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Appraisal Of Moisture Problem Of Inheritance Building Envelope Assemblies Via Visible And Infrared Thermography Methods

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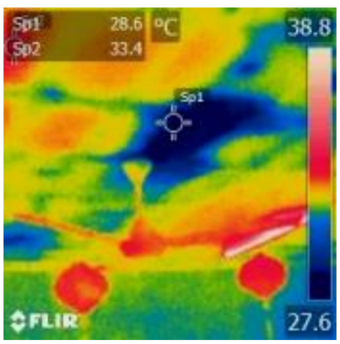
Graphical abstract



Abstract

In order to gauge the moisture performance of walls and roofs there is a need to investigate the paths of moisture penetrating into the wall assembly, how long and where the moisture stays, and whether it causes temporary reduction of performance or permanent damage. The non-contact safe nature and usefulness in temperature measurement of infrared thermography have made it a popular instrument for building diagnostics. Hence, this paper depicts a documentation process which makes use of both visible and infrared thermal images to identify moisture anomalies in heritage building envelope assemblies. In sequence to achieve the purpose, visible and infrared thermal images are recorded for comparison and further analysis. It can be concluded that infrared thermal imaging camera is useful for identification of moisture problems in building façade, whereas combination of both visible and infrared thermal imaging methods produces a more advanced, accurate and effective approach for building diagnostics.

Keywords: Moisture, heritage buildings, documentation, infrared thermography

Abstrak

Untuk mengukur prestasi kelembapan dinding dan bumbung, penyiasatan laluan kelembapan menembusi ke dalam dinding, berapa lama dan di mana kelembapan berkekal, dan sama ada masalah tersebut menyebabkan pengurangan sementara prestasi atau kerosakan yang kekal. Sifat termografi inframerah yang selamat dan keberkesanan dalam pengukuran suhu telah menjadikan teknik ini sesuatu cara yang popular untuk pemeriksaan bangunan. Oleh itu, kertas kerja ini menggambarkan proses dokumentasi yang menggunakan penggambaran digital dan termal inframerah untuk mengenal pasti masalah kelembapan dalam fasad bangunan warisan. Gambar digital dan termal inframerah telah direkod untuk perbandingan dan analisis lanjutan. Konklusinya, kamera termal inframerah adalah amat berguna untuk mengenal pasti masalah kelembapan dalam fasad bangunan manakala penggabungan kedua-dua cara tersebut dapat menghasilkan sesuatu pendekatan yang lebih maju, tepat dan berkesan untuk pemeriksaan bangunan.

Kata kunci: Kelembapan, bangunan warisan, dokumentasi, termografi inframerah

1.0 INTRODUCTION

The moisture performance of the building envelope refers to the capacity of the assembly to control moisture so that no permanent damage is caused to the assembly and no temporary inconveniences are caused to the users of the building. In order to gauge the moisture performance of walls and roofs there is a need to investigate the paths of moisture penetrating into the wall assembly, how long and where the moisture stays, and whether it causes temporary reduction of performance or permanent damage [1].

At present, there is no tool that can offer a moisture performance appraisal that takes into account all the characteristics of the envelope as mentioned above. Designers rely on the state-of-the-art practices and rules of thumbs that come from experience, codes, and guidelines that emanate from research findings, such as the requirements for air and vapour barriers. In the research field, while numerical models are being developed and fine-tuned to simulate moisture performance of envelope assemblies, some complex problems are still better investigated experimentally [2].

Moisture intrusion in building façade has become an inevitable problem. More than 98% of all water vapour movement in building cavities is caused by air movement. Through a small hole or crack, water vapours can be easily transferred by air currents and infiltrate through building envelopes. Besides, leaks from roof and faulty plumbing, seasonal flooding as well as human activities, including bathing, cooking or dishwashing, are all significant sources of high levels of humidity [3].

