The comparison of two different solar collectors systems

Rolandas Jonynas[1*] and Rokas Valančius[2]

[1] Kaunas University of Technology, Department of Thermal and Nuclear Energy, Donelaicio str. 20, 44029 Kaunas, Lithuania

[2] Kaunas University of Technology, Department of Geotechnical Engineering, Studentu str.. 48, 51367 Kaunas, Lithuania

[*] Corresponding Author, rolandas.jonynas@gmail.com

Abstract

The major purpose of this work is to investigate the efficiency of two working solar collectors systems using for domestic hot water in Lithuania (Kaunas city) and to compare their technical – economical indicators either. First system contains flat plate solar collectors, the second one – vacuum tube. The conditions for exploiting the systems mentioned above are basically the same: in both houses live two hot water users. In this research at the first step both systems efficiency and other technical indicators have been calculated using software. Moreover, the amount of heat energy (produced by these systems) is being measured using remote data acquisition system. Considering the technical and economical peculiarities of these systems in Lithuania (the exploitation, system life period, payback time), system with flat plate collectors has more obvious advantages than the other one that has been chosen for comparison in this investigation.

1. Introduction

Lithuania is a geographical centre of Europe. For today statistically [1] in Lithuania are installed about 2200 m^2 of glazed collectors (2009). It is very small value (even hard visible) in comparison with Austria or Germany installations. The major reason of that - there is no stimulation of government. No subsidies for small residential systems installations in Lithuania.

This investigation is one of efforts to determine witch type of solar collector's systems is better according to Lithuanian climate. Therefore two systems with different solar collector types (with vacuum tubes and other – with flat plate) were chosen for investigation. There was performed theoretical simulation of systems work and then it was compared with real measured results.

2. Methodology

2.1. Description of solar collectors systems

In this work two solar collector systems with different type of collectors was investigated. First system named "A system" consists of: evacuated tubes collector Apricus AP 30, total active area – 2,4 m^2 orientated 10 degrees to east with 25 degrees slope to horizon, 300 l hot water storage with two heat exchangers and auxiliary electric heating element , differential controller, pump station. Second system was named "B system". System is aggregated with two flat plate solar collectors model Basicx 2.51 with TiNOX technology, total active area – 4,38 m^2 orientated directly to south (azimuth 0 degrees) with 45 degrees slope to horizon, 300 litres hot water storage, differential controller, pump station.

Specification of systems main parts showed in Table 1.
Systems are mounted in approximately 5 km distance between each other (Lithuania, Kaunas).

Table 1. Specification of main solar collectors' systems parts

Part name	A system	B system
Solar collector	Apricus AP-30 vacuum tube collector (with 30 vacuum tubes) Absorber area $A_{absorber}$ = 2,4 m^2; Gross area A_{Gross} = 4,35 m^2; Conversion factor η_0 = 0,717; Linear heat transfer coefficient k_1 = 1,52 W/m^2 x K; Square heat transfer coefficient k_2 = 0,0085 W/m^2 x K^2.	Sunex Basicx 2.51 l two flat plate collectors Total absorber area (2 collectors) $A_{absorber}$ = 4,38 m^2; Total gross area A_{Gross} = 4,76 m^2; Conversion factor η_0 = 0,79; Linear heat transfer coefficient k_1 = 2,348 W/m^2 x K; Square heat transfer coefficient k_2 = 0,015 W/m^2 x K^2;
Pump station	Thermometer (0 – 120 ^oC), manometer (6 bar) flow meter (8 - 28 l/min), Grundfos 25 – 40 pump, balancing, non –return, filling, drainage valves	Thermometer (0 – 120 ^oC), manometer (6 bar) flow meter (8 -28 l/min), Grundfos 25 – 40 pump, balancing, non –return, filling, drainage valves
Bivalent (twin coil) domestic water heater	Model: Terma VN-300E Volume V_{dwh} = 300 l Integrated electric heater $Q_{el.h}$ = 3 kW	Model: Terma VN-300E Volume V_{dwh} = 300 l Integrated electric heater $Q_{el.h}$ = 3 kW
Differential controller	Seltron ND2 Operating temperature range: 5 °C ÷ +40 °C; D. h. w temperature setting range: 0 °C ÷ 120 °C; Temperature sensor type: KTY 10-5 or Pt1000	Seltron ND2 Operating temperature range: 5 °C ÷ +40 °C; D. h. w temperature setting range: 0 °C ÷ 120 °C; Temperature sensor type: KTY 10-5 or Pt1000
Heat meter with data transfer modem	Temperature range (10 °C ÷ 160 ^oC); Differential range (3 K ÷ 150 K); Temperature sensors Pt500; Flow meter size (1,5 m^3/h).	Temperature range (10 °C ÷ 160 ^oC); Differential range (3 K ÷ 150 K); Temperature sensors Pt500; Flow meter size (1,5 m^3/h).

