University of Utah Environmental Fluid Dynamics Lab
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PHFS-01 Project Summary
August 21, 2019

Overview:

The PHFS-01 is a low-cost heat flux sensor manufactured by Fluxteq LLC. The EFDL is interested in utilizing this sensor to measure heat flux through the walls of buildings. In realistic conditions, heat flux in (or out) of buildings is rarely more than 150 W/m^2. With a sensitivity of 8 $\mu V/(W/m^2)$, the expected signal at any given point is a fraction of a millivolt. Fluxteq offers a high sensitivity amplifier/logger to work alongside this sensor. However, each unit is over $400 and not feasible for widespread data collection. This introduces my goals at the lab…

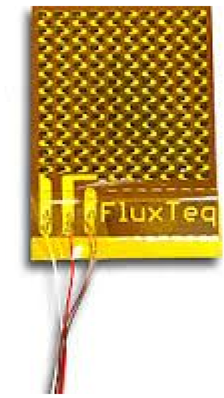
1) Measure, log, and verify the voltage differential across the PHFS-01 in a cost-effective manner.
2) Draw a heat flux reading from the voltage differential, and compare this measurement with expected heat flux values in experimental conditions.

In order to measure the voltage difference across the PHFS-01, I used the MAX31856 Thermocouple Amplifier. Adafruit supplies a low-cost breakout version of this chip with noise-filtering, an on-board 18-bit ADC, and SPI capabilities to communicate with Arduino micro-controller. I compared the performance of this chip with a Campbell CR5000 data logger to verify it's accuracy.

Though I built two variants of a constant-flux test apparatus, I was unable to find results with the PHFS-01 that were consistent with the expected flux. The reason for this should be explored further before the PHFS-01 can be used as a reliable data source.

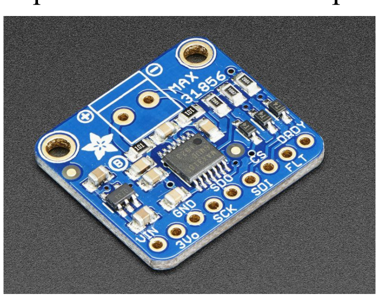
PHFS-01:

The PHFS-01 is a thermopile sensor used to measure heat flux (W/m^2). Along with the heat flux sensor is an encased type-T thermocouple. The datasheet and user manual are in the GitHub address found at the end of this document.



Approximate Sensitivity: 8 µV/(W/m^2)
Temperature Range: -50 C to 120 C
Heat Flux Range: +/- 150 kW/m^2

