Low Temperature Hydronic Heating System with Radiators and Geothermal Ground Source Heat Pump

Miloš Banjac
Assistant Professor

Bogosav Vasiljević
Associate Professor

Milan Gojak
Teaching and Research Assistant

University of Belgrade
Faculty of Mechanical Engineering

The use of a system with a geothermal ground source heat pump, regardless of the relatively low temperature of the available source of geothermal energy (water or ground temperature does not need to exceed 12°C*), allows* 50-80% *of the energy required for heating to be taken from the ground, while the remaining amount is provided by electrical energy. This share of geothermal energy, in the total energy required for heating, primarily depends on the system of its further distribution (radiator system, fan coil heating system or wall and floor heating), and secondarily on water and ground temperature. The paper deals with the comparative analysis of thermal efficiency of two water central-heating systems with radiators, a conventional high-temperature heating system with a boiler* (90°C/70°C) *and a low-temperature heating system with a geothermal ground source heat pump* (65°C/55°C, 55°C/45°C or 50°C/45°C).

Keywords: *heat pump, radiator, geothermal energy, degree-day, saving energy.*

1. INTRODUCTION

In the middle of the last century, in western Europe, as well as in our country, the process of substitution began, that is, the process of switching from, at the time, high temperature regime (120°C/100°C or 110°C/100°C) – the so called steam central-heating system, to at the time, low temperature regime (90°C/70°C) – the hot water central-heating system with radiators. Although the switch from one to the other heating regime can be interpreted in terms of technical-technological, hygienic aspects or the aspects of comfort, which stands out as the most significant reason is the increase in the energetic efficiency of the new heating regime. Namely, during the "production" of heating energy, that is, the heat transfer from the heat source (combustion product or an electric heater) to the heated fluid (water), during its passage through the boiler, the total heat transfer, and accordingly, the degree of the boiler's efficiency are directly correlated with the maximum temperature which the heated fluid can reach. The lower this temperature is, the higher the degree of the boiler's efficiency can be, that is, the whole process of heat transfer can be performed with lower energy "losses." At the same time, the energy saving during the transport of the now heating fluid from the boiler to users cannot be neglected. In this case also, the heating energy "losses," that is, the dissipation of heating energy proportionally decreases with the decrease in the temperature of the heating fluid.

With time, steam heating systems became almost completely substituted by hot water heating systems (90°C/70°C), which thereby became standard systems of central heating in buildings. In order to confirm this claim, standards, starting with DIN 4701, from 1959, DIN 4701 from 1983, to DIN 4701 from 1989, in which the procedures for the examination of heat transfer from different heating bodies that function in a "standard regime" (90/70/20°C) are stated, can be quoted. Furthermore, in the same standards, the data regarding heat transfers from different heating bodies, exactly or the regime (90/70/20°C) are presented.

Due to similar reasons, as it had previously been done with steam heating systems, that is, with the purpose of increasing efficiency and saving energy, in western European countries, at the beginning of the 90-ies, there was a new switch, this time from the old "high-temperature" heating regime (90°C/70°C), to the "new" low temperature heating regime (75°C/65°C). In the standards, actually, this time, in the European norms [1], the procedures for the examination of heat transfers from different heating bodies, as well as the data regarding heat transfers from different heating bodies, for the new heating regime (75/65/20°C) are presented.

The possibilities of switching onto the new low temperature heating regime, besides the neglectable increase in thermal efficiency of the radiator, lie mostly in better thermal insulation of buildings and installation of the doors and windows of better quality, which provides lower transmission and infiltration "losses" in a building, on one hand, and in significant climatic changes in the second half of the last century. Both reasons led to a decrease in the heating load of a building, which have now also become limited by corresponding standards and norms.

