DIFFERENT HEATING SYSTEMS FOR SINGLE FAMILY HOUSE
Energy and Economic Analysis

by

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The existing building stock energy consumption accounts for about 38% of final energy consumption in Republic of Serbia. 70% of that energy is consumed by residential sector, mostly for space heating. This research is addressed to the single family house building placed in the Belgrade city. The house has ground and first floor with total heating area of 130 m^2 and pellet as space heating source. The aim of this paper is to evaluate energy and economic analysis for different heating systems. Several home heating were compared: Option 1 (biomass combustion boiler using pellet as a fuel), Option 2 (gas combustion boiler), and Option 3 (heat pump). The building performance was evaluated by TRNSYS 17 simulation code. Results show estimated savings using renewable energy sources.

Key words: *TRNSYS, single family house, heating system options, renewable energy sources*

Introduction

Energy supply in the future should be safer, more accessible and more environmentally friendly while energy efficiency, in all sectors of energy consumption, will become even more important. To achieve energy efficiency in heating we have to be adapted to the new energy sources use (renewable energy sources) and new ways of energy savings. Energy efficient houses present only one part of the global energy efficiency.

Concept of energy efficiency improving in buildings (in family houses, residential and non-residential buildings) involves the continuous and wide range of activities with a goal to reduce consumption of all kinds of energy, with the same or better conditions in the facility.

Non-renewable energy sources (fossil fuels) consumption reducing by the implementation of energy efficiency measures and renewable energy use, leads to a reduction of greenhouse gas emissions (CO_2, *etc.*) as a consequence. That contributes to the protection of the environment, global warming reduction and sustainable development of the country.

Buildings are responsible for 40% of energy consumption and 36% of CO_2 emissions in the EU. Currently, about 35% of the EU's buildings are over 50 years old. By improving the energy efficiency of buildings, we could reduce total EU energy consumption by 5% to 6% and lower CO_2 emissions by about 5% [1-3]. The Energy Performance of Buildings Directive (2010/31/EU) [4] and the Energy Efficiency Directive (2012/27/EU, amending Directives

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2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC) [5] are the EU's main legislation when it comes to reducing the energy consumption of buildings. EU countries have calculated the cost-optimal minimum energy performance requirements for new as well as renovated buildings. Member states of EU are required that all new buildings have to be nearly zero-energy by the end of 2020 and all new buildings in the public sector by the end of 2018.

The average building energy consumption in Serbia is over 150 kWh/m² per year, while in developed European countries is even below 50 kWh/m². Building sector consumes 41% of the total final energy in Serbia. The analysis of final energy consumption in households shows that 15% are used by electrical appliances, 4% for lighting, 4% for cooking, 17% for DHW, 5% for space cooling and 55% for space heating, [6]. About one third of the energy consumption in buildings is used to provide good dwelling thermal conditions and lighting. Buildings in the Republic of Serbia are great consumers of energy. Energy consumption can be reduced by construction of new energy-efficient buildings as well as by renovation of existing buildings to improve their energy performance. These facts compel Serbia to intensify activities on achieving standards already valid in the EU countries. Directive 2002/91/EC and 2010/31/EU are included in two Serbian lows: the *Law on Planning and Construction* and the *Law Concerning the Rational Use of Energy* [7, 8].

Required object heating energy demand depends on climate, building shape, building orientation, object structure and thermal insulation quality of the building envelope. The data used for calculations, which depend on the climatic conditions are: heating degree-days (HDD), number of heating days and difference between the internal and external average temperatures. Heat transfer coefficient through the thermal elements of the building envelope (U-value) is another information required for the heating energy demand calculation. Heat losses through building thermal envelope elements depend on element structure, their orientation and thermal conductivity of built-in materials. Heat losses through windows and exterior walls amounts approximately 70% of total heat losses in a building. Thermal insulation of the house envelope can reduce heating bills for about 50-80%.

