EXERGY EFFICIENCY OF PANEL HEATING SYSTEMS AT DIFFERENT HEAT SOURCE

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Abstract: This paper aims to compare the exergy efficiency of panel heating system using different energy sources. Natural gas and geothermal heat pump are used as energy sources. Floor panels, wall panels, ceiling panels, and floor-ceiling panels are used as panel heating systems. The analysed house is located in Kragujevac, Serbia. Also, this research is the part of the project "Development of a net-zero-energy house“. The operation of these panels is simulated by software EnergyPlus that is product of Lawrence Berkley Laboratory in USA.

Keywords: exergy efficiency, radiant panel, heat pump, energy consumption, EnergyPlus, ground heat source.

1. INTRODUCTION

In Serbia today, the panel heating systems are increasingly using. The reason for their increasing use is accessible price panel. However, as panel heating systems work with low-temperature of fluids the requirements are set for the proper choice of the heat generator. Today, due to the low investment rates beneficiaries of panel systems usually choose the use of gas boilers. On the other hand, energy-educated people without thinking of decide for a GSHP system. To better understand the effectiveness of the panel heating systems in addition to the analysis of energy flow the exergy analysis must be included.

Exergy analysis is an important tool to determine how efficient thermal systems can be designed or in other words it can reveal unavoidable thermal inefficiencies of the system [1]. There are a lot of papers published on the topic of exergy GSHP devices.

Piechowski [2] studied a relatively new approach to optimisation of a ground heat exchanger (GHE), based on the second law of thermodynamics and was adopted to test for an optimum combination of circulating water flow rate and pipe diameter. Hepbasli and Akdemir [3] described energy and exergy analysis of a GCHP system. The exergy transports between the components and the consumptions in each of the components of the GCHP system were determined for the average measured parameters obtained from the experimental results. Lohani and Schmidt [4] are compared different heat generators with aspect of the energy and exergy analyses. They concluded that the the ground source heat pump heating system is better than air source heat pump or conventional heating system . Hepbasli [5] conducted the thermodynamic analysis of a GSHP system for district heating in terms of both energy and exergy analysis, which aimed at improving the process efficiency. Kharseh et al [6] are investigated the effects of global warning on the GSHP performance. They show that the on-going climatic change has significant impact on GSHP systems.

Some studies are devoted to investigation of performance of panel systems in different heating systems inside the building. Kilkis B [7] showed that optimal operation of radiant panels with ground-source heat pumps driven by renewable energy sources improves the

exergy efficiency and primary energy ratio. Kosir M. et al. [8] applied the low-temperature radiant systems in combination with localized automated ventilation in a museum in Ljubljana, Slovenia. Using this solution with building management system, the energy demand was reduced for heating and cooling by 60.5%. Bojic et al [9] compared wall heating system and radiators connected on non-condensing natural gas boiler.
Also this study is continuation of previous research of Bojic et al [10]. They are compared for different panel heating system (floor, wall, ceiling and floor-ceiling) connected on natural gas boiler.

The aim of this paper is to exergy analysis shows benefits by using low-temperature sources in panel systems. Natural gas boiler and GSHP were chosen because they represent two typical representatives' high-temperature sources and low-temperature, respectively. As panel systems floor heating, wall heating, ceiling heating and newly developed concept floor-ceiling heating were used [10].

2. MATHEMATICAL MODEL

2.1 Building description

The analysed building is a residential family house shown in Figure 1. The house is designed for one family and has a living area of 190 m^2. The envelope of the house is made of 190 mm porous brick, 50 mm thermal insulating layer and 20 mm lime mortar. The U-value is 0,57W/ (m^2K). The windows are double glazed with U-value of 2.72 W/ (m^2K). The overall ratio of glass to the exterior walls is 7.32%, where the total area of exterior walls is 264 m^2 and area of windows 19 m^2.