On the other hand, the intensive development of heat pumps, in the last couple of years, which is mostly reflected in the achieved high temperatures of water as a

Received: Decembar 2007, Accepted: Decembar 2007
Correspondence to: Dr Miloš Banjac
Faculty of Mechanical Engineering,
Kraljice Marije 16, 11120 Belgrade 35, Serbia
E-mail: mbanjac@mas.bg.ac.yu

heating fluid (up to $65°C$), with a still high performance coefficient (*COP*), has enabled their use in central hydronic heating systems with radiators. Namely, even though theoretical basics of the operation of heat pumps were known as early as in 19th century, and the first pump was already constructed in 1920, it was not until the beginning of the 70-ies of the last century, with the occurrence of the first energy crisis, that energetically efficient heating systems started being used and the intensive work on the improvement of the pump's energetic characteristics began. It was then that the first serious attempts at constructing hydronic heating systems with radiators and a heat pump began. Nevertheless, unacceptably big radiator heating surface, on one hand, and the reduction of the performance coefficient while using the outside air as a heat source, on the other hand, exactly when the need for heating energy was the highest, have postponed this kind of its use for a while.

In the meantime, the adoption of strict ecological requirements in the 90-ies of the last century, led not only to the withdrawal of the use of the then "standard" working fluids, but also to the development and appearance of their completely new kinds. In terms of both ecological and thermodynamic criteria, significant improvements were brought by new freons. The so called phenomenon of the "gliding temperature," that is, an increase in freon temperature during its isobaric evaporation, and the decrease in its temperature during the process of isobaric condensation, provide the conditions for the increase of *COP*, as well as for the significant increase in the "final" temperature of evaporation.

At about the same time, the solution to the other problem in the use of the heat pump – the reduction of COP, in the periods in which the need for heating energy was the highest, was being worked on. The solution to this problem was found in the use of ground as a heat source, since, unlike air, ground has almost constant temperature throughout the entire heating season, especially if heat exchangers buried in the ground are properly dimensioned. Moreover, due to the new technologies of the production of plastic pipes, the problems concerning the solidity and durability of the aforementioned exchangers were solved.

In the last couple of years, there have been also technical improvements of the heat pumps themselves. Firstly, a Belgium company *Copelad* managed to produce in practice a scroll compressor, and then the *Swiss Federal Institute of Technology of Lausanne – EPFL* together with the leading French electric power distributor "Electricité de France" - (EDF) managed to develop a new version of the refrigerator cycle with Enhanced Vapor Injection, (the so called EVI system) and thereby to create carry out quasi-two-stage compression refrigeration systems. In that way, an additional increase in *CPO* of the heat pump was accomplished, which brought the heat pump closer to its use in hydronic heating systems with radiators.

Finally, even after all these improvements, the following questions have to be raised: How big would the necessary alterations of the existing hydronic heating system with radiators have to be in order to switch from the classic – high temperature system with a boiler ($90/70/20°C$) to the low temperature, energetically more efficient heating system with a heat pump and how big a decrease in the energy need would actually be accomplished by their use?

2. THE REQUIRED ENLARGMENT OF RADIATOR SURFACES

With the aim of finding answers to the previously posed questions, two analyses were carried out. The first one referred to determining the necessary enlargement of radiator surfaces when switching from high temperature ($90°C/70°C$) to low temperature heating systems with a heat pump ($65°C/55°C$, $55°C/45°C$ and $50°C/45°C$), whereas the other was dedicated to determining total heating output of three different heat pumps ($65°C/55°C$, $55°C/45°C$ and $50°C/45°C$), which they would have been able to achieve if they had been used in three previous heating seasons.

As a part of the first analysis, for the determined model room – one of the rooms of the Thermodynamics Laboratory at the Faculty of Mechanical Engineering in Belgrade, firstly the need in heating consumption was calculated – for all the outside air temperatures that can occur throughout a heating season (from – 18°C to $20°C$). Then, for the outside project conditions for Belgrade, for the case of the "standard" high temperature heating regime ($90°C/70°C$), by using a standard thermo-technical calculation the required number of ribs of the suitable hydronic heating system with radiators was determined. Afterwards, based on the formulas that define the change of heat transfer rate from the surface of the radiator - in the conditions different from normal [5]:

$$\frac{\Phi}{\Phi_{\mathrm{N}}}=\frac{q_{m,\mathrm{w}}\left(\vartheta_{\mathrm{w,in}}-\vartheta_{\mathrm{w,out}}\right)}{q_{m,\mathrm{w,N}}\left(\vartheta_{\mathrm{w,in}}-\vartheta_{\mathrm{w,out}}\right)_{\mathrm{N}}},$$

