A MICROCONTROLLER BASED SOLAR HEATING SYSTEM: DESIGN AND CONSTRUCTION

Sohail Anwar
Division of Business & Engineering
The Pennsylvania State University-Altoona College

Patrick Favier
I.U.T Bethune
Universite Lille Nord de France

Abstract

This paper presents details regarding design and construction of a microcontroller-based solar air heating system. The system was designed by the IUT Bethune electrical engineering students to meet the requirement of a capstone design project. This device has been developed so that it is completely autonomous in terms of its energy supply. It uses solar energy only to power its electronic system and the actuators. This energy is provided through the use of a photovoltaic panel. The experimental tests show the efficiency of this system to be quite good.

Introduction

Energy is becoming increasingly important in the development of our society. The combination of the limited fossil fuel supply together with the concerns regarding global warming, pollution, climate change, and the oil price fluctuations has brought the development of renewable energy sources and technologies to the forefront of future human endeavors [1]. Thus, renewable energy has become an important topical area of research and development for engineers and scientists. The mainstream forms of renewable energy include solar energy, wind power, hydro power, biomass, biofuel, and geothermal energy.

Solar technologies are among many other products that are being developed within the renewable energy sector on an unprecedented scale [2]. Solar energy has been the power supply of choice for industrial applications, where power is required at remote locations. Solar energy is also frequently used on transportation signaling, environmental monitoring equipment, and corrosion protection systems. In addition, solar energy is used in water pumping, area lighting, and air heating applications. The key advantage of solar energy is that it is highly reliable and requires little maintenance.

Due to the rapidly increasing applications of renewable energy, there is clearly a need to educate our society regarding its benefits [3]. Many educational institutions around the world are taking steps to integrate the renewable energy concepts into their engineering and technology curricula. Numerous examples of educational institutions providing renewable energy education to the undergraduate engineering and technology students are clearly described in [4, 5, 6].

A prime example of an educational institution providing effective undergraduate education in renewable energy systems is the IUT Bethune in Universite Lille Nord de France located in Northern France. The electrical engineering students studying at IUT Bethune learn solar energy concepts by conducting capstone design projects which integrate their expertise in microcontrollers with solar energy systems. These projects help students achieve the following skills:

1. Students are able to develop a basic understanding of solar energy systems.

2. Students learn how to use microcontrollers for practical applications.

3. Students learn how to define hardware and software specifications for their solar energy system design projects.

4. Students fabricate hardware for their projects.

This manuscript provides a detailed description of a solar energy capstone design project conducted by a team of two IUT Bethune electrical energy students in 2010. The design project is titled "A Microcontroller Based Solar Heating System". The design and construction details of this 16F877PIC microcontroller based solar air heater are presented in this paper.

Project Overview

This project consists of designing and testing a solar system used to heat fresh air. The hot air is ventilated into a house or used for a variety of applications such as agricultural and manufacturing drying process. This system will serve as a prototype for testing the efficiency of solar air heating and for providing real information about the energy it can bring in for free. Moreover, this device is autonomous. It uses only solar energy through a photovoltaic panel to supply its electronic system and the actuators. The above mentioned project provides a demonstration of environmental sustainability coupled with green energy management.

This system is implemented using a flat box with a glass pane on top exposed to the solar light (Figure 1). The box is built using plastic and glass fibber materials with a thermal insulation to increase the efficiency. The inside surfaces are painted black to capture the maximum energy.

The fresh air is injected through an intake tube into the heating volume. An outlet tube conducts the heated air to the outside process. A fan accelerates the air flux. Using the information

