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ANÁLISIS DE LA MEDIDA DE LA HUMEDAD EN PROBETAS DE YESO PREVIAMENTE HUMEDECIDAS EN RELACIÓN A LA TEMPERATURA MEDIDA SOBRE SU SUPERFICIE USANDO TERMOGRAFÍA DE INFRARROJOS

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ANALYSIS OF THE MEASUREMENT OF MOISTURE WITHIN PREVIOUSLY WET GYPSUM SAMPLE IN RELATION TO THE MEASURED TEMPERATURE ON ITS SURFACE USING INFRARED THERMOGRAPHY

Abstract

The available moisture at a material surface has been identified as most relevant to fungal growth. Infrared thermography is a non-destructive testing technology that can be applied to determine variations in a material's surface moisture. As water evaporation is an endothermic reaction, which induce local surface cooling, the measure of the superficial temperature during evaporation process can be used to detect the presence of moisture. Therefore, infrared thermography can provide insight on those conditions that could lead to fungal proliferation. This research presents a laboratory test, which compare the thermal images obtained during the drying process of a gypsum specimen with respect to the thermal images of other gypsum specimen without pre-wetting, which was used as a reference. The temperature values obtained with the thermal imaging camera were also compared with the temperature values measured by a device with two channels: in-situ probe inside the gypsum and ambient probe. The results show that a relationship exist between the moisture measured by the probe inside the gypsum specimen and the image of the water level detected thermographically.

Key words: *Surface moisture; Hygrothermal behaviour; Infrared thermography*

Resumen

La humedad disponible en la superficie de un material se ha identificado como la más relevante para el crecimiento de hongos. La termografía infrarroja es una técnica no destructiva que se puede aplicar para determinar las variaciones en la humedad de la superficie de un material. Como la evaporación del agua es una reacción endotérmica que induce el enfriamiento de la superficie local, la medida de la temperatura superficial durante el proceso de evaporación puede usarse para detectar la presencia de humedad. Por lo tanto, termografía de infrarrojos puede proporcionar información sobre las condiciones para la proliferación de hongos. Esta investigación presenta un ensayo de laboratorio que compara imágenes térmicas obtenidas durante el proceso de secado de una muestra de yeso con respecto a imágenes térmicas de otra muestra de yeso sin pre-humectación usada como referencia. Los valores de temperatura obtenidos con la cámara térmica se compararon también con los valores de temperaturas medidas con un dispositivo con dos canales: sonda in situ dentro del yeso y sonda ambiente. Los resultados muestran que existe una relación entre la humedad medida por la sonda interior de la muestra de yeso y la imagen del nivel de agua detectado termográficamente.

Palabras clave: *Humedad superficial; Comportamiento higrotérmico; Termografía de infrarrojos*

1. INTRODUCTION

Water can be introduced into a building material through the material pores in several ways: rain, condensation of air humidity, run off from roof and facade and/or capillary rise of water. Uncontrolled indoor moisture in buildings can lead to a number of problems, which include structural damage, material degradation, poor indoor air quality, fungal growth and therefore, potential health problems for the occupants (Glass & Tenwolde, 2009). The measurement of moisture parameters in buildings is associated with moisture in the air, moisture at a material surface, and moisture within a material. However, available moisture at a material surface has been identified as most relevant to fungal growth, and therefore surface measurements are useful for monitoring specific, localised areas of buildings, and will provide the best indication of scenarios that lead to fungal growth (Dedesko & Siegel, 2015). Infrared thermography is a non-destructive testing technology that can be applied to determine variations in a material's surface moisture, which could provide insight on a number of conditions that could lead to fungal proliferation. As water evaporation is an endothermic reaction, which induce local surface cooling, the measure of the superficial temperature during this evaporation process can be used to detect the presence of moisture in the building materials (Barreira & de Freitas, 2007) (Lerma, Cabrelles, & Portalés, 2011) (Kylili, Fokaides, Christou, & Kalogirou, 2014)

