Design and Construction of an Automated Energy Management and Data logging system for PCM based Solar Walls

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Abstract

Solar walls represent an important architectural feature that aids in the ventilation, heating, and cooling of buildings and thus contribute to significant energy saving. Appropriate energy management techniques need to be developed to control and optimize the performance of solar walls. The main scope of the research proposed in this manuscript is to investigate the thermal energy management capability of a PCM based solar wall. Phase I of this research consisted of the construction and testing of an automatic control system for efficient energy management of PCM based solar walls. This automatic control system will be used in the Phase II of this research project which involves design and construction of PCM based solar wall using macro-encapsulation technique. This manuscript focuses on the description of recently completed Phase I of this research, that is, the design, construction, and testing of a micro-controller based energy management system. This manuscript also describes a method of collecting and recording temperature data through data logging.

Keywords: Solar Wall, Phase Change Materials, Energy Management, Control System, Data Acquisition

1. Introduction

The use of Thermal energy systems (TES) to aid in the heating or cooling of buildings has become popular over the years. According to Niall, D. et al., "Over 60% of residential and almost 50% of commercial buildings use thermal energy." TESs seem to be the technological solution to the problem of high energy demand in buildings. To match the high energy demand of buildings, two main types of energy storage methods have been used, sensible heat storage and latent heat storage. Sensible heat storage, the most common thermal storage method, often uses water, stone, brick as the storage material while latent heat storage relies on the phase change of the storage material (usually solid-liquid) [1]. The thermal energy efficiency of a system can be increased by using latent heat storage [7]. Latent heat storage TESs use phase change materials (PCMs), which can be incorporated as a passive system in building walls, ceiling, and floors, or as an active system in separate heat or cold store [2].

PCMs are materials that store energy in the process of changing the aggregate state from solid to liquid [7]. In order for PCMs to be incorporated in a thermal energy system, they need to be encapsulated. The PCMs can be encapsulated in two different ways, microencapsulation, and macro encapsulation. Microencapsulation consists of inserting PCMs into microcapsules, which are " tiny particles of solid, liquid or gas with diameters smaller than 1 mm and larger than 1µm (ussualy5–10µm in diameter)[2]." On the other hand, macro encapsulation consists of inserting the PCM into tubes, spheres, panels or other container.

PCMs are commonly utilized in solar wall systems since solar walls allow for a very effective collection and storage of heat to be used in a "right way" [3]. Solar walls have been studied over the past years as a way of heating buildings from a renewable energy source, such as the sun [8]. Solar walls can offer feasible technique for the exploitation of directional flow of heat in buildings while reducing a building's energy consumption by 30% [5]. However, the performance of PCM solar walls can be negatively affected by several factors, such as overheating.

This paper describes micro-controller-based energy management system which can be used with a macro encapsulated PCM solar wall to prevent overheating of the PCM, assist with the storage and flow of heat within the air space, and increase the efficiency of the solar wall. Moreover, this paper reports a method of collecting and recording temperature data through data logging.

2. Design of a PCM solar Wall

The configuration of a PCM solar wall is based on the concept of a ventilated trombe wall. A ventilated trombe solar wall consists of a sun-facing wall to heat up air for ventilation, used to provide thermal energy to buildings [4]. A trombe wall involves several layers, such as a semi-transparent cover, a mass heating wall, a closed cavity, a ventilated air cavity, and an insulating panel. Figure 1, below, shows the configuration of a trombe solar wall.

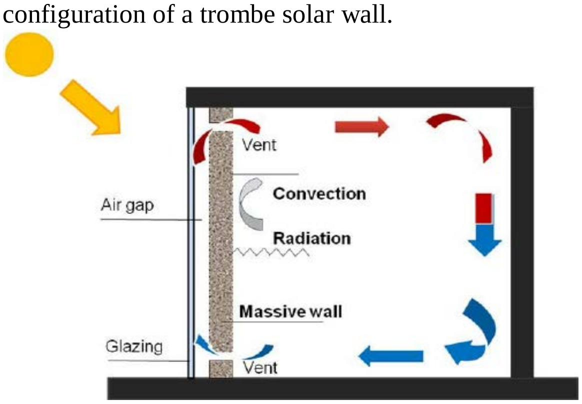

Figure 1. Trombe solar wall

In particular, the PCM solar wall used in the energy management system described in this paper consists of PCM plastic bricks, arranged in a 9x9 placement, that form the storage wall. The PCM bricks are covered by a single glazed aluminum sheet, which absorbs solar radiation during periods of sun. The airspace between the PCM bricks and the sheet of insulation is created by a cross flow electric fan placed at the bottom of the air gap. The sheet of insulation has two vents, at the top and bottom. Thermocouples, a temperature sensor, and other measurement devices are also incorporated in the air gap. Figure 2, below, illustrates the 3D model of the PCM solar wall.