The most common measures taken in order to reduce energy losses and increase energy efficiency are: heated space isolation, windows replacement, inefficient energy appliances replacement by efficient ones, installation of measuring and control devices for energy appliances, replacement of non-renewable resources with renewable, introduction of the tariff system by distributors that will encourage energy saving, *etc.*

Designers can also predict the thermal behavior of buildings prior to their construction and simulate energy costs in existing buildings under its´ current conditions, establishing the best thermal retrofitting measures to be adopted in the buildings under analysis. The energy simulation software tools can be important for reducing the energy cost in buildings. Thermal simulation software tools for buildings allow to: determine the appropriate size of HVAC systems, analyze energy consumption and calculate consumed energy expense.

More recently, focusing on the methodology to estimate building energy consumption, other researchers have used certain simulation programs. Analysis of a possible energy retrofit of an existing hospital buildings using an innovative renewable polygeneration system is presented in the paper [9]. The system is designed and dynamically simulated in TRNSYS environment. The results are analysed from both, energy and economic, points of view. The aim of the paper [10] was to analyse building performance and thermal behaviour of a room chosen for the comparison test between two codes, TRNSYS and EnergyPlus. Results showed that two simulation codes are in good agreement and, the TRNSYS is extremely flexible for the simulation of different transient systems, while the EnergyPlus is more specific for the study of building behaviour. Haddam *et al.* in paper [11] show a new approach for buildings´ modelling and passive houses proper design in an arid region. Improving the thermal comfort in a multi-zone building and direct solar gains control, temperatures and specific humidities was introduced.

This study examines three different options of home heating system where thermal energy´s obtained from different sources. Energy and economic analysis was performed by using TRNSYS simulation cod. The aim of this analysis, with the economic and energy point of view, is compare to obtained thermal energy from the basic (pellet) heating system option with two different heating systems (using gas as fuel and heat pump), for single family house. Also, the general data of analyzed options are shown as well as the financial indicators which are calculated on their bases. The rank of options are made in case when considered the average annual savings, over the lifetime of the heating systems, in relation to the costs of the thermal energy received from the district heating system.

Description of the residential building and its position

Family residential building is located in a municipality of Belgrade city. The house consists of ground and first floor with 130 m^2 of total heated space area. The building is moderately sheltered. All four façades of the houses are open and moderately exposed to dominant winds. At immediate vicinity, there is another house of the same height facing the south west side of the building. All other objects in the close environment are with lower height and do not prevent insolation, fig. 1. Climate data refer to the building under consideration is: number of heating degree days, HDD = 2520, number of heating season days, HD = 175, and the mean outside air temperature for the heating period equal to 5.6 °C. The internal building air temperature for the heating system design is 20 °C.

(a) (b)


Figure 1. Single family house; (a) view of house façade 1, (b) view of house façade 2

For the validation of the simulation model presented in this paper, mean values of temperature measured in the period from February 15, 2009, until April 15, 2009, were used with half-hourly interval recording measured values and owner estimated pellet amount consumed for a heating season. Temperatures were collected by two HOBO logger instruments with a range from –20 to 70 ºC and accuracy of ±0.35 ºC. One logger was places at each object level at a height of about 1.5 m above the floor, at places protected from direct solar radiation, the impact of external walls, air conditioners and heat sources. Methods and instruments for this measurement, were selected in accordance with international standards ISO 7730 (1994): Moderate thermal environments – Determination of the PMV and PPD indices and specification of the conditions for thermal comfort and ISO 7726 (1998): Ergonomics of the Thermal Environment – Instruments for Measuring Physical Quantities.

The exterior wall thickness is 38.6 cm and standard quality floor is set on the heap soil with thickness of 66.5 cm without thermal insulation, tab. 1. The internal partition walls are done with bricks and mortar with different thicknesses. Interior walls and ceilings finishing is made by cement mortar layer. The hip roof is complex with wooden construction and grooved tiles roofing. The insulation of the roof ceiling is mineral wool 5 cm thick. There are built chimneys, double wooden windows and balcony doors, window curtains are wooden shutters, entrance door are wooden, interior doors are flat with double plywood, guttering are of galvanized steel. Characteristics of thermal elements of the building envelope are in tab. 1.