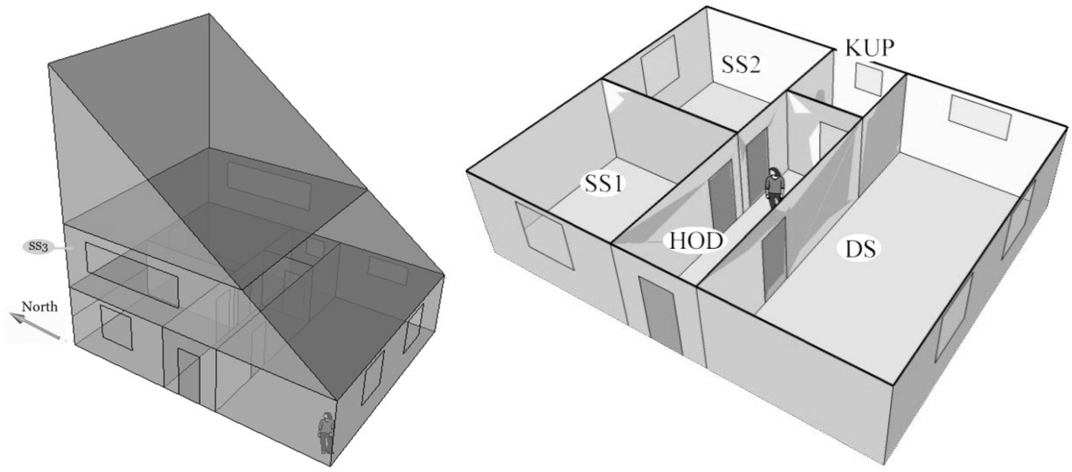

Figure 1 Analyzed building
Here, DS – living room, HOD – hallway, KUP – bathroom, SS1 – bedroom, SS2 – bedroom, SS3 – bedroom.

The analyzed house is located in Kragujevac, Serbia. The elevation of Kragujevac is 209 m, and its latitude and longitude are 44^{o}N and 20^{o}55E. The city has a continental temperate climate with four different seasons (summer, autumn, winter, and spring). As part of the EnergyPlus, weather file used as an epw file generated by the Meteonorm [11]. The heating season runs in Kragujevac from 15 October to 15 April [12].

2.2 Description of heating systems

The used heating systems are consisting of heating panels and heat generator. Four systems are investigated. The first heating system represents the floor heating. The second heating system represents the wall panel heating. The third heating system represents the ceiling heating. The fourth heating system represents the floor-ceiling heating. The floor heating panel has the total surface area of 190 m^2. The wall heating panel is located at the external wall. Its total surface area is 210 m^2. The ceiling heating panel is located at the ceiling of the first and second storey of the house. Its total surface area is 190 m^2. The floor-ceiling heating panel operates as a ceiling heating of the lower story, and as a floor heating of the upper story. Its total surface area is 95 m^2.

The main component of the heating panels is the pipe where the hot water flows. The hot water inlet temperature has the same value of 37^{o}C for all heating systems. The water circulation pump uses electricity to operate. This is taken into account to calculate the primary energy consumption.

As a heat generator natural gas boiler and ground source heat pump (GSHP). For all four heating panels the power of natural gas boiler was 24 kW. The nominal electricity input of GSHP was 4 kW. Also, length of geothermal probe was 76m with two U-pipe.

2.3 Primary energy consumption of heating system

The primary energy consumption per heating season of the analyzed house is calculated by using the following equation:

$$E_{\mathrm{sys}} = E_{\mathrm{ng}} + R\,E_{\mathrm{el}} \qquad (1)$$

or

$$E_{\mathrm{sys}} = R\,E_{\mathrm{el}} \qquad (2)$$

Equation (1) refers to the system with a natural gas boiler, and the equation (2) refers to the heating system with GSHP unit.