$$\frac{\Phi}{\Phi_{\mathrm{N}}}=\frac{q_{m,\mathrm{w}}\left(\vartheta_{\mathrm{w,in}}-\vartheta_{\mathrm{w,out}}\right)}{q_{m,\mathrm{w,N}}\left(90-70\right)}, \tag{1}$$

$$\frac{\Phi}{\Phi_{\mathrm{N}}}=\frac{\Phi_{\mathrm{hb,rad}}+\Phi_{\mathrm{hb,conv}}}{\left(\Phi_{\mathrm{hb,rad}}+\Phi_{\mathrm{hb,conv}}\right)_{\mathrm{N}}}=\frac{A_{\mathrm{s}}}{A_{\mathrm{s,N}}}\cdot\left(\frac{\Delta\vartheta_{\mathrm{ln}}}{\Delta\vartheta_{\mathrm{ln,N}}}\right)^{n}, \tag{2}$$

the change of the effective heat transfer coefficient in the function of the logarithmic mean temperature difference between the heating fluid and the inside air was determined (for the radiators of type Global - VOX 600, it is shown in Figure 1).

Afterwards, according to the formula:

$$\Phi = A_{\mathrm{s}}\cdot h_{\mathrm{ef}}\cdot\Delta\vartheta_{\mathrm{ln}}, \tag{3}$$

heat transfers rate were also determined, that would appear in the previously defined system, but this time with changed temperature regimes. Three customary temperature regimes were considered in this analysis ($65°C/55°C$, $55°C/45°C$ and $50°C/45°C$) that correspond to the operating regimes of three commercial heat pumps, two Viessmann pumps

(WWH-110 Vitocal 350, WW-104 Vitocal 300) and one CIAT pump (Aurelia Ila 20Z). While determining heat transfers, it was assumed that the value of the heat characteristics of the radiator – exponent $n = 1.33$ does not change with the change of the size of the radiator surface. The value of the exponent was determined by the measurements, performed at the Faculty of Mechanical Engineering in Belgrade. The enlargement of the radiator surface in terms of percentages, reduced to the radiator surface in the high temperature heating regime, is shown in Fig. 2.

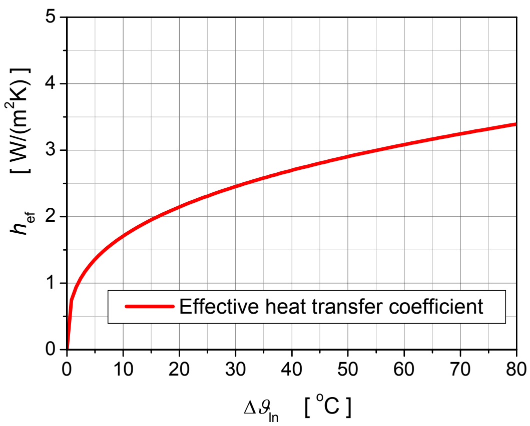


Figure 1. The change of the effective heat transfer coefficient from the surface of the radiator Global-VOX 600

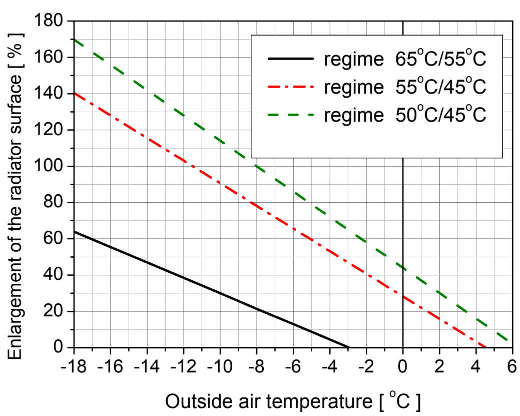


Figure 2. The enlargement of the radiator surface in terms of percentages, reduced to the radiator surface in the high temperature heating regime, depending on the outside air temperature

