

Temperature Profiles of Loomis Laboratory of Physics

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Abstract

In this paper we discuss the measurement of temperature profiles of Loomis Laboratory of Physics. We created four temperature-sensing devices with which we measured temperature both within and outside the building. Inside Loomis, we measured the temperature of Loomis lecture hall 141 as it related to height and time. Outside Loomis, we measured how much heat was escaping through different parts of the building. Our data inside showed temperature of the lecture hall varied with traffic flow of students, and our data outside was inconclusive due to unaccounted effects of emissivity.

Introduction

Environmental sustainability has been of growing interest in the past decade. Improving the efficiency of facilities, such as central heating, is both environmentally and economically sustainable. In our 398 Design Like a Physicist (DLP) course taught and led by Professor George Gollin, we had the opportunity to test the efficiency of a couple of the facilities in Loomis Laboratory of Physics. The issues we looked into were the building temperature control systems and insulation.

The temperatures in the building are monitored by thermostats and the lecture halls are temperature-regulated accordingly. Our concern pertained to the distribution of the heat throughout the building, specifically in the large lecture hall, Loomis 141. Excess energy may be used in an effort to heat the cooler parts of the lecture hall, while heat may be accumulating uselessly in other locations. This type of heat distribution problem could be easily solved with a large fan or some other type of air circulation system.

The efficiency of a heating system is defined as the ratio of heat needed to achieve a comfortable temperature in classrooms to the total heat generated in a building. Maintaining a high efficiency is a problem many institutions face during the winter months in the Midwest. Much heat can be lost through doors and windows of a building, driving up the cost of heating. Loomis is surrounded partially by windows in addition to a brick exterior and multiple doors. Insulating glass could be a solution to heat lost through the windows. While the installation could be costly, depending on the amount of heat lost through these windows, the university could save costs over time.

Data temperature are taken everyday by the thermostats in Loomis 141. These data were sent to us by the facilities manager of Loomis Jerry Cook. The following figure shows the temperature as a function of time over a week. This data set has only one measurement per hour and therefore does not give very much information about how well heat is monitored in the lecture hall. The time period for this graph is November 26, 2018 to December 3 2018, we took our data on November 29, 2018.

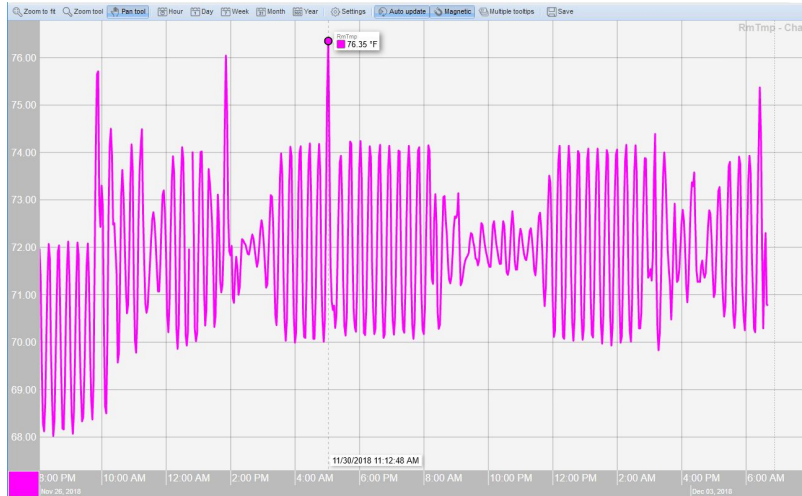


Figure 0.1: Data taken from the thermostat in Loomis 141 over the week of November 26, 2018. Y-axis is the temperature in fahrenheit, and the x-axis is the time.

1. Device

1.1 Boards and Sensors

Many devices were used in our data acquisition. On each device, we used multiple sensors mounted on breakout boards manufactured by Adafruit Industries, and an Arduino Mega 2560. The components were assembled on both breadboards and printed circuit boards (PCB). A total of four devices were created. The breadboard devices were constructed by soldering each sensor to header pins which fit into the breadboard in order to create circuits. We created additional devices using PCBs printed by Chicago Circuits and layout designed by Professor George Gollin. The individual components were soldered onto the PCB. Each device includes a BME680 temperature sensor, an infrared (IR) sensor, a current sensor, a liquid crystal display (LCD), a real-time clock and a microSD card breakout board.

