SEEING IS BELIEVING: VISUALIZING INDOOR AIR POLLUTION FROM GAS STOVES

PREPARED BY
Beyond Toxics, April 2023

AUTHORS
Mason Leavitt, Meet Panchal, Alyssa Rueda, Zach Mulholland and Lisa Arkin

Table of Contents

BEYOND TOXICS' MISSION

We envision a society where everyone has equitable access to healthy food and clean air and water, and underserved communities are included in decision making processes that affect them. Together, we move beyond the damaging environmental practices of the past and collectively work to support and maintain ecological resilience and balance.

ABSTRACT

Public health hazards of gas stoves are increasingly documented and continue to demonstrate an escalating concern around indoor air quality conditions. Even with scientific evidence and media attention, many residents have difficulty conceptualizing the problem of gas stove pollution. Beyond Toxics rented a Forward Looking InfraRed (FLIR) camera capable of visualizing gases generated by burning methane gas (which the gas industry refers to as "natural gas") in gas cooking appliances. The FLIR camera can visualize hydrocarbons that are released into the air from the combustion of methane gas. In addition, a Flow 2 air quality monitor measured levels of nitrogen dioxide (NO2) and volatile organic compounds (VOCs).

The equipment was deployed in 13 homes in Eugene and Springfield, Oregon. The equipment detected several indoor air pollutants, as well as rising NO2 and VOCs in each house. Findings suggest that the FLIR camera can be a powerful public education tool to help residents "see" pollution from gas stoves. Flow 2 results found that using one burner on low for under five minutes, combined with preheating an oven to 350 degrees, resulted in harmful, sometimes hazardous NO2 levels in six of thirteen houses. The report concludes with solutions and recommendations for improving indoor air quality for both homeowners and renters.

INTRODUCTION

Environmental and public health concerns related to indoor air quality are increasing due to the wide range of pollutants people are exposed to every day, as well as changes in social lifestyles. People typically spend 80% of their time indoors. With more people working from home and drastic changes in public health, weather, and wildfires keeping adults and children indoors, indoor air quality now has a greater impact on people's health (Liu et al., 2012).

This report focuses on a study of indoor gas appliances and their emissions in residential housing. Beyond Toxics conducted a pilot study in Eugene and Springfield, two mid-sized, conjoined cities in Oregon, during the first week of February 2023. The purpose of the study is to use a Forward-Looking InfraRed (FLIR) camera with optical gas imaging capabilities to visualize how unburned methane and toxic air pollutants are released into homes during the first few minutes of homeowners turning on their gas stoves (Teledyne FLIR, 2023). As a general note, the terminology "gas stoves" is used to encompass both appliances with a gas range and gas oven, as well as appliances with a gas range and electric oven. A Flow 2 air quality monitor is used simultaneously to measure the concentrations of nitrogen dioxide (NO2) and volatile organic compounds (VOCs) in the air of the homes when a gas stove is in use (Plume Labs, 2023).

Studies conducted as far back as the 1970s have shown that homes with gas stoves have higher rates of asthma and respiratory illnesses compared to homes with electric stoves. This is due to the exposure to air pollutants generated when burning methane gas (Melia et al., 1977). In the late 1990s, studies confirmed that NO2 emissions from stoves can contribute to respiratory issues (Hasselblad et al., 1992).

Today, researchers are aware of a range of pollutants contributing to poor indoor air quality from gas appliances and the illnesses associated with chronic exposure to these pollutants. As of 2023, there are more than 40 million methane gas stoves in American households, all of which contribute to nitrogen dioxide release, methane release, and public health concerns (Lebel et al., 2022).

People who rely on methane gas appliances to prepare food in their homes are repeatedly exposed to toxic chemicals, including NO2, particulate matter of all sizes (PMx), carbon monoxide (CO), and VOCs. These chemicals are formed from the heating and incomplete combustion of "natural" gas. Each of these pollutants has human health impacts associated with their exposure. Generally, pollutants are most harmful to vulnerable communities, such as children, elderly adults, people of color, and those with pre-existing adverse health conditions.

This report will summarize the relevant pollutants from "natural" gas usage in homes, along with their public health concerns and climate health concerns. Following the sections on methodology, results, and discussion, a range of solutions to mitigate the effects of gas stoves are explored, including technological and policy solutions.

EFFECTS OF GAS STOVE POLLUTANTS ON PUBLIC HEALTH

NITROGEN DIOXIDE

The EPA and many scientists have been warning people of the effects of NO2 exposure on human health for decades. Nitrogen dioxide frequently released inside a home triggers respiratory diseases and illness (Lebel et al., 2022). Studies have demonstrated a clear correlation between increased NO2 exposure, even as small as 10 parts per billion (ppb), and increased rates of mortality in older adults (Huangfu & Atkinson, 2020; Atkinson et al., 2018).

Recent studies have shown that children's asthma worsens with incremental increases of NO2 in the air. Increases of just 5 ppb with background levels of at least 6 ppb have been observed to have an effect on children's asthma (Belanger et al., 2014). Background NO2 levels differ between regions of Eugene and Springfield depending on proximity to industrial facilities and major transit thoroughfares. The Lane Regional Air Protection Agency (LRAPA) does not monitor NO2 in Lane County, making it difficult to establish an idea of background NO2 air pollution. Additionally, houses have varying degrees of porous exposure to outdoor air.

Other researchers have found in some instances, regardless of background levels, there is a measurable increase in asthma with increases of 15 ppb (Lin et al., 2013; Li et al., 2006).

In a study published by The Rocky Mountain Institute (RMI), scientists measured peaks in NO2 levels when cooking various foods indoors (Seals and Krasner, 2020). NO2 peaks in parts per billion (ppb) vary with different food preparations (Table 1). The EPA advises that adult individuals avoid exposure to NO2 levels at or above 100 ppb lasting an hour or longer (U.S. EPA Office of Air and Radiation, 2010). This recommendation is for outdoor exposure, as the EPA does not have indoor air quality standards.

Table.1. Measured NO2 Emissions from Gas Stoves

Measured NO2 Emissions from Gas Stoves	Peak (ppb)
Baking cake in oven	230
Baking meat in oven	296
Frying bacon	104
Boiling water	184

Table. 1. NO2 peak levels [in parts per billion (ppb)] from cooking various foods. Data from the Rocky Mountain Institute (RMI) (Seals and Krasner, 2020).

METHANE AND OTHER HYDROCARBONS

The chemical composition of "natural" gas is a combination of hydrocarbons which, according to the National Cancer Institute, may increase the risk of certain types of cancer (NCI, 2023). Commercial "natural" gas contains 85 to 90 percent methane, with the remainder being other hydrocarbons, nitrogen, and trace inert gases (U.S. EPA, 2020). Stoves leak 0.8% to 1.3% of methane unburned. This percentage is equivalent to about 500,000 cars' worth of emissions yearly in the U.S. (Lebel et al., 2022) Methane emissions significantly contribute to climate change, which presents multi-faceted risks to public health.

The World Health Organization (W.H.O.) states that climate change affects the major social and environmental determinants of health – including clean air, safe drinking water, sufficient food and vector-borne illnesses (W.H.O., 2021).

PM2.5 AND PM10

The health effects of the small airborne particulate matter referred to as PM2.5 and PM10 are well studied. It has been found that there is a strong association between PM2.5 and increased rates of respiratory disorders, cardiovascular disorders, and cerebrovascular disorders, as well as mortality rates (Dirgawati et al., 2019; Sharma et al., 2020). Epidemiological studies demonstrate an elevated risk for cardiovascular events with more exposure to PM2.5. These elevated cardiovascular events include stroke, arrhythmia, myocardial infarction (MI), and heart failure. Several studies have demonstrated that living in locations with high, long-term average PMx levels elevates the risk for cardiovascular morbidity and mortality (Simkhovich et al. 2008; Sharma et al., 2020).

PM10 pollution, as a bigger size of particulate matter, is observed to have immediate respiratory effects such as coughing. Children are especially vulnerable to the acute respiratory health effects associated with respirable particulate pollution (Pope III & Dockery, 1992). The long-term adverse health effects include an increase in asthma medication usage; an increase in the number of asthma attacks and pre-existing asthmatic experiences; attacks of chronic obstructive pulmonary disease; hospitalization for cardiovascular issues; and death from heart attacks, strokes, or respiratory issues due to these larger particles entering the lungs and heart (Donaldson et al,. 2001).

Notably, the combustion of fossil fuels is a substantial source of PMx, and Zhang et al. (2010), found that gas stoves produced twice as much PM2.5 as their electrical counterparts when cooking the same meal. In the same study, they noted gas stoves also produced more PM10 and ultrafine particulates, also known as PM1 (Zhang et al., 2010; Hu et al., 2012).

VOLATILE ORGANIC COMPOUNDS

Volatile organic compounds (VOCs) are a class of organic compounds that are produced from burning fossil fuels and are also found in many products. VOC chemicals have a low boiling point and a high vapor pressure at room temperature which results in the shared trait of easily becoming vapors or gasses (volatility) (Wi et al., 2020). Concentrations of VOCs are generally higher indoors than they are outdoors, this is why they are an important pollutant to mention when discussing indoor air pollution (Liu et al., 2012).

Breathing VOCs can irritate the eyes, nose, and throat; can cause difficulty breathing and nausea; and can damage the central nervous system along with other organs. In addition, some VOCs can react with other gasses and form different chemicals, acting as air pollutants once they are in the air. They are associated with the onset and exacerbation of asthma when exposure occurs, especially among children (Chin et al., 2013). Pregnant women exposed to VOCs can have those chemicals travel via the body into the fetus, which can lead their unborn babies to experience health impacts, such as anemia or low birth weight (Boyle et al., 2016).