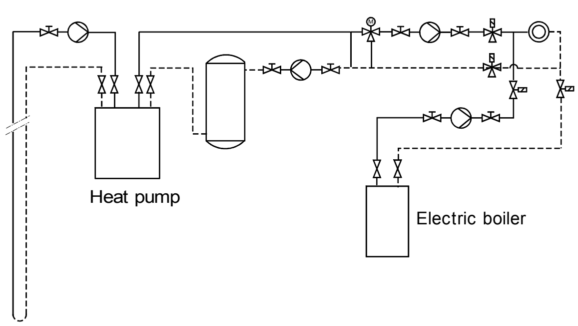


Figure 3. Schematic representation of the combined hydronic heating system with radiators, an electric boiler and a geothermal ground source heat pump

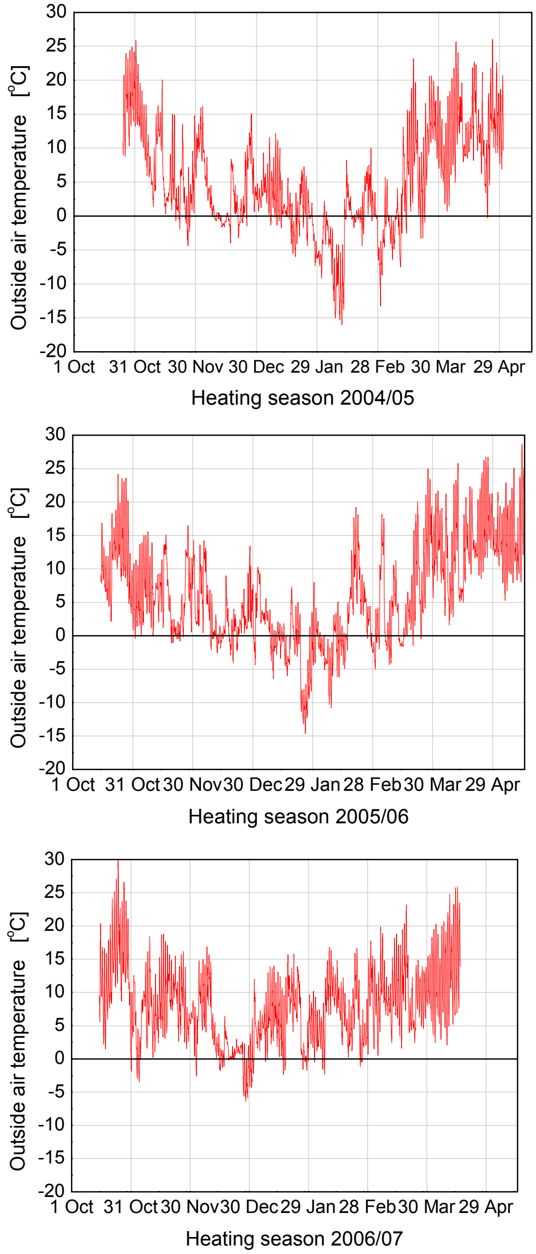
In the graph in Figure 2, it can be noticed that depending on the heating regime ($65°C/55°C$, $55°C/45°C$, or $50°C/45°C$) for fulfilling 100% of the needs for heating energy, or for the outside project temperature of $-18°C$, the radiator heating surface would have to be enlarged for 64%, 140% or 170%. Except in case of the low temperature heating regime $65°C/55°C$, such big enlargements of radiator surfaces are unacceptable, since it is not physically possible to provide so much space to place them.

On the other hand, if a so called combined heating system is applied (one of the possible structures of the combined hydronic heating systems include radiators, an electric boiler, and a geothermal ground source heat pump is schematically shown in Figure 3), it is possible to achieve significant decrease in the need for energy, even without the change of the size of radiator surfaces. Such a heating system would be used if, up to the moderately low temperatures of the outside air and up to the limit that radiators "allow," the need for heating energy was met solely by the heat pump. In extremely low outside temperatures, when a low temperature heating system cannot provide the required heat transfer anymore, the heat pump is turned off, and the system switches to the high temperature operating regime with an electric boiler.

