BU College of Engineering

Department of Mechanical Engineering

Bicycle Mounted Air Pollution Monitor Specification Sheet

First Iteration Based on Initial Testing and Findings

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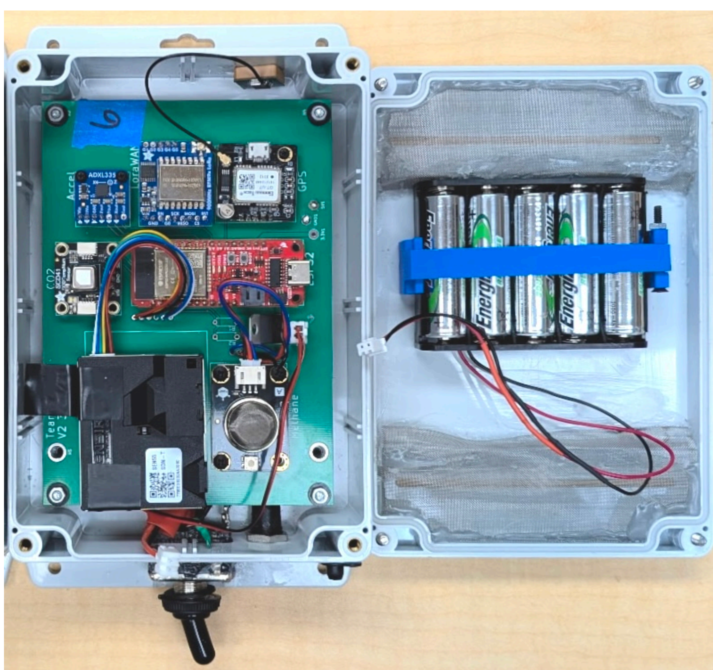


Introduction and Project Background

The Bicycle-Mounted Air Pollution Monitor was developed by two senior design teams during the 2024 and 2025 academic years within the Department of Mechanical Engineering at Boston University's College of Engineering. In the summer of 2025, an additional seven units were constructed based on the original senior design schematics. All nine units were then modified slightly to evaluate their durability across various testing environments and their responsiveness to environmental changes. These efforts supported the development of the first iteration of a specification sheet for these monitors.

Product Features and Part Descriptions

The Bicycle-Mounted Air Pollution Monitor is housed in a light gray Bud Industries PN-1324-MB enclosure, which meets NEMA 4X standards for protection against environmental exposure. The enclosure is secured with four M4 screws and features a row of eleven 0.125 inch diameter airflow holes for ventilation. To prevent moisture intrusion, a hydrophobic metal mesh is affixed over the holes, supported by a piece of HDPE that is bonded to the enclosure using silicone sealant, with the mesh hot-glued in place. Two additional 0.125 inch wide drainage slots were drilled on each short side of the box to enable gravity-driven removal of any water that enters through the airflow holes. Inside, a custom PCB is mounted using heat-set inserts and M3 screws in enlarged enclosure holes. The PCB integrates an ESP32 WROOM microcontroller and supports three key pollutant sensors: the Sensirion SEN55 for particulate matter, the DFRobot MQ4 for methane detection, and the SCD41 from Adafruit for carbon dioxide. Motion is tracked via an ADXL335 accelerometer, and location data is collected using a GPS NEO-6M module. Originally there was wireless data transmission capabilities through an RFM95 LoRa transceiver module, which communicates over a Long-Range Wide Area Network (LoRaWAN) set up in the Computer and Data Science Building (CDS) at Boston University. For the purposes of testing the sensors, this feature was disabled and all data was collected onto a 64GB microSD card formatted to be FAT32. Power is supplied by five rechargeable AA batteries, with all components operating on either 3.3 V or 5 V, which is regulated by the ESP32. Sensors with mounting holes are secured using nylon screws, while those without are carefully glued to the board, ensuring stability during operation. The battery power supply can be substituted with a 6V wall adapter if the testing environment allows.

The initial Arduino code for the ESP32 was designed to collect data only when motion was detected by the accelerometer, and at five-minute intervals. This approach was later revised to collect data continuously at one-second intervals, regardless of motion. Additionally, instead of transmitting the data over the LoRaWAN network, it is now written directly to the microSD card. This change was made to simplify the system and avoid the reliability issues that come with using the LoRaWAN network. However, with future improvements, LoRaWAN integration may be reintroduced. Figure 1 shows the types of environmental parameters the air monitor measures and the physical arrangement of its internal sensors.

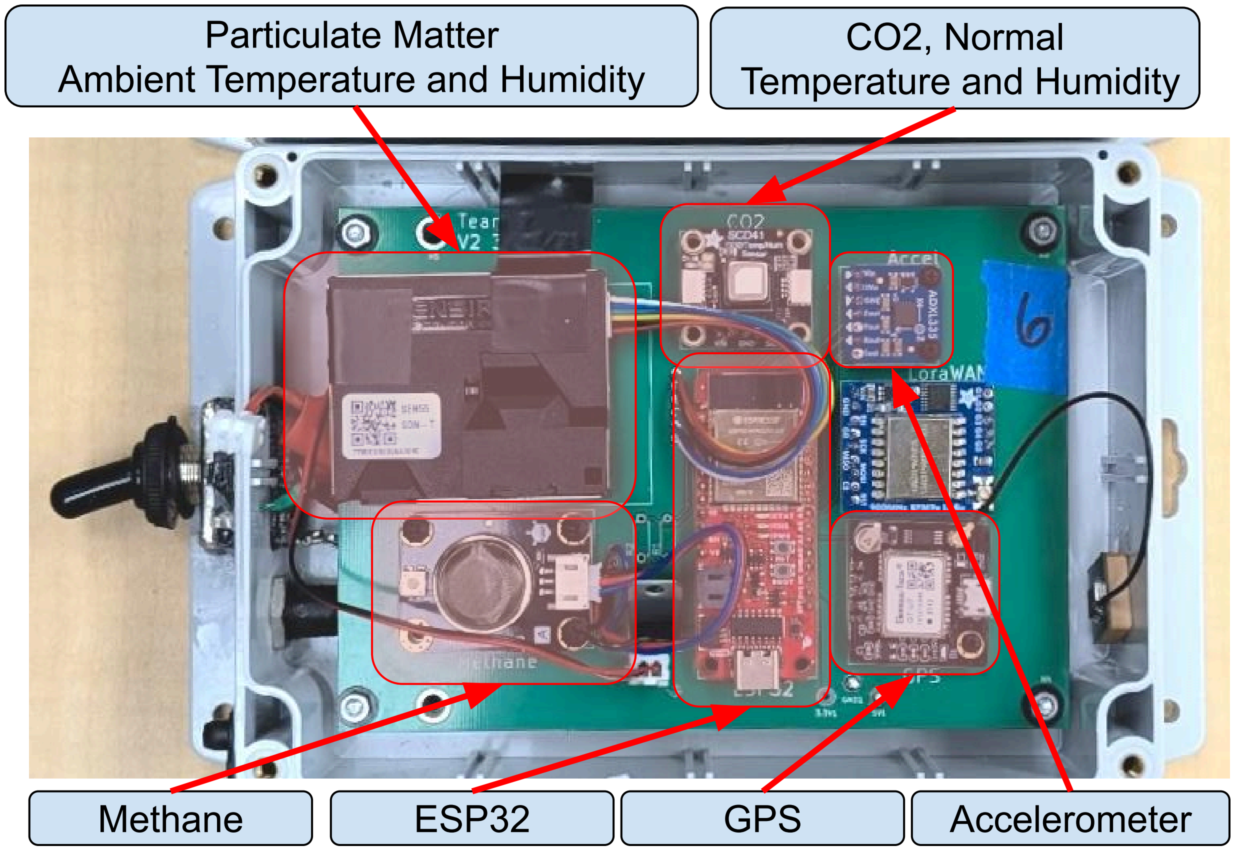


Figure 1: Measured Parameters and Internal Sensor Layout of the Air Monitor

This is an important figure to keep in mind while looking at all the graphs with measured data, because the sensor layout does influence the recorded data, especially when it comes to temperature.

