ACHIEVING SAVINGS BY IMPLEMENTATION OF EFFICIENT HYBRID HEATING SYSTEMS

by

Maja N. TODOROVIĆ**, *Miloš J. BANJAC, Tamara S. BAJC, and Milan R. RISTANOVIĆ

* Faculty of Mechanical Engineering, University of Belgrade, Belgrade, Serbia

Original scientific paper
https://doi.org/10.2298/TSCI180726176T

Regarding to the structure of final energy consumption in buildings and National Action Plans, the paper gives a short overview of energy consumption in buildings in Serbia, showing that the greatest potential for achieving savings lies in the implementation of measures which improve energy efficiency. Considering that over 60% of energy requirements for buildings is related to thermal energy, particular attention should be paid to the centralized heating systems, both during the design of a new system, and in the reconstruction of the existing one. Further discussed are the heat sources for the heating systems. The seasonal heat load duration curve for winter conditions in accordance to the Typical Meteorological Year for Belgrade is constructed and displayed. The analysis of the conventional system with a fossil fuel source, as well as the analysis of a hybrid heat source are conducted. The savings achieved in the primary energy, heating bills and CO_2 emission reduction, which are attained by the use of a hybrid system, are shown in comparison with the conventional systems. Collecting data on investment costs, as well as the prices of energy and fuels in Serbian market, enabled calculation of the payback period when replacing the conventional system by the new hybrid one.

Key words: *central heating systems, hybrid heat sources, energy consumption, savings, CO_2 emission, payback period*

Introduction

Based on numerous analyzes, expertise and energy audits of buildings in the last decade, as well as on the basis of data published by the line ministries responsible for the field of construction and energy sectors, it is evident that the gross final energy consumption in buildings in the Republic of Serbia is dominant and growing, as indicated in the energy balance of the Republic of Serbia [1]. Recognizing the importance of this problem, the Ministries in charge of energy and construction of the Republic of Serbia began a systematic campaign to approach solving the problem of uncontrolled, disorganized, irrational and unsustainable use of energy and fuels in all sectors. Numerous documents are adopted, which provide a route to organized and sustainable treatment of energy issues, including: Energy Law, the Law on Planning and Construction, the Law of Efficient Use of Energy, Energy Development Strategy of the Republic of Serbia, the Regulation on the Implementation Program of the Energy Development Strategy, the First and the Second National Action Plan for Energy Efficiency, Regulation on Energy Efficiency in Buildings, Regulation on conditions, content and manner of issuing certificates on the energy performance of buildings, *etc*. Institute for Standardization of Serbia, through the involvement of several Commissions for Standards, introduced in the national framework a large

*Corresponding author, e-mail: mtodorovic@mas.bg.ac.rs

number of European and International standards in this area, which, to a large extent, facilitated the process of implementation of relevant legal documents. Formed is the Central Register of Energy Passports (CREP), connected to databases of Serbian Chamber of Engineers and Cadastre, a software platform that provides numerous options for all users, starting from a licensed engineers, through legal authorities and persons who need information about the process of energy certification, to Ministry of construction and urban planning, which oversees the entire process.

However, the greatest potential for achieving savings lies in the building sector, through the implementation of measures which improve energy efficiency. Considering that over 60% of energy requirements for buildings is related to thermal energy [2-4], particular attention should be paid to the centralized heating systems, both during the design of a new system, and in the reconstruction of the existing one.

Various authors discussed about possibilities for energy savings using hybrid heating systems. Hohne *et al*. [5] compared traditional water tank with electrical heater and hybrid solar electrical water tank and concluded that energy savings of 75.8% can be reached in winter period. Paspaliaris *et al*. [6] researched the hybrid system consisting of photovoltaic panels, six wind turbines and hydrogen boiler unit for office building and results showed that system had a good efficiency and reached the zero CO_2 emission goals. The study for China, performed by Du *et al*. [7] took into a consideration solar-air source heat pump hybrid heating system connected in parallel and in series and the conclusion was made that the parallel hybrid heating system is better than one in series. Rostamzadeh *et al*. [8, 9] proposed novel multigenerational system driven by hybrid biogas-geothermal heat source which had thermal efficiency of 62.28%. They also suggested the ways to reach higher thermal and exergy efficiencies for proposed system. Having in mind high energy consumption in building sector, Talebi *et al*. [10] proposed the methodology for optimization of a hybrid district heating (DH) systems. The dynamic optimization could decrease the initial costs by 26.7% comparing to the conventional tools. Karki *et al*. [11] researched the performance of solar/gas hybrid water heating system and compared it to the solar and gas mode separately. They suggested hybrid configuration and operational modes in which the system could reach the highest efficiency. Uche *et al*. [12] experimentally tested hybrid trigeneration system which consisted of photovoltaic/thermal collectors and a micro-wind turbine. Photovoltaic/thermal hybrid system was also analyzed by Fine *et al.* [13], who suggested modified method for hybrid mode performance estimation. Taler *et al*. [14] researched the annual operation of hybrid heat source which consisted of condensing gas boiler, ground and air source heat pump and solar collectors and concluded that it was an economically and ecologically good solution, based on measurements and economic analysis given in the study [14]. Bellos and Tzivanidis [15] investigated the hybrid PV collector and heat pump system, where heat pump is driven by solar collector, both for electricity and heat. They concluded that total area of 10 m^2 of hybrid photovoltaic collectors is able to fulfill the needs, thus to provide 4.33 kW for heating and 0.53 kW for electricity. In other study [16] they researched the energetic and financial sustainability of solar assisted heating system in Greece. According to their results, the electricity savings using solar driven heat pump are from 30-40%. From the financial point of view, they concluded that the geographical position of Athens, Istanbul, Madrid, Napoli, Rome, and Thessaloniki gives them the opportunity for sustainable use of solar assisted heat pump, where Madrid has the lowest payback period of about 6.6 years for the high insulation cases. Klein *et al*. [17] simulated hybrid heat pump system for existing residential building for whole year and showed that highest seasonal performance factor was reached for mid-range heat pump capacities due to the temperature dependency of the bivalence point in alternative-parallel bivalent operating scheme given in the study [17]. They concluded that hybrid heating systems could be justified for existing buildings, but with subsides or reduced electricity tariffs. As it is shown in various studies the highest operational efficiencies and the lowest costs depends on a hybrid system control strategies [5, 10, 12, 18-21].