2.2. Theoretical estimation method

In this investigation theoretical model of both systems was estimated using software T*SOL Pro 4.3 [2]. Primary data such as weather conditions for Kaunas city (latitude 54,88 °, irradiation into horizon 985 kWh/m^2) was taken from "T*SOL Pro" data base. Principal schemes of systems showed in Fig. 1. Exploiting conditions for A system were modelled such way: vacuum tube collector orientated 10 degrees to east with 25 degrees slope to horizon, appointed optimal propylene glycol flow rate in solar collector coil is 41,4 $l/m^2/h$ (recommended in collector's specifications) average daily domestic hot water consumption 150 litres (temperature 60 °C), average cold water temperature - 10 °C. Natural gas boiler (26 kW) as primary DHW heater for all seasons is used in model.

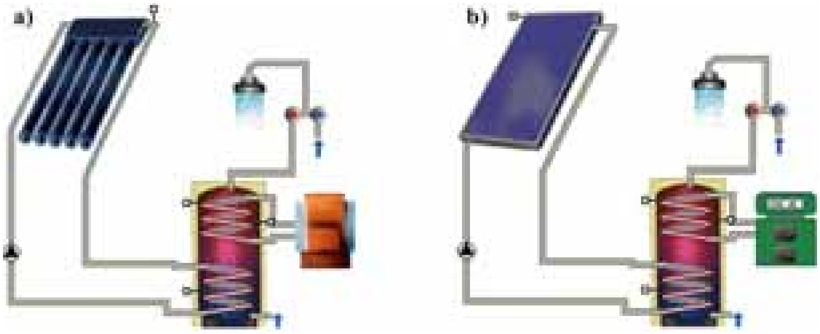

Fig. 1. a) A system (vacuum tube collectors), b) B system (flat plate collectors) (T*SOL Pro 4.3).

For B system modelling exploitation parameters were: collector orientated directly to south with 45 degrees slope to horizon, appointed optimal propylene glycol flow rate in solar collector coil is 25 l/m^2/h (recommended by manufacturer) average daily domestic hot water consumption 150 litres (temperature 60 °C), average cold water temperature - 10 °C. Universal 29 kW wood pellets boiler was used as primary heat generator for house heating and DHW.

Both systems don't have a hot water recirculation line. Energy demands for both houses DHW heating presented in the next table.

Table 2. Energy demands for DHW heating (T*SOL Pro)

No.	Month	Cold water temperature, °C	Energy demand for DHW heating, kWh
1	January	8,23	279,85
2	February	8,02	253,79
3	March	8,32	279,36
4	April	9,08	266,38
5	May	10,08	269,85
6	June	11,06	256,02
7	July	11,75	260,82
8	August	11,97	259,63
9	September	11,66	252,88
10	October	10,89	265,47
11	November	9,89	262,14
12	December	8,92	276,12
	Total per year:		**3182,31**

2.3. Experimental set up and measuring method

Main devices of experimental setup described in 2.1. chapter. System is controlled by differential controller according temperature differences in collector's top fluid temperature and DHW storage temperature.

The basic device for experimental measuring for both systems in this work is heat meter with ultrasonic flow meter and temperature sensors Pt500. Data from heat meter is transmitting using local modem to remote server in witch performs its handling with software "HD -Vision 2.0". Modem every 30 minutes transmits values from heat meter: instantaneous heat power that generates collectors loop Q, temperature of delivery fluid flow in collectors loop T_1, temperature of return fluid T_2, temperature difference between delivery and return fluid flow $\Delta T = T_1 - T_2$, produced heat energy $Q_{produced}$, through the collectors loop leaked fluid volume V, systems working hours h.

Real weather conditions for Kaunas city (in this case irradiation to horizon) was taken from Lithuanian Hydrometeorological service.

Measuring was performed from 01.08.2008 till 31.07.2009.

3. Results

3.1. Theoretical model

Using software T*SOL Pro could be calculated many technical parameters, but we analysed and compared just these: global specific irradiation into inclined surface (Kaunas), A and B system's produced energy, A and B system's monthly and yearly efficiency. Mentioned both systems parameters were calculated and compared for standard (normal) year.

