

**Research Article**
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## Gas vs. Electric Stoves: Evaluating the Impact of Cooking Practices on Particulate Matter and Total Volatile Organic Compounds in Home Kitchens

Summya Khatoon<sup>1\*</sup>, Karen Lizzeth Flores<sup>2</sup> and Afroze Qutab<sup>2</sup>

<sup>1</sup>Department of Environmental Health, Boston University School of Public Health, Boston, MA, USA

<sup>2</sup>Department of Epidemiology, Boston University School of Public Health, Boston, MA, USA

### ABSTRACT

Our daily cooking routine, from the stove we use to how we prepare our meals, significantly affects the air we breathe at home. This study investigated how electric and gas stoves compare when it comes to indoor air quality, focusing on frying and boiling. The research employs real-time monitoring using Awair Element low-cost sensors to assess concentrations of particulate matter (PM<sub>2.5</sub>, µg/m<sup>3</sup>), total volatile organic compounds (TVOCs, ppb), and carbon dioxide (CO<sub>2</sub>, ppm) during cooking sessions. The study carefully considers various cooking methods, pot sizes, and meat types, ensuring a comprehensive evaluation of emissions.

The findings highlight the critical role of both stove type and cooking conditions in determining IAQ. There does not appear to be strong differences in cooking emissions between gas and electric stoves overall. TVOC concentrations remained relatively consistent across stove types and methods, except in one trial—gas boiling with the fan off—which showed an elevated TVOC reading above the baseline-adjusted average. Gas stoves consistently emitted slightly higher levels of harmful pollutants, while electric stoves showed potential concerns related to PM<sub>2.5</sub> spikes during frying, particularly in the final minute of cooking. Proper ventilation emerged as a critical mitigation strategy, effectively reducing overall emissions with varying impacts on PM<sub>2.5</sub> depending on the stove type and cooking method.

This study underscores the importance of considering both stove type and cooking conditions when optimizing IAQ in residential kitchens. While electric stoves may be preferable for reducing overall pollutant emissions, proper ventilation is crucial for both stove types, especially during high-temperature cooking activities like frying. Further research is necessary to elucidate the factors influencing PM<sub>2.5</sub> fluctuations from electric stoves and refine ventilation strategies for both stove types to ensure healthier indoor environments. Despite some study limitations, including sensor sensitivity, the research contributes valuable insights for individuals, researchers, and policymakers seeking to enhance indoor air quality and public health.

### \*Corresponding author

Summya Khatoon, Department of Environmental Health, Boston University School of Public Health, Boston, MA, USA.

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### Introduction

Poor indoor air quality has a significant impact on human health and well-being, as most people spend a considerable amount of time indoors, especially in their homes. Remaining inside can enhance the chance of breathing in more indoor pollutants while reducing exposure to external air pollution [1,2]. Over 237,000 deaths of children under five were attributed to indoor air pollution in 2020, accounting for an estimated 3.2 million fatalities overall [3]. Even though death is the worst consequence, pollutants such as particulate matter 2.5 (PM<sub>2.5</sub>), particulate matter 10 (PM<sub>10</sub>), volatile organic compounds (VOC), and nitrogen dioxide cause diseases including eye dried syndrome, retinopathy, memory impairment, anxiety, dementia, depression, chronic loss of pulmonary function, heart failure, stroke, cardiac arrest, inflammatory bowel disease, appendicitis, fatty liver disease, lower bone mass, lower levels of fertility, among others [4]. Indoor air

pollution occurs due to activities such as cooking, ironing, burning candles, heating, and spraying air fresheners [5]. Because women and children spend more time at home, where pollutant-stoves are frequently used, they are more vulnerable to health issues caused by indoor air pollution [3].

The three types of pollutants that are most problematic are carbon dioxide (CO<sub>2</sub>), volatile organic compounds (VOCs), and particulate matter (PM). Breathing in particulate matter (PM), mainly PM<sub>2.5</sub>, can have adverse health effects, including respiratory problems and cardiovascular diseases [6]. Because PM<sub>2.5</sub> is so small, it can enter the bloodstream by penetrating deeper into the lungs. Once inside, PM<sub>2.5</sub> can spread to other organs, including the heart, where it can impair the health and structure of the cells [7].

VOCs are a class of compounds that can evaporate into the atmosphere and are involved in the production of secondary pollutants such as ground-level ozone [8,9]. VOCs can lead to

headaches, nausea, dizziness, and irritation of the eyes, nose, and throat, among other health issues. Climate change is primarily caused by greenhouse gases, such as CO<sub>2</sub> [10]. It can potentially cause higher-dose health issues, including headaches, dizziness, and dyspnea [11]. Cooking is a significant source of indoor pollution, primarily because it releases a range of pollutants during the cooking process. However, indoor air quality is primarily determined by how efficiently the kitchen is ventilated and how efficiently the stove burners operate [12].

Aside from that, the interior air quality of a home can be significantly impacted by the type of cooking device chosen, whether gas or electric. In the United States, approximately 40% of the population uses gas stoves, while a higher percentage (60%) uses electric stoves [13]. Due to the lack of combustion emissions, electric stoves are generally regarded as cleaner than gas burners. Nevertheless, electric stoves may release pollutants because cooking oils and other organic components degrade at high temperatures and during prolonged usage [14]. It is essential to note that the amount of pollutants released from electric stoves can vary depending on specific circumstances, such as the type of food being prepared, the cooking method, and the efficiency of the kitchen's ventilation system. As Svedahl et al [2]. Discussed, there is a possibility of fine particle and volatile organic compound (VOC) emission into the interior of an electric burner, mainly when it is utilized for searing and frying, and the thermal deterioration of food residues and cooking oils on the cookware surface may be the cause of these emissions [15].

