USE OF INFRARED THERMOGRAPHY IN THE ACTIVITY OF BUILDINGS EXPERTISE

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ABSTRACT

The thermography method CAN NOT be used in assessing thermal flows dissipated through building members, namely assessments of the thermal resistance of building members forming the envelope of a building. In order to prove the lack of the phenomenological support in using thermography in quantifying the so-called "heat losses" through the envelope of a building, a homogeneous wall which is part of a heated enclosure, made of concrete and provided with expanded polystyrene heat insulation, has been considered. The wall is exposed to the solar radiation. Using the INVAR program, the thermal response of the wall was assessed, under an outdoor climatic load specific to an average winter day in Bucharest, in two variants, namely:

- the heat insulation in placed in the inside of the building member,
- the heat insulation adjoins the outdoor environment.

In both of the cases the thermal resistance of the building member is the same. Based on so called outside virtual temperature, the only thermo-dynamic parameter used for thermal resistance calculation, the fact that thermography is one improper method for such type of calculation is demonstrated.

The investigation / scanning of the buildings using an infrared visualization equipment is useful in the buildings energy-related assessments either in view of issuing the energy performance certificate, or in view of analyzing the energy upgrading solutions within the energy audit. A few of the possible applications of the infrared thermography in buildings energy analysis are further presented.

Key words: Energy simulation, infrared thermo-grphy method, thermal bridges, air tightness

REZUMAT

Metoda termografiei în infraroşu nu poate fi utilizată ca metodă pentru evaluarea rezistenței termice a unui element de construcție, parte a anvelopei unei clădiri. În scopul demonstrării celor de mai sus se prezintă un experiment numeric având ca suport un element de construcție confecționat din beton, prevăzut cu izolare termică. Elementul de construcție este expus radiației solare. Răspunsul termic al elementului de tip perete plan a fost determinat cu ajutorul programului de calcul INVAR, în condiții de climă proprie zilei de iarnă medie a oraşului Bucureşti. Izolația termică este amplasată adiacent, fie mediului natural, fie mediului interior, dar rezistența termică îşi păstrează nealterată valoarea în ambele variante de calcul. Avându-se în vedere variația temperaturii exterioare virtuale a elementului de construcție plan, singura care permite determinarea rezistenței termice în cazul regimului nestaționar de transfer de căldură, se demonstrează imposibilitatea determinării valorii rezistenței termice exclusiv pe baza valorilor temperaturilor obținute prin măsurări în spectrul infraroşu.

Investigarea clădirii prin utilizarea termografiei în infraroşu este o metodă calitativă de expertizare. În lucrare sunt prezentate câteva cazuri în care termografia în infraroşu poate fi utilizată cu succes în expertizarea clădirilor supuse activității de modernizare energetică.

Cuvinte cheie: simularea energetică, metoda termografiei în infraroşu, punți termice, etanşarea la aer

1. Introduction

The paper is structured in two complementary parts, of which the first demonstrates the impossibility of using the infrared thermography method in order to assess the real thermal characteristic of a building, and the second represents a data base the content of which includes various situations specific to the infrared investigation of the building as well as of the thermal systems in the buildings. In the case of convex, concave corners, a numerical simulation associated with infrared images is presented, removing the paradoxical conclusion that a perturbation characterized by coefficients of the linear thermal bridges with negative values might represent the energy "virtual source".

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2. Theoretical substantiation of the use of infrared thermography in the field of Building Energy Performance

The thermography method CANNOT be used in assessing thermal flows dissipated through building members, namely assessments of the thermal resistance of building members forming the envelope of a building. In order to prove the lack of the phenomenological support in using thermography in quantifying the so-called "heat losses" through the envelope of a building, we will consider a homogeneous wall which is part of a heated enclosure, made of 15 cm thick concrete and provided with 4.8 cm thick expanded polystyrene heat insulation. The wall is exposed to the solar radiation and its orientation is S-W. Using the INVAR program, the thermal response of the wall was assessed, under an outdoor climatic load specific to an average winter day in Bucharest, in two variants, namely:

- the heat insulation in placed in the inside of the building member,
- the heat insulation adjoins the outdoor environment.

In both of the cases the thermal resistance of the building member is the same, namely R_{Pe} = 1,283 m^{2}K/W. Fig. 1 represents the significant temperatures for the wall thermal response, in the two variants of placing the heat insulation, namely the temperatures on the wall outside area t_{ev}, the virtual outdoor temperatures respectively.

The t_{ev} values are the consequences of the assimilation at any moment τ of the real heat transfer with a virtual transfer process in steady state conditions; the value of the reference heat flow is the one specific to the inside area of the structure under analysis, which delimitates the thermodynamic outline of the heated enclosure.

$$t_{e_v}(\tau) = t_i - \frac{Q_{Pi}(\tau)}{S_{Pi}} \cdot R_{Pe}$$

where: R_{Pe} – thermal resistance of the analyzed structure [m^{2}K / W]; S_{Pi} – inside area of the outside building member [m^2].