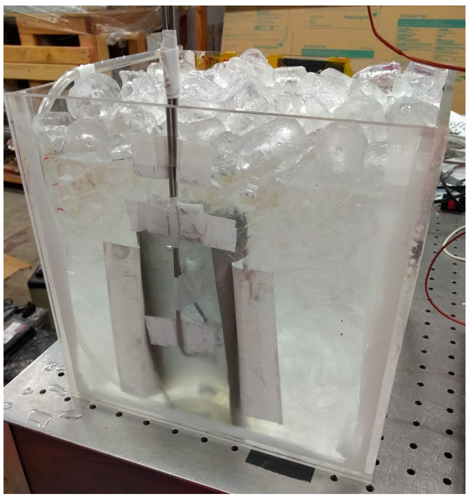
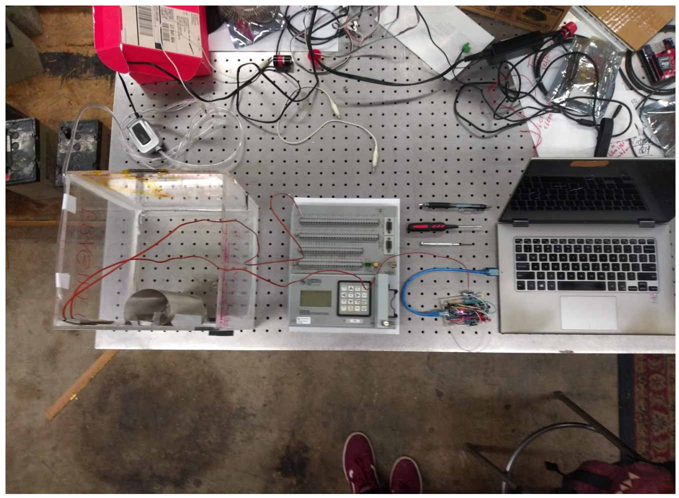
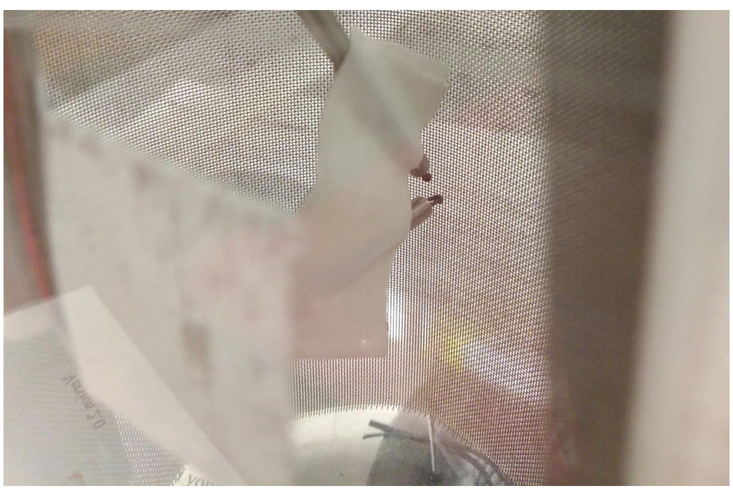
Description of MAX31856:
This IC is designed to measure a thermocouple voltage differential and output a digitized temperature signal. However, it does have two "voltage modes," in which the differential is amplified by either 8 or 32. Adafruit provides a hookup and code tutorial for basic use, but in order to read a voltage differential from the temperature-formatted register, a conversion factor is required. Refer to the sample code in the EFDL PHFS-01 GitHub.



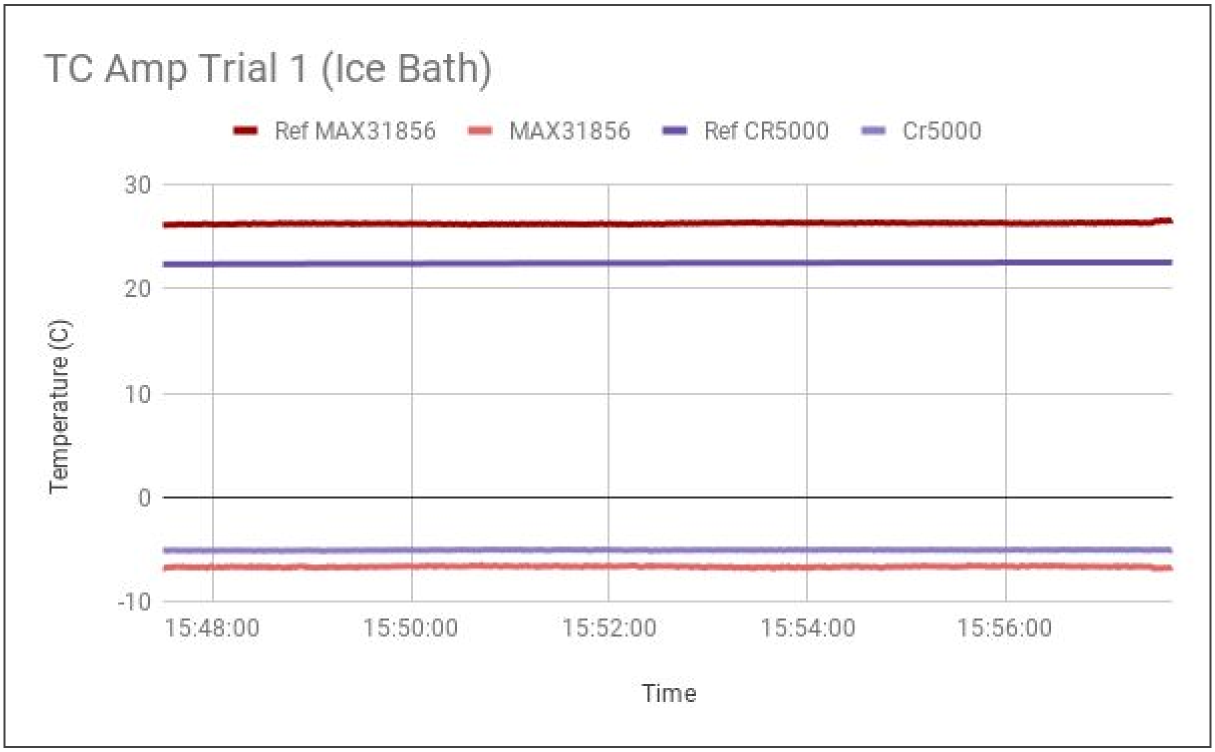
https://learn.adafruit.com/adafruit-max31856-thermocouple-amplifier

