DETERMINATION METHOD OF THERMAL CONDUCTIVITY OF BUILDING PARTS IN SITU THROUGH IR IMAGING BY MINIMIZING THE INFLUENCE OF ENVIRONMENTAL PARAMETERS

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ABSTRACT

Infrared imaging is a non destructive method, which determines the thermal behaviour of building materials in situ. Through infrared imaging, thermal bridges, moisture absorbed by buildings' materials as well as other parameters related to a building's thermal and energy behaviour can be determined.

A building's heat losses can be distinguished into conduction losses through its envelope and losses due to ventilation and infiltration. Losses through a building's envelope are related to the thermal resistance of its different parts and components used. In order that the thermal resistance (R) of the building's parts is determined, the parameter $1/\alpha_\alpha$, (thermal resistance of the exterior surface), which depends on meteorological conditions, should be determined. This work presents a method for the calibration necessary to calculate the thermal resistance (R) of different parts of the building's envelope.

Through the application of this method the thermal behaviour of unknown materials in buildings can be determined in situ.

KEYWORDS: building, ecology, insulation, bioclimatic, infrared imaging

1. INTRODUCTION

In order that thermal behaviour of buildings is optimized in the framework of sustainable development [1], the modern constructor should aim to minimize the amount of energy consumed to obtain thermal comfort for the buildings' users [2].

Although such issues can be dealt with during the study phase of a construction, there is also need for the testing and evaluation of existing buildings [3]. For the test of existing buildings, this paper presents a determination method – minimizing the influence of environmental parameters- of the thermal conductivity of building parts in situ through infrared imaging.

Infrared (IR) imaging is a non destructive method through which matter's thermal radiation at the infrared spectrum is detected providing information on its temperature. The method is widely applied in buildings for the qualitative analysis of the different temperatures on a building's envelope [4, 5, 6], the determination of the thermal behaviour of building materials in situ and the detection of energy losses through thermal bridges, as well as of moisture and indications of mould.

Energy losses of a construction can be distinguished into conduction losses through its envelope and losses due to ventilation and infiltration. This work presents a calibration method for the calculation of the thermal resistance (R) of different parts of a building's envelope. In order that the thermal resistance (R) is determined, the parameter $1/\alpha_\alpha$, (thermal resistance of the exterior surface), which depends on meteorological conditions, should be calibrated [7].

The equation of the heat flow through a single layer of material is described by Fourier's law of conduction:

$$\text{Heat flow} = \frac{\text{Thermal conductivity} * \text{Area} * \text{Temperature difference}}{\text{Thickness of a layer}}$$

Environmental parameters which are not included in the equation, such as sun and wind, affect the temperature of materials in situ (Figure 1). This paper describes how the equation with these parameters can be solved, in order that the thermal conductivity of materials is determined.

Heat between a material and the air is conducted -in both directions- through a thin layer of air adjacent to the materials' surface and depends on the specific conditions of the air (temperature and speed) within that layer. Therefore, when a material's surface is exposed to the air, the coefficient of the thermal conductivity is not constant, as it depends on the specific external conditions that apply. The coefficient a_x describes the conductivity of the surface with respect to the flow of heat.

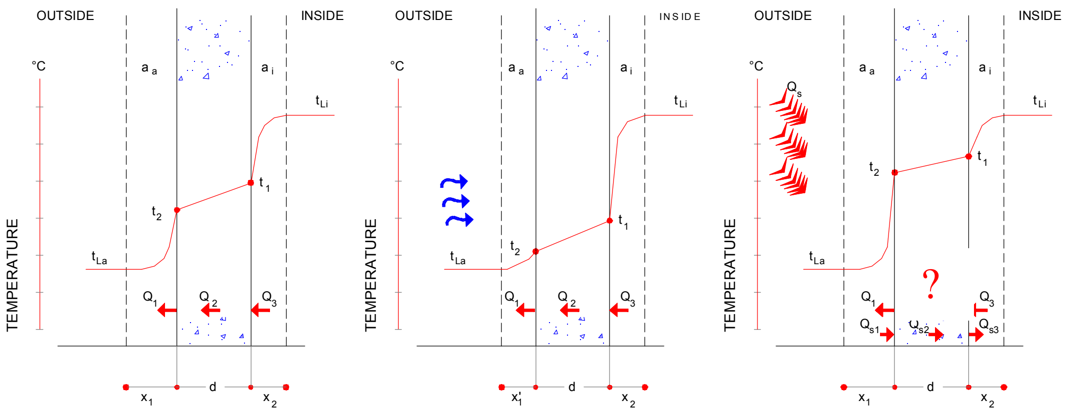


Figure 1: The variation of the surface temperatures in three cases: (a) theoretical, (b) in case of win (blue arrows) and (c) in case of solar radiation (red arrows)

2. METHOD DESCRIPTION

2.1. Test example

Different tests show that the results of temperatures in building materials of the infrared image analysis are a summary of the influence of different environmental parameters [8, 9].

