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Evaluation of the infrared thermography technique for capillarity moisture detection in buildings

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Abstract

Moisture problems are very frequent in buildings and, in most cases, are only visible when they are in advanced stages, thus causing financial losses and damages, and presenting difficulties for repairing to owners. Among nondestructive tests available in the market, infrared thermography has the capacity to be applied for this type of problem, since it can identify hidden problems and inspect large areas besides being fast and easy. In this sense, this article is intended to verify infrared thermography applicability for moisture detection by capillarity in buildings. Work methodology was developed through inspection of a building that presented evident signs of moisture by capillarity as well as potential development of this type of problem. Inspections were carried out during rainy season, when this type of manifestation develops the most. During test period, it was possible to verify that infrared thermography can accurately detect areas affected by humidity. However, it does not provide any information about problem severity. The thermal gradient between affected and intact areas may indicate the best inspection times -which occur when these values are at the highest level- as well as times not suitable for this activity. Despite finding failures, thermography presents many limitations, as it is influenced by environmental conditions, inspection schedule and the type of material where an issue takes place.

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Keywords: Infrared thermography; pathological manifestations; moisture.

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1. Introduction

Issues related to water infiltration present a recurrent and common problem, since humidity is one of the main causes for developing different pathological manifestations in buildings. These issues compromise performance of buildings, cause inadequate conditions for users, and rapidly deteriorate constituent materials (Barreira et al. 2016). Depending on building conditions and characteristics, moisture may arise from soil and rise through capillarity phenomenon, which usually occurs on walls without adequate waterproofing, or when constituent materials reach the end of their useful life (Freitas et al. 2008).

Inspection and evaluation of ambiences affected by infiltrations present many complications because these problems may not be found. When detected, deterioration may be at an advanced stage, representing costly repairs (Freitas et al. 2014). Furthermore, in most cases destructive tests that end up damaging the structure and causing damage to users are used. In this sense, different non-destructive tests have been developed and applied to assess different problems in buildings (Fox et al. 2016, O'Grady et al. 2017). Specifically for moisture detection, infrared thermography has proved its applicability (Edis et al. 2014, Menezes et al. 2015, Barreira and Freitas 2007).

Infrared thermography consists on measuring thermal radiation emitted by an object surface, captured by a thermographic camera. Then it is converted into electrical signals to be presented later as thermal images known as thermograms, so that each color represents a temperature range according to an established scale (Lourenço et al. 2017). Its application is divided in two categories, active and passive, which depend on heat sources. Passive thermography does not require external heat sources, with solar energy and ambient temperature being the main resources used (Rocha and Póvoas 2017). On the other hand, active thermography requires external stimulation sources, which may be subdivided according to nature of stimulation, such as: Lock-in, Pulsed, Pulsed-Phase, among others (Maldague 2001).

Infrared thermography has many advantages: it can perform a quick inspection and analyze large areas; it does not require direct contact with the subject surface; it is capable of defining impacted areas, and analysis is performed in real time. Results are easy to read and may be applied to different purposes. However, it has some limitations: a high equipment cost; it does not provide an anomaly scope, and objects studied must not be in thermal balance with the environment, among others (Melrinho et al. 2015, Grinzato et al. 2011).

According to infrared thermography, moist area temperatures may be lower than dry areas due to evaporation, but temperature may also be higher, depending on high thermal water inertia compared against materials of subject area (Grinzato et al. 2011).

Although infrared thermography technique has been consolidated as a method for civil works inspection, including detection of moisture-related anomalies in building components, no standards to regulate its use for infiltration issues are available. Instead, ambiguities in data treatment and interpretation are present. In this sense, this article aims to prove applicability of infrared thermography for moisture detection by capillarity in buildings, considering not many projects applied in relation to this subject are present.

2. Methodology

This project was developed through case study of a building that showed evident signs of moisture by capillarity. Initially, a visual inspection was performed to verify deterioration degree and pathological manifestations caused by water infiltration. An infrared thermography test was conducted during a rainy period (June), considering that, during this condition there is a greater evolution of this problem.