The elements described above show that, in order to assess the thermal resistance of a building member within the envelope of a building, it is necessary to know the indoor temperature specific to the heated space and the virtual outside temperature of the wall, namely the thermal flow dissipated through the wall at the level of the thermodynamic outline of the heated space. While t_i is a dimensional easily assessed by measurements, and Q_{Pi} may be determined knowing the surface temperature of the wall at the level of the thermodynamic outline of the enclosure and the a_I heat transfer surface coefficient, the virtual outside temperature of the wall cannot be determined by

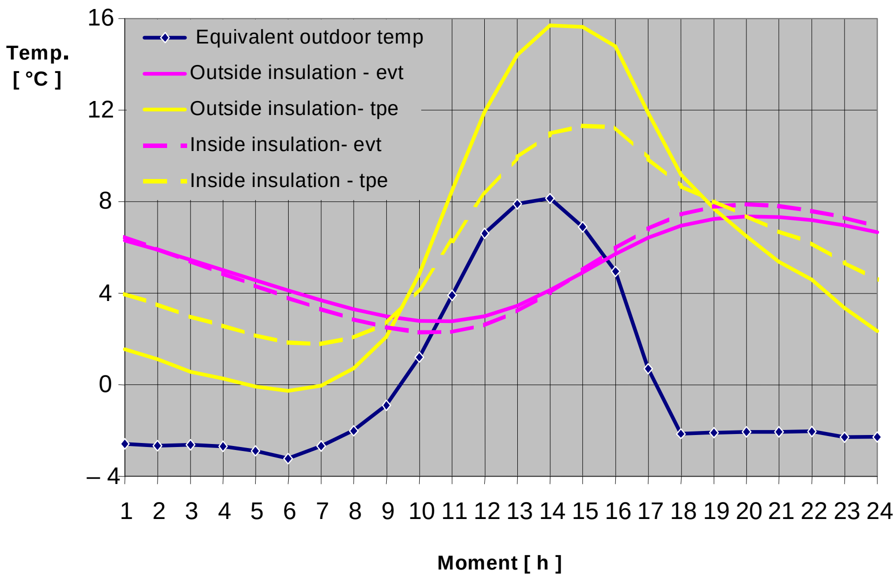


Fig. 1. Variation of the significant temperatures – outside wall in a heated enclosure (concrete + expanded polystyrene) – Bucharest average winter conditions

short-time measurements (specific to the infrared thermo-graphy analysis method); this is the consequence of the heat transfer in non-permanent conditions through the building member under analysis. The function of variation of the outside wall outdoor temperature is characterized both by damping and phase lag compared to the variation of the outdoor climatic parameters. The phase lag is translated by the delay in the manifestation of a variation of the environmental temperature (in this case the t_{Ep} equivalent outdoor temperature) at the level of the inside area of the building member within the building and depends on its thermo-physical and geometrical characteristics. Therefore, in order to know the virtual outside temperature it is necessary to know these characteristics of the wall, which, in fact, are to be assessed using the infrared thermography method.

On the other hand, if the variation of the wall outside area temperature is known (by using the infrared thermography method), the thermal balance of the outside wall is:

$$\frac{Q_{Pe}(\tau)}{S_{Pe}} = \alpha_e \cdot \left[t_{pe}(\tau) - t_{Ep}(\tau)\right] = \frac{1}{R_{Pe}} \cdot \left[t_{i_v}(\tau) - t_{Ep}(\tau)\right]$$

where: $t_{Ep}(\tau)$ – equivalent inside temperature of the outside wall [°C]; $t_{i_v}(\tau)$ – virtual inside temperature of the outside wall [°C]; S_{Pe} – outside area of the outside building member [m^2].

While t_{Ep} may be assessed by measurements (outdoor air temperature and solar radiation intensity) and the heat transfer surface coefficient specific to the wall outside area, α_e may be esti-mated using the McAdams relation (α_e = 15,2 W/m^{2}K for the case under study), the virtual inside temperature of the wall cannot be determined by short-time measurements (specific to the infrared thermography analysis method), as they are, like the virtual outside temperature, the consequences of the heat transfer in non-permanent conditions through the building member under analysis.

Fig. 2 presents the variation of the virtual inside temperature specific to the building member under analysis, for the two positions on the insulating layer (on the inside, respectively out-side part of the wall), together with the variation of the equivalent outside temperature t_{Ep}.

The fact is noticed that at any moment the virtual outside temperature has a higher value than the inside temperature specific to the heated enclosure (t_i = 20°C) which represents the maximum thermodynamic potential specific to the analyzed system. Therefore, the virtual inside temperature, representing the thermodynamic parameter in terms oh which the thermal flow dissipated through the outside area of an outside building member (within a building) may be determined at any moment using the mathematical formalism specific to the heat transfer through wall steady state conditions, cannot represent a physical, measurable dimension.