Harvard researchers found 21 different federally hazardous VOCs leaking from gas stoves while the stove was in off mode. The most frequently detected VOCs are hexane, benzene, and toluene, which were found in 98%, 95%, and 94% of sampled houses (Michanowicz et al., 2022). Cooking with a gas stove increases indoor levels of VOCs, which are especially prominent in an unvented or poorly vented area (Guo et al., 2009). Benzene is known to cause blood disorders and blood cancers. Researchers in California estimate that the entire state's natural gas stoves emit the equivalent benzene emissions of 60,000 fossil fuel cars (Lebel et al., 2022). Exposure to benzene has a cumulative effect, meaning that small or chronic exposures can result in serious health disorders. Scientists suggest that although houses with gas stoves have levels of benzene within current health guidelines, the vapors still pose a danger to everyone breathing in chronic low levels of benzene.

Formaldehyde is another concerning VOC stemming from the use of gas stoves. Formaldehyde naturally occurs through the oxidation of hydrocarbons, which make up 99% of natural gas (U.S. EPA, 2020). Formaldehyde is used globally to produce resins for adhesives in mass-produced wood products, textiles, leather, rubber, and cement (Liu et al., 2012). All of which can be found in the homes of millions. Formaldehyde also works as a preservative and disinfectant in cosmetic products, pesticides, biological specimens, and human or veterinary drugs. There is a large spectrum of indoor formaldehyde emission sources due to its usage in many common-use products. This is coupled with a slow removal rate due to the sealed nature of indoor environments. All of this makes formaldehyde one of the most influential indoor air pollutants (Liu et al., 2012). Formaldehyde leads to cancer in people of all ages and causes lower respiratory infections in infants (National Cancer Institute, 2011; Roda et al., 2011). Lower heat settings on gas burners, particularly for simmering sauces and soups, can substantially expose individuals to formaldehyde (Poppendieck and Gong, 2018; Seals and Krasner, 2020).

CARBON MONOXIDE

Gas stoves emit low levels of carbon monoxide (CO) when turned on, and can emit high levels if the stove is malfunctioning. Oregon requires homes rented or sold to have CO alarms, however, alarms are typically fitted to sound only when CO levels are enough to cause serious acute health problems, and not for lower chronic exposure thresholds (Seals and Krasner, 2020). A study in California, where 70% of residents have gas stoves, found 5% of 316 homes exceeded the state's levels of 1-hour (20,000 ppb) and 8-hour (9,000 ppb) exposure limits (Beal, 2022; Mullen et al., 2013; Seals and Krasner, 2020).

GAS APPLIANCES RUN ON FRACKED GAS

Pollution associated with natural gas usage inside of homes, starts long before its use in gas appliances. Natural gas is a fossil fuel. The process of getting natural gas into millions of homes releases dangerous pollutants into the environment. Pollutants are released from the very beginning of natural gas discovery and extraction all through its distribution and usage. Fracking was introduced in the mid-20th century because it allowed drilling in shale reservoir rocks that were previously believed to be too impermeable. The process made gas extraction more economically feasible. Hydraulic fracturing requires millions of gallons of surface water, an array of chemical additives, and solids (i.e. sand). The water, chemicals, and solids are mixed together, then pumped into the ground under extremely high pressure. This creates fractures in the sediment to release the flow of gas (Madelon et al., 2011).

This technique threatens public health and environmental health all over the world. Many chemicals used to frack are known to cause damage to essential organs such as the lungs, liver, kidneys, and brain (Madelon et al., 2011). These chemicals can and have contaminated the air, soil, and water that people and animals are reliant upon. Most places with drinking wells that are tainted by fracking fluids are rural and underdeveloped, lacking political influence and economic prospects (Royte, 2012).

The consequence of groundwater and air pollution became so apparent to some countries that they outlawed the practice of fracking because “the comfort of life is adversely affected” (Holloway et al., 2013).

Once the fuel is extracted, it is then refined to “clean” the gas and separate the gas from anything unwanted. Refineries and petrochemical industries degrade the air quality because they release pollutants into the surrounding air, including VOCs (Ragothaman et al.,2017). After the gas is refined, the gas is distributed through underground pipelines to reach each consumer. In the United States, there are 2.56 million miles of natural gas pipelines transporting fracked gas to more than 75 million consumers (Anderson, 2020). The construction of each pipeline comes with the risk of explosion and pipeline development requires several acres of land (Peduzzi et al., 2012) (Holloway et al., 2013). Between 2000 and 2019, the Pipeline and Hazardous Materials Safety Administration (PHMSA) counted a total of 12,316 natural gas and hazardous liquid pipeline incidents (Anderson, 2020). The process is not safe and poses an even greater risk to people living in rural, lower-income, or vulnerable areas. Every fracture in the land to extract fossil fuels puts in jeopardy the stability of the land and the well-being of the environment.

METHODS

STUDY SITE

Beyond Toxics reached out to community members to gauge interest in participation. Recruiters looked for houses across neighborhoods in Eugene and opted to include 1 participant in Springfield.

Eventually, 13 residential homes with gas stoves were identified as candidates for the study. The construction years of the study locations range from 1910-2002. The stoves within these homes varied in manufacturers and ranged from the 1980s to 2020. A FLIR camera and Flow 2 meters were deployed in each house. The terminology “gas stoves” is used to encompass both appliances with a gas range and gas oven.

During the analysis of the Flow 2 readings, the two appliances— gas ranges with electric ovens and gas ranges with gas ovens— were separated into two groups to determine their individual rates of air pollution.

EQUIPMENT

Forward Looking InfraRed Camera

To visualize the hydrocarbons and volatile organic compounds (VOCs) released from gas stoves while in use, a Forward-Looking InfraRed (FLIR) GF320 camera is used. The FLIR camera is a portable optical gas imaging camera using infrared technology to visualize by-products of burning fossil fuels.

The camera is rated to pick up the pollutants listed in Table 2. A FLIR GF320 is typically intended to detect leaks in oil and gas facilities, however, the camera and technology are also equipped to visualize the burning of fossil fuels in homes. For this study, the camera is alternated between Auto mode and High Sensitivity Mode (HSM). Auto mode is an adjustment for optical gas imaging that automatically balances the image for the best brightness and contrasts to visualize the pollutants listed in Table 2. HSM is an adjustment method that shows a wider range of pollutants including those in Table 2 plus NO2, NOx, CO2, Formaldehyde, and CO.

Table. 2. *List of pollutants a Forward-Looking InfraRed (FLIR) GF320 camera can detect*

Methane	**Ethane**	**Propane**	**Butane**	**Benzene****
Ethanol	**Ethylbenzene**	**Toluene****	**Heptane**	**Hexane****
Xylene**	**Pentane**	**Methanol**	**Methyl Isobutyl Ketone (MIBK)**	**Octane**
Methyl Ethyl Ketone (MEK)	**Propylene**	**Isoprene**	**Ethylene****	

Table. 2. List of pollutants a Forward-Looking InfraRed (FLIR) GF320 camera can detect in both Auto mode and HSM. Highlighted in red are natural gas hydrocarbon ingredients the camera visualizes. Highlighted in yellow are VOCs the GF 320 can detect and are commonly found in residential natural gas. *** indicates status as a Federally Hazardous Air Pollutant (FHAP)*

Flow 2 Air Monitor

To quantify NO_2 and VOC emissions within the indoor air of the study sites, a Flow 2 monitor is used in all 13 locations. Flow 2 has two filters within its design to detect VOCs and NO_2. The filters are heated up to 250°C to break down the molecules and measure the energy of the molecules. Flow 2 uses light dispersion and a laser to count fine particles that are in the air. To ensure that the air entering the Flow 2 monitor is the same as its outside environment, there is a 5mm fan spinning at 15,000 rpm inside the device to control the air intake. The small and portable monitor is designed to provide real-time air quality measurements.

PROCEDURE

FLIR Camera

To capture video images of methane release from gas ranges in each study location, the FLIR camera was set up on a tripod for steady capture. The tripod was placed within five feet of the stove and the camera was pointed toward the burners and the oven door. To start the video imaging, one burner was turned on to a low setting for 1-5 minutes. During that time, the camera was also pointed toward ventilation hoods in houses that had them. The hoods were turned on for approximately one minute, to capture how the gas movements changed in the presence of a hood. For houses with gas ovens, the ovens were preheated to 350°F. Once the oven had reached the target temperature, the FLIR camera was focused on the oven door to capture gas movements as the oven door was opened. For the purposes of this case study, we observed emissions from cooktops and ovens as they were initially turned on or pre-heated. These are start-up conditions prior to cooking. Most recipes require longer cooking times and may also require multiple burners at higher temperatures. It is anticipated that polluting gasses from actual cooking and baking would continue to be emitted throughout the entire meal preparation. Our upcoming expanded study will demonstrate emissions while cooking and baking with gas appliances.

Flow 2 Air Monitor

As soon as each study location was entered, a timestamp was recorded to later correlate with Flow 2 measurements of NO_2 & VOCs. The Flow 2 monitor was placed near the gas stoves to replicate the chemicals a person could be exposed to in a kitchen when using the burners or opening oven doors. Accurate timestamps were used to later determine where and when there were changes in NO_2 & VOCs.