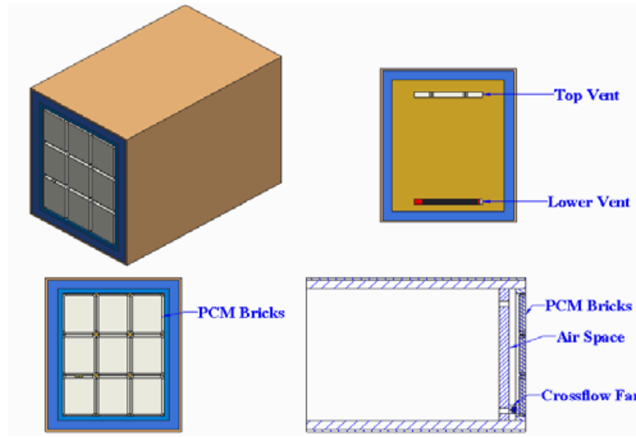

Figure 2. 3D Model of Solar Wall

Controlling the amount of energy collected, stored, and utilized is very important when working with solar systems. Appropriate energy management techniques need to be developed to control and optimize the performance of solar walls. Using fans in solar walls improves the efficiency of the vented solar wall by 8%, subject to size, thickness, color, wall materials, coating materials and glazing specifications of the solar walls [5].

The next section describes an automatic control system that uses energy management techniques to optimize and control the performance of solar walls. The design and construction of this automatic control system is part of a research project on PCM based solar walls that is being conducted at The Pennsylvania State University, Altoona College.

3. Automatic Control System

An automatic control system has been developed for the experimental set-up of a small-scale PCM solar wall that is located at the Altoona campus of The Pennsylvania State University. The automatic control system consists of a microcontroller, a temperature sensor, a fan and a servo. The function of the automatic control system is to prevent the PCM from overheating, assist with the storage and flow of heat within the air space and increase the efficiency of the solar wall. The microcontroller is used to read temperature from a temperature sensor on the PCM bricks. The servo acts as a vent to open and close the air space located at the top and bottom of the sheet of insulation. The fan is located at the bottom vent and acts as the cooling mechanism for the PCM wall and assists with the air flow from the air space into the room.

1. The Microcontroller and Temperature Sensor
A. Hardware

The TM4C123 microcontroller, shown in Fig. 3, controls the vent and fan systems. This Microcontroller was selected because it has 20 inputs/outputs and PWM capabilities. This microcontroller can also be interfaced easily and is relatively inexpensive.

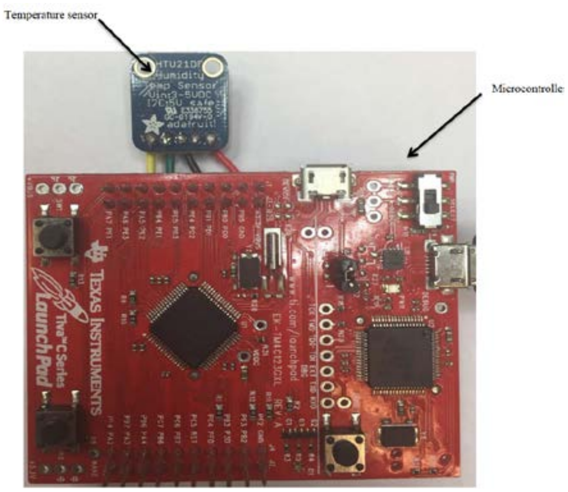

Fig. 3 TM4C123 microcontroller and HTU21D (F) temperature/humidity sensor.

In order to determine the state that the energy management system is in, a temperature reading must be taken for the wall. To do this, a HTU21D (F) temperature/humidity sensor was selected. This sensor was chosen because it has an operating range of -40 to 125 degrees Celsius. Since this experimental set-up will operate at temperatures close to or exceeding room temperature (21 degrees Celsius), the above mentioned sensor is an appropriate selection. This sensor can be read using the TM4C123 Tiva Launchpad. When the temperature is above a certain threshold, the servo will rotate 90 degrees opening a vent and the microcontroller will set a pin high which will then activate a transistor, which turns on the fan. This transistor is a TIP 120. There is a diode placed in between pin 2 and 3 as well as a 220-ohm resistor between the microcontroller output and pin 1 of the transistor. This circuit is made onto a printed circuit board, as shown in Fig. 4 below.