Vallati *et al*. [22] analyzed heat pump heating system coupled with photovoltaic panels for cities: Rome, Milan, and Cracow and concluded that this system has a good potential, covering the 70%, 62%, and 47% of heating demand studied for these cities respectively. Poppi *et al*. [23] published a review for techno-economic analysis of solar heat pump systems for residential heating including also a results from several studies considering hybrid heating systems.

This paper gives a brief overview of energy consumption by sector in the Republic of Serbia with regard to the structure of final energy consumption in buildings and National Action Plans. Further discussed are the heat sources in heating systems. Constructed and displayed is the seasonal heat load duration curve for winter conditions in accordance to the Typical Meteorological Year (hereinafter TMY) for Belgrade [24]. The analysis of the systems with a fossil fuel source, as well as analysis of a hybrid heat sources are conducted. The savings achieved in the primary energy and CO_2 emission reduction, which are attained by the use of a hybrid system, are shown in comparison with the conventional system.

Energy consumption in buildings

According to Energy Balance for 2015, done by Ministry of Infrastructure and Energy, 38% of final energy is consumed in building sector [1].

The processed data for summed share of building stock, according to Study on energy efficiency of Buildings in Serbia, give the average sectors' specific heat consumption, which is higher than specified in national regulations regarding existing buildings. The diagram in fig. 1 shows comparison of the average heat consumption and values specified by national regulations. From the fig. 1 it can be seen that hospitals in Serbia are the biggest specific consumers, followed by schools. Average annual consumption of 142 kWh/m^{2}a is derived for residential sector, but data variations go from 60 to 250 kWh/m^{2}a [25].

According to Article 20 of the Treaty establishing the Energy Community, the Republic of Serbia has accepted the obligation to implement European Directives in the field of use of RES - Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. In accordance with Directive 2009/28/EC binding targets for Member States of the EU are set to ensure that the RES, in 2020, accounted for 20% of the gross final consumption at the level of the EU. The same methodology of the Directive, which was used to calculate the targets in the field of RES for EU member states, is applied to the other members of the Energy Community, with the difference that the base year for calculating the specific targets is set to 2009. instead of 2005. in accordance with Directive 2009/28/EC and the Decision of the Ministerial Council of the Energy Community of

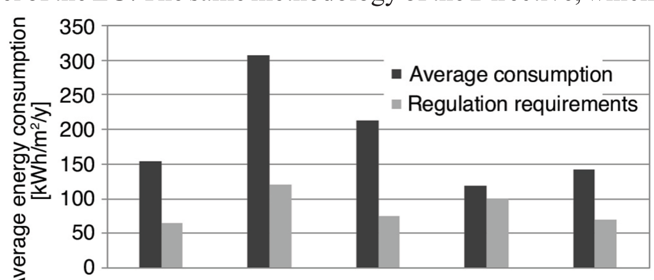

Figure 1. Specific energy consumption for different building types (summarized) [25, 26]

October 18, 2012. an ambitious binding target for the Republic of Serbia is determined, respectively 27% renewable energy in its Gross Final Energy Consumption (hereinafter GFEC) in 2020.

The RES, with an estimated technically exploitable potential of about 5.6 Mtoe per year, can significantly contribute to the fossil fuels use reduction and to the environmental conditions improvement. Republic of Serbia is already using 35% of total available technical potential of RES (881.7 ktoe of hydro potential, 1058.9 ktoe of biomass potential, and 1.2 ktoe of geothermal energy – 1941.8 ktoe in total) [4].

