LabVIEW-Based Solar Air Heater Monitoring System

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Abstract. Solar air heaters are equipment that have the ability to convert solar energy into thermal energy by means of an internal air flow. The operation of such a system is closely related to the presence of solar radiation without which it is not possible to obtain thermal energy. For maximum yields it is necessary to determine the performance or thermal capacity of a solar air heating system. For this purpose, it is recommended to use a monitoring system, which has the ability to indicate the weaknesses of the equipment. This paper presents a model of monitoring using the LabVIEW software via a DAQ USB device, two thermocouple sensors type J, one humidity sensor, a pyranometer and four signal adapters. The commercial solar air heater and a thermostat, are also part of the monitoring system. The work ends with graphically presented results and conclusions that emerge from the study.

1. Introduction

A system to monitor the parameters necessary for the optimal functioning of solar air heater systems carry two or more discrete measurement items that are interconnected by a medium. A monitoring system include the following main components [1]:

- Measuring devices to record information (transducers).
- Signal adaptation devices: filtering, amplification and/or conversion of a physical signal into a measurable signal, most often an electrical signal.
- Software to collect, operate and display the data.
- Communication interface between software and measuring devices, data acquisition board.

Monitoring systems of solar equipment provide support for a variety of indicators: flow, pressure, temperature, solar irradiation, vibrations, status indicators, etc., by using transducers.

All components of a monitoring system ought to be compatible to assure that the system brings the maximum benefits. There may be a multitude of auxiliary components, which are established by the requirements of each distinctive monitoring system, for example energy and power monitoring.

There are many advantages of a system for monitoring solar air heaters, some of which correlate firmly with each other. A rightly designed and assembled monitoring system provides a profound comprehend of the operational indexes of the installation.

A careful assessment of the information generated by a monitoring system can unveil a variety of obvious and refined opportunities, such as [2], [3]:

- Environment. A better acquaintance of how the solar system is used, enables the identification of prospects to improve yield, minimize dissipation and diminish energy consumption, thus empowering the system to be a better administrator of its allocated natural resources.
- Reliability. The evaluation of information in the monitoring system may reveal available or imminent problems that may unfavourably affect the process and output in a unit. Historical data from monitoring systems can help localise and redress both acute and chronic matters, leading to an increased productivity.
- Maintenance. Data tendency can predict and inform the proximate personnel when the equipment's discrete indexes may be overtaken, allowing an overhaul to be planned before an unscheduled closure occurs.
- Safety. Monitoring equipment can reduce the exposure of people to potential risky environments by delivering remote status and operational indexes and characteristics of equipment in dangerous fields.
- Finance. Each advantage treated above indirectly or directly influences the financial outcome of a company. In most processes, the monetary outcome from one or two benefits can promptly justify the acquisition and installation of a complex system for monitoring the parameters of solar air heater systems.

Considering the monitoring of solar temperature and irradiation, the benefit delivered by the monitoring systems may enclose characteristics such as precise assessments of the production output of solar air heaters or the optimal placement of devices to maintain the system in optimal parameters [4].

To monitor the performances of a solar air heater with turbulators on the absorbing plate a test stand was realized out of an anemometer to control the air flow through the system and an outlet and inlet temperature data recorder. A weather station provides meteorological parameters such as: ambient temperature, wind speed and solar irradiation. The acquired results were used to determine the thermal capacity of the studied system [5].

The solar air heater with swirlers inserted on the absorption surface and high flow ventilators was tested monitoring the air flow with an anemometer, inlet and outlet temperature with a data recorder and environment parameters with a specific weather station. Environmental monitored parameters refer to ambient temperature, atmospheric pressure, wind speed and solar irradiation. The analysis of the system was concentrated on the investigation of the operating parameters [6].

2. Sensors for monitoring Solar Air Heaters (SAH) performance

In the structure of the monitoring systems are present transducers, conditioners and procurement plates. Non-electrical physical parameters, such as temperature, flow, pressure, displacement, force, solar irradiation, etc., must be converted into electrical signals (current or voltage) in order to be able to be measured and analyzed with electronic devices. The transducers have the role of generating an electrical signal that depends on the measured non-electrical size. The generated signal is often weak and requires amplification [1].

