the damage caused by soluble salt crystallizing within the pores of masonry materials as can be seen in Figure 3. Salts are brought into the porous masonry in solution in water by a variety means included rising damp. During the dry period, when the moisture evaporates from the masonry wall, the salts will be left behind due to salts cannot be evaporated and the salt solution residue in the wall will become more and more concentrated as time goes by. More and more salt solution will be brought into the wall and accumulated, thus the wall become more and more concentrated. At some point where the solution is reaching a condition which is saturation, or super-saturation, crystals will begin to form in the wall. When the evaporation rate from the wall surface is low, the evaporative front may be at or very the surface, in this case salt crystal will grow as long thin needles, extruding from the wall surfaces (Graham, 2002).

Figure 3. Salt crystallisation on brick wall

i. Salts

Salts consist of a combination of positively and negatively charged ions known as cations and anions. The cations commonly encountered in wall are Sodium (Na^+), Potassium (K^+), Magnesium (Mg^{2+}) and Calcium (Ca^{2+}). The anions commonly in wall are Chloride (Cl^-), Sulphate (SO_4^{2-}), Nitrate (NO_3^{2-}) and Carbonate (CO_3^{2-}). Salts may consist of a combination of any cation with any anion, provided there is a balance of positive and negative charges. The combination of cation and anion which commonly can be found causing salt crystallisation in walls are sodium chloride, sodium sulphate and calcium sulphate. Calcium sulphate is also known as gypsum. When a salt is dissolved in water, it is dissociated into ions. For example,

$$NaCl + H_2O \rightarrow Na^+ + Cl^-$$

When the compounds formed by the crystallisation of a solution can be deriving from the reaction of an acid (eg. HCl) with a base (eg. NaOH).

$$HCl + NaOH \rightarrow H_2O + Na^+ + Cl^-$$

$$Na^+ + Cl^- \; H_2O - \textit{evaporation} \rightarrow NaCl$$

The ions are making up into these salts may be of purely natural origin or may be sourced from other compounds deliberately applied to roads or walls. They may come from the pollutants in the air or water.

ii. Causes of salt crystallisation

The sources of salts in the walls are saline soils and groundwater, sea-spray for coastal sites, air-borne salts, air pollutants, inorganic garden fertilizers, biological sources such as pigeon droppings, salt naturally occurring in the stone, brick clay or mortar sand, salty water used for pudding brick clay or mixing mortar and cleaning compounds that contain or react to produce salts in wall. There are two types of salt contamination depending on the salt penetration. First one is the salt residue on the surface of the wall that will be shown as white powder on the plaster which is known as efflorescence. Efflorescence is considered harmless to the masonry wall this is due to the salt residue are inclined to come out from the wall apart from being unsightly. Figure 4 shows the causes and process of salt crystallisation