3. DETERMINING THE HEAT OUTPUT OF HEAT PUMPS

With the purpose of becoming acquainted with the possibilities of reducing the need for energy, which is possible if the combined heating system is used, as well as, with the influence of the enlargement of heating surfaces on that reduction, the case of heating a model room with such a system has been analyzed. The analysis was carried out for the period of the last three heating seasons (2004/05, 2005/06 and 2006/07), during which the outside air temperatures were measured hourly (Figure 4). Based on the measured data and the calculated numbers of degree-days, the distribution of the consumed invested heating energy was determined, depending on the outside air temperature. Part of the obtained results, the cumulative distribution of the outside air temperature in Belgrade, is shown in Figure 5, and a somewhat clearer graphic presentation of the distribution of the potentially consumed heating energy is shown in Figures 6 and 7. It can easily be seen in these figures that during the last three heating seasons, less than 10% of heating energy was consumed when the outside air temperatures were lower than $-6°C$, and less than 6% of heating energy when the outside air temperatures were lower than $-8°C$.

If the obtained results are viewed from the aspects of the required radiator enlargement, for achieving the needed heat output in low temperature heating systems (Figure 2), what follows is that for fulfilling the 90% of the needs for heating energy, or up to the outside project temperature of –6 °C, the required, as well as, acceptable radiator surface enlargement is that of 13%, 65% or 72%. What should be kept in mind is that the value of the outside project air temperature of $-6°C$ is very close to the possible "new" values of the outside project air temperature [1,5].



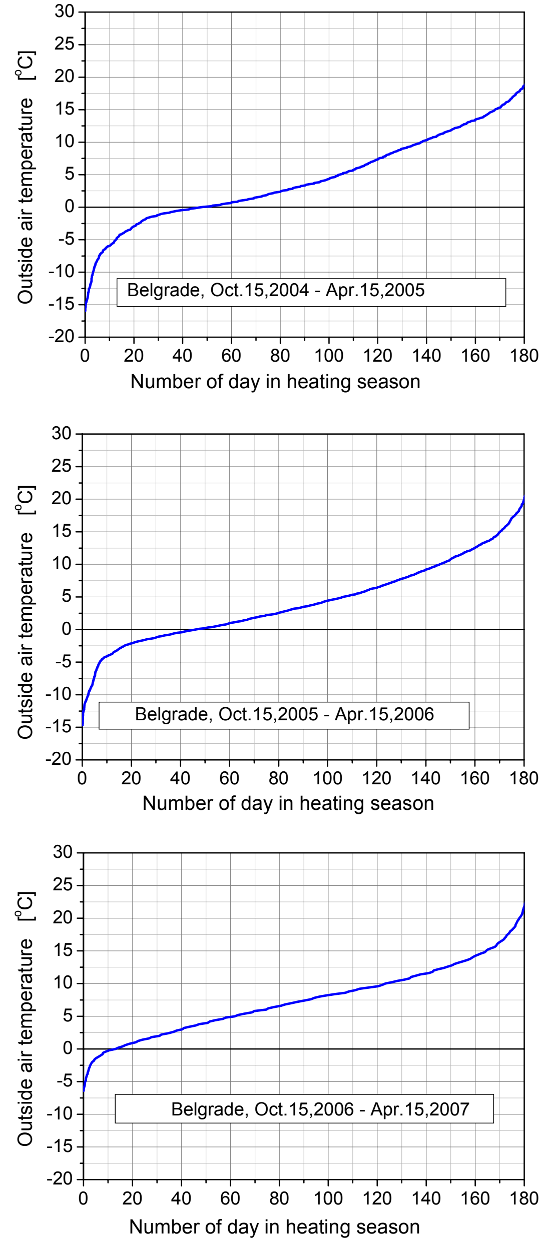


Figure 4. The changes of the outside air temperature in Belgrade, in the heating season 2004/05, 2005/06, 2006/07

Figure 5. Cumulative distribution of the outside air temperature in Belgrade, in the heating season 2004/05, 2005/06, 2006/07

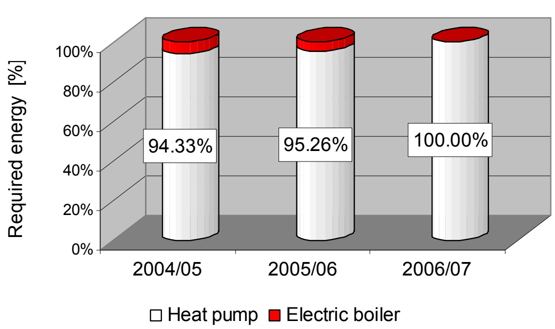


Figure 6. Distribution of the required energy provided by the heat pump and the electric boiler, if radiators are dimensioned for the outside project temperature of - 8°C

