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Thermographic Measurements in a Hall Heated by Radiant Tubes

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Abstract

This paper presents the processed results of the measurements performed with an infrared camera inside an industrial hall heated by radiant tubes. The results confirm the advantages of radiant heating of large volume spaces over the classical system of heating by warm air.

Key words: *radiation heating, thermographic measurements, thermography.*

Introduction

The classical systems of heating used in civil and industrial buildings for ensuring the thermal comfort of the occupants consume liquid or gas fuel and by their operation produce the environmental pollution. In the last few decades, an emphasis has been put on the need of finding efficient heating solutions, which lesser affect the consumption of natural resources and the state of the environment.

The heating by radiant tubes presents many advantages, like: focusing thermal energy on the work area, a lower temperature of the indoor air than the one warmed by convective heating and a low temperature gradient on the vertical, which results in annual savings of fuel and energy between 20% and 50%. Thus, the radiant tubes represent an increasingly used solution for heating the high volume closed spaces, especially for the tall and very tall ones.

The thermographic measurements performed in a hall heated by radiant tubes aim to demonstrate the efficiency of heating systems by radiant tubes for high volume closed spaces, compared with the convective heating by warm air, often accompanied by a heating system with static objects placed around the perimeter.

General Considerations Regarding the Infrared Thermography

The first thermographic measuring system appeared in 1964 and had limited applications, especially for those of electrical nature. Over the years, the thermographic equipments evolved and became more popular, so that today they are being used in various fields, like: constructions, industry, medicine, military applications, etc.

During the evolution of the equipment used in thermography were three important moments which led to indisputable qualitative leaps [4,5,6]:

- the partial or total replacement of the liquid nitrogen cooling system with Stirling or Pulse-tube (1986) thermodynamic microcryogenic systems eased the construction of portable cameras;
- the manufacture of first matrix detectors (1994) – allowed the elimination of optical-mechanical scanning devices and so, the heat flux loss and the errors due to the vibrations were reduced;
- the emergence of cameras without cooling (1998)- when the matrix detector is made from an assembly of microbolometers. An older principle that stood behind construction of bolometers in 1960 was reused for construction of the microbolometers which were included in the last generation radiometers, without a cooling system.

The Romanian Standard SR 13340-1967 [7], respectively the French Norma A 0-400-1987 establish the terminology used in the field. Thus, the Standard defines the infrared thermography as a technical method of giving, by using a suitable device, the thermal image of a thermal scene.

The thermographic scan is made by using a system sensitive to infrared radiation, which generates an image based on apparent radiant temperature of the targeted surface. The thermal radiation emitted by the concerned surface is converted by the system sensitive to infrared radiation into a thermal image, that represents the relative intensity of thermal radiation. The image intensity is function of surface temperature, surface characteristics, environmental conditions and sensor type.

A thermography camera does not measure the temperature but the radiation emitted by the surface of targeted object and converts the infrared radiation (invisible for human eye) into a visible image, which represents the thermal image of the surface. Since radiation is a function of temperature, the thermovision cameras measure and capture radiations and then transforms them into temperature values, after this has been computed.

The obtained thermal images can be presented as black and white thermographs, as grayscale or color thermographs, with various scales of conventional chosen colors. For each point of thermograph (x_i, y_i) a color shade corresponds and so a certain temperature t_{ij}. These thermographs are in fact files that contain the temperature of each point of the thermal image. The file can be processed with the help of dedicated computer programs and depending of the used calculus platforms different types of results can be obtained.

By mapping the measured surface, the thermography cameras are able to detect even small changes of temperature of ± 0,02°C that help to visualize potential defects on the surface or the inside of materials.

The usual range of temperature of infrared images is from – 20°C to + 350°C, but there are thermovision cameras that, with appropriate filters, can perform measuring up to +2000°C. Thermography is a noninvasive measuring method, without contact, which compared with the contact measuring methods, offers the advantage of rapid temperature reading.

The Measurement Principle of an Infrared Camera

The operating principle of an infrared camera is the following: the infrared radiation emitted from a body is captured through an advanced optical system, by a sensor which transforms the radiation into an electrical signal (figure 1). This signal is carried by the electronic equipment, stored, processed and transformed into images. The resulting thermal images are then processed as needed.

