Resident Perceptions of Air Freshness in Apartments with Energy Recovery Ventilation

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Thesis Abstract

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Master of Science in Architecture

Title: Resident Perceptions of Air Freshness in Apartments with Energy Recovery Ventilation

Passive House multifamily buildings rely on airtight envelopes and balanced ventilation to maintain healthy indoor air quality, yet limited post-occupancy research examines whether these systems consistently deliver fresh air—especially for older adults in affordable housing. Although certification depends on modeled performance, such as WUFI Passive, little evidence verifies whether energy-recovery ventilators (ERVs) function as intended post occupancy. Existing studies emphasize energy outcomes rather than how occupants perceive air freshness, how those perceptions shape ventilation behavior, or how sensor feedback influences autonomy and comfort. This gap is increasingly important as states integrate Passive House standards into stretch codes and as aging populations and climate extremes increase reliance on mechanical ventilation systems. This study aims to investigate how occupants' behaviors and perceptions of air freshness shape ventilation use.

This mixed-methods case study combined indoor IAQ monitoring (temperature, CO_2, humidity, $PM_{2.5}$, TVOC) with three semi-structured interviews per participant over two weeks. Following Yin's case study methodology, the research triangulates IAQ measured conditions with resident perceptions. A baseline phase documented typical ventilation habits without sensor cues, followed by an interventional phase in which a sensor indicator light was activated to

assess how real-time feedback shaped behavior and ventilation use. Interview coding and IAQ analysis generated themes related to autonomy, comfort, ventilation strategies, health, and overall perceived air freshness.

Findings show that perceptions of “fresh” or “stale” air often differ from measured IAQ levels. Participants relied on odor, noise, and thermal comfort rather than sensor indicators to adjust ventilation practices. Sensor feedback increased awareness and prompted short-term changes but did not fully resolve misunderstandings/confusion about ERV functionality. Overall, occupant perception of air freshness emerged as the primary driver that influenced behavior relating to ventilation practices, highlighting the need for user-centered design and ongoing tenant education in Passive House housing.

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Chapter I: Introduction

1.1 Statement of Problem

Buildings have a significant impact on energy emissions and therefore direct impacts on climate crisis. In the United States it is noted that buildings have emitted about 80% of the grid's energy based upon the 2050 Energy Challenge (Langevin el at., 2019). The biggest continuing challenge is the transition to net zero energy systems. While it is important to provide stable and affordable energy access, the country is expected to exceed those measures which could cause a major blackout event (Hines el at., 2009). With rising annual temperatures and inefficient mechanical systems in buildings, energy consumption per capita will continue to increase. This specific problem has directly impacted regions across the United States especially within the Pacific Northwest.

Passive House Principles rely on the importance of thermal control, air control, moisture control, and radiation control (Phius 2024 Certification Guidebook). Within these sets of principles, the ones that are most important towards influencing occupants' behavior and ventilation systems are enclosures, airtightness and balanced ventilation. As of 2025, the states of Massachusetts and New York have begun to transition into having Passive House building criteria into their stretch building codes. These principles have been long standing in Europe and proven to be successful when utilized correctly (Hasper el at.).

To be utilized efficiently, educating occupants on ventilation practices is just as important as understanding passive principles themselves. As the demand for passive buildings

increase, post occupancy studies will validate the success of occupant understanding of passive principles.

Climate change has increasingly affected the Pacific Northwest in recent years, particularly during the summer months, resulting in more frequent and intense heat waves (Mote and Salathe, 2010). In response, Like Massachusetts and New York, Oregon is also providing incentives to help increase ERV implementation into multifamily housing (OAR 813-206-000). Because this study was in Vancouver Washington it is also important to note the Housing Finance Commission a 9% low-income tax credit to encourage developers to build towards rehabilitation standards of multifamily housing. Building to rehabilitation standards helps encourage developers to build towards more sustainable design standards which aim to "safeguard health and safety, increase durability, promote sustainable living, preserve the environment, and improve energy and water efficiency" (ESDS).

ERVs supply fresh outdoor air while exhausting stale indoor air, helping maintain indoor air quality with reduced energy loss (Laverge el at., 2011). When properly designed and operated, ERVs can provide significant energy savings; however, research shows that some behaviors can reduce their efficiency (Zhao el at., 2017). While architects, engineers, and builders can install high-performance ventilation systems, long-term performance depends on occupant behavior. Participants will operate these systems daily for months or even years, so it is important to invest in efficient systems while also providing occupant education. To ensure ERVs function as intended, occupants must be informed on how to use them correctly, otherwise the systems might fail in delivering adequate ventilation to occupants.

1.2 Research Questions and Objectives

This research examines how occupant behavior influences ventilation performance in multifamily housing and how perceptions of air freshness shape those behaviors. The objective of the research is to evaluate whether residents' perceptions of indoor air freshness align with actual air quality conditions within their apartment units. The study addresses the following research question: How does perception of air freshness influence active ventilation strategies for older people living in affordable, Passive House apartments?

Chapter II: Literature Review

This literature review examines existing research on passive principles; influence of occupant behavior on ventilation, post occupancy evaluation, monitoring impacts on autonomy, and housing policy. Within this recent research, there is a gap in knowledge regarding how occupants' perception of air freshness can influence ventilation strategies within these areas of research.

Through Passive House principles, there is a growing recognition that buildings account for a substantial amount of energy consumption. As policymakers and designers increasingly adopt Passive House standards, these principles have become a standard for reducing energy use while maintaining thermal comfort. Research demonstrates that Passive House strategies such as airtight envelopes, high-performance insulation, and controlled ventilation offer significant potential for energy savings. However, their effectiveness is shaped by not only design, but also by how occupants interact with ventilation systems post-occupancy (Sun and Hong, 2017).

Another important theme that emerges from this research on passive house principles is the value of Post-Occupancy Evaluation (POE). POE provides a critical lens for understanding how Passive House strategies perform in practice. While many energy-efficient design decisions are embedded during construction, POEs allow researchers to assess whether these strategies function as intended once participants occupy the space. Through a combination of energy monitoring, indoor environmental data, and occupant feedback, POE studies reveal how everyday activities; such as cooking, hosting guests, or adapting to seasonal changes can significantly alter indoor air quality (Mach et al., 2025). These findings demonstrate that

occupant behavior often prompts users to adjust their windows and ventilation systems to restore comfort, sometimes at the expense of energy efficiency.

Occupant behavior in relation to ventilation and thermal comfort also plays a critical role in influencing building performance. Studies on low energy housing show that participants adapt their comfort through behaviors by adjusting their windows and ventilation systems (i.e modifying their heating and cooling systems). These behaviors are influenced by personal preferences, household routines, and changing comfort expectations over time. What constitutes "thermal comfort" is not static; it evolves as people age and varies between individuals (Jia et al., 2017). As a result, ventilation systems that are designed for "optimal energy" may not be used in a way that is optimal towards its user, therefore negatively affecting indoor air quality and energy consumption. Overall, this can impact the importance of viewing ventilation systems as strictly technical.

Additionally, sensor-based monitoring and smart ventilation technologies represent an emerging response to the complexity of occupant behavior. By automating ventilation based on occupancy, indoor air quality, and environmental conditions, smart systems aim to reduce energy use while preserving comfort and minimizing the need for occupant intervention (Clark et al., 2019). Research suggests that these systems can be beneficial in airtight buildings, where it is essential to maintain good indoor air quality. However, sensor-driven approaches also raise questions about occupant autonomy, comfort perception, and trust in automated systems. For older adults in particular, increased thermal sensitivity and reliance on familiar control methods can influence how these technologies are used. While sensor monitoring offers reliable and cost-

effective data on temperature, humidity, and carbon dioxide levels, translating this information into holistic comfort assessments remains a challenge, pointing to the need for further research.

Finally, housing and policy frameworks shape the broader conditions under which energy-efficient buildings are designed, operated, and occupied. Emerging policy recognizes that energy performance is not only a function of building technology, but also of occupant behavior. Models such as the "Softer Landings" approach emphasize long-term engagement, education, and feedback on behavioral support (Zhao et al., 2025). Research shows that resident behavior plays a major role in operational energy use, reinforcing the need for policies that integrate physical infrastructure, efficient equipment, and human-centered design (Mardookhy et al. 2014). As climate change and the aging population grows, it places pressure on housing systems. In turn policies must acknowledge the behavioral dimensions of ventilation and comfort and how it will be necessary for achieving lasting reductions in residential energy consumption.

2.1 Passive Principles

Passive House principles are becoming increasingly used as a standard among policymakers as awareness grows that buildings account for approximately one-third of global primary energy consumption. In response, frameworks have been developed through various studies to quantify the uncertainty associated with energy savings from specific building technologies, such as ventilation systems. The study *A Framework for Quantifying the Impact of Occupant Behavior on Energy Savings of Energy Conservation Measures* (Sun and Hong, 2017) seeks to evaluate both the potential energy savings of these measures and the influence of occupant behavior on overall building energy use.

Further research indicates that, although Passive House standards offer significant energy-saving potential, there remains limited data on the combined impacts of energy efficiency strategies and occupant behavior (Truong and Garvie, 2017). Passive House standards continue to be the leading benchmark for comfort and energy-efficient building design worldwide, particularly in Europe, however, it is critical to understand how these strategies perform across diverse climatic conditions in the United States (Truong and Garvie, 2017). As related policies and regulations are increasingly implemented, understanding how occupant behavior affects building energy performance is essential. Ongoing research and occupant education are necessary to fully capture the holistic impacts of occupant influence on energy savings.

Another important piece of understanding the impact of occupant behavior in residential complexes requires the use and analysis of Post-Occupancy Evaluations (POEs). In Passive House projects, many design principles are implemented during construction, prior to tenant occupancy. Commissioning is essential for assessing whether these passive strategies perform as intended once participants move in and occupy a building.

As Passive House buildings have grown in popularity over the past decade, research by Mach and Colleagues (2025) (Mach el at.., 2025) examined two constructed in Canada using POE methods to evaluate how occupant behavior influenced energy efficiency. In this study, data loggers were installed to monitor heating and cooling loads, while energy bills were collected simultaneously (Mach el at.). Although energy consumption data formed part of the analysis, the primary focus of the research was to understand how emerging building technologies reduce environmental impacts (Mach el at., 2025). The study also analyzed thermal comfort and indoor temperature patterns to predict occupant behavior (Mach el at., 2025). Through POE, the study

surveys and data loggers concluded that behavioral factors such as cooking, dining, and hosting guests were found to significantly affect indoor temperatures (Mach el at., 2025). These effects prompted occupants to adjust window operation and ventilation systems to maintain comfort.

Passive building strategies are also becoming increasingly relevant in multifamily housing, particularly as the global population ages (Feng el at., 2018). As “aging in place” initiatives expand internationally, there is growing value in understanding how architectural design can support elderly participants through improved ventilation and indoor air quality (Feng el at., 2018). It is estimated that within the next 25 years, more than two billion people worldwide will be over the age of 60 (Feng el at., 2018). To promote positive aging through housing, it is essential to adapt to residential environments to support comfort and well-being for this demographic. The framework presented in this research evaluates POEs through themes of personal safety, sensory comfort, and spatial functionality (Feng el at., 2018). Findings indicate that older adults often experience insufficient sensory comfort within their housing environments, highlighting the need for strategies and further research to improve residential satisfaction and overall quality of life (Feng el at., 2018).

As energy vulnerability increasingly intersects with age-related vulnerability, POEs in understanding passive principles play a critical role in understanding the dynamic relationship between occupant behavior and building systems, particularly ventilation (Feng el at., 2018). Identifying gaps in comfort and system usability may inform the development of improved standards principles to better support occupant needs in future housing design.

2.2 Occupant Behavioral Effects on Ventilation Strategies

Low-energy and zero-energy homes are becoming central components of multifamily housing development because of growing concern about climate change, along with the need to reduce energy consumption (Sherriff el at., 2019). There is increased interest in understanding how occupant behavior influences building systems (Sherriff el at.). The article *Coping with Extremes, Creating Comfort: User Experiences of Low-Energy Homes in Australia* (Sherriff el at., 2019) examines heating and cooling practices within the context of low-energy housing. Conducted in Adelaide, South Australia, this study explores the complex relationship between occupants and thermal comfort using surveys and interviews to assess how different households operate building systems and appliances (Sherriff el at., 2019). This study highlights the importance of thermal comfort within low energy buildings, and that what people deem as "thermally comfortable" varies over one's lifetime (Sherriff el at., 2019).

Additionally, understanding the indoor environmental conditions of buildings is essential to assessing how occupants experience and respond to thermal comfort (Jia el at., 2017). The study *From Occupancy to Occupant Behavior* demonstrates that achieving optimal energy efficiency through ventilation strategies depends heavily on maintaining adequate indoor air conditions, particularly those related to thermal comfort (Jia el at., 2017). The research further highlights that ventilation system performance is influenced by both passive and active occupant behaviors (Jia el at., 2017). This is important when looking at the impact of human interaction when evaluating building energy performance through ventilation strategies.

2.3 Sensor Monitoring Influence on Autonomy & Comfort

Understanding the relationship between sensor-based monitoring, occupant autonomy, and comfort is essential for evaluating how behavior influences ventilation use (Hoof el at., 2019). As with previous themes, the aging population is particularly important in this context. Increasing thermal sensitivity can significantly affect how older occupants operate windows and ventilation systems, especially during periods of extreme temperature variation. However, most studies examine thermal comfort among older adults rely primarily on qualitative data, with limited use of qualitative or mixed methods approaches (Hoof el al, 2019). To address this gap, Hoof and colleagues conducted a qualitative study using focus group interviews to capture a wide range of perspectives on how older adults relate to heating, cooling, well-being, and household energy use. This approach aims to maximize diversity in responses and better understand the behavioral and attitudinal factors influencing thermal comfort. Findings from surveys and discussions indicated that older adults tend to interact more frequently with ventilation systems during extreme weather events. The study proposes adaptive thermal comfort strategies that account for varying environmental conditions and individual needs, offering an alternative framework for managing comfort in residential settings (Hoof el at., 2018).

Complementing this behavioral-focused research, other studies suggest that smart ventilation control strategies may offer greater energy efficiency in residential buildings (Clark el at., 2019). Rather than relying on occupant intervention, smart ventilation systems can reduce energy consumption by sensing occupancy and modulating fan operation automatically. Clark and colleagues study focused on indoor air pollutants and contaminants, proposing control

strategies well suited to airtight buildings. The findings indicate that smart ventilation can improve thermal comfort by responding to times when occupants return home and are exposed to higher contaminant levels (Clark el at., 2019).

Despite these advancements, real-time measurement of occupant comfort remains complex. Wireless smart comfort sensor systems have been shown to be both reliable and cost-effective, making them valuable tools for monitoring indoor environmental conditions. For this research, sensors capable of measuring air temperature, humidity, and carbon dioxide were particularly important in evaluating comfort and air quality (Kumar and Hacke, 2014).

Overall, while assessing occupant thermal comfort through sensor-based monitoring presents challenges, there remains limited research quantifying its broader implications. As the global aging population continues to grow, further research is needed to understand how integrated smart sensor systems can support optimal indoor air quality—whether through the development of new comfort metrics or expanded empirical studies.

2.4 Housing & Policy

Understanding the policy is important for interpreting and understanding how ERV performance can influence future research and housing policy. Recent research emphasizes that in order to achieve energy reductions, it requires not only technical solutions but also behavior-responsive solutions. Policy frameworks can support these findings though creating “softer landing communities” and smart, feedback-rich environments can help cultivate the behavioral shifts necessary for low-carbon living (Zhao el at., 2025). The Softer Landings Approach identifies the persistent barriers, like limited policy incentives that slow adoption of

low-carbon communities. By proposing a framework that aligns behavioral interventions with market growth, Zhao demonstrates that behavioral adaptation is achievable when policy and market signals create and reflect a clear demand.

Zhao argues that creating “softer landing communities” and smart, feedback-rich environments can help cultivate the behavioral shifts necessary for low-carbon living (Zhao el at., 2025). Similarly, Mardookhy show that energy-efficient residential performance depends on three components: physical infrastructure, efficient equipment, and occupant behavior (Mardookhy el at. 2014). Through an analysis of 102 single-family homes, they conclude that resident behavior is a dominant factor shaping operational energy use (Mardookhy el at. 2014). Their findings highlight an important policy implication: even well-designed, high-performance buildings cannot meet expected energy outcomes without policies that recognize and support the occupant–system relationship.

Overall, these studies highlight why policy must evolve alongside building technologies. As states increasingly integrate high-performance standards—such as Passive House—into stretch codes, the link between occupant behavior, ventilation practices, and indoor environmental quality becomes central to housing policy. For aging populations and climate impacted regions that rely heavily on mechanical ventilation, understanding how participants perceive and interact with ventilation systems is essential. Strengthening policy through user-centered design, post-occupancy evaluation, and ongoing tenant education is critical for ensuring that high-performance buildings deliver on their intended health and energy outcomes.

Chapter III: Methodology

3.1 Overview

Using a mixed-methods approach, this study combined qualitative analysis of occupant interviews, and quantitative analysis of indoor carbon emissions, air pollutants, and humidity. By integrating both types of data, the research evaluated whether residents' perceptions of indoor air quality align with measured conditions within their apartment units. The analysis used a case study research design, guided by the methodological framework outlined by Yin (2018). This approach was selected to allow for an in-depth examination of understanding occupant behavior and its potential effects on ventilation practices due to perceived air freshness from senior residents. This research explored behaviors within a residential context, where decisions were shaped by environmental conditions, awareness, and intervention-based feedback, which is consistent with Yin's approach.

Data was collected in accordance with Yin's principle of triangulation. These sources included semi-structured interviews and environmental sensor data. The unit of analysis is individual participant behavior related to ventilation use within the dwelling. The boundaries of the case were established by the study duration, the residential setting, and the specific focus on behaviors associated with indoor air quality and ventilation decision-making. Within this study, the participants were recruited through an informational flyer posted within the lobby of Laurel Manor. The participant pool consisted of 11 individuals, which provided an adequate sample size to achieve meaningful saturation as described by Hennink and Kaiser (2022). This level of saturation strengthened the credibility of the findings by ensuring that recurring behavioral and

perceptual patterns were fully captured. (Hennink & Kaiser, 2022). There were also informal conversations with maintenance about the ERV systems prior to the first interview. Additionally, participants received $10 Winco gift cards after each interview, totaling $30.

There were two distinct phases in this study: a baseline phase and an intervention phase. In Phase 1, an initial interview established baseline perceptions, habits, and ventilation use. Following this interview, participants installed a sensor and continued with their normal daily behaviors for a five-day period. In Phase 2, there was a second interview after which the sensor indicator light was activated to provide active visual feedback related to indoor environmental conditions. A third interview and debrief followed this five-day intervention phase.

3.2 Qualitative Data Collection

The researcher conducted in the interview portion of the study in the common space library of Laurel Manor. There were three semi-structured interviews: 1) an initial 40-minute interview; 2) a 20-minute pre-intervention interview; 3) a 40-minute post-intervention interview. All interviews were audio-recorded through zoom and uploaded to the secure browser of OneDrive and audio files will be permanently deleted upon closure of the study as required by the Institutional Review Board.

3.2.1 Initial Interview – 40 Minutes

The interviews followed a semi-structured format prompted by the research themes. The interview began with perceptions of indoor air freshness, asking participants to describe how the air in their apartment feels and whether the air in their apartment is perceived as fresh or stale. These perceptions formed the baseline of the study in which occupants evaluate the effectiveness

of ventilation. Participants were encouraged to reflect on whether these perceptions have shifted over time, particularly since moving in. This allowed insight into how familiar participants are with their space and its systems. The interviews then moved to explore seasonal comfort. Participants were asked to describe how the air feels during winter months compared to summer, and whether colder weather alters how they ventilate their homes.

The key purpose of the interviews was to understand residents' awareness of the ventilation system itself. Participants were asked what they know about the system installed in their apartment and whether they received instructions on its operation. This line of questionings goal was to highlight gaps between system design and occupant understanding. The interviews also addressed ERV usage behavior, focusing on how participants interact with the ventilation system on a day-to-day basis. The interview questions also covered window use. Participants then talked about when and why they open or close windows, considering factors such as time of day, weather conditions, comfort needs, and perceived air quality.

Finally, the interviews assessed perceived control and comfort, asking participants whether they feel they have sufficient control over air quality in their apartment and what factors support or limit that control. Participants were encouraged to consider how indoor air quality affects their overall comfort, breathing, sleep quality, and sense of well-being.

3.2.2 Second Interview – 20 Minutes

This check-in interview was designed to capture and understand residents’ evolving experiences with indoor environmental sensors and to understand how awareness, behavior, and comfort develop over time. Rather than assessing long-term outcomes, the interview serves as an

interim reflection, which prompted participants to give their initial impressions, habits, and any concerns related to the presence of the sensor in their apartment.

The interview began by addressing awareness, focusing on how noticeable the sensor is within participants' daily routines. Participants then addressed if they think about the sensor regularly and if its location influences how often they notice it. Participants were then prompted to reflect on whether the sensor has increased their awareness of air quality or temperature, and when this awareness is most pronounced, such as during moments of discomfort or seasonal change.

The check-in then explored behavioral responses, examining adjustments to their window use or ventilation practices since the sensor was installed. Instead of assuming the sensor has made a change to the participants' daily behavior, the interview allowed participants to describe potential emerging shifts in their daily behavior. Participants also considered how their behavior might differ if the sensors were not present.

The focus of the check-in interview was comfort and trust, recognizing that attitudes toward monitoring can evolve over time. Participants were invited to share how they feel about having the sensor in their apartment at this stage, whether they feel comfortable, neutral, or uneasy, and why. The interview also provided space to discuss privacy and monitoring concerns. To understand if participants had any concerns about being monitored, the check-in provided one opportunity to address potential discomfort before it becomes a barrier to engagement.

Finally, the check-in ends by identifying information gaps and support needs. Participants talked about the sensor and what additional information would help them better understand what

is being measured and why. These responses inform future communication strategies and help ensure that the sensor system supports occupant autonomy.

3.2.3 Final Interview – 40 Minutes

The final interview was designed as a reflective conversation, allowing participants to look back on their experience with indoor air quality monitoring and to evaluate how their awareness, behaviors, and perceptions changed over the course of the study. The interview began by having participants reflect on whether the sensor helped them better understand the air quality in their apartment and how this information could be made more useful. These questions encouraged participants to assess and understand the value of the data in everyday decision-making. Participants were then asked to consider long-term whether they would want this type of monitoring in their home beyond the study period.

A central component of the final interview focused on overall study experience. Participants were encouraged to describe what stood out most during the study, and what aspects were challenging. Participants also reflected on what they learned, what became clearer, and what remains uncertain.

Questions related to energy awareness and behavior examined whether participants would change how they would use windows or ventilation systems during the study, and whether these changes were intentional or incidental. This helps distinguish conscious decision-making from behavioral adaptations prompted by increased awareness throughout the different phases of the study. Participants also assessed their current level of satisfaction with indoor air quality. The interview then broadened to consider energy consciousness beyond air quality, asking whether

participation in the study influenced how participants think about energy use more generally now.

Finally, the interview questions emphasized hopes for future improvement. Participants identified what information was most helpful during the study and what additional information would have been helpful. The interview concluded by inviting suggestions for improving ventilation systems, resident education, and communication with building management or designers, as well as offering space for participants to share any additional thoughts on air quality or comfort that were not previously addressed.

Participant Number	**Pseudonym**
Participant One	**Mary**
Participant Two	**Magestic**
Participant Three	**JD**
Participant Four	**Dragonfly**
Participant Five	**Lemon**
Participant Six	**Charles**
Participant Seven	**Texas**
Participant Eight	**Angels**
Participant Nine	**Blessings**
Participant Ten	**Kennedy**
Participant Eleven	**Ice**

Table 3.2 Participants and their pseudonyms

Caption: This table shows participant pseudonyms which is important in allowing participants to read the final thesis and easily trace how their experiences, behaviors, and insights shaped the findings. In a study focused on lived experience, environmental perception, and behavioral patterns, this practice reinforces transparency. This practice also supports the Interpretative Phenomenological Analysis (IPA) lens by allowing participants to retain a sense of personal identity within the analytic narrative and still protect their confidentiality. This small but meaningful act reinforces participants' agency, affirms their ownership of their stories, and maintains continuity between their lived experience and its portrayal within the study.

3.3 Quantitative Data Collection

3.3.1 In-apartment Air Quality Testing

Broan Smart Outlet Sensors (*Figure 1*) are wall plug-in sensors that have multiple air quality instrucments in a single, compact device. This smart device uses an app (Broane Overture) connected to Wi-Fi.

to track indoor air quality information every five seconds. This data consisted of tracking CO_2, humidity, TVOC (air pollutants), temperature and $PM_{2.5}$ (particulate matter) data. This device allowed the researcher to track the data within each unit in increments of 1 hour, 1 day, 1 week, 1 month and 1 year as well as zooming in to see what happened every ten seconds as it generated data into line graphs so users can see the fluctuation of their indoor environmental air quality in real time, and across the different time intervals. This sensor did not monitor additional information other than the indoor air quality information.

The researcher collected air quality data from each participant's apartment with the Overture monitoring application on an iPad which then automatically uploaded through the University of Oregon OneDrive. The application does not collect any personal or identifying data. Each sensor transmitted data via the building's Wi-Fi network for researcher access.

In Laurel Manor, Panasonic's FV-10EVX ERV were installed and operated as a ventilation system that quietly manages indoor air quality with minimal resident intervention. In everyday use, the ERV pulls stale indoor air out while bringing filtered outdoor air in, and its energy-recovery core transfers heat and moisture between the two air streams so the home stays comfortable without wasting heating or cooling energy. This means the system helps prevent negative pressure, reduces humidity swings, improves indoor air quality, and supports code-required ventilation standards.

Residents can also use the Boost/Max mode to automatically increase airflow from its baseline (e.g., 60 CFM) to its maximum (around 100 CFM) when VOCs, humidity, or CO_2 levels rise, providing IAQ correction. The system's Recirculation mode activates during low outdoor temperatures to prevent frost buildup in the core, prioritizing system protection and IAQ stability. The ERV is part of a controlled ventilation system that aims to correct airflow based on real-time IAQ data.

ENERGY RECOVERY VENTILATOR SCHEDULE

					SUPPLY		EXHAUST		HEAT RECOVERY	ELECTRICAL			WT.	NOISE	
MARK	SERVES	MAKE	MODEL	TYPE	CFM	ESP	CFM	ESP	MIN. SENSIBLE EFF. AHRI 1060	MCA (W)	MOCP	VOLT/PH	LBS	LEVEL	NOTES
ERV-1	CORRIDORS	VENTACITY	VS1200 CMe	INDOOR	1,200	0.5	1,200	0.5	80%	37	40	208 / 1	600	NA	3, 4, 6, 7, 8
ERV-2	CORRIDORS	VENTACITY	VS1200 CMe	INDOOR	1,200	0.5	1,200	0.5	80%	37	40	208 / 1	600	NA	3, 4, 6, 7, 8
ERV-3	MULTIPURPOSE ROOM	VENTACITY	VS900 CMe	INDOOR	500	0.5	500	0.5	80%	29	30	208 / 1	400	NA	2, 3, 4, 6, 8
ERV-4	FIRST FLOOR OFFICES	VENTACITY	VS400 CMe	INDOOR	270	0.5	270	0.5	80%	15.1	15	208 / 1	240	NA	2, 3, 4, 6, 8
ERV-5	SECOND FLOOR AMENITY	PANASONIC	FV-10VEC2	INDOOR	50-100	0.5	50-100	0.5	70%	(100)	N/A	120 / 1	50	40 DBA	1, 2
ERV-R	RESIDENCES	PANASONIC	FV-10VEC2	INDOOR	50-100	0.5	50-100	0.5	70%	(100)	N/A	120 / 1	50	40 DBA	1, 7

NOTES:
1. PROVIDE HANGING ISOLATION OR RUBBER IN SHEAR ISOLATORS
2. INTERLOCK WITH RESPECTIVE HEAT PUMP CONTROL SYSTEM - OPERATES DURING OCCUPIED HOURS
3. 24V TRANSFORMER/RELAY PACKAGE
4. INTEGRATED PROGRAMMABLE CONTROLS
5. PROVIDE WITH ERV WALL CONTROL PANEL
6. BUILT IN DAMPERS FOR DEFROST AND RECIRCULATION CYCLING, CLOSED TO OUTSIDE WHEN UNIT IS OFF
7. OPERATES CONTINUOUSLY
8. PROVIDE WITH PREHEATER

Figure 3.1: Laurel Manor ERV Schedule

Caption: Table showing ERV Schedule for Laurel Manor

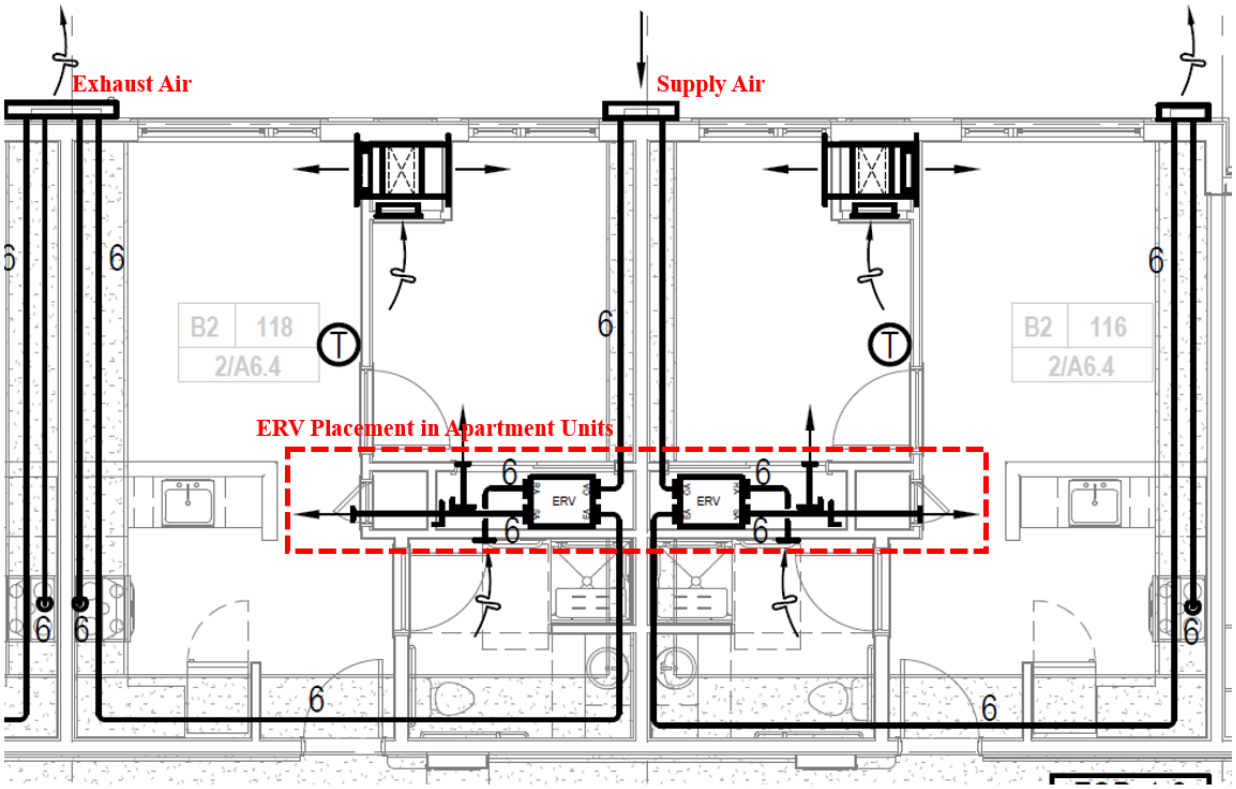


Figure 3.2: Unit Plan

Caption: Unit Plan showing the ERV placement within the unit along with the supply and exhaust intakes.

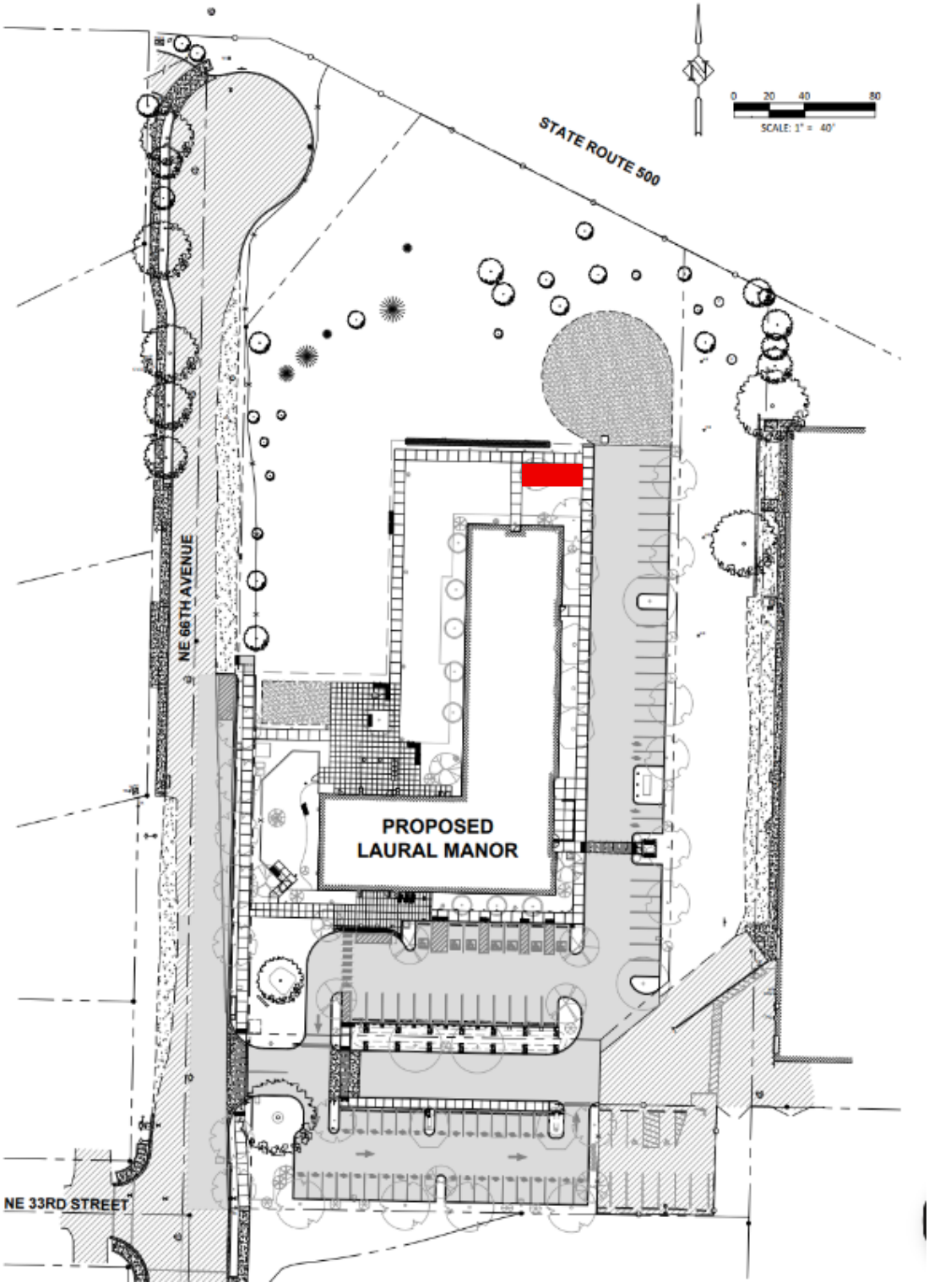

STATE ROUTE 500
NE 66TH AVENUE
PROPOSED
LAURAL MANOR
NE 33RD STREET
0 20 40 80
SCALE: 1" = 40'

Figure 3.3: Site Map

Caption: Site Map with the red box highlighting the smoke shack.