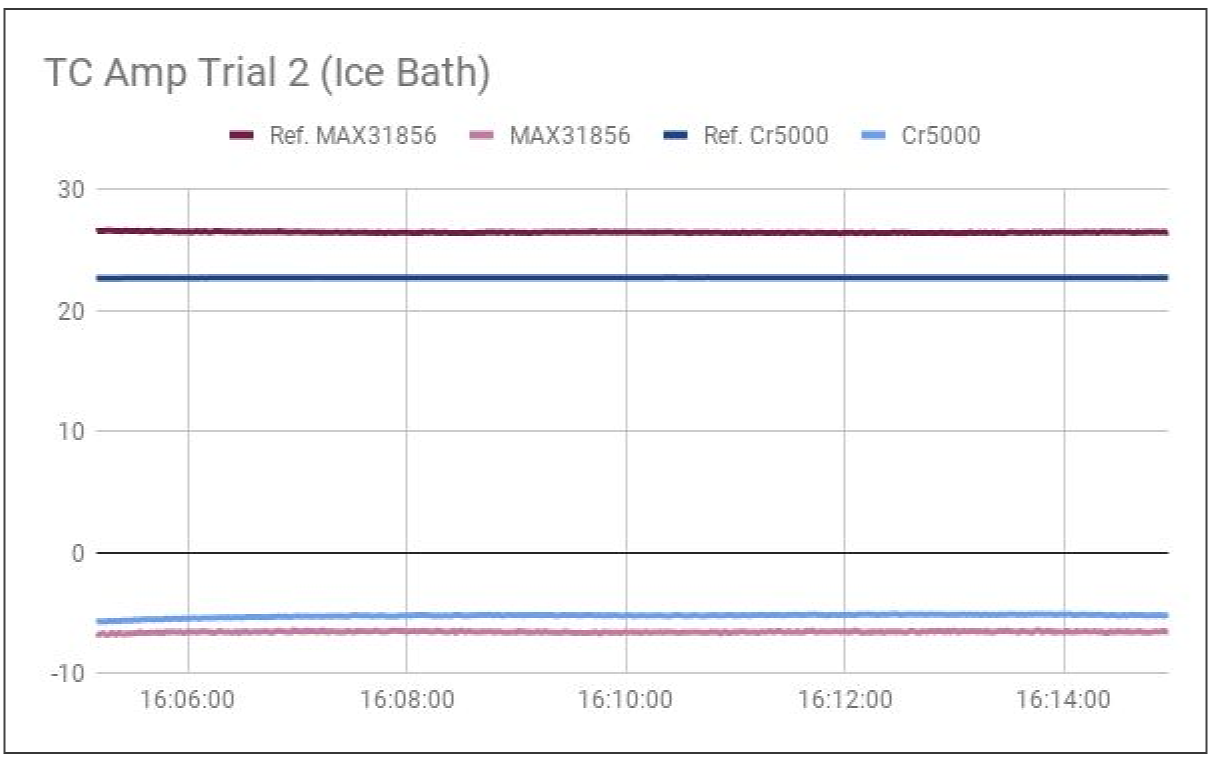
The amplified voltage has a range of +/- .625 and is digitized by a 19 bit *signed* ADC. This gives a **voltage resolution of 4.77 µV**, and (depending on ~8.0 µV sensitivity) an **approximate heat flux resolution of .596 W/m^2**

