Infrared thermograph image analysis for the identification of masonry coatings in historic buildings, in relation to several samples prepared as patterns

L. Palaia, J. Monfort, P. Navarro, R. Sánchez, L. Gil, A. Álvarez, V. López & S. Tormo
Polytechnic University of Valencia, Spain

Abstract

The application of non-destructive methods for architectural heritage knowledge is of extreme importance, in order to avoid producing irreparable damage. The methods to gain this knowledge should be complementary to other types of studies and tests, to make the process of building assessment easier. The detection of previous openings of doors and windows, walls that have been demolished and later disguised under mortar coatings, allows interpretation to act on those points if necessary, without affecting the conservation of the original coatings existing in the building. It is possible to achieve this aim using infrared thermography (IRT); this research group has applied it successfully in some historic buildings. Some samples have been prepared in the laboratory, consisting of bricks coated with different types of mortars hiding iron plates. Later, IRT images of these samples were captured, which were compared with IRT images of the facades of an existing building. Conclusions were reached from this experience that could be extended to other situations.
Keywords: infrared thermography, façade coatings analysis, non-destructive diagnosis, historic buildings.

1 Introduction

The evaluation of historic buildings on site using destructive techniques is against the proper attitude for achieving conservation aims. The development of non-destructive evaluation (NDE) techniques should be considered essential.

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Infrared thermography (IRT) is applied for non-destructive evaluation in many fields. One of these is the surveying of ancient buildings [1–3], producing no damage to the existing construction elements. Research carried out in this field shows that this method could be used as a non-destructive approach to building surveying [4, 5].

According to Maldague [6], each NDE technique has its own strengths and weaknesses. In the case of thermography, the strengths are a fast inspection rate, no contact being established with the building inspected; safety, as no harmful radiation is involved, and results relatively easy to interpret (image format). However, it is also important to consider the effects of thermal losses (due to convection, radiation and conduction), perturbing thermal contrasts; the cost of the equipment (basically of the IRT camera) and that this technique enables the detection of only subsurface defects resulting in a measurable change of thermal properties.

As mentioned above, the technique involves the measurement of radiated electromagnetic energy emitted by a surface at its temperature. It is called the spectral radiance and is governed by Planck's law. Infrared thermographic images are produced by the emitted radiation E of a solid at a specified temperature, per unit surface and time; this value is given by the Stefan-Boltzman expression [7]

$$E(T) = \varepsilon(T)\sigma T^4 \tag{1}$$

where T is the absolute temperature of the solid, σ is the Stefan- Boltzman constant, independent of the solid material and its temperature T, and ε is the material's emissivity. Its value is between 0 and 1, being 1 when it describes a solid with the maximum emissive capacity, the so-called black body.

Emissivity also depends on temperature, though, within specified temperature ranges, it may be considered as a constant for the great majority of solids. This is the case of the building materials commonly used in construction. So, for example, it may be accepted that the emissivity of building materials does not vary significantly within the temperature range corresponding to ambient variations. It also may be assumed that the emissivity of the common building materials lies between 0.7 and 0.9 (except for metallic materials, whose emissivity is lower than these values).

When analysing an IRT image for the assessment of an architectural surface, two factors should be considered: the temperature and the emissivity. For that reason, a qualitative IRT analysis, based on the intensity of the images produced by differences between radiated emissions by architectonic elements situated close to the surface, must be performed considering that the variations shown in the image may be produced by a difference in the emissivity or by a difference in temperature. Obviously, these differences could only be detected between building elements of different nature existing in the same surface.

The difference in temperature between a building element and any point adjacent to it will depend, basically, on its mass, its specific heat or thermal conductivity, properties that may produce a substantial variation in its thermal inertia with respect to its adjacent points. This different thermal inertia will produce variable differences of temperature between this element and its surrounding area, in the heating and cooling processes of the building façade. For this reason, a façade assessment requires the analysis of several IRT images obtained at different moments of the heating or cooling processes.

2 Historic buildings survey

Historic buildings should be preserved from destruction. They need to be conserved, maintained, repaired or restored. This means that no damage must be introduced to the buildings during their assessment. On many occasions, some exploration work is done to gather information about the building materials, the previous layout and structural organization. It is useful to reduce this exploratory work in a way that would lead to less destruction of the original elements. IRT images can be used for this purpose.

