Design of Housing for Stove Use Monitors (SUMs) to Measure Adoption

by

Erica Waller

Submitted to the
Department of Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degree of

Bachelor of Science in Mechanical Engineering

at the

Massachusetts Institute of Technology

June 2017

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ABSTRACT

Billions of people around the globe rely on solid fuels such as wood or charcoal to heat their homes and cook their meals which negatively impacts health as well as the environment. Improved cook stoves negate these problems but are often not used over time. Stove use monitors (SUMs) are attached to improved cook stoves to track adoption rates. Three basic designs were generated of a housing for the SUM. They were analyzed by considering material choices, manufacturing options, and customer needs. Thermal images were taken of an improved cook stove in use to measure temperatures at key locations around the stove. It was found that the sides and handles of the stove attain a maximum temperature of above 150 °C (300 °F), and the feet and base of the stove below that. It was determined the best course of action is to design a housing for the base or feet of the stoves and use resin casting and later injection molding as production needs increase.

Thesis Supervisor: Daniel Frey
Title: Professor of Mechanical Engineering

Acknowledgements

The author would like to thank Prithvi Sundar for allowing me to work with him on this project, Dan Sweeny and Amit Gahndi for getting me started with the project and helping me set things on fire, Matt McCambridge for connecting me with the project in the first place, Dan Frey for being my supervisor and editing this document, and Jack Whipple for supplying sour gummies and shop space.

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1. Background

Billions of people across the globe use open fires and simple cook stoves to cook their meals and heat their homes (1), the effects of which produce consequences for the individuals and for the planet. Household air pollution leads to health problems such as stroke, chronic obstructive pulmonary disease (COPD), pneumonia, and other respiratory and cardiovascular conditions. The burning of solid fuels like wood or coal by households in the developing world contributes to around 21% of global black carbon emissions (2). Deforestation, emissions, and particulates resulting from residential use of solid fuels adds a non-negligible contribution to climate change. A method to combat the negative consequences of solid fuels while remaining economically viable in the developing world is to improve cook stoves. More efficient stoves require less fuel, reducing emissions and impact on the environment.

There are several models of improved cook stoves on the market utilizing different fuel sources. Some use wood but include methods to reduce smoke and increase heating efficiency while others use charcoal. Charcoal burns hotter and cleaner than wood, producing no smoke as volatile gasses are burned off as they are released (3). However, charcoal production still impacts the environment greatly. Both types of fuel can be used under different circumstances to reduce the impact of indoor air pollution on the health and wellbeing of families in the developing world.

High-performance improved cook stoves and other improved cooking technologies are often financially out of reach of many households. Government organizations and non-profits typically employ donations of stoves to distribute the technology to households in need, but adoption rates tend to be low (4). Low adoption of improved cook stoves mitigates their benefits. The purpose of this project is to design a housing for a stove use monitor (SUM) that provides manufacturers and designers with data regarding the adoption of their product. This data can be used to investigate causes for low adoption rates, allowing producers to address these issues and increase adoption among their customers in the long term.

1.1 Design Specifications and Challenges

The SUM consists of a lithium ion battery, a thermal sensor, an SD card reader, and the supporting electronics (see figure 1-1). The thermal sensor must be able to register changes in temperature in order to track use of the stove, but the LiPo battery degrades quickly under high heat. This presents one of the major challenges in the housing design: how to thermally isolate the battery while maintaining a small housing footprint and allowing the thermal sensor to measure temperature changes of the stove.

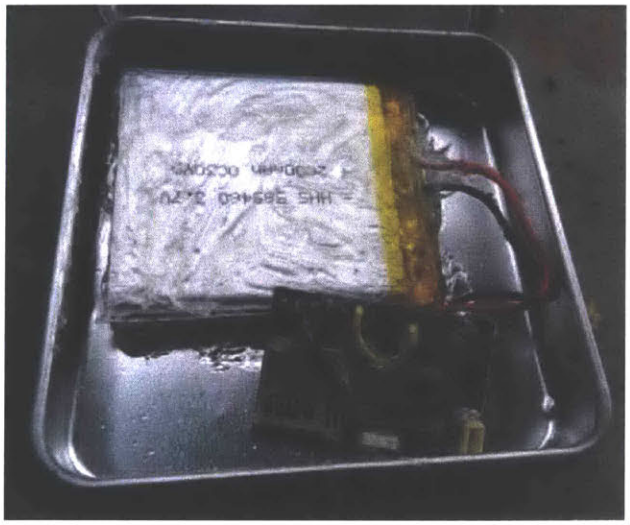


Figure 1-1: SUM internal components (4)

The LiPo battery is the largest component in the housing, driving its shape and size. A table of functional requirements is included below (5). Other customer needs to be considered are aesthetics of the final design, usability of the stove with the SUM attached, ability to clean the SUM as needed, and accessibility of the battery and SD card for data collection and maintenance.

Function	Specification
Heat resistant	Must withstand 100-250 C
Flame-Proof	UL 94 V-1 classification
Shock resistant	Able to withstand falls of 3ft
Water-Proof	IP54 classification

Table 1-1: Functional requirements of the SUM housing

Other challenges considered in this project were material selection, battery type, and scale of production, specifically with regards to heat resistance, resistance to the cooking environment, and cost of production at medium scale. Initial prototypes were made of small metal boxes, but future iterations must blend seamlessly with the stove and not interfere with normal use. Different manufacturing processes were considered such that the design could be changed slightly to suit different techniques as the project scales up. Ideally production would begin with 10s of units, scaling eventually to 1000s of units or more over time. Of particular interest was utilizing 3D printing for prototyping, urethane casting, and eventually small-batch injection molding as production needs increase.

2. Preliminary Designs

Initial design ideas focused on the mounting interface for a Greenway Smart Stove, an improved cook stove that uses wood for fuel (6) (see figure 2-1). The handle in particular was chosen as a potential location for housing the SUM in a way that would not interfere with customer use of the stove and would not change the overall aesthetic of the design.

Figure 2-1: Greenway Smart Stove, from Amazon.com

The scope of the project was later increased to consider a SUM housing that could integrate with many types of improved cook stoves, such as the Makaa Cook Stove, which are often made locally to increase the economic impact of the cook stoves in the communities where they will be used. This adds a challenge because each stove is different, even when the design is the same. Manufacturing tolerances in a local mechanic's shop in Uganda differ greatly from those in a factory in the US or China. In this case, preliminary designs focused more on flexibility of attachment to different stove models. Three main design and mounting ideas were considered, design 1 that attaches as a handle, design 2 that attaches as a foot, and design 3 that can be attached under the stove or on its side, as needed. See Appendix A for detailed sketches and Appendix B for basic CAD models of the main design ideas.

