PAPER ECONOMICAL CONSIDERATIONS CONCERNING RADIANT HEATING SYSTEMS

Mirela Sanda TOROPOC[1], Rodica FRUNZULICA[2]

For industrial buildings with important height, more than 12m, sometimes different heating solutions are proposed without taking into consideration the energetically efficiency of the systems. Such type of buildings represents a problem in selection of the most convenient solution from economical point of view, including initial cost for the heating system but especially for the maintaining costs. The selection of the heating system must be made with objectivity if we consider different solutions and type of heating systems for the same building, with a similar economical and functional efficiency. The present paper analyzes various heating systems for buildings with important height and compares them from cost of investment, maintenance and energy efficiency point of view. The conclusions of this article can be extended to new buildings and their conception, but also to old ones, inefficient, needed to be rehabilitated.

Keywords: convective and radiant heating, energy efficiency.

1. Introduction

Inefficient energy utilization appears in all sectors of the economy, especially in the industrial sectors, which accounts for over 80% of energy consumption.
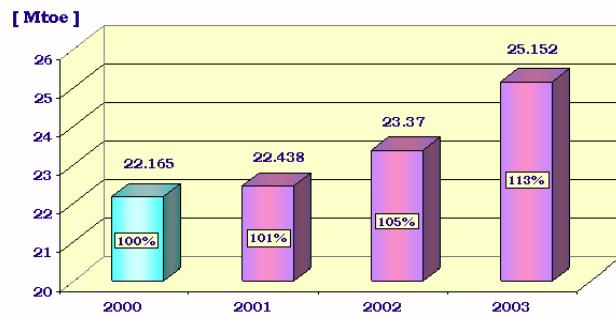
Source: National Institute of Statistics – "Romanian Statistical Yearbook 2004"

Fig 1. Evolution of the Total Final Energy Consumption after year 2000

[1] Assist. Prof., Technical University of Civil Building Engineering Bucharest, Romania
[2] Prof., Technical University of Civil Building Engineering Bucharest, Romania

Such a high energetically intensity in Romania is due to old equipments and obsolete technologies However, actual investments in energy efficiency are low. This is, in large part, due to the absence of appropriate funding mechanisms, coupled with a lack of expertise in identifying and developing commercially viable projects.

2. Industrial buildings

Due to the diversity of activities inside the industrial buildings, strict and specific climate conditions are required, both for technological processes but also for human activity, in order to obtain high productivity. Often, the demands for technological processes are the same as the indoor climate conditions needed for human activity. The particular case studied in this article refers to an airplane repair airshed (with a surface of 2023 m^2) built in Bucharest's periphery. The architecture of this building, by the existence on an exterior wall that opens completely the whole height of the building -16m), but also thru its technological and nature of the activities, imposes certain interior climate conditions. The opportunity of choosing a radiation heating system by comparison to a classic heating system (heating system with boiler and air heaters), was studied. A comparative study was carried after the conception of both heating systems, following the economical implications analysis for the investment and annual consumptions point of view. The heat demand calculation was made for an air heating system and also for a radiation heating system. We suggest, as possible scenarios, two heating systems for the chosen industrial building:
➢ a radiating system, with OHA radiant strip. This solution will be further referred in this article as "radiant";
➢ with hot air by air heaters that utilize thermal agent from a boiler. This solution will be further referred to in this article as "convective";

The heat supply needs to be provided either by its own source in order to ensure operational independence of the building or by combustion units mounted outside the building or by heat plant on GPL fuel. In case of a hot air heating system with air heaters and boiler, the source consists of 2 steel boilers with closed burning chamber, that use GPL as fuel, with a useful power of 400 kW each (in case of damage to one of the boilers, the other one has to cover at least 60% of the total heat demand), that will provide hot water for heating +80/+60°C. The regulation of the heating agent's temperature, provided by the boilers it is made according to the outdoor temperature measured by a temperature sensor (qualitative regulation). In order to determine the heat demand, SR 1907 was applied, but some dynamic regime calculations with TRNSYS were simulated. Following results were obtained:

