STUDY OF MEDIUM SCALE SOLAR WATER HEATING PLANTS IN LITHUANIA

Rolandas Jonynas[1], Rokas Valancius[1], Vykintas Suksteris[2], Eugenijus Perednis[3] and Gintaris Mekas[4]

[1] Kaunas University of Technology, Kaunas (Lithuania)

[2] Terma Consult JSC, Kaunas (Lithuania)

[3] Lithuanian Energy Institute, Kaunas (Lithuania)

[4] Kruonis Pumped Storage Hydroelectric Plant, Kruonis, (Lithuania)

1. Introduction

The EC plan "20-20-20" for the year 2020 encourages Lithuania as a member State to pay more attention to the renewable energy sources. Lithuania took the obligation to increase the part of renewable energy up to 23 percent in the State primary energy balance till 2020.

General problem that existed in Lithuania was slow solar energy market grow due to the absence of promotion schemes. In the beginning of 2011 year Lithuanian Parliament has approved a law on renewable energy sources, introducing different type stimulation mechanisms in Lithuania.

In this study we analyzed two medium – scale solar water heating plants in State owned institution. One of the projects implemented in 2009 year at Kruonis Pumped Storage hydroelectric Plant with 21 m^2 active surface flat solar collectors. Other solar hot water heating system was installed in 2011 year at the same object with 106 m^2 active surface flat type collectors.

Kruonis Pumped storage hydroelectric plant is the only hydro power plant of such type in Baltic States. After commissioning of the fourth unit in 1998, installed capacity of the plant has reached 900 MW. During periods of low demand, usually at night, Kruonis PSHP is operated in pump mode, and, using cheap surplus energy raises water from lower reservoir to upper one. With fully filled upper reservoir the plant can generate 900 MW for about 12 hours. Automatically started, the plant can reach full capacity in less than 2 min.

Fig. 1: Kruonis Pumped Storage hydroelectric Plant

One more already planned the biggest for current time solar hot water heating application will be implemented at Rokiskis Mental Hospital in Lithuania. Currently was prepared a technical project for the system. It should be mounted with 390 m^2 flat – plate solar collectors with 15 m^3 hot water volume.

Simulation of solar hot water systems was performed using T*SOL 5.0 software. During this evaluation were determined indicators of energy production, CO_2 emission savings, and systems' efficiency.

Before the implementation of solar projects needs to make a professional estimation and best decision for specific cases. In this paper analyzed solar applications was estimated and designed by consultancy company "Terma Consult" JSC.

2. Methodology

2.1 Description and estimation of systems

In this work as medium scale solar hot water system was evaluated at Kruonis Pumped Storage Plant (Kruonis PSHP) installed in 2009 year. Official beginning of this application exploitation was in 2009.08.01. System where mounted with: 10 flat type solar collectors (total absorber area - 21,9 m^2) directed to 0º azimuth and 45º slope with horizon; 1 x 1 m^3 and 2 x 0,9 m^3 hot water storages with two heat exchangers and auxiliary electric heating element; differential controller; pump station. Daily hot water consumption is about 1500 liters ± 20 % range with no load at weekends.

Other solar heat water application installed at the same Kruonis PSHP in 2011 year. System is in operation from date 2011.06.01. The solar system's set consisted of: 40 flat type solar collectors (106 m^2 active surface); 3 x 4129 liters hot water storages; differential controller and 2 pump stations. Daily hot water consumption is about 5000 liters ± 20 % and about 2 m^3 at weekends.

Detailed description of these two systems parts in Tab. 1.