Time stamps for Flow 2 movements were recorded during the following intervals:

- Enter the house
- Turn on the oven
- Turn on the stove
- Exit the house

RESULTS

FLIR CAMERA FINDINGS

The combination of methane and other hydrocarbons with oxygen, plus a spark, produce an exothermic combustion reaction. An exothermic reaction releases stored energy in the form of heat, which heats cookware on the stove. Some residual heat is also contained in the by-product gasses from the incomplete combustion of hydrocarbons. The temperature difference between the by-product gasses and the surroundings, combined with the spectral filter of the FLIR camera allows us to "see" the plume of gasses. The chemicals that are formed from incomplete combustion result in a gaseous plume emerging from the burner. This plume cannot be seen with the naked eye (Figure 1(A)). HSM shows the plume of these by-product gasses: uncombusted hydrocarbons, CO2, NOx, NO2, CO, and VOCs including formaldehyde. The gasses are shown in varied tones ranging from white to gray to black in Figure 1(B).

The filters in the FLIR Camera's Auto mode look for specific VOCs and unburned hydrocarbons. As shown in Figure 1(C), there is a vaporous cloud above the central exothermic reaction and metal cooktop. The cloud includes unburned hydrocarbons and likely the following VOCs: Benzene, Ethyl Benzene, Heptane, Hexane, Toluene, and Xylene. There is no way to differentiate between the types of gasses the camera shows, however, the VOCs mentioned are typical products of combusting hydrocarbons with residential gas stoves (Michanowicz et al., 2022).

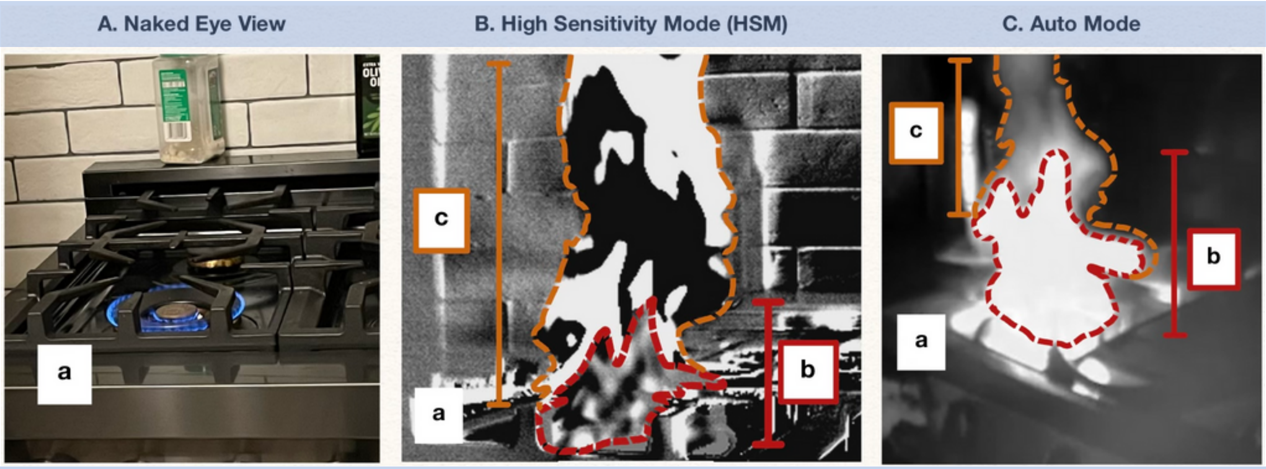
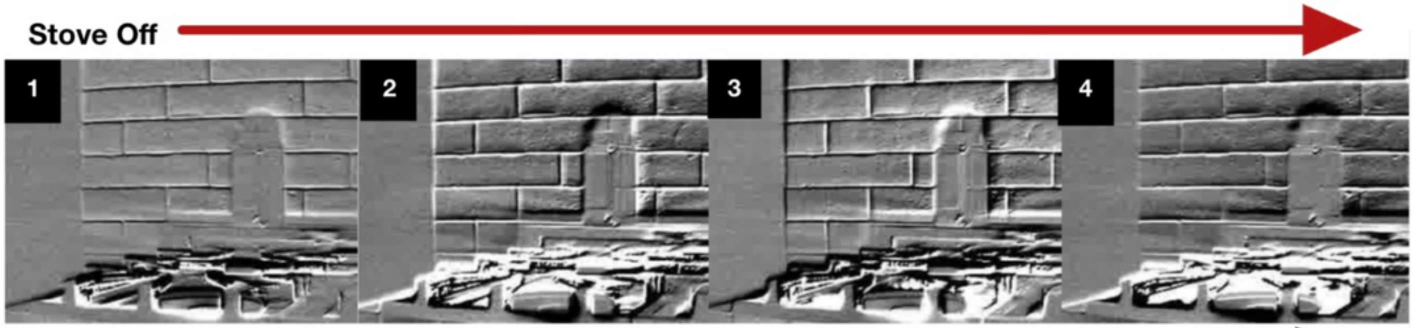


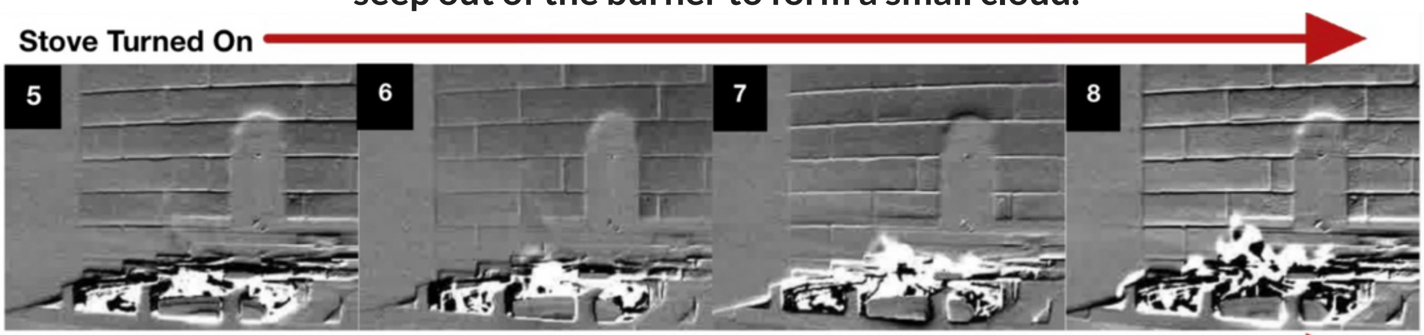
Figure. 1. (a) cooktop burner, (b) central area of exothermic combustion creating heat to cook and by-product gasses (outlined in dashed red line), (c) plume of by-product gasses emerging from combustion (outlined in dashed orange line).
(A.) Features the gas stove and cooktop burner captured on an iPhone camera. There are no methane fumes or volatile organic compounds visible to the naked eye when the stove is turned on. All that is visible is the blue flame that is used to heat cookware for food preparation.
(B.) Features the gas stove and cooktop burner in HSM captured with a FLIR GF320 camera. Above the intense exothermic combustion outlined in red (b), the camera detects a plume of CO2, NOx, NO2, CO, and VOCs outlined in orange.
(C.) Features the gas stove and cooktop burner in Auto mode captured with a FLIR GF320 camera. The camera's Auto mode shows select VOCs (Benzene, Ethyl Benzene, Hexane, Heptane, Toluene, and Xylene) and unburned hydrocarbons, outlined in orange, as vapors emerge above the central area of exothermic combustion-- outlined in the red dashed line (b).

Figure. 2. Frame-by-frame sequence of a FLIR camera video footage showing a chronological process of a stove going from off to on.

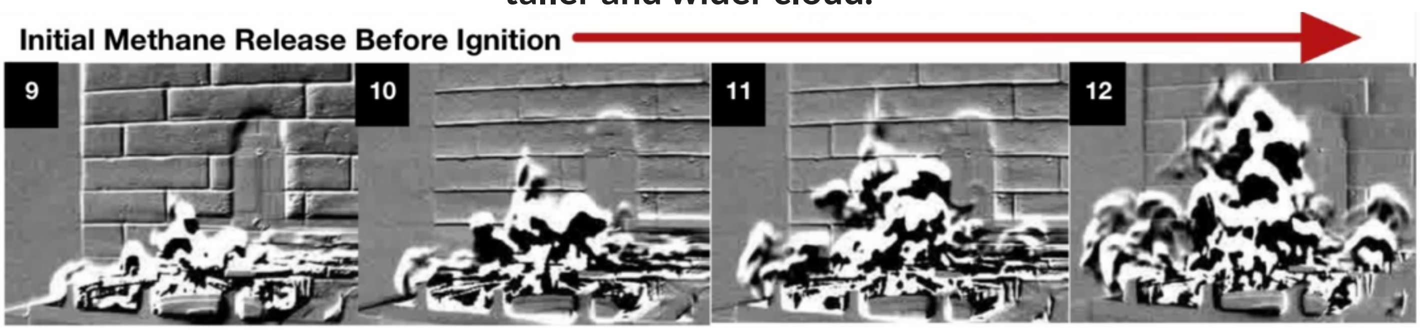
(Frames 1-4) There is no methane and hydrocarbon seepage because the stove is turned off.



(Frames 5-8) When the stove is turned on, we can first see methane and other hydrocarbons seep out of the burner to form a small cloud.

