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THERMAL SYSTEMS MODELING FOR THE HEATING PROCESS EFFICIENCY IMPROVEMENT IN INDUSTRIAL SPACES

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Abstract: The performed analysis aims to assess the spatial distribution of radiant and operative temperatures in order to improve the heating process efficiency and adopt the heating system optimum solution. Thus, is studied the influence of geometrical layout of four categories of radiant systems on the medium radiant temperature at ground level, on operative temperatures related to the model/example geometric sizes, indoor and outdoor temperatures and also on air hourly exchanges.
Keywords: thermal efficiency, temperature, radiant tube, heating, spatial distribution, yield

1. INTRODUCTION

Industrial buildings heating is very difficult to perform due to their constructive type and the activities carried out variety. In order to heat this building category it must be taken into account the most economical heating system in terms of operation and investment. On the other hand, inside the production halls there must be ensured optimum indoor conditions characterized by uniform temperature inside the heated space without air currents and with high operative yields.

Over the years, many studies regarding the thermal performances of radiant systems for building heating were performed. There were developed semi-analytical models based on one-dimensional numerical modeling in order to calculate the heat transfer inside buildings. [1], [2] and [3].

As a result of performed theoretical and experimental researches there were proposed numerous constructive and operational solutions of radiant heating systems, i.e., ceiling radiant heating system, or a warm air heating system. The studies emphasized the significant influence of indoor surface temperature, air temperature and heated area sizes on the system heat capacity [4] and [5]. Researchers as Mohammad Irfana and Walt Chapman (2010) were investigated the thermal stresses that occurred into tubes used in radiant systems [6]. N. Tsioumanisa, J.G. Brammerb, J. Hubertc (2011) studied the combustion process inside the industrial radiant tube burners. They also developed and assessed the characteristics of a radiant system with a concentric tube built-in a radiant panel [7]. Gianfranco Scribano, Giulio Solero and Aldo Coghe (2006) carried out investigations in order to find the optimum operating conditions of radiant tube burners related to the optimum equivalence between heat and nitrogen oxides and carbon monoxide emissions [8]. Research conducted by Maxime Tye-Gingras and Louis Gosselin (2012) on radiation heating shows the temperature field variation and data regarding the environmental comfort depending on the radiant panel size and layout [9].

However, assessing the efficiency of using these systems in industrial area, is very important especially when is taken into account the environmental comfort parameters.

When choosing heating systems for industrial areas, is essential to obtain high energetic performances. Compared to other heating system types, the utilization of thermal radiation systems results in significant energy savings together with greenhouse gases emissions reduction [10] and [11].

2. THE MODEL DESCRIPTION

The radiant heating systems principle/particularities are considered as it follows:

Radiant tube systems

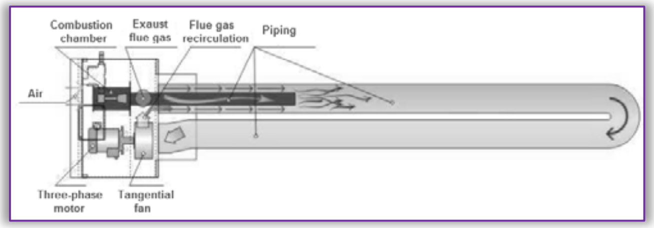


Figure 1. The radiant tube heating system [12]

An industrial building efficient heating solution is represented by radiant tubes thermal systems. These have a very high heating capacity in short time and eliminate the electrical energy additional costs.

By taking into account the large variety of radiant heating systems, it is very important the selection of the optimum heating solution depending on the specifics of technological process and environmental comfort.

In this regard, in the article are studies the radiant tubes systems (OHA and Infra Plus) and those with radiant plates (SCR) used for large industrial buildings heating. The study follows the influence of geometrical layout of the analyzed heating system in order to assess the spatial distribution of radiant and operative temperatures for optimizing the thermal process.

The radiant tube heating system consists of a radiant tube and combustion group which uses the direct combustion of a gaseous fuel and comprises a burner and a fan (Figure 1).

