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GÖDÖLLŐ

MECHANICAL ENGINEERING PhD SCHOOL

Modeling of the operating characteristics of solar collectors

Thesis of PhD work

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CONTENTS

1. INTRODUCTION, OBJECTIVES

Applying devices for utilizing renewable energy resources the time of the exhaustion of the fossil energy resources can be extended. At the installation of a system that uses renewable resources the payback time is an important aspect, it is affected by several technical and economic factor. The payback time is currently very long, this blocks the widespread of these systems. Beside the price the payback time is determined by the efficiency of the collectors among different weather and operating conditions, so its precise knowledge is primary. Determining the function of efficiency with laboratory measurements for small batch produced collectors would increase significantly the development costs. It is well-founded to research and develop a method for the determination of the function of efficiency based on measurement made among natural operating conditions, which is safety and more cost-effective. With this method the price of the collectors may be lower, the time of the development and the pay back shorter.

The goals of the research described in the dissertation are the study of the operating effects of solar collectors, and exploring the limitations and opportunities of the determination of the function of efficiency with measurements among natural operating conditions.

A limitation is the fluctuation of the solar irradiation which may affect the accuracy of the measurements. Igazolni kívánom ezen zavaró tényező hatását. Meg kívánom határozni a pontos, számszerű kritériumokat a mérésre alkalmas időszakok napsugárzási intenzitását illetően.

I intend to verify the proper operation of the measuring gauges – especially the volume flow meters – of the necessary measuring device that I developed for the experiments.

I intend to describe the exact, validated method for the determination of the efficiency curve with the right filtering of the measurement database. I intend to analyze the transient effects of the collectors.

I intend to determine the expected annual energy yield of the analyzed collectors. I want to develop a simple method for the calculation of the optimal annual collector temperature dynamics in advance with known climatic conditions.

2. MATERIAL AND METHOD

According to the criteria described in the analysis of the literature review of the dissertation I developed a new measuring and data logging device, which provides an opportunity for the determination of the function of efficiency and for the study of the operational effects for any fluid operated solar collector. In this chapter I describe the main parts and the operation of the device, the measuring gauges and data loggers, the steps of the measurement and data process.

2.1. Description of the experimental device and its main units

For my research I developed the experimental device shown in Fig. 2.1.

The function of efficiency of a solar collector generally depends on many parameters. For a specific type of collector these parameters are fixed. According to accepted practice in scientific research institutes the function of efficiency of the analyzed solar collector has two independent variables, namely:

- intensity of solar irradiation (G, Wm^{-2}),
- temperature difference between the collector and the ambient air (t_{koll}-t_{lev}, °C).

I want to determine the function of efficiency of the collector at the maximum range of the two independent variables. I made the measurements in natural operating conditions, I did not use artificial light, so I could not control the intensity of irradiation. The other variable the temperature difference from the ambient air is controlled well with the fan coil (4) connected to the system and through which the heat output of the collectors goes to the ambient air. The number of revolutions on the fan coil is continuously adjustable and with a bypass and an adjusting valve can be further reduced. The fan coil can be excluded from the circuit. With this solution the temperature at the fluid inlet of the collectors is controllable: decreasing the cooling capacity of the fan coil the fluid temperature increases at the inlet. It allows fast changes of the temperature difference between the collectors and the ambient air. With the device the collectors can be analyzed in serial and parallel connection.

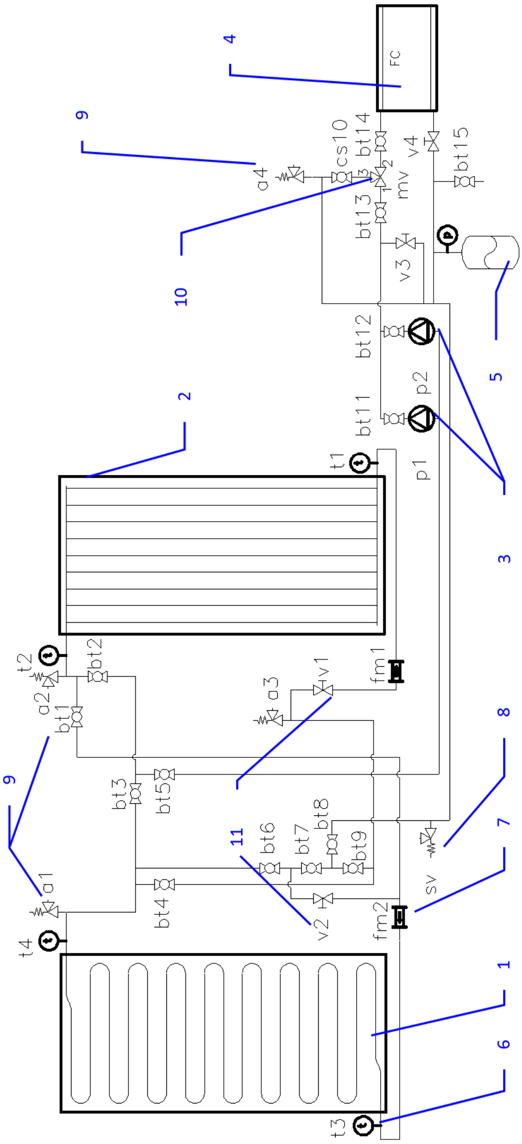

Figure 2.1. Experimental measuring and data logging device for the determination of the function of efficiency of solar collectors

1 – solar collector with single pipe absorber (SP), 2 – solar collector with parallel pipes (PP), 3 – circulation pumps (p1: regulated, p2: unregulated), 4 – fan coil, 5 – expansion tank, 6 – thermometers (t1 – t2 – t3 – t4), 7 – flow meters, 8 – safety pressure relief valve, 9 – deaerators (a1 – a4), 10 – motorized valve for cooling capacity control (mv), 11 – choking valves for volume flow rate adjustment (v1, v2), bt1 – bt14: ball taps for setting the circuit, bt15: filler tap

2.2. Method of the data process and the correction of the measuring errors, evaluation of the results

For the data process of the diurnial measurements I have made an Excel table. The table calculates the next quantities from the results registered by the data loggers every five seconds:

- intensity of solar irradiation: G, [Wm^{-2}],
- volume flow rate of the antifreeze fluid in each collector: $\dot{V}_{PP}$, $\dot{V}_{SP}$, [m^3s^{-1}; $l \cdot min^{-1}$]
- density of the antifreeze fluid in function of the temperature: $\rho = f(t)$, [kgm^{-3}; $kg \cdot l^{-1}$]
- mass flow of the antifreeze fluid: $\dot{m}_{PP}$, $\dot{m}_{SP}$, [$kg \cdot s^{-1}$]
- heat output of the collectors: Φ_{PP}, Φ_{SP}, [W]
- efficiency of the collectors: η_{PP}, η_{SP}
- average temperature of the collectors: $t_{coll\ PP}$, $t_{coll\ SP}$, [°C]
- difference between the average temperature of the collectors and the temperature of the ambient air: t_{coll} - t_{air}, [°C]
- average values of the measured and calculated quantities for every five and ten minute intervals,
- difference between the momentary and the average values of the measuring results,
- sum and average values for the complete diurnial measurements.

3. RESULTS

In this chapter I describe the errors experienced during the measurements, my developed methods for the correction of these, the limitations of the measuring method. I describe the experienced effects of the operation and the developed algorithm for the determination of the function of efficiency and for the calculation of the expected annual energy yield.