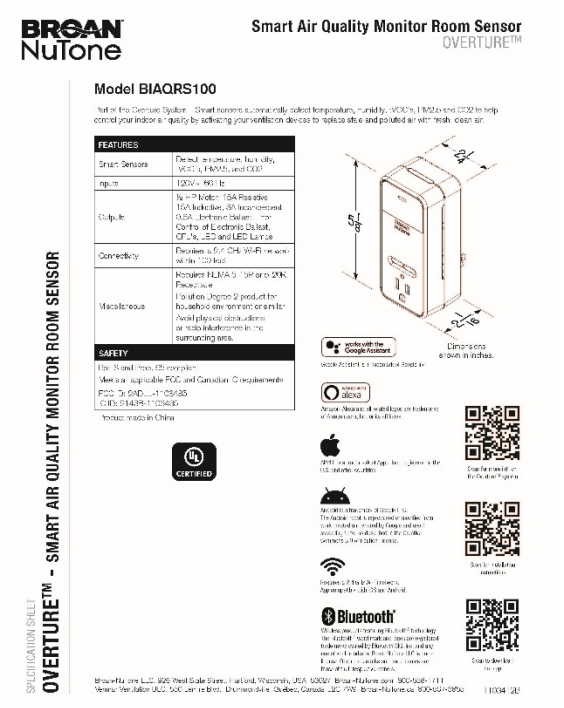


Figure 3.4: Broan Sensor Brochure

Caption: Broan Nutone Air Quality Monitor Brochure. This Brochure describes the dimensions of the device and QR codes to search for tutorials on how to connect the device to WIFI.

3.3.2 CO_2

Carbon dioxide is a widely recognized indicator of ventilation, and both ASHRAE Standard 62.1 and EPA indoor air quality guidance emphasize its value as a proxy for overall air freshness and occupant exposure to air. Although CO_2 itself is not typically harmful at concentrations found in residential settings, elevated levels—commonly above 1,000 ppm—often indicate insufficient outdoor air exchange and the potential accumulation of other indoor pollutants. High CO_2 concentrations are also associated with measurable declines in cognitive

performance, increased reports of headaches, and general perceptions of “stale” or “stuffy” air (ASHRAE Standard 62.1). Monitoring CO_2 therefore provides a critical baseline for understanding whether mechanical ventilation systems are delivering adequate fresh air and whether residents’ behaviors are contributing to underventilation.

3.3.3 Humidity

Relative humidity is a central factor of indoor environmental quality because it influences thermal comfort and pollutants. ASHRAE recommends maintaining indoor humidity between roughly 30–60% to minimize respiratory irritation, reduce airborne pathogens, and prevent mold growth in walls and on other building surfaces (ASHRAE). Levels below this range have been shown to increase dryness, nosebleeds, and respiratory discomfort—symptoms frequently reported by the participating participants at Laurel Manor—while excessive humidity can promote dust, mold and structural degradation (ASHRAE & EPA). Tracking humidity continuously helps identify whether ventilation systems are maintaining stable moisture conditions and whether residents’ supplemental devices (i.e., humidifiers, fans and diffusers) are effectively mitigating concerns relating to comfort.

3.3.4 $PM_{2.5}$

Fine particulate matter ($PM_{2.5}$) is one of the most critical pollutants for assessing indoor air quality due to its well documented health impacts. EPA air quality standards highlight $PM_{2.5}$ as a contributor to potential respiratory and cardiovascular issues and diseases (EPA). This is because particles of this size can penetrate into human lungs. Indoor $PM_{2.5}$ concentrations are further influenced by outdoor infiltration, cooking, smoking, cleaning activities, and overall

mechanical system performance (EPA). In multifamily affordable housing, elevated $PM_{2.5}$ often correlates with inadequate air filtration or insufficient ventilation (World Health Organization). Monitoring $PM_{2.5}$ can provide insight into both potential exposure events and chronic pollutant burdens, enabling a more comprehensive understanding of how building systems and occupant behaviors interact to shape indoor environmental health.

3.3.5 TVOC

Total volatile organic compounds represent potential gaseous pollutants that can be emitted from building materials, cleaning products, furnishings, and occupant activities. While EPA does not set a specific limit for TVOC, both EPA and ASHRAE emphasize the importance of minimizing TVOC exposure due to potential health implications. These implications can be associated with headaches, respiratory irritation, and long-term health risks depending on the specific compounds, much like CO_2 (World Health Organization). Elevated TVOC levels often indicate inadequate ventilation or off-gassing from new construction materials.

3.3.6 Temperature

Temperature is a foundational component of thermal comfort and interacts closely with humidity, ventilation, and pollutants. ASHRAE Standard 55 outlines acceptable temperature ranges for maintaining occupant comfort, noting that certain deviations can influence perceived air quality and air freshness (ASHRAE Standard 55). Elevated temperatures can increase the emission rates of VOCs/TVOCs and can exacerbate overall discomfort. At the same time, temperatures that are too low can contribute to condensation and moisture-related issues and illnesses (World Health Organization). Continuous temperature monitoring can therefore provide

essential context for interpreting other air quality parameters and understanding how environmental conditions shape residents' comfort and perceived air quality. This was a minimal factor in the study, with low standard deviation.

3.4 Data Analysis

3.4.1 Overall Methodology

This mixed-methods case study followed Yin's analytic model, integrating qualitative and quantitative techniques to examine how occupants perceived and responded to indoor air quality. This study relied on two of Yin's core analytic strategies—pattern matching and time-series analysis—to connect behavioral evidence with sensor-derived IAQ trends (Yin, 2018). In this study, Yin's pattern matching technique was used to compare participants' reported ventilation behaviors and perceptions of air freshness with the actual IAQ patterns captured by the sensors. By aligning qualitative themes with sensor trends, the analysis evaluated whether behavior corresponded with measurable changes in indoor air quality (Yin, 2018). Time-series analysis was applied to the IAQ data to examine how CO_2, humidity, and pollutant levels changed over time and whether those changes aligned with key study phases, such as the baseline phase and interventional phase. This technique allowed the researcher to identify meaningful peaks in the sensor data that revealed how and when occupant behaviors were influenced by air quality conditions (Yin, 2018). Each apartment unit functioned as its own case. After individual review, all units were analyzed together to understand and identify cross-case consistencies in ventilation behavior, perceived air freshness, and measured IAQ outcomes. This structure allowed the study to triangulate multiple forms of evidence and evaluate how occupants' interpretations of "fresh"

or “stale” air aligned with the performance of their ventilation systems. The analysis of week-two data focused on whether participants responded to these visual cues by adjusting their behaviors, and if so, how these adjustments potentially influenced the environmental conditions within their units and perceived air freshness of the units.

3.4.2 Qualitative Analysis

Interview data were analyzed using an Interpretive Phenomenological Analysis (IPA) approach to understand how participants made sense of their ventilation systems and indoor air quality (Hartman and Squires, 2024). Transcripts were coded using thematic analysis that was informed by the literature review, helping the identification of recurring patterns and perceptions of residents. Following this, certain codes were refined to further understand how participants interpreted sensor cues, ERV functionality, and their own behavioral adjustments. These qualitative themes were then examined for variation across units, producing a detailed account of how residents’ experiences shaped their ventilation behaviors.

3.4.3 Quantitative Analysis

Quantitative analysis focused on continuous, time-stamped IAQ data generated by the Overture monitoring sensors. Using Yin’s time-series analytic technique, sensor outputs—including CO_2 humidity, particulate matter, TVOC and temperature—were plotted to visualize daily/hourly/minute by minute data, and potential behavior changes. Charts were examined for peaks that ranged one standard deviation below or above the average measurements advised by ASHRAE, WHO and the EPA. Standard deviations were used to assess behavioral responsiveness to IAQ readings within each unit. These visual and statistical patterns provided a

way to evaluate how ventilation behaviors influenced measurable IAQ outcomes over time, particularly during the shift from the baseline phase to the intervention phase.

In order to identify periods when each parameter showed notable fluctuations, an Excel formula was implemented to calculate values that fell one standard deviation above or below the mean. These thresholds served as an initial tool to detect peaks within the dataset. The resulting values were further examined in a summary table, where instances of substantial deviation were highlighted to distinguish data points that warranted a further analysis

3.4.4 Mixing the Methods

The qualitative and quantitative findings were then integrated through pattern matching, comparing resident-reported behaviors and perceptions with corresponding IAQ sensor trends. Themes from the IPA analysis were matched with time-series patterns to determine whether reported behaviors aligned with measurable changes in air quality. Transitional moments, especially the activation of the sensor indicator light, served as key comparison points to assess whether shifts in perception corresponded with observable IAQ improvements. This mixed-methods integration allowed the study to highlight not only what changes occurred in air quality, but why they occurred, by combining behavioral interventions with sensor data.

Chapter IV: Results

4.1 Results from Qualitative Analysis

Across the two-week interventional study, several themes were confirmed through evidence that directly align with the principles outlined in Literature review. Within the context of aging-in-place initiatives and low-income affordable housing, the interviews reinforced four main thematic codes: the influence of sensor monitoring on autonomy, occupant behavior and ventilation strategies, the role of educational intervention, and the relationship between ventilation, air quality, and health outcomes. Each of these codes were further reinforced by a series of subcodes that further illustrated how participants interacted with their ERV systems.

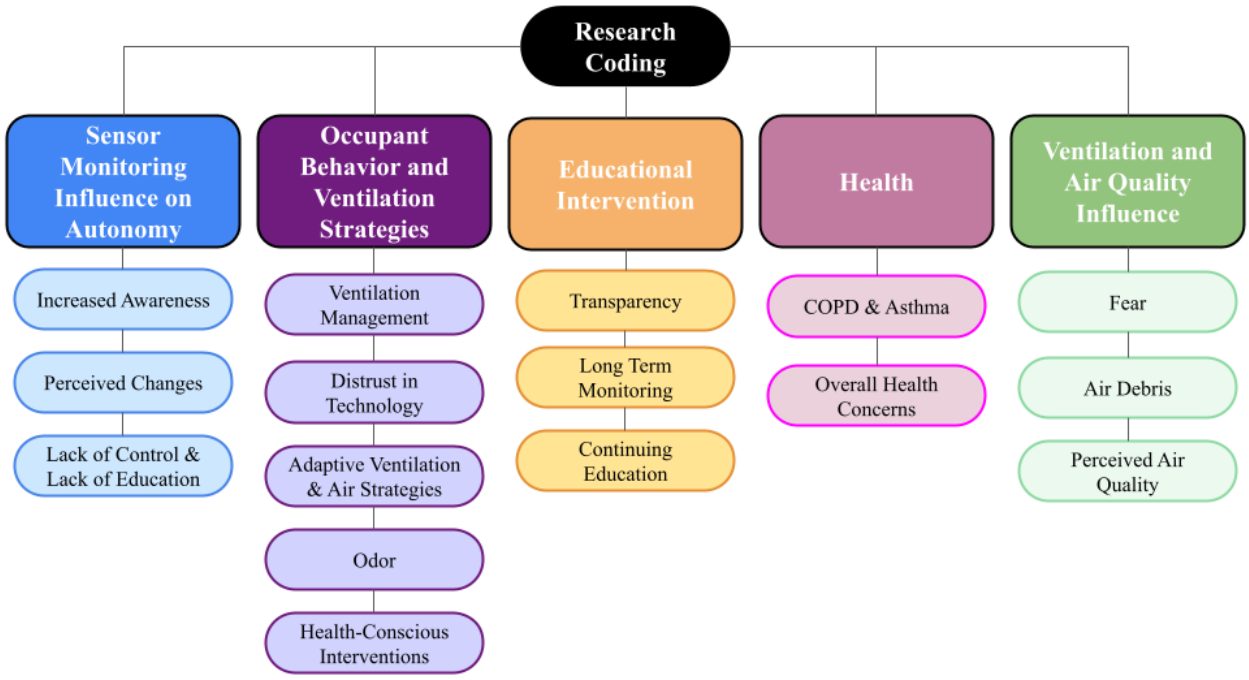


Figure 4.1: Research Coding Tree

Caption: Coding tree created using themes found in the literature review that were reinforced through interview findings.

4.1.2 Sensor Monitoring Influence on Autonomy

Increased Awareness

One of the key findings from the qualitative analysis was residents' intentional or unintentional understanding and heightened awareness of their indoor air quality. At the beginning of the study, participants often expressed concerns about their air quality but demonstrated limited understanding of how their daily behaviors might influence their perception of air freshness within their homes. When asked whether their awareness had shifted, Lemon noted becoming "a little more aware, mostly [when] cooking," highlighting how specific activities triggered greater attention to air quality.

During the intervention phase, the visual feedback provided by the monitor's light played a central role in shaping behavior and understanding. Participants described how the light cues helped them determine when to use their diffuser or adopt additional air-quality-supportive practices. Small but meaningful behavioral adjustments emerged as well. For example, Magestic noted keeping the bathroom door open "when [the sensor] turns yellow" to mitigate humidity. Across interviews, participants consistently reported feeling at least slightly more aware of their air quality, and many emphasized that receiving real-time visual feedback offered a sense of comfort, reassurance, and safety.

Perceived Changes

Overall, the most prominent perceived behavioral shifts related to thermostat use and cleaning habits. This code relates towards residents' perceptions of environmental changes

within their units. Several participants described becoming more aware of shifts in their indoor air quality. For example, Texas noted, “I become more aware of what’s in the environment… like I’ve noticed it’s really cold in my apartment,” which prompted more frequent thermostat adjustments. This heightened awareness also encouraged participants to engage with their windows more intentionally; many reported that they rarely opened them prior to the study and then started to utilize them more frequently during the study. These reflections reinforced the importance of perceived fresh air and the strategies participants took to adopt and maintain a sense of comfortable air quality throughout the day.

Participants also described changes in their cleaning routines and the types of fragrances they used. Charles, for instance, observed that certain cleaning scents affected the monitor differently: “Some does and some doesn’t—like cinnamon apple, [the sensor] stayed green.” Such comments illustrate how participants began to link everyday household products with measurable changes in their indoor environment.

The study also surfaced important accessibility considerations tied to building design. In affordable senior housing, where many participants use mobility aids or rely on caregivers, the usability of environmental controls becomes especially significant. Texas highlighted the difficulty of adjusting the thermostat independently, often requiring assistance to make changes. These insights emphasize the need for future multifamily housing design to prioritize accessible, user-centered environmental controls that support autonomy for aging residents.

Lack of Control and Lack of Education

Prior to the phased intervention, the participants noted a lack of control regarding their indoor air quality. Many participants described significant frustration from a lack of understanding and education regarding their ventilation systems, particularly during their first months of living in the building. Kennedy notes that the ventilation fluctuates often and "some days, [they] don't have any heat on it. I mean, doesn't come on at all… Then other days it gets really cold and the temperature outside is the same." Although some issues appeared to diminish over time, such as the constant debris that was coming out of the filters, participants emphasized that these challenges and frustrations often disrupted daily routines and sense of autonomy within their own homes.

Concerns about air quality were especially prominent within the study. Several participants reported that their perceived air quality was "really bad" when they first moved in, often leading to sleep disturbances, frequent coughing, and overall general discomfort. A few participants described wearing masks to bed because they did not trust the air they were breathing. Ice explained that poor air quality "affects [their] health, especially breathing… it affects [their] mood sometimes too," while Blessings noted that irritation prompted constant cleaning and hyper awareness within their living space. These accounts from the participants show that lack of understanding of ventilation systems can cause a significant emotional and physical toll.

Additional frustrations centered on maintenance practices, particularly inconsistent filter changes. Some participants resorted to improvised solutions like placing dryer sheets behind

intake conduits to manage visible lint and debris. They described sweeping frequently and noticing fluctuations in dust levels. Many participants reported that they did not receive instructions on how to operate their ERV systems until two weeks prior to the study. Because the system was unfamiliar and its functions were not clearly communicated, many participants avoided using it altogether, inadvertently limiting their comfort and environmental control.

4.1.3 Occupant Behavior and Ventilation Strategies

Ventilation Management

In relation to ventilation management, participants expressed a wide range of experiences with how effectively their ERV systems supported their thermal comfort. Lemon reported that their apartment retained heat well, attributing this to strong insulation that allowed the unit to maintain a stable temperature throughout the day. In contrast, several other residents—such as Dragonfly—described persistent challenges in achieving their preferred indoor temperature. They express this when describing the constant need to run the air conditioning, stating that “The air conditioner is really good for me to breathe, you know. It runs twenty-four-seven. That's the only way I can breathe is if it's cool.” This participant noted that they often needed to run their air conditioners continuously or rely on open windows to combat the indoor heat. These actions suggest inconsistencies in system performance or perceived system efficacy across units.

Another recurring theme related to ventilation management was the issue of odor and outdoor air. Participants frequently referenced nearby encampments, the adjacent highway, and the prevalence of smoking on the property as sources of unpleasant smells that infiltrated their units. These conditions were described as highly frustrating and difficult to manage, particularly

for participants who felt they lacked control over their ventilation systems. For other participants, these concerns contributed to a complete avoidance of the ERV system, as they perceived it as a cause for unwanted odors rather than a tool for improving them.

Distrust in Technology

Ventilation management and the behaviors participants adopted in relation to their ERV systems were closely tied to a broader sense of distrust in the technology. This subtheme also intersected with residents' reported lack of control and limited education about how their systems functioned. Kennedy, for example, described an ongoing issue with dust and lint accumulation and its perceived connection to worsening respiratory symptoms. As they explained, "when I do turn it on, I'm affected… the lint particles that are floating around—that has not stopped," a concern that ultimately led them to avoid using the ERV system altogether. This was further reinforced through conversations with maintenance that the initial filters installed were the wrong type and ducts were not cleaned prior to move in, leading to ongoing distrust among participants.

Similarly, Blessings and Charles emphasized the constant presence of lint and debris in their units, noting that it compelled them to clean frequently and even wear masks inside their own homes. These participants did not perceive their indoor air as fresh and developed additional strategies to combat their unreliable ventilation. Whether these concerns stem from actual system performance issues or from shared perceptions reinforced through community dialogue, the outcome was consistent throughout the interviews that exemplify that distrust in the technology

which further discouraged proper system use. Overall, this prompted participants to adopt alternative coping strategies.

Adaptive Ventilation and Air Strategies

Residents' distrust in their ventilation technology directly influenced the alternative strategies they adopted to manage indoor air quality. Many participants described layering additional tools and behaviors onto the existing ERV system in an effort to create what they perceived as "fresh air" within their units. Kennedy, for example, expressed a sense of self-reliance, noting, "I've made it better for myself. I used what they had and what they've provided me to use to keep my air quality good. But my air quality [is] not very good now." Their comments reflect a broader pattern of participants feeling compelled to compensate for systems they viewed as insufficient or unreliable.

Several participants reported purchasing supplemental devices such as humidifiers and air purifiers to address persistent comfort and air-quality concerns. Texas described a noticeable improvement after using a humidifier for just one day, explaining that the dryness and associated nosebleeds "resolved" within hours of turning it on. Most of the participants in the study reported adopting similar strategies to regulate temperature, humidity, and perceived air freshness in their units. For some residents, these adaptations were necessities. JD, for instance, relied on oxygen equipment, which increased the ambient temperature in their unit. Because of this it was important to utilize their fans and their A/C for continuous airflow.

Odor

One of the most prominent subcodes that emerged across the interviews concerned persistent issues with odor. Many participants reported that unwanted smells regularly infiltrated their apartments and remained present despite their efforts to mitigate or eliminate them. These odors were described as intrusive, difficult to control, and a continual source of frustration.

Cigarette smoke was identified as the most significant concern. Although smoking is prohibited inside the units, participants noted that these rules were frequently disregarded. Additionally, while the property designates a smoking area at the southeast corner of the building and with the double door entry, participants emphasized that this measure did little to prevent smoke from entering their apartments.

Blessings explained that the proximity of the smoking area directly influenced their ventilation behavior: “One of the reasons that I don’t open my windows… I can see the smoke shack from my house… I don’t want to take a chance on that.” Similarly, Texas described experiencing “random smoke smell, tobacco smoke” even when their windows remained closed, reinforcing the perception that smoke infiltration was unavoidable.

Odor concerns extended beyond tobacco. Lemon, who is highly sensitive to smells, detected a persistent mildew odor in their unit after they moved in, which was later revealed to be mold, an unexpected issue in a newly constructed building. In the first interview it was revealed that their attributes to sensitivity of odor and feeling unwell led to them getting an Air Doctor which detected the mold within their apartment unit. In this case, the additional

ventilation strategies they adopted played a crucial role in addressing the problem and ultimately prevented them from considering relocation.

Health-Conscious Intervention

Within the broader theme of Occupant Behavior and Ventilation Systems, residents' actions were consistently shaped by a heightened awareness and their perceived indoor air quality. Across interviews, participants described being hyper aware of shifts in freshness, odor, and comfort, which in turn influenced how they engaged with their ERV systems. This was often rooted in distrust of the technology, prompting many participants to take personal responsibility for managing their indoor environment through supplemental ventilation and air-quality strategies. These behaviors were especially highlighted in relation to odor concerns, which participants identified as a major and persistent source of discomfort.

A recurrent thread in these conversations was the perceived link between poor air quality and potential health risks. Blessings, for example, raised concerns about "any correlation between the air not being clean and people having health problems to the point of death," emphasizing a desire to take every possible precaution to protect their well-being. This sense of responsibility was echoed by other participants who described initially avoiding window use because they were uncertain about what contaminants or odors might enter from outside. Their comments reflect a broader pattern of environmental sensitivity and being highly aware of overall and sudden changes within their air quality. Prompting them to address the issues when they arose themselves.

4.1.4 Educational Intervention

Transparency

Initially during the first week of the study, participants expressed an initial intention to avoid being influenced by the presence of the monitor, often noting that they paid little attention to it within their living space. This response conflicts with the common assumptions in research literature that participants are often hyper-aware and against monitoring technologies in their homes. Instead, this study suggests that *when monitoring is shown to be utilized in a transparent way and framed as a tool for improving health, safety, and educational understanding, participants, particularly in affordable housing, may actively welcome additional monitoring*.

In this opposition to common literature findings, participants expressed that they welcomed monitoring and emphasized a strong desire for transparency when learning to navigate unfamiliar ventilation systems in a new living environment. Participants repeatedly noted that they simply wanted someone knowledgeable to explain how their systems worked and what they should expect from them. Several participants even stated that understanding the potential shortcomings of their systems would help them use the technology more effectively.

This desire for transparency was closely tied to residents' recognition that comfort is highly individualized and complex. Participants acknowledged that each person has different thresholds for temperature, humidity, odor, and perceived air quality, and they emphasized the importance of understanding how to achieve their sense of comfort across this spectrum, even if that meant having monitoring devices in their home.

Long Term Monitoring

Building on the previous subcode, participants emphasized the importance of long-term monitoring within their homes. Participants' early concerns that were discussed in the first interview centered around health risks and ventilation performance. A lack of education and system literacy emerged as a significant factor in shaping how participants used and understood their ERV systems. Many participants believed their systems were not providing adequate air quality, and they were eager to engage in problem solving around their perceived persistent ventilation issues. Their comments frequently referred to health, safety, and the desire for clearer guidance as well as a desire for long term monitoring to understand the perceived ventilation issues.

As the study concluded, many participants continued to express concern that a two-week intervention was insufficient to fully understand the performance of their ventilation systems and potential problems with their indoor environmental conditions. Several participants indicated that year-long monitoring, or longer, would provide a more accurate and comprehensive feedback on how their systems function over time. Participants also noted that extended monitoring would be valuable from both a resident perspective and a building-science perspective. Given that the building is newly constructed, many felt that a longer study period could reveal how the systems perform across different seasons, usage patterns, and stages of the building's lifespan.

Continuing Education

Building on the broader theme of Educational Intervention, many participants expressed a clear desire for structured and ongoing guidance on how to use their ERV systems effectively.

Participants described a range of suggestions, including move-in orientations, printed pamphlets, and seasonal or monthly newsletters that would help them adjust their system use throughout the year. Several participants noted that during building tours, property managers often provided only a brief overview of the ventilation system—or, in some cases, no explanation at all. By the time participants moved in, this information was frequently forgotten or had never been communicated in a meaningful way.

As a result, participants emphasized the importance of receiving a dedicated orientation upon move-in, accompanied by accessible written materials that explain how the ERV functions and how it should be used across different seasons. This is especially important since many of these participants have additional help throughout their day-to-day lives. Texas stated that “Well, we didn't get instructions on how to use [our ventilation] until a couple weeks ago”. These educational resources are essential for ensuring that participants and their caregivers can operate their systems efficiently, maintain comfort, and avoid the confusion or misuse that contributed to broader feelings of distrust.

4.1.5 Health

COPD and Asthma

After the first week of the study participants expressed concern about the particles and debris they perceived within their apartments. These participants felt that the indoor air quality was not only uncomfortable but potentially exacerbating their existing health issues. Ice, for example, described ongoing frustration with the air in their unit and the extent to which it disrupted their sleep: “I’d like to be able to breathe. I’d like to be able to go a day without

constantly feeling like I get particles of stuff in my throat, waking me up in the middle of the night. And this has nothing to do with me having COPD or congestive heart failure." Their comments reflect a broader sentiment among participants who believed that the air quality in their apartments was contributing to prolonged or worsening health problems.

Kennedy similarly described recurring flare-ups, noting that "in five months, I mean, I was sick," and emphasized that this pattern had not occurred in any of their previous home environments. These accounts represent the extent to which participants attributed their respiratory symptoms and general discomfort to the indoor environment. They also highlight how health concerns intensified residents' distrust in their ventilation systems and shaped their daily behaviors, avoiding system use to protect their well-being.

Overall Health Concerns

Concerns related to COPD, asthma, and other respiratory conditions were central to many residents' experiences at Laurel Manor. Several participants described health issues that they believed had intensified or become more frequent since moving into the building. As noted in earlier subcodes, participants were highly attuned to changes in their indoor air quality and often felt compelled to be proactive in preventing potential health risks. Texas, for example, recounted developing nosebleeds for the first time after moving in, explaining, "Never had them before… I was sent to an ear, nose and throat specialist." The issue was ultimately attributed to extreme dryness in their apartment, prompting them to adopt additional strategies to increase humidity that was concluded through their doctor's visit discovered during the interview phase.

Kennedy similarly emphasized the vulnerability associated with respiratory illness, noting the difficulty of "getting that dust and that stuff into our lungs… when you have respiratory problems," and acknowledging a perceived link between their worsening symptoms and the indoor environment. These accounts reflect a broader pattern in which participants with pre-existing health conditions felt particularly susceptible to fluctuations in air quality and deeply concerned about the potential long-term consequences.

For participants like Blessings, these concerns extended beyond personal health to the well-being of their neighbors. They described "watching roommates or people that live in this building die off one after the other," highlighting the emotional weight of uncertainty and the desire for greater transparency about ERV conditions. Blessings also highlighted the distress of visible contaminants, stating, "The thing about the issues is that they're not just affecting how we breathe, but they're visual… we can see it. And then you go, wow, what do I do?"

4.1.6 Ventilation and Air Quality Influence

Fear

In terms of ventilation and air-quality concerns, many participants described a sense of fear rooted in their limited understanding of how their ventilation systems functioned and their perceived lack of control over their indoor environment. Several participants recounted episodes in which unexpected odors, particles, or system noises triggered anxiety, particularly when these experiences were accompanied by physical symptoms. "It gives me a lot of anxiety… when it wakes me up out of a dead sleep, I can't stop coughing. It's like whatever it is went down in my lungs."

Other participants highlighted how conversations among neighbors could amplify these fears. Texas noted that "when there's change, there's fear," pointing to the way uncertainty and shared concerns circulated within the community. This dynamic was compounded by residents' frustration with reporting issues to management and feeling unheard or dismissed. This can be especially frustrating when the concerns involved their own living conditions and health.

These fears were closely tied to the broader theme of health and vulnerability. Many participants expressed deep concern about the debris, dust, and odors coming into their homes and the potential link to respiratory symptoms or worsening health conditions. Some wore masks indoors, avoided opening windows, or limited their movement within the building to reduce perceived exposure. A few participants described staying confined to their apartments to avoid unknown environmental triggers outside their units. For individuals already managing chronic health issues, these conditions contributed to heightened panic and ongoing worry.

Air Debris

Across discussions of health, ventilation, and air-quality concerns, one of the most persistent issues raised by participants was the presence of air debris that seemed to be continually blown into their apartments. Participants who were highly vigilant about cleaning described dust and particulate matter reappearing almost immediately. Their primary concern was not only the inconvenience of constant cleaning but the uncertainty about whether the debris posed a health risk. As Kennedy explained, "I don't know that we know that that would affect the air quality, but getting that dust and that stuff into our lungs, breathing into our lungs," showing the anxiety surrounding potential respiratory impacts.

Blessings and Charles expressed additional frustration stemming from not knowing the source of the debris, which left them compelled to clean constantly. Blessings described the experience: “That stuff that comes down… I’m still having to pull the sheets over my face, my mouth, my head at night. Because when it comes on, clicks on, it starts blowing.” Charles recounted the frustration through a potential system failure saying that “it seems like that might be a fatal flaw. There's probably something wrong with, like, flappers if they're flipped, but everything is just blowing back into people's apartments.” Their accounts reflects a deep distrust in the system that is supposed to deliver fresh air, instead perceived as introducing contaminants into their living space.

Texas further emphasized that this issue was not isolated to a single unit but appeared to affect the broader community, reinforcing the sense that the problem was systemic rather than individual. Collectively, these narrative accounts highlight how visible debris, uncertainty about its origin, and concerns about health implications contribute to residents’ broader mistrust of their ventilation systems.

Perceived Air Quality

Residents’ perceptions of indoor air quality were shaped by a heightened sense of awareness and uncertainty. These themes were often rooted in their limited understanding of how the building’s ventilation systems functioned. Many participants described being acutely aware of shifts in odor, humidity, temperature, and particulate matter, interpreting these changes as indicators of potential environmental or health risks. This hyperawareness was intensified by visible debris, recurring odors, and unexplained physical symptoms. All of these attributes

further contributed to a broader sense of distrust in the ERV systems. Participants frequently expressed anxiety about what might be circulating through their vents, with some reporting episodes of coughing, sleep disruption, or respiratory irritation that they believed were linked to poor air quality.

This perceived lack of control over air quality led many participants to adopt alternative strategies to protect themselves and maintain a sense of safety within their homes. The uncertainty surrounding the source and nature of dust, odors, and debris further amplified residents' fears, especially when these issues appeared to affect multiple units across the building. For many, the inability to identify or address the root cause of these concerns created stress, hypervigilance, and ongoing mistrust in the building's systems.

4.2 Results from Quantitative Analysis

In measuring the indoor environmental conditions, the Broan Overture sensor monitored five primary parameters: carbon dioxide (CO_2, ppm), relative humidity (%), particulate matter ($PM_{2.5}$, µg/m³), total volatile organic compounds (TVOC, µg/m³), and temperature (°C). These measurements were recorded at five second intervals throughout the two-week study. The purpose of this monitoring protocol was to understand whether the interventional phase influenced participant behavioral changes faster than during the baseline phase.

The results highlight that during the two-week study for the three parameters regarding carbon dioxide (CO_2, ppm), relative humidity (%), particulate matter ($PM_{2.5}$, µg/m³), the findings support that behavior mitigated adverse environmental factors quicker than during the baseline phase. However, for total volatile organic compounds (TVOC, µg/m³), and temperature (°C) this

was not the case. It is also important to note that there was variation across participants. At a broad scale the interventional phase showed that participants mitigated adverse environmental conditions faster than during the baseline, but it cannot be universally applied to all participants and their behavior.

To assess how the monitored categories functioned throughout the study, all sensor outputs were imported into Excel for systematic analysis. Given the scale of the dataset—comprising of millions of individual measurements—custom formulas, codes, and charts were developed to organize and interpret the data. These highlighted segments informed the selection of time periods (on a minute-by-minute basis) and variables analyzed through charts. This allowed for a more focused analysis of how environmental conditions differed between the two study phases and how participant behavior may have shifted in response to the intervention, if at all.

4.2.1 CO_2

Across the two phases of the study, carbon dioxide (CO_2) emerged as the parameter with the most variability. Standard deviations within individual residential units ranged from approximately 83 ppm to 202 ppm, indicating substantial fluctuations in ventilation and air exchange over the period of the study. A central objective was to determine whether the interventional phase—during which participants received real-time visual feedback—prompted participants to mitigate these deviations more effectively and quickly than during the baseline week. Analysis of participant level graphs and associated standard deviations suggests that, for several residents, the indicator light influenced behavioral adjustments that reduced CO_2

fluctuations more rapidly in week two. However, this pattern was not universal; some participants exhibited minimal or inconsistent changes in response to the visual cues.