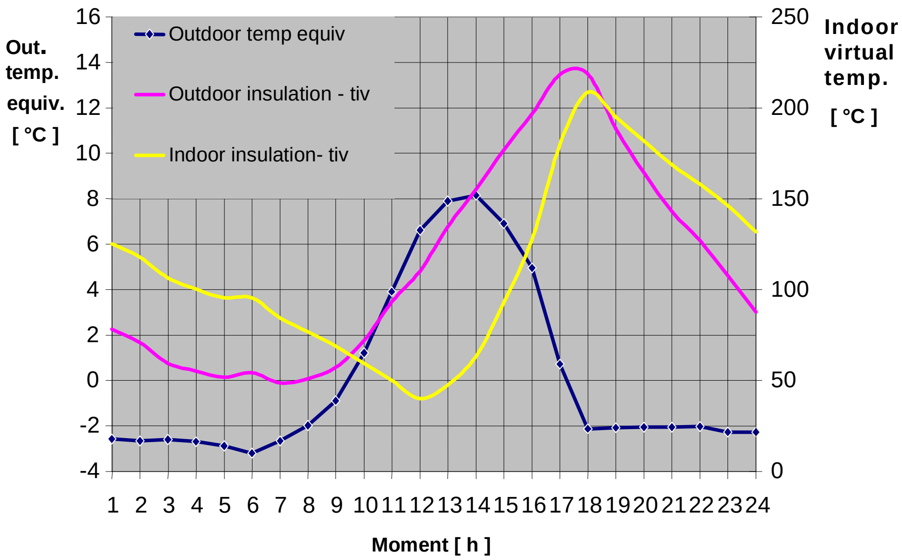


Fig. 2. Variation of the virtual inside temperatures for assessing thermal resistance – outside wall of a heated enclosure (concrete + expanded polystyrene) – Bucharest average winter conditions

The elements above confirm the fact that by short-time measurements (specific to the infrared thermography method) it is impossible to determine the thermal resistance of the opaque building members forming the envelope of a building.

Therefore, the infrared thermography method may be mainly used in emphasizing the variations of the thermal properties, including air tightness, of the building members forming the envelope of a building, the presence of moisture in the structure of the envelope components as well as identifying the areas in systems with heat insulation deficiencies or with deficient flow of the heat carrier. The use of this method in measuring the thermal insulation and air tightness level of the structure or, even more, in assessing the thermal performance of buildings envelopes is a serious phenomenological mistake.

3. Examples of using the infrared thermography technique in identifying the characteristics of the envelope components and of the equipments in buildings thermal systems

The infrared thermography is a method for visualizing and representing the distribution of the apparent temperature on the surface of a building envelope. The principle of the method in based on the fact that the irregularities that may occur in the thermal properties of the building members forming the envelope of a building are translated by temperature variations on the structure surface. The surface temperature is also influenced by the movement of the air inside or outside the building or which crosses the building envelope. The surface temperature distribution may therefore be used in detecting the thermal irregularities caused for instance by the insulation deficiencies, moisture or air infiltrations in the building envelope closing members.

The investigation / scanning of the buildings using an infrared visualization equipment is useful in the buildings energy-related asses-sments either in view of issuing the energy performance certificate, or in view of analyzing the energy upgrading solutions within the energy audit. A few of the possible applications of the infrared thermography in buildings energy analysis are further presented:

a. Identification of the large panels structure (prefabricated panels), dimensions and position of ribs, type of heat insulating material (fig. 3, 4). Knowledge of construc-tion technology, types of structures / joints, building erection technologies is necessary.

b. Identification of thermal bridges (reinfor-ced concrete floor / strap plate, beam, lintel). The thermal bridges in a brick masonry wall can be noticed in fig. 5 (reinforced concrete pierced components).

The zones where the heating units are placed may also be noticed in fig. 5, as they are warmer (visible also because of the reduced thermal resistance of the wall). The shutter of the ground floor window of the building is noticeable.

The reinforced concrete strap at the joint with the roof reinforced concrete plate is visible in fig. 6

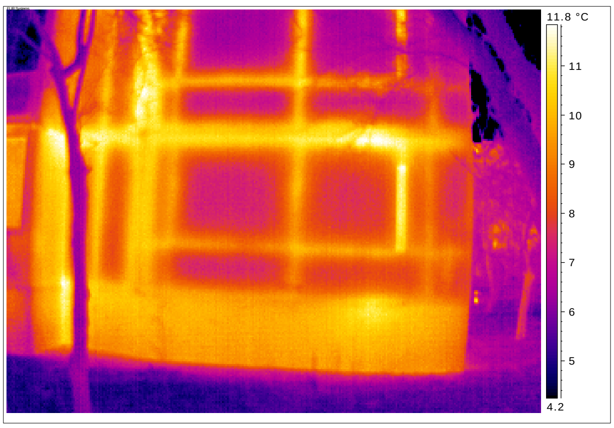


Fig. 3. Large panel wall – plates insulation (mineral wool, polystyrene)

