DIAGNOSIS OF DAMPNESS IN CONSERVATION OF HISTORIC BUILDING

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ABSTRACT

Historic buildings are old aged buildings that have a unique architecture which relates to its history and events of the construction. Historic buildings usually experience physical defects like cracks, peeling paints, decays and others. The main factor that contributes to these defects is building dampness. Most decisions that have been made to overcome dampness are ad hoc decisions. It is because by looking at the current situation there is no comprehensive scientific research in explaining the exact factor of dampness. Most of the scientific research done cannot be comprehended by contractors because the procedure used is ambiguous. As a result, faulty in the repair works will occur and lead to severe effects in which the same or even worse defects or damages can happen in the future. The goals of this study are to investigate the dampness problems on the historic buildings and introduce a straightforward procedure in investigating the building dampness. There are four processes of investigation used in this study which are visual inspection, a test that will not damage the building, a test that will damage the building (lab test) and comprehensive research. All of these processes have been completed in UK. A comprehensive or detailed research will be conducted by experimenting and the data will be analysed thoroughly. Through the research that has been done, one simple method in inspecting the dampness of the building will be presented. In addition, one method or technique in analysing the dampness will be presented manually in order to be understood and followed without difficulty.

Keywords: Dampness, diagnosis, conservation, historic building

INTRODUCTION

Historical buildings are buildings that have old age and unique architectural and historical events associated with its construction. Historical building was commonly experienced the physical impairment such as cracks, paint peeling, dampness and if maintenance have been neglected, it will become more serious defects due to obsolescence of materials from the threat of climate and environment. One of the major causes of defects of historic buildings is a problem with moisture or dampness. Scientific research on dampness in historic building is very important. The research is to detect the exact sources of dampness then to suggest the most proper conservation methods to make sure historical buildings can keep its original condition and to continue the extend of its lifespan in the future. In Malaysia, the practice of conservation of historic buildings is in accordance with the guidelines provided by the National Heritage Department Malaysia (NHDM). One of the conservation procedures is the investigation and the study of building defects. This study needs a conservator to directly engage with historic building to find out the real causes of defects and to propose the actual or accurate repair techniques and remediation works. Each historical building has various problems according to the type of building and the factors that lead to defects. This is due to the variation of materials, building design and the setting of the building in term of its location. The process of investigation and the study of building defects is a must because it will reflect negative consequences towards historical building if the task that being carried out is conducted without following the exact method. There are two types of basic procedures commonly used in the dampness study applied by NHDM, the first procedure is by visual inspection and the second procedure is to record the reading of moisture content by using moisture equipments such as moisture meter or protimeter. By utilising these two methods, the cause of dampness can be identified through a careful observation on the symptoms of dampness. Generally, the observation is carried out by looking at factors that contribute to dampness such as dampness that was caused by leakage, rising damp and condensation. The area that has been damaged by dampness can be recognised by using moisture meter where the dampness level exceeds 20% rH. This illustrates that the dampness is critical and the remedial works must be conducted in a proper method. It is not an easy task in choosing and utilising a remedial work for conservation of historic building. Visual inspection and non – destructive test are commonly use in determining resolution for remedial work in conservation project in Malaysia. However, this form of decision is based on in-situ process and the proposed remedial work is based on ad-hoc decision which means it only consider the current preservation decisions and cannot be measured for long-term that is commensurate with the effort to extend the life of the building. Based on these circumstances, the investigation of building defects and the diagnosis in early stage of conservation practices is very important to be carried out with a structured procedure, a clear framework and the appropriate manual in the form of a checklist that can be found and adapted to any type of historic buildings. This research investigates the procedure of defects diagnosis technique that has been conducted in conservation project and to develop a structured and clear framework in investigation related to the dampness problem.

