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TEMPERATURE MONITORING SYSTEM AND WATER CONTROL FROM A THERMOSOLAR PANEL

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Abstract. ***The present work aims to present the operation mode, both theoretically and practically, of an automatic monitoring and control system of the water circuit in a system with thermosolar panels, as well as the main advantages that it constitutes as an automated system of this kind, both in industry and in the everyday life of each of us.***

Keywords: thermosolar panel, SCADA, Arduino Mega, shield Ethernet W5500.

1. INTRODUCTION

Renewable energy is also called alternative energy, usable energy derived from sources that can renew themselves, such as the Sun (solar energy), wind (wind energy), rivers (hydroelectric energy), thermal springs (geothermal energy), tides (tidal power) and biomass (biofuels) [1-3].

As we well know, the Sun is an environmentally friendly and inexhaustible source of energy, and it will only disappear when it stops shining. Being entirely environmentally friendly and free, it emits no fumes, produces no residues, and requires no processing or transport. The sun is not tied to a specific location and does not have a finite amount of energy, so its energy can be used by each individual plant inhabitant.

Solar panels are the only systems using solar energy. The main advantages and benefits of these are:
- long duration of exploitation, minimum 20 years.
- minimal maintenance costs – it works without complicated mechanisms.
- high reliability – resistance to 25 mm hail.
- the collected heat energy can be stored.
- are simple to install.
- can supply up to 70% of domestic hot water needs per year.
- amortization of the investment after 2-3 years (however, this period depends on the intensity of use, the more often it is used, the less this period can decrease).

We have two types of solar panels:

- thermal solar panels (the one I use), this type of panel uses energy from the sun to heat water. Domestic hot water is obtained by heating the thermal agent (water, antifreeze) inside the installation, more precisely the inside of the copper tube, which transfers thermal energy from the sun to water. Since the entire amount of fixed solar radiation is used for this purpose, the efficiency of solar thermal panels is quite high, having a percentage of over 70% compared to the energy of the incident rays, thus being very efficient. These panels are usually installed above the highest consumer, on the roof of the house to be able to absorb and concentrate throughout the day as much solar energy as possibly.
- solar photovoltaic panels, they transform solar energy into electrical energy. This transformation is made possible by the internal photoelectric effect and the photovoltaic effect, both produced in semiconductor materials. Photovoltaic panels are made up of photovoltaic cells, each cell being wrapped in a semiconductor material, usually silicon.

The only disadvantage that the solar panel could have been the fact that the sun did not shine with the same intensity every day, of course there were days without sun, but batteries appeared that store the energy from sunny days, which can be used on the days when we need it.

Due to the multiple advantages and benefits that solar panels offer, several projects have been debated on this topic, such as:
- Solar energy measurement using Arduino [4].
- Acquisition and recording of real-time voltage data using Arduino [5-6].
- Solar energy could be taken to another level, say researchers from NASA. They want to make a system of solar panels in space [7].
- Temperature differential regulator for solar thermal systems. This controller can incorporate 13 systems in a single product [8-9].

2. MONITORING AND CONTROL SYSTEMS

2.1 Wi-Fi systems

Due to the complexity of the project, we decided that a data monitoring and control system was essential. A solar monitoring system can make us more aware of solar panel performance. As the solar panel receives solar energy, the temperature of the water in the panel and thus the water circuit to its user changes, and this information is collected and sent to the cloud-based monitoring system and its accompanying applications. Users can access this information in several ways, including through mobile applications and associated smart devices.

Systems with power optimizers do not rely on a wireless connection to send data, so monitoring continues even during an Internet outage. Depending on the interface on which it is configured, we may have access to the monitoring data even when there is no Internet connection. However, some systems require an internet connection (e.g., microinverter monitoring systems). They rely on a Wi-Fi connection to check each panel individually, in real time. This means that when there is no Internet connection, parameter monitoring cannot be performed [10].

