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DEVELOPMENT OF DATA PROCESSING ALGORYTHM FOR THE RECOGNITION AND CORRECTION OF MEASURING ERRORS OCCURED DURING THE TEST OF SOLAR COLLECTORS

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ABSTRACT: *One of the main problems of the utilizing of the systems that use renewable resources is the long payback time. An important factor is the efficiency of the collectors that is the function of the specific solar irradiation and the temperature difference between the collector and the ambient air. During the analysis of the collectors generally we can calculate the efficiency by average values of a time-period. The calculation of the momentary efficiency is conditioned, for example, it needs cloudless sky and – of course – correct temperature and volume flow rate values. From the transient effects we need to save this value by five seconds. To process the large amount of data we need to automate the correction of the errors in the database and, also the selection of the values that suitable to calculate momentary efficiencies.*

KEYWORDS: *solar collector, efficiency, solar energy, volume flow rate, pyranometer*

INTRODUCTION

The efficiency of the collectors is most affected by the difference between the temperature of the collector and the external air and the intensity of the solar irradiation. It means that this measuring is not reproducible. According to this fact it needs to make numerous measuring. During the processing of the database we have to average the results that have similar external parameters.

With our unit we can operate the collectors in parallel or serial connection.

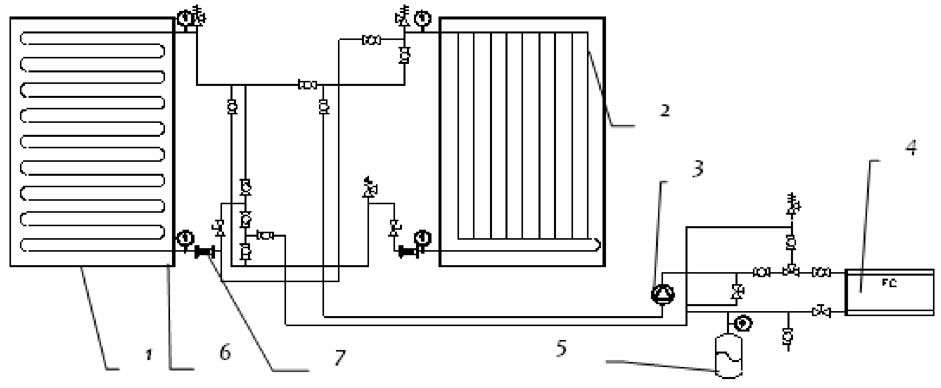

Figure 1. Experimental equipment for measuring the efficiency of solar collectors
1 – collector with single pipe, 2 – collector with parallel pipes, 3 – circulation pump, 4 – fancoil,
5 – expansion tank, 6 – thermometers, 7 – volume flow rate measuring

The equipment transfers the heat output of the collectors to the external air by a fancoil. The cooling fan can be adjusted continuously and the cooling capacity can be decreased further with a bypass pipe, so we can adjust the temperature of the entering fluid of the collectors.

Besides the measuring of the volume flow rates and the temperatures we measured the temperature and humidity of the external air and the solar irradiation. The irradiation was measured by a Lambrecht 16131 pyranometer mounted between the collectors in the same plane.

With the device we can analyse the transient processes of the collectors in the event of changing weather.

MEASURING THE VOLUME FLOW RATE BY IMPULSE DATA LOGGING

During the measuring two flowmeters of the two collectors add impulses by 10 liters and a datalogger saves the times of the signals. We calculate the values of the volume flow rates with a spreadsheet.