Through the burner, energy is generated in the form of heat. The combustion group fan ensures an underpression inside the combustion chamber and the achievement of the flue gases circuit. This circuit which is achieved at variable temperature is inside sealed radiant tubing in depression compared to the heated environment. The gases from the return circuit are recycled absorbing heat from the walls and, then are mixed with the new combustion products. A part of flue gases is exhausted trough a collector which is located outside the heated environment. The remaining gas returns into the radiant tubing circuit which radiates infrared electromagnetic waves. These waves are propagated in a straight line at a speed equal to the light one and hits the bodies surfaces. The result of this process is the heating of bodies surfaces and persons in the room.

The advantage of using radiant tubes consists in the possibility of reaching the maximum yield, mainly due to the high emission coefficient of the tube.

Ceramic plates heating system

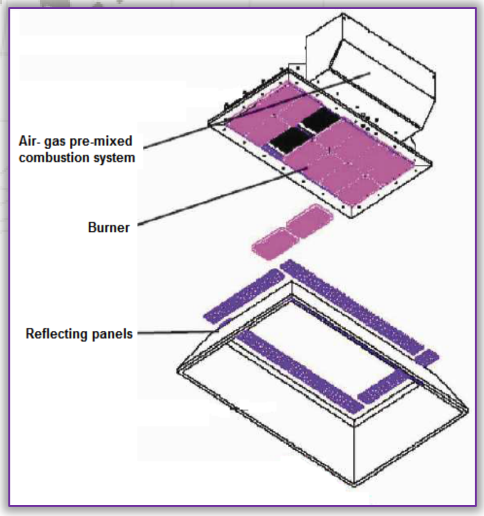


Figure 2. Radiant ceramic plate system [12]

The radiant infrared heating systems operating with gas contain ceramic plates at which level occurs the combustion (Figure 2). The air temperature is constant without thermal peaks caused by the on / off of the equipment. The pre-mixed system of the burner has a high efficiency and offers the possibility to adjust the thermal power. This fact leads to the radiation transfer efficiency increasment. Inside the pre-mixed casing of the SCR radiant system, an air filter or tubing can be mounted in order to exhaust the air-gas mixture. The air-gas combustion system has a fan with rotative speed and the gas solenoid valve ensures the gas pressure stabilization [12].

The thermal efficiency of this thermal system type increases due to the presence of a grid resistant to high temperatures. The grid absorbs respective transmits a part of thermal energy and the result of these processes is the enhancement of the heat exchange between the flame and ceramic plates.

Ceramic plates and grid at high temperature emit infrared radiations which are then directed by the reflectors towards the bodies to be heated.

The flue gas flow along a pre-mix chamber, heating the materials for the combustion process, resulting the efficiency increase.

3. THE HEATING SYSTEMS ANALYSIS FOR OPTIMUM SOLUTION DETERMINATION

In order to establish the optimum heating solution, it is taken under consideration an industrial hall for which the modeling of the heating system is performed by the Systema SpA V2.2 software. The defining of the analyzed field is carried out by creating the contour that has to be heated. There are established the geometrical dimensions in Cartesian coordinates, x, y and z (80m, 30m and 8m), the values of indoor air temperature (16°C) and number of hourly air exchanges (0,5 change/hour). The outdoor temperature of air (-15°C) is imposed depending on the climatic zone (considered as zone II) where the hall is located [13] and [14]. For the considered hall there are analyzed the heating conditions with four versions of radiant thermal systems, such as: OHA 100-100 U, OHA 100-100 M, Infra 6 Plus and SCR 25M. Those system technical features are shown in Table 1, in compliance with the technical documentation [12]. In Table 2, there are shown the physical and thermal features of the building elements materials.

Table 1. Technical features of the analyzed radiant thermal systems

OHA 100-100 U, OHA 100-100 M						
Nominal thermal capacity	Effective thermal power	Average combustion efficiency		Nominal consumption 15°C and 1013, 25 mbar		Maximum absorbed electrical power
				Methane	GPL	
kW(Hi)	kW(Hi)	%		Nm³/h	kg/h	W
100	93	93		10.58	7.77	1350
INFRA PLUS						
Nominal thermal capacity	Effective thermal power	Combustion efficiency		Nominal consumption 15°C and 1013, 25 mbar		Maximum absorbed thermal power
		minim	effective	Methane	Natural gas	
kW	kW	%	%	Nm³/h	Nm³/h	kW
28	24.1	86.1	90.1	2.96	3.45	0.16
SCR						
Maximum thermal power	Minimum thermal power	Nominal consumption 15°C and 1013, 25 mbar				Maximum absorbed electrical power
		Maximum methane	Minimum methane	Maximum GPL	Minimum GPL	
kW	kW	Nm³/h	W	kg/h	kg/h	W
24	12	2.54	1.27	1.86	0.93	60