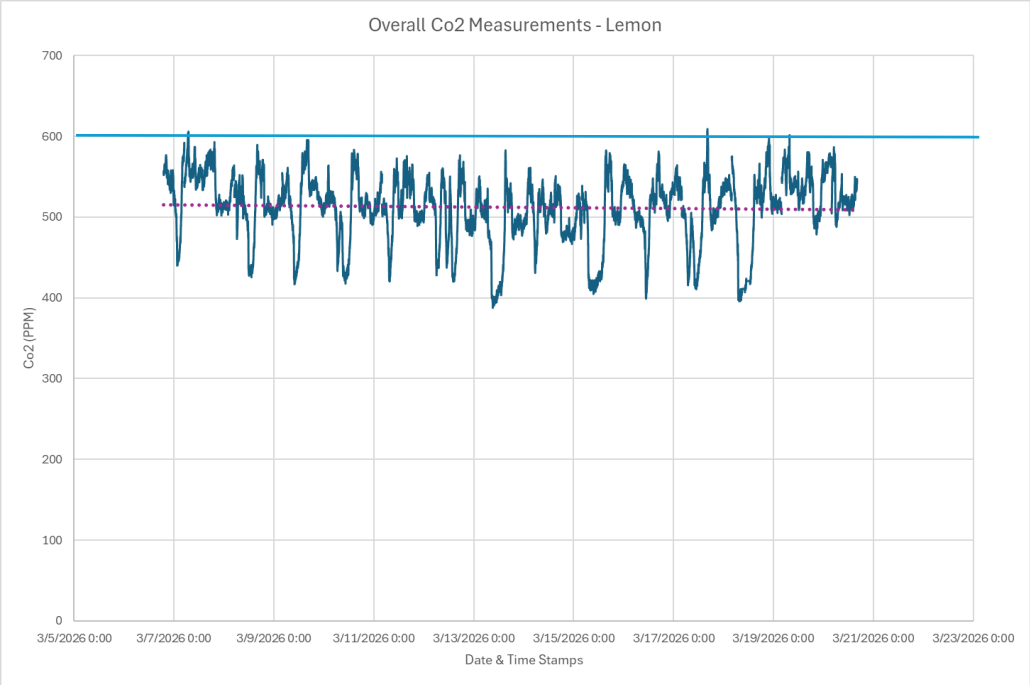


Figure 4.2.1: Lemon's Overall CO_2 Measurements

Caption: This graph shows the overall measurements of CO_2 in Lemons apartment for the duration of the study. The dark blue indicated the CO_2 measurements, the light blue line indicates that average CO_2 measurements set by ASHRAE for indoor air quality for indoor apartment units. The pink line represents the average CO_2 over the course of the study.

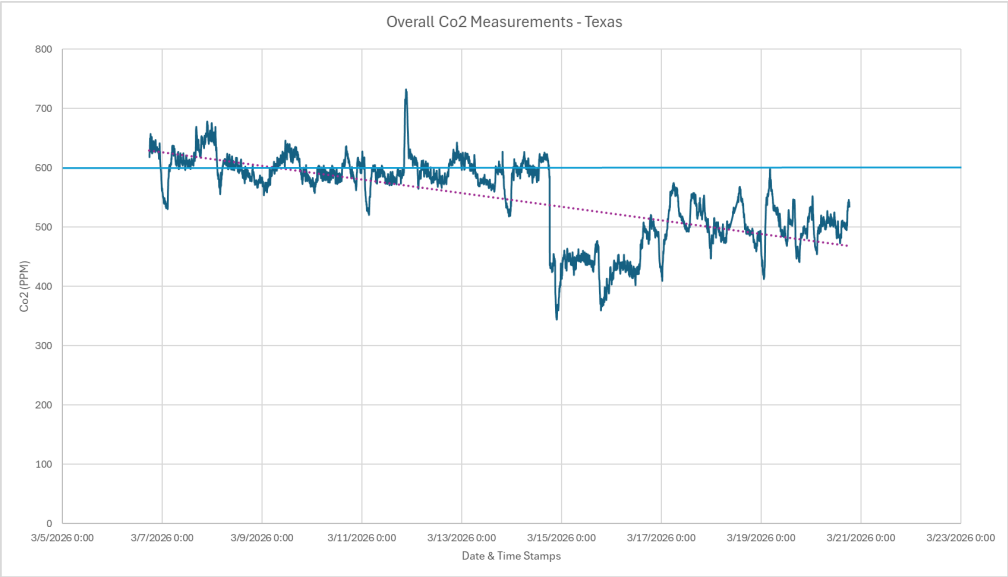


Figure 4.2.2: Texas's Overall CO_2 Measurements

Caption: This graph shows the overall measurements of CO_2 in Texas apartment for the duration of the study. The dark blue indicated the CO_2 measurements, the light blue line indicates the trendline of CO_2 measurements set by ASHRAE for indoor air quality for indoor apartment units. The pink line represents the average CO_2 over the course of the study.

CO_2 variability was particularly notable among seven of the ten participants, with measurements frequently deviating from the 600 ppm reference point commonly used in relation to ASHRAE Standard 62.1 for assessing ventilation. Mary's data *(Figure 4.2.3)* provides a representative example. Their week-two graph demonstrates a visible reduction in the scale and frequency of CO_2 spikes, suggesting that the introduction of visual feedback contributed to more prompt ventilation-related actions. This was similar to JD, Dragonfly, Charles, and Kennedy. For Texas *(Figure 4.2.2)* and Lemon *(Figure 4.2.1)*, this trend was not consistent. Their graphs highlight that the peak of CO_2 measurements decreases slightly. Overall, there were still high fluctuations towards the end of the interventional phase.

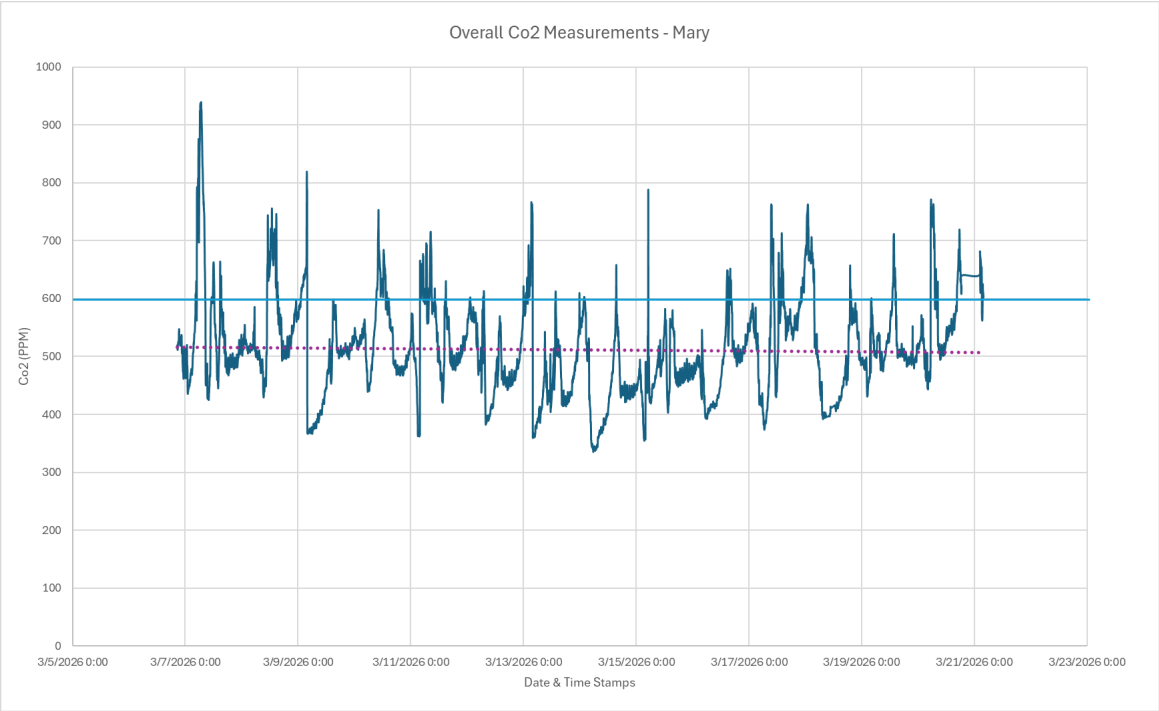


Figure 4.2.3: Mary's Overall CO_2 Measurements

Caption: This graph shows the overall measurements of CO_2 in Mary's apartment for the duration of the study. The dark blue indicated the CO_2 measurements, the light blue line indicates the trendline of CO_2 measurements set by ASHRAE for indoor air quality for indoor apartment units. The pink line represents the average CO_2 over the course of the study.

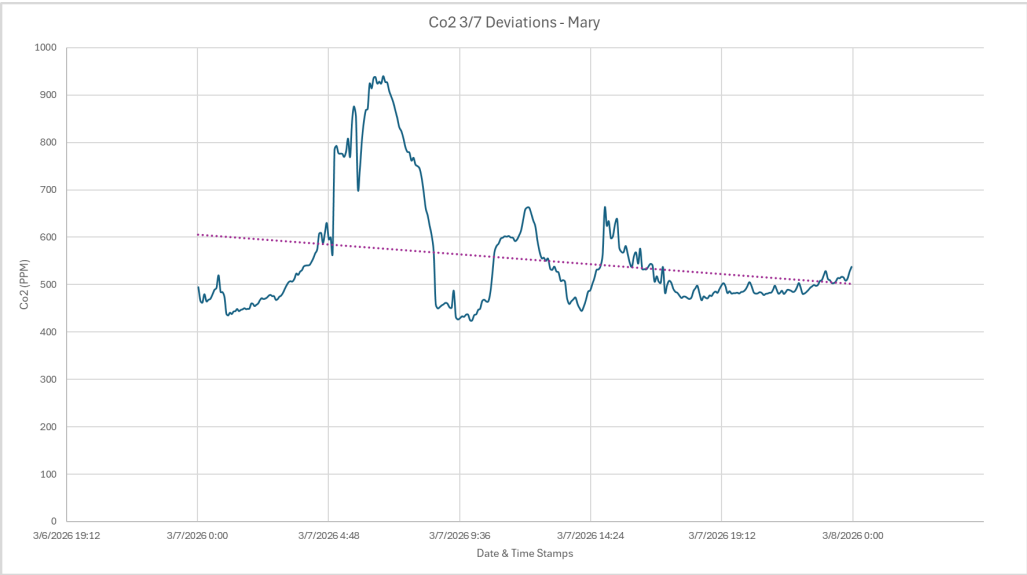


Figure 4.2.4: Mary's CO_2 Deviations on March 7th 2026

Caption: This graph represents Mary's CO_2 deviations on March 7th, during the baseline phase of the study because this days data was one standard deviation above their overall CO_2 average for the entire study. The blue line represents the CO_2 and the pink line represents the trendline. It peaks above the recommended ASHRAE average by 300ppm and peaks three times throughout the day.

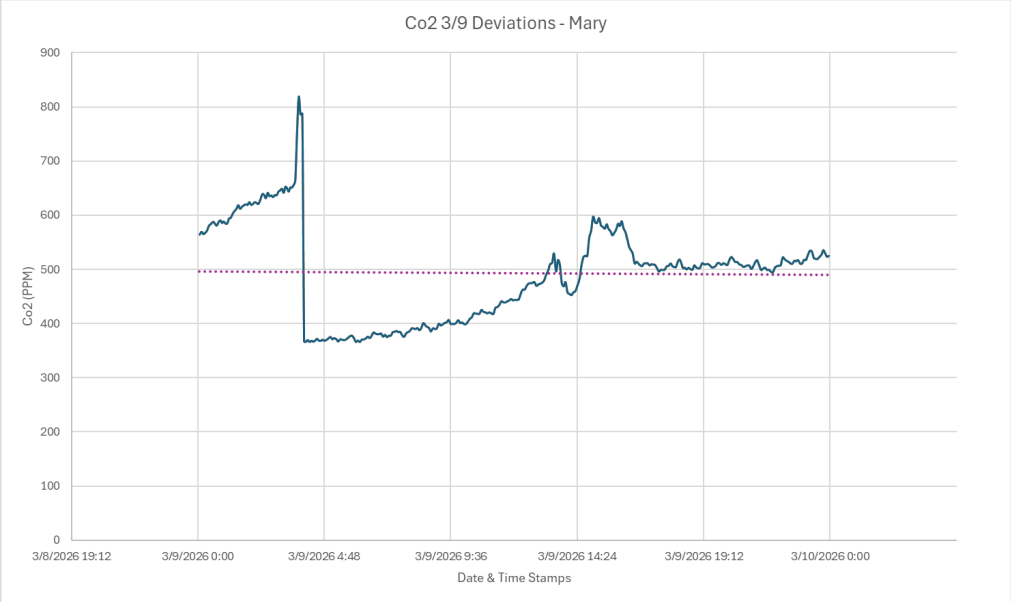


Figure 4.2.5: Mary's CO_2 Deviations on March 9th 2026

Caption: This graph represents Mary's CO_2 deviations on March 9th, during the baseline phase of the study because this days data was one standard deviation above their overall CO_2 average for the entire study. The blue line represents the CO_2 and the pink line represents the trendline. It peaks above the recommended ASHRAE average by 200ppm and peaks twice throughout the day.

These trends suggest that the interventional phase—specifically residents' engagement with the indicator lights—supported effective and quick behavioral adjustments. When examining the peaks in the dataset, it was notable that CO_2 spikes occurred on the same days across multiple units. The most common spike dates were March 9, March 11, and March 15, each of which fell within different phases of the study. This indicates that potential external or building ventilation factors may have contributed to elevated CO_2 levels, independent of individual resident behavior.

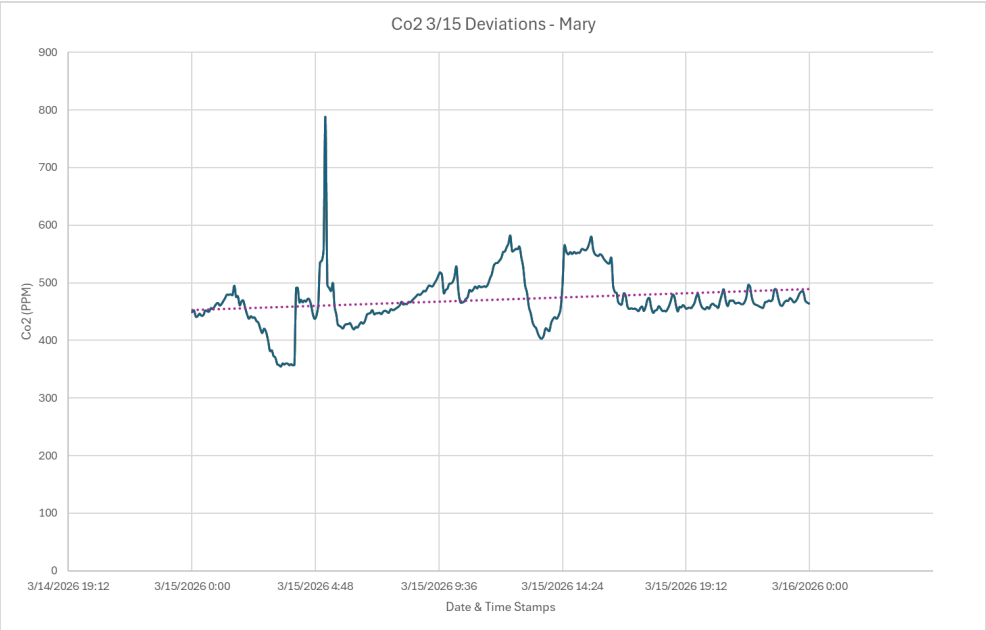


Figure 4.2.6: Mary's CO_2 Deviations on March 15th 2026

Caption: This graph represents Mary's CO_2 deviations on March 15th, during the interventional phase of the study because this days data was one standard deviation above their overall CO_2 average for the entire study. The blue line represents the CO_2 and the pink line represents the trendline. It peaks above the recommended ASHRAE average by but the peaks last a shorter time period than during the baseline phase the study.

Dragonflys Graphs

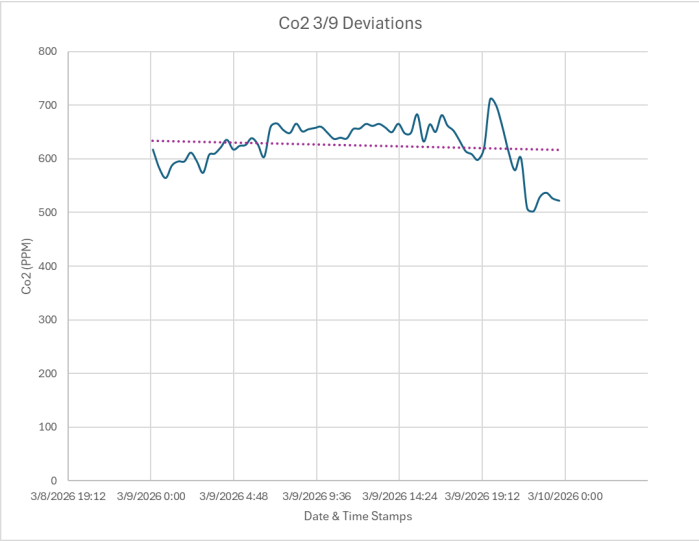


Figure 4.2.7: Dragonfly's CO_2 Deviations on March 9th 2026

Caption: This graph represents Dragonfly's CO_2 deviations on March 9th, during the first phase of the study because this days data was one standard deviation above their overall CO_2 average for the entire study. The blue line represents the CO_2 and the pink line represents the trendline. It peaks above the recommended ASHRAE average by 100ppm and has one peak throughout the course of the day that takes the whole day to mitigate.

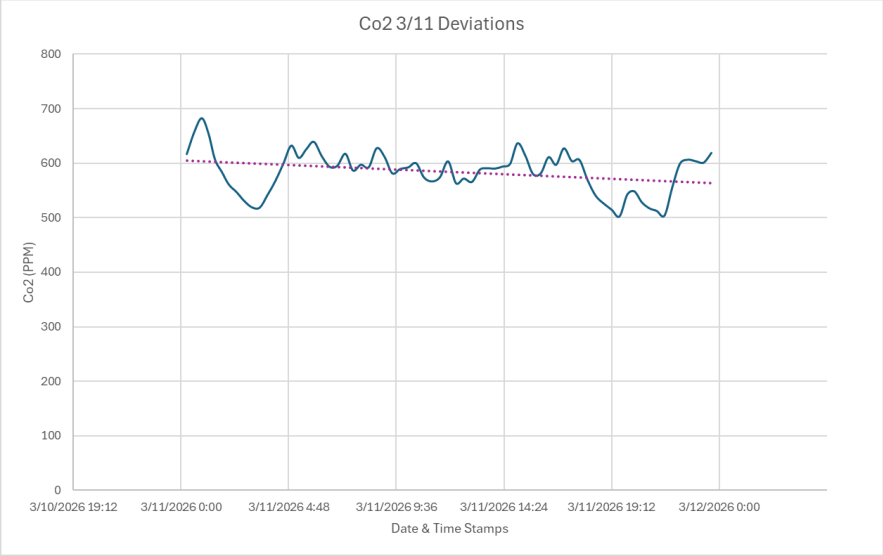


Figure 4.2.8: Dragonfly's CO_2 Deviations on March 11h 2026

Caption: This graph represents Dragonfly's CO_2 deviations on March 11th, during the transitional phase of the study because this days data was one standard deviation above their overall CO_2 average for the entire study. The blue line represents the CO_2 and the pink line represents the trendline. It peaks above the recommended ASHRAE average by 50ppm and has multiple small peaks throughout the course of the day.

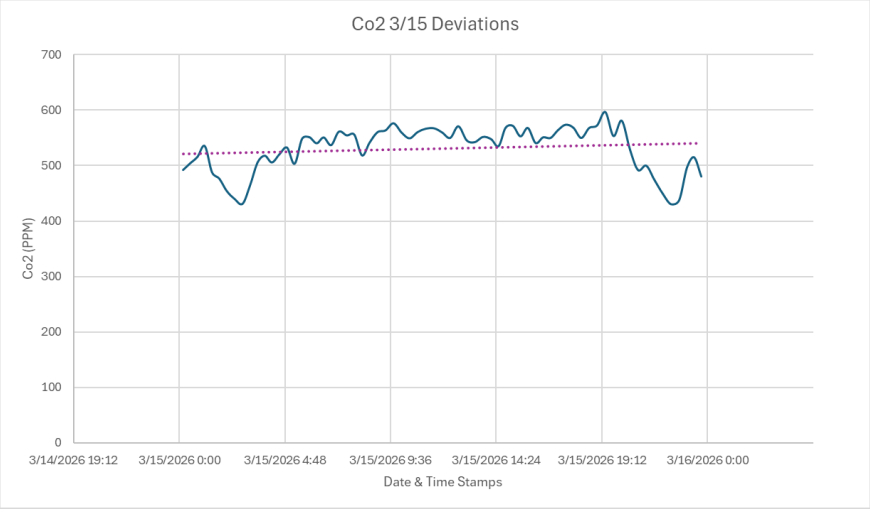


Figure 4.2.9: Dragonflys CO_2 Deviations on March 15th 2026

Caption: This graph represents Dragonfly's CO_2 deviations on March 15th, during the interventional phase of the study because this days data was one standard deviation above their overall CO_2 average for the entire study. The blue line represents the CO_2 and the pink line represents the trendline. It peaks stay with ASHRAES recommended range of 600ppm.

Charles Graphs

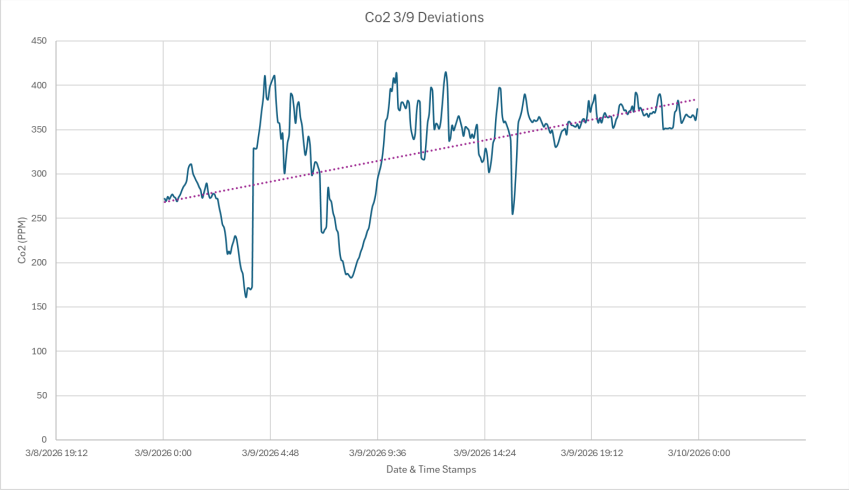


Figure 4.2.10: Charles's CO_2 Deviations on March 9th 2026

Caption: This graph represents Charles CO_2 deviations on March 9th, during the baseline phase of the study because this days data was one standard deviation above their overall CO_2 average for the entire study. The blue line represents the CO_2 and the pink line represents the trendline. It peaks deviate one standard deviation below and above the overall average data and continue to get smaller throughout the day but the overall CO_2 average increases.

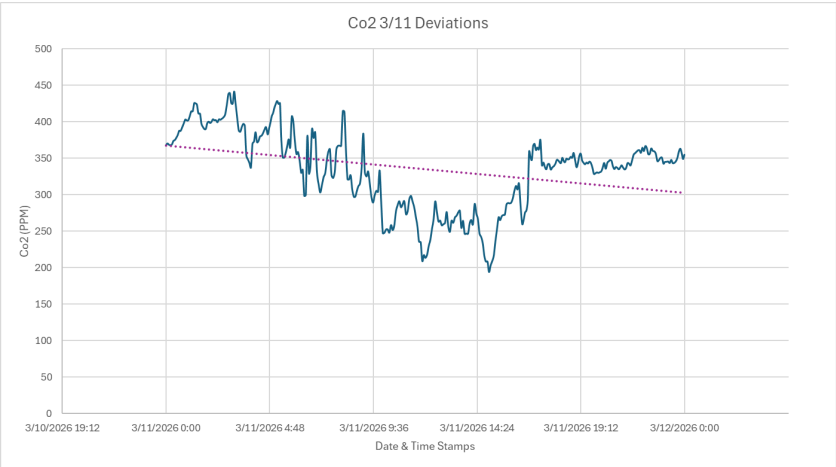


Figure 4.2.11: Charles's CO_2 Deviations on March 11th 2026

Caption: This graph represents Charles CO_2 deviations on March 11th, during the baseline phase of the study because this days data was one standard deviation above their overall CO_2 average for the entire study. The blue line represents the CO_2 and the pink line represents the average. It peaks deviate one standard deviation below and above the overall average data. The overall CO_2 increase and decrease multiple times throughout the day, but remain below ASHRAES recommended average of 600ppm.

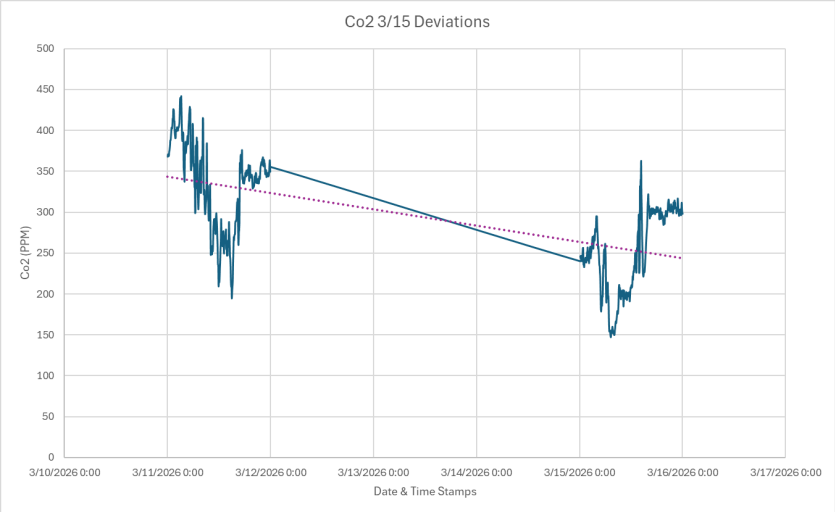


Figure 4.2.12: Charles's CO_2 Deviations on March 15th 2026

Caption: This graph represents Charles CO_2 deviations on March 15th, during the interventional phase of the study because this days data was one standard deviation above their overall CO_2 average for the entire study. The blue line represents the CO_2 and the pink line represents the trendline. The data shows a steady decline in the middle of the day, potentially due to a power outage or the sensor getting disconnected. The overall CO_2 drops drastically throughout this day.

Kennedys Graphs

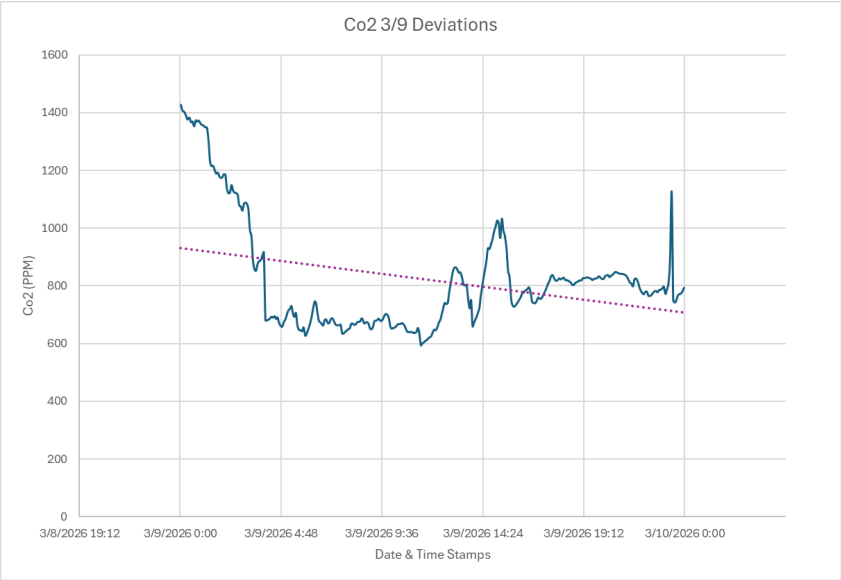


Figure 4.2.13: Kennedy's CO_2 Deviations on March 9th 2026

Caption: This graph represents Kennedy's CO_2 deviations on March 9th, during the baseline phase of the study because this days data was one standard deviation above their overall CO_2 average for the entire study. The blue line represents the CO_2 and the pink line represents the trendline. It peaks deviate one standard deviation below and above the overall average data. The overall CO_2 increase and decrease multiple times throughout the day, but remain way above the recommended CO_2 levels.

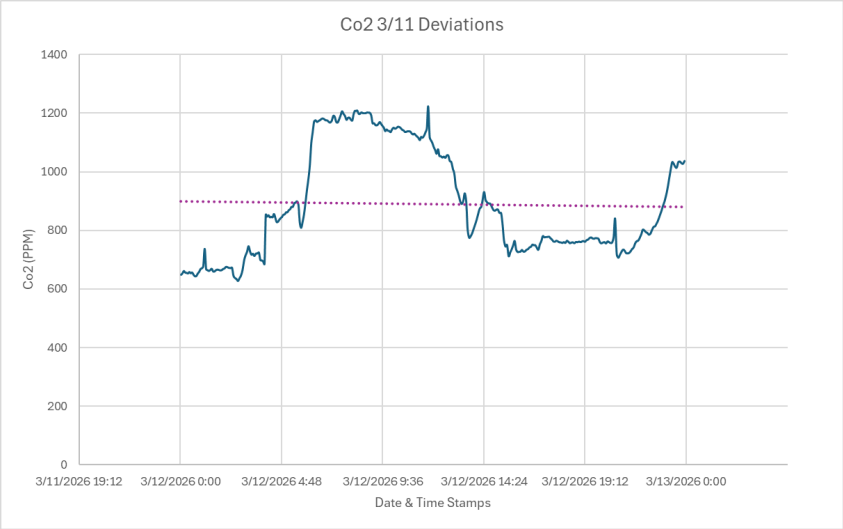


Figure 4.2.14: Kennedy's CO_2 Deviations on March 11th 2026

Caption: This graph represents Kennedy's CO_2 deviations on March 9th, during the transitional phase of the study because this days data was one standard deviation above their overall CO_2 average for the entire study. The blue line

represents the CO_2 and the pink line represents the trendline. It peaks deviate one standard deviation below and above the overall average data. The overall CO_2 has one major peak during the middle of the day and reaches about double the recommended ppm for an indoor residential unit.

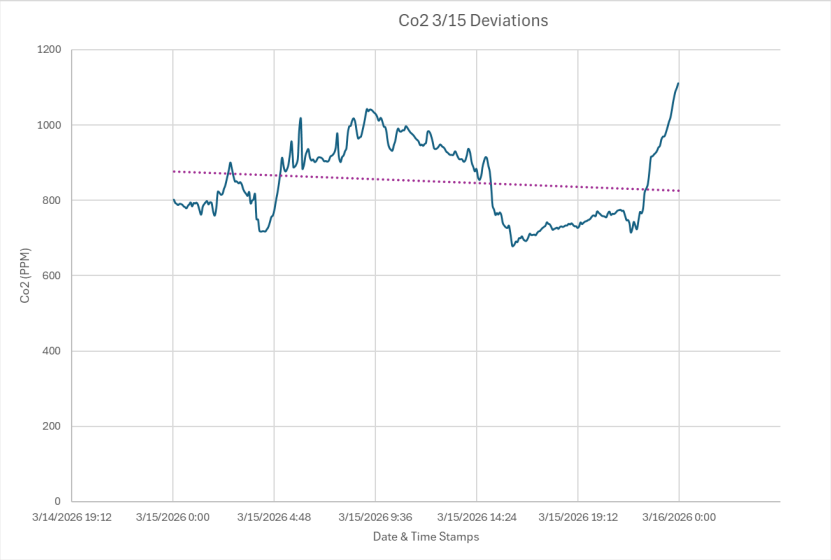


Figure 4.2.15: Kennedy's CO_2 Deviations on March 15th 2026

Caption: This graph represents Kennedy's CO_2 deviations on March 9th, during the interventional phase of the study because this days data was one standard deviation above their overall CO_2 average for the entire study. The blue line represents the CO_2 and the pink line represents the trendline. It peaks deviate one standard deviation below and above the overall average data. The overall CO_2 has one major peak during the middle of the day and reaches about double the recommended ppm for an indoor residential unit. Towards the end of the day it spikes up drastically.

In real time, however, the visual feedback appeared to shape how participants interpreted and responded to these peaks. By receiving immediate cues that their ERV systems might not be delivering adequate ventilation, participants became more attentive to changes in indoor air quality and more proactive in identifying potential causes of inadequate air. This heightened awareness translated into quicker behavioral modifications—such as opening windows—to mitigate potential declines of factors like air pollutants within their indoor air quality in their units.

4.2.2 Humidity

According to the quantitative analysis across participants, only Ice's humidity measurements exhibited a relatively high deviation from the mean (7.87%). However, upon closer examination, the raw data shows that these fluctuations remained within the ASHRAE-recommended humidity range of 30–60%, with the exception of March 15*(Figure 4.2.17)*. This distinction is important: while elevated standard deviation values can signal the need for further investigation, they do not inherently indicate that conditions fall outside the standard acceptable thresholds.

Although their humidity values represent the greatest deviation relative to the mean among all participants, the measurements themselves remained mostly compliant with ASHRAE guidelines. This highlights that even though statistical variability prompted further analysis, the environmental conditions of humidity were still within the recommended operational range.

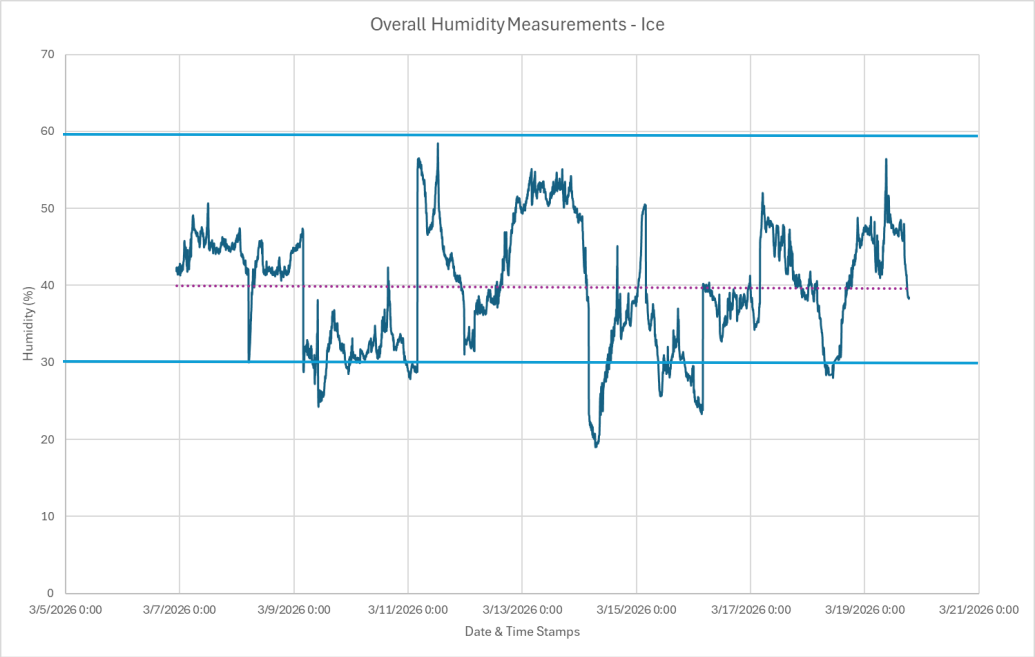


Figure 4.2.16: Ice's Overall Humidity Deviations

Caption: This graph represents Ice's overall humidity deviations throughout the course of the study. The dark blue line indicates the humidity, the light blue line is the range of appropriate humidity given by WHO standards, and the pink line is the overall average. This graph fluctuates one standard deviation above and below the average but still stays between the recommended limit.

