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Lifecycle and ecomonical study of selected thermal solar installations

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Abstract

Creating a scheme of solar thermal installations is a mighty move forward to develop a suitable energy standards of residential buildings. In recent years were done many studies, which did a several energy simulations for residence buildings. If design of thermal installation is false, it can lead to rise in the expensive overall energy costs and unsatisfactory thermal comfort in the building. Nowdays, in Slovakia using solar thermal installations are increasing more than in recent years. This research investigates twelve modern solar water heating systems, formed on the roof of the family house. We tried to make analysis, where designed solar energy systems were appropriate and fulfill energy requirements of DHW and heating. The study deals with the best financial alternative of the prepared installations of the house. According to overall prices of installation, energy production of additional source for heating and total system efficiency and lifespan, we found out the best possible choice. Expected amount of the various energy contribution is simulated in specialized program. If we talk about midterm energy values, we can see the best possible choice for the alternatives. In this case we made analysis of these schemes for typical family house in Kosice. We set the limits of the building and analyzed which scheme is the best for need of the yearly average water consumption and heating.

Key words: solar thermal energy; cost analysis; domestic hot water

1 Introduction

Building integration has long been recognized as a promising approach for a more successful dissemination of solar thermal systems for domestic hot water and space heating. An improved architectural and constructional quality of the installation can increase the acceptance among architects and end-users and at the same time reduce the system cost thanks to synergic effects [1]. The application technologies of renewable energy have developed rapidly around the world; the solar hot water system is the most basic application of solar energy, and currently has rather obvious economic benefits. The solar energy technology has many advantages and disadvantages comparing to others energy. The potential advantages are: it works on noiseless environment; it does not produce any unwanted waste such as radioactive materials; it has high performance and reliable system; it uses clean technology – it does not produce any toxic waste or radioactive material; it has highly credible system with life span expectation, between 20 and 30 years; it has a low maintenance system [2]. New Renewable energy supply allows achieving long-term sustainability by limiting the impact on future generations. Efficiency improvement refers to increasing the efficiency of energy conversion equipment, which results in less primary energy use during energy generation and delivery procedures. Demand energy reduction requires a social behavior change. Renewable energy generated from regenerative energy sources such as hydro, solar, wind, geothermal and biomass remains a prime objective in the RED policy [3]. Concentrating solar power (CSP) refers to the technology that collects solar energy and converts it into high-temperature thermal energy for heat transfer fluid (HTF), which is then converted into electrical energy using a conventional thermal engine or other forms of power generation technology. Utilizing solar power to generate thermal energy is an effective method for realizing grid-scale dispatch able power generation and replacing conventional energy, which may bring revolutionary solutions to serious energy problems [4]. The solar-thermal conversion is another superb approach for utilization of solar energy, in which the solar energy can be harvested and stored in heat storage materials as thermal energy. The conversion efficiency of solar to thermal energy can reach as high as 80% proving that this approach tends to be a promising direction for the future development of solar energy utilization [5]. 84% of the heating and cooling energy consumption in the EU is still based on fossil fuels while only 16% is provided by the renewable energy sector [6].

This paper deals with evaluating the twelve schemes with five solar panels and other differences and overall cost over the lifetime of the system. Proposed schemes were simulated using program “T*SOL”. This software returns the energy from auxiliary heating, the energy delivered to collectors, the solar contribution to heating and DHW for every choice. There is calculated the net present value for the new ST system for their lifespan and ranked alternatives from the best alternative solar energy installation to the worst. In short, the greater the revenues after the installation lifespan, the better the alternative. We used climate conditions for city Košice (Slovakia) for twelve cases.

2 Materials and Methods

Input data of experimental house are used in TSOL software, such a location of building, thermal installation, latitude and outside and inside temperatures of house. For the following simulations we also needed characteristics of solar panel system and his equipment. One of the important input data are also consumption of domestic hot water (DHW) and characteristic of space heating. For successful study is appropriate to have an economic data such as price of total solar system installations and prices of fuel, energy, pellets etc. In this article we divided our solution into these steps: first step we need to input data of house and solar installation to software. In step two we designed alternatives and got the midterm results of energy delivered by solar thermal panels, which are based on additional heat source. In next part we compared results from software to results in reality. Another step is to do an economic research based on prices of systems and prices of energy from additional sources.

