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# Quantitative thermography for the estimation of the U-value: state of the art and a case study

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**Abstract.** Energy consumption of buildings could be significantly reduced by improving the efficiency of the envelope. Currently, the estimation of the energy performance of existing buildings requires the knowledge of the overall heat transfer coefficient (U-value) of the walls. U-values can be calculated through a theoretical approach, knowing the thermal conductivity and thickness of each material that constitutes the wall stratigraphy, from project data or coring. Alternatively, U-values can be obtained experimentally, through the ISO recommended heat flow meter measurements. Although generally accepted, the heat flow meter method suffers from some disadvantages. Recently, an alternative approach based on infrared thermography (IRT) has been proposed for in situ measurements. Main advantages of this new approach are non invasivity and the possibility of inspecting relatively large areas in real time. In this paper, after a brief description of the state of the art in the field of U-value measurement by IRT, a case study is described. In particular, the results obtained by IRT on an existing building are compared with U-values given by the standard ISO calculation and heat flow meter measurements; advantages and limitations of the new method are outlined. Some suggestions for a successful exploiting of the IRT approach are also given.

## 1. Introduction

According to IEA data, residential buildings are responsible of about 32% of total final energy consumption; in terms of primary energy consumption, they represent around 40% in most IEA countries.

Heat transfer through a composite wall, a key parameter for the assessment of the energy sustainability of the whole structure, can be described by a single number, the U-value (in Europe) or its reciprocal, the R-value (in the USA).

The estimation of thermal transmittance (U-value) is held through two methodologies, both standardized.

The first approach [1, 2], is based on the knowledge of wall stratigraphy, gathered from project data, coring or endoscopic surveys through the wall, or by similarity to coeval buildings.

This method, however, is quite uncertain: it is not always possible to know the wall stratigraphy from projects, because they are often missing. Furthermore, for historical buildings, often of cultural interest, it is not possible to carry out the destructive surveys mentioned above to identify the stratigraphy.

Considering that more than 60% of world historical constructions is located in Italy, the optimization of the energy efficiency of this architectural heritage is very important.



Moreover, conductivity values provided in literature often do not match with the real one, because of aging and installation features.

The second approach, normalized by ISO 9869 [3], uses a heat flow meter (HFM), an instrument able to calculate instantaneous and averaged value of transmittance as ratio between heat flux through the wall and the difference between interior and exterior wall surface temperature, after an acquisition time of at least 72 hours (more for high thermal inertia walls).

One of the disadvantages of this method is that it gives only punctual values, so the transmittance determination in another point requires another measurement campaign. Furthermore, in order to have reliable values, a minimum gradient of 10 °C between indoor and outdoor temperature is required.

The measured values can also be influenced by thermal bridges, humidity, mold and partial adhesion of the sensors to the wall (especially if the wall façade is rough).

In conclusion, the experimental values obtained by the heat flow meter method are often very different from the calculated ones. This mismatch is particularly important for historical buildings, for which the differences between standard and measured U-values can vary from 2% to 58%, depending on the composition of the ancient walls [4].

In the last years, induced by the advances in infrared detection technology and infrared imaging applications [5, 6], the use of infrared thermography (IRT) for applications in buildings has been proposed by many authors [7-12].

IRT is widely accepted as a tool for the analysis of the energy efficiency of new and existing buildings in a qualitative way [13, 14] but, recently, several research groups proposed a method based on quantitative thermography for the in situ measurement of wall transmittance.

Albatici and Tonelli [15, 16], for evaluating wall transmittance, use a relation that involves parameters measured by IRT, except for the wind velocity (measured by a hot-wire anemometer in proximity of the wall). They also give an experimental procedure to measure the surface emissivity in the spectrum range related to the thermography. They reported three case studies [16]: differences with U-values determined by HFM are of the order of 30%, while differences with calculated U-values (ISO 6946) can grow up to 80%. Environmental conditions are very important for a reliable measurement: direct solar irradiation must be avoided; wind speed must be lower than 1m/s (best condition is lower than 0.2 m/s) and the difference between inner and outer temperature during the test realization must be of at least 10–15°C.