The absence of an impulse signal causes wrong flow rate values, so first we have to correct these absenced impulses. We can see these errors in the Figure 2:

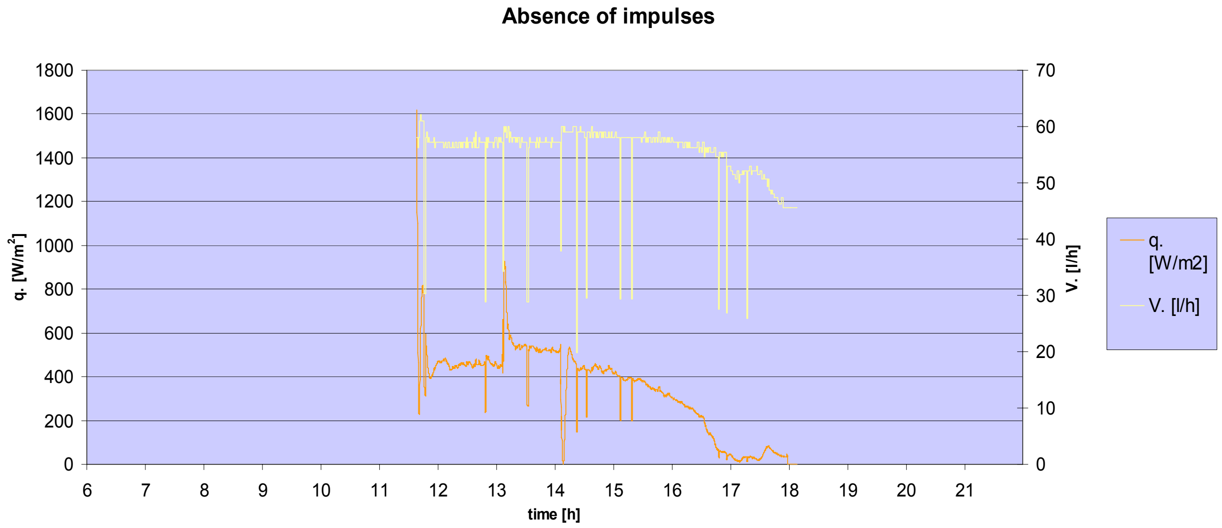

Figure 2. Raw volume flow rate data of a diurnial measuring

During this diurnial measuring the volume flow rate suddenly dimidiated and increased to double again. In this day it happened 12 times as we can see in the diagram. These effects indicate absence of impulses. Of course, these errors appear in the function of the heat output of the collector. So during the data process we have to correct these errors. We have applied this method: for every flow rate value we calculate the average of the previous two and next two values. If the ratio of the flow rate value and this average is smaller than 2/3, we assume an absence of impulses, and we substitute the wrong flow rate value with the average:

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

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

The other cause of the inaccuracy of the flow rates is the assuming of a constant average value between two impulse. This is not correct in every moment. To decrease this inaccuracy after the correction of the absences of impulses we have made the smoothing of the curve. We have substituted every flow rate values with the average of the previous two and next two values:

$$\dot{V}_i{}'' = \frac{\dot{V}_{i-2}{}'+\dot{V}_{i-1}{}'+\dot{V}_{i+1}{}'+\dot{V}_{i+2}{}'}{4} \qquad (3)$$

In the Figure 3 we can see the curve after the correction of the absences of impulses (yellow) and the smoothed one (blue):