The data collected by the Bicycle-Mounted Air Pollution Monitor can give insight into a wide range of environmental and positional parameters critical for understanding air quality in real-world conditions. GPS data, including latitude and longitude, is collected using the NEO-6M GPS module to track the location of each measurement, enabling spatial mapping of pollutant levels. The SCD41 sensor from Adafruit measures carbon dioxide (CO_2) concentration over time, providing insights into ventilation, traffic-related emissions and concentration of human beings. Both ambient and internal (normal) temperature and humidity are tracked using the Sensirion SEN55, which also measures particulate matter (PM1.0, PM2.5, PM4.0 and PM10) concentrations—essential indicators of air pollution caused by combustion, dust, and other airborne particles. The SEN55 also provides a volatile organic compounds (VOC) index, which reflects the presence of gases emitted from sources like vehicles and industrial activity. Nitrogen oxides (NOx), key indicators of combustion-related pollution, are monitored via built-in capabilities of the SEN55 as well. It is important to note that NOx data could not be collected during any of the testing periods across all sensors. This is likely due to limitations in the sensor's sensitivity or calibration issues, as well as potentially low ambient concentrations of

NOx that fell below the detection threshold of the SEN55. Methane concentration is specifically measured using the DFRobot MQ4 sensor, offering data on natural gas leaks and biogenic emissions. Motion and acceleration data along the X, Y, and Z axes are captured by the ADXL335 accelerometer to correlate environmental measurements with bike movement and potential vibration artifacts. Together, these parameters enable comprehensive environmental monitoring, linking pollutant data to both spatial location and dynamic motion.

Procedure For Optimal Data Collection

During the testing process, the main problem faced over and over again, was the sensors simply not recording any data. For this reason, not all planned data collection set ups were able to happen with all nine sensors. This major set back did lead to the development of a procedure that should be followed for optimal data collection. The two primary factors that led to data collection failures were excessively high ambient temperatures (above 25°C) and insufficient voltage to both initialize the ESP32 and power all connected components. After extensive trial and error, Figure 2 illustrates a step-by-step flowchart that outlines the recommended procedure to increase the chances of reliable data collection.

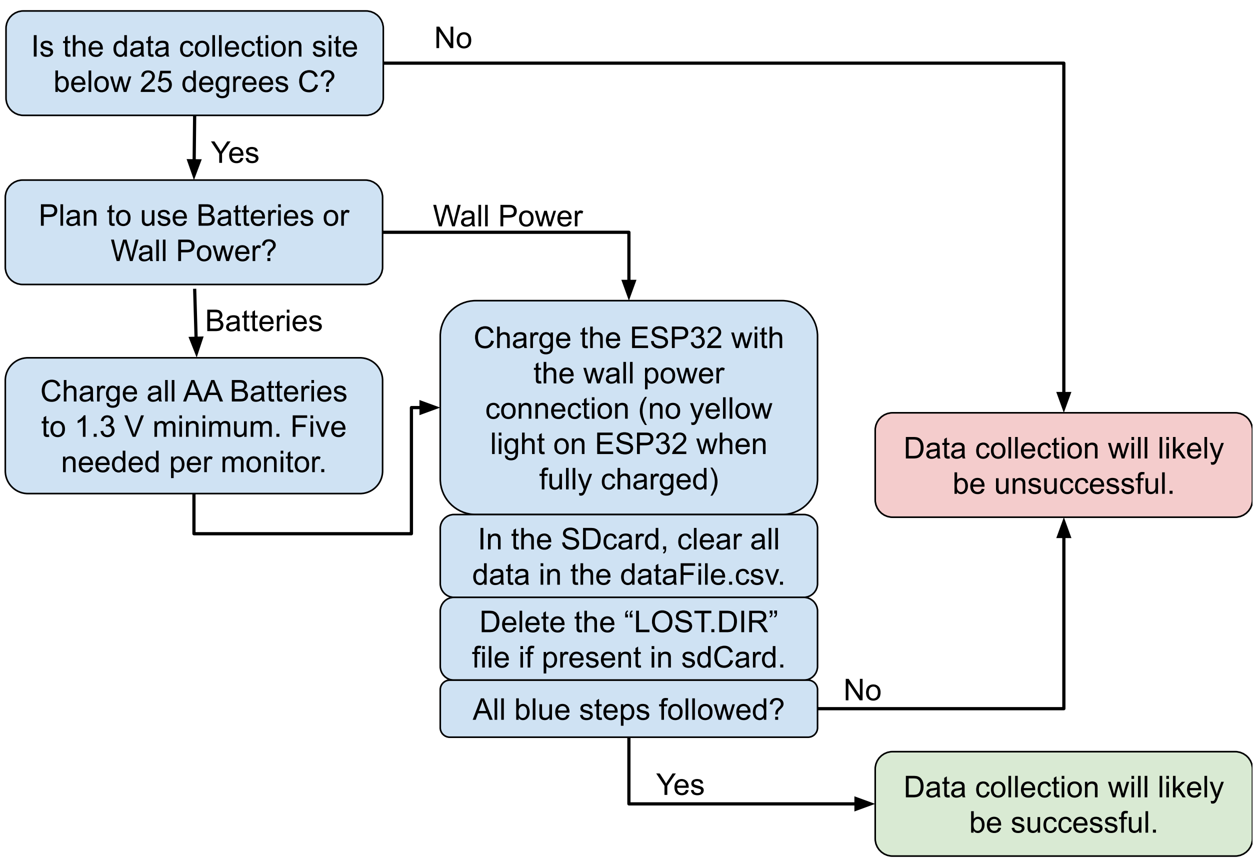


Figure 2: Flow Chart of Suggested Preparations to Increase the Chances of Successful Data Collection using the Bicycle-Mounted Air Pollution Monitor

Experiment Description Overview

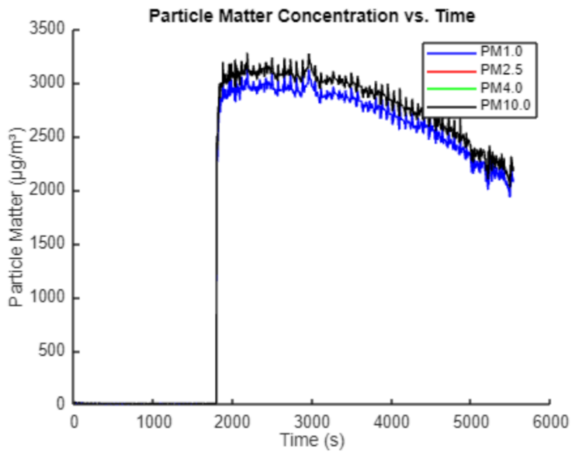
The experiments conducted for this study evaluated the air monitoring system's performance under a range of stationary and mobile conditions, using both battery and wall power. Stationary testing was performed at multiple campus locations to identify sensor functionality, observe baseline behavior, and assess interactions between components. Plugged-in stationary trials were introduced to mitigate battery failures in hot weather, revealing improved stability and responsiveness to environmental changes indoors and outdoors. Movement-based tests, including walks through Allston with GPS shadow mapping, examined sensor responses to traffic, shade, and stopping at intersections. A final set of trials aboard the Green Line B train to Boston College demonstrated how readings change when moving from outdoor conditions to an air-conditioned environment.