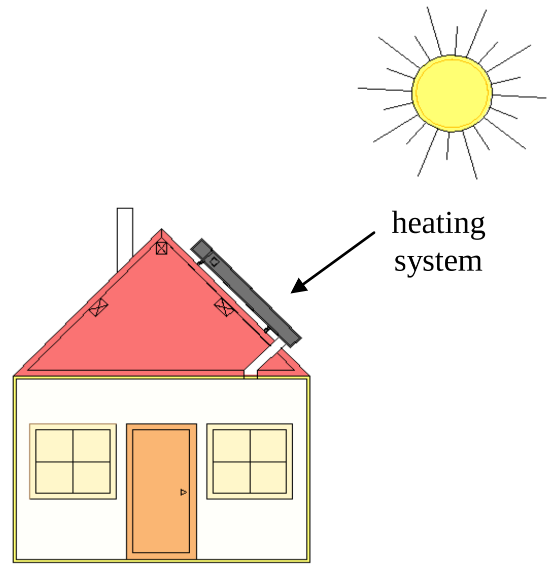

Figure 1: Solar air heating system.

from temperature sensors, the electronic part controls the fan in order to extract the maximum thermal energy.

The above mentioned solar heater has been tested under the sun light. The inside temperature increases quickly and can reach above 60 °C. At this point, the fan is running and ventilates hot air toward the outlet tube. A photovoltaic panel recharges the battery.

This manuscript focuses on the description of the above mentioned solar heater. Details regarding the design and implementation of this solar heating system are provided. The experimental results obtained from testing the system are also discussed.

Thermal System

The prototype of this project is constructed completely autonomous. The electrical energy used by this system is obtained from a 10- Watt photovoltaic panel and it is stored in the battery. This panel is installed in the heating room exposed to the sun and it can produce sufficient electrical energy for the solar control system. As illustrated in Figure 2, the heating system has two key parts:

- the first part consists of a solar collector painted in black and glazed by a plate glass to absorb the electromagnetic waves emitted by the sun. The electromagnetic waves will be transformed into heat. To capture the maximum amount of solar energy, the internal surface is constructed using an aluminium sheet. This metal allows collecting the UV rays and transforming them to thermal energy. Polystyrene plates are placed between the aluminium sheet and the body of the heater, on the back and on each side. This arrangement provides a good thermal insulation to reduce the energy losses.

- the second part consists of the electronics components (including a microcontroller) and a battery which is used for the storage of electrical energy.

In Figure 2, the dimensions of solar thermal system are presented in centimetres. The heating room has two openings with the exterior. The gate placed in the thermal system can be moved by a DC motor. A fan has been installed in the system to provide a forced air flow.

The dimensions of the system were selected taking into account the constraints of installation on a roof. To be able to recover maximum energy from the solar heating system, the air flow must be adapted according to the house interior temperature which can be measured by a complementary temperature sensor.

For this prototype only one temperature sensor has be used. The fan speed depends on the flow “d” of the cold air which is given by:

$$d = s * v \quad (1)$$

where s (measured in square meters) is the surface of the admission pipe and υ (measured in meters per second) is the air displacement speed. The power *P* (measured in watts) provided by the heating system is given by:

$$P = \frac{E_o - E_i}{\Delta t} \quad (2)$$

where E_i =energy contained in air at the input and E_0 =energy contained in air at the exit.

For a given temperature difference T_0- T_i between the output air temperature T_o and the input air temperature T_i, the power can be expressed as:

$$P = C_{pm} * \rho \frac{V}{\Delta t} * (T_O - T_i) \quad (3)$$

where V is the air volume introduced by the ventilator into the heating room, ρ =1.25kg/m^3

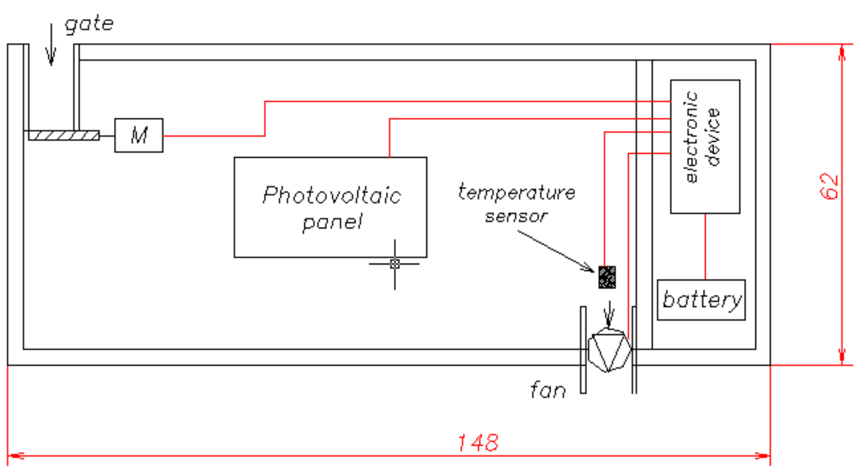

Figure 2: Solar thermal system.