Table 2. Physical and thermal features of the building elements materials

Wall			Ceiling			Floor		
Material	Thickness	Overall heat transfer coefficient	Material	Thickness	Overall heat transfer coefficient	Material	Thickness	Overall heat transfer coefficient
	[cm]	[W/m²K]		[cm]	[W/m²K]		[cm]	[W/m²K]
Sandwich panels	10	0.175	Sandwich panels	25	0.071	Concrete	20	0.145

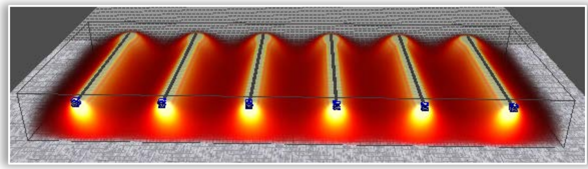
In order to carry out the proposed analysis there are taken into account the human physiological balance in artificial environments, such as: orientation, position, human body absorption and emission coefficients, cloth resistance and activity yield (Table 3) [12], [13], [15]. For the environment, there are imposed and presented in Table 4 the following features: air temperature, relative humidity, relative air speed, ground absorption and emission coefficients [13], [14] and [15].

Table 3. The human physiological balance in artificial environments

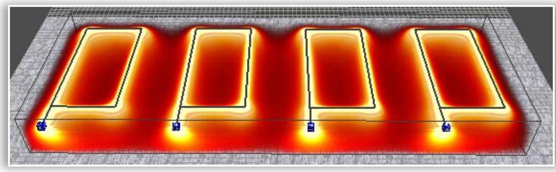
Orientation	Position	Absorption coefficient	Emission coefficient	Activity yield	Cloth resistance
[°]		[-]	[-]		
90	standing	0.65	0.95	0.70	1

Table 4. The environment features

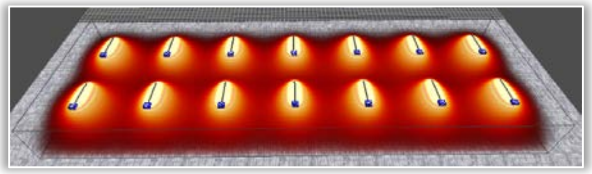
Relative speed of air [m/s]	Relative humidity of air [%]	Ground absorption coefficient [-]	Ground emission coefficient [-]
0.10	60	0.88	0.85



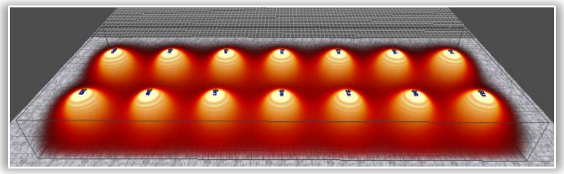
a) OHA 100-100U



b) OHA 100-100M



c) INFRA 6PLUS



d) SCR 25

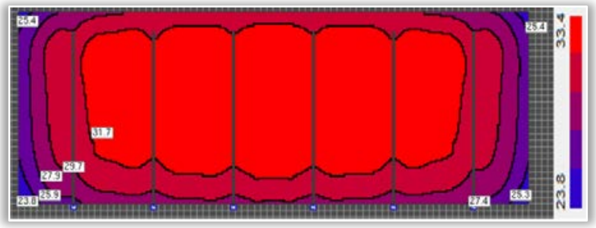
Figure 3. The heating systems placement

For the analyzed hall it is taken into account a ratio between the thermal bridge width and separation element thickness of 3%. The heating system operation period is equal to 10hours/day. The simulation was performed by taking under consideration the radiant piping mounting height of 7m [15]. As a result of the software running there were obtained the model plane and spatial representations, shown in Figure 3.

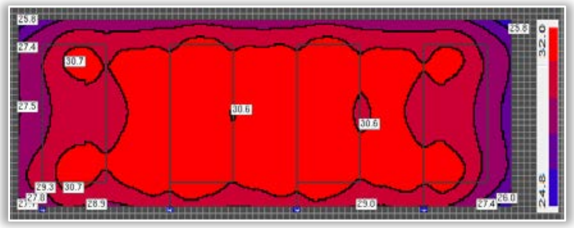
4. RESULTS AND DISCUSSIONS

The temperature distribution is obtained by simulating the thermal field inside a heating field with radiant systems. The discretization was performed with finite plane elements.