Transducers are often called measuring transducers and consist of sensors and signal adapters. The sensor makes it possible to detect the physical size to be measured and eliminates the influences that the other physical quantities existing in the analyzed environment exert on it. The signal adapters have the role of bringing the sensor information to the requirements required by the user. Adapters convert sensor status changes into calibrated signals that represent the input size value [1]. Depending on the measured size, the transducers can be: heat resistors, galvanic cells, measuring electrodes, thermocouples, pyranometers, etc. [7].

2.1. Thermocouple sensors

Thermocouples are electrical junctions consisting of two different conductors that, due to the Seebeck effect, produce a temperature-dependent voltage. The Seebeck effect is the electromotor force developed between two points of an electrical material when the temperature between those points is different.

Since the measured voltage can be considered temperature, thermocouples are used as temperature sensors. These temperature sensors are inexpensive, easy to change, can measure a large range of temperatures and are self-powered. Thermocouples are used to measure the temperature of furnaces, gas turbines, diesel engines, thermostats and safety devices for gas-powered equipment. The alloy combination used in the construction of thermocouples is selected on the basis of the required sensitivity and temperature range and is determined by the cost, chemical properties, stability, melting point and availability of the necessary alloys [8].

Nickel (Ni) alloy thermocouples:

- Type E – Cromel and Constantan with the temperature range between -270°C and +740°C [8].
- Type J – Iron (Fe) and Constantan with a temperature range between -40°C and +750°C [9].
- Type K – Cromel and Alumel with temperature measurement between -200°C and +1350°C [10].
- Type M – 82% Nickel and 18% Molybdenum (Mo) – 99.2% Nickel and 0.8% Cobalt (Co) with the upper temperature of +1400°C [8].
- Type N – Nicrosil and Nisil with temperatures between -270°C and +1300°C [11].
- Type T – Copper (Cu)/ Constantan with temperatures between -200°C and +350°C [12].

Platinum (Pt) and Rhodium (Rh) alloy thermocouples:

- Type B – 70% Pt and 30% Rh – 94% Pt and 6% Rh with temperature measurement up to +1800°C [13].
- Type R – 100% Pt – 87% Pt and 13% Rh, temperatures between 0°C and 1600°C [8].
- Type S – 100% Pt – 90% Pt and 10% Rh used up to temperatures of +1600°C [14].

Tungsten (W) and Rhenium (Re) alloy thermocouple [15]:

- Type C – 95% W and 5% Re – 74% W and 26% Re with the maximum measured temperature of +2329°C.
- Type D – 97% W and 3% Re – 75% W and 25% Re.
- Type G – 100 % W – 74% W and 26% Re.

For high accuracy and sensitivity, the following types of thermocouples are used:

- Chromium-Gold and Iron alloy thermocouples with temperatures between 1.2K and 4.2K [8].
- P-type thermocouple called Platine II – 55% Pd, 31% Pt and 14% Au – 65% Au and 35% Pd with temperatures between 500°C and 1400°C [16].
- Platinum and Molybdenum alloy thermocouples – 95% Pt and 5% Mo – 99.9% Pt and 0.1% Mo used mainly in nuclear reactors [17].
- Iridium and Rhodium alloy thermocouples used at temperatures up to 2000°C in inert atmospheres [17].
- Pure thermocouples made of noble metals – Au-Pt and Pt-Pd, simple and economical [18].
- HTIR-TC thermocouples, working with radiation resistance at high temperatures of +1700°C [19], [20].

Thermocouple temperature sensors are used at temperatures between -270°C and +3000 °C, in an inert atmosphere for a short time. For applications where small temperature differences with high accuracy have to be measured, thermistors, resistance thermometers or temperature sensors with a prohibited silicon band are preferred to be used [21].

2.2. Humidity sensors

Humidity sensors are tools used to measure the moisture content in the air or soil. Usually, equipment that measures humidity, is based on measuring another size such as temperature, mass, pressure or electrical modification of a substance when it absorbs humidity. With the help of physical calculations, by calibration with the help of a standard and by measuring the quantities listed above we can determine the humidity. Modern equipment uses condensate temperature, changes in strength or electrical capacity to determine humidity variations [22].

