POBOLJŠANJE ENERGETSKE EFIKASNOSTI GREJNIH SISTEMA KORIŠĆENJEM GSHP I FOTONAPONSKIH PANELA

IMPROVING ENERGY EFFICIENCY OF PANEL HEATING SYSTEMS USING GSHP AND PV PANELS

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U Srbiji se sve više koriste panelni sistemi za grejanje. Iako se zna da ovi sistemi mogu da rade sa izvorom toplote znatno niže temperature, zbog većih troškova ulaganja korisnici biraju gas ili električnu energiju kao izvor toplote za ove sisteme. Cilj ove studije jeste da pokaže stvarnu uštedu korišćenjem GHSP i PV panela u panelnim sistemima za grejanje. PV paneli se koriste za snabdevanje GHSP električnom energijom. Analizirana kuća se nalazi u Kragujevcu, Srbija. Takođe, ovo istraživanje je deo projekta „Razvoj neto nulte energetske kuće“. Rad ovih panela simulira softver EnergyPlus, koji je proizvod laboratorije „Lawrence Berkley Laboratory“ iz SAD.

Ključne reči*: zračeći panel; toplotna pumpa; fotonaponski (PV) paneli; potrošnja energije; EnergyPlus*

In Serbia is increasingly using of panel heating systems. Although it is well known that these systems can operate at much lower temperature heat source, due to the high investment customers are opting for gas or electricity as a heat source in these systems. The aim of this study is to demonstrate the actual savings using the GHSP and PV panels in panel heating systems. The PV panels are used for supplying of GHSP with electricity. 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.

Key words*: radiant panel; heat pump; PV panels; energy consumption; EnergyPlus*

1. INTRODUCTION

In Serbia even today, low temperature panel heating system for residential buildings are increasingly used. Reason for this is the cheapening price of installing the panels. But the price of low-temperature heat generator is still high. For this reason, the panel systems in Serbia are mainly connected to the gas boilers as a heat generator.

Some studies are devoted to investigation of performance of panel systems in different heating systems inside the building. Kilkis B [1] 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. [2] 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 [3] compared wall heating system and radiators connected on non-condensing natural gas boiler.

Various experimental and analytical studies have been undertaken on GSHP systems. Hepbasli [4] 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. Sankaranarayanan [5] simulated a hybrid ground source heat pump system in which supplemental heat rejecters were used together with the ground loop by using EnergyPlus. Salsbury and Diamond [6] validated the performance of a heating, ventilation, and air conditioning (HVAC) system using a simulation model. Kharseh et al [7] are investigated the effects of global warning on the GSHP performance. They show that the ongoing climatic change has significant impact on GSHP systems.
Also this study is continuation of previous research of Bojic et al [8]. They are compared for different panel heating system (floor, wall, ceiling and floor-ceiling) connected on natural gas boiler.

The objective of this paper is to investigate the possibility of improving energy efficiency of panel heating system using low-temperature source. The most commonly used gas boiler was compared with heat pump. As a heat source the heat pump is used ground source heat pump (GSHP). In order to decrease of primary energy consumption of GSHP coupling between GSHP and PV cells is also research.

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^{2}K). The windows are double glazed with U-value of 2.72 W/ (m^{2}K). 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.