In addition to displaying circuit data and water flow at the time, monitoring systems offer many tools to help us configure it. Monitoring software can often help detect problems and faults with solar panels and recommend their repair. It can also track historical data from the system.

2.2 SCADA systems

SCADA (Supervisory Control and Data Acquisition) is a combination between telemetry and data acquisition. SCADA includes collecting information, transferring it to the site, processing and displaying information.

There are many advantages of such a system:
- The data can be viewed from anywhere, not only on-site.
- The operator can integrate into the system simulations of real data.
- Data can be displayed in any way the user wishes.
- Computer can record and store very large amount of data.

The disadvantages are:
- The system is rather complicated.
- The programming of such a system is quite complicated.
- User cannot get to the programming part.

As the requirement for small and smart systems has increased, sensors have been designed intelligently to get data, communicate with other devices, and store data.

Local Area Networks (LANs) are all about sharing information and resources. To activate all nodes in the SCADA network and to share information, they must be connected to the transmission medium. The nodes must share this transmission medium without disturbing a stable sender. A LAN is a communication path between computers, file servers, terminals, workstations, and various other intelligent peripherals, which are generally referred to as devices or hosts. A LAN provides access to devices with full connectivity between network stations. A LAN is usually owned and used by a private owner and is in a localized group of buildings [11].

2.3 Ethernet systems

Ethernet is the most widely used LAN (Local Area Network) because it is inexpensive and easy to use. This is implemented as a 10 Mbps coaxial cable network. There are three types of Ethernet cable: Standard Ethernet; Coaxial Ethernet/10BASE2; 0BASET.

Sometimes it is essential that projects based on the Arduino development board can exchange data with other devices connected to a network or even the Internet. This involves connecting the board to a local area network created around a device (router) that "goes out" into the Internet. You can use physical (Ethernet) or wireless (Wi-Fi) connections to connect to the router. So, with the help of the Ethernet shield, you can easily connect electronic circuits to the network. A network is a set of autonomous interconnected computers, capable of communicating with each other, using communication channels (transmission media) [12].

Among the examples provided by the Arduino programming environment there are several that show how the board can be connected to the Internet. Access to these examples is done from the application menu. Among the recommended examples are "Web server" and "Web client" where the applications implement the roles of web server and client. These examples show the sequence of commands needed to make an HTTP connection and send and receive web pages. Certain signals got by the board can be viewed through these web pages. The communication functions in the network are solved by the "Ethernet" library accessible through the Ethernet.h header file [13].

3. DESCRIPTION OF EQUIPMENT USED IN PRACTICAL PERFORMANCE

3.1 General issues

In implementing the system, we used the following equipment:
- Arduino Mega R3.
- Ethernet module W5500.
- The SD card reader module.
- The LCD displays: the water temperature in the thermosolar panel; network water temperature; the flow of hot water coming out of the panel.
- LED instead of solenoid valves to show if the solenoid valve is completely open or completely closed.
- Switches – which allow the closing or opening of the valves when the manual mode of operation is indicated.

3.2 Arduino Mega 2560 R3

The Arduino Mega platform has the structure shown in Figure 1 [14].

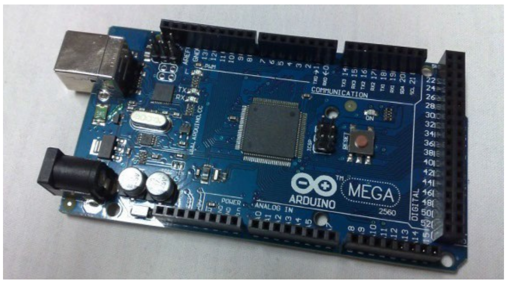

Figure 1. Arduino Mega platform version R3

The platform contains the following components: an Atmega2560 microcontroller, 54 digital input and output pins, of which 14 can also be used as PW output; 16 analogue inputs and 4 serial ports with 2 pins each, one TX and the other RX; 2 I2C bus pins; reset button; USB connector, protection for USB, responsible for USB communication; regulator of 5V; 7 to 12V power supply; regulator of 3, 3V.