3.1. Mathematical modeling for the correction of errors occurring from the omission of the impulse-signals

I have created a mathematical algorithm for the automatic correction of the errors of missing impulse-signals of the data loggers (Fig. 3.1) and for the smoothing of the corrected volume flow rate curves.

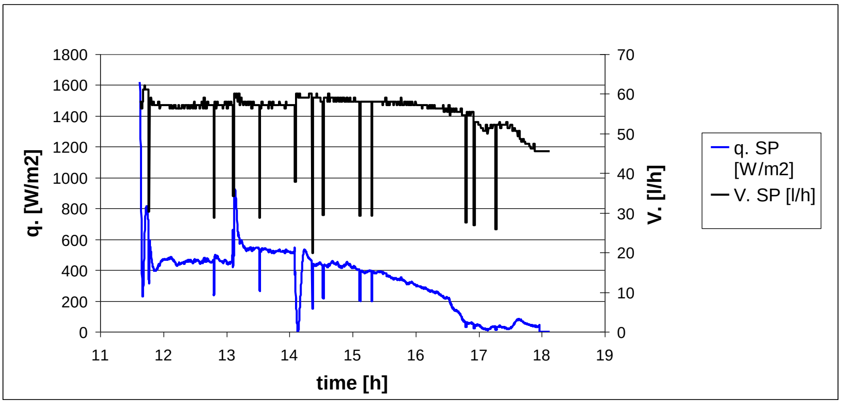

Figure 3.1. Raw volume flow rate data of a diurnial measuring, 22.08.2010

If the ratio of a calculated volume flow rate value and the average of the previous two and following two values is 2/3 or less, then an omission of an impulse-signal is supposed, and the false data is replaced with the average of the previous two and next two values. (Equation 3.1 and 3.2):

$$\frac{\dot{V}_i}{\frac{\dot{V}_{i-2}+\dot{V}_{i-1}+\dot{V}_{i+1}+\dot{V}_{i+2}}{4}} > \frac{2}{3} \Rightarrow \dot{V}_i{}' = \dot{V}_i \tag{3.1}$$

$$\frac{\dot{V}_i}{\frac{\dot{V}_{i-2}+\dot{V}_{i-1}+\dot{V}_{i+1}+\dot{V}_{i+2}}{4}} \leq \frac{2}{3} \Rightarrow \dot{V}_i{}' = \frac{\dot{V}_{i-2}+\dot{V}_{i-1}+\dot{V}_{i+1}+\dot{V}_{i+2}}{4} \tag{3.2}$$

Smoothing the volume flow rate curve

I have increased the accuracy of the measurement with the smoothing of the corrected volume flow rate curve. I have replaced the values calculated by the impulse signals with the average of the previous two and next two values (Equation 3.3).

$$\dot{V}_i'' = \frac{\dot{V}_{i-2}' + \dot{V}_{i-1}' + \dot{V}_{i+1}' + \dot{V}_{i+2}'}{4} \tag{3.3}$$

Fig. 3.2 compares the smoothed and the corrected curves:

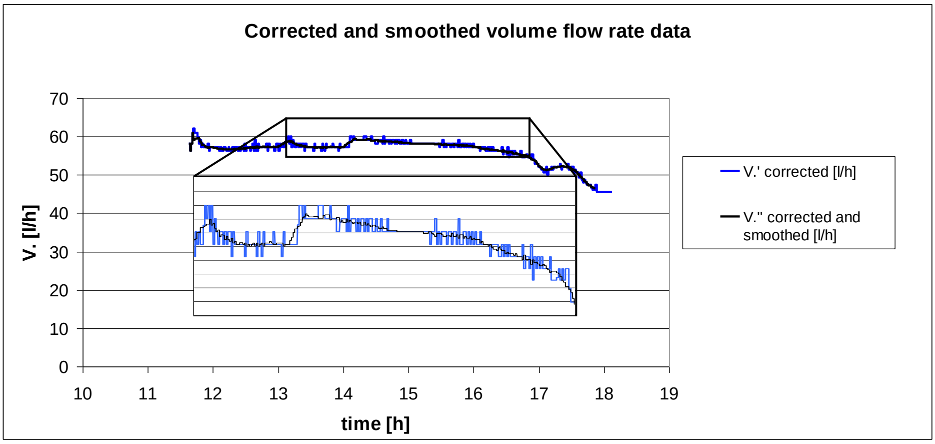

Figure 3.2. Corrected and smoothed curves, 22.08.2010

The scientific novelty of my method that this is capable not only for the analysis of solar collectors but for all measurements made by logging impulse signals.

3.2. Mathematical formula for marking the cloudless periods

My researches verified that the cloudy periods occurs errors during the calculaton of the momentary efficiency of solar collectors. I developed a logical function that divides the measurements into cloudy and cloudless periods. With this logical function the cloudless periods that cause errors can be filtered out.

I have formulated three criteria. If all of these three equations are fulfilled, the tested moment can be marked as cloudless. The moment is cloudless if the three criteria (Equation 3.4, 3.5, 3.6) are also valid during the previous 5 minutes:

$$\Delta G_{spec} = \frac{G_i - G_{i-1}}{G_i} \leq 0{,}05 \tag{3.4}$$

$$G_{max} - G_{min} \leq 50 \frac{W}{m^2} \tag{3.5}$$

$$G_{min} \geq 100 \frac{W}{m^2} \tag{3.6}$$

The value of the logic function is 1 if the moment is cloudless, and zero if cloudy. Fig. 3.3 represents the operation of the function:

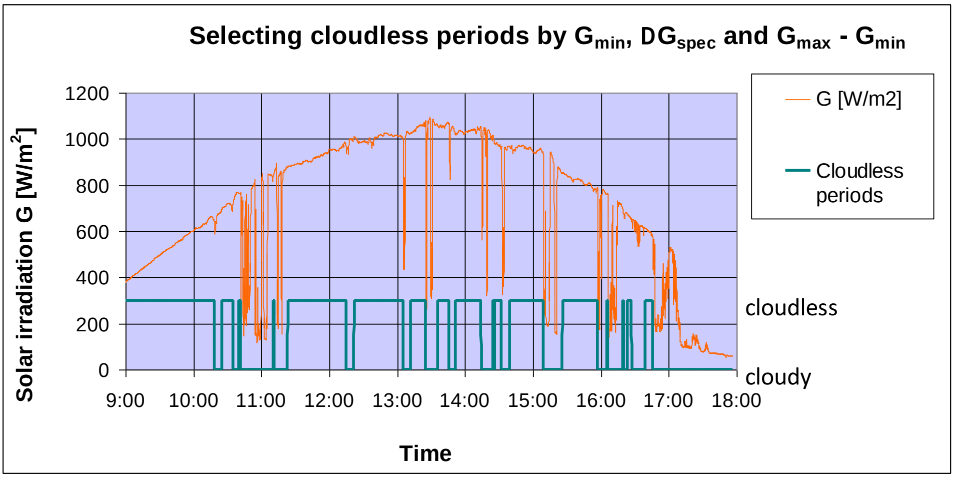

Figure 3.3. Marking of the cloudless periods with own logic function (based on the measurement in 2010.08.11)

3.3. Changes of the efficiency in serial connection

I have identified the differences between the efficiencies of the collectors connected in line.