Subject building is a residence located at Olindense street, Jardim Fragoso, Olinda/PE (Fig. 1a). The main facade faces northeast; however, the subject wall is located in the inner area of the building and does not get any direct sunlight (Fig. 1b).

This building was built is approximately seven years old. It consists of a ground floor and a first floor. Both internal and external walls are covered with mortar and paint only on the ground floor, since the first floor is under construction. Fig. 2 shows current building condition.

For this study, passive thermography was used, since no external heat source was required for temperature differentials to be present. A test was performed over a period of 9 hours, which included a period from 8:00 AM to

5:00 PM, taking thermograms at one hour intervals. In addition, values of ambient temperature and relative humidity of inspected environment were recorded by a thermohygrometer.

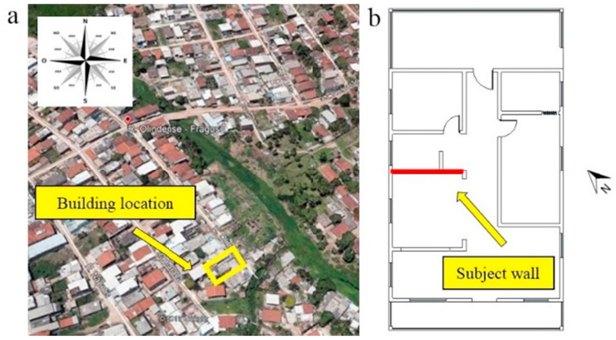

Fig. 1. (a) Building location and (b) scheme of subject wall. Source: Google Earth (2017).

Fig. 2. Main façade of the building.

Distance between the subject wall and the thermographic camera was 2 meters, a value that was consistent with space availability in the room and the potential for capturing the whole affected area.

A FLIR E-60 camera with a resolution of 320x240 pixels and a thermal sensitivity lower than 0,05 ° C, among other characteristics (FLIR 2013), was used.

Emissivity of the subject wall was determined by the "black tape method", which consists of using a tape with known emissivity, where a piece is placed on the wall and then emissivity value up to the temperature of the same temperature of the tape is interacted. This corresponds with material emissivity. The value obtained was 0.94. Temperature was obtained by means of reflection method described in the camera manual (FLIR 2013), which consists on measuring the temperature of an aluminum piece folded and kneaded using the value as emissivity of 1; this parameter was determined for each thermogram.

For analysis of results, we used the thermal contrast expressed in Equation 1, which compares a region unaffected by humidity (reference area) with an area influenced by humidity that presents physical characteristics of deterioration.

$$\Delta T = P2 - P1 \tag{1}$$

Where:
ΔT = Temperature difference between the dry area and the area affected by water (° C)
P1 = Dry area temperature (° C)
P2 = Temperature of the area affected by water (° C).
Fig. 3 shows location of points P1 and P2 in the subject wall.

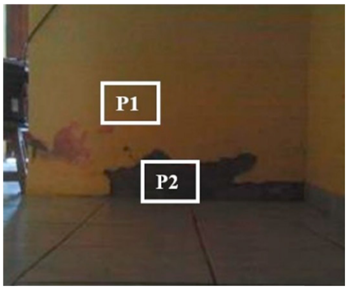

Fig. 3. Location of subject areas.

3. Analysis and discussion of results

3.1. Pathological manifestations

Pathological manifestations found during visual inspection of this building include: crypto-fluorescence, water spots on the wall and window, skirting lamination and coating cracks (Fig. 4), which are common problems related to water infiltration (Henriques 2007). On subject wall, ink detachment was mainly observed as shown in Fig. 3.

a b c

Fig. 4. Problems found: (a) Efflorescence, (b) water stain on the wall and (c) coating detachment at the wall bottom.

3.2. Infrared Thermography

Fig. 5 shows a temperature evolution in points P1 and P2 during test time, in addition to ambient temperature and relative humidity recorded. It can be observed that during the first morning hours, high relative humidity and low values of ambient temperature are present, according to points P1 and P2; but as day progresses, temperatures of the subject points increase until they reach the maximum values at noon, contrary to relative humidity with the day's lowest value. However, this behavior is reversed in the afternoon, when temperatures of points P1 and P2, as well as that of the environment, decrease as the relative humidity increases.