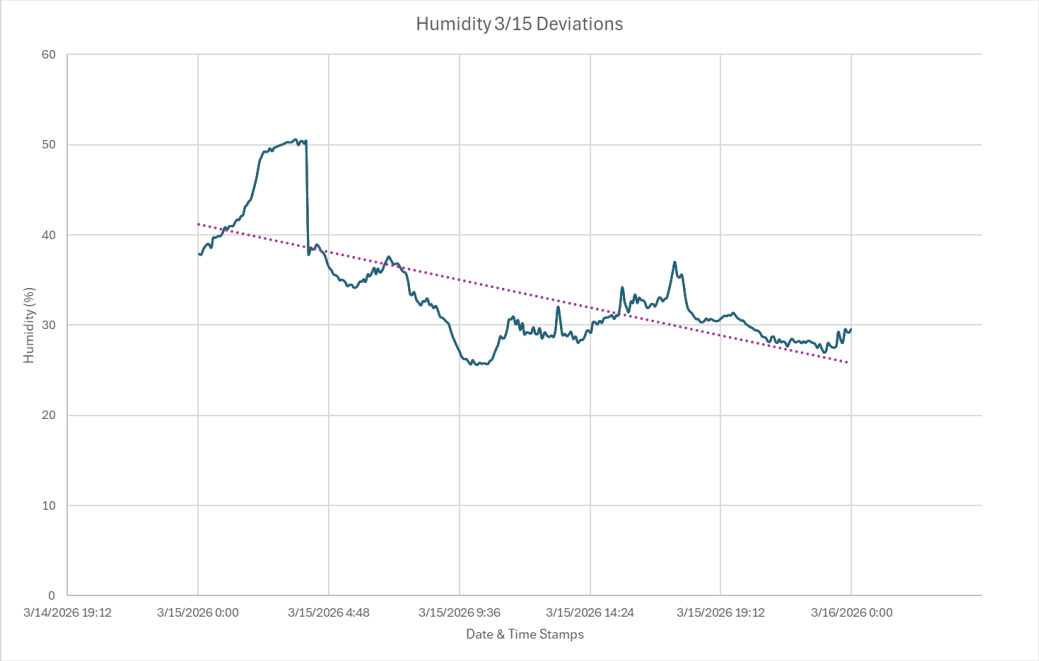


Figure 4.2.17: Ice's Humidity on March 15 2026

Caption: This graph represents Ice's humidity where it peaked the greatest, which was during the interventional phase of the study. Although it peaked high at the beginning of the day, it decreased throughout the day bringing down the average.

4.2.3 $PM_{2.5}$

Alongside CO_2, $PM_{2.5}$ had the highest amount of participant data that ranged one standard deviation above and below the mean of the overall data set. These results closely align with participant complaints of worsening illnesses like COPD, and concerns with smoke infiltration within their units. Similar to CO_2, $PM_{2.5}$ stayed within the acceptable range that is outlined by WHO (World Health Organization): $PM_{2.5}$ 24-hour guideline: 15 $\mu g/m^3$. Only one participant, Kennedy, greatly deviated from this standard showing in *Figure 4.2.17-4.2.19*. Their dataset

showed persistent spikes throughout both the baseline and intervention phases of the study. Several contextual factors may help explain these elevated concentrations such as being located directly above the designated smoking area and adjacent to encampments along the property boundary. Both of these contexts are likely sources of outdoor particulate infiltration. Behavioral factors may also contribute to the consistently high $PM_{2.5}$ levels. Throughout the interviews Kennedy expressed significant distrust in their mechanical ventilation system and reported rarely using it. Instead, they rely primarily on passive heating and cooling strategies, including cross-ventilation through opening windows. While these strategies can improve thermal comfort, they may also increase exposure to outdoor particulate sources, particularly given the proximity of their unit to known emission points.

Kennedy's Graphs

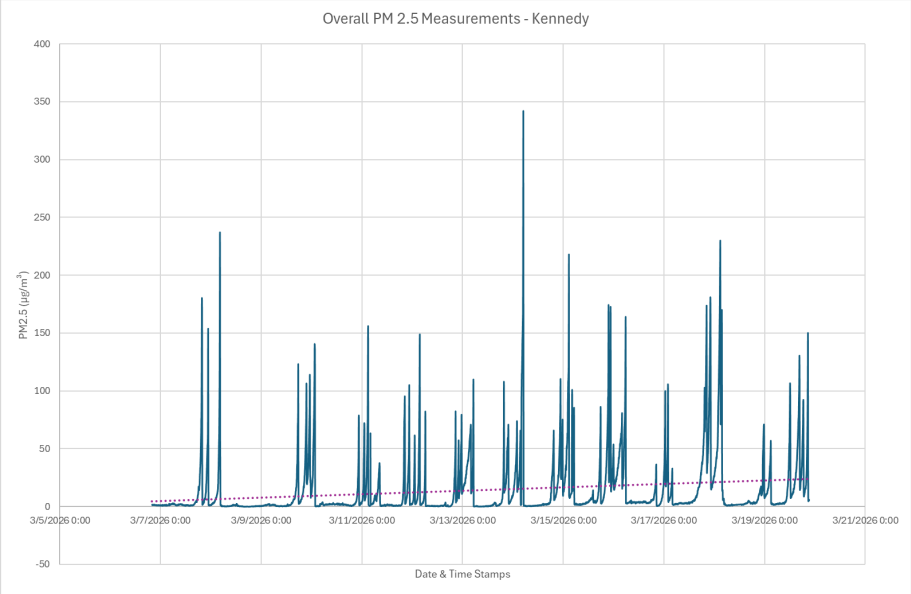


Figure 4.2.17: Kennedy's Overall $PM_{2.5}$ Deviations

Caption: This graph represents Kennedys overall $PM_{2.5}$ standard deviations throughout the course of the study. The blue line shows the $PM_{2.5}$ measurements throughout the study and the pink line shows the average during the study

the spikes of particulate matter are consistent and trend upwards during the interventional phase of the study instead of decreasing.

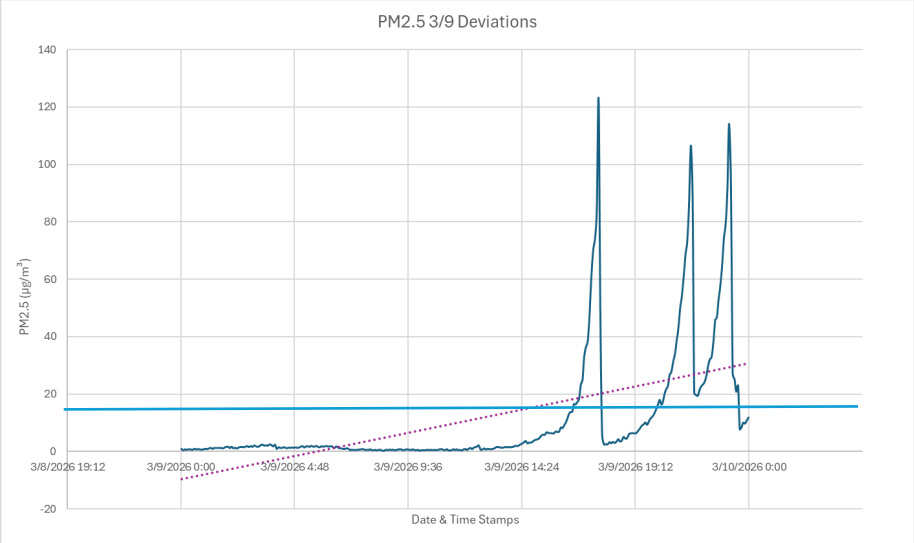


Figure 4.2.18: Kennedy's $PM_{2.5}$ Measurements March 9th 2026

Caption: This graph represents Kennedys $PM_{2.5}$ measurements on March 9th. The graph shows the blue line spiking into the 10th. The pink line represents the average over the course of the day and the blue line recommends the safe standard in a residential unit.

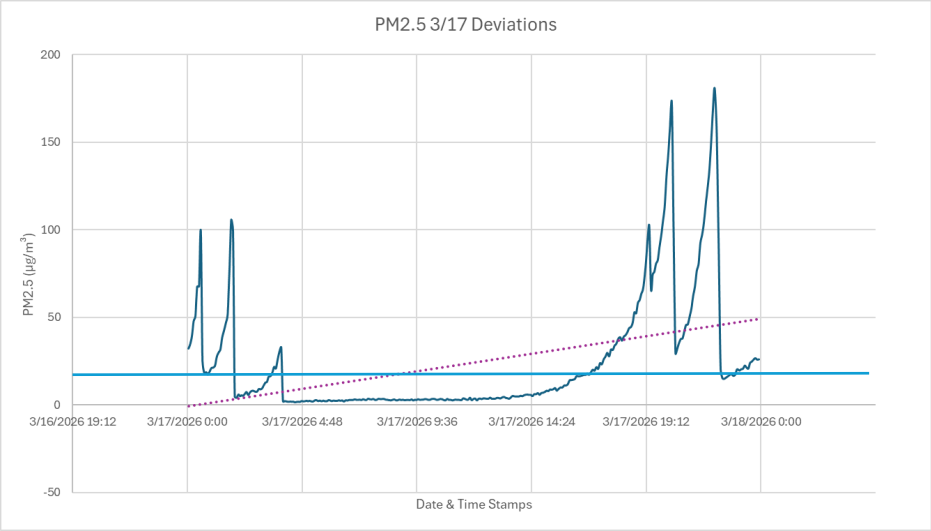


Figure 4.2.18: Kennedy's $PM_{2.5}$ Measurements March 17th 2026

Caption: This graph represents Kennedys $PM_{2.5}$ measurements on March 17th. The dark blue line represent the actual measurements, the pink line represents the average over the course of the day and the light blue line recommends the safe standard in a residential unit. There is two peaks at the beginning and end of the day with it being almost zero during the middle of the day.

Across the remaining participants data set, $PM_{2.5}$ levels exhibited consistent spikes; however, the magnitude of these peaks declined over time. This downward trend suggests that the behavioral interventions supported more rapid mitigation of particulate matter through behavioral changes. Similar to the CO_2 patterns, $PM_{2.5}$ spikes clustered on the same days across all participants, indicating that potential environmental factors likely contributed to elevated pollutant levels within the residential units *(Figure 4.2.19)*.

CO_2 and $PM_{2.5}$ Comparison Chart – Mary

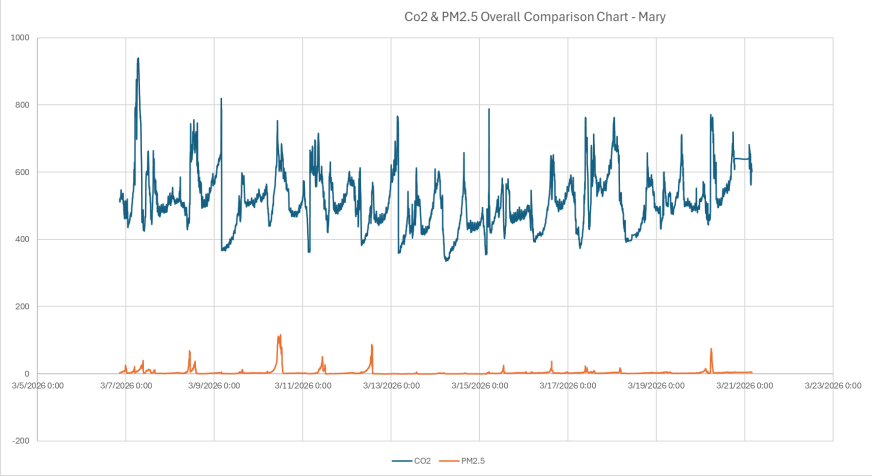


Figure 4.2.19: Mary's CO_2 & $PM_{2.5}$ Comparison Data

Caption: This graph represents Mary's overall CO_2 and $PM_{2.5}$ measurements throughout the course of the study. The data was compared to see if these two measurements peak at the same time during the same days.

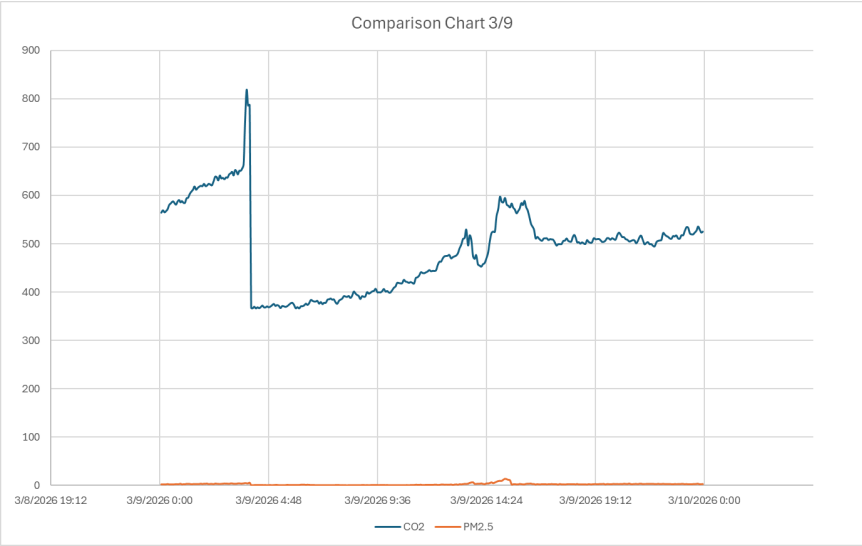


Figure 4.2.20: Mary's CO_2 & $PM_{2.5}$ Comparison Data March 9th 2026

Caption: This graph represents Mary's CO_2 and $PM_{2.5}$ measurements on March 9th . This data was during the baseline phase of the study. The data was compared to see if these two measurements peak at the same time during the same days. It peaks at the same time later in the day at the 14:24 timestamp.

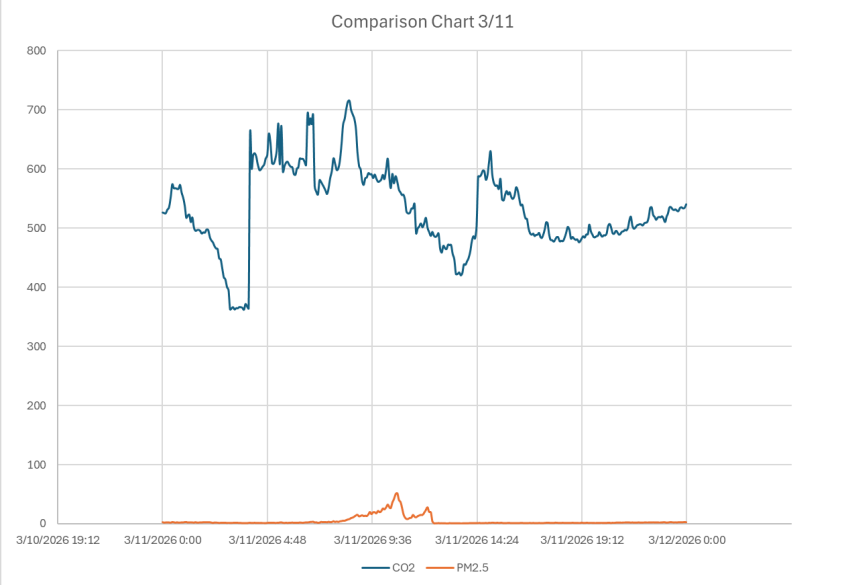


Figure 4.2.21: Mary's CO_2 & $PM_{2.5}$ Comparison Data March 11th 2026

Caption: This graph represents Mary's CO_2 and $PM_{2.5}$ measurements on March 11th. This data was during the transitional phase of the study. The data was compared to see if these two measurements peak at the same time during the same days. In this data set the CO_2 dips when the $PM_{2.5}$ peaks.

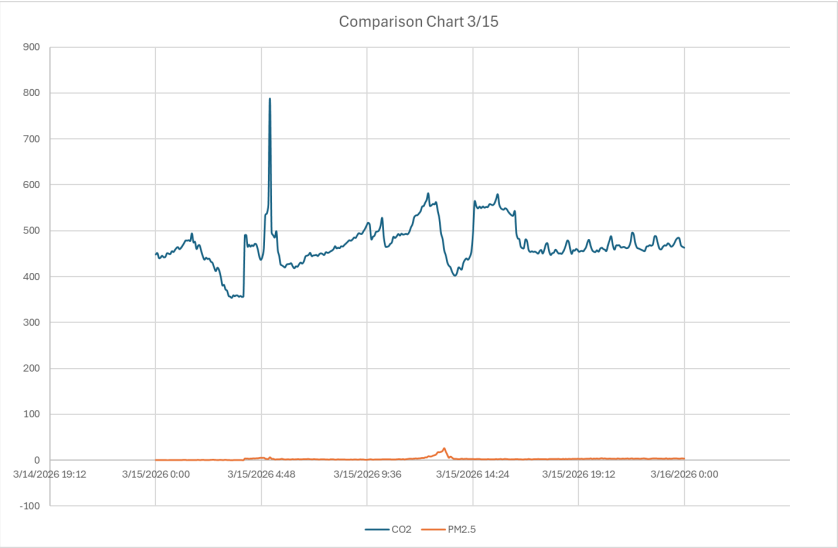


Figure 4.2.22: Mary's CO_2 & $PM_{2.5}$ Comparison Data March 15th 2026

Caption: This graph represents Mary's CO_2 and $PM_{2.5}$ measurements on March 15th. This data was during the interventional phase of the study. The data was compared to see if these two measurements peak at the same time during the same days. In this data set the CO_2 dips when the $PM_{2.5}$ peaks.

Dragonfly's graphs further illustrate this pattern: while the timing of the spikes remains consistent, the amplitude of those spikes diminishes during the interventional phase*(Figure 4.2.23)*. The peaks become less severe and more quickly resolved, reflecting both increased awareness and more immediate interventional behavioral responses. Together, these trends indicate that the interventional phase enabled participants to recognize and address particulate matter more effectively than during the baseline period.

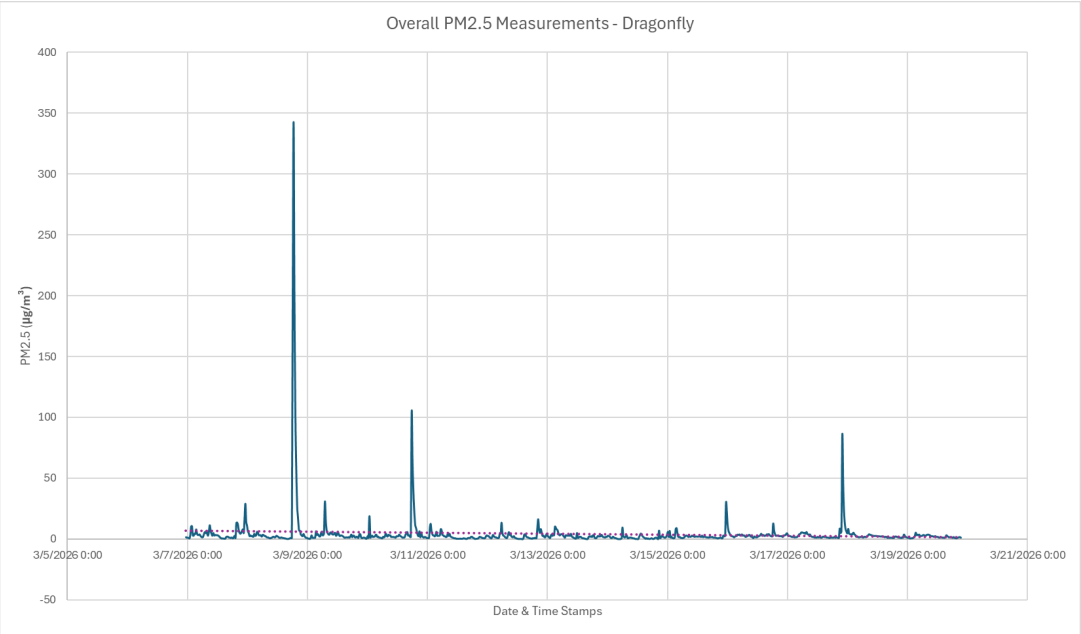


Figure 4.2.23: Dragonfly's overall $PM_{2.5}$ Data

Caption: This graph represents Dragonfly's overall $PM_{2.5}$ data. The dark blue is the measurements and the pink line is the average. This graph illustrates that throughout the different phases of the study, the peaks get smaller.

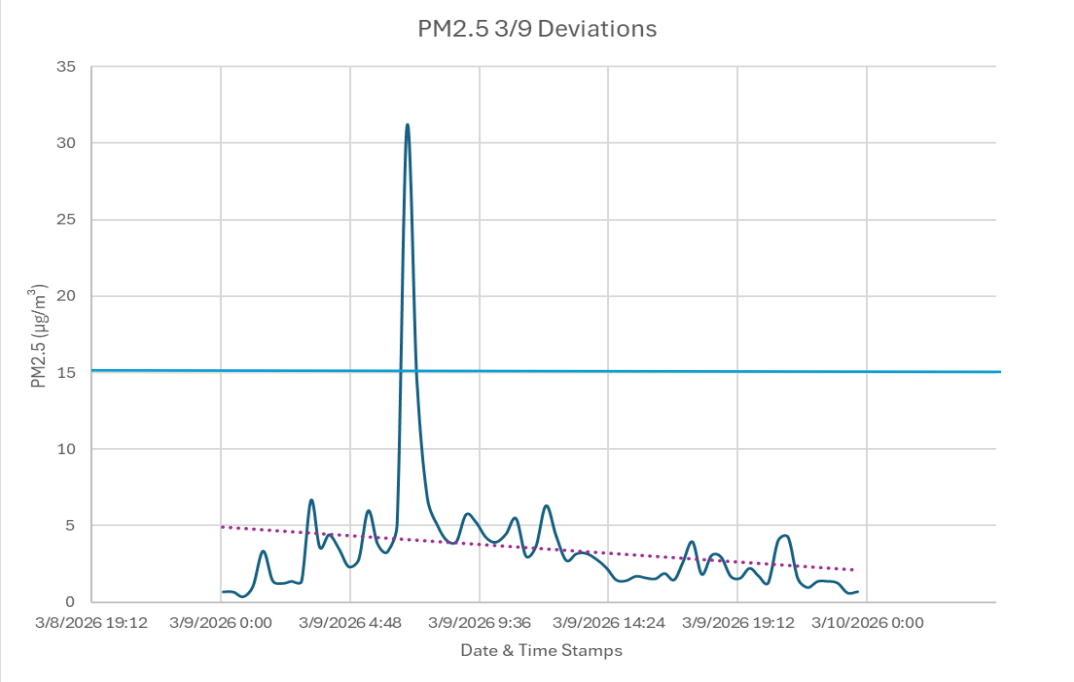


Figure 4.2.24: Dragonfly's $PM_{2.5}$ Data March 9th 2026

Caption: This graph represents Dragonfly's $PM_{2.5}$ data on March 9th during the baseline phase of the study. The dark blue represents the measurements, the pink line represents the trendline throughout the day, and the light blue is the acceptable standard. In this graph there is one major peak during the day which diminishes at the end of the day.

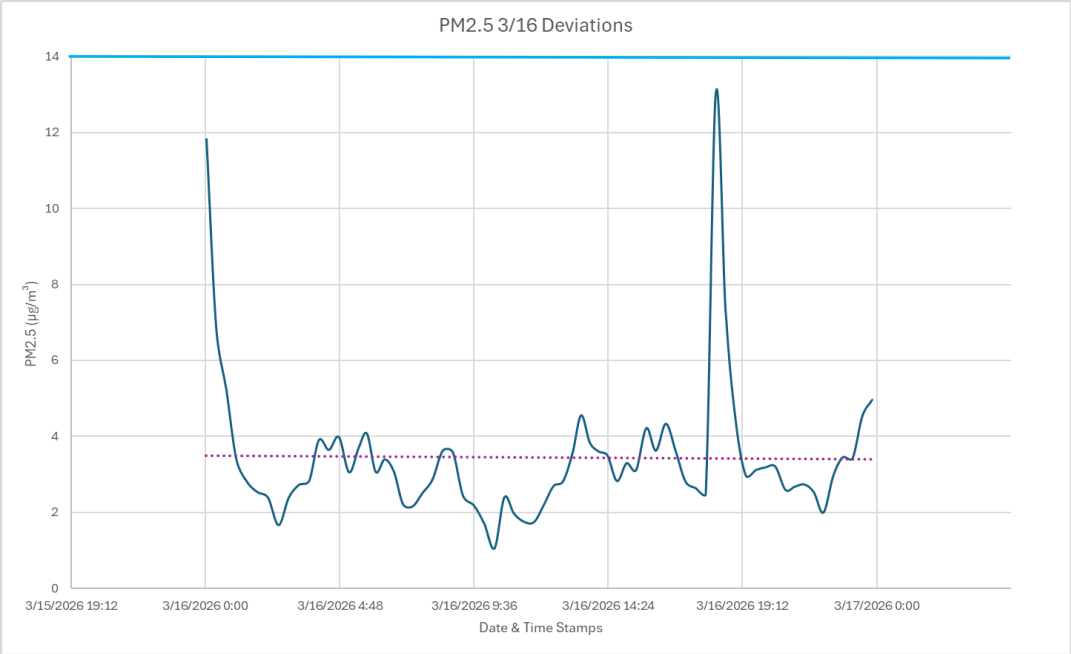


Figure 4.2.25: Dragonfly's $PM_{2.5}$ Data March 16th 2026

Caption: This graph represents Dragonfly's $PM_{2.5}$ data on March 16th during the interventional phase of the study. The dark blue represents the measurements, the pink line represents the trendline throughout the day, and the light blue is the acceptable standard. In this graph there are two major peaks throughout the day, but unlike during the baseline phase, during the interventional phase even the peaks remain under the acceptable threshold.

In conclusion the $PM_{2.5}$ findings reiterate the complex relationships between building conditions, potential environmental exposures and resident behavior. All of these factors shape indoor air quality within multifamily affordable housing. While most participants maintained concentrations within recommended guidelines and displayed an increase of improvements during the interventional phase, Kennedy's case illustrates system distrust can lead to vulnerability to particulate pollution. The overall reduction in spike severity during the interventional phase suggests that real-time visual feedback can meaningfully support

participants in identifying and mitigating pollutant events more quickly. These patterns highlight both the potential of low-cost monitoring to enhance environmental understanding and the ongoing need for building-level strategies that address external pollution sources, ventilation performance, and resident trust in mechanical systems.

4.3 Key Findings

Across the study, participants demonstrated a growing awareness of their indoor air quality, shaped both by lived experience and by the introduction of real-time sensor feedback. It was evident that in analyzing some of the measurements (like CO_2), the visual light cues during the intervention phase played an important role in prompting small but intentional behavioral adjustments. Participants also reported notable shifts in thermostat use, window operation, and cleaning habits. These changes were tied to perceived environmental fluctuations, including temperature swings, humidity, and odors.

Quantitative data further supported these experiences. CO_2 and $PM_{2.5}$ findings showed the greatest variability, with several participants demonstrating quicker mitigation during the intervention week. However, spikes often aligned across units, suggesting building-level or environmental influences beyond individual behavior. Overall, the findings highlight the importance of transparency, long-term monitoring, and accessible education to support resident autonomy, and health in affordable multifamily housing.

V: Discussion

5.1 Alignment Between Qualitative Health Concerns and EPA/WHO Guidelines

Residents' qualitative reports of respiratory irritation, sleep disruption, coughing, and concerns about particulate exposure closely aligned with the health risks identified by the EPA and WHO standards for elevated CO_2 and $PM_{2.5}$ levels. Participants with chronic respiratory conditions, such as Ice and Kennedy, described symptoms that mirror documented effects of poor ventilation and fine particulate matter. Examples of this were that Ice reported waking up with "particles of stuff in [their] throat," while Kennedy described recurring flare-ups and worsening respiratory discomfort after moving into the building.

Other participants also described symptoms that are consistent with WHO-identified risks associated with low humidity and inadequate ventilation. Texas, for example, developed nosebleeds for the first time after moving into the building, a condition later attributed to extreme dryness in their unit. WHO guidance notes that low humidity can irritate mucous membranes and exacerbate respiratory discomfort. Their symptoms resolved only after using a humidifier, demonstrating how environmental conditions directly shaped health outcomes.

Other participants also expressed fear and anxiety about visible debris and odors entering their units. For example, Blessings described pulling sheets over their face at night because debris "starts blowing" when the system turns on, while Charles and Kennedy reported constant cleaning due to lint and dust accumulation. These experiences reflect the EPA's emphasis on the health risks of particulate matter that can be small enough to be inhaled into the lungs. Overall, residents' narratives show a clear alignment between their lived experiences and the potential

health impacts associated with elevated $PM_{2.5}$ and poor ventilation, even if their data charts showed that these values stayed within the recommended range.

When discussing the health concerns among residents, it's important to reiterate that distrust in the ERV system was likely reinforced by the early maintenance issues participants encountered. Participants stopped trusting their systems especially during the discovery that improper filters had been installed and that ducts were never cleaned prior to move-in, despite residents only having lived in the building for about a year and a half.

These problems signified to participants that the system had not been set up with care, and for many, this initial issue shaped their ongoing interpretation of odors, debris, and air quality. In a context where residents were already unsure how the ERV functioned, the idea that the system was installed "already wrong" made it easier to attribute later discomfort—dryness, dust, perceived contaminants, or inconsistent airflow—to system failure rather than normal operation. This aligns with broader findings, like health concerns when symptoms aligned with EPA/WHO guidelines and potential perceived health impacts. These implications not only impact ERV's physical performance but social and psychological impacts in which residents understood and evaluated their systems, making distrust a rational response to what they experienced as a pattern of neglect.

These findings illustrate the multi-dimensional relationship between measured environmental conditions, resident perceptions, and public-health guidance. While the quantitative data remained within recommended standards, participant interviews provided evidence for discomfort and health concerns that mirror EPA and WHO warnings about CO_2 and

$PM_{2.5}$ exposure. It is also important to note that during peak times in the data sets, these spikes could have further adversely affected participants. Furthermore, the interventional phase demonstrated that real-time visual feedback can lead to participants responding quicker and more efficiently to potentially harmful air quality. Ultimately, the case study and cross analysis of qualitative and quantitative data show that monitoring environmental changes and behavioral combined with education can help support healthier indoor air quality in multifamily housing.

5.2 Quantitative Data and Standard Deviation

Although the quantitative dataset showed high standard deviations across CO_2 and $PM_{2.5}$ measurements, the overall data including the spikes, consistently remained within recommended thresholds. These findings indicate that environmental fluctuations in these two categories did not exceed levels considered unsafe. This pattern was especially evident in the $PM_{2.5}$ data, where most participants' values stayed below the WHO 24-hour guideline of 15 $\mu g/m^3$, despite noticeable peaks. Even participants who experienced frequent spikes like Kennedy still had metrics that fell within acceptable limits.

These findings are important given the environmental and behavioral contexts described by participants in their interviews. For example, several participants reported frequent odor infiltration from nearby encampments, the adjacent highway, and the designated smoking area. However, despite these perceived issues, the quantitative data did not show that it exceeded EPA or WHO thresholds. This suggests that while participants perceived their air quality as poor or unstable, in actuality, the measured conditions remained within a range considered safe by public health standards.

The high standard deviation also reflects fluctuation due to daily activities such as cooking, cleaning, and window use. All of these were described by participants as influencing their perceived air quality. Lemon, for instance, noted becoming more aware of air changes "mostly when cooking," while Charles observed that certain cleaning scents triggered the monitor differently. These activity-based fluctuations contributed to the dataset, but because the peaks were over a short period of time and quickly resolved, they did not push the overall averages beyond recommended limits. This reinforces the importance of interpreting high variability within the broader context to understand safe long-term exposure levels.

5.3 Behavioral Adjustment During Interventional Phase

The interventional phase clearly prompted meaningful behavioral adjustments in participants as they responded in real time to visual feedback. This also represented increased awareness and better use of intentional ventilation strategies. Participants repeatedly described how the monitor's color-coded light system shaped their actions: Magestic explained that the yellow indicator prompted them to "keep the bathroom door open" to reduce humidity, while Lemon noted becoming "a little more aware, mostly [when] cooking," prompting them to start utilizing their exhaust fan, demonstrating how specific activities triggered increased attention to air quality.

Participants also described adopting new ventilation habits that they had not used prior to the study. Many participants reported that they rarely opened their windows before the intervention but began doing so more often once they saw the monitor shift from green to yellow or red. Texas, for example, became more aware to environmental changes and began adjusting

their thermostat more frequently after noticing how indoor temperature shifts that aligned with the monitor's feedback. These examples show how the intervention increased residents' environmental understanding and encouraged them to take more active control over their indoor air quality, promoting user autonomy.

The visual feedback also influenced cleaning routines and product choices. Charles noted that certain fragrances—like cinnamon apple—kept the monitor green, while others triggered yellow or red responses. This led several participants to modify their cleaning habits or switch to products that did not elevate particulate levels. These subtle but meaningful behavioral shifts demonstrate how real-time feedback can reshape daily behaviors, even among participants who initially intended to ignore the monitor. The intervention ultimately provided a sense of reassurance and autonomy, countering earlier feelings of uncertainty and lack of control.

