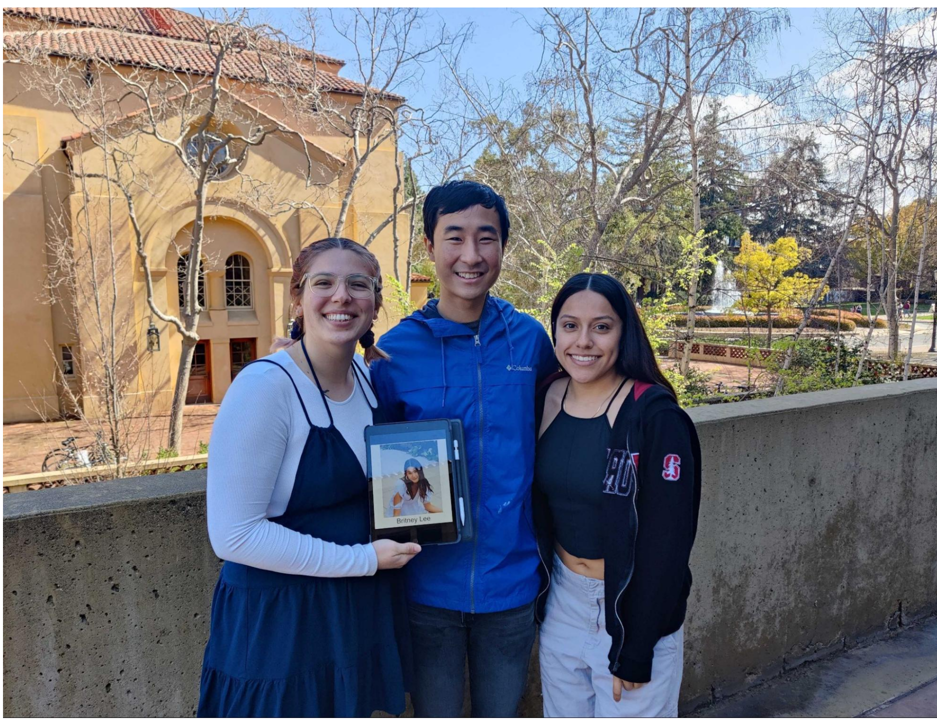
Automatic Flux Chamber for the Monitoring of Carbon Dioxide and Methane Emissions from Peatlands



by
Peat Peeps

Olivia Schroeder, Raymond Zhen, Jessica Quiroz, Britney Lee

Second Quarter Final Report for
ME 170B Mechanical Engineering Design
Integrating Context with Engineering

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1 Abstract

Peatlands are a type of wetlands that act as a carbon sink to prevent dead plant material from biodegrading and releasing carbon emissions into the atmosphere. Peatlands are currently being destroyed for the production of palm oil and other agricultural products, which releases greenhouse gases, that were previously confined underwater, into the atmosphere; these agricultural practices contribute to potentially catastrophic global warming events. Climate researchers seek to understand such impacts by collecting data on greenhouse gases that are released from Indonesian peatlands. However, current modes of collecting peatland emissions data are inadequate because they are expensive, non-portable, and not long-lasting. We seek to address these issues through the design and production of a floating greenhouse gas flux chamber that collects data from the water surface of peatlands. Thus, we created PEAT, the Peatlands Environmental Assessment Tool, which floats on a body of water, traps gases emitted from the surface, collects data on gas concentrations, and releases the gases in a continuous cycle. Our chamber integrates a methane and carbon dioxide sensor on a printed circuit board. PEAT is protected from humid environments, uses an actuated linear sliding door for venting, floats using a foam ring, can be easily tethered to a stationary object, and can collect data autonomously for one month before any maintenance is required. We conducted the following tests on PEAT: a flotation test that verified its ability to stabilize itself under rainy and windy conditions, a sealing test that verified the device can trap gases, a venting test that verified the device can reset greenhouse gas concentrations to ambient conditions, and desiccant lifespan test to ensure that the electronics will be kept at a safe humidity for the duration of autonomous data collection. The implication of PEAT's robust design is a long-lasting, low-cost, and portable solution that supports the research of greenhouse gas emissions and can impact climate regulations.

2 Cover Image

3 Acknowledgements

We would like to express our deepest thanks to Jack Lamb, Lester Su, Lawrence Domingo, the Precourt Institute of Energy, and the ME 170 teaching team for guiding and motivating us throughout this project.

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4 Table of Acronyms

Acronym	Term
PEAT	Peatlands Environmental Assessment Tool
GHG	Greenhouse Gas
CO2	Carbon Dioxide
CH4	Methane
PCB	Printed Circuit Board
AFC	Automatic Flux Chamber
CFM	Cubic Feet Per Minute
LFM	Linear Feet Per Minute

Contents

5 Introduction

When dead vegetation subsides, peatlands (a type of wetland) are created (Figure 1) through the accumulation of dead and decaying plant material. They act as a carbon sink because the waterlogged soils and high water levels limit the oxygen in the wetlands and prevent the dead plant material from fully biodegrading. The water traps greenhouse gases (GHGs) that plants capture from the air and prevent the release of carbon dioxide and methane into the atmosphere. Although peatland environments cover just 3% of the land on Earth's surface, they hold 30% of the soil's carbon [8]. However, many peatlands are being cleared, drained, and burned to make room for palm oil and agricultural plantations. The draining of peatlands causes large-scale flooding, making the land unusable; scientists predict 42% of the 850,000 hectares of coastal peatland will experience flooding in 25 years [9]. These unsustainable agricultural practices risk releasing millions of tons of GHGs into the atmosphere.

Fig. 1. Peatland environments contain large amounts of water, low pH, low oxygen supply and low nutrient content. These environmental conditions slow down plant decomposition and, as a result, cause a build-up of partially decomposed plant remains.

GHGs such as methane and carbon dioxide are thought to cause climate change through trapping heat, which causes rising temperatures and potentially catastrophic weather events. Emissions from natural tropical wetlands contribute approximately 20-30% of the total methane budget [7]. As tropical ecosystems undergo changes due to land use and climate change, it is important to understand the implications of these changes on the global climate. However, researchers have a limited understanding of the impact that wetlands have on the carbon cycle because GHG production in these areas is not well documented.

To address this issue, researchers have developed innovative methods for capturing GHG emissions. One such method is the use of a flux chamber, which is a device that sits on the peatland waterbed and traps small volumes of air. This device measures carbon dioxide and methane emissions by capturing the gas that bubbles up to the surface. Our goal is to improve on existing flux chambers by creating a portable, low-cost, and mass manufacturable device. Our device must float stably and regulate GHG concentrations through ventilation and sealing to ensure measurement accuracy. The latter poses significant challenges because it requires the prevention of air, moisture, and debris, while still allowing for controlled ventilation of gases. A tight seal is required, while remaining within the power restrictions of the batteries on the device and interfacing with the electronics developed by researchers at the Precourt Institute for Energy. Our work is a step towards the creation of a device that supports large-scale ecological measurement efforts in tropical wetlands.

6 Background

6.1 Problem Background and Existing Solutions

Collecting GHG emission data is difficult in peatlands environments because of the weather conditions. For instance, the Manaus region of the Amazon is characterized by high precipitation (about 2000 mm per year), high temperatures (annual average of 27°C), and high relative humidity (ranging from 74-82%) [1]. These environmental challenges can result in inaccurate GHG data because GHG sensors are designed to measure at a constant temperature and humidity of 20 ± 2°C. Thus, researchers require measurement techniques that isolate gases from the outside environment.

Flux chambers are devices that directly measure emissions from the ground or water surface to the atmosphere and can be used to measure carbon dioxide and methane emissions from peatlands. These devices trap carbon dioxide and methane which (1) diffuses from the water or (2) bubbles up from the ground (through a process called ebullition) into an enclosed volume, as shown in Figure 2. Methods to measure the accumulated gas vary, but the most common method is manually collecting samples of gas from the flux chamber and analyzing the sample contents in a laboratory. Flux chambers can collect data from different locations, such as on the soil or on a peatland's water surface (the latter is the focus of this project).

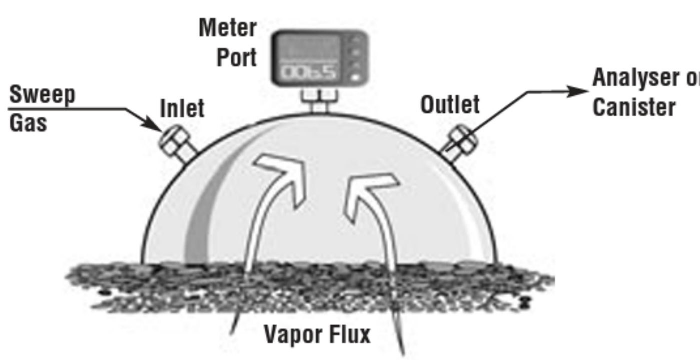


Fig. 2. Diagram of a Surface Flux-Chamber [6]. This is a chamber on solid ground with both an inlet for constant oxygen flow and an outlet for measuring the emission levels.

Traditional flux chambers are often deployed for a short term (about 30 minutes at a time before being taken out of the water) because they are limited in the number of samples they can collect. Although they can accurately measure diffusion, they suffer low accuracy for ebullition. Trends in ebullition can take a long time (usually over a month) to emerge, thus necessitating long time periods for measurement [2]. In addition, ebullition bubbles contribute 60% or more to total GHG flux values [3]. To collect data that accurately reflects both diffusion and ebullition, long-term measurements are necessary. Short-term flux chambers are the standard, yet they require repeated measurements, analysis, and redeployment. Thus, current research focuses on long-deployment Automatic Flux Chambers (AFCs).

There have been multiple successful iterations of AFCs in prior research [3]. Duc et al. proposed a two-part AFC, in which one part collects gas samples, and the other logs data. The components for this are shown in Figure 3.

In this AFC, the measurement cycle begins by clearing the polyurethane tubing carrying the gas from the chamber to the vials of any previous GHG sample residue. By pumping this gas into a

Fig. 3. AFC including (a) a FC with attached inner tube and major parts of control box, (b) a 12 VDC battery, (c) a solar panel, (d) PIC data logger and power control board in a plastic box, (e) a diaphragm pump, (f) electrical valves, and (g) a sample holder.

balloon that raises one side of the chamber, the remaining gases can passively flow through the gap and out of the chamber. Then, GHGs accumulate while a sensor stores data on the gas levels as they rise. The chamber then collects the gas and pumps it into sample holders.

While an advanced design, there is still some gas in the flux chamber left over from the venting cycle that can affect data collected for the next sample. A later iteration, shown in Figure 4, replaces the balloon venting system with an air pump and a valve that clears the tubing collecting the gas. By repeating this three times each cycle, the system ensures that the space under the flux chamber is clear of any GHGs from the previous measurement [10].

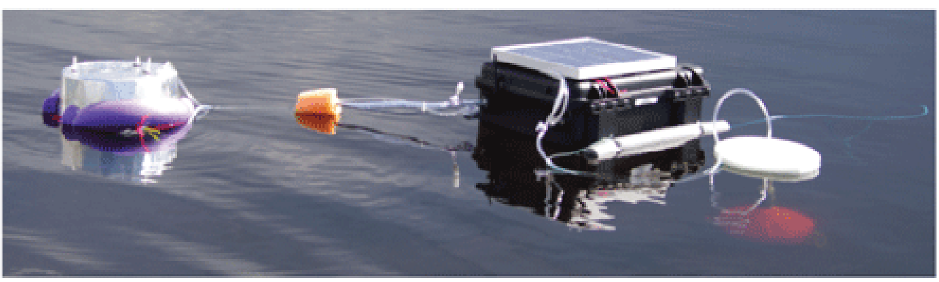


Fig. 4. The updated AFC which uses a pump and valve system to trap and release gas. From left to right: the flux chamber, which is connected to a storage box with all the electronic components and pump, and a funnel that detects GHG bubbles [10].

Another method to perform methane and carbon dioxide measurements is using a gas analyzer within the AFC [5]. While a gas analyzer offers accurate flux measurements, devices such as the methane analyzer (LI-7700, LI-COR Inc.) or the H2O/CO2 analyzer (LI-7500, LI-COR Inc.) can cost over a thousand dollars each. If the goal is to take measurements in various regions using automatic flux chambers that can be mass manufactured, then using an expensive gas analyzer is impractical. Complex designs, such as the one for Duc et al.'s first AFC, are challenging to mass produce since they require assembling a system with multiple moving parts and are too expensive to deploy widely. However, Duc et al.'s second AFC (with the more effective ventilation system using an air pump) helped guide our designs by ensuring we had the proper requirements and equipment for a floating automatic flux chamber that accurately collects GHG emission data and is easily assembled at large scale.

6.2 User Research

There are two main user groups for the project: (1) researchers and (2) local land managers or farmers. The first group refers to those who are using the flux chamber to collect data to support research on carbon cycling and GHG budgets. For these researchers, measurement capability is the single biggest limitation to understanding the tropical carbon cycle. Flux chambers specifically help to collect information on carbon dioxide and methane emissions. Researchers set up flux chambers in Indonesian and Brazilian peatlands to collect data to further study (Figure 5).

The second user group consists of more traditional end-user customers. The Association of South-East Asian Nations, like other nations with peatlands, is beginning to implement sustainability programs to promote peatland protection [4]. By providing landowners with technologies meant to preserve peatlands, the government provides farmers with other sources of funding, shifting income streams away from clearing peatlands for palm oil. Clearing peatlands for palm oil or cattle grazing further increases the carbon emissions, so ensuring landowners have other sources of income that promote peatland preservation is important. Through these programs, farmers and land managers may collect emissions data on their own property because carbon markets and governments have programs that financially reward emission reductions; they would set up and use a flux chamber to gain information on the emissions coming from their land.

(a)

(b)

Fig. 5. Representation of the two user groups in discussion: researchers (a) and local land managers or farmers (b).

6.3 Engineering Requirements

From specifying the user groups and their intentions, we identified specific user requirements and the corresponding engineering requirements. The high priority requirements most prominently address the problem statement and the users' needs. First, the design needs to be built for its environment: the chamber needs to float (UR 1-1), return GHGs to ambient conditions prior to subsequent measurements (UR 1-5), keep the chamber leakproof while gas is being collected (UR 1-4), and withstand the weather in peatland environments (UR 2-1). Next, users need to locate the chamber (UR 2-2) so that they can pull data and replace the batteries. Additionally, the printed circuit board (PCB) needs to be accessible (UR 1-6). Finally, since researchers will be shipping the device internationally, our device must fit within dimension restrictions and not contain hazardous materials (UR 4-1). The high priority user and engineering requirements are summarized below.

1-1

- UR 1-1: Chamber must float stably on water. (Justification: Chamber will be used on bodies of water.)
- ER 1-1a: Water line must not rise above half the height of the chamber. (Justification: Above half the height of the chamber, the electronics may experience liquid ingress or the chamber may tip over.)
- ER 1-1b: The chamber must equilibrate when tilted 30 degrees from horizontal. (Justification: The chamber must return to a stable position in case of wind or water disturbance.)

1-4

- UR 1-4: Chamber must be isolated from its environment to collect gas data with minimal leakage every 5 minutes. (Justification: In order to collect accurate data over time, the chamber must not leak GHGs when not venting.)
- ER 1-4: Keep GHG concentrations from leaking more than 3% over 5 minutes. (Justification: According to our research partners, 3% is the maximum allowable leakage for the gas collection to still be accurate. In these 5 minutes, PEAT accumulates gases from the water surface below.)

1-5

- UR 1-5: Chamber must return to ambient concentrations before each gas collection period. (Justification: In order to collect accurate data, the chamber must reflect the peatland's environmental conditions.)
- ER 1-5: After collecting gases, the chamber must 'reset' to ambient GHG concentrations, or vent gases to within ± 5% of steady state values within 5 minutes. (Justification: According to our research partners, the chamber must vent to ambient GHG concentrations for the data to still be accurate, by allowing time for the humidity and temperature readings on the sensor to recalibrate.)

1-6

- UR 1-6: The data chip and batteries must be accessible by the user. (Justification: The user will need to remove the data card and batteries for data collection and replacement.)
- ER 1-6: Once the user has the device, they must be able to access the data chip and batteries within 2 minutes of opening the device. (Justification: Our users will deploy many iterations of PEAT in situ, in the 10s or 100s, and we wish to make data collection a low-maintenance process.)

