Case Studies in Construction Materials 1 (2014) 53–59

Contents lists available at ScienceDirect

Case Studies in Construction Materials

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

Case Study

Evaluating in situ thermal transmittance of green buildings masonries—A case study

Francesco Asdrubali *, Francesco D'Alessandro, Giorgio Baldinelli, Francesco Bianchi

University of Perugia, Department of Engineering, Via G. Duranti 65, 06125 Perugia, Italy

ARTICLE INFO

Article history:
Received 20 December 2013
Received in revised form 14 April 2014
Accepted 14 April 2014
Available online 19 April 2014

Keywords:
Masonry
Green buildings
U-value
Heat flux measurements
Infrared thermography
Performance gap

ABSTRACT

The determination of the thermal properties of a building envelope is fundamental for the correct design of energy efficient constructions. Opaque walls can be easily modeled as parallel and homogeneous layers, being characterized by a monodimensional thermal flux which allows to evaluate the thermal transmittance with analytical models. These procedures are well established and they lead to reliable results; however, it is important to verify the actual performance with in situ thermal transmittance measurements. This analysis is more important when the wall performance is high, being closely linked to economic assessments.

The paper presents the results of a measurement campaign of in situ thermal transmittance, performed in some buildings in the Umbria Region (Italy), designed implementing bio-architecture solutions. The analyzed walls were previously monitored with thermographic surveys in order to assess the correct application of the sensors. Results of the investigation show that in situ thermal transmittance measurements and theoretical calculated *U*-value are not in perfect agreement. The mismatch becomes important for monolithic structures such as walls made of thermal blocks without insulating layers.

1. Introduction

Thermal insulation in buildings is a key factor to achieve the thermal comfort of the occupants and the reduction of heat losses, so diminishing the energy requirement for heating and cooling. The main ways of heat transfer, conduction, radiation and convection, can be reduced through appropriate construction techniques and materials selection.

The growing attention to energy savings in the building sector has led to more and more performing walls characterized by very low values of thermal transmittance. This parameter describes the insulating capacity of a wall; it depends on its global layout and on the characteristics of the single layers. The thermal properties of multilayer walls can be deduced from the declared data of heat transmission of the single layers given by the manufacturers (ISO, 2007). Such declarations, issued on the basis of current regulations, report values obtained by laboratory measurements (ISO, 1991, 1994a; Asdrubali et al., 2010; Asdrubali and Baldinelli, 2011) or numerical simulations (ECSS, 2012). The values of thermal conductivity for highly insulating layers are generally well established and often supported by experimental evidences; on the contrary, the situation is less defined for other components of the vertical walls such as bricks and tiles, whose thermal properties can be

* Corresponding author. Tel.: +39 0755853716; fax: +39 0755853697.
E-mail addresses: francesco.asdrubali@unipg.it (F. Asdrubali), dalessandro.unipg@ciriaf.it (F. D'Alessandro), giorgio.baldinelli@unipg.it (G. Baldinelli), bianchi.unipg@ciriaf.it (F. Bianchi).

http://dx.doi.org/10.1016/j.cscm.2014.04.004
2214-5095/

evaluated only through complex analyses (Kus et al., 2013; Morales et al., 2011). Therefore, in situ thermal transmittance measurements become strategic to evaluate the correctness of masonry installation and to determine its behavior during the use of the building. This phase is definitely the most energy consuming of the entire life cycle of a building (around 80%), as shown in (Asdrubali et al., 2013a).

The paper presents the results of some in situ thermal transmittance measurements performed on selected buildings, located in central Italy. The buildings construction was partially funded by the Umbria Region, through various tenders, in order to diffuse good practices of energy efficient buildings. The study is part of a wider monitoring activity involving construction site inspections, energy-environmental assessments (monitoring of actual energy consumption and proper operation of the plants) and field measurements of hygrothermal, acoustic and lighting parameters (Asdrubali et al., 2013b). The buildings were built between 2007 and 2008 and monitored between 2010 and 2013.

2. Methodology for in situ thermal transmittance measurements

The thermal transmittance of opaque walls is the main parameter to assess building efficiency during the heating season, while during the warm period other parameters (above all mass and heat capacity) have to be taken into account because of the dynamic behavior of the structure. Generally, this parameter is measured by laboratory tests with steady-state conditions on the surfaces of the wall in compliance with EN 1934 (ECS, 1998). During the test, the temperatures of the two wall surfaces have to be kept as constant as possible in order to avoid fluctuations, generating consequently a stable and adequate flux through the sample. The hot box apparatus allows to create these conditions and the measurement results can be compared with the outputs of numerical simulations, as shown in (Wakili and Tanner, 2003). Although the laboratory assessment is a robust methodology that allows standard comparisons between different opaque structures, it is still useful to evaluate the thermal transmittance of walls in real conditions, viz. on existing buildings. Different techniques can be employed to measure in situ thermal transmittance such as, for instance, thermographic surveys (Albatici and Tonelli, 2010; Fokaides and Kalogirou, 2011); however, the common in situ methodology is the one that uses thermal flux sensors (Peng and Wu, 2008; Desogus et al., 2011), described in the present paper.

Measurements of in situ thermal transmittance have to be performed according to the Standard ISO 9869 (ISO, 1994b), which gives the measurement methodologies, the equipment to be used and the data processing procedures, considering the variability of the measured phenomenon. The measure consists in the acquisition of the values of heat flux density passing through the sample and of the (surface or air) temperature values of the measurement area defined in the internal and external sides. At least one heat flux sensor and two temperature probes on each side of the system under test are required; temperature probes are usually installed on the surface of the sample in order to obtain the conductance value of the masonry.

A thermographic analysis is performed to properly install the sensors, hence avoiding singularities (such as thermal bridges or other defects) that could bring to incorrect results (Asdrubali et al., 2012).

Furthermore, the wall should not be irradiated by sunlight during the measurement; if this is not possible, a proper protective screen should be employed. The occurrence of a variable regime, mainly due to external conditions, requires a long measurement time period, in order to consider the transient effects related to energy absorption and release.

Measurements reported in the present paper were carried out with a wireless instrumentation and processed using the progressive average procedure: the acquisition time is three days if the indoor temperature is stable, otherwise, the time interval must be extended to seven days.

In order to take into account of the above mentioned transient effects, the values of heat flux density and temperature averaged on an adequately long time period must be used in the calculation of the thermal resistance R in place of the instantaneous values (Eq. (1)):

$$R = \frac{\int_0^t [T_{si}(t) - T_{se}(t)]dt}{\int_0^t q(t)dt} \tag{1}$$

where $T_{si}(t)$ is the function of indoor surface temperature vs. time; $T_{se}(t)$ is the function of outdoor surface temperature vs. time; $q(t)$ is the function of heat flux passing through the unit area of the sample vs. time.

Once the experimental data measured at finite and equal time intervals are collected, Eq. (1) is discretized by calculating the ratio between the sum of the differences of surface temperatures and the sum of the heat flux per unit area, acquired for the considered period (Eq. (2)):

$$R = \frac{\sum_{j=1}^{n}(T_{sij} - T_{sej})}{\sum_{j=1}^{n} q_j} \tag{2}$$

where T_{sij} is the indoor surface temperature at jth instant; T_{sej} is the outdoor surface temperature at jth instant; q_j is the heat flux passing through the unit area of the sample at jth instant.

The thermal conductance Λ in non-steady state can be calculated in the same way using Eq. (3):

$$\Lambda = \frac{\sum_{j=1}^{n} q_j}{\sum_{j=1}^{n}(T_{sij} - T_{sej})} \tag{3}$$