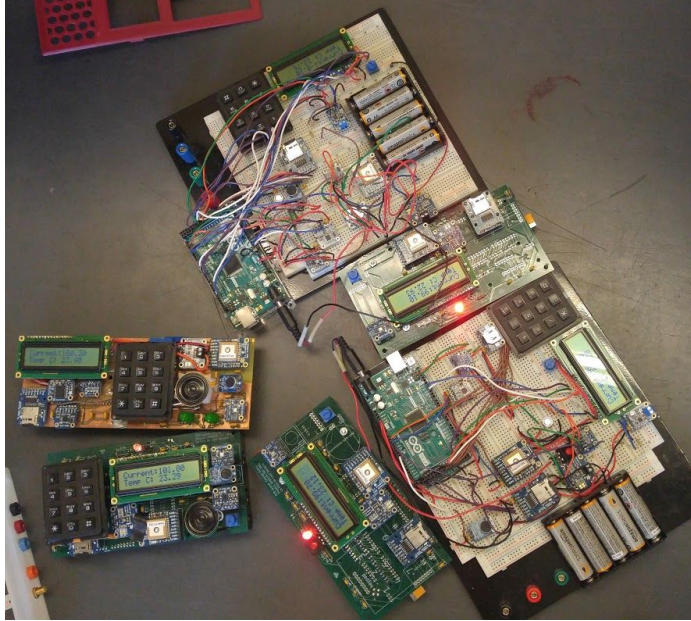


Figure 1.1: Photograph of the four created devices, and two additional devices on loan to us from Professor George Gollin, from above. The two larger square devices are the breadboards and the smaller rectangular devices are PCBs.

The BME680 sensor performs a variety of measurements with great accuracy. These include ambient temperature, humidity, barometric pressure and volatile organic compounds gas sensing capabilities. In our project, we mostly used this sensor for the ambient temperature readings. Ambient temperatures are defined as the temperature of the device.

We also used an IR sensor for temperature readings. The infrared spectrum is invisible to the naked eye, and includes wavelengths from 700 nm to 1 mm. The MLX90614 non-contact sensor measures the infrared light observed from objects in order to gauge their temperature. The sensor assumes all the light observed was emitted from the object, and none was reflected off. The resulting temperature is representative of a back body with the observed emission; this temperature reading is referred to as the “object” temperature. The IR sensor also takes an ambient temperature reading. Together, the IR sensor and the BME680 sensor give us a range of temperature measurements.

The microSD card breakout board allows us to record the measurements from our device. The microSD card fits into the breakout board and measurements can be saved onto a file on the card. When the SD card is removed from the device, the data is saved and can be interpreted later on a computer. The device can also print data onto an LCD in real time which allows us to ensure the device is working correctly.

Other important sensors the devices utilize are the DS3231 real-time clock and the INA219 current sensor. The DS3231 contains a back up battery which keeps the time extremely accurate over long periods of time. The INA219 current sensor breakout board was used to

monitor the current produced by the battery pack. By connecting the battery pack first to the current sensor, then to a switch, before connecting to the MEGA Arduino 2560, we were able to turn the power on and off without removing the batteries [1].

A Mega Arduino 2560 was used for communication between the difference sensors. Arduino is a company that produces open source device with easily programed hardware and software. The Mega Arduino uses an ATmega2560 microcontroller which is preprogrammed with a bootloader meaning the microcontroller does not need external hardware to upload new code [2]. To communicate, the Arduino mainly relied on inter-integrated circuit (I2C) communication protocol. I2C allows a master (the Mega Arduino 2560) to communicate with multiple slaves (the sensors) concurrently. This communication protocol only needs two lines to transfer data, a serial clock for synchronization, and a serial data line for transmitting the actual data[3].

The MEGA Arduino 2560 was programmed using an integrated development environment contained in an application called Arduino. The Arduino application uses built-in functions and a modified version of C++. We created a data acquisition code on this application which collected data from the sensors and printed it to the micro SD card. The data was saved in a comma separated variable (csv) formatt for straightforward data analysis. In addition to writing to the SD, the code also printed to the LCD. The LCD printed the current from the INA126, and the temperature from the BME680. These displayed values were to ensure that the code was running smoothly.