2-1

- UR 2-1: The chamber must withstand weather conditions of heavy rain, humidity, and sun exposure. (Justification: The chamber must withstand the range of weather conditions in the peatlands in order to collect accurate data over time.)
- ER 2-1a: Sensors must be fully operational in conditions of 80%+ humidity. IP (Ingress Protection) rating 4: "Protected against water splashes from all directions. Limited ingress permitted." (Justification: According to the electronics' data sheets, measurements are not accurate at extremely high humidity. Limited ingress is permitted because water can exit from the hole that gas is collected in.)
- ER 2-1b: Material must resist deformation in maximum temperatures of 57°C and minimum temperatures of 2°C. (Justification: The chamber must hold its shape when exposed to continuous sunlight and heat.)

2-2

- UR 2-2: The user must be able to locate the chamber after deployment. (Justification: The users need to be able to return to the device to collect data from the device after deployment.)
- ER 2-2: Chamber must be able to be tethered to a stationary object. (Justification: Our users will deploy many iterations of PEAT in situ, in the 10s or 100s, and it is crucial that each location can be mapped to gas data points.)

4-1

- UR 4-1: Meet international shipping requirements. (Justification: Researchers ship the chambers to project partners in the field (when qty. 20+).)
- ER 4-1: Maximum combined length and girth is 108 inches. Maximum length 45 inches, height 46 inches, and width 35 inches. Cannot contain hazardous materials or be greater than 70 lbs as per USPS shipping regulation.(Justification: These are the maximum dimensions and weight for international shipping.)

6.4 Ethical Considerations

The primary ethical considerations with our project are the environmental impacts of the project and the implications of "helicopter research." Our project's goal is centered around the environment and peatland conservation. As such, we kept the possible environmental impacts in mind during our design process. In industry, there are often conflicts between cost optimization and sustainability (e.g. choice of materials). Our design for the flux chamber must be low-cost in order to maintain this goal of scalable deployment; however, low-cost materials are often mass produced in ways that are harmful to the environment and contribute to the climate crisis. Additionally, there may be material options that are produced sustainably and suit the requirements of the flux chamber design, but are mildly toxic or degrade peatlands. Throughout our design process, minimized environmental impact while maintaining low cost and adhering to the engineering requirements.

We also evaluated the downstream effects of how our device will be used. The floating flux chamber will be used in peatlands in countries such as Indonesia and Brazil. By conducting research in less developed countries, researchers often run the risk of conducting "helicopter research," or when researchers from privileged settings, such as Stanford, conduct studies in lower-income settings or with marginalized populations who are minimally involved in the research process. Peatlands are often owned by landowners and farmers in developing countries, serving as economic income and having cultural significance to locals. Without their direct involvement in the studies, researchers can overlook the effect of research on the population that is most impacted by it. We believe it is extremely important that locals are consulted for guidance on how to navigate the methods and possible effects of the Precourt Institute's research. As engineers, we do not have direct control over the future researcher-to-landowner/farmer interactions, but we communicated this concern to the Precourt Institute and highlighted the importance of local community interactions.

These ethical considerations may present themselves as out of our hands, since we are unable to predict the exact outcome of our actions. However, we believe that we can still take steps during the design process to predict areas where we might have a negative impact and make ethical decisions to minimize them. We have taken steps toward these ethical resolutions by having conversations about potential community impacts with our liaison for the Precourt Institute for Energy, as well as integrating discussions on material choices and overall engineering design within our team at every step of the project.

However, we believe the risk of intrusion into local communities and potential environmental harm is outweighed by the overall potential benefit that may come from this project. This project has the potential to shed light on GHG emissions and catalyze the implementation of legislation that will conserve peatlands, minimizing emissions and aiding in the prevention of global warming. Ultimately, the implications of this research and the positive contributions it offers minimizes the overall risks for ethical harm.

7 Design

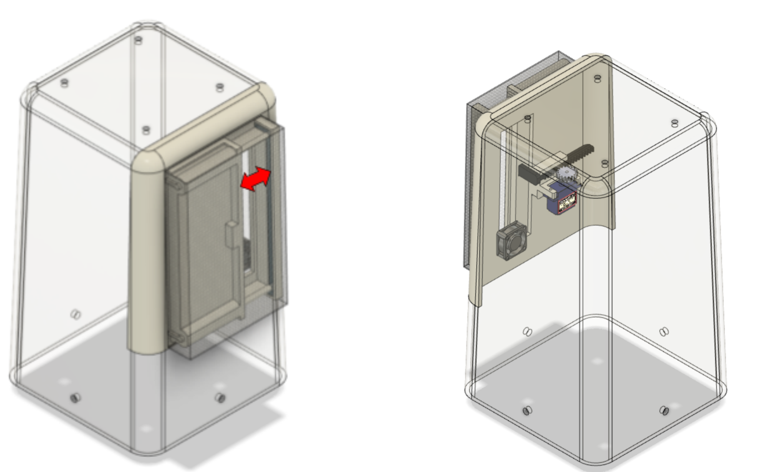
After prototyping and iterating on our design, we created PEAT: the Peatlands Environmental Assessment Tool (shown in Figure 6). PEAT's central features are: an actuated door with a fan that facilitates venting and sealing of gases, a floating base that keeps the chamber upright and stable, a sensor housing that keeps the electronics unit (provided to us by the Precourt Institute) in a safe humidity range, and a tethering clip that prevents the chamber from drifting in the water.

Fig. 6. PEAT: the Peatlands Environmental Assessment Tool incorporates venting and sealing, flotation, sensor protection, and tethering.

7.1 Design Details

7.1.1 Linear Sliding Door

PEAT's door vents gas from the chamber when opened after each data collection period. As described in ER 1-5, proper ventilation of the chamber requires the concentrations of carbon dioxide and methane gases to fall within 5% of ambient concentrations during the 5 minute ventilation period. Once the ventilation period ends, the door closes, sealing the chamber and allowing gases to accumulate for the next data collection period. The sealing of the chamber must keep gas concentrations within the chamber from leaking more than 3% over the 5 minute collection period as stated in ER 1-4. In order to meet these requirements, we designed the rack and pinion sliding door shown in Figures 7 and 8.



(a) (b)

Fig. 7. The exterior of the linear sliding door with horizontal direction of motion (a), and the interior of the linear sliding door with a rack and pinion system and fan for ventilation (b).

Wall Mount: The wall mount is the largest part in the door mechanism. On the outside of the wall are two rails on which the door slides open and closed. When open, the large rectangular window allows air flow out of the chamber. The width of this window is maximized for the complete range of motion possible by the servo motor, while the height of the chamber is designed for the largest cross sectional opening while maintaining a 4 inch distance from the bottom of the bucket to allow for the flotation attachment.

On either side of the window are extrusions with pockets filled with EcoFlex 00-20 silicone. The door slides along the rails and presses into the silicone when closed, sealing the chamber. The inside of the wall mount includes an interface for attaching the motor. Above the motor screw mounts, this feature includes a slot that holds the rack level as it slides back and forth with the door.

Attached to a large hole in the bucket via high strength, weather-resistant epoxy, the wall mount replaces most of the front wall of the chamber. Through the testing of earlier prototypes that attached the door via railed directly fastened to the bucket itself, we observed deflection of the bucket wall in response to the force applied from the door when closed. This deflection prevented

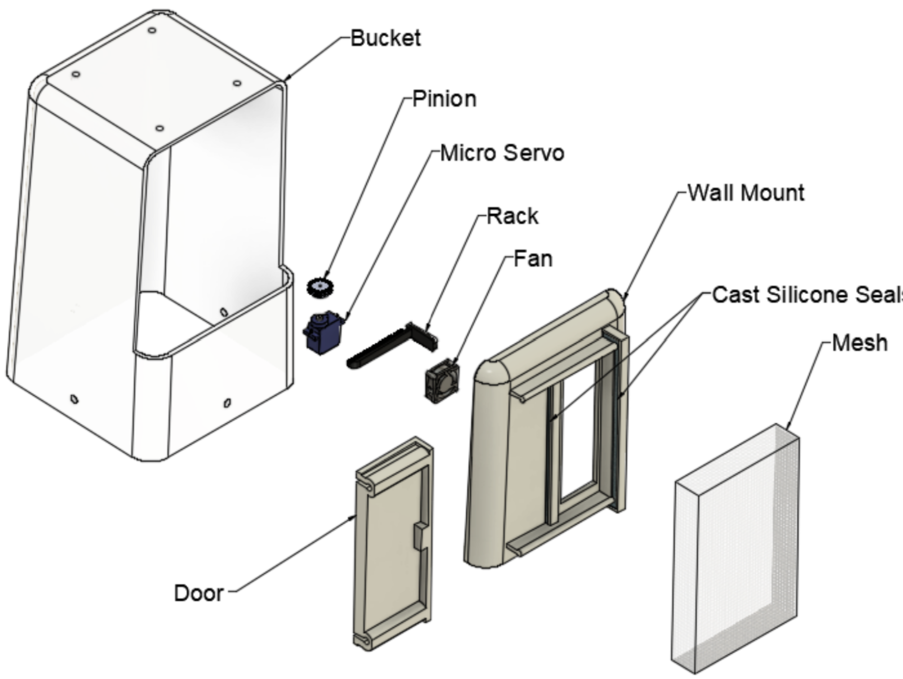


Fig. 8. Door Mechanism Components, with Bucket, Pinion, Micro Servo, Rack, Fan, Wall Mount, Cast Silicone Seals, Door, Mesh

proper sealing of the chamber. Learning from this, we incorporated the rails onto a wall mount for future design iterations. The implementation of the wall mount increases the stiffness of the interface between the wall and the door, thus increasing sealing reliability.

The wall mount is made using stereolithography 3D printing. We chose this process because of the watertight parts it can produce. Additionally, SLA prints are aesthetically pleasing as it is more difficult to see the individual layers, giving the part a smooth finish. We chose FormLab's White Resin due to the low cost compared to the other resins available to us.

Design rationale:

- We chose to replace the wall of the bucket with the door because it increases reliability, durability, and ensures less deflection when the door pushes against the silicone seals.
- We chose epoxy to secure the wall mount because of its strength and waterproof/sealing properties.
- We chose silicone as the interface between the door and the bucket when closed because of its waterproof and sealing properties.

Door: The chamber door is also made using stereolithography 3D printing with the same White Resin as the wall mount. The rectangular part includes cutouts near the top and bottom of the inside face that interface with the rails of the wall mount, allowing the door to slide open and closed. The inside face also has a pocket where the rack attaches to the door to drive its motion. On the left and right sides of the door are extrusions that fit into the silicone-filled pockets of the wall mount when the door is in the closed position. The outer face of the door is shelled to decrease material costs and weight.

Pinion Gear and Servo Motor: The rack is a narrow bar with teeth along the inner face. The cross section is designed to fit securely in the slot of the wall mount with minimal friction. At one end, a tab extrudes out to connect with the door. The pinion gear is pressed onto the shaft of the micro server. The pinion gear teeth interlock with the teeth of the rack, driving the rack and door along their linear path of motion.

Design rationale:

- The rack and pinion is easy to implement, and removes the need for a door that swings out and exposes more surface area of the chamber to wind and rain.
- In addition, the teeth of the rack keeps the door in place, limiting power consumption to only when the servo is actuated.

Lubricant: Coating the rails, a viscous lubricant seals any gaps left between the rails and door that would allow the gases to leak from the chamber. This lubricant also acts to decrease friction between the door and the rail. We chose this grease because it is waterproof, plant-based, and biodegradable.

Fan: Attached to the top right corner of the window is a small fan. Through forced convection, this fan increases the airflow through the window, thus decreasing the time required to vent the chamber to acceptable concentrations. Through previous prototype testing, we concluded that a fan was needed to meet our ventilation requirement of 5 minutes.

Mesh: Covering the outside of the door mechanism, a thin wire mesh prevents debris from catching on the rails or in the window, preventing the door from sealing.

7.1.2 Foam for Flotation

PEAT includes a ring of foam around the outside base of the chamber for stability and flotation on water. We chose Foamular® 250 Extruded Polystyrene as the material because it is lightweight, strong, and buoyant (polystyrene is a common material used in surfboards). In particular, the volume of low density foam at the base would displace water equal to the weight of the chamber system per Archimedes's Principle and the equilibrium of forces. We tested PEAT's ability to float in still water (a bathtub), under wavy and rainy conditions (a fountain), and in-situ-like conditions (Lake Lagunita) as seen in Figure 9. We added counterweights hanging from the bottom of the

(a) (b) (c)

Fig. 9. Different flotation prototypes tested in various conditions such as a) a bathtub, b) Old Union fountain, and c) Lake Lagunita.

chamber, as seen in Figure 10, to lower the center of mass and prevent tipping. By lowering the center of mass, PEAT is less likely to tip by creating a restoring moment. Each 100 gram weight is stainless steel, to prevent corrosion in water over multiple deployments. This design aimed to have PEAT float stably on water in order to meet user requirement UR1-1 and engineering requirements ER1-1a and ER 1-1b.

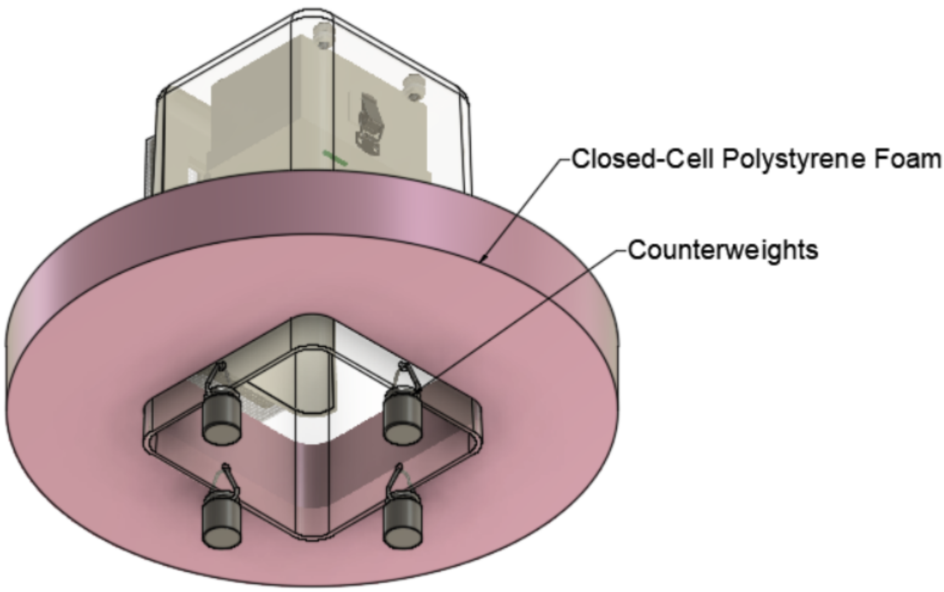


Fig. 10. Foam base made of extruded polystyrene foam with 15.5 inch diameter. Stainless steel counterweights hang 1 inch from the bottom of the chamber, weighing 100 gram each, to prevent PEAT from tipping over.

7.1.3 Sensor Weatherproofing

As described in ER2-1, the flux chamber must be able to collect data under weather conditions of heavy rain, humidity, and heat. Material choice and chamber structure address protection from thermal radiation from the sun and water ingress from rainfall. However, the electronics' performance is vulnerable to humidity: the sensing unit, consisting of the PCB, GHG sensors, and batteries, must not exceed 80%+ relative humidity for an extended period of time. To address this vulnerability, we designed a housing, shown in Figure 11, that protects the sensing unit, shown in Figure 12, and mounts it to the top of the chamber using o-rings to seal the mounting holes. Additionally, the housing uses desiccant (a drying agent) to absorb moisture through holes in the grid that secures it in place, keeping the humidity within the housing below 80%. The housing lid features a cast silicone seal around the inner lip that seals the housing when latched onto the base. The lid also features holes that allow the sensors to protrude from the housing in order to collect data on the gas concentrations in the chamber. Similar to the door mount, the sensor housing was made using White Resin from stereolithography 3D printing because of its strong and waterproof properties.

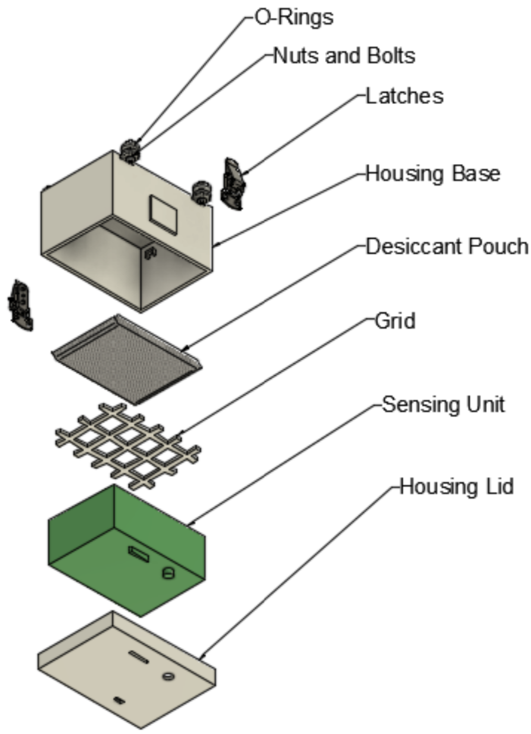


Fig. 11. Sensor housing exploded view in CAD.

