Available online at www.sciencedirect.com
SCIENCE DIRECT®
Infrared Physics & Technology 46 (2004) 161–166
INFRARED PHYSICS & TECHNOLOGY
www.elsevier.com/locate/infrared

Moisture detection in wood and plaster by IR thermography

N. Ludwig [a,*], V. Redaelli [a], E. Rosina [b], F. Augelli [c]

[a] Institute of General Applied Physics, V. Celoria 16, 20133 Milan, Italy
[b] Department of Conservation and History of Architecture, Polytechnic of Milan, V. Durando 38/A, 20158 Milan, Italy
[c] Department of Architecture Planning, Polytechnic of Milan, Italy

Available online 5 May 2004

Abstract

In the last decade, many research have been carried on the application of IRT to detect moisture in the materials of historic buildings, but only few studies are comprehensive of IRT application on wood. The thermal characteristics of timber are highly different from the porous materials ones; particularly, the thermal capacity of wood is lower than bricks, stone and mortar. Laboratory researches and scientific literature determined that the water content detection in porous materials is more related the evaporation rate of the surfaces and the presence of soluble salts than to the absorption capability of the materials. Moreover a correlation between moisture content, evaporation and boundary conditions was studied by analyzing evaporation fluxes at different environmental conditions and water content. Because of the lower heat capacity of the timber, the thermographic shot after the heating can be affected by the influence of water presence. Lab tests and study cases show the advantages and the limit of the IRT techniques, and the results obtained permit the comparison between the different heating systems applied.

Keywords: Wood; Plaster; Moisture

1. Introduction

A lot of research was conducted since the 1980s regarding the application of IRT on solid masonry construction.[1] Over the last decade, some improvements in techniques, instruments and the algorithms for mathematical modeling have

* Corresponding author. Tel.: +39-258-357473; fax: +39-258-357422.
E-mail address: nicola.ludwig@unimi.it (N. Ludwig).

[1] In the proceedings of Thermosense, the annual conference of SPIE, many papers were published in 1982–88. Chief among these are the systematic overviews by A. Colantonio, S.A. Ljungberg, T. Kauppinen, J. Snell. Many examples of application can be found in the proceedings of the International Conference of Nondestructive Testing and Nondestructive Testing applied to Cultural Heritage. Most frequently presented topics are moisture detection and heat loss due to insulating defects, or air leakage in building envelopes. The greater number of these papers deals with modern buildings, but attention to cultural heritage and the application of nondestructive on historic buildings testing increased in the 1990s.

1350-4495/$ - see front matter
doi:10.1016/j.infrared.2004.03.020

facilitated additional research on both solid and hollow-core masonry walls. The used procedures, that were developed in 1990–2001 for studying masonry buildings in Italy [1], proved to be suitable also in the inspection of wooden buildings in North America too [2]. The visual examination of the surface from short distance remains the best procedure for evaluating of defects and damage of any architectural materials. Nevertheless IRT provides a remote sensing method to locate the areas at the highest risk for damage, or to locate areas already damaged. The moisture content measurement in only one point of the analyzed zone is valid for the entire area having at the same temperature, within the limits of the analysis (and obviously for the same material, state of conservation, and boundary conditions). Thus, only a few measurements must be taken in order to define the moisture contents which correspond to a given surface temperature. The starting hypothesis is that high rates of water content (wood can be filled by water over 100% of its weight) highly modify the thermal parameters (density, specific heat and thermal conductivity) of the material, and therefore the active approach would be the most effective investigative procedure on wood; on the other side the obtained results allow to define that the inorganic building materials keep lower water content (e.g.: maximum 25% in bricks) and the passive approach is preferable [3], because the spontaneous evaporation flux can be detected without heating. Moisture content in wood structures typically varies between 7% and 18%. The threshold of moisture content that encourages the growth of damaging fungus is between 20% and 25%. Note that 12% is the international code reference for maximum wood moisture content for sound wood, and 25% is the limit for the survival of many biotic aggressors. Both figures, however, are below the cellular saturation point [4,5]. While damage to plaster, brick and stone is more related to the cyclic changes of water state near the surface, the damage in wood is directly correlated to the moisture content deep in the material. In fact, it is well known that the highest risk of fungal and parasitic growth is near 18% of moisture content, and that between 12% and 25%, any additional 1% of moisture content causes a 3% decrease in the strength of wood.

2. Method for the detection of water

The method for measuring the water content consists of the comparison of the temperature increasing in the different areas, after the application of a homogeneous heating. In fact, the water content highly affects the thermal capacity of the materials [6]. The water diffusing in the wood fibres causes an increasing of the specific heat of the material (4–5 times the specific heat of traditional building materials), thermal conductivity (about 25 times the thermal conductivity of air), and density. The dependence of these three parameters on the water content (W) is expressed as follows: [2]

$$Cp = \frac{Cp_{\mathrm{d}} + WCp_{\mathrm{w}}}{1+W}$$
$$K = \frac{K_d + WK_w}{1+W} \qquad (1a,b,c)$$
$$\rho = \rho_{\mathrm{d}}(1+W)$$

In the case of constant heating (Q) flux applied to the separation surface of a seminfinitive medium, the expression of the evolution of the surface temperature T, starting from the initial temperature T_0, is:

$$T = T_0 + \frac{Q2\sqrt{t}}{\sqrt{\pi k \rho c_{\mathrm{p}}}} \qquad (2)$$

therefore,

$$T - T_0 = m\sqrt{t} \qquad (3)$$

where

$$m = \frac{2Q}{e\sqrt{\pi}}$$

and

$$e = \sqrt{k\rho C_{\mathrm{p}}} \qquad (4)$$

represents thermal effusivity.

The trend of the temperature based on the experimental data fits the theoric model and it allows to calculate m.

[2] This expression of thermal conductivity was assumed in analogy of the electrical conductivity. As know the Fourier law and the Ohm law present the same form, furthermore electrical and thermal conduction lay on the same physical phenomena.