Gypsum is widely used to coat the interior walls of houses because of its ability to regulate humidity. From the chemical point of view, the plaster conglomerate is essentially, calcium sulphate hemihydrate ($CaSO_4 \cdot 1/2H_2O$) that it is obtained after a partial dehydration of the natural gypsum. The hemihydrate form sets and hardens by hydration to convert in dihydrated calcium sulphate ($CaSO_4 \cdot 2H_2O$). The gypsum plaster is considered to a conglomerating material of rapid setting time, and of low initial resistances (Borrachero et al., 2008). This work presents an experimental study, which compare the thermal images obtained during the wetting and drying process of a gypsum specimen with respect to the thermal images of other gypsum specimen without pre-wetting, which was used as a reference.

2. METHODOLOGY

2.1. The characterization of gypsum plaster

The gypsum samples used in this research correspond exactly to the dosage of the samples used for the test methods for gypsum plasters (EN 13279-2, 2014). The effective density for dry gypsum plaster was 1200 kg/m^3. This density was determined by weighing the samples in a mold of 40 mm x 40 mm x 160 mm. Helium pycnometer Micromeritics was used for the determination of skeletal density. The obtained value for skeletal density was 2436 kg/m^3. The skeletal density is higher that effective density because helium gas enters in the accessible voids and the determined skeletal volume is less. That is, in the gypsum sample a great number of voids exists and helium gas permeable cavities and probably a part of these cavities are also accessible to water.

The characterization of the gypsum plaster was performed by thermogravimetric analysis, CHNS elemental analysis and by an X-ray diffraction to verify the composition and purity of the raw materials used which lacked detailed labelling. The CHNS analysis shows the expected chemical composition for gypsum plaster, which contain sulphur (22%) and hydrogen (2%). In addition, the presence of dihydrated calcium sulphate ($CaSO_4 \cdot 2H_2O$) in the powdered sample was found by using of the X-ray diffraction method using a PANalytical Empyrean X-ray diffractometer (Figure 1a). From X-ray diffractograms it can be seen that dihydrated gypsum shows prominent peaks at 11.6°, 20.7°, 23.4°,29.1°, 31.1° and 33.3°. These peaks coincide with those found for $CaSO_4 \cdot 2H_2O$ in the literature (Pundir, Garg, & Singh, 2015)

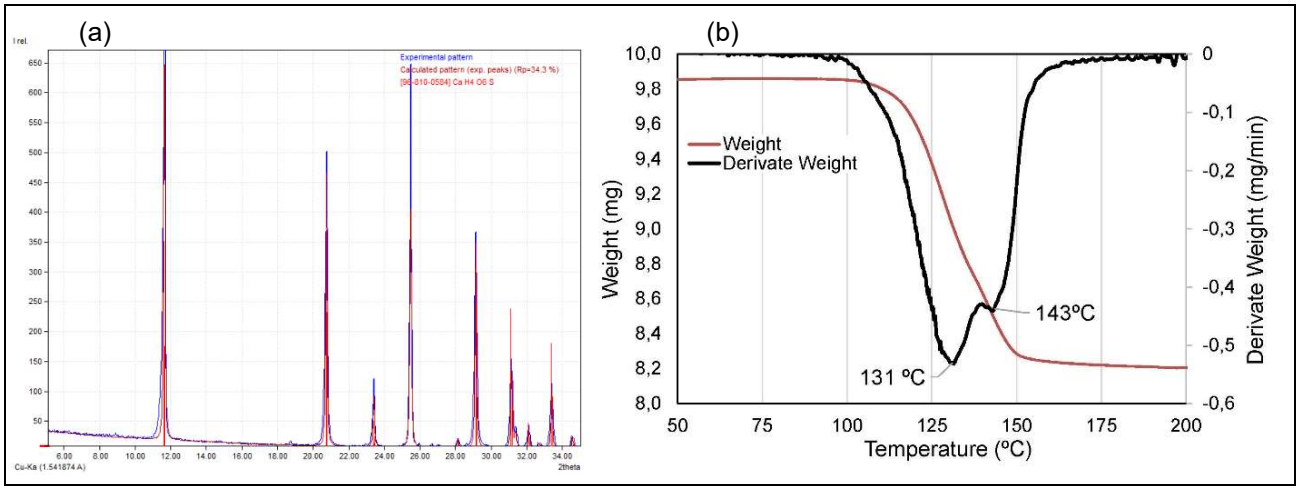

Fig. 1: X-ray diffractogram obtained for the sample of gypsum plaster (a) and loss of weight (TG) and derivate weight (DTG) curves for calcium sulphate dehydrate (b)