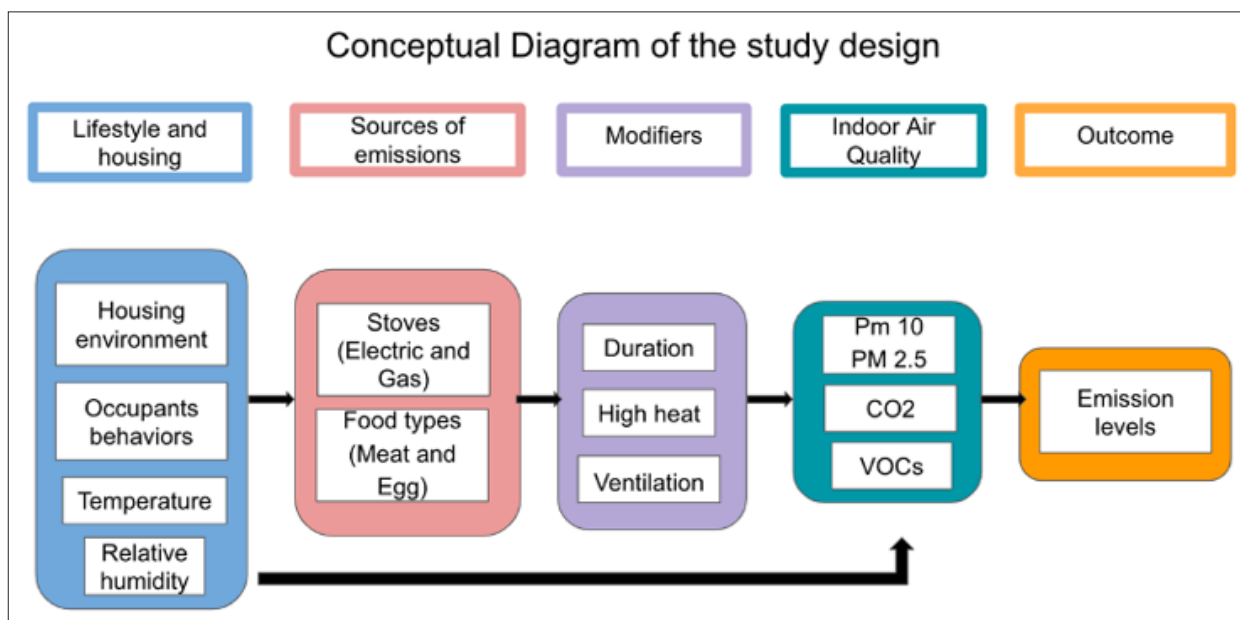
Different cooking procedures affect the quantity of emissions produced. Deep-frying has been associated with the highest amounts of PM 2.5, followed by stir-frying, boiling, and steaming [16]. A different study evaluated the contribution of various food kinds to PM 2.5 levels. It was discovered that stewing Chinese food produces 40–50% less PM<sub>2.5</sub> than pan- and stir-frying. Compared to boiling vegetables, heating high-fat foods like beef and pork makes fat pyrolysis, which raises the concentration of PM<sub>2.5</sub> emissions [6].

Gas stove emissions are well-known as a source of indoor air quality problems; however, there are few research papers on how electric stoves affect air quality [17]. This study aims to examine how long-term high-temperature cooking on electric stoves affects indoor air quality and compares the release of dangerous substances such as PM<sub>2.5</sub> and VOCs to gas stoves.

## Methods

### Framework

The conceptual model of the study design provides a framework and roadmap for the study, as we aim to examine the complex interplay of various factors, including lifestyle and housing conditions, sources of emissions, modifiers, indoor air quality, and outcome.



### Lifestyle and Housing Conditions

Living conditions can vary widely, which may impact the study's findings. To ensure quality control, we will aim to maintain a standardized set of factors to minimize confounding. These factors include the type of housing (apartment, house), occupant behaviors, temperature, and relative humidity.

### Sources of Emissions

Emissions vary widely depending on the type of stove and the food being cooked. For this research, we considered electric and gas stoves and will compare their emissions. For performing comparisons, we will only use meat as a food type.

### Modifiers

A significant factor that researchers mentioned as contributing to reducing human exposure to these indoor pollutants is the use of hood ventilators [13]. Therefore, we have considered the ventilation status as a modifier. Other modifiers of exposure to indoor pollutants include cooking duration and heat level, which were obtained from the literature review.

## Data Collection Procedures

### Selection of Cooking Materials

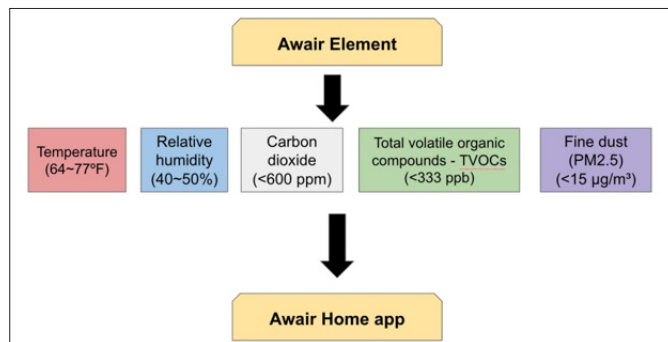
We selected various everyday cooking materials, such as vegetable oil, water, and beef, for a comprehensive assessment.

### Method of Cooking

We considered two methods of cooking, boiling and frying, to compare pollutant emissions.

### Instrument

We used two Awair Element monitors in the kitchen area to gather data, placing them 20 inches away from the stovetop. The Awair Element monitor measures PM2.5, VOCs, and CO2 emissions, along with environmental temperature and humidity. Additionally, it provides an overall score that takes into account all the individual measurements. The Awair Element monitors provide real-time pollutant levels, which are displayed on the device. Levels for each pollutant can be shown by scrolling through the display. Ranges of measurement for every one of the components that support comfort and health include 18-20°C (for temperature), 40-50% (for relative humidity), up to 600 ppm (for Carbon Dioxide), up to 333 ppb (for TVOC), and up to 15 µg/m<sup>3</sup> (for PM 2.5). Levels that are above or below the ranges mentioned before are considered dangerous levels of the components (see Appendix B and C)



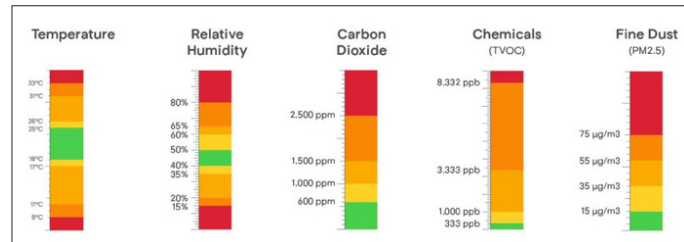
The Awair Element monitor records measurements at 5-minute intervals, and it can be connected to the Awair app via Bluetooth, which is installed on the user's mobile device. Later on, the data can be downloaded from the trial version of the app.

