Efficiency measurement and energy yield estimation of solar collectors

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***Abstract*— We have determinated the functions of efficiency of our experimental solar collectors (Fig. 2) with our self-designed measurint equipment (Fig. 1). With the knowledge of these functions and the climatic properties the annual energy yield could be calculated. With our method we can determine the annual energy yield and the annual average efficiency in functions of the operating parameters of the collectors.**

***Index Terms* — efficiency measurement, solar energy, solar collector.**

I. Introduction

During our study we have used our own-designed experimental solar collectors. The housings of our collectors are made of galvanized steel sheet. It can be installed on above tile or directly to the roof structure. We use two kind of absorber piping: one of them is equipped with a single pipe (1), the other one has parallel pipes (2). The coverings are cellular polycarbonate sheets. The light transmittance value for a typical polycarbonate sheet is lower than for a solar glass, but the cellular polycarbonate sheet has a better heat insulation capability. The covering is removable, so during our research we could test more types of polycarbonate sheets and we used the collectors without covering, too.We have mounted two pumps, one of them controls the volume flow rate by the temperature of the fluid, and the other one is uncontrolled. The two pumps do not run simultaneously (3). The temperature difference between the collector and the ambient air in our system is well-controlled with the fan coil (4) which transfers the heat from the collectors to the ambient air. The number of revolution of the fan is continuously adjustable. The volume flow rate meters (7) measure by displacement with rotary pistons. With this devices we can measure from 7,5 lh^{-1}. The accuracy is ± 2 %. We have measured the temperatures with K-type thermocouples and Testo 177-T4 data loggers. The accuracy is ± 0,3 °C. We have measured the temperature and humidity of the ambient air and by a Lambrecht 16131 pyranometer the intensity of the solar irradiation. The pyranometer is mounted between the collectors at the same plane. The pyranometer conforms to ISO 9060 “First class” standard.

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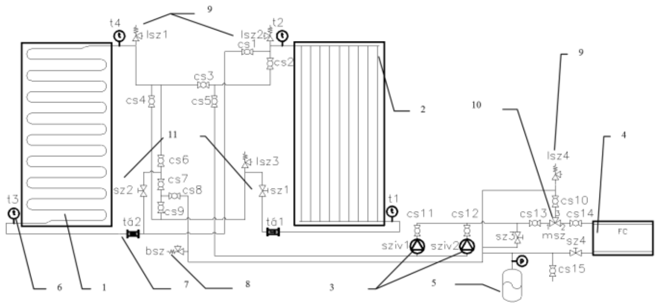

Figure 1. Experimental measuring and datalogging equipment for the determination of the efficiency of solar collectors. 1 – collector with single-pipe absorber, 2 – collector with parallel pipes, 3 – circulation pumps (sziv1: regulated, sziv2: without regulation), 4 – fancool, 5 – expansion tank, 6 – thermocouples (t1 – t2 – t3 – t4), 7 – flowmeters, 8 – safety pressure limiting valve, 9 – automatic vent valves (lsz1 – lsz4), 10 – motorized valve for cooling performance control (msz), 11 – choking valves for volume flow control (sz1, sz2), cs1 – cs14: ball valves for changing the connection, cs15: filling valve

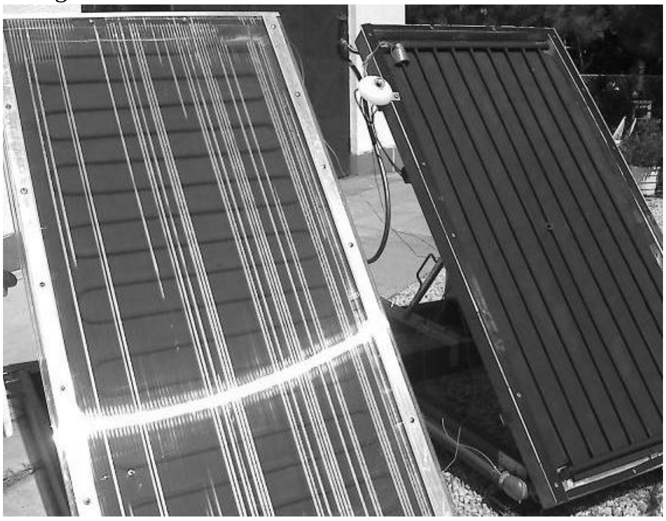

Figure 2. Experimental solar equipment.

