Applied Energy 138 (2015) 404–413

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Decreasing energy use and influence to environment by radiant panel heating using different energy sources

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HIGHLIGHTS

- Currently in Serbia the use of GSHP over natural gas boiler and GSHP with PV is not justified.
- The impact of the embodied energy, embodied carbon, and investment is included in this paper.
- The operation of this house is simulated by software EnergyPlus.
- The newly-developed floor-ceiling radiant heating has the best performances.
- In future with decrease in *R*, the panel heating by GSHP may have lower total energy consumption than that by natural gas.

ARTICLE INFO

Article history:
Received 4 April 2014
Received in revised form 20 September 2014
Accepted 24 October 2014

Keywords:
Radiant heating panel
Heat pump
PV panel
Energy consumption
EnergyPlus

ABSTRACT

In Serbia, radiant heating is increasingly used. Also, in Serbia, the largest portion of produced electricity is from the fossil fuels which results in a high value of primary energy consumption coefficient (*R*). This situation raises the question of the justification of the use of ground sources heat pump (GHSP) over natural gas boiler and GSHP with PV array. Also, the impact of the embodied energy and embodied carbon was included in this paper. The operation of this house is simulated by software EnergyPlus. The results indicated that the newly-developed floor-ceiling radiant heating system has the best performances and classical ceiling heating has the worst performances. However in future with decrease of *R*, it is shown that the panel heating powered by GSHP may have lower total energy consumption than that of such a system powered by natural gas. For the wall panel heating, this would happen for the highest value of *R*, while in the case of the ceiling heating, it would appear for the lowest value of *R*.

1. Introduction

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

Some studies were devoted to investigation of performance of radiant panel systems in different heating systems inside the building. Kilkis [1] showed that optimal operation of radiant panels with ground-source heat pump (GSHP) driven by renewable energy sources improves the exergy efficiency and primary energy ratio. Kosir 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 radiant wall heating and radiators connected to the natural gas boiler. They showed that properly executed radiant wall panels compared to radiators achieve primary energy savings of 28%. Also, there are many studies about hydronic cooling systems [4–9].

Various experimental and analytical studies were undertaken on GSHPs. Hepbasli [10] conducted the thermodynamic analysis of a GSHP for district heating in terms of both energy and exergy analysis, which aimed at improving the process efficiency. Sankaranarayanan [11] simulated a hybrid GSHP in which supplemental heat rejecters were used together with the ground loop by using EnergyPlus. Kharseh et al. [12] investigated the effects of global warning on the GSHP performance. They show that the ongoing climatic change had significant impact on GSHP systems. Michopoulos et al. [13] studied the operational performance of a GSHP installed in Northern Greece for heating and cooling modes.

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http://dx.doi.org/10.1016/j.apenergy.2014.10.063
0306-2619/

Nomenclature

C	operation cost (Euro)
E	annual energy (kW h)
f	specific cost (€/m^2)
g	specific carbon dioxide emission factor
k	correction coefficient of the natural gas consumption
m_1	fixed monthly cost for metering (Euro)
R	primary energy consumption coefficient
S	Carbon dioxide emission
U	coefficient of heat transfer (W/(m^2 K))

Subscripts and superscripts

el	electricity
emb	emobided
eq	equipment
ng	natural gas
sys	system
tot	total

Abbreviations

ASHP	air-source heat pump
GSHP	ground source heat pump
PV	photovoltaic

They observed that during one cyclic operation the maximum seasonal COP was observed to be 5.2 and 4.5 for heating and cooling modes, respectively. Montagud et al. [14] studied performance of GSHP for space heating and cooling installed in a university building in Spain. Along with experimental study, they created a model in TRNSYS and GLHEPRO software and monitored the operating performance for seven years to see the consistency between experimental and numerical data. For this purpose they recorded the outlet temperature of the borehole heat exchanger and their experimental data were in close agreement with their numerical data.

