Creation of a Small Scale Zero Energy Building

Ashley Thompson, Wes Gibson, and Chuck Margraves
University of Tennessee at Chattanooga

Abstract

The work presented in this paper details the creation of a small scale model, designed and built by a senior capstone design group, which simulates several attributes of a Zero+ Energy Building (ZEB). This model included a small solar array used to charge a Lithium Ion (LI) Battery, a set of strip heaters designed to hold a set point above the ambient temperature, and removable insulation to demonstrate the increase in consumed power when poor insulation is present. Instrumentation was also added to the small scale model that was capable of monitoring both power consumption by the building and power generation from the solar panels. Finally, a controller was implemented that was capable of wirelessly transmitting the data to a website set up by the students. The completion of this work has provided an excellent demonstration model that can be set up in both middle and high school classrooms.

Keywords

Zero-Energy Building, Sustainability, Efficiency

Introduction

The goal of this project was to create a model of a Zero + Energy Building (ZEB) capable of effectively demonstrating ideas of sustainability to both high school and middle school students. Our working definition of a ZEB is a structure that generates more electrical energy, through renewable energy sources, than is consumed by the building itself. This work stems from two previous projects, one focused on examining the heat transfer through various materials using thermal imaging cameras and a second that examined solar tracking efficiency.[1,2] The model presented in this paper consisted of a small dollhouse like structure whose internal temperature was controlled by the use of two strip heaters. These heaters were powered indirectly by solar panels through the use of a Lithium Ion battery. The house was also equipped with removable insulation to demonstrate the increase in required load when poor insulation was present, as well as several monitoring devices that helped demonstrate the effectiveness of the building.

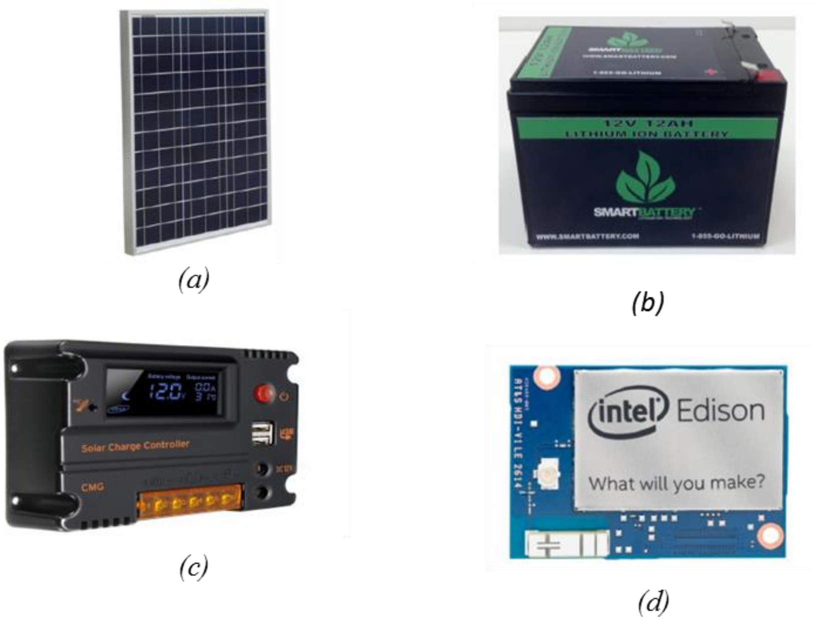
Apparatus

The model house, shown in Figure 1, has a footprint of 12 inches by 18 inches, and a wall height of 15 inches. Easily removable insulation was installed on the four vertical walls with permanent insulation applied to both the top and bottom surfaces. The main physical structure was built using quarter inch thick medium density fiberboard (MDF) with a thermal conductivity value of 0.3W/m$*$K. All insulation used in the small-scale building was one-half inch thick foam board with an R-value of 0.6164m^2*K/W. This insulation was chosen due to its ease of handling and compact nature.

Figure 1: Physical Model of the House on Platform

In order to determine the overall load for the house, a baseline temperature difference was set between the interior and surroundings of 10^oC. A one dimensional heat transfer analysis was then conducted using Fourier's Law for conduction, to estimate the expected heat loss. Initially all walls were considered insulated and the calculations were completed. Next a situation was considered in which the insulation was removed from a single wall. While testing would be conducted for complete insulation and no insulation, sizing was done for what were considered more realistic circumstances. For case one, the power requirement to maintain the internal temperature was calculated to be 2.53 Watts, while case two resulted in a substantial increase of 24.63 Watts. This order of magnitude change provides clear evidence to students on the importance of choosing effective insulation.