The thermogravimetric analysis (TG) technique is widely used in the characterization of diverse types of construction materials related to binders, such as plasters (Borrachero et al., 2008). Therefore, a powder obtained from the gypsum was analysed by TGA determining the loss of mass as a function of the temperature between 50ºC and 200ºC. A Perkin Elmer thermogravimetric balance Pyris Diamond TGA/DTG was used. To reduce the difference in heat transfer, the weight of the sample included in platinum crucible was less than 10 mg. The heating rate during assay was constant (β=10 K/min). Pure nitrogen was used as a carrier gas to obtain an inert atmosphere during the test. Figure 1b shows two serial dehydration steps corresponding to two endothermic dehydration reactions, which are given below:

$$CaSO_4 \cdot 2H_2O \rightarrow CaSO_4 \cdot \tfrac{1}{2}H_2O + \tfrac{3}{2}H_2O \quad (1)$$

$$CaSO_4 \cdot \tfrac{1}{2}H_2O \rightarrow CaSO_4 + \tfrac{1}{2}H_2O \quad (2)$$

The thermal decomposition of the dihydrated calcium sulphate happens in two serial processes according to Figure 1b. Numerous reports concluded that the setting process of the plaster and its decomposition strongly depends on the conditions in that the experiments of thermal analysis have been carried out (Borrachero et al., 2008).

2.2. Monitoring during the process of capillary absorption and drying.

Capillary rise is the most important mechanism of water penetration into building materials in liquid phase (Karagiannis, Karoglou, Bakolas, & Moropoulou, 2016). A gypsum sample was used to visualize the capillary absorption of water and its subsequent drying process. For the absorption process, a gypsum specimen was introduced into a Petri dish with water during one minute (Figure 2a). The amount of water absorbed by the gypsum specimen was 8.9 grams. The drying process began after the specimen was removed from water. This process was monitored using a moisture meter Hygropin along with a FLIR thermal imaging camera.

The moisture meter Hygropin is a multifunction indicator with data logging capability that can be used for identifying, diagnosing and monitoring potential moisture problems. Each of the two probe inputs can be configured independently. The integrated real time clock keeps track of date and time while recording data. The in-situ probe for measuring relative humidity and temperature within the gypsum plaster specimen was placed at a depth of 105 mm and at 20 mm of the external surface. This probe was introduced inside the measuring sleeves embedded into the gypsum specimen. Figure 2b show both measuring channels: in situ and ambient probe.

A thermal imaging camera is a non-contact device, which is able to scan and visualize the temperature distribution of entire surfaces quickly and accurately. Scanning with a thermal imager was used to visualize the changes of humidity during the drying process. Thermal images were obtained using a value of emissivity equal to 0,85, which was taken from (Chen, Punati, Sinha Ray, Yang, & Prasad, 2017). The distance between the camera and the samples was 0.5 m.