In serial connection, it is verifiable that going ahead the value of the momentary collector efficiency decreases. This occurs due to the increasing collector average temperature. I have measured this effect in different orders of serial connections (Fig. 3.4). As we can see, if we change the order of the collector in line, the relation of the efficiencies also changes. The efficiency of the second collector is always lower. (The outliers come from the transient effects during the changing of the order.)

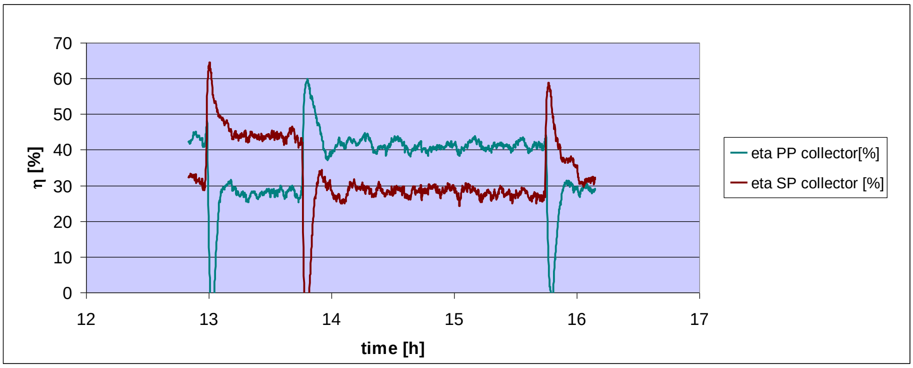

Figure 3.4. Serial connection in different orders
(PP – collector with parallel pipes, SP – collector with single pipe absorber)
Before 13:00: PP-SP, from 13:00 to 13:45: SP-PP, from
13:45 to 15:45: PP-SP, after 15:45: SP-PP, 08.21.2010

3.4. Parallel connection of collectors with different piping

I have identified that in parallel connection, the ratio of the volume flow rates in different collectors filled with viscous material is not a constant value, it changes according to the temperature variation. The reason for the effect is the temperature-dependence of the viscosity.

3.5. Analyzing the transient effects

I have determined that the first collector in a serial connection reacts faster to the decreasing of the inlet fluid temperature. I have also determined that the second collector reacts not only later but slower than the first one.

The reaction to the change of the fancoil performance appears faster in the first collector and needs less time than in the second one.

In the fluctuations of solar irradiation, I have observed similar effects. In the Fig. 3.5 these can be clearly seen.

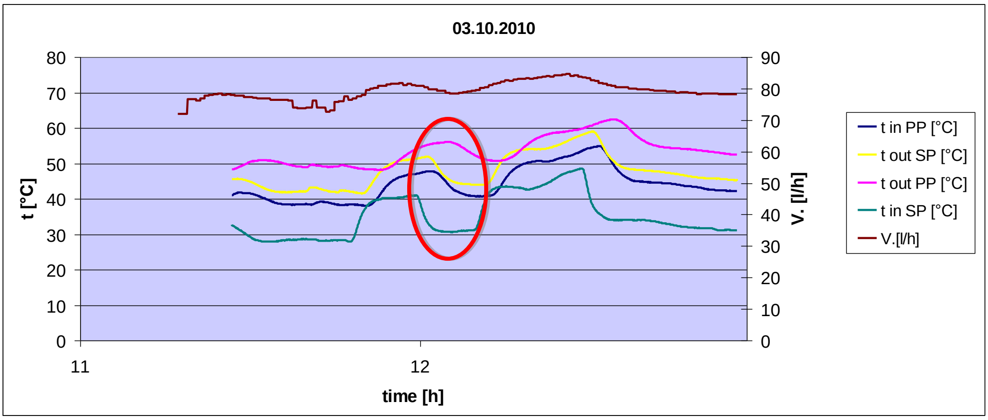

Figure 3.5. Collector inlet and outlet temperature in linear connection in the order of single pipe – parallel pipes collector

I have verified the results of my experiments with a reverse-ordered (collector with parallel pipes – single pipe collector) linear connection. From the different types of collectors, on the first in line the transient effect appears earlier and its running-down is faster.

The results could be readily applied for the control of large collector fields.

3.6. Calculating the functions of the efficiency

I have developed a method for processing the results of measurements performed in natural operating conditions and for determining the function of efficiency.

For the determination of the functions of efficiency I have made the next inquiry from the database of the measurement:

Table 3.1. Parameters of the inquiry for the function of the efficiency at 1000 Wm^{-2} solar irradiation intensity

max. deviation of G	± 10 Wm^{-2}
$t_{out} - t_{in}$	> 5°C
cloudless periods	yes
cover	Makrolon mUV 10
incident angle of solar irradiation in vertical plane	not limited

I separated the 1803 values of the inquiry by the difference of the collector and the ambient air temperature by 2 °C increments. I have calculated the average, median, minimum, maximum and the number of values for these ranges. Table 3.2 represents these results:

Table 3.2.: Properties of the measured values of the efficiency of the collector with parallel pipes at 1000 Wm^{-2}

$t_{coll} - t_{ambient}$	14-16 15	20-22 21	22-24 23	24-26 25	26-28 27	28-30 29	34-36 35	36-38 37
average	44,23	52,87	51,46	52,27	52,00	50,83	39,49	39,30
median	43,43	52,72	51,91	52,28	51,66	51,09	39,86	39,11
maximum	46,75	54,00	54,44	56,15	55,59	51,97	40,60	42,32
minimum	42,90	51,109	47,36	48,80	49,51	45,97	37,56	36,62
deviation	1,481	0,943	1,727	1,551	1,698	1,16	0,801	1,098
count	18	30	471	622	348	110	79	125

I assigned the calculated values to the middle values of the 2 °C ranges. I have carried out the same operation with the single pipe collector.

Fig. 3.6 represents the efficiency of the collector with parallel pipes at 1000 Wm^{-2} intensity of solar irradiation in function of the temperature different between the collector and the ambient air:

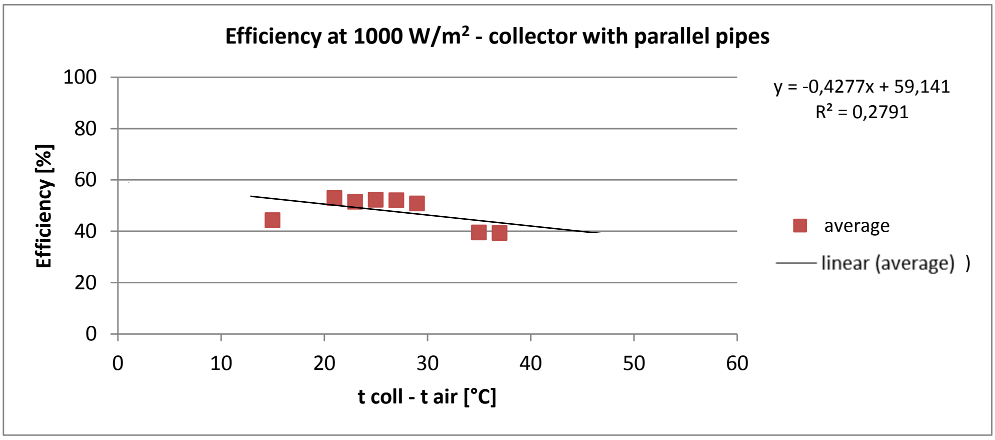

Figure 3.6. Function of the efficiency at 1000 Wm^{-2} of the collector equipped with parallel pipes on the absorber

With further inquiry I have calculated the function of the efficiency at 600, 800 and 1000 Wm^{-2} intensity of solar irradiation for each collector, so I have determined the curve family according to the different values of the intensity of solar irradiation (Fig. 3.7). Similarly I have determined the diagram for the collector with single pipe (Fig. 3.8).

