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Application of G100/120 Thermal Imaging Camera in Energy Efficiency Measuring in Building Construction

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Abstract: A measurement of energy efficiency in the construction industry aims to reduce permanently energy requirements in design, construction and use of new buildings, sannation and reconstruction of the existing ones. Over the long term, with the expected increasing in the price of energy and the development of awareness about energy conservation and environmental protection, thermal imaging methods will certainly find their wide application in the construction industry. Infrared thermal camera is used to estimate the temperature. However, we do not see all the details of interest on the thermal image, therefore we suggest using the fusion of visual and thermal images of the same part of the building recorded simultaneously. The analysis images of the object obtained by fusion of television and infrared thermal imaging shows the areas of interest for further processing.

Keywords: Thermal infrared imaging, Temperature estimate, Temperature and emissivity, Fusion of images data.

1 Introduction

Energy efficiency programs in the construction industry are important for reducing the energy consumption of expensive imported raw materials as well as for the development of urban areas with preserved quality of human habitats and also for increasing the international competitiveness of the products and services of the Serbian economy.

The goal of energy efficiency in the construction is to be more rational in consumption of energy required for the construction-reconstruction, heating and utility supply of office space, and to permanently reduce the current significant losses in the distribution and use of existing and new construction and infrastructural facilities.

The energy passport is based on measurements of infrared thermal imaging camera and heat transfer calculations. The calculation of the energy efficiency of buildings is carried out on the basis of the measurements (external and

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internal building temperature, emissivity of the outer and inner surfaces of the wall) and the appropriate construction parameters.

In Serbia, today, we consume 2-3 times more energy per square meter of housing or office space [1], it is clear the importance of development of energy efficiency in buildings, which should contribute to increasing energy efficiency and reducing energy consumption in the residential sector. This is an engineering problem that can be solved in several ways, and in this paper, we propose assessing fusion as the first step in the detection of "bad places" of building.

Television and infrared thermal images and their analysis can be used in construction supervision, checking insulation in terms of detection of thermal bridges and poorly installed insulation, infiltration of air below the partition, revealing the path of moisture and moisture in walls, floors, roofs, detection diffuser, settling walls, woodwork and metalwork tightness due to the fact that the greatest heat loss is in windows. The television and infrared thermal cameras are becoming more affordable every day the technology, simply because their price is decreasing every day. The software used for the processing of generated images (fusion, detecting Hold/Cold spots) allows us to reach the required result quickly and easily.

The fusion of television image and infrared thermal image of objects being controlled, gives the possibility of discovering places being heated or cooled, above the allowable limit, detection of so-called "bad place", which cannot be seen otherwise, as a rough estimate of heat loss. Their images also indicate mechanical, insulation, or other disorders, television and infrared thermal camera is ideal tool for finding energy losses. The possibility of software fusion television and infrared thermal images allows detecting irregularities in parts of buildings being measured.

This paper describes an experiment of measuring parameters that are important for the development of buildings energy passport (external and internal building temperature and emissivity of the outer and inner surfaces of the walls), using thermal imaging camera. This paper also describes the use of TV and infrared thermal images of the same object and their fusion to evaluate some effects of energy efficiency in buildings. The images of parts of the building are formed using G100/120 camera. The image analysis has been done using the software package Thermography Studio [2].

2 What do We Measure?

The infrared energy emitted from the measured object is converted into an electrical signal by the imaging sensor (microbolometer) and displayed as a color or black & white thermal image. The infrared ray is a form of an electro-magnetic wave as well as a visual light or a radio wave. The wavelength band is

0.78 to 1000 μm, that is longer than visual light yet shorter than radio wave, and the wavelengths are classified from the near infrared to the far infrared region.

Energy radiated from the blackbody is described as follows and called "Plank's law"

$$M_\lambda^{CT} = \frac{c_1}{\lambda^5} \frac{1}{\exp(c_2 / \lambda T) - 1}, \quad (1)$$

where: λ is wavelength [μm], T is absolute temperature [K], $c_1 = 3.7418 \times 10^4$ is first radiation constant [Wm^{-2}μm^4] and $c_2 = 1.4388 \times 10^4$ is second radiation constant [Kμm].