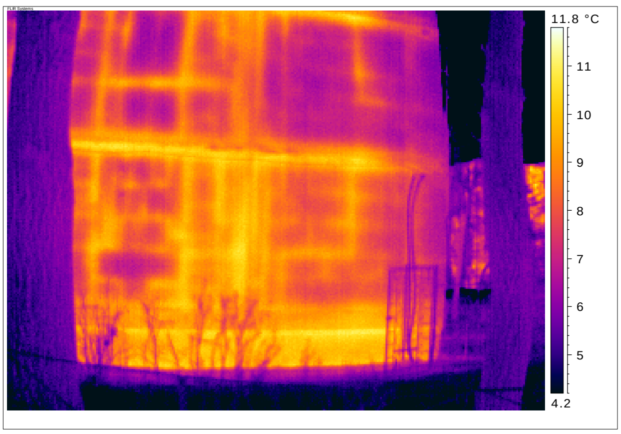
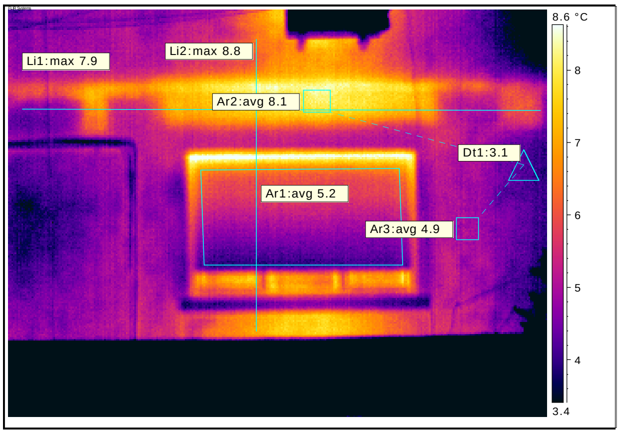
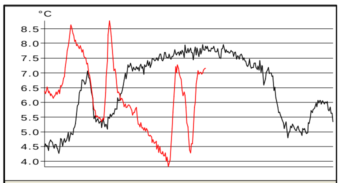


Fig. 4. Large panel wall – BCA (autoclaved lightweight concrete) strips insulation

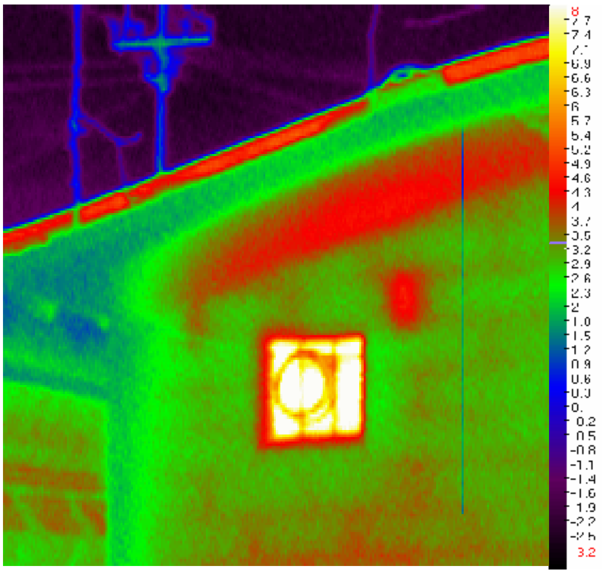


Object Parameter	Value	Label	Value
Emissivity	0.90	IR: Date Of Creation	15.02.20
Object Distance	7.0 m	IR: Time Of Creation	00:09:18
Reflected Temperature	5.0 °C	IR: Max	9.0 °C
Atmospheric Temperature	3.0 °C	IR: Min	0.3 °C
		Ar1: Average	5.2 °C
		Ar2: Average	8.1 °C
		Ar3: Average	4.9 °C



Label	Min	Max	Avg
Li1	4.3	7.9	6.5
Li2	3.8	8.8	6.2

Fig. 5. Brick masonry wall – identification of pierced thermal bridges



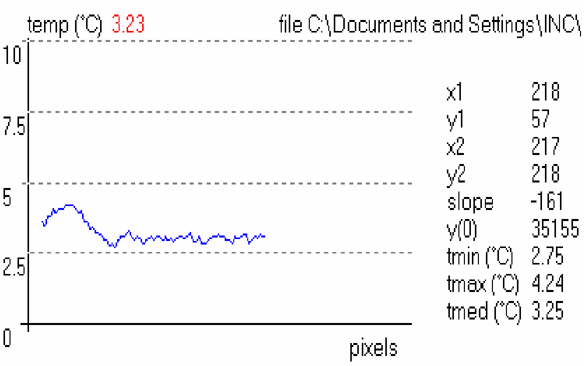


Fig. 6. INCERC experimental house – reinforced concrete strap

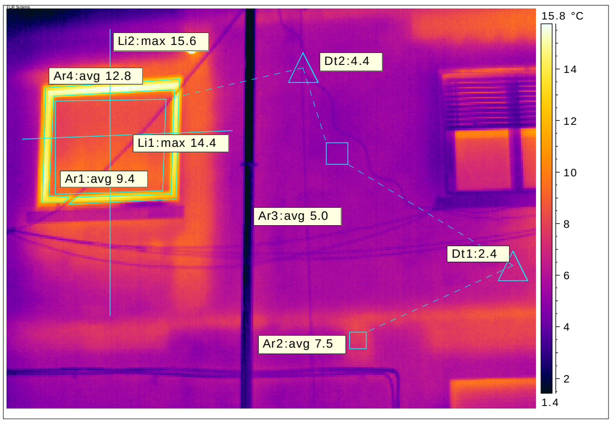
– supported on the BCA (autoclaved lightweight concrete) masonry walls.