Here, E_{ng} stands for the consumption of natural gas per heating season, E_{el} stands for the consumption of electricity per heating season and R stands for the primary energy consumption coefficient. This coefficient defined as the ratio of the total input energy of energy resources (hydro, coal, oil and natural gas) and the finally produced electric energy. Its value for the Serbian energy mix for electrical energy production is R = 3.01 [13].

2.4. Consumed exergy

The consumed exergy by the analyzed heating panels is calculated by using the following equation:

$$Ex_{cons} = \sum_{i}^{n} Ex_{cons_i} = \sum_{1}^{n=6}\left(1 - \frac{T_o}{\left(\frac{T_{in_i} - T_{ret_i}}{2}\right)}\right)E_{h,t} \qquad (3)$$

Here, n stands for the number of heating rooms, T_o stands for the reference temperature, T_{ini} and T_{reti} stands for the inlet and return temperatures of heating emission panels in the observed room, $E_{h,t}$ - transferred heat from the panels.

2.4 Destroyed exergy

The destroyed exergy presents exergy supplied by natural gas to the boiler through combustion. This term is calculated using the following equation:

$$Ex_{dest} = (1-T_o/T_f)E_{h,s} \tag{4}$$

Here, T_f stands for the temperature of heat source, (combustion temperature for natural gas, T_f = 2000 K [7], average fluid temperature from ground exchanger T_f = 283.03 K), $E_{h,s}$ – transferred energy from heat source.

2.6 Exergy efficiency of heat transfer

A value of exergy efficiency of heat transfer between the boiler and the heating panels is calculated by using the following equation:

$$Y_R = Ex_{dest}/Ex_{sup} \tag{5}$$

3. RESULTS AND DISCUSSION

For a better understanding of the flow exergy on the figure 3 and 4 the final and primary energy consumption are shown.
Comparing used panel systems Fig. 3, floor-ceiling heating has the lowest consumption of final energy. The consumption of the floor-ceiling panels connected with natural gas boiler and GSHP was 48 kWh/m^{2}a and 20 kWh/m^{2}a, respectively. On the other hand the classical ceiling heating has the highest consumption of final energy 104 kWh/m^{2}a and 45 kWh/m^{2}a for natural gas boiler and GSHP, respectively.

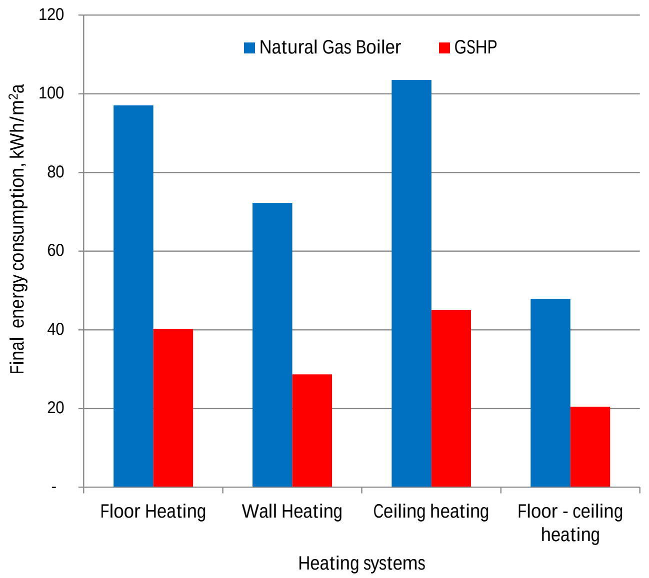

Figure 3. The final energy consumption of heating panel system connected on natural gas boiler and GSHP

Figure 4 shows the primary energy consumption of four observed panel heating systems. The ratio of primary energy consumption among the four analyzed panel heating systems remained the same. However, as a result of higher primary energy conversion factors for electricity from National grid (R = 3.01) primary energy consumption of panel heating systems connected to the heat pump will be higher than the panel heating systems connected to the natural gas boiler. As at the final energy the floor-ceiling panel heating system least consuming of energy, 54 kWh/m^{2}a for the system connected to the natural gas boiler and 63 kWh/m^{2}a for the floor-ceiling heating system connected. Also, classic ceiling heating consumes the most energy 115 kWh/m^{2}a for system connected to the natural gas boiler and 137 kWh/m^{2}a for the system connected to the GSHP.