Fig. 12. Sensing unit provided by the Precourt Institute for Energy. The sensor is mounted to the battery pack, and integrated with the housing assembly.

7.1.4 Tethering

We used a metal mount attached to the side of the chamber as a tethering interface as shown in Figure 13. This mount allows the user to tie one end of a rope or other tether to the chamber and the other end to a tree, stake, buoy, or other object depending on what is available to them in the nearby environment. By providing a tethering interface, we give the user the needed connection to successfully meet ER 2-2. The metal hoop provides a simple connection to a variety of tethering options. This simplicity allows the user to pick a tether that is best suited for their specific deployment environment and needs.

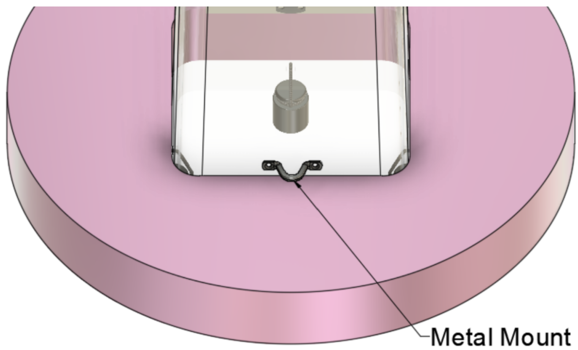


Fig. 13. Tether Design CAD Detail

7.2 Calculations, Simulations, and Analysis

7.2.1 Finite State Diagram of PEAT's Functions

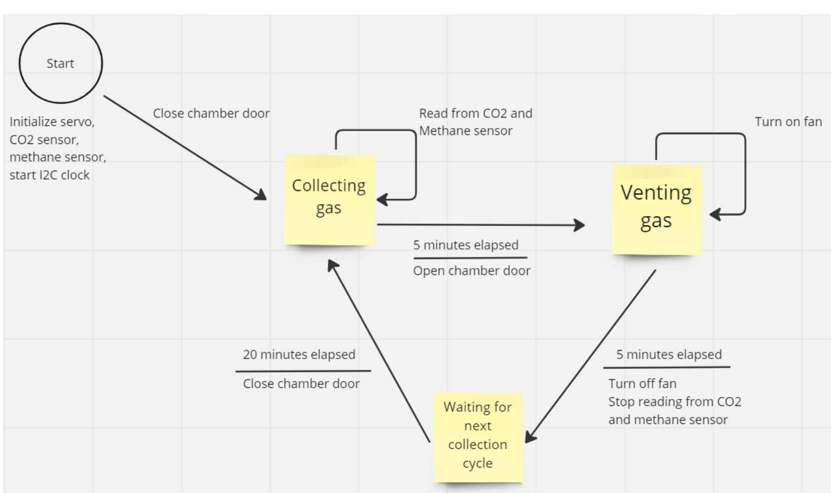


Fig. 14. A finite state diagram that describes PEAT's functionality and measurement cycle, which repeats every 30 minutes.

7.2.2 Energy Draw of Electronic Components

We used the datasheets of all electronic components to determine if PEAT could satisfy ER 1-2, or operation of least 2 months without battery replacement. Based on the worst case power draw, we could only guarantee that PEAT could operate for 32 days on 3x D batteries.

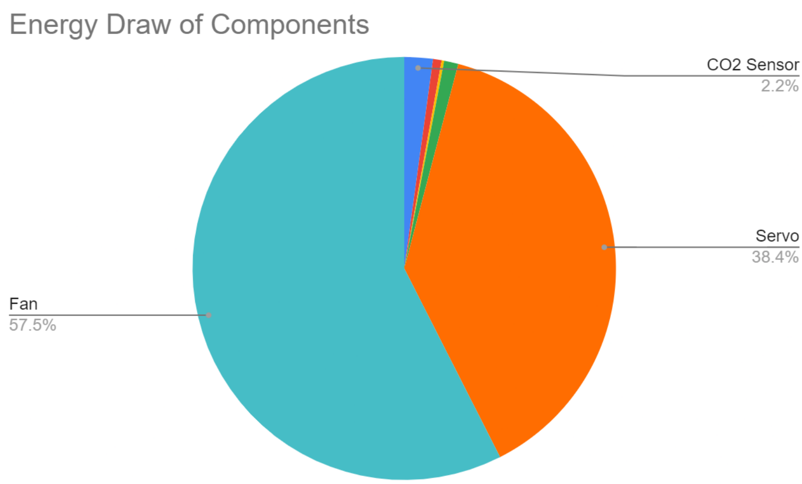


Fig. 15. This pie chart shows that PEAT's largest energy expenditure comes from running the fan for 5 minutes, followed by operating the servo, followed by the CO2 sensor.

Component	On Current [mA]	Off Current [mA]	Duty Cycle %	Avg Current [mA]	Days on 3x AA	Days on 3x D
Figaro TGS2611: Methane Sensor	60.00	0.00	0.10	6.00	20.8	156.25
SCD30: CO2, Temperature, Humidity Sensor	5.000	0.00	0.10	0.50	250.0	1875.0
DS32131: I2C Real-Time Clock	0.150	0.15	1.00	0.15	833.3	6250.0
Atmega328P: Microcontroller	3.500	0.01	0.01	0.045	2783	20879
SD Card	20.00	0.05	0.01	0.250	501.0	3757.5
SG90: Servo	700.0	5.00	0.005	8.82	14.16	106.26
YDM4010B05: 5V Brushless Cooling Fan	200.0	0.00	0.066	13.2	9.47	71.0
TOTAL				28.9	4.31	**32.3**

Table 1. Table of calculations showing how each component contributes to battery drain. These estimates for the battery capacity are reflective of standard batteries (Energizer E95 D batteries) that would be available locally, operating in the temperature range of -18°C to 55°C.

7.2.3 Flotation and Buoyancy Calculations

To determine the necessary foam diameter for PEAT's stability, we sketched two free body diagrams of the prototype, one with the untitled flux chamber (shown in Figure 16) and one with the flux chamber tilted at angle θ from the water surface (shown in Figure 17) due to the surface water's strong currents or changing wind speeds that could destabilize the flux chamber. First, we calculated what the new center of mass would be given additional counterweights hanging 1 inch from the bottom of the bucket. Here, m represents 2x counterbalance weights:

$$m_1 = m_2 = 200g$$

Assuming the bucket mass is negligible:

$$Y_G = \frac{m_1 * y_1 + m_2 * y_2 + m_{sensor} * y_{sensor} + m_{door} * y_{door}}{m_1 + m_2 + m_{sensor} + m_{door}}$$

$$Y_G = \frac{200g * 1in + 200g * 1in + 750g * 10in + 300g * 7in}{200g + 200g + 750g + 300g}$$

$$Y_G \approx 7in$$

Using the new center of gravity taking into account the counterweights, we have the free body diagram seen below in Figure 16. Gravity acts on the center of gravity and the buoyant force acts on the center of buoyancy, which in this case is half the height of the foam.

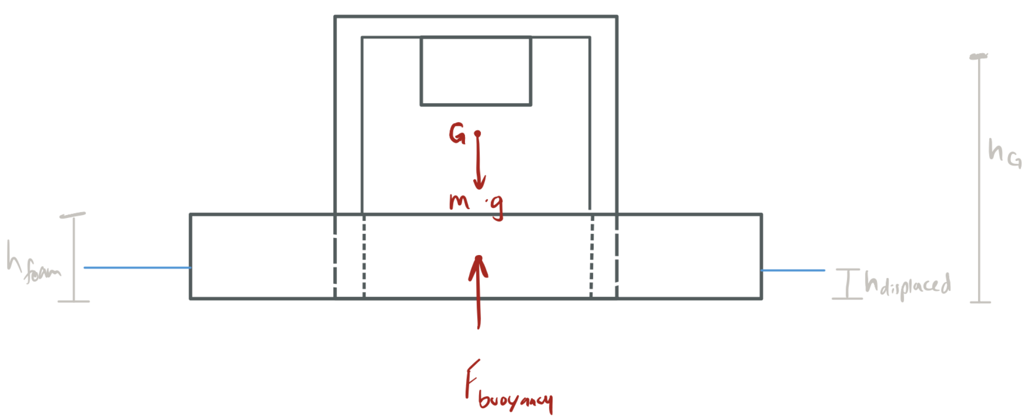


Fig. 16. Simplified free body diagram showing forces acting on a prototype with foam attached to the outside of the chamber base, in an untitled state.

The force balance equation for the untilted chamber provides an equation for the diameter of the foam in terms of the mass of the sensor m_{sensor}, mass of the door m_{door}, mass of the weights $m_{weights}$, height of water displaced $h_{displaced}$, width of the bucket w, length of the bucket ℓ, density of water ρ_{water}, and volume of water displaced by PEAT $V_{waterdisplaced}$.

$$\sum F_y = 0 \longrightarrow F_{gravity} = F_{buoyancy}$$

$$\longrightarrow (m_{door} + m_{sensor} + m_{weights}) * g = \rho_{water} * V_{waterdisplaced} * g$$

$$\longrightarrow 1450g = 16.39g/in^3 * V_{waterdisplaced}$$

$$V_{waterdisplaced} = 88.47in^3$$

Where

$$V_{waterdisplaced} = (\frac{\pi}{4} * D_{foam}^2 * h_{displaced}) - (w * \ell * h_{displaced})$$

Assuming the foam height is the maximum that could be displaced,

$$h_{displaced} = 2in$$

$$V_{waterdisplaced} = (\frac{\pi}{4} * D_{foam}^2 * 2in) - (7.5in * 7.5in * 2in)$$
$$D_{foam} = 11.31in$$

Our calculations show that as long as the weight of PEAT and the buoyancy force are equal, PEAT will remain stable and not sink. To ensure this, a minimum foam diameter of 11.31 inches is required. We must also confirm PEAT's stability by finding the minimum diameter needed for the restoring moment to return the chamber to stability when tilted.

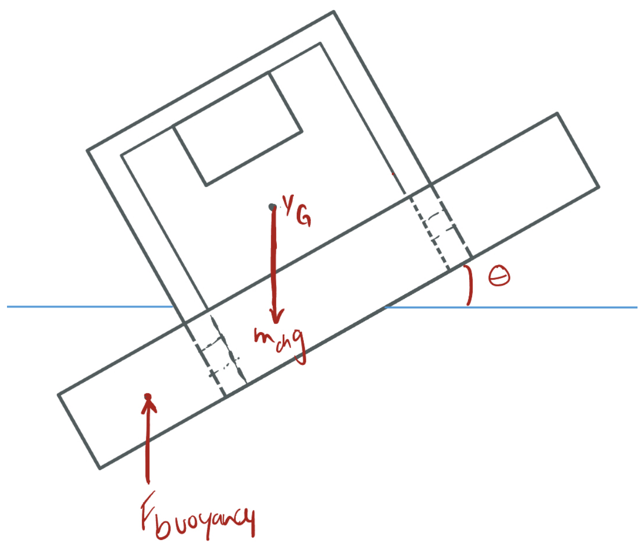


Fig. 17. Free body diagram showing forces acting on a prototype with foam attached to the outside of the chamber base, tilted at an angle θ from the water surface. The length $\ell_{F_b}G$ represents the distance from G the center of gravity to the center of buoyancy.

$$\sum M_g = F_{buoyancy} * \ell_{F_b}G * cos(\theta)$$

By taking the moment balance about the center of gravity, we concluded that the larger the distance from the center of gravity to the center of buoyancy, the larger the moment to restabilize the flux chamber. One way to increase the distance is to increase the diameter of the foam. To determine the ideal foam diameter for stability, we considered the metacentric height, or the point where a vertical line drawn upwards from the new center of buoyancy from tipping intersects the line of symmetry of the body. More importantly, the value of the metacentric height must be greater than zero to ensure stability. The metacentric height formula is

$$MG = \frac{\ell}{V_{displaced}} - (y_G - y_{F_{buoyancy}})$$

Where

$$y_{F_{buoyancy}} = (\frac{D}{4} - \frac{w}{4} * sin(\theta)$$
$$y_G = 7in$$

$$I = \frac{\pi * D_{foam}^4}{64} - \frac{w * \ell^3}{12}$$

Assuming half the foam is submerged underwater while it is tipped,

$$V_{displaced} = \frac{m}{\rho_{water}} = \frac{\frac{\pi}{4} * D_{foam}^2 * h_{displaced} - w * \ell * h_{displaced}}{2}$$

To check that our previously calculated diameter is stable, we plugged in the known values to the equation for MG. Assuming an angle of 80 degrees:

$$MG = \frac{I}{V_{displaced}} - (y_G - y_{F_{buoyancy}})$$

$$0 < \frac{I}{V_{displaced}} - (y_G - y_{F_{buoyancy}})$$

$$0 < \frac{\frac{\pi D_{foam}^4}{64} - \frac{w * \ell^3}{12}}{\frac{m}{\rho_{water}}} - 7in - (\frac{D}{4} - \frac{w}{4}) * sin(80)$$

$$\rightarrow 0 < 0.036$$

We confirmed that a flux chamber with the chosen foam diameter was stable. To ensure stability at higher tipping angles caused by waves, rain, or heavy debris, we chose a factor of safety of 3, and even with this additional safety factor, PEAT would still be stable.

$$FOS = 3 = \frac{m_{tot}}{h_{displaced}} = \frac{2in}{h_{displaced}}$$

$$V_{displaced} = \frac{m}{\rho_{water}} = \frac{\frac{\pi}{4} * D_{foam}^2 * h_{displaced} - w * \ell * h_{displaced}}{2}$$

$$\rightarrow 88.47in^3 = \frac{\frac{\pi}{4} * D_{foam}^2 * 0.67in - 7.5in * 7.5in * 0.67in}{2}$$

$$D_{foam} \approx 15.5in$$

$$MG = \frac{I}{V_{displaced}} - (y_G - y_{F_{buoyancy}})$$

$$0 < \frac{I}{V_{displaced}} - (y_G - y_{F_{buoyancy}})$$

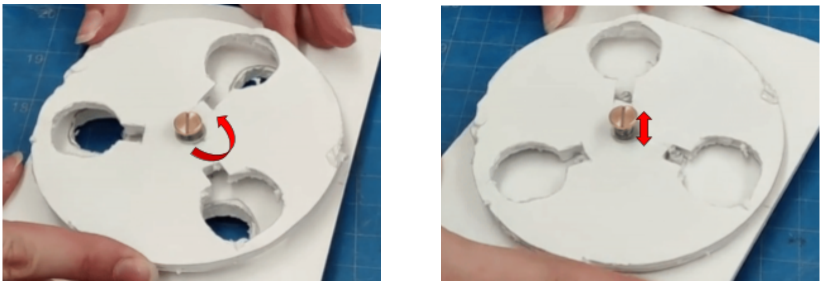
$$\rightarrow 0 < 24.01$$

Thus, 15.5 inch foam diameter is stable and fits within our dimensional constraints for shipping as per requirement UR 4-1. To prevent high material costs, we used the smallest foam diameter with a factor of safety we deemed appropriate given the risk of losing data if PEAT were to become unstable.

7.3 Prototypes

7.3.1 Door Mechanism Prototypes

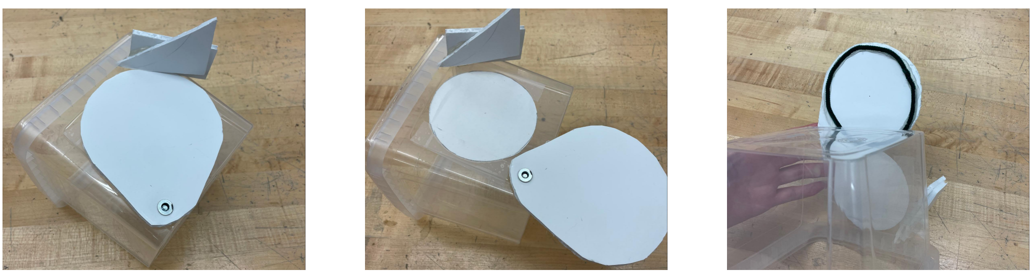
When designing our door mechanism, we began by brainstorming ideas before moving on to rapid prototyping. Our first prototype, shown in Figure 18, was inspired by the rotating lids on some salt shakers. Our "salt shaker" prototype door is made of two foamcore plates, one representing the bucket wall and the other the door. The plates are attached via a pin in the center with a spring that pushes the door into the wall for sealing. The wall includes three holes for venting, and the door features three corresponding openings. When rotated so the holes line up, air can escape the chamber and pins on the wall push the door away from the wall. When rotated to seal the door, these pins fit into notches on the door, allowing the spring to press the door against the wall to seal the chamber. While this design was promising, the maximum venting outlet area was insufficient to properly vent the chamber.