Figure 2-2: Makaa Cook Stove

3. Thermal Analysis

In order to better understand the temperature changes seen by various locations on a cook stove during normal use, a burn test was conducted on a Makaa Cook Stove. A Seek Thermal thermal imaging camera was used along with an Android smartphone to take pictures of specific locations on the stove approximately every 5 minutes until max temperature was reached for each location and the fire had died down to embers.

3.1 Experimental Setup and Results

A Makaa cook stove was set under a fume hood in the IDC burn lab. The clay liner of the stove was filled with natural wood lump charcoal and a fire starting cube of wax and wood shavings was placed on top. This cube was lit with a lighter and the Seek Thermal camera was inserted into the smartphone. Once the fire began burning steadily, a pot of water was placed on top of the stove to simulate cooking. The burn lasted about two hours, and thermal images were taken focusing on the sides of the stove, the handles, the base of the stove, and the feet. The experimental setup can be seen in figure 3-1 and thermal images can be found in Appendix C.

Figure 3-1: Experimental setup with a Makaa stove

The resulting data showed the approximate maximum temperatures reached for each part of the stove. The sides of the stove saw the highest temperatures of around 320 °C (600 °F), followed by the handles at 150 °C (300 °F), the base at 135 °C (275 °F), and the feet at 60 °C (140 °F). As expected, the temperature dropped with the distance from the fire, but the handles got much hotter than expected given that they should be able to be touched. This should be less of a problem using a Greenway Smart Stove or any other type of improved cook stove that

employs plastic handles, but many use metal handles as the Makaa stove does. The LiPo batteries currently being used for the SUM have a discharge temperature range of -20 °C – 60 °C (-4 °F – 140 °F) (7). The temperature of the battery should not exceed this temperature range or the life of the battery will be negatively impacted, so housing designs must also protect the battery thermally.

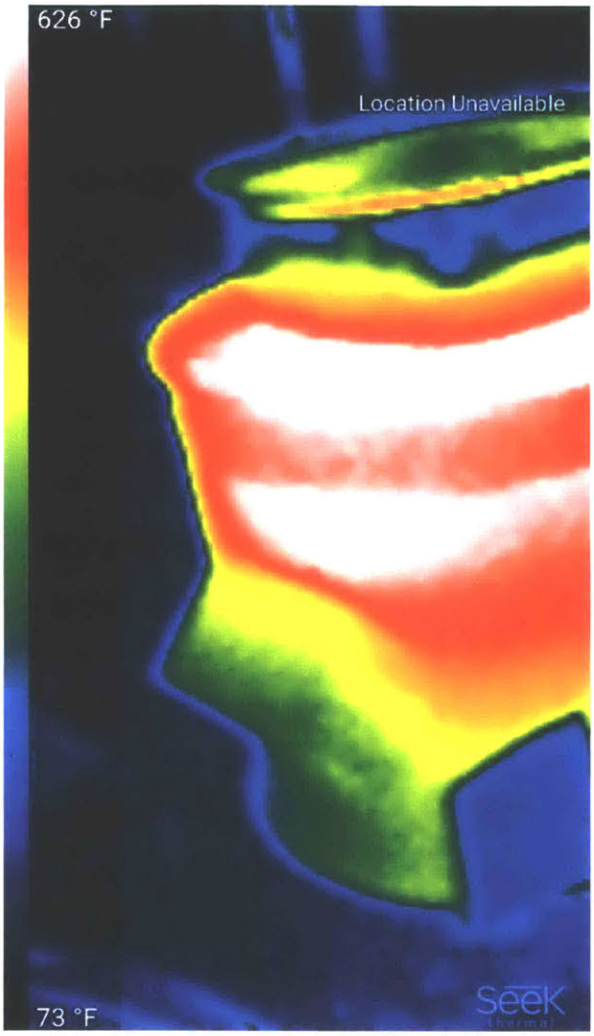


Figure 3-2a: Thermal image of max handle and side temps.

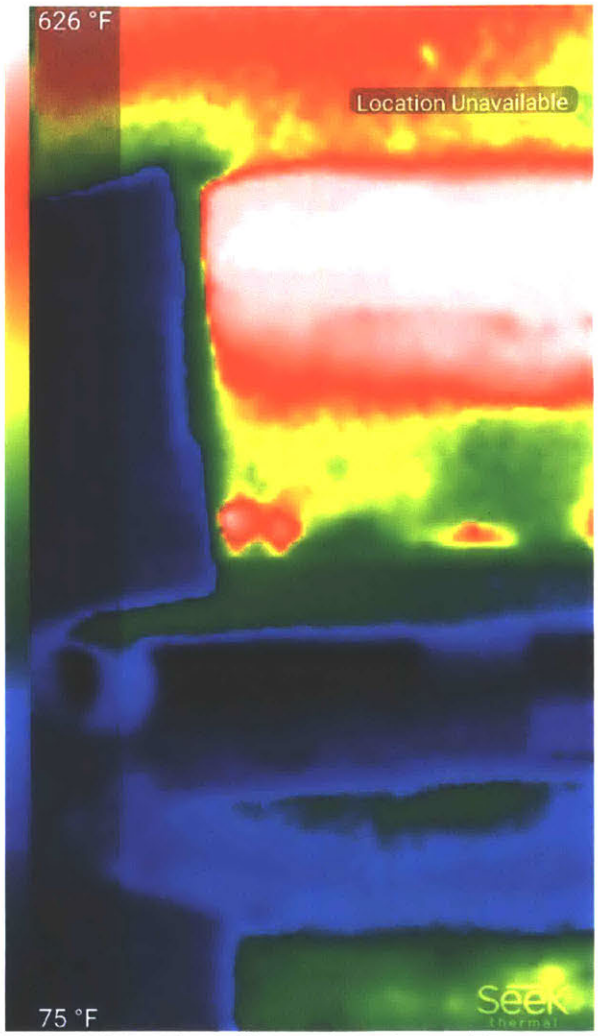


Figure 3-2b: Thermal image of max base and foot temps

4. Manufacturing Considerations

Based on the current scale of the project and the thermal imaging data, manufacturing options were explored including method of manufacture and choice of materials for small and medium stages of production. For small-scale production in the 10s – 100s of parts, casting was determined to be the best choice to produce plastic parts. There are several different resins that provide the necessary heat resistance, shock load resistance, and meet flammability requirements (8). That said, designs 1 and 3, if placed near the top of the stove, would require costlier high temperature resins than design 2 or 3, if placed at the base of the stove. The benefits of casting include lower cost for smaller volume production, accessibility, and low lead times. At medium volumes of production, 1000s of parts, small scale injection molding becomes feasible. At this

stage, material choices widen further to include thermoplastics like nylon or ABS, which are low cost and easily machined. There are also high temperature plastics like PEEK which have higher costs but offer significantly increased thermal performance (9).