HEAT SYSTEM	THERMAL NEEDS [kW] SR 1907	THERMAL NEEDS [kW] Dynamic regime
Convective	648,6	602,8
Radiant	567,6	518,4

It can be seen that the difference between the heat demand calculated appling SR 1907 for convective heating using **hot air** and **radiation heating**, its **81 kW**, which represents only **12 %.** For certain technological processes the air's parameters inside the room, as a result of technological reasons, do not coincide with the optimum for human activities conditions. Therefore certain measures must be taken in order to reduce their influence over the workers. These measures aim the individual protection means, or reducing the activity, or simply periodically move the activity of the workers outside.
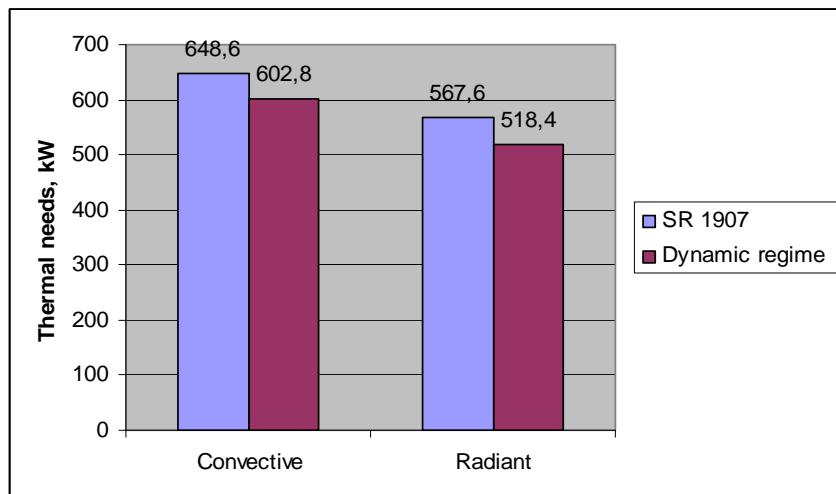

Fig. 2. Thermal needs for convective and radiant heating system indicated with two methods of calcule

In the same time, in order to obtain some supplementary energy savings a zonal heating could be taken into consideration, the radiation heating system being designed to divide into 4 zones the working space, each one having its own, independent, system.

The indoor air temperature is one of the main thermal comfort's factors. We can act directly on it with the help of a heating or ventilation system. In case of

relatively small variations of the interior temperature, the thermo regulating function of the human body quickly reestablishes the heat exchange between the human body and the surrounding environment. When the temperature drops, the human body reduces peripherical blood flow, which leads to skin temperature dropping thus reducing heat losses, but also it intensifies internal burning thus increasing the body heat. When the air temperature increases, the human body intensifies peripherical blood flow thus increasing the skin temperature.

Reestablishing the necessary temperature difference between the human body and the environment, the discharge of internal heat is assured.

The heat that cannot be discharged by the human body thru convection and radiation it's used to evaporate the humidity eliminated thru the skin as sweat, so that the human body – environment thermal equilibrium is maintained.

The indoor air temperature in the rooms where people are sitting or doing an easy work needs to be more elevated and in case of sustained effort activity, the air temperature needs to be decreased.

Table 2

The indoor air temperatures for industrial buildings in production spaces without technological conditions, are chosen as follows :

Type of releases	Work category		
	Easy	Medium	Heavy
With heat and humidity releases	16	**15**	10
With big humidity releases (φ>70%)			
With big heat releases particularly in radiant form	15	13	8

The indoor air velocity needs to correspond to the air temperature in accordance to the occupants activity. In the case of industrial spaces, in winter, the air curents have a smaller temperature than the room, and also the flow turned towards certain parts of the body, disturbs the occupants. On the opposite side, in summer, the increased speed of the air creates a agreable sensation of coolness, even if the temperature of the air that moves is the same as the environment. The air draft sensibility is very different for each person and it depends on the health state, sex, age, clothing, season etc. In accordance with confort demanded different limits for the air speed are request. For a very high thermal confort, in winter, the air speed needs to be around 0.12-0.15 m/s, while for a industrial enclosure in which intense physical activities are in course, the air speed is 0.50-0.60m/s.