HISTORICAL BUILDING DEFECTS

The rapid development in this country has been threatening a lot of historic buildings in the country. In fact, the historic building that was left, continue to deteriorate without any maintenance. The primary cause of building defects is neglect of historic buildings caused by high maintenance costs. A large part of this historic building has been abandoned (Ahmad, 2004). What is the most distressing is there are several historical building is being attacked by ruination due to neglection from owner and be demolished upon insistence of development and lack of public concern about the effort to maintain and retain the heritage of this country's properties (Ali. et. al., 2002). Meanwhile, with the recognition given by UNESCO on the listing of Malacca town as world heritage site and also been called as The Historic Cities of The Straits of

Malacca under the category of Culture heritage site on 7th July 2008 (Jabatan Warisan Negara, 2008) had created awareness among the public society in Malaysia about the requirement to preserve and appreciate the legacy in this country, especially on historical buildings. It is the time to retain and make an effort to conserve on historical building in this country in bigger scale and completely planned conservation works to ensure the longer its lifespan. Hence, to protect the national heritage from the threat of destruction is become a must.

Insall (1972) defined historical building as a building that have significant on its architecture, and also the history behind the building itself which portrays the architectural style, socio economic life, technology which associated with important events and characters of individuals, including the community in an important group. Fielden (2000) found that as buildings that have architectural, aesthetic, history, documentary, archaeological, economic, social, political and spiritual or symbolic values. If it has survived the hazards of one hundred years of usefulness, it has a good claim to being called historic. Meanwhile, he also added that historic buildings are ones that give us a sense of wonder and make us want to know more about people and culture that produced it.

To study the context of historical building defects in Malaysia, there are several defects can be found which are fungal attack, unwanted growth, erosion in mortar binding, paint flaking and blistering, defective plaster, wall cracking, defective rain water downpipe, wood or timer decay, insect and termites attack, defective roof structure, dampness, unstable foundation and installation of air-conditioning system that can be a source of building's dampness in historical building. (Ahmad, 2003). According to National Building Agency (1985), building defects occur because of design deficiency, or poor quality workmanship, or because of the building was not built based on the original design, or because of it is follow to the factors that do not fit with the design requirements. Whether the cause of building defects involved a single factor or combination of factors that indicated to defects, it would result in obvious defects due to changes in the composition of the building itself, with the shape, size or weight of the material, or just with the visibility of defects. Many building defects arise from dampness or high moisture content in the historic building. This is what had been proved by Trotman (1994) that dampness contributed more than 50% of all known building failure while Hollis (2000) expressed that dampness is inextricably linked to most building deterioration. The building which is close to the source of water will have to bear the various problems associated with dampness. They are symptoms of dampness like the effects of dirt spots on the building, biological plant like the growth of fungi, mosses and creeping plants, and dampness affects into the paint like paint flaking, paint flaking peeling and blistering of paint flaking. In addition, the cracks occurred also due to soil water content are too high to cause settlement on historic buildings. To learn more about the dampness in the historic building, dampness in the building should be understood in order to find the exact cause of dampness in the building. An understanding of dampness, the factor that causes dampness and its impact towards the historic buildings should be identified first.

DAMPNESS IN BUILDING

Dampness can be defined as water penetration through the walls and certain elements of the building where it is near to a water source. It is not only can speed up the building defects, but also it would detrimental to the building equipment. In addition, dampness can also be defined as extreme moisture that will lead to dampness problems. Problems such as cosmetics defect is harmful in terms of decor, fabric damage, structural problems, or at a certain circumstance it would has an adverse impact on the health of residents (Oxley, R, 2003). Other definitions that have been expressed by Gobert (1994) are extreme moisture can cause structural damage, it would lead to wood decay, and it would damage the decorations and bolster growth of mould and fungus that can harm health. Meanwhile, Briffett, C. (1994) described dampness as the excessive quantity of moisture contained within building materials and components which cause adverse movements or deterioration and results in unacceptable internal environmental conditions.

According to Sharon (1996), there are five generally accepted cause of dampness in the historic building. Dampness emanating from the top of the building wall and absorbed into the wall, dampness caused by capillary action of the damp soil and through foundation or wall that hit the ground, leaking of water pipes or mechanical equipment in buildings, the internal dampness resulting from the internal activities such as cooking and building processes such as human respiratory system or temperature control, dampness resulting from the restoration and maintenance of buildings. An analysis conducted by Professor Malcolm Hollis (2000) in a book entitled "Building Surveying classifies the factors that cause dampness to four categories, rising damp infiltration condensation and leaking pipes in the building. While Burkinshaw et. al.(2004) explains that there were five factors that caused dampness that started with the water vapor condensation infiltration leaking pipes in the building water from the underground and the source such as a specific site.