In the earlier work by Madding [17], a better matching between measured and calculated values (within 13%) is reported. No comparison is given with HFM results as well as no details about the thermo physical parameters involved in the measurements. According to Madding's uncertainty analysis, the most sensitive variables are the emissivity and the difference between the reflected apparent temperature and the wall temperature.

Grinzato *et al.* [18] proposed a more rigorous and complex procedure: a light metallic frame is inserted near the wall and in the field of view of the thermal camera; the frame holds several targets on which particular parameters, useful for accurate measurements of wall and air temperatures, are recorded. Then the entire system is scanned by IRT in an automatic way. Reported experimental results show a difference with U-values determined by HFM of the order of 30-35%.

Fokaides and Kalogirou [19] examined 5 case studies. They refer that U-values by IRT are within 10-20% of notional values (ISO 6946). For one case study, they also made a comparison with HFM value, the difference being well within 10%.

More recently, Dall'O *et al.* [20] presented an extensive investigation on different buildings. They reported that percentage absolute deviation between the notional and the measured U-values for IR thermography has an acceptable level, being within 40-45%, as long as suitable cautions are taken. Their survey also showed that IRT evaluation is more reliable for solid-mass walls, for which the error percentage is lower if compared to HFM method.

In the following, a case study is described. In particular, the results obtained by IRT are compared with U-values given by the standard ISO calculation and heat flow meter measurements; advantages

and limitations of the new method are outlined. Some suggestions for a successful exploiting of the IRT approach are also given.

## 2. Methodology

There isn't a normative concerning the U-value estimation by means of IRT, since this technique is still a topic of study by several research groups, as explained in section 1.

In this study, transmittance is calculated approximating the overall heat exchanged through the wall with the heat exchanged with the outdoor by radiation, that is [16]:

$$U = \frac{5.67 \varepsilon_{tot} \left[ \left( \frac{T_w}{100} \right)^4 - \left( \frac{T_{out}}{100} \right)^4 \right] + 3.8054 v (T_w - T_{out})}{(T_{int} - T_{out})} \quad (1)$$

where  $T_{int}$  is the indoor environment temperature [K],  $T_{out}$  is the outdoor environment temperature [K],  $T_w$  is the surface temperature of the element [K],  $\varepsilon_{tot}$  is the emissivity on the entire spectrum and  $v$  is the wind velocity.

All the values involved in Equation (1) can be estimated through IRT.

First of all, mean apparent reflected temperature (defined as “the apparent temperature of other objects that are reflected by the target into the infrared thermography camera” [21]) must be calculated. This can be accomplished, as suggested in [21], by using a high reflective surface, like an aluminum foil stretched after crumpling. The foil must be located near the wall, with the reflective leaf towards the outside: if the IR camera emissivity is set to equal 1, the mean foil temperature is the reflected ambient temperature.

The second parameter to be evaluated is emissivity. In Equation (1) total emissivity, gathered from literature, is involved, since the aim is to calculate the whole radiant energy emanated from the surface. Bearing in mind that wall temperature is determined through a tool (IR camera) that works between specific wavelengths, it is clear that for detecting wall temperature it is necessary to know walls' spectral emissivity, that strongly depends on its roughness and conditions (like humidity and pollution). Wall spectral emissivity can be evaluated using target of known emissivity higher than 0.9 located on the wall. After a suitable time, needed to the target for reaching wall temperature, a thermogram is acquired setting on the IR camera target emissivity.

Target and wall temperature can be calculated using a proprietary software (in our case, ThermaCAM Researcher Pro 2.8) and through the placement of two spots. Theoretically, those temperatures should be the same, since the target, well stuck to the wall, has the wall temperature.

However, target and wall have different emissivities, so two different values of radiative energy arrive to the thermal camera sensor, and they are converted, at the same emissivity (target emissivity, set on thermal camera), in two temperature values. In fact, target shape can be clearly individuated. Then, the emissivity set on IR camera is varied till the wall temperature equals the one previously detected on the target. This procedure, once again, complies with international standard [21].