However, the spectral density of the radiation power of real bodies depends on the spectral emissivity. To define the emissivity, we use experiment and theory of energy conservation. Spectral irradiance, which falls on the surface of the object, and the components of irradiance are shown in Fig. 1 [2].

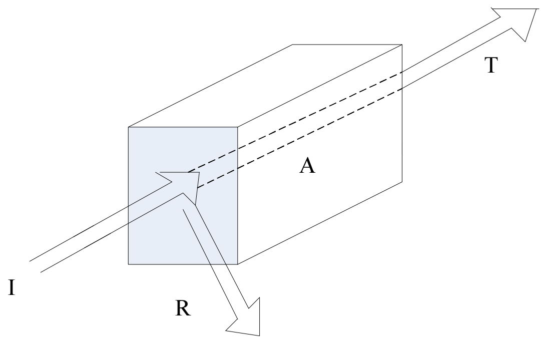

Fig. 1 – *The components of irradiance.*

Total incident irradiance or spectral radiation is divided into components

$$E_\lambda^I = E_\lambda^R + E_\lambda^A + E_\lambda^T, \quad (2)$$

where the indices in the exponent specify certain spectral components: the reflected (*R*), absorbed (*A*) and transmitted (*T*). After dividing with the total irradiance, we obtain known relation

$$1 = \frac{E_\lambda^R}{E_\lambda^I} + \frac{E_\lambda^A}{E_\lambda^I} + \frac{E_\lambda^T}{E_\lambda^I} = \rho_\lambda + \alpha_\lambda + \tau_\lambda, \quad (3)$$

where the values of spectral reflectance (ρ_λ), spectral absorptance (α_λ) and spectral transmittance τ_λ are from 0 to 1.

Based on Kirchhoff's law, a good absorber is a good emitter on the same wavelength, and the relation (3) can be written as

$$\varepsilon_\lambda + \rho_\lambda + \tau_\lambda = 1, \quad (4)$$

where ε_λ is spectral emissivity.

The consequences of (4) are: ideal reflector $\rho = 1$, $\varepsilon = 0$, $\tau = 0$, ideal window $\tau = 1$, $\rho = 0$, $\varepsilon = 0$, and ideal black body $\varepsilon = 1$, $\rho = 0$, $\tau = 0$.

Spectral density of the radiation power of real body depends not only on temperature but also on the spectral emissivity. The spectral emissivity is defined as the ratio between the spectral density power of radiation real body and black body

$$\varepsilon_\lambda = \frac{M_\lambda}{M_\lambda^{CT}}, \quad (5)$$

where M_λ is spectral density power of real body.

Therefore, to determine the spectral density power of real bodies in addition to temperature, we should know spectral emissivity of the body surface as well. Spectral density of the radiation power of the body is, from (5)

$$M_\lambda = \varepsilon_\lambda \frac{c_1}{\lambda^5} \frac{1}{\exp(c_2 / \lambda T) - 1}. \quad (6)$$

Since the spectral emissivity is less than 1, it follows that the spectral density of the radiation power of real body is lower at all wavelengths of the spectral density of radiation of ideal black body.

It is known that thermal imaging sensors operate in the wavelength range, density of power is given with relation

$$M = \int_{\lambda_1}^{\lambda_2} \varepsilon_\lambda M_\lambda^{CT} \, \mathrm{d}\lambda. \quad (7)$$

From (7), we can see that in order to obtain a true temperature of an object, it is necessary to obtain the emissivity correctly.

Emissivity of the body is an ability of the body to radiate thermal energy, depending on the actual temperature. Practically, it is an indicator of the efficiency of the sources. Its value is between 0 and 1, and can be found in tables or determined practically, and it depends on the material (type and preparation) and surfaces (treatment) [3].