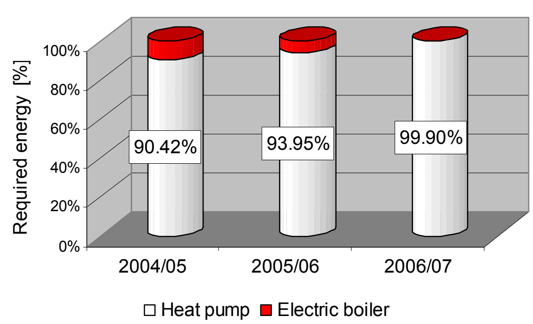


Figure 7. Distribution of the required energy provided by the heat pump and the electric boiler, if radiators are dimensioned for the outside project temperature of - 6°C

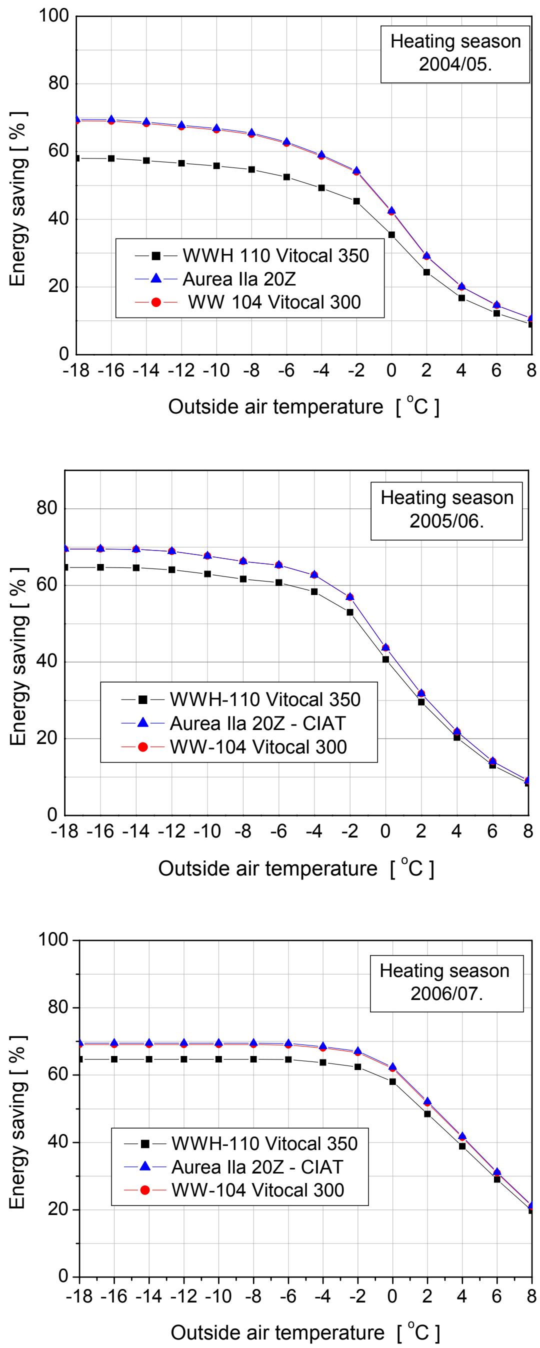


Figure 8. Energy saving with the use of hydronic heating system with radiators and geothermal ground source heat pump combined with an electric boiler

Finally, depending on the size of radiator surfaces, and the outside air temperature values up to which radiators can perform the function of heating, the amounts of the energy that could be "saved" by the use of such a combined heating system were also calculated. The analysis was performed for the use of two *Wiessmann* heat pumps - WWH-110, VITOCAL 350 and WW-104 VITOCAL 300 and one CIAT AUREA ILA 20Z heat pump. The data from the manufacturers' catalogues were used for the calculation (for WWH-110, VITOCAL 350, performance coefficient was $COP = 2.83$, for the heat source temperature of $8°C$ and for the heating regime $65°C/55°C$; for WW-104 VITOCAL 300, performance coefficient was $COP = 3.23$, for the heat source temperature of $8°C$ and for the heating regime $55°C/45°C$ while for the CIAT pump, AUREA Ila 20Z, performance coefficient was $COP = 3.287$, for the heat source temperature of $8°C$ and for the heating regime $50°C/45°C$). The obtained results for three analyzed heating seasons are shown in Figure 8.