Indoor temperature has been measured using thermography, as suggested by Albatici and Tonelli [16], through a partial opening of a window, that can be assimilated to a black body.

Outdoor temperature can be assessed setting emissivity equal to 1 and detecting temperature of a black PVC tube left outside (to reach outdoor temperature), with a tapped side and whose length is 5-6 time the opening diameter (which is comparable to the diameter of the thermal camera lens).

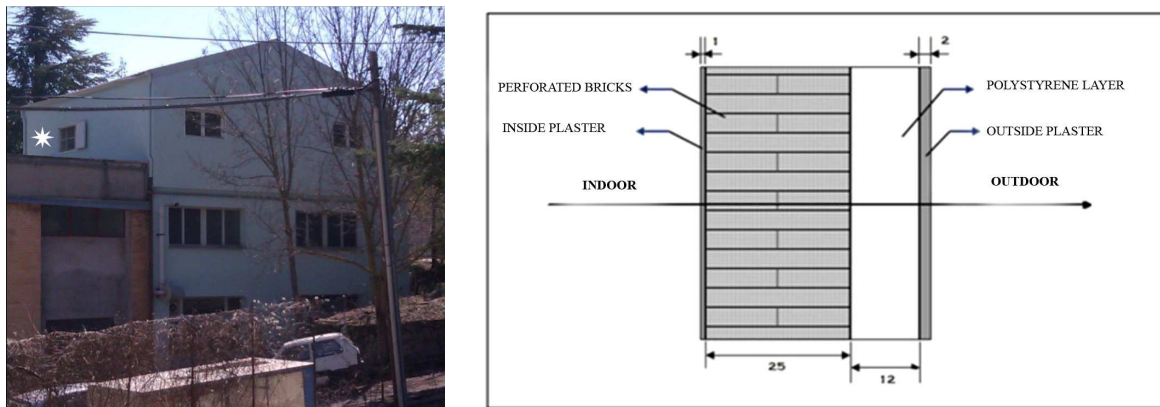
The wind velocity  $v$  can be measured near the wall by a hot-wire anemometer. In the following experimental campaigns, we performed the measurements in quiet days, therefore a wind velocity  $v \approx 0$  m/s was assumed.

### 3. Case study

As a case study, an university small building was considered: the “Solar house”, placed in Monteluco di Roio (960 m a.s.l.), district of L’Aquila (climatic zone: E; degree days: 2514). The building (category E.7 according to D.P.R. 412/93) was built in the 1970s; it has a masonry of perforated bricks, coated with an insulating layer of polystyrene after the refurbishment consequent to 2009 earthquake, and painted green. Details are given in Table 1, while the building and its stratigraphy are shown in Figure 1. The design (ISO 6946) U-value is  $U = 0.31 \text{ W m}^{-2}\text{K}^{-1}$ .

**Table 1.** Case study stratigraphy.

| Layer           | Thickness<br>[m] | Conductivity<br>[ $\text{W m}^{-1}\text{K}^{-1}$ ] | Thermal resistance<br>for unit area<br>[ $\text{m}^2\text{K W}^{-1}$ ] |
|-----------------|------------------|--|--|
| Outside plaster | 0.02             | 0.9  | 0.022  |
| EPS layer       | 0.12             | 0.054  | 2.22   |
| Bricks          | 0.25             | 0.3  | 0.833  |
| Inside plaster  | 0.01             | 0.9  | 0.011  |



**Figure 1.** Case study “Solar house”; exterior of the building (with the asterisk marking the wall under test, North – North East façade) and stratigraphy.

### 4. Experimental results

The acquisition of thermograms has been carried out by an infrared camera model ThermaCAM S65 HS from FLIR System, equipped with a focal plane array uncooled microbolometer. Some technical specifications are listed in Table 2.