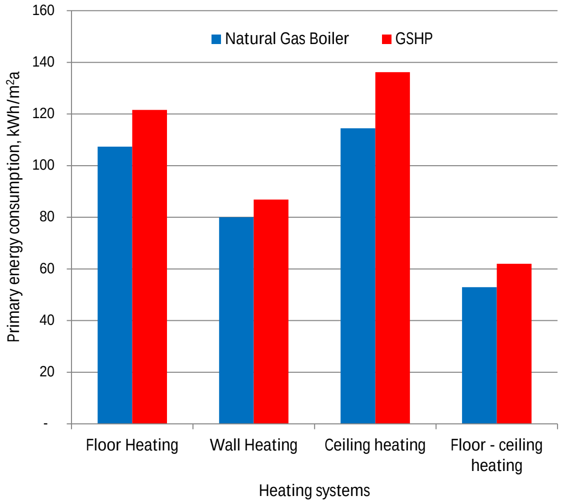

Figure 4. The primary energy consumption of heating panel system connected on natural gas boiler and GSHP

Figure 5 shows the exergy consumption of four observed panel heating systems. Proportional to the energy consumption among comparison panels the exist relations in exergy consumption. The floor-ceiling panel has the lowest exergy consumption, 0.69 GJ for the system connected to the natural gas boiler and 0.73 GJ for the system connected to the GSHP. Also, the classic ceiling heating system has the highest exergy consumption, and it is 5.1 GJ for the system connected to the natural gas boiler and 1.8 GJ for the system connected to the GSHP.

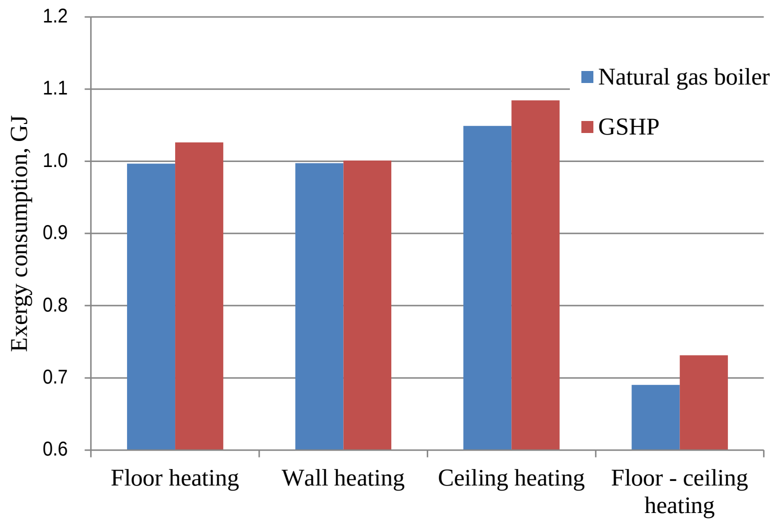

Figure 5. The exergy consumption of heating panel system connected on natural gas boiler and GSHP

Figure 6 shows the amount of exergy destroyed in the gas boiler (top figure) and GSHP (lower figure). It is obvious that much more exergy destroyed during combustion of natural gas in the boiler than for operation of the GSHP. In both cases, the floor-ceiling panels are destroyed the least exergy, 5.81 GJ for the system connected to the natural gas boiler and 0.09 GJ for the system connected to the GSHP. Also, the most exergy is destroyed at the classical ceiling panels, 12.68 GJ for the system connected to the natural gas boiler and 0.11 for the system connected to the GSHP.

