SOLAR-BASED SYSTEM FOR HOT WATER PREPARATION IN SCHOOL BUILDING

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Abstract

This paper investigates economic and environmental benefits of usage of renewable energy for hot water preparation system in elementary school in Bosnia and Herzegovina. Case study includes field measurements on hot water preparation system which consist of conventional electric water heaters, commonly found in educational facilities in region. Values from long-time measurements of system electrical energy and water consumption, along with simultaneously measured thermal energy supplied to the hot water, are presented. Measured values of solar radiation on the exact location are presented and compared with local meteorological data. Based on the measurements, actual energy and water consumption of system as well as related expenses are calculated. It is shown that actual water and energy consumption of system is substantially low when compared to the values prescribed by standard. This shows that hygienic standards are not met in the object, which is a common situation in many educational facilities in the region. In order to meet the minimum energy and water needs for hot water system and to prevent high operational costs, solar-based system for hot water preparation is proposed. New system provides better technical performance with reduced operational costs, primary energy consumption and CO₂ emission.

Keywords: School buildings; Solar energy; Renewable energy; Hot water preparation.

1. Introduction

Use of renewable energy in Bosnia and Herzegovina (BiH) is stimulated via Action plan for Use of renewable energy, adopted at both entity and national level in 2014 and 2016, respectively [1]. This Action Plan for the Use of Renewable Energy in BiH is in line with Directive 2009/28 / EC. Additionally, according to current legislation in the Federation of BiH, for existing and refurbished buildings with a useful, heated area of more than 1000 m², it is obligatory to take in-to a consideration alternative energy supply systems [2]. The analysis of alternative systems encounters the usage of renewable energy sources for energy supply, energy supply provided via district heating systems based on renewable energy sources, and so on. Therefore, legislative related to the usage of renewable energy for energy supply is present, but percentage of buildings in BiH for which energy supply system is completely or partially based on renewable energy is very low.

Educational facilities, due to their importance as an energy usage category, number of user and their age, also for its role in knowledge sharing, are put in the focus of this analysis. When investigating the share of schools which have

renewable energy systems introduced as an energy source in the energy supply system, it is revealed that one of the 81 primary schools in Canton Sarajevo has a solar panels installed. Energy supply system in schools in Canton Sarajevo is mostly based on fossil fuels, while Domestic Hot Water preparation system (DHW) system is mostly based on conventional electric water heater.

In the process of reduction of energy use in educational facilities, the current focus is on reducing the energy need for heating by introducing the envelope refurbishment measures and reduction of electrical energy consumption by replacing the light bulbs with LED light. Renewable energy sources are introduced when transforming the heating system based on fossil fuel with pellets as ecological fuel while other forms of renewable energy are neglected. This approach is very rational, since costs related to the energy need for heating is dominant in total facility costs and largest saving potential is related to this area [3]. Refurbishment of other systems, such as DHW, ventilation and cooling are not in the focus right now. The DHW systems in the educational facilities in Canton Sarajevo are predominantly based on electric accumulator boilers. According to energy audits, taking in-to account the number and mode of boiler usage, it is shown that specific energy consumption for DHW preparation is extremely low. This is not the result of an aspiration to achieve energy-efficient consumption or implementation of new technological solutions, but an indicator that hygienic conditions in the facilities are not met, which is a common situation in all educational facilities in the region [4]. This situation results in low level of hygiene of pupils, which is relevant not only from the aspect of energy saving and its efficient usage but also for children health. Taking this in-to account these facts and that these systems are generally overlooked when implementing the refurbishment measures [5], we have performed detail analysis of implementation of solar based DHW system in one primary school in Canton Sarajevo. Presented solution will be beneficial from two perspectives; it will ensure that minimum hygienic standards are met in this facility and introduction of renewable energy in energy supply system. These systems are beneficiary over a conventional system due to their eco-friendly nature and its economic feasibility, as presented in [6]. Some researcher has presented the potentials for using the solar water heating systems for hot water production presented for the countries, such as Turkey [7], Malaysia [8], Taiwan [9], etc.