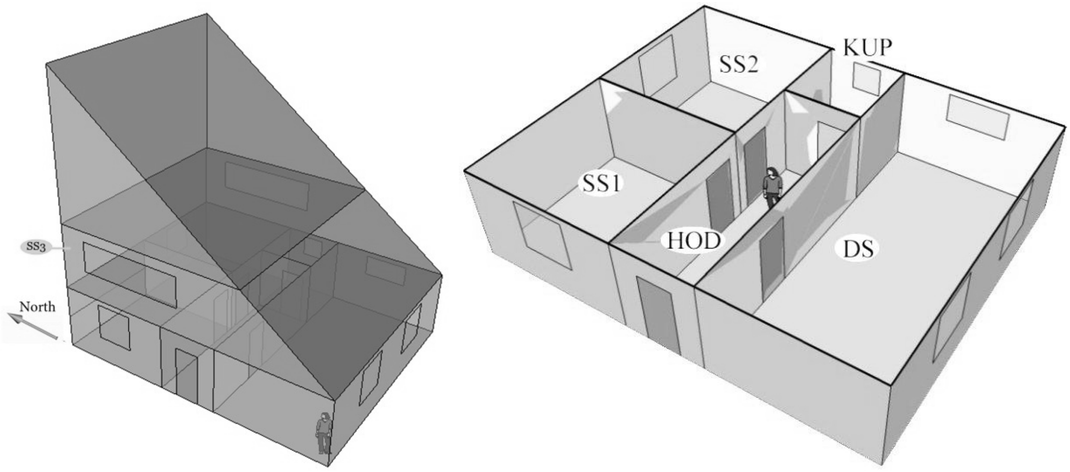

Figure 1 Analyzed building
Here, DS – living room, HOD – hallway, KUP – bathroom, SS1 – bedroom, SS2 – bedroom, SS3 – bedroom.

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 [9]. The heating season runs in Kragujevac from 15 October to 15 April [10].

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, ground source heat pump (GSHP), and GSHP connected with PV cells are used. 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. The monocrystalline PV cells are used where are of PV cells was 120m2.

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:

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

or

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

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 [11].

2.4 Total primary energy consumption of heating system

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

$$E_{tot} = E_{sys} + E_{emb} \quad (3)$$

Here, E_{emb} stands for the embodied energy of applied heat generator. The values of embodied energy are given in table 2.

2.5 The carbon dioxide emission of heating system

The carbon dioxide emission of heating system during a system operation is calculated by using the following equation:

$$S_{sys} = g_{ng} E_{ng} + g_{el} E_{el} \quad (4)$$

Here, g_{ng} stands for specific carbon dioxide emission factor of natural gas (kg/GJ), g_{el} stands for specific carbon dioxide emission factor of electrical energy (kg/GJ). The stands for emission factors g_{ng} and g_{el} are 56.1 and 206.53 respectively [11].

2.6 The total carbon dioxide emission

The total carbon dioxide emission per heating season of the analyzed house is calculated by using the following equation:

$$S_{tot} = S_{sys} + S_{emb} \quad (5)$$

Here, S_{emb} stands for the embodied carbon of applied heat generator. The values of embodied CO2 are given in table 2.

2.7 Operation cost of heating systems

The operation costs to run a heating system are calculated by using the following equation:

$$C_{sys} = f_{ng} E_{ng} + \mathrm{k}\, m_1 f_{el} E_{el}. \quad (6)$$

Here, f_{ng} stands for the specific cost of consumption of natural gas with energy value of 33338 kJ/m^3 (in €/GJ), and f_{el} stands for the specific cost of consumption of electrical energy (in €/GJ), k=1.068 stands for the coefficient of correction quantity of consumed natural gas and m_1 stands for the fixed monthly cost for meter reading [12]. In this equation, the fixed monthly cost for meter reading of electricity is not included. The cost factors are given in Table 1.

Table 1.The price of energy in Serbia in May 2011 [12]

Final energy	Class of consumption	Price
Electric energy	f_{el} for green tariff (<350 kWh)[1]	0.059 €/kWh
	f_{el} for blue tariff (351-1600 kWh)	0.089 €/kWh
	f_{el} for red tariff (>1601 kWh)	0.177 €/kWh
Natural gas	f_{ng}	0.45 €/m^3
	fixed monthly cost for meter reading m_1	0.012 €/month

[1]Monthly electricity consumption per house

2.8 The total operation cost of heating systems

The total operation costs to run a heating system are calculated by using the following equation:

$$C_{tot} = C_{sys} + C_{eq} \quad (7)$$

Here, C_{eq} stands for price for equipment of heat source units. The values of price for equipment for heat source are given in table 1.