5.4 Passive Principles

The results of this study reinforce the central argument in Passive House literature that building performance is linked to occupant behavior. As Literature review highlights, POE research demonstrates that even well-designed passive house ventilation systems depend on how participants interact with those systems and thermal controls (Mach el at.., 2025). This dynamic was clearly reflected in the results, where participants frequently adjusted windows, thermostats, and used supplemental devices to achieve their own comfort. For example, Texas described becoming "more aware of what's in the environment" and adjusting their thermostat more frequently, while others relied on opening windows to compensate for perceived ventilation

failings. These behaviors mirror POE findings that everyday activities such as cooking, cleaning, and environmental changes can significantly alter indoor air quality and cause occupants to use alternative passive strategies.

The study also aligns with literature emphasizing that passive strategies must account for aging populations and diverse sensory needs (Feng el at.., 2018). Many participants in this study, particularly older adults, expressed difficulty using environmental controls or understanding how their ERV systems functioned. Texas, for instance, struggled to adjust the thermostat independently due to mobility limitations, highlighting the need for accessible and user-centered design. These findings suggest that passive principles cannot rely solely on system performance, but that they must integrate usability and accessibility to support autonomy for older residents.

Finally, the results highlight the literature's argument that passive systems require ongoing education to function as intended. Literature review notes that occupant education is essential for understanding energy savings and maintaining comfort (Sun & Hong, 2017). Within this study, participants reported receiving no meaningful instruction on ERV operation until two weeks before the intervention. This lack of system literacy led to misuse, avoidance, and frustration. The findings support the broader claim that passive principles must be paired with long-term engagement and clear communication/education to ensure that participants can effectively maintain good indoor environmental quality and fresh air.

5.5 Occupant Behavioral Effects on Ventilation

The results of the study also strongly support existing research showing that occupant behavior plays an important role in ventilation performance. Thermal comfort is dynamic and

shaped by personal routines, preferences, and adaptive strategies (Sherriff el at.., 2019). This was evident in the findings. For example, participants like Dragonfly ran their air conditioners continuously, while others opened windows daily during the intervention phase which directly influenced indoor air quality and fresh air. Lemon's observed that their unit retained heat well, contrasted with others' struggles to cool their apartments.

The analysis also reinforces the literature's argument that ventilation behavior is often shaped by perceived air quality rather than just trusting system use. Participants frequently avoided using their ERV systems due to distrust, odors, and visible debris. Kennedy's avoidance of the ERV because "lint particles… have not stopped" and Blessings' decision to wear masks indoors reflect behavioral adaptations driven by this distrust. These behaviors align with Jia el at.. (2017), who argue that ventilation performance is influenced by both passive and active occupant decisions—particularly when participants perceive systems as unreliable or unsafe.

The study further demonstrates that participants adopt additional ventilation strategies when building systems do not meet their comfort expectations. More than half of participants purchased humidifiers, purifiers, or fans to supplement their ERVs, echoing literature showing that occupants often modify or override ventilation systems to achieve comfort (Jia el at.., 2017). Texas's rapid improvement in nosebleeds after using a humidifier exemplifies how participants compensate for poor environmental conditions. These findings highlight the importance of designing ventilation systems that anticipate diverse behavioral responses and provide participants with clear ways to achieve comfort.

5.6 Sensor Monitoring Influence on Autonomy & Comfort

The interventional phase of the study provides strong evidence for the literature's claim that sensor-based monitoring can enhance occupant autonomy when implemented thoughtfully. Literature review notes that smart systems can reduce energy use while supporting comfort, but only when participants trust and understand them (Hoof el at.., 2019). In the analysis, it was clear that real-time visual feedback increased residents' awareness and confidence in managing their indoor air. Magestic's use of the monitor to decide when to run their diffuser and Lemon's increased awareness "mostly when cooking" demonstrate how simple feedback mechanisms can give participants autonomy to make informed decisions.

However, the results also highlight the limitations of sensor-based systems when participants lack foundational system understanding. While the monitor increased awareness, many participants still expressed confusion or distrust toward their ERV systems. This aligns with Hoof el at.. (2019), who emphasize that older adults often rely on familiar control methods and may struggle to integrate new technologies into daily routines. Participants like Kennedy, who avoided the ERV entirely due to perceived health risks, illustrate how sensor feedback alone cannot overcome thoughts about system reliability or safety.

At the same time, the study demonstrates that real-time monitoring can meaningfully improve comfort when paired with meaningful behavioral adaptation. The reduction in $PM_{2.5}$ spike severity during the interventional phase reflects residents' increased responsiveness to the monitor's cues. Participants opened windows more frequently, adjusted cleaning routines, and modified humidity levels based on the monitor's color changes. These findings support Kumar

and Hacke's (2014) argument that sensor systems provide valuable data for managing indoor environmental conditions, while also showing that such systems can enhance comfort when participants understand how to act on the information provided.

5.7 Housing & Policy

The overall analysis highlights policy literature arguments that building performance is deeply integrated with resident behavior and system understanding. Literature review highlights the Softer Landings approach, which emphasizes long-term engagement and behavioral support (Zhao el at.., 2025). Participants in the study repeatedly expressed a desire for transparency, ongoing education, and long-term monitoring which directly align with this policy framework. Their requests for move-in orientations, printed guides, and seasonal reminders demonstrate a clear need for structured support that extends beyond initial occupancy.

The study also reveals how policy gaps can worsen environmental vulnerability in affordable housing. Participants reported persistent odor infiltration, visible debris, and inconsistent maintenance practices. Blessings' fear of contaminants, Texas's experience with dryness-related medical issues, and Kennedy's respiratory flare-ups illustrate how inadequate system communication and maintenance can disproportionately affect vulnerable populations. These findings align with Mardookhy el at.. (2014), who argue that energy-efficient infrastructure must be paired with resident-centered policies to ensure equitable outcomes.

Finally, the results highlight the need for policy frameworks that integrate environmental health, aging-in-place priorities, and resident autonomy. As Literature review notes, the aging population and climate pressures demand housing policies that address both physical

infrastructure and human behavior. The results of this study express that participants want long-term monitoring, clearer communication, and systems that support autonomy rather than undermine it. The link between participants lived experiences and EPA/WHO health guidance further highlight the urgency of policy interventions the need to prioritize indoor environmental quality as a public-health issue, not merely a technical one.

Chapter VI: Conclusion

6.1 Importance/Relevance of Occupant Perception of Air Freshness

Perception of air freshness emerged as a central theme in understandings of comfort, safety, and trust in their building's ventilation systems. The literature review emphasizes how indoor air quality often outweighs measured IAQ data in shaping occupant satisfaction. The results of the study reinforce this analysis: participants like Lemon described becoming "a little more aware, mostly when cooking," while others expressed heightened concern during sleep, when stale or humid air felt most uncomfortable. The study's participants relied heavily on these sensory indicators to their perceived air freshness, demonstrating that air freshness is not only a comfort metric but a metric for safety and control.

This becomes even more prevalent when considering the emotional and health-related concerns that surfaced in interviews. Blessings' fear of a potential "correlation between the air not being clean and people having health problems to the point of death" exemplifies how perceived air freshness can escalate into further concern when there is high distrust in building systems. Literature on environmental stressors in low-income housing similarly notes that uncertainty about system performance amplifies anxiety and drives hypervigilance. The results show this through how participants monitored odors, humidity, and airflow with sensitivity, and interpreted these minor shifts as signals of system failure.

6.2 Influence of Occupant Behavior on Ventilation Systems

The results demonstrate that occupant behavior is not a passive issue, but an active one in shaping ventilation outcomes. participants frequently modified, supplemented, or ignored their ERV systems based on perceived performance, distrust, or discomfort. Kennedy's avoidance of the ERV due to lint accumulation and Texas's use of a humidifier to address nosebleeds illustrates how participants adopt alternative strategies when mechanical systems feel unreliable. These behaviors mirror literature showing that when system design is unintuitive, occupants default to familiar, controllable interventions. This study's findings confirm that behavior is both a response to system shortcomings and system inefficiency.

Additionally, the intervention period revealed how real-time feedback can reshape these behaviors. Participants like Magestic used the sensor light as a behavioral cue—opening bathroom doors when the light turned yellow or activating diffusers when air felt stale. This aligns with research, which suggests that simple, intuitive sensor indicators can increase environmental awareness and promote positive adaptive behaviors. However, the findings of this study also highlight the limits of behavior-based solutions: participants hyper-awareness of air quality often led to overcompensation, such as excessive window closure due to fear of outdoor contaminants. This tension reinforces insight from the literature that highlights how occupant behavior is deeply intertwined with trust, literacy, expressing that ventilation systems cannot function optimally without addressing these behavioral factors.

6.3 Limitations and Future Research

Several limitations shape the interpretation of the findings and point toward opportunities for future research. The two-week intervention period, as participants themselves noted, was insufficient for fully understanding long-term ventilation patterns or system performance across seasons. Literature on behavioral adaptation suggests that meaningful shifts in system use often require extended exposure, active learning, and behavioral reinforcement. The study also relied heavily on self-reported perceptions that can introduce subjectivity and preconceived notions towards continuous IAQ monitoring or other systematic monitoring.

Future research should continue to explore longer-term interventions that integrate system education, real-time feedback, and participatory design approaches that center resident experiences. The overall findings of this research suggest that participants might be eager to understand their systems and highly motivated to manage in order to understand their indoor air quality better. Additionally, expanding this work across multiple building types, climates, and demographic groups would deepen understanding of how perception, behavior, and system design interact. Furthermore, policy-oriented research could examine how building codes, building practices, and post-occupancy education requirements might better support resident autonomy and system usability. Together, these factors can build on the main insight: ventilation performance is an integrated human-environment relationship that requires interdisciplinary action in shaping residents' perception of fresh air.

APPENDIX A: GLOSSARY

Important Policies, Codes & Institutions

OAR 813-206-000

“OAR 813-206-0000 through 813-206-0070 address protocols, standards, and requirements with respect to the Multifamily Energy Program (the "Program"), the purpose of which is to address energy efficiency needs of low-income households in multifamily housing. Additional policies and instructions for this program are outlined in the Multifamily Energy Program Manual dated effective January 1, 2025, incorporated herein by this reference (“Manual”). Other applicable policies, standards, and requirements are contained in the department’s descriptive and procedural rules found in Division 1, in the department’s general rules found in Division 5, and in the department’s general procedures for public contracts and procurements found in Division 6. The department allocates funds for this program to eligible affordable multifamily rental housing developments (“Projects”) through developers and owners of such projects. Program funds are made available to the department from SB 1149 Electricity Public Purpose Charge account established in ORS 757.612(3)(b)(C) for this and other purposes under ORS 757.612(3)(b)(C). “ (OAR 813-206-000).

See Also: Oregon Secretary of State Administrative Rules

Massachusetts Phius Compliant Stretch Codes

“DOER received a lot of feedback on the specific wording for both Phius and PHI compliance, in addition to a large amount of support for a “third option” for compliance. This “third option”

will allow projects to proceed through funding and final occupancy, where projects narrowly fail to meet the full Passive House certification standards but still exceed other building code performance pathways." (C407.3 Passive House).

See Also: 2025 Webinar MA StretchSpecialized Code updates 2-25-25.pdf

New York Phius Compliant Stretch Codes

"The NYStretch Energy Code 2020 project was undertaken by NYSERDA to develop a pivotal tool for New York jurisdictions to support the State's energy and climate goals by accelerating the savings obtained through their local building energy codes. Authorities having jurisdiction have the legal ability to voluntarily adopt NYStretch-Energy. The NYStretch Code was developed as a statewide model code to save more energy than New York's minimum code and to be readily adopted as a more stringent local standard to the ECCCNYS." (NYStretch Energy Code 2020).

See Also: Perma | www.nyserda.ny.gov

Portland Vancouver Metro Climate Action Plan

"Metro is leading development of the Comprehensive Climate Action Plan (CCAP) on behalf of the local and regional agencies in the seven-county Portland-Vancouver metropolitan statistical area, which is the required geographic area for the CCAP and extends beyond Metro's boundaries. Prior to beginning this project, Metro convened agency partners across the metropolitan statistical area who agreed that Metro was best-positioned to lead this work on

behalf of the metropolitan area. Metro has a strong tradition of coordinated planning in the part of the Portland-Vancouver area with most of the region's people and jobs." (CCAP 2025).

See Also: metro-ccap-final-standalone-main-document.pdf

Phius

"Phius trains and certifies professionals, maintains the Phius climate-specific passive building standard, certifies and quality assures passive buildings, certifies high-performance building products and conducts research to advance high-performance building" (Phius).

See Also: Phius

2050 Building Challenge

"Recognizing that structural materials account for at least 50% of the carbon emitted in production, delivery, and installation of materials for new construction and the latest IPCC reports tell us that the building sector only has until 2050 to reach carbon neutrality, now more than ever, structural engineers members have an opportunity to change the trajectory of the building sector. The SE 2050 Challenge, an initiative conceived of and developed by members of the Carbon Leadership Forum, was designed to ignite structural engineers and their firms to meet embodied carbon benchmarks and ambitious reduction goals, and be recognized for the significant role they can play towards these targets" (SEI).

See Also: SE 2050 Challenge - Carbon Leadership Forum

EPA

The Environmental Protection Agency's mission is to protect human health and the environment, a charge it fulfills through several interconnected responsibilities. The agency works to ensure that Americans have access to clean air, land, and water, and that national efforts to reduce environmental risks rely on the best available scientific evidence. It administers and enforces federal environmental laws fairly and effectively, while integrating environmental stewardship into broader U.S. policies related to natural resources, public health, economic growth, energy, transportation, agriculture, industry, and international trade. The EPA also prioritizes public access to accurate information so that communities, individuals, businesses, and all levels of government can meaningfully participate in managing environmental and health risks. In addition, the agency oversees the cleanup and revitalization of contaminated lands and toxic sites by responsible parties, and ensures that chemicals entering the marketplace undergo appropriate safety review.

See Also: Our Mission and What We Do | US EPA

WHO

The World Health Organization leads and coordinates global efforts to improve health outcomes and advance health equity for all people. By connecting countries, partners, and communities, the organization works to ensure that everyone has an equal opportunity to live a safe and healthy life. From emerging epidemics such as COVID-19 and Zika to persistent communicable diseases including HIV, malaria, Ebola, Marburg, and tuberculosis, as well as chronic conditions like diabetes, heart disease, and cancer, the WHO mobilizes 194 countries and operates in more

than 150 locations worldwide. Through this global presence, it confronts the most pressing health challenges of our time and works to measurably strengthen the well-being of populations across the world.

See Also: Our work

ASHRAE

A dedicated to advancing human well-being through sustainable technology for the built environment. The Society and its members focus on building systems, energy efficiency, indoor air quality, refrigeration and sustainability within the industry. Through research, standards writing, publishing and continuing education, ASHRAE shapes tomorrow's built environment today. ASHRAE was formed as the American Society of Heating, Refrigerating and Air-Conditioning Engineers by the merger in 1959 of American Society of Heating and Air-Conditioning Engineers (ASHAE) founded in 1894 and The American Society of Refrigerating Engineers (ASRE) founded in 1904.

See Also: Home | ashrae.org

ASHRAE 62.2 Standard

ASHRAE 62.2 establishes minimum ventilation and air-quality requirements for residential buildings to ensure adequate fresh air and limit indoor pollutant buildup. It outlines mechanical ventilation rates, source-control measures, and system performance standards to support overall healthy indoor environments.

See Also: ASHRAE - iWrapper

ASHRAE 55 Standard

ASHRAE 55 defines the environmental conditions needed to achieve thermal comfort for most occupants, considering factors such as temperature, humidity, air speed, and metabolic activity.

See Also: ASHRAE - iWrapper

APPENDIX B: DATA COLLECTION STRATEGIES

Recruitment Method, Interview Questions & Data Coding

Recruiting Method



Figure 9.1: Recruitment Flyer

Interview Questions

First Interview – 60 Minutes

Research Theme / Question	Interview Question	Probes/Follow Ups

Introduction	What is your name, race, gender and age?	n/a
Perception of indoor air freshness	How would you describe the air quality in your apartment?	What makes it feel fresh or stale? Has this changed since you moved in?
Perception of indoor air freshness	Do you think that your ERV and HVAC systems are automatic?	Do you feel like you have the ability to control them?
Seasonal comfort	How does the air feel during the winter months?	Is it different from summer? Does cold weather affect how you ventilate?
Awareness	What do you know about the ventilation system in your apartment?	Were you given instructions? Do you know what it does?
ERV usage behavior	How do you typically use the ventilation system day to day?	Do you adjust settings? How often? Why or why not? Do you understand how these systems work?

Window use behavior	When do you usually open or close your windows?	Time of day? Weather conditions? Comfort or air quality reasons?
Control	What prompts you to change how you ventilate your apartment?	Smells? Temperature? Health concerns? Noise or safety?
Control	Do you feel you have control over the air quality in your apartment?	What helps or limits that control?
Control/Comfort	Does the air quality affect how comfortable you feel at home?	Breathing comfort? Sleep? General well-being?

Table 9.1: First Interview Questions and Probes

Second Interview – 20 Minutes

The goal of the second interview is to understand how sensors are impacting behavior and to answer participant questions about the study.

Interview Questions

Research Theme / Question	**Interview Question**	**Probes/Follow Ups**

Awareness	How noticeable is the sensor in your daily routine?	Do you think about it often? Does its location affect your awareness of it?
Behavior	Since the sensor was installed, have you changed how you use your windows or ventilation system?	Can you describe a specific change? What motivated it?
Awareness	Has the sensor made you more aware of air quality or temperature?	In what situations do you notice this most?
Behavior	Do you think your behavior would be different if the sensor were not present?	How so?
Comfort	How do you feel about having the sensor in your apartment?	Comfortable, uncomfortable, or neutral? Why?

Comfort	Do you trust the sensor to accurately measure air quality?	What makes you trust or question it?
Comfort	Do you have any concerns about being monitored?	What kinds of concerns, if any?
Comfort	What questions do you have about the sensor or what it measures?	What additional information would be helpful?

Table 9.2: Second Interview Questions and Probes

Final Interview – 60 Minutes

Goal: What participants learned from the study and what can be helpful for future studies

Interview Questions

Research Theme / Question	**Interview Question**	**Probes/Follow Ups**
Reflection	Has the sensor helped you understand your apartment's air quality better?	How could this information be more useful?

Reflection	Would you want this kind of monitoring in your home long-term?	Why or why not?
Reflection	How would you describe your overall experience participating in this study?	What stood out most? What was challenging?
Reflection	Has your perception of air quality in your apartment changed during the study?	What did you learn? What is still unclear?
Energy Awareness	Did you change how you used your windows or ventilation during the study?	Were these changes intentional or unintentional?
Energy Awareness	How satisfied are you with the air quality in your apartment now?	What makes it better or worse?

Reflection	Has participating in the study changed how you think about energy use?	In what situations do you think about it most?
Reflection	What information was most helpful during the study?	What additional information would you want?
Reflection	Do you think you will continue any behaviors you adopted during the study?	Which ones? Why or why not?
Reflection	What changes would you suggest to improve ventilation or resident education?	For building management? Designers?
Reflection	Is there anything else you would like to share about air quality or comfort in your apartment?	Anything we didn't ask that feels important?

Table 9.3: Third Interview Questions and Probes

Averages and Standard Deviations

PARTICIPANT	DATE	CO_2	HUMIDITY	$PM_{2.5}$	TVOC	TEMPERATURE

P00 - OFFICE	**AVERAGE**	478.76	42.26	1.74	0.48	18.83
	STANDARD DEV	96.56	6.69	0.84	0.175	2.31
	NOTES					
P00 - LIBRARY	**AVERAGE**	628.27	46.54	1.29	0.13	17.34
	STANDARD DEV	122.09	6.31	6.12	0.37	1.2
	NOTES					
P1 - MARY	**AVERAGE**	511.75	48.83	4.81	0.65	18.25
	STANDARD DEV	83.72	4.88	9.98	0.47	0.91
	NOTES					
P2 - MAGESTIC	**AVERAGE**	602.03	48.81	2.22	0.6	18.15
	STANDARD DEV	86.43	5.81	1.67	0.44	0.79
	NOTES					
P3 - JD	**AVERAGE**	562.8	45.66	1.59	1.11	20.51
	STANDARD DEV	84.69	2.13	1.06	0.26	0.62
	NOTES: graphs are on overall data, 3/12 and 3/14					
P4 - DRAGONFLY	**AVERAGE**	588.74	38.11	4.49	0.58	21.4
	STANDARD DEV	56.77	2.15	17.86	0.47	1.28
	NOTES					
P5 - LEMON	**AVERAGE**	512.19	39.59	0.39	0.48	21.04
	STANDARD DEV	40.79	4.33	1.88	0.36	1.25
	NOTES					

P6 - CHARLES	**AVERAGE**	294.57	38.73	3.94	0.42	20.35
	STANDARD DEV	85.47	4.73	13.07	0.4	1.06
	NOTES					
P7 - TEXAS	**AVERAGE**	547.88	43.88	0.76	0.5	19.88
	STANDARD DEV	68.11	5.48	0.92	0.47	0.71
	NOTES					
P9 - ANGELS	**AVERAGE**	813.68	44.48	1.59	0.36	20.49
	STANDARD DEV	124.35	2.96	3.82	0.31	0.64
	NOTES					
P10 - KENNEDY	**AVERAGE**	874.78	47.96	14.19	0.48	18.88
	STANDARD DEV	202.91	4.96	27.38	0.38	0.84
	NOTES					
P11 - ICE	**AVERAGE**	573.65	39.76	2.23	0.65	20.07
	STANDARD DEV	54.34	7.87	8.16	0.43	1.27
	NOTES - Humidity never fixes itself fluxuates between 42-28					
STANDARDS		600ppm	30%-60%	50	1	Cooling Season - 73 Heating Season 68
		ashrae	ashrae	broan	broan	ashrae

Table 9.4: Overall Averages of Data & Standard Deviations

Caption: This table shows the overall data that was synthesized in the analysis. The highlighted cells represent numbers that are one standard deviation above or below the average for that participant and that standard of measurement.

Coding Table

Color	Parent code	Code	Cod. seg. (all documents)	Cod. seg. (activ.documents)
●	OCCUPANT BEHAVIOR ON VENTILATION STRATEGIES	HEALTH CONSCIOUS	10	0
●	OCCUPANT BEHAVIOR ON VENTILATION STRATEGIES	TRUST IN TECHNOLOGY	4	0
●	VENTILATION AND AIR QUALITY INFLUENCE	SEASONAL CONCERNS	7	0
●	CONTINUING EDUCATION	POSITIVE EXPERIENCE WITH STUDY	8	0
●	OCCUPANT BEHAVIOR ON VENTILATION STRATEGIES	TRUST	1	0
●	SENSOR MONITORING INFLUENCE ON AUTONOMY	BEHAVIOR ADAPTATION	4	0
●	FURTHER HEALTH CONCERNS	COUGHING FITS	1	0
●	HEALTH	COPD	4	0

●	CONTINUING EDUCATION	NEUTRAL EXPERIENCE	8	0
●	FURTHER HEALTH CONCERNS	COPD	2	0
●	SENSOR MONITORING INFLUENCE ON AUTONOMY	LACK OF CONTROL	34	0
●	HEALTH	ASTHMA	5	0
●	VENTILATION AND AIR QUALITY INFLUENCE	CHEMICAL SENSITIVITY	1	0
●	VENTILATION AND AIR QUALITY INFLUENCE	WINDOW USE	19	0
●		EDUCATIONAL INTERVENTION	6	0
●	BEHAVIOR ADAPTATION	PROVIDED COMFORT	14	0
●	OCCUPANT BEHAVIOR ON VENTILATION STRATEGIES	DISTRUST IN TECHNOLOGY	19	0
●	LONG TERM MONITORING	MONITORING OF AIR PARTICULATES	1	0

●	VENTILATION AND AIR QUALITY INFLUENCE	PERCIEVED AIR QUALITY	15	0
●	EDUCATIONAL INTERVENTION	TRANSPARENCY	14	0
●	OCCUPANT BEHAVIOR ON VENTILATION STRATEGIES	NOISE	6	0
●	OCCUPANT BEHAVIOR ON VENTILATION STRATEGIES	ADDITIONAL VENTILATION / AIR STRATEGIES	13	0
●	OCCUPANT BEHAVIOR ON VENTILATION STRATEGIES	BEHAVIOR MODIFICATIONS	2	0
●	HOUSING AND POLICY	CONTINUING EDUCATION	15	0
●	SENSOR MONITORING INFLUENCE ON AUTONOMY	POST OCCUPANCY MONITORING	3	0
●	SENSOR MONITORING INFLUENCE ON AUTONOMY	FURTHER HEALTH CONCERNS	3	0
●	VENTILATION AND AIR QUALITY INFLUENCE	AIR POLLUTANT SENSITIVITY	9	0

●	SENSOR MONITORING INFLUENCE ON AUTONOMY	LACK OF EDUCATION	14	0
●	OCCUPANT BEHAVIOR ON VENTILATION STRATEGIES	ODER	18	0
●	BEHAVIOR ADAPTATION	NO PERCIEVED CHANGES	5	0
●	SENSOR MONITORING INFLUENCE ON AUTONOMY	INDIVIDUAL MANAGEMENT	14	0
●	VENTILATION AND AIR QUALITY INFLUENCE	PERCIEVED INSIDE VS OUTSIDE AIR	2	0
●		OCCUPANT BEHAVIOR ON VENTILATION STRATEGIES	1	0
●	HEALTH	SEASONAL ALLERGIES	1	0
●	OCCUPANT BEHAVIOR ON VENTILATION STRATEGIES	COMFORT	8	0
●	HEALTH	HEALTH CONCENS	29	0

•	VENTILATION AND AIR QUALITY INFLUENCE	COLD / DRY	3	0
•	SENSOR MONITORING INFLUENCE ON AUTONOMY	SENSOR OBTRUSIVNESS	5	0
•		ERV MANAGEMENT ISSUES	15	0
•	VENTILATION AND AIR QUALITY INFLUENCE	SMOKE SENSITIVITY	7	0
•	PASSIVE PRINCIPLES	NIGH PASSIVE STRATEGIES	6	0
•	VENTILATION AND AIR QUALITY INFLUENCE	AIR DEBRIS	19	0
•	VENTILATION AND AIR QUALITY INFLUENCE	STUFFY / STALE / HOT	8	0
•	OCCUPANT BEHAVIOR ON VENTILATION STRATEGIES	VENTILATION MANGEMENT	17	0
•	VENTILATION AND AIR QUALITY INFLUENCE	HEALTH ISSUES	5	0

●	SENSOR MONITORING INFLUENCE ON AUTONOMY	PERCIEVED CHANGES	19	0
●	HOUSING AND POLICY	LONG TERM MONITORING	8	0
●	VENTILATION AND AIR QUALITY INFLUENCE	FEAR	15	0
●	PASSIVE PRINCIPLES	FAN USE	1	0
●	OCCUPANT BEHAVIOR ON VENTILATION STRATEGIES	LOVE LIVING IN THIS APARTMENT	2	0
●	SENSOR MONITORING INFLUENCE ON AUTONOMY	INCREASED AWARENESS	25	0

Table 9.5: Coding Table

Caption: This table is a generative table from the coding platform MAXQDA that show all of the times that codes and subcodes appeared throughout the interviews.

Appendix C: Participant Overall Quantitative Data

Participant Overall Quantitative Graphs

Mary

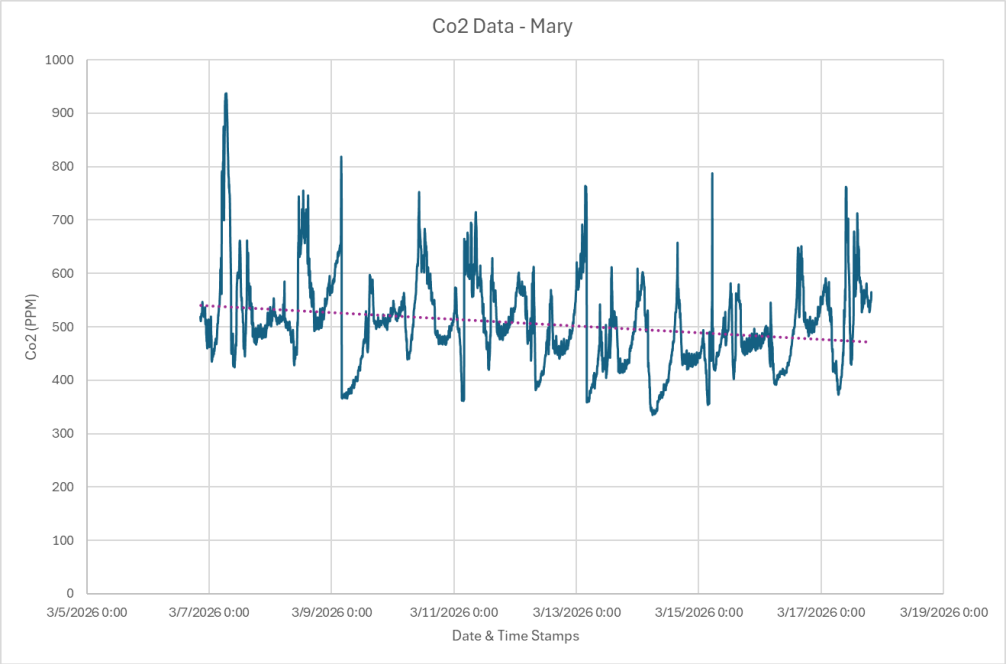


Figure 9.1: Mary's Overall CO_2 Data

Caption: This table shows Mary's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that her CO_2 decreased over the course of the study as well as the variation of the peaks within the data.

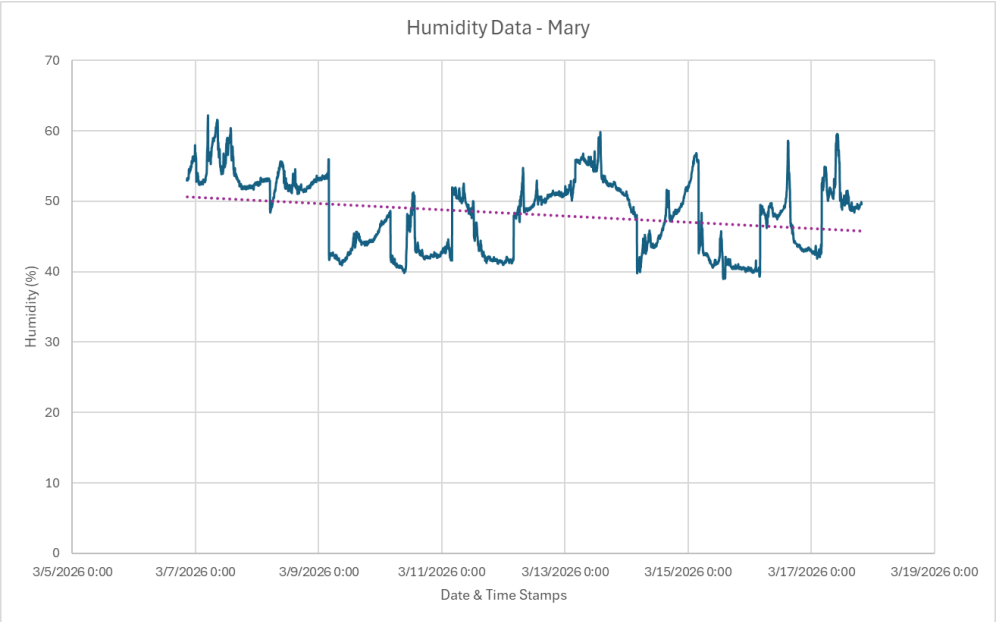


Figure 9.2: Mary's Overall Humidity Data

Caption: This table shows Mary's overall data over the course of the study. The dark blue line represents the measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that her humidity decreased over the course of the study.

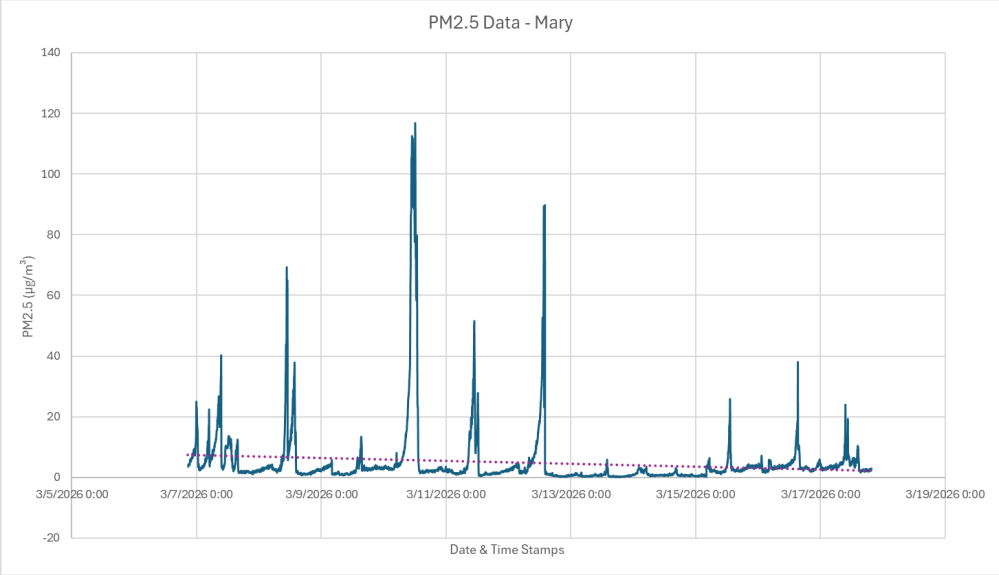


Figure 9.3: Mary's Overall $PM_{2.5}$ Data

Caption: This table shows Mary's overall data over the course of the study. The dark blue line represents the measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that her $PM_{2.5}$ decreased over the course of the study as well as the height of the peaks.