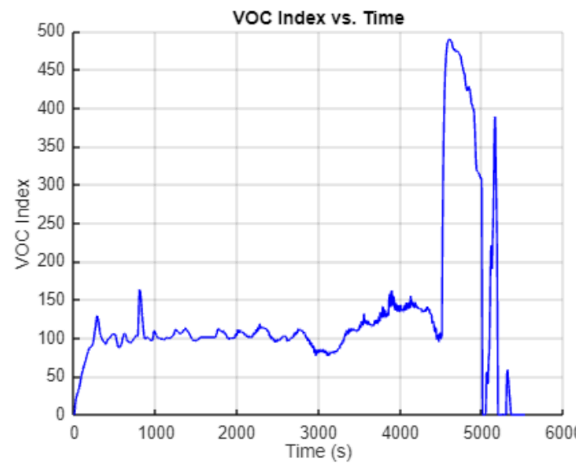
1. Stationary Testing on Batteries

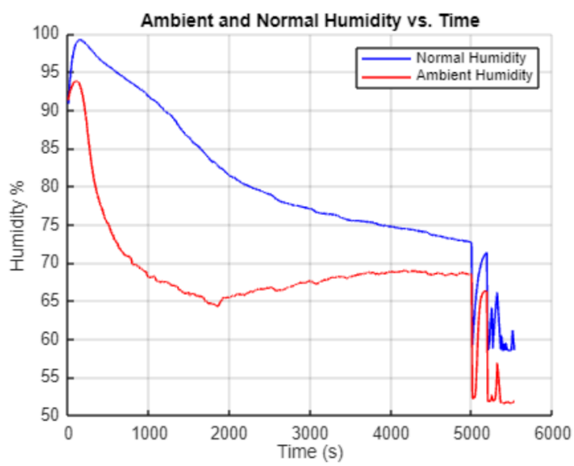
Four locations across the Boston University campus were selected for stationary testing, where each of the nine sensors was cycled through all sites, collecting approximately two hours of data per location at various times during the day. The exact locations of each of the four sites are described in detail in Figure 5. The primary goal of this testing was to assess which sensors were functioning correctly and which were not, serving as a foundation for developing the procedural flowchart shown in Figure 2. Additionally, the testing revealed general performance trends and behavior patterns for each sensor. T

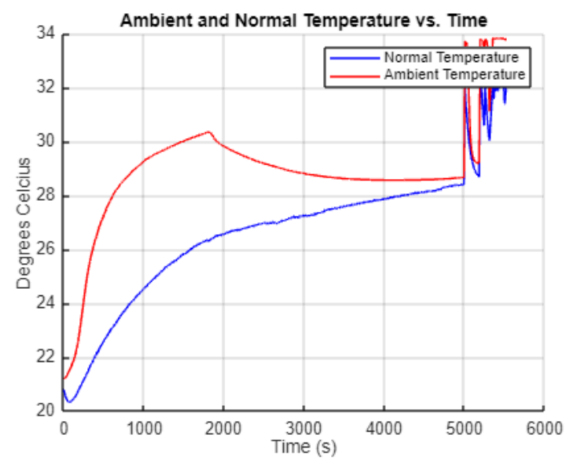
1.1 Particulate Matter Sensor Effect on Other Sensors

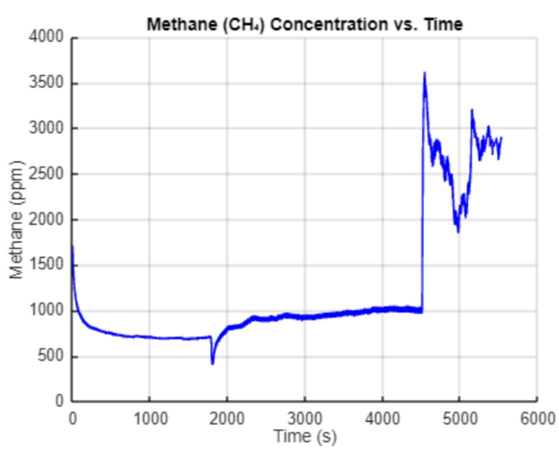
The particulate matter sensor includes a built-in fan, which is expected to influence readings from nearby sensors depending on whether the fan is operational. This effect is most noticeable on the temperature, humidity, methane, and accelerometer sensors, due to airflow-induced changes inside the sensor and the mechanical vibrations affecting sensor stability. Figure 3 is an array of graphs collected by sensor 8, next to storrow drive on BU Beach during the early morning on a weekday (7am to 9am). In Figure 3 around the 2,000-second mark, when the particulate matter sensor activates, its recorded ambient temperature begins to drop. As shown in Figure 2, the methane sensor, which is positioned directly beside the particulate matter sensor, generates heat during data collection. This proximity explains why the particulate matter sensor's ambient temperature reading is elevated before its fan turns on. At the same mark, the accelerometer behaviour changes due to the vibration induced by the working fan.

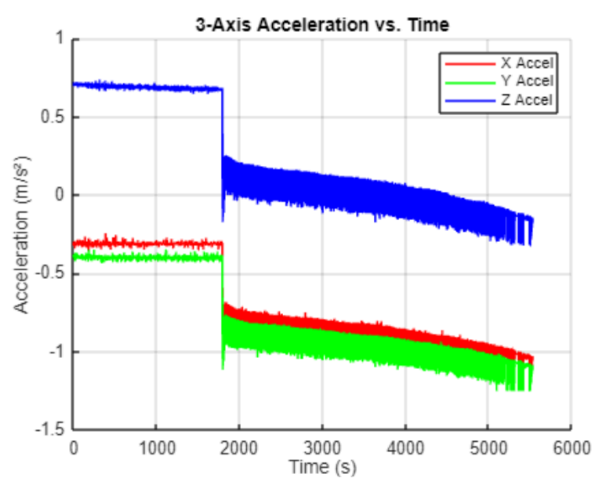

Particle Matter Concentration vs. Time
Particle Matter (μg/m³)
Time (s)
PM1.0
PM2.5
PM4.0
PM10.0


VOC Index vs. Time
VOC Index
Time (s)


Ambient and Normal Humidity vs. Time
Humidity %
Time (s)
Normal Humidity
Ambient Humidity


Ambient and Normal Temperature vs. Time
Degrees Celcius
Time (s)
Normal Temperature
Ambient Temperature


Methane (CH₄) Concentration vs. Time
Methane (ppm)
Time (s)


3-Axis Acceleration vs. Time
Acceleration (m/s²)
Time (s)
X Accel
Y Accel
Z Accel

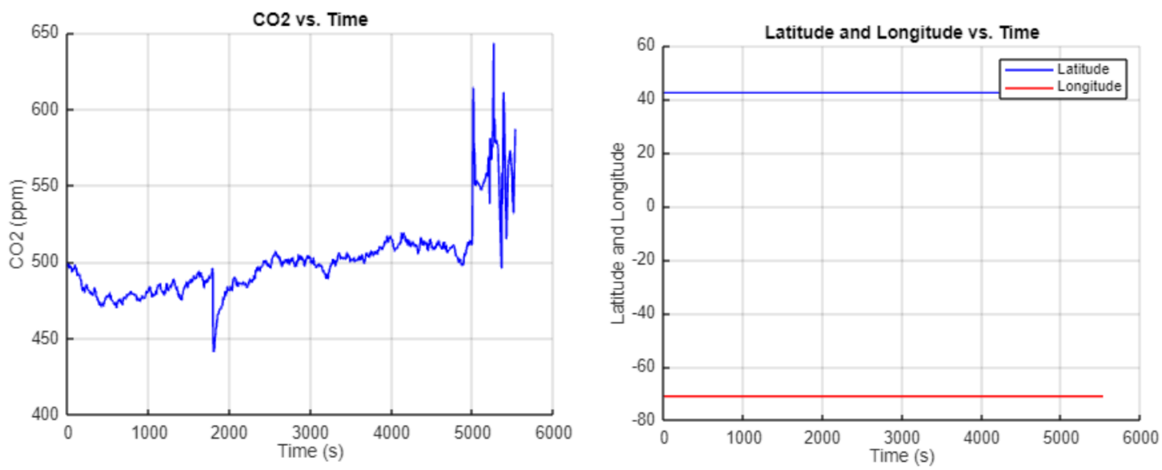
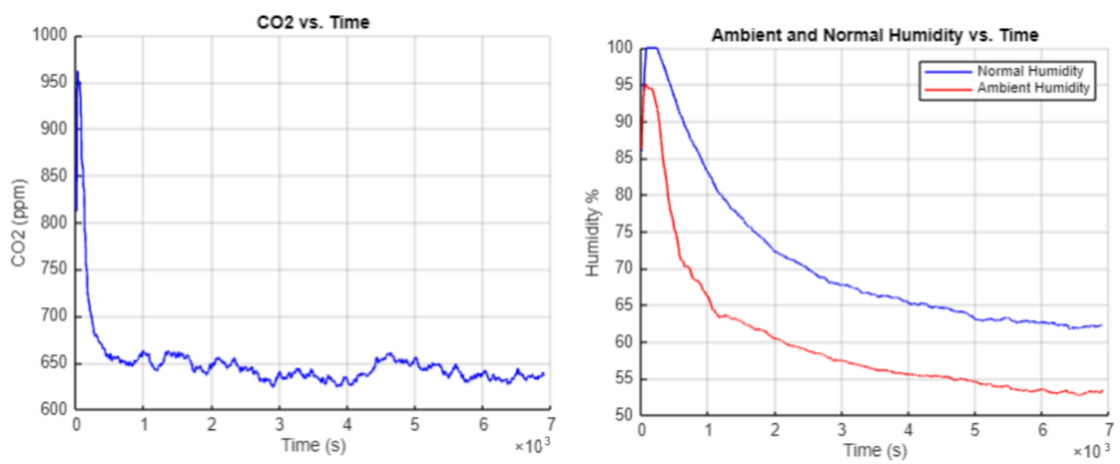


