Improved Thermal Transmittance Measurement with HFM Technique on Building Envelopes in the Mediterranean Area

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Abstract

Although the designed theoretical value of U can be derived from the thermal parameters of layers composing an opaque element, according to ISO 6946:2007, measurements are necessary to confirm the expected behaviour. Currently, the measurements of thermal transmittance based on Heat Flow Meter method (HFM) and according to standard ISO 9869-1:2014 are widely accepted. Anyway, some issues related to difficulties in measurements are present: the roughness of wall surfaces, the proper contact between the heat flow plate and the temperature probes with wall surfaces, undesired changes in weather conditions. This work presents the results obtained in thermal transmittance measurements with a modified HFM method, widely described in this paper. Differences between U-values obtained with the modified HFM method and theoretical ones were in the range 0.6 – 6.5 %. Moreover, the modified HFM method provided a result closer to the theoretical one, when compared to that obtained with standard HFM method (discrepancy with theoretical value were 0.6% and 16.4%, respectively).

Key words: thermal transmittance, heat flow meter, opaque element, buildings.

1 Introduction

Since several years, problems related to climate change and the causes that generate it are treated with special attention, because of the negative consequences it entails on nature and people. The problem has spread worldwide and therefore is dutifully treated by many nations. In particular, The United Nations Framework Convention on Climate Change (UNFCCC) composed by 19 Countries (December 2015), was founded with the aim to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The last conference held by the UNFCCC was the "2015 United Nations Climate Change Conference" (COP 21), held in Paris, France, from November 30th to December 12th 2015, where Countries agreed, by consensus, to the final global pact (the Paris Agreement) to reduce emissions as part of the method for reducing GreenHouse Gases (GHG). Moreover, the members agreed to reduce their carbon "as soon as possible" and to do their best to keep global warming "to well below 2 degrees C".

In this framework, a great positive impact can be obtained by acting properly on buildings. As a matter of fact, buildings use about 40% of global energy, 25% of global water, 40% of global resources, and they emit approximately 1/3 of GHG emissions. Residential and commercial buildings consume approximately 60% of the world's electricity and the building sector is the largest contributor to global GHG emissions. Yet, buildings also offer the greatest potential for achieving significant GHG emission reductions, at least cost, in developed and developing countries.

One important aspect on which one can adopt solutions in order to reduce energy in buildings is the thermal behaviour of wall, expressed by its thermal transmittance U, which describes the ability of wall of opposing to heat-flux: the lower the thermal transmittance, the greater this opposition. Thermal transmittance of wall can be estimated if its stratigraphy and the thermal parameters of layers which compose it (basically thicknesses and thermal conductivities) are known, according to standard ISO 6946:2007 [1] which assumes conditions that often diverge from reality: uniformity of layers, proper installation, no irregularities within the cross-section. To these factors, the natural obsolescence of the walls must be added, which inevitably leads to reduce the performance over time. For these reasons, experimental measurements of thermal transmittances are mandatory for a proper evaluation of thermal behaviour of walls.

Currently, the experimental measurements of the thermal transmittance based on heat flow meter (HFM) and according to standard ISO 9869-1:2014 [2] are widely accepted. It is based on a continuous and protracted for several days measurement of heat-flux and surface temperatures of opaque elements [3-7]. Several works relate to effectiveness of HFM method technique and address the issues raised. Asdrubali et al. [6] performed a measurement campaign of in situ thermal transmittances in Umbria Region (Italy) and highlighted that measurements and theoretical U-values were not in perfect agreement, in particular for walls without insulating materials. In all the cases the differences were not less than 14%. Ahmad et al [7] also investigated the thermal transmittances of buildings in according to ISO 9869-1:2014, highlighting that wall orientation and the outside weather conditions affect the results. Peng and Wu [8] applied HFM technique on a building in Nanjing, comparing three different designed methods to evaluate the thermal insulation of the test chamber. Differences between measured and designed U-values were in the range 2-24%. Generally, comparison between U-values resulting from HFM and designed ones shows differences up to 16% [3, 9-12].

Even if we strictly adhere to the approach described by the reference standards, the HFM method presents some uncertainties. It is evident that the calculated values could be affected from temperatures and heat-flux measurement: Meng et al. [13] studied which factors affect the in situ measurement of U when the HFM method is applied. They found that thermocouples and heat flow meter locations, as well as pasting angle, size and shape of heat flow meter affect the measurement at different extent. In particular, the mortar joints must be avoided as location for the thermocouples. Desogus et al. [12] highlighted that measurement via HFM method could be affected by plastering of heat flow meter on the surface, because of changing in temperature fields around it.