II. Collector Efficiency Measurement

The calibrated Lambrecht pyranometer senses the changes of the irradiation intensity within 18 seconds. The mass – and so the thermal inertia – of the collectors is much higher than the pyranometer’s. The reaction of the collector is much slower. So during a period of a decreased irradiation that caused by a cloud rack the heat output of the collectors still high – caused by the higher irradiation of the previous minutes. If we calculate the momentary efficiency in this time, it will add wrong result. The momentary efficiency could be calculated only in sunny periods. Because of the big amount of data we need to define a function to filter out the clody periods automatically.

We have made three requirements that have to be satisfied for selecting cloudless periods during the previous 5 minutes to mark a moment as cloudless:

$$\Delta G_{spec} \leq 0{,}05, \tag{1}$$

$$\Delta G_{max} - \Delta G_{min} \leq 50, \tag{2}$$

$$G_{min} = 100 \frac{W}{m^2}. \tag{3}$$

Using these requirements the logical function can mark the cloudless and cloudy periods as represented in Figure 3:

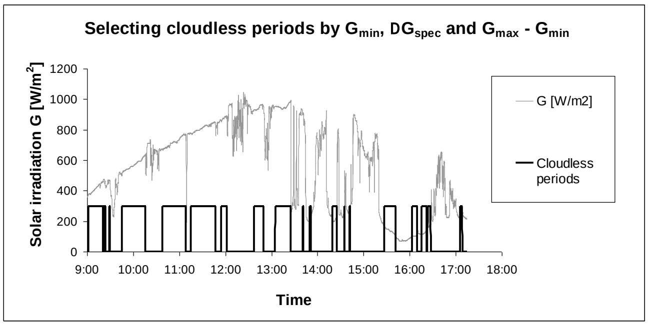

Figure 3: Selecting cloudless periods by three requirements.

The value of the logical function is zero during the cloudy periods.

By the filtering of the database of our measurements we have determined the functions of the efficiency for the two experimental solar collectors. The function of the efficiency is determined from 600 to 1000 Wm^{-2} intensity of solar irradiation. Table 2 represents the filtering parameters for the measuring points of the function of efficiency:

Table 2: Filtering parameters of the measuring points of the function of efficiency

maximum deviation of the solar irradiation intensity	± 10 Wm^{-2}
difference between the collector inlet and outlet temperature: $t_{out} - t_{in}$	> 5°C
cloudless period marked	yes
covering	Makrolon mUV 10

III. Functions Of The Annual Efficiency

Knowing the meteorological data, the operating parameters and the function of the efficiency of the collectors our functions determine the annual energy yield. About the measuring of the efficiency among operating conditions we have published our results in several scientific papers ([1], [2], [3]).

With the determinated function of the efficiency for the experimental solar collectors we have analyzed the amount of the available annual energy yield. For the calculations we used the temperature and solar irradiation data of the year of 2012, in ten-minute resolution. It is available a meteorological model in one-our resolution for the design of solar systems [4].

The specific annual energy yield is the annual energy yield relative to the collector surface (MJm^{-2}).

The annual average efficiency is the ratio of the annual energy yield and the energy irradiated to the absorber surface of the collector (%).

The average of the instantaneous efficiency values according to the meteorological database is the average of the efficiencies of the ten-minute intervals (%). It is not equal to the annual average efficiency.

From the meteorological database we have filtered out the night periods, we have used only the data with mensurable solar irradiation value.

With our equipment we have tested two own-designed experimental solar collectors, one with a single pipe absorber and an other with parallel pipes. With the processing of the measurements we have determinated the functions of the efficiency for the two collectors. With these functions we have calculated the estimated annual values for the experimental collectors.

There are several ways to change the efficiency during the annual period according to the operation of the collector. Usually the control keeps a specified temperature difference between the collector fluid and the water of the solar tank, so the temperature of the collector follows the temperature of the solar tank. In case of this operation the annual average efficiency depends on several parameters: the size of the solar tank [5], the volume, the time, the rate of water usage and the heat loss of the system. We did not want to analyze these effects, our goal was the comparing of the collectors.