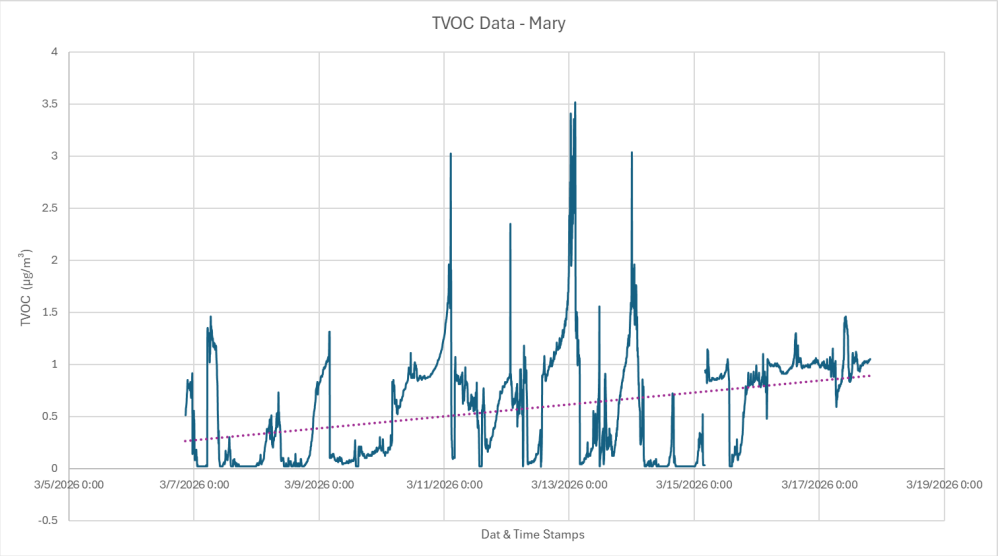


Figure 9.4: Mary's Overall TVOC Data

Caption: This table shows Mary's overall data over the course of the study. The dark blue line represents the measurements throughout the study and the pink link represents the trendline throughout the study.

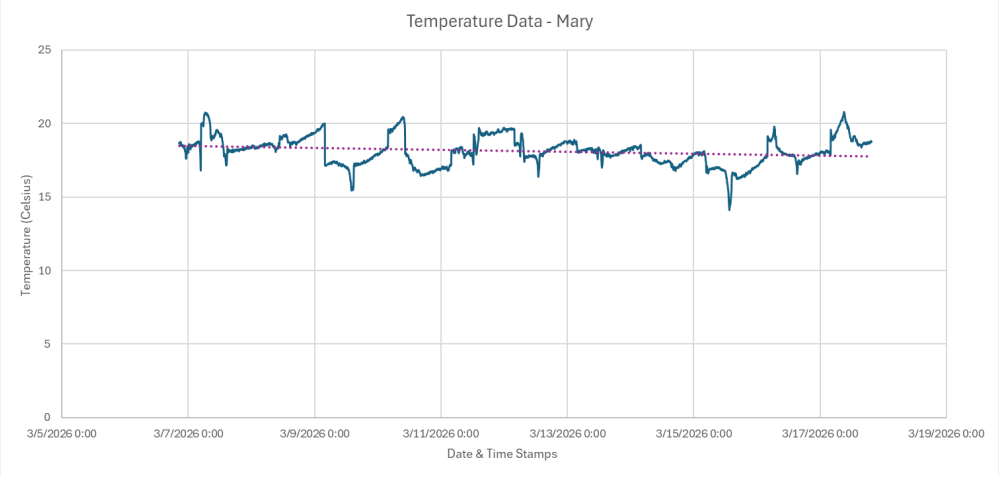


Figure 9.5: Mary's Overall Temperature Data

Caption: This table shows Mary's overall data over the course of the study. The dark blue line represents the measurements throughout the study and the pink link represents the trendline throughout the study.

Magestic

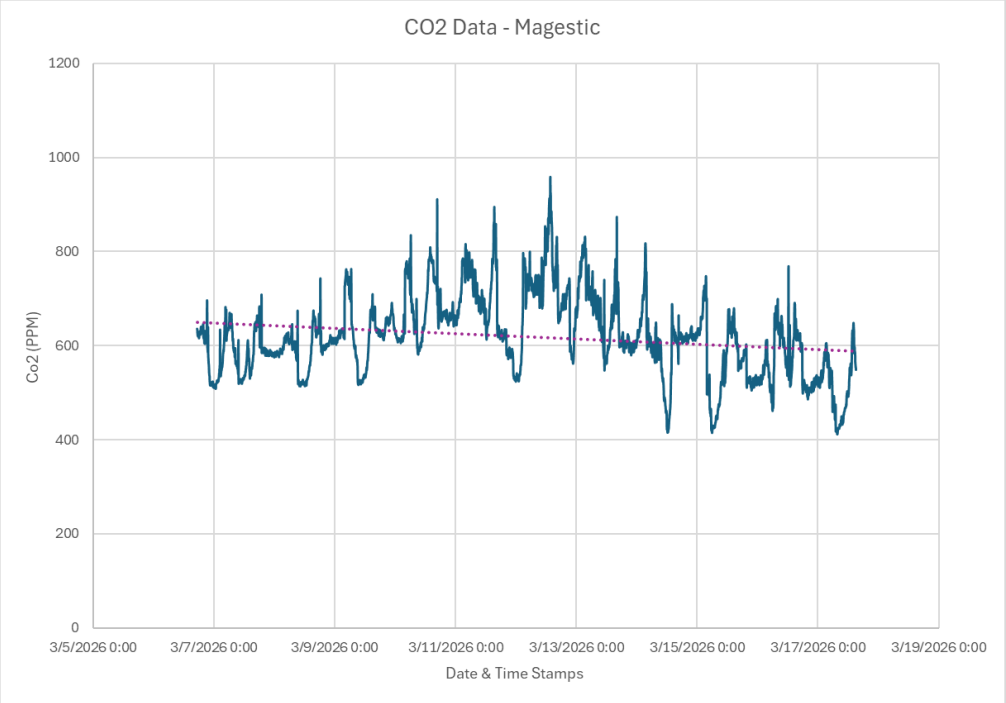


Figure 9.6: Magestic's Overall CO_2 Data

Caption: This table shows Magestic's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their CO_2 decreased over the course of the study as well as the variation of the peaks within the data.

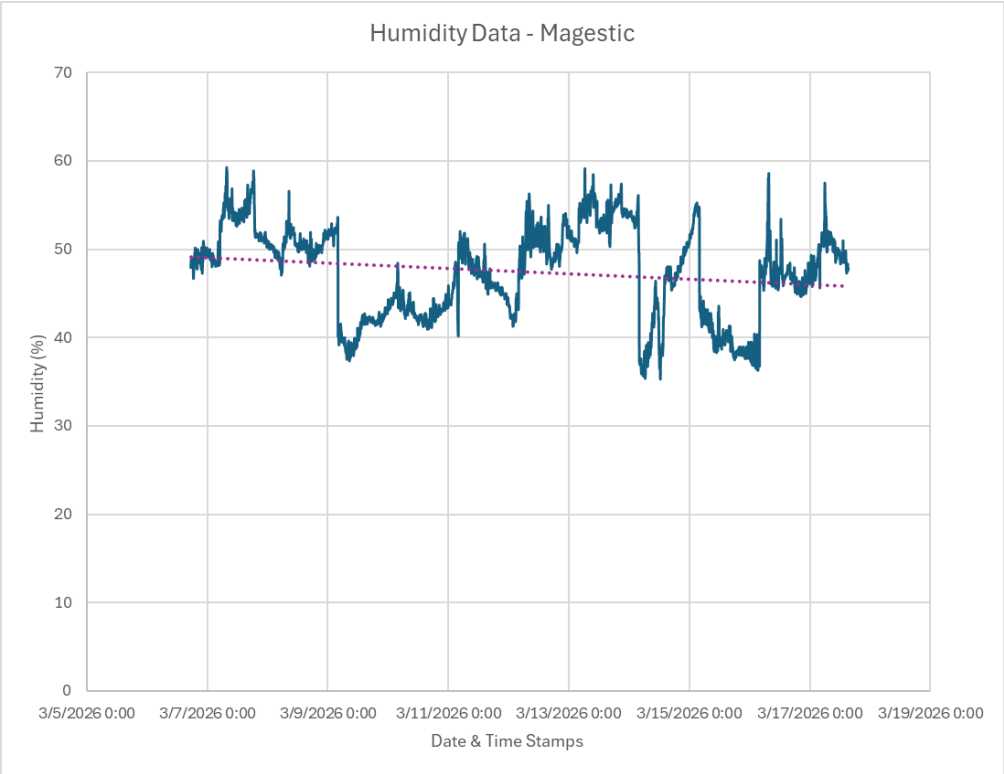


Figure 9.7: Magestic's Overall Humidity Data

Caption: This table shows Magestic's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their humidity had large fluctuations throughout the study but decreased throughout the course of the study overall.

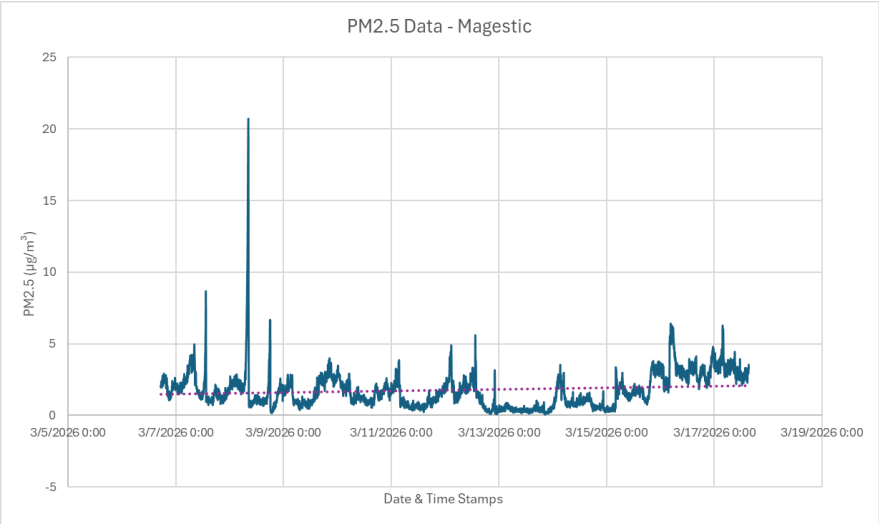


Figure 9.8: Magestic's Overall $PM_{2.5}$ Data

Caption: This table shows Magestic's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their $PM_{2.5}$ decreased over the course of the study as well as the variation of the peaks within the data.

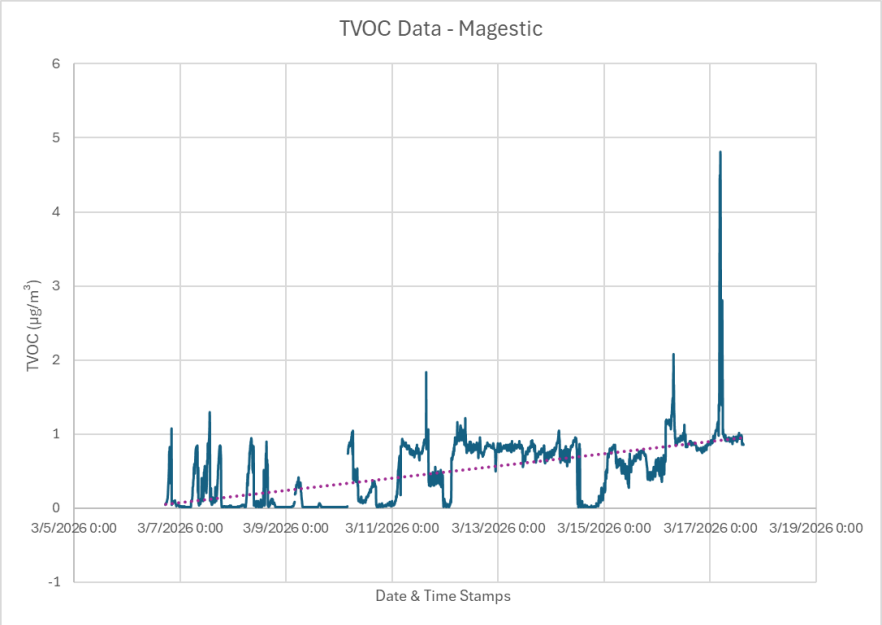


Figure 9.9: Magestic's Overall TVOC Data

Caption: This table shows Magestic's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their TVOC increased throughout the course of the study, with a large spike at the end.

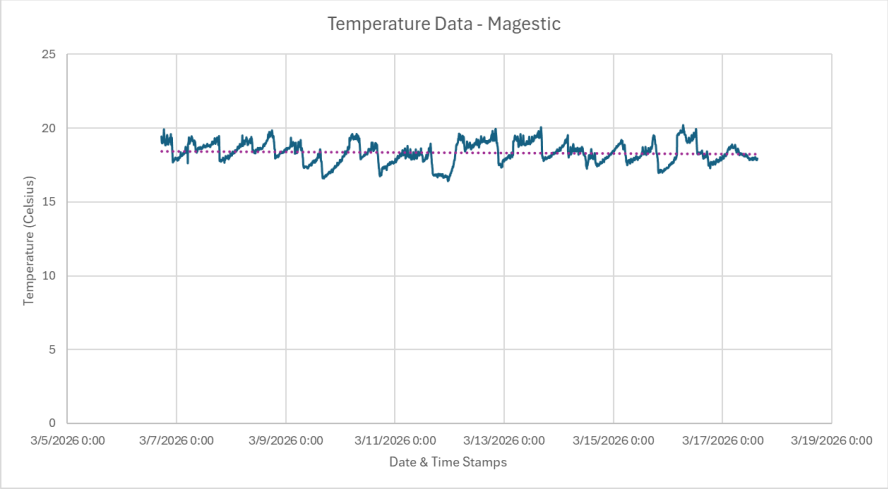


Figure 9.10: Magestic's Overall Temperature Data

Caption: This table shows Magestic's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their temperature fluctuated consistently throughout the course of the study.

JD

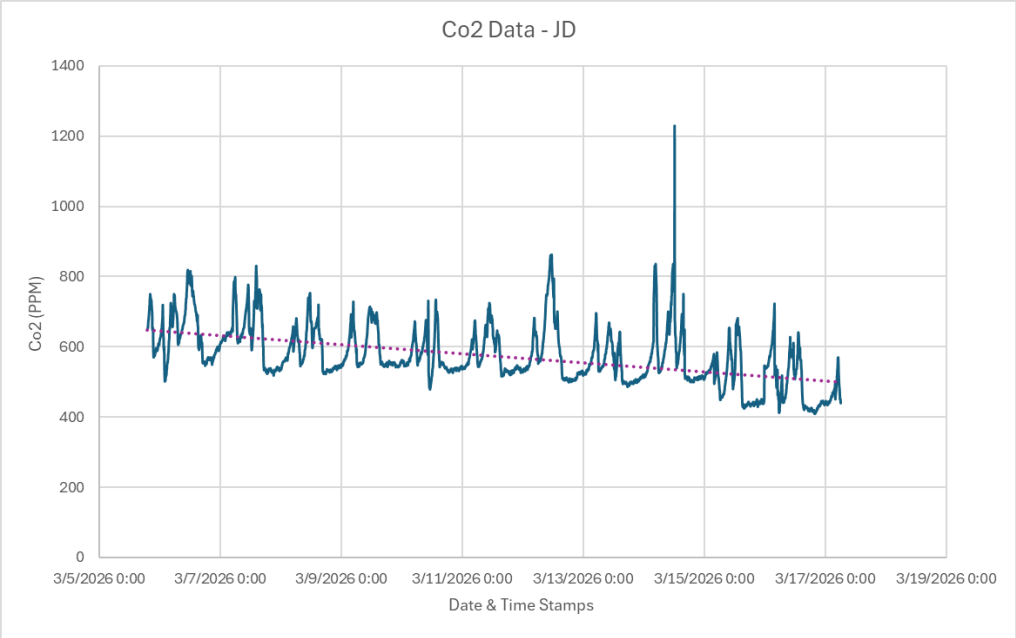


Figure 9.11: JD's Overall CO_2 Data

Caption: This table shows JD's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their CO_2 decreased throughout the course of the study, but there was still a relatively high peak towards the beginning of the interventional phase.

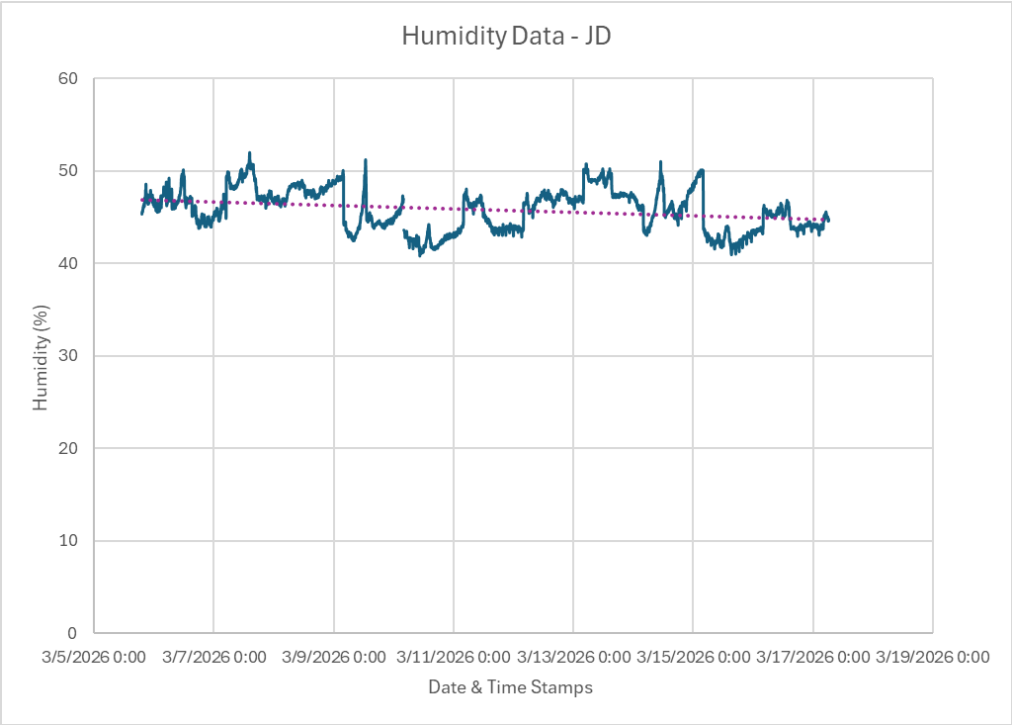


Figure 9.12: JD's Overall Humidity Data

Caption: This table shows JD's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their humidity slightly decrease throughout the course of the study, but had consistent peaks as well.

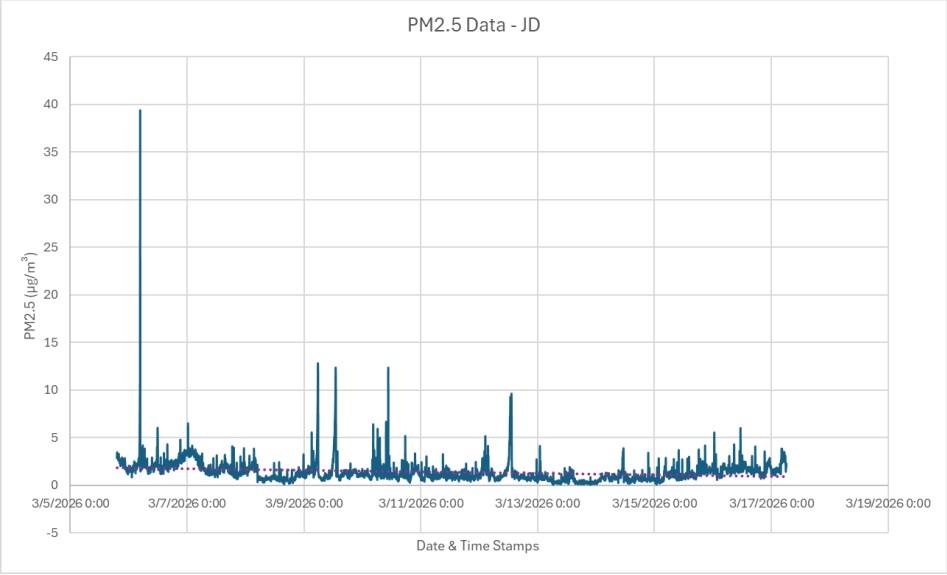


Figure 9.13: JD's Overall $PM_{2.5}$ Data

Caption: This table shows JD's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their $PM_{2.5}$ decreased throughout the course of the study, but there was still a relatively high peak towards the beginning of the baseline phase.

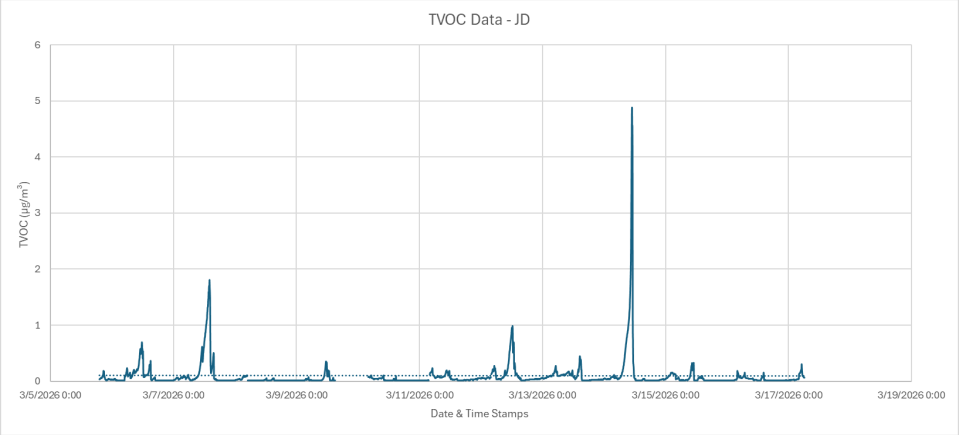


Figure 9.14: JD's Overall TVOC Data

Caption: This table shows JD's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their TVOC peaked consistently throughout the course of the study with one large spike at the beginning of the interventional phase.

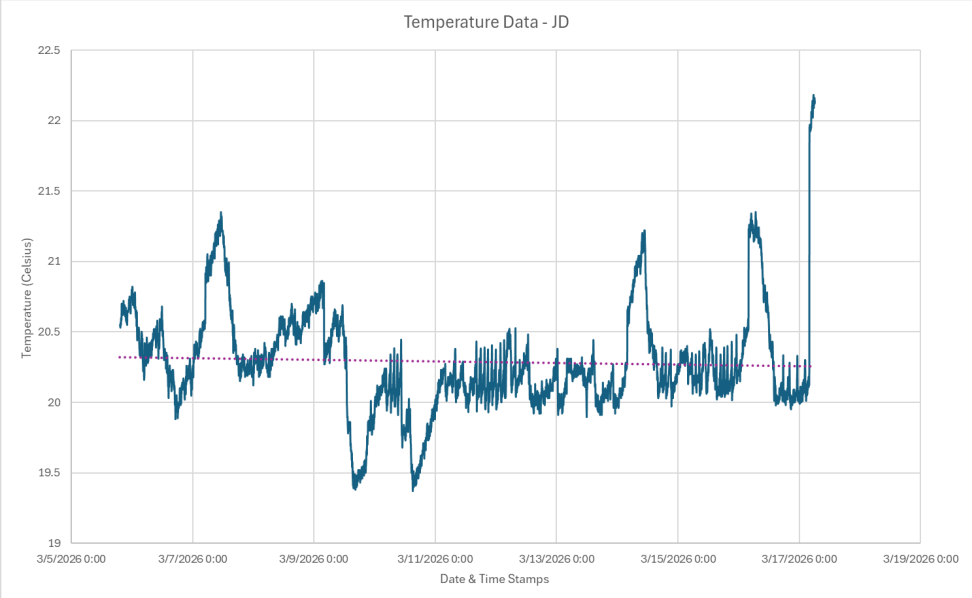


Figure 9.15: JD's Overall Temperature Data

Caption: This table shows JD's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their temperature was very inconsistent throughout the study which could be attributed to the need for storing oxygen tanks in their apartment.

Dragonfly

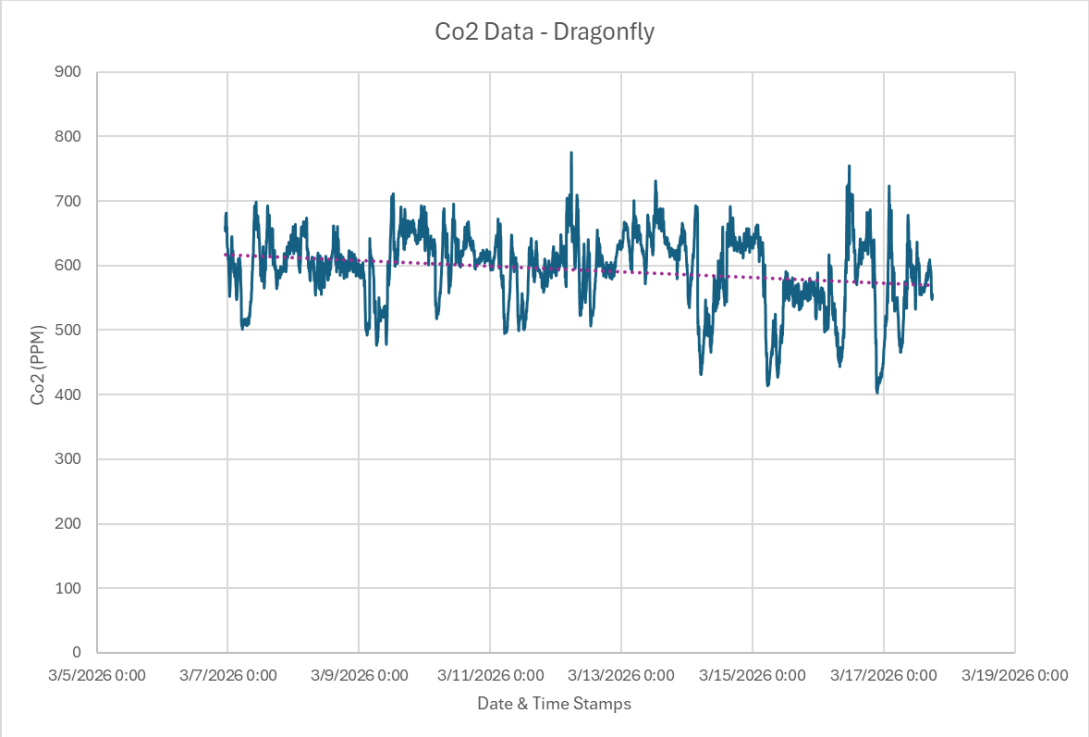


Figure 9.16: Dragonfly's Overall CO_2 Data

Caption: This table shows Dragonfly's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their CO_2 decreased throughout the course of the study, but there were consistent peaks throughout the study.

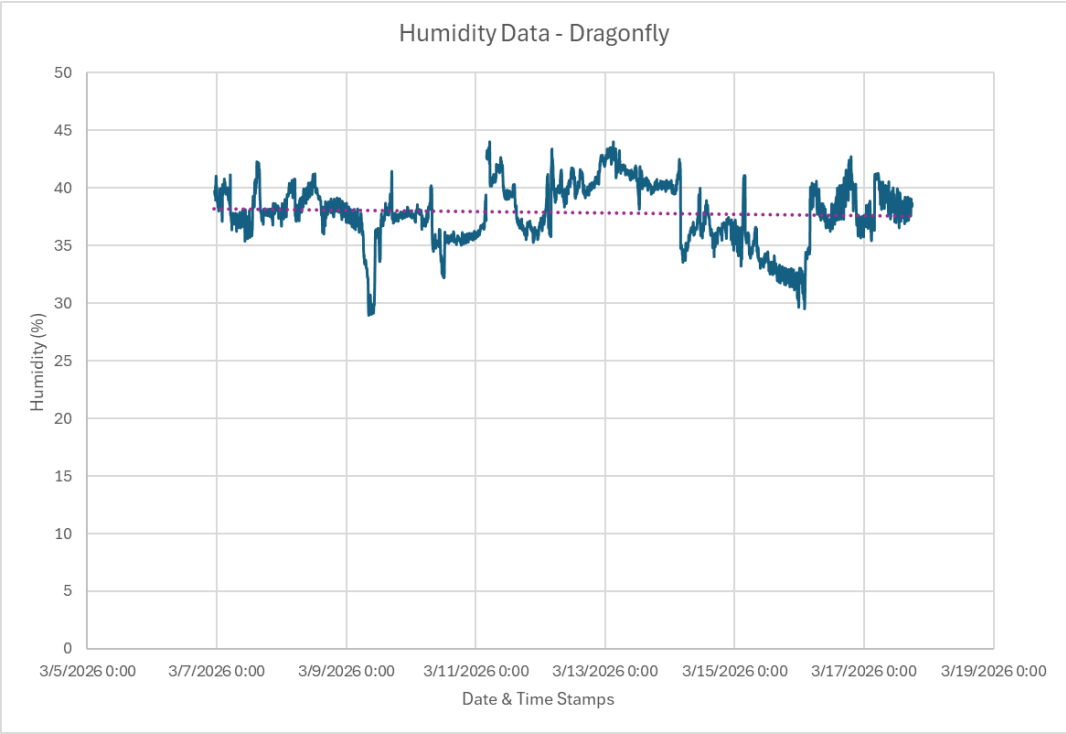


Figure 9.17: Dragonfly's Overall Humidity Data

Caption: This table shows Dragonfly's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their humidity stayed consistent throughout the study with two major dips during the baseline and interventional phase.

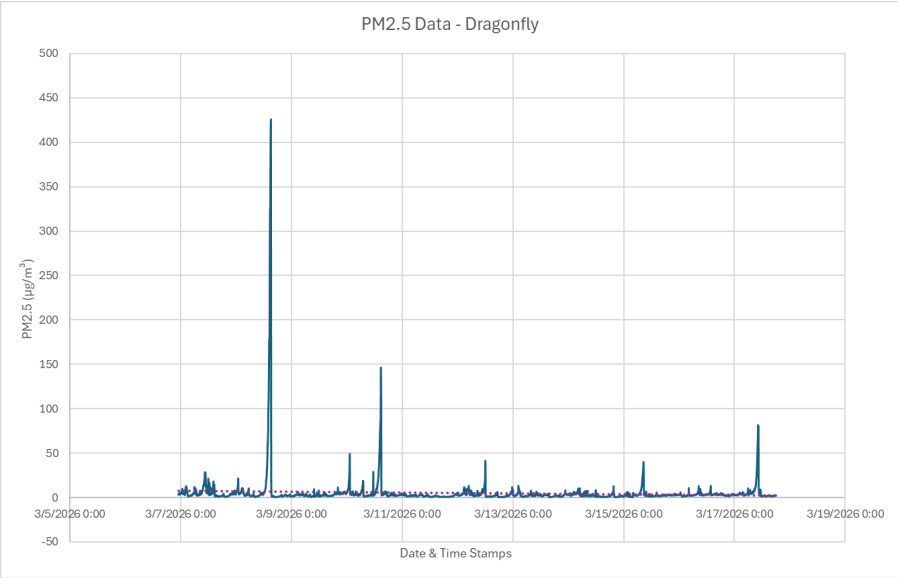


Figure 9.18: Dragonfly's Overall $PM_{2.5}$ Data

Caption: This table shows Dragonfly's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their $PM_{2.5}$ decreased throughout the course of the study, but there were consistent peaks throughout the study. However, one can see the spikes decreasing in intensity and longevity.

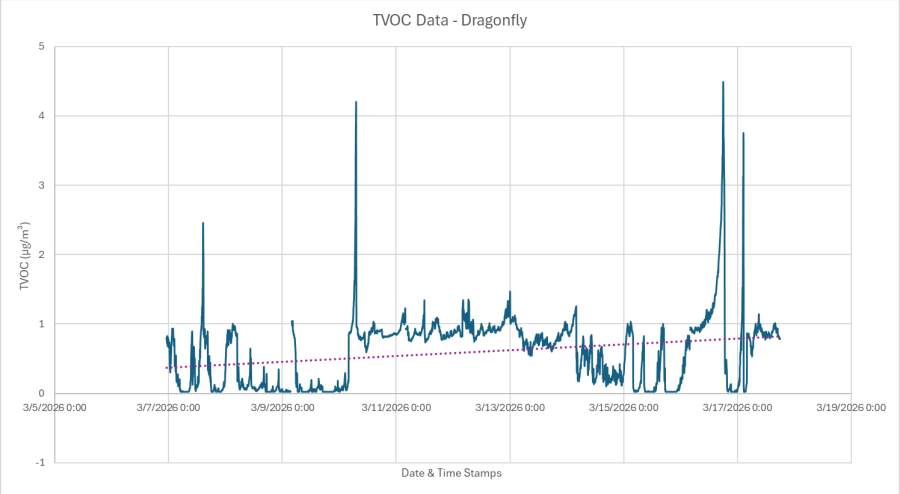


Figure 9.19: Dragonfly's Overall TVOC Data

Caption: This table shows Dragonfly's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their TVOC increas4ed throughout the study with two major spikes at the end of the baseline base and in the middle of the interventional phase.

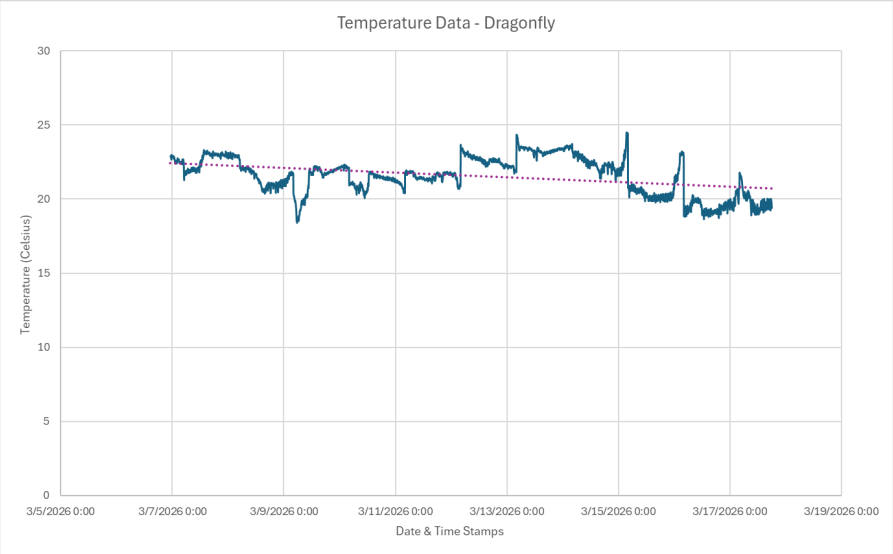


Figure 9.20: Dragonfly's Overall Temperature Data

Caption: This table shows Dragonfly's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their temperature fluctuated consistently.