### Measurements

Ideally, instruments should be set up at the venue two days before the trial is performed. Measurements were recorded before the cooking procedure, during the process, and after the cooking until the measurements returned to baseline values. Because the averaging time for the Awair element monitor is 5 minutes, we recorded real-time levels on the field log every 1 minute to obtain more highly temporally resolved data. Every trial has a baseline recording and five more measurements taken during the trial.

### Cooking Procedures

Researchers recorded environmental conditions, such as temperature and humidity, and maintained constant heating and ventilation conditions across multiple trials. We used a 10-inch non-stick pan and a standardized pot size for boiling and frying the meat. The cooking process was monitored and documented, including pan/pot temperature, meat temperature, cooking time, cooking method, and ventilation status. Half of the cooking trials were conducted with the stove fan on, and half with the stove fan off. The fan setting was kept at "low speed" to ensure comparable airflow for both electric and gas stoves. Every trial was repeated twice, and the obtained pollutant levels were recorded on the field log (see Appendix D).



## Appendix D

Step	Before Each Trial	During Each Trial	After Each Trial	Conditions Between Trials
1. Preparation	Ensure all equipment is ready	Set up equipment and ingredients.	Clean cooking utensils to prevent cross-contamination	N/A
2. Baseline Measurements	Calibrate monitoring equipment.  Collect baseline air quality data 15 minutes before the start of the cooking procedure to account for indoor air quality	After the readings have adjusted to baseline levels, start data collection for the cooking trial	Record post-trial measurements for up to 15 minutes to account for how long emissions persist  Wait for 15 minutes before pollutant levels return to baseline before the next trial	Ensure indoor air quality remains uninfluenced by outdoor factors by shutting off windows  Ensure control variables remain constant

3. Ventilation settings	Adjust ventilation settings based on the procedure to be conducted. Close doors to prevent outdoor air influencing results	For stove hood off trial: Keep the stove hood off during the cooking procedure  For stove hood on trial: Keep the stove hood on during the cooking procedure	15 minutes after the last measurement for the cooking procedure is done, we will turn the stove hood on to help reach baseline characteristics.	Ensure the ventilation is maintained by keeping windows shut and the stove hood off between cooking trial for up to 15 minutes.  Open windows after to return levels to return to baseline and prevent carryover
4. Cooking Procedure	Make sure the control variable checklist is being followed:	Measure and record measurements on the field log every 1 minute		
	<ul style="list-style-type: none"> <li>- Ventilation</li> <li>- Pan/pot size and material</li> <li>- Cooking duration</li> <li>- Meat Type</li> <li>- Cooking oil</li> </ul>	Take the surface temperature of pan and pot before adding the meat with the infrared thermometer		
5. Post Trial measurements and clean up	NA	NA	Clean cooking pots/ pans before the next procedure to avoid contamination Ensure ventilation	Recalibrate Awair after every two cooking trials
7. Repeat	Replicate for each subsequent cooking trial			

### Trials

Researchers kept the hood fan on for the Gas - Boiling– Fan On, used a standard-sized pot, and added 3 cups of water. Then, they turned the stove on and let the water reach 212°F; finally, they recorded the water temperature with an infrared thermometer. At this point, researchers added 3oz. lean beef and boil for 5 minutes until the meat reaches 165°F, which is the safe temperature for the meat. After this, they turned off the stove and allowed it to rest until the values returned to baseline characteristics, minimizing carryover between trials.

Researchers kept the hood fan off for the Gas - Boiling– Fan Off, used a standard-sized pot, and added 3 cups of water. Then, they turned the stove on and let the water reach 212°F; finally, they recorded the water temperature with an infrared thermometer. At this point, researchers added 3oz. lean beef and boil for 5 minutes until the meat reaches 160°F, which is the safe temperature for the meat. After this, they turned off the stove and allowed it to rest until its values returned to baseline characteristics.

For the Gas-frying– Fan On, researchers kept the hood fan on, used a 10-inch non-stick pan, and added 4 tablespoons of vegetable oil. Then, they turned the stove on and let the oil temperature reach 300°F; finally, they recorded the water temperature with an infrared thermometer. At this point, researchers added 3oz. lean beef and fry for 5 minutes (half the time on each side) until the meat reaches 160°F. After this, they turned off the stove and let it rest until values returned to baseline characteristics.

Researchers kept the hood fan off for the Gas-frying– Fan Off, used a 10-inch non-stick pan, and added four tablespoons of vegetable oil. Then, they turned the stove on and let the oil temperature reach 300°F; finally, they recorded the oil temperature with an infrared thermometer. At this point, researchers added 3oz. lean beef and fry for 5 minutes (half of the time on each side) until the meat reaches 160°F. After this, they turned off the stove and let it rest until values returned to baseline characteristics (see Appendix E).

## Appendix E

Stove type	Stove Fan	Cooking method	Instructions
Gas	On/Off	Boiling meat	<ul style="list-style-type: none"> <li>Use a standard-sized pot and add 3 cups of water</li> <li>Turn on the stove and bring the water to a boil (212 F)</li> <li>Record water temperature with an infrared thermometer</li> <li>Add 3oz. lean beef and boil for 10 minutes</li> <li>Turn off the stove and let it rest</li> </ul>
		Frying, meat	<ul style="list-style-type: none"> <li>Use a standard-sized frying pan and add four tablespoons of vegetable oil</li> <li>Record the surface temperature of the pan with an infrared thermometer</li> <li>Once the temperature reaches 300F, add 3oz. lean beef and cook for 5 minutes (160F)</li> <li>Flip sides halfway through (at minute 2.5)</li> <li>Turn off the stove and let it rest</li> </ul>
Electric	On/Off	Boiling meat	<ul style="list-style-type: none"> <li>Use a standard-sized pot and add three cups of tap water</li> <li>Turn on the stove fan</li> <li>Turn on the stove and bring the water to a boil (212 F)</li> <li>Record water temperature with an infrared thermometer</li> <li>Add 3oz. lean beef and boil for 10 minutes</li> <li>Turn off the stove and let it rest</li> <li>Turn off the stove fan.</li> </ul>
		Frying meat	<ul style="list-style-type: none"> <li>Use a standard-sized frying pan and add four tablespoons of vegetable oil</li> <li>Turn on the stove fan</li> <li>Record the surface temperature of the pan with an infrared thermometer</li> <li>Once the temperature reaches 300F, add 3oz. lean beef and cook for 5 minutes (160F)</li> <li>Flip sides halfway through</li> <li>Turn off the stove and let it rest</li> <li>Turn off stove fan</li> </ul>