The use of RES in the previous period was based on the production of electricity from large river flows, and the use of biomass mainly for heating purposes in households, to a lesser extent in the industry. According to the data from the energy balance of the Republic of Serbia for period 2009-2017, revised in accordance with EUROSTAT methodology, the share of electricity from hydropower in GFEC amounted to 9.55% (28.25% in the electricity sector), while the share of thermal energy from biomass in GFEC amounted to 11.47% (26.47% in the sector of heating and cooling) [4]. The share of RES in final electricity consumption (RES-E), in transport sector (RES-T) and in sector of heating and cooling (RES-H&C), calculated in accordance with EUROSTAT methodology, is shown in tab.1 [4].

Table 1. The share of RES in three sectors of GFEC in Serbia, for the period 2009-2017 [4]

	2009	2010	2011	2012	2013	2014	2015	2016	2017
RES-E [%]	28.25	28.18	27.53	28.51	27.97	30.28	28.92	29.16	28.72
RES-T [%]	1.46	0.67	1.88	2.00	1.68	1.17	1.18	1.23	1.18
RES-H&C [%]	26.50	23.20	21.09	23.20	25.15	28.85	26.54	24.65	24.43
RES [%]	21.02	19.76	19.12	20.79	21.10	22.87	21.85	20.99	20.61

The main reasons causing a negative trend in the share of RES after 2014 are:
- An unplanned increase in GFEC caused by increased industrial consumption.
- Unbalanced dynamics of RES development.

In the period from 2009 to the end of 2018, only 115 MW of new RES power plants were connected to the network. At the same time, from 2019 to 2020, the 500 MW of wind power plants will be built and connected to the electricity power network. Therefore, it is possible to conclude that the trend of RES share will be positive for the period from 2018. to 2020.

Predicted changes of GFEC according to the scenario with measures for energy efficiency, for the period from 2010 to 2020, is shown in fig. 2. It can be seen clearly, with the diagram shown in fig. 2, that the biggest savings are projected in the heating and cooling sector [4].

Previous research related to improving the energy efficiency of the heating systems in buildings have shown that the following energy savings can be achieved [25]:
- Cutting the heat loses, by piping insolation – from 5 to 8%.
- System balancing and introducing central and local automatic control – up to 15%.
- Heat recovery in air handling units in winter – up to 30%.
- Replacement of heat source – from 20 to 55%.

It can be concluded that the biggest savings of primary energy for heating just derive from careful and proper selection of heat source for the heating system. In order to design efficient heating system it is necessary to analyze building heating needs during the heating season and to adjust a system and its operational regimes to the requirements. Considering that dynamic change of heating needs is present during the heating season, it is very important to construct seasonal heat load duration curve, according to climate date for the location of the building.

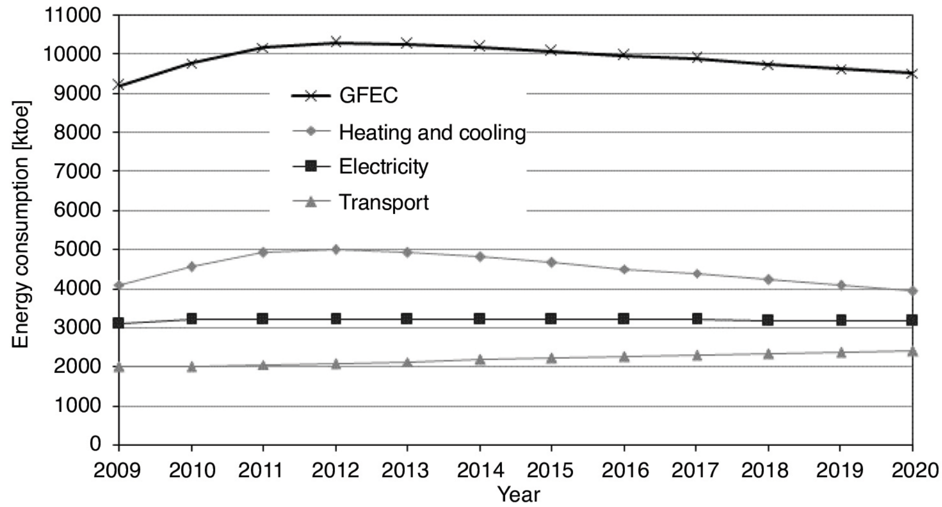

Figure 2. The GFEC in total and by sectors - according to the scenario with EE measures [27]

Seasonal heat load duration curve

In order to gain a better overview of the heating system operation during the entire heating season, it is necessary to observe frequency of outdoor air temperature values. For this reason, the annual heat load duration curve is constructed, using data of TMY for Belgrade [24], which is based on annual frequency of outdoor air temperature, fig. 3. One can see that less than 5% of time during the season external temperature drops under limit value of -5°C. Also, the number of days with outdoor temperature below freezing is rather small, and it accounts to around 40 days, representing approximately 20% of the heating season duration.