Figure 3: Array of Graphs Collected by a Stationary Test in the BU Beach Location

1.2 Elevated Temperature Due to Methane Sensor

Across all stationary tests, it was determined that there is approximately a 10 °C difference between the ambient temperature inside the enclosure and the outside temperature reported by the weather app. This indicates that heat generated by the sensors and electronics, combined with limited airflow, causes the internal environment to run significantly warmer than ambient outdoor conditions. This heating inside made it very difficult to collect any data in weather conditions with a temperature greater than 25 degrees celsius. Figure 4 shows the generic trends each of the sensors will show before collecting reliable data. The CO2, particulate matter methane and humidity sensors all show an initial spike but then the logarithmically settles. On the other hand the VOC and the temperature start from zero. This shows that at least 20 minutes of operation (~1,000 seconds) are required before reliable data can be obtained. During this warm-up period, the ESP32 is also charging, which contributes to the main consumption of battery power and may influence sensor readings until the system reaches stability.



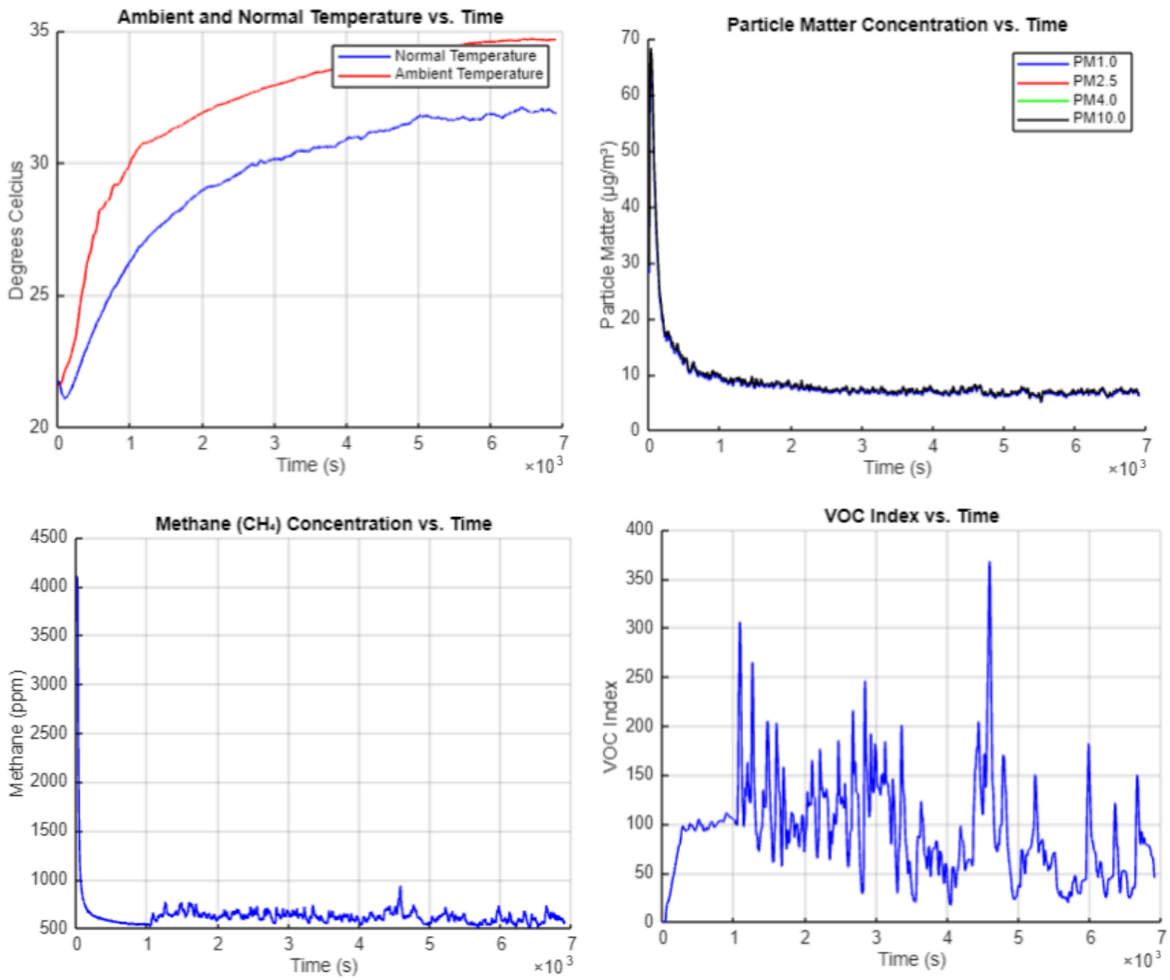
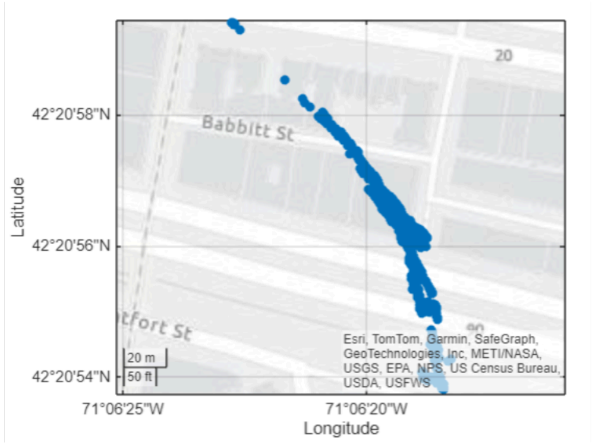


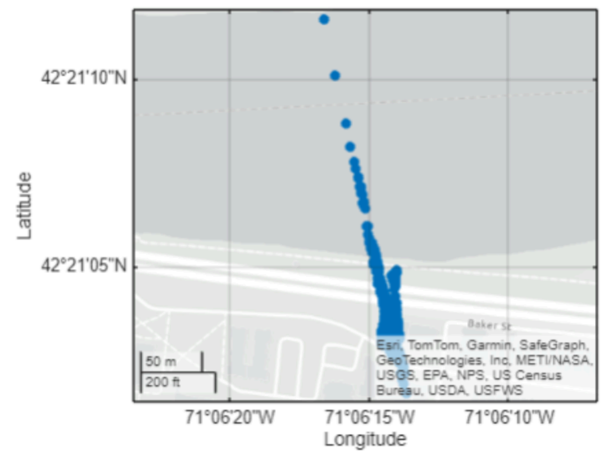
Figure 4: Demonstration of Expected Trends Before Actual Data Collection

1.3 GPS Data Variability During Stationary Testing

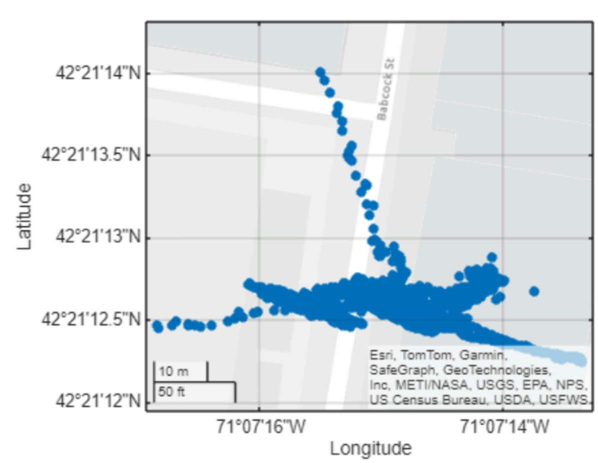
Stationary data collection proved most effective for highlighting the behavior of individual sensors; however, the GPS sensor exhibited considerable noise when the device remained in place. Figure 5 presents the four selected stationary data collection locations alongside the corresponding GPS data patterns. This is not a significant issue because, during mobile data collection, the GPS sensor performs reliably. Movement provides varying satellite geometry and signal conditions, which reduces positional drift and noise, resulting in more accurate and stable location data compared to when the device is stationary.