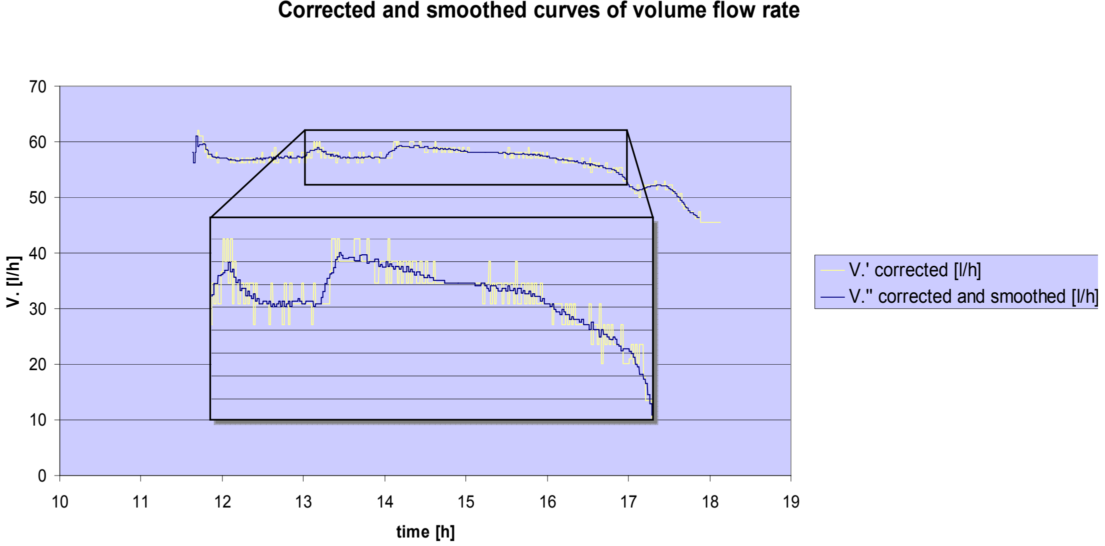

Figure 3. Corrected and smoothed curves of volume flow rate

The heat output of the collector is calculated by multiplying the difference of the outlet and inlet temperature of the fluid by the volume flow rate. We can decrease the inaccuracy with the increasing of the temperature difference. Accordingly we have to keep the volume flow rate at low level.

In the Figure 4 we can see the wrong results of volume flow rate measuring made with conventional water meters. Impulses added by 10 liters. The two collectors were connected in line, so the two water meters should have measure the same values.

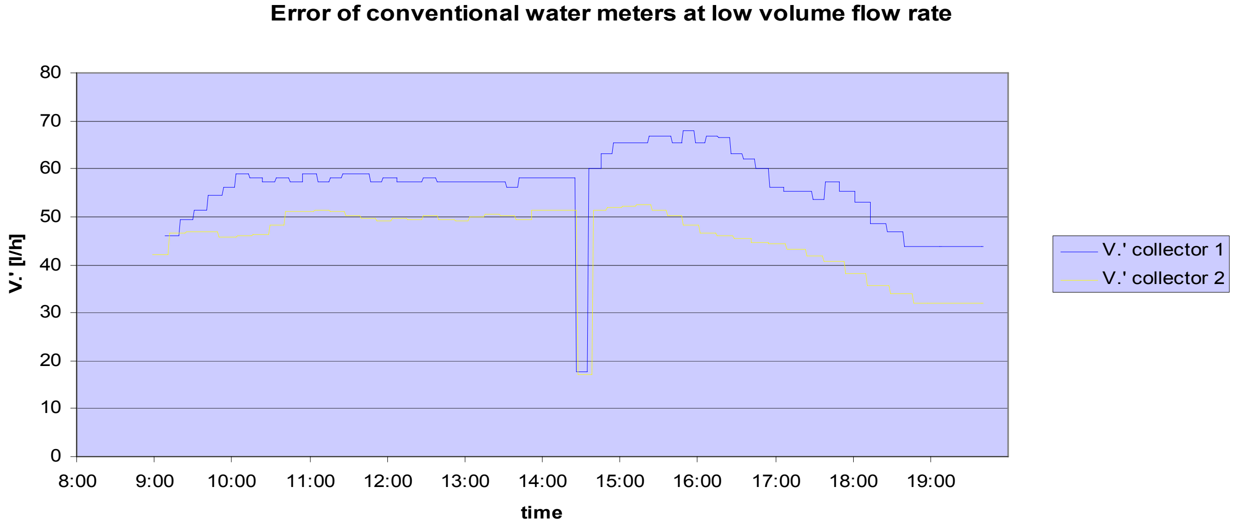

Figure 4. Wrong volume flow rate values measured with conventional water meters

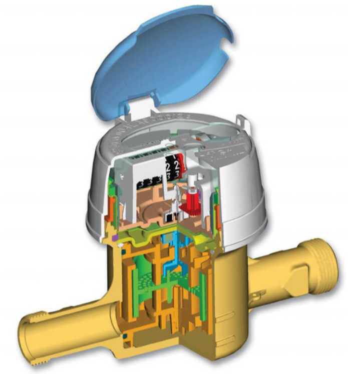

Figure 5. Water meter with rotating piston to measure by displacement

We can see significant differences between the two curves. The cause of errors is the low volume flow rate. The measuring range of the conventional water meters is higher. We have changed the water meters to other ones that measure by displacement (Figure 5):

By the specifications the low measuring limit is 7.5 l/h. During our tests if this two water meters are connected in line the corrected values of the volume flow rates are the same.