The main components of the electrical system included a solar panel, an Intel Edison Controller, two 20 W heating elements, a charge controller, power meters, and a 12 V battery. The solar panel, controllers and battery are shown in Figure 2 below. The solar panel chosen was capable of producing 50 W of power in full sunlight and at the proper angle for the corresponding time of day. This was selected to ensure that more power is available to the system than the system required, as determined by the initial heat transfer analysis. The selected solar panel was an Eco-Worthy polycrystalline panel that requires direct sunlight for sufficient operation. It is not possible to output power using an artificial light source as originally planned; thus, the solar panel had to be placed outside with a cord running inside to the connection on the charge controller.



(a)

(b)

(c)

(d)

Figure 2: (a) Polycrystalline solar panel (b) Lithium Ion Battery, (c) Charge Controller (d) Intel Edison Controller

The charge controller for this system serves multiple roles. First, it protects the solar panel from reverse current flow and protects the battery from undercharge or overcharge by regulating incoming power. Next, it gives a visual representation of the power, voltage, and current going from the solar panel to the battery and from the battery to the load while testing. Additionally, it enables the user to stop and start output to the heaters with the touch of a button. Finally, the charge controller directs power to the load when the battery is fully charged and the solar panel is delivering power, and it also directs power from the battery to the load when the solar panel is not producing power. The charge controller is a 20 A, 12 V Moohoo Autoswitch LCD Intelligent Charge Controller, connecting directly to the battery and the load.

The Smart Battery 12 V 12 AH Lithium Ion Battery with a capacity of 144 W was chosen for this project because it is a deep cycle battery, which enables a large amount of storage and very long battery life. This was necessary since the battery is the primary source of power to the heating elements and the other electrical components in the system. To power the electronics using this battery, a 50 W DC-DC converter was used which was capable of converting an unstable 8 V to 40 V DC power supply into a stable 5 V 10 A DC power output.

The Intel Edison controller selected for this project is a system-on-a-chip (SoC) microarchitecture, which includes built-in Wi-Fi, Bluetooth LE, memory, and onboard storage. This system runs an Intel Atom processor and is designed as an Internet of Things device which requires very little power. This controller interfaces with an Arduino-Edison breakout board that has I/O connection points as well as communication terminals for the I2C communication. The system controls the internal temperature of the house by monitoring internal house temperature and comparing it to the ambient air temperature. The Intel Edison regulates power flow to the heating elements by toggling an onboard relay to keep the house at the specified temperature. Both Wi-Fi and Bluetooth LE are used to display data on a remote server through Ubidots.

The Intel Edison measures power into the house by connecting to an INA219 power sensor using I2C communication protocol. The INA219 is onboard an Adafruit INA219 Current Sensor Breakout capable of measuring up to 26 V at +/- 3.2 A. The INA219 is configured through software, and there is one INA219 sensor located inside the house. The Intel Edison determines temperature by connecting to two MCP9808 temperature sensors to the system. The MCP9808 sensors communicate with the controller via the I2C communication bus. The MCP9808 is a High Accuracy Digital Temperature Sensor that has a precision to 0.0625 ^{O}C, exceeding the 0.1 ^{O}F accuracy necessary for this project. Finally, the controller toggles a relay to pass power to two UXCELL 12 V, 20 W heating elements, which have a maximum service temperature of 200 ^{O}C.

To simulate an actual residence and clean up the look of the physical model, a small shed and surrounding green space were created (Figure 3) to help hide the electrical components. The house and electrical components reside on a 2.5 feet by 3 feet platform made of medium density fiberboard. As shown in Figure 3, the platform has a permanent setting for the house on one side with the shed sitting at the back of the main structure. This provides a neat presentation piece and ensures that the electronics are protected from accidental damage when transporting the system or making modifications to the insulation for testing.

Figure 3: Shed and External Wiring

Testing

After confirming that all systems were functioning properly, a set of transient response tests were completed. Initially, the insulation on each inside wall was removed and the heaters were set to their maximum power output of 17 Watts (34 total Watts). An average interior temperature was taken from four different thermocouples that were uniformly distributed at the midpoint of the interior. A fifth thermocouple was used to determine the surrounding temperature (exterior to the box), and the test was completed when the temperature difference reached 10°C. For the second test, all of the insulation was reinstalled, and data was taken for the same time interval as the first test. Figure 4 shows the results of these tests. For the non-insulated test the time to reach the 10°C temperature difference was approximately 30 minutes while the insulated test took only about 6 minutes.