Comparing MAX31856 and Campbell CR5000:
This test was run to compare the MAX31856 amplifier with a more sensitive, reliable instrument (Cr5000). Two type-k thermocouples were placed in close proximity with each other (<1 cm), and submerged in an ice bath. One TC was connected to the MAX31856 and logged via Arduino Nano. The other was connected to the Cr5000. An air bubbler provided circulation, and a mesh sheet prevented either thermocouple from coming in direct contact with an ice cube. Two 10 minute trials were conducted, between which the TC's logging instruments swapped (Cr5000/MAX31856).

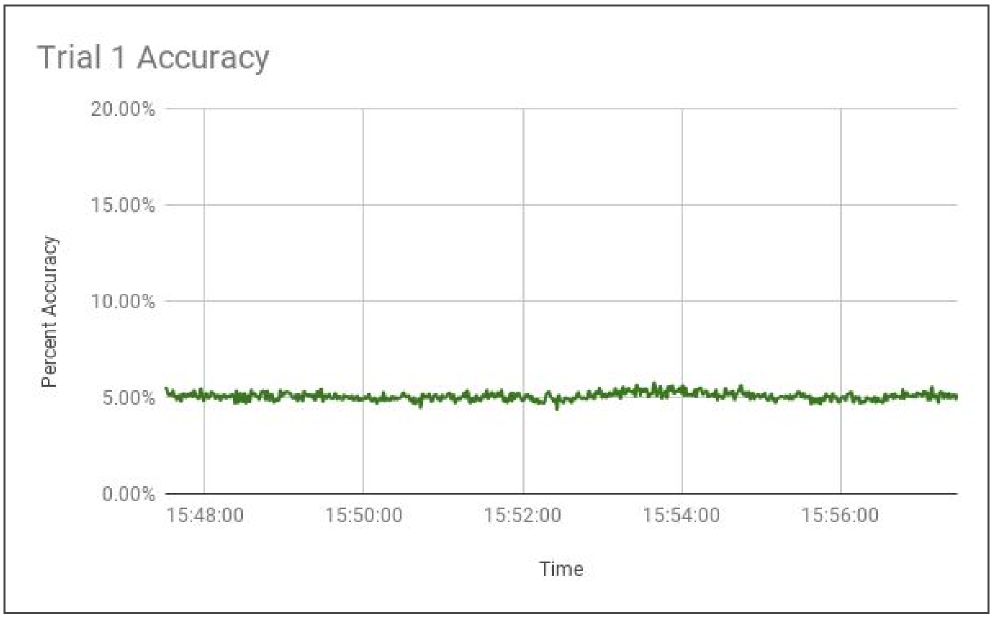

Results-

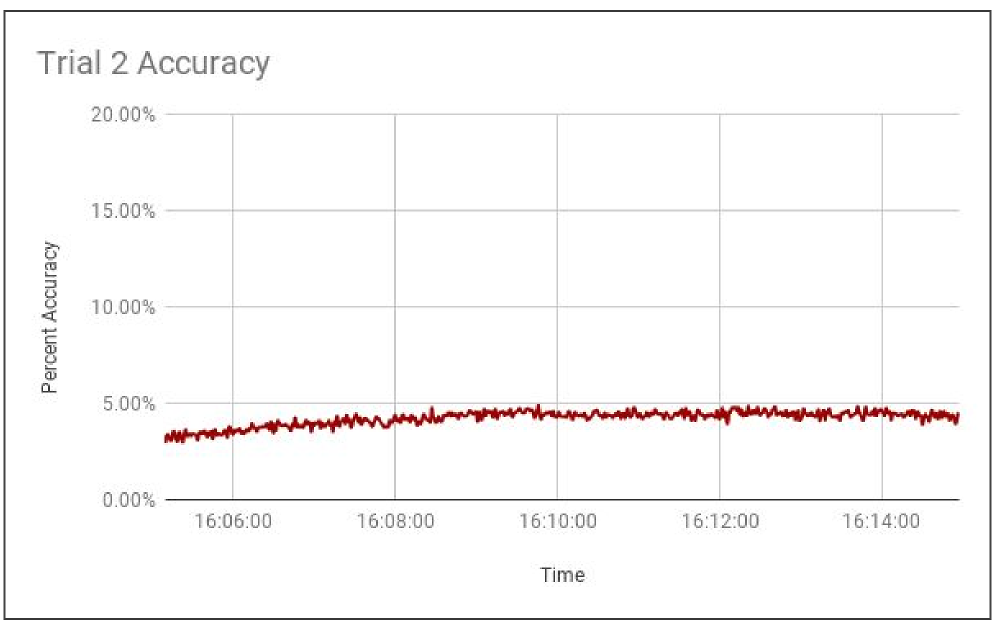

TC Amp Trial 1 (Ice Bath)
Ref MAX31856
MAX31856
Ref CR5000
Cr5000
Temperature (C)
30
20
10
0
-10
15:48:00
15:50:00
15:52:00
15:54:00
15:56:00
Time


TC Amp Trial 2 (Ice Bath)
Ref. MAX31856
MAX31856
Ref. Cr5000
Cr5000
30
20
10
0
-10
16:06:00
16:08:00
