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Anomalies detection in adhesive wall tiling systems by infrared thermography

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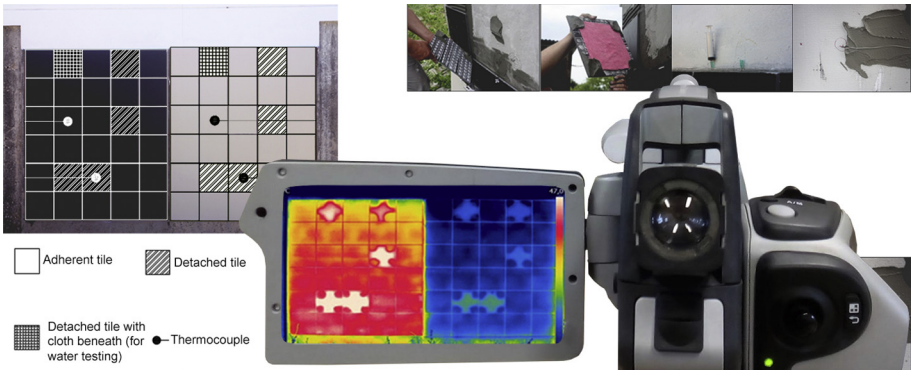
HIGHLIGHTS

- Assessing the capacity of infrared thermography in detection of lack of adhesion in tilling systems.
- Proving the capacity of detecting moisture in tilling systems and relating it with the presence of detachments.
- Analysing the influence of the tiles' colour and kind of support on thermographic inspections.
- Determination of the best period of the day to conduct a thermographic survey.
- Understanding the repercussions of thermal variations in tilling systems.

GRAPHICAL ABSTRACT



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ABSTRACT

Adherent tiling systems are widely used all over the world as wall cladding because of their aesthetic and technical characteristics. However, anomalous behaviours often occur; compromising the overall behaviour of facades, and possibly raising safety risks. The need to create expeditious, non-destructive and accurate methods of inspection that can encourage these systems' inspection and maintenance fomented a research study on infrared thermography's capacity of early detect anomalous zones in adhesive tiling systems, such as detachments or presence of humidity, in controlled *in situ* conditions, proving it as a valuable diagnostic tool.

1. Introduction

Adherent tiling systems are one of the most used wall cladding techniques in several countries. Despite widely used due to its known aesthetic and technical characteristics, it is considered as a complex system, being composed by three components with different characteristics, purposes and technical requirements: the adhesive grout [1], the tiles [2] and the joint filling grout [3].

The complexity of this cladding system makes it vulnerable to numerous possible anomalies that can compromise the systems' purpose of cladding the wall, protecting it against weathering agents. Among the anomalies that can occur in this kind of cladding - such as the tiles' cracking, detachment of the tiles' glaze, efflorescences -, lack of adhesion and detachment of tiles deserves

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special attention. This happens not only because tiles detachment is the most commonly verified anomaly in adherent tiling systems - representing approximately 50% of the verified anomalies [4,5] or even reaching 71% in the case of Brasília [6] - but also because of the consequences it comes with, implying the loss of the cladding's aesthetic purpose, its functional requirements and raising safety risks.

Detachment of tiles occurs either due to lack of cohesion of the mortar which is traditionally applied to level the surface of the wall or because of loss of adhesion between at least two of the following layers: the support (in this case the surface of the wall to be cladded), the adhesive grout and the tile. At first the loss of adhesion gives place to an empty space that can be filled with air or water. The problem usually evolves into a complete detachment and consequent falling of the tile. In the meantime, especially if the detachment is provoked by thermal expansion [7], the tiles' buckling can be observed. The earlier phase, characterized by the lack of adhesion between components, is the one that will be studied and, therefore, tiles with lack of adhesion will be named as detached, despite not being actually separated from the wall. Besides the mentioned problems, there is the fact that this anomaly can only be detected by contact and sometimes destructive methods (such as percussion method, sphere-crash test, ultrasounds or pull-off [8,9]). Furthermore, there is no easy way of solving it but removing and re-adhering the tiles, which in some cases is very difficult due to dimensional variations. The injection of a grout to re-adhering the tiles can be used in a preliminary phase, when the detached tile is not yet significantly displaced from their original position.

Given all the inconvenience and limitations associated with this anomaly it is necessary to study more practical and expeditious methods of inspection, capable of detecting anomalies in a preliminary phase.

