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A model for the improvement of thermal bridges quantitative assessment by infrared thermography

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HIGHLIGHTS

- Improvement of energy diagnosis of the building envelope.
- Influence factor of the thermal bridge definition and improvement.
- Experimental campaign in the Hot Box apparatus performing thermal analysis on thermal bridges sample.
- Mathematical algorithm for the enhancement of the image resolution.
- Physical contours extracting method of thermal bridges from the infrared image.

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ABSTRACT

The intervention on the existing building envelope thermal insulation is the main and effective solution in order to achieve a significant reduction of the building stock energy needs. The infrared technique is the methodology of the energy diagnosis aimed to identify qualitatively the principal causes of energy losses: the presence of thermal bridges. Those weak parts of the building envelope in terms of heat transfer result not easy to treat with an energy efficiency intervention, while they are gaining importance in the buildings total energy dispersion, as the level of insulation of opaque and transparent materials is continuously increasing. It is generally possible to evaluate the energy dispersions through these zones with a deep knowledge of the materials and the geometry using a numerical method. Besides, authors proposed in the past a methodology to assess the flux passing through thermal bridges with an infrared image correctly framed. The analysis of surface temperatures of the undisturbed wall and of the zone with thermal bridge, allows to define the *Incidence Factor of the thermal Bridge* (I_{tb}). This parameter is strongly affected by the thermographic image accuracy, therefore, this paper deals with the development and validation of an innovative mathematical algorithm to enhance the image resolution and the consequent accuracy of the energy losses assessment. An experimental campaign in a controlled environment (hot box apparatus) has been conducted on three typologies of thermal bridge, firstly performing the thermographic survey and then applying the enhancement algorithm to the infrared images in order to compare the I_{tb} and the linear thermal transmittance ψ values. Results showed that the proposed methodology could bring to an accuracy improvement up to 2% of the total buildings envelope energy losses evaluated by quantitative infrared thermography. Moreover, the proposed algorithm allows the implementation of a further process applicable to the images, in order to extract the physical boundaries of the hidden materials causing the thermal bridge, so revealing itself as a useful tool to identify exactly the suitable points of intervention for the thermal bridge correction. The application of the imaging process on the quantitative infrared thermography is an innovative approach that makes more accurate the evaluation of the actual heat loss of highly insulating buildings and reaching a higher detail on the detection and treating of thermal bridges.

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Nomenclature

A	area (m^2)
I	incidence factor (–)
l	length (m)
N	number of pixels
R	scaling factor
Q	heat flux (W)
T	temperature (K)
$TB1$	thermal bridge sample 1
$TB2$	thermal bridge sample 2
$TB3$	thermal bridge sample 3
P	peak
U	thermal transmittance (W/m^2 K)
φ	density of thermal flux (W/m^2)
ψ	linear thermal transmittance (W/m K)

Subscripts

i	internal air
p	relative to each pixel
$1D$	one-dimensional
HFM	evaluated with heat flux meter
tb	thermal bridge
tb_k	relative to kth heat flux meter
1	relative to peak 1
2	relative to peak 2
m	relative to the minimum between two peaks

1. Introduction

Most of the European building stock is made of existing constructions and the improvement of the envelope insulation (together with old thermal plants replacement) constitutes the primary intervention to reduce the energy consumption of the building sector [1]. The experimental analyses of the opaque and transparent elements insulation performance complements the theoretical approach, at the aim of reaching the assessment of the real building energy needs [2,3].

The thermographic survey on the building envelope is a useful method to detect defects and irregularities responsible of the reduction of its overall energy performance. According to the depth and scope of the audit, different evaluations may arise from the analysis of the thermographic images. A first approach can give qualitative information of the proper placement of the building element, eventually suggesting possible solutions. A deeper reading of the thermogram, with an accurate definition of the measurement conditions, leads to a quantitative analysis that supplies data about the heat transfer on the studied element [4]. For the retrofit process of a building envelope it results strategic to lead a deep energy diagnosis on the real conditions of the overall elements of the building [5,6]. The quantitative thermography helps designers and manufacturers to improve the current energy behavior of the building envelope, in particular zones such as thermal bridges, which play a more and more important role in the global energy dispersion of buildings.

Grinzato et al. [7] studied the application of the infrared thermography to detect defects in civil constructions. Air leakages, moisture problems, plaster detachments and thermal bridges in buildings can be detected using thermographic inspections. The authors consider that the quantitative methodology is a helpful technique to solve inverse heat conduction problems in transient regime.

Zalewski et al. [8] analysed thermal bridges in a light wall with a steel frame, aiming to realise a support for designers. The thermal bridges were detected by means of infrared thermography, then the heat flow and surface temperatures were measured. A numerical simulation was carried out to predict the heat losses and this model was validated by the measured parameters.

When the building envelope is investigated with infrared thermography, a correct interpretation of the images is needed to identify the real defects. In fact, several parameters can affect the retrieved surface temperature, such as environmental conditions, emissivity and reflected temperature [9–11].

Lehmann et al. [12] tried to reduce misunderstandings in the interpretation of the thermal images, carrying out a numerical study on the environmental conditions to better understand the effects on the thermograms.

Building diagnoses were usually carried out by means of a passive approach and images were interpreted by qualitative or quantitative methods. Fokaides and Kalogirou [13] proposed a methodology to calculate the thermal transmittance of a building element through the retrieval of its external surface temperature by infrared cameras. The thermal transmittance was calculated from the heat transferred to the camera by radiation and convection. They analysed five dwellings during winter and summer season, comparing the standard transmittances with those evaluated by the infrared images and those estimated by thermohygrometric measurements. They found that the values calculated with the measured temperature differ from 10% to 20% in terms of absolute deviation with respect to the ones estimated with theoretical input. They also noted that the measured temperature was particularly affected by the variation of emissivity and reflected temperature.

Albatici et al. [14] presented a measurement procedure and its validation: five different walls of an experimental building were analysed during three winter seasons from 2010 to 2013. The thermal

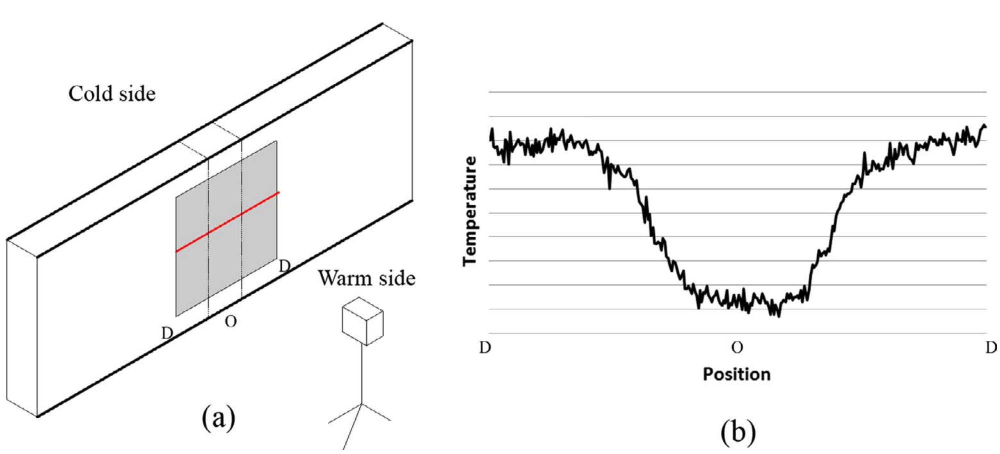

Fig. 1. Sketch of the structural pillar thermal bridge (a) and IR thermography temperature trend (b) in the red line. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)