## Quality Assurance

To get the highest level of accuracy, each sensor of the Awair Element monitor is first pre-calibrated by the manufacturer and then undergoes batch testing and calibration in a laboratory with a controlled atmosphere. The instrument utilizes dynamic and automatic calibration logic in the various sensors to achieve the highest level of accuracy possible throughout the sensor's lifetime. In essence, the sensor is constantly self-correcting through the Dynamic Automatic Background Calibration Logic (ABCLoGic), and each component has a specific sensor, type, range, resolution, and accuracy.

For temperature, the instrument utilizes the Sensirion SHT31 sensor, a type of complementary metal-oxide semiconductor (CMOS) sensor, measuring a range of 0 °C to 90°C (32°F to 194°F) with a resolution of 0.015 °C and an accuracy of ±0.2°C. Regarding relative humidity, the instrument utilizes the Sensirion SHT31 sensor, a type of complementary metal-oxide semiconductor (CMOS) sensor, measuring a range of 0-100% RH with a resolution of 0.01% RH and an accuracy of ±2% RH. For measuring carbon dioxide, the instrument uses the sensor named Amphenol-Telair T6703, which is a Non-Dispersive Infrared Sensor (NDIR), measuring a range of 400 - 5,000ppm, with a resolution of 1ppm, and an accuracy of ±75ppm or 10% (whichever is greater). Besides that, the TVOC instrument uses the sensor named Sensirion SGP30, which is a Multi-pixel metal oxide gas sensor, measuring a range of 20 - 36,000ppb, with a resolution of 1ppb, and an accuracy of ±15%. Finally, regarding PM<sub>2.5</sub>, the instrument uses the sensor Honeywell HPMA115S0, which sensor type is a Laser-based light scattering sensor, measuring a range of 0 - 1,000 µg/m<sup>3</sup>, with a resolution of 1 µg/m<sup>3</sup>, and an accuracy of ±15 µg/m<sup>3</sup> or 15% (whichever is greater).

Quality assurance measures are crucial to guarantee the validity of our study's findings, so we kept all variables constant in gas and electric stove settings to maintain consistency. During the trials, the kitchen windows and doors were closed to ensure that outdoor air pollution influences did not alter the outcome. Additionally, to ensure a reliable comparison, we have calibrated the monitor equipment at the beginning of every day we performed the trials. This calibration process enabled the acquisition of accurate data throughout the study, allowing us to draw valid comparisons between electric and gas stoves.

We needed to download the Awair app and connect our Awair Element monitor to the Wi-Fi to calibrate the instrument. Then, turn on location services on our mobile device so we can record where the Awair Element monitor documents the reading. It is essential to recalibrate the device regularly, which can be done by placing the device in a well-ventilated area and running the recalibration process through the Awair app. The recalibration process took approximately 15 minutes to complete, and it was crucial not to move or touch the device during this time.



10.41	60	40	1060	32	5
10.42	61	40	1060	35	4
10.43	61	39	1068	29	3

**Table 7: Table of the Raw Measurements - Gas Stove - First Measurement - Frying Fan On**

-	Temp	Humid	CO2	VOC	PM
Experiment: 1 Frying Meat (Stove Fan On) - Gas Stove					
Baseline	57	33	529	21	2
11.16	59	32.9	578.2	46.2	2.5
11.17	59	32.8	462	118	2.7
11.18	59	32.3	469	105.6	2.6
11.19	59	32.6	472.8	80.6	2.4
11.2	60	33.5	485.6	69.8	2.4

**Table 8: Table of the Raw Measurements - Gas Stove - First Measurement - Boiling Fan Off**

-	Temp	Humid	CO2	VOC	PM
Experiment: 2 Frying Meat (Stove Fan Off) - Gas Stove					
Baseline	56	30	522	142	2
12.05	57	35.2	559.2	72.4	2.2
12.06	57	39.1	847.2	46.6	3
12.07	58	45	1182.2	35.8	4
12.08	58	51.3	1391.4	40.6	4.2
12.09	59	51.8	1444.6	41.4	3.8

**Table 9: Table of the Raw Measurements - Electric Stove - Replicate - Boiling Fan On**

-	Temp	Humid	CO2	VOC	PM
Experiment: 1 Boiling Meat (Stove Fan On)					
Baseline	69	21	503	118	2
10.33	72	33	574	115	2
10.34	72	35	579	181	2
10.35	71	45	581	181	3
10.36	71	47	577	156	2
10.37	71	39	572	169	2

**Table 10: Table of the Raw Measurements - Electric Stove - Replicate - Boiling Fan Off**

-	Temp	Humid	CO2	VOC	PM
Experiment: 2 Boiling Meat (Stove Fan Off)					
Baseline	67	24	480	109	2
11.04	72	37	573	150	3
11.05	72	37	675	191	4
11.06	72	41	675	191	4
11.07	73	37	657	164	3
11.08	73	37	641	176	4

**Table 11: Table of the Raw Measurements - Electric Stove - Replicate - Frying Fan On**

-	Temp	Humid	CO2	VOC	PM
Experiment: 2 Frying Meat (Stove Fan On)					
Baseline	71	25	501	147	

11.30	71	26	510	137	4
11.31	71	23	509	144	8
11.32	71	30	513	160	10
11.33	72	29	518	139	18
11.34	72	31	530	330	51