(a) (b)

Fig. 18. "Salt shaker" door mechanism prototype

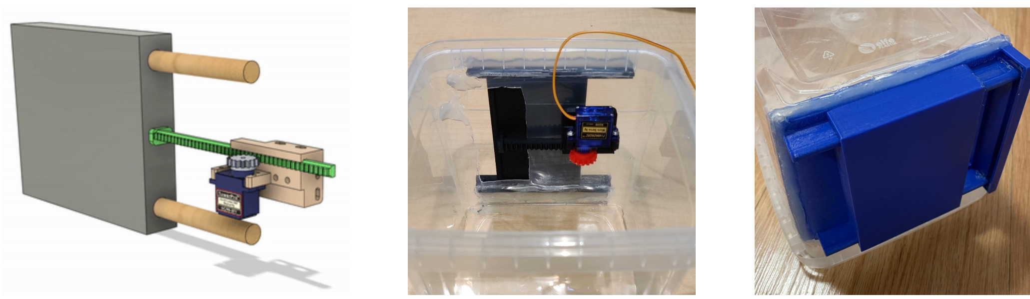
Our second rapid prototype, shown in Figure 19, featured a rotating door. As the door rotates closed, a ramp interface pushes the door into the chamber wall. On the interior of the door, an o-ring (represented by a pipe cleaner) seals the chamber. However, we decided to move away from this design because of the negative interactions that would occur between the door and wind. When opened, the door sticks up above the chamber, acting as a sail to catch the wind and resulting in unwanted forces on the chamber.



(a) (b) (c)

Fig. 19. Rotating door rapid prototype

Additionally, we iteratively prototyped a sliding door actuated by a rack and pinion (Figure 20). Initially, we prototyped a stand alone door mechanism to see how it functioned. After altering the design to fit within the dimensions of the bucket, we mounted the door for testing. Our next iteration on the design included the wall mount and changed rail interface along with pockets on the wall mount for sealing. These prototype iterations led to our final door design.

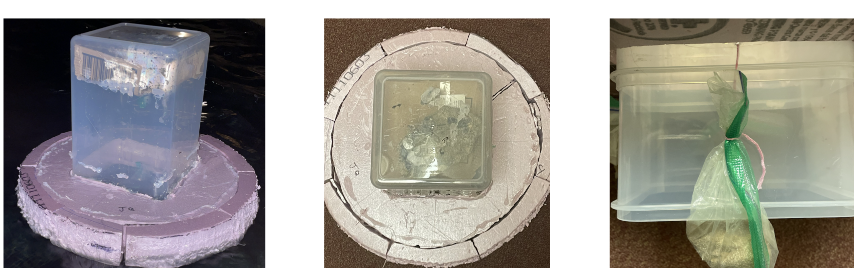


(a) (b) (c)

Fig. 20. Sliding door design iterations

7.3.2 Foam Base Prototype

To test chamber flotation and stability, we assembled the prototype in Figure 21. A 450 gram rock was used to simulate the weight of the PCB and batteries, while a plastic bag with 250 milliliters of water was used to simulate the weight of the venting door. Below the foam base, a counterweight of 100g each was hung from each side of the bucket. The counterweights were made using rocks inside a Ziploc bag. To see how well the prototypes achieved each of the user requirement and engineering requirements goals, three tests were designed as described below.



(a) (b) (c)

Fig. 21. The flotation prototype was constructed by attaching a 15.5 in. diameter ring of Foamular 250 pink foam to the outside base of a 7.5 in x 7.5 in square bucket using hot glue. We attached cardboard under the rock to ensure the 450 gram rock would stay in place. A Ziploc bag with 250 milliliters of water was also glued to a side of the bucket to simulate the mass of the venting door.

7.4 Experimental Plan/Test Setups

7.4.1 Flotation and Self-Righting

Objective: What is PEAT's ability to remain stable in water? We hypothesized that our calculated foam geometry would be able to 1) stay afloat and 2) stabilize after being tilted at a certain angle. To confirm this, we ran the following tests:
Test 1:

(1) Place the chamber in a body of water deeper than 12 inches so results are not affected by the prototype touching the bottom.
(2) Measure the water height relative to the bottom of the foam base with a ruler and record the result.
(3) Observe the chamber for 10 minutes (Figure 22) and remeasure the water height to see if the chamber sank.

Fig. 22. Flotation prototype left in water for 10 minutes.

Test 2:

(1) Place the chamber in a body of water deeper than 12 inches so results are not affected by the prototype touching the bottom.
(2) Tilt the chamber 5 degrees from the horizontal.
(3) Release the chamber and make note of the chamber's response. (Does it stabilize? If so, how long does it take to stabilize? Did it flip over?)
(4) Repeat steps 1 through 3, increasing the angle at 5 degree intervals (Figure 23) until the chamber flips when released.

Fig. 23. Flotation prototype being tilted in water.

Test 3:

(1) Place the chamber in a body of water deeper than 12 inches so results are not affected by the prototype touching the bottom.
(2) Move the chamber under the rain (in this case water falling from a fountain) and start a 10 minute timer. Ensure that the chamber is kept under rainfall for the duration of the timer.
(3) After 10 minutes, measure the water level relative to the foam base.
(4) Repeat steps 1 through 3, 2x more times for a total of 30 minutes under rainfall.

Fig. 24. Flotation prototype under "rainfall" in Old Union Fountain.

7.4.2 *Chamber Venting*

Objective: While the chamber door is open, how long does it take PEAT to equilibrate CO2 concentrations relative to ambient? We hypothesized that opening the chamber door and turning on the fan would be sufficient to return the concentration of CO2 to a level (within 5% of the steady state value) that is acceptable for our users' sensor measurements within 5 minutes of ventilation.

Equipment: bucket, 3D printed door + rack + pinion, SG90 Servo, Arduino Uno (see Appendix H for schematic) , Memmert Climate Chamber

(1) Place PEAT (with CO_2 sensor) in the Memmert Climate Chamber* at 80% humidity, 35°C. These conditions simulate worst-case conditions in natural peatlands, in which the environment is hot and humid.
(2) Leave PEAT's lid ajar. Breathe into the chamber entrance 5 times, creating an initial CO_2 concentration.
(3) Fully open PEAT's door and turn on the fan (Figure 25).
(4) Record the CO_2 concentration over time for 6 minutes. Plot CO_2 concentration (ppm) vs. time elapsed (seconds). Compare with average ambient CO_2 concentration.

*Memmert Climate Chamber: Automated enclosure used to simulate user-specified environments. The user can set a specified temperature and humidity for the chamber. Humidification is created by a hot steam generator that uses distilled water from an external tank. The humidity setting accuracy is 0.5%.

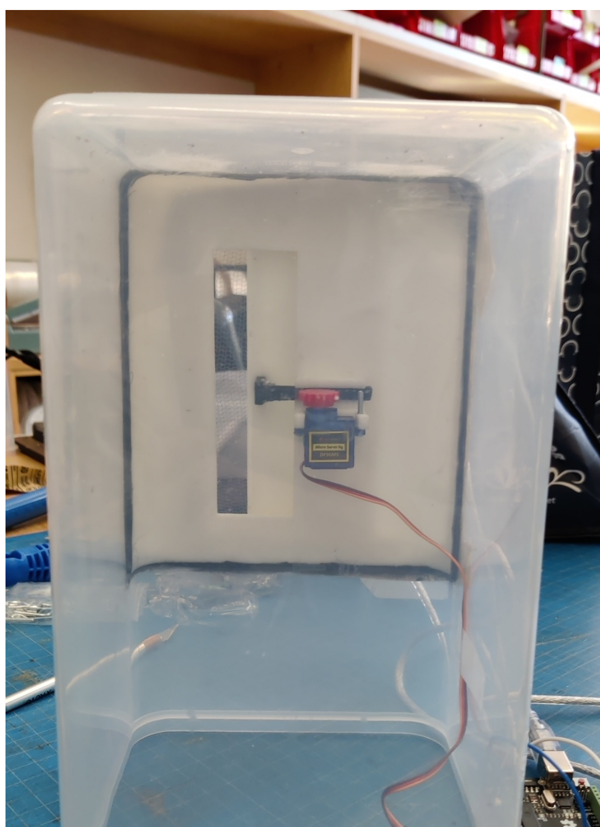


Fig. 25. PEAT in the venting state, with servo keeping the door closed.

7.4.3 *Chamber Sealing*

Objective: While the door is closed: can PEAT keep CO_2 concentrations from leaking >3% over 5 minutes? We hypothesized that the chamber door would keep leaking under 3% to allow for gases to accumulate sufficiently.

Equipment: bucket, 3D printed door + rack + pinion, SG90 Servo, ArduinoUno (see Appendix H for schematic), Memmert Climate Chamber

(1) Repeat steps 1-2 of the previous experiment, keeping PEAT's door closed instead of open and the fan off (Figure 26).
(2) Record the CO2 concentration over time for 6 minutes. Plot the CO2 concentration over ambient (normalized ppm) vs. time elapsed (seconds).

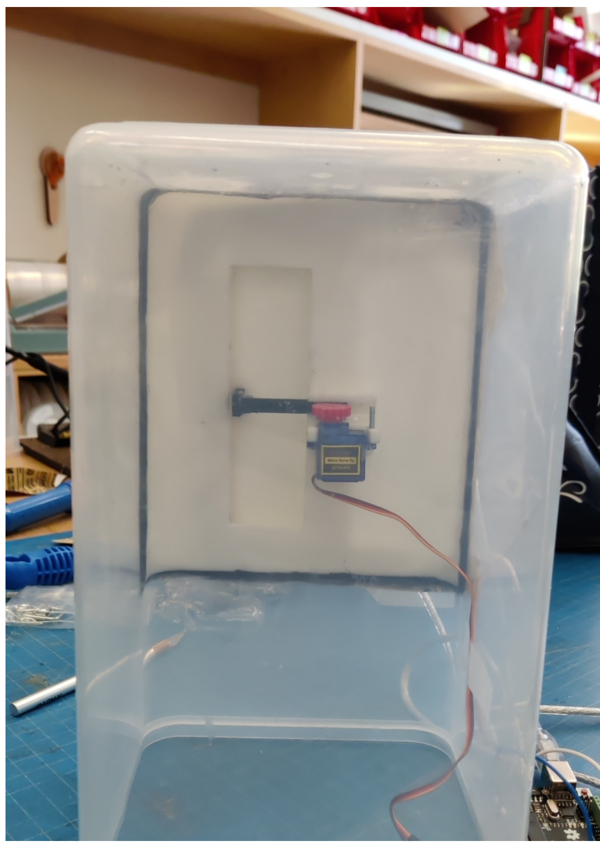


Fig. 26. PEAT in the sealing state, with servo keeping the door closed.

7.4.4 Sensor Housing

Objective: Understand how the different ways of housing the PCB or using absorbent materials (such as desiccant) could impact its relative humidity (RH).

$$RH = \frac{\rho}{\rho_s}$$

Relative humidity ρ is defined as the vapor pressure in the air divided by the saturated vapor pressure ρ_s. To decrease the relative humidity, the vapor pressure can be changed proportionally. One way of doing this is to use a material or device that absorbs or transfers moisture out of the air; in our prototype, we used desiccant. In this experiment, we varied the geometry of the enclosure and amount of absorbent materials and measured how relative humidity changed as a result.
Setup:

(1) Measure the dimensions of the SensorPush sensor**.
(2) Design and iterate on a sensor housing (Figure 27) after repeating the experiment.
(3) 3D print the housing using PLA (Figure 28).

**SensorPush Humidity Sensor: A 40mm x 40mm x 16.5 sensor that monitors humidity and transfers the data to one's cellular device. Humidity accuracy is ±3% typical, ±4.5% maximum for 20%-80% relative humidity.

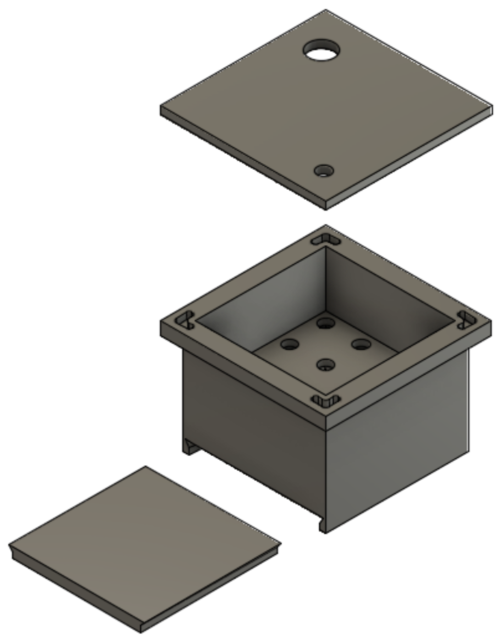


Fig. 27. Sensor test housing CAD exploded view. The top half fully fits the sensor and has a corresponding lid, the bottom half has room to hold desiccant packets, and the top and bottom halves are separated by a thin wall with holes to allow the humid air to reach the packets of desiccant.

Experiment:

(1) Connect the SensorPush humidity sensor to a mobile device.
(2) Place the SensorPush sensor in the housing with NO desiccant packets (this acts as the control group).
(3) Set the Memmert climate chamber to 35°C with 80% humidity. These conditions simulate worst-case conditions in natural peatlands, in which the environment is hot and humid.
(4) Place the housing in a climate chamber while the humidity is still low.
(5) As the humidity in the climate chamber climbs, record both the humidity of the climate chamber and record the relative humidity of the sensor in the housing.
(6) Once humidity reaches 80%, remove the housing from the chamber and air out the climate chamber to lower the humidity.
(7) Place one packet of desiccant in the housing and repeat steps 2-6 to collect further data.
(8) Once humidity reaches 80%, remove the housing from the chamber and air out the climate chamber to lower the humidity.

(9) Remove the desiccant and cover the inlet with tape.
(10) Remove the housing from the climate chamber and turn the climate chamber off.

(a) (b)

Fig. 28. a) SensorPush, the relative humidity sensor, in the upper housing and b) the bottom half of the housing where desiccant is integrated.

7.4.5 Desiccant Life Span Test

Objective: After reviewing the results of testing and concluding that the integration of desiccant would allow the humidity inside of the PCB housing to meet the engineering requirements (ER2-1a), we conducted an experiment to determine if the amount of desiccant in a single packet would become ineffective after one month in worst-case peatland environments.

In order to identify if desiccant could remain effective in absorbing humidity after one month, we conducted an accelerated weathering test, by simulating 1 month of peatlands conditions through 9 hours of a fan pushing humid air through color-changing desiccant (Figure 29). In other words, the independent variable was time in which humid air was blown through the chamber, and our dependent variable was desiccant quality. We hypothesized that one desiccant packet would be sufficient in one month of peatlands environments.

Supporting calculations:

Air velocity (distance traveled per unit of time) is usually expressed in Linear Feet per Minute (LFM). By multiplying air velocity by the cross section area of a duct, one can determine the air volume flowing past a point in the duct per unit of time. Volume flow is measured in Cubic Feet per Minute (CFM).

An average wind speed of 1 m/s results in 0.56 CFM with PEAT's inlet geometry. Additionally, the door is opened 5 minutes and closed for 25 minutes.

$$\text{1440 minutes/day /30 minutes } = 48/\text{day}$$

$$48/\text{day } * \text{5 minutes } = \text{240 minutes / day}$$

$$\text{24 minutes/day } * \text{31 day/month } = \text{7440 minutes}$$

$$\text{.56 CFM } * \text{7440 minutes } = 4166.4\text{ft}^3$$

The fan has 7.56 CFM,

$$\frac{41.66ft^3}{\text{7.56 CFM}} = \text{551.5 minutes}$$

$$\frac{551.5 \text{ minutes}}{60 \text{ minutes/hour}} = 91.9 \text{ hours}$$

Setup:

(1) Fill a porous bag with indicating desiccant.
(2) Measure the dimensions of the fan, and cut a hole the size of the fan in the center of the lid.
(3) Drill holes in the bottom of the bucket for ventilation.
(4) Use superglue to adhere the mesh to the sides of the interior of the bucket to create a platform for the desiccant packet.