Types of humidity sensors [22]:

- Metal/paper coil type, where moisture is absorbed by a strip of paper, impregnated with salt and attached to a metal coil, thus changing the shape of the paper.
- Hair type, where the length of the hair changes with moisture.
- Chilled mirror dew point type, which uses a cooled mirror and an optoelectronic mechanism to measure condensation on the mirror.
- Capacitive sensors of humidity, which measure the effect of moisture on the dielectric constant of a metal or polymer oxide material.
- Humidity resistive sensors, which measure the change in the electrical resistance of materials such as salts or conductive polymers.
- Thermal conductivity humidity sensors measure variation in the thermal conductivity of air due to the presence of moisture.

2.3. Pyranometers sensors

Pyranometers are radiometers developed with the intention of measuring global solar irradiation, resulting from a flat surface from radiant streams with wavelengths between 300 and 3000 nm [23].

This type of solar device has the ability to measure global solar radiation, diffuse solar radiation and the number of hours of sunshine. The pyranometer is a meteorological instrument with the following basic characteristics: it belongs to a higher class of measuring equipment, is equipped with its own heating, long-lasting use in outdoor conditions, works in any area of the globe. The constructive components of the sensor are: glass dome with superior clarity; the sensor that measures solar irradiation is a broadband thermocouple; spectral response and cosine are close to ideal; standard output sensitivity [24].

The advantages of the solar irradiation measuring equipment are [24]:

- Capacity to measure the overall and diffuse radiation in W/m^2.
- The sunlight threshold is 120 W/m^2 beam directly, according to WMO.
- It does not require calibration, routine adjustments or polar alignment.
- No shading rings and no tracking of the movement of the sun.
- It can be used at any latitude.

The solar irradiation measuring pyranometer provides two analog voltages for global and diffuse radiation at the output, and a digital one for the duration of sunlight. These outputs allow the data measured by the sensor to be retrieved using a separate GP1 data logger. The device allows accurate measurements even in extreme climatic conditions because the internal heater keeps the dome free of dew, snow and ice up to -20°C [24].

2.4. Signal adapters

The adapter is able to record signals from different sensors like thermocouple, pyranometers, resistors, resistance and RTD. The device allows two-wire, three-wire and four-wire connections when using RTD temperature probe or resistors. Linear, temperature-linear and configurable customer-specific linearization variants are available depending on the selected measurement input. The linearization, measuring range (user configurable), connection technology of the probe and transmitter configuration with respect to probe type are carried out by a setup program on the computer. The connection to the computer is established through a USB interface which does not require additional auxiliary voltage [25], [26].

Amongst the special features of the adapters, we name the following [25], [26]:

- Output and Input electrically isolated.
- High galvanic signal separation.
- Option to specify the temperature in °F for temperature sensors.
- Customer-specific linearization.
- Intuitive operation and configuration directly via USB cable without additional auxiliary voltage.
- Measuring input for voltage, resistance transmitter, resistor/potentiometer, thermocouple and RTD temperature probe.
- Advanced adapters offer visualization of measured values and configuration directly via device's screen.

3. LabVIEW virtual instrument

The monitoring scheme contains the following sensors: two thermocouple sensors type J to acquire the temperature inside the panel and the air temperature at the systems output; one humidity sensor to obtain the humidity inside the solar air heater and a pyranometer to measure the solar irradiation. To calibrate the signal acquired from the sensors, four adapters were used powered by a 24V/6.5A source. A thermostat, the commercial solar air heater, a DAQ USB NI 6001 device and LabVIEW software are also part of the monitoring system.

The operating diagram can be seen and analyzed in Figure 1.

