# Efficiency and Economy Solutions Regarding the Industrial Buildings Heating

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*Abstract:* - One of the Romanian energy policy priorities is to increase energy efficiency. Energy efficiency is crucial when a heating system is selected. Compared with other systems, heating by radiation can save up to 40% energy, while maintaining a pleasant indoor climate. For these heating systems are presented solutions in terms of efficiency and economy. There was analyzed the operation of heating radiant tubes with three types of fuels (methane, LPG, gasoline) in terms of cost and consumption in order to achieve the same comfort conditions. For the installation operating with methane, there were accomplished emission measurements with Testo 350 S gas analyzer. As a future solution it is proposed the use of bio fuels in heating system combustors (pellets from biomass), given that Romania exports in EU 95% of its annual production.

*Key-Words:* - radiant tube, heating, efficiency, economy, fuel, pollutant emission, pellet, gas analyzer

## 1 Introduction

National energy sector has to face major challenges that have appeared at national and global levels: the security of energy supply, economic competitiveness increase and impact reduction on the environment. These challenges are particularly important, given that Romania has to recover the economic performance advance from the developed countries of the EU.

A major contribution to accomplish these objectives is to increase the energetic efficiency which is one of the priorities of the Romanian energy policy. Energy efficiency is crucial when a heating system is selected. Compared with other systems, heating by radiation ones can save up to 40% energy, while a pleasant indoor climate is maintained. [12]

When heating is achieved through radiant panels mounted on the ceiling, the room air temperature is lower, even if the resulted temperature is the same. The heat loss due to smaller difference between the room and outdoor air temperatures is reduced (Fig.1) [11].

By using these heating systems, energy will be saved and the sensed temperature will be the same. The temperature distribution is uniform throughout the whole room height (Fig.2). [4] The desired power source can be chosen and alternative energy sources, heat pumps, heat recovery technology by condensation technology can be used.

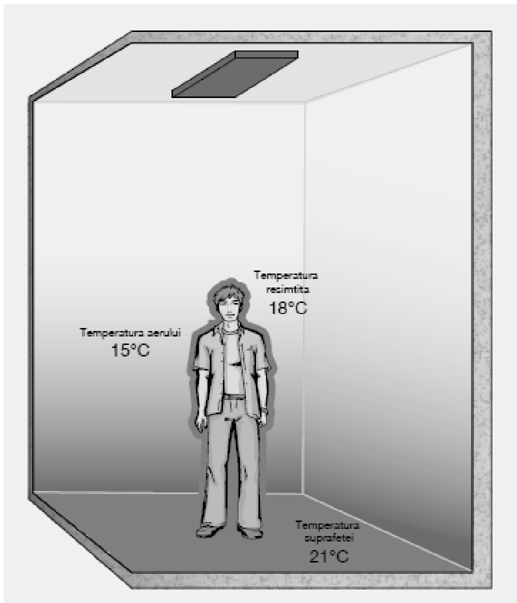


Fig.1 The air temperature and temperature sensed for heating with radiant panels

Heating capacity is very large, the warm-up time is reduced and there are no additional electricity costs for fans. In particular these systems are successfully used for heating the industrial halls, gyms, commercial spaces, offices and public buildings such as schools or hospitals. They are considered an essential component in modern design [2].

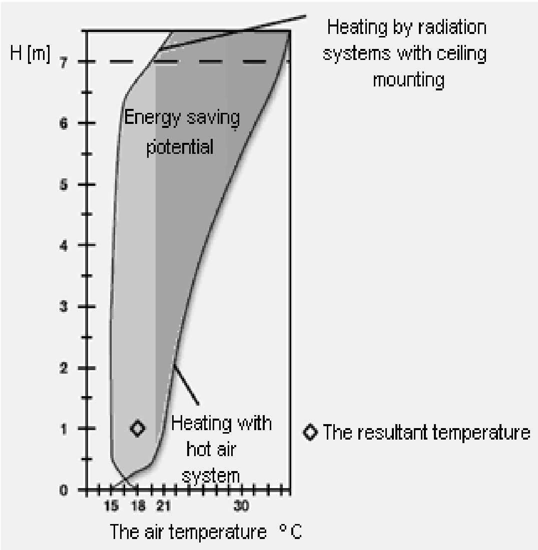


Fig.2. Energy saving potentials by using heating systems with radiation tubes mounted on the ceiling compared to the hot air heatng systems at the same sensed temperature