Table 2. The characteristic for equipment of heat generator [13,14]

	Embodied energy, MJ/kg	Embodied CO2, kg CO2/kg	Price for equipment, €/m^{2}a
Natural gas	2450	180	1.85
GSHP	1850	165	4.48
PV	4750	242	8.04

3. RESULTS AND DISCUSSION

Simulation is performed for each of the analysed panel system. The calculated quantities are the energy consumption, the operation cost of heating of the building, the carbon dioxide emission due to the building heating.

Figure 2 shows the final and primary energy consumption of four different heating panels which used natural gas boiler, GSHP and GSHP+PV as heat source. If we compare the panel systems the lowest energy consumption has the floor-ceiling heating and the highest energy consumption has a ceiling heating. In addition, if we compare the used heat source than the heating system equipped with natural gas boiler has lower primary energy consumption than the heating systems equipped with GSHP unit. However, the GSHP system has significantly lower consumption of the final energy than the system equipped with natural gas boiler. This is a consequence of the ratio of the primary energy coefficient (*R*) for the natural gas (R=1.1) and electricity (R=3.01). Also, using the PV panels to produce the electricity in conjunction with GSHP unit is achieved reduction of the required amount of the electricity from grid. The final energy consumption of the floor-ceiling heating system was 48, 20 and 6 kWh/m^{2}a using natural gas boiler, GSHP and GSHP with PV as a heat source, respectively. Also, the primary energy consumption of floor-ceiling heating system was 53, 62 and 62 kWh/m^{2}a using natural gas boiler, GSHP and GSHP with PV as a heat source, respectively. However, if we consider only the energy that is taken from the grid values of energy demand for the heating system equipped with natural gas boiler and GSHP stay the same, but the final and primary energy consumption of the floor-ceiling heating system equipped with the GSHP and PV was 6 and 32 kWh/m^{2}a, respectively.

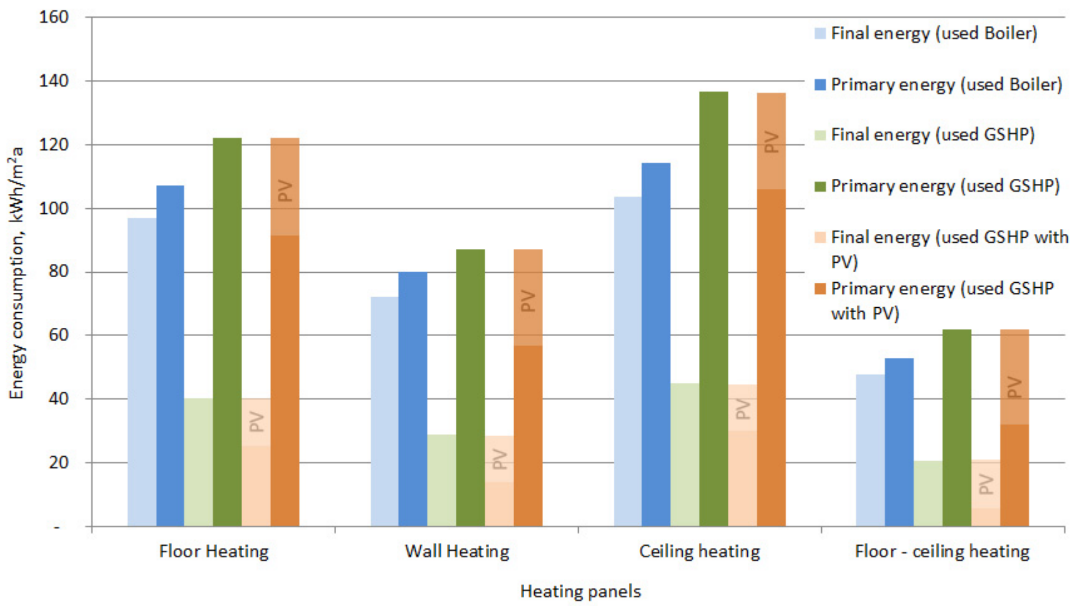

Figure 2. The final and primary energy consumption of panel heating system using different heat source