Due to high moisture content in building facade and its changes of state (solid-liquid-gas), a building deteriorates fast and leads to other critical problems, not only to the building itself, but also to the occupants of the building [3, 4]. Mould growth is one of the common moisture-related problems. High level of moisture in building envelopes creates an optimum habitat for mould to grow. This may results in fatality if the occupants are facing health ailments, such as asthma, lung disease or compromised immune systems, after being exposed to elevated levels of airborne mould spores. Moreover, high moisture content in building envelopes can also corrodes metal and decays timber, and eventually leads to building degradation [3, 5]. In short, it is clear that moisture intrusion in building envelopes needs to be identified and repaired in early stage before it leads to further damages to the building and its occupants. Hence, moisture intrusion has become one of the emphases in this dissertation.

Nevertheless, a wet building envelope anomaly cannot be easily detected due to its changes in shape, location and content as conditions dictate. A tool, which can scan the building surface to determine whether an excessive moisture condition presents, is essential during building diagnostics. An infrared thermograph which is able to provide such function has made it a more versatile tool for in-situ moisture detection [6].

Discovered by a British astronomer, William Herschel in 1800, infrared thermography is now one of the popular non-destructive testing (NDT) methods among building inspectors [7]. An infrared thermograph's non-contact characteristic makes it a powerful tool to detect moisture by conducting quick periodic inspections [8]. By using an infrared thermograph, temperature of an object can be measured in real time from a distance without contacting it and meanwhile a visual picture is shown so that inspectors are able to temperatures over a large area of building envelopes can be compared [9]. The exact source of high moisture can be located without demolition [10]. Since the precise problem area can be targeted, the reconstruction and repair costs are lowered.

Thermal imaging is a technique frequently used to establish the location of thermal breaks during laboratory work and field inspections; it can also be utilized to measure the moisture distribution within a material. When a material has moisture content higher than that of the surrounding environment, the moisture within the material will begin to evaporate, which causes the surface temperature of the material to decrease. The greater the moisture content, the greater the evaporative heat loss and the measured temperature drop. Thus, if the temperature decrease is measured with an infrared camera with a high degree of precision, the moisture distribution on the surface of the material can be determined.

2.0 LITERATURE REVIEW

2.1 Heritage Buildings in Penang

The restoration works of either cultural heritage monuments or traditional buildings necessitate different surveys in sequence to extort appropriate information and make practical decisions. It is quite frequent the provision of ground and elevation drawings by means of surveying or photogrammetric techniques, including in recent years also measurements with terrestrial laser scanning systems. Originally, those drawings were 2D line-based. In the 1990s, texture-based products such as digital rectified photography or orthoimagery started to complement or even replace the former in the digital era. Nowadays, it seems that exhaustive 3D models such as digital surface models are essential to analyze both outer and inner superficial features, mainly when dealing with complex scenarios and shapes.

Located at 5° north and 100° east, George Town of Penang became a popular trade center due to its strategic location. During the colonial time, successful monetary economy was achieved in Peninsular Malaysia due to agriculture and natural resources on the land. In Penang, many buildings were built by British for their administration and settlements purposes. They were also built with different religious backgrounds as well as colonial influence. Heritage buildings in Penang can be categorized according to their functions. The categories are Religious Buildings and Monuments, Government Institution Buildings, Educational Institution Buildings, Landmarks and Villas and Shophouses [11].

2.2 Infrared Thermography Method in Assessment of Moisture

Infrared thermography is a process that enables the spatial variations in infrared radiance from a surface to be converted a two-dimensional image, while the infrared radiance are presented as a range of colors or tones. Generally, lighter colour indicates a warmer object whereas darker colour represents a cooler object [6]. Moisture distribution within a building material can be measured using infrared thermography method. When the moisture content in a material is high, the moisture within the material begins to evaporate. As a result, the surface temperature of a material will decrease. Hence, it is logical to say that when a lower temperature is detected by a thermal imaging camera, it indicates that the surface has greater moisture content and thus has greater evaporative heat loss [12].

2.3 Parameters that Affect Infrared Thermography

Several parameters can affect the results obtained from infrared thermography method. The parameters are listed as follows:

- Different materials have different values of emissivity. It is a surface property that highly dependent on types of materials and defines the material's capacity to emit energy [13].
- Environmental conditions such as air temperature, wind speed and direct sunlight can affect the result of thermal images, as the transfer of energy is affected [14].
- The distance between the object and thermal imaging camera has to be within 10 m, so that the value of thermal radiation will not be reduced [15].