In order to reduce the systematic errors in measurement, in our work we focused the attention on some aspects of the HFM method that could be improved. In particular, first a preliminary investigation of different opaque envelopes and with a thermal camera, in accordance with standard ISO 6781:1983 [14] was performed, in order to individuate the most appropriate area for the measurement of thermal transmittance. Then a slightly modified HFM method, based

on a multiple measurement of wall temperatures and on an improved adhesion between the temperature probes and the wall surface, was applied. The accuracy of the proposed method and results obtained were evaluated by direct comparison with standard HFM method and with designed values obtained in according to standard ISO 6946:2007.

Another issue related to HFM method is that ISO 9869:1-2014 requires a long measurement time period, in order to remove uncertainties of measurements due to fluctuations in temperatures, mainly for walls exposed to outdoor where sunlight exposure or changings in weather conditions cannot be avoided. A general rule suggests that an acquisition time of at least 72 hours is sufficient, provided that the variations in the transmittance value measured in the last 24 hours are less than 5% of the initial value of this interval (ISO 9869:1-2014).

The experimental campaign was performed in Apulia Region, in the south-east of Italy (Mediterranean Area), where high differences in temperatures between indoors and outdoors are not frequent. Anyway, ISO 9869:1-2014 states that heat flow meter measurement requires a difference of fifteen degree, or at least ten degree, between temperatures of internal and external sides of walls, therefore this condition has been ensured through forced conditioning (heating or cooling) of the internal rooms.

Conditioning of at least one side of vertical walls is important also related to the following issue: in terms of energy upgrading of buildings, the Apulia Region may provide that a feasibility study which includes the transmittance measurement of the vertical walls must be completed within 30 working days from the assignment of a contract. If within this period changings in weather conditions makes difficult the measurement, the feasibility study would be compromised. It is therefore necessary to get rid from this issue, through the possibility of performing measurements in a conditioned environment, or at least conditioning the inner side of the vertical wall.

2 Materials and Apparatus

Thermographic investigation of the opaque elements was performed with a thermal camera Flir T620 with uncooled microbolometer detector (image resolution 640×680 pixels, spectral range from 7.8 to 14 μm, thermal sensitivity less than 0.04 °C, range of measurements from -40°C to 150 °C with an accuracy of ±2 °C and picture frequency equal to 30 Hz).

Heat flow meter (HFM) investigation was performed with apparatus according standard ISO 8301:1991 [15], provided by an Italian Company (*Capetti Elettronica srl*) and composed by:

- heat flow meter plate: diameter 50 mm, thickness 5 mm, sensitivity 50 μV/m^2, accuracy ± 5% (@T=20°C), temperature range from -30°C to +70°C, thermal resistance of sensor less than $6.25 \cdot 10^{-3}$ m^{2}K/W, range from -2000 to +2000 W/m^2;
- probe for temperature and humidity measurement: PT1000 class A with aluminum sensitive parts for better detection of the wall temperature, range of measurement from -40°C to 80°C, resolution 0.01°C, accuracy 0.1°C, range for relative humidity from 10 to 90 %;
- encapsulated probe for outdoor measurement of temperature and relative humidity: range of measurement from -10°C to 60 °C, resolution 0.01°C, accuracy 0.2 °C, range for relative humidity from 0 to 90%, resolution 0.05%.

The measurements with the apparatus above described were compared with measurements performed with a standard HFM method and by a Company that provided the thermal insulation, which used the following instrumentations:

- heat flow meter plate model *ThermoZig Optivelox*: range of power from -300 to +300 Wm^2, resolution 0.01 Wm^{-2}, accuracy ± 5% (@T=20°C), range of temperature from 20°C to 60 °C, thermal resistance 0.006 m^2K/W.
- a probe for indoor temperature measurement: range of measurement from -20°C to 60 °C, positioned at 1.5 m above the floor (hang with a clip);
- a probe for outdoor temperature measurement: range of measurement from -20°C to 60 °C, positioned at 1.5 m above the floor (hang with a clip).

The experimental investigation was performed on some different opaque elements hereinafter listed.