Also at medium scale production, sheet metal parts become feasible. Simple boxes can be easily stamped for fairly low cost given higher volumes of production. Metal offers excellent thermal capacity though increased conductivity could prove troublesome with regards to the battery. In this case, insulation materials like fiberglass become vital to maintain battery life. At low volumes of production, metal parts are too costly to produce as they must be machined or individually assembled, as in welding steel boxes. As a result, casting seems to be the best choice for low volume followed by either stamping or low volume injection molding as production scales up.

5. Summary and Conclusions

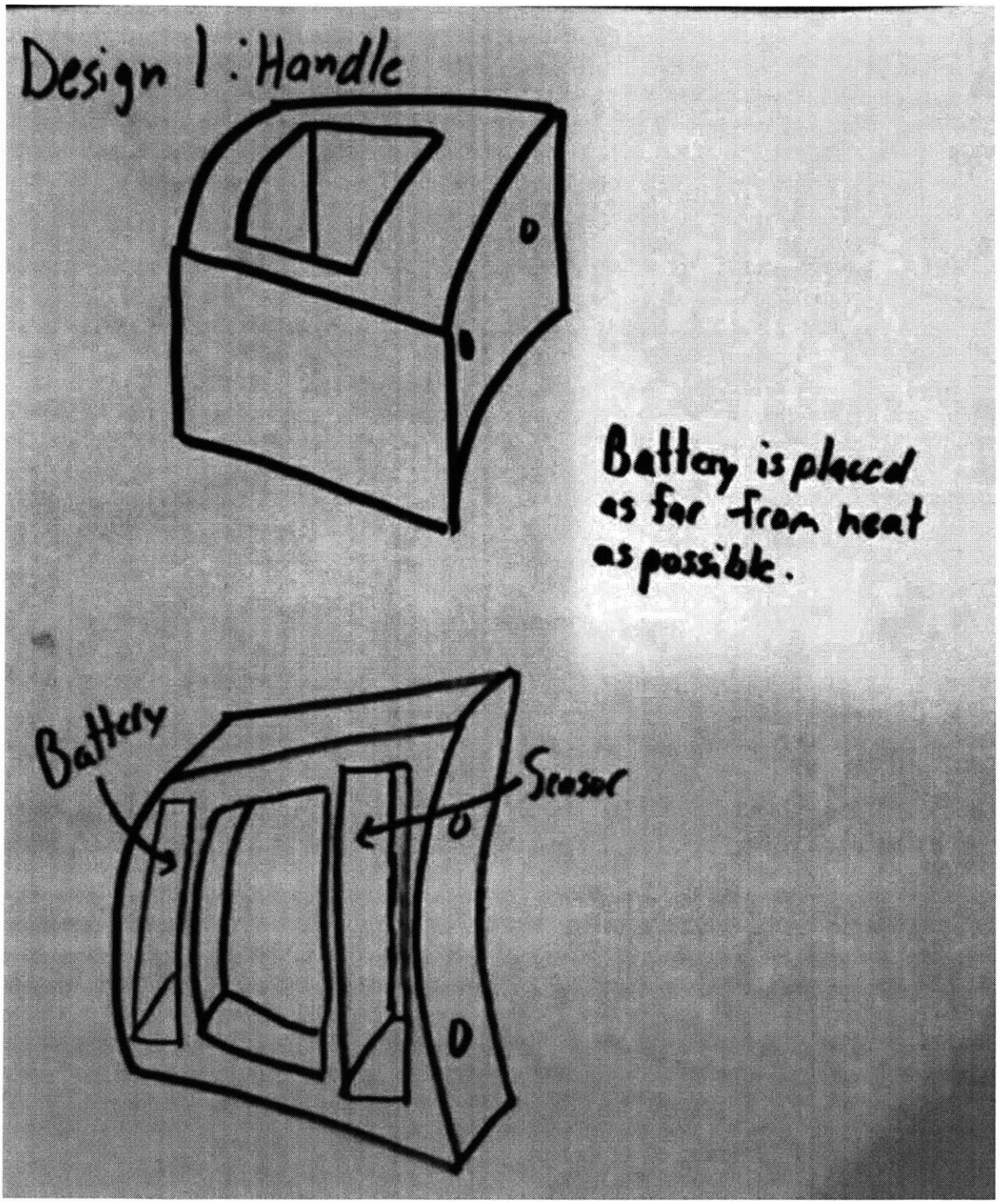
After consideration of production needs, cost limitations, thermal data, and customer needs, it was determined that design 2 was most promising. This design provides minimal disruption to the user unlike a mount to the side of the stove. It also allows the handles to be any size or material. Also, the temperature of the base and feet of the stove remained much lower than the handles or sides opening up material and manufacturing options that would be otherwise unusable due to thermal constraints. The recommendation is to iterate design 2 to be easily molded and to provide the appropriate insulation for the battery. This design will likely work best if the thermal sensor is located on top of the battery so the battery is as far removed from the heat source as possible. The temperature at the base remains low enough for cheaper plastics like ABS to be used but high enough for the sensor to detect a noticeable change when the stove is in use.