3.0 METHODOLOGY

In this research, a case study strategy was used to achieve the research objectives in a qualitative nature. A total of four buildings are selected from the core zone and the buffer zone. In order to have a better coverage on the heritage buildings in Penang, a building located outside of the World Heritage Site is also selected as case study.

(a) (b)

Figure 1 Cameras: a) Nikon D3200; b) FLIR i7 thermal camera

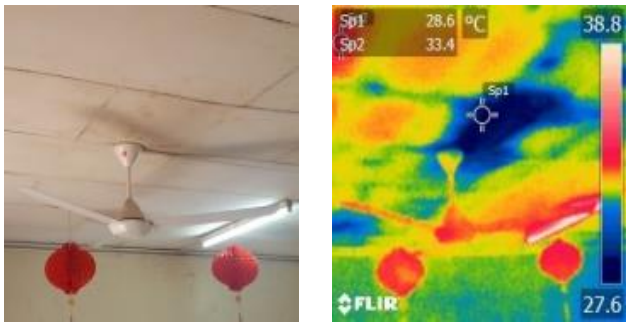
Building assessment was done at selected sites to identify moisture problems in the buildings. To conduct this research, the suspected areas of moisture in the buildings were firstly observed and recorded using a digital camera (Figure 1a). The areas were further inspected using an infrared thermal imaging camera to determine whether moisture intrusion occurred at the suspected areas. In order to prevent inaccuracy in data collection, researcher had to avoid the period of time when the sun shined directly on the building façade. The thermal imaging camera as been shown in Figure 1b is highly sensitive to temperature changes, thus overheated or shaded building façade will affect the results of the inspection. Two devices were used to carry out this study: digital camera and infrared thermal imaging camera. The digital camera used is a digital single-lens reflex camera, Nikon D3200, with 6016 x 4000 maximum resolution (24.2 effective megapixels) and wide angle lens. For the infrared thermal imaging camera, a FLIR i7 thermal camera was used. It has a high thermal sensitivity as low as 0.10°C and produces infrared images with a resolution of 140 x 140 pixels and a field of view of 29° (H) x 29° (V).

4.0 RESULTS AND DISCUSSION

Building assessment was conducted in the aforementioned heritage buildings to identify moisture anomalies in their building envelopes. Representative infrared thermal images and the corresponding photographs are shown in the sets of figures below. The emissivity options available in the infrared thermal imaging camera are 0.95, 0.80, 0.60 and 0.30. Since most the coefficients of emissivity of the building materials fall in the range of 0.90 to 0.95 (dry concrete = 0.95, masonry brick = 0.94, dry mortar = 0.94, plaster = 0.91) [16], the emissivity was set at 0.95 during building assessment. A colour bar is attached with each thermal image to show the range of temperature detected. Lower temperature is indicated using cold colours, such as blue and purple, whereas higher temperature is indicated using warm colours, such as yellow, orange and red.

4.1 Koo Saing Wooi Koon at King Street

During the day of inspection, a pail of water was accidentally poured on the floor in the room above. The water seeped through the ceiling and leave water stain on the ceiling, which can hardly be seen in Figure 2a.

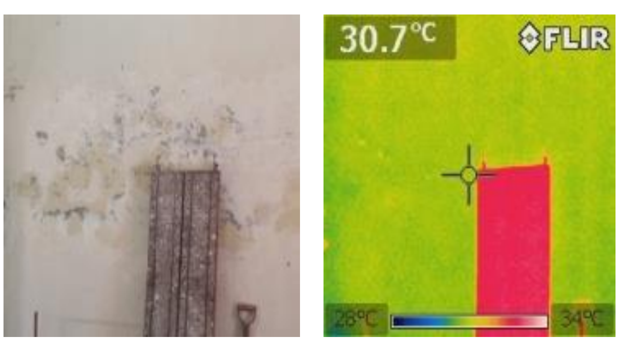


(a) (b)

Figure 2 Ceiling at the ground floor main hall: (a) visible; (b) infrared thermal image

It is possible that there are cracks on the ceiling, but exact position of the cracks cannot be identified. In the thermal image, signs of moisture, which are indicated in dark blue colour, can be clearly seen in Figure 1b. The application of infrared thermal imaging camera helps the researcher to identify the location of leakage on the ceiling.