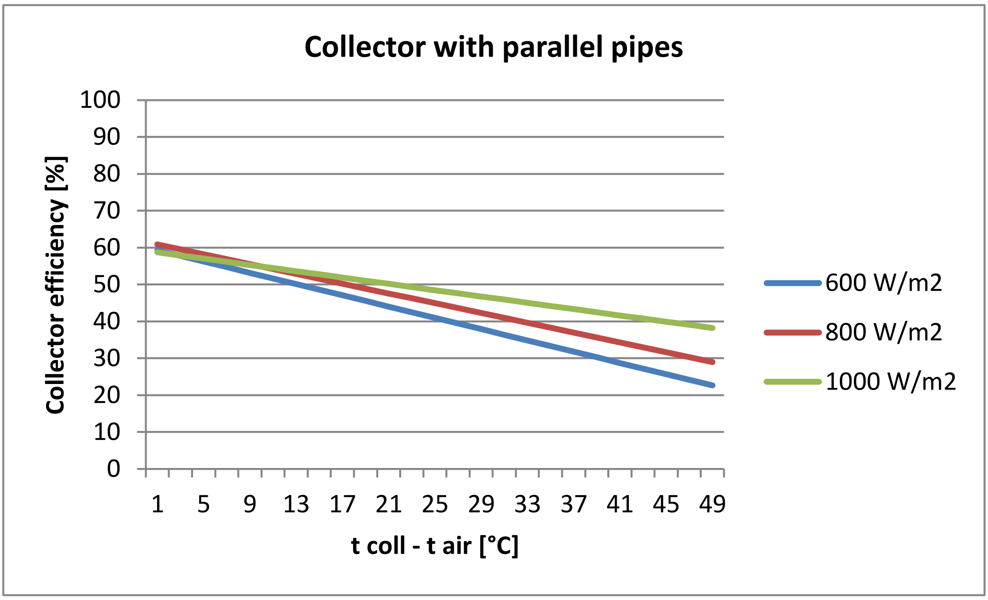

Figure 3.7. Functions of the efficiency at different intensities of solar irradiation of the collector with parallel pipes

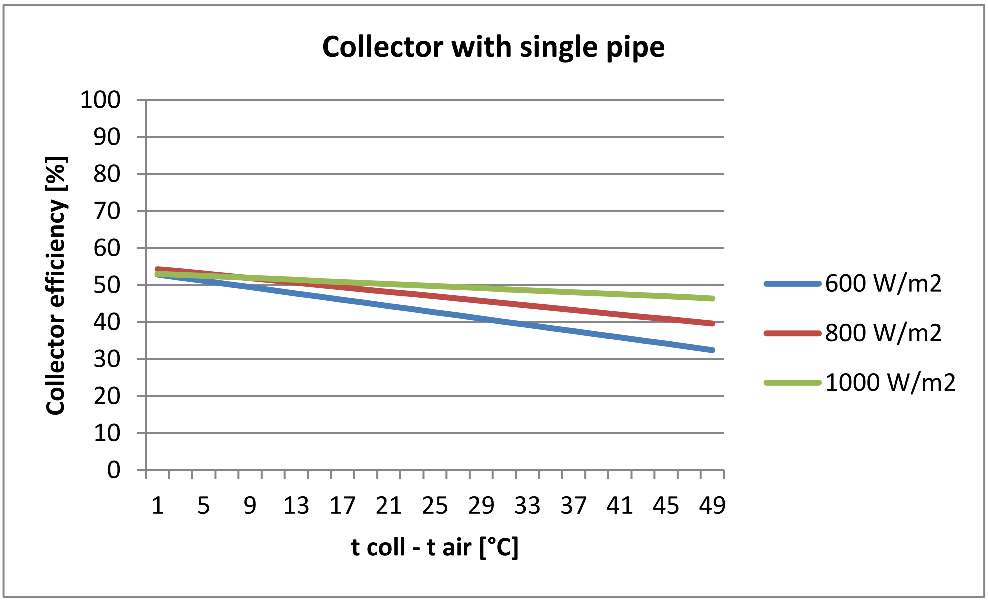

Figure 3.8. Functions of the efficiency at different intensities of solar irradiation of the collector with single pipe

Transforming each curve-family from Fig. 3.7 and 3.8 to one curve in function of the reduced temperature-difference Fig. 14 shows the function of the efficiency of the two collectors:

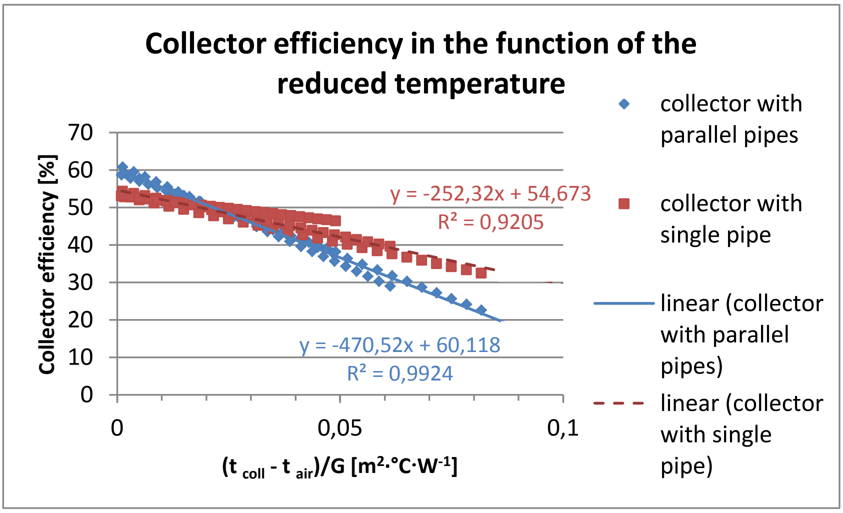

Figure 3.9. Efficiency of the collector with parallel pipes and the collector with single pipe in function of the reduced temperature difference with linear approximation

The correct approximation of the linear functions is representative in the full range from the 1000 Wm^{-2} irrariadion intensity of the laboratory measurements to the 630 Wm^{-2} minimal irradiation intensity required in professional literature.

3.7. Operating the collectors with polycarbonate sheet cover and without cover

During my experiments, I have determined the effect of the Makrolon Multi UV 2/10-10.5 polycarbonate sheet on the efficiency of the collector. The accuracy of the approximation to the results of the measurement is acceptable but less precise than the measurement results of the covered collector. The 95 % confidence interval for the collector with parallel pipes is ± 1,466 %, for the collector with single pipe is 3,116 %.

3.8. Measuring a collector with known efficiency

For the verification of my efficiency measurement method with the device I have examined a known Buderus SKN 3.0 collector whose function of efficiency is known.

In the tested range the results of the measurement made with the device follows accurately the curve created by the data of the manufacturer's catalogue. The maximum of the absolute error is 3,02 %.

3.9. The expected annual efficiency and annual energy yield

With the determined function of the efficiency of the analyzed experimental solar collectors I have analyzed the achievable annual energy yield.