## 2 Radiating Systems Operating Principles and Construction Elements

### 2.1 Operating Principles

The radiant systems represent a newer heating solution through thermal waves. Infrared radiating systems transmit the heat directly through radiation to solid objects heating them. In turn, the heated objects warm the air in the room. This type of heating is more efficient and more economical than the convection one. The primary heating medium is overpressured natural gas, which is transported at high speed through nozzles, mixing it with the total quantity of air necessary for combustion in the primary circuit. Into the mixing chamber, where downstream Venturi tubes are mounted, the perfect mixture of air and gas is achieved. Due to the overpressure effect the gas-air mixture leaves the mixture room, which is designed in accordance with hydraulic principles, and is exhausted in the environment through the ceramic plates holes. The gas mixture once ignited, burns at the beginning with blue flame then it retracts into the overheated ceramic plate holes which operate as catalysts and bring their internal and external surfaces to incandescence. After a 1-2 minutes preheating interval the device operating mode becomes stable - the plate radiation has a light red colour - to an operating temperature of about *850-900* $^0$C. The thermal radiation principle of flameless combustion of the gas - air mixture transported through the ceramic plate holes consists of bringing them to incandescence, which causes the acceleration of the combustion process to the "without flame" range. Flameless combustion is the effect of pyrogenic decomposition of carbon compounds, which have a limited thermal resistance, and also the catalytic effect of carbon fine particles occurred during the process together with the high speed combustion due to the "wall" effect of perforated plates that became incandescent. At high temperature (*800-900*$^0$C), the catalytic effect of the incandescent surface of various solids is practically the same. The device caloric consumption will increase respectively decrease if the gas-air mixture pressure changes (increases respectively decreases) in the space of the ceramic plates. Unlike all other types of gas burners, the pressure reduction of the gas-air mixture will not cause the combustion instability and flareback. Conditions for “flameless” burning are simultaneously accomplished by the combustion plan stability, gas-air flow energy balance and ceramic plate thermal balance. Heating systems consist of automation elements for ignition and combustion monitoring. These elements also ensure the high voltage spark ignition and double closure magnetic valve operation. Electronic automation components are also connected in order to provide the possibility of device programming and adjustment (for example, adjusting the weekly program, automation in three points 0 - 50 - 100%, sector differential heating schemes, etc.). In terms of construction, these devices do not have exhausting combustion gases elements. Therefore, these can be used only in areas in which the dilution and exhaust of combustion gases are properly achieved. [9]

Devices with properly controlled operation have the noxes concentration resulted from combustion less than the prescribed values for labour and environmental protection.

Infrared radiant tubes are manufactured in many constructive variants, with a wide range of possible uses:

- Low heat output devices, operating with natural gas used in zootechnics (e.g. pigling increase), in poultry (e.g. growth of chickens and turkeys - as artificial mother).

- Devices operating on LPG (liquefied petroleum gas) which can be used to small warehouses heating, well-ventilated garages and workshops, etc.

- Devices with large thermal power used in industrial halls, pavilions and semi-enclosed spaces heating.

## 2.2 Constructive Elements

The basic components of the system are usually suspended on the hall ceiling. The radiant body consists of two parallel tubes (Fig.3). The top tubes are surrounded by insulating screens in order to increase the radiation efficiency.

Infrared radiant tube casing has a special construction with the purpose of minimizing losses by convection.

Due to the tubes surface temperature a hot air area is formed inside the case. However, because the isolated protections stretch back to the lower edge of the tube, the hot air cannot escape, thus losses by convection are removed.

For the radiant tubes using as protective screen the standard solution, consisting of only one reflective panel without insulation and guidance, it is much easier for the hot air to be distributed to the hall upper part.

Losses by convection produce unwanted hot air under the ceiling and moreover the proportion of radiation is reduced. In the burning flame area one of the two radiant tubes is equipped with an internal heat-resistant insulation that provides uniform heat distribution along the whole length of the radiant tubes. Heat is radiated from the tubes surfaces in the environment without conducted energy.

## 2.3 The Combustion Group

The tubes are heated with a special burner with depression (Fig.4). The combustion group consists of: burner 1, combustion chamber 2, control switchboard 3, electrical control panel with temperature probe 4, tubulature for transporting the heat carrier fluid 5, tubulature for returning the heat carrier fluid 6, recirculation and exhaust gases fan 7, exhaust gases 8.

Fig.3. Basic components of a radiant system

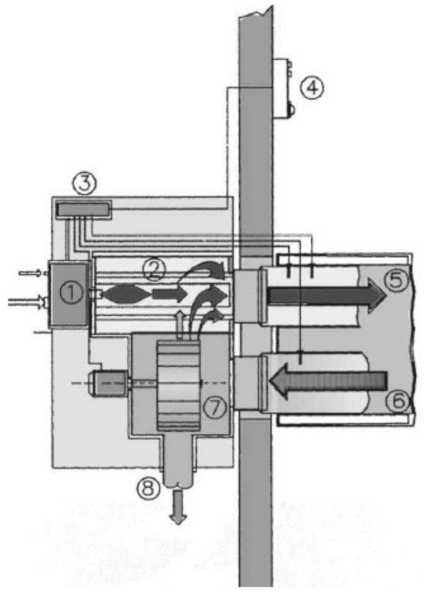


Fig.4. Combustion group

Inside the radiant tubes, the burner flame is produced by a particular burner and is held by depression. With depression burners a long flame can be produced which itself creates a temperature distribution. By a ceramic coating of different thickness, the temperature inside the tubes is evenly distributed throughout their length. For the radiation increase, the lower tube area has a special coating and through this inferior surface, the energy as radiation with long wavelength is transmitted to the hall. Due to the compact construction of the radiant tubes casing, which prevents convection losses, higher radiation efficiency can be achieved.