The main components of an infrared camera are [4]:

- **The optical system –** collects the infrared radiation from the measuring surface and focuses it onto the sensor. The materials used for manufacturing the optical system must be perfectly transparent for infrared radiation and must have: high coefficient of transmission, low energy absorption, low emissivity, high resistance and life span and low coefficient of thermal expansion. From the most often used materials, the best and most expensive, are the Germanium and ZnSe.

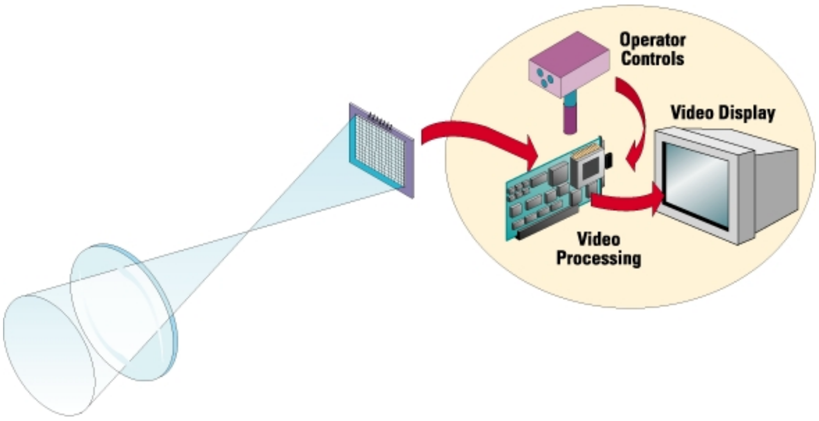


Fig. 1. The infrared system scheme with perimeter sensors [1]

- **The sensor (radiation detector) –** is the most important part of a thermographic system and its purpose is to transform the energy carried by the thermal radiation into an electric signal. The size of a sensor is specified in pixels. Each pixel of the sensor represents a thermal point which is represented on the display as a colored image. The more precise the scanning system is, the greater the number of pixels will be and the image resolution will improve. For current applications, sensors have a resolution of 320x240 pixels, but for performance measurements sensors must have a resolution of 640x480 pixels. They are placed in Dewar containers, to minimize the influence of exterior temperature. The used materials are crystals, based on InSb or CdHgTe.
- **The cooling system –** must ensure the same reference temperature for the 320x240 pixels. This is extremely difficult to achieve considering the high thermal resolution of 0.02°C. Compared to the first thermographic equipment cooled by liquid nitrogen, the last years generation models are cooled by thermodynamic or thermoelectric minicryogenerators, which lead to smaller dimensions and so, the infrared cameras became portable. The most performing infrared cameras are the ones with sensors cooled by Stirling or Pulse-tube microcoolers. Thus, the achieved temperature is about 97 K.

The first generation of infrared cameras emerged in 1998 with FPA (Focal Plan Array) matrix detectors built from microbolometers which do not require cooling. The microbolometers are sensitive elements to infrared radiation, which is absorbed within a certain spectral interval and their electrical resistance is modified depending on the amount of absorbed flux. For ordinary applications the performance of infrared cameras without cooling are comparable to those of cameras having cooling systems [4].

The optical system, the scanning mode and the electronic equipment for processing the radiation into an electrical signal, form an assembly that makes the differences between thermographic systems.

Thermographic Measurements for Radiant Tube Heating

The infrared thermography is not a simple measuring method, but it assumes applying some basic rules when the temperature is measured without contact.

To ensure the measuring precision, the following must be taken into consideration [7]: the distance to the measured object, the environmental conditions and the emissivity of the material.

The optical system that captures the infrared radiation has the optical resolution defined as the ratio between the distance from the camera to the object with respect to the size of the object. The greater the ratio is, the better the camera resolution, and a small object can be measured from distance without including unwanted background temperatures. The smaller the measured object is, the more the distance between the camera and the object is reduced. For small distances, under 100 meters, the influence of the distance can be neglected.

The environmental conditions from the work zone, such as: steam, dust, smoke, exhaust gasses etc, may affect in a negative way the radiation transmission from the object to the infrared camera and thus the measurements are not as precise, because the following effects may appear:

o the attenuation of the useful thermal flux;

o the appearance of parasite radiations;

o deformation of the object emitted beam due to atmospherical turbulences.

The above mentioned effects are obvious for thermographic examinations taken outside buildings, when the atmosphere may contain water particles (frost or fog) or even water as form of precipitation (rain or snow).

At the present case, the measurements have been performed inside a car shop (Figure 2) where the temperature and the interior relative humidity have been +18.4°C, respectively 32.9%. During the measurements, the temperature and inside air velocity have not recorded significant modifications.