Table 1. Data of thermal building envelope

Data of the building thermal envelope	U [$Wm^{-2}K^{-1}$)]	U_{max} [$Wm^{-2}K^{-1}$)]	Structure
Exterior walls	0.371	0.40	Insulation Knauf 0.8 cm; polystyrene board 2 cm; gas concrete block 29 cm; compo mortar 1 cm; polystyrene board 5 cm; compo lime mortar 0.8 cm
The floor construction towards unheated space	0.283	0.40	Compo mortar 1 cm; insulation Knauf 2 cm; reed insolation 10 cm; insulation Knauf 2 cm; cement mortar 1 cm
The floor construction over outer space	0.356	0.30	Parquet 2 cm; cementitious screed 4 cm; ferro-concrete 16 cm; polystyrene board 10 cm, compo lime mortar 0.8 cm
The floor on the ground (type I)	1.194	0.40	Parquet 2 cm; cementitious screed 4 cm; waterproofing 0.5 cm; resurfacing layer of concrete 10 cm; layer of compacted stone 50 cm
The floor on the ground (type II)	1.320	0.40	Ceramic tiles 2 cm; cementitious screed 4 cm; waterproofing 0.5 cm; resurfacing layer of concrete 10 cm; layer of compacted stone 50 cm
The windows of rooms which was heated	2.687	1.50	Wood with double-layer glass package (4-12-4), vacuum, usually glass
Exterior door	2.000	1.60	Wood

In the courtyard of the analyzed object, there is an extra building serving as a boiler room. Indoor air room temperatures in the winter and summer period are held within the limits of comfort. All windows in the house have window blinds or wooden shutters as a protection from a direct sunlight during the summer months. Calculated heat transfer coefficient U-value [$Wm^{-2}K^{-1}$] for building structure and envelope elements, whose values are less than the maximum allowable for existing facilities, shows that materials of the building structure and envelope elements have been properly sized and selected and realized acceptable thermal comfort. Maximum heat transfer coefficient U_{max}, which are shown in tab. 1 are taken from [12]. The house ventilation is done in a natural way.

Description of the considered heating system options

The thermal energy required for heating is produced in individual boiler room placed in the courtyard. This paper discusses three different options of thermal energy sources for the space heating. The first option (Option I) is a heating system with a biomass-fired boiler, fig. 2(a). Heat source is a boiler burning pellet as a fuel (woody biomass), installed in 2011, with 25 kW of heating capacity, boiler efficiency η = 90% and the price of the investment of 850 €. Wooden pellet with calorific value H_d = 18.6 MJ/kg is automatically fed into the boiler. There is a two-pipe radiator systems with steel radiators. The heating fluid is water entering the radiator with 60 °C and leaving with 40 °C. Second option of heating system (Option II) is a boiler burning gas as a fuel with heating system designed for 60/40 °C in/out water temperatures, the efficiency of 94% and investment cost 950 €, fig. 2(b). Third option (Option III) are system supplied with air-water heat pump with two units, outdoor and indoor, as shown in fig. 2(c). The rated heating power of the heating pump is 2.5 kW and the price of the investment of 5000 €.

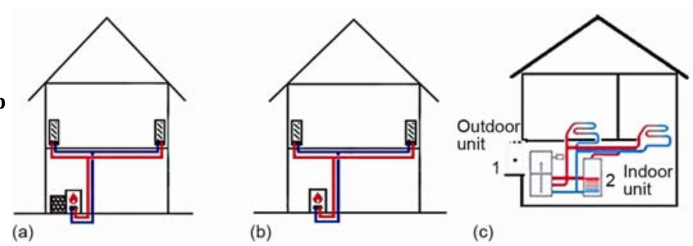


Figure 2. (a) Option 1 (biomass boiler); (b) Option 2 (gas boiler); (c) Option 3 (heat pump air-water)

Building simulation program TRNSYS and Trnbuild

The TRNSYS is a transient system simulation software tool with a modular structure and has been specially designed to develop complex systems related to energy, outlining the problem in a number of smaller components. The components (Types) are configured through the graphical user interface known as TRNSYS Simulation Studio. In this paper, to simulate building thermal behaviour, TRNSYS version 17 and the multi-zone building model (Type 56) are used. This component model deals with the thermal balances and herein presented a building has 13 thermal zones.