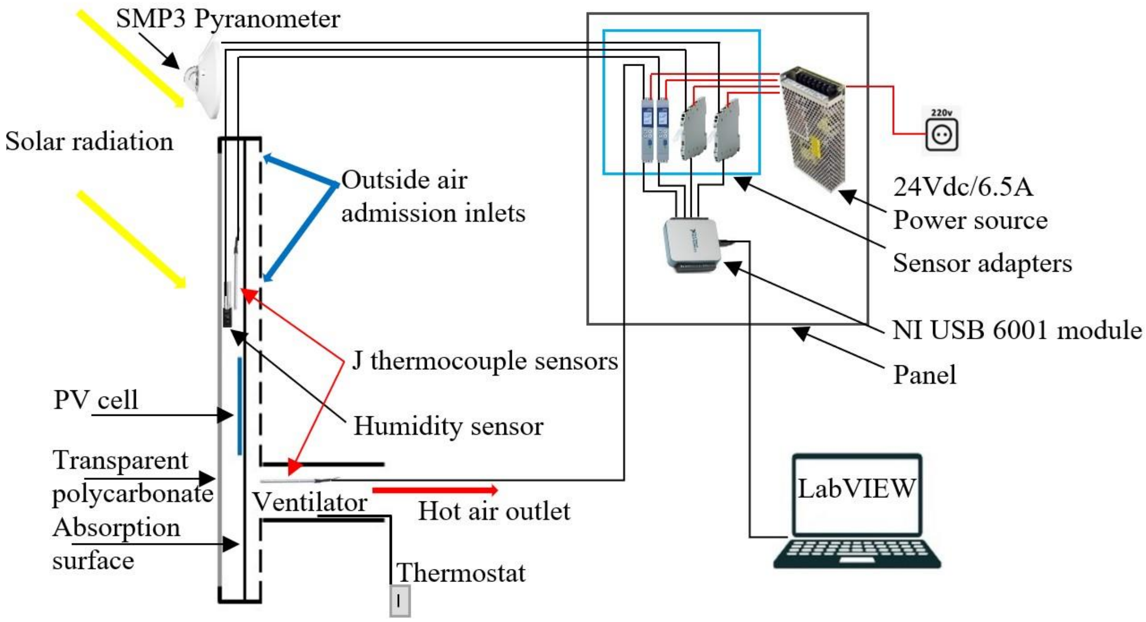

Figure 1. Solar air heater monitoring system diagram.

The solar air heating panel used in the system and presented in Figure 1 is suitable for surfaces up to 50 m^2, manages to prevent moisture and achieves a complete air exchange from such a room in about two hours. For an indoor air flow of 90 m^3/h, the panel has a thermal efficiency in the presence of solar irradiation of 62%. The thermal efficiency of such a panel is represented by the capacities to capture the solar irradiation respectively to transfer the thermal energy from the absorption surface to the air flow passing through the equipment. Obtaining the air flow necessary for thermal exchange is achieved with the help of a 3.4-watt ventilator powered by a PV panel with solar cells that generates a power of 12 watts. The panel frame is made of aluminum and its upper part is covered with transparent polycarbonate built in two layers [27].

The sensors used to measure the internal temperature of the air heating solar panel and the temperature at the panel outlet are of thermocouple type J with class 1 measurement accuracy. The measurement range of the type J sensor is between -50°C and 800°C and the cable type and PFA insulation allows it to be used at outside temperatures from -50°C to 260°C. We can recall a number of advantages over ordinary sensors used to measure temperatures such as:

- Hard-to-reach areas ability due to its small size.
- Measurement without delay at temperature variation.
- High resistance to pressure and vibration.
- Simple, airtight and special construction that prevents corrosion, oxidation, mechanical stress and chemical impurities [28].

The sensor used to measure the inner humidity of the SAH panel has a measuring range in the interval of 0-100% RH, is supplied with a voltage between 4 and 5.8 volts, zero offset equal to 0.826 V, slope valued at 31.483 mV/%RH and it's working temperature when measuring ranges from -40°C to 85°C. At the output the sensor shows a linear voltage and a measurement error with values in the range of -3.5% and 3.5% RH [29].

Solar irradiation is measured using the SMP3 pyranometer which requires minimal maintenance. The equipment allows multiple analog outputs, 0V to 1 V and 4 mA to 20 mA, and a digital output at industry standards, fast response time and allows Modbus interface. The sensor used by the device it's thermopile type with short circuit protection, reverse polarity and surges. Due to the low power consumption and the large supply range, with voltages from 5 Vdc up to 30 Vdc, this model of pyranometer can be easily integrated into weather measuring stations. For temperature influences on irradiance measurements, in the range of -40°C and 80°C, the equipment has an active correction capability [30].

A number of technical characteristics of the SMP3 pyranometer are given in Table 1.

Table 1. SMP3 pyranometer characteristics [30].