Fig. 2. The hall and the radiant tube where the thermovision measuring has been performed

Also, the distances between the examined objects and the infrared camera were small, 1-2 meters, thus the presence of possible disruptive factors was reduce to minimum.

The recorded radiation by the infrared camera is formed with the object emitted, reflected and transmitted infrared radiation in the visual field of the camera.

The objects that have a large difference of temperature from the ambient can influence the infrared measurement due to their own radiation and must be avoided. The light sources emit infrared radiations that can affect the temperature of nearby objects.

Establishing the correct emissivity of the material from which the examined object is made is essential because it represents the material capacity to emit radiations. The emissivity (ε) value is manually set in the thermovision camera and a wrong set of values involves incorrect measurements. Setting a high emissivity leads to displaying a higher temperature, respectively a low emissivity leads to displaying a low temperature.

Since the actual emissivity for the surface of the measured object may be different from references values, before any temperature measurement it is necessary to determine the emissivity with the use of infrared camera [3]. Thus, on the examined object a piece of tape is pated with a known emissivity. After a while, when the thermal equilibrium is reached, the temperature of the tape is measured, having known the emissivity. This temperature represents the reference temperature and the emissivity value is measured and changed while the camera indicates the same temperature in the area without tape. The emissivity now set is the real emissivity of the measured object surface. For accuracy, in this article, the measurements were performed for the actual emissivity of the surface (figure 3).

a – real image b – thermal equilibrium achievement

Fig. 3. Stages of determining the emissivity

Data Processing after Taking the Measurements

On the international market there are programs specially designed for processing the infrared images developed by the producers of thermovision cameras.

The program used for processing, in this case for the camera which took the measurements, is named ThermaCAM Reporter 7. The program includes a series of instruments for processing infrared images, such as:

- spot- measures the temperature in a single point of the image;
- line – reveals the temperature values onto the drawn line and shows the minimum, mean or maximum temperature value;
- closed geometry: polygon, circle, ellipse - it shows the minimum, mean or maximum temperature value or builds a temperature histogram for the selected area;
- isothermals – present the colored image after defining temperature zones;
- modifying the color palette and the temperature interval;
- delta T – shows the temperature difference between two or more selected points onto the infrared image;

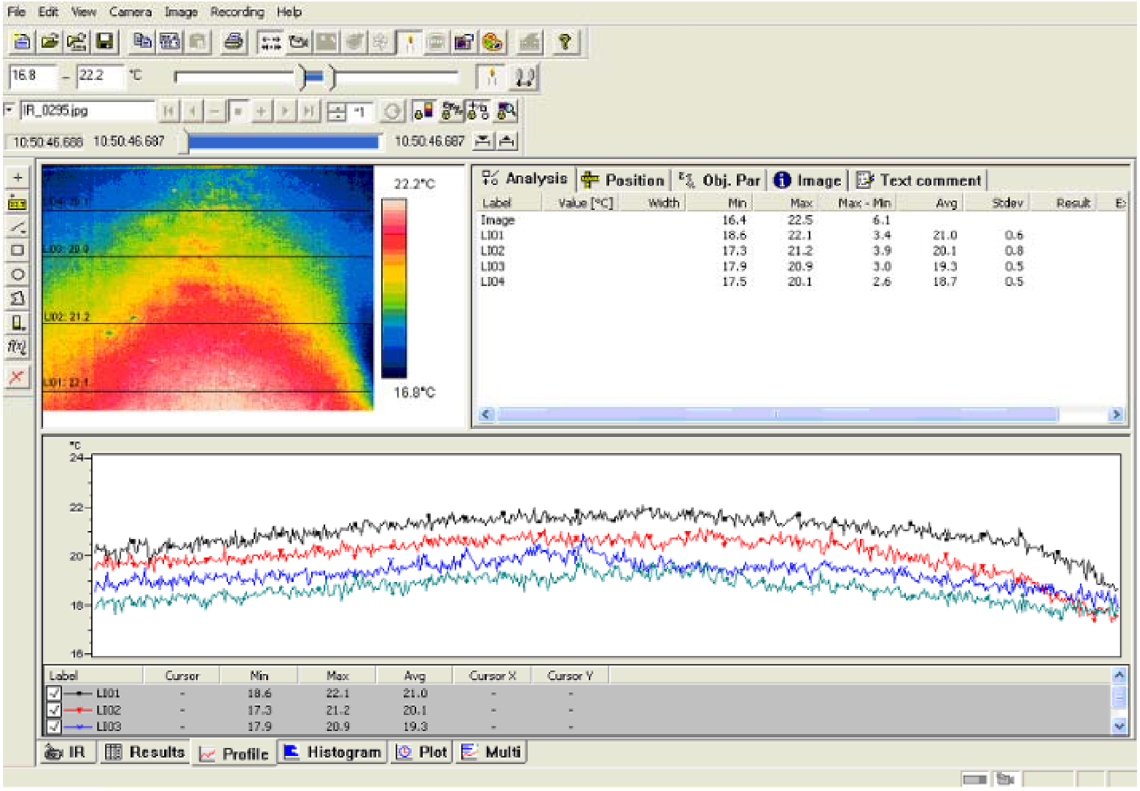
- the information given by an image can be arranged as values within a chart, graphic or histogram.