The 3-D modeling of the single family house has been done in GoogleSketchUp by using OpenStudio (allows to create a building geometry: add zones, draw heat transfer surfaces, draw windows, draw shading surfaces, *etc.*) that was taken as an input file in program TRNSYS. Figure 3 shows 3-D modeling of the single family house.

Figure 3. 3-D modeling of the single family house

In order to use Type 56 before that the model of the building must be made in a separate program. This is performed in a program called Trnbuild. The inputs and outputs of TYPE 56 depend upon the building description and options within the Trnbuild program. The Trnbuild program reads in and

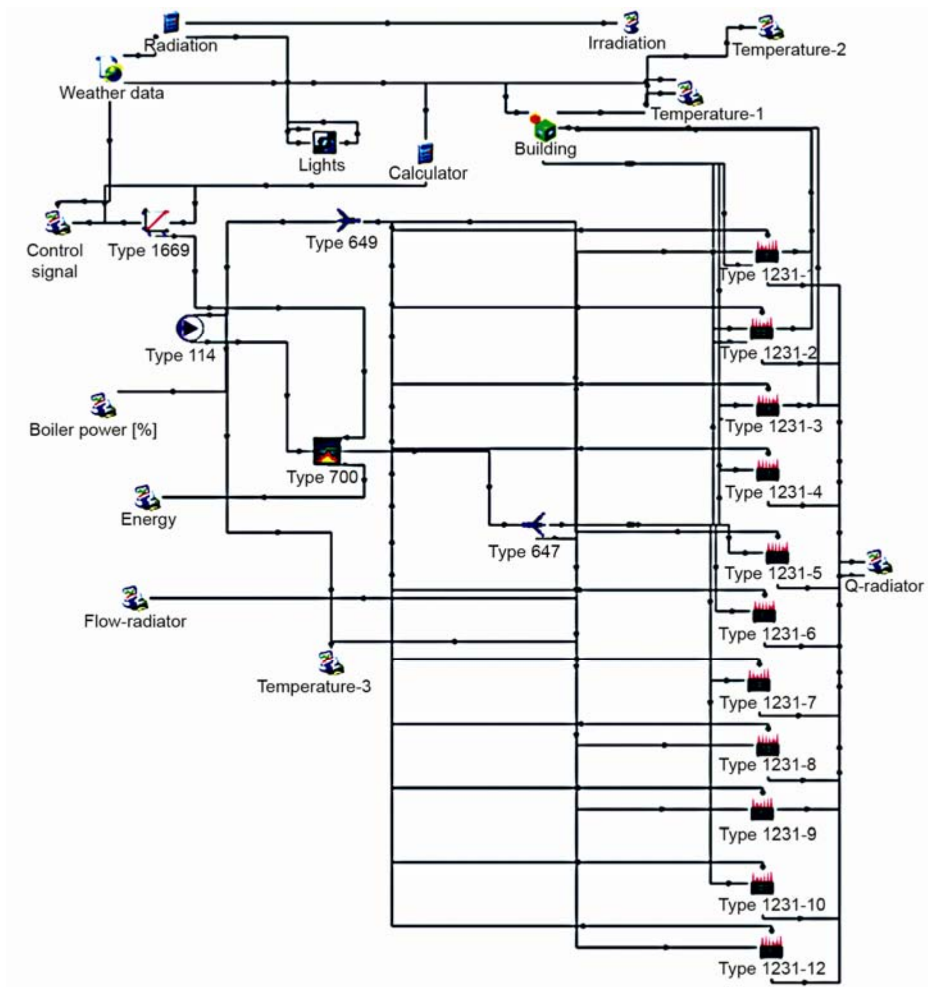
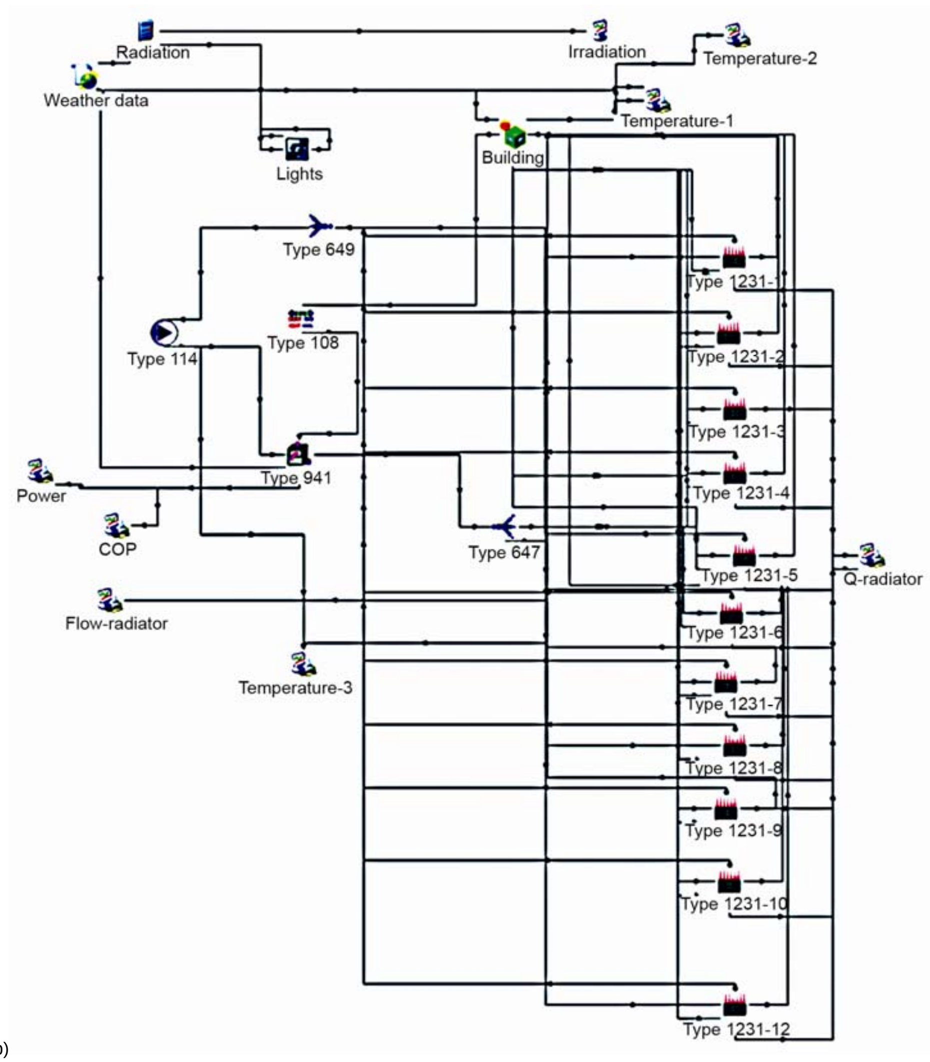