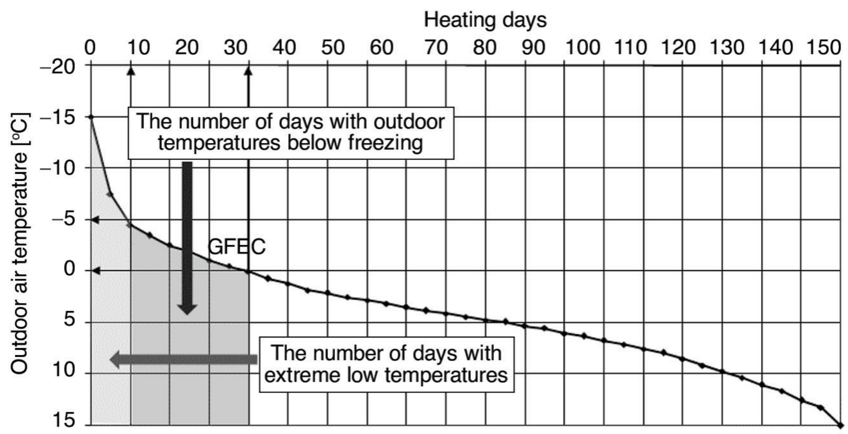

Figure 3. Frequency of outdoor air temperature for Belgrade weather data

During the transitional periods, at the beginning and the end of the heating season, the outdoor temperature is high, resulting in a favorable application of renewable energy sources. However, during the aforementioned periods (October and April), the consumption of energy for heating is not high, that is, the proportion of energy consumed in those periods is less than 20% in total consumption for heating on an annual basis.

The seasonal heat load duration curve is constructed for the family house, located in Belgrade. The methodology of heat losses calculation used in the paper is in accordance with the standard SRPS EN 12831-1:2017 [28], taking into account both transmission and ventilation heat losses. The heat losses are varied depending on the outdoor air temperature in order to obtain the dependence function of heating capacity on outdoor temperature fig. 4(a) and heating curve fig. 4(b).

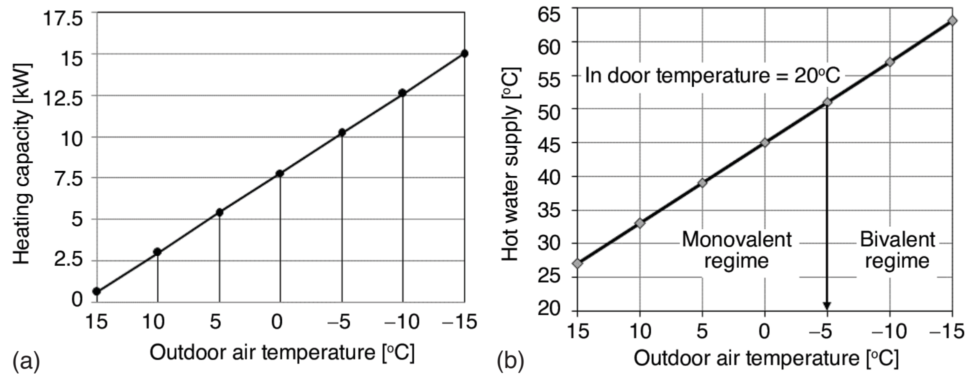

Figure 4. Heating capacity in dependence of outdoor temperature (a) and heating curve (b)

Net heating area of the house is 150 m^2, with radiator central heating system in temperature regime of 63-48°C, with installed electrical boiler, with heating output of 18 kW. Preparation of domestic hot water (DHW) is done by conventional electrical system. Final energy need for heating amounts to 100 kWh/m^2, which was calculated using a fully prescribed monthly quasi-steady-state calculation method [29].

In order to obtain efficient use of energy for heating, the replacement of existing boiler with the hybrid heat source that includes RES is recommended. Seasonal heat load duration curve is constructed based on frequency of outdoor air temperature for Belgrade weather data and heating capacity in dependence of outdoor temperature. Seasonal heat load duration curve for Belgrade weather data is shown on fig.5.

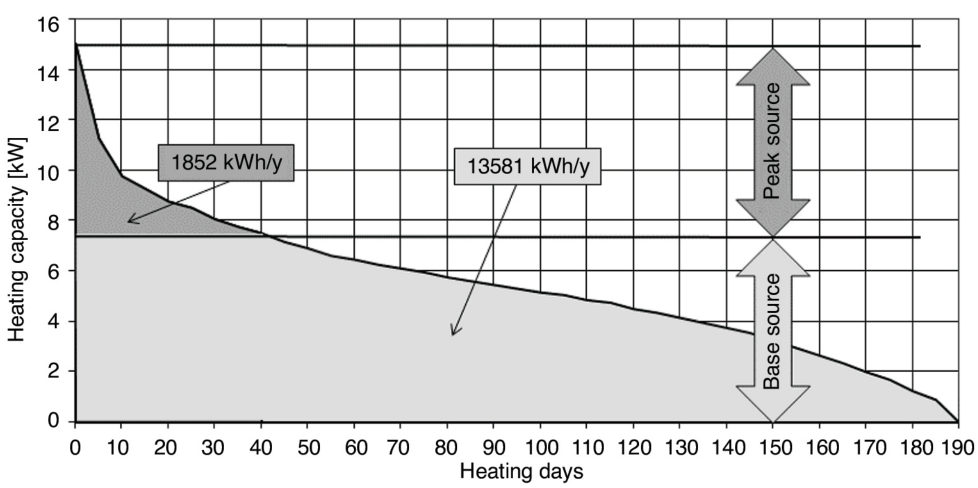

Figure 5. Seasonal heat load duration curve for Belgrade weather data and selection of base and peak heat source