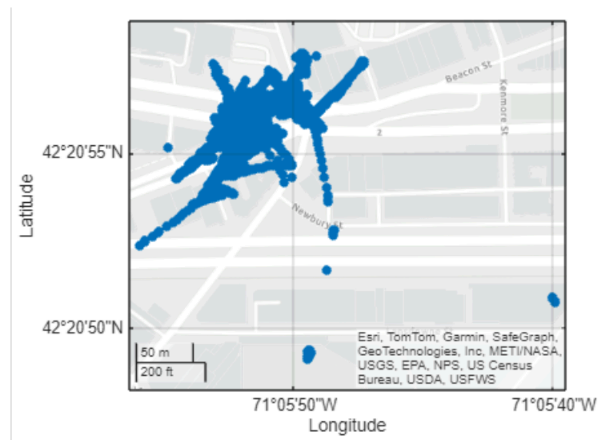
Outside Meche Building: on the cement block on the left side of the bike rack.



BU Beach next to Storrow Drive: behind the BU Admissions Office on the ledge in the opening in the bushes.



Babcock St Parking Lot: on the ledge close the parking lot wall in the tree area.



Kenmore Square: behind the Mass Air Online sensor.

Figure 5: Examples of the GPS Data Collected at all of the Sites Picked for Stationary Collection

2. Stationary Testing on Wall Plug

2.1 Plugged in Outside During Rush Hour

The repeated failed attempts at collecting data led to the assumption that the failures were caused by the batteries dying due to heat exposure. To test this, data collection with the device plugged in was introduced. One key benefit of charging the ESP32 immediately before actual data collection is that it helps eliminate the initial voltage drops and unstable behavior often seen during startup, which can cause sudden jumps or fluctuations in sensor readings. Keeping the ESP32 powered and fully charged before recording ensures more stable operation and more reliable data from the very beginning of the monitoring period. Figure 6 presents an array of graphs collected during a stationary, plugged-in test conducted outdoors, demonstrating the improved stability and consistency of sensor readings when the device is continuously powered.

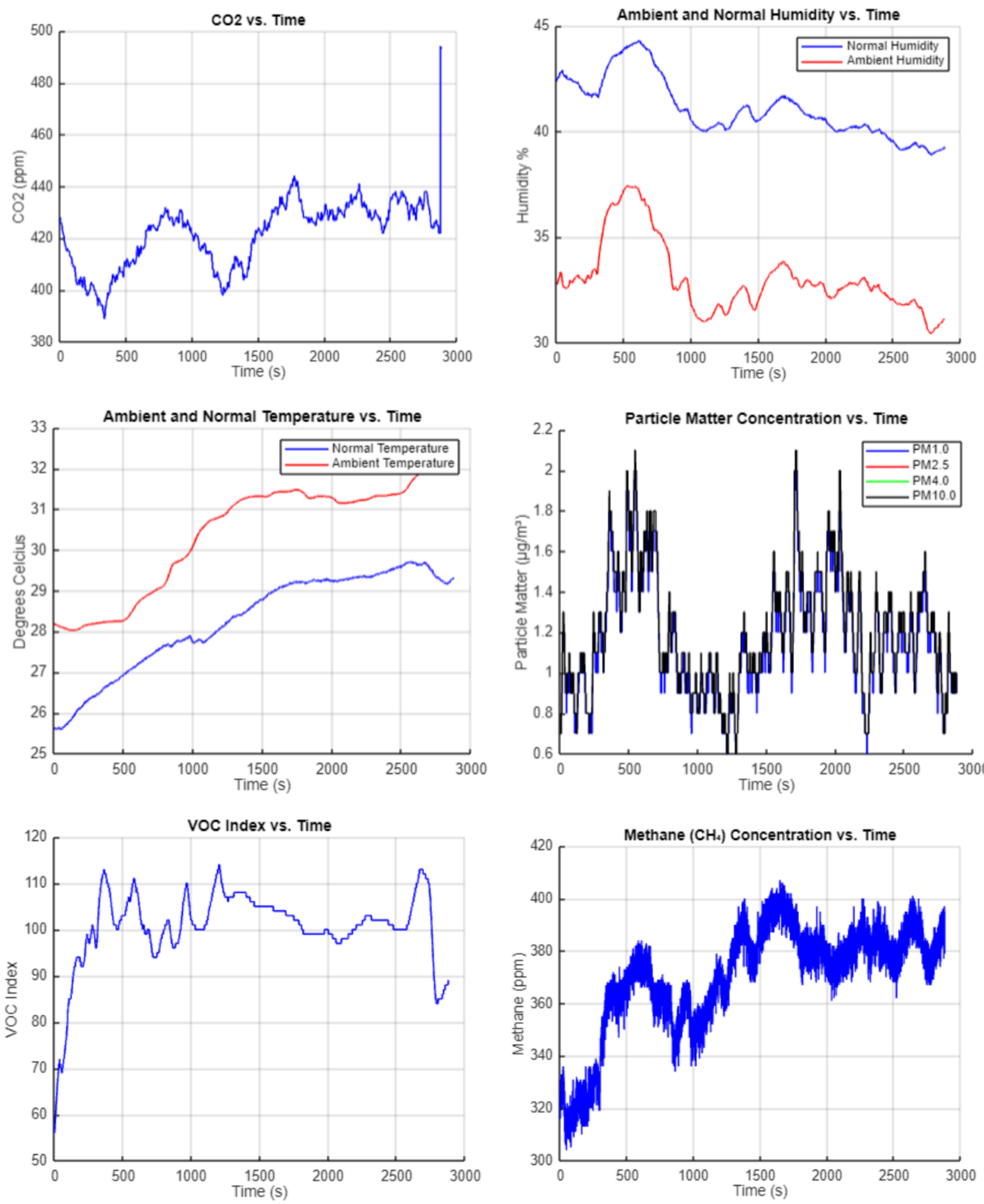


Figure 6: Array of Graphs Collected During a Stationary Plugged in Test Outside

2.2 Plugged in Inside Before Lunch and During Lunch Time in Food Court

During the heat waves, indoor locations such as the food court area in the George Sherman Union (GSU) building at BU were also tested. The GSU's summer hours, from 11 a.m. to 2 p.m., see a significant fluctuation in occupancy levels. Figure 7 displays air quality measurements taken from 10 a.m. to 1 p.m. while the device was plugged in at the GSU. This experiment showed the sensors effectively respond to indoor air quality changes linked to foot traffic and activity levels.