3 Previous experiences

The first approaches with the IR thermocamera gave interesting results for the detection of building material discontinuity under the façade coatings. This device was able to capture images of the building walls, producing thermal images showing lintel elements as in figs. 1 and 2, also previous repairs and signs of demolished walls on the existing ones, as in figs. 3 and 4. A previous window that had been walled up was also identified, as in figs. 4–6.

Figure 1: Existing window.

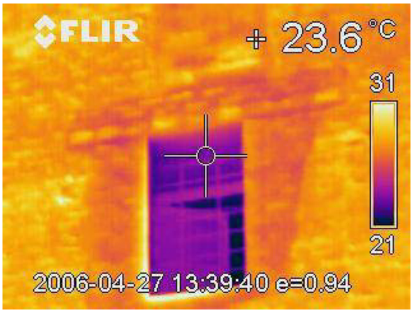

Figure 2: IRT image showing the lintel.

A medieval tower was surveyed by means of IRT images, with promising results, so the research group resolved to improve the applied method. In this tower, located at Torrent village, close to Valencia City [7], different IRT images were captured in the same day, at different hours, in order to detect the best time to capture IRT images. The factors considered for the IRT images analysis were insulation level, orientation and wind velocity.

Images were compared and it was determined that the best hour of the day to take the IRT images was from 20:00 hours onwards, in summer time, when the building materials were cooling down after a sunny day. It was possible to identify walled up hollows and to determine the humidity presence.

Figure 3: Image of the wall.

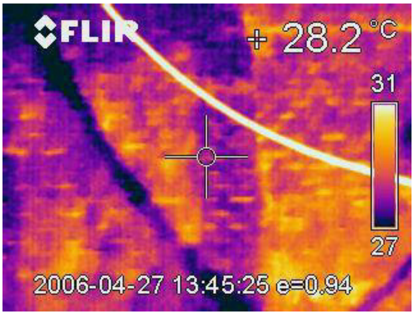

Figure 4: IRT image showing a previous transversal wall, today demolished.

Figure 5: Image of a wall.

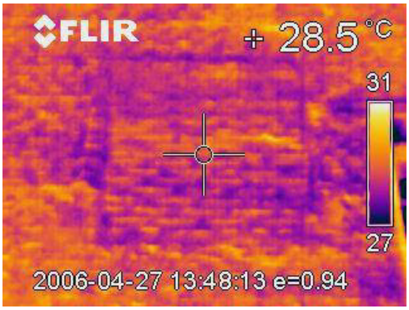

Figure 6: IRT image showing a walled up window.

Figure 7: Detail of the tower.

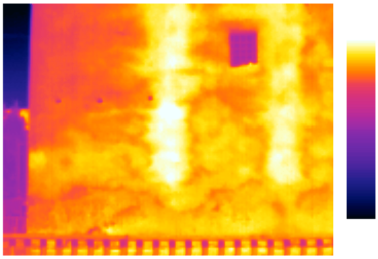

Figure 8: IRT image of the same area, showing a previous opening.

4 Experimental procedures

As mentioned earlier, the majority of building materials usually employed in construction have emissive values, lying within the 0.7–0.9 range. Different mortar coatings have special relevance because of their frequent use in historic building facades.

An IRT analysis of the mortar coatings of historic buildings demands a preliminary study of the emissive behaviour of different mortar types. For this purpose, a comparative study of several mortar types was carried out as part of this research, in order to quantify the thermographic appraisal of their possible emissive differences.

The passive infrared thermographic approach was employed using a B2 thermocamera by FLIR System, with field of view/min focus distance of 34°×25°/0.1 m Automatic, thermal sensitivity <0.10°C at 25°C, a Detector Type Focal plane array (FPA) uncooled micro bolometer and spectral range 7.5 to 13 µm. The temperature range of the IRT detector extends from –40 to +300°C.

Mortar samples were prepared with the following characteristics: manual bricks, measuring: 22.5×10.8×3.4 cm^3; wooden frames to provide uniform thickness of mortar coatings, 4.6, 5.5×6.5×3 cm^3 (section); iron plates, 30×120×2 mm^3; current sand for mortar coatings, cement CEM II-B L 32.5 N; gypsum YG and soaked lime.