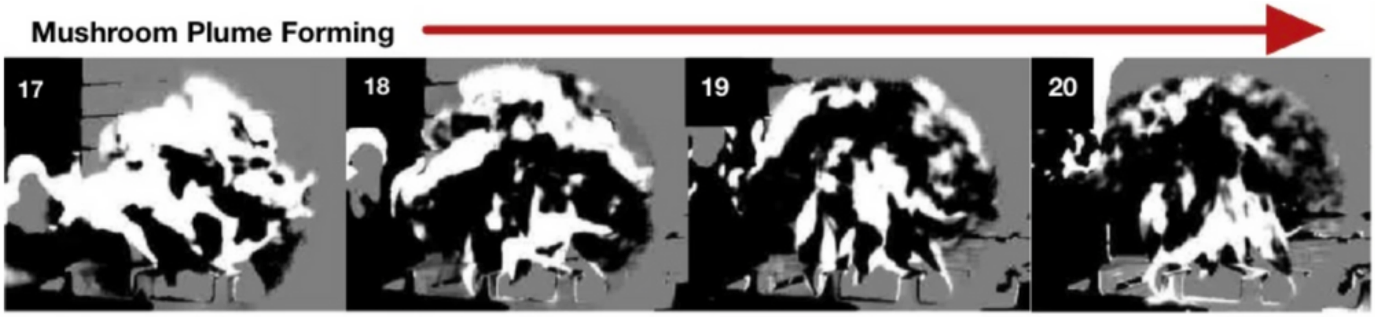


(Frames 9-12) The methane and hydrocarbons accumulate above the burner to form a taller and wider cloud.

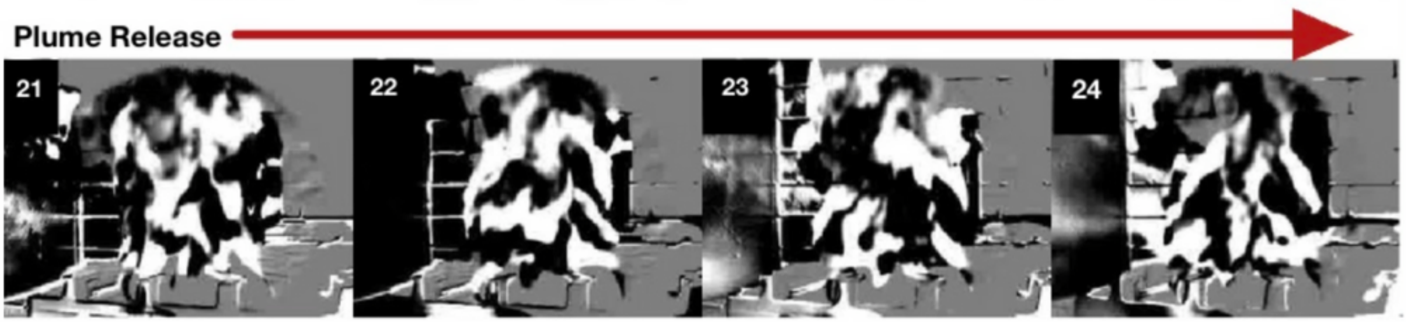


(Frames 13-16) The stove's electric ignition spark goes off and ignites the gas to form the blue flame used to cook.

(Frames 17-20) The initial plume of combustion by-product gasses forms a mushroom shaped plume above the stove burner.



(Frames 21-24) The combustion of by-product gasses creates a continuously moving upward plume to fill the space. The time elapsed between the entirety of the frame-by-frame sequence is approximately 3 seconds.



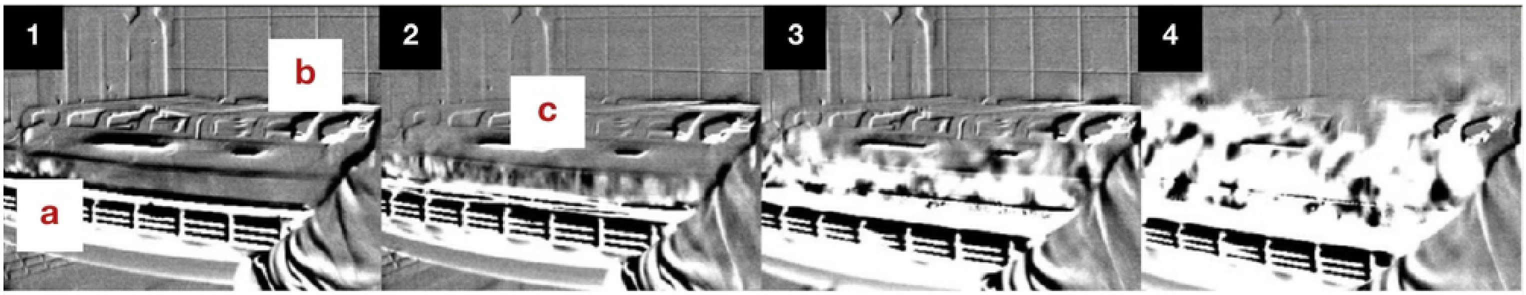
FLIR CAMERA AND OVEN EMISSIONS

The ovens within eight study locations were preheated to 350°F. After reaching the target temperature the oven doors were opened while the FLIR camera recorded the event. In HSM mode, the FLIR camera captured a thick plume of gas escaping the oven as the door was opening for roughly 15 seconds (Figure 3). The plume contains emissions of CO2, NOx, NO2, CO, and VOCs entering the surrounding kitchen area. While preheating the oven, before the door was opened, gasses were also observed venting out from the back of the range through small oven vents. As discussed later, it appears that hydrocarbons, including methane and TVOCs, are emitted in substantial quantities from gas ovens, as measured by Flow 2. Figure 3 shows an oven door opening after preheating to 350°F.

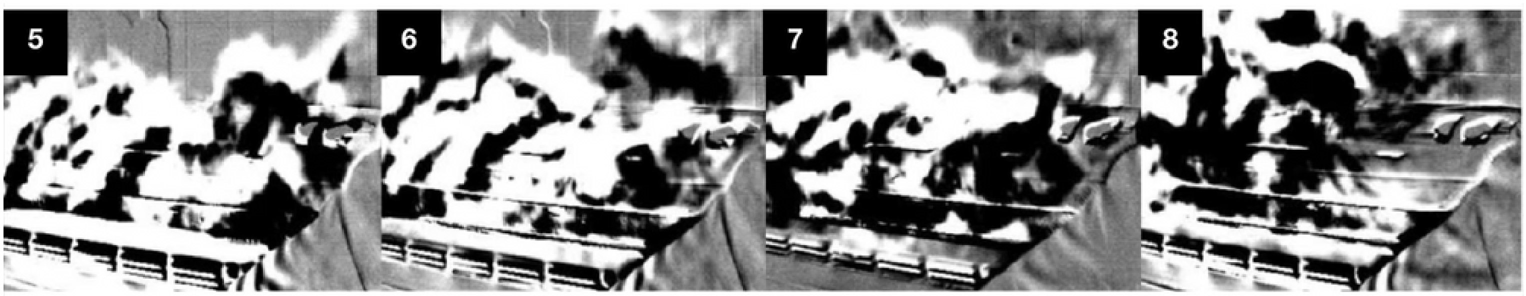
Figure. 3.

Frame-by-frame HSM FLIR Footage of a preheated oven door opening.

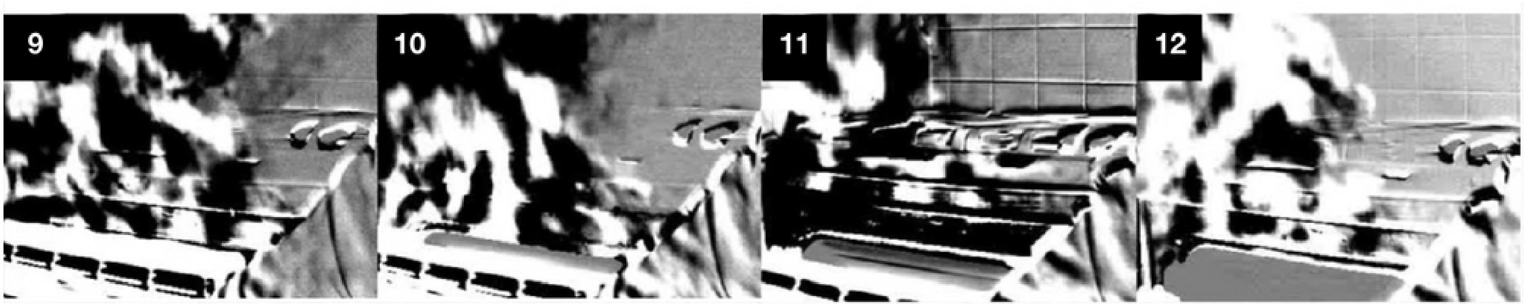
(Frame 1) Captured here is an oven preheated to 350°F, (a) depicts the edge of the oven door and the oven handle, (b) depicts the gas stove burners on top of the oven. (Frame 2) (c) indicates emissions of CO_2, NOx, NO_2, CO, and VOCs escaping the oven as soon as the oven door begins to open.



(Frames 3-10) Captured in the frames is a growing cloud of pollution leaving the oven and entering the kitchen as the door fully opens.



(Frames 11-12) Featured is a shrinking cloud of pollution coming from the oven as the majority has escaped the oven and entered the surrounding area.



FLIR CAMERA, VAPORS AND VENTILATION

Two of the thirteen kitchens had no ventilation at all. Seven of thirteen had ventilation hoods, and they differed in their effectiveness to capture and remove gas emissions. As viewed through the filters on the FLIR camera, six of the seven flat ventilation hoods seemed ineffective in capturing and ventilating the fumes (see Figure 4A for reference). One of those six ventilation hoods merely covered the back row of stove burners and failed to capture any pollutants produced by the front burners. The seventh hood worked effectively only when a window right next to the stove was opened to create an airflow that could guide more pollutants into the ventilation system.