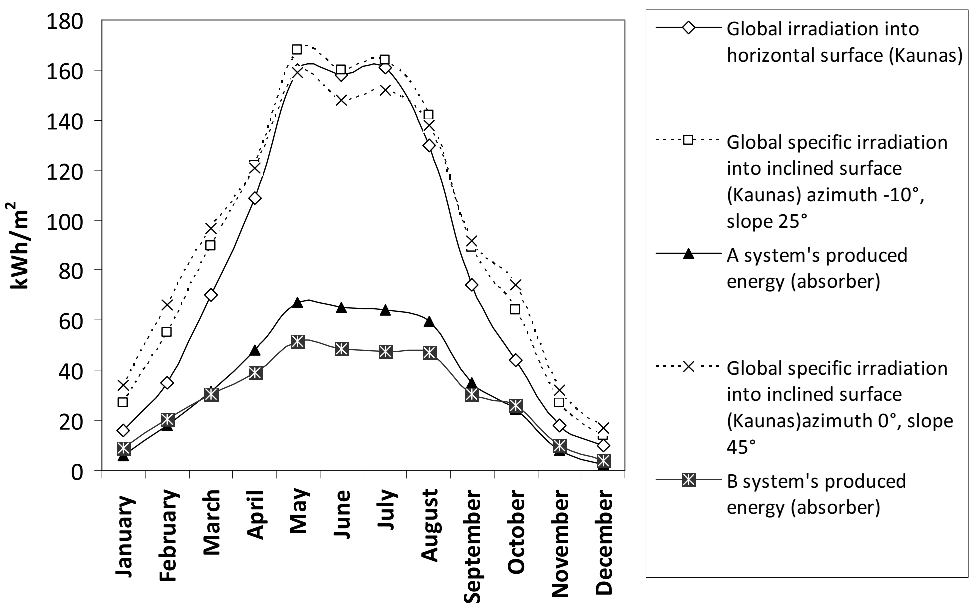

Fig. 2. Estimated global irradiation (Kaunas), global specific irradiation for a A and B systems, A and B systems produced energy ($kWh/m^2_{absorber}$)

At Fig. 2. showed global specific solar irradiation for A and B systems estimation. Obviously we can see that B system's collectors' inclination angle in winter time is better than A system's, but worse in summer season. Influence of collector's inclination angle for the both systems isn't very impacting factor looking at all year average. Total yearly solar irradiation to A system's collector with 25 degrees inclination angle with horizon brings 1122 kWh/m^2. It is just 0,7 % less than for B system – 1130 kWh/m^2 (45 degrees inclination).
Calculated yearly heat production for A system equal 430 kWh/m$^2_{absorber}$. B system produced just 366 kWh/m$^2_{absorber}$.
Systems efficiency were calculated as produced energy divided of inclined global solar irradiation and expressed as:

$$\eta_{\text{system}} = \frac{Q_{produced}}{G_{inc}}; \qquad (1)$$

There η - efficiency of system, $Q_{produced}$ – solar collectors system produced energy; G_{inc} – solar irradiation into inclined collectors.
Solar fraction is the ratio of produced heat energy over energy demand for DWH.
Yearly efficiency for modelled A system obtained as 38 % and for B system 32 %.
Estimated A system's yearly solar fraction is 32 %, for B system it raises till 50 %. These values shows that A system seems was designed as too small (need to increase solar collectors absorber), because normally solar collector system must be designed such way that yearly solar fraction in DHW heating would reach 40 – 60 %.
Performed estimation for B system show, that solar fraction in DWH is average about 74 % from the start of the April till the end of September. It indicates that system is designed optimal.