c. Identification of the less insulated areas of the envelope (e.g. in the left zone – fig. 7 is noticed an extension of the house, made of materials with a higher thermal conductivity that the brick masonry – right zone – fig. 7) and of the sections of the envelope with very low thermal characteristics (e.g. low quality joinery – fig. 7).

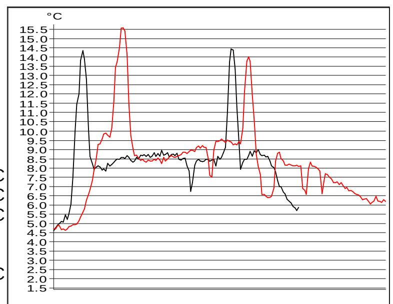
d. The assessment of the masonry walls homogeneity (e.g. in fig. 8, the walls structure is rather homogeneous, the masonry blocks forming the walls and the corresponding joints are noticeable. The existence of the small props is nevertheless not visible).

e. Assessment of the uniformity of the temperature field on the heating units surface (fig. 9 and 10).

The analysis of the thermographic images of fig. 9 and 10 emphasizes irregularities of hydraulic nature caused by the reduction of the section of flowing through certain heating units elements



Object Parameter	Value
Emissivity	0.90
Object Distance	7.0 m
Reflected Temperature	3.0 °C
Atmospheric Temperature	3.0 °C
Atmospheric Transmission	0.99
Label	**Value**
Li1: Max	14.4 °C
Li2: Max	15.6 °C
Ar1: Max	11.9 °C
Ar2: Max	8.0 °C
Ar3: Max	5.3 °C
Ar4: Max	14.8 °C
Dt1: [ana.Ar2.avg] - [ana.Ar3.avg]	2.4 °C
Dt2: [ana.Ar1.avg] - [ana.Ar3.avg]	4.4 °C



Label	Cursor	Min	Max
Li1	-	4.6	14.4
Li2	-	4.6	15.6

Fig. 7. Identification of less insulated sections of envelope

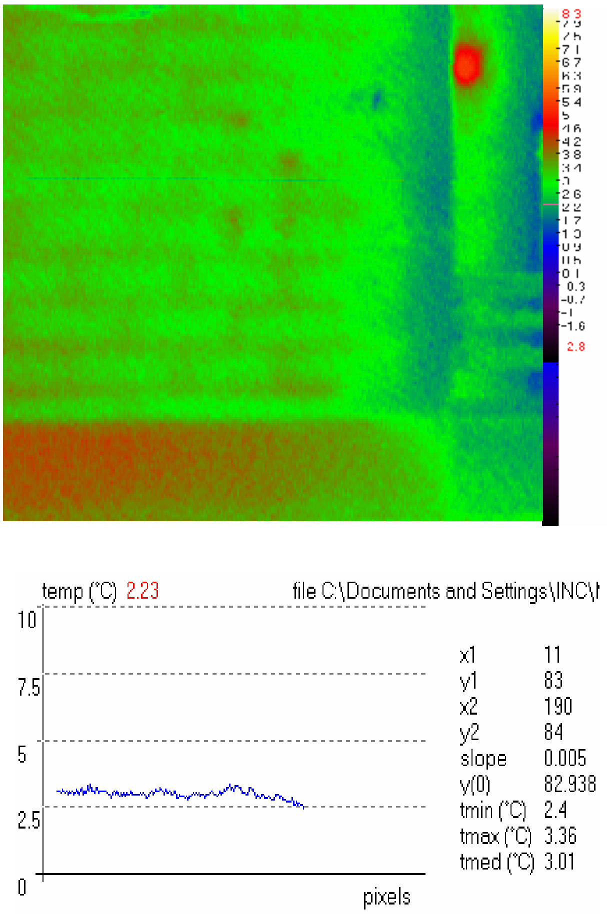


Fig. 8. INCERC experimental house – North wall (BCA masonry)

because of organic and inorganic deposits inside the heating units.

f. Identification of air exfiltrations or infiltrations. In fig. 11 is visible a hot air exfiltration behind an outdoor wooden shutter, which made impossible the inspection of the window in the visible range.

g. Identification of fitting problems in the case of decorative or functional inside or outside plating (faience, sandstone, heat insulation etc.) by emphasizing the zones where there are thermo-physical properties differences. In general, they are caused by the fact that the sticker is not uniformly applied, in a continuous layer. Air layers occur therefore, with a lower thermal conductivity than that of the building materials. This method may be used in emphasizing the sections where such problems occur in connection with plating and where the supporting plating layer may detach. This is of course unpleasant in the case of inside plating, but very important in the case of outside plating with heavy finishing (facing brick, ceramics decorative components, etc.) whose unfore-seeable detaching may damage the persons in the zone.