1.2 Calibration

Many of our devices were factory calibrated, but we made sure to run tests of our own to ensure the data we would be collecting would be accurate. The IR object readings are most sensitive. The IR object readings require no equilibration time, as the readings only depend on the collected available light. The ambient temperature readings took more time to equilibrate. However, since the ambient temperature does not make a black body assumption, these data are more accurate. We timed the IR sensor ambient readings, and the BME680 readings took about 12 minutes to stabilize. The real-time clock was calibrated using code downloaded from the adafruit website. After running the code, the time was accurate to a few milliseconds. The only time we had to recalibrate the real-time clock was for daylight savings time.

Before analyzing the data, we calibrated the BME680 sensors. In order to do this, we ran six of these sensors for half an hour and analyzed their outputs. We found that the sensors are fairly consistent in their readings with some offset between different sensors. We corrected this offset by averaging the six temperature readings in order to calculate an average temperature as a function of time. For each sensor, we then calculated the average distance from this calculated average temperature for each sensor. The values of these distances are recorded in Table 1. We modified the readings from each sensor by adding the respective distance to that measurement.

We also calculated the root mean square (RMS) values for each corrected temperature reading from the calculated average using the following equation. These are also recorded in Table 2.

$$RMS = \sqrt{\left\langle (T' - T_{avg})^2 \right\rangle - \left\langle (T' - T_{avg}) \right\rangle^2}$$

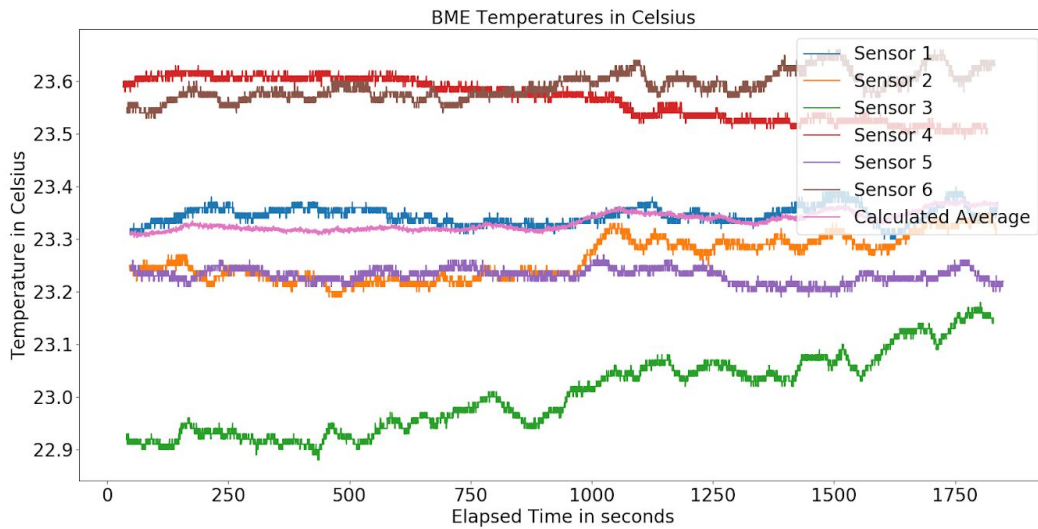


Figure 1.2: Temperature readings over half an hour from six BME680 sensors running in the same room.

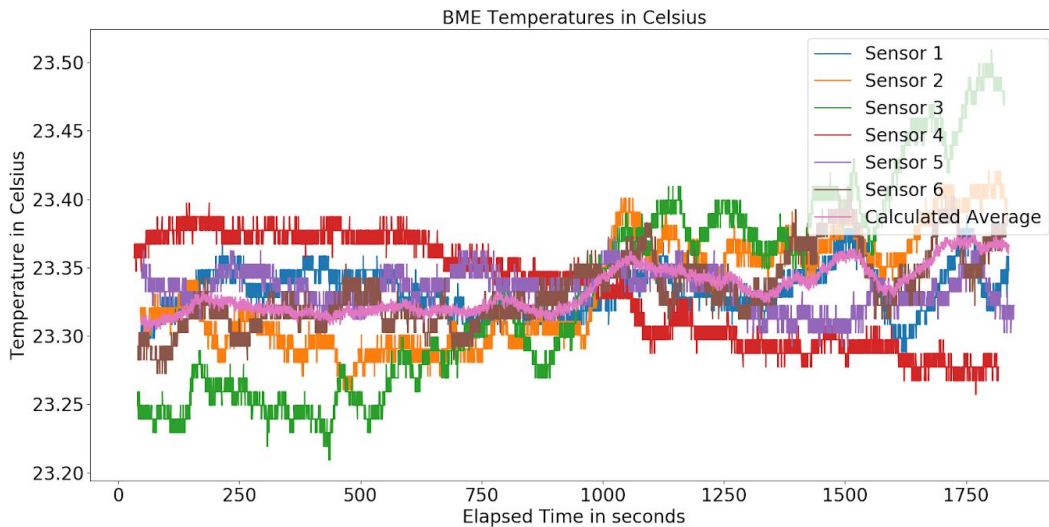


Figure 1.3: Modified temperature readings for the data plotted in Figure 1.2 after correcting the average temperature offset of each devices.