In Figure 3a, peeled-off paint on the wall can be clearly observed. It will usually be suspected that moisture is only present at the defected area. However, in the infrared thermal image, it shows that the particular area have similar temperature as the rest of the wall (Figure 3b). Moisture spots are present in the whole wall, indicated by the blue spots covering all over the wall. The application of infrared thermal imaging camera helps the research to determine the defect more accurately

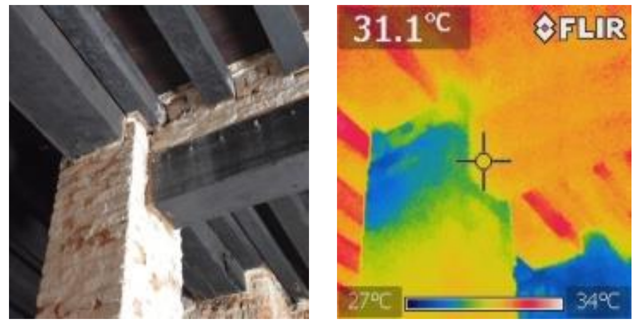


(a) (b)

Figure 3 Right wall at the courtyard: (a) visible; (b) infrared thermal image

4.2 Boon San Tong Khoo Kongsi at Victoria Street

In Figure 4a, the researcher could not detect any sign of moisture intrusion on the column through observation. When it was further inspected using infrared thermal camera, a clear image of area with lower temperature was shown (Figure 4b). Sign of moisture was detected at the upper part of the column. This indicates the presence of defected insulation in the column as the beams which are in contact with the column shows no sign of moisture. The lowest and highest temperatures detected on the column are 28.7°C and 31.2°C respectively, recorded a difference of 2.5°C.



(a) (b)

Figure 4 Column in the room at ground floor: (a) visible; (b) infrared thermal image

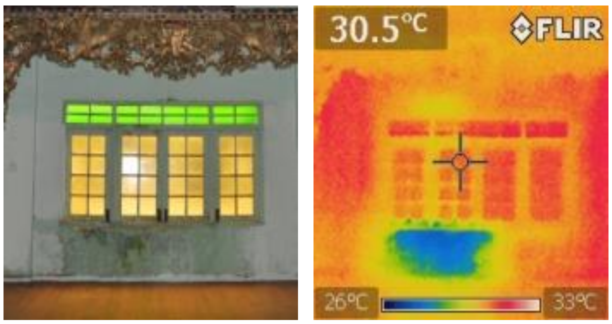
Similar to the aforementioned images, no sign of moisture was observed on the wall in the room, as shown in Figure 5a. With inspection using infrared thermal imaging camera, it shows that moisture presents at the floor-wall joint as well as the middle of the wall (Figure 5b). This may imply the missing of insulation at the particular area and penetration of ground water from the floor. The lowest and highest temperatures detected on the wall are 28.8°C and 32.4°C respectively, recorded a difference of 3.6°C.

(a) (b)

Figure 5 Left wall of the room at ground floor: (a) visible; (b) infrared thermal image

4.3 Loo Pun Hong Association at Love Lane

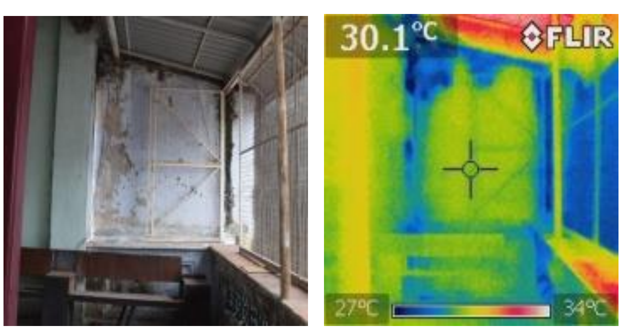
Peeled-off paint was clearly observed on the wall, as shown in Figure 6a. It can be suspected that moisture intrusion appears in the façade. Inspection through infrared thermography method shows that, only a small part of the wall faces moisture problem. Lower temperature can also be detected at the window pane, which implies that the affected area is caused by seepage of water from the window pane. Generally, the wall has the same colour tone, which is red in colour; however the area around the defected area shows yellowish tone, which depicts that temperature reduces gradually while getting closer to the defected area (Figure 6b). This helps the researcher to identify potential areas where moisture problem may present. The lowest and highest temperatures detected on the wall are 27.9°C and 30.8°C correspondingly, recorded a difference of 2.9°C.