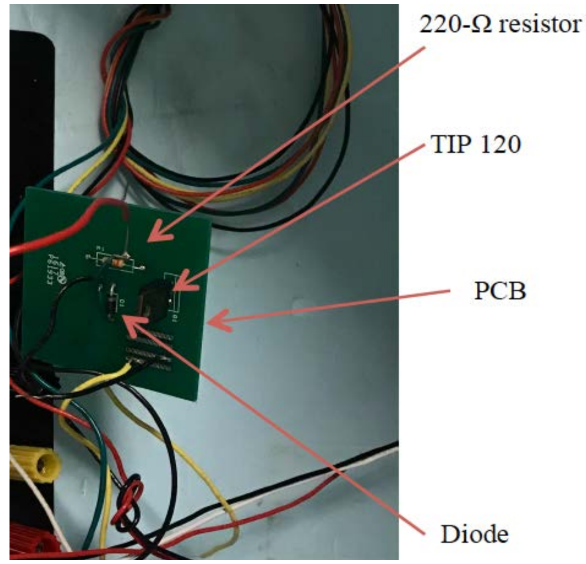

Fig. 4 Printed circuit board circuit.

B. Software

For the software used in the energy management system, the TM4C123 Tiva Launch pad was coded using Code Composer Studios 6.1.0. The system's purpose is to read a temperature from the HTU21DF temperature/humidity sensor, print the temperature reading into UART and view it using PUTTY, as well as use that reading to control an IF, ELSE IF statement: IF the temperature is above room temperature, 21 degrees Celsius, turn the motor on and move the servo 90 degrees; IF the temperature is less than room temperature, the servo will remain at the home position and the fan will be off. Fig. 5, below presents a flow chart that summarizes the microcontroller code.

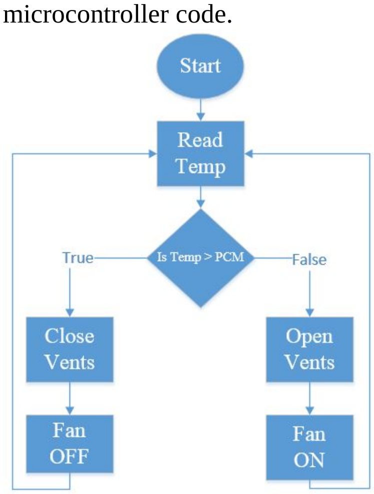

Fig. 5 Flow chart for the microcontroller code.

2. The Vent System

The vent system will allow for the heated airspace to store more heat until the PCM bricks heat up above the melting point. The vent system consists of two hinged vents, 22ga steel wire linkage, and a Futaba FP-S148 servo, as shown in Fig. 6.

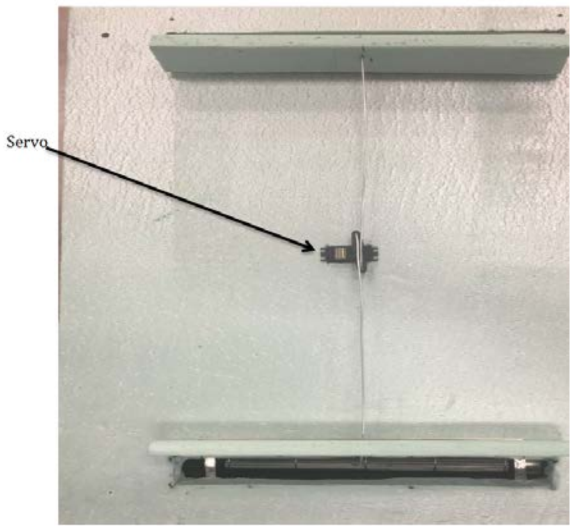

Fig. 6 Picture of the vent system

This servo has a torque rating of 33 oz-in at 4.8v. This torque rating will be capable of lifting the 2 foam vents, shown in the picture above. This servo is also a 180-degree servo and the PWM timing for the neutral position is 1.52ms. For this project, the servo is programmed to rotate 90 degrees. When in the home position, the vents will be closed. When in the on position, the vents will be open.

3. The Electric Fan

The electric cross flow fan is located behind the lower vent, as shown in Fig. 7 below. The fan will be used to assist the thermal air flow from the lower vent to the upper vent.