- *Case A*: a partition wall of a Building hosting the Department of Engineering of the Politecnico di Bari (Italy), composed by a hollow brick (30 cm) plastered on both the sides (1 cm) and which separates two rooms with different climatic condition. The building is located in Bari, in Apulia Region, in the south-east of Italy: coordinates are 41°06′41″ N, 16°51′19″ E. Bari is in the group Csa of Köppen climate classification (Mediterranean climates with Hot Summer) [16]. The city has a degree day of 1185, calculated as in the Italian presidential Decree 412/93 and subsequent amendments and additions.
- *Case B*: a perimetral wall of a High school separates an internal room from external side. It is composed by (from internal to external): plaster (2 cm), tuff (25 cm), cavity wall (6 cm), tuff (25 cm), plaster (2 cm). The high school is in Mesagne, located in Apulia Region, in the south-east of Italy: coordinates are 40° 34′ 0″ N, 17° 48′ 0″ E. Mesagne is in the group Csa of Köppen climate classification (Mediterranean climates with Hot Summer) [16]. The city has a degree day of 1237, calculated as in the Italian presidential Decree 412/93 and subsequent amendments and additions. The addition of an outer layer in rock wool (thickness of 10 cm), type Frontrock max E, provided by Rockwool® which declared a thermal conductivity of 0.036 W/mK was applied on the outer surface of this perimetral wall, in order to improve its energy efficiency. Both the arrangements were studied, and hereinafter we will refer as Case B1 and Case B2 respectively for the wall without and with the thermal insulation layer.

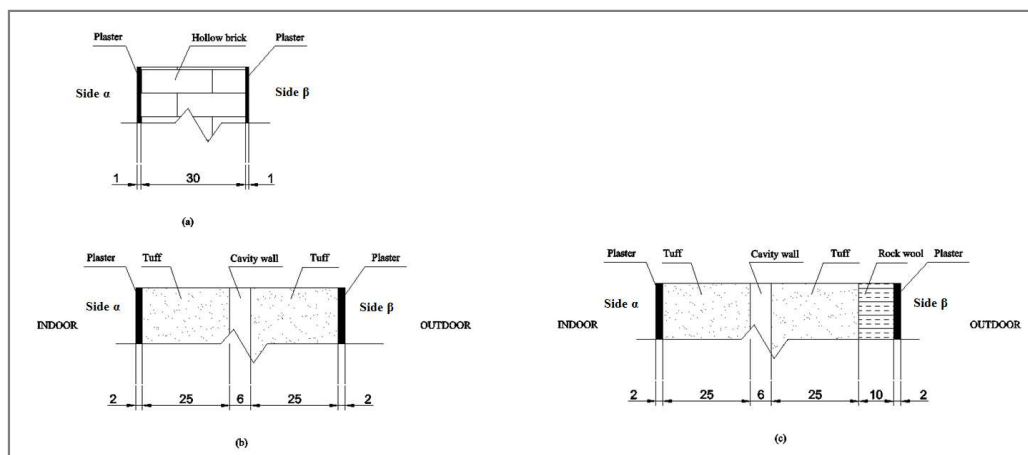The cross-section of investigated walls are clearly depicted in Fig. 1.

Figure 1: Cross-sections of investigated walls: Cases A (a), B1 (b) and B2 (c).

It is worth to mention that all the rooms investigated were exposed on the north-west side but protected from direct solar radiation by means of near buildings. Moreover, all the windows in the investigated rooms were shielded by roller shutters in order to exclude the impact of solar gains or reduce the thermal dispersion through them.

All the rooms were kept empty and not frequented by students during the testing period.

Fig. 2 shows a map with position of Bari and Mesagne and Fig. 3 shows the expected trends in temperature and relative humidity (RH) of air during a solar year, based on data recorded in Bari in the last 10 years obtained from ENEA archive [17]: the months are indicated with numbers from 1 to 12 (1 indicates January and 12 indicates December), the mean value is marked by a continuous line, while the minimum and maximum expected values are marked with dashed lines.
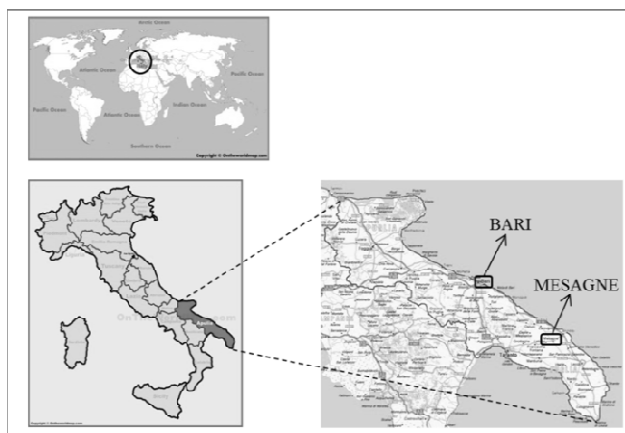

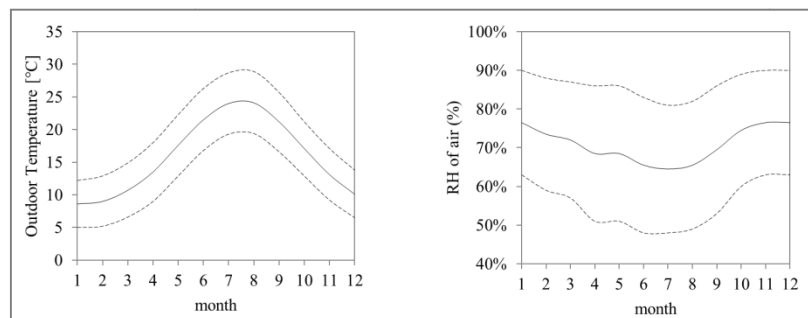Figure 2: Geographical locations of investigated walls.