We defined two kinds of annual efficiency. In the first case keeping a constant temperature difference between the collector and the ambient air we can see the available annual efficiency in function of this temperature difference in Figure 4 and Figure 5 for the tested experimental solar collectors:

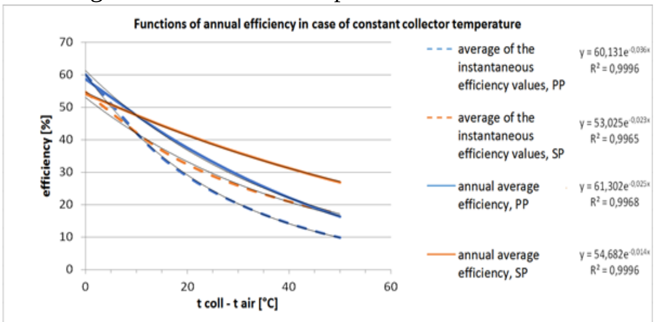

Figure 4: Annual average efficiency of the experimental solar collectors.

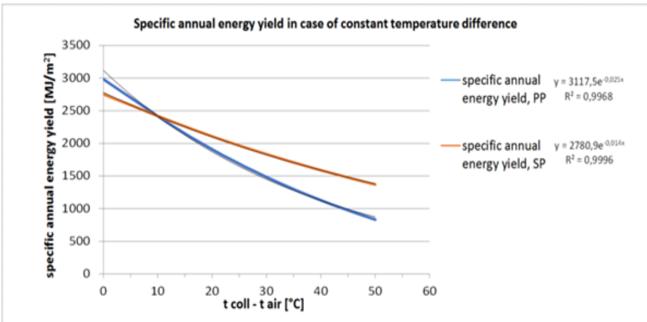

Figure 5: Specific annual energy yield of the experimental solar collectors in case of constant temperature difference between the collector and the ambient air.

In the second case keeping a constant collector temperature we can see the functions of the annual efficiency in the function of the collector temperature in Figure 6 and Figure 7:

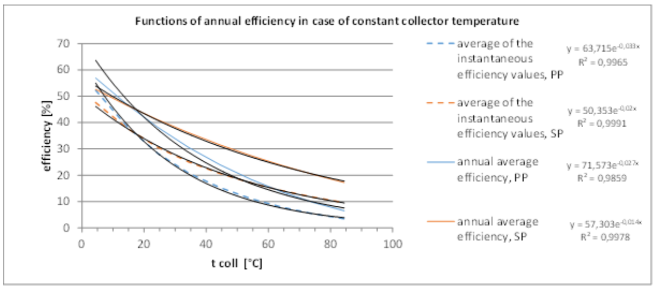

Figure 6: Functions of annual efficiency of the experimental solar collectors in case of constant collector temperature.

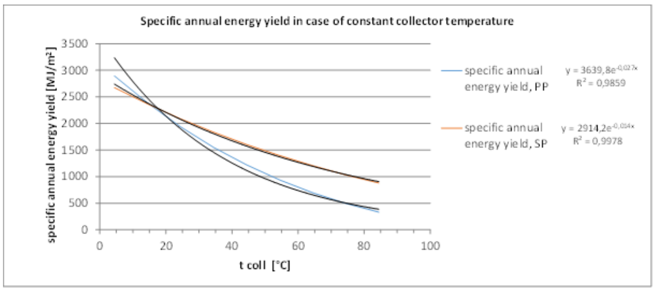

Figure 7: Specific annual energy yield of the experimental solar collectors in case of constant collector temperature.

The next example shows the meaning of the functions: if the test collectors among the weather conditions of 2012 were operated at 20 °C above the air temperature all year round, the collector with parallel pipes would generate 1910 MJm^{-2} heat from the irradiated 5086 MJm^{-2} energy (Figure 4). The annual average efficiency is the ratio of these two quantities: 37,52 % (Figure 3). The average of the efficiency values of the ten-minute periods of the year is 28,7 % (Figure 3). The meaning of functions of Figure 6 and Figure 7 are the same in case of a constant collector temperature during the year.

IV. Calculation Of The Expected Annual Energy Yield

If the expected intensity of the solar irradiation, the air temperature and the operating parameters of the collectors are known, the expected annual energy yield is predictable. Using the meteorological data of 2012 the energy yield is integrated numerically from the ten-minute periods.

If the temperature difference between the collectors and the ambient air were a constant value during the year, the monthly average efficiency shown the function of the Figure 8. The diagram presents the changes in efficiency in the range of 0-50 °C temperature difference, in 5 °C increments.