Efficient hybrid heating systems

The main idea of this research was to show the impact of different types of hybrid systems on energy savings, comparing to the conventional systems and for this purpose, three different hybrid heat source systems are proposed:

- Hybrid 1: air to water heat pump (base source) + electric heaters (peak source).
- Hybrid 2: air to water heat pump + thermal solar energy panels (base source) + electric heaters (peak source).
- Hybrid 3: air to water heat pump + thermal solar energy panels (base source) + gas boiler (peak source).

The recommended hybrid heat source consists of: air to water heat pump, with heating output of 7.5 kW and seasonal COP of 3.45 [3], thermal solar energy panels (of 5 m^2 with the efficiency of 78.5%, with heating output of 100 W/m^2 – for Cases 2 and 3) – as a base source, and additional heaters of 7.5 kW – as a peak source (electrical heaters for Cases 1 and 2; gas boiler for Case 3). In the case of application of hybrid system it is possible to cover both heating needs and needs for DHW by adding a hot water tank. It is highly recommended to use the same heat source for both purposes – space heating and preparation of DHW. Such a solution does not require an additional heat source for DHW and an investment cost is very profitable.

Diagram in fig. 6 is showing the share of each heat source in providing heating energy on annual basis.

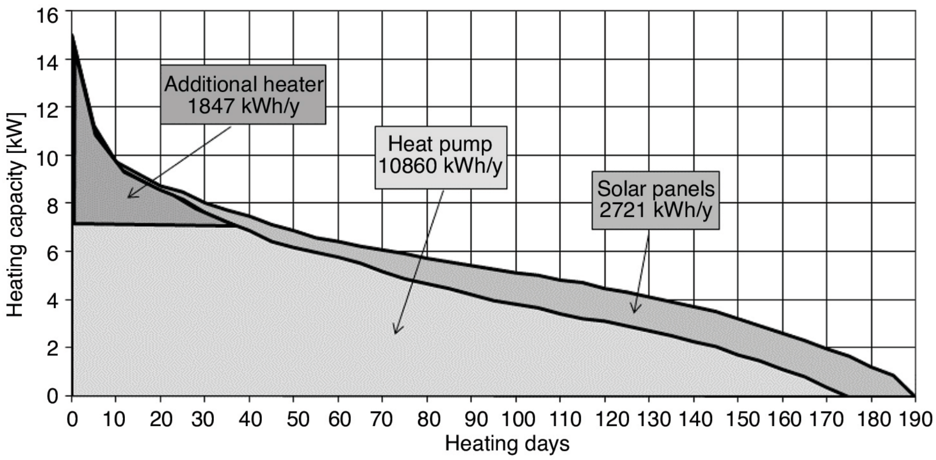

Figure 6. Seasonal heat load duration curve for hybrid heat source (Cases 2 and 3)

The conventional heat source is operating in monovalent mode during the whole heating season, covering total heat demand of 15433 kWh per year. In the case of application of Hybrid 1 fig. 5, the heat pump is covering 13581 kWh per year (88% of annual heat demands), while the electrical heaters are covering 1852 kWh per year (12% of annual heat demands). In the case of Hybrid 2 and Hybrid 3, the heat pump is covering 10860 kWh per year (70% of annual heat demands), solar panels are covering 2721 kWh per year (18% of annual heat demands), while the additional heaters are covering 1847 kWh per year (12% of annual heat demands).

Results and discussion

In order to investigate the justification of the hybrid systems application, the analysis of the substitution of different conventional systems with hybrids was carried out. The analysis included following parameters: primary energy consumption; seasonal heating bills and CO_2

emissions generated by the operation of the heating system. The required annual primary energy for the operation of the heating system, as well as the annual CO_2 emissions, are calculated in accordance with the methodology prescribed by the Regulation on Energy Efficiency of Buildings [30]. The annual heating bills were calculated in accordance with the tariff systems for energy payment (electricity and DH) and the prices of fuels on the market in the Republic of Serbia. Accordingly, the obtained values are shown in tab. 2.