Figure 3 shows the total primary energy consumption of the four panel heating systems using natural gas boiler, GSHP and GSHP with PV as a heat source. The total primary energy consumption is a function of primary and embodied energy demand for heating. The lowest total primary energy consumption has the floor-ceiling heating system using a natural gas boiler as a heat source 54 kWh/m^{2}a. And the highest total primary energy consumption has the ceiling heating using a GSHP with PV 257 kWh/m^{2}a. The high value of embodied energy for production of PV cells causes to the heating system equipped with GSHP and PV has the significantly higher the total primary energy consumption then the other system.

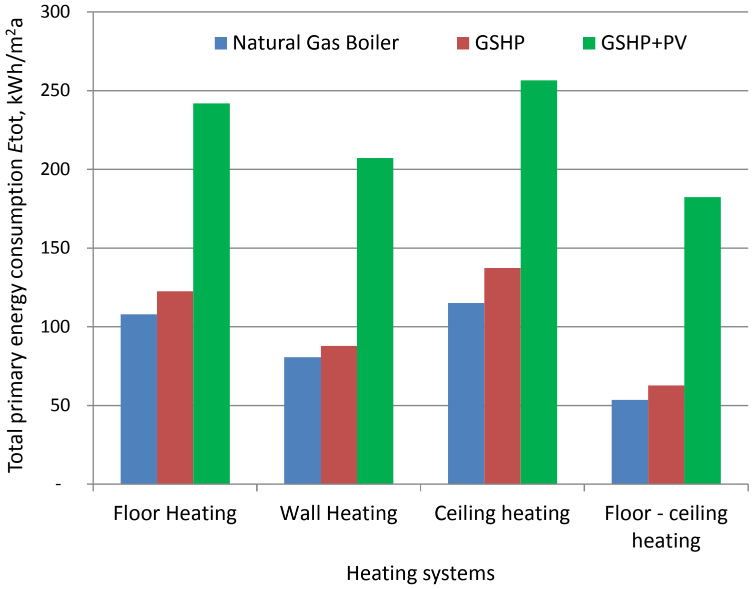

Figure 3. The total primary energy consumption of panel heating system using different heat source

Figure 4 shows the CO2 emission of four different heating panels which used natural gas boiler, GSHP and GSHP+PV as heat source. Floor-ceiling heating panel has the lowest energy demand so that the CO2 emission is the lowest for that system. If we consider the floor-ceiling heating system the CO2 emission for the system equipped with GSHP is the highest 16.9 kgCO2/m^{2}a and the lowest for the heating system equipped with natural gas boiler 12.02 kgCO2/m^{2}a.