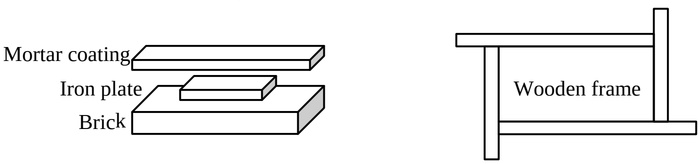

Figure 9: Samples scheme.

The mortars prepared as samples were: cement mortar, 1:3; lime mortar, 1:3; gypsum mortar, 1:2, with increasing thickness as shown in table 1. Iron plates were introduced beneath the mortar coatings in nine of the mortar samples (1 to 9), with the aim of detecting their presence thermographically. The preparation of the samples can be seen in figs. 10–15. The samples exposure to sun radiation is shown in fig. 16 and the corresponding IRT images at 16:30 hours are shown in figs. 17 and 18.

Table 1: Samples characteristics.

Sample Nº	Mortar type	Thickness	Iron plate
1, 4, 7	Cement mortar	1, 2 and 3 cm	yes
10	Cement mortar	3 cm	no
2, 5, 8	Lime mortar	1, 2 and 3 cm	yes
11	Lime mortar	3 cm	no
3, 6, 9	Gypsum mortar	1, 2 and 3 cm	yes
12	Gypsum mortar	3 cm	no

Samples 1, 4, 7 and 10 were prepared with cement mortar, those numbered 2, 5, 8 and 11 were prepared with lime mortar, and finally, samples 3, 6, 9 and 12 were prepared with gypsum mortar, always varying the thickness: 1, 2 and 3 cm. Samples 10, 11 and 12 did not contain iron plates and have a 3 cm thick coating. IRT images were captured at different times: 15:30, 16:30 and 17:30. The obtained results were very revealing.

Figure 10: Wooden frame preparation.

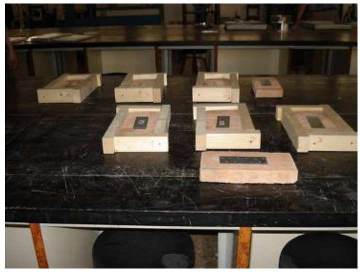

Figure 11: General view of the samples with the bricks and iron plates present.

Figure 12: Cement mortar samples.

Figure 13: Lime mortar samples.

Figure 14: Gypsum mortar preparation.

Figure 15: Gypsum mortar samples.

Firstly it should be mentioned that the temperature reached by the samples of the same thickness was the same. For this reason, the different emissivity must be analysed between samples of the same thickness. This can be seen in the first group of samples, numbered 1 to 3; the sample with the highest emissivity is the cement mortar type (nº 1) and the sample with the least emissivity is the gypsum mortar type (nº 3). The same behaviour is clearly observed in samples nº 4–6, where the thickness of the mortar coating is 2 cm. For samples nº 7–9 and 10–12, the differences between emissivity are not detectable. Considering that all of these six samples were coated with 3 cm mortar thickness, their temperature is less than that of the first six samples, nº 1–6, with 1 and 2 cm coating thickness.

Figure 16: General view of the mortar samples.

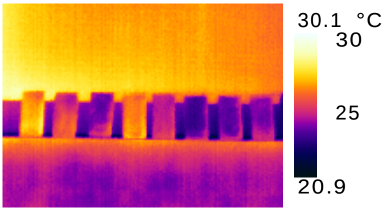

Figure 17: IRT images, samples 1–8.

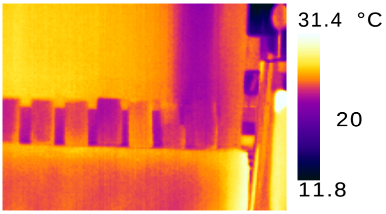

Figure 18: IRT images, samples 6–12.

At this point, a very important conclusion can be reached: the differences between the emissivity of different coatings of various compositions at the same temperature are clearly identified in an IRT image at a high enough temperature. Cement mortar coatings present higher emissivity than lime mortar coatings and the latter show higher emissivity than those made with gypsum mortar. A clear value where this step is produced cannot be determined.