For the purpose of the analysis, energy consumption for the DHW system as well as the value of the solar radiation are measured over a long period in one school in Sarajevo Canton. Data from measurements are compared with guidelines for minimum required energy for DHW preparation. Analysis of results provided an input data for design of a DHW system based on solar energy as renewable energy sources.

2. Case study

Collection of data related to energy consumption of the DHW system was carried out in the premises of the Fatima Gunic Elementary School in Sarajevo. School was built in 1977 and consists of basement, ground floor and one upper floor, with useful, heated area of 4934,5 m² (Figure 1). Energy need for heating is provided via heat substation connected to the district heating system. Average number of pupils is 744, and the number of staff is 62.

In the 2015. detailed energy audit of facility was performed. Detail analysis shown that thermal comfort inside the object was not met due to the poor condition of the object envelope, which was the source of significant heat losses, as visible from thermovision image (Figure 2). Based on the recommendation given in detail energy audit, the school management undergoes the envelope refurbishment and additional remediation that resulted in significant improvement of thermal comfort in the facility and reduction of energy costs from 50564,00 Eur/year to 30000,00 Eur/year. The photographs of the building before and after remediation are given in Figure 1 and Figure 3, respectively, it can be noticed that the complete envelope refurbishment was performed which included the replacement of the windows and the installation of thermal insulation on the outer walls and on the roof of the building.

Fig. 1. Main entrance (state before the remediation)

Fig. 2. Thermal image of the envelope (state before the remediation)

Fig. 3. School object after the remediation

DHW system in the school is based on 5 electrical boilers, with total installed nominal power of 10 kW. For the purpose of the analysis in the detail energy audit, electricity consumption of boilers is estimated according to the installed power and the number of operating hours per year as shown in Table 1. According to the data presented, the assumed annual electricity consumption of DHW system is 4850,00 kWh /a or 0,98 kWh/m², expressed as a specific value per usable heated area of the object and 6,02 kWh/a expressed as a specific value by number of users. Consumption of electrical energy of DHW system accounts for 10,3% of total electricity consumption.

The estimated water consumption of the DHW system amounts to 90 m³ of water per year, which is about 4,55% of the total water consumption in the facility.

Device	Power	Number	Time of usage	Working days	Annual consumption
	W		h/day		kWh
Electrical boiler (50 l)	2000	3	2	250	3000
Electrical boiler (5 l)	2000	2	5	185	1850
Total	-	-	-	-	4850

Table 1. Energy consumption of DHW system (data from detailed energy audit)

For accurate estimation of actual energy consumption and potentials for energy savings of the DHW system, representative part of the system was selected for measurements of actual water and energy consumption, as presented in following chapters.

2.1. Measurement performed on DHW system

In selected sanitary node the water consumption and the heat delivered to hot water are measured using Danfos Sonometer 1000, while electricity consumption is measured using Energy logger 4000, as shown in Figure 4.

The Sonometer 1000 metering unit is used for measurements and as a data-logger for following parameters: current water flow, cumulative water flow, current heat power, hot water temperature, cold water temperature, temperature difference between warm and cold water and cumulative heat delivered to warm water. Energy logger 4000 is used for measurements and as a data-logger for following parameters: voltage, current, frequency, active and reactive power and cosfi. Simultaneous measurement was performed for a period of 32 days.

Fig. 4. Electrical boiler with installed ultrasonic heat meter and electricity consumption meter

Along with measurement on DHW system, measurement of solar irradiation on the site are performed. Measurement are performed using solar radiation intensity meter Volcraft, tip DL-131 deluxe, and a positioning device for inclination angle of 45° and facing south. Measurement are performed for selected days: sunny, partially cloudy and cloudy days for November, December and January.