(air density), and C_{pm} =1004 J/kg*K is air specific heat capacity. The equation 3 can be written as:

$$P = C_{pm} * \rho * (s * \nu) * (T_O - T_i) \qquad (4)$$

For heating system with a pipe diameter D=0.08m, Δ T=10K, and an air displacement speed υ =3m/s, the estimated power given by system is P=189W.

Microcontroller Based Control of the Thermal Energy

The above mentioned solar heater is an automatic and active energy transfer system. It is an autonomous system which does not need any external electrical supply.

This prototype uses sensors and electrical actuators to control the hot air flux in order to run when the solar energy is available and to extract the maximum thermal energy.

Figure 3 presents the block diagram of the electrical/electronic system of the prototype:

A 12V DC battery supplies power to the different parts. The intake gate is moved by a small DC motor, the rotation of which is reduced by a gearing system. Two limit switches detect the end displacement positions of the gate corresponding to the fully open and completely closed states. The signals from the limit switches are connected to the inputs of a special board to control the gate motor through a microcontroller (µC) which is a PIC 16F877. A PWM output of the microcontroller drives a full bridge chopper to supply the motor. The inputs of the gate board are the stop/run signal and the open/close signal (to open and close the gate). These signals originate from the main electronic board.

The control part of this system consists of two different electronic subsystems. The gate electronic subsystem opens or closes the gate and the main electronic subsystem provides the active management of thermal energy.

The main electronic subsystem implements another PIC µC to send the control signals to the gate subsystem and to drive the electrical fan which is mounted in the outlet pipe. In order to

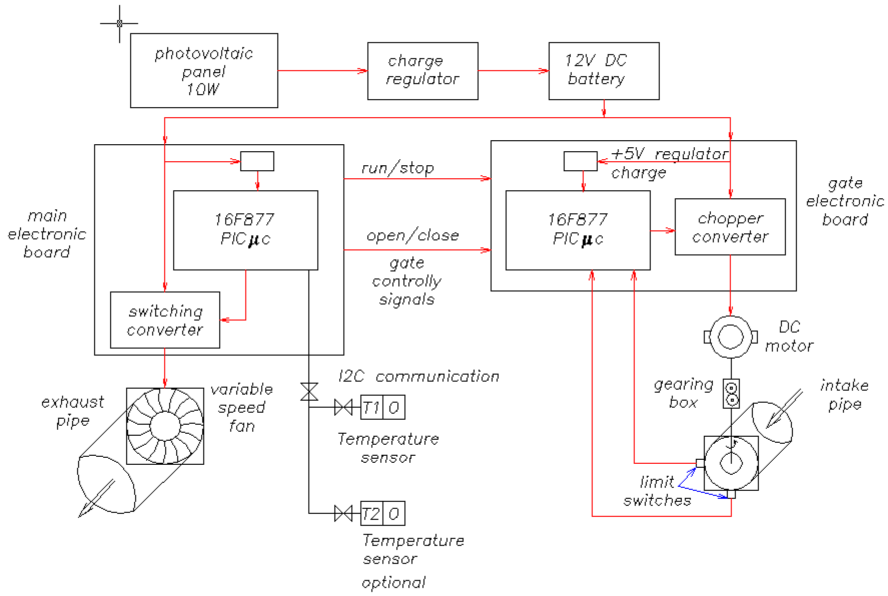

Figure 3: The functional block diagram of the electrical system.

control the air flux, the speed of the fan can be automatically adjusted by the PIC µC depending on the temperature information. The speed variation is realized by the DC voltage variation provided by a switching converter driven from a PWM output of the µC. The frequency is constant at 5 kHz and thus the duty cycle is the parameter to adjust the speed of the fan from 0 to 3000 rpm.