By using depression burners a long flame can be produced which itself creates a uniform temperature distribution that determine the mixture of recirculated flue gas (at low temperature) with the newer gases produced by combustion (Fig.5).

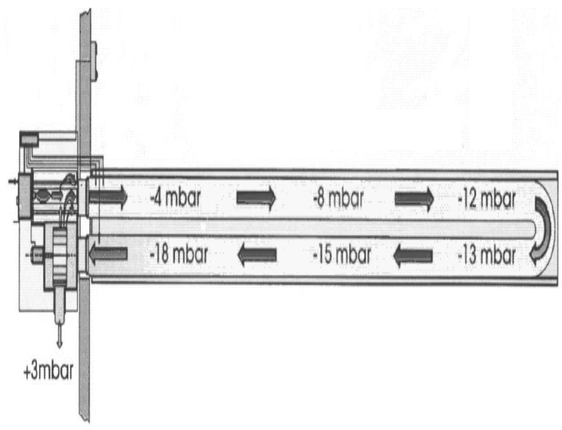


Fig.5. Flue gases forced circulation

The temperature control is achieved with a command and control system that allows day/night and weekly programming, being equipped with a digital clock, thermostats, remote locking, manual/automatic switch.

The most complex systems allow fully automatic process control, bus network data transmission, monitoring display, data and temperatures storage, and optionally modem connections, remote computer maintenance and graphic display of stored data.

## 3 Radiant Tubes Efficiency

Infrared heating systems operate the same way as the sun. The sun is the best example to explain and understand the propagation of caloric radiation and the created warm sensation. In the solar radiation area, the warm sensation depends only partially on the actual air temperature. Everyone knows it and this is exactly the operating principle of a device with radiant tubes.

For heating large spaces, systems with radiant tubes use long-wave radiation that produces a very pleasant sensation. The covered areas are heated by radiation and not by convection. The air in the hall is heated only indirectly through the floor and other solids heated surfaces.

Long wave heat radiation creates the sensation of temperature higher than the real air temperature that surrounds the human body. The temperature of the hall heated by radiation is determined by the heat transmitted from the floor. [10]

The concentration of hot air under the ceiling will be avoided. Radiant heat is maintained even when the doors are opened and due to the lack of air movement the dust will not rise up.

Personnel and equipment, goods or vehicles, floors or walls, are heated by wavelength rays and transmit the heat to the environment.

Indirect heating has a result in uniform temperature distribution. At the ceiling level the temperature is only slightly higher than the one from the ground level.

The radiant tubes efficiency is due to the fact that heat radiation penetrates the air almost without resistance. The radiation does not become effective before reaching any solids.

Due to the direct transmission of heat, radiation is reaching even from greater heights in the area where the staffs are.

Energy savings in case of heating by radiation compared with hot air heating has two sources of origin:

- A lower calculated temperature value of the indoor air;
- A lower value of the temperature gradient for the vertical spreading case.

Both aspects determine energy consumption savings for the heating by radiation case, because the difference between indoor and outdoor air temperature is lower. Technical literature indicates that heating by radiation leads to energy consumption savings if the installation operates at optimum parameters. Obviously it results that heating by radiation can be designed for lower values of the installed thermal power compared to hot air and convective heating.

Another important aspect of heating by radiation is that it has lower thermal inertia in comparison with hot air heating.

Other domain of application is the protection of materials against freezing such as: maintaining a certain temperature of foundry sand, frost protection of dosing bunkers entrances of concrete preparation stations, setting and reinforcing of poured concrete, heating compensation or frost protection in greenhouses, the technological process of drying the agricultural products, etc.

Heating by radiation is used for drying technological processes in textile and cellulose industry because of their ability to provide a wide range of the heat flow by using quantitative adjustment of gas-air and the possibility of its automatic adjustment.