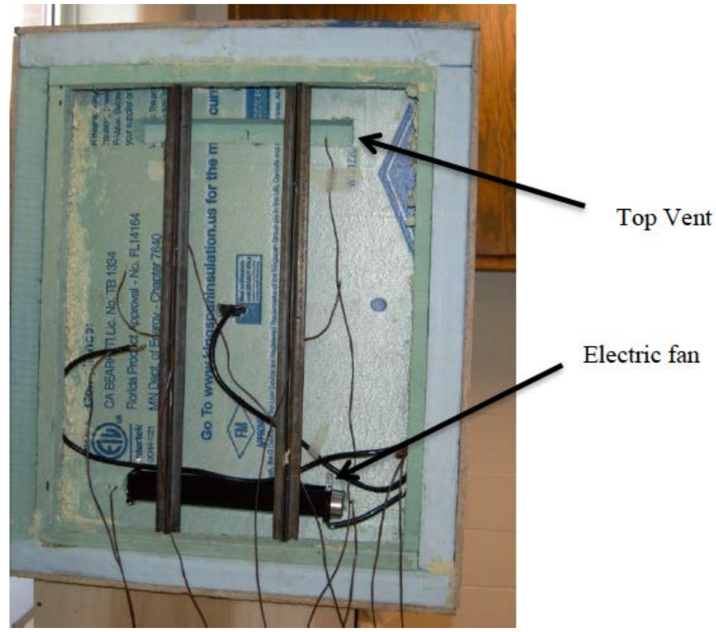

Fig. 7 Picture of the Electric fan in the experimental set-up

This fan is powered by a 12-volt power supply and is capable of an air flow rate of 36 CFM. This will provide more than enough cool air to cool the phase change material bricks and sufficient air flow to heat the room as well. When the fan is off and the vents are closed, the air gap will heat up as the PCM transfers energy into the insulated environment. When the air gap temperature is above room temperature the fan will turn on and the vents will open thus cooling the PCM and heating the room.

4. Data logging System

The data logging component of the system consists of a Lab Jack T7 pro, Mux80 AIN Expansion board, LabJack CB37, T-type thermocouples, thin film heat flux sensors, pyranometer, anemometer and NI 6009 DAQ. Ambient and surface temperature data are recorded using the thermocouples. The LabJack differential analog inputs are used to record the temperature difference between the Copper and Constantan wire. A 1 Mega ohm resistor is placed across the negative analog input to the GND pin of the LabJack. This is done to provide current generated from the negative analog input a path to the GND. The Mux 80 is an expansion board to provide 80 additional analog inputs to the LabJack. The CB37 is connected to the

MUX80 to create the input slots. Fig. 8 shows the data logging system components.

Fig. 8 Data Logging components

The data logger will log and store thermal energy data in an excel file so that it can be analyzed in the future. The software for the data logging includes Kipling, LabVIEW and Excel. Kipling is a free software provided by LabJack used to configure their devices. Using Kipling, the LabJack was configured to write directly to the LabJack differential analog registers on the CB37's connected to the Mux 80. Once the LabJack was configured, LabVIEW is used to read the differential analog inputs from the thermocouples. Fig. 9 shows the LabView code used to read the differential analog inputs.

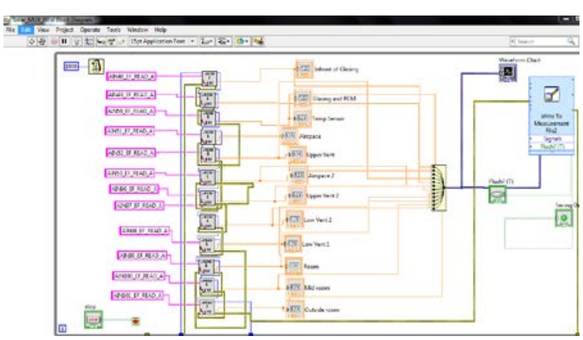

Fig 9. LabView code

Fig. 10 shows a block diagram of the entire system.

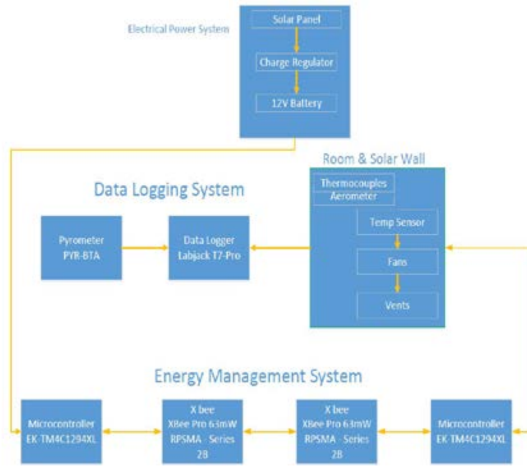

Fig 10. Block diagram of the system

5. Conclusions

In conclusion, both the data logging and the energy management systems will be incorporated in a solar wall located at The Pennsylvania State University, Altoona College as part of a research project on PCM based solar walls. The goal is to collect data that will help in the analysis of the performance of the solar wall. Thus, in the first stage, data will be collected on the solar wall system described in this paper. Eventually, a smart glass will be incorporated to the solar wall system and data will be analyzed again to determine the most efficient system.

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