Arduino-based design and implementation of experimental rooms with a trombe wall for solar cells applications

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ABSTRACT

The simplicity of design and construction following the researcher's or company's notion is the most typical description of solar panels. There will be a set of sensors in every design to derive information about the environment's shifting seasons and days. Two chambers of 1 m^2 and 2 m^2 in height were constructed for this study. A solar panel made from a unique exchangeable material has been installed instead of one of the walls, allowing a space between them for experimental reasons. Several temperature sensors were mounted inside and outside the chamber, as well as on the surface of the solar panel and within the air openings, in this work to record the temperature readings in various places. The used controller, an Arduino, is in charge of several operations, including controlling the solar panel's cooling device, reading and recording sensor data and storing it in RAM, controlling the orientation of the solar panel, controlling the vacuums, and regulating the on-off time of the motors. The findings show that by using sensor data, the system can keep the temperature constant when it is turned on. Additionally, the battery life will be preserved to the greatest extent feasible thanks to the well-balanced regulation of the loads.

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1. INTRODUCTION

In tropical places, where sunlight is copious, solar panels can produce enough electricity for lighting systems [1]. The efficiency of photovoltaic (PV) cells has significantly increased in recent years, increasing the attraction of solar energy for both residential and commercial structures [2]. The PV effect is used by solar panels to harness solar energy for electricity production. When there is no sun irradiation, this can serve as a reliable power source [3]. Solar energy is the main energy source and is regarded as fuel for the majority of renewable energy (RE) systems [4]. The panels are constructed using ineffective silicon and germanium semiconductor materials [5]. The best method for increasing efficiency is thought to use solar trackers [6]. An improvement is gained by keeping the solar panels aligned with the sun [7]. Buildings in the US use 40% of all primary energy and 76% of all electricity, according to estimates [8]. Its percentage of the nation's yearly power usage has increased significantly from 25% in the 1950 s to 40% in the early 1970 s to more than 76% in 2012 [9]. To obtain the highest interior comfort with the least amount of energy usage, smart building management becomes crucial [10]. The PV-Trombe wall (PV-TW) proposed design is shown in Figure 1. The other three sides will be ordinary walls; just one of the four sides will resemble the image.

Through the efficient control of key building elements like heating, ventilation, air conditioning, and lighting systems, smart buildings have the potential to save 34.78% more energy than traditional ones [11].

Recent years have seen an increase in the use of TW systems for passive heating/cooling in buildings. There are many different types and classifications of TW systems in the literature; writers have presented an in-depth analysis of these systems in references [12]–[14]. Khalifa and Abbas [15] put a TW system to the test using a huge concrete, paraffin wax, and hydrated salt wall. The results demonstrated that the hydrated salt functioned at its peak when coupled with concrete and paraffin wax. Research by Yu *et al.* [16], an experimental and numerical investigation of the effectiveness of a traditional TW system was carried. When compared to a typical room, the experimental and numerical findings demonstrated significant energy savings and great agreement. The traditional TW technology's functionality has recently been improved. A TW system was created by Wu *et al.* [17] to purify the air and chill the space. The technology produced power and improved system efficiency when a solar system and a typical TW were combined. This technique has far more potential for energy savings and health benefits than the conventional approach [18].

The photocatalytic-PV-TW (PC-PV-TW) is a new, multi-purpose passive solar wall that concurrently generates heat, energy, and fresh air. It was first introduced in [19]. The effectiveness of the PC-PV-TW was then evaluated using a multi-physical fields coupling model (velocity, temperature, and concentration fields). The performance of the PC-PV-TW, integrated PV-TW, and PC-TW under various solar radiation intensities and ambient temperatures were then evaluated. The author of this work develops a flexible, wall-based paradigm that is quite powerful. A high-end passive refugee home described by [20] that is suited for the climate in Sweden uses three passive heating and cooling technologies: the earth air heat exchanger, the TW, and the green wall. The home uses RE sources to meet its energy demands while being built to create 180 kWh/m^2/year of extra energy. For budgetary considerations, this project aims to build a better TW utilizing a range of materials. According to Li *et al.* [21], comparative tests were carried out in a hot and humid region of China throughout the summer to assess the phase change material (PCM) TW-system (TWS) thermal performance. The PCM cold storage plate released its chilling capacity during the day at a peak heat flow rate of -25.1 w/m^2, while it accumulated cold energy at a peak heat flow rate of 20.1 w/m^2 during the night.