2.2. Measured values

Results of measurements are presented for each day as well as cumulative values. It is shown that for a first two weeks, energy consumption (electrical and heat) as well as water consumption was very low which is an indication of low hygiene level. After that, the notice for pupils was placed in the toilet and informing campaign was performed, so overall results improved, as it is shown in Figure 5. It is noticeable that water and energy consumption are higher for third and fourth week of measurement. Water consumption during the weekend is zero or smaller than consumption during the working days. Electricity consumption is present even for the weekends, due to the high energy losses of the system.

Fig. 5. Electrical energy and water consumption (daily values)

Fig. 6. Electrical energy, heat energy and water consumption (cumulative values)

Cumulative values of energy (electrical and heat delivered to the water), as well as water consumption are shown in Figure 6. All measurement shows a similar trend for all three parameters, with a higher consumption in the third and fourth weeks. The total amount of electricity consumed for the measuring period is 31,15 kWh. Water consumption is in total 517 l or 22,5 l per working day. Results have shown that hot water consumption per user is 0,27 l/user/day, when taking in-to account working days. Standard prescribes the value of hot water usage should be in range from 5 to 15 l/user/day for educational facilities. This clearly shows that hygienic standards in facility are not met.

Average temperature of heated water is $33,3^\circ\text{C}$ while temperature of cold water is in average $9,9^\circ\text{C}$. Total heat delivered to the heated water is 14 kWh or 0,67 kWh/working day. It is visible that the electricity consumption is higher than the consumption of heat energy. The reasons for this are the system losses, which cumulatively amount to 17,15 kWh, or 55,06 % of the overall electricity consumption of the system.

Fig. 7. Energy consumption of DHW system for representative week

Fig. 8. Solar irradiance measured in November

For further analysis, measurements taken in last week are selected. They are shown in Figure 7. It is visible that system losses are present since electrical energy is higher than heat energy delivered to the hot water system. Electrical energy consumption for this week is 9,42 kWh/week, while system losses are 41,61 %.

Values of measured solar irradiance for a three days in November are shown in Figure 8. It is visible that solar irradiance varies during the day and it is a function of weather conditions. Same trend is present for other days and months when measurements are taken.

3. Analysis

Measured data are used to estimate energy consumption (electrical and thermal) as well as the hot water consumption for the DHW system for the complete facility. Given that 82 pupils are using the boiler where measurements were taken, the specific consumption per user is calculated. Values are extrapolated to the total number of users and operating days of the facility which is 185 therefore decrease in consumption during the summer and winter break are encountered. Based on the results of electric energy consumption per reference week (9,42 kWh) and for 82 users, it is calculated that all users in building will consume 92,59 kWh of electrical energy per week. For the period of one year, it is 3240,71 kWh/year. Using the result of energy audit, measurement results and guides from national and DIN standards [10], energy and water consumption and relating costs are calculated as shown in Table 2. For the purpose of this analysis, average price of electricity from energy bills is taken.

Energy and water consumption of DHW system are calculated using different approaches: estimated values from detail energy audit, values based on measurements, values using national calculation methodology and DIN 18599 standard.

Energy need for DHW system from national methodology is calculated as:

$$Q_{W,nd} = 4,182 \cdot V_{W,dan} \cdot f \cdot (t_{W,del} - t_{W,0}) \frac{d}{3600}, \text{ (kWh/year)}, \text{ (kWh/year)} \quad (1)$$

were:

$V_{W,dan}$	- daily hot water consumption per user	(l/user/day)
f	- number of users	(-)
$t_{W,del}$	- hot water temperature, 60 °C	(°C)
$t_{W,0}$	- cold water temperature, 13,5 °C	(°C)

For educational facilities recommended minimum, daily hot water consumption is from 5 to 15 l /user/day. For this analysis, value of 5 l/user/day is taken.

