IR thermography applied in church heritage conservation

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Abstract. IRT – infrared thermography has met an extensive popularity among the non-destructive technologies. This paper is presenting some of the monumental church that had been examine with thermovision camera in order to assess the behavior of structure to ageing, earthquake damages, detect hidden characteristics or order anomalies. IRT investigation is based on principle that heat flowing in a material is altered by presence of all kind of anomalies, our job been to discover and interpreting. Thus heat bridges can be detected, heat loses and air leakage can be identify or the presence of mold, moisture is growing in a particular area.

1. Introduction

Discovered by William Herschel in 1800 and after the thermoelectric effect been discovered in 1821 infrared radiation or IR, have preoccupied the scientific world to find technique of interpretation and test methods for different building structures that were examined. [4]

The first infrared camera was invented in 1929 by Tihanyi been employed by the military in Britain for anti-aircraft defence. Also, significant progress has been made during the period between World War I and II. Today infrared thermography (IRT) is widely employed for buildings diagnostics. [3]

The first generation of commercial infrared cameras appeared in the end of 60’s. Only in ‘90s a new generation of equipment with array detector appeared, the new equipment been capable both of temperature readings at different points and did not required special cooling systems. [2]

Finally, the thermography is based on the emission of objects and has three essential radiation law:

1. Kirchhoff’s law of thermal radiation that define de relation between emission and absorption of energy. Accord to this principle, the emission coefficient, ϵ, is introduced in equation as the ratio of emissivity, E, of a real body to the emissivity, Ez, of the black body under the same temperature \( \epsilon = \frac{E}{E_z} \). ϵ can take value between 0 and 1, based to the temperature, surface texture and wavelength.

2. Planck’s law of radiation describes the specific spectral radiation \( I' \):

\[
I'(\lambda, T) = \frac{2\pi h c^2}{\lambda^5} \times \frac{1}{e^{hc/\lambda kT} - 1}
\]

Where: \( \lambda \) – is the wavelength, T – the absolute temperature, h – the Planck constant and c – the speed of light.

3. Stefan – Boltzman law, applied to the emission of a surface over all wavelengths, integrated the Planck law and discovered that the radiant power, I, [W/m²], grows with the fourth power of the temperature, \( I = \sigma T^4 \), where \( \sigma = 5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4 \). [4]

2. Infrared thermography applied to building physics

It is essential that studies be performed to evaluate the performance of building materials, especially when we talk about buildings that have century ahead. These studies are a step towards improving technical solutions and regulations to ensure the building’s durability and to guarantee user comfort and satisfaction.
Most material pathologies are related with temperature action. Therefore, measuring a material’s temperature is crucial for understanding the causes of those defects. The use of non-destructive techniques to test a building material may be very useful by making it possible to evaluate a material behavior without destroying it and without interfering with the users’ life. [2]

3. Case study
The main objective of this work was to evaluate the applicability of thermography in order to study the behavior of building materials, to evaluate the building performance, age, heat loss through windows, dampness and “hidden details” (subsurface pipes, flues, ducts, wall ties, etc.). It can also be used for examination of heating systems and preventive maintenance. To do so, different heritage church was subjected to study. IR camera used for this study was a FLIR B335 (9Hz, 2010 model). Measures were made during winter.

4. Results
The main areas for using IR thermography in building diagnostics are presented in detail by [1]. In this study, it is suggested that building IR thermography on external building elements should be performed either at night or during a cloudy day. This was found to be important in order to avoid the problem of temperature increase which occurs as a result of the incident solar radiation, and the impact from the absorbed solar energy, which presents a time lag of a few hours. Additionally, in this work it is pointed out that measurements should be carried at low wind speeds in order to minimise as much as possible the influence of convective heat losses.