Technical specifications:
- Operating voltage: 5V.
- Input Voltage (Recommended): 7-12V.
- Output Current: 40mA.
- Flash memory: 256 KB.
- SRAM: 8 KB.
- EEPROM: 4 KB.
- Clock: 16 MHz.

The Arduino Mega can use expansion boards with integrated circuits, called shields, that connect to the Arduino platform pins. To make the project I used an Ethernet module W5500 to which I added an SD card reader module.

3.3 Ethernet module W5500

The Ethernet module W5500 has the structure as shown in Figure 2 and enables a much simpler and much more secure and stable Internet connection. It uses an internal data communication memory of 32 KB. Programming is simple using a socket; eight independent hardware sockets can be used at the same time. For easy integration SPI is provided with external MCU. It supports up to 80 MHz speed and SPI protocol for high-speed network communication. For low power consumption it offers WoL (Wake on LAN) and a boot mode [15].

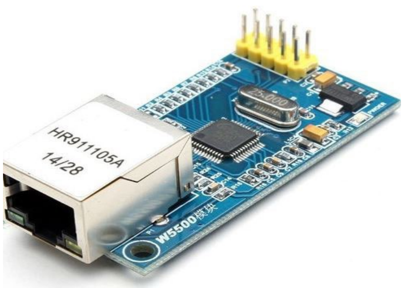

Figure 2. Ethernet module W5500

Technical specifications:
- uses the following TCP/IP protocols: TCP, UDP, ICMP, IPv4, ARP, IGMP, PPPoE;
- Supports the power down mode.
- Wake on LAN is provided via UDP.
- Internal storage is used for TX and RX.
- It doesn't support IP fragmentation.
- 3.3 V operation with I/O signal tolerance of 5V.

2.4 SD card reader module

The slot of this type of card allows you to attach a memory card to a microcontroller on which you can store large amounts of information (Figure 3). It needs 3.3V to work, so we need a level shifter to convert the 5V signal given by the Arduino to 3.3V. To communicate with the Arduino, an SD card of maximum 2 GB, formatted in the FAT16 file system is needed.

Figure 3. SD card reader module

Technical specifications:
- Power supply: 3.3 V.
- SD SPI output pins: MOSI, MISO, SCK, CS.
- Logical level of the interface: 5 V/3.3 V [16].

2.6 LCD (Liquid Crystal Display)

The liquid crystal display has the structure as in Figure 4 and is a device used to display numbers, letters, and images; It acts under the influence of a current or magnetic field by changing the colour of the liquid cells of which the matrix of which it is built is formed.

It is used to display the temperature of the water from the mains, from the outlet of the panel as well as the flow of water from the shower. The backlight must be protected with a 10 kΩ potentiometer.

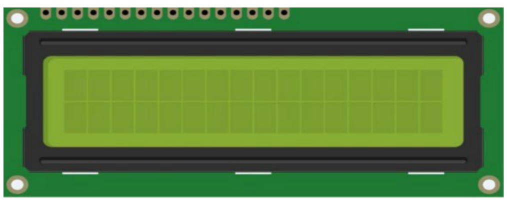

Figure 4. LCD

Technical specifications:
- Power supply: 5 V.
- Current: 1.1 mA.
- Backlight power supply voltage: 4.2 V.
- Backlight current: 100 mA [17].

4. MONITORING AND CONTROL SYSTEM OF WATER FROM A THERMOSOLAR PANEL

4.1 Setting up applications

The software used to program the Arduino is called the IDE (Integrated Development Environment). The IDE is a Java application that runs on several different platforms, including PCs, Macs, and Linux systems.

Programming an Arduino is easy: use the IDE code editor to write the program, then compile and upload with a single click.

An Arduino program has two main functions:
1. setup () - to initialize the board settings; run only once when board is powered.
2. loop () - it runs continuously [18].