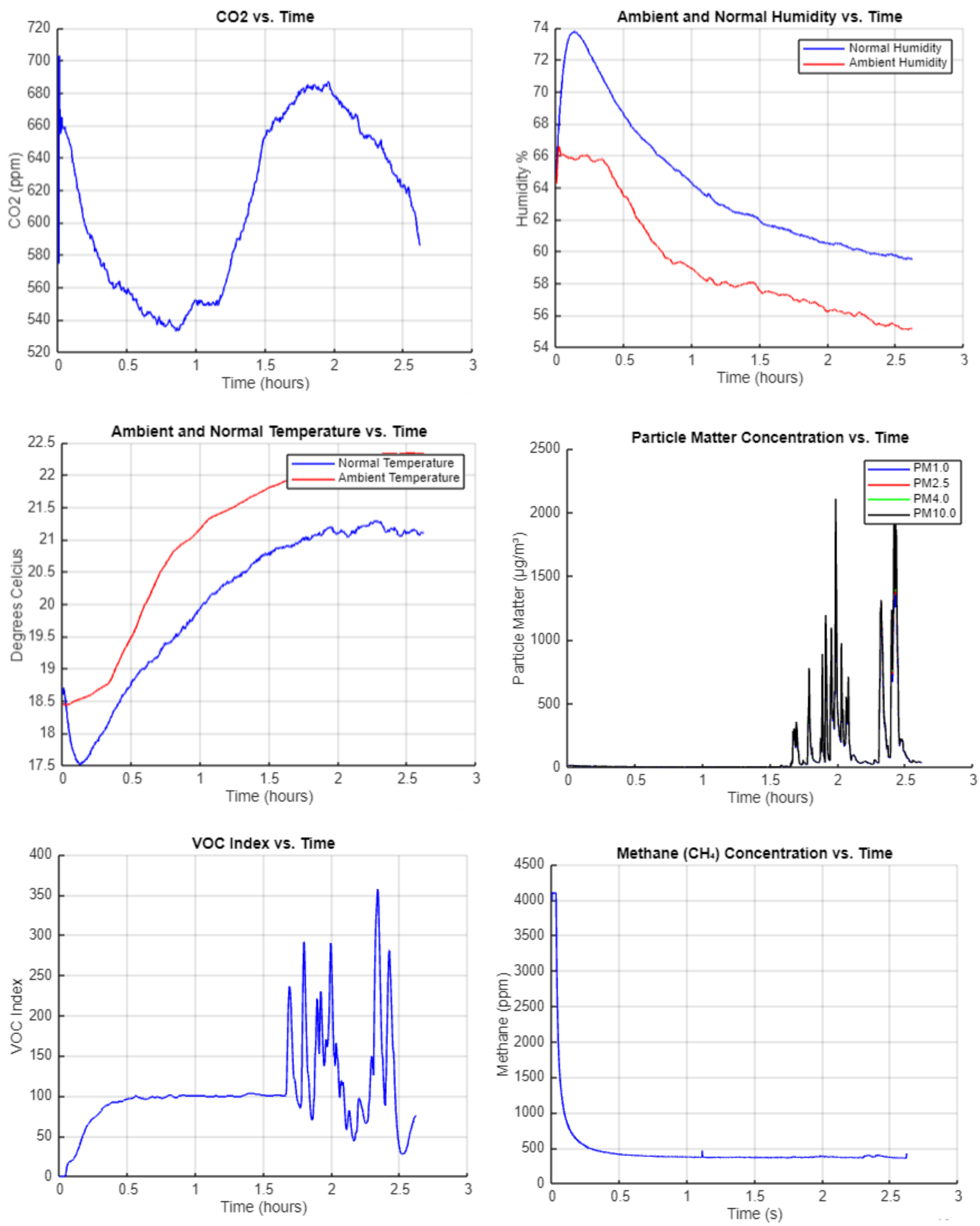


Figure 7: Array of Graphs Collected Indoor Before Lunch and During Lunch Time in Food Court

3. Movement Testing

3.1 Effect of Shade on Moving Sensor Collection

The most important testing was movement testing during busy afternoons when there are lots of cars driving around. The route chosen was a walk through Allston on Commonwealth Avenue. Figure 8 shows the GPS-recorded route overlaid with a shadow map from ShadeMap.app for the same time period, allowing comparison of whether shaded areas and stops at intersections are reflected in the sensor data. Notably, the temperature and humidity drops in shadow regions and peaks in sunny regions. Figure 9 provides an array of graphs from the same walk, further illustrating how dynamic, real-world factors such as traffic flow, sunlight exposure, and movement patterns are reflected in the sensor readings during mobile data collection.

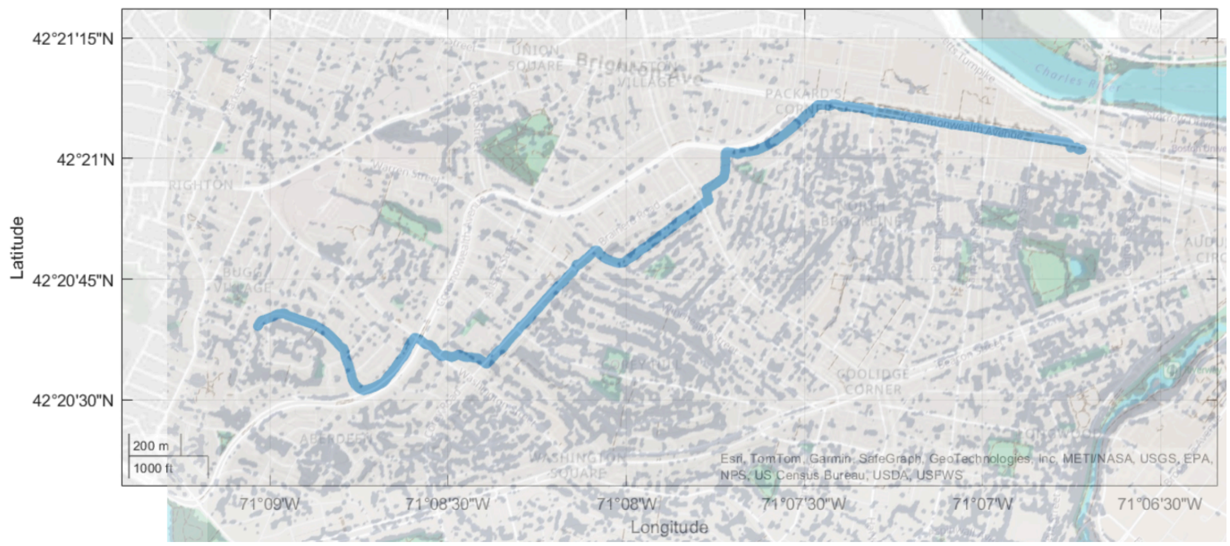
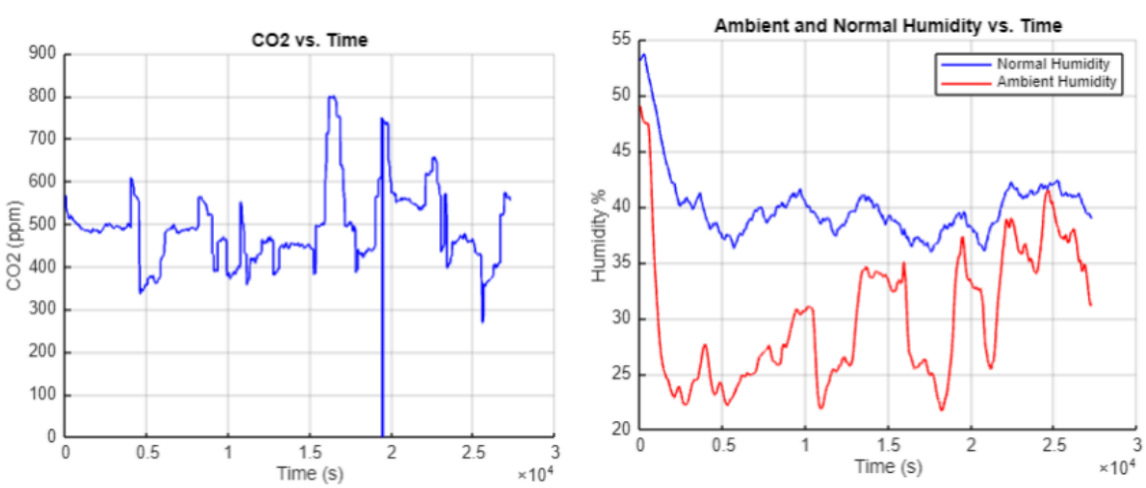


Figure 8: Moving Route Walking Through Allston During a Busy Afternoon with Recorded Shadows During the Collection Interval