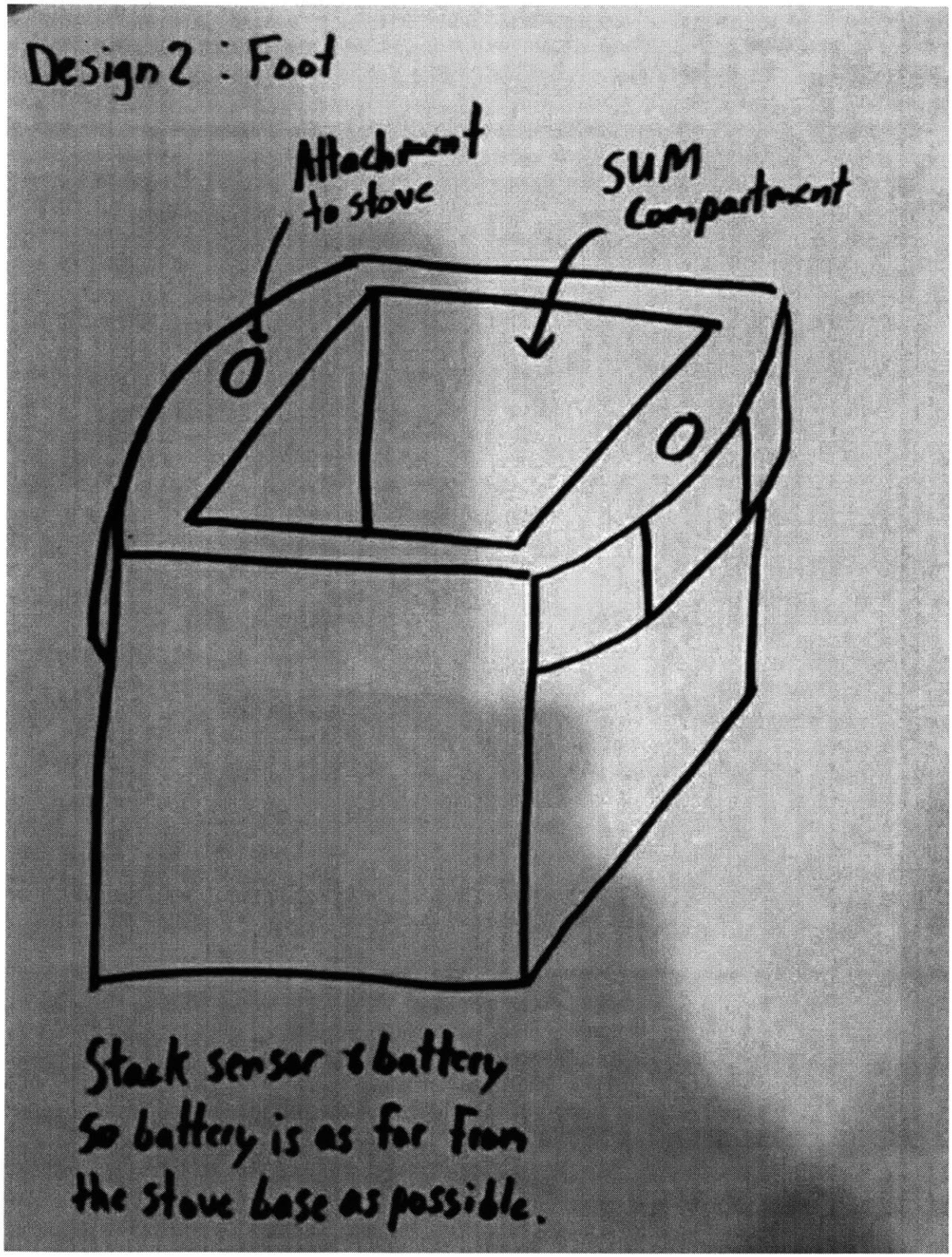
For increasing production, rapid prototyping is recommended in the small scale stage and low volume injection molding for medium scale and beyond. The small scale production is best done using resin casting for its low cost and ease of use. Injection molding makes the most sense in medium production because shifting from casting to sheet metal stamping would require a rather dramatic shift in design and previous prototyping work would likely be wasted since the challenges of stamping differ from molding.

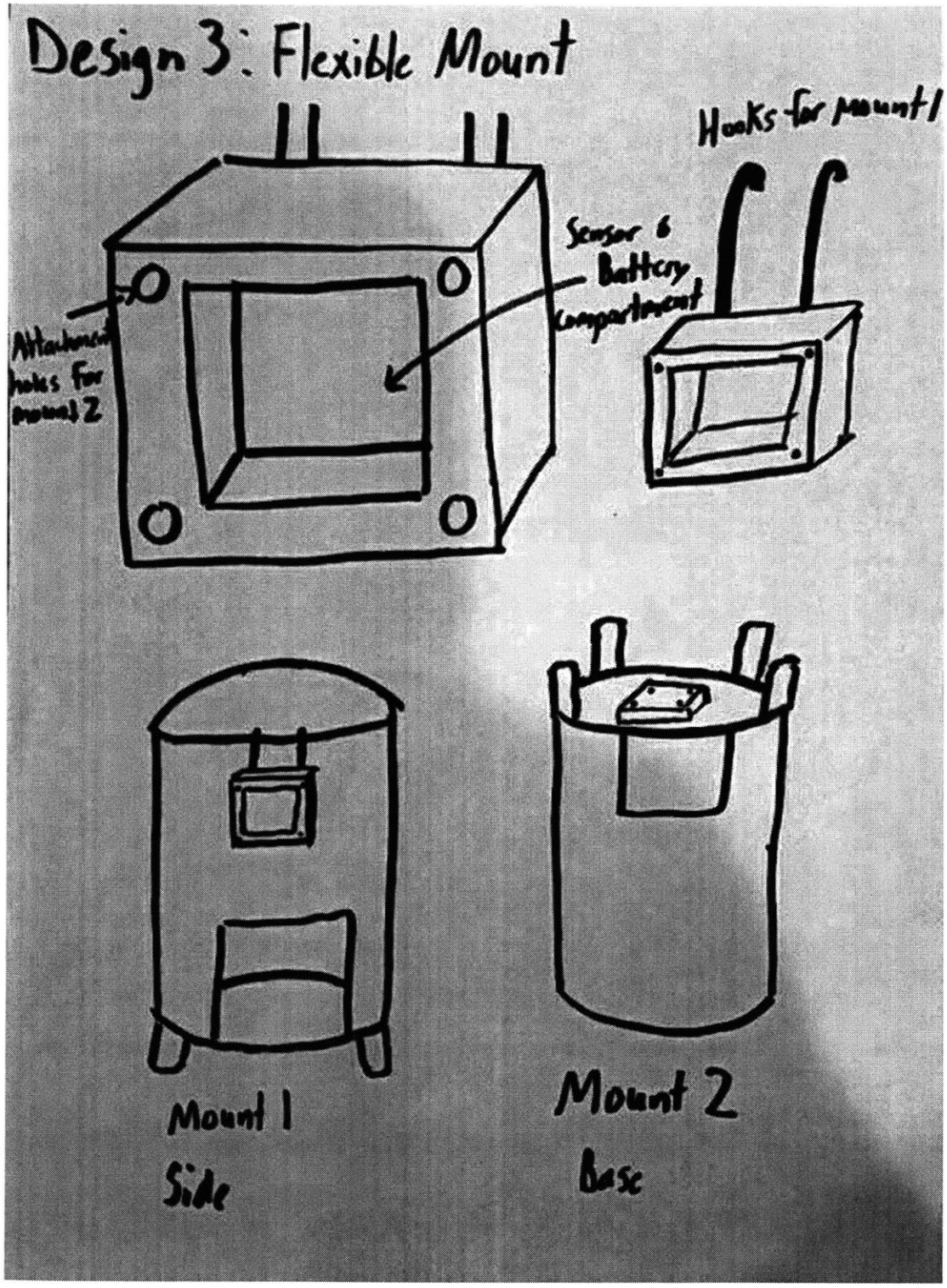
Future work should focus on optimizing the basic design for mold production and thermal analysis to verify that the battery is properly insulated given the materials and wall thicknesses chosen. Ideally the final design would be unnoticeable to the user entirely so as to increase the number of users willing to allow data collection via the SUM about their stove use habits.