Lemon

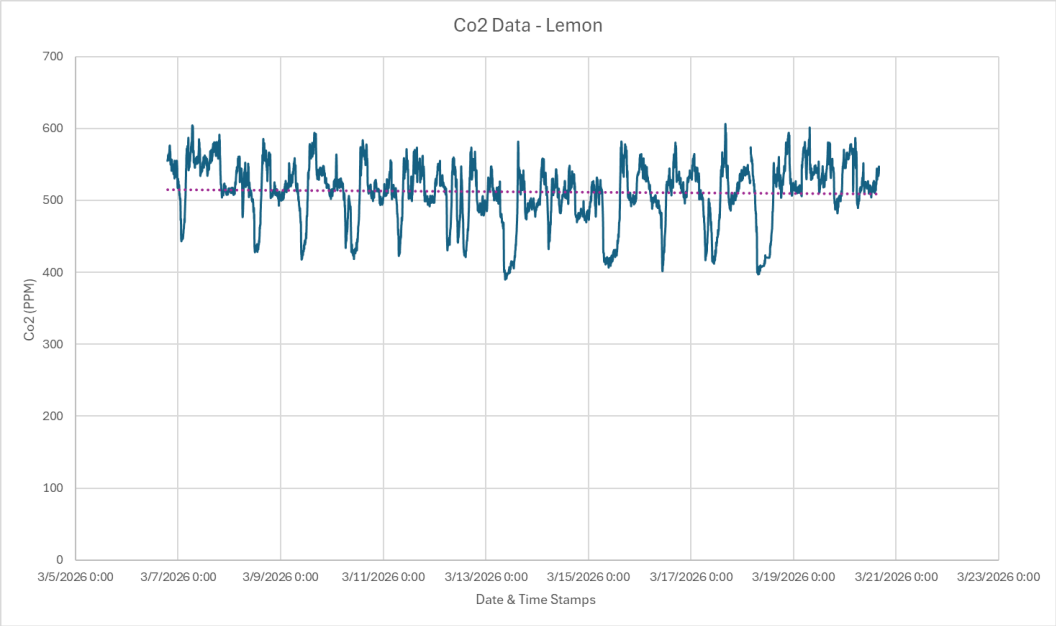


Figure 9.21: Lemon's Overall CO_2 Data

Caption: This table shows Lemon's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their CO_2 being consistent across the course of the study.

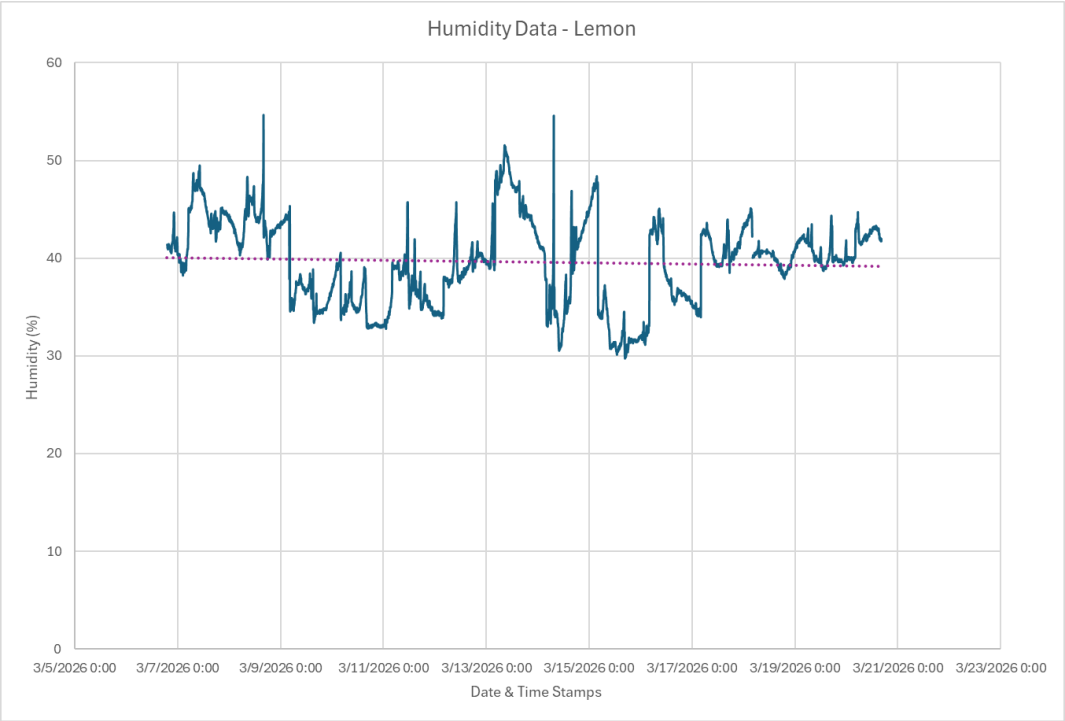


Figure 9.22: Lemon's Overall Humidity Data

Caption: This table shows Lemon's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their humidity decreasing slightly across the course of the study.

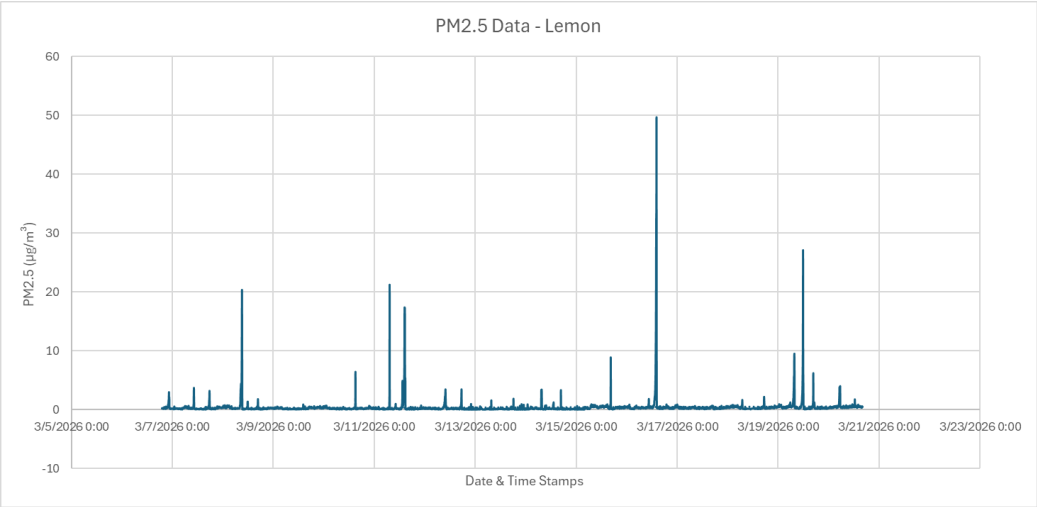


Figure 9.23: Lemon's Overall $PM_{2.5}$ Data

Caption: This table shows Lemon's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their $PM_{2.5}$ being consistent across the course of the study, with small occasional spikes besides on March 17th.

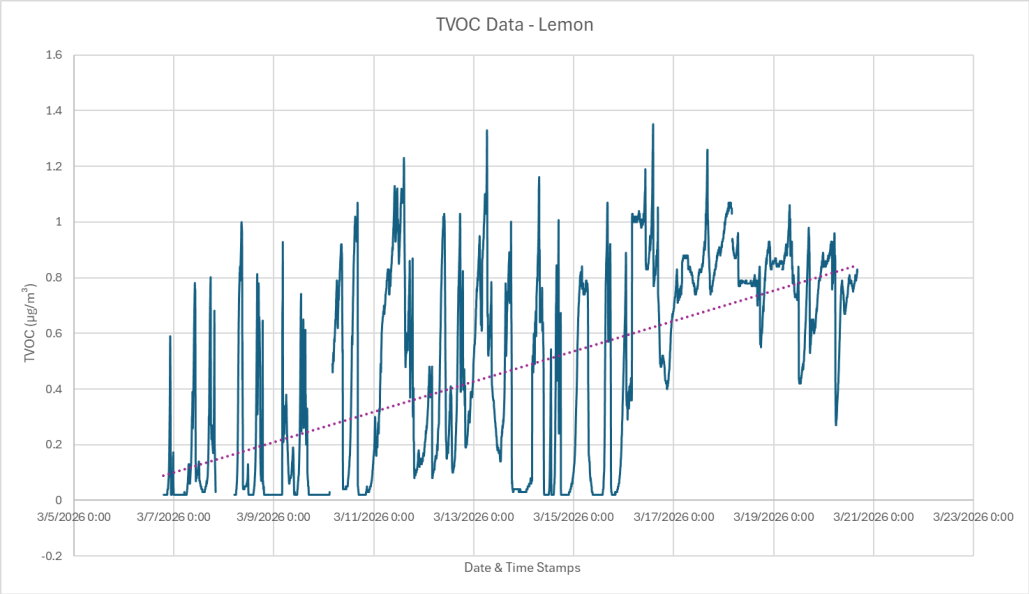


Figure 9.24: Lemon's Overall TVOC Data

Caption: This table shows Lemon's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their TVOC increasing exponentially during the course of the study.

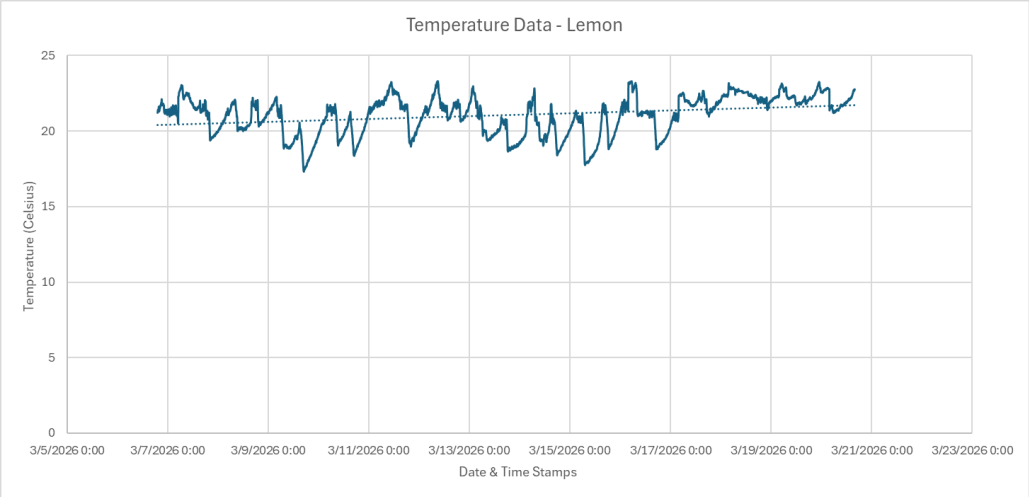


Figure 9.25: Lemon's Overall Temperature Data

Caption: This table shows Lemon's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their temperature staying consistent across the course of the study.

Charles

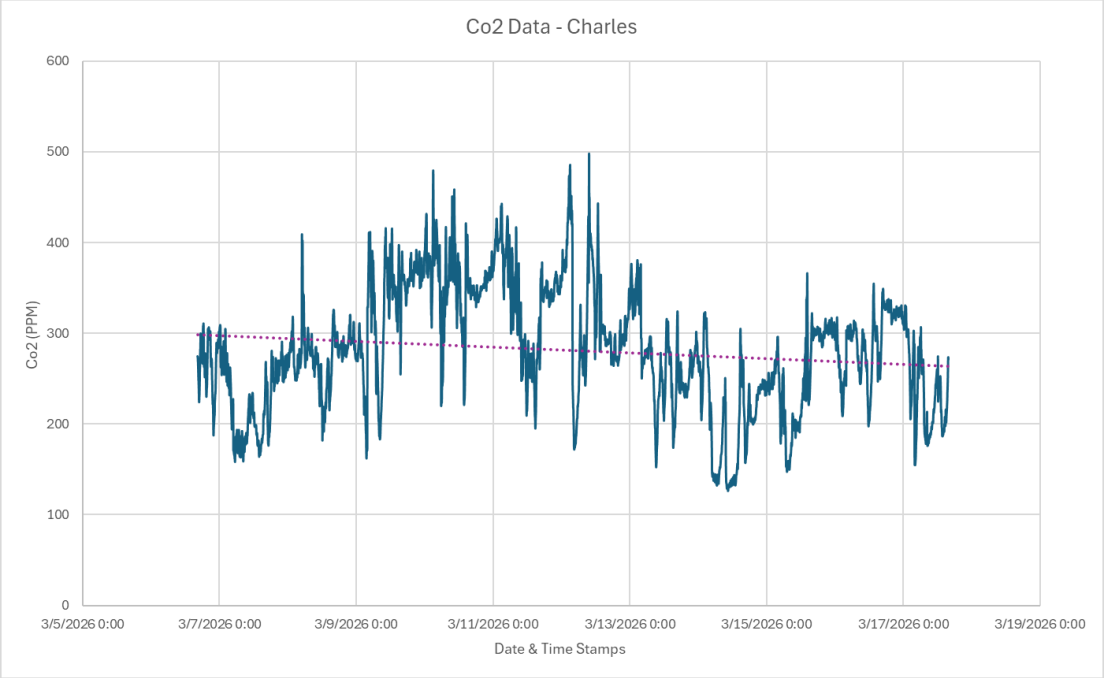


Figure 9.26: Charles' Overall CO_2 Data

Caption: This table shows Charles' overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their CO_2 data declined over the course of a the study with a four day uptick in CO_2 before it steadily decreased during the baseline intervention.

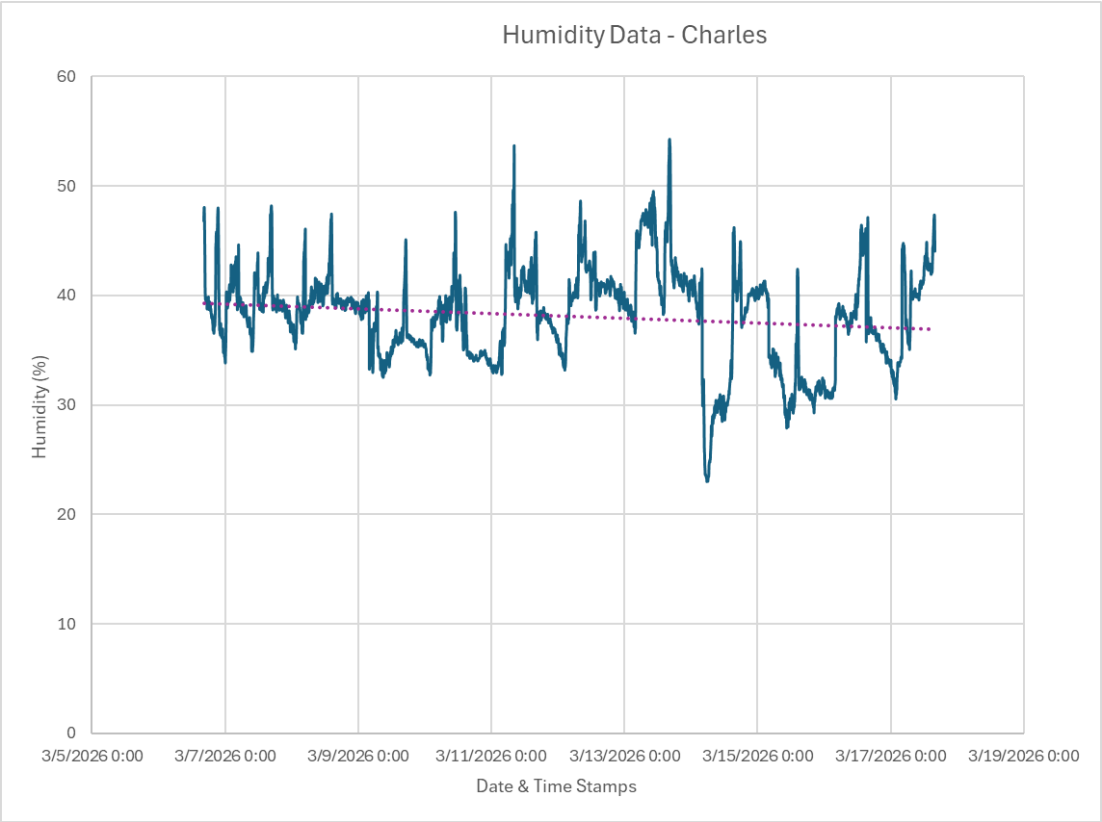


Figure 9.27: Charles' Overall Humidity Data

Caption: This table shows Charles' overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their humidity consistently declined during the course of the study.

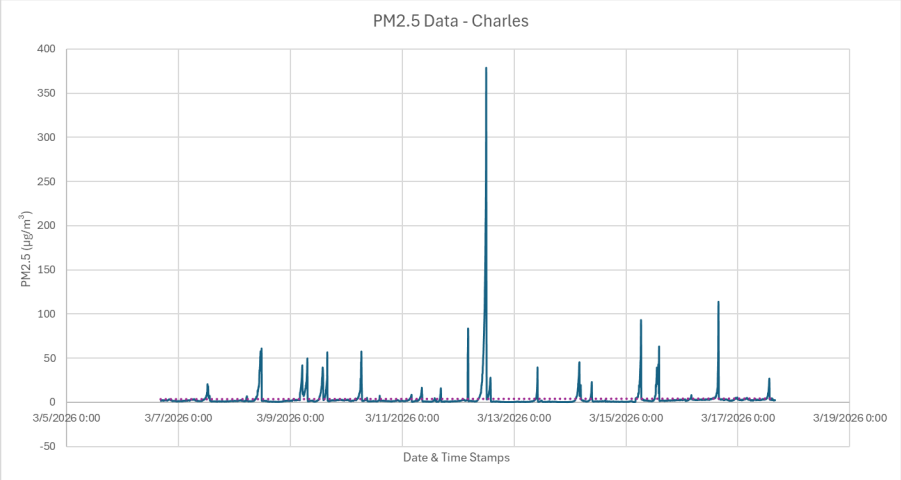


Figure 9.28: Charles's Overall $PM_{2.5}$ Data

Caption: This table shows Charles' overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their $PM_{2.5}$ data stayed about the same across the course of their study with a large spike in $PM_{2.5}$ on March 15th.

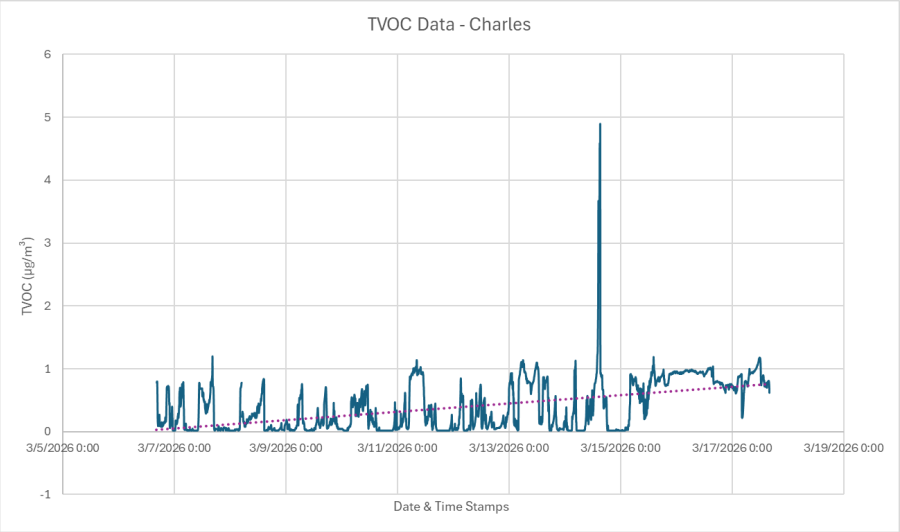


Figure 9.29: Charles's Overall TVOC Data

Caption: This table shows Charles' overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their TVOC steadily increasing along the course of the study, with a drastic spike on March 15th.

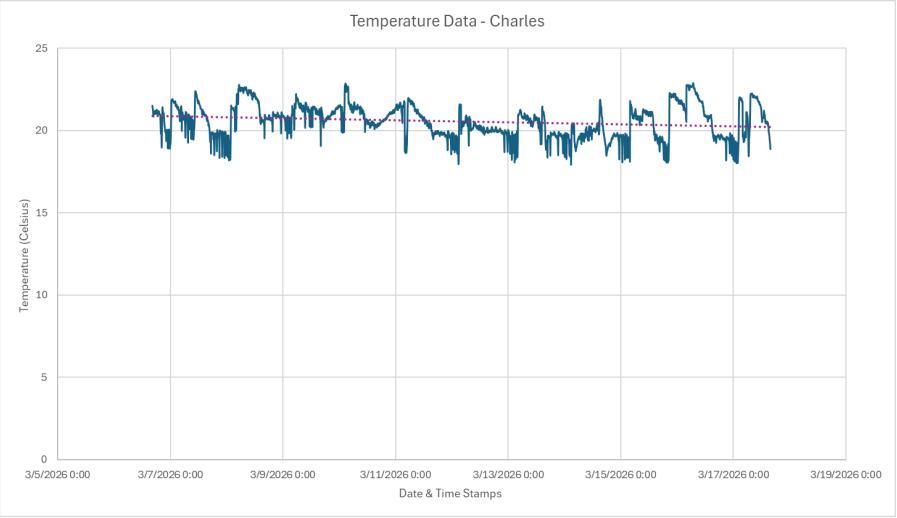


Figure 9.30: Charles's Overall Temperature Data

Caption: This table shows Charles' overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their temperature data being consistent across the course of the study.

Texas

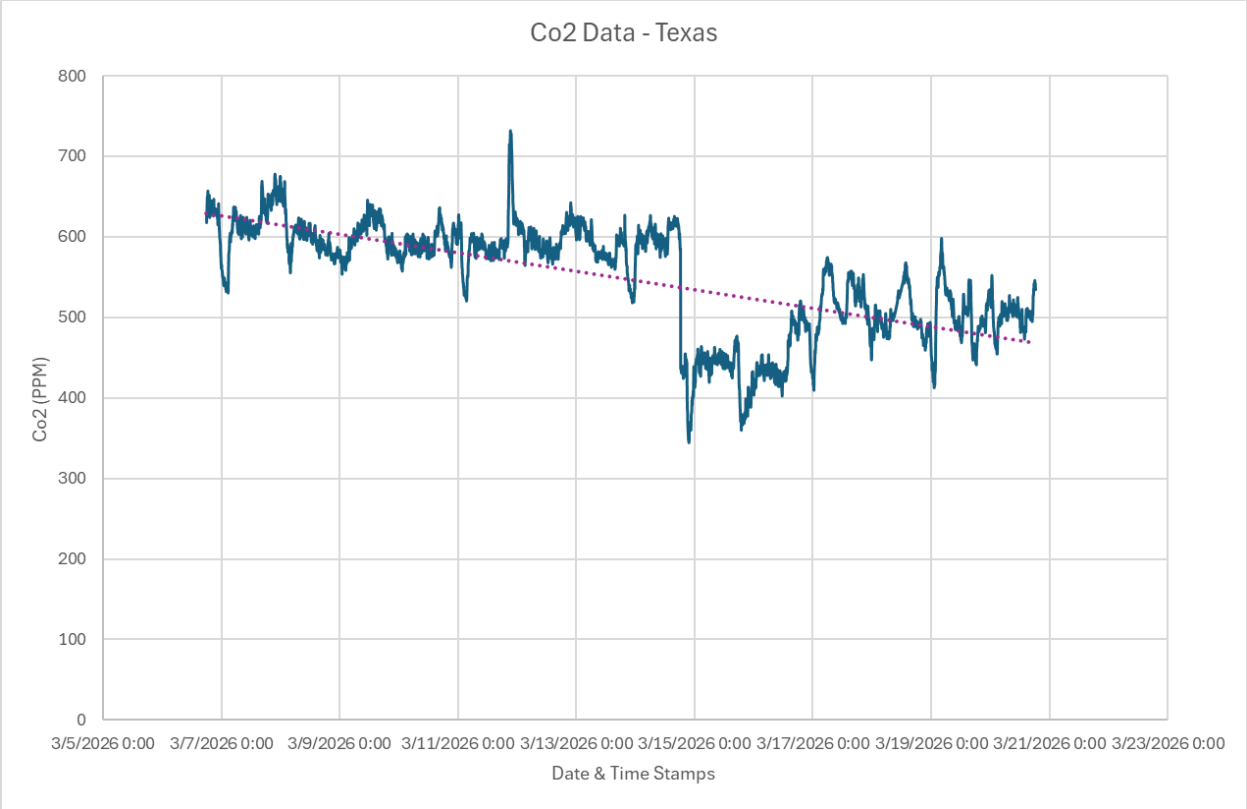


Figure 9.31: Texas's Overall CO_2 Data

Caption: This table shows Texas's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their CO_2 data steadily decreasing throughout the course of their study, with a drastic decline on March 15th.

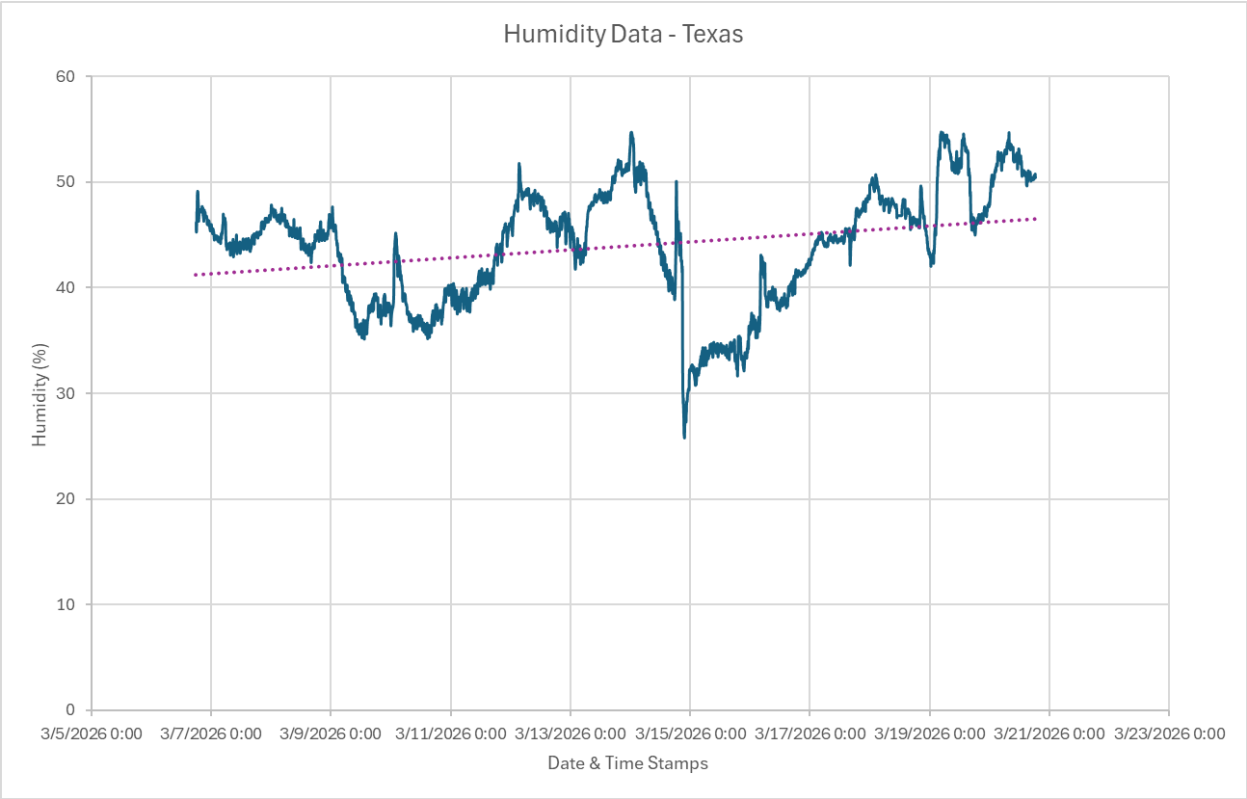


Figure 9.32: Texas's Overall Humidity Data

Caption: This table shows Texas's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their humidity data steadily increasing throughout the course of their study, with a drastic decline on March 15th.

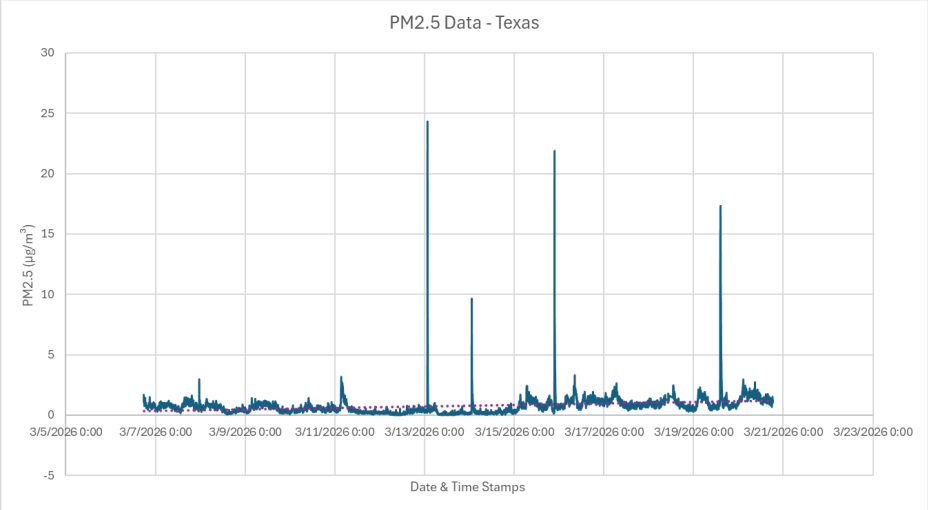


Figure 9.33: Texas's Overall $PM_{2.5}$ Data

Caption: This table shows Texas's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their $PM_{2.5}$ data steadily increasing during the interventional phase with three major spikes.

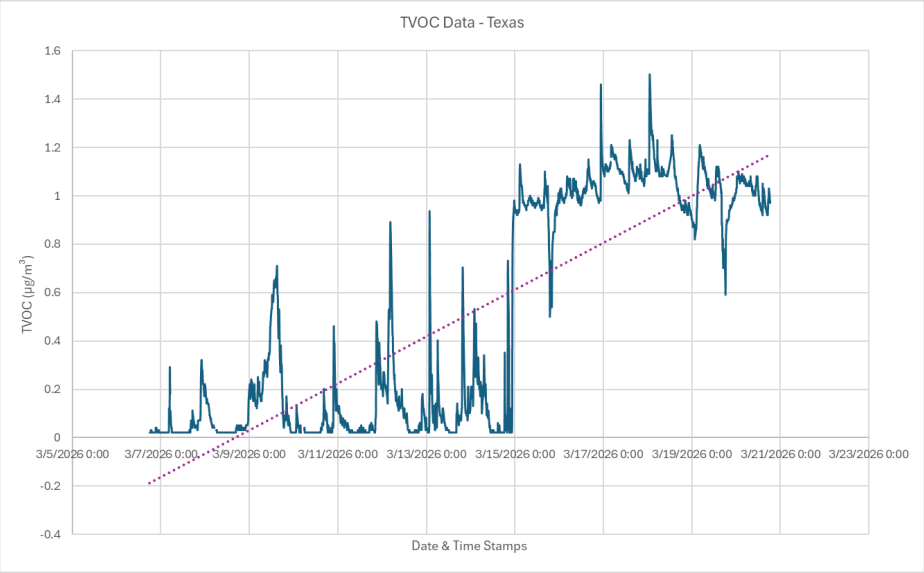


Figure 9.34: Texas's Overall TVOC Data

Caption: This table shows Texas's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their TVOC exponentially increasing throughout the course of the study.

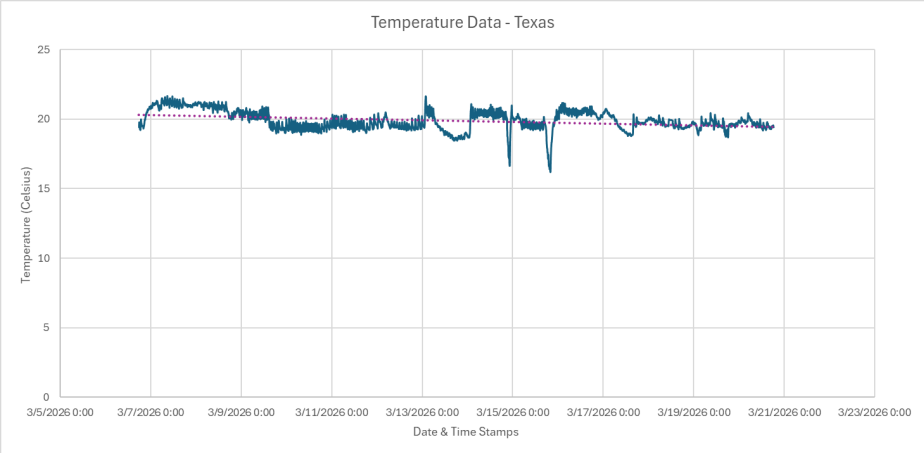


Figure 9.35: Texas's Overall Temperature Data

Caption: This table shows Texas's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their temperature steadily decreasing throughout the course of the study.

Angels

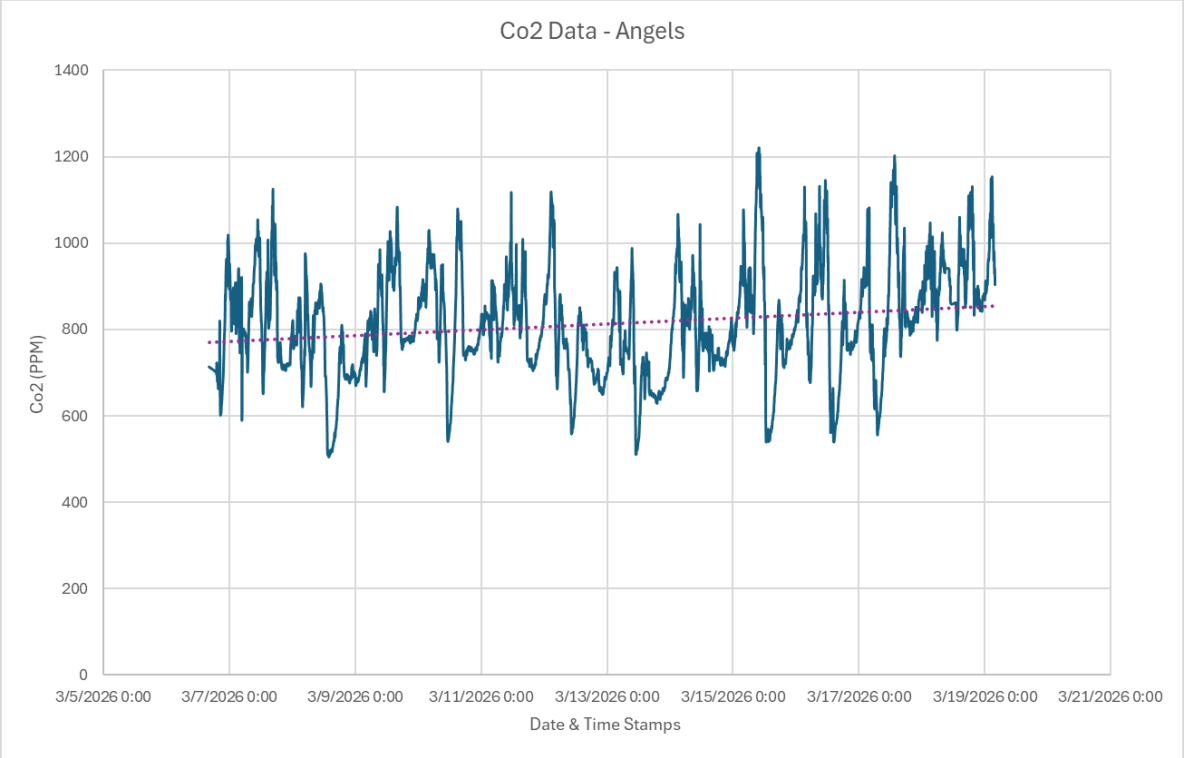


Figure 9.26: Angels Overall CO_2 Data

Caption: This table shows Angel's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their CO_2 data steadily increasing consistently throughout the course of the study.