**Table 12: Table of the Raw Measurements - Electric Stove - Replicate - Frying Fan Off**

-	Temp	Humid	CO2	VOC	PM
Experiment: 1 Frying Meat (Stove Fan Off)					
Baseline	67	26	443	100	2
12.15	69	23	457	154	8
12.16	69	26	470	223	26
12.17	70	25	470	294	30
12.18	70	23	485	439	35
12.19	71	26	489	644	64

**Table 13: Table of the Raw Measurements - Gas Stove - Replicate - Boiling Fan On**

-	Temp	Humid	CO2	VOC	PM
Experiment: 1 Boiling Meat (Stove Fan On)					
Time	Temp	Humid	CO2	VOC	PM
Baseline	59	35	677	107.5	4
9.47	64	38	1053	101.5	6
9.48	64-65	39	1107	80.5	7
9.49	65	39	2256	88.5	6
9.5	64	43	1146	88.5	9
9.51	65	43	1206	79	10

**Table 14: Table of the Raw Measurements - Gas Stove - Replicate - Boiling Fan Off**

-	Temp	Humid	CO2	VOC	PM
Experiment: 2 Boiling Meat (Stove Fan Off)					
Baseline	62.5	38	725	497.5	4
9.21	64	39	1095.5	366.5	4
9.22	65	38.5	1142	331.5	5
9.23	64.5	42	1154	316.5	6
9.24	65	41.5	1279.5	278	6
9.25	65	44.5	1326	276.5	7

**Table 15: Table of the Raw Measurements - Gas Stove - Replicate - Frying Fan On**

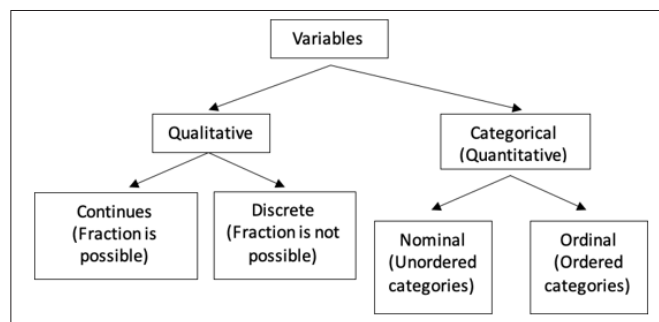
-	Temp	Humid	CO2	VOC	PM
Experiment: 1 Frying Meat (Stove Fan On)					
Baseline	57	32	605	61	4.5
10.1	61	34	592.5	86.5	4
10.11	62	35	621.5	148.5	4
10.12	62	35	639.5	137.5	5
10.13	63	35	654.5	142.5	7
10.14	64	36	676	133.5	10
11.15	64	35	703	124.5	11

**Table 16: Table of the Raw Measurements - Gas Stove - Replicate - Frying Fan Off**

-	Temp	Humid	CO2	VOC	PM
Experiment: 2 Frying Meat (Stove Fan Off)					
Baseline	56	31	488.5	66.5	4.5
10.48	59	31	491.5	71.5	6
10.49	61	31	522	107	5
10.5	61	31	534	119	6
10.51	62	31	548.5	135	7
10.52	62	35	720.5	110	39

**Data Analysis Variables**

All of our variables are continuous: Time is measured in hours; total score will give us a general idea of the overall indoor quality measurements, considering specific components; temperature is measured in Fahrenheit; humidity is measured in percentages; CO2 is measured in ppm; VOC is measured in ppb; and PM 2.5 is measured in ug/m3 (see Appendix H).



**Validation**

To have a valid investigation, each cooking trial is being carried out twice. Researchers compiled the data from each cooking trial into a structured dataset sheet. Additionally, two Awair Element monitors were used to record data, and two investigators simultaneously recorded the values in an Excel spreadsheet. The third researcher oversees the beef cooking trial and times the minutes every 1-minute interval.

**Analysis**

The data was analyzed in R Studio. The first analysis included descriptive statistics presented through tables and figures, which showed geometric means for PM, TVOC, and CO2 adjusted for baseline. It means that we did not consider the baseline values as a starting point because they varied in some of the trials, and it would not be accurate to use a high final reading as the starting point, as the baseline was not the same in all the trials. Some of the results of calculating the geometric means included negative values, so to facilitate the interpretation and understanding of the results, we decided not to use them. At this point, for the following figures, we have decided to include only PM2.5 and TVOC concentrations as pollutants of indoor quality. We did not include CO2 because it primarily increases when there is a lack of ventilation, rather than from cooking emissions.

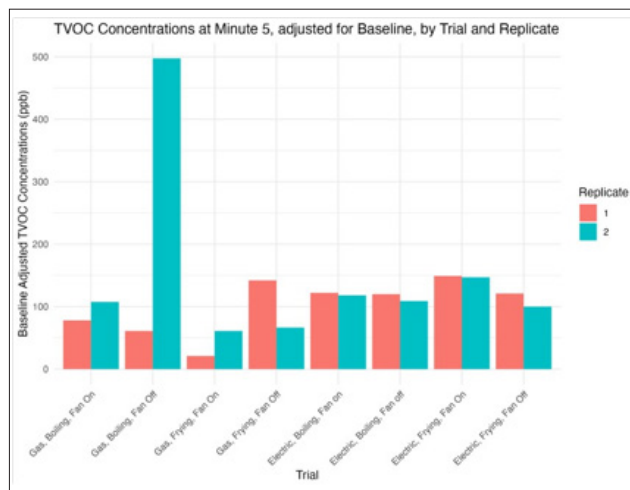
The posterior analysis included figures such as a boxplot of TVOC concentrations (ppb) adjusted for baseline, a boxplot of PM 2.5 concentrations (ugm3) adjusted for baseline, a line plot that shows the trend in TVOC Concentrations over 5 Minutes of Cooking, and a line plot that shows the trend in PM 2.5 Concentrations over 5 Minutes of Cooking.

In the third stage of the analysis, we got two bar plots in which we compared concentrations at minute 5, adjusted for baseline by trial, and replicate 1 and 2 for TVOC and PM 2.5. Due to inconsistencies between the replicates, we decided to select one replicate for each trial condition. For the trials cooked on the electric stove, we chose replicate one, while for the trials cooked on the gas stove, we chose replicate 2. The reason why we picked a replicate one for the electric stove is that the instrument was already set in the venue three days before the trial, so we believe that it was better calibrated compared to replicate 2, based on the information that the instrument manual suggest to set the instrument 48 hours before the readings. Regarding the gas stove trials, we chose replicate two because we were more familiar with the procedure and were more careful to follow every detail of the procedure.