For the simulation I used the meteorological data of 2012 registered with 10 minute intervals. According to the prescribed criteria of the simulated collector operation the efficiency and the energy yield can be calculated to the either ten-minute period of the year. The annual energy yield is the sum of the energy yield of these ten-minute periods of the full year (MJ):

$$Q_a = \sum_{i=1}^{n} Q_{10i} \tag{3.7}$$

The specific annual energy yield is the annual energy yield related to the area of the collector (MJm^{-2}):

$$q_a = \frac{Q_a}{A} \tag{3.8}$$

The annual average efficiency is the ratio of the specific annual energy yield and the annual energy amount irradiated to the unit area of the collector (%):

$$\overline{\eta}_a = \frac{q_a}{\sum_{i=1}^{n} G_i \cdot \Delta t_i} \tag{3.9}$$

The annual amount of the irradiated energy is the annual sum of the measured intensity of irradiation multiplied by the time difference between two measurement.

The average of the momentary efficiency values is the average of the efficiency calculated to the ten-minute period intervals of the year (%):

$$\overline{\eta}_{10} = \frac{\sum_{i=1}^{n} \eta_{10}}{n} \tag{3.10}$$

It is not equal to the annual average efficiency, because the amount of the irradiated energy is not the same value for all of the ten-minute intervals.

If the prescribed minimal collector temperature is 30 °C and the maximal is 60 °C the functions formed as show non Fig. 3.10.

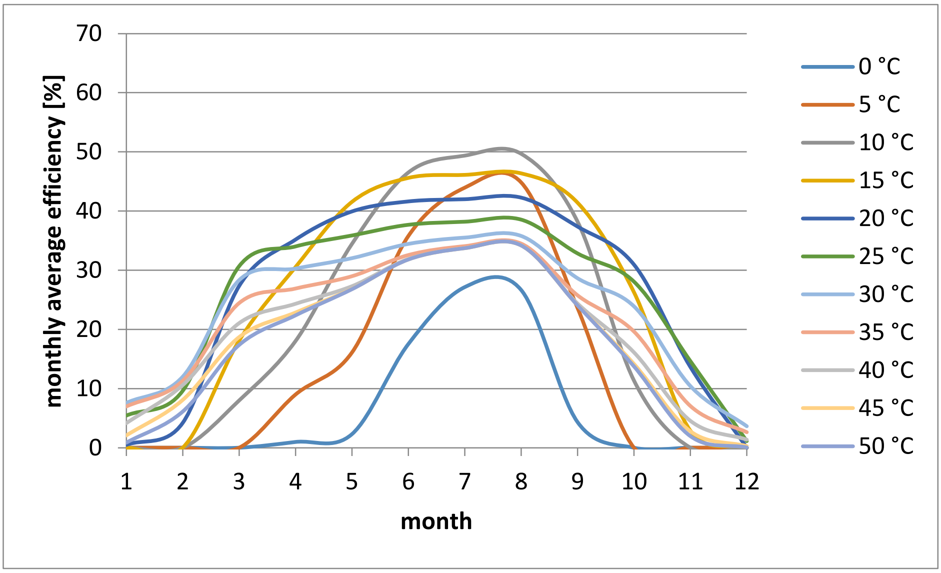

Figure 3.10. Monthly average efficiency of the collector with parallel pipes assigned to different values of the temperature difference between the collector and the ambient air, in case of 30 °C minimal and 60 °C maximal collector temperature

In function of the temperature difference between the collector and the ambient air the annual parameters could be calculated with the Fig. 3.11.

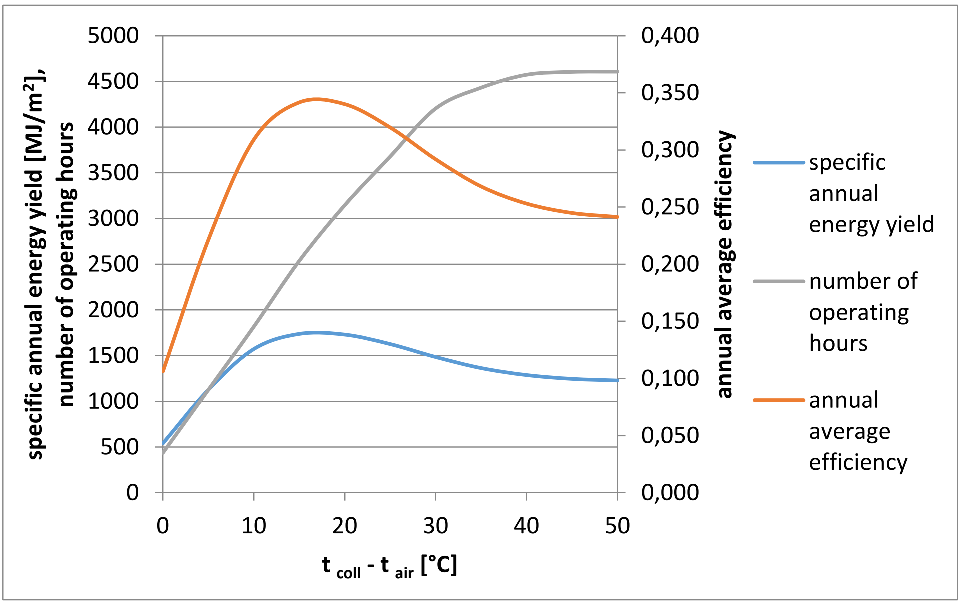

Figure 3.11. The annual operating parameters of the collector with parallel pipes in case of 30 °C minimal and 60 °C maximal collector temperature

3.10. Mathematical modeling of a solar collector

With Matlab I have developed a mathematical model to simulate the operation of the collector with parallel pipes (Fig 3.12 and 3.13).