Tab. 1: Description of main solar collector systems' parts in Kruonis PSP

Name	10 collectors system	40 collectors system
Solar collector	10 x Sunex Basicx 2.38 flat plate collectors Total absorber area (10 collectors) $A_{absorber}$ = 21,9 m^2; Total gross area A_{Gross} = 23,7 m^2; Conversion factor η_0 = 0,78; Linear heat transfer coefficient k_1 = 3,545 W/m^2 x K; Square heat transfer coefficient k_2 = 0,011 W/m^2 x K^2;	40 x Sunex Basicx 2.85 flat plate collectors Total absorber area (40 collectors) $A_{absorber}$ = 106 m^2; Total gross area A_{Gross} = 114 m^2; Conversion factor η_0 = 0,78; Linear heat transfer coefficient k_1 = 3,545 W/m^2 x K; Square heat transfer coefficient k_2 = 0,011 W/m^2 x K^2;
Hot water storage	1 x Sunex FISH 1000 S1 Capacity V = 1000 liters; 2 x OSO 17RD – 1000, V = 809 liters; V_{total} = 2618 liters	1 x OSO 17R 1-5000, V = 4129 liters; 2 x OSO 17RD-5000, V = 4129 liters; V_{total} = 12387 liters
Pump station	Model: Sorel S2 Solar3 with thermometer (0 – 120 °C), manometer (6 bar) flow meter (2 - 12 l/min), Wilo ST 25/7 pump, balancing, non –return, filling, drainage valves	Model: 2 x BRV S2 Solar2 with Wilo Stratos PARA 25/1-8, flow meter (5-42 l/min), thermometer, manometer.
Differential controller	Model: Sorel TDC4 with flow meter	Terma freely programmable whit heat meter Kamstrup Multical 402

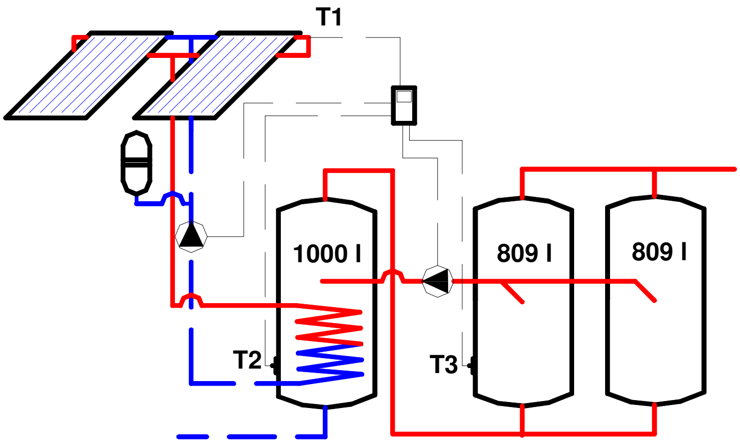
In the figures below are shown a view of installed solar collectors on the roof.

Fig. 2: 10 and 40 solar collectors on the roof at Kruonis PSHP

2.2 Estimated model of energy production

In this study using software T*SOL Pro theoretical model of systems was estimated. Climatic data were selected for the nearest city - Kaunas (solar irradiation into horizontal surface 985 kWh/m^2/year) taken from "T*SOL Pro" data base. Principal schemes of systems showed in Fig. 3.

a)



b)

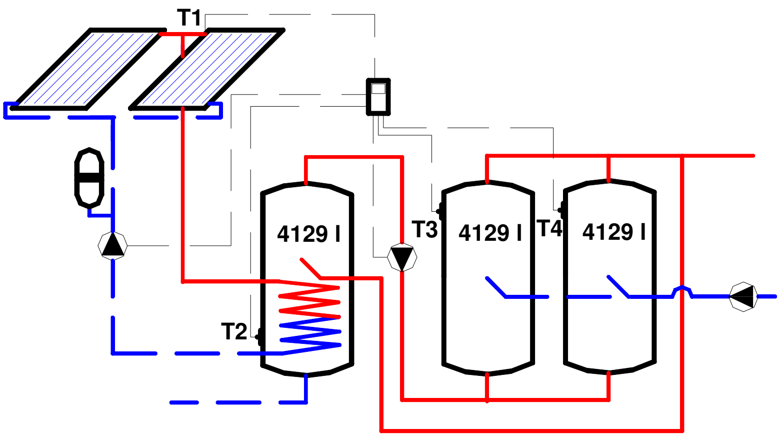


Fig. 3. a) 10 collector system principal scheme, b) 40 collector system principal scheme

3. Results

3.1 Theoretical estimations and measured systems performance

Theoretical model of both solar applications was estimated with T*SOL Pro software which has facilities to calculate many technical - economical parameters. We have analyzed and compared just global specific irradiation into inclined surface (Kaunas), system's produced energy and monthly efficiency. Systems' parameters of performance were calculated and compared for standard year.