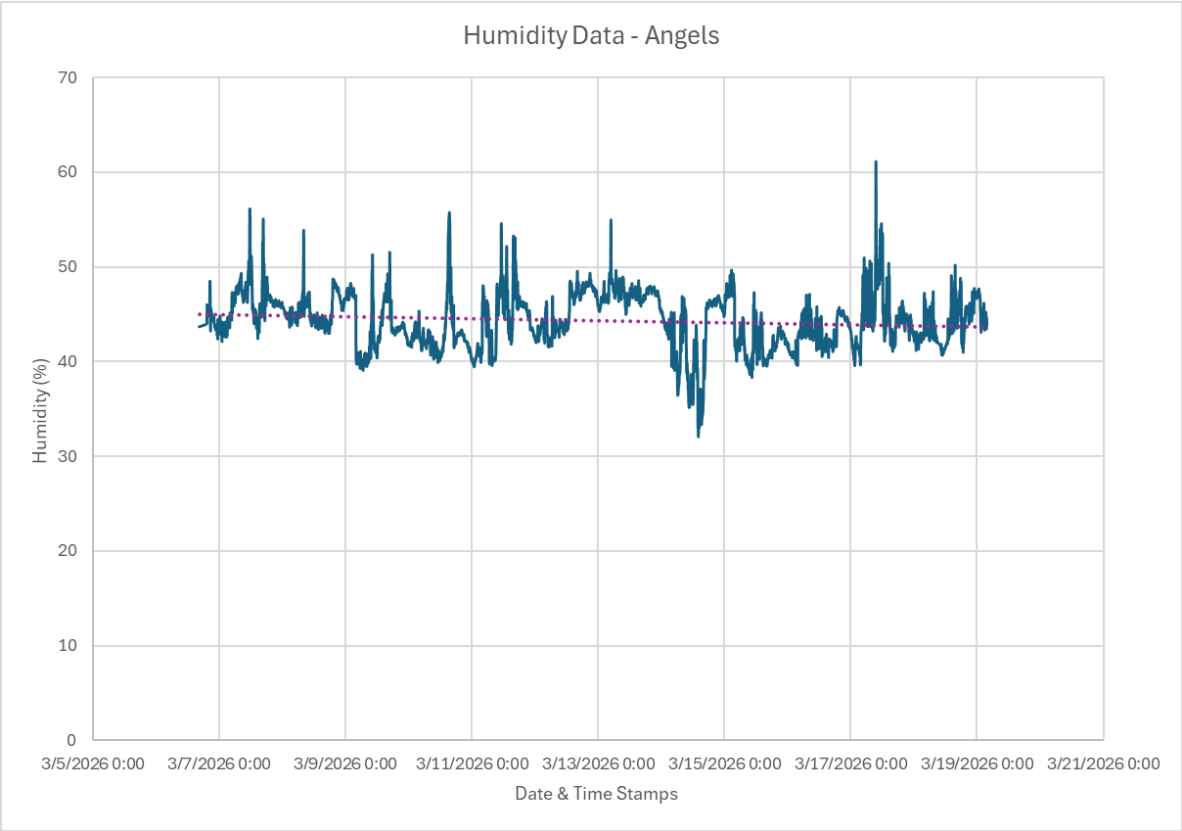


Figure 9.37: Angels Overall Humidity Data

Caption: This table shows Angel's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their humidity slightly and consistently decreasing throughout the course of the study.

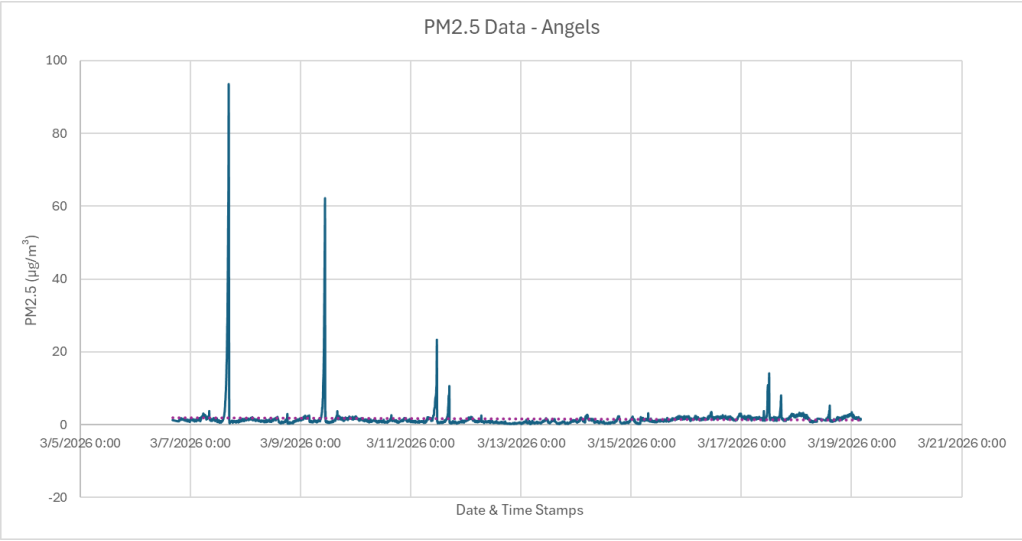


Figure 9.38: Angel's Overall $PM_{2.5}$ Data

Caption: This table shows Angel's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their $PM_{2.5}$ data stays relatively the same with two major spikes at the beginning of the study, but none in the interventional phase.

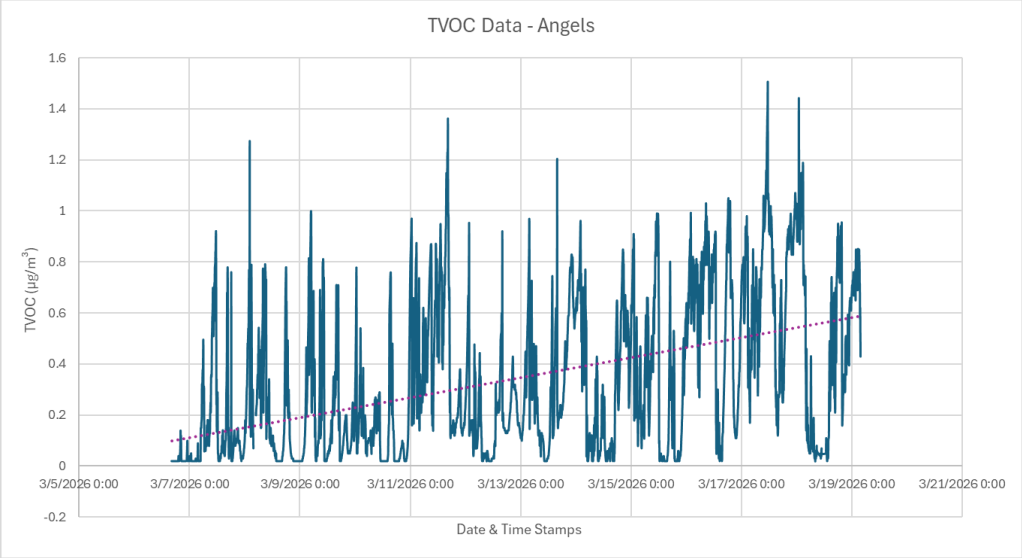


Figure 9.39: Angel's Overall TVOC Data

Caption: This table shows Angel's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their TVOC exponentially increasing throughout the course of the study.

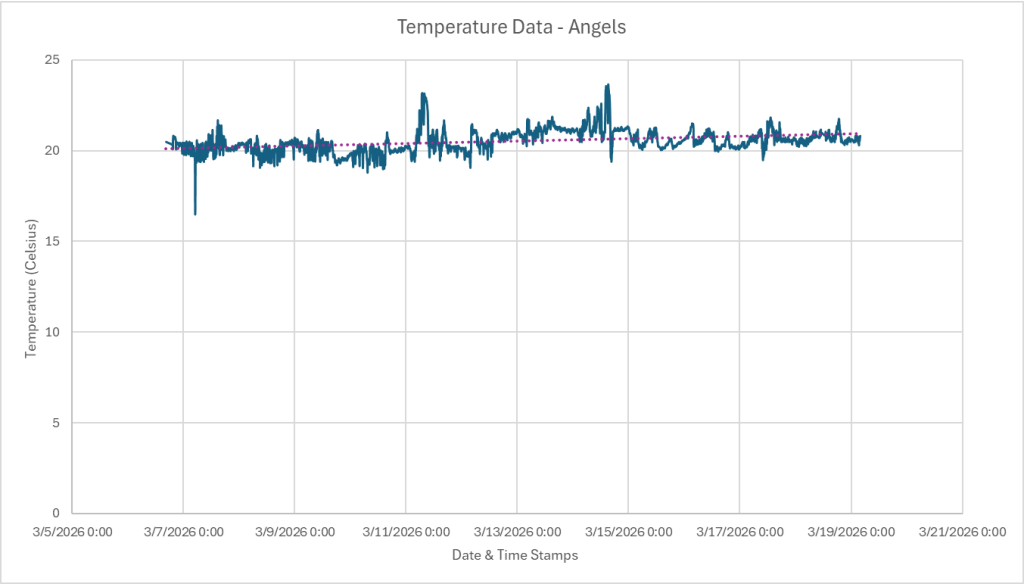


Figure 9.40: Angel's Overall Temperature Data

Caption: This table shows Angel's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their temperature data consistently fluctuating throughout the course of the study.

Kennedy

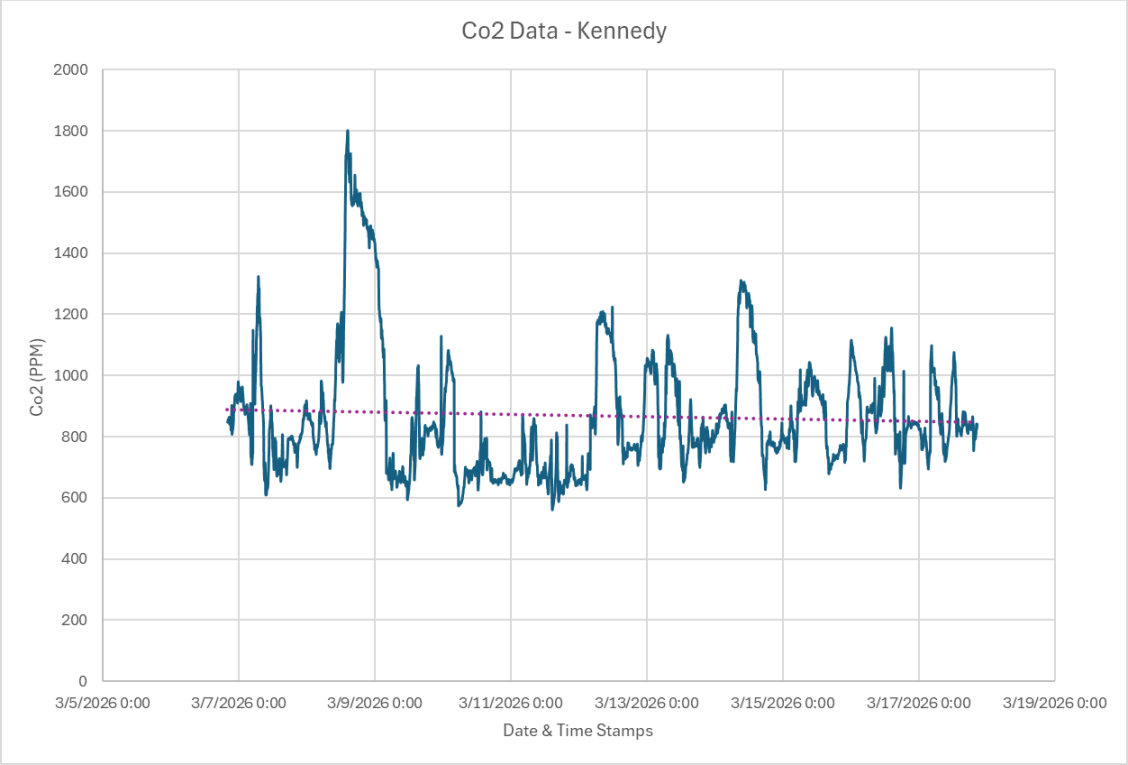


Figure 9.41: Kennedy's Overall CO_2 Data

Caption: This table shows Kennedy's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their CO_2 slowly decreasing throughout the two phases of the study, with the spikes mitigating in the interventional phase.

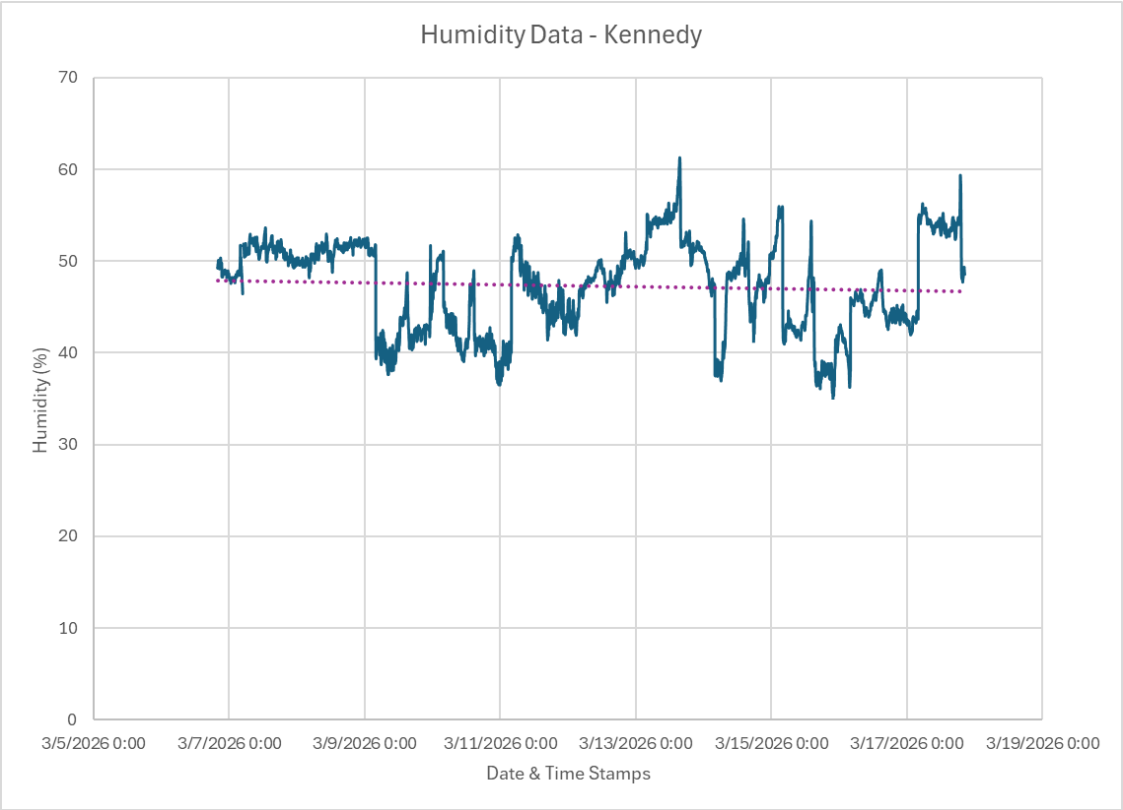


Figure 9.42: Kennedy's Overall Humidity Data

Caption: This table shows Kennedy's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their humidity data decreasing throughout the course of the study.

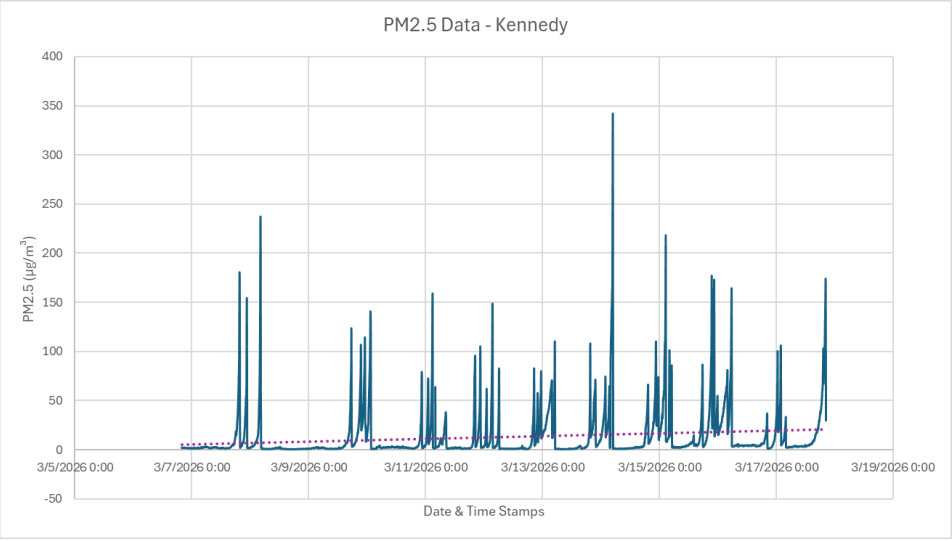


Figure 9.43: Kennedy's Overall $PM_{2.5}$ Data

Caption: This table shows Kennedy's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their $PM_{2.5}$ staying consistent throughout the course of the study.

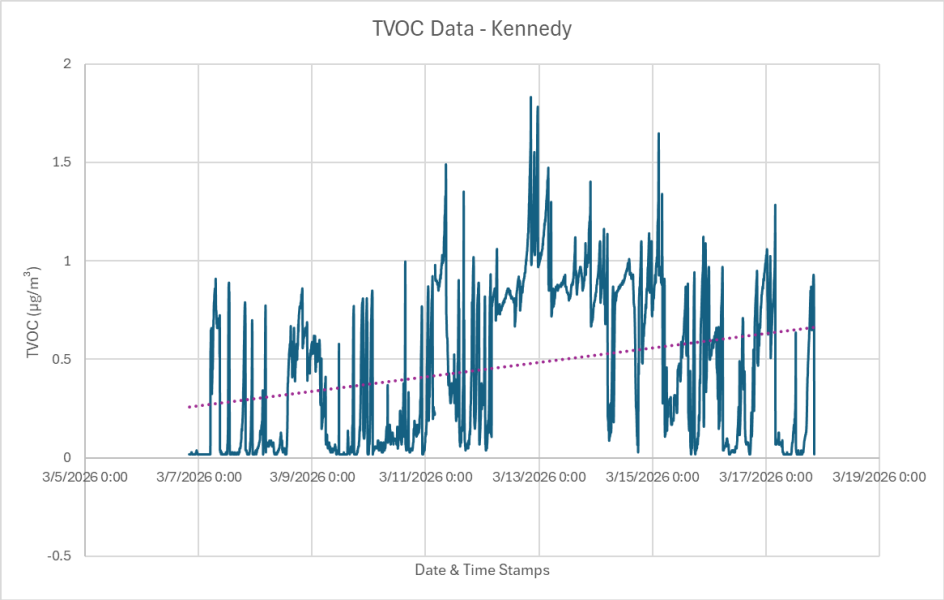


Figure 9.44: Kennedy's Overall TVOC Data

Caption: This table shows Kennedy's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their TVOC increasing exponentially during the course of the study.

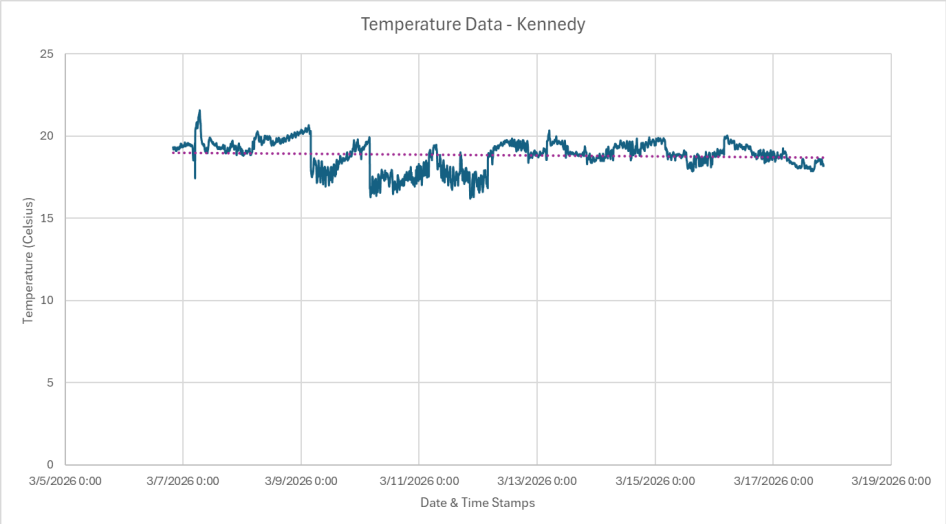


Figure 9.45: Kennedy's Overall Temperature Data

Caption: This table shows Kennedy's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their temperature fluctuating consistently throughout the course of the study.

Ice

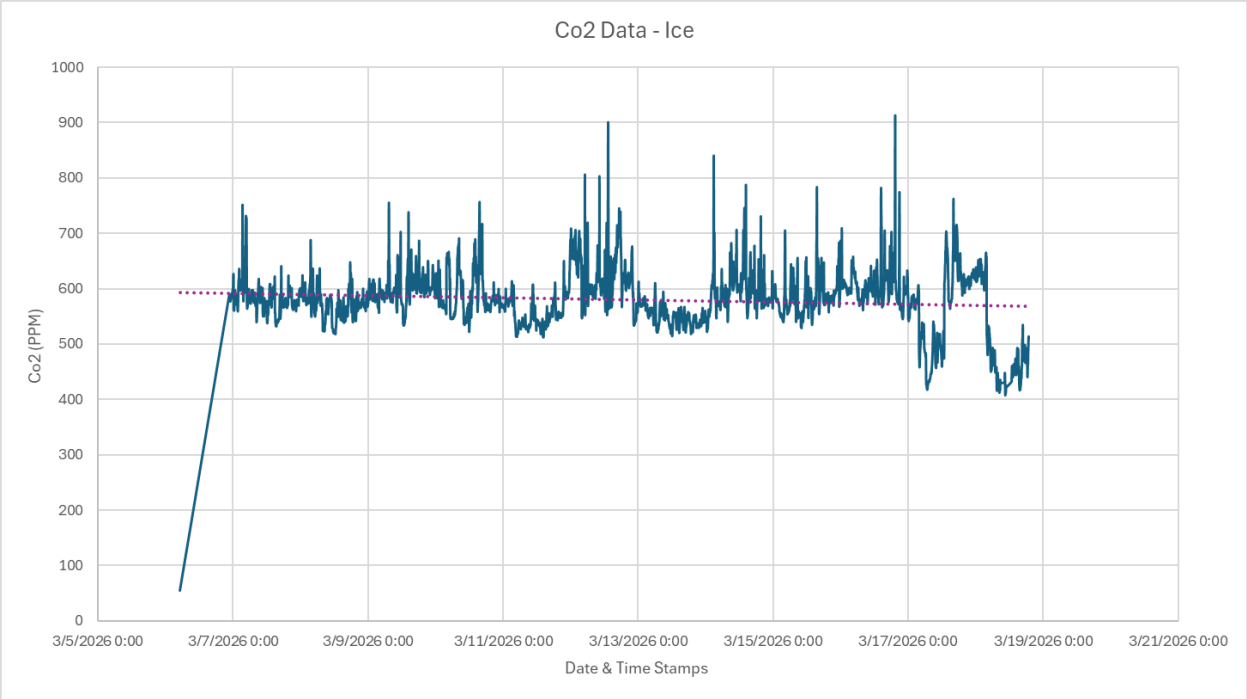


Figure 9.46: Ice's Overall CO_2 Data

Caption: This table shows Ice's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their CO_2 staying consistent throughout the course of the study.

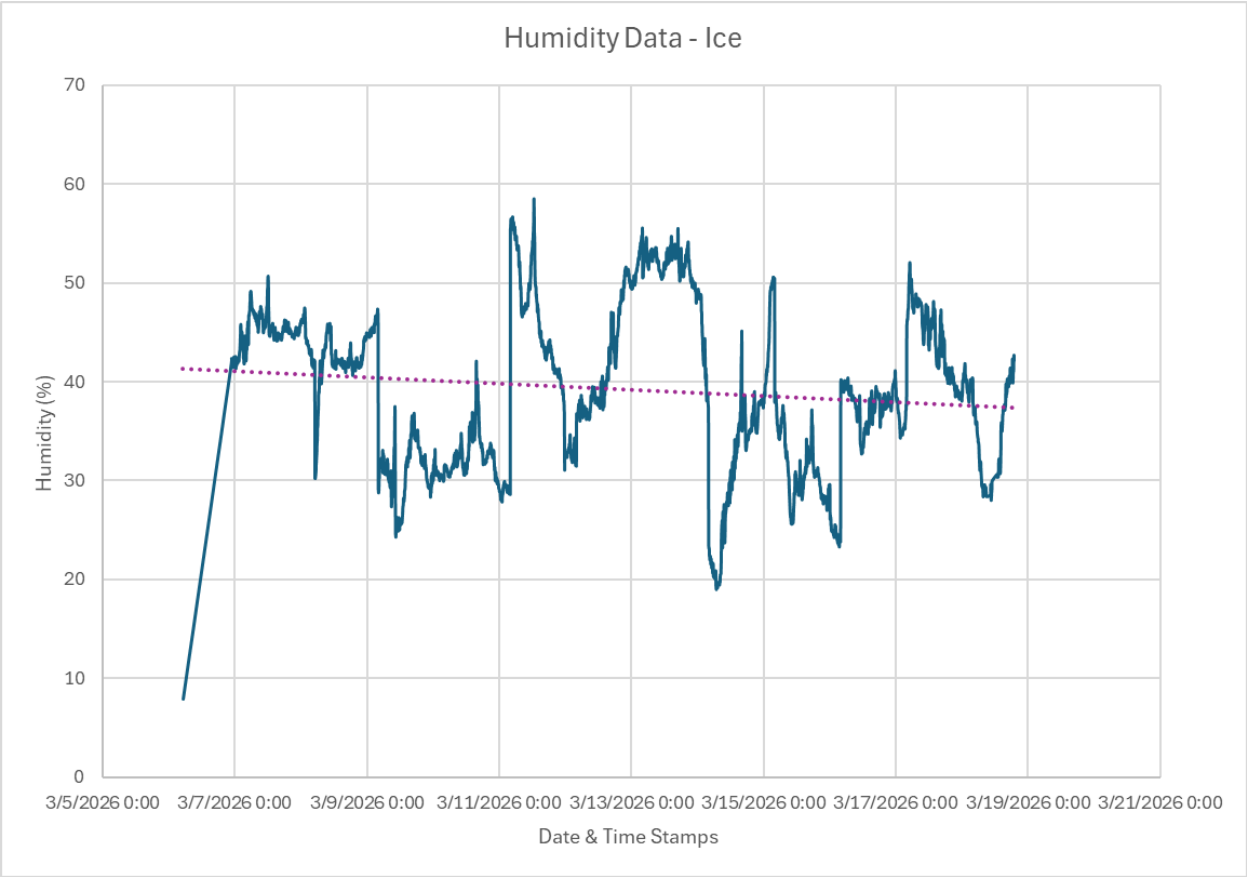


Figure 9.47: Ice's Overall Humidity Data

Caption: This table shows Ice's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their humidity decreasing across the course of the study.

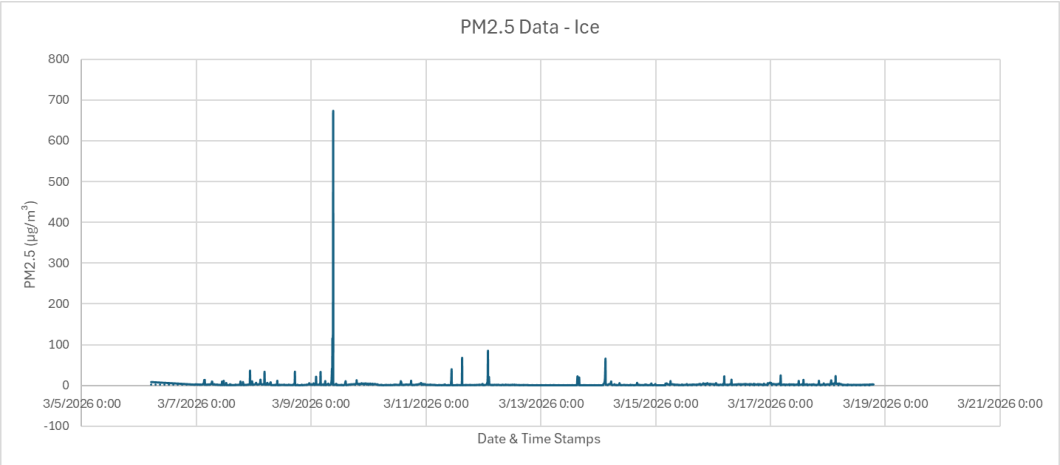


Figure 9.48: Ice's Overall $PM_{2.5}$ Data

Caption: This table shows Ice's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their $PM_{2.5}$ staying consistent throughout the course of the study.

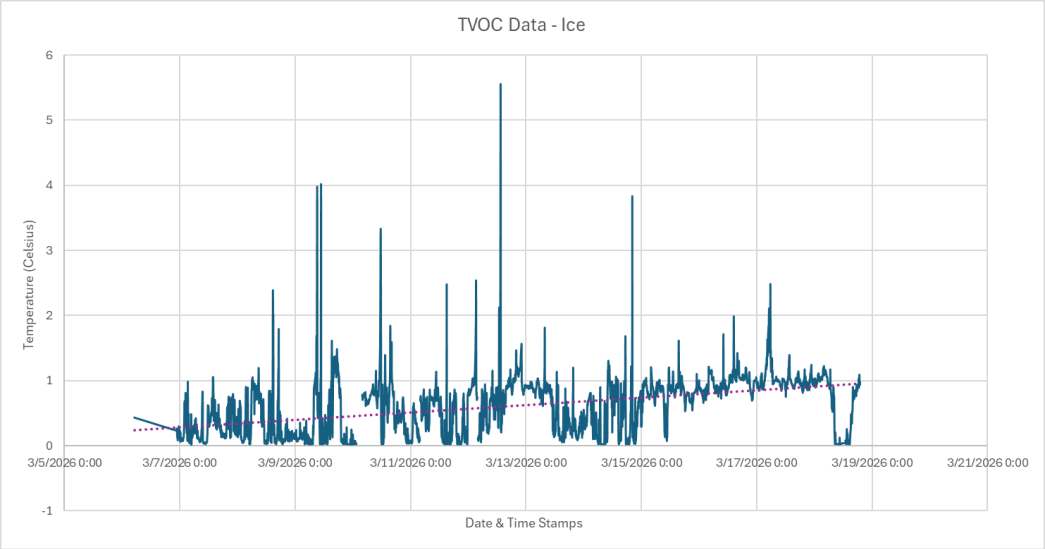


Figure 9.49: Ice's Overall TVOC Data

Caption: This table shows Ice's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their TVOC increasing exponentially throughout the course of the study.

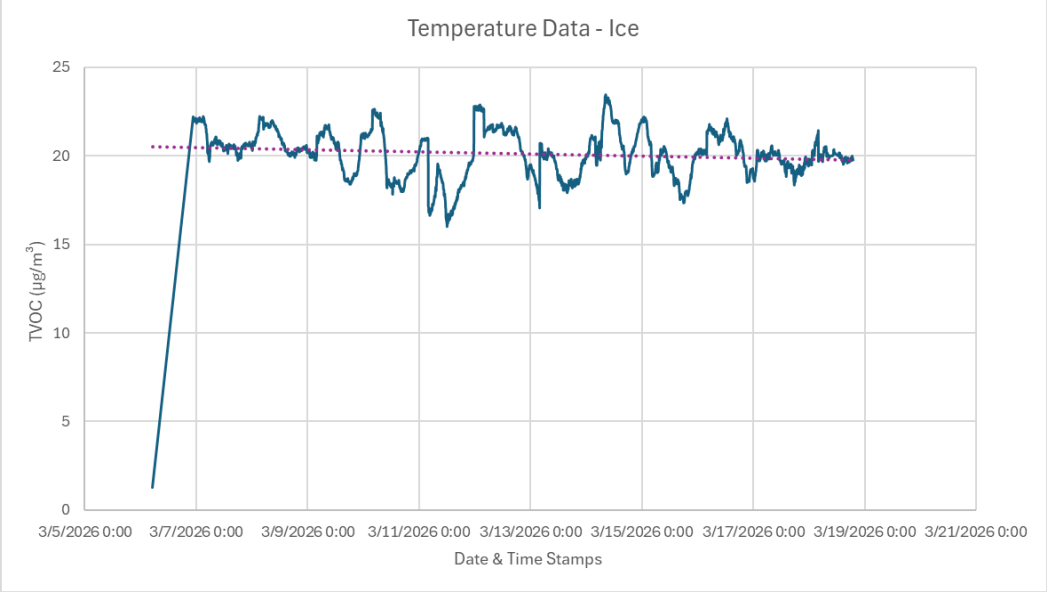


Figure 9.50: Ice's Overall Temperature Data

Caption: This table shows Ice's overall data over the course of the study. The dark blue line represents measurements throughout the study and the pink link represents the trendline throughout the study. This data shows that their temperature staying consistent throughout the course of the study.

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