To regulate the hot air flux, a temperature sensor is mounted into the solar heater. It measures the temperature of the air closed to the outlet pipe. A digital temperature sensor TC74 provided by the Microchip Company is used. This circuit is particularly well suited for low cost and small form-factor applications. Temperature data is obtained from the onboard thermal sensing element and it is available as an 8-bit digital word. Communication between the TC74 and the PIC µC is accomplished via an I²C serial port. Two pins are used for data transfer. The SCL pin is the clock, and the SDA pin is the data. The temperature resolution is 1°C and the power consumption is very low. The I²C standard allows the connection of several TC74 sensors and the other I²C devices on the same bus. Each I²C module has its own address to communicate with the master PIC µC.

As mentioned previously, this solar heater is an autonomous electric device. It does not need any external electrical supply and any electrical line. A photovoltaic panel obtains the needed energy from sun light and converts it into an electrical current to charge a 12V battery through a special charge regulator. The photovoltaic panel SM10 type from Sunset Constructor is mounted on the top of the collector. Its dimensions are 434mm, 238mm, and 20mm. It is able to give 10 W under the standard testing conditions of 1000W/m², 25°C, and an Air Mass of 1.5. The optimum point is 17.2V at 0.58A.The stored electrical energy allows the functioning of the electrical part of the solar heater device. When the solar heater is exposed to the sun light, the internal battery is recharged and the solar energy is captured and transferred to a hot air flux.

The main computing task for the design of this solar heater consists of receiving the temperature information and driving the actuators in order to regulate the energy transfer. This is accomplished by first measuring the temperature (T_0) of the air in the top part of the heater and comparing this value to a threshold temperature (T_{thr}) programmed into the µC. When the temperature T_0 is below T_{thr}, the µC sends signals to the gate electronic subsystem to close the intake gate and to stop the outlet fan. When the temperature Tout increases up to Tthr, the gate is opened and the fan starts the ventilation process to extract the hot air from the solar heater and send it forward through the outlet tube. Thus, the air flux is automatically controlled to transfer the thermal energy when the heater system is exposed to solar radiation.

The Figures 4,5,6, and 7 show the electrical gate into the intake tube with the small DC motor and the gearing system, the electrical fan to extract the hot air forward in the outlet tube, the main electronic board/subsystem with the PIC microcontroller, and the 10 W photovoltaic panel to supply the autonomous device.

Testing of the System

The first practical test consisted of measuring the temperature at different points when the heater is exposed to the sun light in order to get the curves of the dynamic thermal response of this system and to get the parameters needed to calculate the free energy this collector is able to capture.

A GL200A data logger from Graphtec Company has been used to record the temperature curves. This device is compact and lightweight. It provides 10 input channels to connect different sensors or signals. It is equipped with a high capacity internal memory to enable the data capture with a short sampling interval on a long time and the data are transferable via USB to a computer.

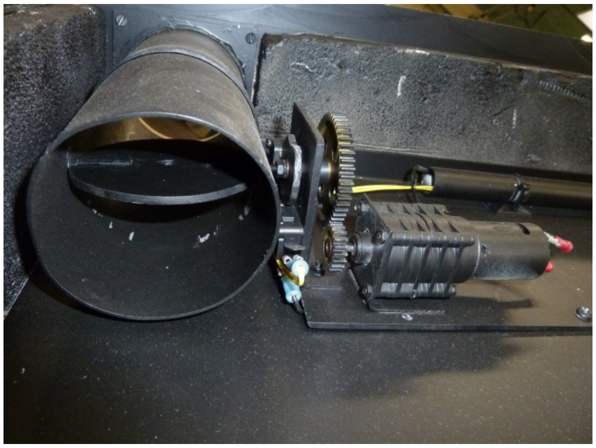

Figure 4: The intake electrical gate.