METHOD FOR SELECTING THE CLOUDLESS PERIODS

For the measuring of the solar irradiation we use a calibrated Lambrecht pyranometer that senses the changes within 18 seconds. Thermopile pyranometers consist of an absorbing detector covered by two glass filter domes. Solar radiation in the wavelength region from 285 nanometers (nm) to 2800 nm, often called "short-wave radiation", passes through the glass domes and hits a black, heat-absorbing sensor. Attached to this absorbing surface under the black sensor are thermopile detectors that become heated. A thermopile is a collection of junctions of dissimilar metals (e.g., copper, constantan) connected in series. One group of junctions is in thermal contact with the absorber (the "hot" or "measuring" junctions). A second, equal number of junctions, the "cold" or "reference" junctions, are not in thermal contact with the absorbing surface (Haeffelin et al., 2001).

The Table 1. contains the specifications of our pyranometer:

Table I. Specifications of the Lambrecht 16131 pyranometer (www.lambrecht.net)

Measuring range	*0÷2000 W/m^2, global radiation within a range of 305÷2800 nm*
Range of application	*temperatures -40÷+80 °C*
Accuracies	*< ±5 % (305÷2800 nm), tilt deviation < ±2 %*
Non-linearity	*< ±1 %*
Sensitivity	*10÷40 μV/(W/m^2)*
Response time (95 %)	*< 18 s*
Directional deviation	*< 20 W/m^2*
Impedance	*40÷60 Ω*
Output	*typical 0.1÷50 mV*
Standards:	*ISO 9060 "First class", certificate for sensitivity*

The mass – and so the thermal inertia – of the collectors is much higher than the pyranometer's, and the reaction 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, as we can see in Figure 6.*

The cloudy periods are indicated by the significant deviation of the curve of the solar irradiation from 15:00. During the same periods the calculated values of the momentary efficiency shows bigger fluctuation and assume meaningless values above 100 %. It is an obvious measuring error. These periods must be filtered out.

The momentary efficiency could be calculated only in sunny periods. In cloudy condition we can calculate average values for a term. In the diagram we can see the cloudy periods well, but because of the big amount of data we need to define a function to filter out the clody periods automatically. For making this method we have chosen a diurnial measuring that contains cloudy and cloudless periods, too.

