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A measuring campaign of thermal conductance in situ and possible impacts on net energy demand in buildings

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ABSTRACT

In the last years many studies concerning the evaluation of the thermal conductance of building elements via measurements have been carried out; this value has to be ensued from the analysis of recorded temperature and heat flux profiles. The determination of this property in situ would allow a more accurate a more accurate evaluation of the real heating energy demand of a building. Papers discussing different data analysis methods are present in literature and measurements on test components under real conditions and evaluations on different theoretical aspects by means of numerical simulations have been already developed. This paper aims at widening the existent literature of the in situ evaluation of the thermal conductance, through the discussion of the results of a measuring campaign which lasted four years on real buildings, and by comparing the reference specific thermal conductance (C) values with those computed on the basis of the measurements. Various tests on the same elements are discussed. Finally an analysis on the influence of the C value on the evaluation of the net heating energy demand of a building in different climates is presented.

1. Introduction

The evaluation in situ of the thermal conductance can be a useful tool for a proper building envelope diagnosis. Nevertheless, many factors can influence this evaluation which is based on the analysis of the measured data and on post processing methods. In the last years many in-depth studies have been carried out to improve the in situ thermal conductance evaluation. In particular several approaches and software tools able to perform dynamic analysis have been developed and are currently available. Bloem [1] and Bloem et al. [2] reported the work of two system identification competitions, where, for example, the spread in expectable results regarding the application of different models and techniques to the same benchmark data was studied. Androutsopoulos et al. [3] summarised the results obtained in that framework. A wide research effort has been carried out within the PASLINK Network, where procedures for determining thermal and solar characteristics of building components under real dynamic outdoor conditions have been developed. Measurements were performed over test cells within PASLINK framework; Wouters et al. [4] summarised the main characteristics of these PASSYS test cells, while Jiménez et al. [5] discussed a method to improve the accuracy in evaluating the thermal transmittance and solar factor of windows under real weather conditions by means of measurements in a PASLINK test cell. The PASLINK studies have been furthered in the IQ-Test thematic network, where different workshops have been organised to improve, update and maintain a uniform level of participant analysis skill. Results of exercises and analyses are discussed in Baker [6] while Androutsopoulos et al. [3] summarised the results of IQ-Test workshops. Further comparisons of the analysis methods are reported in Jiménez et al. [7], where the authors discussed the achievable agreement when different analysis approaches are applied to the same and to different datasets for the evaluation of the thermal transmittance value of a given building component. Cucumo et al. [8] proposed a method for the experimental determination of the in situ building wall conductance which can be easily implemented and could also allow the evaluation of the equivalent thermal capacity. This method was applied to a test wall in different periods of time, finding results in agreement with values obtained by means of progressive method.

Concerning the effect of the heat flux perturbation introduced by the presence of the Heat Flux Metre (HFM), deep analyses have been carried out by Trethowen [9]. The work described in this last paper has been more recently furthered in Cesaratto et al. [10]. Moreover, Cesaratto et al. discussed the problem of analysing input data with significant drift in temperature, as well as the possibility of recording the HFM surface temperature. Finally in the same paper

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Nomenclature

C	specific thermal conductance ($W\,m^{-2}\,K^{-1}$)
C_{des}	design specific thermal conductance ($W\,m^{-2}\,K^{-1}$)
Black Box*	Black Box method analysis with last third data validation
Black Box**	Black Box method analysis with all data validation
LORDt	LORD tool analysis adopting the node with internal surface temperature series as output node
LORDq	LORD tool analysis adopting the node with internal heat flux series as output node
n	air change per hour (h^{-1})
E_D	specific net heating energy demand evaluated considering design C values ($kWh\,m^{-2}$)
E'_D	specific net heating energy demand evaluated considering interpolated C values ($kWh\,m^{-2}$)

a difference in emissivity between the HFM and the internal plaster surfaces by means of Finite Element Method simulations has been considered and an overall estimation of the occurred deviations in the different cases has been presented.