16:10:00
16:12:00
16:14:00

As can be seen, the two instruments varied significantly in measurement. The difference between the actual temperature of the TC (given by Cr5000) and the MAX31856 reference temperature is compared to the measured MAX31856 temperature difference. This is done for all 600 data points, giving the accuracy at a given time. The percent accuracy is averaged over the course of the test.

Accuracy = Measured Temp. Diff. (MAX ref - Actual Temp. Diff. (MAX ref. - Cr5000 TC)





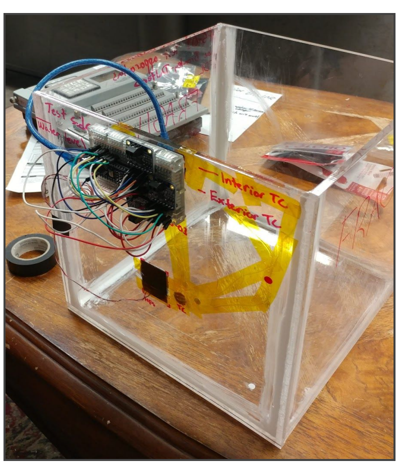
Accuracy Trial 1:	5.06%
Accuracy Trial 2:	4.21%

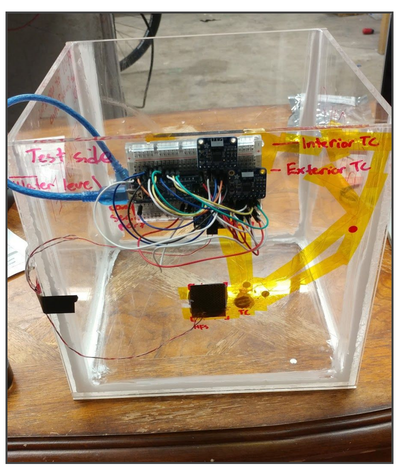
This supports an **approximate accuracy of 5%.** Only two official tests were run due to time constraints, but earlier unofficial measurements were consistent with this data. Either way, this accuracy value should be further established. Depending on the application, this may or may not be acceptable.