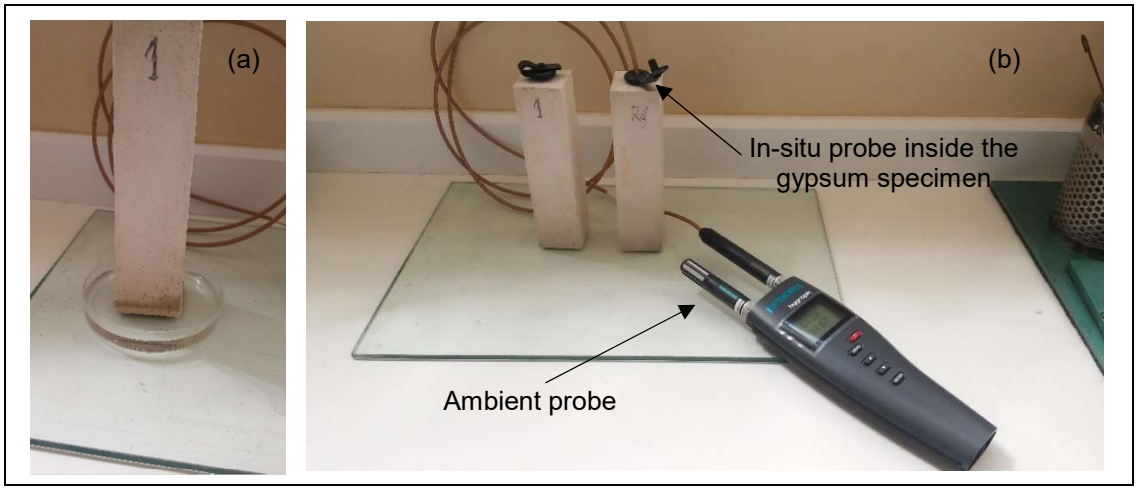

Fig. 2: Gypsum specimen during water absorption process (a). Measurement of moisture and temperature within gypsum reference specimen using moisture Meter Hygropin (b)

3. RESULTS AND DISCUSSION

The values of relative humidity and temperature obtained for both measurement channels (in situ and ambient probe) were measured during almost two days for the reference sample without wetting. Figure 3 show the variation of moisture and temperature within gypsum reference specimen under environmental conditions with respect to relative humidity and temperature present in air. The relative humidity under environmental conditions was always lower than the humidity within the gypsum reference sample. However, the measured temperature was approximately the same for both probes. Figure 3 also show a small and logical delay in the measurement of these variables given by both probes, but following the same trend. This delay is due to the time of transfer of heat and humidity between the inside and the outside of the specimen.

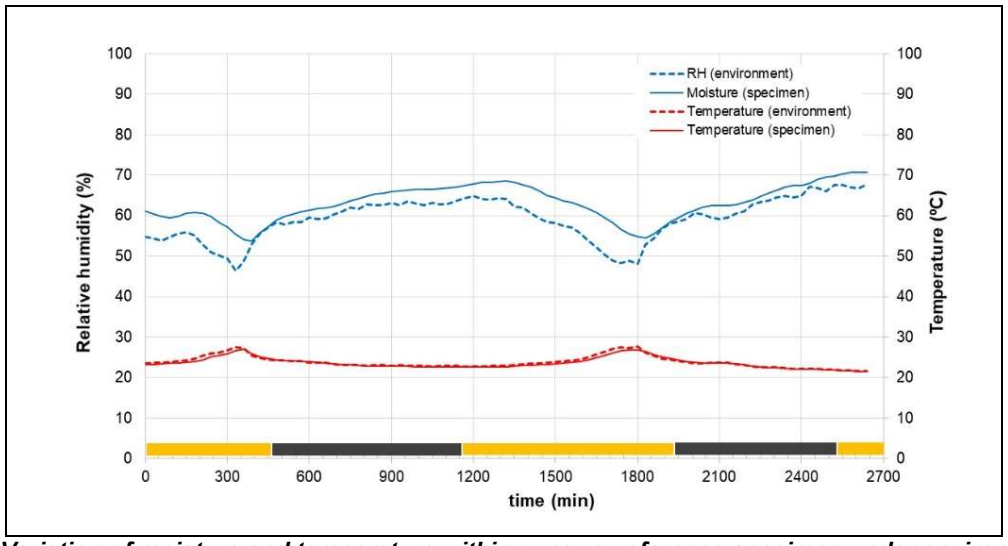

Fig. 3: Variation of moisture and temperature within gypsum reference specimen under environmental conditions with respect to relative humidity and temperature present in air. The yellow and grey wide lines represent hours with and without sunlight during the day, respectively.

