Energy and Buildings 78 (2014) 248–255

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Thermal characterization of homogeneous walls using inverse method

Khaled Chaffar, Alexis Chauchois*, Didier Defer, Laurent Zalewski

LGCgE—Laboratory of Civil Engineering and Geo-Environment, Faculty of Applied Sciences of the University of Artois, Technoparc FUTURA, 62400 Béthune, France

ARTICLE INFO

Article history:
Received 7 February 2014
Accepted 21 April 2014
Available online 28 April 2014

Keywords:
Gypsum tile
Inverse method
In situ wall thermal properties
Infrared thermography
Thermophysical properties
Building energy saving
Experimental methodology

ABSTRACT

Current environmental concerns have promoted efforts to reduce the consumption of energy. In moving towards improving existing buildings, the study of the thermal behaviour of a wall is not easy because its actual thermophysical properties are not well-known. These parameters are nevertheless fundamental for the economic optimisation of building refurbishment or for the verification of their performance in situ. It is thus important to be able to characterize existing building walls.

The objective of our study was to develop a method to thermally characterize a wall adapted to in situ applications based on an active approach. The principle of identification consists of thermally examining an access surface by applying a heat flux and studying the response in terms of the temperature recorded by infrared thermography on the opposite surface. Based on signals of flux and of temperatures measured at the edges of the wall, the thermophysical properties (thermal conductivity and volumetric heat) of the wall are estimated by inverse method.

The method was applied first to a homogeneous gypsum-tile panel in laboratory. The results were compared to reference values obtained from a classical procedure. Then, the method has been implemented in situ on a homogeneous reinforced concrete shell.

1. Introduction

To respond to crucial economic and environmental issues, the energy consumption of buildings has become a major concern of public authorities, of all stakeholders in construction, and of all building managers and users. Among all of the sources of energy waste, the transmission of heat through the envelope of a building is an important energy-performance parameter. In the case of new constructions, planners foresee walls with strong insulating abilities. Nevertheless, once built, walls can exhibit lower performance. Conscientious management of construction, ageing of materials, and humidity all can reduce the thermal resistance of a wall. Materials from agricultural by-products or from recycled products are now more broadly used. These materials often exhibit strong hygroscopicity [1] and a strong ability to settle and lead to a higher variability in the characteristics of walls. For old buildings, the cost of a complete thermal renovation can be high. During a programme of rehabilitation, investments should often be optimised. Different technical options can be considered. For instance replace the windows, the door, upgrade walls insulation and others. The knowledge of thermal properties is essential during the diagnostic phase of wall construction. This knowledge can, among other things, assist in choosing an appropriate renovation strategy. It can allow calculating the return on investment. These problems highlight the interest in being able to estimate the thermal properties of walls in situ. Various approaches have been considered in this regard.

There are many methods of non-destructive testing and among them thermal methods [2,3]. Certain methods are based on outfitting walls with temperature and flux sensors [4,5]. These methods require the recording of data during rather long periods, ranging from several hours to several days. The sensors can be left in place for long-term follow-up. A normalised fluxmeter method is presented in the norm EN 12494 [6]. In this case, the conductance of a wall is obtained based on a method of calculating sliding means after at least 72 h of recording. Cucumo et al. [7] have indicated that this method has its limitations and that it is important for the thermal energy stored in the wall to be negligible in comparison with the energy passing through the wall during the test period. These researchers proposed an alternative data analysis based on modelling using finite differences in heat transfer through the wall. Peng et al. [8] made measurements in buildings and used recordings made over the period of one year in three different ways.

* Corresponding author. Tel.: +33 3 21 63 71 33/+33 3 21 63 71 31; fax: +33 3 21 63 71 23.

E-mail addresses: khaled_chaffar@yahoo.fr (K. Chaffar), alexis.chauchois@univ-artois.fr (A. Chauchois), didier.defer@univ-artois.fr (D. Defer), laurent.zalewski@univ-artois.fr (L. Zalewski).

http://dx.doi.org/10.1016/j.enbuild.2014.04.038
0378-7788/

Nomenclature

h	surface film coefficient ($W\,m^{-2}\,K^{-1}$)
q_0	density of heat flux ($W\,m^{-2}$)
q_e	density of surface flux ($W\,m^{-2}$)
x	Cartesian coordinate
Δx	axial pitch (cm)
$\partial/\partial x$	spatial derivation
t	time (s)
Δt	time steps (s)
T_i^n	evolution of simulated temperature (°C)
T_{room}	room temperature (°C)
T_s	surface temperature (°C)

Greek symbols

λ	thermal conductivity ($W\,m^{-1}\,K^{-1}$)
ρc	specific heat ($J\,K^{-1}\,m^{-3}$)

Index

0	heat pulse
e	surface flux
n	index of the parameter considered
i	index

These researchers observed that the conductance values that were obtained experimentally were inferior to those calculated according to the design data. Wu et al. [9] proposed a method based on the frequency analysis of the evolution of flux and temperature. This method allows the conductance and global capacity of the wall to be estimated.