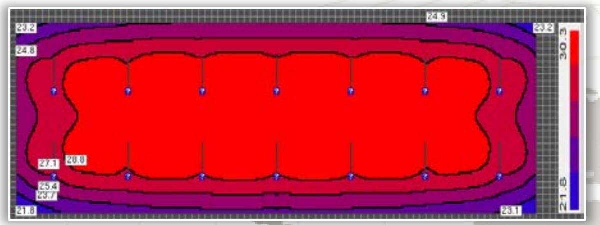
On the simulated thermal maps there are highlighted the surfaces and isothermal lines of the plane thermal field which correspond to radiant and operative temperatures, in order to obtain the system optimum (Figure 4 and Figure 5).



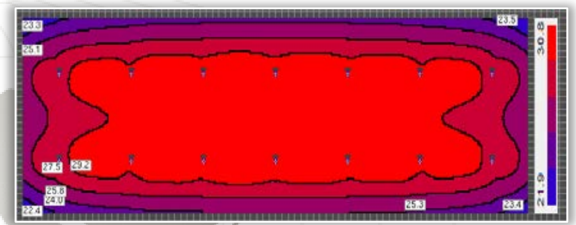
a) OHA 100-100U



b) OHA 100-100M

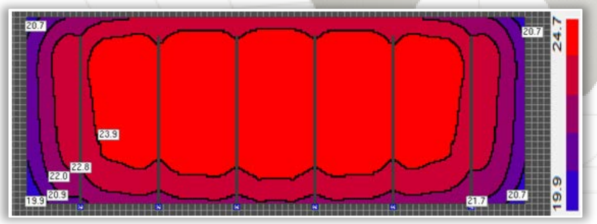


c) INFRA 6PLUS

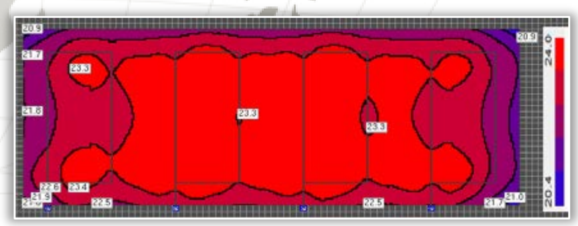


d)SCR 25

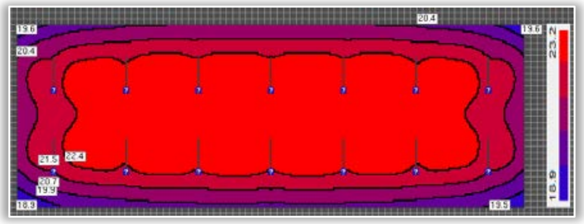
Figure 4. Radiant temperature distribution



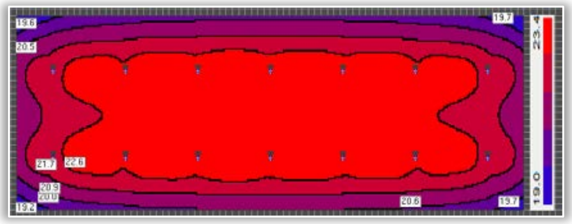
a) OHA 100-100U



b) OHA 100-100M



c) INFRA 6PLUS



d) SCR 25

Figure 5. Operative temperature distribution

On the thermal maps the colors represent the temperature variation. The darkest shades correspond to lower temperature values and the light shades to the highest temperature ones. Thus, there can be observe five isothermal surfaces, separated by isothermal curves. For each analyzed case, are shown the spectral bands that represent the temperature range in which the system provides the required temperature.

The positioning of heating elements was simulated in order to avoid the occurrence of the asymmetric thermal radiation.

From Figure 4 and Figure 5, it can be observed that there are no vertical differences higher than 10ºC, when temperature varies between floor and ceiling.

In order to avoid local thermal discomfort, the simulation of the analyzed systems was carried out by taking into account the features values from Table 4.