![Image](image1.png)

**Figure 1.** a) – Thermal bridges at The Dormition of Mother of God church from Jassy
b) Thermal bridges at The Three Holy Hierarchs Monastery from Jassy

4.1. Thermal characterization of walls
IRT can be used in a qualitative way to locate the surface thermal anomalies related to different material properties, such as thermal conductivity (λ-value), heat capacity (cp), ε-value, thermal diffusivity (α), and density (ρ) [6]. Short- and long-term measurements are possible. Short-term IRT surveys are used to characterize: (i) building ages [2]; (ii) wall thicknesses [3]; (iii) material or structural components (e.g. solid or hollow bricks, concrete, thermal insulation, etc.) [4]; (iv) geometries [4] (figure 1); (v) surface properties (ε-value) [2]; and (v) energy problems related to layering techniques. They follow the standard procedures for the qualitative thermography in the building sector [2], which requires the control of whether and boundary conditions and environmental deficiencies [1]. In general, to minimize their impact, the IRT surveys should be undertaken during the cooler months, especially in evening and night-time [1]. Several multi-methodological approaches have been proposed to improve the energy assessment using the following high-depth techniques: (i) sonic trials for identifying the wall density [2]; (ii) HFM measurements for quantifying the U-value of the element [4]; (iii) ultrasonic and...
electric-type micro-geophysical methods for discovering the presence of structural defects [6]; (iv) gravimetric tests for determining the moisture content [6]; (v) stratigraphic and chemical investigations for characterizing the material properties [5]; and (vi) computer simulation for understanding the defect through the comparison with thermal models [6]. Besides, long-term IRT surveys are used for the dynamic characterization of the $\alpha$-value of walls [5], figure 2, figure 3, to consider the variation of the solar irradiance overcoming the limitations of traditional contact sensors [4]. In parallel, a novel in situ measurement procedure based on a single IR-camera and a thermal mirror has been proposed to quantify the time-shift and the temperature oscillation in thick walls, also reducing times and costs of traditional techniques [6]. Finally, IRT with periodic temperature variations has been applied to classify the percentage of moisture in traditional masonries [7].

Figure 2. a) Radiator heating element inside the Saint Peter and Pavel Monastery in Jassy, b) Heat loss in towers of the same monastery church

Figure 3. a) Crack view with thermovision camera in Saint Mary Church in Jassy b) Heat loss through thermal bridges at junction between wall and ground

4.2. Thermal bridging and excessive heat loss areas detection

Thermal bridging is defined as additional heat losses in the building façade. It is classified into [7]: (i) “geometrical” connected to the shape of the envelope (i.e. corner of an external wall; junctions between walls, roofs or floors; adjacent walls or windows and walls); (ii) “linear” caused by discontinuities due to different materials or construction methods (i.e. corner areas between two outer walls, structural junctions between pillar and masonry, walls around windows, doors and hatches); and
“repeating” characterized by a regular pattern and distributed over a big area (i.e. mortar joints in a wall, timber studwork and beams in timber frame construction and steel wall ties in masonry cavities). IRT survey clearly identifies in a qualitative way their presence in the building façades, using standard procedures [8] (figure 4). As well, the presence of post processing techniques in the professional software permits to verify the risk of condensation and mould growth linked with the thermal bridging [9]. More recently, IRT surveys have been used in a quantitative way to investigate their impact on building envelope during in situ measurements [7] and laboratory tests [10]. Different numerical models have been proposed to overcome the perturbations caused by the climatic parameters on the external surface temperature (Ts), especially during in situ IRT surveys [10]. These models concern mainly linear thermal bridging for their diffusion in new and existing buildings. Due to the impact of boundary conditions, the studies don’t consider the risk of surface condensation [11]. Furthermore, to reduce completely the impact of weather conditions, a simulation model has been defined without considering detailed meteorological observations [12]. Finally, a method for the quantitative measurement of thermal bridging performance without any supporting methods (neither numerical models nor HFM measurements) has been introduced [13]. The novelty of this approach includes the evaluation of the real heat flow rate caused by the thermal bridging and the linear thermal transmittance calculation using only IRT surveys.