In practice, while determining thermal conductivity [10] at an in situ study (Figure 2), environmental conditions are different than theoretical assumptions (Figure 3, 4). The difference is in outdoor surface's conductivity that affects the heat flow. The aim is to calculate the outdoor surface's conductivity a_{FAN}, which varies for different measurements, as a function of the heat flow and solve the new heat balance of Fourier's Law for different environmental parameters each time (Figure 5).

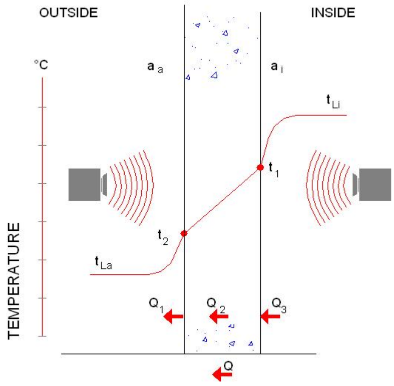


Figure 2: Infrared imaging testing

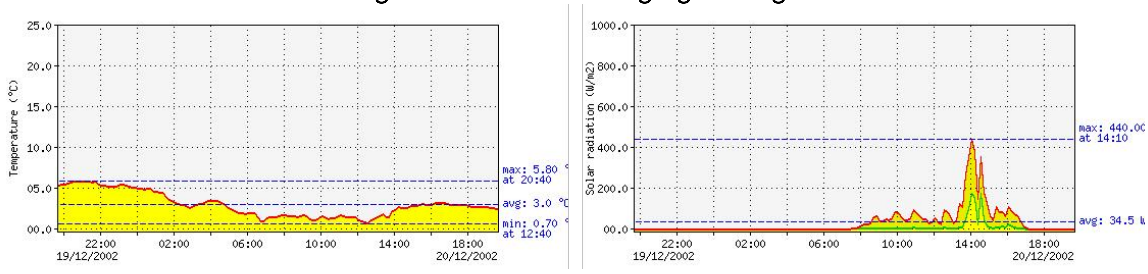


Figure 3: Temperature and solar energy diagram during the measurements

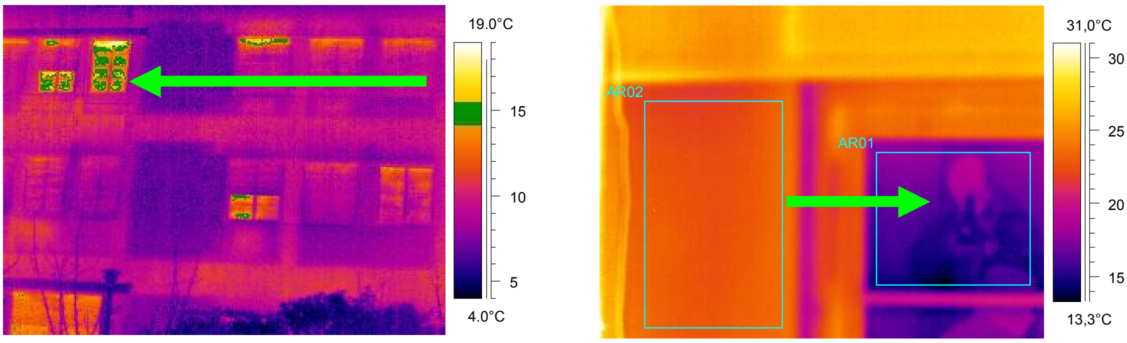
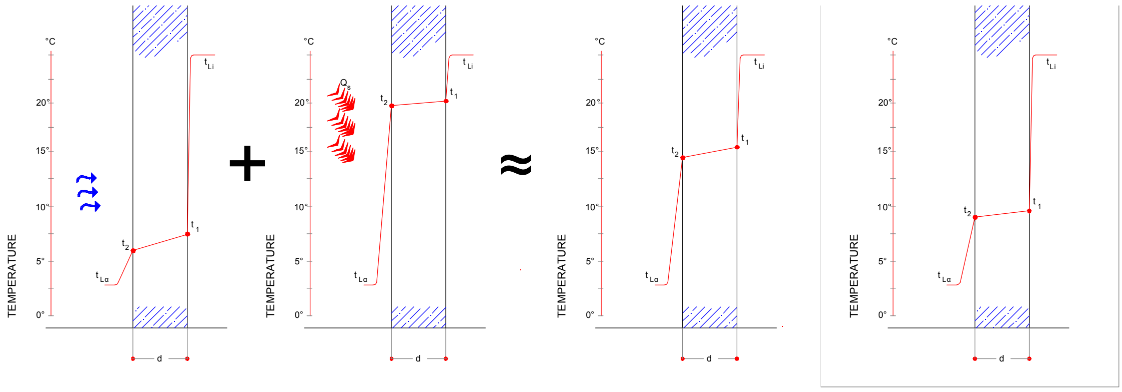