Figure 3: Yearly temperature and RH in air trends in Bari. Mean (continuous line) and expected maximum and minimum values (dashed lines).

3 Methods

For both the investigated walls, a preliminary investigation with the thermal camera Flir T620 and in accordance with standard ISO 6781:1983 allowed the individuation of the most appropriate area for the measurement of thermal transmittance by HFM method.

More in details, the wall surfaces was investigated by means of IR thermography with the purpose to verify the absence of thermal bridges or deteriorations of the plaster, or the

presence of moisture by water infiltration in the opaque elements, in order to appropriately choose the area in which the measurement of transmittance would be performed. After the thermal conditioning, the wall presented thermal uniformity and the absence of thermal bridges: this situation has ensured that the wall was adequate to measurement.

The HFM method represents the most common and accepted method for measuring the thermal transmittance of opaque elements, according to the Standard ISO 9869-1:2014. It is based on monitoring and measuring of time variations of temperatures on both sides of an opaque element and of heat-flux passing through the wall. The state of art foresees the installation of the heat flow meter plate in the chosen point of the surface wall, for the measurement of the heat-flux through the cross section of the opaque element. Then a temperature probe is placed in contact with the surface, just few centimeters far from the heat flow meter plate. The contact between the temperature probe and the surface wall is generally not very meticulous: it is locked with the use of adhesive tape, or with a wall nail on which is hung. Our approach is different in some aspects (modified method):

i. the rooms separated by the wall for the case A, and the internal room for the cases B1 and B2, were conditioned (heated or cooled) for 48 hours in order to assure uniform and constant temperatures and a difference in temperatures between the sides of the wall not less than 10 °C. Values of temperatures were different for the investigated cases and they are reported in section "Results".

ii. the most appropriate portion of the wall surface for the measurement of thermal transmittance was individuated by means of the thermographic investigation;

iii. In this area, a template in stiff cardboard (in Italian called DIMA) having an area of about 0.5 m^2 (side of 0.7 m) and including holes which allow to find the correct location of the temperature probes and the heat flow meter plate in a quick and precise way, was positioned. The DIMA was positioned in such a way that the heat flow meter plate was at 1.5 m far from the floor. The holes had different colors to help technicians in the proper individuation of the position of sensors on the inner and outer sides of the opaque wall (red and blue, respectively). DIMA allows the preservation of the relative positions of the sensors with respect to the heat flow plate, if manifold measurements are performed in different areas of the opaque wall (Fig. 4a).

iv. the DIMA was applied to the opaque wall with the aid of easily removable adhesive tape at the end of use. Then with a pencil the exact positions of the probes on both the inner and the outer walls were drawn (Fig. 4b). In particular, the heat flow meter plate was installed at the center of this square area, while the temperature probes were positioned at the vertices of a triangle, as shown in Fig. 4d. The same happens to the other side, where other three temperature probes were installed.

v. The contact between the temperature probe and the wall surface was improved in order to reduce undesired thermal resistance due to bad contact. More in detail, in the points chosen for the positioning of the temperature probes, the wall was coated with a commercial high thermal silicon grease, in order to reduce the surface roughness. Then the temperature probe, previously embedded in an envelope consisting of aluminum in the part of contact with the surface (because of its high thermal conductivity) and plastic in the outer part, was glued to the silicone. In addition, a layer of mastic surrounded the entire envelope, in order to reduce any lateral thermal dispersions (*UHU*® *Patafix*) (Fig. 4c).