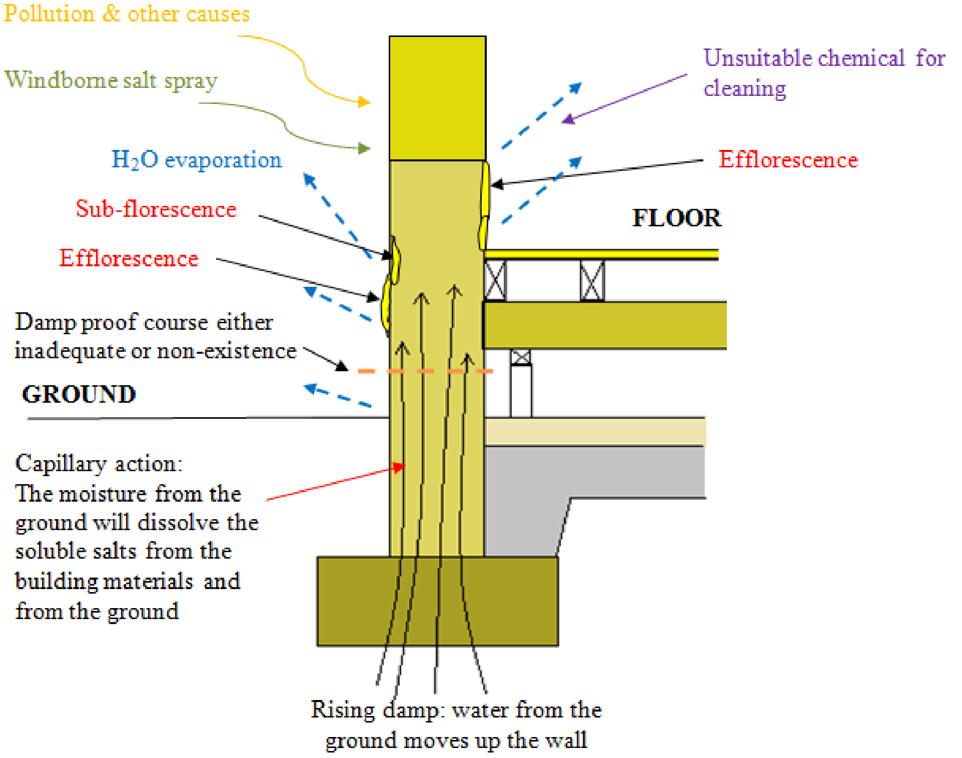

Figure 4. Causes and process of salt crystallisation (Harun, 2011)

iii. Effects of salt crystallisation

Salt crystallisation will lead to the destructive plastering work such as peeling, spalling and flaking of plastering works. The wall finishes such as paint will also be affected. Other than that, the salt contamination and rising damp area are susceptible to growth of fungi and mould. It would have unfavourable musty damp smell and the health of the occupant might be affected. Over the time, salts migrate into porous masonry materials and start to clog pore spaces. Cyclic of crystallisation and hydration has lead the pores become filled. This process will lead to the imposition of considerable stress on the surrounding pore walls (Harun, 2011).

Rising damp

Rising damp is one of the most common yet severe damage that leads to decay and deterioration of many buildings especially heritage buildings as been shown in Figure 5. Rising damp is the upward movement of moisture caused by the capillary action which draws the moisture from the ground or the soil through the network of pores in the permeable masonry material. Capillary suction becomes stronger as the pore size gets smaller.

Figure 5. Rising damp on masonry wall

i. Causes of rising damp

Rising damp refers to the moisture upward movement from the ground and soil. Thus, the common source of water that leads to rising damp problems in masonry wall is from the ground water and soil water itself. The severity of rising damp is depending on the water table underneath the soil. However, the water table is varied from one to another place depending on the geographic location and type of soil underneath. Despite of the geographic location, the defects of the surface drainage and ground drainage also leakage plumbing system underground can be the factor to the rising damp problem (Hassan et al., 2015).

ii. Effects of rising damp

The rising damp in a building can lead to several problems. The moisture content in the masonry can be reached to a level where the decay organisms may grow, or the materials themselves may be adversely affected (Kariya et al., 2016). Heritage buildings are susceptible to experience severe rising damp problem especially the timber structure which is widely use in the building structure include floor, roof, and wall and so on. This is due to moisture condition is an optimum condition for the growth of insects, fungi and mould. The rising damp affected wall allows the growth of the mould is aesthetically unacceptable. Moreover, the growth of mould can be a significant health hazard to the occupants. The finishes on the wall might be damaging. The plastering works and paints on the wall might be flaking and blistering. Where evaporation takes place, the precipitation of the soluble salts on the surface of the wall and within the pores of the building materials can cause aesthetic and structural damages (Mei and Othuman Mydin, 2015).

CASE STUDY

Shih Chung School

Figure 6. Shih Chung School

Figure 6 shows the Shih Chung School which is situated at No. 11, Jalan Sultan Ahamd Shah, 10050 Georgetown, Penang. It is built in year 1880 by Cheah Tek Soon. This building has been unoccupied since 1994. In early year, this building is functioning as a shelter for the family of Cheah Tek Soon. Then, it was once become as Chinese Consulate. Later, this building was function as a school which known as Shih Chung School until year 1994. After Shih Chung School, this building was left unoccupied until now. Now, this building is being fenced up and no entry is allowed as the building is deteriorated severely and might danger the visitor.

Boon San Tong Khoo Kongsi

Figure 7 shows the Boon San Tong Khoo Kongsi which is located at No. 117-A, Lebuh Victoria, 10300 Georgetown, Penang. It was built in year 1878. The building of Boon San Tong Khoo Kongsi itself does not occupied by any occupant. However, there are few houses along the two sides of the building. On the left is the side office of the Boon San Tong Khoo Kongsi. On the right is the house of a family. Back in year 1907, the Lebuh Victoria road previously was a sea before the creation of road. The current entrance of this building was changed into the newly created street in 1907. Currently, the building is under some renovation works included re-plastering, repainting, repair the traditional element in the building and so on.