6. Appendices

Appendix A: Design Sketches

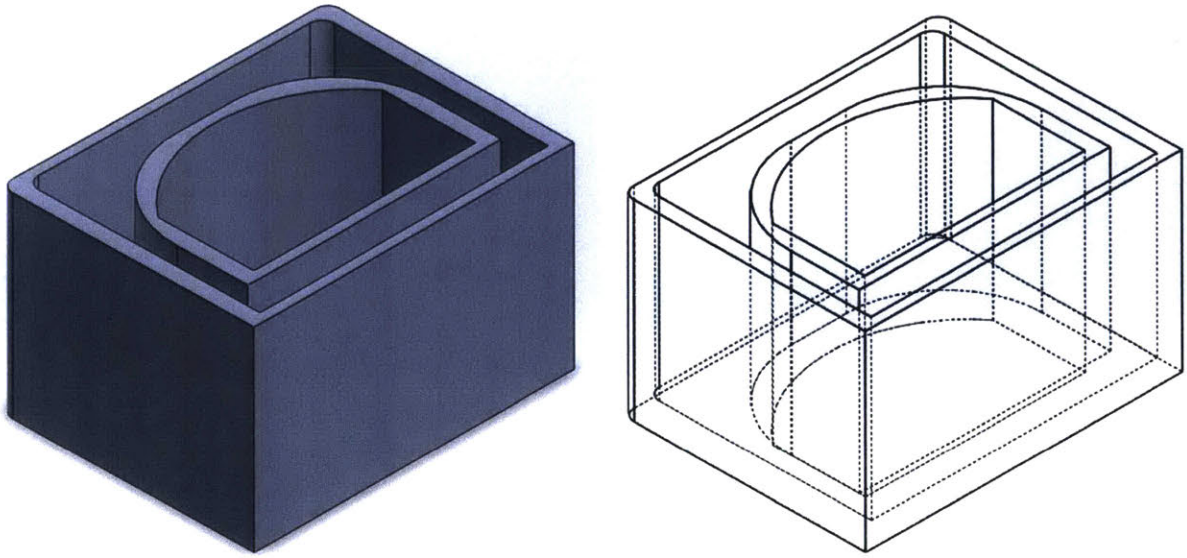



Design 2 : Foot
Attachment to stove
SUM Compartment
Stack sensor & battery so battery is as far from the stove base as possible.

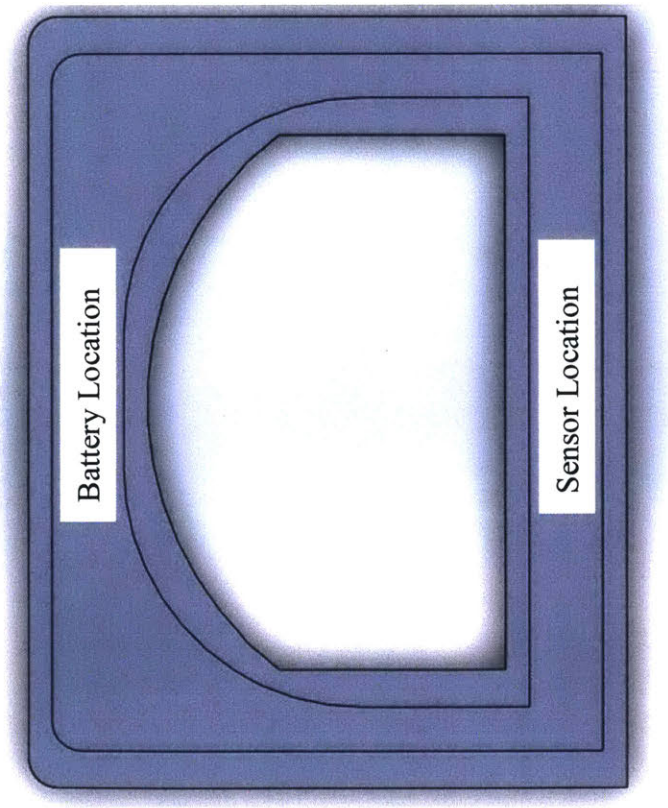

Design 3: Flexible Mount
Hooks for mount 1
Sensor & Battery Compartment
Attachment holes for mount 2
Mount 1
Side
Mount 2
Base

Appendix B: Basic CAD Renderings

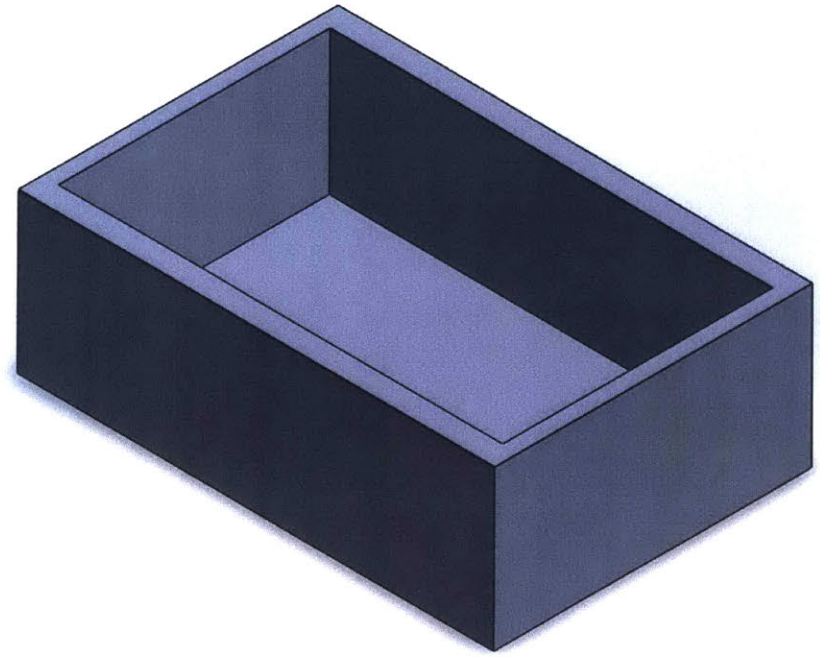
Design 1



Concerns here are the thickness of the handle required for the battery to fit. The handle may be too large for comfortable use.