## 4 The Heating System Design for an Industrial Hall with the SP IT Systema Software

### 4.1. The Constructive Solution Generated by Systema SP IT Software

The industrial hall is average isolated with length x width x height dimensions: 50x20x8 meters; the external temperature $t_{ext}$ = $-5°C$, the internal temperature $t_{int}$ = $16°C$, the number of air exchanges per hour <0.5 (Fig.6). [1]

Data regarding the construction geometric dimensions, construction materials, climatic conditions, system operation period, type of developed activity, the necessary of air exchanges per hour according to the space purpose, the degree of sunlight, the fuel unit price, the equipment price (from the equipment suppliers databases), mounting height, fuel type are all inserted (Fig.7). The heating system type is chosen. [1]

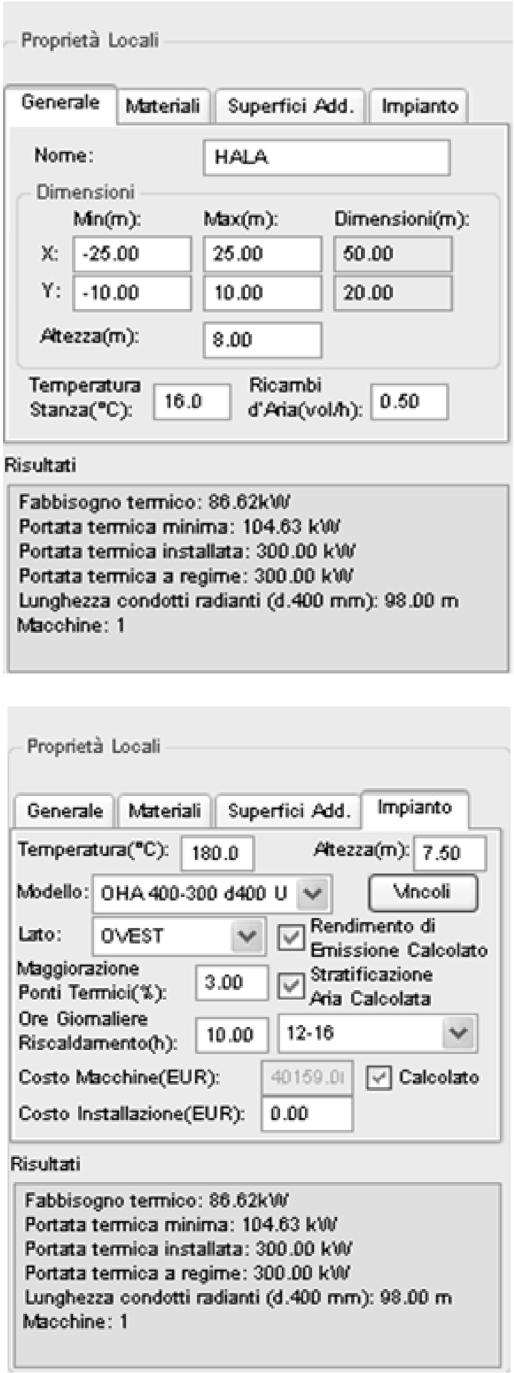


Fig.6. Local properties input data

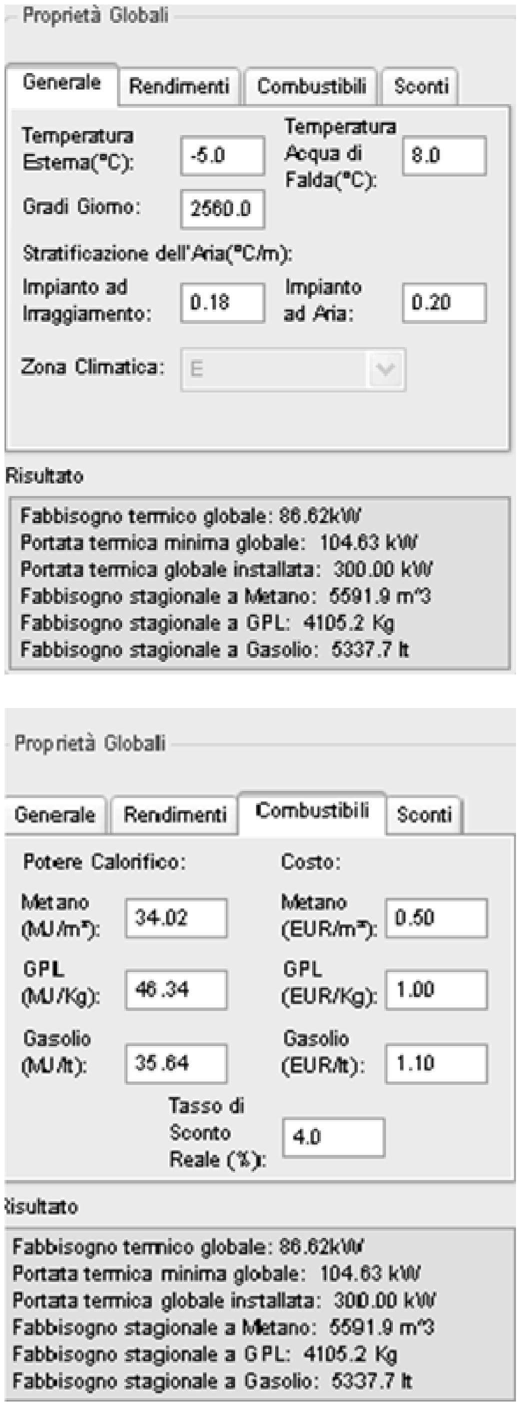


Fig.7. Global properties input data

Following the calculations, will result the design heating solution (Fig.8)

The installation assembling was achieved according to the constructive solution generated by the computation program (Fig.9).