Research by Zhang *et al*. [22] uses numerical analysis to investigate the upgraded TW's thermal properties. The improved TW outperformed a regular TW in terms of average air temperature at the top vent, average air velocity at the top vent, heating capacity, and overall thermal efficiency by 1.9 °C, 30.4%, 57.1%, and 55.7%, respectively. The restored TW's temperature and flow fields were likewise much superior to those of the original Trombe. According to a comparison of the heating characteristics of improved TWs with various air channel thicknesses ranging from 50 to 130 mm, the best heating characteristics of the improved TW with a height of 2.7 m could be achieved when the air channel thickness ranged from 70 to 80 mm. The thermal performance of a TW is improved in the current study by the employment of phase change materials and an outside insulation component [23]. First, a heating maintenance design strategy must be chosen. Using this model, the thermal performance of the outer insulation component's design features is assessed. The working medium of the heat exchanger in the PV/TW was water nano-fluid (Al_2O_3) [24]. For different coolant flow rates and design configurations, two concentrations of the nano-particles (0.1% and 0.5%) were taken into consideration. It has been shown that at a nanofluid concentration of 0.5%, solar cells and interior parts suffer the greatest temperature reduction. The interior space temperature and the solar cell temperature had the largest reductions, 9 °C, and 14.4 °C, respectively. The system's maximum electrical and thermal efficiencies at operational settings (with Fan+300 L/day+Nano 0.5%) were 9.2% and 62.99%, respectively.

Studies are done and solutions are suggested [25] to minimize the discrepancy between a 150 m^2 single-family home's electrical demand and RE output. Two examples of RE are micro-wind turbines and PV technologies. Although the essay ends with a discussion of grid feed-in, it also offers a brief economic analysis that concentrates on the scenario in which grid feed-in is absent. The goal of the current work is to use a porous material to improve the performance of a hybrid PV/TW system [26]. This article's experimental setup was developed to investigate the effects of a porous material, a DC fan, and a glass cover on PV performance. In addition to the storage of electrical energy, this work proposes a ground-breaking energy approach for the creation of thermal energy, hydrogen fuel, and electricity [27]. The system consists of an organic ranking cycle (ORC), a proton-exchange membrane fuel cell (PEMFC), a parabolic trough collector (PTC), an electrolyzer a thermoelectric generator (TEG). The pumped hydro-compressed air (PHCA) combination technology is used for electricity storage. The suggested system's conceptual design takes two distinct eventualities into account (based on the production of energy and hydrogen fuel). The solar collector is necessary for energy generation in both cases. Additionally, around 3.4 kg/day of hydrogen gas is produced in the second scenario. To accomplish this, a cooling system that comprises fans, sprinklers, and wipers was designed and built [28]. Its purpose is to remove additional heat from solar panels when temperatures are at their highest. Sprinklers and wipers can help keep solar panels clean because dust is a problem that reduces their ability to produce electricity. A microcontroller that was created using Proteus 8, Arduino, and MATLAB 2016 controls the cooling system. This energy can be used to generate electricity while also being consumed by a PV-thermal (PVT) system [29]. In contrast to conventional systems, the collector in this instance is external to the PV panel and is linked through pipes. To track and store system characteristics received from the PV-TEG source in large memory storage, a data acquisition system (DAQ) for a hybrid PV-TEG was designed [30]. The 200 W panels and 192 TEG are coupled in series and parallel on the hybrid system to maximize output power. For data gathering, the technology transforms the original data into digital input and saves it on a secure digital card (SD card). The rising temperature of solar panels is one factor that lowers the effectiveness of solar systems [31]. To avoid this, a cooling fan can be mounted on the back of the solar panel. Efficiency rose by around 4.7% when the full system was built and tested [32]. A simple pipe was used as a spiral heat exchanger for active cooling on a PV module. The technique may also be readily extended to large-scale systems.