DIAGNOSING DAMP

There are four stages of dampness diagnosis have been implemented to this research which was:

Stage 1 – Visual Inspection

This procedure is required to inspect the defect closely and act as a preliminary assessment for further investigation and confirmation of the defect assessed. This stage is highly subjective and based largely on experience and skill of the personnel involved. The identification of dampness problem is depends on the symptom of defect i.e. staining of water, cracking, rotten timber, decay, blister etc. The diagnosis require a knowledge of the behaviour of relevant building materials, construction knowledge, knowledge of how the use (past, present and future) of the building. The surveyor need to records the defect by description, measurement, photograph or sketch drawing. The disadvantage of this technique is the surveyor may need adopt a more scientific approach to diagnosis if the symptoms complex or conflict with other available information.

Stage 2 – Non-Destructive Test

The most widely used instrument for the diagnosis of the dampness buildings is the moisture meter. The two types of moisture meter in most common use are protimeter and moisture meter. This technique may be used to inspect or observe materials or elements of construction in place without causing alteration, damage or destruction to the fabric of the building.

I. Protimeter will be placed on the wall and the reading is determined by relative humidity reading on the equipment.

II. There are between 9 to 10 points will be pinned by using the form of grid taken in 300mm distance at wall location. It is very important to see the movement of moisture from low to high readings. From the protimeter reading the source of dampness can be determined by the interpretation of surveyor.

III. There are 3 sections of reading on moisture meter for non-wood material:
   a. Low humidity rate between 6% rH - 16% rH.
   b. Average humidity from 18% rH - 21% rH.
   c. High humidity (serious) from 22% rH - 100% rH

IV. Readings are taken and recorded in the inspection checklist.
V. The results obtained will be analysed to find the source of the problem.

Stage 3 – Destructive Test

This technique is able to provide a specific set of measurements or data in response to known or suspected dampness conditions. In this assessment it requires a collection of techniques that may be used to inspect or observe materials or elements of construction in place with causing alteration, damage or destruction to the fabric of the building. Tools or techniques that been used such as cutting pieces of material, drilling, Ion test and oven drying method. Oven drying method is the most accurate method of determining the moisture content of material is to take sample, weigh it, dry it to constant weight in an oven at a suitable temperature (100^{o}C) and then re-weigh. The dampness is expressed by the weight loss achieved by drying as a percentage of the oven dry weight of the material being examined.

Stage 4 – Assessment study

First, second and third procedures were analysed simultaneously with in-depth study based on a first procedure used to see the symptoms of dampness, second procedure to find the cause of dampness in the grid reading, and third procedures for verifying the source that was found by ion chromatography testing. The data will be analysed and interpreted in detail to confirm the presence of dampness in dampness locations.

ANALYSIS OF CASE STUDY

From the presentation of the dampness method of diagnosis is made. The analysis is conducted in order to identify the symptoms of defects caused by dampness problems and the causes that cause dampness in Fort Cornwallis

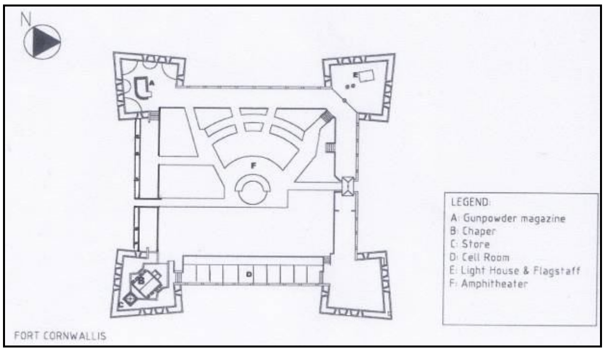

Figure 5.1: Fort Cornwallis Plan

The first stage is carried out by visual inspection according to three procedures. The first procedure is the initial preparation of dampness investigation. Initial preparation covers six criteria, which are the history of the building, construction material, soil condition, building location, surrounding and weather condition and lastly building plan and checklist. Second Procedure is initial inspection where it is divided into three criteria for inspection starting from the roof and rainwater components, drainage and underground pipe system and lastly inspection of building foundation. The third procedure in the visual inspection is to check the area of dampness zone to identify the symptoms of defects due to moisture and the causes that lead to the dampness of building. The symptoms of moisture and defects should be recorded in special form. The best method is each defect will use one checklist. The photograph of the symptom of dampness is shown in photograph 5.1 below.