Computer program is running on heat loss calculation and the geometric arrangement of the radiating pipe:

a) Verification on heat loss calculation is done using the relations:

$$\dot{Q} = k \cdot S \cdot \Delta T$$

$$\dot{Q} = \dot{m} \cdot c \cdot \Delta T$$

$$\dot{Q}_{nec} = \dot{Q}_T + \dot{Q}_i$$

b) Verification based on geometric arrangement of the pipe radiant (Fig.10).

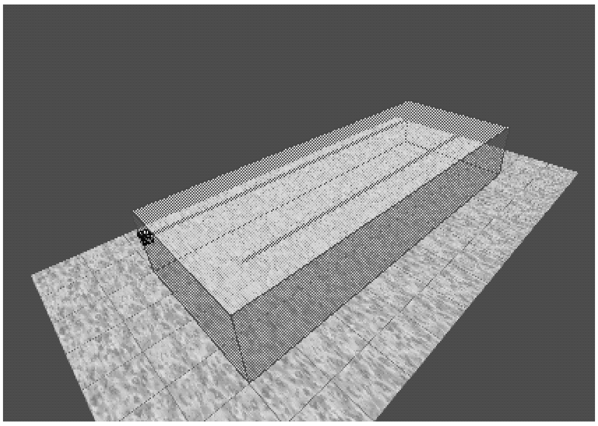

Fig.8. Presentation in 3D of the designed heating solution (Type U system)

Fig.9. The radiant tubes layout on the metallic structure

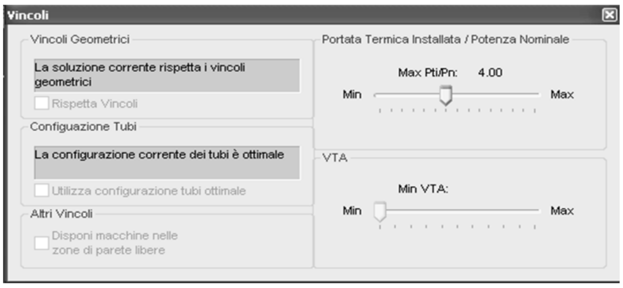


Fig.10. Heating system displacement verification

### 4.2. Operation with Petroleum Fuels for Radiant Tubes Heating

The design software allows choosing the following fuels:

- Methane;
- Gasoline;
- LPG.

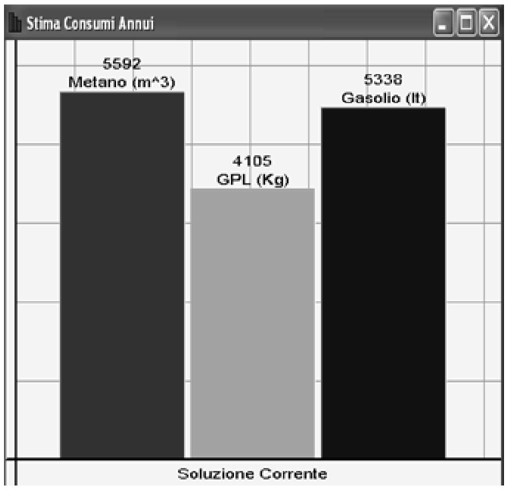


Fig.11. Annual consumption estimation for the three types of fuel

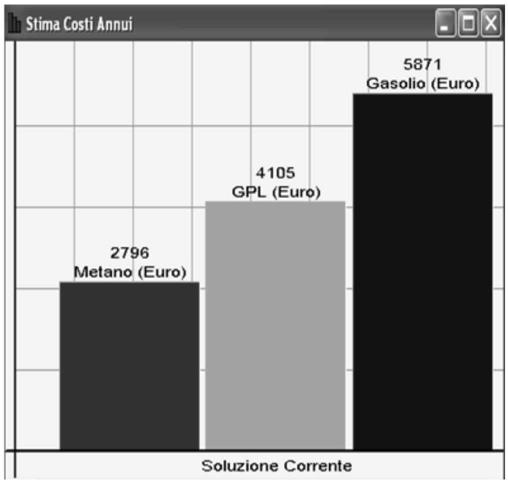


Fig.12. Annual costs estimation for the three types of fuel

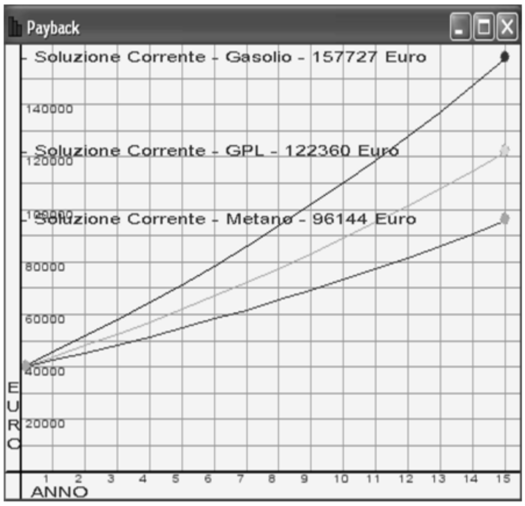


Fig.13. Economy comparative estimation by using the three fuel types

By using this software, a comparative study based on the used fuel, both in terms of annual fuel consumption and annual cost (Fig.11 and Fig.12) together with comparative economy estimation (Fig.13) can be performed. [11]