The implemented system consists of two panels that perform the simulation of the water circuit, where:
- with the blue LEDs being represented by cold water.
- hot water with the red ones.
- with the orange one's warm water, optimal for the user.

Water from the mains goes to the solar panel and the boiler. From the solar panel, the water follows three routes that will be described further.

For panel 1, the proposed system works in simulated mode with the help of LEDs as follows: cold water from the mains (approx. 5°C or a range of 3-8°C) goes to the panel, and from there the water circuit is next:
- case 1: to the user, in our case directly to the shower, when by turning the potentiometer, the temperature reaches more than 50°C.
- case 2: at the water heater, when the potentiometer rotates between 8 and 50°C, not lower than 8°C and not higher than 50°C, these values being the minimum and largest threshold of this case. Thus, it is easier for the boiler to heat the water from a higher temperature than from a lower one (the water temperature from the mains being below 8°C). At the same time, it is much more energy efficient to heat water from 30-40 °C to just above 50°C than it would have to heat it from below 8 °C to 50°C.
- case 3: the water stays in the panel, if its temperature is lower than 8°C, and the water heater is supplied directly from the network.

In the real operating mode, only the electrovalves that close or open a certain water path light up, but to exemplify this path more easily, we have created the simulation mode.

To ease and improve the monitoring of such a system, I decided to make a second panel, which has the following components:
- Graphic LCD of 128*64 pixels that displays the temperature of the water in the panel, the temperature of the water in the boiler and where the consumer is being fed at the time.
- the three potentiometers that replace the water temperature sensor both on the mains and on the panel, but also the flow meter.
- six switches symbolized with green LEDs to see the state of switching.
- an Ethernet module with a slot for an SD card.

The Ethernet module was used to transfer the collected data to the web server with the help of a regular internet cable. The design of the web server has been simplified to make it much easier to view and watch data in real time. The SD card was used to load the data necessary to implement the site.

4.1.1 Case 1 – temperatures above 50^{0}C

If by turning the potentiometer, the temperature in the panel reaches over 50°C, then the water will go directly to the user, as in the diagram below (Figure 5):

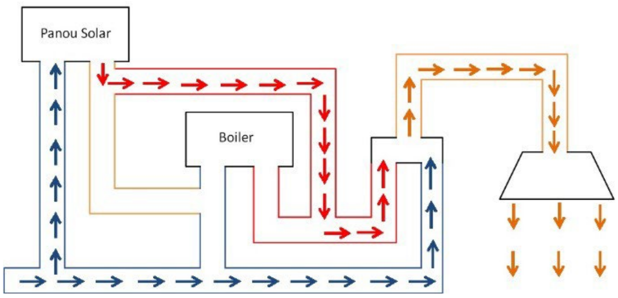

Figure 5. Case 1 – temperatures above 50^{0}C

With the help of the LCD, I showed on the first row on the left: the water temperature from the mains, on the second row also on the left: the water temperature from the panel and on the first row on the right: the water flow from the shower, which can be varied by turning the potentiometers (Figure 6).

When the temperature of the water in the panel is above 50°C, for example 60°C as the LCD also shows (Figure 6), the water used by the user comes from the solar thermal panel (Figure 7).

Figure 6. LCD display of got data in case 1

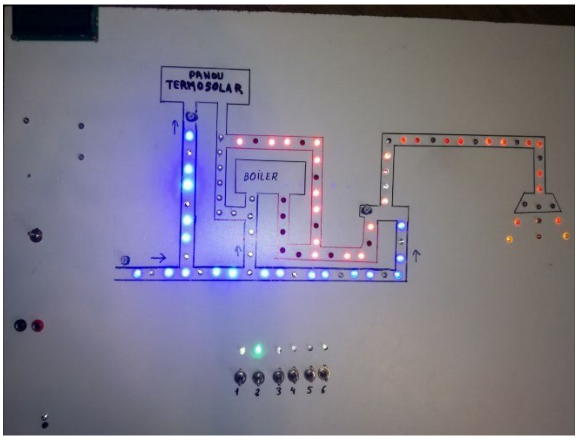

Figure 7. Operation of the system in case 1

4.1.2 Case 2 – temperatures ranging between 8^{0}C and 50^{0}C

If, by rotating the potentiometer, the temperature of the water in the panel is between 8°C and 50°C, then the water in the panel will go to the boiler, as it will heat it faster and easier, than if it comes from the network and has under 8°C (Figure 8).