However, it can be established as a second conclusion that the IRT image of a building façade will be significant if it has reached a minimum temperature with enough uniformity. For this reason, the IRT image should be obtained after the heating process of the surface, and, as mentioned previously, in different moments of the cooling down process to evaluate the different thermal inertia effect of its elements.

It was not possible to identify the iron plates through the thermographic images. It must be considered that the emissive values are measured under conditions of emissivity involving radiation in the open air. Therefore, even with the metallic element emissivity being lower to that of the mortar coating it, the less radiation of the iron plate is masked by the emissivity of the mortar covering. This issue should be examined further, but an initial hypothesis about it may be established, by proposing that hidden elements could be detected when they have enough mass with a different specific heat or thermal conductivity, to show a different temperature to their coatings, so a different emissivity from that emitted by their coatings could be seen.

A better approach whereby this behaviour could be detected is when the mortar coatings are applied to a historic building façade. In this way, the adjustment to the heating process of the façade is simulated with one of the mortar samples, avoiding the isolated heating effects of the samples previously considered.

The next phase of the research was to apply the same mortar coverings over the existing walls of an ancient building, located at Picanya (fig. 19), which is going to be reused as an administrative centre. It is a free standing building, with orientation to all directions in the four façades and different construction systems in the walls, such as brick walls, pisè, and masonry work.

As the wall coatings had deteriorated, it was possible to prepare "in situ" samples, 30×30 cm^2, 1 cm thick, using the same proportions as of those prepared in the laboratory. A small coin was introduced at the centre of each sample, in order to detect them with the IRT images.

Figure 19: Picanya – historic building. Principal façade (east).

Figure 20: Mortar samples at the south façade.

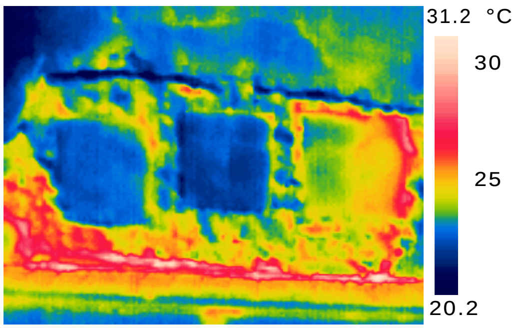

Figure 21: IRT image of the mortar samples at the south façade.

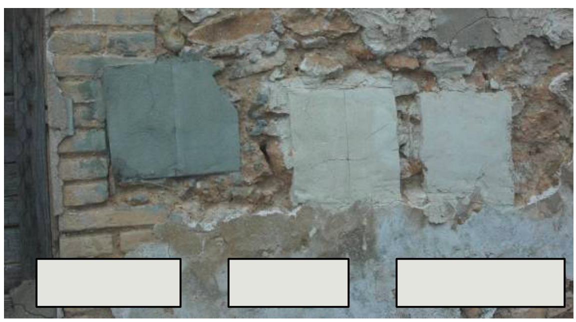

Figure 22: Samples at the west façade.

The emissive behaviour of the different mortar types can be observed in these ITR images of the samples as before, so that the conclusions reached previously can be valid for mortar coatings applied to the walls. When the building materials present a high emissivity in the same temperature ranges, the different composition can be clearly detected by IRT images.

This work opens an interesting line of research in IRT images of historic buildings analysis based on the comparison of IRT images with qualitative sample images of materials or elements previously studied.

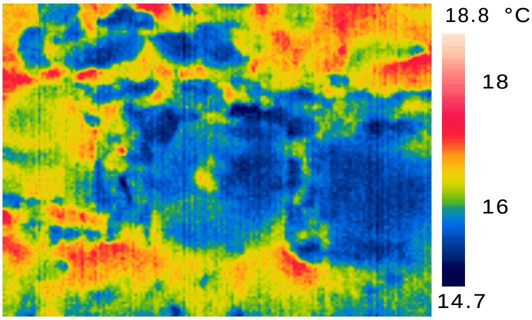

Figure 23: IRT image of the mortar samples at the west façade.

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