As a result of the installation operation for a period of 15 years, the use of methane leads to an economy of 26216 Euro. From the comparative study regarding the tree fuels used into the heating system (methane, LPG, gasoline), it can be observed that from the cost point of view methane is most recommended, and from the consumption point of view LPG is recommended.

### 4.3. Operation with solid fuels (pellets) for Radiant Tubes Heating

The ecological solution for conventional thermal systems is achieved by introducing an innovative heating process system using granular biomass burning as pellet (Fig.14). [7]

Radiant tube burners are designed for burning granular biomass as pellets and transforming the thermal energy in infrared radiations through radiant tubes and reflector, accomplishing a heating mode similar by the one given by the sun.

Burning process is completel, without smoke, soot and creosote deposition (tar) and is accomplished in an automatic operation mode, which made possible the use of burners to transmit thermal energy required by radiant tubes. The radiant tubes can be designed in a wide range of powers and configurations.

The optimum operating temperatures of radiant tubes is *550°C* at entrance and *200°C* at exit, temperatures measured on the radiant tubes external surfaces. In this case the exhaust gases temperature is equal to *250°C*. At the tube entrance, the temperature of the flue gases is about *900°C*. The exit temperature can be further recovered to a value up to *100ºC* by plugging a heat exchanger into the system and can be reused to heat related facilities, for example water or soil of a greenhouse.

Pellets are solid fuels with low moisture content, obtained from sawdust, wood chips, bark and other waste wood (are 100% produced from natural materials). For their production also can be used as raw materials various agricultural waste of low quality as straw, green plants as energy grass, energy willow, energy reed, etc. These materials are chopped to obtain a fine grain and are pressed at high pressure without binders added. Resins and binders (lignin) naturally existing in the sawdust pellets keep the pellets compact and therefore they do not contain additives.

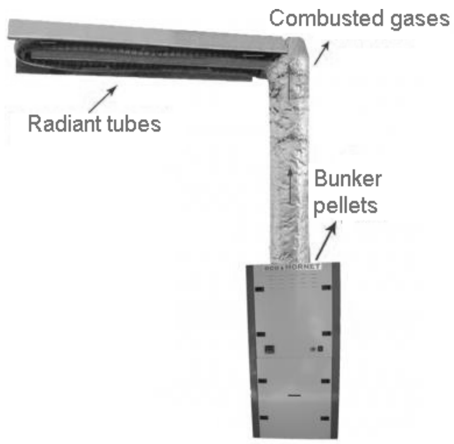


Fig.14. Heating installation with radiant tubes using pellets as fuel

During combustion pellets are emitting the quantity of $CO_2$ that was stored by plants from which they are made, so one can say that they are neutral in terms of $CO_2$ and do not contribute to increase the harmful gases quantity in the atmosphere or the greenhouse effect. The advantage is that they are inexhaustible, being a renewable energy source and by using this type of fuel, the following advantages result:

- Low costs for system installation, a funnel construction being unnecessary;
- Thermal energy production with minimum pollutant emissions;
- Small spaces for their storage;
- The combustion air is feded from outside;
- Complete automatization;
- Constant high efficiency during the whole operating period (94% minimum);
- The reduction of heating costs with at least 30%.
- 100% organic, complete burning process, without smoke and the quantity of $CO_2$ is equal to the one inhalated by a tree during its lifetime.
- Cost of heating with pellets is up to 60% lower than petroleum products cost and at least 40% lower than the electric energy (ex. 1 pellet bag (15 kg) = 8 $m^3$ gas = 35 kg wood). [8]

## 5 Verification of the Radiant Tubes Heating Installation Emissions

### 5.1 Presentation of the Gas Analyzer

The emission verification of the radiant tubes heating installation was achieved by measuring these emissions with Testo 350 S gas analyzer (Fig.15). [6]

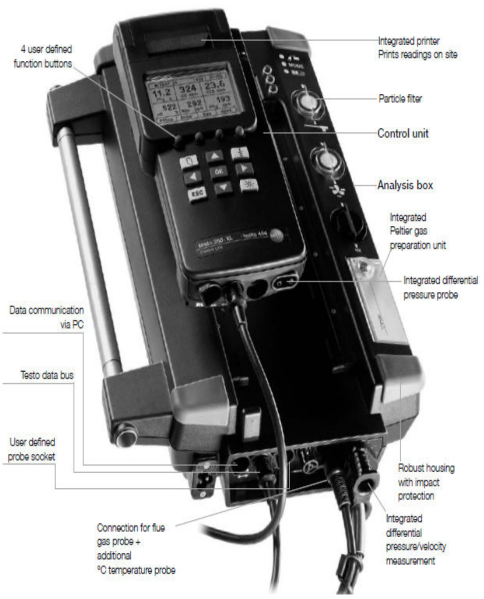


Fig.15. Testo 350 S gas analyzer

By using Testo 350 S gas analyzer, very precise measurements results of the exhaust gases can be obtained due to electrochemical properties of high precision sensors.