Three houses had commercial kitchen-sized hoods, and two of the three were residential co-ops with commercial-grade gas stoves and ventilation hoods. These kitchens are atypical because they are designed to serve up to 25 students, and the larger usage demand requires gas stoves and more powerful ventilation. The other household selected a commercial hood due to their large kitchen and aesthetic look. Commercial-sized hoods offer a wide catchment basin that can more effectively pull in a greater quantity of air to trap the pollutants post-combustion (Figure 4C).

Two hoods were parallel to the top of the range, while the third had a 45-degree angle from the ceiling to the wall (see Figure 4B for example). The FLIR camera was able to make the path of the rising pollutants visible. The commercial hoods set parallel to the stove top are more effective at capturing the expanding cloud of hydrocarbons and other pollutants compared to the angled commercial hood (Figure 4B). The angled hood was ineffective because a significant portion of the plume of pollutants was blown around the sides of the catchment area. This could be due to the natural airflow of the kitchen in combination with the hood's catchment basin being angled in such a way that pollutants were circulated past the side of the hood. See Figure 4 for a reference of the ventilation hood designs.

Figure. 4. Stove Ventilation Hoods

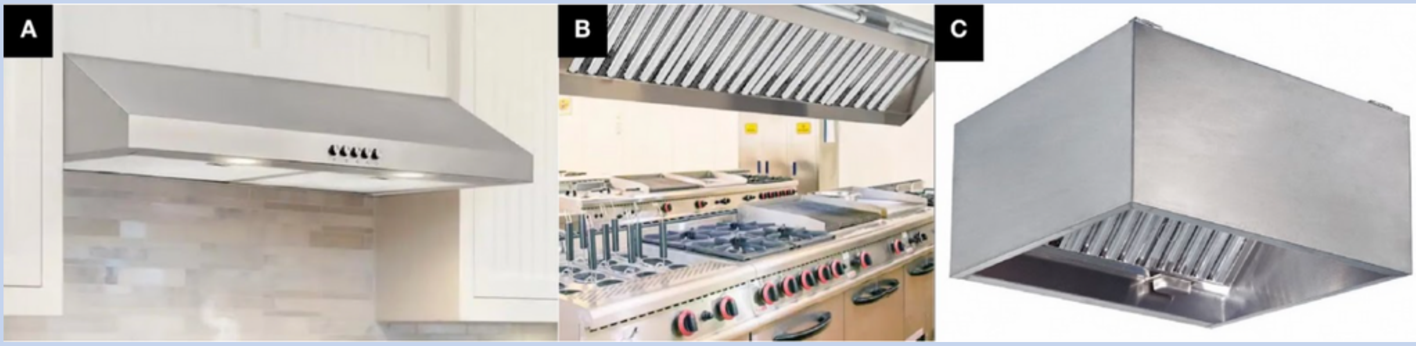


Figure. 4. (A) This is a standard range hood. This is ineffective in capturing fumes from cooking because the flat surface of the hood allows the fumes to accumulate near the fans and disperse into the kitchen before they can get sucked in by the fans. (B) This is a 45-degree angled hood, which is observed to be ineffective in capturing all fumes from cooking due to the migration of the rising plume of pollutants escaping around the sides of the fan area. (C) This hood catchment basin is situated parallel to the stovetop and the fan is set more deeply into the walls of the ventilation system. The large catchment area was observed to be better at capturing and holding onto the air pollutants from cooking prior to venting outdoors.

Disclaimer

Beyond Toxics does not promote any particular products.
Image sources: The Home Depot (A & B), Grainger Industrial Supply (C)

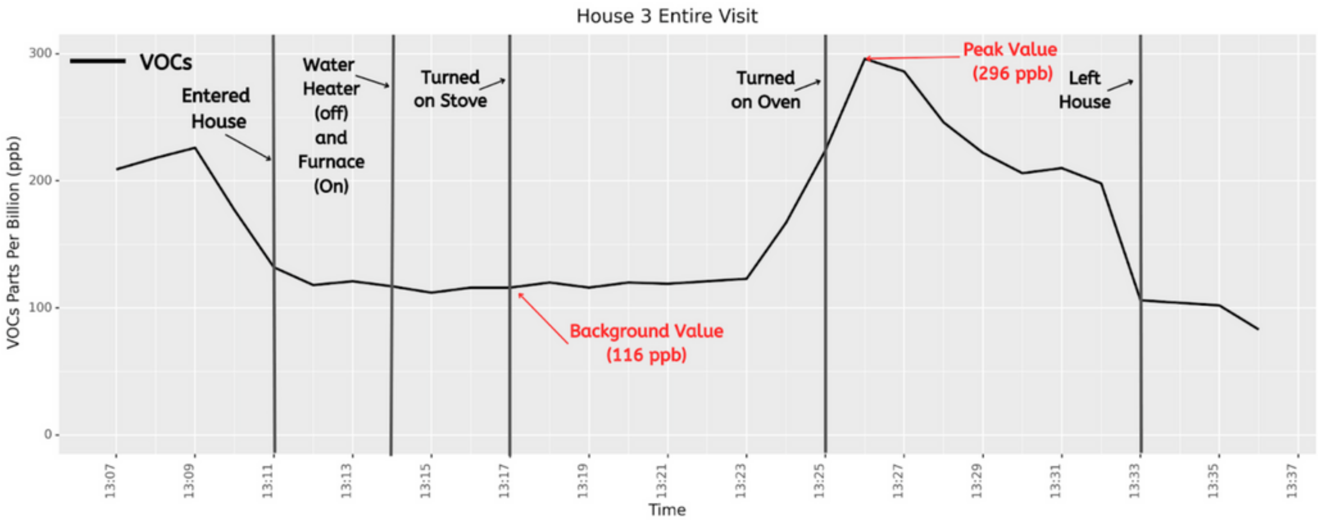
FLOW 2 MEASUREMENTS OF VOLATILE ORGANIC COMPOUNDS (VOCS)

Flow 2 is capable of measuring the concentration of Total VOCs (TVOCs) in the air. This equipment does not differentiate individual VOCs such as benzene or formaldehyde. It should be noted that the number of VOCs measured cannot be entirely attributed to the usage of gas stoves because there are many household sources of VOCs, including but not limited to scented candles, aerosol sprays, cleaning products, deodorizers, carpets, wood flooring, and more. However, we can look for spikes in VOCs correlating with the use of natural gas stoves as a product of the incomplete combustion of hydrocarbons.

To determine increases in the presence of VOC pollution, we measured the initial background value of VOC pollution when we entered the kitchen prior to turning on the gas for the stove or oven. Peak VOC value was then measured while the stove and oven were running. The first value (background level) was subtracted from the second value (air quality after a gas stove or oven was turned on) to measure the increase in VOCs. For example, if a house had an initial background measurement of 60 ppb for VOCs before the oven was turned on, and, after turning on the oven, VOCs peaked at 104 ppb, the increase would be 44 ppb. This is shown in the graph in Figure 5.

Figure. 5.

Measured Background and Peak Levels of TVOCs. TVOC levels measured by Flow 2 during a visit to houses 3 and 10. Red text calls out the background and peak levels used to determine an increase in VOCs.



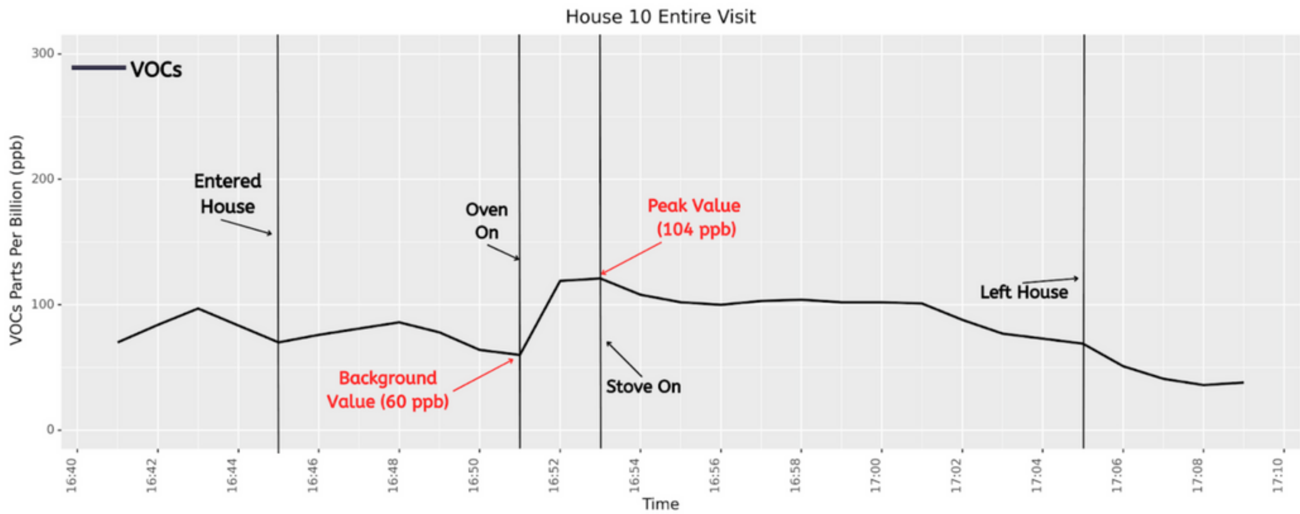


Figure. 5. VOC levels measured by Flow 2 during House Visits 3 and 10. The vertical y-axis shows the level of VOCs in ppb (parts per billion). The horizontal x-axis shows elapsed time in hours and minutes in 24-hour clock time (For instance, 1:00 pm = 13:00 hrs., 2:00 pm = 14:00 hrs.). The red text calls out the background and peak levels used to determine an increase in VOCs. In House 3, the total elapsed time from turning on the stove to the peak rise in VOCs was 9 minutes. In those 9 minutes, VOC increase is 180 ppb. In House 10, the total elapsed time from turning on the oven to the peak rise in VOCs was 2 minutes. In those 2 minutes, VOC increase is 44 ppb.