In this experiment [33] perforated aluminum plates were used as a passive cooling technique to decrease excessive heat in solar panels and boost the output power produced by the 100 Wp monocrystalline solar panel. Hammoumi *et al.* [34] presents an experimental examination of small-scale floating photovoltaic systems (FPVS). It was designed with study and demonstration in mind and is the first attempt to test this idea under operational circumstances in Morocco. To gather experimental data for thermal and electrical modeling, a test bench for PV-T panels must be built [35]. A self-developed open-source system built on the Arduino platform is used to monitor data from the test bench's multiple sensors and actuators. The primary objective of this research is to increase PV panel efficiency while maximizing energy output to lower panel temperature [6]. For small solar systems to work well, both careful hardware and software development is required. The goal of this study [18] is to create an autonomous, intelligent TW system that can adapt to keep a room's temperature constant despite abrupt changes in the weather. A DAQ device based on Arduino has been developed, constructed, and tested in this work to monitor the PV system characteristics of the solar home systems (SHS) prototype [36]. A signal processing module, such as an Arduino Mega board with an ATmega 2,560 chip microcontroller, sensor modules (such as the voltage, current, temperature, and humidity), a storage module using an SD card shield with an embedded real-time clock of DS1307, and a liquid crystal display (LCD) 20×4 display module make up the DAQ device.

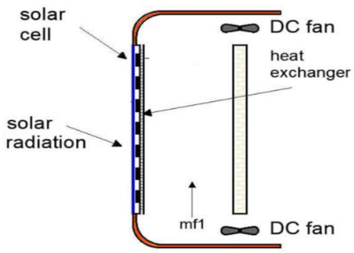

Figure 1. Proposed design for the PV-TW for experimental issues

2. METHOD

The idea of this work is based on the observation of several projects by previous researchers and the problems they have to record the data, control the coolness of the room as well as choose the right load. Many efforts were achieved to get standard data of any application for the PV Trumbe wall. Time reduction and fewer efforts are the main goals for the proposed work.

2.1. General structure

This work adopts the traditional measurements of the previous works with dimensions of 1*1*2. As this is the basis for most of the experiments and research in this field. The main idea of this proposal is to implement the principle of an ideal, smart, clean room that uses only solar energy to adapt to most traditional home uses in addition to thermal insulation by choosing the optimal type of walls.

2.2. Solar panels

The solar panels are placed on one of the four walls of the room and fixed in such a position that there is a space between them and the inner wall of the room to allow researchers to place a phase-changing substance or a specific gas or leave it filled with air, depending on the chosen application. The benefits of PV are electric power generation, water heating, and room conditioning through heat exchange. If the work is applied to a larger area and more attachments, either, the number of panels will be or the panel size will be increased according to the choice. The use of panels in experiment rooms based on the TW is completely different from those used in solar energy systems that are used to generate electrical power only, as it is controlled by determining the optimal angle for the cells to make the most of the sunlight with the necessary cooling for the cells. In the case of a TW, the direction of the board is only vertical, so the difference in angles is compensated by attaching mirrors to increase the focus of the rays.

2.3. Arduino

Arduino Uno is what was used in this work to control the workflow in the proposed rooms for laboratory experiments and researchers' projects related to the uses of solar panels and TWs or performance improvements. Arduino layout with the most used pins and input/output ports is shown in Figure 2. In the previous controllers, to change a certain element within the circuit of control we have to repeat the entire program. The programming process does not take a lot of time. It only requires accumulated experience using programming in general with how to prepare conditional functions and deal with the outside world, as the principle of the controlling work is a function (if), through the values of variables obtained through sensors or through mathematical equations that It also depends on the sensor values.