Penultimate step is to make a summarization based on overall investments and yearly savings. After all these results, we did the final step, which is the total life cost.

2.1 Simulation software characteristics and midterm results

We used simulation software TSOL 2018 (Valentin Software GmbH, 10243 Berlin, Germany, which is created for modelling various solar thermal installations. Software contains most of the schemes, which are used around the world. Results are based on outside conditions such as location etc., and energy values such as heat load, type of space heating. Yearly results, which we need are for each alternative are:

- Energy from solar thermal collectors (kWh),
- Total energy produced by system which contains energy to DHW and energy to space heating (kWh),
- Energy produced by additional heat source (kWh),
- Saving by wood boiler (kg), gas savings (m^3), CO_2 emissions avoided by additional source- heat pump (kg).

3 Case study

For this case we used experimental house which is located in Košice, Slovakia. Designed house has one floor, usable area is 53 m^2, indoor temperature 20°C, heat load 5 kW, specific heat load 94.34 W/m^3, specific annual energy supply 163.585 W/m^3. Latitude is 48.7°, longitude -21,3°, total annual global irradiation 1144.4 kWh/m^2, diffuse radiation percentage 53.90%, mean outside temperature 9.8°C, lowest outside temperature is -13°C.
Solar thermal panels have active surface of 1.78 m^2, gross collector area is 2.03 m^2, orientation is on south - 180°, inclination 45° and azimuth angles is 0°. Figure 1 shows each alternative contains and numbers presents following:

1 - Solar collector Thermosolar Žiar TS 300;
2 - Solar preheating tank, 200 liters;
3 - DHW (Domestic hot water) standby tank, 120 liters;
4 - Gas boiler, 15 kW;
5 - Combination tank, 1000 liters;
6 - Dual coil indirect water tank, 300 liters;
7 - space-heating buffer tank, 500 liters;
8 - Heat exchanger;
9 - Floor heating;
10 - DHW consumption;
11 - Heat pump, 14 kW;
12 - Wood fired-boiler 14kW.