Parameter Label	Value
Sensor type	Thermopile
Measuring class	2nd
Analog output voltage range (0 to 1 V)	-200 to 2000 W/m^2
Analog output current range (4 to 20 mA)	0 to 1600 W/m^2
Modbus output range	-400 to 2000 W/m^2
Humidity range	-40°C to 80°C
Temperature range	0% to 100% RH
Maximum irradiance	2200 W/m^2
Zero offset	200 W/m^2

In order to obtain the most accurate data, the proposed system uses four adapters as follows: two adapters of type dTRANS T06 for the sensors that measure the temperatures inside the panel, respectively from the output of the panel; two adapters of type dTRANS T05 for the sensor that measures the humidity existing in the panel and for the pyranometer sensor that measures solar irradiation. The difference between the two types of adapters is that the dTRANS T06 model offers the possibility of measuring a system with double thermocouples. This is useful in the case of systems that require permanent and accurate temperature monitoring. Thus, the dTRANS T06 adapter uses double thermocouples to signal defects in temperature measurement [25], [26].

A number of characteristics of the used adapters are specified in Table 2.

Table 2. Comparison between two dTRANS adapters [25], [26].

Characteristics	dTRANS T05	dTRANS T06
Analog input signal	Thermocouples RTD Resistor/Potentiometer Resistance Tension	Thermocouples Double thermocouples RTD Resistor/Potentiometer Resistance Tension Current
Analog output signal	4 – 20 mA 0 – 10 V	0 – 20 mA 4 – 20 mA 0 – 10 V 2 – 10 V
Supply voltage	DC 11 – 35 V	AC 110 – 240 V, +10/-15 % DC 24 V, +10/-15 %
Setup interface	USB – micro-B	USB – micro B RS485 Modbus RTU
Keyboard	No	4 keys
Display	No	Yes
Linearization	Specific Custom	
Isolation	Input – Output	Galvanic separation
Measuring range Fe-CuNi “J”	-210°C to +1200°C	

To record and centralize the data provided by the sensors, the NI USB 6001 module was used with the integrated NI DAQmx software, marketed by NI, using the LabVIEW program. The USB-6001 module is a low-priced multifunctional DAQ device with analog/ digital inputs/ outputs and a 32-bit counter. The basic functionalities of the NI USB-6001 are specialized for applications such as academic lab experiments, portable measurements, and simple data recording. The device has a light mechanical case and is powered directly by the USB connection to have easy portability. With the help of screw terminals various sensors and signals can easily connect to the connection with the USB-6001 module. The device has an included NI-DAQmx driver installed and the configuration guide simplifies installation and subsequent measurements. NI-DAQmx is the newest generation of driver for data acquisition with the help of DAQ modules. Compared to previous versions, the driver incorporates a totally new architecture, development tools and new functions to control DAQ equipment [31], [32].

The newest function to retrieve and record data from sensors is the function called “Continuous Measurement and Logging (NI-DAQmx)” which once started, automatically acquires and saves the data provided by the measuring equipment connected to the NI USB 6001 module. Depending on the number of data desired to be recorded per second, the program saves the information in a specific file with the extension tdms, which can be converted to Microsoft Excel file for further processing. An important thing that should be mentioned is that the data is acquired and supplied in voltage or current depending on the settings of the adapters used. Because of its importance in determining efficiencies, the data achieved for this study were recorded using the function provided by the program. Also, the data gained from the live sensors are gathered and recorded in voltage considering a number of values retained per second equal to 6.

Since the data taken captured from sensors are values in voltage, different formulas extracted from the sensor data sheets, were applied to convert voltage data into temperature, humidity and radiation. The sensor's assigned equations are presented below as follows.

The equation used to determine the temperature from voltage values is [28], [29], [30], [33]:

$$T = \left(\frac{V_1}{10} \times M_{Rt}\right) - M_{Rmin} \tag{1}$$

The equation used to convert voltage values into humidity is:

$$RH = \frac{V_2 - Z_{OH}}{S} \tag{2}$$

The equation to determine the values of solar irradiation from the voltage supplied at the output by the SMP3 pyranometer is:

$$I_R = \left(\frac{V_3}{10} \times I_{Rmax}\right) - Z_{OP} \tag{3}$$

All acquired voltages for each sensor were converted to temperatures, humidity and radiance using formulas into a Microsoft Excel file and processed to determine the performance of the chosen type of SAH panel [33], [34], [35].