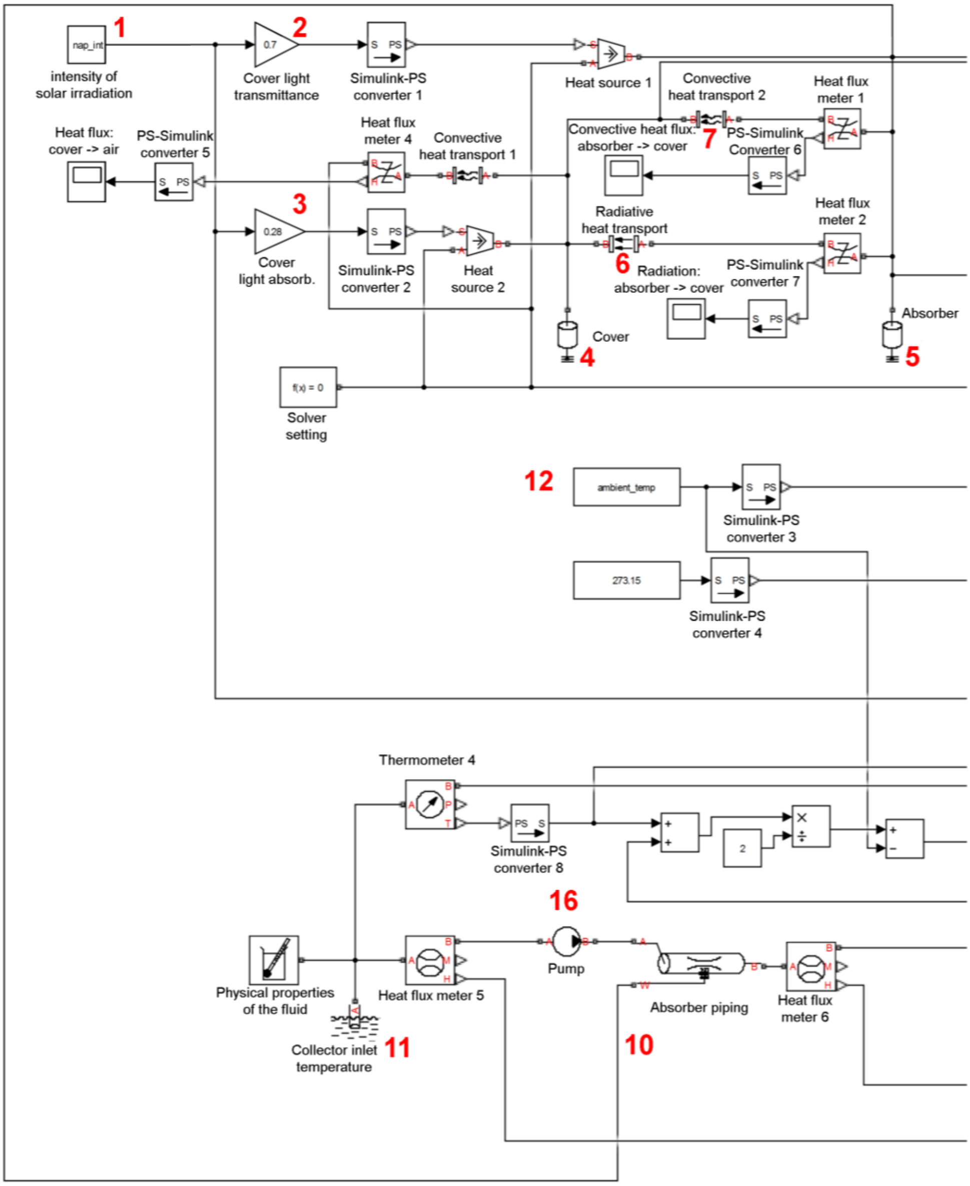

Figure 3.12. Matlab diagram of the mathematical model of the collector with parallel pipes, part one

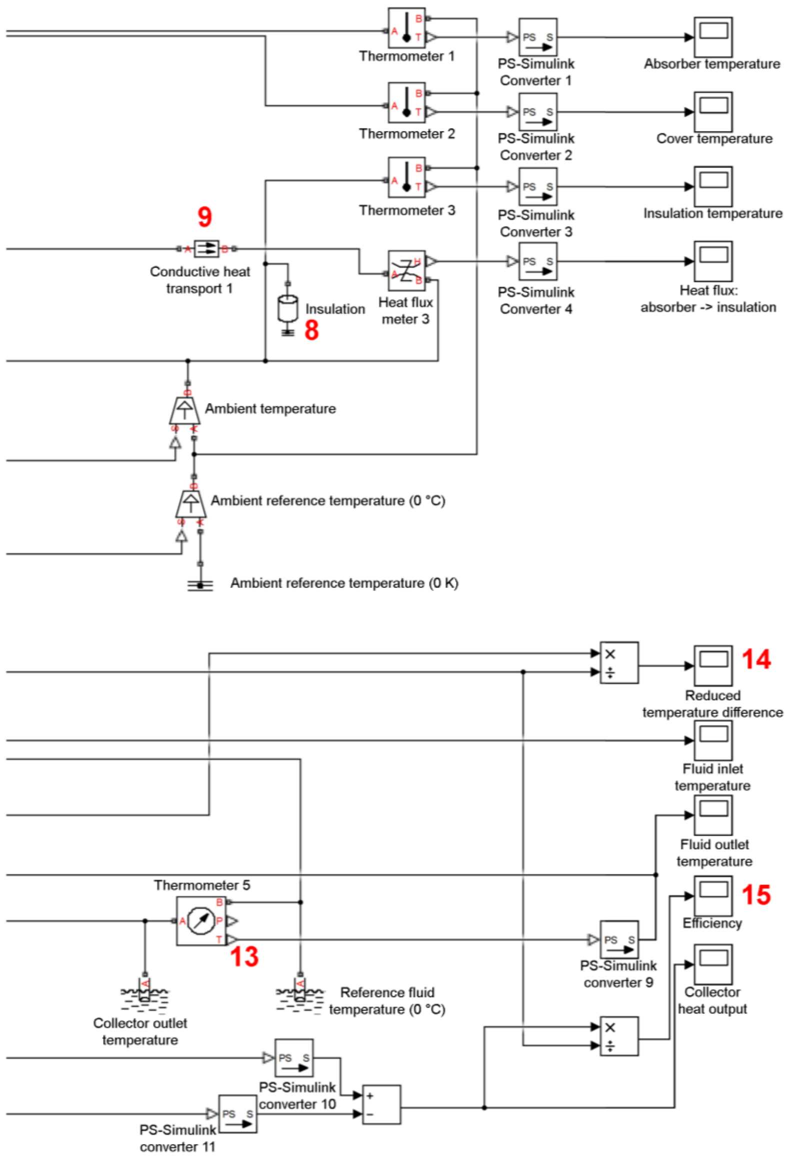

Figure 3.13. Matlab diagram of the mathematical model of the collector with parallel pipes, part two

The diagram of the model made with Matlab simulates the operation of the collector as a thermal network according to the prescribed operating parameters. The intensity of the solar irradiation (1) is adjustable, in accordance with the light transmission capability of the cover the reduced radiation intensity reaches the absorber, a proportion proper to the light-absorbing ability (3) heats the cover (4), the cover reflects the remaining amount. The radiative heat flux reached the absorber (5) is particularly reflected to the cover (6), another part reaches the cover in a convective way (7) from the warm absorber, the third part goes to the heat insulation as a conductive heat flux (9). The remaining part of the absorbed heat flux (10) reaches the flowing fluid in the piping of the absorber. The temperature of the fluid inlet (11) and the ambient air (12) are adjustable. The average of the temperature of the fluid outlet (13) and inlet and the intensity of the solar irradiation determine the reduced temperature difference (14). The efficiency (15) is the ratio of the intensity of the solar irradiation (1) and the heat flux from the absorber to the fluid (10).

Changing the values of the intensity of solar irradiation (1) the temperature of the ambient air (12) and the fluid inlet (11), the fluid flow rate with the pump (16) in any operating status we can calculate the efficiency, so the function of the efficiency is determined. Fig. 3.13 represents the results of the simulation.