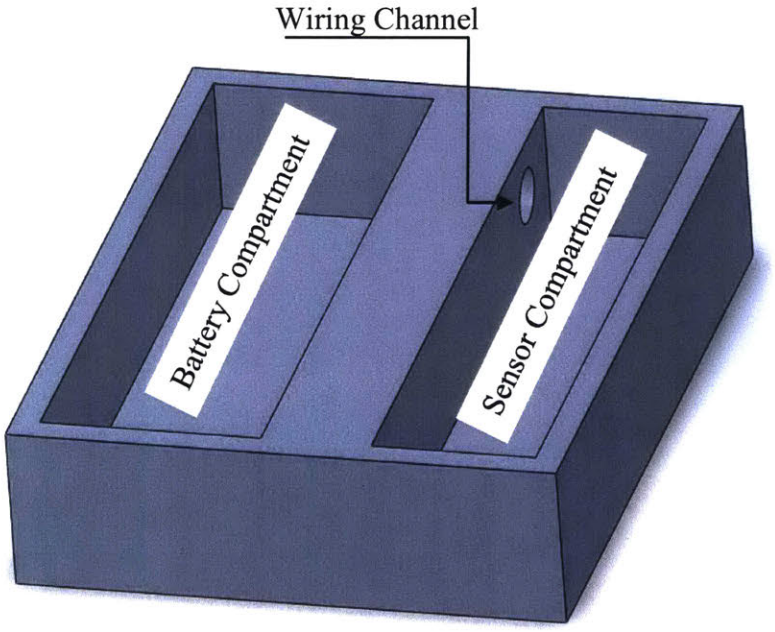


Design 2

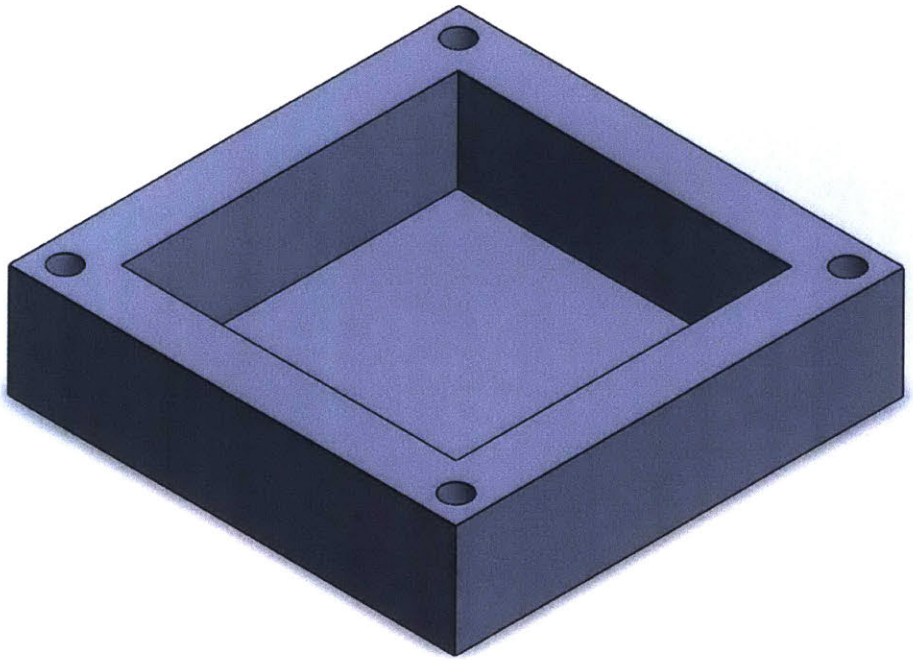


Design could be shrunk slightly to be just big enough for the battery, or left as is to allow insulation to be placed around it.

Design 3



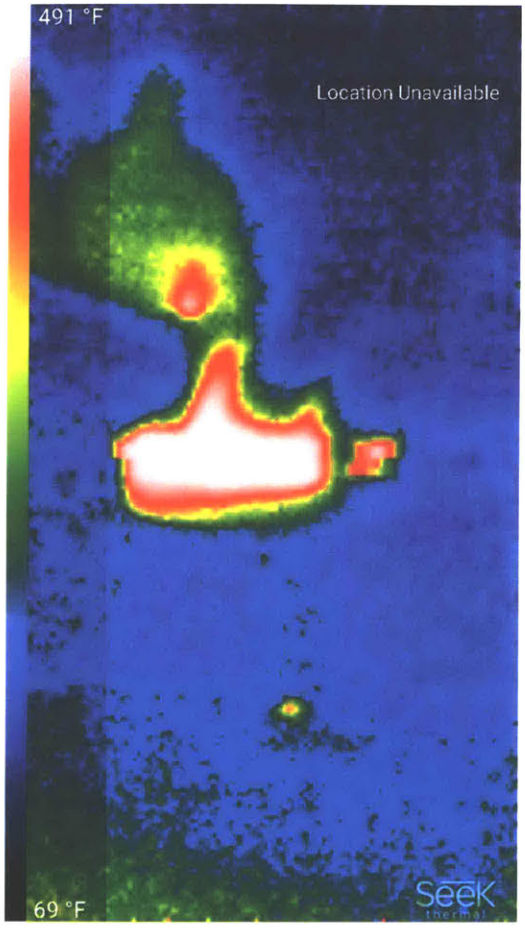
Option A separates the battery and sensor with a wall to help hold the components in place.