Experiment:

(1) Weigh the desiccant packet.
(2) Turn on the fan.
(3) Place a testing bucket (with desiccant) in the Memmert climate chamber at 90% humidity, 35°C.
(4) After time periods of 10 minutes / 1 hour / 9 hours, remove the bucket from the humidity chamber.
(5) Take off the lid and obtain the desiccant packet. Observe any saturation and weight differences.

Fig. 29. Desiccant Accelerated Weathering Test Setup

7.5 FMEA Summary

Based on our FMEA report (see appendix D), the top three risks to PEAT's design were: 1) ensuring that PEAT adequately seals and vents gases 2) ensuring that our housing geometry could protect sensors from liquid ingress and 3) developing a method for PEAT to stay in the same location. These risks were prioritized based on their likelihood of failure and the effects of their failure. Our final design addressed these concerns through the following:

(1) Adding a silicone seal, improving the rails on the rack and pinion, adding grease to the door design to improve chamber sealing, and adding a fan to ensure proper venting of gases for data collection.
(2) Conducting humidity testing with color-coded desiccant to simulate peatlands' conditions, and increase the size of the bucket to allow for the integration of the sensor housing to the chamber without risk of liquid ingress.

(3) Attaching a metal clip to PEAT so that researchers can use a rope to tether the device to a stationary object, such as a tree or a pole.

8 Results and Discussion

8.1 Summary of Findings

Our findings showed that:

- PEAT can float and stay stable when rotated 70 degrees from horizontal.
- PEAT can adequately vent gases during data collection.
- PEAT can adequately accumulate and seal gases during data collection.
- PEAT's sensor housing can keep humidity below 80%.
- The amount of desiccant in PEAT's housing will last for at least 1 month.

8.2 Test Results

8.2.1 Flotation and Self-Righting

We hypothesized that the prototype would be stable due to its wide base and given the factor of safety of 3 used to calculate the foam diameter. During Test 1, the prototype immediately floated with the waterline at no more than 0.5 inch from the bottom of the foam. Waves from the fountain caused fluctuations in this measurement, but the waterline never went past 0.75 inch and remained consistent after the 10 minute waiting period. During Test 2, the prototype successfully stabilized when we tilted it up until approximately 70 degrees from horizontal. It took about 1-2 seconds for the prototype to restore stability after it was tilted. At 70 degrees, the prototype became unstable and would tip over. Finally, Test 3 results showed that after 30 minutes, the water height only increased 0.25 inch more than before the test. Because this was seen at the beginning of the test, we presume it is due to initial water puddling on the prototype or between the foam and the bucket.

The results of these tests showed that foam diameter of 15.5 inches was sufficient for keeping the chamber upright, given the mass of the PCB, batteries, and venting door. The foam ring around the outside of the base prevented it from flipping over even when tilted over 70 degrees from the horizontal which meets the minimum 30 degree requirement. This does not take into account the small waves the fountain caused, showing that even at an angle with strong currents, the chamber still restored itself to stability. The prototypes were successful in meeting UR1-1, ER1-1a, and ER1-1b.

8.2.2 Chamber Venting

Venting was successful: CO_2 returned to ambient concentrations (within 5% of the ambient concentration of 658 ppm) within 5 minutes through the use of a fan and a sufficiently large outlet, as shown in Figure 30.

8.2.3 Chamber Sealing

Sealing was successful: The concentration of CO_2 leaked less than 3% over 5 minutes through the use of the sliding door mechanism with rails, and grease to keep leakage out, as shown in Figure 31.

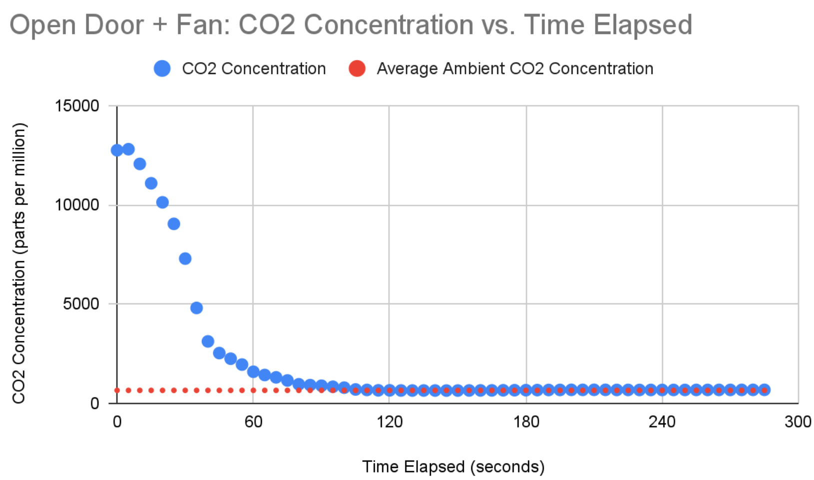


Fig. 30. This plot shows the decay of CO2 over a 6 minute time period, in which CO2 concentration measurements were taken by the sensor every 5 seconds. With the fan and open door, PEAT was able to return CO2 concentrations to ambient conditions within 2 minutes.

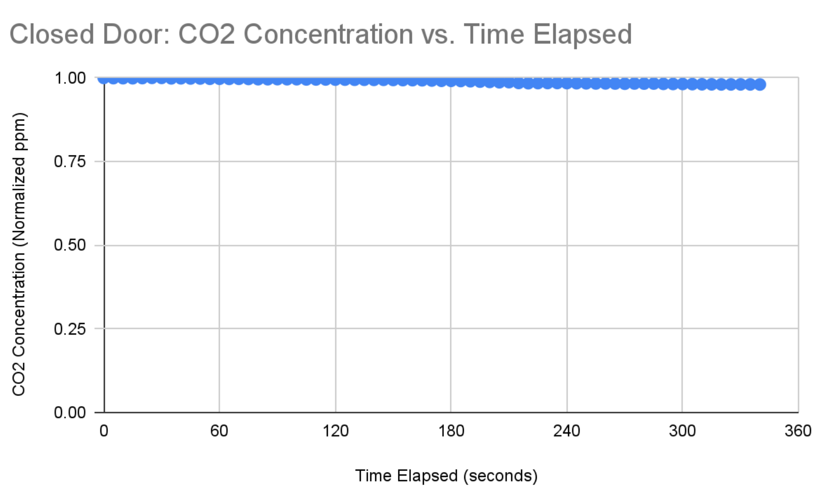


Fig. 31. This plot shows the decay of CO2 over a 6 minute time period, in which CO2 concentration measurements were taken by the sensor every 5 seconds. With PEAT's door closed and sealed, PEAT was able to prevent >3% of CO2 from leaking. After 5 minutes, 98% of the initial CO2 concentration remained.

8.2.4 Sensor Housing

Through this prototype, we obtained a better understanding of how to keep the PCB under the 80% RH requirement via a semi-enclosed space. The trendline for the control group was linear, validating a close linear relationship between the relative humidity of the sensor by itself and the external air (in this case the external air was the air in the Memmert climate chamber). In the control group, the sensor simply recorded the humidity of the chamber (blue curve in Figure 32). The second test case examined the humidity inside an enclosure with desiccant (orange curve in Figure 32). This test was motivated by the understanding that desiccant could absorb some of the moisture in the air and lower the humidity of the surrounding air. In this case, the relationship between the recorded relative humidity and the chamber humidity shifted and the relationship was no longer linear. The housing and desiccant lowered the recorded relative humidity. Although these tests were conducted in a controlled climate chamber, the temperature fluctuated ±3°C as the humidity was being recorded. This may have slightly altered the relative humidity recorded, as temperature affects relative humidity. However, multiple tests were conducted to account for these possible discrepancies.

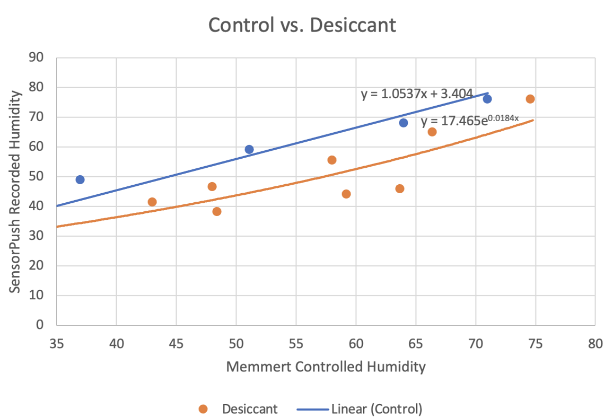


Fig. 32. Plot of SensorPush Recorded Humidity vs. Memmert Controlled Humidity, comparing the control group (without desiccant, in blue) and with desiccant (in orange).

Through covering one of the inlets on the top of the sensor housing lid (shown in Figure 33), the relative humidity decreased significantly. Our project's goal was to keep the PCB's humidity to below 80% humidity and this testing shows initial success, since the relative humidity inside the sensor box remained between 50% and 77% humidity in the climate chamber. These tests revealed that when prototyping for the actual PCB housing, it was pertinent that we 1) minimized the amount of inlet surface area and 2) since tropical wetlands have high humidity, integrated a larger amount of desiccant.

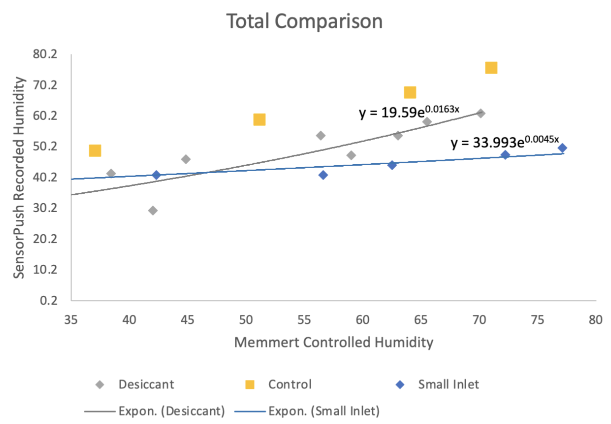


Fig. 33. Plot of SensorPush Recorded Humidity vs. Memmert Controlled Humidity, comparing the control group (without desiccant, in blue) and with desiccant (in orange).

8.2.5 Desiccant Lifespan

We simulated what a desiccant packet would experience through a month of peak peatland environmental conditions in a 9 hour time span. The desiccant beads after this time period showed an increase in saturation (Figures 34 and 35). The weight increased 2.1 grams, around 7% of its initial weight. Additionally, after opening the desiccant packet, many of the beads changed from dark blue to a range from light blue to dark pink/brown (indicating fully saturated beads). Less than 3% of the beads were fully saturated, the other 97% were either unsaturated entirely or approximately 20% saturated, revealing that they would remain effective for a longer period of time. From this information, we concluded that using desiccant would meet the requirements for lowering relative humidity of the PCB for one month. However, as part of the maintenance of PEAT, the user will need to replace the desiccant packet with a new one once a month.

Fig. 34. Desiccant beads after 9 hours of accelerated weathering. After 9 hours, there was minimal weight change. Additionally, if all of the desiccant was fully saturated, all of the beads would look pink. Instead, there were still many blue and dark blue beads, which indicated that the packet was not fully saturated, and that one desiccant packet would last at least one month.

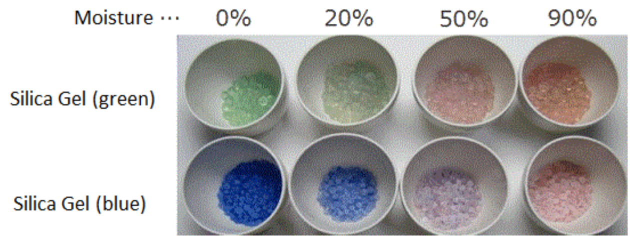


Fig. 35. Saturation indicator color chart for reference. For blue desiccant, the color becomes purple and then faded pink as saturation increases.

8.3 Implications of Experiments

The results of these experiments indicate that PEAT can serve as an AFC that is capable of floating in peatlands, collecting greenhouse gases and monitoring them, resisting humidity, temperature, and wind, and is easily locatable. The chamber's ability to resist its environment is crucial for accurate gas flux measurements.

From the flotation tests, PEAT's ability to stay upright in the presence of waves ensures that the chamber remains stable and does not drift away. In addition, PEAT's weatherproof design, which preserves its sensors and mechanical components even in rain, ensures that the device remains functional over an extended period. The chamber's ease of locatability makes it a valuable tool for large-scale environmental monitoring efforts. Researchers can deploy the chamber in multiple locations, increasing the amount of data collected and improving our understanding of greenhouse gas fluxes on a broader scale. PEAT can be left on its own for one month before replacement of the batteries is required. Finally, PEAT's easily manufacturable design, using simple off-the-shelf parts means that it can be produced cost-effectively and in large quantities, making it accessible to a broad range of researchers and environmental monitoring organizations, enabling more comprehensive insights into greenhouse gas emissions in wetland environments.

8.4 Engineering Requirements and Current Status

Engineering Requirement	Status
ER 1-1a: Water line must not rise above half the height of the chamber.	Verified. Current flotation geometry floats stably, without the water line rising over a period of 10 minutes.
ER 1-1b: The chamber must equilibrate when tilted 30 degrees from horizontal.	Verified. The chamber can be tilted up to 60 degrees and return to the horizontal without getting water inside the chamber due to instability.
ER 1-2: With 3 D batteries supplying 4.5V, the sensor and actuation package must function for at least 2 months.	Amended. The entire assembly will last 32 days using current components. We confirmed with our project partners that this is sufficient.

Engineering Requirement	Status
ER 1-3a: PEAT can be assembled by 1 person without the use of power tools.	Verified.
ER 1-3b: The chamber must be no greater than 36 lbs to be easily moved by the user.	Verified. PEAT weighs 4.2 lbs.
ER 1-4: Keep GHG concentrations from leaking over 3% over 5 minutes.	Verified. The 3D printed resin door with silicone seal and rail assembly provides adequate sealing.
ER 1-5: After collecting gases, the chamber must 'reset' to ambient GHG concentrations, or vent gases to within ± 5% of steady state values within 5 minutes.	Verified. The use of the fan and servo keeping the door open allows for PEAT to adequately vent.
ER 1-6: Once the user has the device, they must be able to access the data chip and batteries within 2 minutes of opening the device.	Verified.
ER 2-1a: Sensors must be fully operational in conditions of 80%+ humidity. IP (Ingress Protection) rating 4: "Protected against water splashes from all directions. Limited ingress permitted."	Partially validated. 3D printed resin does not deform between temperatures of 57°C and 2°C, and the material is non-porous. The sensor housing with desiccant retains a safe humidity range. However, we did not conduct a formal ingress protection test.
ER 2-1b: Amount of desiccant must be sufficient to reduce interior humidity.	Verified. After conducting the accelerated weathering test, we have confirmed that desiccant will last for at least one month.
ER 2-2: Chamber must be able to be tethered to a stationary object.	Verified, PEAT's metal hoop allows for any rope or tether to be used.
ER 2-3: Exposed materials should not include string and foam since it is vulnerable to wildlife.	Not validated. We chose Foamular 250 pink foam as the base material because of its waterproof and durable properties. PEAT remains somewhat susceptible to wildlife encounters, and we address will address this in future iterations.

Engineering Requirement	Status
ER 3-1: PEAT can be mass produced reliably. Every module we manufacture is the same. Any form of actuation affects the device to the same level and degree, +/- 5%; every module has the same length, width, height +/- 5%	Not validated. We only manufactured one final PEAT design, and were unable to test multiple iterations.
ER 3-2: Minimum of 2 year lifespan before PEAT needs to be replaced from wear and tear.	Not validated. We did not conduct wear and tear testing, but we have confirmed that PEAT's electronics will stay intact for at least one month without maintenance.
ER 4-1: Maximum combined length and girth is 108 inches. Maximum length 45 inches, height 46 inches, and width 35 inches. Cannot contain hazardous materials or be greater than 70 lbs as per USPS shipping regulation.	Validated. The current foam diameter of 17 inches can fit inside the dimensions set by international shipping requirements, and the device weighs only 4.2 lbs.

Table 2. The abbreviated engineering requirements and their status after testing.