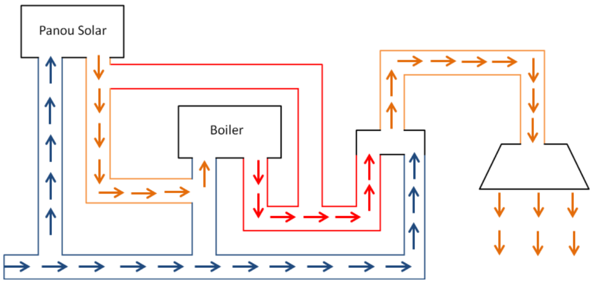

Figure 8. Case 2 – temperatures ranging between 8^{0}C and 50^{0}C

As can be seen, the water has a certain route depending on its temperature (Figure 8 and Figure 10), when the temperature of the water in the panel is between 8°C and 50°C, as the LCD (Figure 9) shows, the boiler is powered by the solar panel, because from an economic point of view, it is much easier for it to heat water from a higher temperature, such as 44°C, than if it was mains water and it had a temperature lower than 6°C.

Figure 9. Display of got data on LCD in case 2

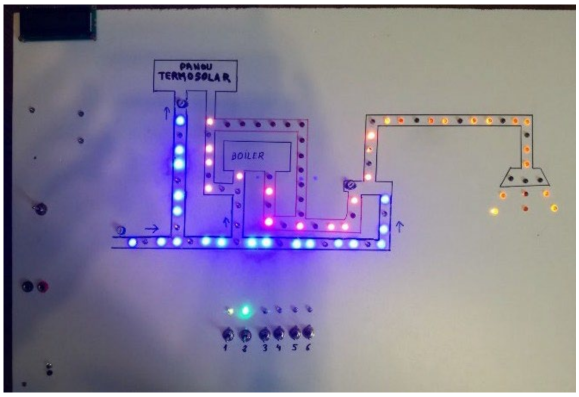

Figure 10. Operation of the system in case 2

4.1.3 Case 3 - temperatures under 8^{0}C

If, by turning the potentiometer, the water temperature reaches below 8°C, then the water heater will be powered directly from the network (Figure 11):

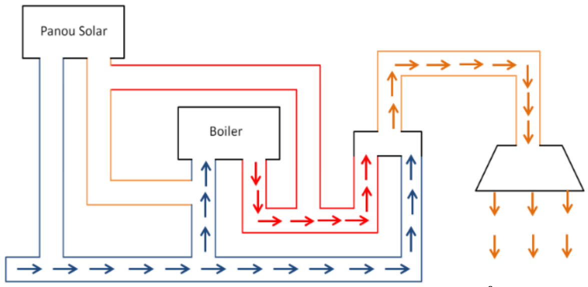

Figure 11. Case 3 – temperatures under 8^{0}C

4.2 Description of system operation

The water flow can be increased or decreased as shown on the right side of the LCD by turning the potentiometer, which stands in for the flow meter (Figure 12). Also, by rotating it, the speed of the play of lights changes. In the lower left, you can also see the fluctuation of water from the network, depending on the season.