Infrared thermography (IRT) is a non-destructive (NDT) and non-contact testing method that consists in measuring the thermal radiation that comes from a surface and transform it into electrical signals equivalent to temperatures that are displayed in the form of a thermal image (thermogram) in which different colours correspond to different temperatures, according to a defined scale.

Despite these NDT's raising recognition as a building inspection method, being currently used to analyse for example the existence of thermal bridges, lack of thermal insulation, air infiltrations/exfiltrations, presence of moisture or anomalies in waterproofing systems [10,11], at the moment there are no standards covering its use on tiling systems' inspections. Therefore, following the examples of some studies already made on tilling systems' inspections [12–16] or directly related subjects, for example detection of moist in waterproofing systems or detection of detachments in renders [17–24], it is important to continue the study of this NDT's capacities under different conditions to promote its acceptance.

Despite IRT's capacity in detecting moisture problems has already been proven *in situ* [14,16,22–28] it is not an anomaly specifically related with tiling systems, as it can happen in almost all kinds of constructive solutions; there are two main reasons that lead to believe that humidity detection in tiling systems is considerably different from its detectability in other claddings. In first place the different characteristics between this system's components, which are known as a challenge to an infrared inspection. In second place, the very low water absorptivity of some tiles (especially the porcelain tiles) which makes it very difficult for the water to be present within the tiles. Hence, unlike in other kinds of façade finishing coatings such as plasters or porous stone claddings, water will only be present either beneath the tile (which might difficult inspections) or over it (visible to the human eye). However, as water evaporation is an endothermic reaction inducing local surface cooling [24,25], it is considered that, with solar heating, a cooler zone will be noticed when water is introduced beneath the panels. Therefore, studying the humidity detection in this kind of cladding is considered important.

2. Infrared thermography and anomalies' detection in building facades

In order to understand infrared thermography it is needed to perceive some basic principles on heat transfer by radiation. Every time there is a temperature differential, energy flows in three different ways: conduction, convection or radiation (obviously the most important to understand when studying IRT).

Thermal radiation (whose wavelengths are between 0.1 μm and 100 μm) is mainly composed by a infrared radiation (0.78 μm to 100 μm) and is a product of every body's capacity in emitting energy according to their emittance (capacity to emit radiation in comparison with the maximum efficiency of a black body), regardless off the wavelength and direction.

Each body, at a given temperature, emits radiation in many wavelengths; however, according to Wien's law of thermal radiation, each temperature corresponds to an emitted wavelength of maximum power. For instance, in the case of the tiling systems whose temperatures are between 15°C and 70°C, the maximum emissive power corresponds to wavelengths between about 8.5 μm and 10 μm. Therefore, in order to read the temperature from a surface, just like photography captures visible radiation (with wavelengths between 0.4 μm and 0.78 μm) to create images, the infrared cameras used in building inspections capture radiation with wavelengths mostly comprehended between 7.5 μm and 13 μm.

Despite being a reasonably simple method of inspection (especially when leading qualitative surveys) it is needed to understand how thermal radiation (mainly infrared) interacts with bodies in order to achieve the most accurate and fit to the purpose thermograms, just like photographers play with light in order to achieve the aimed photos.

When radiation reaches a body, three processes can occur: absorption, transmission and reflection [29]. Despite thermal cameras being designed to "transform" the readings of emitted radiation in temperature graphics, this is not the only portion of radiation that comes to the camera. Therefore, in order to achieve accurate thermograms, the equipment must be able to "separate" emitted radiation from the resting portions of radiation reaching it - such as the reflected radiation, the radiation emitted by the atmosphere between the camera and the surface and the result of atmospheric attenuation - function of the atmosphere's transmissivity - towards all the portions of radiation [30]. Thus, in order to minimize the errors in the thermogram some aspects must be taken into account such as the constitution of the inspected element, the presence of secondary heat sources, reflective or shadowing elements in the surroundings and the introduction of the parameters asked by the equipment as accurately as possible (such as the emissivity of the object, air temperature, relative humidity, reflected temperature and distance to the target) described in [31].

The principle behind anomalies' detection in building facades (including tiles' detachment detection) is that anomalous areas will have a different behaviour towards heat transfer, creating superficial thermal differentials. So, in order to identify an anomaly, it is almost always needed the imposition of thermal variations to the target in study using the adequate technique, as factors such as the anomaly deepness or dimension will certainly influence the inspection. Thus, the right thermographic method must be adopted in order to properly identify the anomaly that is being looked for. Thermographic techniques are usually divided in analysis techniques and imaging techniques.