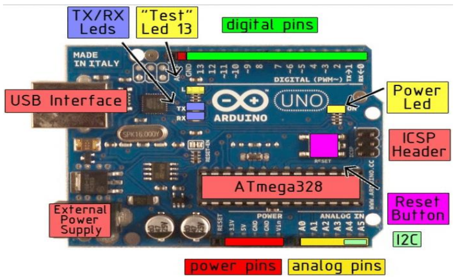

Figure 2. Arduino UNO parts and i/o pins

The Arduino is programmed to record the readings of the sensors after connecting them to a single line and through serial data, which in turn serves as a basis for making decisions later and obtaining the best performance of the work-related system. The process of recording data is by storing it on a fixed memory inside the Arduino and then it is obtained using an external USB memory whenever the user wants, where the controller records the readings according to what is programmed on it. For every hour of reading or whatever the researcher wants in the timing of the recording. In this proposed work, the recording was used on internal memory, and then the data was pulled from the Arduino memory to external memory, to study the case and fix the variables in the proposed design by the researchers. It is mentioned that may take 15-25 minutes to obtain the data, which is a loss in time and inhomogeneity of the recorded readings because there are more than 10 minutes between the first and last sensors. Through the proposed work, and as mentioned above, after recording the data, it is withdrawn via USB with the same values and the same degree of accuracy that was recorded on the sensor without any significant error rate. In order not to lose the ability of the Arduino, the limit did not stop at recording the readings only but also went beyond the work to control the operation of cooling systems, air vacuums, and the loads associated with the proposed work. For example, in the process of cooling the solar panel, researchers used to operate the air fans in the back space of the panel to work on discharging the hot air and replacing it with cold air, as the fans were working constantly and at the same speed. In this work, the Arduino was programmed to control the speed of the fans as it gives them differently depending on the recorded temperatures of the slab. In the same way, the fans are controlled, and the water motor is dedicated to cooling the cell. The heating of the water was also controlled, as it was programmed to work according to the temperatures generated by the panel, i.e. it pushes varying amounts of water during the day, meaning that at high temperatures it increases the thrust to get More hot water and more cooling for the cell, and vice versa. One of the things that are also controlled is the process of controlling the loads, and the time allotted to them. The purpose of that is to save the efficiency of the solar panel, or the capacity of the battery that stores energy, as the Arduino turns on and off the load only when reading the variables associated with the type of study and separates the load after it.

3. RESULTS AND DISCUSSION

The proposed work was run according to the standard data mentioned earlier. One of the important things in the process of operating such types of projects is the rate of power generated in the solar panel, the amount of heat applied to the panel, and the electric current. The model's response was accurately corrected during the timely data collection, and the multi-control objectives were met.

3.1. Temperatures

The second matter, which is no less important than the first, is the recording of temperatures for the various parts of the work, which is necessary for solar panel projects associated with electrical energy applications, as high temperatures harm the efficiency of the solar panel. The work contains more than 40 sensors, as mentioned previously, which must be taken periodically at the same time to study the response to the various areas of the project. In this proposal, the Arduino controller is used to collect these readings through a complex of signals from all sensors and connect them to a single line to the Arduino using the sequential data theory. A program has been developed to work so that the time is fixed by the researcher in the project under work and according to what he wants to time between reading and another. For example, every hour the sensor readings are recorded and stored on the internal memory via a USB memory stick. Previously, by the traditional method, the authors take approximately 15-20 minutes to obtain the readings, which negatively affects the case study due to the timing discrepancy between the first and last sensors, Figure 3, an example of power records. In addition, the Arduino takes temperature values from the sensor with instant accuracy and with the standard installed in the program, meaning that the data does not enter into an intermediate stage to find the temperature value from the resistance value generated by the sensor. The record for the proposed model is more than 40 and Figure 4 shows the temperature for the PV on a given day. Other records for the inside room are fixed for the same day and shown in Figure 5.