For a better observation of temperature difference between the dry area and the affected area, Fig. 6 shows a thermal contrast between points P1 and P2 during test time. It is observed that the highest values occur between 10:00 AM and 2:00 PM, when affected areas are clearly detected (Fig. 7a). However, values do not exceed 0,6 ° C. At 3:00 PM, as in the first morning hours (8:00 AM), small gradients, 0.1 ° C are present, which do not allow for efficient detection of these areas, as shown in Fig. 7b, thus representing inadequate periods of anomaly detection. In thermograms shown, purple areas correspond to low temperatures and yellow areas correspond to high temperatures.

While an ink detachment is present in Fig. 3, the thermogram in Fig. 7a shows that the affected area involves the whole lower area and not just the detached part.

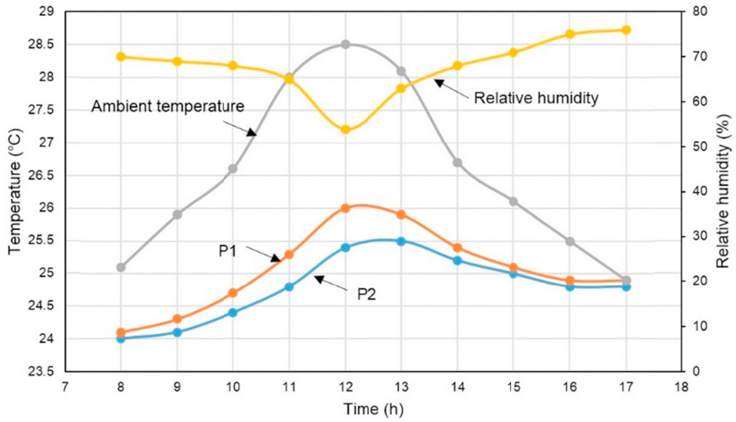

Fig. 5. P1, P2 and ambient temperatures related to relative humidity.

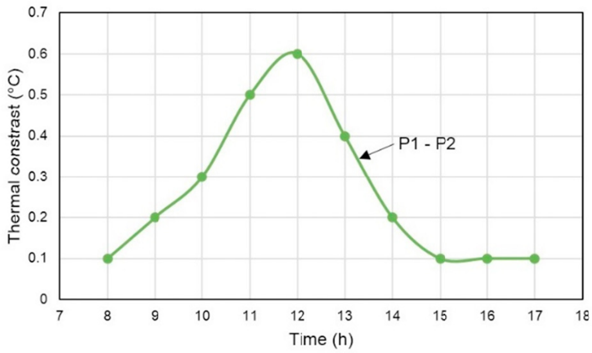

Fig. 6. Thermal contrast between P1 and P2.

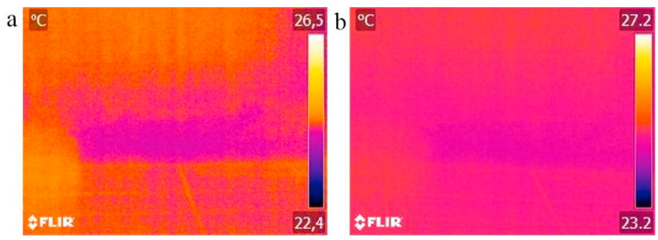

Fig. 7. Thermograms taken at: (a) noon and (b) 5:00 PM

It is important to note that thermal gradients occur when there is a noticeable difference between ambient temperature and moist area (P2). In Fig. 8 this difference is observed during test time. This detection occurred only in a period between 9:00 AM and 2:00 PM, when the difference between ambient temperature and affected area was higher than 1 ° C, whereas for smaller values, detection was limited and inaccurate. It can be concluded that detectable thermal gradients are produced when there is more than 1 ° C difference between studied areas and the environment, which is also reported and recommended by Barreira and Freitas (2007).