9 Conclusion

We present the design and development of PEAT (Figure 36): a floating flux chamber for measuring CO2 and methane emissions from peatlands. Peatlands are vital ecosystems that store large amounts of carbon, and their degradation has been linked to significant greenhouse gas emissions. However, accurate measurements of these emissions are challenging due to the complex nature of peatland environments. In addition, current flux chambers for peatlands are expensive, non-portable, and cannot be mass produced. PEAT addresses all of these above challenges by incorporating low-cost sensors, lightweight materials, and a design that could be injection molded. The proposed flux chamber enables measurements of gas emissions from the entire surface area of the water, and incorporates features such as a waterproof enclosure and an automatically actuated system for gas sampling. More specifically:

(1) Flotation: Through engineering analysis and experimentation, we determined that lining the cylinder's outer circumference with foam of 15.5 in diameter allows PEAT to displace 70 degrees from horizontal and return to a stable position on the water surface. This feature enables PEAT to function during inclement weather conditions, such as rain or flooding.
(2) Sensor Resistance to Humidity: To ensure the sensor's longevity and accuracy, we developed a housing that uses a desiccant packet to maintain humidity levels below 80% around the PCB and sensors. To confirm its effectiveness, we conducted controlled humidity and temperature chamber testing.
(3) Sealing and Venting: Using a servo-powered rack and pinion system mounted to the chamber wall, with the use of a fan, allowed for CO2 and methane flow in and out of PEAT such that data can be collected accurately.

(4) Tethering: A metal loop mounted to the chamber provides a versatile way for researchers to secure the chamber to any stationary object with a rope.

The chamber was tested in both laboratory and field settings, and the results demonstrate its effectiveness in measuring gas emissions from peatlands. The importance of collecting accurate data in peatlands cannot be overstated, as this information is crucial for developing effective conservation strategies and mitigating the impacts of climate change. These findings indicate that it is feasible to create a plug-and-play flux chamber that satisfies our users' needs. We look forward to the researchers at the Precourt Institute for Energy using PEAT to monitor the global carbon cycle and contribute to sustainability efforts.

Fig. 36. The final iteration of PEAT on a water surface.

10 Future Work

10.1 Pictorial Instructions

Based on the consideration we made in our FMEA document line D12, there is a high probability that non-English speaking users might have to deploy PEAT. This poses a large issue, as misuse of PEAT could cause substantial data loss or damage to the flux chamber components. As a way to prevent any language or literacy barriers from causing user issues, one possible next step would be to add illustrations as instructions for the user. These signifiers could be universally understood, in a location on PEAT that would be visible to the user, and ideally have a large amount of user feedback to ensure effectiveness.

10.2 Off-Gassing

An issue identified in FMEA document line D11, is that the materials inside the chamber can affect the sensor readings through off-gassing. Off-gassing occurs when materials release gas that was dissolved, trapped, frozen, or absorbed into some material. In this case, any of the materials we used for the venting door, sensor housing, and even the bucket may cause this. Due to the little amount of research found, it was extremely difficult to find out how much our materials off-gassed. A potential next step would be to investigate our materials more in-depth and test the materials for off-gassing by testing in different conditions such as high temperatures.

10.3 Mass Manufacturing

Because many of the parts PEAT uses are custom, they can be easily 3D-printed. Various materials we used could also be found off the shelf, making them easier to source even in other countries. If PEAT is manufactured at large scale in the future, parts of this device could be injection molded.

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11 Appendices

11.1 Appendix A: Team Members, Roles and Responsibilities

Raymond Zhen: Document Focal Point
Britney Lee: Project Manager
Olivia Schroeder: Engineering Requirements Manager
Jessica Quiroz: Materials Manager, Liaison Interface

11.2 Appendix B: Gantt Chart

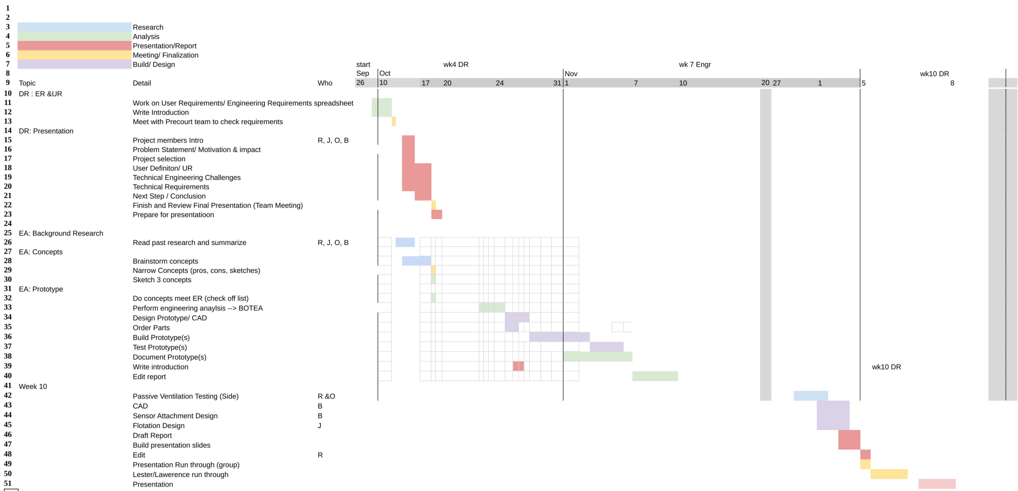

Fig. 37. Gantt chart for the first 10 weeks of the project, through the end of ME170A.

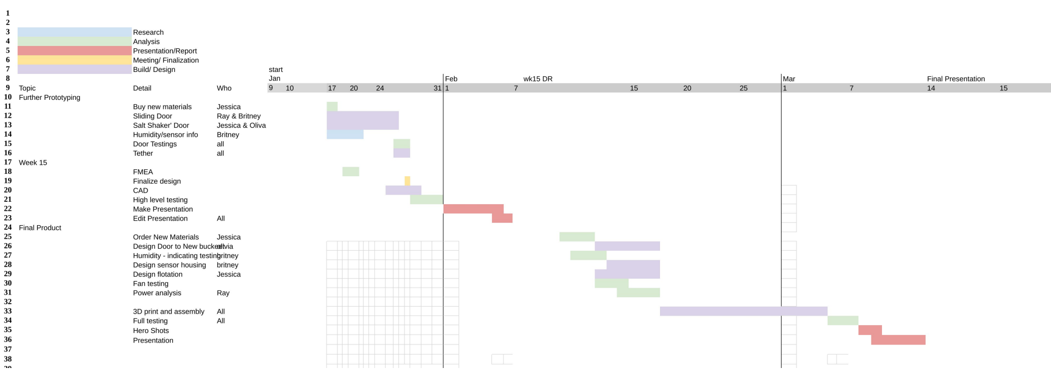

Fig. 38. Gantt chart for weeks 10-20 of the project, through the end of ME170B.

11.3 Appendix C: User and Engineering Requirements

The following section provides the full user and engineering requirements, priorities, justifications, measurement methods, and statuses.

UR 1-1 (HIGH Priority): Chamber must float stably on water. (Chamber will be used on bodies of water.)
ER 1-1a: Water line must not rise above half the height of the chamber. (Above half the height of the chamber, the electronics may experience liquid ingress or the chamber may tip over.)
Measurement: Place the chamber on water and measure the water level with a ruler. Measure again after 10 minutes to ensure the water line has not risen.
Status: Current flotation geometry floats stably, without the water line rising over a period of 10 minutes.
ER 1-1b: The chamber must equilibrate when tilted 30 degrees from horizontal. (The chamber must return to a stable position in case of wind or water disturbance.)
Measurement: Place the chamber on water, tilt the chamber 30 degrees from the horizontal, release, and observe the chamber's reacting motion.
Status: The chamber can be tilted up to 60 degrees and return to the horizontal without getting water inside the chamber due to instability.

UR 1-2 (HIGH Priority): Chamber functions must operate for at least 2 months without maintenance. (Researchers travel to check the chambers infrequently, so they must operate without frequent maintenance.)
ER 1-2: With 3 D batteries supplying 4.5V, the sensor and actuation package must function for at least 2 months.
Measurement: Find the worst case current draw from the data sheets of sensors, microcontroller, servos, and fans. Calculate how long the batteries will last.
Status: The entire assembly will last 32 days using current components. We confirmed with our project partners that this is sufficient.

UR 1-3 (MED Priority): Chamber must be portable and usable by one person. (Users must be able to move chambers to sites or between sites and perform necessary setup or maintenance without assistance.)
ER1-3a: PEAT can be assembled by 1 person without the use of power tools.
Status: PEAT can be assembled and disassembled without power tools.
ER1-3b: The chamber must be no greater than 36 lbs to be easily moved by the user. Status: PEAT weighs 4.2 lbs.

UR 1-4 (HIGH Priority): Chamber must be isolated from its environment to collect gas data with minimal leakage every 5 minutes. (In order to collect accurate data over time, the chamber must not leak GHGs when not venting.)
ER 1-4: Keep GHG concentrations from leaking over 3% over 5 minutes.
Measurement: Using the sensor package, record the CO_2 and CH_4 concentrations every 5 seconds for 5 minutes with the chamber door closed. The final concentration must differ less than 5% from the initial concentration.
Status: The 3D printed resin door with silicone seal and rail assembly provides adequate sealing.

UR 1-5 (HIGH Priority): Chamber must return to ambient concentrations before each gas collection period. (In order to collect accurate data, the chamber must reflect the peatland's environmental

conditions.)
ER 1-5: After collecting gases, the chamber must 'reset' to ambient GHG concentrations, or vent gases to within ± 5% of steady state values within 5 minutes.
Measurement: Using the sensor package, provide an initial CO2 concentration. Turn on the fan and open the chamber door. Within 5 minutes, the final concentration must be within 5% of ambient values.
Status: The use of the fan and servo keeping the door open allows for PEAT to adequately vent.

UR 1-6 (HIGH Priority): The data chip and batteries must be accessible by the user. (The user will need to remove the data card and batteries for data collection and replacement.)
ER 1-6: Once the user has the device, they must be able to access the data chip and batteries within 2 minutes of opening the device. (Our users will deploy many iterations of PEAT in situ, in the 10s or 100s, and we wish to make data collection a low-maintenance process.)
Measurement: Have a researcher try our device and measure the time it takes for them to access the data chip or replace the battery.
Status: Users can easily disassemble our device to access the data chip and replace batteries.

UR 2-1 (HIGH Priority): Chamber must withstand weather conditions of heavy rain, humidity, and sun exposure. (The flux chamber will be in water, therefore the chamber itself should not be made with porous material or allow water to enter the chamber. Water in the chamber could lead to increased mass and sinking as well as damage to the operating system.)
ER 2-1a: Sensors must be fully operational in conditions of 80%+ humidity. IP (Ingress Protection) rating 4: "Protected against water splashes from all directions. Limited ingress permitted." Materials must not deform under varying temperatures in peatlands. Materials must not deform under varying temperatures in peatlands.
Measurement: Test the porosity of 3D printed resin by pouring water on the material and observing for leakage. Research the material deformation range of resin under various temperatures. Use a humidity sensor to detect changes in humidity in the device under rainy conditions.
Status: 3D printed resin does not deform between temperatures of 57°C and 2°C, and the material is non-porous. The sensor housing with desiccant retains a safe humidity range. However, we did not conduct a formal ingress protection test.
ER 2-1b: Amount of desiccant must be sufficient to reduce interior humidity.
Measurement: Record/track time between desiccant packet replacements. Conduct testing to see the lifespan of the desiccant and if it will remain effective for a month-long period in the specified environment.
Status: After conducting the accelerated weathering test, we have confirmed that desiccant will last for at least one month.

UR 2-2 (HIGH Priority): The user must be able to locate the chamber after deployment. (Users need to be able to return to the device to collect data from the device after deployment.)
ER 2-2: Chamber must be able to be tethered to a stationary object. (Our users will deploy many iterations of PEAT in situ, in the 10s or 100s, and it is crucial that each location can be mapped to gas data points.)
Measurement: Deploy the chamber in a large body of water and return to it an hour later to see if it has drifted or broken its tether.
Status: PEAT's metal hoop allows for any rope or tether to be used, and will function in conjunction with any stationary object.

UR 2-3 (MED Priority): Chamber must be able to resist interference from peatlands wildlife. (Birds may land on the object, or aquatic life may bump into the object or try to bite off pieces. Some materials such as foam and string are vulnerable to damage from animals like ants, termites, and rodents.)
ER 2-3: Exposed materials should not include string and foam since it is vulnerable to wildlife.
Status: We chose Foamular 250 pink foam as the base material because of its waterproof and durable properties. PEAT remains somewhat susceptible to wildlife encounters, and we address will address this in future iterations.

UR 3-1 (MED Priority): The flux values at the same location under the same conditions are consistent across flux chambers. (Researchers must ensure that their data collection is accurate. An unexpectedly larger or smaller chamber, or actuation to a different degree could result in an inaccurate flux measurement.) ER 3-1: PEAT can be mass produced reliably. Every module we manufacture is the same. Any form of actuation affects the device to the same level and degree, +/- 5%; every module has the same length, width, height +/- 5% Status: We only manufactured one final PEAT design, and were unable to test multiple iterations.

UR 3-2 (MED Priority): Each chamber can be collected from the in situ environment and reused again after replacing the batteries. (Researchers will be deploying the device in natural peatlands and taking multiple measurements with each chamber over its lifespan.) ER 3-2: Minimum of 2 year lifespan before PEAT needs to be replaced from wear and tear. Status: We did not conduct wear and tear testing, but we have confirmed that PEAT's electronics will stay intact for at least one month without maintenance.

UR 4-1 (MED Priority): Meet international shipping requirements. (Researchers ship the chambers to project partners in the field (when qty. 20+).) ER 4-1: Maximum combined length and girth is 108 inches. Maximum length 45 inches, height 46 inches, and width 35 inches. Cannot contain hazardous materials or be greater than 70 lbs as per USPS shipping regulation. (These are the maximum dimensions and weight for international shipping.) Measurement: Use a measuring tape and a scale to confirm dimensions and weight. Status: The current foam diameter of 17 inches can fit inside the dimensions set by international shipping requirements, and the device weighs only 4.2 lbs.

11.4 Appendix D: FMEA

	Functions		Potential Failure Mode(s)			Potential Causes						Recommended			Action Results					
dFMEA line item	Component	Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Crit	Recommended Action(s)	Responsibility	Target Completion Date	Actions Taken	New Sev	New Occ	New Det	New RPN	New Crit
d1	Chamber System	Remain upright in environmental conditions	Flips upside down	No longer able to collect data, possible damage to electronics	8	Weather (wind, waves/flooding)	2	Tipping testing conducted	2	**32**	16	None, risk accepted for now.	-	-					0	0
d2	Chamber System	Remain upright in environmental conditions	Flips upside down	No longer able to collect data, possible damage to electronics	8	Animal interference	2	Tipping testing conducted	2	**32**	16	None, risk accepted for now.	-	-						
d3	Sensor housing	Keep sensor dry	Sensor suffers liquid ingress damage (humidity level exceeds data sheet specs)	PCB and sensors no longer collect data, damage	8	Liquid Ingress through Rain or Peatlands Water	4	In progress: adjusting geometry of sensor housing	9	**288**	32	Liquid ingress testing of PCB in enclosure to be performed	Britney	2/1/2023	Sealed sensor housing with silicone molding and o-rings to prevent liquid ingress.	8	3	3	72	24
d4	Sensor housing	Keep sensor dry	Sensor suffers liquid ingress damage (humidity level exceeds data sheet specs)	PCB and sensors no longer collect data, damage	8	Liquid Ingress through Humidity	8	Humidity testing of PCB in enclosure	7	**448**	64	Finalize sensor housing geometry	Britney	1/28/2023	Updated sensor housing geometry to include dessicant, ran accelerated weather test to ensure month-long protection over 1x deployment (31 days).	8	4	3	96	32
d5	Door mechanism fails to open or close properly	Venting and sealing of chamber for data collection	Door mechanism jam/damage	Data is inaccurate	6	Liquid Ingress in motor / actuation electronics	8	In progress: prototyping door mechanisms	9	**432**	48	Liquid ingress testing of door actuation to be performed	Ray	2/1/2023	Prototyped a sliding door using a rack and pinion + servo, with silicone molding and lubricant used for sealing.	7	4	3	84	28
d6	Door mechanism fails to open or close properly	Venting and sealing of chamber for data collection	Door mechanism jam/damage	Data is inaccurate	6	Door fracture due to fatigue (cyclical venting)	3	In Progress: FEA of door, choosing material and thickness that improves stiffness	9	**162**	18	Cylical venting testing to be peformed	Future work	2/1/2023					0	0
d7	Door mechanism fails to open or close properly	Venting and sealing of chamber for data collection	Out of battery/ battery failure	Data is inaccurate	5	Battery life runs out before replacement	4	In Progress: prototyping door mechanisms	9	**180**	20	TBD Calculations for battery usage over 1 deployment period	Ray	1/28/2023	For a first prototype, we will be using FS90 servos. Calculations resulted in battery life expected to be 32 days.	5	3	5	75	15
d8	Tethering System	Tether keeps PEAT within a 3 m radius of original location	PEAT no longer tethered, not able to be located after deployment	Unit lost, cannot collect data, becomes trash in the environment	8	Weather (wind, water) damages or detaches tether	6	In Progress: selecting design	9	**432**	48	Finalize tether design	All	1/28/2023	Added attachment interface (hook) for user to tether PEAT.	8	2	4	64	16

Fig. 39. Failure Modes and Effects Analysis. Using this tool, we categorized and addressed the biggest design risks to PEAT.