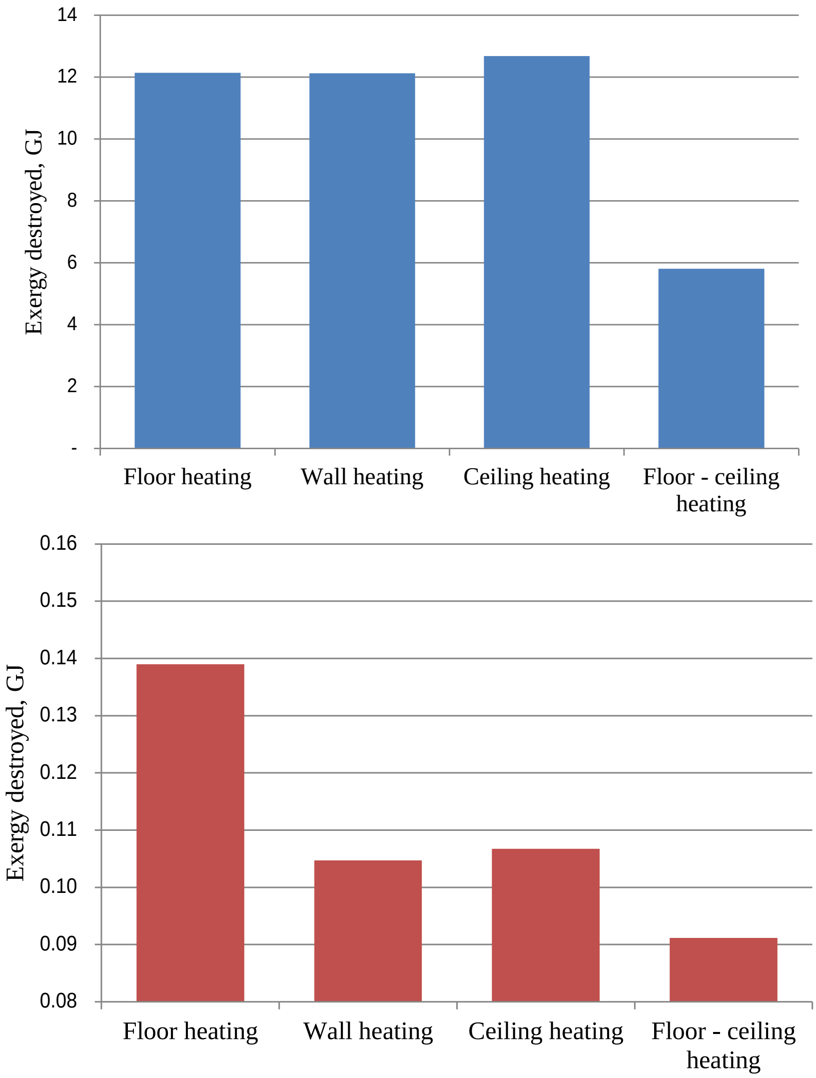

Figure 6. The exergy destroyed of heating panel system connected on natural gas boiler (above) or GSHP (below)

Figure 7 shows the exergy efficiency of panel heating systems connected to the boiler (top figure) or a GSHP (bottom figure). The exergy efficiency actually poses a mismatch between consumed and destroyed exergy. Less disagreement will provide higher efficiency and vice versa. As with combustion of natural gas in the boiler spent far more the amount of exergy than the GSHP the level of exergy efficiency will be much lower for panel system equipped with natural gas boiler. In panel systems connected to the natural gas boiler the floor-ceiling heating is the most exergy effective 0.0118 while the other three systems has approximately the same efficiency of about 0.082.

When it comes to panel systems connected to the GSHP that exergy efficiency values are much higher, 10.16 for classical ceiling heating, 8.02 to floor-ceiling heating, 7.38 for floor heating and 9.56 for the wall heating. Of course, this is due to the smaller differences between consumed and destroyed exergy.