To cover spatial and temporal variations, for these analyzed systems the operative temperatures in all points of the isothermal surfaces are within the range specified by ISO7730 [16]. Thus, for the OHA 100-100U heating system, the outdoor walls operative temperature is within 19.9-20.7°C, while indoor it is recoded a uniform temperature value of 23.9°C in all points of the isothermal surface.

For the others analyzed radiant heating systems, the temperature range are:

- for OHA 100-100M radiant system, the outdoor walls operative temperature range is 20.9-21.0°C, and the indoor uniform one is equal to 23.3°C;
- for INFRA 6Plus radiant system, the outdoor walls operative temperature is between 18.9 ºC and 19.6°C, and the indoor uniform temperature is of 22.4°C;
- for SCR25M radiant system, the outdoor walls operative temperature range is 19.2-19.7°C, and the indoor uniform temperature is equal to 22.6°C.

The differences between the minimum and maximum values of the radiant temperatures, respective of those operative, which limit the thermal surfaces are within 7.2-9.6°C, respective 3.6-4.8°C. From these values point of view, it is recommended for heating the considered plant the utilization of OHA 100-100M radiant tubes. However, by analyzing the thermal maps of this system version (Figure 4b and Figure 5b), there can be observe areas with temperature discontinuities, which are not in accordance with the simulation purpose.

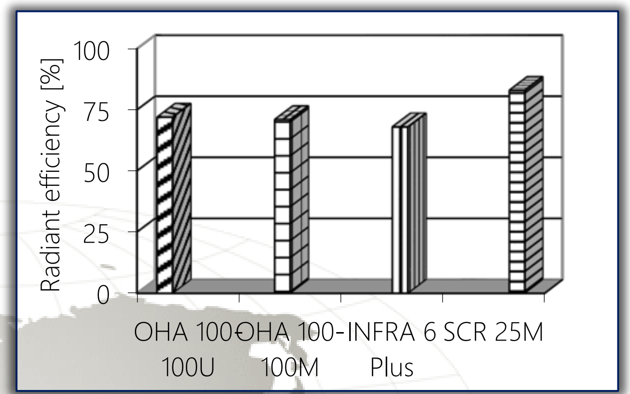


Figure 6. Radiation efficiency

For the radiant heating systems, it can be noted that at the hall marginal points, shape differences of the thermal fields occur as a result of the non-uniform radiant thermal transfer. The sharpest differences are recorded for OHA 100-100M and SCR 25M heating systems.

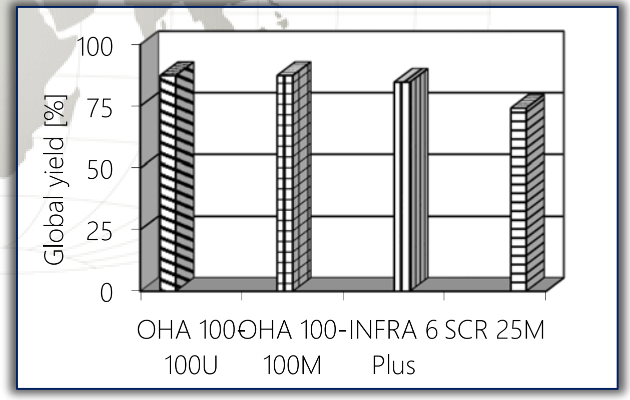


Figure 7. Global yield

In order to eliminate any uncertainty in choosing the optimal radiant system, for the four heating systems there were comparative analyzed the radiation efficiency shown in Figure 6 and the global yield presented in Figure 7.

From Figure 6 and Figure 7, it can be observed that the highest radiation efficiency is typical to SCR 25M system followed by OHA 100-100U. The highest global yield was recorded for OHA 100-100U heating version. For this reason, the OHA 100-100U represents the optimum radiant system for heating the analyzed hall.

5. CONCLUSIONS

The simulation of the radiant thermal heating systems was carried out in order to choose the optimum system as to avoid the air stratification phenomenon, both on horizontally and vertically. Thus, there can be avoided the temperature discontinuities inside the thermal field. In this respect, it can be observed that the OHA 100-100U heating system with radiant tubes and those INFRA 6Plus are comparable from temperature uniformity point of view.

As a result of the overall analysis regarding radiant heating systems, it results that the OHA 100-100U one represents the most efficient solution from stability and thermal comfort point of view.

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