Figure 7. Boon San Tong Khoo Kongsi

Doubled-storey Mansion at Jalan Dato Koyah

This double-storey building is located at No. 38, Jalan Dato Koyah 10050 Georgetown, Penang (Figure 8). It is built in early 19th century. It is a doubled-storey mansion which is used to be a shelter for a family. It has been unoccupied for more than 10 years. Currently the building is severely deteriorated and unable to accommodate occupants.

Figure 8. Doubled-storey Mansion at Jalan Dato Koyah

There are plenty of plants growing and even the roof of the building is no more. The condition of the building is not safe for use, thus it has been fencing up to prohibit any entry. This building did not undergo any repairing work before that. However, conservation work of this building will be begun soon by a conservator architect in Penang.

Double-storey old house at Lebuh Carnarvon

The case study is situated at No. 11-21, Lebuh Carnarvon, 10100 Georgetown, Penang (Figure 9). It was built in early 19th century. It is a doubled-storey old house. There is several building defects occurred in the building included decay of timber on the ceiling and staircase, peeling paints, dampness problem and salt attack problem. Thus, currently these houses are undergoing conservation and renovation work in order to repair the building defects in the building.

Figure 9. Double-storey old house at Lebuh Carnarvon

Double-storey house at Lorong Prangin

This case study is situated at No. 69, Lorong Prangin 10100 Georgetown, Penang has been shown in Figure 10. It is built in early 19th century as well. It is a doubled storey house which is previously occupied by a family. However, this house has been unoccupied since year 1996. There are many defects occurred in the house such as bird damage, salt attack, dampness, decay of timber and so on. Due to unoccupied, birds take this house as their own shelter and bird droppings can be found scattered everywhere in the house. The health of the occupants might be affected. Conservation work will be begun soon by a conservator architect in Penang.

Figure 10. Double-storey house at Lorong Prangin

DATA ANALYSIS

Shih Chung School

Moisture anomalies of the Shih Chung School

From the Table 1, it can be told that, rising dampness contributed to the dampness problem on the wall. Generally, moisture comes from the ground and travel up to the wall. As can be seen, the moisture content at the lower ground level has quite high percentage in moisture content. The capillary action is decelerating as the height is increasing, thus the moisture content is decreasing. However, in Shih Chung School, the dampness occurred not only contributed by rising damp but falling damp as well. Due to the deterioration of the roof of the building, rainwater is directly entered the building. This can be told by the reading of moisture content at the height of 2.0m. From Figure 11, it can be clearly seen that the temperature of the wall is low. Rising damp occurred in this building might be due to the location of the sa is near to this building which is less than 20 metres.

Table 1. Moisture content of Shih Chung School

Height from ground level (m)	Average moisture content (%)
0.5	4.6
1.0	3.6
1.5	3.2
2.0	>6.0 (out from scale)

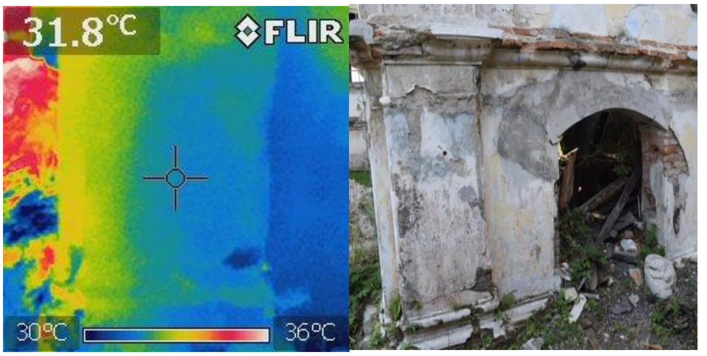

Figure 11. Infrared thermograph of Shih Chung School

X-Ray Fluorescence (XRF) test for Shih Chung School

From the Table 2 above, it depicts the salt concentration contained in the sample which collected from the case study. The elements of MgO, CaO, Na_2O and K_2O are added up due to salt are made up by the cations of Mg^{2+}, Ca^{2+}, Na^{+}, and K^{+}. This has proven that the wall is contaminated by salt. The salt content at 15mm depth is the highest which is 13.64% and the percentage of salt concentration is getting lower as the depth increasing. The salt contained in the sample at 30mm depth and 45mm depth are 10.74% and 8.22% respectively. This shows that the salts are inclined to come out from the wall along with the evaporation of moisture. The salt contaminated the wall are efflorescence but not sub-fluorescence. From the Table 2 above, Calcium (Ca) has the highest percentage for the salt content which is come from the source of limestone, gypsum and fluoride. This is followed by Potassium (K) which is from soils and electrolysis of chloride and hydroxide.