FLOW 2 MEASUREMENTS NITROGEN DIOXIDE (NO2)

Residential houses included in this case study contained two possible sources of NO2:

1) Background levels from outdoor residual emissions such as cars and industrial sources.
2) Gas stoves and ovens.

Rapid spikes of NO2 measured by the Flow 2 meter correlated with the combustion of methane gas from turning on the gas stoves. The same process is detailed in VOCs to measure the background levels and peak concentration to determine increases in NO2 air pollution.

There are two categories of natural gas stoves included in our data. First, appliances that were all natural gas for both the range and oven; and second, appliances that used natural gas for only the range and electricity for the oven. In both groups, a single stove burner was turned on low for 1-5 minutes. Where applicable, gas ovens were preheated to 350°F. Average data for houses with gas ovens are graphed separately from those with electric ovens (Figures 6, 7). The results in Figure 6 show that gas ranges with gas ovens resulted in far more NO2 in the air and moderately more VOCs than gas ranges with electric ovens.

Figure. 6.
Average NO2 & VOC increase for houses with a gas range and gas oven

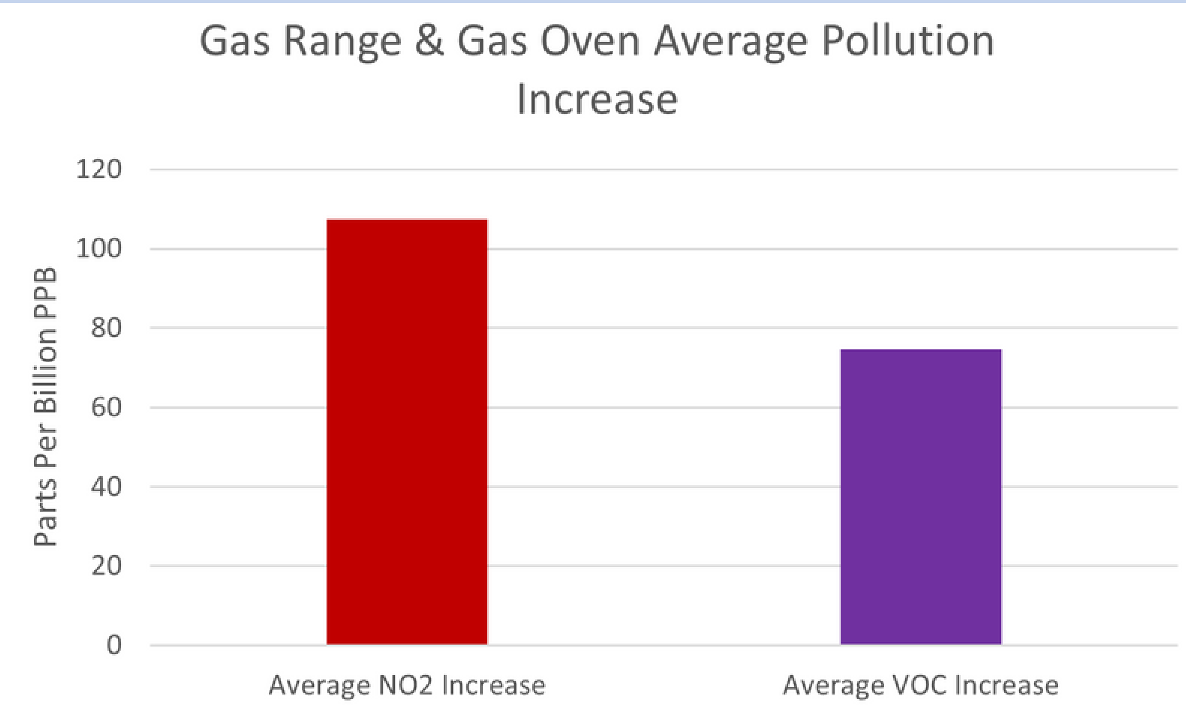


Figure. 6. The graph shows the average peaks from eight houses of NO2 and VOCs in parts per billion (ppb) after a gas stove or gas oven was turned on. The red bar represents average NO2 levels. The purple bar represents the average VOC levels.

Figure. 7.

Average NO2 & VOC increase for houses with a gas range and electric oven

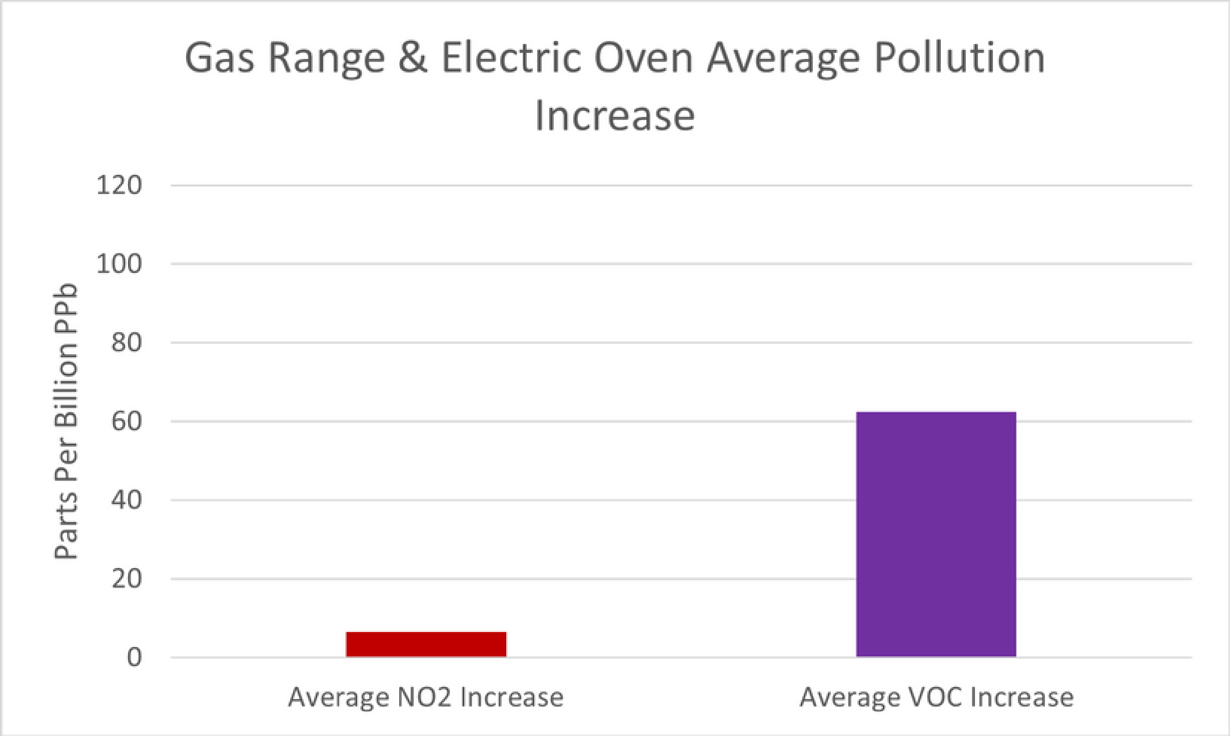


Figure. 7. The graph shows the average of five household peaks of NO2 and VOCs in parts per billion (ppb) after a gas cooktop was turned on. The red bar represents average NO2 levels. The purple bar represents the average VOC levels.

One way to understand NO2 from a public health perspective is to convert the ppb values to the Plume Air Quality Index (P-AQI). Figure 8 displays this conversion. The P-AQI follows the World Health Organization (WHO), the international public health agency overseen by the United Nations. Plume Labs states that the company uses WHO guidelines as well as international standards developed by the United States Environmental Protection Agency (EPA) to define the Plume AQI and its seven associated categories. PAQI categories of air quality are listed below in Figure 8. Measurements of NO2 in ppb are converted into PAQI, and graphed with the health risk levels.

Flow monitors only provide a measurement of total VOCs. They are not designed to differentiate which VOCs are in the air. Due to this limitation, the PAQI scale is not appropriate to analyze individual VOC levels inside homes and their health impacts. There are many different VOCs, and each has different levels of chronic exposure leading to negative health outcomes. However, the air quality monitoring collected for this project clearly shows an increase in VOC concentrations correlating to the time a gas stove was turned on.

FIGURE. 8.

Plume Air Quality Index (PAQI)

NO2: 515+ (ppb) PAQI: 200+	Constitutes emergency conditions. Harmful effects can happen to anyone. Avoid any physical activity. Even short-term exposure can be hazardous.
NO2: 106-315 (ppb) PAQI: 101-200	Surpasses WHO's hourly exposure limit. Individuals, especially vulnerable populations, likely experience adverse health effects.
NO2: 44-106 (ppb) PAQI: 51-100	Over WHO's daily exposure limit. Everyone may experience health consequences from prolonged exposure. Sensitive population must take extra precautions.
NO2: 22-42 (ppb) PAQI: 21-50	Above WHO's annual exposure limit. However, only vulnerable populations are likely to experience health consequences from prolonged exposure.
NO2: 0-21 (ppb) PAQI: 0-20	Healthy range. WHO rates this as a safe level of chronic exposure. Ideally, everyone's average exposure stays within this range over a year.