4. Results

The processed data were acquired between 18.06.2022 – 25.06.2022 inclusive, in Ipotești, Suceava County. The solar air heater was installed on the facade of a residential building on a wall related to the proposed room to be heated. All specific equipment for data retrieval were installed in the immediate vicinity of the panel, respectively inside the room.

The room reserved for the study is in the direction of the ESW i.e., sunrise, noon, dusk and the solar panel is positioned in the direction of the cardinal point south, the amount of solar irradiance captured and converted into thermal energy is in the direction of the SW. Since the proposed system recorded in the analyzed period a large volume of data, six measurements per second, only a part of this information was selected for this research, namely the data recorded between 12:00 and 20:00. The chosen interval represents the period during which the solar radiation was incident on the SAH panel. Thus, due to the positioning, the excluded ranges are not part of the study.

Following the data taken and analyzed, the difference between the temperature inside the solar air panel and the temperature at the outlet was determined for the chosen period. For the measurement range, 6 measurements per second, the variation in the average of the temperature difference is shown in the graph in Figure 2. From the analysis of the graph shown in Figure it can be seen that the maximum value during the period studied, of the average of the difference between the two temperatures, was 7,25°C. Also, the negative values represented in the graph belong to the period when the temperature at the exit from the panel was higher than that inside the panel, due to the sudden change in weather conditions.

The highest daily average of the difference between the two temperatures was 18.18°C.

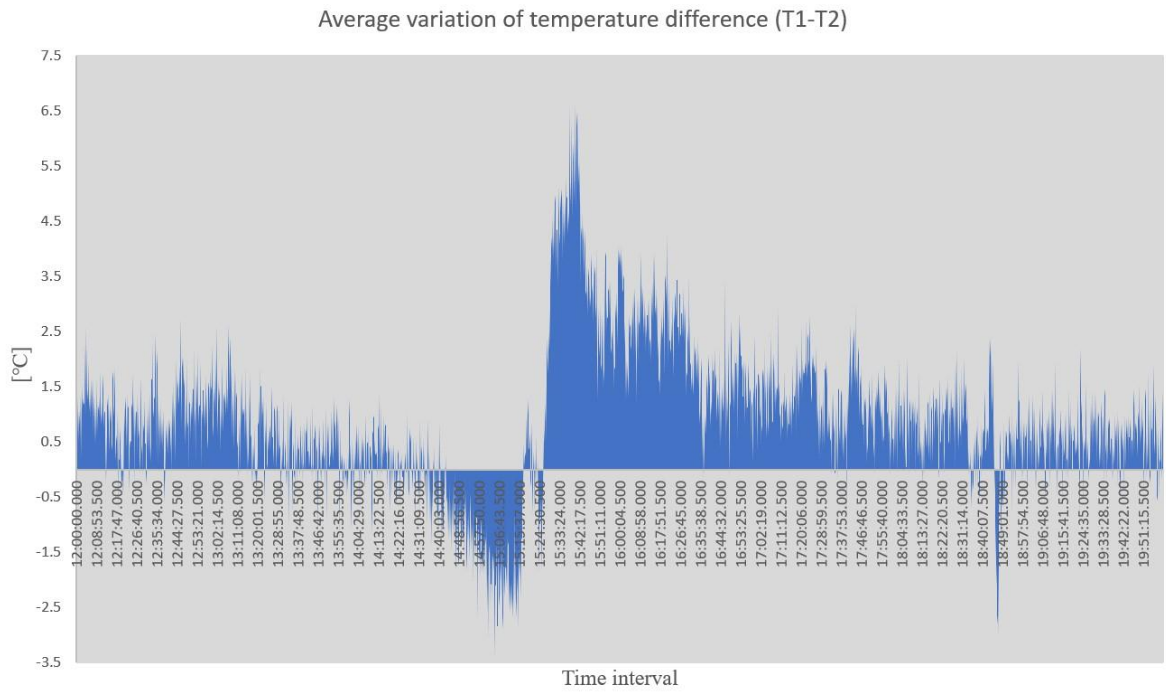

Figure 2. Variation of the average temperature difference (T1-T2).