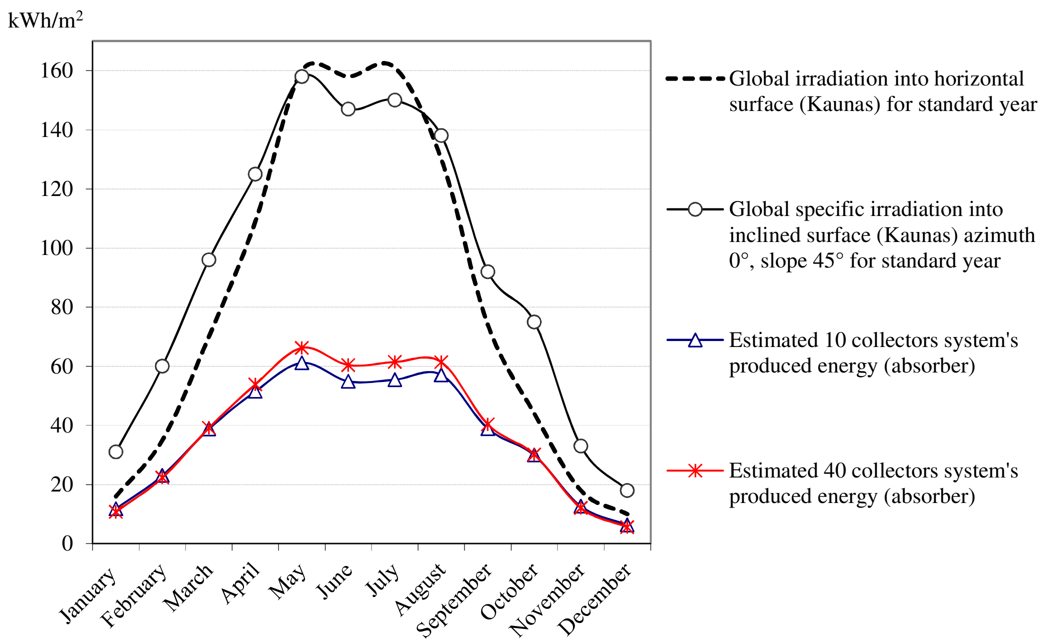


Fig. 4. Estimated standard year global irradiation (Kaunas), global specific irradiation and produced energy for the 10 and 40 collectors systems ($kWh/m^2_{absorber}$)

As we can see in the figure 3 total standard year solar irradiation to 10 collectors and for a new 40 collectors systems' collectors with 45 degrees inclination angle with horizon is variable from 18 kWh/m^2 (in December) till 158 kWh/m^2 (in June). Total estimated yearly irradiation is 1123 kWh/m^2 on Kaunas climate conditions and using described inclination angle with direct to south orientation.

Estimated and measured 10 collectors systems' efficiency were calculated as produced energy divided of inclined global solar irradiation and expressed as:

$$\eta_{system} = \frac{Q_{produced}}{G_{inc}} \quad \text{(eq. 1)}$$

There η_{system} - efficiency of system, $Q_{produced}$ – solar collectors system produced energy; G_{inc} – solar irradiation into inclined collectors.

Measuring results presented in Fig. 5. as usually and like in theoretical model repeats the same tendencies of global and specific solar irradiation to inclined collectors. Standard year solar irradiation taken from software data base, collected from 1961 – 1991 year.

It was measured that 10 collectors system produced 523 $kWh/m^2_{absorber}$ (season 2009 – 2010 yr.) It is 18 % more than in estimated model. Measured solar collectors system' yearly efficiency reached 45 % and it's almost 6 % higher than was estimated. This variance of estimated and measured values appears because of higher solar irradiation than in standard year.