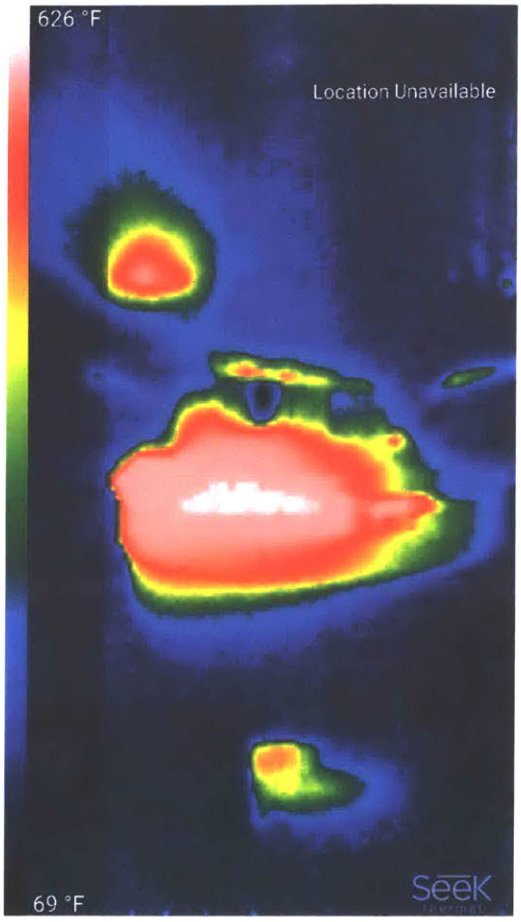


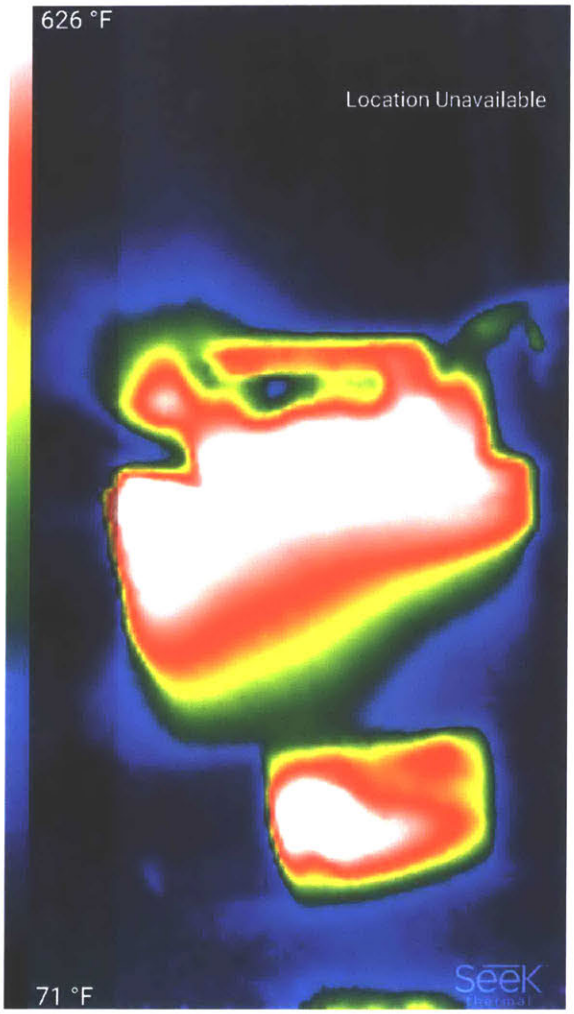
Option B allows the battery and sensor to be configured in several different ways but may require additional material to keep the components from moving.