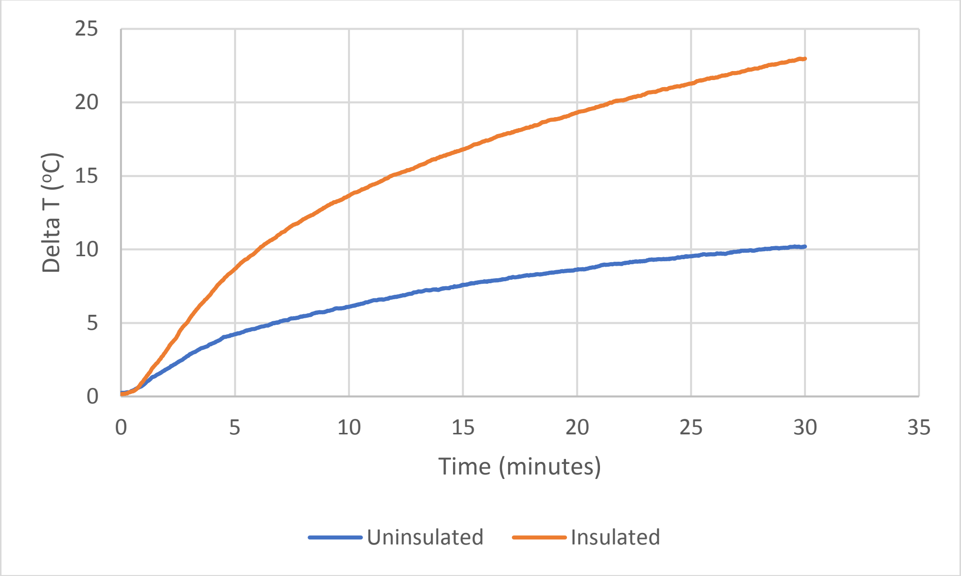


Figure 4: Insulated versus uninsulated transient response

The next set of tests were completed under steady state conditions. Because the temperature of the heaters at max power was deemed unsafe (well over 120°C) the power was reduced to 6, 10 and 20 Watts for the subsequent tests. For each of the chosen input power settings, a fully insulated case was conducted as well as a non-insulated case. The test was allowed to run for approximately eight hours with the temperature checked at various times to insure steady state conditions had been reached. Table 1 shows the temperature difference between the interior and exterior of the house for each case as well as the percent difference between the insulated and uninsulated cases.

Table 1 – Insulated Versus Uninsulated Steady State Temperatures

Temp. Difference (°F)	6 Watt Heater Input	10 Watt Heater Input	20 Watt Heater Input
Insulated	10.73	13.98	23.60
Uninsulated	6.76	8.56	9.27
Percent Difference	37	39	61

As observed in the table, the uninsulated case provided a significantly smaller temperature difference than the insulated case under the same power input. It was also demonstrated that as the power to the heaters is increased, the percent difference between the two conditions increases non-linearly.

Conclusions and Recommendations

The completion of this work has resulted in a fully functioning model of a Zero + Energy Building that is small enough to demonstrate at area high school and middle schools. The model is also capable of demonstrating the effects of poor insulation through both transient and steady state testing. For future work, a complete computational fluid dynamics model is being built in an attempt to match the experimental work. This would be used to demonstrate to students how engineering modeling can be leveraged to improve designs before incurring the cost of manufacturing and testing.

Name of the paper's First Author

Ashley Thompson is a recent honors college graduate from The University Of Tennessee At Chattanooga. She completed her BSME degree in May of 2017 and graduated Magna Cum Laude. She is currently working as a Production Engineer at Denso Manufacturing.

Name of the paper's Second Author

Wes Gibson is a senior mechanical engineering student at The University Of Tennessee At Chattanooga. He is scheduled to graduate in the spring of 2018.

Name of the paper's Third Author

Dr. Chuck Margraves is a UC Foundation Assistant Professor of Mechanical Engineering at the University of Tennessee at Chattanooga. His current research focus is on STEM Education, particularly in the area of energy sustainability, at the collegiate and high school levels.

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