The given thermographs show the temperature distribution on the item's surface using different colors for different temperature values. The image contrast can be modified by choosing the color palette. Intuitively, red and yellow are associated with warmth, and consequently, green and blue with cool. Choosing the right color palette can render a thermograph more suggestive and more easily to interpret by only looking at it.

The termographs obtained for the areas under the radiant tube and heated by this show the temperature variation on these surfaces.

The floor temperature variation in the cross section (figure 4) presents a maximum on the radiant's tube axis and it drops with the distance increase with respect to the tube's axis.

In the longitudinal sections (figure 5) the floor temperature drops with the distance increase with respect to the burner, which is made accordingly to the radiant tube temperature variation. According to the temperature variation in both cross and longitudinal sections, the maximum temperature values are reached in the radiant tube's axis and drop proportional to the distance increase with respect to the tube's axis.



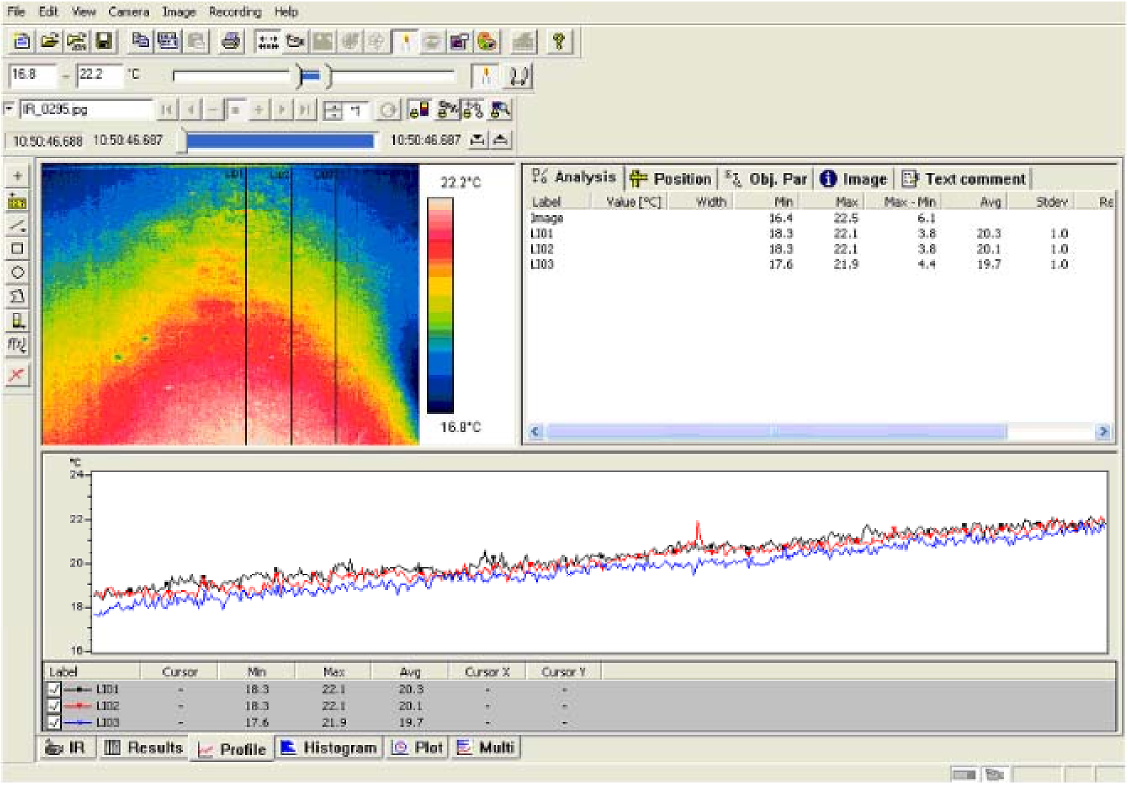
Label	Value [°C]	Width	Min	Max	Max - Min	Avg	Stdev	Result
Image			16.4	22.5	6.1			
LI01			18.6	22.1	3.4	21.0	0.6	
LI02			17.3	21.2	3.9	20.1	0.8	
LI03			17.9	20.9	3.0	19.3	0.5	
LI04			17.5	20.1	2.6	18.7	0.5	