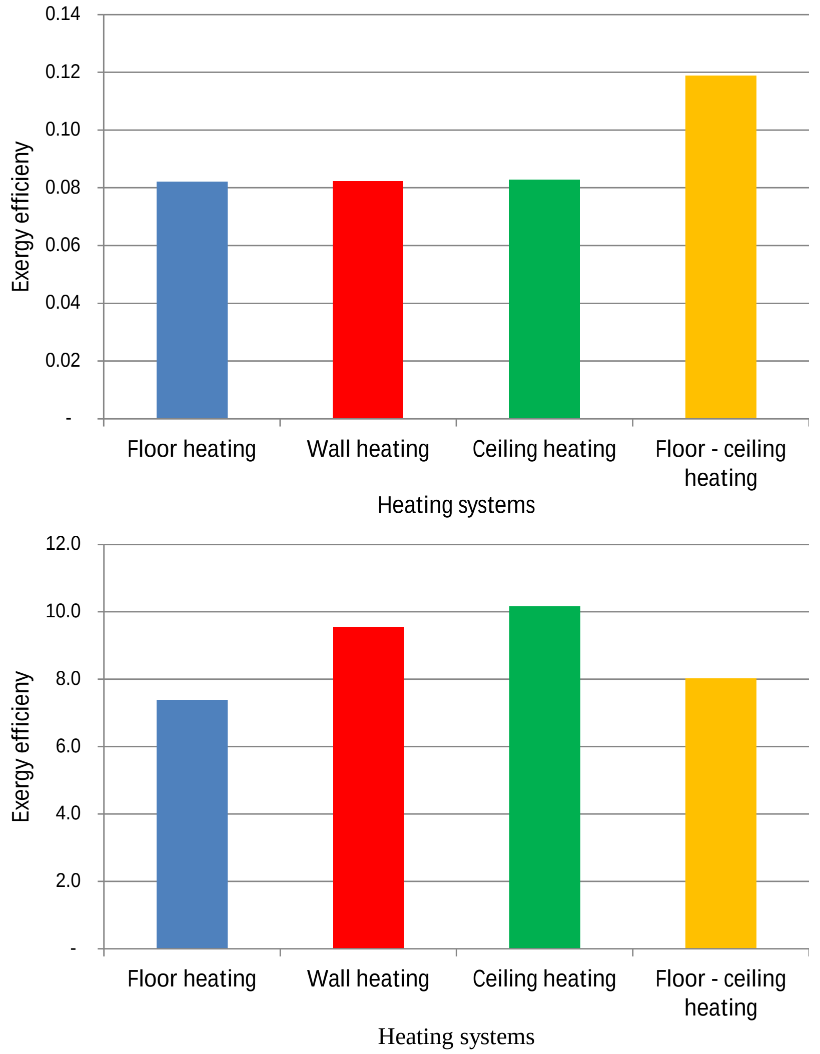

Figure 7. The exergy efficiency of heating panel system connected on natural gas boiler (above) or GSHP (below)

Conclusions

In this paper the exergy analysis of panel heating systems are shown. As a panel heating systems the floor heating, wall heating, ceiling heating and floor-ceiling heating are used. As heat generators two most commonly used devices are elected: the natural gas boiler, and the geothermal heat pump.

To compare the spent energy of panel systems the floor-ceiling panels has the minimum requirements for the amount of energy, while the classical ceiling panels have the highest requirements. Also, the same ratio holds for the required amount of exergy. If it compares the heat sources, the gas boilers use more final energy then the GSHP. However, due the high transformation factor of primary energy from the power grid the GSHP require more primary energy.

When considering exergy consumption of analyzed panel heating systems, the exergy consumption is slightly higher for the panel systems connected to the GSHP. However, drastic differences occur in quantity exergy that is destroyed in generating heat. It is much higher for the panel systems connected to the natural gas boiler. Of course this is due to the high temperature combustion of natural gas. In addition, the level of exergy efficiency is much higher for the panel systems connected to the GSHP $\Psi = 7.38$ to 10.16.

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