Photo 5.1: Dampness Symptoms

The second stage was done by using in situ testing or site by non-destructive test in the zone of high level of dampness that has been identified. Three criteria must be considered when carrying out non-destructive test by determining the scale dampness level in their respective level such as high dampness level, moderate dampness level and the most serious dampness level. Testing procedures at the site using a tool called moisture meters. Measurement of moisture will focus on the elements of the wall to see the symptoms such as peeling paint, friable, fungus and moss attack and so forth. Dampness level is measured by measuring the relative humidity (RH). Eleven samples were tested and the location of samples is shown in Figure 5.2.

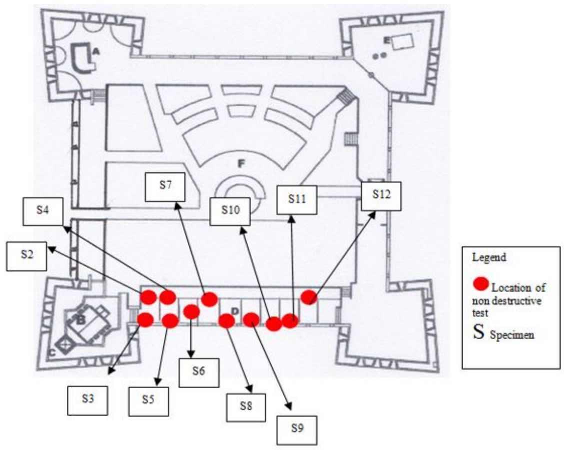

Figure 5.2: Total location for non-destructive testing

In stage 3, two types of test were conducted, first is Gravimetric (Oven drying) Method and second test is Ion Chromatography Test. The Hygroscopic and Capillary Moisture Analysis using Gravimetric (Oven drying) Method – BRE Digest 245 has been carried out. Procedure for the analysis of walls for rising dampness and the determination of hygroscopic and capillary moisture are as follow:-

1. Samples to be examined should be taken from the wall at floor or ground level at least 300mm above the height of the indicated dampness.
2. The samples should be taken by drilling, preferably in the mortar courses at about 300mm centres, to the centre of the wall. It is preferable if the inner samples are separated from samples derived from plaster, as it is frequently desirable to analyse both the masonry and the plaster.
3. The samples are obtained by drilling at a low speed with a masonry bit of about 9 to 15mm diameter. They are collected in airtight containers. Details on the position of the sample must be recorded.
4. In the laboratory, about 2g of the sample are accurately weighed (Ww) and then are exposed in a container which has a 75% relative humidity for at least 12 hours. After reweighing (W75RH), the samples are placed in an oven at 100°C until dry, and then reweighed. (Wd)

Hygroscopic moisture content at 75 RH is calculated as follows and shows in Table 3 below:

HMC = W 75RH - W4 / W 75RH x 100
TOTAL MOISTURE CONTENT (TMC) is calculated as follows:-
TMC = WW - W4 / W W x 100
CAPILLARY MOISTURE CONTENT (CMC) is calculated by subtracting HMC from TMC:-
CMC= TMC – HMC

Table 5.1: Gravimetric Method (Oven Drying)

No. Of Sample	1	2	3	4	5	6	7	8	9	10	11	12	13
Location	Soil Sample I	Soil Sample II	Room 1 Arch	Room 1 Window	Room 2 Arch	Room 2 Window	Room 3 (Roof)	Room 4 (Wall below)	Room 5 (Internal Wall Upper)	Room 6 (below window	Room 7 (window)	Room 8 (Below window)	Room 9 (Arch)
Container No.	Specimen 1		Specimen 2	Specimen 3	Specimen 4	Specimen 5	Specimen 6	Specimen 7	Specimen 8	Specimen 9	Specimen 10	Specimen 11	Specimen 12
Weight													
Container Weight	23.20	23.20	23.20	23.20	23.07	21.33	23.20	23.20	23.20	22.81	23.20	23.20	21.00
1. Original Sample (Ww)	25.20	25.20	25.20	25.20	25.07	23.33	25.20	25.20	25.20	24.81	25.20	25.20	23.00
2. Wet Density (W75)	25.17	25.20	25.19	25.15	25.11	23.28	25.19	25.17	25.19	24.75	25.20	25.17	22.99
4. Dry Density (W4) (After 24 hours)	24.74	24.46	25.04	25.13	24.71	23.27	25.76	25.16	24.80	24.73	24.66	25.14	22.98

Note: (W75) - Container in open air with Relative Humidity RH 75% for 12 hours.