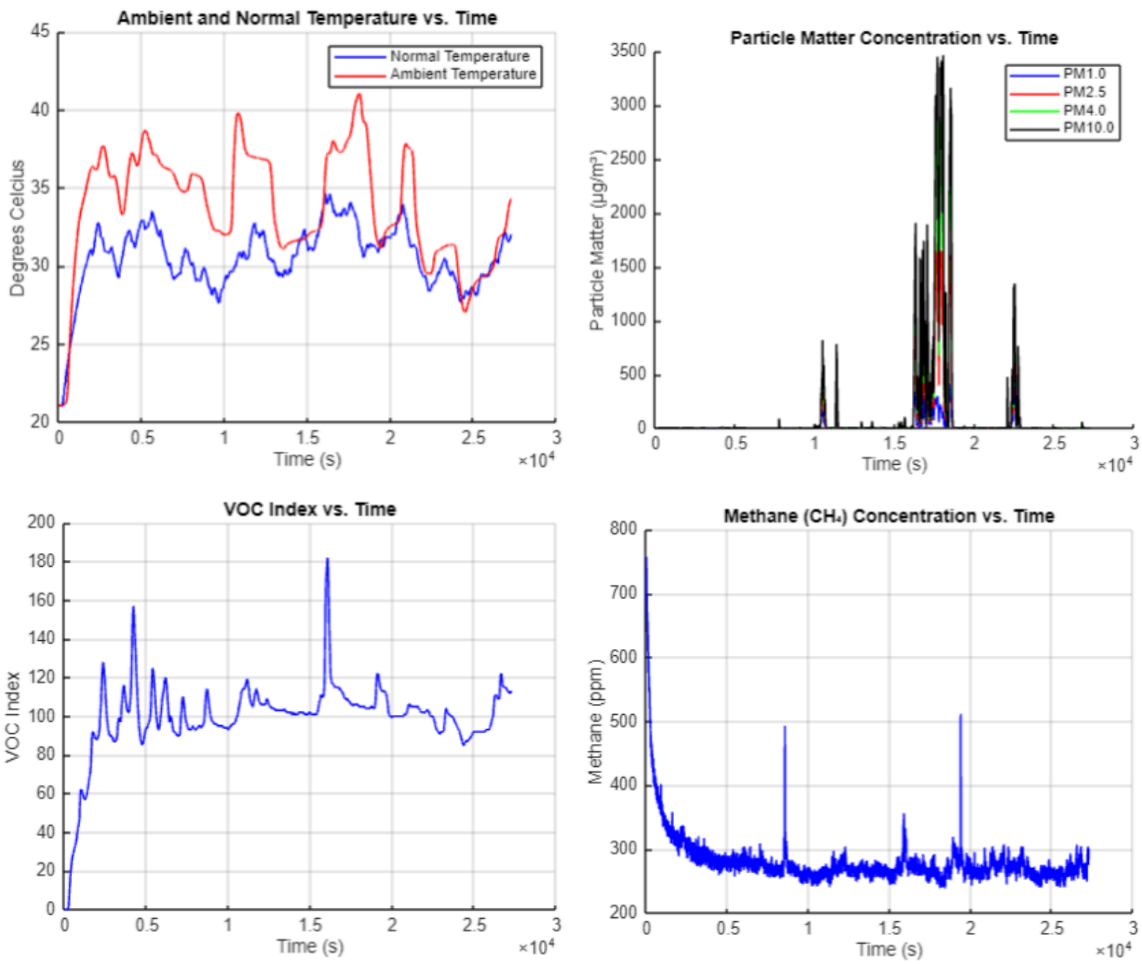


Figure 9: Array of Graphs Collected During Moving Data Collection Walking Through Allston During a Busy Afternoon

3.2 Movement to Immediate Plugged in Stationary Data Collection

Another interesting test combined moving data collection on battery power with a subsequent stationary, plugged-in period to observe how the sensors transition between operating modes. Figure 10 presents an array of graphs from this experiment, illustrating the data collected during both the mobile and stationary phases. The mobile data came from walking the same route illustrated in Figure 8 and the stationary phase was inside a parking lot on Babcock St. The data reveal that VOC levels varied and were much higher than stationary collection during the moving portion, likely due to emissions outside and the constant change in air. Inside the parking lot the air is much more stationary and the occasional spikes come from the cars driving by the sensor. This setup highlights how changes in both environmental conditions and power configuration can influence sensor behavior and proves that it is very responsive.

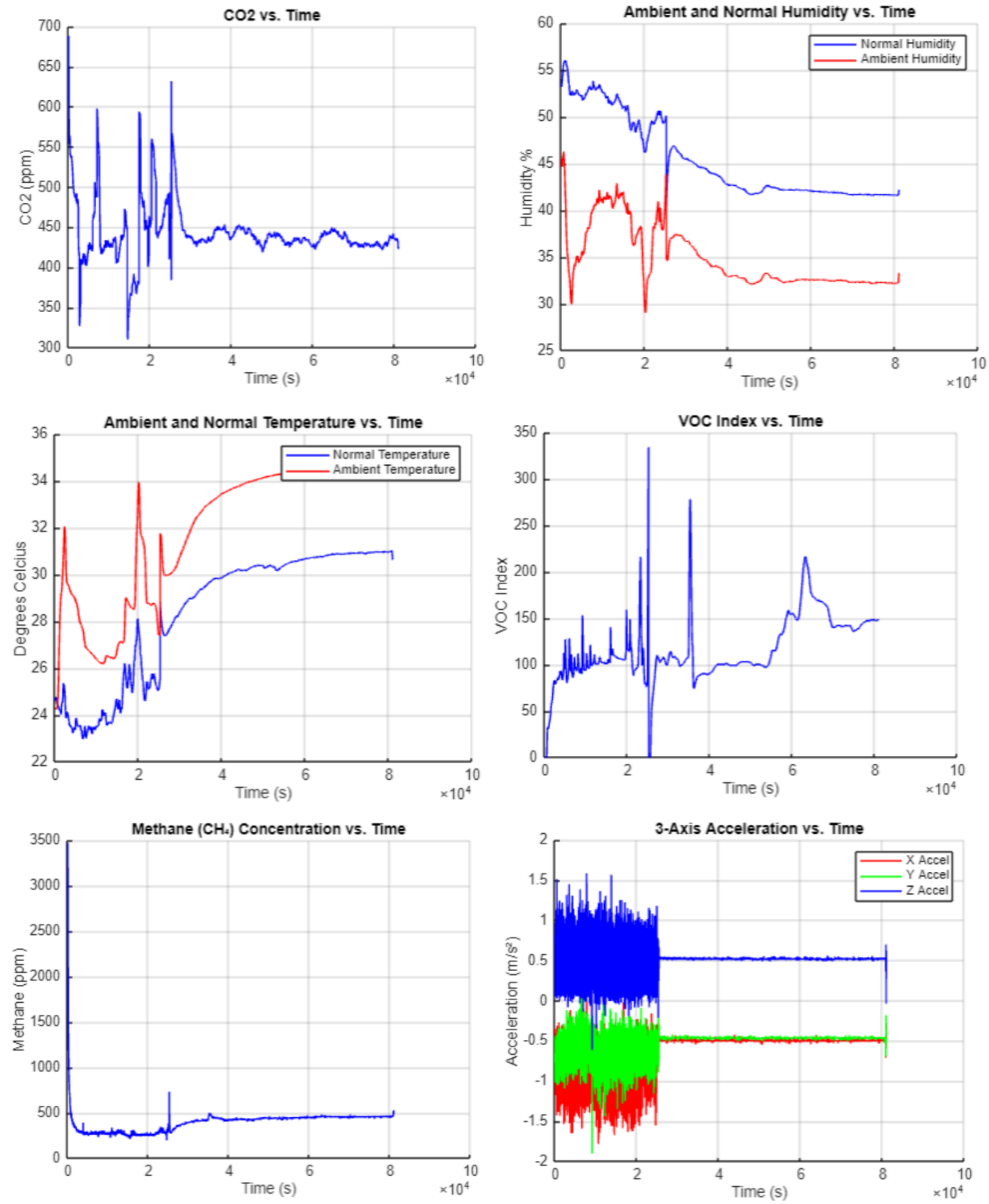
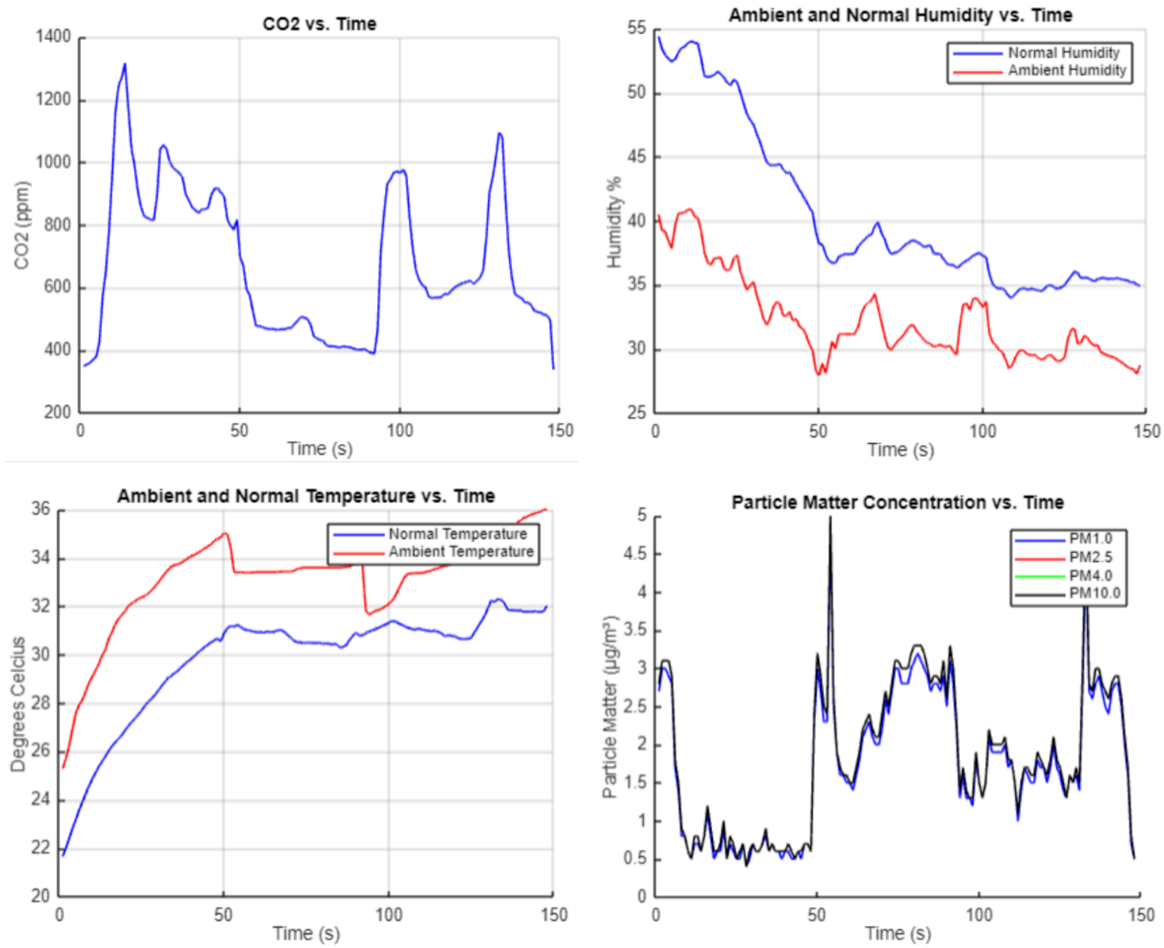


