A thermography-based methodology for assessing the key parameters of rising damp in porous materials

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Abstract

Capillary rising damp is one of the main causes of deterioration in historic buildings and is difficult to assess. Conventional methods are invasive and unsuitable for the conservation of cultural heritage. This study promotes the use of quantitative infrared thermography for monitoring capillary moisture in masonry. Experiments were conducted here on clay bricks. The thermal data allowed us to trace the wetting front and extract parameters such as the inflection point and the rate of rise. The results confirm that QIRT is a reliable and non-invasive method for moisture, supporting its standardization for in-situ diagnostics.

1. Introduction

Rising damp is one of the main degradation mechanisms affecting historic masonry buildings and represents a major challenge for the conservation of cultural heritage. Assessing it is inherently complex due to the heterogeneous nature of masonry and the strong interaction between absorption, transport, and evaporation processes. Conventional diagnostic approaches are often based on invasive sampling or gravimetric measurements, which are poorly suited for in situ investigations and are incompatible with the requirements of cultural heritage conservation. Consequently, there is a growing demand for non-destructive techniques (NDT)[1], [2] capable of providing quantitative information on moisture transport while preserving the integrity of historic structures. Within this framework, Quantitative InfraRed Thermography (QIRT) offers a promising non-destructive alternative, as it enables the observation of surface thermal patterns associated with moisture-related phenomena. Variations in surface temperature are strongly influenced by evaporation processes occurring in wet areas, making IR thermography particularly suitable for detecting and monitoring moisture in porous building materials.

The present contribution represents the continuation and methodological advancement of the work presented by Guolo et al. (2024)[2], [3], [4], in which passive IR thermography was applied to the monitoring of moisture diffusion and capillary rising damp in masonry materials. Building upon those results, this study aims to establish quantitative correlations between capillary rise parameters derived from thermographic analysis and the physical properties of the materials, with the objective of advancing toward a standardized and fully non-invasive diagnostic methodology. Experimental investigations were carried out on clay bricks commonly employed in restoration interventions and representative of traditional Venetian architecture. The selection of Venice as a case study is motivated by its unique environmental and architectural conditions, including buildings in direct contact with brackish water, the influence of tidal fluctuations, and consistently high levels of relative humidity.

The proposed approach represents a further step toward the standardization of IR thermography for the in-situ assessment of rising damp and supports its application for long-term monitoring and preventive conservation strategies in historic masonry structures.

2. Material and method

The materials analysed, new industrial brick were characterized through measurements of bulk density, porosity, and capillary water absorption, obtained using standardized laboratory procedures (Table 1). These results highlight the discrepancies between porosity measurements obtained using different techniques, reflecting the sensitivities and measurement principles inherent to each method. MIP characterizes only the network of accessible pores in an approximate range between 3 nm and 100 µm, while vacuum pump and hydrostatic weighing provide a more comprehensive assessment of total open porosity, including larger pores. Furthermore, hydrostatic weighing allows partial access to finer pores, while the vacuum saturation method exhibits limited sensitivity toward smaller pore fractions.

Table 1. *Physical properties of the new industrial brick, results obtained by 10 samples*

Sample dimension [m]	ρ [kg m^{-3}]	φ [%] by MIP	φ [%] by vacuum pump	φ [%] by hydrostatic weight
0.04 x 0.04 x 0.04 (*AC* by EN 15801) 0.125 x 0.25 x 0.055 (test by IR/visible)	1581 ± 56	32 ± 2	36 ± 1	42

2.1. Capillary water penetration (AC)

International standard EN 15801 [5], defines the method for calculating the capillary water absorption coefficient *AC* of a porous material, which involves monitoring the increase in weight over time during the capillary absorption of the liquid. To determine the *AC* coefficient, it is first necessary to calculate the amount of water absorbed per unit area Q_i [kg m^{-2}] at time t_i [s], by the cubic material sample 0.04 x 0.04 x 0.04 m after dried in an oven at 105°C:

$$Q_i = \frac{m_i - m_0}{A} \tag{1}$$

where m_i is the mass of the specimen at time t_i [kg], m_0 is the mass of the dry specimen [kg] and *A* is the area of the specimen in contact with water [m^2].