Table 5.2: Interpretation of Gravimetric Method (Oven Drying)

Specimen	HMC (%)	TMC(%)	CMC(%)	Interpretation
1	1.71	1.83	0.12	Soil sample
2	0.59	0.63	0.04	0.59 > 0.04. (HMC > CMC) This is confirmed not rising damp. However the possibility of rainwater penetration could be further investigate.
3	0.08	0.28	0.2	0.2 > 0.08. (CMC > HMC) This is confirmed of rising damp. Location of sample taken below window.
4	1.59	1.44	-0.15	1.59 > -0.15. (HMC > CMC) This is confirmed not rising damp.
5	0.04	0.34	0.3	0.3 > 0.04 (CMC > HMC). This is confirmed of rising damp.
6	1.70	1.78	0.08	1.70 > 0.08 (HMC > CMC). This is confirmed of other than phenomenon rather than rising damp occurs. i.e rainwater penetration (roof).
7	0.04	0.16	0.12	0.12 > 0.04 (CMC > HMC). This is confirmed of rising damp. Location of sample taken below window.
8	1.55	1.59	0.04	1.55 > 0.04 (HMC > CMC). This is confirmed of other than phenomenon rather than rising damp occurs. i.e rainwater penetration.

9	0.08	0.24	0.16	0.16 > 0.08 (CMC > HMC). This is confirmed of rising damp.
10	2.14	2.14	0	0 > 2.14 (HMC > CMC). This is confirmed of other than phenomenon rather than rising damp occurs. i.e rainwater penetration.
11	0.12	0.24	0.12	0.12 = 0.12 Unidentified
12	0.04	0.09	0.05	0.05 > 0.04 (CMC > HMC). This is confirmed of rising damp.

For ion chromatography test, wall plaster has been drilled and collected brick dust for a salts test. All the collected samples then are sent to the Chemical Laboratory USM and Civil Engineering Laboratory UTP for further analysis. It is indicated into several names for the sample for easy explanation. Table 5.3 shows the indication of the specimens taken from Fort Cornwallis Building.

Table 5.3: Indication of the specimens

No	Specimens	Indications
1	Specimen 1	Soil Sample I
2	Specimen 2	Room 1 Arch
3	Specimen 3	Room 1 window
4	Specimen 4	Room 2 Arch
5	Specimen 5	Room 2 window
6	Specimen 6	Room 3 (Roof)
7	Specimen 7	Room 4 (Wall below)
8	Specimen 8	Room 5 (Internal Wall Upper)
9	Specimen 9	Room 6 (below window)
10	Specimen 10	Room 7 (window)
11	Specimen 11	Room 8 (Below window)
12	Specimen 12	Room 9 Arch

Procedure for the analysis of walls for rising dampness, rain penetration, condensation and the determination of chloride, nitrate and sulphate are as follow:-

1) An analysis using 792 Basic IC (Ion Chromatograph) Metrohm with (column) Metrosep A SUPP5 150 x 4.0mm.
2) In the laboratory, about 0.5g of the sample is accurately beingdissolved in 100ml air ultrapure. 1 ml being put into IC using syringe which has micro filter 0.2 urn Nylon.
3) 3 series of standard 1, 2 and 5 ppm (mg/1) being provided for chloride, nitrate and sulphate.
4) All samples will be analyzed duplicate. Only blank (air ultrapure) and control sample not being duplicated.