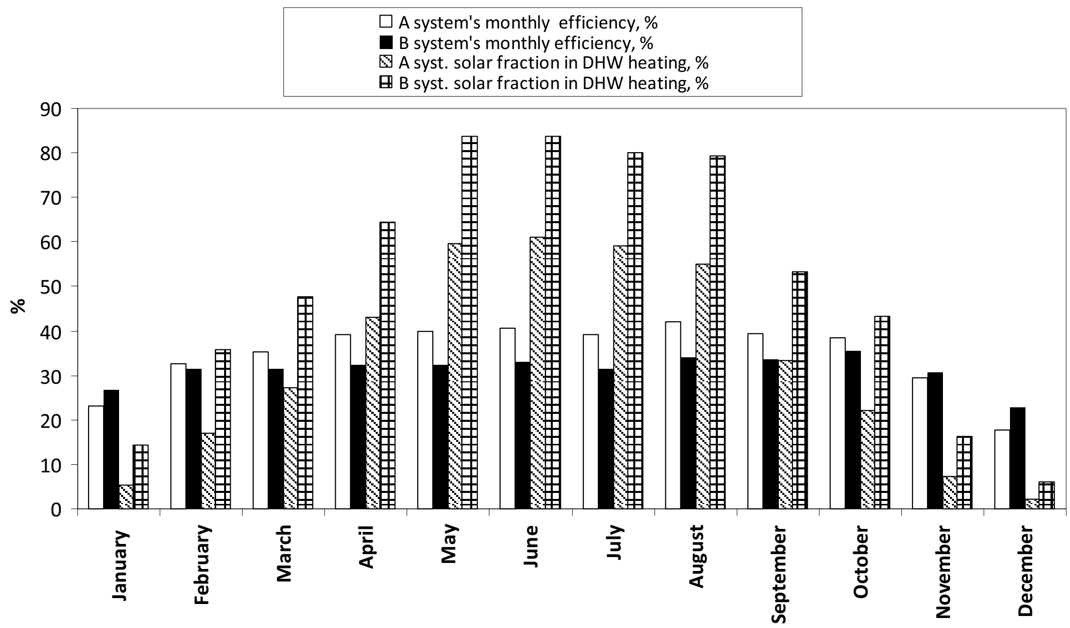

Fig. 3. Estimated monthly efficiency and solar fraction of A and B solar collectors systems

3.2. Results of real systems performance

Measuring results showed in Fig. 4. as usually and like in theoretical model repeats the same tendencies of global and specific solar irradiation to inclined collectors. Some solar irradiation fluctuations are notable for year of investigation in comparing with standard year. Standard year solar irradiation taken from software data base is collected from 1961 – 1991 year. Nowadays meteorological outlook shows that in winter solar irradiation is bit lower and in summer – higher. Moreover notable and some longer lasting solar irradiation and outside air temperature extremes.
It was measured that A system produced 380 $kWh/m^2_{absorber.}$ It is 13,16 % less than in theoretical model but yearly global irradiation into inclined collectors was 3,48 % higher. It could be explained in such way: from the beginning of A system exploitation was noticed that system produced less energy than it should produce. For one day vacuum tubes collector were demounted and vacuum tubes were tested one by one for persuade that all collector works fine. At the result due technical mismatches in the collector of 30 tubes was replaced 5 vacuum tubes with new (date 31.03.2009). Real A system's efficiency 33 % and it is 5 % less than in theoretical estimation.

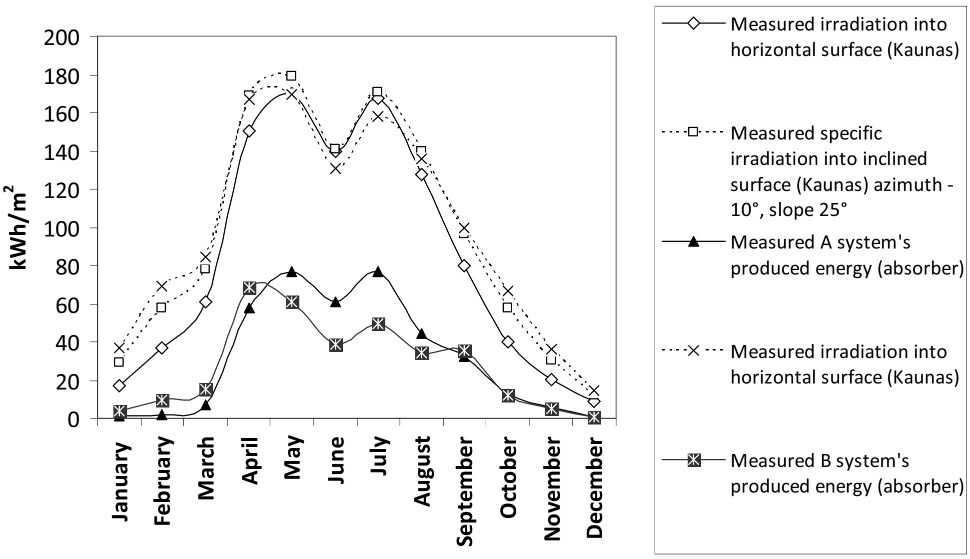

Fig. 4. Measured global irradiation (Kaunas), global specific irradiation for a A and B systems, A and B systems produced energy ($kWh/m^2_{absorber}$)

B system's yearly energy production was 335,2 $kWh/m^2_{absorber.}$ This value is 8,5 % lower than theoretical, solar irradiation to inclined collectors 3,3 % higher. These errors could originate due inaccuracy of measuring devices and solar collectors inclination angle deviation. One of the major origin of errors is too big flow meter size ((1,5 m^3/h)) so it works out of his boundaries.
Measured efficiency for B system is about 29 %. This value in theoretical model was 3 % higher. Unfortunately yearly energy consumption wasn't measured so we couldn't calculate real yearly solar fraction in DHW heating.