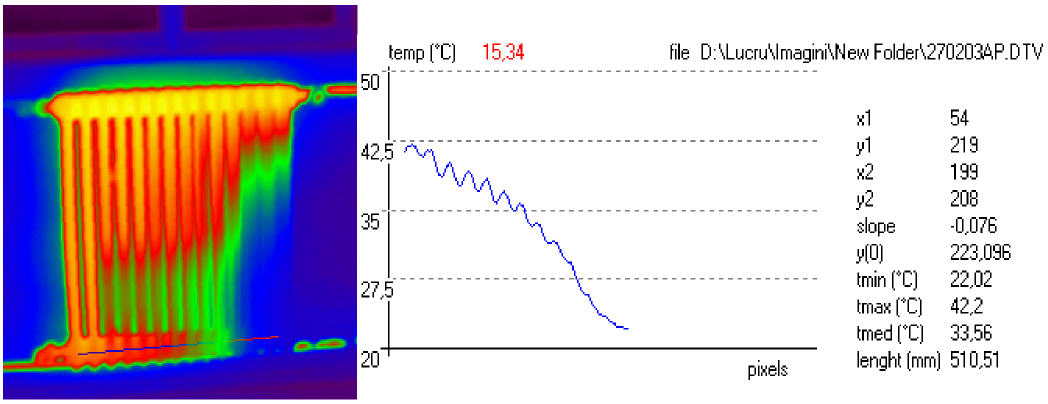


Fig. 9. INCERC experimental house – SW bedroom heating unit

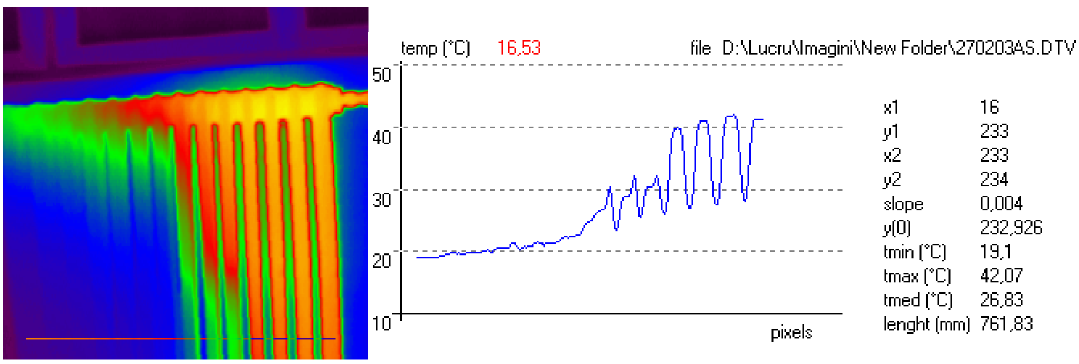


Fig. 10. INCERC experimental house – kitchen heating unit

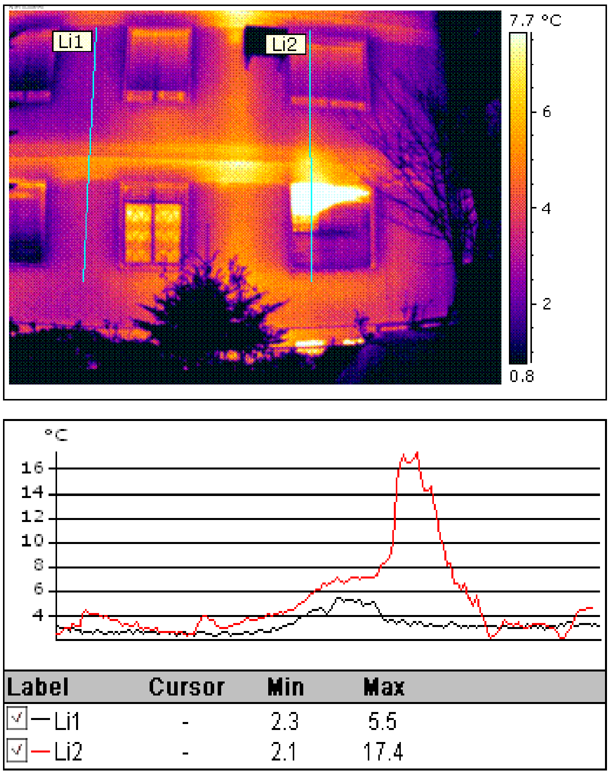
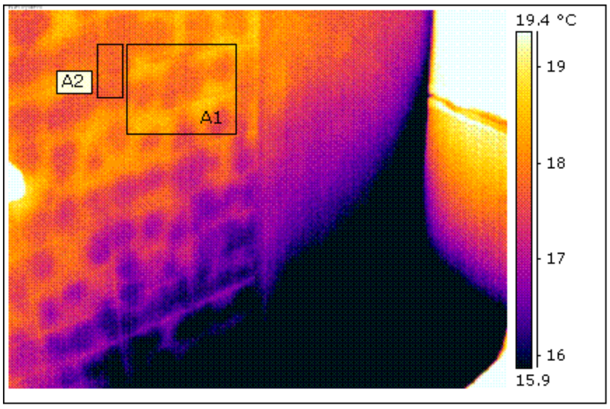