Table 2. Percentage of elements of the destructive salts in the sample of the Shih Chung School

Depth (mm)	MgO	CaO	Na_2O	K_2O	Total
15	0.23	12.06	0.15	1.20	13.64
30	0.49	8.63	0.16	1.46	10.74
45	0.53	5.89	0.15	1.55	8.12

Boon San Tong Khoo Kongsi

Moisture anomalies of the Boon San Tong Khoo Kongsi

From Table 3 above, the lower area of the affected column have very high moisture content until the reading is exceeding the scale. From Figure 12 above, the thermograph has captured that the temperature of the column is low. The moisture content in the wall is decreasing while further up to the column. However, the moisture content is still very high which is recorded as 5.0%. This shows the indications of rising damp. The possible cause of such high moisture content might be the location of the building which is previously a sea. Thus, the moisture of the ground is comparing high than others and the building is more susceptible to moisture.

Table 3. Moisture content of Boon San Tong Khoo Kongsi

Height from ground level (m)	Average moisture content (%)
0.5	>6.0 (out from scale)
1.0	5.8
1.5	5.0
2.0	5.0

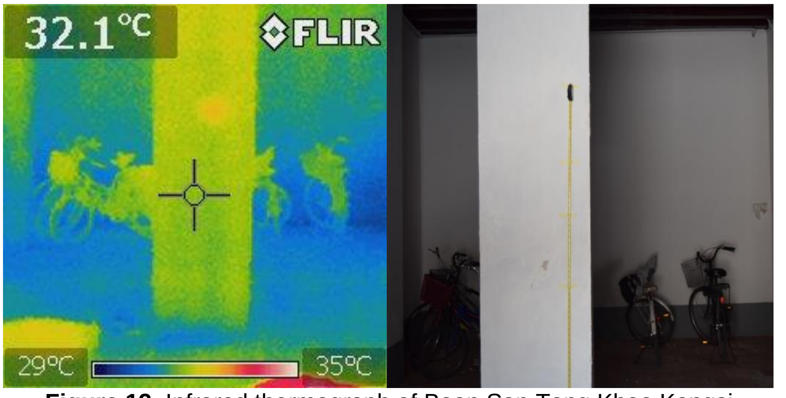

Figure 12. Infrared thermograph of Boon San Tong Khoo Kongsi

X-Ray Fluorescence (XRF) test for Boon San Tong Khoo Kongsi

From the Table 4 above, the highest salt content was recorded at the depth of 15mm of the wall. This is followed by 45mm and 30mm at 13.52% and 12.36% respectively. This portrays that the salt deposit is inclined to come out to the surface of the wall. Thus, it can be concluded that the salt contaminating the wall is efflorescence. Calcium (Ca) has occupied the highest percentage for the salt content which is come from the source of limestone, gypsum and fluoride. This is followed by Potassium (K) which is from soils and electrolysis of chloride and hydroxide. The source of Sodium (Na) basically is sea water and other natural water.

Table 4. Percentage of elements of the destructive salts in the sample of the Boon San Tong Khoo Kongsi

Depth (mm)	MgO	CaO	Na_2O	K_2O	Total
15	0.43	12.38	2.05	2.26	17.12
30	0.72	8.03	1.75	1.86	12.36
45	0.62	8.46	2.81	1.63	13.52

No. 38 Jalan Dato Koyah

Moisture anomalies of the No. 38 Jalan Dato Koyah

Table 5. Moisture content of No.38 Jalan Dato Koyah

Height from ground level (m)	Average moisture content (%)
0.5	2.8
1.0	2.2
1.5	1.6
2.0	2.0