The average variation in the percentage of humidity inside the panel is shown in Figure 3 as a function of the average temperature variation within the solar panel during the considered period. Also, the average variation in the temperature inside the panel is shown in Figure 4 as a function of the average variation in solar irradiance over the period considered.

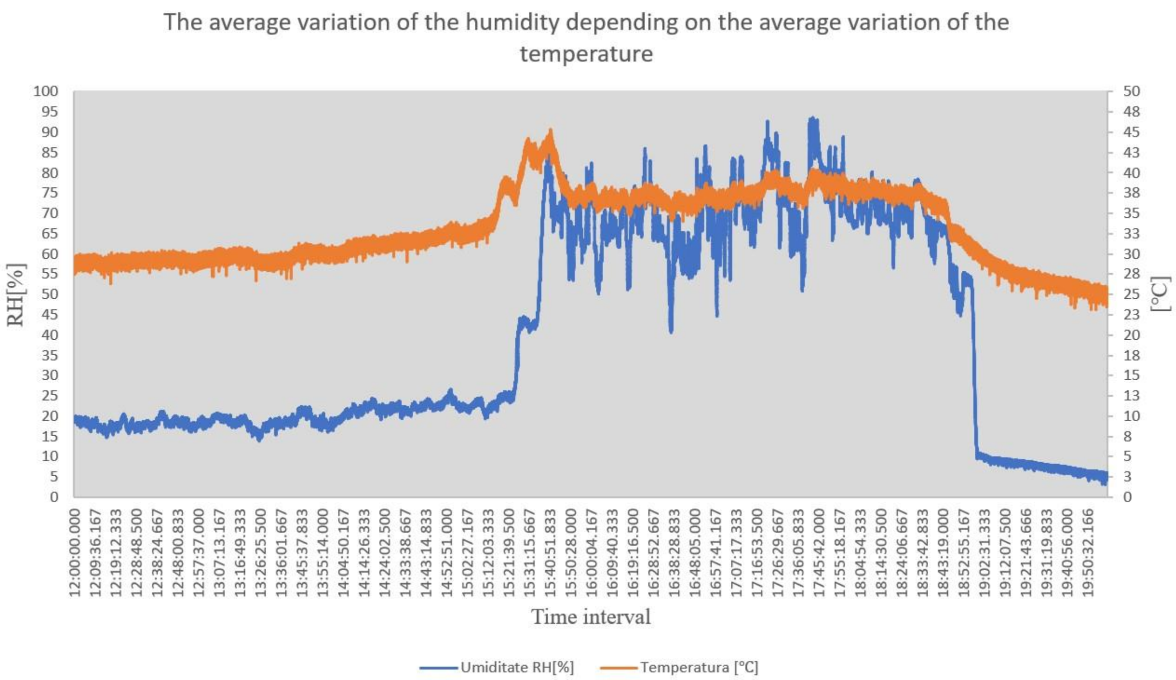

Figure 3. Average humidity variation in the interior of the panel depending on the average temperature variation in the interior of the panel.

From the analysis of the graph shown in Figure 3 it can be inferred that with the increase in temperature inside the solar air heating panel also increases its humidity. The average variation in humidity shall be maintained at a high value until the temperature inside the panel is stabilized at the outside temperature value. Also, in the graph shown in Figure 4, the average temperature variation in the interior of the SAH panel increases at the time of the high average value of the incident solar irradiance on the panel. The maximum mean values of the relative humidity inside the panel and solar irradiance were 93.64 [%] and 805.42 [W/m2] respectively. Also, the maximum internal average temperature of the panel was 45.37 [°C] for the considered period.