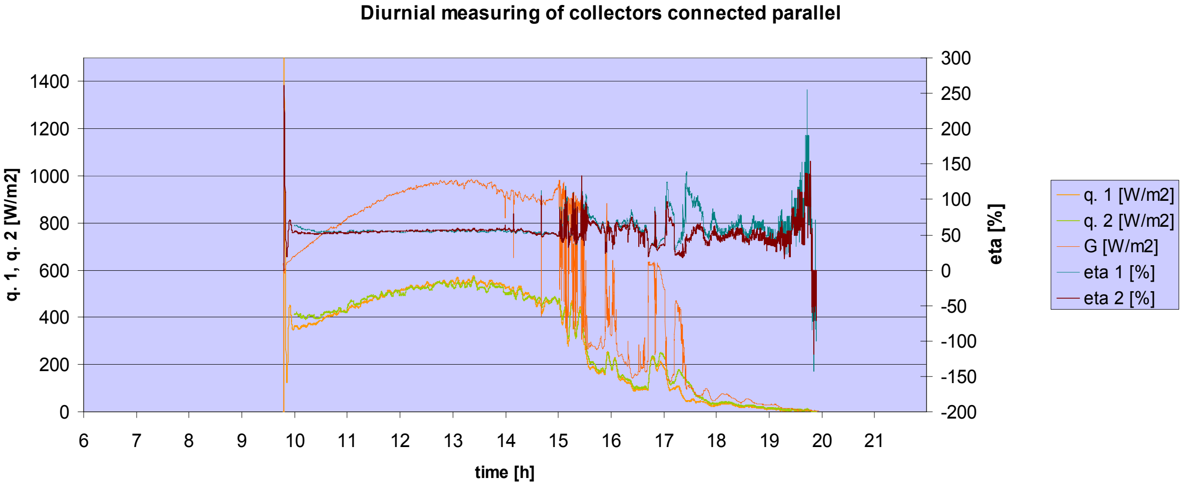

Figure 6. Solar irradiation and momentary efficiency – the cloudy periods give incorrect results

Through a signal amplifier the pyranometer is connected to a datalogger. It saves the 0÷20 mA signal by 5 seconds.

Computations have been performed to select the optimum time interval (Δτ) for calculations and also for data sampling. The results show that estimation of the parameters within ±4% of the steady state values could be obtained using Δτ of 5 s (E.H. Amer et al., 1999).

20 mA corresponds to 1400 W/m² irradiation intensity, so from the saved values of current the intensity of irradiation could be calculated by the next formula:

$$G_i = I_i \cdot \frac{1400}{20} \tag{4}$$

Legend: G_i – the i-th calculated value of the solar irradiation intensity [W/m²]; I_i – the i-th saved value of the current signal by the datalogger [mA]

Theoretically there could be wrong data records with zero values, caused by an outage or something else. We did not experience this kind of errors, but with applying a logical function we have assured the filtering of the zero values.

To every i-th row of a new column we have calculated the specific change of solar irradiation intensity:

$$\Delta G_{spec} = \frac{G_i - G_{i-1}}{G_i} \tag{5}$$

By our first method if this specific change exceeds a threshold value, the time is marked as cloudy. In Figure 7 we can see the results (blue). The function assumes 0 under cloudy and 100 under cloudless periods, according to specific change of solar irradiation. (The value of 100 is not important, it is necessary only for the easier representation in the diagram.)

As we can see in the diagram of Figure 7, the function filter out the cloudy periods in the morning well, but from 14:00 to 17:00 the short cloudy periods marked as sunny. We have tried to solve this problem with the increasing of the threshold value of the scpecific change of solar irradiation. The yellow curve of the diagram was made with 0,1 threshold value. As we can see the problem of the afternoon period was not resolved, but the new function discards the cloudiness in the morning. So this operation in itself is not enough to select the coudy periods well.