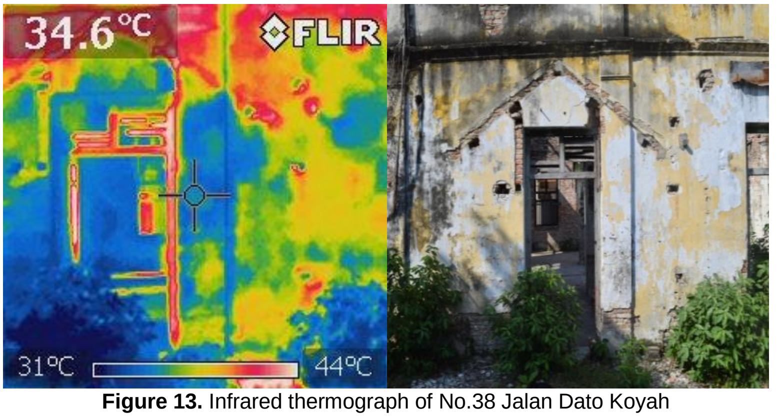

Figure 13. Infrared thermograph of No.38 Jalan Dato Koyah

From Table 5 above, the moisture content recorded has depicted the indication of rising damp problem. The moisture content recorded is increasing from 0.5m, 1.0m to 1.5m. From the Figure 13, the temperature captured on the wall is low at the lower area of the wall. The moisture content is recorded 2.0% at height of 2.0m. This might be caused by the rainwater enters the building because the roof of the building is deteriorated and currently the building is roofless and direct exposure to sunlight or rainwater.

X-Ray Fluorescence (XRF) test for No. 38 Jalan Dato Koyah

From Table 6 above, the percentage of elements of the destructive salts in the sample has proven that the building is contaminated by salt. Same as the other case studies, this case study has the highest salt content of 13.60% at the depth of 15mm then only followed by the depth of 30mm and 45mm at 9.09% and 8.86% respectively. This shows that the salt deposit is inclined to come out to the surface of the wall which can be concluded that the salt deposits are efflorescence. Calcium (Ca) is the largest composition portrays that the salt contaminated which is sourced from limestone, gypsum and fluoride. The composition of Potassium (K) is made up from soils.

Table 6. Percentage of elements of the destructive salts in the sample of the No.38 Jalan Dato Koyah

Depth (mm)	MgO	CaO	Na_2O	K_2O	Total
15	0.18	12.09	0.14	1.19	13.60
30	0.51	5.68	0.31	2.59	9.09
45	0.56	5.31	0.33	2.66	8.86

No. 11-21 Lebuh Carnarvon

Moisture anomalies of the No. 11-21 Lebuh Carnarvon

From the Table 7 and Figure 14 above, they depicts that the dampness problem in this case study is severe. The moisture content in the wall at the height of 0.5m, 1.0m and 1.5m are exceeding the scale of moisture metre. At the height of 2.0m, the moisture content has recorded at 5.6 %. The moisture content recorded portrays the indication of rising damp. The possible factor causing the rising damp problem might be the location of the building is close to the sea and the lack of exposure of sunlight on the wall. Thus, the evaporation rate is slower especially at the bottom part of the wall, it seems barely evaporates.

Table 7. Moisture content of No.11-21 Lebuh Carnarvon

Height from ground level (m)	Average moisture content (%)
0.5	>6.0 (out from scale)
1.0	>6.0 (out from scale)
1.5	>6.0 (out from scale)
2.0	5.6

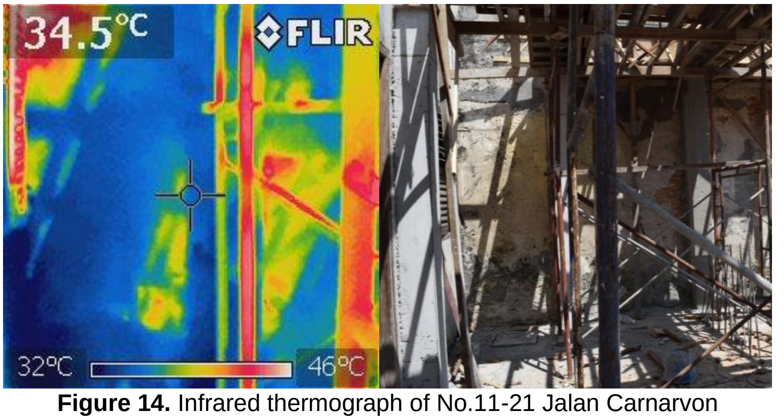

Figure 14. Infrared thermograph of No.11-21 Jalan Carnarvon

X-Ray Fluorescence (XRF) test for No. 11-21 Lebuh Carnarvon

From the Table 8 above, the percentage of elements of the destructive salts in the sample is gradually decreasing as it goes deeper into the wall. This implies that the salt deposits are tend to come out to the surface of wall and portrays that the salt deposits are efflorescence. The highest composition of salt identified is calcium (Ca) which is sourced from limestone, gypsum and fluoride. The second largest composition of sodium (Na) is come from the seawater and other natural water.