Sensor	Average Distance from Calculated Average Temperature	Root Mean Square Value
1	-0.0116859903382	0.0182753042149
2	0.0705942028985	0.0252187766847
3	0.329208695652	0.058751121592
4	-0.232806763285	0.05252697814
5	0.102256038647	0.0222151059809
6	-0.257566183575	0.0152955073159

Table 1: Average distances from calculated average temperature and RMS values for six BME680 sensors.

2. Methods

2.1 Temperature Profile of Lecture Hall 141

Our first project was creating a vertical temperature profile in the largest lecture hall in the building, Loomis 141. We collected temperatures over an eight and a half hour period from five devices placed at various heights in the lecture hall. Data were taken as fast as the device would allow, which was around three points per second. Two of the devices were attached to the wall near the floor, just under the chalkboards where the lecturer stands. We hung the remaining three devices from a chain attached to the ceiling. The highest device was at the ceiling height, approximately 16.5 feet above the floor. The next hung three and a half feet below at about 13 feet above the floor and the last device at about 6 feet above the floor. The figures below illustrate the locations of all the devices. The devices ran from 8:00AM to 4:30PM as classes were ongoing and students were frequently walking in and out of the lecture hall.

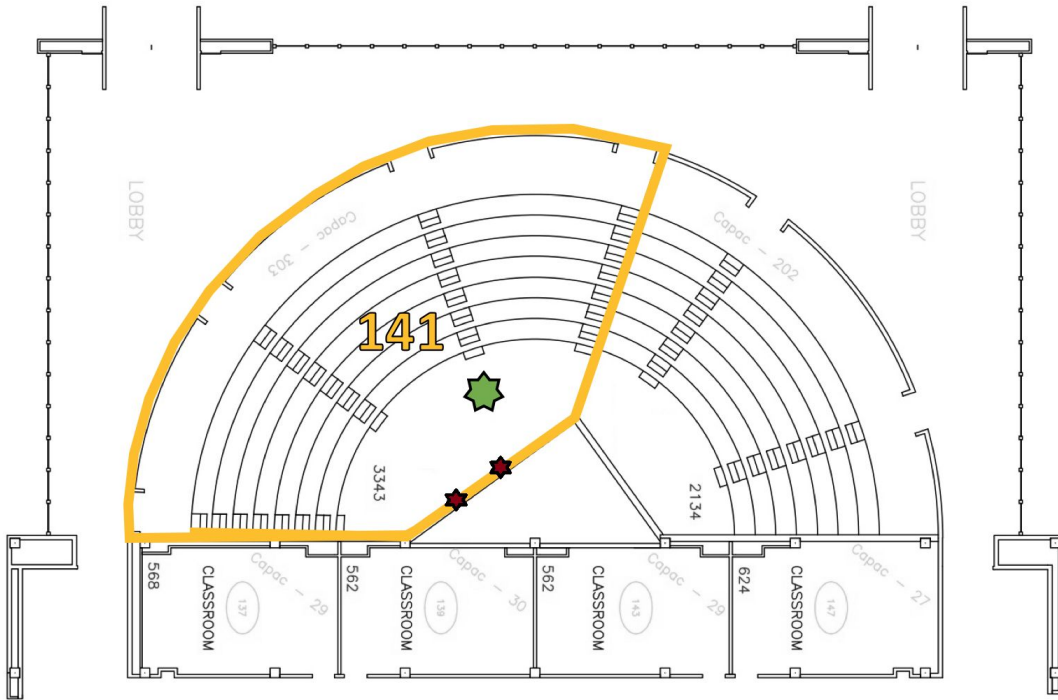


Figure 2.1: Lecture hall 141 in Loomis Laboratory of Physics. Green star represents the chain of devices, and the two red stars represent the devices near the ground.



Figure 2.2: Photograph of the devices hanging on the chain in Loomis 141

plotted the data from the files using the pyplot library and used the datetime library to print the time and dates on the various plots.