3 Blackbody Type Source and Emissivity Determination

Although a blackbody is actually only a theoretical idea, an object can be formed which approximates it. A low closely related to the blackbody is Kirchhoff’s law that defines reflection, transmission, absorption and radiation (4). In order to obtain a true temperature of an object, it is necessary to obtain the emissivity correctly. Therefore, the emissivity of the object has to be measured by using blackbody-type source which is nearest to a blackbody as much as possible.

Emissivity is the ratio of energy radiated from an object to the exterior and energy radiated from blackbody. The emissivity varies with the surface condition of the object and also with temperature variation and wavelength. If this value is not accurate, then the true temperature cannot be measured. In other words, a variation or change in emissivity will cause a change in the indication on the thermo imaging camera.

There are several ways to determine the emissivity of objects, and the paper deals with the following: the temperature of the blackbody is measured with thermo imaging camera, for which we assumed to have emissivity approximately 1. By using the thermo imaging function for emissivity correction, emissivity of the measured object is reduced until its temperature is equalized with the temperature of the blackbody. The obtained emissivity will be emissivity of the measured object.

4 Camera Type G100/120

To create a television image and infrared thermal image base, a G100/G120 camera has been used. The camera contains two lenses and two detectors for visible and infrared range. Visual images have been obtained with the camera of the visible range of 0.4 to 0.7 µm, while the infrared thermal images have been obtained with the same camera, but in the working range of 7-14 µm. **Tables 1** and **2** contain specifications for the camera, working in the visual range (**Table 1**) and in the infrared range (**Table 2**) [4].

Table 1
Camera Specifications G100/120 (*visual range*).

Item	Specification
Detector	CMOS sensor
Effective pixels	2 megapixels (1600×1200)
Display/record pixels	0.94 megapixels (1120×840)
Spectral range	0.4 – 0.7 [µm]
Focus	Pan – focus
Focus distance	50 cm do ∞
AGC	Provides

Table 2
Camera Specifications G100/120 (*infrared range*).

Item	Specifications
Detector	Microbolometer
Number of pixels	320(H)×240(V)
Measuring range	– 400°C do 5000°C
Spectral range	8 to 14 [μm]
Minimum detectable temperature difference	0.08°C
Instantaneous field of view	1.78 mrad
Focus range	from 10 cm to ∞

The important parameters during the base formation of images with the camera G100/120 are:

- Object reflectance
- Object emissivity
- Object temperature
- Atmospheric temperature
- Relative air humidity
- The distance (it does not influence up to 10 m).

5 The Measurement Procedure of Temperature and Emissivity of the Building Wall Surfaces

Temperature and emissivity of the walls were assessed using thermal imaging camera. Figs. 2 and 3 give the inner and outer surfaces of the building wall in the visible range. Figs. 4 and 5 give the same surface of the walls, in the infrared domain.

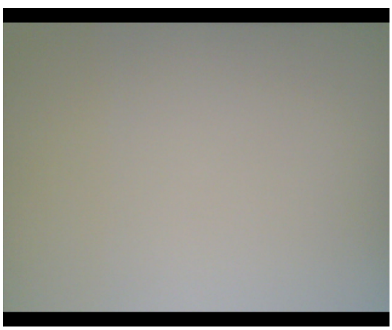

Fig. 2 – *Inner surface of wall* (*visual image*).

Fig. 3 – *Outer surface of the wall* (*visual image*).

Fig. 4 – *Inner surface of the wal* (*thermovision image*).

Fig. 5 – *Outer surface of the wal* (*thermovision image*).

In order to verify the results of temperature measurement with thermal imaging camera, contact thermometer with a probe was used. It was measured the temperature of an object that represents approximately black body (black bag) and the measured value was 28°C. By using the thermal imaging camera function for emissivity correction, emissivity of the measured object was reduced until its temperature was equalized with the temperature of the blackbody. In this way, the emissivity of the walls was measured, and the results were as follows: the emissivity surface of the inner wall was 0.65, while the emissivity of the outer wall surface was 0.74. By using contact thermometer the temperature of the inner and outer walls was measured, and the following values were obtained: the temperature of the inner wall was 26°C and the temperature of the outer wall was 27°C. Temperature of the walls was measured using the thermal imaging camera (after adjusted measured emissivity) and the results were as follows: the temperature of the inner wall was 25.6°C and the temperature of the outer wall was 26.5°C.