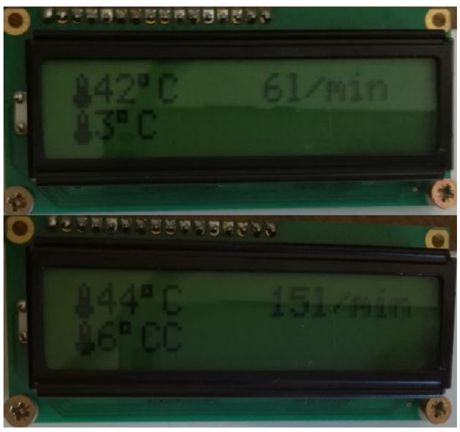

Figure 12. Display of temperature and flow on LCD

The board can be powered directly by the Arduino and the water path switching is done automatically, but it can also be powered from an external battery and the water path switching is done manually by closing or opening the valves.

At the bottom of the panel, I used six switches, symbolized by turning on or off the LEDs the two states of each (Figure 13). The first switch symbolized by the green LED colour shows that the panel is powered. The second switch refers to the board being powered by the Arduino and running automatically, and the LED is green; and when the LED is red, it means the panel is working manually, and the water path is switching according to the user's preference at the time. The following four switches show me by turning on the green LED and the corresponding valve, respectively the water route and which valves are closed at that time.

In the first example, I showed that when you are in manual mode, so the red led next to it is lit, and you switch switches 5 and 6, and the green LEDs next to them light up, the outlet valves are closed from the panel and from the boiler. At this moment, the user only receives cold water from the network (Figure 13).

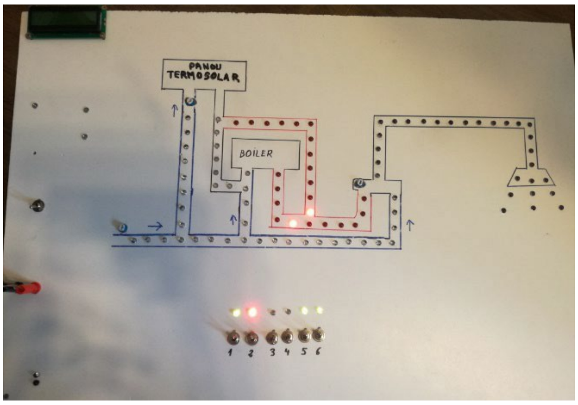

Figure 13. System operation in manual mode - cold water from the network

In the second example, I showed that when you switch switches 4 and 6, the green LEDs next to them light up and close the valve that comes from the mains and enters the boiler and the valve that leaves the panel. At this moment, the user receives shower water only from the boiler, not from the panel (Figure 14).

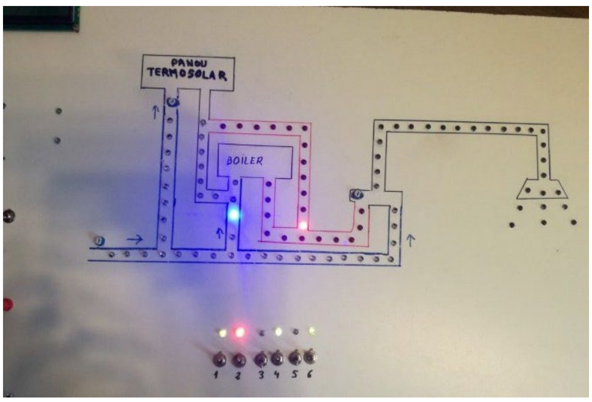

Figure 14. Operation of the system in manual mode – cold water from the boiler

I also made a second panel, which includes a graphic LCD of 128*64 pixels, three potentiometers that replace the water temperature sensor both from the network and from the panel, but also the flow meter, the six switches symbolized with the help of LEDs green to see switching status and an Ethernet module with SD card slot.

Graphical LCD shows me the temperature of mains water, boiler and panel. Depending on the temperature of the water in the panel, it shows me where the consumer is being fed from in real time, by the fact that the water flow moves next to each location where it is being fed from.

For case 1, the temperature of the water in the panel can be in the range of 0-3°C, but in my example, the water in the panel is 0°C, which means that the user is supplied directly from the mains, as indicated by the LCD graphic, that is, the position of the flow is next to the position of the water coming from the network (Figure 15).