Table 2. Primary energy consumption, CO_2 emissions and seasonal heating bills depending on applied heat source

	Electricity	DH	Coal	Fuel oil	Gas	Hybrid 1	Hybrid 2	Hybrid 3
Primary, energy [kWh per year]	42,441	28,057	23,072	20,372	18,674	14,202	12,293	9,853
CO_2 emission [kg per year]	22,494	9,259	9,229	5,704	3,735	7,527	6,515	5,685
Annual bill [€/per year]	1,175	1,818	552	1,714	810	365	318	295

Diagrams on fig. 7 are showing, respectively, relative reduction of primary energy and heating bills regarding the application of different Hybrids.

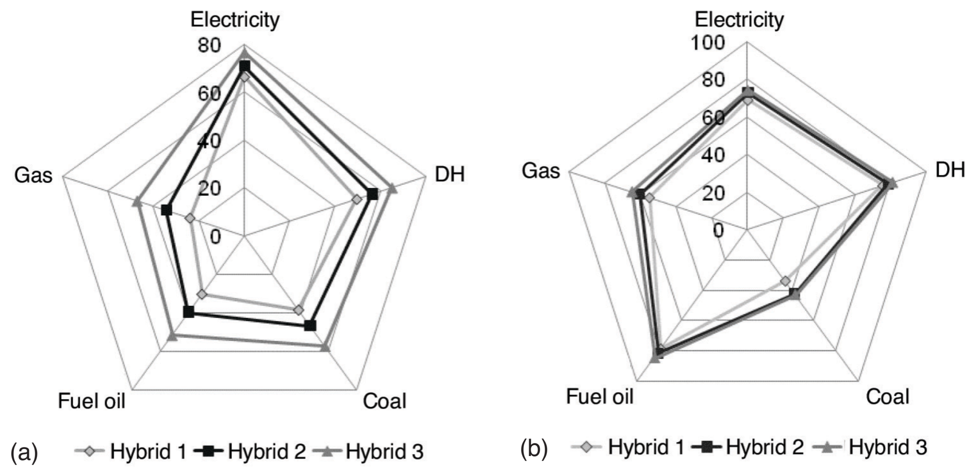

Figure 7. Relative reduction of primary energy (a) and heating bills (b)

Regarding primary energy savings it is evident that all hybrid systems would provide significant reductions. The highest savings can be achieved in the case of substitution of an electrical heater with hybrids, resulting in relative primary energy reduction of 67 up to 77%, while substitution of a gas boiler with hybrid system results in relative primary energy reduction of 24 up to 47% fig. 7(a). When analyzing the annual heating costs, it is noted that the greatest savings are achieved by replacing the fuel oil boiler with a hybrid system, when the savings can be over 80%. The lowest cost reduction is achieved by replacing the boiler with coal, with a reduction in the cost of about 40%. Figure 8 shows a diagram of specific annual heating bills, depending on the heat source used.

Reduction in CO_2 emission are achieved in the cases of substitution conventional heat sources like electricity, district heat and coal. Relative reduction in CO_2 emission are varied from 70% regarding electricity heat source replacement, to about 30% regarding substitution of DH and coal boiler. On the other hand, by replacing fuel oil and natural gas boilers with proposed hybrid systems, CO_2 emissions are not reduced. This is due to the fact that the heat pump uses electricity to drive the compressor, as well as the air fan in the outer unit.

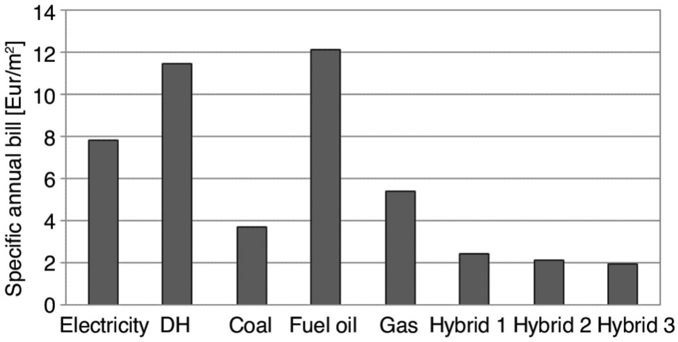

Figure 8. Specific annual bills for heating regarding energy source

From the previous analysis it is clear to notice the advantages of hybrid systems in relation to conventional ones, when energy savings and heating bills reduction are in focus. However, there remains a question of the profitability of the application of hybrid systems. In order to determine the financial justification of the application of hybrid systems, financial benefits during the technical life cycle must be evaluated. For this purpose, the calculation of works and equipment prices for the implementation of hybrid systems was made. The investment cost of Hybrid 1 is 5500 €, concerning installation of air to water heat pump with integrated electric heaters. The installation of solar panels, buffer tank and connection to the system amounts to 2430 €, while installation of gas boiler amounts to 1060 €. Thus, specific investment cost are ranging from 37 €/m^2 up to 60 €/m^2. The payback period for each of hybrid system is calculated, regarding substitution of different conventional energy source for heating, fig. 9. Only in the case of substitution conventional system with gas boiler, investment cost of a new gas boiler are excluded, since it is possible to use an existing one.