Label	Cursor	Min	Max	Avg	Cursor X	Cursor Y
☑ LI01	-	18.6	22.1	21.0	-	-
☑ LI02	-	17.3	21.2	20.1	-	-
☑ LI03	-	17.9	20.9	19.3	-	-

Fig. 4. Floor temperatures in the cross sections

A 3D termograph shows the temperature distribution onto a radiant tube heated surface in a more suggestive way (figure 6).

In the termograph ran on the hall roof (figure 7) it shows that the temperature values are the greatest in the hump of the roof at approximately 17°C, and that at a meter below the maximum height they drop with almost 1°C. The fact confirms that radiant tubes concentrate the heat on the work zone and not in the superior atmosphere, as it happens in using warm air generators in heating. The 7 and 8 measure points (figure 7) have greater temperatures than the points situated on the roof thanks to the evacuation chimney for burnt gasses, but in no case a heat accumulation can be mentioned in the superior atmosphere of the hall.



Label	Value [°C]	Width	Min	Max	Max - Min	Avg	Stdev	Re
Image			16.4	22.5	6.1			
LI01			18.3	22.1	3.8	20.3	1.0	
LI02			18.3	22.1	3.8	20.1	1.0	
LI03			17.6	21.9	4.4	19.7	1.0	

Label	Cursor	Min	Max	Avg	Cursor X	Cursor Y
☑ LI01	-	18.3	22.1	20.3	-	-
☑ LI02	-	18.3	22.1	20.1	-	-
☑ LI03	-	17.6	21.9	19.7	-	-

Fig. 5. Floor temperatures in the longitudinal sections

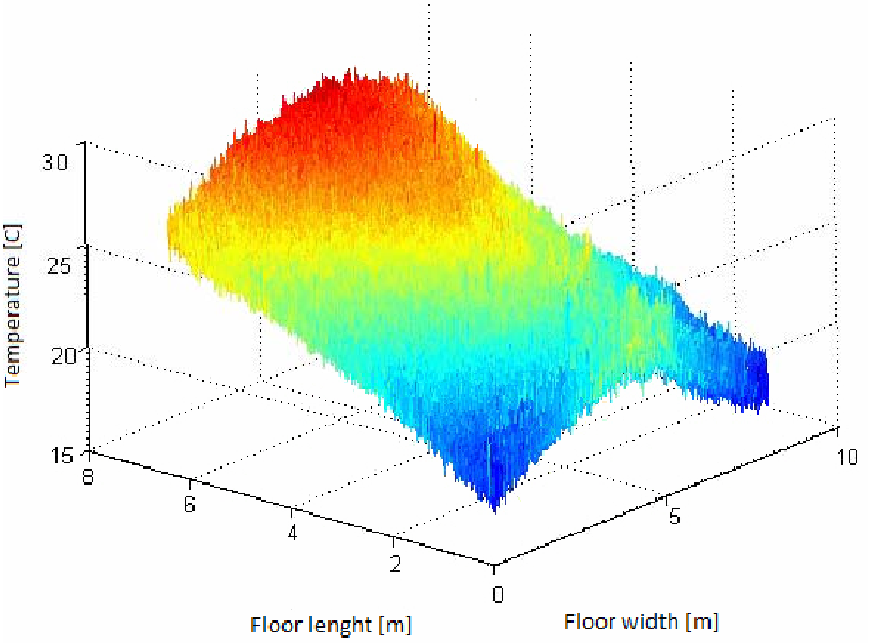
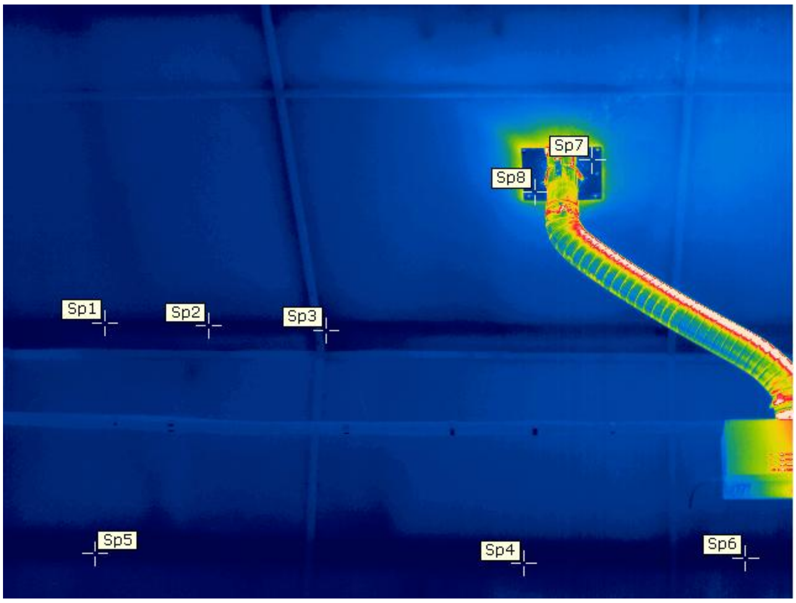