Figure 4(a). Heating systems schema for Options 1 and 2 in TRNSYS Simulation Studio

processes a file containing the building description and generates two files that are used by the Type 56 component during a TRNSYS simulation.

The aim of this paper is to evaluated energy and economic analysis of different building heating systems. The envisaged three options of the building heating systems, which were herein presented, were modelled and simulated in TRNSYS 17 [13]. Following options are considered for energy performance rating: Option 1 presents baseline model (biomass combustion boiler using pellet as a fuel), fig 4(a), Option 2 (gas combustion boiler), fig 4(a), Option 3 (heat pump), fig 4(b). A schematic representation of the heating system in TRNSYS Simulation Studio is the same for Option 1 and 2, while the input parameters such as boiler and combustion efficiency for Type 700 (boiler) depend on the used fuel. In Option 3 Type 941 shows heat source, fig. 4(b).

In order to introduce meteorological data into a mathematical model the component of Type 15-TMY2 (outdoor temperature, humidity, the amount of solar radiation, *etc.*) is used.



(b)

Figure 4(b). Heating systems schema for Options 3 in TRNSYS Simulation Studio

The input of Type 15 is CS-Belgrade-Surcin-132720.TM2. The output values of this module are the input data for the module Type 56. Each of the 12 defined thermal zones has radiator as a Type 1231, fig. 4, which gives zone thermal energy required to maintain thermal comfort.

Results and discussion

Mean values of inner temperatures measured in the period from February 15, 2009, until April 15, 2009, at two places (at first and second floor) in the building were used as a start point in this simulation. At first, Q sends values obtained as an output of Type 56 for each zone and for ideal heating with set temperatures equal to mean measured values, were exploited for the heat gains (radiators) dimensioning. After that, three different heating systems were established in term of different heat sources (boiler fed by pellet, boiler fed by gas and *air to water* heat pump. Heat source devices parameters were adjusted in a way to get indoor mean temperatures approximately equal to mean measured temperatures. Figure 5 presents output zone temperatures (zones from 1-8) obtained in the thermal behavior simulation for the modeled building and the ambient temperature for the whole heating season (from middle of October to middle of April).

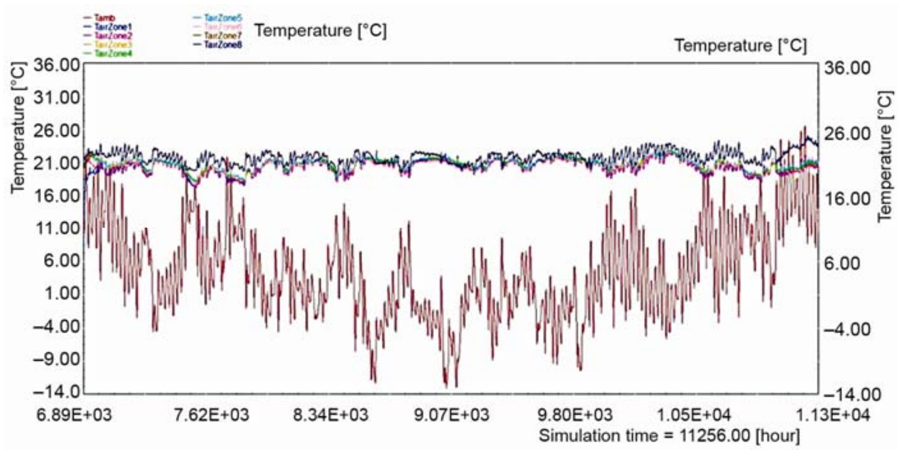


Figure 5. Zone temperatures (1-8) with ambient temperature

Figures 6 and 7 show the required boiler energy input as the rate at which fuel is being consumed by the boiler to heat the fluid, respectively, for boilers fed by pellet and by gas. This term is calculated by dividing the energy provided to the fluid by the boiler efficiency.

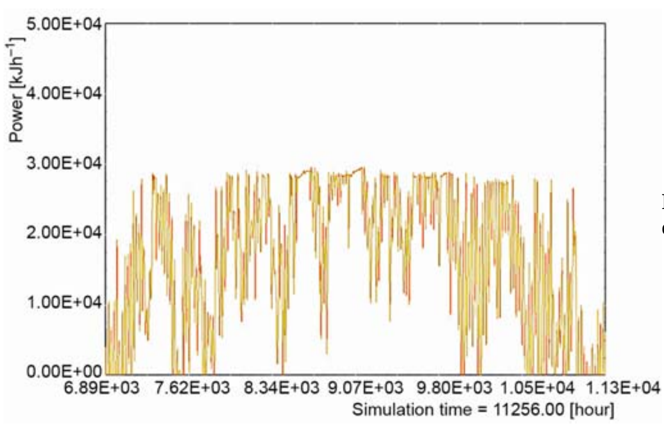


Figure 6. Required pellet boiler energy input

Figure 8 shows the heat pump power which is total power for compressor, controls, and blower consumed by the heat pump while operating.