3. Results

3.1 Temperature Profile of Lecture Hall 141

The results from our data collection on November 29th are shown in Figure 3.1 below. The results were not what we had initially hypothesized. The temperature of the room had some variance in height, but the biggest change in heat came from the students filling and emptying the lecture hall.

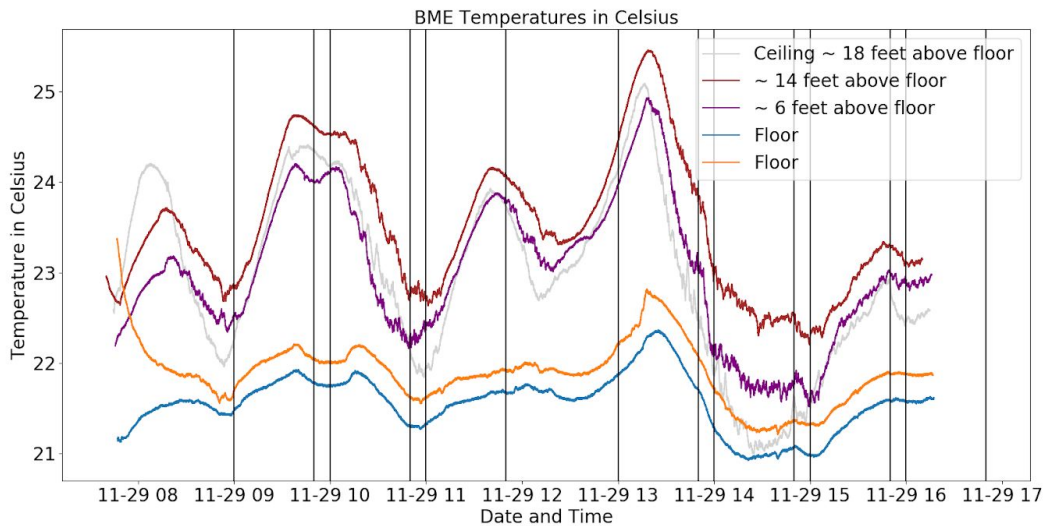


Figure 3.1: Temperature of Loomis 141 measured at different heights over the course of eight and a half hours. Data were taken from the BME680 sensor, and were calibrated using the results from section 1.2.

As seen from the data set above, the fluctuations in heat occur when there is a class in the room. The heat rises with the body heat of the students populating the room. The temperature rises, then stays high until the class ends and the students leave or the heating system turns off. In figure 3.1 above, the lines represent when classes end and begin. Every Tuesday, there are classes from 9:00 am to 9:50 am, 10:00 am to 10:50 am, 11:00 am to 11:50 am, 1:00 pm to 1:50 pm, 2:00 pm to 2:50 pm, 3:00 pm to 3:50 pm, and 4:00 pm to 4:50 pm. These classes tend to mostly fill the lecture hall. In the figure, the slow rise in the temperature is caused by the equilibration time of the BME680, and the time needed for the body heat of the students to equilibrate with the temperature of the room.

The two devices on the floor were placed behind a lab table against the wall. It is unlikely that the temperature difference between these devices and the ones hanging from the chain was

caused by height. The drop in temperature could possibly have been caused by drafts along the walls, or shielding from the body heat of the students.

It is possible that the device closest to the ceiling was a lower temperature as a result of the opening in the ceiling. The room above the ceiling as slightly cooler than 141, and most likely there was a draft which cooled down the temperature of the device.

3.2 Heat release through glass windows and doors

The following plots are representative of two of our data runs. The graphs represent the temperatures measured by the IR sensors outside of the windows, doors and walls of the building over a ten minute period. The first day we took data, November 7, was a sunny day and the outside temperature was about seven degrees Celsius. On the next day, there were more clouds and the temperature was about six degrees Celsius.