Table 5.4: Result from Ion Chromatograph (ppm)

No	Specimens	Chloride	Nitrate	Sulphate
1	Specimen 1	2.070	2.003	5.115
2	Specimen 2	111.441	70.776	396.569
3	Specimen 3	2.68	2.304	5.059
4	Specimen 4	101.70	62.34	445.19
5	Specimen 5	73.153	0.165	19.449
6	Specimen 6	1.27	0.46	1.48
7	Specimen 7	29.28	84.89	22.30
8	Specimen 8	111.90	71.44	554.95
9	Specimen 9	120.270	41.604	314.335
10	Specimen 10	22.40	4.83	6.08
11	Specimen 11	128.64	35.76	197.07
12	Specimen 12	210.064	15.915	230.021

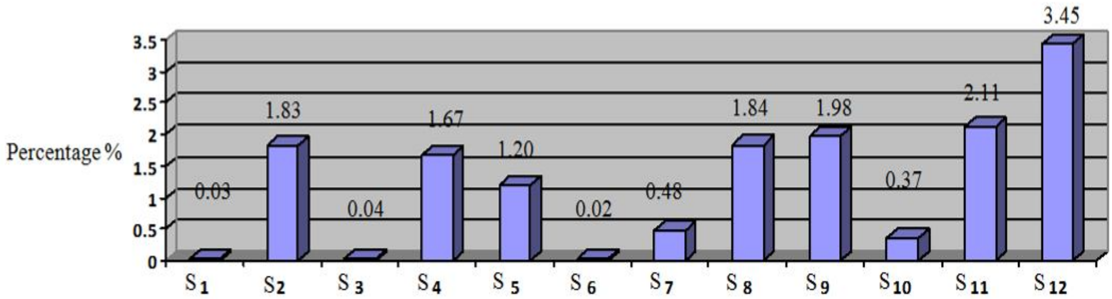

Chart 1 – Result for Chloride (Cl) of the eleven drilling sample and one soil sample

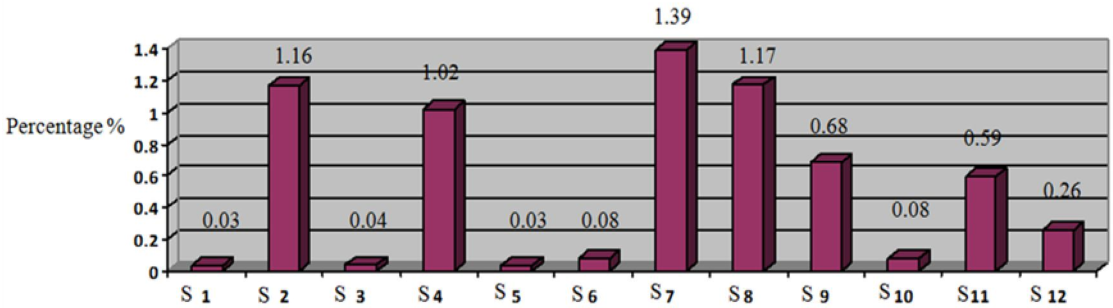

Chart 2 – Result for Nitrate (NO3) of the eleven drilling sample and one soil sample

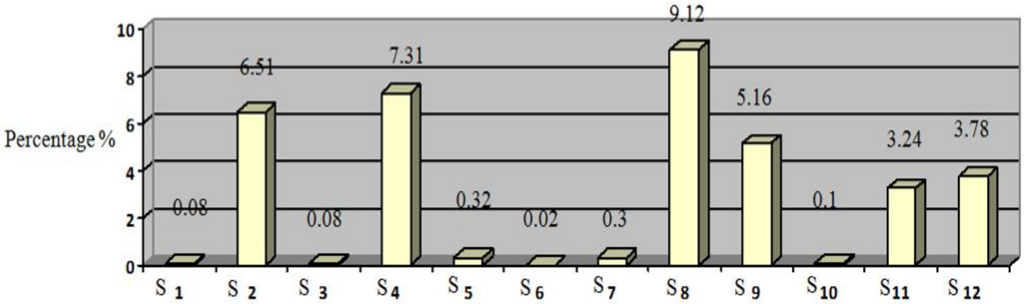

Chart 3 – Result for Sulphate (SO4) of the eleven drilling sample and one soil sample

In September 2003, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) released the results of the level of salt content in the samples tested (in the percentage of total ions). Salts in the form of Chloride (Cl), Nitrate (NO3) and Sulphate (SO4) deposits, in brick walls were found to be at an unacceptable level as the process of crystallization and hydration has caused damage to both plaster walls and brick faces (Ahmad, 2010). All percentage of salt exceeding 0.020% of total ions is considered unsafe and could cause serious damage to the brick walls and lime plaster. The CSRIO results have indicated that the percentage of total ions for SO4 in all drilling samples exceeded the safe level of 0.020%, with the highest level recorded at 9.12%. As for the percentage of Nitrate (NO3) total ions, all drilling samples also exceeded the safe level, with the highest percentage registered at 1.39%. While, the Chloride (Cl) percentage of total ions were also high in all readings, the highest being 3.45%.