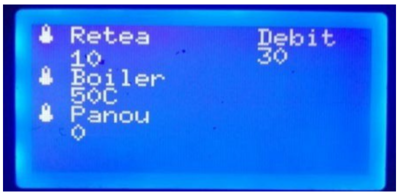

Figure 15. Display of results on LCD 128*64 pixels – case of temperature 0-3^{0}C

For case 2, the temperature of the water in the panel can be in the range of 3-50° C, but in my example, the water in the panel is 29°C which means that the user is fed directly from the boiler as indicated by the graphic LCD, that is, the position of the flow is next to the position of the water coming from the boiler (Figure 16).

Figure 16. Display of results on LCD 128*64 pixels – case of temperature 3-50^{0}C

For case 3, the temperature of the water in the panel can be in the range of 50-250°C, but in my example, the water in the panel is 86°C, which means that the user is directly powered by the solar thermal panel as indicated by the graphic LCD , i.e. the position of the flow is next to the position of the water coming from the panel (Figure 17).

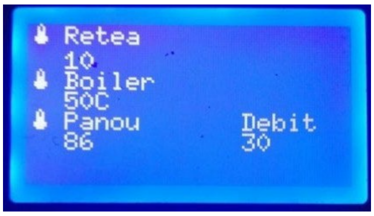

Figure 17. Display of results on LCD 128*64 pixels – case of temperature 50-250^{0}C

4.3 Graphical interface for parameter monitoring

I also chose to create a site for data monitoring, which shows in real time the temperature of the water from the network, the temperature of the water in the panel, the water flow, water, and energy consumption (Figure 18). To create the website, we used Ajax (Asynchronous JavaScript and XML) and HTML [19] as programming languages. Both the data from the potentiometers and the formulas for water and energy consumption were mapped, written, and calculated on the Arduino, only their results being displayed on the website.

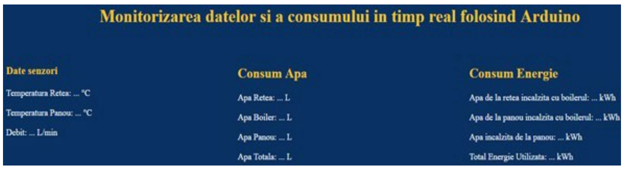

Figure 18. The graphical interface for displaying the acquired data

In the interface we have three columns of which:
- The first shows the data taken from the sensors, in my case the potentiometer data, respectively the water temperature from the network, the water temperature from the panel and the water flow.
- The second column shows us the water consumption, which is based on the water temperature in the panel. The consumption of water from the mains is counted when the water in the panel is between 0° and 3°C and the water flow rate is greater than 0 (Figure 19). The water in the boiler is metered when the water temperature in the panel is between 3° and 50° C, the water flow being greater than 0 (Figure 20). The water in the panel being metered only when its temperature exceeds 50°C and the water flow is higher than 0 (Figure 21). Total water collects any litre of water from anywhere when the flow rate is greater than 0.
- The third column shows the energy consumption of the boiler when it heats the water from the network, and when it reheats the water in the panel, which has a higher temperature than the one from the network.

Figure 19. Data acquisition when the water in the panel is between 0° and 3°C and the water flow is greater than 0

Figure 20. Data acquisition when the water in the panel is between 3° and 50° C and the water flow is greater than 0

Figure 21. Data acquisition when the water in the panel exceeds 50° C and the water flow rate is greater than 0

In Figure 22 we presented a particular case where for 5.07l coming from the mains, at a temperature of 9°C, 240.76 kWh were consumed, and for the same number of litres coming from the panel and having a temperature of 46°C, only 25.05kWh were consumed. One can see the enormous difference in electricity used for the same amount of water if there was no solar thermal panel and the water was heated only from the mains. In this way, the great advantage of such a system with a thermosolar panel can be outlined much more intensively, namely the automatic switching of the valves: if the system neglects its water with a temperature below 50°C, which can be even 49°C, and it is fed directly from the mains, and the water having a maximum temperature of 10°C, as most systems do, it would not have been able to save 215 kWh for the same amount of water used. Total Energy used adds up only the electricity consumed by the boiler when it heats the water from the network and the electricity consumed by the boiler when it heats the water from the panel, because to heat the water from the thermosolar panel we do not need electricity but only the rays Sun.