The amount of required boiler energy input, heat sources transmit to the house (for systems I, II, and III), is result of simulation in TRNSYS Simulation Studio, and it is shown in figs. 6-8. Differences in the amount of energy input for heating the object under consideration in systems I and II are very small, while the amount of heating energy is much smaller in

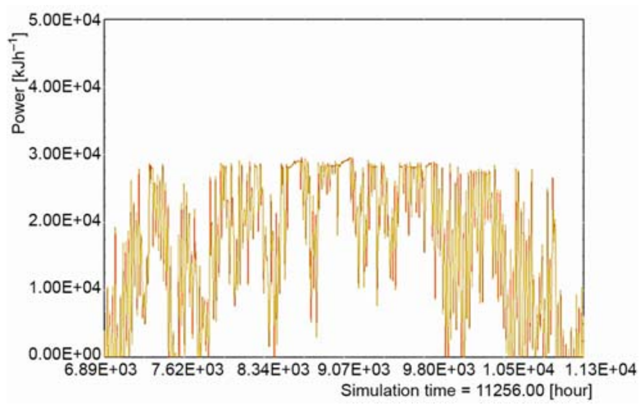


Figure 7. Required gas boiler energy input

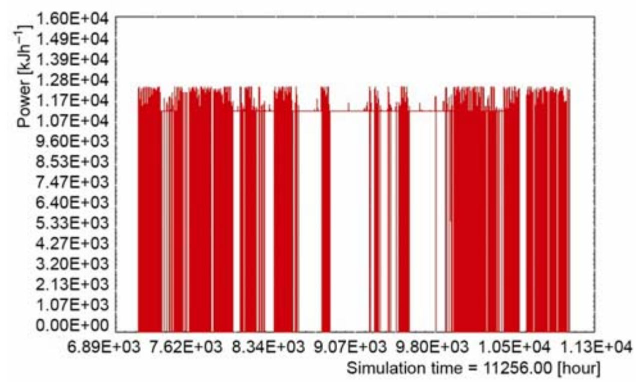


Figure 8. Heat pump power of the air-water heat pump

the case of system III with a heat pump as an energy source. The differences appear due to the different energy efficiency coefficients of the considered heating systems. Systems I and II require greater amount of heating energy and differences of those two systems are smaller as a consequence of approximately equal energy efficiency coefficients. Energy necessary for heating is much lower in the case of system III, based on much higher heat pump energy efficiency coefficient for the entire heating season in comparison with first two heating systems under consideration.

By integration of required boiler energy input values (pellet and gas) throughout the whole heating season (figs. 6 and 7) and heat values of pellet and natural gas, the amounts of combusted fuels were obtained as information relevant for economic analysis. On the other hand, integration of heat pump power value throughout the whole heating season gave amount of electrical energy consumption needed for this analysis, too (tab. 2). Figures 5-8 present the TRNSYS Simulation Studio outputs.

The evaluation of the economic and financial sustainability of the considered options of heating systems

In order to make decisions about heating system options investment and to rank options on the economic effects, the gains and costs have to be assessed. This paper shows the economic and financial sustainability assess of the considered options [14] in regard to base case when the single family house was linked to district heating system. Table 2 presents general information, such as the duration of the project, the tax rate, the

Table 2. General data of considered options that are used in the financial analysis

	Unit	Option 1 (pellet)	Option 2 (gas)	Option 3 (heat pump)
Project duration	[year]	15	15	15
Total initial investment	[€]	3350[(a)]	2150[(b)]	5000[(c)]
The period of periodic costs of the system	[year]	15	15	15
Tax rate	[%]	10.00	10.00	10.00
The annual discount rate (time value of money)	[%]	8.00	8.00	8.00
Annual rate of inflation	[%]	2.00	2.00	2.00
The annual rate of electricity prices increase	[%]	5.00	5.00	5.00
The annual rate of thermal energy prices increase	[%]	5.00	5.00	5.00
The annual rate of pellet prices increase	[%]	2.00	2.00	2.00
The annual rate of natural gas prices increase	[%]	2.00	2.00	2.00
Avoided cost payments of thermal energy	[€/year]	1080[15]	1080[15]	1080[15]
The cost payments of pellets	[€/year]	780[(d)]	0	0
The cost payments of natural gas	[€/year]	0	735[16]	0
The cost payments of electricity	[€/year]	0	0	600[17]
Operating and maintenance costs	[€/year]	50	50	50
Recurring expenses of the system	[€/year]	50	50	50