Based on the ion chromatograph laboratory test, specimen 1 shows that the salt contamination is low on chloride, nitrate and sulphate because this is the original sample taken from soil up to 4.5 meters from soil surface. No significant dampness was found in this area.

Specimen 5 (1.20%) and specimen 10 (0.37%) show the present of amount chloride are high due rising damp. The location of specimen 5 and 10 are located below the window which is 300 mm from floor surface.

Specimen 2 (1.83%, 1.16%, 6.51%), specimen 4 (1.67%, 1.02%, 7.31%) and specimen 8 (1.84%, 1.17%, 9.12%) show the salt contamination is high on chloride, nitrate and sulphate. The positive result for all those salts could not have been in anyway indicative of rising damp because the salts were sample and tested up from 300 mm from ceiling. Salts at the surface had most likely leached through construction material by lateral rain penetration due to erosion mortar joint.

Specimen 9 (5.16%) and specimen 11 (3.24%) show the salt contamination is high on sulphate, followed by chloride and then nitrate. The location of specimen 9 and 11 are below window and exposed to two different sources which is from ground water and rainwater.

Specimen 12 shows the salt contamination is high on sulphate and chloride but low in nitrate. Thus, it is confirm as rising damp because the location of sample is 600 meters from floor surface.

Specimen 7 shows the salt contamination is high on nitrate, followed by chloride but low in sulphate. The location of sample is 900 meters from floor surface and close to air cond ducting. The suspected cause may be from leaks plumbing from air conditioning ducting.

Specimen 3 and 6 show all the salt contamination is very low. The dampness confirmed that it does not come from the rising damp phenomena for specimen 6 due to the hygroscopic test. While the low amount of sulphate and nitrate found in the sample while specimen 3 shows rising damp during hygroscopic test. The possibility of the chloride present and dampness occurs in this area maybe from rainwater for specimen 6 because the location of specimens is at the ceiling.

Assessment study includes analysis and comparison of samples with four indicators (Visual inspection, on-destructive test, oven drying and ion chromatograph) and come out with the right diagnosis Table 5.5 below shows the comparison that had been made including the analysis.

Table 5.5: Detailed study – analysis and comparison study

No	**Visual Inspection**	**Non destructive Test(sample)**	**Oven drying Method**	**Ion Chromatograph**	**Analysis**
Specimen 2 (Room 1 Arch)	Plaster detached	100% RH Expected causes: Condensation and rainwater penetration	0.04 < 0.59 CMC < HMC Not Rising damp	High on sulphate, chloride and nitrate. Expected causes:Rainwater penetration	Rainwater penetration , condensation
Specimen 3(Room 1 window)	Dark stain and wet	88.9% RH Expected causes: Rising damp	0.2 > 0.08 CMC > HMC Rising damp	All salts contamination is very low	Rising damp
Specimen 4(Room 2 Arch)	Plaster detached	100% RH Expected causes: Rainwater penetration, condensation	-0.15 < 1.59 CMC < HMC Not Rising damp	High on nitrate, chloride and sulphate. Expected causes:Condensation and plumbing leaks (air cond)	Condensation Rainwater penetration ,
Specimen 5(Room 2 window)	Plaster crumbling	94.9 % RH Expected causes: ground water	0.3 > 0.04 CMC > HMC Rising damp	High in chloride Expected causes: Rising damp	Rising damp