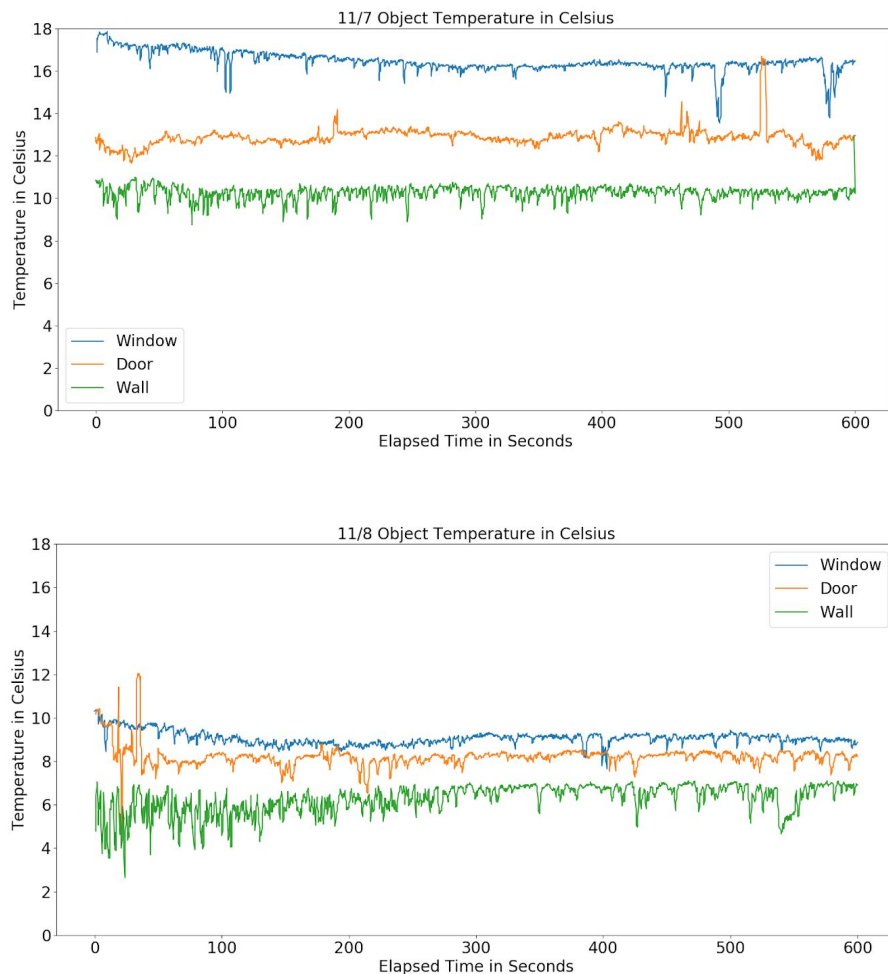


Figure 3.2: Temperature of the exterior of Loomis measured in celsius over the course of ten minutes on November 7th and 8th 2018. Data is the object reading of the IR sensor.

The data show the effect of sunlight on the IR sensor readings. During the sunnier day, the measured temperature outside the reflective window surface is as high as eighteen degrees Celsius, over ten degrees higher than the actual outside temperature. On the cloudy day, the measured temperature outside the window is still significantly warmer than outside the wall. The measured temperature outside the glass door is also higher than the measured temperature outside of the wall. Although the IR sensor data shows an extremely clear difference in temperatures by location, we feel these data cannot be interpreted because of the issue of emissivity. Emissivity is the property of a material that defines the ratio of the material's radiated light to that of a black body[4]. Since the IR sensor interprets observed light only as emitted light, it ignores the contribution of emissivity. The temperatures outside of the windows and the doors may be higher than in front of the walls as a result of heat leakage. However, we cannot make this assumption because it is also possible that the glass is reflecting more light due to its higher emissivity value, leading to a higher temperature reading.

Conclusion

While our project about the insulation of Loomis was inconclusive, we believe that our data on the lecture hall 141 had some conclusive results. Based on our data, the heating cycles of the lecture hall could be managed to account for expected rises and falls in temperature. When the students enter the hall and the heat rises due to their body temperature, the heat generation should decrease. An improvement to heating cycle would increase the efficiency of the building because heat would only be generated when needed as opposed to all day long or on a random cycle. Not running the heat as often would lower the cost of the power bill for Loomis and be more environmentally friendly. To make our outdoor data more conclusive, we plan to run tests on the emissivity of the glass, brick, and doors. Once we can ensure that our results are not skewed by the emissivity, we will be able to predict how much heat is lost through the exterior of Loomis.

References:

1. <https://www.adafruit.com/>
2. <https://www.arduino.cc/>
3. <http://www.circuitbasics.com/basics-of-the-i2c-communication-protocol/>
4. [http://www.npl.co.uk/reference/faqs/what-is-emissivity-and-why-is-it-important-\(faq-thermal\)](http://www.npl.co.uk/reference/faqs/what-is-emissivity-and-why-is-it-important-(faq-thermal))