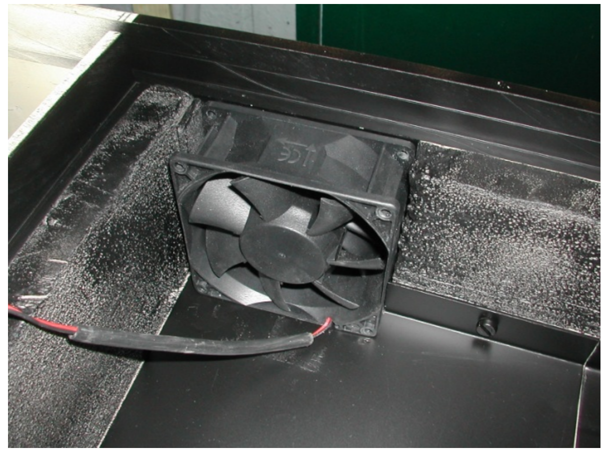

Figure 5: The outlet fan.

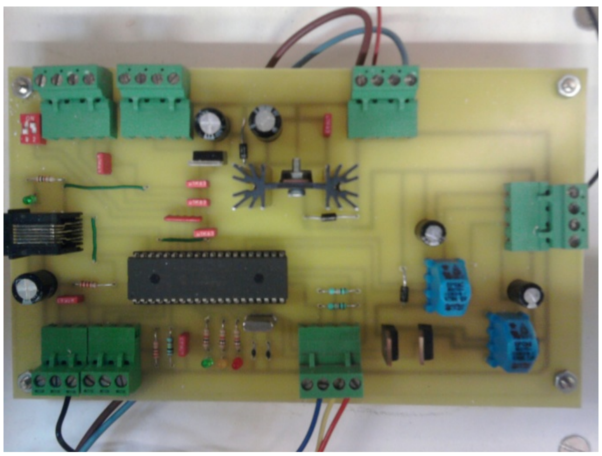

Figure 6: The main electronic board.

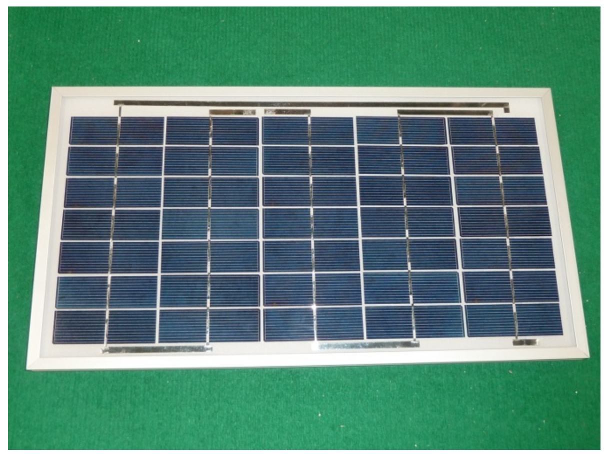

Figure 7: The photovoltaic panel.

A type K thermocouple has been connected directly to the CH1 input of the data logger to perform temperature measurement. This input has been configured to indicate the Celsius degree units. The chosen sampling interval is 1 second. A special key allows starting or stopping the captured data into a file in the internal memory. After the experimentation, the captured data are sent to a computer on which a special software gives very nice representation of the measured values in a numerical or graphical form.

The first experiment consists of recording the free temperature response when the collector is exposed to the sun light with the intake gate closed and the fan stopped. Figure 9 shows the curve with the rising temperature from 21°C to 67°C. The temperature is measured in the internal part closed to the outlet tube.

During this recording, the solar irradiation was 936 W/m² measured with a solar power meter pointed to the normal direction from the collector glass surface. It is obvious that the increasing of the temperature goes fast for 15 minutes to a high temperature that could reach 80 °C and cause damage if the test is not stopped.

To test the active energy management, a second experiment was conducted for which the results are shown in Figure 10.

After heating under the sun light, the temperature reaches 73°C. Now the gate is open

Figure 8: The GL200A data logger with the thermocouple.

and the fan is ventilating to extract the hot air. Of course, the fresh air is coming to the bottom of the collector at an outside temperature 19°C. So the output temperature quickly decreases in less than 30 seconds. After this permanent functioning, the outlet temperature is stabilized to 42°C. This test proves that the air heater can capture the solar energy and transfer it to the thermal energy in a hot air flow with a rise of temperature equal to 23°C.