The Testo 350 S is used for the following basic applications:

- The verification/configuration of the industrial combustion installations (process systems, thermo power plants);
- Emissions verification and their framing in environmental protection standards and norms during reparing/asambling boilers/combustors in the industrial sector;
- Measurements of any type of turbines/engines.

Testo 350 S is a flexible, portable analysis system which is basically made up of a control unit, a flue gas analyzer and a flue gas probe, depending on customer requirements.

The detachable control unit can control the analysis system and read out data. The Testo 350 S control unit can also be used as a separate handhold analyzer for differential pressure (built-in) and also for temperature, humidity, flow, etc. thanks to its additional probe socket. Readings are printed on the built-in printer.

The flue gas analyzer is the "heart" of the analysis system and is available in two different versions: Testo 350 S Basic version and XL Advanced version.

The Testo 350 S flue gas analyzer is equipped with a measuring module for $O_2$ as standard. One measuring module must be fitted or up to 5 additional measuring modules for NO (option), $NO_2$ (option), $SO_2$ (option), $NO_{low}$ (option), CO (option) or $CO_2$ via infrared measuring module (option) can be fitted. Temperature and differential pressure as well as the usual parameters such as $\Delta$, $qA$, etc. are also calculated.

The flue gas analyzer can be equipped with up to 6 measuring modules, have a built-in rechargeable battery as standard, (for battery operation), data logger (25000 readings ) as well as Testo data by connection (Fig.15). [6]

## 5.2 Computation Relations

The calculation relations, based on which the analyzer gives the final values, are: [5]

The carbon dioxide:

$$CO_2 = \frac{CO_{2max} \cdot \left(O_{2ref} - O_2\right)}{O_{2ref}}$$

$CO_{2max}$ – the $CO_2$ maximum specific value of the fuel

$O_{2ref}$ – the $O_2$ reference value

$O_2$ – the oxygen content, measured in %

Flue gas losses:

$$qA = \left[\left(t_g - t_a\right) \cdot \left(\frac{A_2}{O_{2ref} - O_2} + B\right)\right] - C_c$$

$t_g$ – the gas temperature

$t_a$ – the ambient air temperature

$A_2$, $B$ – specific parameters

$C_c$ – the calculated value considering the condensing heat recovered when the dew point is inferior (for condensation power stations)

If the gas specific parameters $A_2$ and $B$ are equal to zero, $qA$ is calculated using Sieger formula:

$$qA = f \cdot \frac{\left(t_g - t_a\right)}{CO_2}$$

$f$ – the specific parameter

$CO_2$ – the calculated content of $CO_2$

The efficiency:

$$\eta = 100 - qA$$

$qA$ – gas losses

The air excess coefficient:

$$\lambda = \frac{CO_{2max}}{CO_2}$$

The nitrogen oxides relations:
The cell of $NO_2$ is not installed:

$$NO_x = NO + \left(NO_{2add} \cdot NO\right)$$

The cell of $NO_2$ is installed:

$$NO_x = NO + NO_2$$

*NO* – the measured value of nitrogen monoxide
$NO_{2add}$ – the additional factor of $NO_2$

The undiluted carbon monoxide:

$$CO_{undiluted} = CO \cdot \lambda$$

$CO_{undiluted}$ – the undiluted carbon monoxide
*CO* – the measured value of carbon monoxide
*λ* – the calculated air excess coefficient

The gas dew point:

$$td = \frac{ln\left(\dfrac{f_{H_2O} \cdot p_{abs}}{610{,}78}\right) \cdot 234{,}175}{ln\left(\dfrac{f_{H_2O} \cdot p_{abs}}{610{,}78}\right) - 17{,}08085}$$

$f_{H2O}$ – the specific factor of vapours content, vol %
$p_{abs}$ – the absolute pressure, *mbar/hPa*

The gas speed:

$$v = \frac{\sqrt{75 \cdot \Delta p \cdot \left(t_g + 273.15\right) \cdot \alpha}}{p_{abs}}$$

*Δp* – the gas temperature
*α* – the factor of Pitot tube

The volumetric flow:

$$V = v \cdot A$$

*v* – the gas speed
*A* – section area

The CO mass flow:

$$MCO = CO\left[kg/h\right]\left[ppm\right] \cdot f_{gaz} \cdot 1.25\left[kg/m^3\right] \cdot Z$$