![Figure 4](image-url)

**Figure 4.** a) With dark spot can be seen to heat loss in Saint Michael Church from Sâbăoani b) Heat loss trough thermal bridges in The Three Holy Hierarchs Monastery from Jassy

### 4.3. Indoor temperature measurements

Although IR-cameras with sensors tuned at specific micrometre wave bands are used for the detection of specific gas leakages, they cannot measure the indoor air temperature [11]. Traditional IRT procedures are mainly applicable for opaque objects with substantial $\varepsilon$-value. Thus, the use of opaque mock targets that reach in short time the thermal equilibrium with the environment can accurately represent $T_i$. Mock target IRT is based on the extraction of their $T_s$ from the radiation emitted [11], figure 4, figure 5. The interpolation of consecutive measurements provides a quick and reliable monitoring of the multidimensional spatial distribution of $T_s$. The thermal equilibrium of the mock targets with the environment permits to define quickly the spatial distribution of $T_i$. Its major advantages are the simplicity of the method and the reduced time to carry out the measurement. Several advices are suggested to easily distinguished the mock target from the environment: (i) use of IR cameras with an appropriate minimum focus distance to cut the influence of the air (e.g. 0.3 m); (ii) selection of the option picture in picture to better visualize the mock targets; and (iii) place the mock targets at least 0.5 m from walls and away from heat sources to avoid thermal reflections (e.g. radiators, windows, and so on).
5. Conclusion

Thermography is a non-destructive testing technology with much potential, having a great application to building materials. Research studies developed at different church revealed that emissivity is an essential parameter, since it greatly influences thermographic measurements and may restrict application of this technology to buildings. However, if the study aims for a qualitative analysis of the results, the selected emissivity value is not very important. It was also possible to confirm that thermography cannot be used to study objects in thermal or hygroscopic equilibrium, as temperature differences between the object and the environment must be significant, because of this the measure were made in winter, at -16°C. Colour and thermal reflection must also be considered during thermographic testing, as they may mask the results and cause misinterpretation.

Thermography allowed studying the wetting and drying process of building materials. Temperature differences due to superficial water evaporation provided a means of recognising “wet” and “dry” areas. It was also possible to evaluate a material’s approximate drying time since small superficial temperature variations indicate that moisture is rather significant. Thermography, however, detects only superficial moisture.

Advantages of IR thermography for building study:
- the temperature measurement of the targets can be done remotely without direct contact;
- the measurement is non-destructive (it does not require sampling);
- the method is non-polluting
- the thermal image is geometrically consistent with the studied object;
- thermal, global or detailed information is obtained in real time;
- measuring accuracy is high;
- electricity consumption is insignificant;
- simple operation and relatively small gauges ensure handling, the equipment may be carried out by a single person;
- the thermal imaging system provides an image that allows a quick identification and the exact points of potential defects;
- allows association with complex recording, storage and processing equipment

Qualitative analyses are widely treated by literature, standards and practical reports. They focus on: (i) thermal characterization of walls, glazing and windows; (ii) thermal bridging and excessive heat loss areas detection; (iii) thermal insulation examination; (iv) air leakage inspection; (v) moisture and water detection; (vi) HVAC and electrical systems characterization; (vii) indoor temperature measurements; and (viii) human comfort assessment. On the contrary, quantitative studies are worthy of investigation.
Currently, they concentrate on: (i) determination of the areas with thermal anomalies; (ii) insulation level detection; (iii) U-value measurements and dynamic characterization of building elements; (iv) moisture content determination; and (v) damage evolution analysis. The literature review presents also the possible topics for the research in this field, suggesting the themes that need to be further explored. They are synthetized above:

- Comparison among different passive methodologies for the building stock analysis;
- Development of procedures and tools for:
  - U-value measurement and dynamic characterization of building components (particularly for walls and glazing systems);
  - Gas concentration determination of glass units and glazing systems;
  - Moisture content determination;
  - Damage evolution detection;
  - Long-term environmental monitoring using the mock target IRT;
  - Human comfort assessment;
  - Integration of different non-destructive testing for the building energy audit;
  - Integration of energy audit, damage, and structural assessments;
- Development of smart sensors for indoor monitoring, environmental control, and human comfort assessments.

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