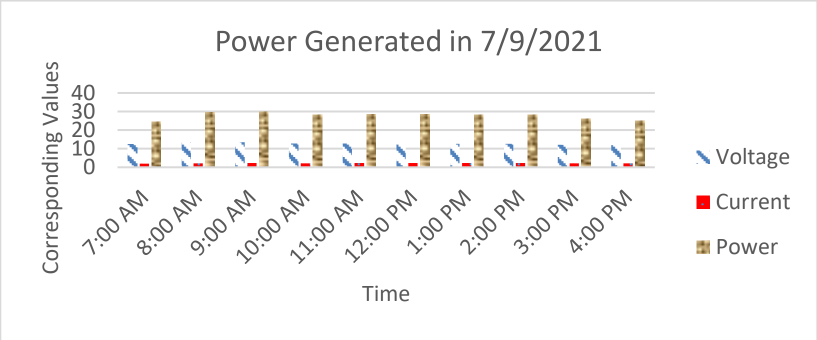

Figure 3. Generated power from PV on one day of the year

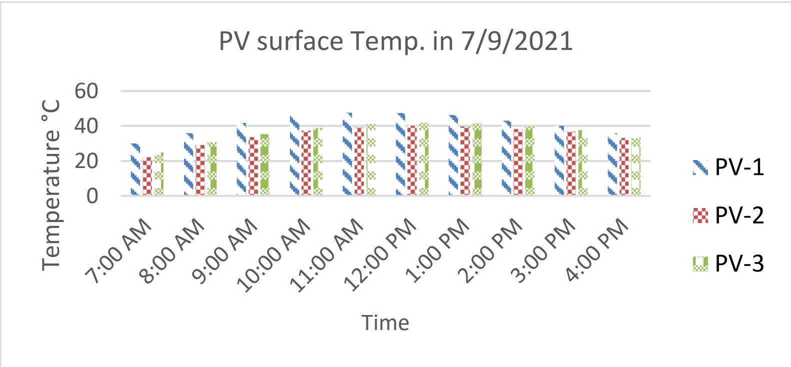

Figure 4. Temperature record for a given day as Arduino read

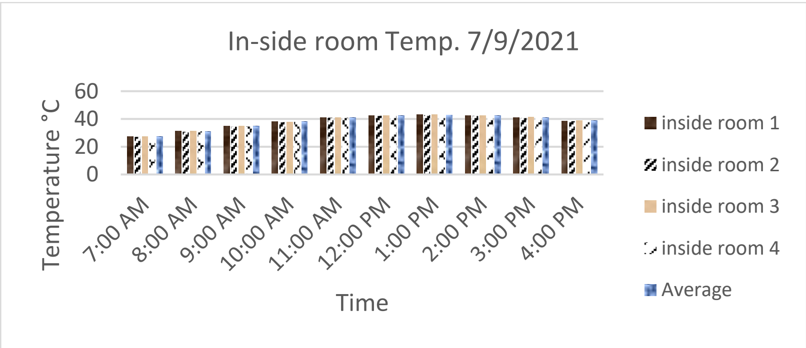

Figure 5. Inside room temperature for one day

3.2. Loads and cooling

Also, controlling the loads is one of the factors affecting the efficiency of the batteries first, and the solar panel used to generate electrical energy second. It is known that the electrical voltage generated by the solar panel and the energy stored in the batteries is somewhat limited and cannot be exploited continuously at the maximum load. Solutions to this issue have been developed within the Arduino program to control loads through software instructions, which turn off and operate the cooling fans according to the need of the board and according to the temperature recorded on its surface. As it is known for the topics of solar panels and their use for more than one purpose (electrical power generation and water heating), the maximum electrical voltage of the solar panel must be loaded to measure its efficiency and bearing loads.