After choosing one replicate for trial, we thought it would be better to show the trend of the concentrations under different conditions. Considering all the readings from minute 0 to minute 5, the type of stove, the cooking condition, and the hood ventilator on/off, we made this decision. Therefore, we got two strip plots for the final stage of the analysis, one for TVOC and another one for PM 2.5, that show concentrations at minute 5 of cooking, adjusted by baseline, cooking condition, and stove type. In most trials, the last reading was the highest concentration, regardless of the type of stove, ventilation condition, and cooking method. Therefore, we decided to display the strip plots, including only the last reading.

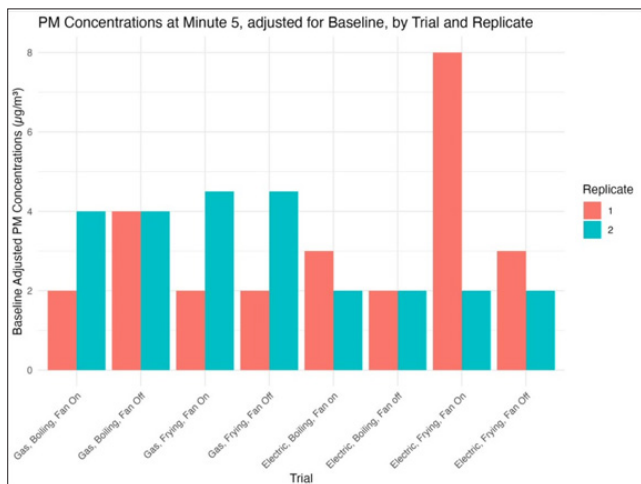
**Results**

In this investigation, 16 trials were conducted, with eight replicates for the first eight trials. We wanted to determine if there is a difference in the concentrations of TVOC and PM2.5 under various conditions, including the type of stove, cooking method, and ventilation. To visualize the difference between replicates one and two for the concentrations of TVOC and PM2.5, we created graphs 1 and 2, which compare the concentrations at minute five for the two replicates under the different conditions, adjusted for baseline. Graph 1 illustrates a discrepancy between replicates one and two. This inconsistency is particularly notable in the trials conducted on the gas stove. We can see that the highest difference between replicates is taken from replicate two, cooking on a gas stove, boiling the meat, and the hood ventilator off. It gives a value of 500 ppb, while replicate one under the same conditions gave us a value of <100 ppb.



**Graph 1: TVOC Concentrations at Minute 5, Adjusted for Baseline, by Trial and Replicate**

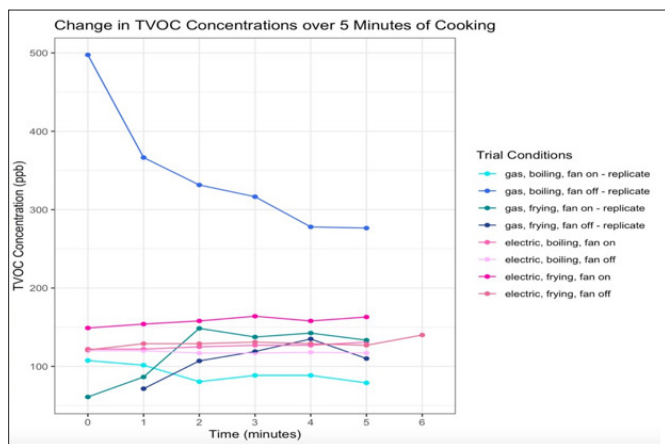
The second graph gave us similar information regarding the difference between the replicates. From all the comparisons, we can observe that only two trials give us the same values between replicates. They are cooking on an electric stove, boiling the meat, and the hood ventilator is off; and the other is cooking on a gas stove, boiling the meat, and the hood ventilator is off. The other 12 conditions do not show consistency between replicates one and two, and among all, the highest difference is shown in cooking on an electric stove, frying the meat, and with the hood ventilator on.



**Graph 2:** PM 2.5 Concentrations at Minute 5, Adjusted for Baseline, by Trial Replicate

Because there was inconsistency between the replicates, we decided to pick one replicate for each trial condition and made graphs 3 and 4, considering blue tones for the gas stove and pink tones for the electric stove.

Graph 3 shows that the TVOC's highest concentration at the beginning of the trial was 500 ppb, while the highest concentration at minute five, or the end of the trial, was approximately 275 ppb. These two highest concentrations were caused by cooking on a gas stove, boiling the meat, and having the hood ventilator off. We also observed an increased concentration of TVOC in the trial performed on an electric stove, frying the meat and having the hood ventilator off. Interestingly, the characteristic they have in common is ventilation, in both cases, the hood ventilator was off.

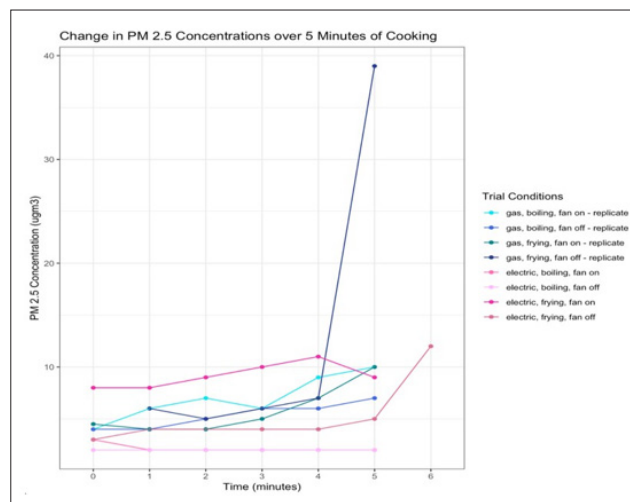


**Graph 3:** TVOC Concentrations Over 5 Minutes of Cooking

Graph 4 shows that the highest concentration of PM 2.5 at the beginning of the trial was approximately eight ugm<sup>3</sup> from cooking on an electric stove, frying the meat, and having a hood ventilator on. The highest concentration of PM 2.5 at the end of the trial was