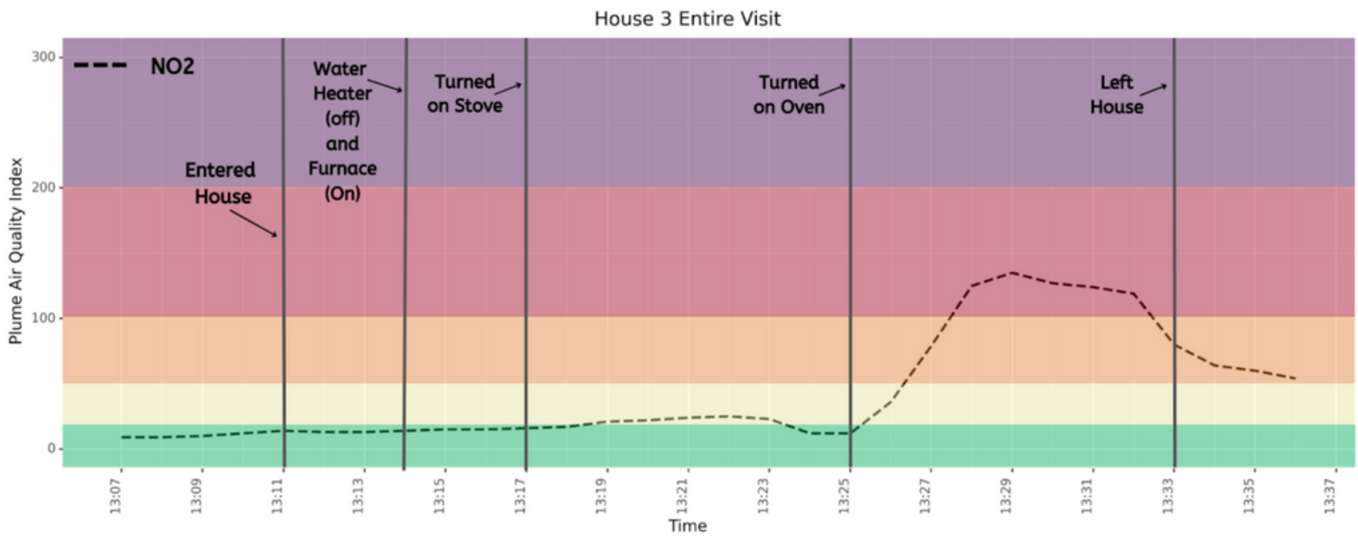
The left column of the legend features the ppb levels of NO2 with the converted PAQI range values. The middle column features a color assigned to the health exposure thresholds. These colors are used in the graph below to indicate the level of known harm with the level of NO2, measured in ppb, that was measured in each kitchen. Each PAQI range and color is associated with a description. To learn more about Plumes Air Quality Index, visit the PlumeLabs website here.

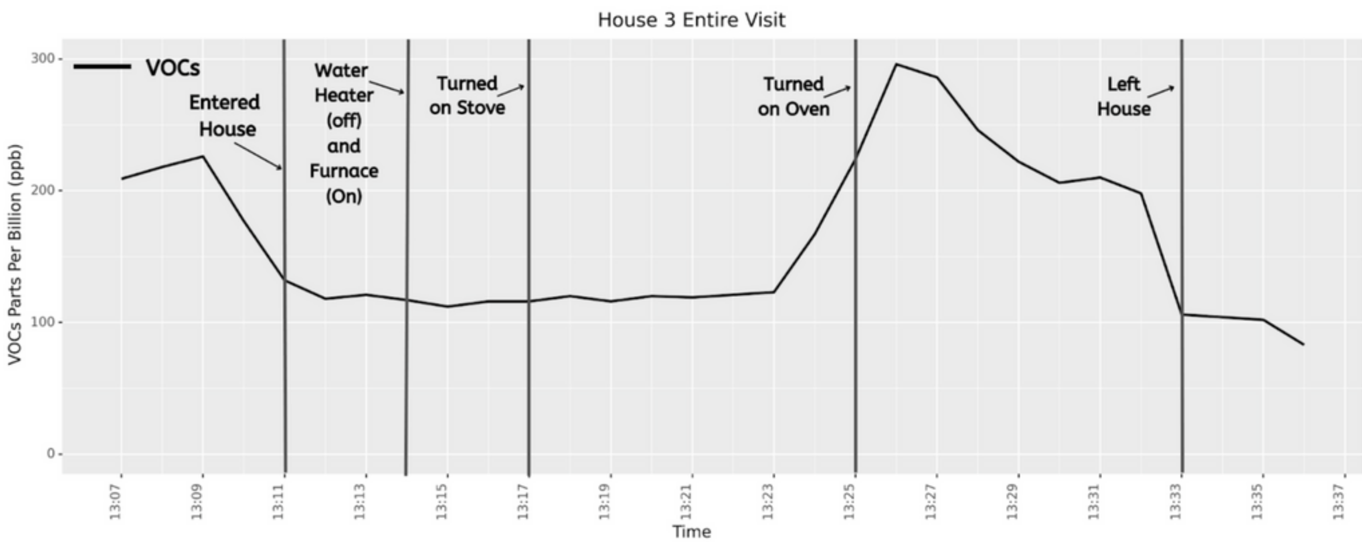
NO2 & VOCS IN HOUSE 3

The Flow 2 Air monitor was used and placed on the kitchen countertop to monitor VOCs and NO2 in House 3. A subtle increase in both pollutants as measured in ppb for VOCs and PAQI for NO2 (shown along the y-axis) is visible when the stove is turned on at 13:17. NO2 went from a PAQI of 16 before peaking at 25 PAQI (yellow- negative health outcomes for vulnerable populations over long periods of time) five minutes later at 13:22. In the same time frame, VOCs increase from 116 ppb to 167 ppb just before turning on the oven. Turning on the oven at 13:25 saw a steeper increase for both pollutants. NO2 increased from 13 PAQI (green- safe) at 13:25 to 181 PAQI (red- everyone can experience negative health outcomes regardless of how long they are exposed). VOCs crested at 286 ppb. The Flow 2 monitor began to move away from the kitchen before 13:33 and eventually was removed from the house.

FIGURE. 9.