Figure 4: Isotherm temperatures area of windows
Average outside temperature of windows is about 15°C
Average inside temperature of windows is about 16.2°C



Temperature expected results with wind (qualitative)

Temperature expected results with sun (qualitative)

Temperature results by IR testing
t_1 16,2
t_2 15

Theoretical analysis of temperature
t_1 13,15
t_2 13,92

Figure 5: Environmental aspects of infrared imaging testing

2.2. Calculations

There are various approaches to determine and evaluate the thermal conductivity of buildings' parts in situ through IR imaging [11, 12, 13].

The following analysis is a method to combine Thermal insulation for building equipment and industrial installations - Calculation rules of the Hellenic Organization for Standardization, (based on DIN 4108) [14], with Thermal insulation - Qualitative detection of thermal irregularities in building envelopes - Infrared method of the Hellenic Organization for Standardization [10].

In this method of analysis, the parameters used are:

- t_{La}: outside temperature
- t_{Li}: inside temperature
- t_1 : surface temperature (interior)
- t_2 : surface temperature (exterior)
- a_x : surface conductivity
- K: thermal conductivity of part of the building's envelope
- R: thermal resistance of part of the building's envelope =1/K
- $1/\Lambda$: thermal resistance of the material

A first approach of the thermal conductivity from the interior temperature and the surface conductivity a_i of the interior of the building can be found in equation 1:

$$K' * (t_{Li} - t_{La}) = a_i * (t_{Li} - t_1) \rightarrow K' = \frac{a_i (t_{Li} - t_1)}{(t_{Li} - t_{La})} \quad (1)$$

The outdoor surface conductivity a_{FAN} is determined in equation 2:

$$a_{FAN} * (t_2 - t_{La}) = a_i * (t_{Li} - t_1) \rightarrow a_{FAN} = \frac{a_i (t_{Li} - t_1)}{(t_2 - t_{La})} \quad (2)$$

The thermal resistance of the materials $1/\Lambda$ according to previous data is calculated in equation 3:

$$R' = 1/K' = 1/a_{FAN} + 1/\Lambda + 1/a_i \rightarrow 1/\Lambda = 1/K' - 1/a_{FAN} - 1/a_i \quad (3)$$

The thermal resistance of a building's envelope according to the Greek Standards for the thermal insulation of buildings is given in equation 4:

$$R_{\text{in situ}} = 1/K_{\text{in situ}} = 1/a_a + 1/\Lambda + 1/a_i \quad (4)$$

A comparison of the experimental results from buildings, taken using the methodology presented, with the respective theoretical approach of the Hellenic Organization for Standardization's thermal insulations standards (based on DIN 4108) [14], can be found below. At this point it should be highlighted that some measurements were conducted with solar influence; the presence of the sun was the main constraint for the calibration of the parameter a_x in situ.

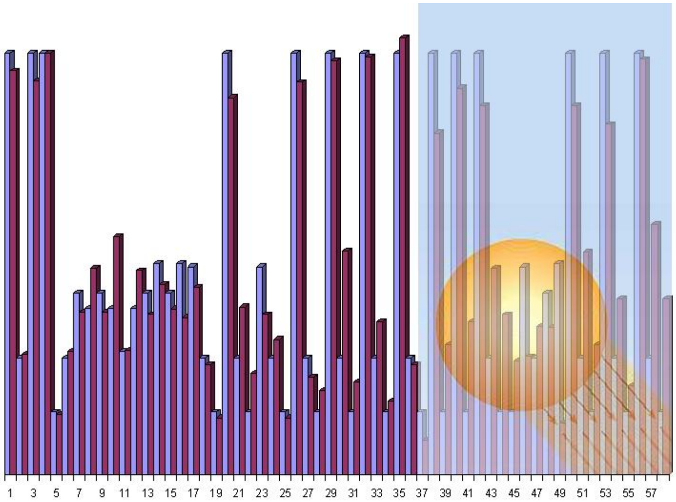


Figure 6: Theoretical data (red bars) and experimental data (blue bars) of K, without solar radiation (1-37) and with solar radiation (37-58)