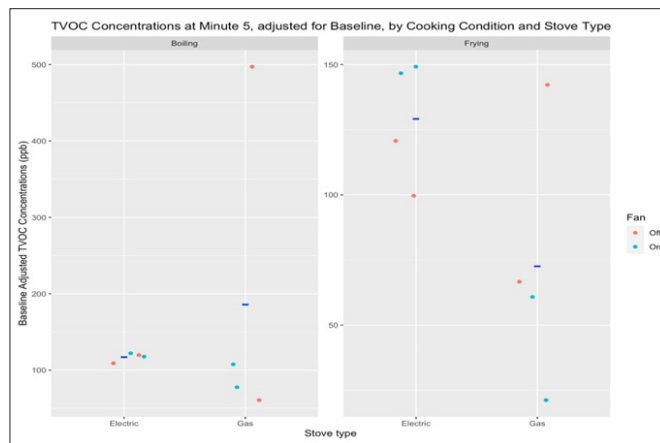
around 39 ugm<sup>3</sup>. This value is extremely high compared to other final concentrations from other conditions, and it was obtained after cooking on a gas stove, frying the meat, and having the hood ventilator off.

From this graph, we can also note that the concentration increases from the penultimate reading to the last one in five trials; however, another trial (cooking on an electric stove, frying the meat, and having the hood ventilator on) shows precisely the opposite, a decrease in the concentration from the penultimate reading to the last. The trial in which researchers cooked on an electric stove, boiled the meat, and had the hood ventilator off showed that all the readings were the same, with no increases or decreases; it is just the same value along the trial.



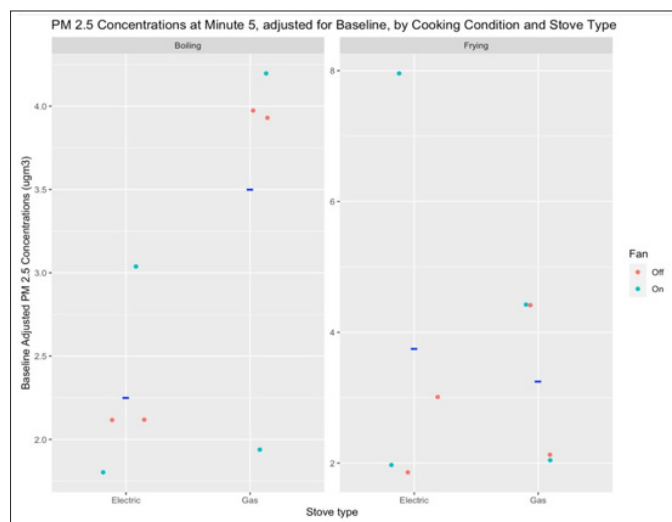
**Graph 4:** PM 2.5 Concentrations over 5 Minutes of Cooking

Graph 5 shows the TVOC concentrations at minute 5 of cooking, adjusted by baseline, cooking condition, and stove type. In this graph, we can see that cooking on a gas stove with the hood ventilator off resulted in the highest concentration (500 ppb). This value is far above the mean of the gas stove concentrations, which is about 180 ppb, while all other trials under boiling conditions in a gas stove are below the mean. We can observe that all readings are near the mean for the electric stove trials and boiling as a cooking method. Regarding the readings from the frying cooking method trial, we can see that they vary, with the ventilator-on readings above the mean for the electric stove and one ventilator-on trial way above the mean in the gas stove trials.



**Graph 5:** TVOC Concentrations at Minutes 5 of Cooking, Adjusted by Baseline, Cooking Condition and Stove Type

Graph 6 shows the PM 2.5 concentrations at minute 5 of cooking, adjusted by baseline, cooking condition, and stove type. This graph shows that boiling the meat and having the hood ventilator on while cooking on the electric stove, gave us a reading above the mean, while all other trials fall under it. Cooking in a gas stove under boiling conditions gave us the opposite result: three readings above the mean and one of the ventilator-on trials under the mean. For the frying condition trials, we observe that the graph shows an extremely high value of 8ugm3 because of a ventilator-on and cooking on an electric stove.



Graph 6: PM 2.5 Concentrations at Minute 5 of Cooking, Adjusted by Baseline, Cooking Condition, and Stove Type

### Discussion

In this study, we found that TVOC concentrations are similar regardless of the stove type, cooking method, and hood ventilator; however, one trial yielded a reading that exceeded the TVOC concentration. The gas-boiling-fan-off trial produces it. Regarding the cooking method, either frying or boiling, there was no substantial difference between the two conditions. For the PM<sub>2.5</sub> concentrations, we can see that most of the trials cause similar readings, except the last reading of the gas-frying-fan-off trial, which shows an abrupt increase from the fourth to the fifth reading, with the last reading being the highest value of PM<sub>2.5</sub> concentrations.

Interestingly, these two exceptions for the results of TVOC and PM 2.5 have in common the ventilation condition. In both cases, the hood ventilator was off, so this fact enables us to claim that ventilation plays a significant role in people's exposure to indoor air pollutants. Additionally, for the PM 2.5 concentrations, the trial that showed a difference was attributed to the frying cooking method. This result is consistent to Abdullahi et al [16], who stated that deep-frying has been associated with the highest amounts of PM 2.5, followed by stir-frying, boiling, and steaming.

The results of this research are consistent with the research carried out by Tao et al. which mentioned that electric stoves may release pollutants because cooking oils and other organic components that degrade at high temperatures and during prolonged usage [14]. This fact may be the reason why we observed similar concentrations of VOC and PM<sub>2.5</sub> in most readings from the electric and gas stoves. The Awair Element monitor read CO<sub>2</sub> concentrations, but for purposes of this study, we did not consider that in our results, as we believe that higher CO<sub>2</sub> concentrations are more related to a lack of good ventilation than emissions from the cooking.

On the one hand, our study has some limitations that could influence the results and serve as a reference for future research. For instance, the instruments were not set 48 hours before the gas stove trial because we used a kitchen where we performed those trials. Besides that, when we saw that readings from every instrument were inconsistent, we averaged the values obtained from the two instruments for PM 2.5 and TVOC concentration and input them into the dataset. On the other hand, our study has several advantages, including a comparison of the emissions from an electric stove versus a gas stove. We also compare two different cooking methods, such as boiling and frying. Not many studies consider these comparisons, so our study is a pioneer in this type of research.