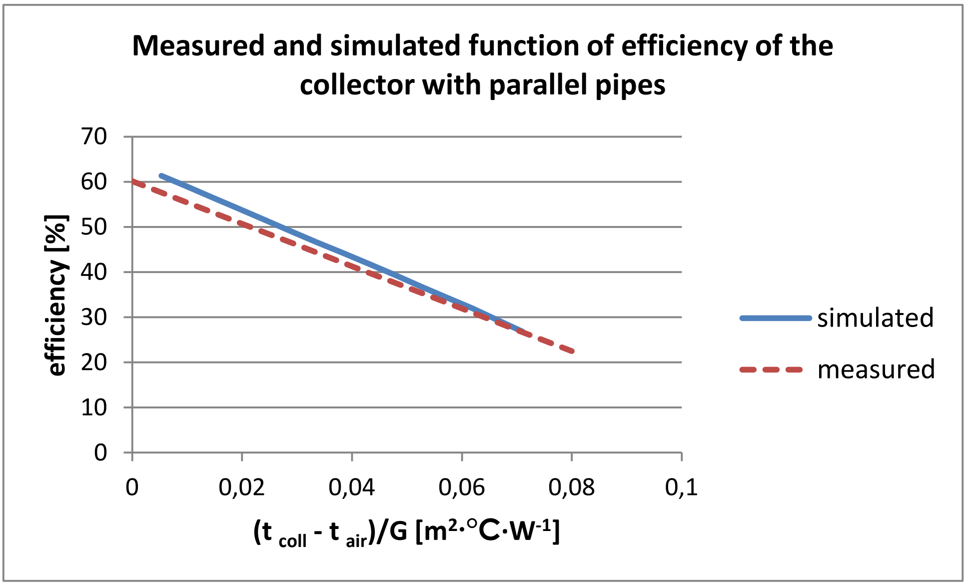

Figure 3.13. Measured and simulated function of the efficiency of the collector with parallel pipes

With the model I have analyzed the components of the heat loss. Fig. 3.14. shows the results of the simulation in function of the reduced temperature difference.

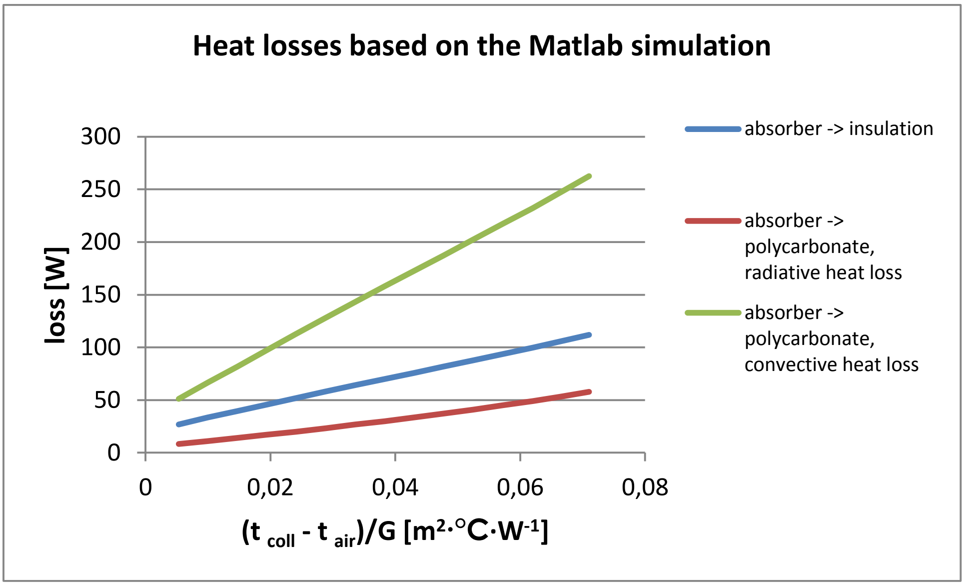

Figure 3.14. Heat losses of the absorber in function of the reduced temperature difference

The diagram does not include the loss according to the light transmission capability of the cover. The optical efficiency of the collector with parallel pipes is 60,12 % (Figure 3.9), it causes 399 W heat loss at the 1000 Wm^{-2} intensity of solar irradiation of the simulation. For the experimental solar collector it is established that the largest heat loss is the part of the solar irradiation that absorbed and reflected by the cover. The next one is the convective heat flux from the absorber to the cover, the third one is the conductive heat loss through the thermal insulation at the back, than the radiated heat flux from the absorber to the polycarbonate cover.

From the results of the modeling it is established that during the further researches more types of polycarbonate sheet, solar glass and insulated glass should be modeled for the cover, and applying these covers the function of the efficiency for the modified collector should be measured.

4. NEW SCIENTIFIC RESULTS

I summarize below the new scientific results obtained during the processing of the results of my experiments which are useful conclusions in the fields of measurement technology, the determination of the solar collectors' function of the efficiency and the operation and control of solar collectors.

1. Mathematical modeling for the correction of errors occurring from the omission of the impulse-signals

I have created a mathematical algorithm for the automatic correction of the errors of missing impulse-signals of the data loggers and for the smoothing of the corrected volume flow rate curves.

The developed algorithm corrects the errors of the missing impulse-signals, so the processing of the large amount of data becomes significantly faster.

$$\frac{\dot{V}_i}{\frac{\dot{V}_{i-2}+\dot{V}_{i-1}+\dot{V}_{i+1}+\dot{V}_{i+2}}{4}} > \frac{2}{3} \Rightarrow \dot{V}_i' = \dot{V}_i \tag{4.1}$$

$$\frac{\dot{V}_i}{\frac{\dot{V}_{i-2}+\dot{V}_{i-1}+\dot{V}_{i+1}+\dot{V}_{i+2}}{4}} \le \frac{2}{3} \Rightarrow \dot{V}_i' = \frac{\dot{V}_{i-2}+\dot{V}_{i-1}+\dot{V}_{i+1}+\dot{V}_{i+2}}{4} \tag{4.2}$$

$$\dot{V}_i'' = \frac{\dot{V}_{i-2}'+\dot{V}_{i-1}'+\dot{V}_{i+1}'+\dot{V}_{i+2}'}{4} \tag{4.3}$$

My method is capable not only for the analysis of solar collectors but for all measurements made by logging impulse signals.

2. Mathematical formula for marking the cloudless periods

I developed a logical function that divides the measurements into cloudy and cloudless periods. With this logical function the cloudless periods that cause errors can be filtered out.

I verified that the cloudy periods occurs errors during the calculaton of the momentary efficiency of solar collectors.

Having examined several options I have formulated three criteria. If all of these three equations are fulfilled, the tested moment can be marked as cloudless. The moment is cloudless if the three criteria are also valid during the previous 5 minutes:

$$\Delta G_{fajl} = \frac{G_i - G_{i-1}}{G_i} \leq 0{,}05 \tag{4.4}$$

$$G_{max} - G_{min} \leq 50 \frac{W}{m^2} \tag{4.5}$$

$$G_{min} \geq 100 \frac{W}{m^2} \tag{4.6}$$

The developed method allows the rapid filtering of data excluding the intervals which could cause incorrect values and unsuitable for the calculation of the momentary efficiency.

3. *Data filtering and error correction method for determining the functions of efficiency*

I have developed the mathematical method for filtering out and correcting the original wrong and partially uninterpretable data: I have corrected the functions of the volume flow rate, filtered out the errors caused by the cloudy periods, then using the modified database I have developed the method for determinating the functions of the efficiency.

I have made the next criteria for the measurement database inquiry:

- The maximal deviation of the measured values from the characteristic value of the curve is ± 10 Wm^{-2}.
- The temperature difference between the outlet and inlet of the collector is minimum 5 °C.
- The inquiry may include only the data from the cloudless periods.

I have validated the developed method with the experimental flat collectors, I have determined the functions of efficiency of those in the range of 600 – 1000 Wm^{-2} intensity of solar irradiation. At 1000 Wm^{-2} intensity of solar irradiation the 95 % confidence interval is ± 1,315 % for the collector with parallel pipes and ± 0,824 % for the single pipe collector. At 800 Wm^{-2} intensity of solar irradiation ± 1,378 % and ± 1,378 %, at 600 Wm^{-2} the interval is ± 1,131 % for the collector with parallel pipes and ± 1,05 % for the single pipe collector.