11.5 Appendix E: Summary of Expenses and Budget

Team:	Peat Peeps	Budget:	$3,000		Legend - color the rows as follows for easy status
Financial Officer	Jessica Quiroz	Spent:	$1,020.68	(incl Tax col.)	Proposed purchase, still to review with CA
		Remaining	$1,979.32		CA has made the purchase

Purchaser	Item	Expense Type	Expenditure Date	Vendor	Purchase amount	was tax collected?	Expense amount including tax	Shipping Address	Notes
Lawrence Domingo	Extreme Freeze Reditainer 64 oz.	Team expense	10/28/2022	Clear Lake Enterprise	$18.95	No	$20.66	658 Lomita Ct. Stanford, CA	
Lawrence Domingo	BAENRCY Air Pump 5V-6VDC Miniature	Team expense	10/28/2022	BAENRCY	$8.99	No	$9.80	658 Lomita Ct. Stanford, CA	
Lawrence Domingo	Mini Nano V3.0 ATmega328P	Team expense	10/28/2022	Deegoo-FPV	$12.99	No	$14.16	658 Lomita Ct. Stanford, CA	
Lawrence Domingo	ALITOVE 5V 3A 15W AC 100V~240V to	Team expense	10/28/2022	ALITOVE	$8.99	No	$9.80	658 Lomita Ct. Stanford, CA	
Lawrence Domingo	(Pack of 10 Pieces) MCIGICM 1000uf 25V Capacitor, Aluminum Electrolytic Capacitor 1000uf 25v 10x17	Team expense	10/28/2022	MCIGICM	$4.99	No	$5.44	658 Lomita Ct. Stanford, CA 94305. United States	
Lawrence Domingo	12V DC Power Connector 5.5mm x 2.1mm	Team expense	11/1/2022	ZHTECK-SHOP	$4.99	No	$5.44	658 Lomita Ct. Stanford, CA	
Lawrence Domingo	Dry & Dry 5 Gram [30 Packets] Premium	Team expense	11/3/2022	Dry & Dry	$8.99	No	$9.80	658 Lomita Ct. Stanford, CA	
Lawrence Domingo	SanDisk 256GB Extreme microSDXC	Team expense	11/3/2022	Nityamaa	$31.99	No	$34.87	658 Lomita Ct. Stanford, CA	
Lawrence Domingo	64-oz. Square Clear Deli Containers with Lids | Stackable, Tamper-Proof BPA-Free Food Storage Containers | Recyclable	Team expense	1/18/2023	NYHI®	$39.89	No	$43.48	Jessica Quiroz - jessqui 459 Lagunita Drive c/o Stanford Tresidder Package	
Lawrence Domingo	4Pcs SG90 9g Micro Servos for RC Robot	Team expense	1/18/2023	Deegoo-FPV	$9.99	No	$10.89	Jessica Quiroz - jessqui	
Lawrence Domingo	Oil-Resistant Buna-N O-Ring	Team expense	1/18/2023	McMaster-Carr	$12.61	No	$13.74	Jessica Quiroz - jessqui	
Lawrence Domingo	Weather Stripping Brush for Sliding	Team expense	1/18/2023	LOVEC	$5.58	No	$6.08	Jessica Quiroz - jessqui	
Lawrence Domingo	Peohud 4 Pack Sanitizing Buckets, 3 Qu Bucket with Spout and Handle for Home	Team expense	1/29/2023	Dicunoy	$19.99	No	$21.79	Jessica Quiroz - jessqui 459 Lagunita Drive c/o Stanford Tresidder Package Center Stanford, CA 94305	
Lawrence Domingo	ANVISION 2-Pack 40mm x 10mm DC 5V USB Brushless Cooling Fan, Dual Ball Bearing, YDM4010B05	Team expense	1/29/2023	Amazon	$14.38	No	$15.67	Jessica Quiroz - jessqui 459 Lagunita Drive c/o Stanford Tresidder Package	
Lawrence Domingo	3pcs DC 3V 30RPM N20 High Torque	Team expense	2/1/2023	Amazon	$15.99	No	$17.43	Jessica Quiroz - jessqui	
Lawrence Domingo	Wisesorb Silica Gel 2LBS, Indicating Silica	Team expense	2/14/2023	Amazon	$17.79	No	$19.39	Britney Lee - briterin	
Lawrence Domingo	mountainFLOW Bike Grease | Plant-Based	Team expense	1/14/2023	Amazon	$15.95	No	$17.39	Britney Lee- briterin	
Lawrence Domingo	Smooth-On Ecoflex 00-20 Super Soft	Team expense	1/14/23	Amazon	$36.99	No	$40.32	Olivia Schroeder - olivia00	
Lawrence Domingo	2 Pack Customizable Polyurethane	Team expense	2/16/23	Amazon	$24.99	No	$27.24	Olivia Schroeder - olivia00	
Lawrence Domingo	2 inches Thick Foam Board, 17x11" EPS	Team expense	2/16/23	Amazon	$22.99	No	$25.06	Olivia Schroeder - olivia00	
Lawrence Domingo	Tong Gu 39 inch Kite Flag Tent Material	Team expense	2/16/23	Amazon	$11.99	No	$13.07	Olivia Schroeder - olivia00	Please purchase red, 59 x 78 inch
Lawrence Domingo	J-B Weld Plastic Bonder Black 25ml	Team expense	2/16/23	Amazon	$15.74	No	$17.16	Olivia Schroeder - olivia00	2 pack
Lawrence Domingo	Vtopmart Extra Large Tall Airtight Food	Team expense	2/21/23	Amazon	$24.99	No	$27.24	Jessica Quiroz - jessqui	
Lawrence Domingo	ZZHXSM 4pcs Toggle Latches Catch	Team expense	2/21/23	Amazon	$7.99	No	$8.71	Jessica Quiroz - jessqui	
Lawrence Domingo	Aksuaple Eco-Fil Disposable Tea Filter	Team expense	2/21/23	Amazon	$6.39	No	$6.97	Jessica Quiroz - jessqui	
Lawrence Domingo	Official 3D Printer Filament Ender PLA Filam	Team expense	2/24/23	Amazon	$19.19	No	$20.92	Olivia Schroeder - olivia00	
Lawrence Domingo	Incense for air flow visualization - Satya	Team expense	2/24/23	Amazon	$6.00	No	$6.54	Olivia Schroeder - olivia00	
Lawrence Domingo	4 Pcs 2 x 1.6 Inch 304 Stainless Steel	Team expense	2/24/23	Amazon	$7.99	No	$8.71	Olivia Schroeder - olivia00	
Lawrence Domingo	650lb Paracord/Parachute Cord - 9	Team expense	2/24/23	Amazon	$10.99	No	$11.98	Olivia Schroeder - olivia00	
All team members	Room 36 Hardware - 3D prints, foam,	Team expense	3/20/2023	Room 36	$150.00	No	$163.50	N/A	Cumulative purchases over 2 quarters
Britney Lee	Cord for testing, Epoxy, duct tape,	Team expense	3/8/2023	ACE Hardware	$70.15	Yes	$70.15	N/A	
Jessica Quiroz	Buckets for new prototypes - 5 gal	Team expense	1/31/2023	Home Depot	$27.42	Yes	$27.42	N/A	
Lawrence Domingo	4x stainless steel 100g weights	Team expense	3/6/23	McMaster-Carr	$134.94	Yes	$134.94	Jessica Quiroz - jessqui	Purchase due to shipping address error,
Lawrence Domingo	4x stainless steel 100g weights	Team expense	3/6/23	McMaster-Carr	$134.94	Yes	$134.94	Jessica Quiroz	

Fig. 40. The design and development of PEAT cost $1020.68, out of a maximum allowable budget of $3000.

11.6 Appendix F: Bill of Materials

Part	QTY	Source	Description	Cost
Chamber	1x	Amazon	11 in. x 7.5 in. x 7.5 in. plastic bucket	$6.24
Foam	1x	Room 36	Owens Corning FOAMULAR 250 XPS Insulation Board	$4.00
Counterweights	4x	McMaster-Carr	4x stainless steel 100g test weights	$134.94
Twisted Nylon Twine	1x	ACE Hardware	Diameter: 24 in., Length: 185 ft., Twisted Nylon	$5.99
Wall Mount	1x	Formlabs Form 3	FormsLabs SLA Printed White Resin	$57.00
Door	1x	Formlabs Form 3	FormsLabs SLA Printed White Resin	
Fan	1x	Amazon	ANVISION 2-Pack 40mm x 10mm DC 5V USB Brushless Cooling Fan	$7.19
Micro-Servo	1x	Amazon	SG90 9g Micro Servo for RC Robot	$2.50
Rack	1x	Ultimaker FDM Printer	PLA	$10.00
Pinion	1x	Ultimaker FDM Printer	PLA	
Silicone Sealant	1x	Amazon	Smooth-On Ecoflex 00-20 Super Soft Silicone Rubber	$36.99
Mesh	1x	Amazon	TORIS Stainless Steel Woven Wire Mesh Cabinets Wire Mesh Air Vent	$3.35
Sensing Unit	1x	Precourt Institute	PCB with methane sensor, carbon dioxide sensor, and D-Cell Batteries	Custom
O-rings	8x	ACE Hardware	Zinc Plated Stainless Steel	$8.00
Nuts	4x	ACE Hardware	Zinc Plated Stainless Steel	$1.35
Bolts	4x	ACE Hardware	Zinc Plated Stainless Steel	$1.35
Toggle Latches	2x	Amazon	Iron Toggle Hasp Latches with Screws	$2.00
Color-Changing Dessicant	1x	Amazon	Wisesorb 2LBS, Indicating Silica Beads, Reusable Silica Gel Desiccant	$17.79
Tea Filter Bag	1x	Amazon	Aksuaple Eco-Fil Disposable Tea Filter Bags, 100 Pack (3.2inch x 4.0in	$6.39
Sensor Housing Base	1x	Formlabs Form 3 SLA Printer	FormsLabs SLA Printed White Resin	$50.00
Sensor Housing Grid	1x	Formlabs Form 3 SLA Printer	FormsLabs SLA Printed White Resin	
Sensor Housing Lid	1x	Formlabs Form 3 SLA Printer	FormsLabs SLA Printed White Resin	
Hook	1x	Amazon	4 Pcs 2 x 1.6 Inch 304 Stainless Steel Ceiling Hooks with Screws	$7.99
Hook Screws	4x	Amazon		
Bike Grease Lubricant	1x	Amazon	mountainFLOW Bike Grease, Plant-Based and Biodegradable	$15.95
Epoxy	3x	ACE Hardware	Clear JB-Weld Epoxy	$29.97
			TOTAL	379.02

Fig. 41. The design and development of PEAT cost $1020.68, out of a maximum allowable budget of $3000.

11.7 Appendix G: Circuit Diagrams

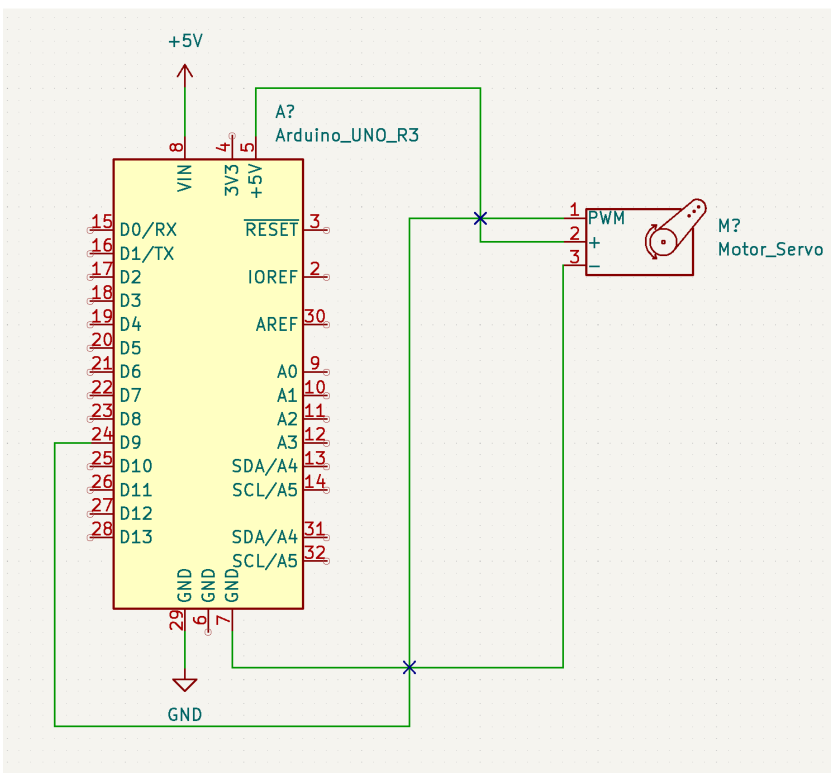

Fig. 42. Circuit diagram of PEAT's linear sliding door, which is powered by a single servo connected to the Arduino Uno microcontroller.

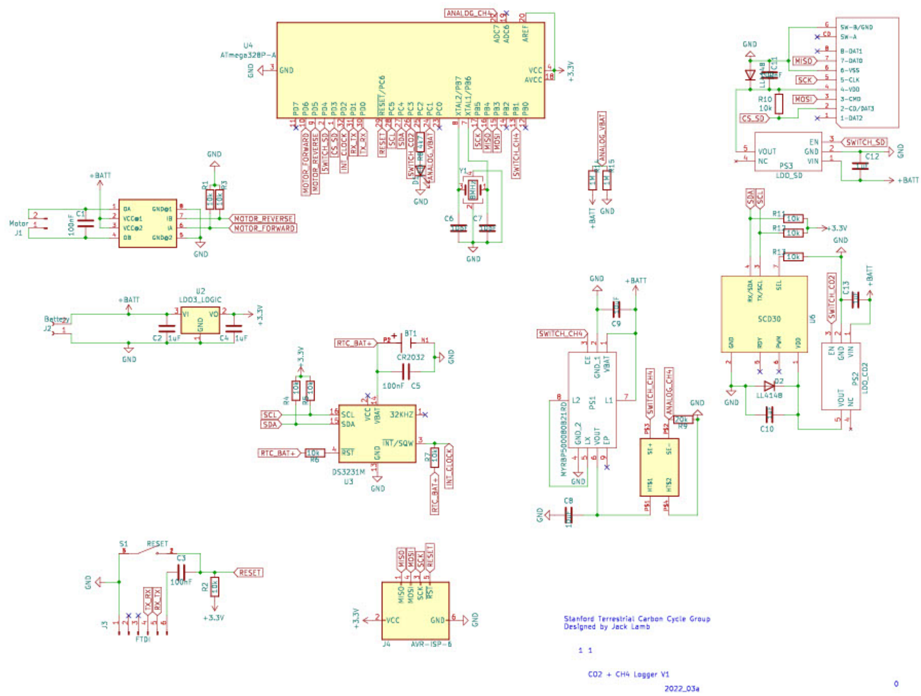

Fig. 43. Circuit diagram of the CO2 and CH4 logger components for greenhouse gas sensing, provided by Jack Lamb.

11.8 Appendix H: Code and Sensor Datasheets

The Arduino code for PEAT, as well as CO2 and CH4 sensor datasheets can be found at:
Peat Peeps Github Repository [LINK] or https://github.com/rayicez/Peat-Peeps

11.9 Appendix I: Project Summary

11.9.1 Background The rise in greenhouse gas (GHG) emissions is correlated with the rise in global temperatures, worsening global disasters like wildfires, droughts, and storms and ultimately threatening life. The current methods of collecting GHG emissions data are expensive, non-portable, or not suitable for large-scale production. Methane emissions from tropical wetlands, such as peatlands, alone are thought to contribute 20-30% of the total global GHG budget, yet the challenge of effectively measuring these emissions causes it to remain a major uncertainty.

11.9.2 Project Motivation The current lack of suitable instrumentation requires the development of a low-cost, easily deployable sensing device for greenhouse gas (GHG) emissions. An automated floating flux chamber would enable the large-scale collection of GHG emissions data to better understand Earth's changing climate and inform actions for environmental sustainability.