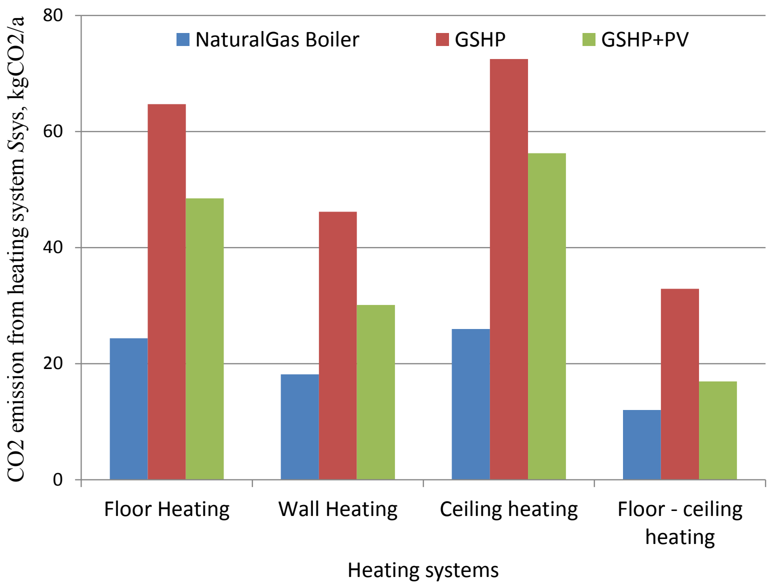

Figure 4. The CO2 emissions of panel heating system using different heat source

Figure 5 shows the total CO2 emission of four different heating panels which used natural gas boiler, GSHP and GSHP+PV as a heat source. The lowest total CO2 emission has a floor-ceiling heating system. Also, for that heating system the lowest CO2 emission has a system connected on natural gas boiler 12.1 $kgCO_2/m^2a$. And the highest CO2 emission for the same system has a GSHP with PV 32.9 $kgCO_2/m^2a$. The large increase of total CO2 emission at heating system equipped with GSHP and PV is due to the large value emitted CO2 at production of PV cells (i.e. embodied CO_2).

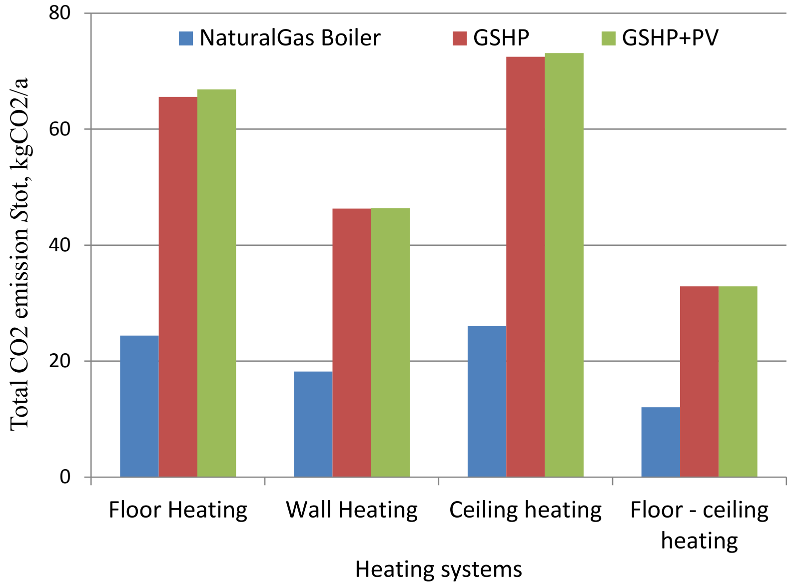

Figure 5. The total CO2 emissions of panel heating system using different heat source

Figure 6 shows the price for heating during heating season using four different heating panels which connected on natural gas boiler, GSHP and GSHP+PV as a heat source. The lowest price for heating has a floor-ceiling heating. Also, for that panel system the lowest price was when is connected on GSHP with PV 1.09 €/m^2a and the highest when is connected on natural gas boiler 3.52 €/m^2a.