This particular configuration was applied on all the investigated walls.
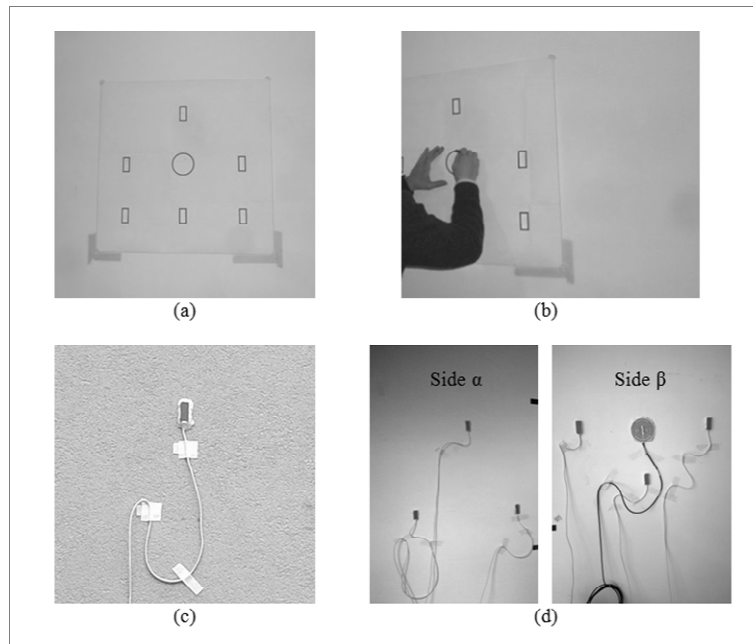
Figure 4: DIMA in modified HFM technique: template(a), marking of sensor positions (b), sensor adhesion on the wall (c) and final layout on both the sides (d).

The experimentation campaign aspired also to evaluate the effectiveness of the approach on walls placed in rooms strongly thermally conditioned; therefore, after conditioning of rooms, when done, the temperatures and heat-flux were monitored and recorded for three days and once the acquisition has been completed, an integral approach in measuring of thermal conductance was applied. In particular the thermal conductance Λ was estimated as the mean value in the interval $[0, t^*]$:

$$\Lambda = \frac{\int_0^{t^*} q(t)dt}{\int_0^{t^*} [T_\alpha(t) - T_\beta(t)]dt} \tag{1}$$

where T_α and T_β are the mean values of the three instantaneous temperature measurement obtained with the probes, on both the sides α and β, respectively.

Of course, the greater the interval between 0 and t^*, the lower the uncertainty in the thermal conductance value. In all the cases t^* was at least three days.

Once the thermal conductance has been calculated, the thermal transmittance U of the opaque element was calculated took in account the internal and external convection resistances ($1/h_{si}$ and $1/h_{se}$ respectively):

$$U = \frac{1}{\frac{1}{h_{si}} + \frac{1}{\Lambda} + \frac{1}{h_{se}}} \tag{2}$$

Since measurements of temperatures and heat-flux are performed at regular intervals, the integral equation (1) is discretized assuming the form:

$$\Lambda = \frac{\sum_{i=1}^n q_i}{\sum_{i=1}^n (T_{\alpha i} - T_{\beta i})} \tag{3}$$

in which *n* is the number of temperatures and heat-flux measurements performed from t=0 to t=t*.

4 Results

For all the cases, measurements of temperatures wall on both the sides and heat-flux through the wall were continuously performed and registered. Fig. 5 shows the trends of temperatures and heat-flux registered. For the case A, measurements were performed in July and the rooms separated by the opaque element investigated were differently conditioned (heated and cooled respectively at T=37°C and T=26 °C), in order to assure a difference in temperature above 10°C as requested by the standard. For the case B1, measurements were performed in March when external temperatures were always less than 13 °C, and internal room was heated to about 25 °C, so also in this case a difference in temperature above 10 °C was assured. On the other hand, with regard to case B2, at certain times a difference between internal and external temperature greater than 10 °C was not satisfied, due to large oscillations in outdoor temperature; apart from the peak at time 48:30 (when the difference in temperature reached 7.1 °C), the difference in temperatures between the two sides of the room was not less than 9.1 °C. In particular this is verified from 50:40 to the end of the measurement (91:40), therefore in the last 41 hours of the experimental campaign.
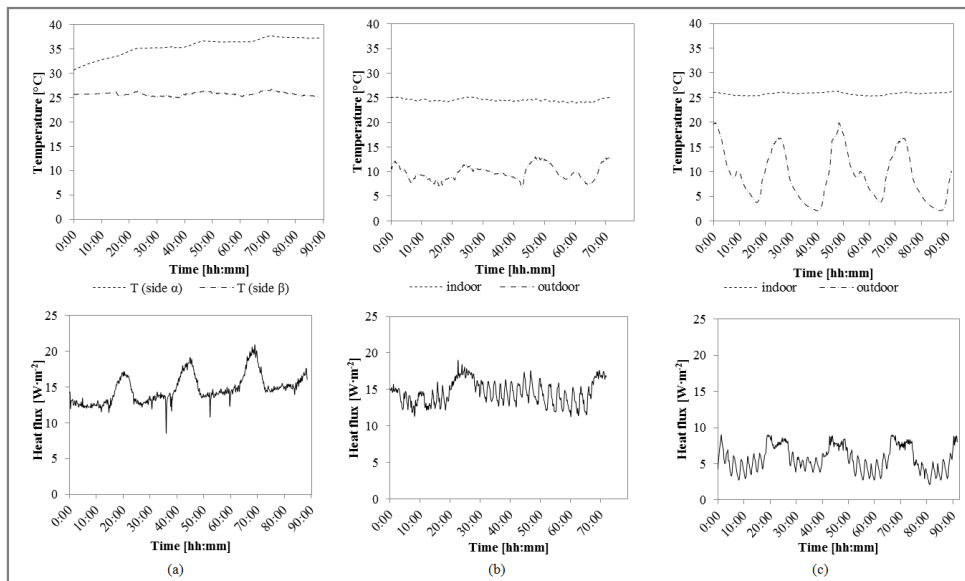