After plotting Q_i as a function of the square root of time $t_i^{1/2}$, it is possible to calculate the capillary water absorption coefficient *AC* [kg m^{-2} s$^{-1/2}$] as slope of the linear section of the curve, before the plateau, using linear regression. The average value obtained from 10 samples is 0.45 ± 0.03 kg m^{-2} s$^{-1/2}$ (Figure 1).

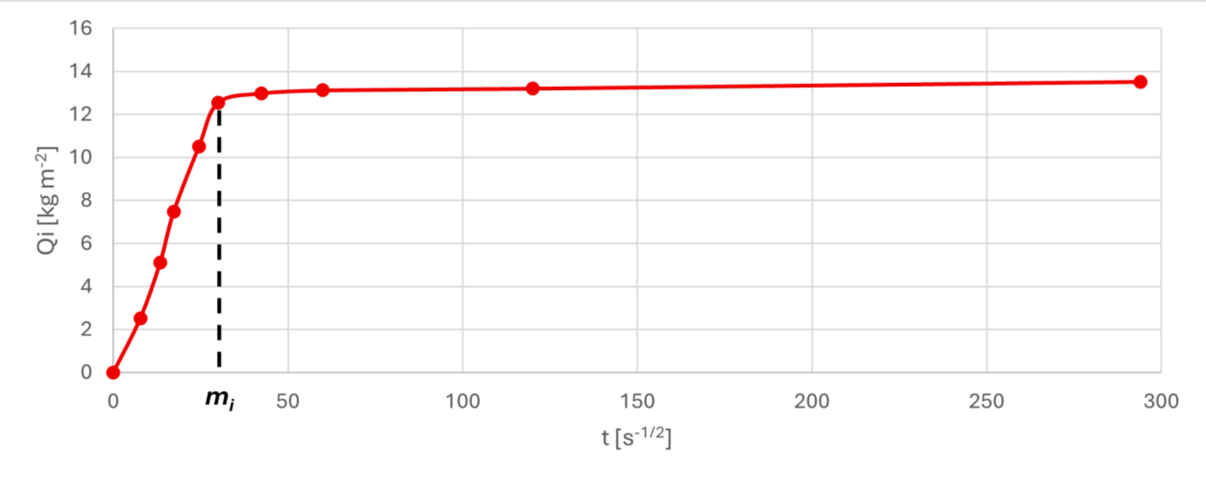

Figure 1. *Water absorbed per unit area Q_i as a function of time; average of the values for 10 samples.*

2.2. Capillary rise by NDT methods

The capillary absorption process was observed using passive IR thermography and simultaneously the visible images. The tool used consisted of a FLIR T1020 thermal camera (1024 x 768 mm, 7.5-14 µm, FOV 12° x 9°, IR lens 36 mm), configured with the following input parameters: emissivity 0.95, reflected and internal temperature 20°C, and relative humidity 60%. The boundary conditions, corresponding to laboratory environment, were maintained around a temperature of 20°C and a relative humidity of 60%.

The capillary rise test on the material samples was conducted by positioning them vertically (0.125 x 0.25 x 0.055), with the base in direct contact with distilled water (approximately 1 mm). The material was monitored using IR thermography, with thermal and visible images acquired at regular intervals – every minute during the first 6 hours of wetting, and then every 10 minutes – until approximate pore saturation was reached. The individual thermal images recorded were processed as a time series to extract quantitative data. The same procedures were used to process and extract quantitative data from the visible images, by splitting the image into its three colour channels (R – red, G – green, B – blue), to process it subsequently as a time series.

The recorded temperature data allowed the qualitative identification of dry and wet regions and the quantitative tracking of the wetting front progression, enabling the determination of characteristic parameters such as the inflection point and the rising velocity of the capillary front.

3. Results

Analysis of the IR images reveals a lower surface temperature in the evaporation zone and a higher temperature in the dry zone, with a clearly distinguishable temperature gradient exceeding 2 °C across the entire surface. The resulting thermal profile exhibits a characteristic sigmoid curve, described in the equation *T(h)* as a function of height *h*, the distance from the base (*h* = 0) in contact with water (Figure 2):

$$\mathrm{T(h)} = S_1 \frac{1}{1+e^{-\frac{1}{S_2}(h-h_0)}} + S_3 \tag{2}$$

where S_1 is the amplitude [°C], S_2 defines the steepness of the sigmoid [m], h_0 is the inflection point [m] and S_3 is the sigmoid ground value [°C].