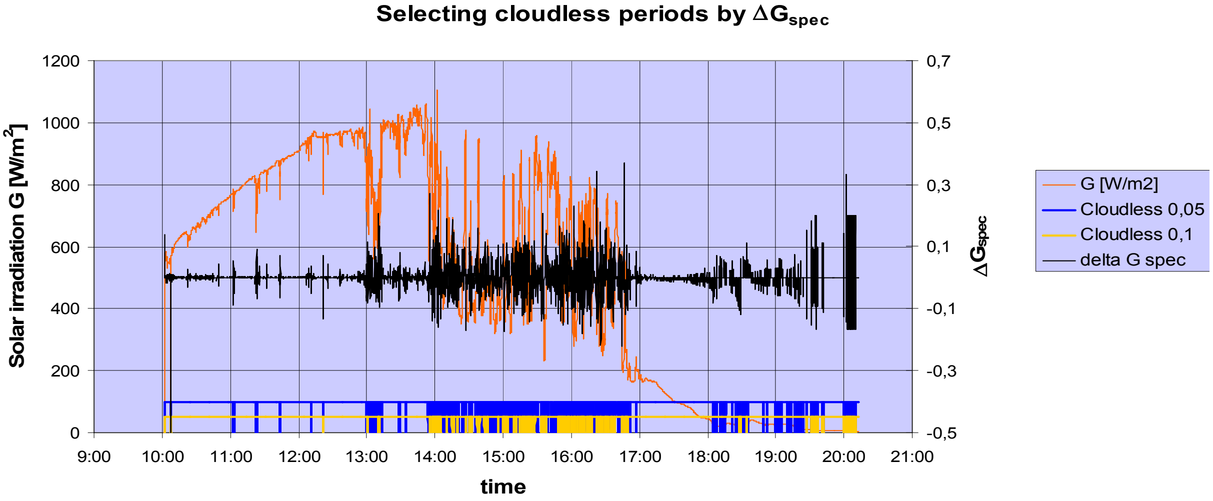

Figure 7. Selecting cloudless periods if the specific change of solar irradiation less than 0,05 (blue curve) or less than 0,1 (yellow curve)

In our second method we have set the threshold value to 0,05 again. We have complemented the first method with a new requirement: to mark a time as sunny, the previous five minutes have to satisfy the condition about the threshold of ΔG_{spec}. We can see the result in the Figure 8. (yellow curve).