For future investigations, we recommend setting the Awair Element monitor at least 48 hours before performing the trial, calibrating the instrument before every trial, cooking for longer periods than 5 minutes, and measuring PM 2.5 and TVOC more than 30 minutes after the cooking trial finishes.

### Conclusion

In conclusion, the study found no substantial differences in cooking emissions between gas and electric stoves. However, we found that the use of a stove hood fan efficiently decreases Total Volatile Organic Compound (TVOC) concentrations, providing an effective means of minimizing these emissions during cooking. Moreover, opting for boiling as a cooking method is more effective in reducing PM<sub>2.5</sub> concentrations. The findings emphasize the importance of proper ventilation, as activating the stove hood fan proved effective in reducing TVOCs, particularly for gas stoves. Electric stoves, while generally producing lower emissions, showed unexpected increases in PM levels during frying with the fan on, indicating the need for further research and optimization of stove hood ventilation strategies. The study highlights the critical role of cooking conditions and stove type in indoor air quality management, with implications for informed choices and proper ventilation systems in domestic settings. Despite some study limitations, the research contributes valuable insights for individuals, researchers, and policymakers seeking to enhance indoor air quality and public health. While the study offers valuable insights, it is important to acknowledge the use of a low-cost sensor, which may have limitations in accuracy. Future studies employing higher-grade instruments could help validate and refine these findings [17-20].

### References

1. Martins N R, Da Graca GC (2018) Impact of PM<sub>2.5</sub> in Indoor Urban Environments: A review. *Sustainable Cities and Society* 42: 259-275.
2. Buonanno G, Morawska L, Stabile LJA (2009) Particle Emission Factors During Cooking Activities. *Atmospheric Environment* 43: 3235-3242.
3. (2022) Household air pollution. World Health Organization <https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health>.
4. (2022) A Deep Dive on The Health Impacts of Air Pollution. Clarity <https://www.clarity.io/blog/deep-dive-health-impacts-of-air-pollution>.
5. (2022) A Deep Dive on The Health Impacts of Air Pollution. Clarity <https://www.clarity.io/blog/deep-dive-health-impacts-of-air-pollution>.
6. Thangavel P, Park D, Lee YC (2022) Recent Insights into Particulate Matter (pm<sub>2.5</sub>)-Mediated Toxicity in Humans: an Overview. *International Journal of Environmental Research and Public Health* 19: 7511.

7. Feng S, Gao D, Liao F, Zhou F, Wang X (2016) The Health Effects of Ambient pm 2. 5 and Potential Mechanisms. *Ecotoxicology and Environmental Safety* 128: 67-74.
8. Anand SS, Philip BK, Mehendale HM (2014) Volatile organic compounds. *Encyclopedia of Toxicology* 967-970.
9. Lebel ED, Michanowicz DR, Bilsback KR, Hill LAL, Goldman JS, et al. (2022) Composition, Emissions and Air Quality Impacts of Hazardous Air Pollutants in Unburned Natural Gas from Residential Stoves in California. *Environmental Science & Technology* 56: 15828-15838.
10. (2022) Gas Stoves are a Bigger Climate Threat than Previously Thought, Study Finds. *World Economic Forum* <https://www.weforum.org/agenda/2022/02/gas-stoves-climate-change-study-methane/>.
11. (2023) Carbon Dioxide. Wisconsin Department of Health Services <https://www.dhs.wisconsin.gov/chemical/carbondioxide.html>.
12. Logue J M, Klepeis NE, Lobscheid A B, Singer BC (2014) Pollutant Exposures from Natural Gas Cooking Burners: A Simulation-Based Assessment for Southern California. *Environmental Health Perspectives* 122: 43-50.
13. Wallace L, Wang F, Howard Reed C, Persily A (2008) Contribution of Gas and Electric Stoves to Residential Ultrafine Particle Concentrations Between 2 and 64 Nm: Size Distributions and Emission and Coagulation Rates. *Environmental Science & Technology* 42: 8641-8647.
14. Tao C, He L, Zhou X, Li H, Ren Q, et al. (2023) Review of Emission Characteristics and Purification Methods of Volatile Organic Compounds (VOCs) in Cooking Oil Fume. *Processes* 11: 705.
15. Rondinella A, Andreatta F, Turrin D, Fedrizzi L (2021) Degradation Mechanisms Occurring in PTFE-Based Coatings Employed in Food-Processing Applications. *Coatings* 11: 1419.
16. Abdullahi KL, Delgado Saborit JM, Harrison RM (2013) Emissions and indoor concentrations of particulate matter and its specific chemical components from cooking: A review. *Atmospheric Environment* 71: 260-294.
17. Nicole W (2014) Cooking up Indoor Air Pollution: Emissions from Natural Gas Stoves. *Environmental Health Perspectives* 122: A27.
18. Lyu J, Shi Y, Chen C, Zhang X, Chu W, et al. (2022) Characteristics of PM<sub>2.5</sub> Emissions from Six Types of Commercial Cooking in Chinese Cities and Their Health Effects. *Environmental Pollution* 313: 120180.
19. Svedahl, S, Svendsen K, Qvenild T, Sjaastad AK, Hilt B (2009) Short Term Exposure to Cooking Fumes and Pulmonary Function. *Journal of Occupational Medicine and Toxicology* 4: 1-8.
20. (2022) Ambient (outdoor) air pollution. *World Health Organization* [https://www.who.int/news-room/fact-sheets/detail/ambient-\(outdoor\)-air-quality-and-health?gclid=CjwKCAjw69moBhBgEiwAUF Cx2H4c\\_GaJVmkMIgZVVVeCzsZYZRrg4Pz2A18y-YDUv2b3aGkIXwHTkRoC8EMQAvD\\_BwE](https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health?gclid=CjwKCAjw69moBhBgEiwAUF Cx2H4c_GaJVmkMIgZVVVeCzsZYZRrg4Pz2A18y-YDUv2b3aGkIXwHTkRoC8EMQAvD_BwE).

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