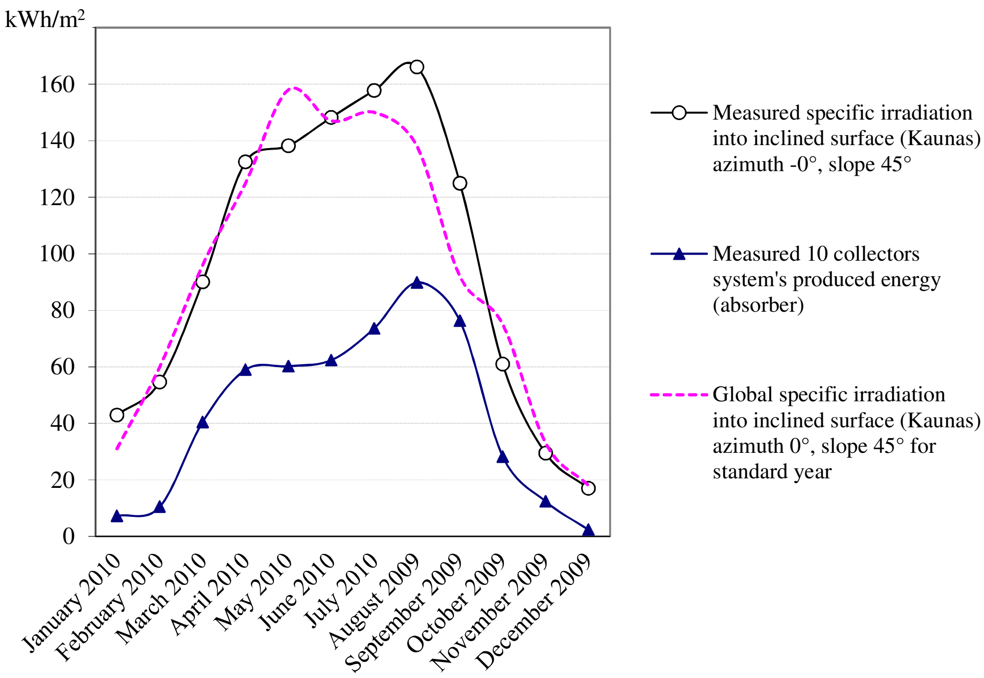


Fig. 5. Measured 2009 - 2010 year global irradiation (Kaunas), global specific irradiation and produced energy for the 10 collectors system (kWh/m$^2_{absorber}$)

New 40 collector's hot water system's measured energy production is just for two months only. Values of produced energy represented in the table 2.

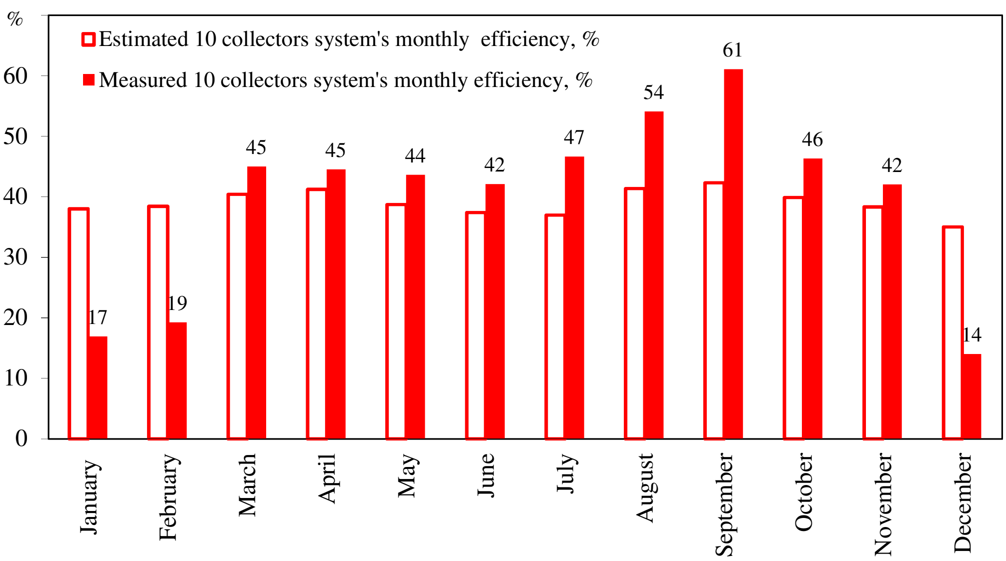


Fig. 6. Estimated and measured 2009 - 2010 year monthly efficiency of 10 collectors solar system at Kruonis PSHP

For 40 collectors system measured energy production for standard year June was 47 % more and for July it was 10 % more than estimated values (June - 60 kWh/m$^2_{absorber}$, July – 61 kWh/m$^2_{absorber}$). This mismatch is explainable by higher solar irradiation level at analyzed months in comparison with standard year.