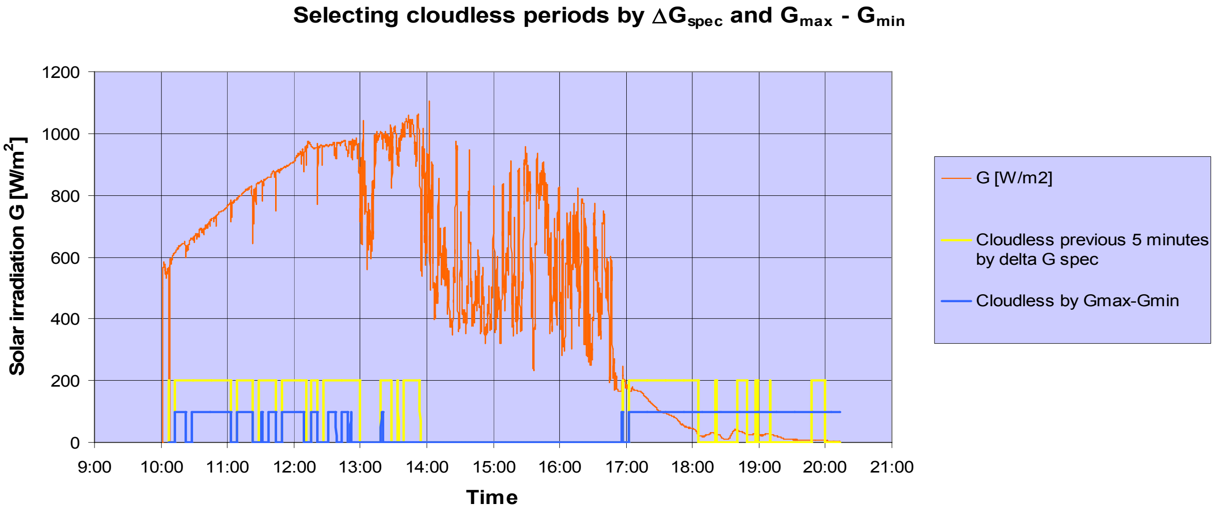

Figure 8. Selecting cloudless periods considering the previous 5 minutes

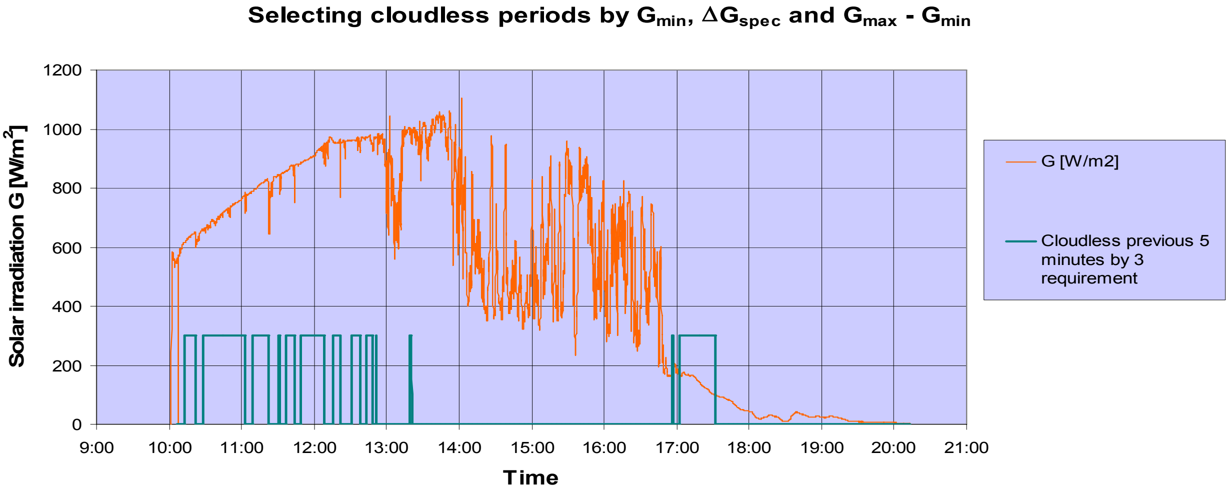

Figure 9. Selecting cloudless periods by absolute and relative change and minimal value of solar irradiation

As we can see, this method eliminates the former wrong selections between 14:00 and 17:00. The 5 minutes long periods are required for the correct efficiency calculating because of the heat inertia of the collectors. At the same time we must see the wrong "cloudless" mark between 12:45 and 13:00.

The blue function in the diagram analyse the previous 5 minutes as the yellow one, but according to absolute changes of solar irradiance, not specific. It marks the moments that satisfy that during the previous 5 minutes the difference between the minimum and the maximum of the solar irradiation is not greater than 50 W/m^2. Accordant to more experiment this value is suitable, but we can see in the diagram that after 18:00 the yellow curve is correct, not the blue one.

We can mark the cloudless periods correctly by the combination of these two functions. The most correct method is to mark cloudless the moments that satisfy the two requirements: the maximal absolute and relative deviations during the previous 5 minutes as written above.

In addition we have specified a third requirement related to a minimal irradiation, because the very low solar irradiance makes the measurement incorrect, as we can see in the Figure 6. The filtering out of the low solar irradiation could be found in other publications, too (A. Lester, D.R. Myers, 2006). So we have filtered out the period after 18:00, but the function handles the same kind of irradiation curve at higher intensity during another measurements.

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

$$\Delta G_{spec} \leq 0{,}05 \tag{6}$$

$$\Delta G_{max} - \Delta G_{min} \leq 50 \tag{7}$$

$$G_{min} = 100 \, \frac{W}{m^2} \tag{8}$$

CONCLUSIONS

At the University of Szeged, Faculty of Engineering we have developed new equipment that is suitable for measuring the efficiency of our self-designed experimental collectors or other ones. Actually we have processed the data of 135 days. We have saved the temperature and solar irradiation values by 5 seconds. During the process of the large amount of data we have get numerous experiences. To the correct results it needs the correction of the volume flow rate and the filtering out of the cloudy periods. Because of the large amount of data we have to automate these operations. In this article we represent our methods.

Filtering out the wrong values of volume flow rate based on the searching of sudden changes. We measure the volume flow rate by impulses that indicate flow-through of 10 litres. If the calculated volume flow rate suddenly dimidiates and increases to double again, we should assume absence of impulses. First, we filter out these wrong values. Second, we smooth out the curve which has a staired graph because of the averaging between two impulses.

We measure the solar irradiation by a pyranometer that senses the changes very quickly. The reaction of a collector is much slower. The heat from the collector results from the previous, sunny period before the appearing of the cloud. It causes an error if we relate this higher heat output to the decreased intensity of solar irradiation. For this cause it needs to filter out the cloudy periods from a diurnal measuring. In this article we represent our method.

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