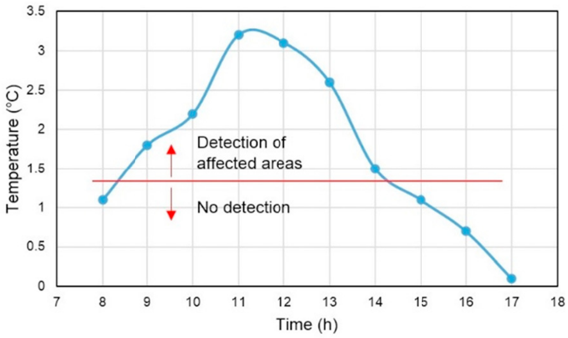

Fig. 8. Thermograms taken at: (a) noon and (b) 5:00 PM.

During all measurements, dry area temperature (P1) is higher than that of the affected area (P2), as expected. It was observed that in the first morning hours and at night these differences are considerably lower, which denotes a thermal balance between the subject wall and the environment during nocturnal period.

This behavior is mainly due to evaporation phenomenon during morning and part of the afternoon, where ambient temperature increase warms wall surfaces. However, the area affected by water presents a slower heating process, thus creating detectable thermal differentials with the thermographic camera and obtaining the highest values when the ambient temperature is higher. Even in the afternoon and at night, a balance process between the wall and the ambient temperature occurs in the presence of high values for relative humidity, thus discouraging evaporation process and expanding a cold front (Torres 2014), and therefore avoiding the creation of thermal contrasts.

Melrinho et al. (2015) point out that areas affected by humidity have lower temperatures than dry areas because water modifies the thermal inertia for material, since water has high thermal inertia, requiring greater thermal energy for a change in temperature and, therefore, emitting less radiation than dry areas. Fig. 9 diagram demonstrates this situation for the case studied.

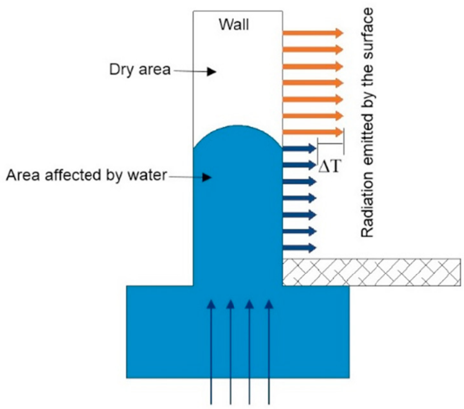

Fig. 9. Thermograms taken at: (a) noon and (b) 5:00 PM.

Through results presented, infrared thermography can distinguish those areas affected by moisture and specifically when it comes to groundwater infiltration, it shows the potential for this technique to identify the cause of these issues and predict localized and specific repairs.

Some authors indicate that thermal contrasts higher than 1 ° C reveal failures in a proper manner (Maldague 2001). However, in this study, it has been found that these values may be lower, and even detection may be possible when contrasts are higher than 0.2 ° C, considering that, being an internal wall, the main heat source to develop gradients is the ambient temperature through a convection mechanism. However, these gradients would be larger if the wall had one of its faces exposed to the environment, specifically to the sun (Rocha et al. 2018).

As this technique depends on radiation emitted by object surfaces, the use of active thermography, that is, the use of external heat source may help define and characterize these problems in a better way, since they can develop greater thermal contrasts.

Although it is possible to detect problems with infrared thermography, there is no certainty on deterioration degree or humidity level of the surface studied, for which other non-destructive equipment, such as a humidity meter, may be used, in order to provide further information on these anomalies.

4. Final considerations

In this article, a case study was developed to verify the applicability of infrared thermography to detect moisture by capillarity, by studying behavior during a rainy season day.

This test can detect areas affected by moisture accurately, although only small thermal contrasts are present, and verify that detection is possible indoors when the only heat source is room temperature.

The best detection times are those in which the greatest difference between the ambient temperature and the area inspected is present. In this case, it corresponds to hours near noon. Nighttime and first morning hours are inadequate inspection times due to a thermal balance between subject areas and the ambient temperature.

Combining with other non-destructive tests and even using active thermography may characterize these problems in a better way by providing information on the amount of water present and materials properties.

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