6 The Process of Fusion TV and Infrared Thermal Image of Object

The base of images of the object (in the visible and infrared domain) is formed using the G100/120 camera. It has been recorded three pairs of television and infrared thermal images of the same object, and each pair of the images is formed simultaneously. The base of images is analyzed in the software package Thermography Studio. The fusion procedure is based on the overlapping of television image and infrared thermal image. Prior the fusion of visual image and infrared thermal images, GL-Global Alpha factor should be adjusted in percentages. The low percentage of GL factors means the presence of dominant visual image, while a high percentage of GL factor means the presence of a dominant infrared thermal imagery. In this paper, the maximum factor GL (GL = 100%) has been used. The software package allows as to set vertical and horizontal pixels overlapping, and reduction of the temperature range, and distribution of color palette across the new region, in order to be better displayed. The software enables reduction in the region of interest, also due to better display of desired places.

The first image shows a part of a window in a masonry building. Fig. 6 shows a visual image of the window [8].

Fig. 6 – *Poorly built and installed windows and insulation problem* (*visual image*).

In Fig. 6 the voids can be seen between the wall parts of the set of elements (plates), filled with mortar. As for the window, we do not observe any defects.

Fig. 7 shows the same part of the window in thermovision image, formed shortly after the television images [8].

In Fig. 7, we clearly see the existence of colder places, marked by points ‘a’, ‘b’ and ‘c’. On a scale of temperature, we can see the temperature difference between the coldest spots and other image points (light blue), being about 7°C. However, it can not be seen clearly from this image what are these parts of the image precisely (frame, window, cavity).

Fig. 8 shows an image of part of the window, obtained by the fusion of television Image 6 and infrared thermal Image 7 [8].

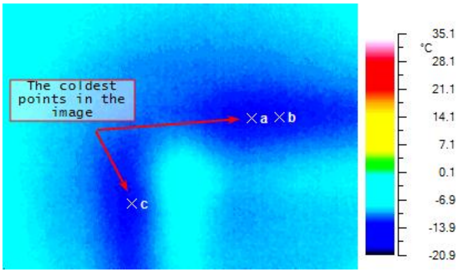

Fig. 7 – *Poorly built and installed windows and the problem with the insulation (thermovision image).*

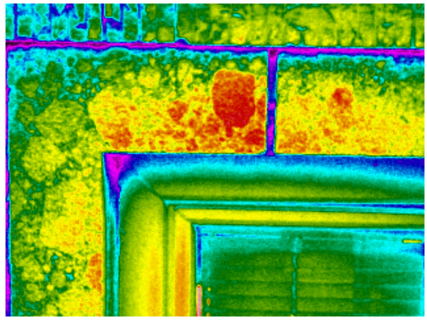

Fig. 8 – *Poorly built and installed windows and insulation problem (fusion).*

In Fig. 8, obtained by fusion, it can be easily seen bad parts of the building, and at the previous two images, we could not clearly see them otherwise. Specifically, the image clearly shows the site (marked in blue and purple) experiencing penetration of air due to poor embedded window. The problem is also evident in the place of joining glass and aluminum compound, caused due to poor construction of the window. Also, the cavity between the plates placed on the wall have insulation problems, where there is the loss of heat and moisture problems in cavities.

Another pair of images is relating to the building's interior, having moisture on the walls. Fig. 9 shows the television image of the wall and the ceiling [8].

Fig. 9 – *The infiltration of water and moisture problem (visual image).*

In Fig. 9 we observed field of yellow and black spots. Also, the changes in color have been observed, and both mechanical damage caused by moisture.

Fig. 10 shows the same part of the premises in termovision image, as in Fig. 9 [8].