The third experiment tests the automatic functioning of the solar heater system with respect to the outlet temperature measured by the sensor connected to the µC. The results of the third test are presented in Figure 11 showing that the µC drives the electrical gate and the fan to regulate the hot air flow.

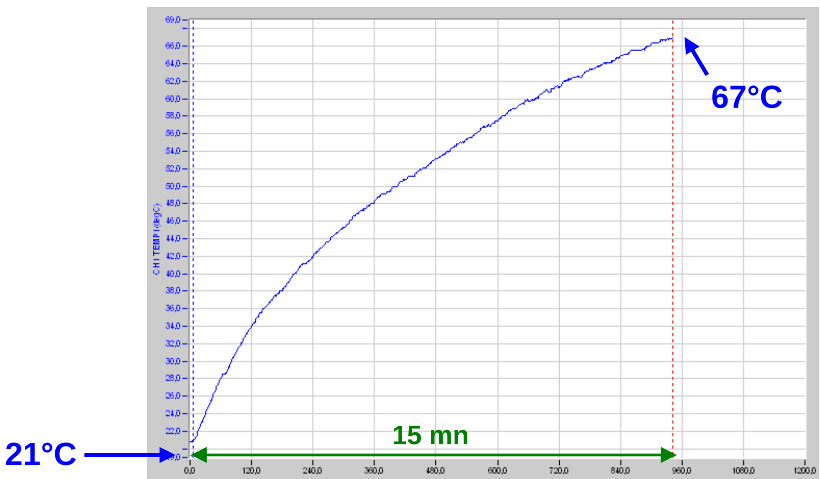

Figure 9: Rising temperature curve.

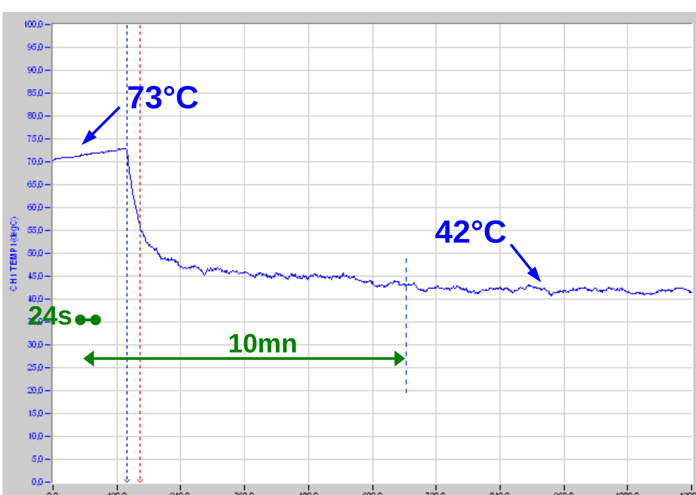

Figure10: Functioning with gate open and running fan.

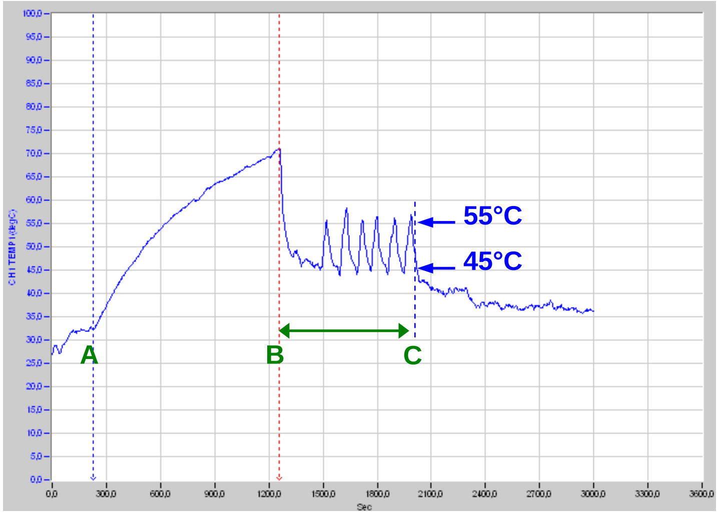

Figure 11: Regulation of the hot air flow at a solar irradiation of 808W/m².