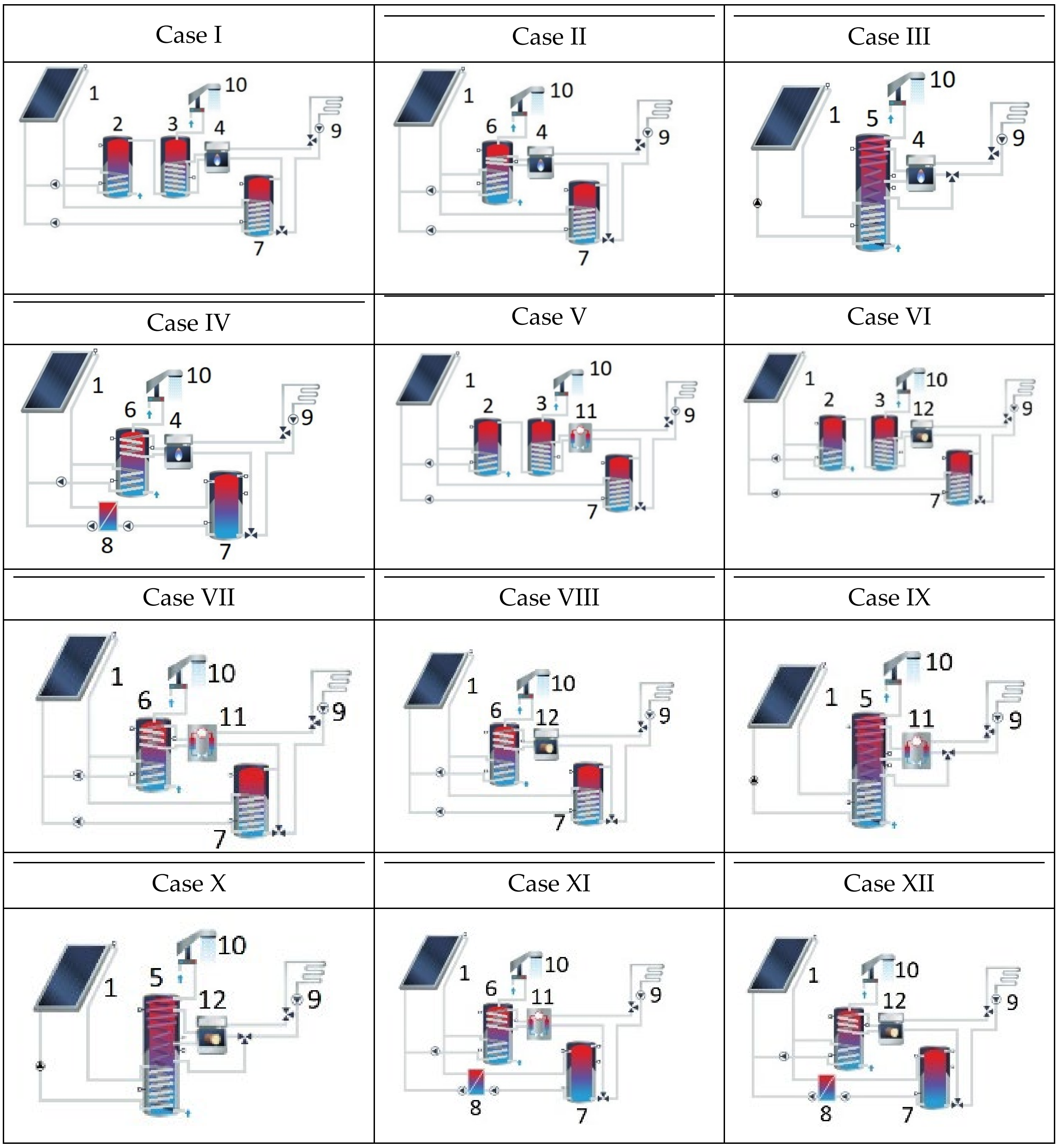

Figure 1 solar thermal schemes

3.1 Financial analysis

Economic analysis of total solar thermal equipment and their lifespan are described in table 1. The lowest starting price has case VI (4664.2 Euro) and the most expensive is case IX (20828.89 Euro). Energy results of simulation in software, which we needed are from additional heating, gas boiler performance with 15 kilowatts and their cost is between 7253 and 4981 euro. In additional heat source heat-pump with performance of 15 kilowatts are prices 20828.89 and 18556.2 euro. In cases where is wood fired boiler as additional source the prices are among 6936.89 and 4664.2 euro.

Table 1 Prices of equipment and lifespan

Equipment	**Case I**	**Case II**	**Case III**	**Case IV**	**Lifespan**
Solar collector TS 300 5x	2128.8	2128.8	2128.8	2128.8	30
Solar Preheating tank 200 l	401.4	-	-	-	20
DHW standby tank 120 l	376.0	-	-		15
Gas Boiler 15 kW	1169.0	1169.0	1169.0	1169.0	15
Combination tank	-	-	3956.1	-	15
Dual coil indirect water tank 300 l	-	1944.8	-	1944.8	25
Space-heating buffer tank 500 l	906.0	906.0	-	906.0	15
Collector loop heat exchanger	-		-	100.0	30
Total Investment	4981.2	6148.6	7253.9	6248.6	
Equipment	**Case V**	**Case VI**	**Case VII**	**Case VIII**	**Lifespan**
Solar collector TS 300 5x	2128.8	2128.8	2128.8	2128.8	30
Solar Preheating tank 200 l	401.4	401.4	-	-	20
DHW standby tank 120 l	376.0	376.0	-	-	15
Heat pump - 14 kW	14744.0	-	14744.0	-	15
Wood fire boiler - 14 kW	-	852.0	-	852.0	15
Combination tank	-	-	-	-	25
Dual coil indirect water tank 120 l	-	-	1944.8	1944.8	15
Space-heating buffer tank 500 l	906.0	906.0	-	906.0	30
Collector loop heat exchanger	-	-	-	-	30
Total Investment	18556.2	4664.2	18817,6	5831.6	
Equipment	**Case IX**	**Case X**	**Case XI**	**Case XII**	**Lifespan**
Solar collector TS 300 5x	2128.8	2128.8	2128.8	2128.8	30
DHW standby tank 120 l	-	-	-	-	20
Heat pump - 14 kW	14744.0	-	14744.0	-	15
Wood fire boiler - 14 kW	-	852.0	-	852.0	15
Combination tank	3956.09	3956.09	-	-	15
Dual coil indirect water tank 120 l	-	-	1944.8	1944.8	25
Space-heating buffer tank 500 l	-	-	906.0	906.0	15
Collector loop heat exchanger	-	-	100.0	100.0	30
Total Investment	20828.89	6936.89	19823.6	5931.6	30