Before starting the test, a thermal image was obtained from both gypsum specimens to show its superficial temperature when the samples do not contain water. Figure 4 show approximately the same temperature (25ºC) for both specimens. During the absorption process, the water level was visually observed and thermographically detected by its superficial temperature changes. The level water can be seen in Figure 4 for absorption time equal to one minute (t_a = 1min). The visible top water level was displayed as upper limit of the darker shade. At the end of the absorption process, the temperature difference is close to 1°C. The temperature varies because the water evaporation is an endothermic reaction, which induce a local cooling (Barreira & de Freitas, 2007)

The drying process began immediately after the specimen was removed from the water under environmental conditions. In the early stages of the drying process, thermographic image showed significant temperature differences. Therefore, during the first 8 hours, the surface temperature difference was around 4°C. The temperature of both specimens was not similar until reached 24 hours (1440 min). During this period, the humidity inside the gypsum specimen was higher than 90%. At the end of the test, superficial temperature was almost uniform and therefore moisture distribution was very similar between both gypsum specimens (see graphic of figure 4)

4. CONCLUSIONS

The results show that a relationship exist between the moisture measured by the probe inside the gypsum specimen and the image of the water level thermographically detected. The thermographic images allow studying the wetting and drying process of gypsum plaster used to coat the interior walls of houses. Temperature differences due to superficial water evaporation provided a tool to evaluate superficial moisture, which is associated with fungal growth.