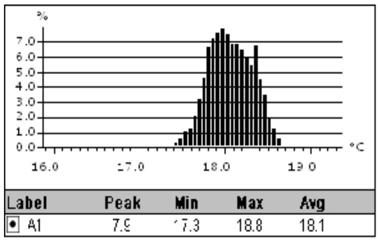
Fig. 11. Air exfiltration identification

Figure 12 presents the thermography of a faience plated wall. The colder zones are zones where the faience plate is properly fixed on the supporting plate. The warmer zones, although favorable from the thermal point of view, emphasize a low mechanical resistance. The quantity analysis carried out in fig. 12 refers to the temperature field dispersion for the two defined areas: A2 with a less large area and a rather uniform apparent temperature, which may be considered a “witness” of proper plating, and A1 proving a strong temperature dispersion, therefore a deficient execution.

h. Identification of the zones where condensation may occur on the building members surface. In fig. 13 is emphasized in green a zone whose apparent low temperature may allow the occurrence of condensation on the wall surface.

i. Identification of the trace-lines of heat carrier distribution and of the power supply networks if they generate heat by the Joule effect (mainly if they are improperly dimensioned, overloaded or with local deficiencies) and in general of any zone whose apparent temperature is different from that considered normal for the analyzed environment.





Label	Value
A1: Max - Min	1.5 °C
A1: Average	18.1 °C
A2: Max - Min	0.6 °C
A2: Average	17.8 °C

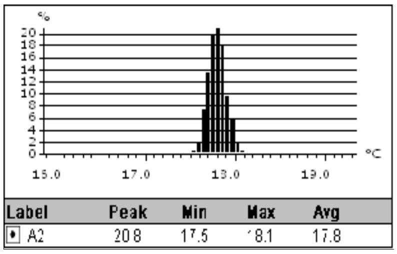


Fig. 12. Identification of plating problems

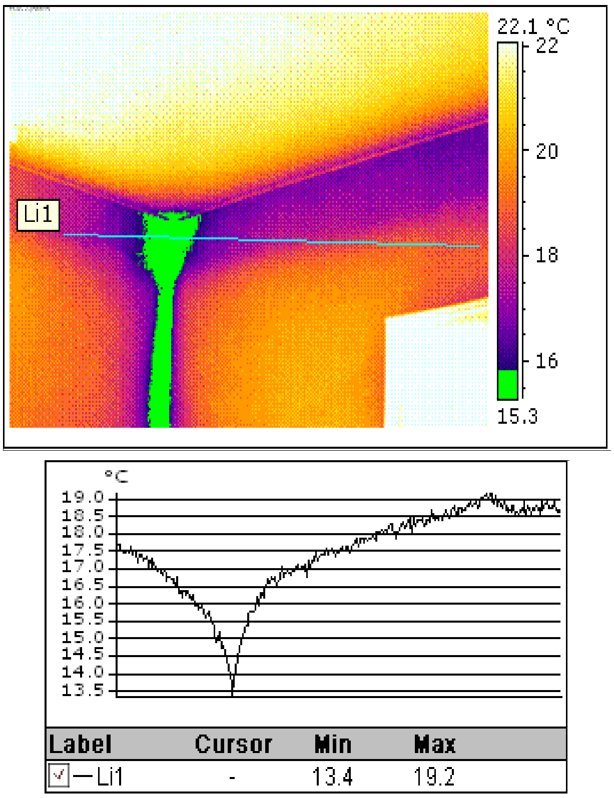


Fig. 13. Identification of plating problems

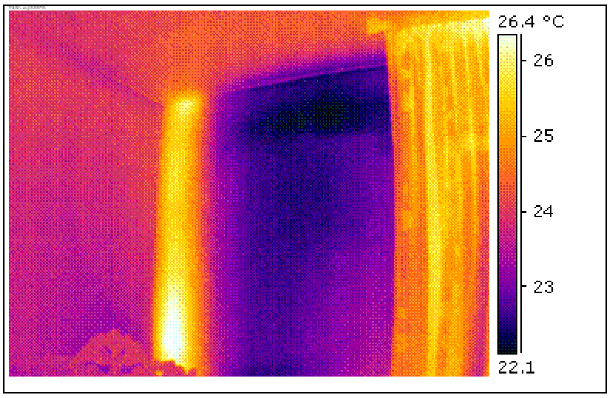


Fig. 14. Tracking of heat carrier distribution in the case of a system with concealed distribution columns