[(a)] 850 boiler + 2500 boiler room, [(b)] 950 boiler + gas network connection cost, [(c)] heat pump cost, [(d)] 200 [€/t]

annual rate of fuel prices increase, costs of fuel, maintenance costs, recurrent costs, *etc.* The financial indicators are calculated based on general data, tab. 3.

The financial indicators are investment simple rate return and mean annual savings over the lifetime of the facility and they are static parameters which determine the rating of the sustainability options.

Annual net cost savings realized from an investment were added usage by these methods and compared to initial investment. A simple rate of return in investment is the average annual income on the invested assets as a percentage of the initial investment value. Table 3 shows that the simple rate of return on invested funds in the first year was minimum for Option 1 (pellet) –4.06%, followed by Option 3 (heat pump) –3.46%, and the highest was for Option 2 (gas) 2.22%.

Table 3. Financial indicators of the considered heating system options

Financial indicators	Unit	Option 1 (pellet)	Option 2 (gas)	Option 3 (heat pump)
A simple rate of return in investment (first year)	[%]	–4.06	2.22	–3.46
Period of return on investment	[year]	16.75	7.05	11.63
Mean annual savings over the lifetime	[€/year]	110	317	–43

Payback period is the period of time necessary for the return of the initial investment through net cash earnings of investment. Payback period is the highest for Option 1 (pellet)

16.75 year and a minimum for Option 2 (gas) is 7.05 year, while 11.63 years for Option 3 (heat pump). The mean annual savings over the lifetime of the heating system is the highest for Option 2 (gas) 317 €/year, then following savings of 110 €/year for Option 1 (pellet), while there was not savings for Option 3, tab. 3.

This rank of options is a result of the huge initial investment in pellet heating system (boiler-room building in the courtyard) and for a heat pump (high prices on the market) and a relatively small investment for a system of gas heating.

Conclusions

Key features of the energy sector in Serbia are low energy efficiency, both in production and consumption of energy. Buildings can be recognized as relatively large energy consumers of energy. Heating and air-conditioning systems and the renewable energy use are increasingly important role in improving energy efficiency.

The research addresses the single family house building placed in the Belgrade. The pellet is used as a source for space heating. In order to compare different heating systems with the basic option (pellet) the heating systems using gas as fuel and heat pump were considered.

The creation of the building is performed in the earlier stage of an energy simulation, in the software Google Sketch Up. For building energy losses and thermal energy supply systems TRNSYS 17, *component*-based simulation modelling tool is used. The building description (geometry and materials used in the components of the building architecture) has been made in Trnbuild program which generates two files used by the Type 56 component during a TRNSYS simulation.

The paper presents figures of output values obtained in the simulation, such as: zone temperatures and ambient temperature, required pellet boiler energy input, required gas boiler energy input and heat pump power of the air-water heat pump. Also, the paper shows the evaluation of the economic and financial viability of the considered options of the heating system. The general data for the analyzed options are shown: the duration of the project, the tax rate, the annual rate of increase in fuel prices, the annual rate of increase of thermal energy and electricity prices, maintenance costs, recurrent costs, *etc.* The financial indicators are calculated based on general data: investment simple rate return and mean annual savings over the lifetime of the facility. The payback period is the highest for Option 1 (pellet) and the lowest was for Option 2 (gas). This rank of options is a result of the huge initial investment in pellet heating system (boiler-room building in the courtyard) and for a heat pump (high prices on the market) and a relatively small investment for a system of gas heating. In relation to the costs that would be obtained in case that the thermal energy received from the district heating system, average annual savings over the lifetime of the heating system is the largest for Option 2 (gas), followed by Option 1 (pellet), while for Option 3 savings are not available.

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