From the diagram in fig. 9, it is noted that the investment payback period of the hybrid system is acceptable in the case of substitution of conventional systems using fuel oil, electricity or district heat. The payback period ranges between 4.5 and 5.5 years when it comes to replacing sources using fuel oil and district heat. A somewhat longer payback period occurs in the case of replacement electrical heaters, and varies within the limits of 6.5 to 9 years. The case of replacing the source with a gas boiler is at the limit of profitability and the most appropriate application is the application of Hybrid 3. In this case, the payback period is 12 years. When it comes to replacing the boiler that burns coal, one can not talk about profitable solution.

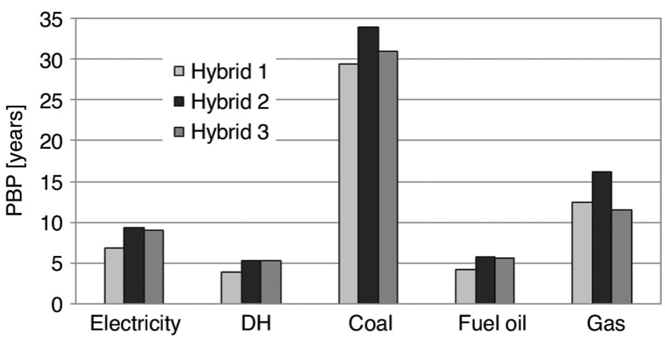

Figure 9. Payback period of hybrid systems regarding substitution of different conventional energy source for heating

Conclusions

The analysis of application of hybrid heating system, conducted in this paper, has shown significant potential for energy savings by application of renewable energy sources. In order to gain a better overview of hybrid system operation during the entire heating season, annual heat load duration curve is constructed, using data of TMY for Belgrade. It is shown that heat pump, together with solar system can cover over 90% of heat demands. Calculation of the energy consumption for each day of the heating season is performed in order to determine energy consumption. The results obtained through the conducted analysis are showing that all proposed hybrid systems would provide significant reductions in primary energy and heating bills. The reduction in primary energy varies from 24 up to 77% in dependence of applied hybrid system and conventional which should be substituted. Regarding annual heating bills it is shown that reduction varies from 40 up to 80% in dependence of applied hybrid system and substituted conventional one. The investment costs are reasonable, varying in the range of 37 to 60 €/m^2. Also, financial parameters are in favor of hybrids when it comes to replacement of conventional heat sources like fuel oil, electricity and district heat, providing profitable energy efficiency projects for house owners.

The most important advantages of the hybrid system application are the following:

- The possibility of application when reconstructing the building envelope, without changing the heating system, but switching to low-temperature regime.
- Relatively low investment costs with payback period from 4.5 up to 9 years.
- Very low exploitation expenses for heating (from 1.7 to 2.2 € per day).
- Improving thermal comfort by maintaining indoor temperature within the desired limits throughout the season, as well as continuous supply of DHW.
- Engagement of the user is minimal considering fully automated operation.
- The possibility of simultaneous application for heating and central preparation of domestic hot water.

References

[1] ***, Energy Balance for 2015, Official Gazette 147/2014, 2015, http://www.mre.gov.rs.
[2] ***, Statistical Yearbook of Serbia, Belgrade, Serbia, 2010, http://webrzs.stat.gov.rs/WebSite/repository/documents/00/00/08/46/god2010pog07.pdf and http://webrzs.stat.gov.rs/WebSite/repository/documents/00/00/48/23/SGS-Potrosnja_stanovnistva.pdf.
[3] Todorović, M. N., Grujujicki, B., Application of Ait to Water Heat Pump in Serbian Climate Conditions, *Proceedings*, SIMTERM 2015, Soko Banja, Serbia, 2015
[4] ***, Statistical Office of the European Union - Eurostat: https://ec.europa.eu/eurostat/web/energy/data/shares
[5] Hohne, P. A., *et al*., Optimal Energy Management and Economic Analysis of a Grid-Connected Hybrid Solar Water Heating System: A Case of Bloemfontein, South Africa, *Sustainable Energy Technologies and Assessments*, *31* (2019), Feb., pp. 273-291
[6] Paspaliaris, I., *et al*., Application of a Hybrid Energy System Combining RES and H2 in an Office Building in Lavrion Greece, *Renewable Energy Power and Quality Journal*, *1* (2017), Mar., pp. 797-801
[7] Du, H., *et al*., Performance Analysis of Solar and Air Source Heat Pump Hybrid Heating Systems applied in Shandong Rural Area, IOP Conferences Series: Earth and Environmental Sciences, *Proceedings*, 4th Asia Conference of Interantional Building Performance Simulation Association, Hong Kong, China, 2018
[8] Rostamzadeh, H., *et al*., A Novel Multigeneration System Driven by a Hybrid Biogas-Geothermal Heat source, Part I: Thermodynamic modeling, *Energy Conversion and Management*, *177* (2018), Dec., pp. 535-562
[9] Rostamzadeh, H., *et al*., A Novel Multigeneration System Driven by a Hybrid Biogas-Geothermal Heat Source, Part II: Multi-Criteria Optimization, *Energy Conversion and Management*, *180* (2019), Jan., pp. 859-888
[10] Talebi, B., *et al*., Optimization of a Hybrid Community District Heating System Integrated with Thermal Energy Storage System, *Journal of Energy Storage*, *23* (2019), June, pp. 128-137