Concerning the in situ measurements of building elements, Haralambopoulos and Paparsenos [11] proposed a methodology for determining the level of thermal insulation in old buildings through spot measurements of thermal resistance, analysing a test case whose build-up was not known. Moreover they highlighted that the discussed approach was suitable also for new buildings and old buildings after renovation. Feuermann [12] suggested a procedure to determine the effective envelope thermal transmittance of multifamily buildings based on a steady state heat balance, averaged over many days, for an apartment of a building used as a sample. In the same paper, a comparison between the standard U-value and the measured one is carried out for a case study. Baker in [13] aimed at characterising the actual performance of Scottish traditional building elements, in order to provide guidance for energy performance assessments. He discussed the results of measurements on un-insulated elements, and showed in some cases a comparison between measured and calculated values. In the same work it has been underlined that, for Scottish traditional buildings, U-value calculations tend to overestimate the U-values compared with the results from the in situ measurements, also because there is an uncertainty regarding the build-up, particularly for the ratio of mortar to stone in a traditional solid wall construction. Peng and Wu [14] first discussed the in situ measurement of total R value of a test room following the ISO 9869 [15] procedure, then used three different methods to evaluate the thermal insulation of the test chamber. Finally they compared these results analysed in situ with the reference design values and investigated the possible causes of the differences. Wang et al. [16], proposed a method for the dynamic analysis of in situ data considering wind velocity on the basis of measuring the temperatures and heat fluxes on both the internal and external sides. The method has been theoretically and experimentally validated.

In the mentioned literature, as well as according to ISO 9869 [15], the calculated values of thermal transmittance present a large uncertainty for several reasons. One possible explanation is that the calculations are usually based on the assumption of one dimensional heat flux and on nominal material properties which can differ from site to site, or for variable construction practices. As a consequence, the estimated thermal energy demand seems to be affected by a great uncertainty. As above mentioned, papers developed so far discuss the problems related to the in situ measurement of C value via laboratory analyses, by means of numerical simulations, or by studying test components with known build-up. There is no paper available in literature discussing the results of in situ measurements for real buildings compared to the reference design values.

The aim of the present work is to analyse results of a measuring campaign, showing an analysis based on different methods for estimating the C values. In particular, measurements were carried out during autumn and winter seasons from year 2006 to 2010 in the North-East of Italy (Veneto and Friuli Venezia Giulia regions) on walls of buildings for which the build-up was known with a good accuracy, and consequently their design C value. The criteria reported in ISO 9869 [15] have been followed. For some cases, measurements have been repeated on the same point for the same element shortly afterwards and on different positions of the same element in different periods of the year; moreover measurements on elements with the same build-up but on different buildings have been compared.

Measurements hereafter discussed aim at evaluating the in situ real thermal behaviour of walls; problems and procedures described both in ISO 9869 and in literature papers have been followed for the analysis. As a result, design C values have been compared to the values ensued from measurements; a correlation between design and measured values has been developed. Based on this correlation the simulation tool TRNSYS [17] has been used for evaluating the net heating energy demand of a building in three climates (Venice, Frankfurt and Stockholm). In this way, the net energy demands based on the design and the measured C values have been compared in the different climates.

2. The measuring apparatus

The measuring apparatus used for the test campaign was the same described in Cesaratto et al. [10]. It was composed by a HFM plate and four thermocouples with an acquisition system. The HFM was of a common type, with an area of 250 mm × 250 mm, a 1.5 mm thickness and the thermopile embedded in an epoxy resin layer. Its thermal resistance was expected, according to manufacturer information [18] and data available in literature [19], to be in the range 0.05–0.075 $m^2\,K\,W^{-1}$. Thermocouples, presenting a length of 5 m, were type T (Cu–CuNi), with the ice point electronically compensated. Further details about the measuring system are available in the manufacturer manual [18]. Based on the information provided by the manufacturer, and considering results in Cesaratto et al. [10], an uncertainty of 5% on the read value, referred to a uniform distribution, was considered for heat flux measurements, while an uncertainty of 0.4 K, with reference to a uniform distribution, was assumed for temperature measurements, following the criteria expressed in ISO Guide [20]. The measuring apparatus was tested in laboratory, as described in Cesaratto et al. [10]: the HFM was positioned on an insulating layer of a material with known values of thermal conductivity and thickness (thus its C value was determined) while the internal and external surface temperature profiles were recorded, so as to determine the nominal specific heat flux and then to make comparisons with the HFM readings. Even if the optimal testing conditions were not achieved (stationary thermal stress and radiant flux balance), the mean deviation of HFM readings compared with nominal specific heat flux values was under the value declared by the manufacturer. Concerning the thermocouples, the comparison was carried out by resorting to a Pt100 with a declared uncertainty of ±0.02 °C and a level of confidence of 95% [20]. By means of a thermostatic bath, three measuring points were acquired at three different temperature values representative of the in situ conditions. After reaching a steady state temperature inside the bath, a suitable set of readings was acquired and compared with the values measured by the reference probe; in this way it was possible to expect a deviation with the tested thermocouples