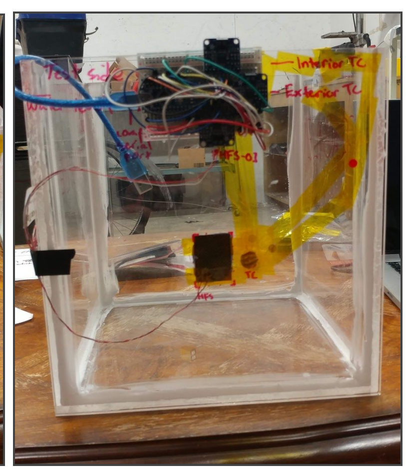
Constant Flux Test Apparati:
Expecting accurate voltage measurements from the ADC, I preemptively began designing a constant heat-flux test. There were two different setups that I opted to experiment with, both operating on the same premise…

Fourier's Law in one dimension defines heat flux to be $\phi_q = -k * dT/dx$
In an experiment that allows for one-dimensional heat flow, flux through a material can be found with a known thermal conductivity, temperature gradient, and thickness. This will provide an accurate control with which to compare the PHFS-01.

Acrylic Tank-
This apparatus is a 10x10x10 inch tank made of 6 mm acrylic sheets. Acrylic has a thermal conductivity of ~.2 W/m*K. Heat flux on the sides can be treated one dimensionally, as the thickness is significantly smaller than the size of the wall and the size of the tank. The PHFS-01 should detect a heat flux consistent with Fourier's Law for a given temperature gradient. In my setup, one type-E TC was placed on the inside wall, and one on the outside to measure the Temperature gradient. Immediately next to the exterior TC, the PHFS-01 was secured with thermal paste and kapton tape. Notably, just looking at readings taken with the Cr5000 showed that the Fourier's Law approximation was significantly higher than the PHFS-01.







Aluminum Plate-
Having run some quick tests with the acrylic tank, I noticed a few areas of potential improvement. First, the ice melted fairly quickly. To minimize the unnecessary heat loss and maintain a more stable environment, a styrofoam housing replaced the acrylic tank. Secondly, I was unable to track down the acrylic manufacturer to find an exact thermal conductivity. Instead, an embedded 6x6x.375" aluminum plate is used for the flux test. Aluminum 6061-T6 has a thermal conductivity of 167 W/m*K. This is higher and more precise than the acrylic being used. In the future, I would recommend installing more than one thermocouple on the interior/exterior.
**Five new type-E thermocouples are currently in the project box for this purpose.*

Recommendations:
-The MAX31856 amplifier should be tested more rigorously. If tested using the same thermocouple methodology as before, it may be helpful to use boiling water as another measuring point.
-I'd recommend adding a Real Time Clock to the microcontroller set-up. This will make long-term testing easier, as well as comparing data with the Cr5000.
-More thought should be given to the aluminum plate test apparatus. I found the bubbler and mesh to be useful for maintaining thermal homogeneity. I also recommend placing multiple TC's on the interior/exterior.
-The PHFS-01 sensed a lower heat flux than expected. This is likely due to heat loss between the surface and the sensor. I would test various methods of mounting the sensor; particularly

double-sided tape, thermal glue (permanent), or using another plate to apply pressure from the outside (though I suspect this would significantly change the flux).

Lessons Learned:

-Most circuits have already been made. There was no need to build my own, and I spent a lot of time trying. Everything I needed was online.

-Bare wire thermocouples are susceptible to noise and interference. They are also fragile. My last purchase order for insulated type-E thermocouples will be more appropriate for this project and easier to use

-Originally, I used the Arduino's ADC to read an amplified signal from the PHFS-01. The onboard ADC is not effective. Using an external chip which communicated with the microcontroller via digital SPI was more reliable.

-Datasheets are best accompanied by online forums and advice from other EFDL lab employees.

Conclusion:

Using the MAX31856 amplifier with an Arduino (or another microcontroller) is a feasible option for logging heat flux in a cost-effective manner. However, long-term accuracy and the method by which the sensor is mounted should be explored further before reliable data can be collected.

https://github.com/i-bd/phfs-01-EFDL