During warm time of the year the air speed values requested are higher.

The average radiation temperature represents the 3-rd main parameter of the thermal comfort. The value of the average radiation temperature determines the size of the radiant heat exchange between the human body and the environment. The average radiation temperature always needs to be correlated to the indoor air temperature. The increase of the average radiation temperature needs to be followed by the decrease of indoorair temperature and vice-versa.

The indoor air temperature and the average radiation temperature have an important role over the thermal comfort. The human body always senses the combined simultaneous effect of these temperatures. For this reason, it is necessary to define the concept of resultant temperature. The resultant temperature t_R is usually calculated as arithmetic average of the indoor air temperature and the average radiation temperature. The resultant temperature is indirectly influenced by the type of heating system. With the adopted heating system comes a certain average radiation temperature for a given building as a consequence a certain radiant exchange between the human body and the defined surfaces. The effect of average radiation temperature leads to a certain temperature resented by the occupants. It results that for the same room equipped with different heating systems, the resultant temperature will be different, so that it should be a specific resultant temperature for every particularly case. The arithmetic average doesn't reflect the physical reality completely. For example, for rooms equipped with radiation heating systems a **resultant temperature** is:

$$t_r = 0,45 \cdot t_i + 0,55 \cdot t_{ms} , \qquad\qquad (1)$$

where: t_i is the indoor air temperature and t_{ms} is the average radiation temperature.

As a first conclusion: the radiation heating system allows the maintaining of the indoor air temperature at values with 2-3 degrees less than for a classical heating system. This is possible only because utilising a radiation heating system, the average radiation temperature of the surfaces placed in the radiation cone increases. Therefore, in order to maintain the same resultant temperatures we need a lower temperature of the interior air.

When we compare a radiation heating system vs. a hot air heating system, the heat demand in the first case will be lower and it will get even lower if the building's air volume is bigger. This is the one of the final conclusions of the comparative study, based on calculations.

3. Comparative analysis of the advanced solutions

The necessary equipment for each case was established and following calculations were effectuated: the acquisition price of the equipments, the work quotations on which basis was established the mounting price and the total price of the investment for each solution. From the analysis of the work quotations we concluded that the mounting price is approximately **10%** of the acquisition price of the equipments in case of the radiation heating system and approximately **30%** of the acquisition price of the equipments in case of air heater heating system.

Table 3

Total costs of the investments for heating solution

| Heat System	Heating system price [Eur]	Installing price [Eur]	Total investment [Eur]
Convective	52429,44	15728,83	68158,27
Radiant	65228,00	5360,00	70588,00
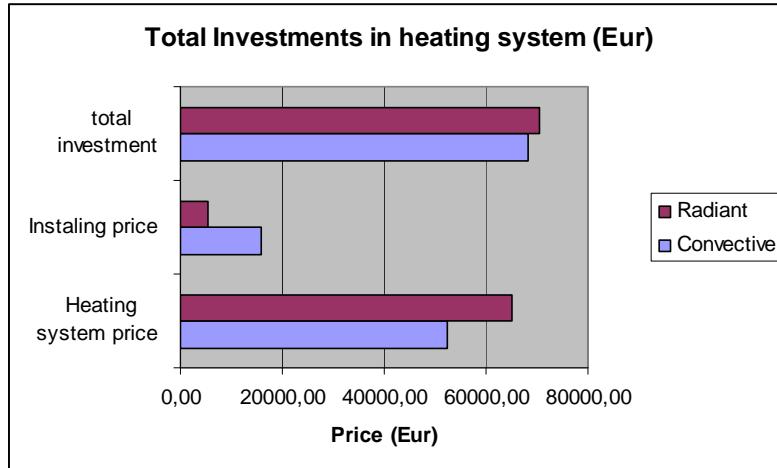
Fig. 3. Total investments for convective and radiant heating system for an airplane repair airshed

4. Fuel consumption

In order to design the fuel supply system and the gas exhaust system, the fuel demand calculation it's made hourly, dayly, for the peak month, heating period and yearly, according to the heat consumption for each type of consumer and taking into account the operating mode.