DIN standard (DIN 18599) provides a guideline for energy need of DHW system of educational facilities as a specific value of 10 kWh/m²year, presented as a function of useful building area. This value is used as starting point for calculation, and resulted annual electrical and water consumption are calculated.

	Heat energy	Electricity consump.	Water consump.	No. of users	System losses	Water temper.	Electricity costs	Water costs
	kWh/a	kWh/a	m ³ /a	-	%	°C	€/ya	€/a
Detailed energy audit	3880	4850	90	806	80	60/13,5	577,6	83,7
Site measurements	1892,1	3241	72,9	806	55	33,2/9,9	386,1	67,9
National methodology	37175	46468	688,2	744	80	60/13,5	5532,6	642,4
DIN 18599	49345	61681	965,7	744	80	60/13,5	7343,9	901,3

Table 2. Consumption and costs of DHW system calculated using various approaches (electrical boilers system)

Annual values of the energy need for DHW system, electricity and water consumption and related costs, calculated using the different approaches are shown in Table 2. Values from detailed energy audit, extrapolated values from measured results, values calculated using national methodology and DIN 18599 standard are shown. It is noticeable that results of detailed energy audit and site measurements do not differ significantly. In energy audit, system efficiency was overestimated when compared to the actual conditions as well as water temperature. When compared to the national values or DIN 18599, results show high discrepancy, where consumption and related costs are much higher than measured values. Highest values are prescribed by DIN 18599, where DHW system should provide 49345 kWh/year heat energy and consume 966 m³/year of water. Costs for this state are 8245,3 €/year. According to national methodology, DHW system should provide 37175 kWh/year of heat energy and 688,2 m³ of water per year. It is worth to mention that actual annual water consumption of the facility is in average 1980 m³/year. According to the national methodology, for system based on electrical boilers, annual cost for DHW system is 6175 €/year. Results shows that current water consumption of DHW system is insufficient to meet the hygienic terms in the facility.

Based on the results, introduction of solar panels for DHW system is analysed and energy and water consumption is determined according to the national methodology.

4. Solar based system

Design of an active solar system is done with solar energy receivers i.e. solar collectors in which the solar radiation is converted into heat energy. Heat energy can be used to supply particular system in the facility. The power absorbed by the collector can be determined by means of an equation that includes elements of the collector function (collector glass transmission factor, absorption factor of the absorbent plate and collector absorber surface) and total solar radiation.

To improve the process of selection of component of solar based system, values of solar radiation at the particular location are measured. On the basis of the measurements, the mean intensity of the total solar irradiation obtained during sunny days was obtained. This value is multiplied by the number of sunshine hours per month, so solar radiation was obtained. Calculated values are compared with metrological yearly averaged values, as presented in Figure 10, where it is shown that locally measured values are smaller than yearly averaged values. Since, yearly averaged values are gained for a continuous and long-time period measurements, they are considered as more accurate and used for future calculations.

Fig. 9. Solar radiation

Fig. 10. Percentage of solar energy in DHW system

As mentioned in the previous chapter, system is constructed to meet the national methodology, where minimum hygienic consumption of hot water is 5 l/day/user. For the purpose of calculation, it is assumed that system will be 100 % solar based in June, as shown in Figure 10. In other months, percentage of solar energy in DHW system is smaller due to the smaller solar radiation. In this period, DHW system is supplied with electrical energy along with solar energy. July, August and January are not taken in-to account since there are no classes in this period.

Figure 11. shows the installation scheme for DHW system with plate solar collectors. The basic elements of the system are: solar collectors that are associated with solar radiation, automation that manages the entire system, solar sets that contain all the power to run and system security, hot water tank with electric heater and installation that connects these elements.