4. Describing the transient effects

I have determined that the first collector in a serial connection reacts faster to the decreasing of the inlet fluid temperature. I have also determined that the second collector reacts not only later but slower than the first one. It is determined that the transient effects take an average of 22,4 % more time at the outlet of the second collector in line than at the inlet of the first collector. The temperature drop rate at the outlet of the second collector is averagely 48,2 % of the value measured at the inlet of the first collector.

I have confirmed the results of my experiments with a serial connection in the opposite order. The transient effect appears first and runs down faster at the first collector, independently of the order of the different types of collectors.

My conclusions can be utilized well in the control of great collector plants.

5. The annual energy yield and the optimal collector temperature dynamics

Knowing the constant temperature difference to the ambient air and the temperature range of the collectors I have determined the annual efficiency and the specific annual energy yield of the collectors. Prescribing these parameters and knowing the climatic conditions the expected annual energy yield of the collectors is calculated with the simulation.

I have developed a method for the calculation of the maximal value of the expected annual energy yield. The fixed parameters are the minimal és maximal collector temperature. According to these parameters the expected annual energy yield could be calculated for any collector which has a known function of efficiency. The temperature difference between the collector and the ambient air belonging to the maximal annual energy yield and so the maximal annual average efficiency could be calculated.

6. Mathematical model of the experimental solar collector for the analysis of the losses

I have developed the mathematical model of the experimental solar collector whose absorber has parallel piping. With the model the value of each component of the heat loss are calculated. It is established that the largest part of the loss of the experimental solar collector is the radiation that absorbed and reflected by the cover. With the model the expected effects of the further modifications to be carried out on the collector for the better efficiency could be calculated. Giving the physical parameters of a collector the model determinates the functions of efficiency and the value of each component of loss, so it could be a useful tool of the analysis of other solar collectors.

5. CONCLUSIONS AND SUGGESTIONS

The goals of my research are the study of the operating effects of solar collectors, the determination of the function of efficiency with measurements among natural operating conditions and the elaboration this measurement method and exploring its limitations.

For my research I have developed a measuring and data logging device. During the analysis of the collectors I have studied more operating conditions.

During the measurements among natural operating conditions the main problem is the changing of the intensity of solar irradiation and the temperature of the ambient air. The related standards mentions that during the measurement the intensity of solar irradiation have to be constant as far as possible, but numerical determinations were not available about it. During my measurements I have determined that the fluctuation in the intensity of irradiation caused by lamb clouds excludes the measuring the momentary efficiency. With the study of the databases of the measurements I have determined criteria which capable for clearly establishing that the analyzed period is cloudless or not, so suitable or not for the measuring the momentary efficiency of the solar collectors.

I measured the volume flow rate with flow-meters equipped with impulse relays. In the diagrams of the measurements the errors caused by the absence of impulse signals are well visible, I have developed a method for the correction of these errors.

During the study of the database of my measurements I made statements about the transient effects of the solar collectors.

The analyzed experimental solar collectors have different absorber pipings. By my measurements with parallel connected two collectors it is established that in a system filled with viscous fluid the volume flow rate balance at low temperature is upset if the temperature increases – and the viscosity decreases. By this effect it is stated that in parallel connected two collectors or collector lines which has different hydrodynamic properties the keeping of the equal volume flow rates needs control during the changes of the temperature.

As an other planned development it is recommended to apply an albedometer, it would allow measuring not only the global but separately the diffused and as the difference of these the direct solar irradiation to the surface of the collector. It could be important in a measurement with concentrated solar collectors.

6. SUMMARY

At the University of Szeged Faculty of Engineering we research the field of solar energy utilizing since 2005. Our first collectors were commercialized in 2006, which were designed with the primary goal of the the low level manufacturing costs.

Availing my research experiences from the measurements I have started to design and build a new measuring device for testing collectors in natural operating conditions for the research introduced in this dissertation.

By the results of my research I have elaborated the operating algorithm for the measuring and datalogging device, so the automated device is suitable for testing solar collectors in operating conditions, for the logging and calculating the function of the efficiency and the comparing measurements of working parameters of different types of solar collectors and for the classification measurement of the manufactured product. With the data processing of the measurements I have determined theses not only about the method of the calculation of the efficiency but the working effects of the solar collectors.

During my work I have studied the limitations and errors of the measurement of efficiency among natural operating conditions. After the analysis of the measurements I have elaborated the criteria of the intensity of the solar radiation. By the algorythm the signing of the cloudy and cloudless periods becomes automatically, so the filtering out of the cloudy periods with wrong results is much faster. I have elaborated the steps for the logging and calculation of the function of the efficiency, I have made the operation of the device more accurate and formulated thesises about the operating of the solar collectors.

I have described the working effects observed in linear and parallel connection. I have elaborated the effect of the polycarbonate sheets to the function of the efficiency. I have studied the running down of the transient effects, I have elaborated a method to estimate the annual energy yield and the annual efficiency and to determine the optimal collector temperature variation to reach the maximal annual efficiency.

7. MOST IMPORTANT PUBLICATIONS RELATED TO THE THESIS

Referred articles in foreign language:

1. **Péter Szabó, I.** – Szabó, G. (2010): Design of an experimental PCM solar tank. Analecta Technica Szegediensia, University of Szeged Faculty of Engineering. 2010/2-3 pp. 200-205. ISSN 1788-6392
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4. **Péter Szabó, I.** – Véha, A. – Szabó, G. (2012): Research and education of the application of renewable resources at the Faculty of Engineering University of Szeged. Analecta Technica Szegediensia, 2012/1-2, pp. 19-25. ISSN: 1788-6392
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7. **Péter Szabó, I.** – Szabó, G. (2013): Study of the efficiency and other working parameters of solar collectors. Acta Technica Corviniensis, Bulletin of Engineering, 2013/1 pp. 143-145. ISSN 2067-3809
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9. **Péter Szabó I.** (2005): Rövid megtérülési idejű napkollektorok tervezése és hatásfokuk vizsgálata. Műszaki Tudományos Füzetek 2005, Kolozsvár, Erdélyi Múzeum-Egyesület, Műszaki Tudományok Szakosztálya, X. Fiatal Műszakiak Tudományos Ülésszaka, 97-100. o., ISBN 973-8231-44-2
10. **Péter Szabó I.,** Szendrő P., Szabó G. (2013): Berendezés kifejlesztése napkollektorok üzemi jellemzőinek mérésére. Analecta Technica Szegediensia, 2013 Special Issue, University of Szeged Faculty of Engineering. ISSN 1788-6392, 59-64. o.
11. **Péter Szabó I.,** Szendrő P., Szabó G. (2014): Kísérleti berendezés kifejlesztése napkollektorok hatásfokának mérésére. Energiagazdálkodás folyóirat, Energiagazdálkodási Tudományos Egyesület, 2014. október, 20 - 23. o., ISSN 0021-0757.
12. **Péter Szabó I.,** Szendrő P., Szabó G. (2014): Napkollektorok várható éves energiahozamának becslése. Magyar Épületgépészet, Épületgépészet Kiadó Kft., 2014.10., 3-6. o.