Hourly fuel consumption B_h

Depending on the heat flow provided by the heat plant's boiler, the **theoretical hourly fuel demand** is calculated as follows:

$$B_h = \frac{3600}{\eta \cdot P_{ci}} \cdot Q_I \ [\text{kg/h}], \tag{2}$$

where: η – the system yeld, defined as burning yeld multiplied by transport, distribution and adjustement yelds; Q – heat flows [kW]; P_{ci} – lower calorific value of the fuel [kJ/kg].

Anual heat demand for heating

$$Q_{Ia} = Q_{Im} \cdot \frac{t_{mi} - t_e^{''}}{t_{mi} - t_e} \cdot n_I \cdot Z \ [\text{kW/an}]. \tag{3}$$

where: $t_e^{''} = \dfrac{\Sigma t_e^{'}}{6}$ is the average exterior conventional temperature during heating season; Z is the number of heating days; t_{mi} - the average air temperature of the heated spaces [°C]; t_e' – is the average exterior conventional temperature for the peak month [°C]; n is the number of daily functioning hours of each consumer.

Average temperature of the interior air
It's calculated as a weighted average with the room's volume V_i:

$$t_{im} = \frac{\displaystyle\sum_{i=1}^{n} V_i \cdot t_{int}}{\displaystyle\sum_{i=1}^{n} V_i} \tag{4}$$

For this airshed, the indoor temperature is equal to the average indoor air temperature, the interior space being not defined.

Annual heating fuel consumption

$$B_{Ia} = \frac{3600 \cdot Q_{Ia}}{\eta \cdot P_{Ci}} \ [\text{kg/year}]. \tag{5}$$

Based on the results obtained for the annual fuel consumption , we obtained the annual costs for each type of system used, the fuel price being considered as follows:
- for Romania de 0,47 EURO/l = 0,94 EURO/kg (Butane)

Annual exploitation costs

Heating system	Fuel consumption	Price GPL
	[kg/an]	[EURO/an]
CONVECTIVE	25453	23926
RADIANT	17183	16152

5. Conclusions

Radiation heating fuel consumption is lower than for a boiler and heaters heating system by approx. 48%, and that investment is only 3.5% higher. This is a result of the possibility of a zonal heating. The time recovery for the difference between the two systems is 4 months only from fuel consumption. The full return of the investment is around 9 months. The special area represented by the industrial sector requires the consideration of several issues involved in achieving and maintaining a state of comfort in industrial premise.

A brief enumeration of these observations leads to the reasons why the particularities in industry conduct to a different approach of the thermal comfort must be achieved:

- in industry, the ambient temperature for human activity is often lower in winter and higher in summer than for the residential or administrative buildings;

- the activity performed in the industry sector is clearly different from one performed in residential buildings (its intensity is higher and varies during the working day);

- the type of clothing beard by the occupants for industrial buildings is different from those who are living in residential buildings;

- sometimes the technological processes require microclimate conditions that do not match those for human thermal comfort.

Whatever type of heating system (convection or radiation) is pursues the same goal: achieving thermal comfort. Each heating has its advantages and inconvenients, so the setting must be pursued both heating solution implementation and technical aspects of the economic (cost and energy consumption as low).

Energy savings can be achieved using thermal heating by radiation increases when the process requires zonal activity that can be covered by a full heating system perfectly adequate. Such zoning can not be quantified as energy saving in the absence of clear data on execution times and areas of specific work flow technology. When all the technical solutions are combined so as to cooperate to get the best for comfort, low energy consumption and reduce environmental impact are achieved.