**Table 2.** Main technical specifications of ThermaCAM S65 HS.

| IFOV     | Spectral range         | Image size       | Accuracy   | Thermal sensitivity   |
|----------|------------------------|------------------|--|---|
| 1.1 mrad | 7,5 ~ 13 $\mu\text{m}$ | 320 x 240 pixels | $\pm 2 \text{ }^\circ\text{C}$ or $\pm 2\%$ of reading | $< 0.05 \text{ }^\circ\text{C}$ with respect to $30 \text{ }^\circ\text{C}$ blackbody temperature |

At first, a thermal inspection of outdoor walls has been performed in order to detect heat losses and the possible presence of thermal bridges or surface humidity.

The main difficulty for in-situ examination is linked to non-stationary boundary conditions. Due to changes of ambient temperatures, not only thermal conductivity but also specific heat and density of materials vary, and this influences in a significant way the heat transfer through buildings envelope. The influence on non-stationary conditions may be, to some extent, reduced by making the inspection during a period carefully selected and characterized by limited ambient parameters variations.

To quantify the thermal field, a series of parameters have been acquired, according to the procedure described in section 2.

The ambient parameters have been monitored for checking and comparison during the measurements with thermo-hygroscopic sensors (KIMO HD100 and with HOBO®).

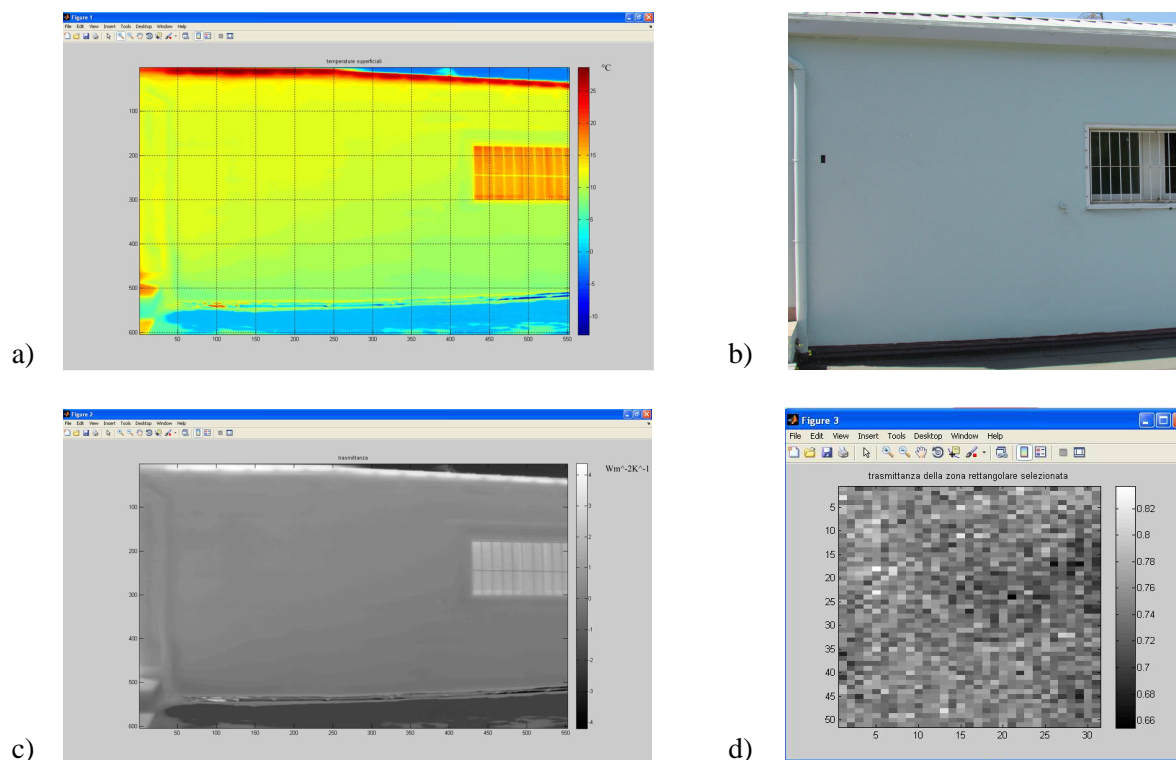
U-values determined by IRT have been compared with U-values measured by HFM, according to ISO 9869; the thermopile heat flow sensor (ESR240, uncertainty 5% on 12 hrs measurement) and the surface thermocouples (EST124, uncertainty 0.15 °C) were by LSI Lastem, while the measurements were recorded by M-LOG Mini data logger (LSI Lastem). Data were processed by INFOflux program. For the case study, a long measurement campaign was carried out. Taking into account the preliminary thermal inspection, the HFM was positioned far from thermal bridges and non homogeneous regions of the wall. The measured data were analyzed by the average method [3].