Specimen 6(Room 3 Roof)	Dark stain and wet	83.9% RH Expected causes: from roof	0.08 < 1.70 CMC < HMC Not Rising damp	All salts contamination is very low	from rainwater or condensation
Specimen 7-Room 4 (Wall below)	Water stains	69.4% RH Expected Causes: Water penetration and condensation	0.16 > 0.04 CMC > HMC Rising damp	High on nitrate, followed by chloride but low in sulphate Expected causes: Rising damp and condensation	Rising damp
Specimen 8(Room 5 (Internal Wall Upper)	Dark stain	24.5 % RH Expected Causes: Water penetration	0.04 < 1.55 CMC < HMC Not Rising damp	High on nitrate, chloride and sulphate.	Rainwater penetration, condensation
Specimen 9(Room 6 (below window)	Plaster detached	68.5% RH Expected Causes: From ground water	0.16 > 0.08 CMC > HMC Rising damp	High on sulphate, followed by chloride and then nitrate Expected causes: Rain water and rising damp	From ground water, rainwater penetration,
Specimen 10(Room 7-Window)	Mould growth	100% RH Expected Causes: Water penetration	0 < 2.14 CMC < HMC Not Rising damp	High in chloride	Rain penetration, condensation
Specimen 11(Room 8 (Below window)	Mold Growth	99.0% RH Expected causes: Various sources	0.12 = 0.12 Unidentified	High on sulphate, followed by chloride and then nitrate. from ground water and rainwater	from ground water and rainwater penetration, condensation
Specimen 12(Room 9 Arch)	Fungus attack Plaster detached	100% RH Rising damp	0.05 > 0.04 CMC > HMC Rising damp	High on sulphate and chloride but low in nitrate	Rising damp and rainwater penetration

Based on the comparison above there are several thing that did not really follow with the two types of destructive testing and unexpected result occur. For example in specimen 10 at room 7 below window, the analysis of hygroscopic salt didn't match with the ion reading. For the ion reading, it can be said that the source of dampness is from ground water because of the high chloride in the sample. However, by looking at the location that near to the window, it is probably came from rain water. It can be conclude that the sources of dampness for Fort Cornwallis building is come from various sources whether from water penetration, water splashing, rising damp and so forth. A further discussion on dampness analysis can be referred on the next sub topic.

CONCLUSION

There are many conclusions about the diagnosis of dampness problem in historical building can be drawn from this paper. The diagnosis of the dampness problem is conducted through four stages and the result had been summarised. The result interpretation has been laid down in this paper to confirm the causes of the dampness problem found from a case study. An understanding of the result is a vital part for the diagnosis because it will lead to the true diagnosis and investigation of the dampness problem in the historic building.

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REFERENCES

A Ghafar Ahmad (2004). *Undrstanding Common Building Defects The Dilapidation Survey*, Majalah Arkitek Volume 16, Issue 1 .

Zuraini Mohd Ali and Hamilton, W.N (2002), *Building Survey Role in Conservation Works*. Paper presented at 2nd National Conference on Building Control, Selangor, Malaysia, 22-23 January 2002.

Jabatan Warisan Negara (JWN) (2008). *Historic Cities of The Straits of Malacca: Melaka and George Town Towards World Heritage Listing*. Kementerian Perpaduan, Kebudayaan, Kesenian dan Warisan Malaysia, Kuala Lumpu

Insall. D. W. (1972). *The Care of Old Buildings Today*. London: The Architectural Press.

Fielden, B. M. (2000). *Conservation of Historic Buildings*. Oxford: Butterworth Architecture.

National Building Agency (NBA). (1985) *Building Defects: Diagnosis and Remedy*. London: Construction Press.

Trotman P. (1994) *An examination of the BRE Advising service database compiled from property inspection*, Paper presented at the ‘Dealing with Defects in Building Symposium, CIN/ICTE-CNR/DISET, 27-30 September, Verenna, Itay.

Hollis M. (2000) *Surveying Building*, Coventry, RB-RICS Books

Oxley, R. (2003) *Survey and Repair of Traditional Buildings, A Sustainable Approach*. Great Britain: Bath Press.

Briffett, C. (1994) *Building Maintenance Technology in Tropical Climates -Investigating dampness problem in buildings*, Singapore, Singapore University Press

Sharon C. Park, (1996) *Controlling Unwanted Moisture in Historic Buildings* retrieved from http://historichomeworks.com/hhw/pbriefs/pb39.htm

Burkinshaw, R. & Parrett, M. (2004) *Diagnosing Damp*, Coventry: RICS Book