By the analysis of the graph, it can be concluded that proportionally the biggest energy "savings" can be achieved by the enlargement of radiator surfaces to the sizes that enable the required heat transfer with the outside air temperature of $-6°C$. The achieved "savings," depending on the heating season and the type of heating regime, vary in the interval from 50% to 70%. With further enlargement of the radiator surfaces, the increase in the energy saving is almost neglectable.

4. CONCLUSION

With the purpose of reducing the need for energy, it is desirable to switch from the customary high temperature hydronic central-heating system with radiators to the combined, energetically by far more efficient hydronic heating system with a geothermal ground source heat pump. At the same time, proportionally the biggest energy savings can be achieved by the enlargement of radiator surfaces to the sizes that, in the low temperature operational regime, provide the required heat transfer with the outside air temperature of –6°C. Depending on the heating regime that a particular heat pump can achieve (65°C/55°C, 55°C/45°C or 50°C/45°C), the necessary enlargements of the existing heating system with radiators should be 13%, 65%, or 72%. The achieved energy "savings," for the territory of the city of Belgrade, depending on the heating season and the type of the heating regime, vary in the interval from 50% to 70%. With further enlargement of the radiator surfaces, the increase in the energy saving is relatively small.

Furthermore, it should be kept in mind that the stated percentages of the enlargement of radiator surfaces were calculated without taking into account the possibility of decreasing the needs for heating energy that can be achieved by the passive measures of energy saving – by the better insulation of the building (thermal insulation of the walls, roof, replacing doors and windows etc.) Such analysis, which encompasses both kinds of measures, is planned for the future period.

ACKNOWLEDGMENT

This work was supported by the Ministry of Science, Republic of Serbia, Project Number E253007b, which is gratefully acknowledged.

REFERENCES

[1] DIN - EN 12831: *Heizungsanlagen in Gebauden - Verfahren zur Berechnung der Norm-Heizlas*t; 2003.

[2] De Swardt, C. A., Meyer, J. P.: A performance comparison between an air-source and a ground-source reversible heat pump, International Journal of Energy Research, 25, pp. 899-910, 2001.

[3] Nagano, K., Katsura, T., Takeda, S.: Development of a design and performance prediction tool for the ground source heat pump system, Applied Thermal Engineering, 26, pp. 1578–1592, 2006.

[4] Brudeerer, H., Hol, H.: Für die Heizungssanierung: Wärmepumpen mit 65°C Vorlauf, Spektrum der Gebäudetechnik, 5, pp. 90–96, 2002.

[5] Recknagel, H., Sprenger, E., Schramek, E. R., Čeperković, Z.: *Heating and Air-Conditioning 05/06*, Interklima, Vrnjačka Banja, 2004. (in Serbian)

ЦЕНТРАЛНИ НИСКОТЕМПЕРАТУРНИ ГРЕЈНИ СИСТЕМ СА ТОПЛОТНОМ ПУМПОМ И ЗЕМЉОМ КАО ИЗВОРОМ ЕНЕРГИЈЕ

Милош Бањац, Богосав Васиљевић, Милан Гојак

Употреба грејног система с топлотном пумпом и земљом као извором енергије, без обзира на релативно ниску температуру расположивог „извора” геотермалне енергије (температура воде или тла не мора бити виша од 12°C), омогућава да се 50-80% енергије потребне за грејање преузме од земље, а да се остатак надомештава електричном енергијом. Овај удео геотермалне енергије, у укупној енергији потребној за грејање, зависи пре свега од система њене даље расподеле (радијаторски систем, систем грејања помоћу фанцоил-а или зидно и подно грејање), а тек потом и од темпертуре воде, односно тла. У раду је дата упоредна анализа термичке ефикасности два система центарлног грејања са радијаторима као грејним телима, високотемпертурног котловског система грејања (90°C/70°C) и нискотемпературног система са топлотном пумпом и земљом као извором енергије (65°C/55°C , 55°C/45°C или 50°C/45°C).