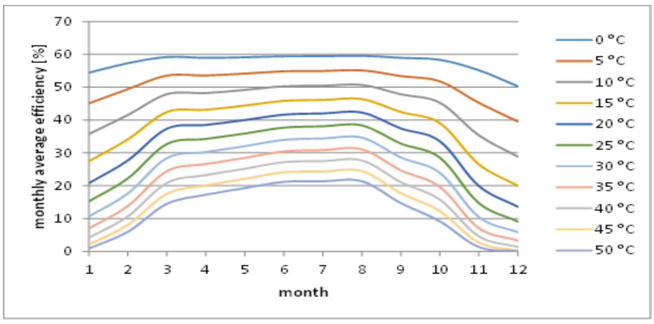

Figure 8: Monthly average efficiency of the collector with parallel pipes belonging to different values of constant temperature difference between the collector and the ambient air.

The monthly average efficiency of the collector that works on the ambient air temperature shows an approximately constant value during the year, but as we increase the temperature of the collector this uniformity terminated: the decrease of the efficiency is greater during the winter months than in the summer period.

The values of the Figure 8 are theoretical, on real operating conditions do not occur, because the collectors could be operated on ambient air temperature possibly in summer. Typically there is not material for heat absorbing at a lower temperature than the ambient air in winter, so the collector can not operate at the ambient air temperature.

Approximating the real average efficiency values we have to take into account the temperature of the ablative medium which determinates the minimal operating temperature. The other parameter is the achieved maximal temperature. In case of 20 °C minimal and 70 °C maximal temperature the functions takes the following form (Figure 9):

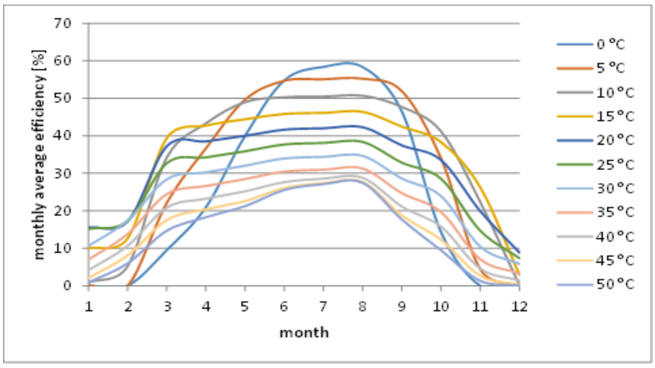

Figure 9: Monthly average efficiency of the collector with parallel pipes for several values of temperature difference between the collector and the ambient air, between 20 °C minimal and 70 °C maximal collector temperature.

With these criteria Figure 10 represents the values of the annual parameters (specific annual energy yield, hours of operation, annual efficiency) in function of the temperature difference between the collector and the ambient air:

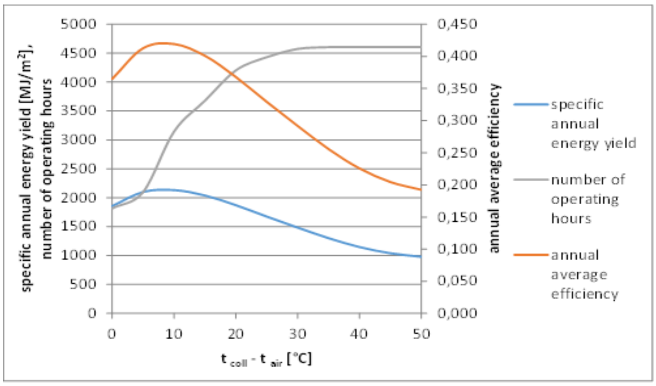

Figure 10: Annual operating parameters of the collector with parallel pipes in case of 20 °C minimal and 70 °C maximal collector temperature.

As we can see, among the meteorological conditions of 2012 in the range of 20 and 70 °C collector temperature the collector with parallel pipes operates optimally if the temperature difference between the collector and the ambient air is 8 °C. In this case the specific annual energy yield is

2137,5 MJm^{-2}, the annual average efficiency is 42 %, the number of hours of operation is 2885.