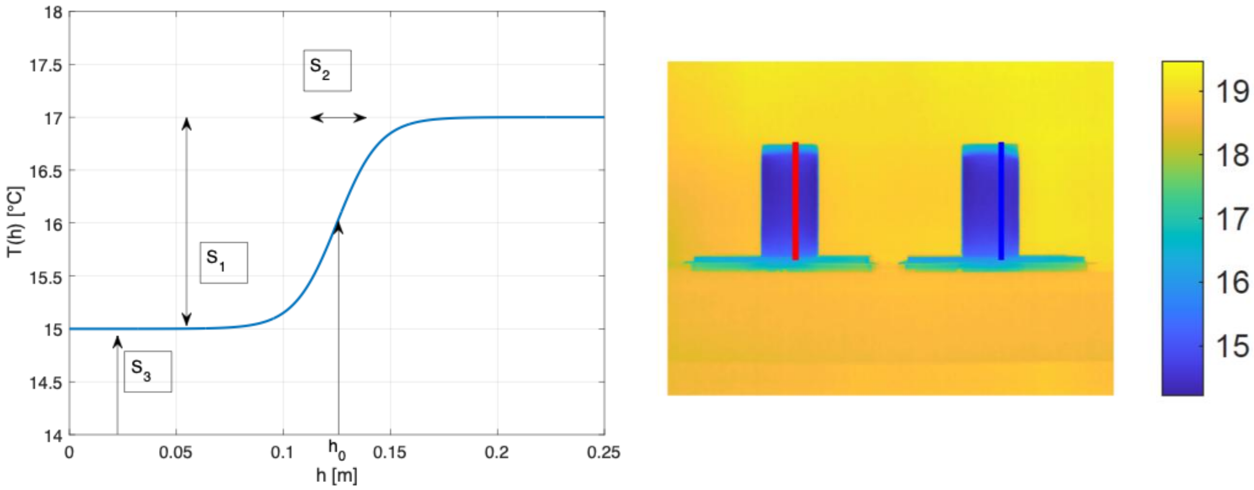

Figure 2. *At left, sigmoid as a function of height, to fit temperature data during the rising damp experiment. At right, IR image with vertical profile used in the fit of the data.*

During the rise in humidity, the inflection point $h_0 = h_0(t)$, which represents the advance of the moisture front, shows an advance that increases with the square root of time. In the visible spectrum, absorbed water alters surface reflectance, although this effect is much less pronounced than its influence on temperature. That is, the signal-to-noise ratio (SNR) due to the variation in emittance in the IR band is much stronger than the SNR due to the variation in reflectance in the visible band, as is evident from the comparison between the top graphs in Figure 3 and Figure 4.