Table 3 shows the results obtained by HFM; percentage absolute deviations between the design and the HFM U-values range from 11% to 29%, while the value averaged over the whole period has a deviation of about 14%.

**Table 3.** U-values obtained by HFM.

| Period               | U-value<br>[Wm <sup>-2</sup> K <sup>-1</sup> ] |
|----------------------|--|
| 08 Feb – 11 Feb 2013 | 0.276  |
| 11 Feb – 14 Feb 2013 | 0.392  |
| 14 Feb – 17 Feb 2013 | 0.356  |
| 17 Feb – 20 Feb 2013 | 0.375  |
| 20 Feb – 22 Feb 2013 | 0.400  |
| 08 Feb – 22 Feb 2013 | 0.354  |

Then U-values have been determined by IRT and thermal images have been processed in MATLAB® environment. Figure 2 shows the results obtained on 22<sup>nd</sup> Feb 2013, a cloudy day.



**Figure 2.** Case study: (a) surface temperatures; (b) visible image; (c) U-values calculated according to Equation 1; (d) U-values in the selected area.

A homogeneous area of about 20 cm × 20 cm, close to the known emissivity label and near the position on which the heat flow sensor was mounted, was selected. U-value has been calculated for each pixel of the selected area (see Figure 2 d)) and these values have been averaged to estimate the wall transmittance; this, to avoid to re-set the emissivity for the calculation of wall temperature underneath the label, and therefore to avoid possible contact resistance.

Measurement was repeated on 27<sup>th</sup> Feb 2013, a sunny day.

Results are shown in Table 4.  $\Delta_1$  and  $\Delta_2$  are the percentage deviations with respect to the design U-value ( $0.31 \text{ Wm}^{-2}\text{K}^{-1}$ ) and the average HFM U-value ( $0.354 \text{ Wm}^{-2}\text{K}^{-1}$ ); the deviations range from very good (about 2%) to acceptable (about 37%).

The difference between outdoor and reflected temperature is equal to 3.6 °C (22<sup>nd</sup> Febr.) and 11.59 °C (27<sup>th</sup> Febr. ).

**Table 4.** U-values obtained by IRT.

| Date        | U-value<br>[Wm <sup>-2</sup> K <sup>-1</sup> ] | $\Delta_1$ | $\Delta_2$ |
|-------------|--|------------|------------|
| 22 Feb 2013 | 0.360  | 16.12%     | 1.69%      |
| 27 Feb 2013 | 0.222  | 28.38%     | 37.28%     |

## 5. Conclusions

In this paper, after a brief description of the state of the art in the field of U-value measurement by IRT, a case study is described. The results obtained by IRT on an existing building are compared with U-values given by the standard ISO calculation and heat flow meter measurements.

Measurement campaign involved an extensive investigation by HFM in different weather conditions. Then, measurements by IRT were performed.

Another building, of recent construction and high energy efficiency, has been investigated too. In this case, it was not possible to perform a long HFM measurement campaign, and IRT has been applied only once, being the building a private one. For this reason, the case has not been discussed in this work, although preliminary results show a more accurate transmittance estimation. In fact, percentage deviations of the U-value with respect to the design and the average HFM ones range, respectively, from very good (less than 1%) to good (within 12%).

According to our experience, IRT can give reliable results if a series of conditions (some of them outlined in literature) are fulfilled.