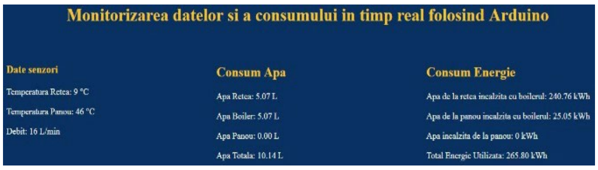

Figure 22. Example of data acquisitions

The calculation of the electrical energy consumed by the boiler to heat the water from the mains was made using the following formula:

grid_energy_b = ***grid_energy*** + *((sensors[2] / def_m) * 4.19 * (50 - sensors[1]))/3.6;*
grid_energy = *mains_water * 1000 * 4.19 * (50 - sensors[1])*

were:
def_m=60 s
4.19 = 1 calorie (the calorie is the unit of measurement for energy)
50 = the ideal water temperature for the user at the outlet of the boiler
mains_water = total amount of water from the network
sensors[0] = map(analogRead(PIN_Panel), 0, 1023, 0, 2500)/10.0; (value taken from the first potentiometer)

sensors[1] = map(analogRead(PIN_Mains), 0, 1023, 0, 100)/10.0; (value taken from second potentiometer)
sensors[2] = map(analogRead(PIN_Flow), 0, 1023, 0, 500)/10.0; (value taken from the third potentiometer)

To calculate the electrical energy consumed by the boiler to reheat the water in the panel, we used the following formula:

***boiler_energy_p** = boiler_energy + ((sensors[2] / def_m) * 4.19 * (50 - sensors[0]))/3.6;*
*boiler_energy = boiler_water * 1000 * 4.19 * (50 - sensors[0])*

were:
def_m = 60 s
4.19 = 1 calorie (the calorie is the unit of measurement for energy)
50 = the ideal water temperature for the user at the outlet of the boiler
mains_water = total amount of water from the network
sensors[0] = map(analogRead(PIN_Panel), 0, 1023, 0, 2500)/10.0; (value taken from the first potentiometer)
sensors[1] = map(analogRead(PIN_Mains), 0, 1023, 0, 100)/10.0; (value taken from second potentiometer)
sensors[2] = map(analogRead(PIN_Flow), 0, 1023, 0, 500)/10.0; (value taken from the third potentiometer)
boiler_water = the total amount of water coming from the boiler by heating the water coming from the panel (3 - 50 degrees)

To calculate the total energy used, I used the formula:

*energy_used = **grid_energy_b** + **boiler_energy_p**;*

5. RESULTS AND CONCLUSIONS

Using such a system based on a thermal solar panel that transfers the thermal energy taken from the sun to the water to heat it, offers us a series of advantages and benefits. Minimal maintenance costs, long operating life, amortization of the investment over time, as well as high reliability are just a few advantages of using such a system.

To ease the monitoring and supervision of such a system, we created two stands, panel 1 - which simulates the water circuit and panel 2 - which displays the values corresponding to the water from the network, boiler, thermosolar panel and the flow rate, presented in the work. For the second stand I used a graphic LCD. To monitor in real time, the data acquired by the system, we created a website, using the AJAX software, which displays the data from the potentiometers and shows the water and energy consumption. To program the Arduino Mega platform, we developed a program that allows the acquisition of data from various inputs.

A rather important factor that cannot be found in other similar systems on the market is the automatic switching of the water circuit depending on the water temperature in the panel. If the temperature of the water in the panel is 30°C, and the boiler is powered directly from the panel and not from the network where the water temperature can be 5°C, the time and the electricity used are cut in half.

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