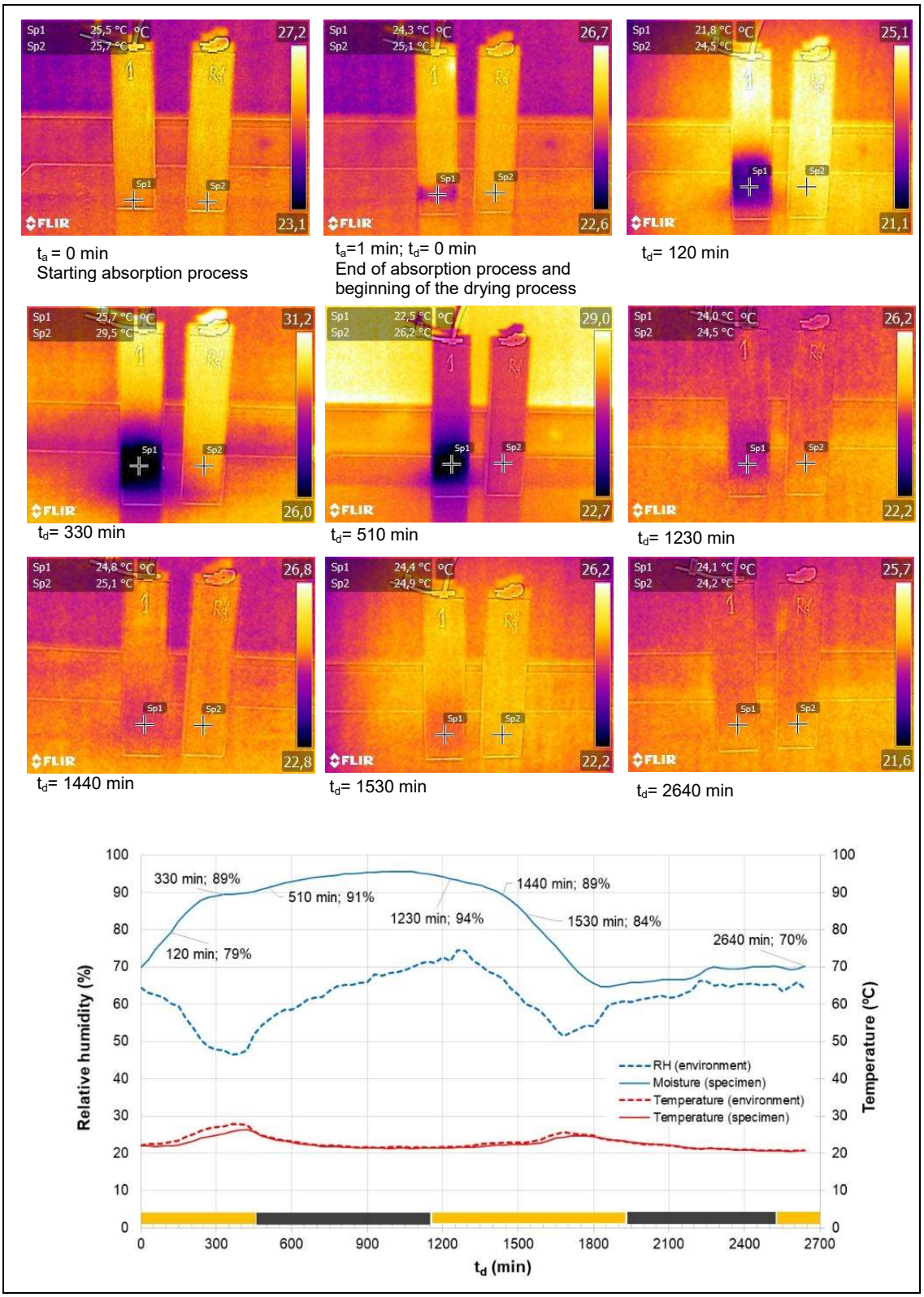

Fig. 4: Thermograms obtained during the absorption and drying process (t_a and t_d are times during absorption and drying process, respectively). The graph below shows the variation of humidity for the reference specimen and the studied specimen during the drying process.

5. ACKNOWLEDGEMENTS

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6. BIBLIOGRAPHICAL REFERENCES

Barreira, E., & de Freitas, V. P. (2007). Evaluation of building materials using infrared thermography. *Construction and Building Materials*, *21*(1), 218–224. https://doi.org/10.1016/j.conbuildmat.2005.06.049

Borrachero, M. V., Payá, J., Bonilla, M., Monzó, J., Paya, J., Bonilla, M., & Monzo, J. (2008). The use of thermogravimetric analysis technique for the characterization of construction materials. The gypsum case. *Journal of Thermal Analysis and Calorimetry*, *91*(2), 503–509. https://doi.org/10.1007/s10973-006-7739-3

Chen, Y., Punati, N., Sinha Ray, S., Yang, L., & Prasad, K. (2017). Thermal failure time of non-loadbearing gypsum board assemblies in standard furnace tests. *Applied Thermal Engineering*, *127*, 1285–1292. https://doi.org/10.1016/j.applthermaleng.2017.08.141

Dedesko, S., & Siegel, J. A. (2015). Moisture parameters and fungal communities associated with gypsum drywall in buildings. *Microbiome*, *3*(1), 71. https://doi.org/10.1186/s40168-015-0137-y

EN 13279-2. (2014). Gypsum binders and gypsum plasters. Part 2: Test methods.

Glass, S. V., & Tenwolde, A. (2009). Review of moisture balance models for residential indoor humidity. *12th Canadian Conference on Building Science and Technology*, 231–246. Retrieved from http://dx.doi.org/10.1016/j.buildenv.2011.07.016

Karagiannis, N., Karoglou, M., Bakolas, A., & Moropoulou, A. (2016). New Approaches to Building Pathology and Durability, *6*. https://doi.org/10.1007/978-981-10-0648-7

Kylili, A., Fokaides, P. A., Christou, P., & Kalogirou, S. A. (2014). Infrared thermography (IRT) applications for building diagnostics: A review. *Applied Energy*. https://doi.org/10.1016/j.apenergy.2014.08.005

Lerma, J. L., Cabrelles, M., & Portalés, C. (2011). Multitemporal thermal analysis to detect moisture on a building faade. *Construction and Building Materials*, *25*(5), 2190–2197. https://doi.org/10.1016/j.conbuildmat.2010.10.007

Pundir, A., Garg, M., & Singh, R. (2015). Evaluation of properties of gypsum plaster-superplasticizer blends of improved performance. *Journal of Building Engineering*, *4*, 223–230. https://doi.org/10.1016/j.jobe.2015.09.012