In this work, more than part of the loads were connected to monitor changes in the project, loads from 50 watts to 80 watts were connected. According to the size of the board, of course, where the controller turns on the load before the date of recording the readings specified by the user and then turns it off after only five minutes, to preserve the battery level from loss and continue to work without causing any problems. By the same mechanism, the controller controls the work of the DC motor, which in turn is a load and cooling for the solar panel at the same time, as it pumps water along the back of the panel to absorb the heat generated as a result of converting solar energy to electric. If the engine continues to work, it will not be enough for an hour or two, but if the controller is present, there will be a working program, which is pumping water in a programmatic way that depends on the temperature of the panel and the daily timing between day and night. In this way, we achieve the principle of cooling the cell and getting its best performance with hot water on demand. The cooling diagram is shown in Figure 6 which illustrates the mechanism of the water flow through the controlled operated motor and then to PV and how to get hot water. The interfacing display for the Arduino gives messages for the instantaneous operation, recording data, the load is ON, fan is OFF and others, see Figures 7 and 8.

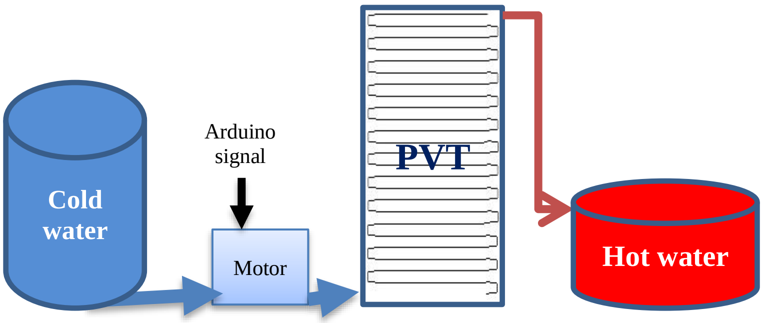

Figure 6. Cooling diagram for the proposed experimental module

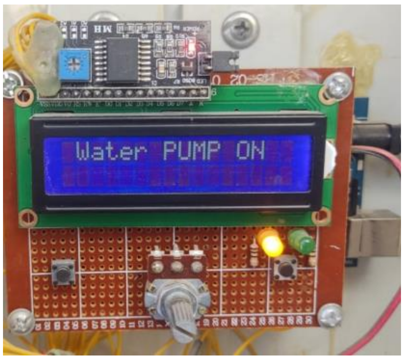

Figure 7. The water pump is ON

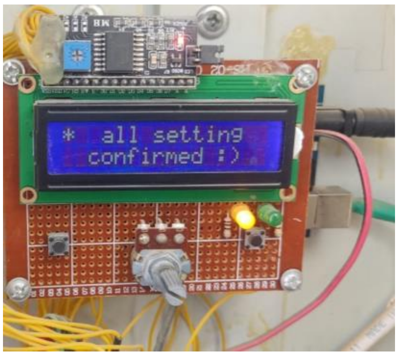

Figure 8. Module setting is ok

4. CONCLUSION

The used controller, an Arduino, is in charge of several operations, including controlling the solar panel's cooling device, reading and recording sensor data and storing it in RAM, controlling the orientation of the solar panel, controlling the vacuums, and regulating the on-off time of the motors. The findings show that by using sensor data, it is possible to keep the temperature constant during on-time while simultaneously preserving as much battery life as is practicable. The suggested module is an experimental workbench where authors and students can conduct several projects. In order to maintain the generated energy at specific times, the quantity of hot water and electricity may be simply determined. This module may be used to improve and regulate TW and PV system efficiency. Additional points may be involved in the proposed module, such as an online decision maker, automatic on-off door, and time schedule for the loads or pumps; all of the mentioned points can execute in future work. Long battery life, continuous hot water, improved PV efficiency, and simple data collection are the most important practical and satisfying goals of the proposed work.

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