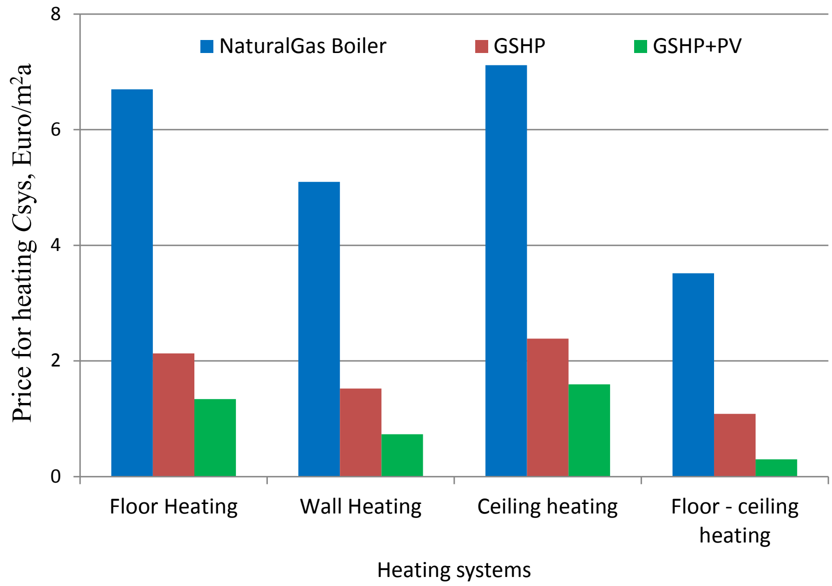

Figure 6. The operating cost of panel heating system using different heat source

Figure 7 shows the total price for heating during heating season using four different heating panels which connected on natural gas boiler, GSHP and GSHP+PV as a heat source. When taking into account the cost of investment in installation of mentioned energy sources (natural gas boiler, GSHP and GSHP with PV) the prices for heating are significantly changed. Now, the lowest price has a floor-ceiling heating connected on natural gas boiler 3.91 €/m^{2}a. Also, the highest price for heating was for floor-ceiling heating system connected on GSHP with PV 8.34 €/m^{2}a.

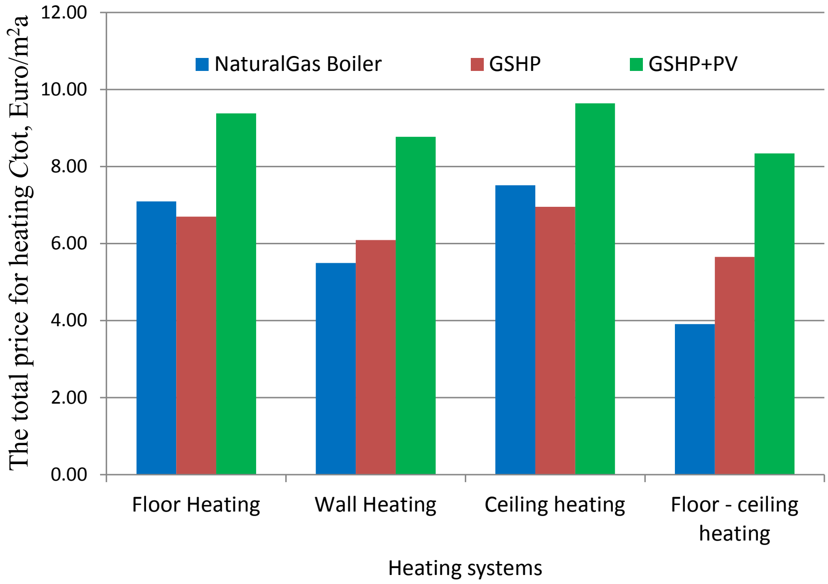

Figure 7. The total operating cost of panel heating system using different heat source

Conclusions

This study aimed to investigate the performance of panel heating systems when working with different energy sources. The paper analyses the four low-temperature radiant panel systems: floor heating, wall heating, ceiling heating and floor-ceiling hating. Also, as a heat sources the natural gas boiler (high temperature source) GSHP and GSHP with PV (low temperature source) are used.
The characteristics of analysed heating system were compared with aspect of energy consumption, CO2 emission and cost for heating.
Considering the panel heating systems the floor-ceiling heating system has the best characteristics and the ceiling heating system has the worst characteristics.
One of the goals of this study was to show the advantage of application of GSHP (low temperature source) compared to natural gas boilers (high temperature source) at the panel heating systems. However, the results showed that the consumption of primary energy in the GSHP system is higher than the system with a natural gas boiler. The problem is the high factor of primary energy for electricity from national electric grid. For that reason in the research is included GSHP with PV cells.
If we considered the heat sources the situation varies depending on whether we look at in terms of the end user or from a global the standpoint. The consumption of final energy from grid is the lowest for the system with GSHP with PV. Also, using PV cells reduce the consumption of the primary energy from the grid. And price for heating is the lowest for this system. However, if considered from global aspect (taking account the embodied energy, the embodied carbon and the cost of investment) the GSHP with PV gives the worst results.
Finally, it should be noted that these results were obtained for the Serbia weather conditions (high transformation coefficient of primary energy and the lack of sunlight in winter season).

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