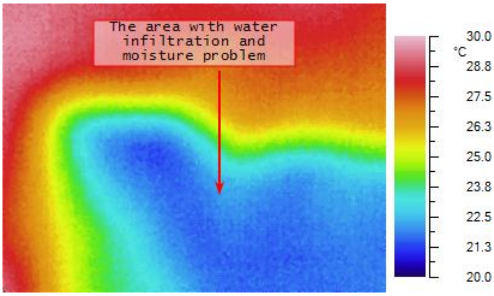

Fig. 10 – *Water infiltration and moisture problems* (*thermovision image*).

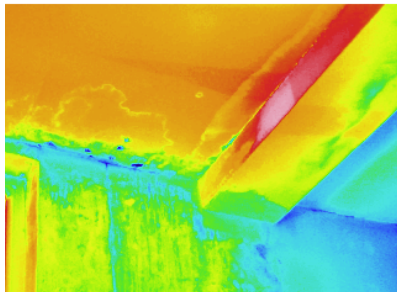

Fig. 11 – *Water infiltration and moisture problems* (*a fusion*).

In Fig. 10, it has been observed a large area being blue colored, indicating the colder part of the wall or an area having a problem with moisture and water infiltration, due to burst pipes.

The fusion of Figs. 9 and 10 has been shown in Fig. 11 [8].

In Fig. 11 it can be clearly recognized the places having problems with water infiltration and moisture in the wall.

It should be noted that the moisture does not only exist in the parts of the walls and ceilings where yellow and black spots are present in the visual image, but the moisture is greatly expanded to the second part of the wall, on the right of the beam, where the visual field cannot be seen. Humidity has affected significantly the larger part of the wall, and it can be said there is a larger problem with moisture in it.

The third pair of images is relating to the problem of cracking of the wall, and the problem of thermal bridges of the room. Fig. 12 shows the cracking's of the wall and problem areas of thermal bridges in the visible domain [8].

Fig. 12 – *The problem of cracking of the wall* (*visual image*).

Fig. 12 shows and a small part of the window. The figure clearly shows crackings caused by mechanical damages. However, in this figure, the problem has not been seen due to air infiltration and heat loss.

Fig. 13 shows the cracking's in the wall from Fig. 12, in thermal image [8].

In Fig. 13, it has been observed a place with the heat loss (marked in blue). In the temperature chart, it can be read off the difference in temperature from 2°C to 4°C between the wall and parts of the circuit wall, and particularly parts of the wall with cracking's.

In Fig. 14 it has been shown the image obtained by fusion of Fig. 12 and 13 [8].

Fig. 13 – *The problem of cracking of the wall (thermovision image).*

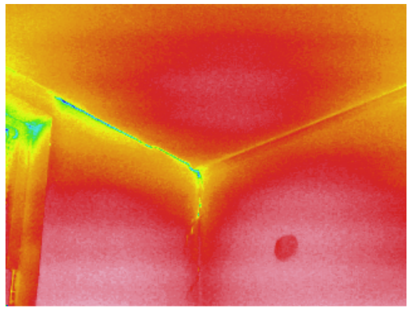

Fig. 14 – *The problem of cracking of the wall (a fusion).*

From Fig. 14, it is clearly seen the problem of heat loss at the site of cracking a wall (colored blue), and the problem of thermal bridges (yellow in places where there are the connecting parts of the ceiling). From the figure, the problem of poorly built window has been noticed, and the one could not be observed in the visible domain. The problem of poorly built window also leads to a significant heat loss and air infiltration.

7 Conclusion

Making a building energy passport is a necessary step in building new facilities, and also in regular maintenance and monitoring of already constructed buildings, especially public facilities. The analysis shows the introduction of modern principles of energy efficiency in construction enables energy savings as much as 50-80%.

The proposed procedure of the analysis of television images and infrared thermal images, and images obtained by their fusion allows a better assessment of the effects of energy efficiency than the analysis of infrared thermal images only.

The analysis of images obtained by fusion of television image and infrared thermal image of the same object in a short interval of time, represents an acceptable procedure for finding the energy losses, as shown in the previous three examples. By this process, the detection and location of a lack of insulation has been facilitated, also the moisture problems, problems with the air penetration, and the cracking's in the walls.

8 Acknowledgment

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