[11] Karki, S., *et al*, Investigation of the Combined Efficiency of a Solar/Gas Hybrid Water Heating System, *Applied Thermal Engineering*, *149* (2019), Feb., pp. 1035-1043
[12] Uche, J., *et al*., Analysis of a Domestic Trigeneration Scheme with Hybrid Renewable Energy Sources and Desalting Techniques, *Journal of Cleaner Production*, *212* (2019), Mar., pp. 1409-1422
[13] Fine, J. P., *et al*., A Methodology for Predicting Hybrid Solar Panel Performance in Different Operating Modes, *Renewable Energy*, *130* (2019), Jan., pp. 1198-1206
[14] Taler, D., *et al*., Operation Assessment of Hybrid Heat Source for Heating the Building and Preparation of Hot Water in the Fire Brigade Building, *Journal of Cleaner Production*, *214* (2019), Mar., pp. 962-974
[15] Bellos, E., Tzivanidis, C., Multi-Objective Optimization of a Solar Assisted Heat Pump-Driven by Hybrid PV, *Applied Thermal Engineering*, *149* (2019), Feb., pp. 528-535
[16] Bellos, E., Tzivanidis, C., Energetic and Financial Sustainability of Solar Assisted Heat Pump Heating Systems in Europe, Sustainable Cities and Society, *33* (2017), Aug., pp. 70-84
[17] Klein, K., *et al*., Numerical Study on Hybrid Heat Pump Systems in Existing Buildings, *Energy and Buildings*, *69* (2014), Feb., pp. 193-201
[18] D'Ettorre, F., *et al*., Model Predictive Control of a Hybrid Heat Pump System and Impact of the Prediction Horizon on Cost-Saving Potential and Optimal Storage Capacity, *Applied Thermal Engineering*, *148* (2019), Feb., pp. 524-535
[19] Bartolucci, L., *et al*., Hybrid Renewable Energy Systems for Household Ancillary Services, *International Journal of Electrical Power and Energy Systems*, *107* (2019), May, pp. 282-297
[20] Cui, B., *et al*., A Hybrid Building Thermal Modeling Approach for Predicting Temperatures in Typical, Detached, Two-Story Houses, *Applied Energy*, *236* (2019), Feb., pp. 101-116
[21] Bartolucci, L., *et al*., Renewable Sources Integration Through the Optimization of the Load for Residential Applications., *Energy Procedia*, *142* (2017), Dec., pp. 2208-2213
[22] Vallati, A., *et al*., Energy Analysis of a Thermal System Composed by a Heat Pump Coupled with a PVT Solar Collector, *Energy*, *174* (2019), May, pp. 91-96
[23] Poppi, S., *et al*., Techno-Economic Review of Solar Heat Pump Systems for Residential Heating Applications, Renewable and Sustainable Energy Reviews, *81* (2018), Part 1, pp. 22-32
[24] ***, Weather Data for Typical Meteorology Year for Belgrade, http://www.eere.energy.gov/buildings /energyplus/weather_data.cfm.
[25] Todorović, M. N., *et al*., Survey of Potential Energy Savings in the Building Sector in Serbia and Needed Investments, *Proceedings*, SIMTERM 2013, Soko Banja, Serbia, 2013
[26] Todorović, M. N., Energy Efficiency and Use of Renewable Energy Sources in Serbia, *Proceedings*, Society of Thermal Engineers of Serbia, IEEP 2015, Zlatibor, Serbia, 2015
[27] ***, National Action Plan for Renewable Energy Sources (in Serbian), Belgrade, Serbia, 2013, http://www.mre.gov.rs/doc/efikasnostizvori/NREAP%20OF%20REPUBLIC%20OF%20SERBIA%2028 _June_2013.pdf?uri=CELEX:32009L0028
[28] ***, Standard SRPS EN 12831-1:2017 - Energy Performance of Buildings - Method for Calculation of the Design Heat Load; Part 1 - Heat Load of Heated Space, Module M3-3, 2017
[29] ***, Standard SRPS EN ISO 13790:2010 - Energy Performance of Buildings - Calculation of Energy Use for Space Heating and Cooling, 2010
[30] ***, The Regulation on Energy Efficiency of Buildings (in Serbian), Official Gazette of the Republic of Serbia, No. 61/2011, 2011, http://www.ingkomora.org.rs/strucniispiti/download/ee/PRAVILNIK_O_EEZ_ za% 20obuku.pdf

Paper submitted: July 26, 2018
Paper revised: April 5, 2019
Paper accepted: April 21, 2019