3.2 Energy analysis

Additional source in every case produces relatively the same amount of energy (8900 kWh) a year, which is showed in table 2. This house has 5 solar thermal panels by brand Thermosolar Žiar TS 300 in each case as a result of domestic hot water consumption 120 liters a day. Table 3 represents difference between simulated energy values and energy values in real-time. Real-time value for example heat-pump we calculated with house area ($53m^2$) multiplied by his performance 21.34 kWh/ (m^2 a year) which resulted in 3467.79 kWh a year.

Table 2 Energy required from additional heating

Gas Boiler		**Heat pump**		**Wood pellet boiler**	
Case I	8970.7	**Case V**	8969.9	**Case VI**	8970.8
Case II	8911.9	**Case VII**	8970.8	**Case VIII**	8910.2
Case III	8934.1	**Case IX**	8931.5	**Case X**	8930.2
Case IV	8947.5	**Case XI**	8942.2	**Case XII**	8943.7

Table 3 Energy comparison between cases and real time

Heating			**Domestic hot water**	
Cases	Software	Real-time	Software	Real-time
ST heat pump	8969.90	1131.02	2040.65	768.50
ST wood-fired boiler	8943.70	4547.40	2040.65	725.57
ST gas boiler	8970.70	3467.79	2040.65	792.35

3.3 Economic and lifespan analysis

Table 4 Financial savings for each case (euro/month)

Case I	**Case II**	**Case III**	**Case IV**
159.14	159.81	159.56	159.41
Case V	**Case VI**	**Case VII**	**Case VIII**
247.47	230.73	247.56	230.94
Case IX	**Case X**	**Case XI**	**Case XII**
247.53	230.87	230.87	247.51

In this study we found that for example for case IV monthly savings are 159.4 euro. Following calculations for yearly savings give us 1909.71 euro/year. According to these, there was calculated the net present value which shows equation 2. Total investment for each case we calculated with equation 1.

$$I_0 = 4981.2 + (376.0 + 1169 + 376)e^{-15r} + (401.4)e^{-20r} \quad (1)$$

$$NPV = -\sum I_0 e^{-rt} + \int_0^{T^*} S_i e^{-rt}\,dt = -4981.2 - (376.0 + 1169 + 376)e^{-15*0.02} - -(401.4)e^{-20*0.02} + \int_0^{30} 1909.71 e^{-0.02t}\,dt$$ =37496,36 EUR (2)

Table 5 net present value for every case

Case I	Case II	Case III	Case IV
37496.36	35884.69	33628.54	35671.05
Case V	**Case VI**	**Case VII**	**Case VIII**
49519.68	58207.72	49063.36	56205.22
Case IX	**Case X**	**Case XI**	**Case XII**
45551.76	54261.96	47371.21	61262.56

Calculation results shows that the best choice would be Case VI, instead of Case XII because the payback period is not so relevant priority in this study. Nevertheless, Case VI has the lowest payback period, but from the lifespan criteria is the best case XII.

4 Conclusion

This study demonstrates that applying gas boiler into solar thermal systems may help to meaningful savings. We introduce an approach, how to calculate which option is more suitable considering different additional heat sources. Concerning with future financial investments and savings for the lifespan establishments, we found the best alternative among all the alternatives in a family house in Kosice, Slovakia. The biggest annual working yields are related to heating and DHW preparation. There is no way to decide which is the optimal heating system without calculations and their corresponding results, that's why specialists should have approach to each building separately. In Slovakia, professionals take most of the time only financial site into detail research during the design stage of a house and technical systems. Another important thing to consideration is the maintenance cost, total system establishment and operation. Results of the systems lifespan and their cycle costs may allow us to see the most favorable plan, in cost-effective heating criterion and DHW system criterion.

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