11.9.3 Problem Statement Design an automated floating flux chamber for collection of data on concentrations of carbon dioxide and methane gases emitted from the water surface of peatland environments. The flux chamber should 1) float on the water surface, 2) close and vent autonomously for up to 1 month, 3) collect carbon dioxide and methane gas concentrations data using the sensing unit provided by the Precourt Institute for Energy.

11.9.4 High Priority Requirements User / Engineering Requirements 1-1 UR 1-1: Chamber must float stably on water. ER 1-1a: Water line must not rise above half the height of the chamber. ER 1-1b: The chamber must equilibrate when tilted 30 degrees from horizontal.
User / Engineering Requirements 1-4 UR 1-4: Chamber must be isolated from its environment to collect gas data with minimal leakage every 5 minutes.
ER 1-4: Keep GHG concentrations from leaking over 3% over 5 minutes.
User / Engineering Requirements 1-5 UR 1-5: Chamber must return to ambient concentrations before each gas collection period. ER 1-5: After collecting gases, the chamber must 'reset' to ambient GHG concentrations, or vent gases to within ± 5% of steady state values within 5 minutes.
User / Engineering Requirements 1-6 UR 1-6: The data chip and batteries must be accessible by the user. ER 1-6: Once the user has the device, they must be able to access the data chip and batteries within 2 minutes of opening the device.
User / Engineering Requirements 2-1 UR 2-1: The chamber must withstand weather conditions of heavy rain, humidity, and sun exposure. ER 2-1a: Sensors must be fully operational in conditions of 80%+ humidity. IP (Ingress Protection) rating 4: "Protected against water splashes from all directions. Limited ingress permitted." ER 2-1b: Material needs to be able resist deformation in maximum temperatures of 57°C and minimum temperatures of 2°C.
User / Engineering Requirements 2-2 UR 2-2: The user must be able to locate the chamber after deployment. ER 2-2: Chamber must be able to be tethered to a stationary object.
User / Engineering Requirements 4-1 UR 4-1: Meet international shipping requirements. ER 4-1: Maximum combined length and girth is 108 inches. Maximum length 45 inches, height 46 inches, and width 35 inches. Cannot contain hazardous materials or be greater than 70 lbs as per USPS shipping regulation.

11.9.5 Ethical Considerations

- Environmental Impact
- Helicopter Research
- User Accessibility

11.9.6 Solution Designed and built PEAT: the Peatlands Environmental Assessment Tool, an automated floating flux chamber that collects methane and carbon dioxide emissions data from the water surface of peatland environments. The chamber includes a foam ring and counterweights around the base for flotation and stability. One side of the chamber features a sliding door that seals the chamber when closed and vents the chamber, with the help of a fan, when opened. The other side features a metal mount for the user to attach a tether to keep the chamber locatable after deployment. Inside the chamber, a sensor housing protects the sensing unit from water and humidity using desiccant. Tested for flotation stability, ventilation, sealing, and humidity control, PEAT successfully meets our engineering requirements.

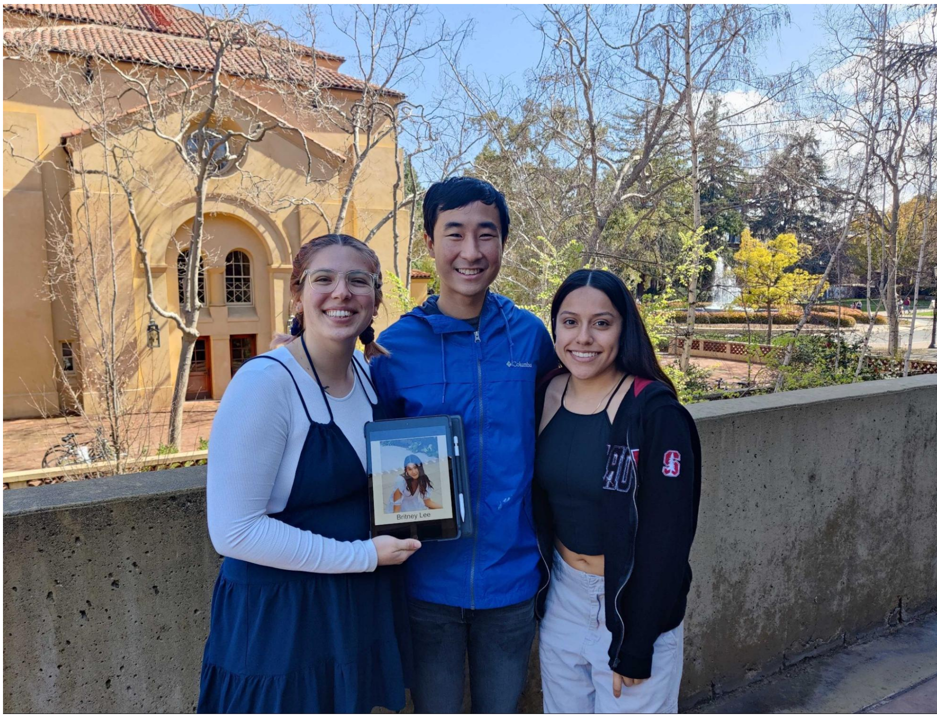

Fig. 44. Team Picture

11.9.7 Photos

Fig. 45. Working Hardware Photo 1 The final iteration of PEAT on a water surface.

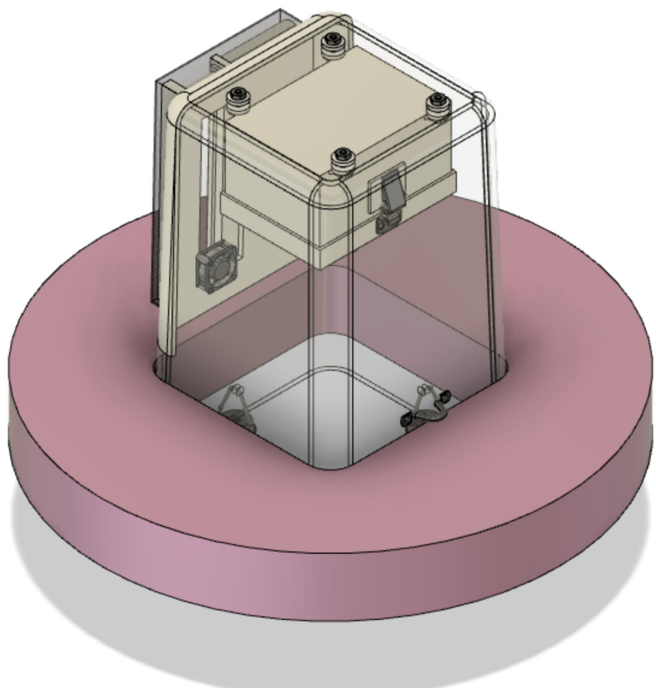

Fig. 46. Working Hardware Photo 2 PEAT CAD back view

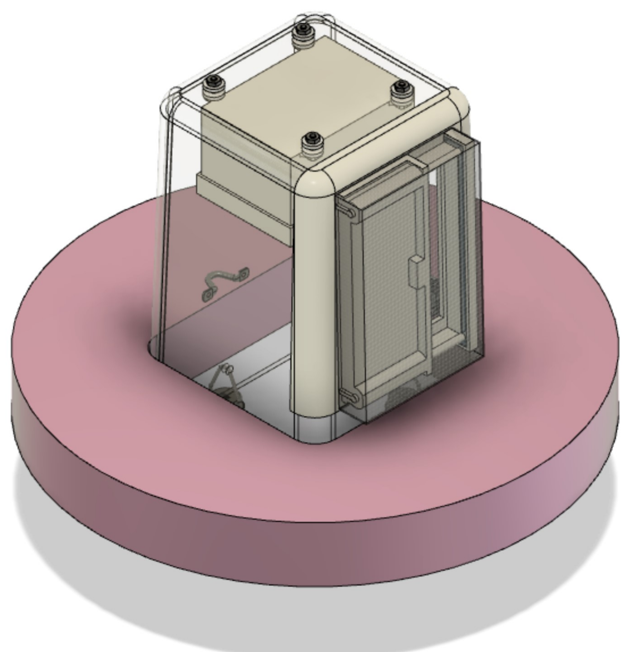

Fig. 47. Working Hardware Photo 2 PEAT CAD front view

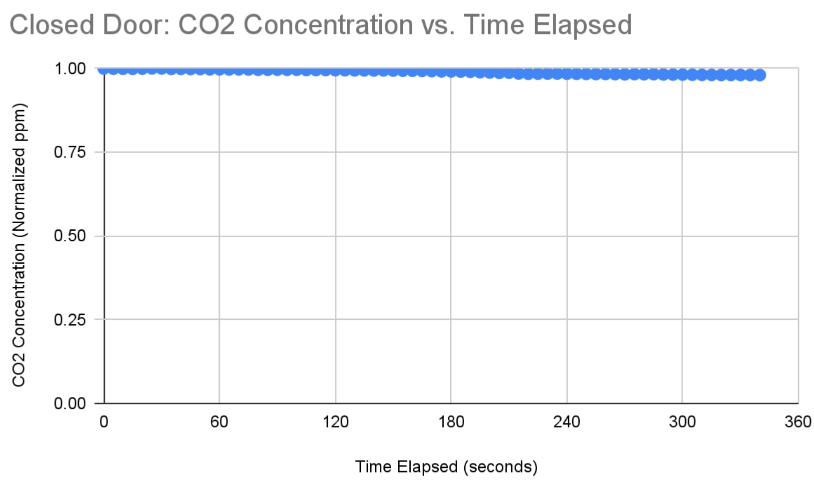

Fig. 48. Testing Photo 1 This plot shows the decay of CO2 over a 6 minute time period, in which CO2 concentration measurements were taken by the sensor every 5 seconds. With PEAT's door closed and sealed, PEAT was able to prevent >3% of CO2 from leaking. After 5 minutes, 98% of the initial CO2 concentration remained.

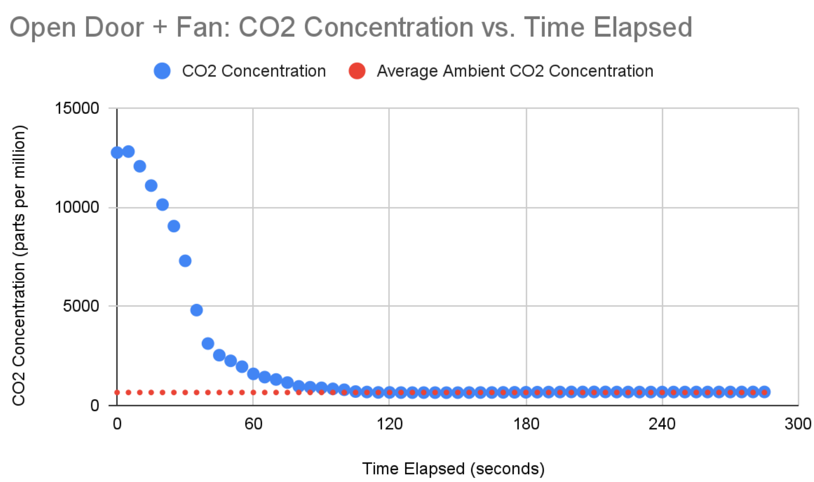

Fig. 49. Testing Photo 2 This plot shows the decay of CO2 over a 6 minute time period, in which CO2 concentration measurements were taken by the sensor every 5 seconds. With the fan and open door, PEAT was able to return CO2 concentrations to ambient conditions within 2 minutes.

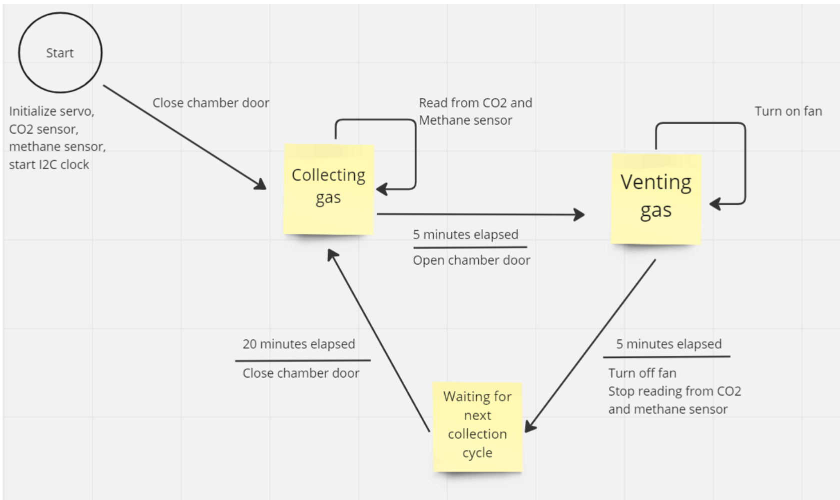

Fig. 50. Interesting Photo 1 PEAT finite state diagram

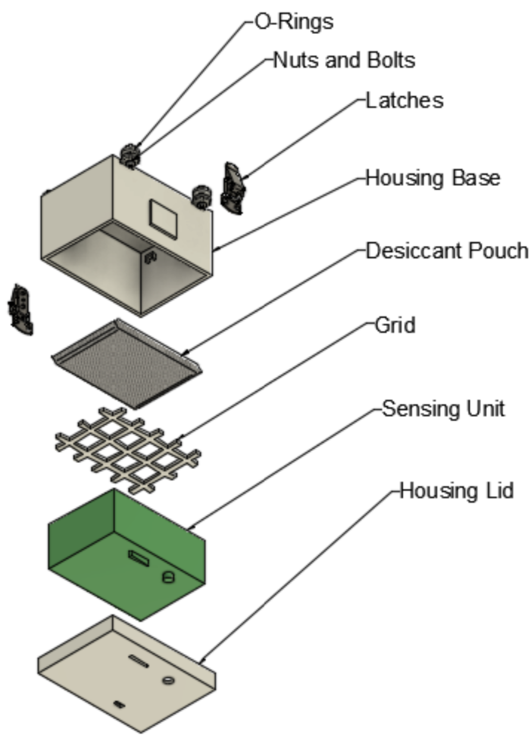

Fig. 51. Interesting Photo 2 Sensor housing CAD exploded view

Fig. 52. Interesting Photo 3 PEAT: the Peatlands Environmental Assessment Tool incorporates venting and sealing, flotation, sensor protection, and tethering.

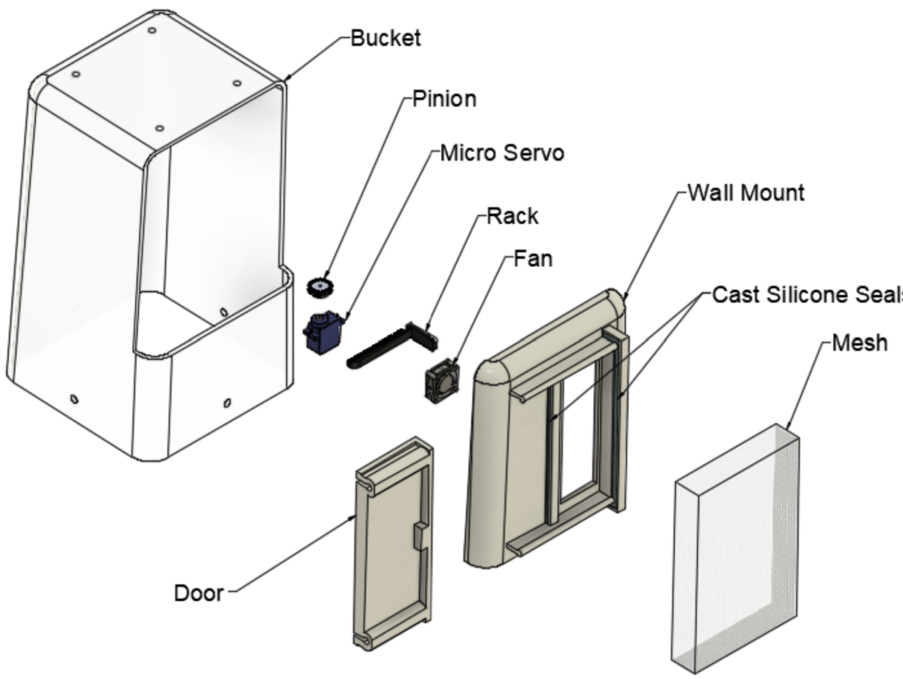

Fig. 53. Interesting Photo 4 Door Mechanism Components, with Bucket, Pinion, Micro Servo, Rack, Fan, Wall Mount, Cast Silicone Seals, Door, Mesh

Fig. 54. Interesting Photo 5

Fig. 55. Interesting Photo 6