The $NO_x$ mass flow:

$$MNO_x = NO_x\left[kg/h\right]\left[ppm\right] \cdot f_{gaz} \cdot 2.05\left[kg/m^3\right] \cdot Z$$

The $SO_2$ mass flow:

$$MSO_2 = SO_2\left[kg/h\right]\left[ppm\right] \cdot f_{gaz} \cdot 2.86\left[kg/m^3\right] \cdot Z$$

$f_{gas}$ – the humidity specific
*t* – the dew point
*Z* – calculation term

The calculation term:

$$Z = \frac{273.15 \cdot p_{abs}\left[mbar\right]}{273.15 + t\left[^\circ C\right] \cdot 1013} \cdot V\left[m^3/s\right] \cdot 10^{-6}\left[1/ppm\right] \cdot 3600$$

## 5.3 Experimental Results

The registration of the burned gas emissions resulting from the combustion of natural gas burnt into the radiant tubes heating installation was accomplished. [1]

As a result of the measurements it can be observed that the value of 6.54% CO2 is placed into the admitted limits.

Although the NOx value slightly overtakes the admitted value, it can be observed that from the heating instalation efficiency point of view, a higher value is obtained (Fig.16).

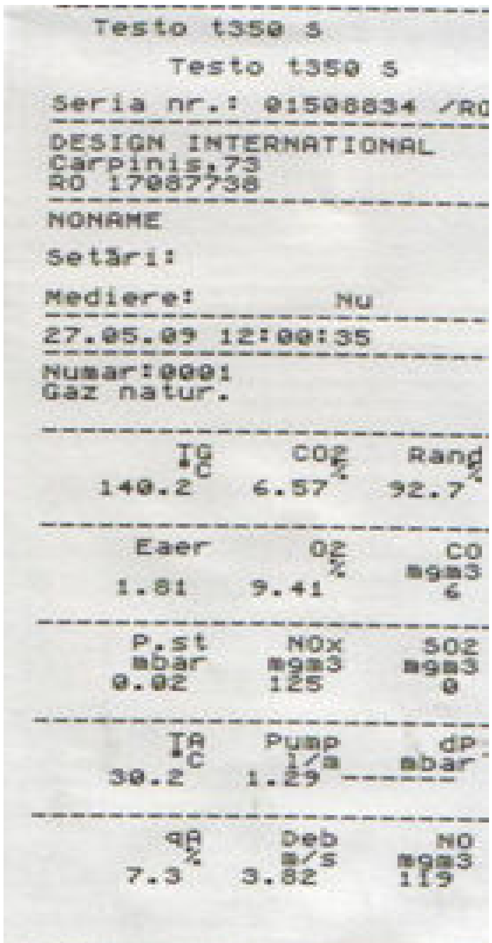


Fig.16. Emission measurements

# 6 Conclusion

Infrared radiation is propagating in a straight line as light, so it travels through the air without losses, heating the solids surface which is in contact with.

In the thermal radiation area the body temperature is with 40*°C* higher than the air temperature. [3], [4]

Knowing this effect, the following conclusions are resulting:

- To achieve the same thermal comfort fuel and energy consumptions are much lower than for the convective heating case.
- Vertical temperature variation is very small; the floors, walls, bodies from the working area become radiant elements of low intensity which are warming the air.
- Due to the lack of training air, heating systems inertia using thermal radiation is very small so it leads to less power consumption and to reach the nominal operating conditions within a short period of time.
- Heating elements are simple, light, modulated, requiring a reduced time for installation.
- Lack of thermal fluid increases the heating elements safety to frost.
- Dust and suspention particles are not airborne, due to minimal air movement.
- Due to the specific elements design, if it is necessary the sector by sector heating of large halls can be achieved.
- As the elements are modulated, the configuration of the heating system is achieved according to beneficiary needs.

The disadvantages of radiant tube heating systems are:

- The safe distance from flamable substances and elements must strictly be respected.
- Imposibility of elements mounting at less than 2.2*m* heights from ground.
- The interdiction to use heating elements in flammable spaces. [4]

As a result of the installation operation for a period of 15 years, the use of methane leads to an economy of 26216 Euro (Fig.13). From the comparative study regarding the tree fuels used into the heating system (methane, LPG, gasoline), it can be observed that from the cost point of view methane is most recommended, and from the consumption point of view LPG is recommended.

Within the EU there is an increasing trend in the use of biofuels in all industrial fields as a solution for the future. An alternative of biofuel in radiant tube heating systems is using the pellets of biomass.

Annual production of pellets in Romania amounted to 10 million tonnes, of which more than 95% are exported to Western countries.

For this reason, the use of these fuels in heating systems is an advantageous solution in terms of economics and efficiency to be implemented in our country.

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