The threshold temperature values programmed into the PIC µC are 45°C and 55°C. Above 55°C, the µC opens the gate and runs the fan to a constant speed. Below 45°C , the gate is closed and the fan is stopped. This operation takes place during the time interval between points A and B in Figure11. It is observed that the outlet temperature is regulated between the two threshold values.

From a measurement of the temperature increase and the air flux speed, the energy power extracted by the solar collector during a steady functioning was computed. With a thermocouple thermometer, the intake temperature was measured as 19°C and the outlet temperature was 39°C. The air flux speed was measured with an air speedometer; it indicated a value of 3.1 m/s. According to the Equation (4) with $T_o - T_i = 20°C$ and $\upsilon = 3.1m/s$, the extracted thermal power P equals 391W.

During the experimentation, the normal sun irradiation was 936W/m². The collecting surface area of the heater with the glass pane dimensions of 1250mm*600mm, equals 0.75 m². So the incident power equals 702W.These values allow the calculation of the efficiency of the heater computed to be 391/702 = 0.557. Using Equation (1), the airflow is computed to as $d = s^* \upsilon = 0.0156\ m^3/s$.

These numerical values prove that the above mentioned prototype is able to provide a large flow of hot air at a right temperature to heat a room. The 56% efficiency is specific to a good capture of the solar energy.

Conclusion

The manuscript presented a detailed description of a PIC 16F877 microcontroller based solar heating system designed and constructed by a team of two IUT Bethune electrical engineering students to meet their capstone design project requirement. This microcontroller based solar heating system provides a good demonstration of environmental sustainability and green energy management. All the electrical energy needed by this system is obtained from a 10-Watt photovoltaic panel. The test results described in this manuscript show that the solar heating system constructed by the IUT Bethune electrical engineering students is capable of providing a large flow of hot air at the right temperature to heat a room.

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Biographical Information

Dr. Sohail Anwar is an Associate Professor of Engineering at the Altoona College of The Pennsylvania State University. In addition, he is a Professional Associate of the Management Development Programs and Services at The Pennsylvania State University, University Park. Also, since 2009, he has been serving as an Invited Professor of Electrical Engineering at the Shanghai Normal University, China. Dr. Anwar is currently serving as the Editor-in-Chief of the ***Journal of Engineering Technology*** and as the Series Editor of the Nanotechnology and Energy Series, Taylor and Francis Group/CRC Press. Dr. Anwar recently edited a book titled ***Nanotechnology for Telecommunications*** published by the Taylor and Francis Group/CRC Press in June 2010. Moreover, he is co-editing a book titled ***Advanced Nanoelectronics and Graphene Nanoribbon Technology*** to be published by the Taylor and Francis Group/CRC Press in 2012.

Dr. Patrick Favier is an associate professor of Electrical Engineering at the IUT Bethune, University d’Artois, France. His research specialities are electrical drives, power electronics, and renewable energy. Since 1984, he has been teaching electrical drives and power electronics in the I.U.T Bethune. He served as the Electrical Engineering Department Head from 1997 to 2004. Since 1992, he has been serving as the Director of the IUT Bethune teaching laboratory in electro-energetics. He is actively involved in several international academic linkages. At present, he is developing an International Collaboration in Engineering Education focusing on projects conducted by multinational student teams.

ERRATA

The authors of the manuscript " A Framework for the Integration of Information Security and Risk Analysis Concepts into an Undergraduate Engineering Technology Degree " published in Volume 1, Number 4 of ***Computers in Education Journal*** wish to clarify several statements made in the aforementioned manuscript :

1. The framework described in this manuscript is, at present, a concept developed by the authors. It is not going through the implementation process.

2. The segment of this manuscript starting from " The Penn State University Altoona College Electro-Mechanical ...... " and ending at " ....modern instrumentation and control concepts " is a direct quotation from the Penn State University Altoona College Electromechanical Engineering Technology Program description provided at the College website (http://www.aa.psu.edu/academics/bsemet_default.asp).