Table 8. Percentage of elements of the destructive salts in the sample of the No.11-21 Lebuh Carnarvon

Depth (mm)	MgO	CaO	Na_2O	K_2O	Total
15	0.60	13.77	0.42	0.99	15.78
30	0.78	5.36	0.43	1.18	7.75
45	0.82	3.83	0.38	1.14	6.17

No. 69 Lorong Prangin

Moisture anomalies of the No. 69 Lorong Prangin

Table 9: Moisture content of No.69 Lorong Prangin

Height from ground level (m)	Average moisture content (%)
0.5	4.6
1.0	4.0
1.5	4.4
2.0	2.6

From the Table 9 and Figure 15, the average moisture content recorded shows a gradual decrease as the height of the wall increases. This implies that the dampness occurred is rising dampness. However, as from the data obtained, the average moisture content increase and reach to 4.4% at the height of 1.5m. This dramatically changes can be seen on the wall in the building as there is a severe and significant spalling paint at the height of 1.5m on the wall which can be vividly seen by naked eyes. The possible factor causing to the rising damp and salt contamination in this case study might be the location of the building close to the sea. This case study is located not far from the case study located at Lebuh Carnarvon. Moreover, less exposure to sunlight which lead to low evaporation rate of the moisture from the wall which has lead to accumulation of moisture and salt deposits on the wall.

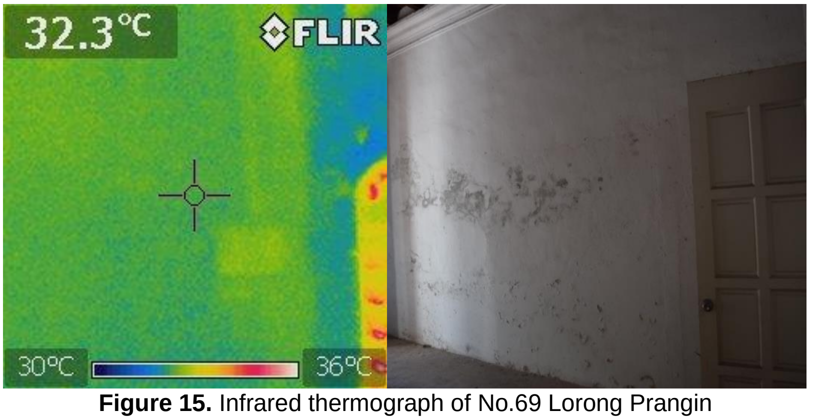

Figure 15. Infrared thermograph of No.69 Lorong Prangin

X-Ray Fluorescence (XRF) test for No. 69 Lorong Prangin

Table 10. Percentage of elements of the destructive salts in the sample of the No.69 Lorong Prangin

Depth (mm)	MgO	CaO	Na_2O	K_2O	Total
15	0.45	10.65	0.36	1.49	12.95
30	0.15	5.99	0.29	1.25	7.68
45	0.10	5.75	0.19	0.94	6.98

From Table 10 above, the percentage of elements of the destructive salts in the sample proves that the wall is destructed by salt. From the table above, it can be seen that the salt content is gradually reduce as goes into the wall. This implies that the salt deposits are efflorescence and the deposits are inclined to move out to the surface of the wall. In this case study, the major composition of the elements in the salt is Calcium (Ca) which is sourced from limestone, gypsum and fluoride. This is followed by Potassium (K) where it comes from soils and electrolysis of chloride and hydroxide.

CONCLUSION

Inheritance building are susceptible to salt contamination and rising damp this is due to lack of Damp Proof Course (DPC), the location of the building close to the sea and also some other factors. Salt contamination and rising damp can be a threat to the building deterioration if left untreated. It is very important to understand the factor and the source of the salt contamination and the type of contamination occurred in order to have an effective conservation works. A precise dilapidation survey and scientific analyses includes laboratory test is required in order to have a better understanding on the problem. From the five case studies in this research, basically the factors causing the salt contamination and rising damp to occur are the location of building and the lacking of Damp Proof Course (DPC). From the data analysed, the source of salt mostly are come from the soils and limestone. Thus, a precise treatment and repair works can be taken with the reference from the data collected and laboratory result

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