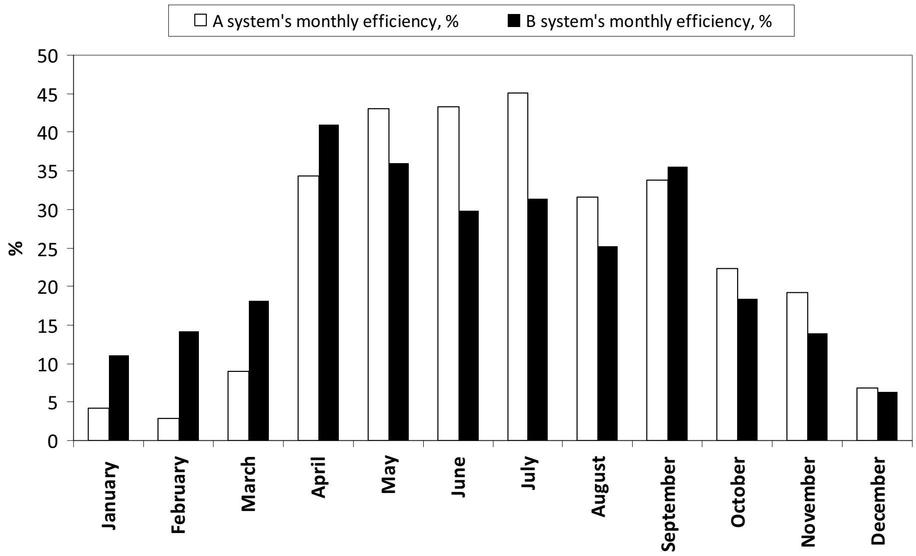

Fig. 5. Measured monthly efficiency of A and B solar collectors systems

4. Economical evaluation

4.1. Economical assumptions

Both systems were analysed from technical view, but every system with technological process must have and economical reasoning. Using theoretical model we attempted to calculate mostly usable economical indicators – simple payback (SPB), net present value (NPV) and internal rate of return (IRR). Calculating the investment for the systems wasn't evaluated cost of twin coil DHW heater (storage) because anyhow it is a concurrent part of boiler room installation.

Economical evaluation was performed according these assumptions:

Project estimation period – 20 years;
Nominal discount rate – 5 % [3];
Energy price index – 2,5 %/yr;
Inflation – 3 %/yr;
Electricity price – 0,130 €/kWh,
Investment (equipment with montage and transportation):

Table 3. Investment for systems

System	A system	B system
Total investment, €	3860,47	3423,14
Specific investment, €/m^2 absorber	1608,53	781,54

4.2. Economical indicators for theoretical model

Economical indicators were calculated using MS Excel and showed in the next table. Savings of money were calculated using electricity energy price. Electricity energy consumption of systems' pumps wasn't evaluated in economical estimation.

Table 3. Economical indicators for solar collectors systems

Indicator/System	A system	B system
Simple payback time, yr.	N/A	16,41
NPV, €	-1125,61	701,25
IRR, %	1,6%	7,0%

5. Conclusions

Using software and direct measurement method were investigated two solar collectors systems - A system with vacuum tube and B system with flat plate collectors. It emerged that A system was designed with too small absorber area. It was measured that A system though the one year produced 380 $kWh/m^2_{absorber.}$ A system's efficiency is about 33 %. It seems that A system needs to be mounted with additional 20 vacuum tubes that to be reached same solar fraction as B system in theoretical model.

B system's measured yearly energy production was 335,2 $kWh/m^2_{absorber}$ with 29 % efficiency.

An economical indicator shows that B system is competitive economically. It has 16,4 yr. simple payback time and 7 % of IRR. Beside the physical hardiness of flat plate collectors is very high in comparison with vacuum tubes.

Using of vacuum tubes collectors have no economical validity in analyzed case.

References

[1] European solar thermal industry federation (2010 June). Solar Thermal Markets in Europe Trends and Market Statistics, www.estif.org.

[2] Website of software http://www.valentin.de/.

[3] EUROPEAN COMMISSION (2008). Guide to COST-BENEFIT ANALYSIS of investment projects.