There are some studies that investigated the performances of different heating systems. When observing the efficiency of the heating system it is essential which the heaters are used. Water source heat pump systems are the fastest growing application of renewable energy in the world [15]. A performance comparison between an air–water heat pump and GSHP systems was obtained [16] and the authors found that especially at low ambient air temperatures the GSHP system has about 24% higher heating capacity and efficiency improvements of 20% compared to an air-to-water heat pump system. Esen and Yuksel [17] studied the possibility of using various renewable energy sources for green house heating and they concluded that GSHP also can be used for green house heating. Lohani and Schmidt [18] modelled and compared the energy and exergy flow for a space heating system with different heat generation plants and found GSHP heating is better than air source heat pump or conventional heating. Self et al. [19] compared GSHP, air source heat pump, electric baseboard heaters and natural gas systems in term of efficiencies, emissions and costs for three Canadian provinces. They concluded that the GSHP was highly efficient heating technology that allows reductions in CO_2 emissions. Marini [20] using EnergyPlus software found that GSHP compared to the boiler systems saved 59.6% of primary energy. He conducted investigation for one residential building complex that consisted of 15 apartments. Tagliabue et al. [21] showed the technical and economical comparison between three technical systems: gas boiler, air-source heat pump (ASHP), and GSHP. Each of them was an option to replace an oil boiler after a whole refurbishment of an apartment residential building in Milan, Italy. They concluded that the ASHP showed better results in term of cost-optimal performance in the short term. However, the GSHP was cost-effective in a period compatible with the operating life of the building. Entchev et al. [22] compared the hybrid GSHP/photovoltaic thermal micro-generation system with conventional system that utilized a boiler and chiller to meet the thermal loads of two buildings. The simulation results showed that, by implementing a single GSHP system an overall energy saving was close to 46%. The integrated hybrid GSHP/PVT system, however, resulted in a much higher overall energy saving of 58% due to the contribution of both geothermal and solar energy. Badescu [23] used the energy and exergy analysis to determine the GSHP in order better to design the system. The GSHP system used the photovoltaic (PV) array to drive the compressor. The results showed that the PV array can provide all the energy required to drive the heat pump compressor, if an appropriate electrical energy storage system was provided. Chen et al. [24] conducted an experimental analysis on a hybrid PV based heat pump process to investigate the system efficiency. They found that, the COP of the integrated system was increased from 2.9 to 4.6 with the increasing solar radiation coming on the PV/T collector from 200 W/m^2 to 800 W/m^2 but decreased from 5.2 to 3.2 and from 6.7 to 2.8 with the increasing condenser water supply temperature from 25 °C to 45 °C and water flow rate from 1 L/min to 5 L/min, respectively. Analysis of the GSHP systems [25] with dynamic simulation tool was also performed. The author found that primary energy savings vary in relation to the compared reference systems. The feasibility of these systems strongly depended on electricity and natural gas costs. In Serbia, a negative, zero, and positive-net residential building energized by electricity from the grid and from the PV array were studied using site energy metric balance [26]. Leckner and Zmeureanu [27] conducted life cost and energy analyses for the net zero energy house for cold climate of Montreal, Canada. They used a combisystem with active solar technologies to provide heating, domestic water, and electricity. They showed that due to the high cost of the solar technologies and the low cost of electricity in Montreal, the financial payback was never achieved. Nguyen et al. [28] investigated effects that an operating cost, inflation, geographical location within North America, and seasonality control strategy had on sizing hybrid GSHP systems. They concluded that for heating dominant buildings, the low rates for natural gas found in many parts of North America made it uneconomical to install a GSHP system.

This study is continuation of previous research by Bojic et al. [29]. Then, they compared four different radiant panel heating systems (floor, wall, ceiling and floor-ceiling) connected to a natural gas boiler. The floor-ceiling panel heating system represents newly-developed panel heating system. The objective of this paper is to investigate the possibility of improving energy efficiency of radiant panel heating by using lower temperature heat source such as GSHP and newly-developed floor-ceiling panel heating systems. The conventionally used gas boiler is compared with GSHP. GSHPs use electricity to extract heat from the ground and deliver to the space to be heated. Thus, they indirectly contribute more to greenhouse gas mitigation than that by the conventional heating systems. To decrease of electricity consumption of GSHP, the GSHP is coupled to PV array.