Tab. 2: Measured 40 collectors system's produced energy in 2011

Month	Average outside air temperature (standard yr./2011 yr.), ºC	System's produced energy, kWh	System's produced energy, kWh/m^2 $_{absorber}$
June	15,5/18	9366	88,69
July	18,5/19	7110	67,33

3.2 Economical evaluation

Systems were analyzed from technical view, but every system with technological process must have and economical reasoning. Using theoretical model we attempted to calculate mostly usable economic indicators – simple payback (SPB), net present value (NPV) and internal rate of return (IRR).

Economical evaluation was performed according these assumptions: project estimation period – 20 years; nominal discount rate – 5 %; electricity price yearly grow index – 4,5 %/yr (2 % due impact of green electricity till 2020 yr. + 2,5 % average energy price grow according by historical oil prices) ; inflation – 3 %/ yr; electricity price – 0,087 €$_{2011}$/kWh (average electricity price for Kruonis PSHP) and 0,112 €$_{2011}$/kWh (for households which have the electricity consumption more than 12 MWh/year) .

Investment (equipment with montage) for both systems is shown in Tab. 3.

Tab. 3: Investment costs for both solar collectors systems' in Kruonis PSHP

System	10 collectors system	40 collectors system
Investment costs, €	13.142	59.082
Specific investment, €/m^2 absorber	600	559

Savings of money were calculated using electricity energy price. Electricity energy consumption of systems' pumps wasn't evaluated in economical estimation.

Tab. 4: Estimated economic indicators

System	10 collectors system		40 collectors system	
	Electricity tariff for Kruonis PSHP	Electricity tariff for households (more than 12 MWh/ year)	Electricity tariff for Kruonis PSHP	Electricity tariff for households (more than 12 MWh/ year)
Simple payback time, yr.	15,0	11,6	13,3	10,3
NPV, €	1851,3	6041,5	16479,9	37696,3
IRR, %	6,5%	9,5%	7,9%	11,1%

3.3 Environmental impact

One of major purposes in the world is to produce more green energy.

In evaluation of environment pollution with CO_2 we follow indirect emissions method then electricity is produced in Lithuanian power plants. Indirect CO_2 emissions factor for electricity in Lithuania determined as 0,707 t CO_2/MWh (it is relative average CO_2 emission for MWh electricity for Lithuanian stock company "Lietuvos elektrine" electricity producing in condensing mode). In the table below are represented estimated CO_2 emissions saving for Kruonis PSHP systems with 10 collectors and 40 collectors.

Tab. 5: Estimated CO_2 emissions savings for Kruonis PSHP solar hot water systems

System	10 collectors system	40 collectors system
CO_2 emissions avoided in standard year for estimated systems' energy production, tones CO_2/year	6,84	34,61
tones CO_2/20 year	136,72	692,27
kg $CO_2/m^2_{absorber}$/year	312,15	327,78

4. Discussion

The evidence that solar systems have a high potentiality in Lithuania was determined. Currently absolute majority of solar systems in Lithuania are small size and installed at the detached houses. Two solar hot water heating applications in detached houses we analyzed previously (Jonynas and Valancius, 2010).

In this paper the first part of feasibility study of medium scale solar system in Lithuania was presented. In order to validate the obtained results, more solar systems will be involved in the future studies. Some of medium and large solar systems that are going to be installed in Lithuania will be evaluated over the next few years.

5. Conclusions

1. Measured 10 flat type solar collectors system produced 523 kWh/$m^2_{absorber}$ per year (01.08.2009 – 30.07.2010). Due to the higher global solar irradiation that time-period it was 18 % more than was estimated for standard year. Higher than estimated solar water heating system's efficiency shows that it was well designed. Other system with 40 flat type solar collectors at the same Kruonis PSHP running 2 months from 01.06.2011 and produced 88,69 kWh/$m^2_{absorber}$ in June 2011, 67,33 kWh/$m^2_{absorber}$ in July 2011 already.
2. In the economic estimation of solar systems there determined very high internal rate of return values - 9,5% for system with 10 collectors and 11,1 % for system with 40 collectors. An economic indicator shows that solar water heating instead electric heating is good investment with acceptable payback. State support would be appreciated as soon as possible giving possible influence for more quick market development.
3. It is important that any implementation of solar collectors' system in Lithuania will let to avoid 312 – 328 kg $CO_2/m^2_{absorber}$/year.
4. Higher energy independence for State is additional advantage of renewable energy sources projects implementation.

References

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