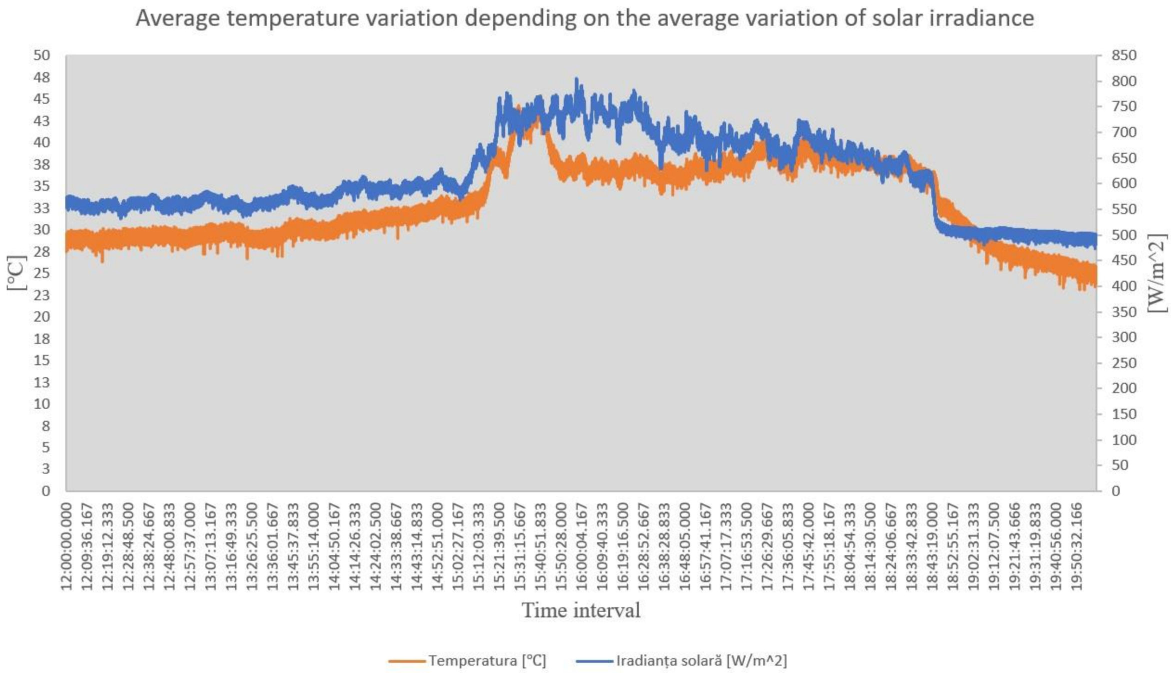

Figure 4. Average temperature variation in the interior of the panel depending on the average variation in solar irradiance.

5. Conclusions

Climate and equipment monitoring systems are among the most important tools installed in solar systems because they contribute to their efficiency and performance. The data taken by the equipment informs about the behavior of solar systems in variable climatic conditions, allows the analysis of the efficiency of the system and the possibility of anticipating how the system will behave, which will lead to increased efficiency [36], [37].

The proposed and designed monitoring system is based on the acquisition of data from different sensors: temperature, humidity and solar irradiation with the help of a module from NI called USB 6001 and with the help of the LabVIEW program. Since the program has integrated different functions and modules of monitoring programs, such a function was used for this study. The motivation for choosing a program provided by LabVIEW is the possibility of accurate measurement and recording of data in the form of editable files. The results are clear in terms of the system. Thus, the efficiency is high as long as the solar radiation falls directly on the absorption surface [38].

The values of the solar radiation correspond to the analyzed period and the area of location of the solar equipment. The high humidity values inside the panel can be caused by the temperature of the outside environment, lower than the inner temperature in the panel, or by sudden variations in solar radiation.

Nomenclature

Meanings of the equation's parameters are the following:

T – The temperatures inside the SAH panel (T_1) respectively, at the panel outlet (T_2);

M_{Rt} – The total number of measurable temperatures in the minimum-maximum range of the adapter depending on the type of chosen thermocouple;

M_{Rmin} – The minimum measurable temperatures of the adapter depending on the type of the thermocouple;

RH – Relative humidity [%];

Z_{OH} – Zero Offset of the HIH-4000 humidity sensor [V];

S – Slope of humidity sensor HIH-4000 [mV/%RH];

I_R – Solar irradiation (W/m^2);

I_{Rmax} – Maximum irradiance of the SMP3 pyranometer [W/m^2];

Z_{OP} – Zero Offset of the SMP3 [W/m2] pyranometer;

V_1 – The voltage supplied by the thermocouple type J temperature sensor [V];

V_2 – The voltage supplied by the humidity sensor HIH-4000 [V];

V_3 – The voltage supplied by the pyranometer SMP3 [V].

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