Several authors have demonstrated that infrared thermography is a useful tool for inspecting the elements of construction and that it allows for the evaluation of the thermal behaviour of walls [10]. Measurement by infrared thermography [11] has the advantage of being a non-contact, non-intrusive approach and of not modifying the heat exchanges on the surface being observed. However, the radiation perceived by the camera is the result of many phenomena: surface emission, radiation emitted by the atmosphere and its reflection by, for instance, the surface and absorption by the atmosphere. This radiation depends largely on environmental conditions [12]. To the best of our knowledge, in situ applications of this technique for the characterization of walls have only been used in combination with passive approaches, i.e., with specifically implemented thermal stresses. Certain hypotheses on how to fully exploit the quantitative information gathered from measurements performed have been proposed, the validity of which may be debatable. To estimate conductance, Albatici et al. [13] measured, by infrared thermography, the exterior surface temperature of a wall and the interior surface temperature of the surrounding building while suddenly opening a window. This method requires considering the wind speed and the temperature of the object representing the temperature of the exterior environment, as well as estimating the emissivity of the exterior surface of the wall.

This article presents an original set-up of thermal solicitation combined with temperature measurements by infrared (IR) thermography intended for the in situ determination of the thermophysical properties of building envelop. The method is different from the classic Flash method [14] as it is applied in situ, and the size of the samples is bigger: in fact, we cannot use optical excitation (e.g., halogen lamps) to perform the measurements in a uniform manner because of the large size of the studied zone (and especially in in situ conditions). The procedure consists of applying a heat solicitation on one of the surfaces of the panel being studied (Fig. 1) and recording the evolution of the temperature on the other surface by means of an IR camera. This allows a non-contact measurement of temperature evolution and to assess the homogeneity of the temperature. (This verifies that the assumption of unidirectionality is verified.) The characteristics of the panel are obtained using an inverse method based on a finite-difference model. In this first phase, the method is intended to study the running part of a panel, where the conduction of heat can be considered to be unidirectional. To test our procedure, the goal was to be able to determine the thermophysical properties of a panel based on trials lasting approximately one day. The first trials were performed on homogeneous panels in a laboratory.

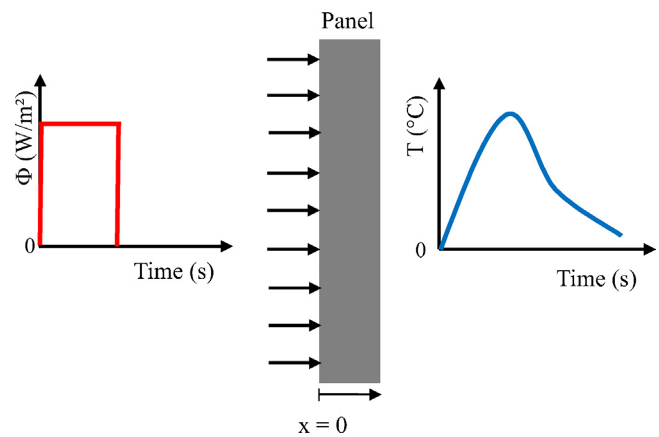

Fig. 1. Scheme of the protocol.

2. Theoretical aspects

In this study, the thermal parameters of a panel were identified by an inversion process [15]. The identification was intended to determine the grouping of the parameters of a model that allows the numerical minimisation of the deviation between the measured and simulated surface temperatures. A numerical model allowing for the calculation of the surface temperature of the wall in response to a flux stress on the other surface was developed. The model was integrated into an inversion algorithm with the goal of identifying the thermophysical parameters of the wall tested. Note that an analytical solution for the temperature evolution of the rear surface of the sample is not given. It could be only given in the case of a Dirac impulsion signal

2.1. Numerical model

A numerical model with finite differences was programmed in the Matlab® environment. This model simulates the monodimensional diffusion of heat based on a discretisation of the heat equation. An implicit schema was retained, as it authorises the unconstrained choice of the steps for spatial discretisation and steps for time. The heat equation was discretised based on a second-order central differentiation.

$$\left.\frac{\partial^2 T}{\partial x^2}\right|_{i,n+1} = \frac{T_{i-1}^{n+1} - 2T_i^{n+1} + T_{i+1}^{n+1}}{(\Delta x)^2} + 0\left[(\Delta x)^2\right] \quad (1)$$

where $T(x, t) = T(i\,\Delta x, n\,\Delta t) = T_i^n$.

The panel was assumed to be in a steady initial state. The temperature field within the material depends on temporal variations in temperature and flux density at the geometric limits of the environment. The boundary conditions were defined as follows:at $x = 0$, the panel is subjected to a heat pulse

$$-\lambda \frac{\partial T}{\partial x} = q_0 \quad (2)$$