Fig. 6. 3D thermograph



Measure point	Temperature [°C]
Sp1	17.0 °C
Sp2	16.9 °C
Sp3	17.0 °C
Sp4	15.8 °C
Sp5	15.6 °C
Sp6	15.9 °C
Sp6	26.0 °C
Sp8	23.8 °C

Fig. 7. Roof termograph

Conclusions

The thermographic measurements taken in a radiant tube heated hall presented in this paper had the following target objectives: the temperature distribution visualization of the floor surface heated through radiation, determining the surface temperature for the radiant tube and its deflector, but also the temperature of random areas inside the hall with the purpose of spectrum analysis regarding the advantages of using radiation as a heating source inside large volume enclosures.

Although known for a long while, thermography represents a unique measuring technique which developed in time thanks to the evolution of the used equipment, capable of offering precise results in a very short period of time. At the present, infrared thermovision cameras with thermal resolutions up to 0.02°C are built, and the obtained thermographs can be processed and easily analyzed using special and very precise programs.

The practical utility of thermography for the taken measurements was: the possibility of effectively taking the measurements on the spot and the fact that two sets of data were taken at two separate temperature intervals. With the same infrared thermovision camera the measurements were made for the ambient temperature and over 200°C, the last one needing special thermovision camera filters.

Analyzing the given thermographs based on the hall floor and roof measurements we note that the floor mean temperature is situated within the recommended limits for the thermal comfort (29°C according to ASHRAE) [9], and also the fact that the temperatures in the higher atmosphere of the hall were smaller than the ones on the ground.

Measurements proved that radiation heating for large volume enclosures holds the following advantages towards traditional heating systems [2]:

- the heat is transmitted through radiation directly into the work zone; this advantage is emphasized as the room is taller and larger. Focusing the thermal energy at the level of the work zone makes the floor temperature to be higher (26°C compared to 18°C for convective systems);

- the temperature gradient on the vertical doesn't exceed 0. 2°C/m, which leads to a warmth reduction in the superior zones with respect to the work zone and accomplishes the comfort criteria which imposes that the temperature difference on the vertical, between the level of your head and the one of your soles for a standing occupant is smaller than 3°C, and respectively 1.5°C for a sitting occupant;
- due to lower temperatures of the inside air the losses through infiltrations are lower.

In conclusion, the energy spare in case of the radiation heating has two sources: the small value for the indoor air temperature and the small value for the temperature gradient.

The low temperature of indoor air reduces the energy requirements with respect to classical systems. Research has proved that a drop of the ambient temperature with 1°C reduces the energy costs with 7%.

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Măsurători termografice într-o hală încălzită cu tuburi radiante

Rezumat

În lucrare sunt prezentate rezultatele prelucrării măsurătorilor efectuate cu o cameră de termoviziune într-o hală industrială încălzită cu tuburi radiante. Rezultatele confirmă avantajele încălzirii prin radiaţie a incintelor cu volum mare faţă de încălzirea clasică convectivă cu aer cald.