Figure 10: Array of Graphs Collected During Both Battery Moving Collection and Plugged in Stationary Collection

3.3 Data Collection Outside and Inside the T (Air Conditioned Train)

The final test followed the same route shown in Figure 8, but this time aboard the Green Line B train to Boston College. Figure 11 presents graphs illustrating how various measured quantities change as soon as the sensor enters the T. The accelerometer data most clearly captures the transition, reflecting the motion characteristics of the train. However, the most notable trend appears in the CO_2 readings: upon entering the air-conditioned train, concentrations immediately stabilize in the 400–500 ppm range, which is considered normal. In contrast, outdoor CO_2 levels fluctuated significantly, showing pronounced oscillations likely influenced by traffic emissions and variable airflow conditions.



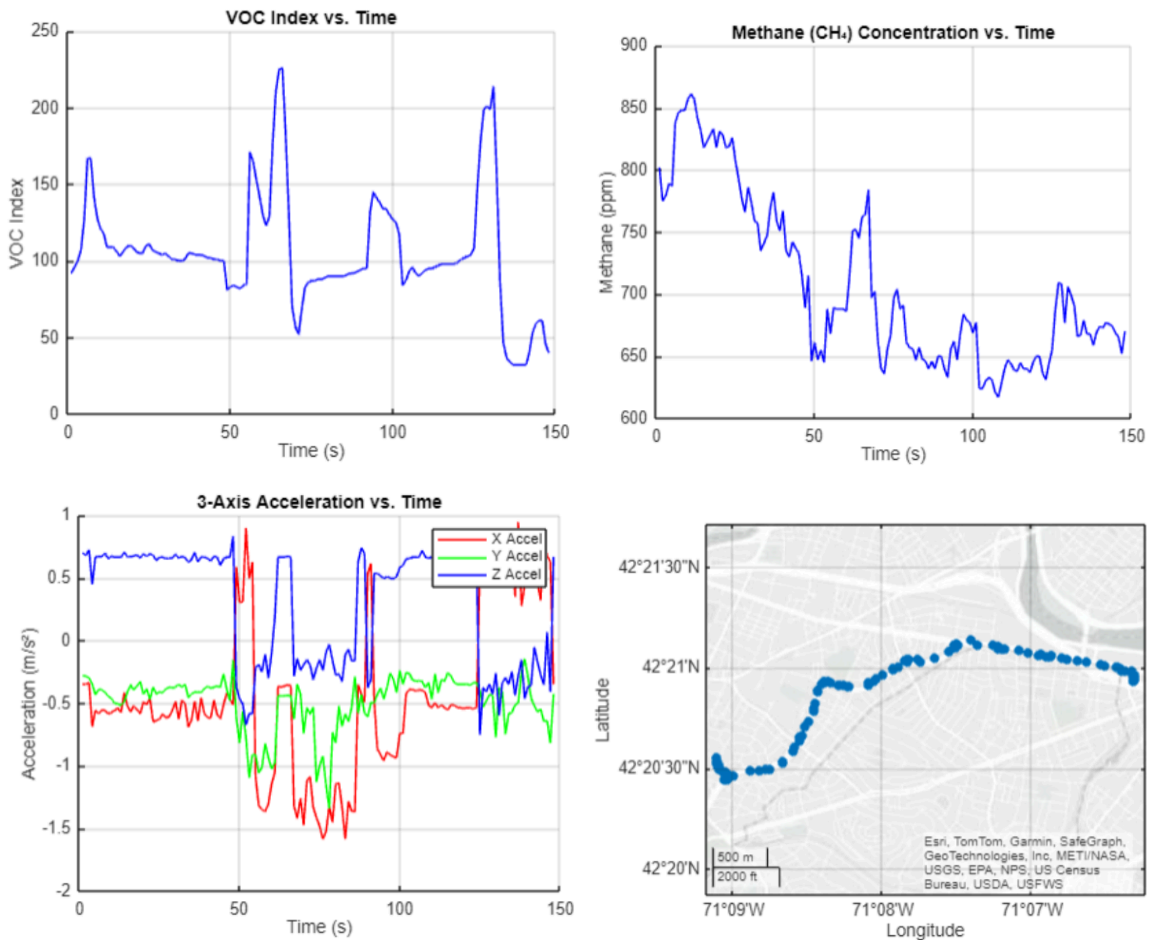


Figure 11: Array of Data Collected During Moving Battery Collection of both Walking and Riding the Air Conditioned T

Future Testing Recommendations and Conclusions

Additional testing involved running data collection in various parts of Boston, including trials that combined mobile and plugged-in operation to mimic bus-based data collection, potentially by connecting the sensor directly to a vehicle's power supply. Speed tests can also be conducted to examine how the sensor performs within the vehicle's boundary layer. Cold weather trials, ranging from 0–15 °C and potentially below freezing, can also be carried out to evaluate performance in harsher conditions. During the initial testing, efforts were made to ensure all sensors were functioning correctly, with observations suggesting that failures were more often due to data collection issues, rather than sensor hardware failure. Overall, this testing revealed that the current sensors lack robustness, indicating a need for reevaluation of their design and durability.