Based on the values in Figure 9 we have determined the maximal annual energy yield in the range of 20÷70 °C collector temperature. We have chosen the temperature difference between the collector and the ambient air in every period for the maximal monthly efficiency (Table 1):

Table 1: Maximal annual energy yield of the collectors

	$t_{coll} - t_{air}$	q PP	q SP	monthly average efficiency PP	monthly average efficiency SP	global irradiated energy
	[°C]	[MJ/m^2]	[MJ/m^2]	[%]	[%]	[MJ/m^2]
January	25	22,82	37,83	15,13	25,07	150,87
February	30	39,44	61,43	17,39	27,08	226,84
March	15	178,15	186,62	39,40	41,27	452,14
April	10	213,83	211,09	43,33	42,77	493,53
May	5	311,28	293,37	49,68	46,82	626,57
June	0	393,04	357,45	54,80	49,83	717,28
July	0	442,39	402,32	58,37	53,09	757,86
August	0	370,81	337,22	58,36	53,07	635,41
September	5	233,15	221,64	51,90	49,34	449,19
Oktober	10	130,01	131,87	41,17	41,75	315,82
November	15	40,91	52,43	26,25	33,64	155,87
December	20	9,20	14,90	8,84	14,31	104,14

Based on the data of Table 1 the monthly average efficiency and specific energy yield values of the collector with parallel pipes are (Figure 11):

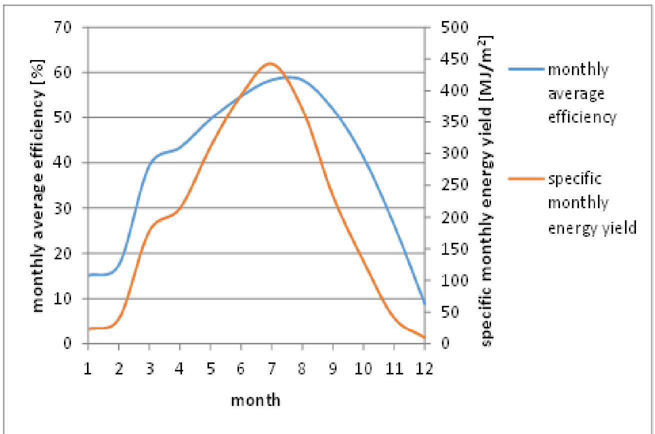

Figure 11: Monthly average efficiency and specific energy yield values of the collector with parallel pipes in the range of 20÷70 °C collector temperature in case of the maximal annual energy yield.

The specific annual energy yield of the collector with parallel pipes with the $t_{coll} - t_{air}$ settings of the Table 1 increases to 2385 Wm^{-2}, the annual average efficiency increases to 45,4 %.

As above the characteristic of the collector with a single pipe are represented in Figure 12:

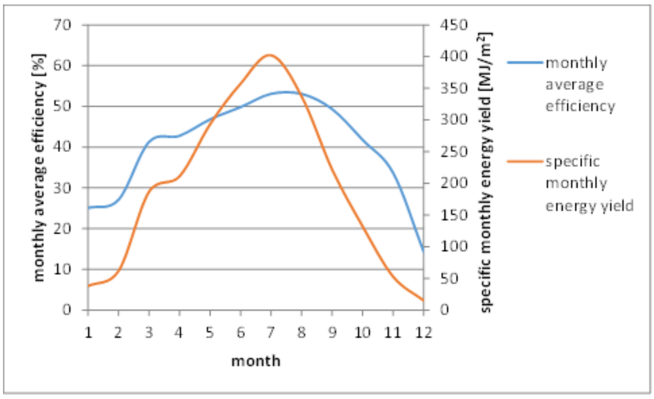

Figure 12: The annual average efficiency and specific energy yield of the collector with single pipe in the range of 20÷70 °C collector temperature.

The specific annual energy yield of the collector with a single pipe with the $t_{coll} - t_{air}$ settings of the Table 1 is 2308,2 Wm^{-2}, the annual average efficiency is 45,4 %.

Knowing the function of efficiency and the climatic properties with our tables the optimum could be calculated for any solar collector.

V. Conclusion

At the University of Szeged Faculty of Engineering we have developed a measuring unit for testing of our own-designed experimental solar collectors. With this unit we can determine the function of efficiency of solar collectors and test the operating characteristics. Using the determined functions of efficiency and the registered meteorological data of 2012 we have analysed the annual energy yield and the annual average efficiency of the experimental collectors in function of the operating parameters. We have determined the collector temperature values during the year for the maximal annual energy yield.

VI. Acknowledgment

For the calculations we used the registered air temperature and intensity of solar irradiation data of 2012 in ten-minute resolution. This database is provided by the University of Szeged Faculty of Science and Informatics Institute of Geography and Geology Department of Climatology and Landscape Ecology. We would like to thank Dr. Janos Unger, Head of Department.

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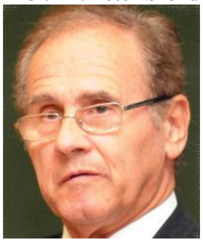

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