Figure 5: Temperatures and heat flows trends for Case A (a), B1 (b) and B2 (c).

Fig. 6 shows the thermal transmittance trend calculated in accordance with equation (2); it is evident that, in all the cases investigated, after several hours of measurement the thermal transmittance tends to a constant value. In particular, the amplitude of oscillations was calculated in the last 24 hours, according to equation:

$$\Delta U \ (\%) = \frac{U_{max}(t) - U_{min}(t)}{U_{in}(t)} \tag{4}$$

where U_{max}, U_{min} and U_{in} are respectively the maximum, minimum and initial values in the last 24 hours. They were 2.94%, 2.32% and 4.98% for Case *A*, *B1* and *B2* respectively. Therefore, in all the cases they were less than 5% as requested by ISO 9869-1:2014. In particular the thermal transmittance calculated for the case A can be considered acceptable despite the heat-flux in figure 5a seems to be increasing also at time 90:00 toward the steady state condition.
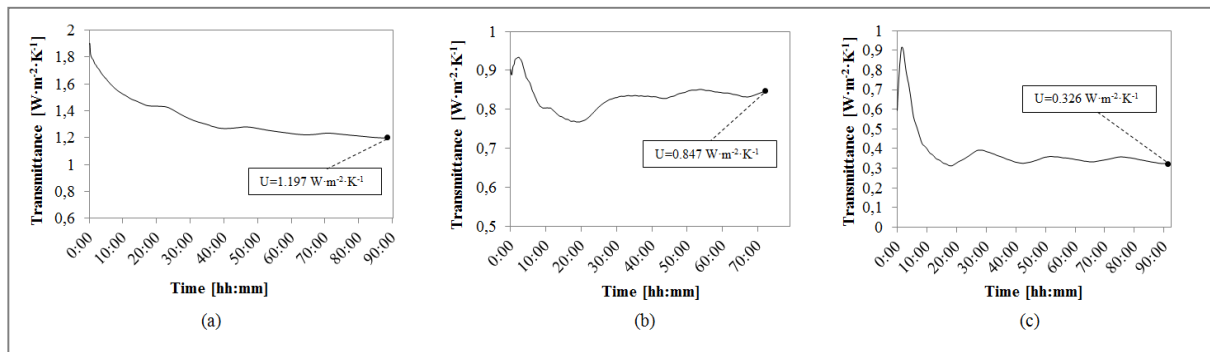

Figure 6*:* Thermal transmittances for Case A (a), B1 (b) and B2 (c).

The experimental results were then compared with the theoretical thermal transmittances calculated according to standard ISO 6946:2007, which applies to components and elements consisting of thermally homogeneous layers and is based on thermal conductivities or design thermal resistances of the materials and products for the application concerned. More in detail the theoretical thermal transmittance in accordance to ISO 6946:2007 is calculated as the reciprocal of the sum of the thermal resistances of each layer; Fig. 7 shows this approach for Case B1.
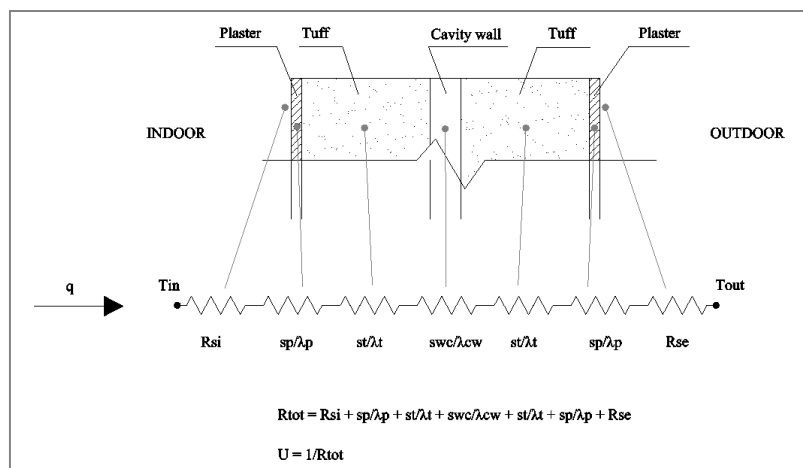

Figure 7: Calculation of U-value with standard ISO 6946:2007 for case B1.