Appendix C: Thermal Imaging Pictures

Images are presented chronologically



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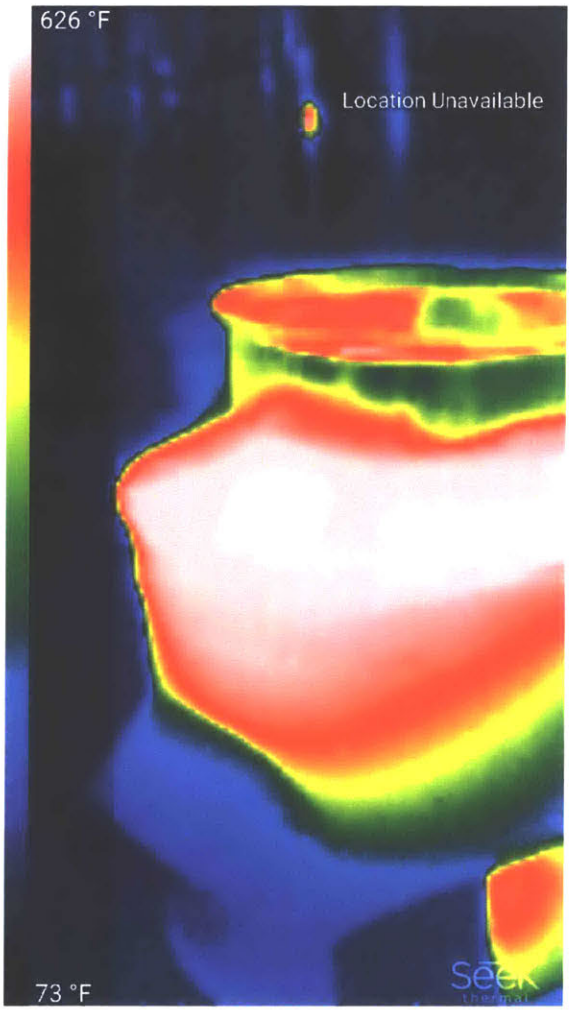
71 °F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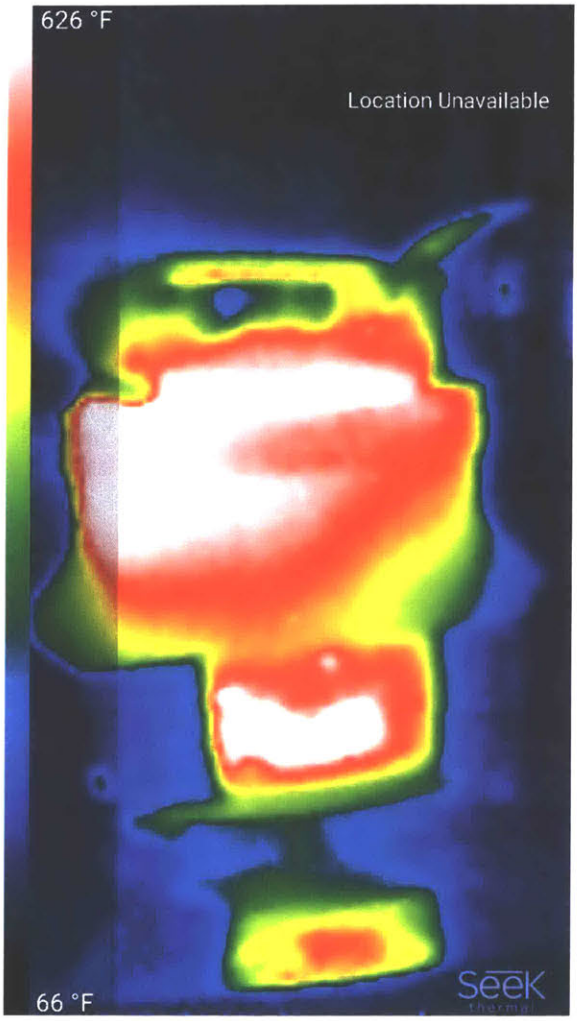
73 °F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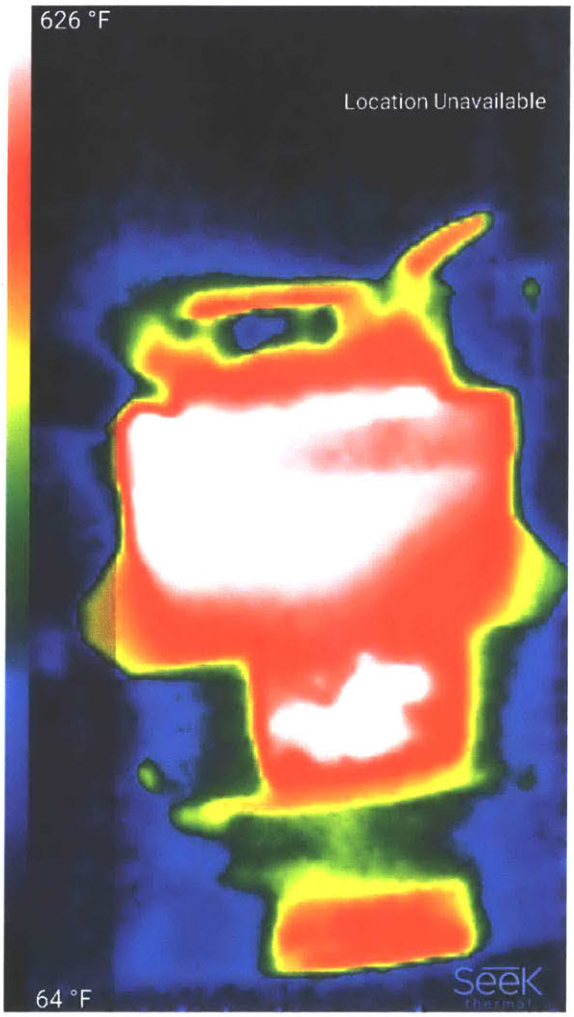
66 °F
SeeK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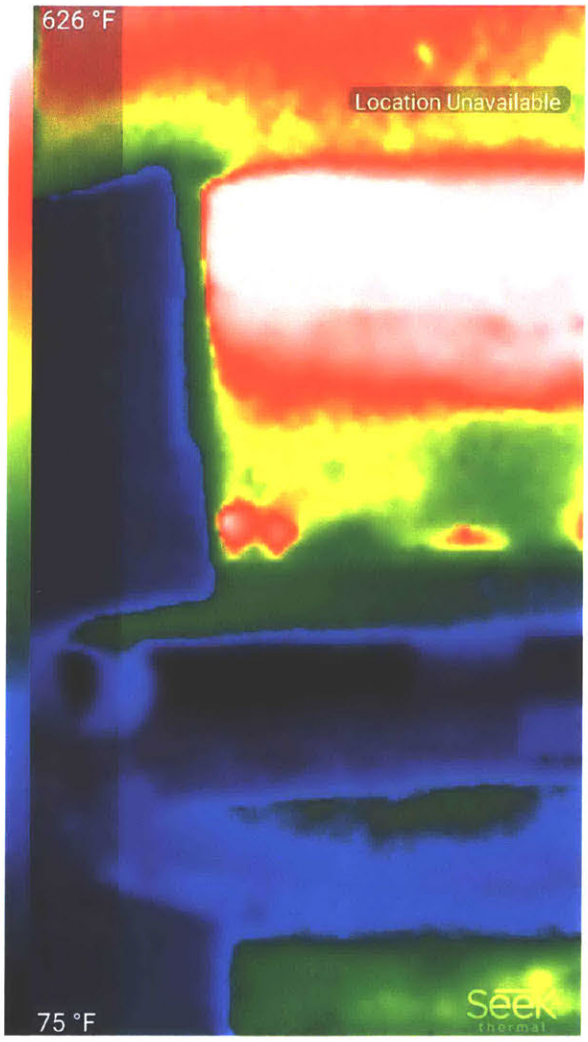
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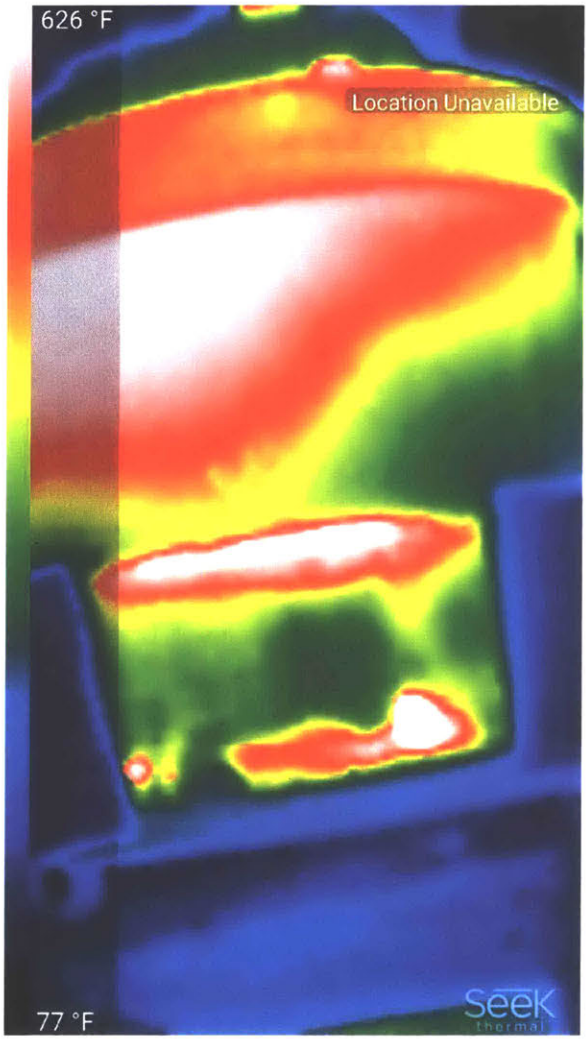
thermal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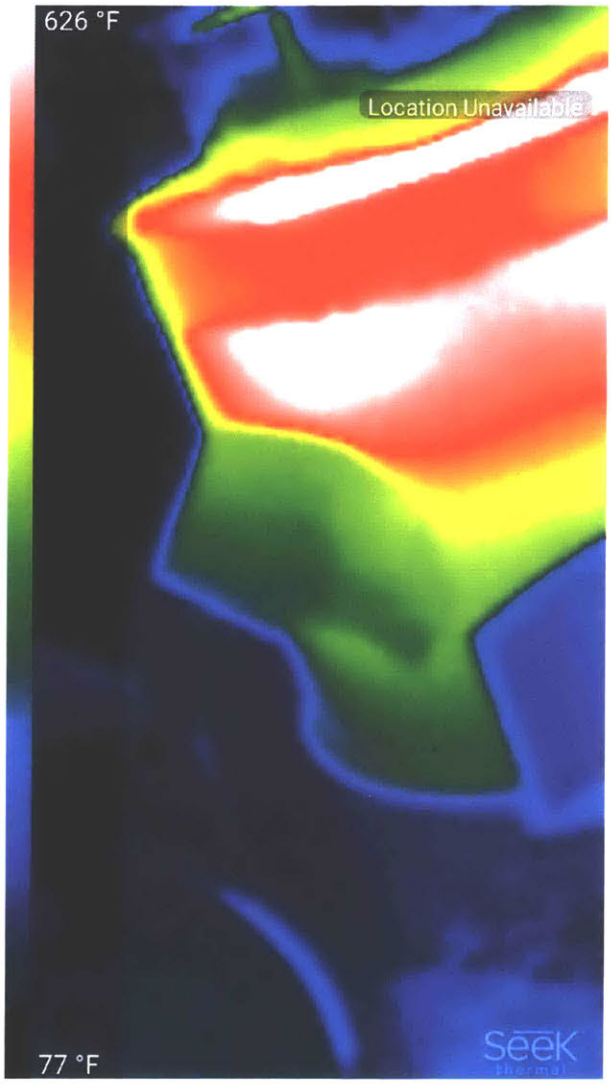

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