According to statistical analysis, the precision of the method (%) is described by the following efficiency factor:

$$d = 1 - \frac{\sum (x_i - y_i)^2}{\sum (y_i - \bar{y}_i)^2} \qquad (5)$$

where:

- d = efficiency factor
- x_i = experimental data
- y_i = theoretical approach

The efficiency factor of the method in cases of absence of solar radiation is 94%, while its value in the presence of solar influence is 70% (for solar radiation inferior to 50 W/m^2).

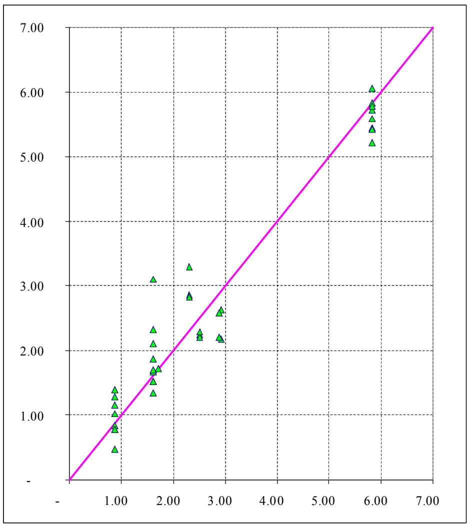


Figure 7: Test of the method without influence from the sun

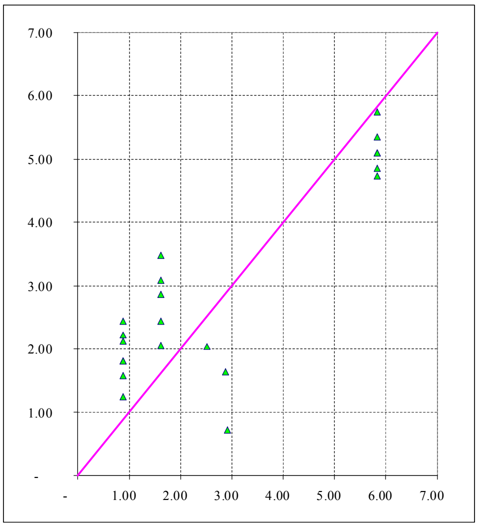


Figure 8: Test of the method with influence from the sun

3. DISCUSSION

The conclusion is that the application of this method minimises the influence of parameter a_x, related to the thermal conductivity, which depends on the air flow on the exterior surface of a material. However, air flow at the exterior surface does not affect the accuracy of the method. On the other hand, the accuracy of the method's results obtained is not satisfactory when there is considerable influence of solar radiation on the external surface of the building's parts.

There are some difficulties in applying the method in specific type of materials with high thermal storage capacity, such as stone. Experimental data show that for the application of the method for the calculation of the thermal conductivity in this type of materials, the following conditions should apply:

- Elimination of environmental interruption (solar energy, wind)
- Maximization of the temperature difference (indoor - outdoor)
- Stable thermal flow for more than three hours

Therefore, the optimal measurement is taken during cold winter nights, and at the same time when inside temperature of the building is the highest possible.

So the method is defined to provide results for the thermal behaviour of different parts of a building with precision of more than 80% if the following conditions apply:

- Stable thermal flow between indoor and outdoor system for more than 1 hour
- Minimum variation of the outdoor temperature
- Difference between indoor and outdoor temperatures superior to 15°C
- No measurements are taken while there is solar radiation on the building. Solar influence is accepted if the sun is present for no more than one hour before the in situ measurement and -according to a statistical analysis of the metrological conditions at the time of the measurements- for solar radiation inferior to 50 W/m^2.

According to the calculations conducted, in some cases outdoor surface conductivity a_x was negative. In these cases there were thermal inversions and the heat flow was different than in the case of the hypothesis.

4. CONCLUSIONS

Through this method, infrared imaging, mostly used as an approach for qualitative analysis, becomes a quantitative analysis tool for improving the accuracy of the in situ determination of the thermal conductivity of buildings' materials.

Based on this method, existing buildings' parts can be evaluated quantitatively with regard to their thermal conductivity, which is related to the buildings' energy requirements. In addition, failures in buildings' envelopes, such as thermal bridges, can be detected and analysed quantitatively, while also measures for improving the insulation of buildings can be evaluated through quantitative and accurate data.

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