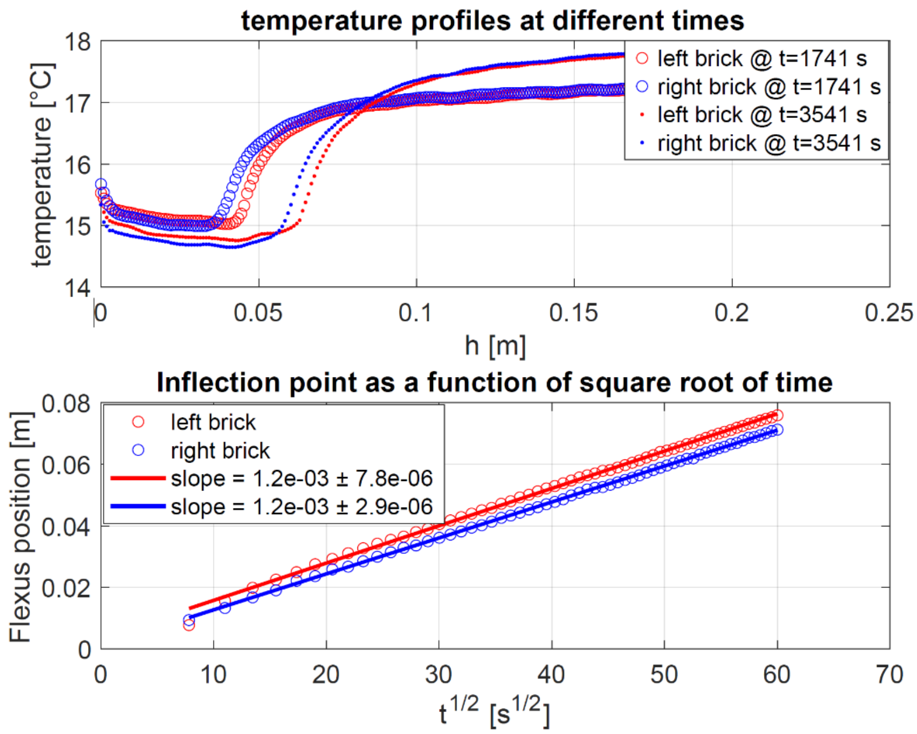

***Figure 3**. Inflection points of the sigmoid as a function of square root of time, for IR images.*

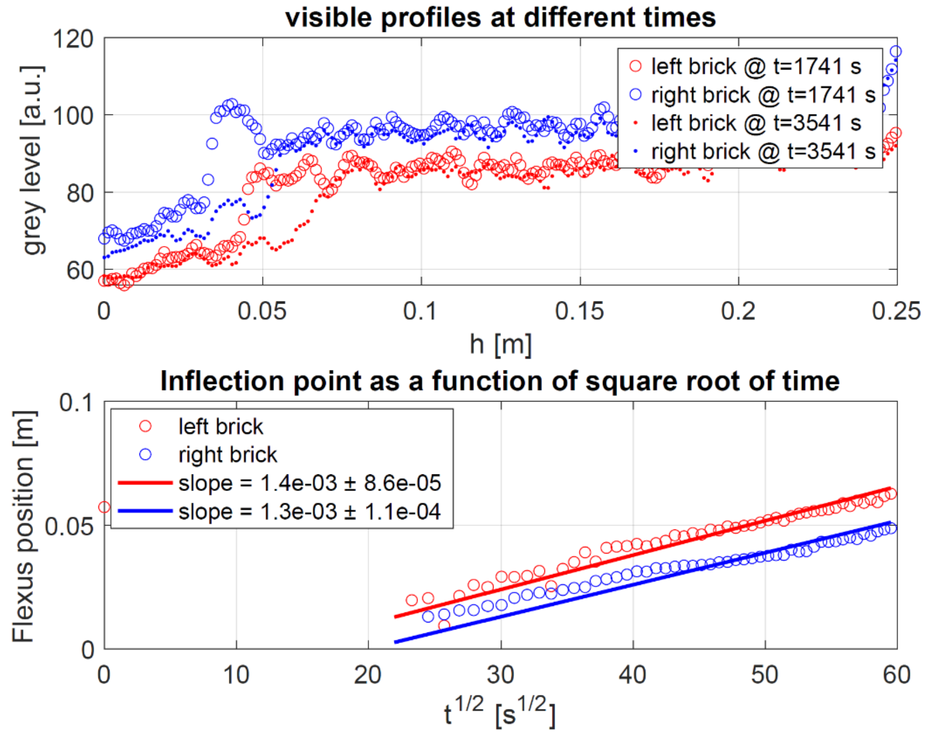

Figure 3. Inflection points of the sigmoid as a function of square root of time, for IR images.

The capillary penetration coefficient of water measured using IR thermography and visible images is defined as$B$ [m s^{-2}] = S/θ_w. Using IR images, the value obtained is B = 1.2 ± 0.003 × 10^{-3} m s^{-2}, which is in good agreement with the value obtained from visible images, B = 1.4 ± 0.07 × 10^{-3} m s$^{-½}$, although the IR method has a significantly higher signal-to-noise ratio (SNR), making it the most reliable and accurate technique for practical in-situ applications. The volumetric moisture content at the wetting front, derived from combined gravimetric and thermographic data as $\theta_w = AC/(\rho_w \cdot B)$, was found to be 37 ± 2% (IR) and 32 ± 3% (visible), both in good agreement with the measured open porosity of 42 ± 4%, confirming the physical consistency of the approach.

4. Conclusions

This study demonstrates that QIRT is a reliable and non-invasive method for quantifying capillary moisture dynamics in porous masonry materials, allowing for the estimation of physical parameters consistent with those obtained using conventional laboratory techniques. The approach is particularly suitable for the diagnostic assessment of historic buildings and cultural heritage sites, where material sampling using gravimetric techniques is not permitted. Future work will focus on extending the methodology to heterogeneous masonry systems, including mortar joints, and on analysing the effects of salt contamination and variable environmental conditions on the observed thermographic signatures.

References

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