Table 1 shows the stratigraphy of the investigated opaque elements with theoretical thermal transmittance and comparison with experimental results: very similar results are obtained, and in all cases the measured values are slightly higher than theoretical ones,

confirming a general rule that the theoretical values generally overestimate the performance of a wall. The reasons for this are manifold: from one side, the Companies that provide components (plaster, hollow brick, etc…) tend to overestimate the performance of their products for commercial purposes and, moreover, generally the material properties are characterized in laboratory where boundary conditions (temperature and humidity) are strongly controlled; this situation diverges from environmental real conditions where temperature and humidity could not be controlled and can affect the behaviour of opaque elements.

In addition, installation work can present some irregularities which tend to deviate the real behaviour from the expected one. Lastly, the aging of the investigated walls must be considered.

For case B1, also the thermal transmittance value obtained with conventional HFM method, below described and discussed is reported.

Table 1: Opaque elements stratigraphy and comparison between thermal transmittances.

	layers	s [cm]	λ [W·m·K^{-1}]	R [m^2·K·W^{-1}]
Case A	Internal surface	-	-	0.13
	Plaster	1	0.90	0.01
	Hollow brick	30	0.43	0.70
	Plaster	1	0.90	0.01
	External surface	-	-	0.04

Theoretical thermal transmittance : 1.124 W·m^{-2}·K^{-1}
Measured thermal transmittance with modified HFM method: 1.197 W·m^{-2}·K^{-1}

	layers	s [cm]	λ [W·m·K^{-1}]	R [m^2·K·W^{-1}]
Case B1	Internal surface	-	-	0.13
	Plaster	2	0.90	0.02
	Tuff	25	0.63	0.40
	Cavity air	-	-	0.18
	Tuff	25	0.63	0.40
	Plaster	2	0.90	0.02
	External surface	-	-	0.04

Theoretical thermal transmittance: 0.842 W·m·K^{-1}
Measured thermal transmittance with modified HFM method: 0.847 W·m^{-2}·K^{-1}
Measured thermal transmittance with conventional HFM method: 0.952 W·m^{-2}·K^{-1}

	layers	s [cm]	λ [W·m·K^{-1}]	R [m^2·K·W^{-1}]
Case B2	Internal surface	-	-	0.13
	Plaster	2	0.90	0.02
	Tuff	25	0.63	0.40
	Cavity air	-	-	0.18
	Tuff	25	0.63	0.40
	Rock wool	10	0.036	2.78
	Plaster	2	0.90	0.02
	External surface	-	-	0.04

Theoretical thermal transmittance: 0.252 W·m^{-2}·K^{-1}
Measured thermal transmittance with modified HFM method: 0.326 W·m^{-2}·K^{-1}

However, the differences between theoretical and measured thermal transmittance with modified HFM method and calculated as equation (5) are very low for Case A and B$_1$ (respectively, 6.5% and 0.6%), therefore lower than average values in literature (up to 16% [3, 9-12] or 24% [8]):

$$\varepsilon = \frac{U_m - U_t}{U_t} \times 100 \qquad (5)$$

with U_m and U_t were the measured and theoretical U values, respectively.

On the other hand, a consistent difference equal to 29.4% was observed in case B2, which can be attributed basically to large amplitude in temperature variations during the period of measurements. Indeed, contrary to the expected values shown in Fig. 3 for March, the temperature fluctuated between 2 °C and 19 °C, therefore, in different moments of the measuring period, a difference of 10 °C between the two sides of the investigated wall was not achieved (Fig. 5c). Another aspect that could have affected the measurement is the non-complete drying of the wall after the addition of the insulating layer and the plastering. Unfortunately, in this case the measures could not be performed at a later time, due to the "foreseen and not deferrable" switching off of the building air conditioning: in such a case the conditioning of the internal room would not have been made. Therefore the above mentioned two issues could not been avoided.

Nevertheless, we take into account to replicate the measurement in the next months, when issues related to drying will be overcome.

In any case, we cannot completely exclude the possibility that the performance of the thermal insulation has been overestimated; Asdrubali et al. [6] argued the same assumption when they found a difference between theoretical and experimental values of an investigated perimetral wall equal to 43%, which differed a lot from other 5 cases considered in which the discrepancy range was between -14 and + 26%.

At last, the investigated wall in case B2 has a thickness of 70 cm, which is unusual when compared with the thicknesses commonly adopted.