(a) (b)

Figure 6 A wall at the front hall at first floor: (a) visible; (b) infrared thermal image

Figure 7a was taken at the balcony at the first floor of the assessed building. Fungus stain was discovered at the corner of the wall which was in contact with the roof. The infrared thermal image (Figure 7b) shows the heat flow in the wall. The temperatures at the corners and sides area are relatively low as compared to the middle of the wall. It can be implied that those areas are consistently exposed to water. Water flows down the corners through the gaps between wall and roof, gradually penetrates through the building façade. Although the metal sheet roof was exposed under sunlight, signs of moisture could still be detected at the corner of the roof. The lowest and highest temperatures detected on the wall are 27.7°C and 30.5°C respectively, recorded a difference of 2.8°C.

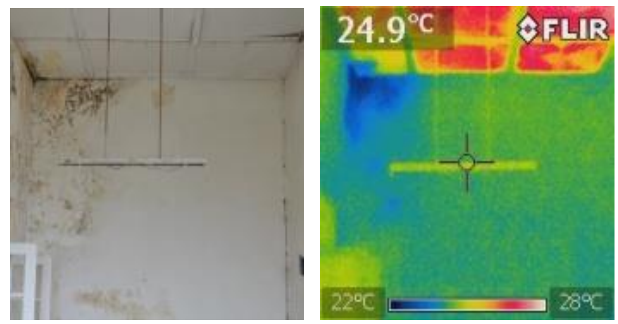


(a) (b)

Figure 7 Left wall at the balcony at first floor: (a) visible; (b) infrared thermal image

4.4 Bel Retiro Gatehouse at Penang Hill

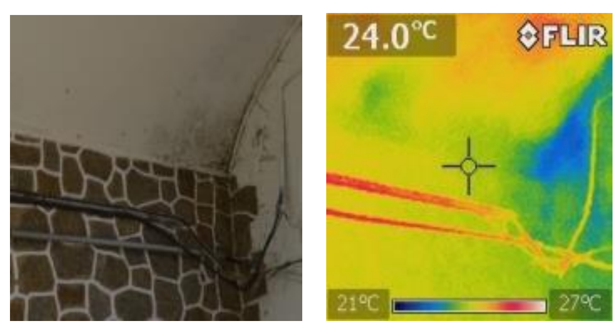
Fungus and water stain at the corner of the wall can be clearly seen in Figure 8a. It is logical to suspect that there are cracks at the ceiling where water flows into the building through the gaps. In Figure 8b, the assumption is confirmed as lower temperature is detected at the connection area between the wall and ceiling. Water vapour is trapped at the corner of the wall and gradually spread to other parts with lower moisture content.



(a) (b)

Figure 8 A wall in the left room at ground floor: (a) visible; (b) infrared thermal image

Similar to the aforementioned figure, fungus stain can also be seen at the arch of the main entrance (Figure 9a). External façade has higher potential to be intruded with moisture as it exposes to external environmental conditions more than the internal façade. With the help of infrared thermal imaging camera, the exact location of leakage of water can be determined as can be seen from Figure 9b. The darkest area indicates the lowest temperature detected, which is most probably the location of cracks that causes seepage of water.



(a) (b)

Figure 9 Arch at the main entrance of gatehouse: (a) visible; (b) infrared thermal image

5.0 CONCLUSION

This paper shows the process of documentation in indentifying moisture problem in heritage building envelopes using visible and infrared thermography method. Through this study, it can be concluded that application of both visible and infrared thermal images gives some promising results in detection of moisture problem with heritage building envelopes. There are findings which cannot be obtained through visible images. With the help of infrared thermography method, invisible moisture shapes due to water infiltration can be detected.

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