In particular, the surface temperature of the wall should be greater than the outdoor environment temperature (at least 2 °C) and the difference between indoor environment temperature and outdoor environment temperature should be great. The measurement of the spectral emissivity should be accurate and the weather conditions should be stable.

The next step would consist in experimental measurements in a controlled environment to fully characterize the influence of different parameters on the final results.

## References

- [1] UNI TS 11300: 2008 Prestazioni energetiche degli edifici
- [2] EN ISO 6946: 2007. Building components and building elements. Thermal resistance and thermal transmittance Calculation method
- [3] ISO 9869:1994 Thermal insulation. Building elements. In-situ measurement of thermal resistance and thermal transmittance
- [4] Adhikari RS, Lucchi E and Pracchi V 2012 Experimental Measurements on Thermal Transmittance of the Opaque Vertical Walls in the Historical Buildings *Proc PLEA2012 - 28th Conference, Opportunities, Limits & Needs Towards an environmentally responsible architecture (Lima, Perù)*
- [5] Maldague X 2001 *Theory and practice of infrared technology for nondestructive testing* (New York: Wiley)
- [6] Bagavathiappan S, Lahiri BB, Saravanan T, Philip J and Jayakumar T 2013 Infrared thermography for condition monitoring – A review *Infrared Phys. Technol.* **60** 35
- [7] Balaras CA and Argiriou AA 2002 Infrared technology for building diagnostics *Energy Build* **34** 171
- [8] Grinzato E, Bison PG and Marinetti S 2002 Monitoring of ancient buildings by the thermal method *J Cult Herit* **3** 21
- [9] Avdelidis NP and Moropoulou A 2004 Applications of infrared thermography for the investigation of historic structures *J Cult Herit* **5** 119
- [10] Grinzato E, Cadelano G, Bison PG and Petracca A 2009 Seismic risk evaluation aided by IR thermography *Thermosense XXXI Proc. SPIE* **7299** 72990C
- [11] Paoletti D, Ambrosini D, Sfarra S and Bisegna F 2013 Preventive thermographic diagnosis of historical buildings for consolidation *J Cult Herit* **14** 116
- [12] Bisegna F, Ambrosini D, Paoletti D, Sfarra S and Gugliermetti F 2014 A qualitative method for

- combining thermal imprints to emerging weak points of ancient wall structures by passive infrared thermography – A case study *J Cult Herit* **15** 199
- [13] Kauppinen T 2009 The use of thermography in energy performance of buildings-directive (EPBD)-applications *Thermosense XXXI Proc. SPIE* **7299** 729908
- [14] EN 13187: 1998 Thermal performance of buildings. Qualitative detection of thermal irregularities in building envelopes. Infrared method
- [15] Albatici R and Tonelli AM 2008 On site evaluation of U-value of opaque building elements: a new methodology *Proc PLEA 2008 - 25th Conference on Passive and Low Energy Architecture (Dublin, Ireland)*
- [16] Albatici R and Tonelli AM 2010 Infrared thermovision technique for the assessment of thermal transmittance of opaque buildings elements on site *Energ Build* **42** 2177
- [17] Madding R 2008 Finding R-values of stud frame constructed houses with IR thermography *Proc InfraMation 2008 (Reno, USA)*
- [18] Grinzato E, Bison P, Cadelano G and Peron F 2010 R-value estimation by local thermographic analysis *Thermosense XXXII Proc. SPIE* **7661** 76610H
- [19] Fokaides PA and Kalogirou SA 2011 Application of infrared thermography for the determination of the overall heat transfer coefficient (U-value) in building envelopes *Appl Energ* **88** 4358
- [20] Dall’O G, Sarto L and Panza A 2013 Infrared screening of residential buildings for energy audit purposes: results of a field test *Energies* **6** 3859 [www.mdpi.com/journal/energies](http://www.mdpi.com/journal/energies)
- [21] ISO 18434-1:2008. Condition monitoring and diagnostics of machines – Thermography. Part 1: General procedures. Annex A “Field measurements of reflected apparent temperature and emissivity”