For case B1, results obtained with our modified HFM method were compared with results obtained with conventional HFM method, performed by the Company that provided the thermal insulation. Measurements were carried out in November, with external temperatures between 14°C and 19°C, while no conditioning was applied on internal room, where the temperature was in the range 19–20°C. Therefore it is evident that the required difference of 10°C between the two sides of the wall was not ensured. This evidence confirms that the weather can make difficult the measurement if the conditioning of at least one side of the vertical walls is not performed.

Anyway, Fig. 8 shows temperature, heat flow and thermal transmittance trends resulting from conventional HFM measurement, from which a thermal transmittance of 0.952 W/m^{2}K was obtained.
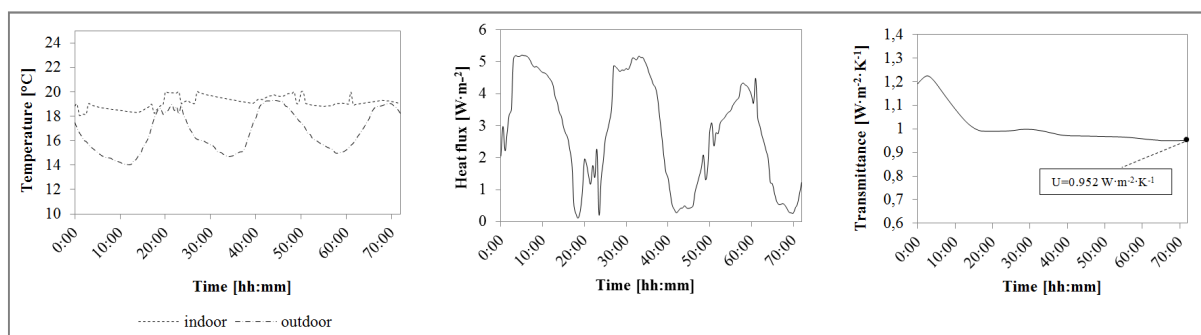

Figure 8: Temperature, heat flow and U for case B1 and with conventional HFM method .

Regardless of issues related on adequate differences in temperature between the two sides of the wall, the discrepancy with respect to the theoretical value of 0.842 Wm^{-2}K^{-1} obtained

from ISO 6946:2007, and calculated with equation (5), was greater of that obtained with modified HFM method (16.4% and 0.6%, respectively).

Moreover, the amplitude of oscillations of thermal transmittance calculated in the last 24 hours in according to equation (4) was 1.95%, therefore less than 5% as requested by ISO 9869-1:2014.

5   Conclusions

This paper refers to measuring of thermal transmittances of walls with a heat flow meter method slightly modified with respect to that described in standard reference method ISO 9869-1:2014. Main differences are based on a threefold measurement of wall temperatures and on an improved adhesion between temperature probes and wall surface, with the aim to reduce problems related to roughness and bad adhesion of surfaces. Moreover, the conditioning of at least one side of walls investigated is done, to assure the required difference in temperature between internal and external sides (at least 10°C), which otherwise would not be ensured in the Mediterranean areas, to which this paper refers. This last aspect is particularly important also from a bureaucratic point of view: indeed, in terms of energy upgrading of buildings, the Apulia Region may provide that a feasibility study that includes the transmittance measurement of the vertical walls must be completed within 30 working days from the assignment of a contract. If within this period changings in weather conditions makes difficult the measurement, the feasibility study would be compromised. Clearly, the conditioning of walls helps to get rid from this issue.

The modified HFM method was applied on three cases: an internal wall and a perimetral wall before and after the introduction of an outer insulating layer (rock wool). Results obtained were compared to theoretical U-values obtained with ISO 6946:2007, and also with standard HFM method in case of the perimetral wall without insulating layer. Main results are hereinafter summarized:

- the differences between U-values obtained with the modified HFM method and theoretical ones were in the range 0.6–6.5 % for cases in which no high fluctuations in temperatures were observed.
- the difference between U-value obtained with the modified HFM method and theoretical one was 29.4% for perimetral wall with insulating layer, in which high fluctuations in external temperature was observed.
- The measurements performed on the perimetral wall and after the conditioning of the internal rooms (heating or cooling) assured a difference in temperature wall surface between internal and external sides of at least 10°C. This was not assured when the conditioning of internal room was not performed. This aspect confirms that the conditioning of rooms can resolve the problem related to variability of weather conditions that may affect the measurements.
- The modified HFM method provided a result closer to the theoretical one, when compared to that obtained with the standard HFM method (discrepancy with theoretical value were 0.6% and 16.4%, respectively).
- In all the measurements performed, the amplitude of the thermal transmittance oscillations, calculated in the last 24 hours, were less than 5% as requested by the ISO 9869-1:2014.

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