Fig. 11. DHW system with plate solar collectors

Efficiency of plate collector is 75 %. Solar based heat delivered from hot water tank during the day is 200,89 kWh. Taking in-to account working days, energy need for June is 4219,9 kWh. With heat losses from hot water tank of 1,4 kWh/day or 43,4 kWh per month, total energy that need to be supplied towards the plate surface is:

$$Q_{\text{sol}} = \frac{Q_{\text{W,nd}} + Q_{\text{W,los}}}{\eta_{\text{col}}} = \frac{4219,86 + 43,4}{0,75} = 5684,35 \text{ (kWh/month)} \quad (2)$$

To provide this energy, 38,4 m² of solar collectors is needed. Total surface of the flat roof is 2800 m² so solar collectors can be easily placed on the roof. One unit of solar collector has a surface of 0,6 x 1,6 m, so number of solar collectors for this system is 42 (40 + 2 spare collectors). DHW system will comprise of two units shown in Figure 11, with hot water tank of 600 l and 21 solar collectors. Price of the system is 2 x 6403,48=12806,9 €.

Operational costs of system with solar collectors includes costs for electricity for a period when electric heater is in function and operational costs of two electrical pump. Comparison of costs when all energy is provided from electricity and new system where solar panels are introduced is given in Table 3. Also, primary energy is calculated, using the primary energy factor from national methodology which is 3,0 for electricity. Also, comparison of CO₂ emission of two systems is given. It is visible that DHW system with solar panels provides significant savings in operational costs, primary energy and CO₂ emission when compared with conventional system based solely on electrical boilers.

	Operational costs	Primary energy	CO₂ emission
	€/year	kWh/year	t/year
DHW system based on electrical boilers	5532,63	139406	34,6
DHW system with solar panels	1687,15	43147	10,7
Savings	3845,48	96259	23,9

Table 3. Operational costs, primary energy and CO₂ emission for two system configuration

5. Conclusion

At the moment, energy and water consumption of DHW system in educational facilities in region is very low. This is not the result of aspiration to increase system energy-efficiency or implementation of new technological solutions, but an indicator that hygienic conditions in the facilities are not met. This situation results in low level of hygiene of pupils, which can affect children health in negative manner.

In order to gather exact data, measurements of energy and water consumption in selected DHW system in one elementary school in Sarajevo, are performed. Measurements were performed during the period of 32 days. In selected sanitary node the water consumption and the heat delivered to hot water are measured, with simultaneous measurement of consumption of electrical energy. Along with measurement on DHW system, measurement of solar irradiation on the site are performed. Results have shown that hot water consumption per user is 0,27 l/user/day while, according to the national methodology the value of hot water usage should be in range from 5 to 15 l/user/day for educational facilities. Also, electrical boiler has significant energy loss, which was in total 55,06 % for overall electricity consumption of the system. Comparison of energy and water consumption from energy audit, measurement results and guides from national and DIN standards, shown that current system is insufficient to meet the hygienic terms in the facility.

In order to supply the sufficient amount of hot water with minimum operational cost, DHW system which includes solar panels is analysed. The basic elements of the system are: solar collectors which are associated with solar radiation, automation that manages the entire system, solar sets that contain all the power to run and system security, hot water tank with electric heater and installation that connects these elements. For the purpose of calculation, it is assumed that system will be 100 % solar based in June, while in other months' additional energy will be provided from electrical heater. For particular facility, calculated surface area of solar collectors is 38,4 m², which can be placed on flat roof. Investment cost for this system is 12806,9 €.

It is shown that solar based system can provide hot water for elementary school with 744 pupils with operational costs of 1687,15 €/year. Analysis is based on water consumption prescribed by national standard, which ensures that hygienic terms are met. When compared to conventional, electricity based system, annual cost savings is 3845,48 €/year, primary energy savings is 96259 kWh/year and CO₂ emission savings is 23,9 t/year.

Results have shown that there is a great energy saving potential related to the use of solar based DHW system in educational facilities. Most important, these systems will ensure that hygienic conditions related to hot water consumption are met. Presented analysis is performed in one elementary school. In future research, results from this facility will be extrapolated on all elementary schools in Canton Sarajevo.

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