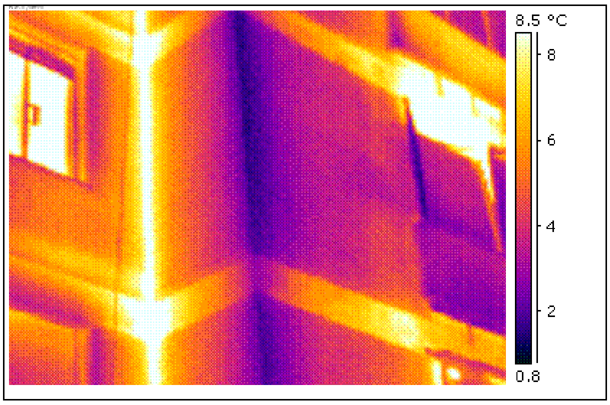


Fig. 15. Thermal bridges – convex corner and concave corner

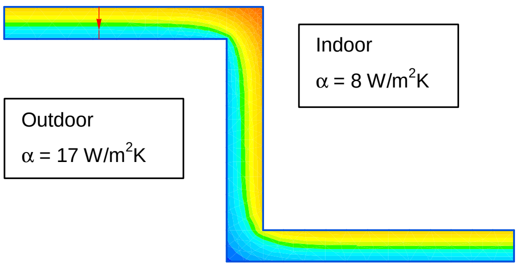


Fig. 16. Temperature field in a section of the structure with geometric perturbations of convex and concave corners type – cold season

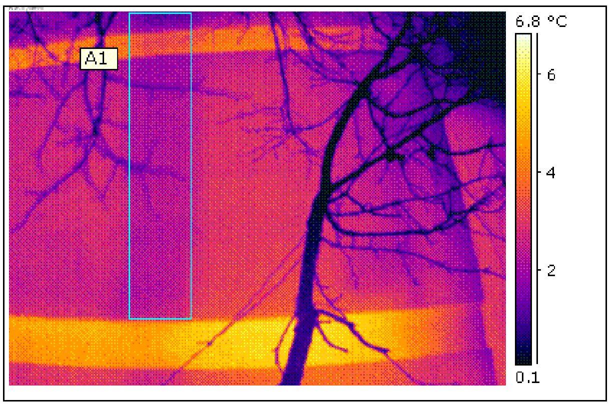


Fig. 17. Zone subjected to water leaks

Fig. 14 presents a quality analysis empha-sizing the heat carrier distribution network concealed in the wall.

j. Emphasizing of the geometric thermal bridge effect. Fig. 15 presents a selection of the thermo-graphy of a condominium façade, focused on the vertical geometric thermal bridges (convex corner and concave corner). The diffe-rence in the apparent temperature distribution in the two structures is noticed, caused in this case by the different values of the areas of heat exchange between the indoor and outdoor environments.

As concerns the apparent advantage of the concave corner type thermal bridge, fig. 16 presents the numerical solution of the heat transfer through a corner structure, similar to that presented in the thermography of fig. 15. It results that the low value of the concave corner tempe-rature is a consequence of the difference in size between the indoor area (adjoining the warm space) and the outdoor area (adjoining the outdoor space). The temperature value in the concave corner zone, adjoining the warm space is important.

According to the simulation and watching the isotherms in the building member structure, it is clear that the indoor corner temperature is lower than the temperature of the wall in the so-called field zone (far from the thermal bridge). In the case of the convex corner, the temperature on the outdoor area is clearly higher than that of the area adjoining the outdoor environment in the field zone. But the indoor corner has an advantage in the presence of a zone whose temperature is higher than that of the field zone. Actually such a zone specific to the convex geometric perturbations in terms of the outdoor environment has a minimum risk of surface condensation occurrence, although the outdoor thermographic image may represent an alarm signal suggesting a maximum thermal flow dissipated towards the outside. This is a flow dissipated outside and not at the level of the thermodynamic outline of the occupied space, the only one of interest in any energy expert analysis of the occupied buildings.

We mention that the terms convex and concave are considered in conformity with the mathematical definition of homologous functions and in terms of the outdoor environment.

k. The thermography and the interpretation of the results obtained should be examined by specialists with expertise and extensive knowledge in the field. Fig. 17 presents a darker zone, marked A1, on the outside facade of a building. This zone which might be interpreted as a better thermally insulated zone, represents in fact a modification of the thermo-physical characteristics of the building member, because of the water. Actually, the figure presents a water infiltration from the building roof, which locally alters both the thermal conductivity and the thermal capacity of the building materials.

4. Conclusion

The message of the paper is very clearly demonstrated both analytically and numerically but mainly in terms of imagery, and is synthesized in two conclusions, as follows:

1. The measurements in the infrared spectrum, in the case of buildings cannot be used in assessing the real thermal characteristics of the envelope of a building;

2. The images specific to the investigation in the infrared spectrum, which are presented, are useful in the investigation of the building envelope in terms of quality as well as in checking the operation of the thermal systems in buildings.

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