Heating with radiant tubes offers the possibility of zonal heating of open or part-open spaces, reducing the stratification phenomena to a minimum and creates other advantages such as:

-concentrating the heat in the working area ;

-the air speed inside the space is around 0,15 m/s, falling within the optimum training comfort and avoiding dust particles settled;

- vertical temperature gradient does not exceed 0.20 C / m, which leads to a reduction of heating in relation to the upper area of work;

-allows local, zonal or total heating of a production space, including the possibility of assuring a guard temperature, needed to protect systems that transport other fluids;
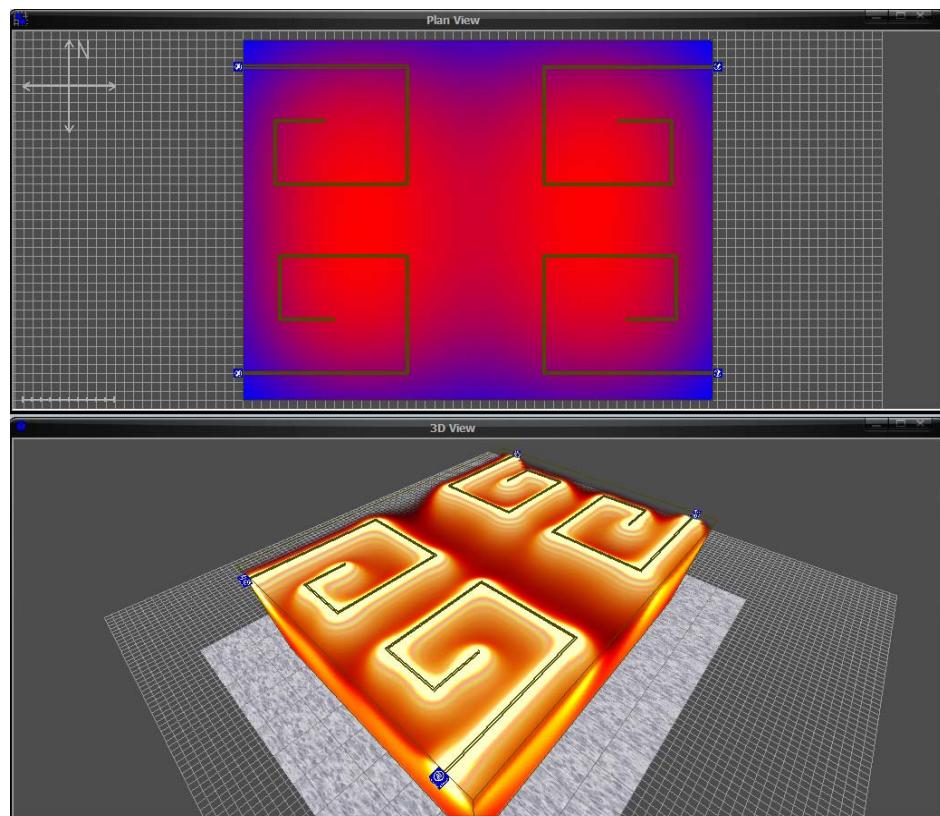

Fig. 4. Heating zoning according to the activity zoning; average radiation temperature at floor level; aadiation distribution; systema simulation

R E F E R E N C E S

[1]   *Lebrun J, Mawrret D*, Efficacite de differents systems de chauffage, CSTC, Nr.2, 1978
[2]   *Sarbu I, Kalmar F*, Building's Energetic efficiency, Editura MatrixRom, Bucuresti, 2002
[3]   *Zold A*, Thermal Confort at Transient Conditions, PLEA World Congress, Cambridge, 2000.
[4] *** Theoretical and Experimental Research Concerning energy efficiency and fire safety systems for industrial buildings heating. Raport Tehnic – PNCDI Programul AMTRANS, Bucuresti 2004-2007
[5]   *Toropoc M, Frunzulică R,-* Overview on heating systems energy efficiency in industrial and residential   buildings from Romania, WSEAS International Conference on ENERGY, ENVIRONMENT, ECOSYSTEMS and SUSTAINABLE DEVELOPMENT (Tenerife EEESD'10) ISSN 1790-5005, ISBN 978-960-474-903-2