Graphing the rise in NO2 and VOC levels during House 3 visit



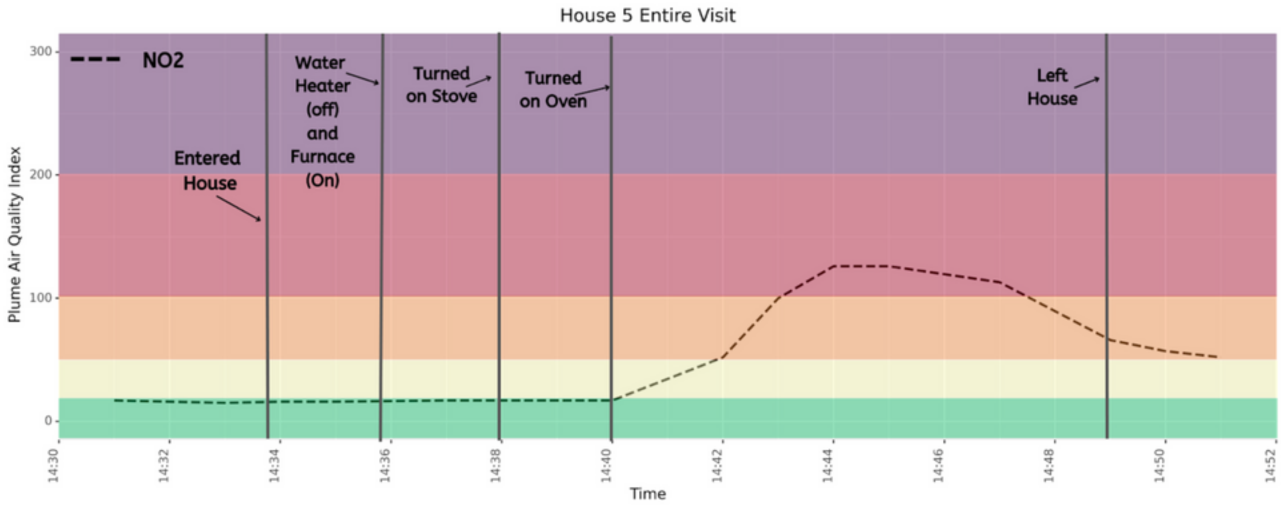


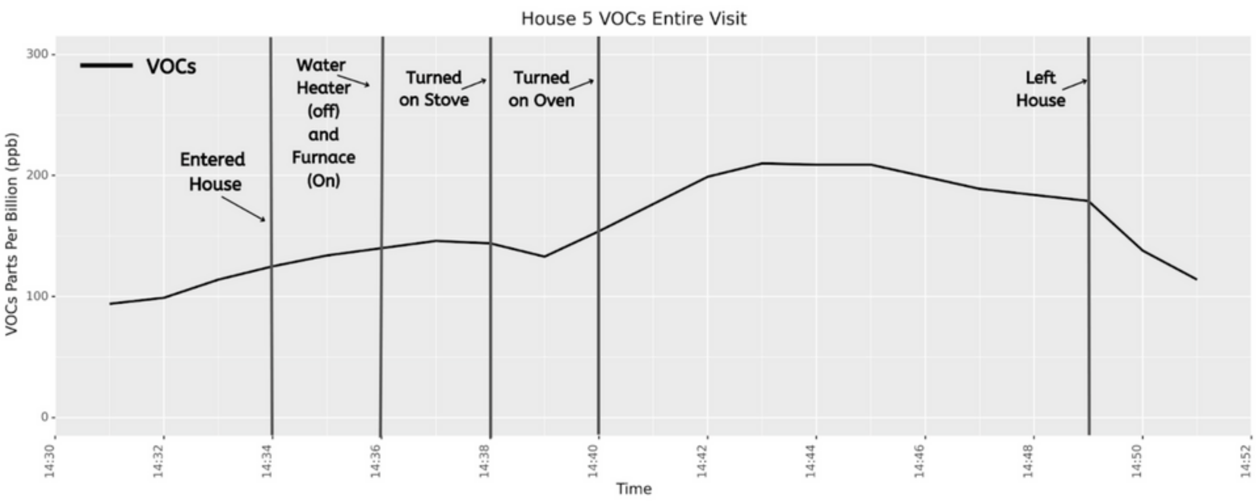
NO2 & VOCS IN HOUSE 5

The Flow 2 Air monitor was placed on the kitchen countertop to monitor NO2 and VOCs in house 5. The stove and oven were turned on at 14:38 and 14:40 respectively. NO2 started at a background PAQI of 17 (Green- safe), and VOCs started at 154 ppb. NO2 peaked at 126 PAQI (Red- everyone can experience negative health outcomes regardless of how long they are exposed). VOCs peaked at 14:43 to 210 ppb. The team remained in the kitchen the rest of the visit, but turned off all gas by 14:45.

FIGURE. 10.

Graphing the rise in NO2 and TVOC levels during House 5 visit.



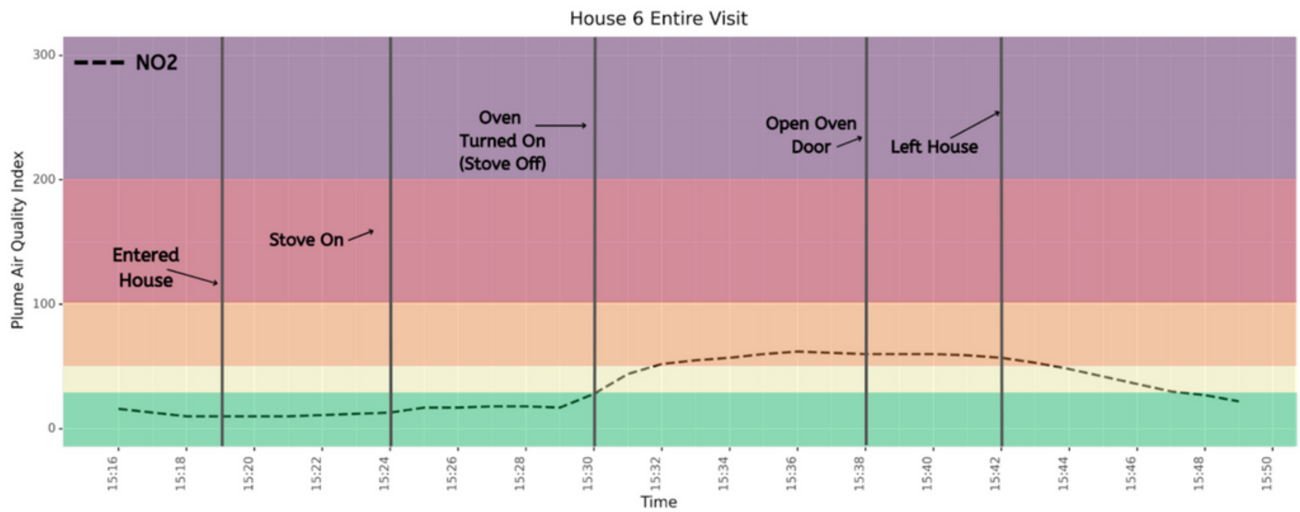


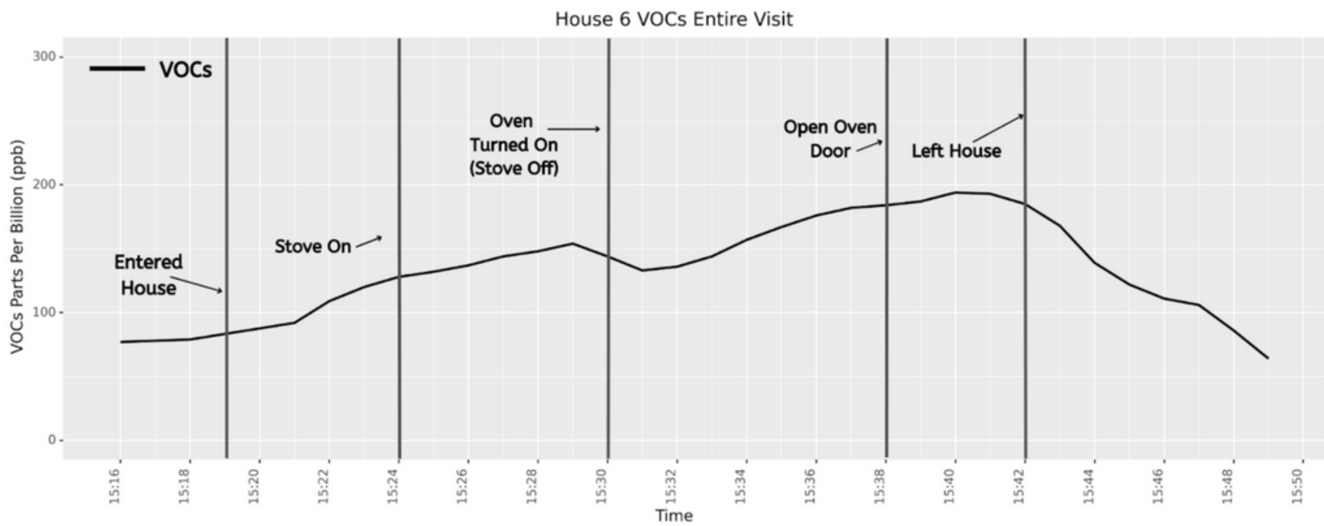
NO2 & VOCS IN HOUSE 6

The Flow 2 Air monitors were placed on the kitchen countertop to monitor NO2 and VOCs in house 6. The stove was turned on for three minutes at 15:24 seeing a minor increase in NO2 from 13 PAQI (Green- safe) to 20 PAQI (Green- safe), and an increase in VOCs from 128 ppb to 154 ppb. The oven is turned on at 15:30. NO2 can be seen gradually increasing from 20 PAQI (Green- safe) to 62 Plume AQI (Orange- unhealthy for everyone if exposed for an hour or more and vulnerable groups might experience symptoms) at 15:36. VOCs also increased from 144 ppb to 194 ppb at the peak after opening the oven door. At 15:42 the air monitor is out of the house and the AQI can be seen decreasing.

FIGURE. 11.

Graphing the rise in NO2 and TVOC levels during House 6 visit.



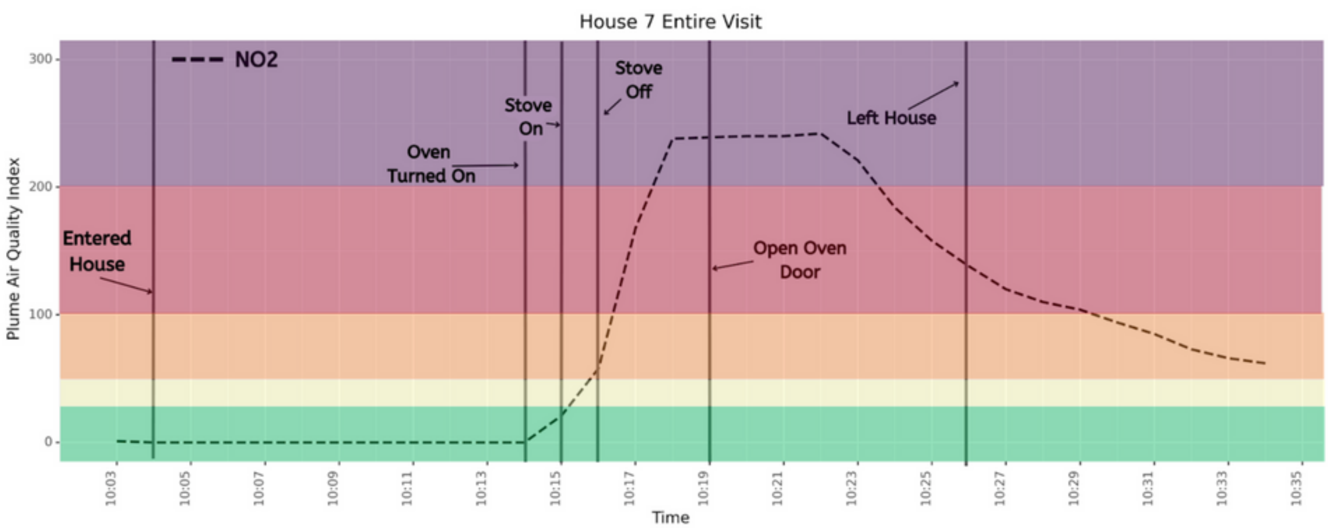


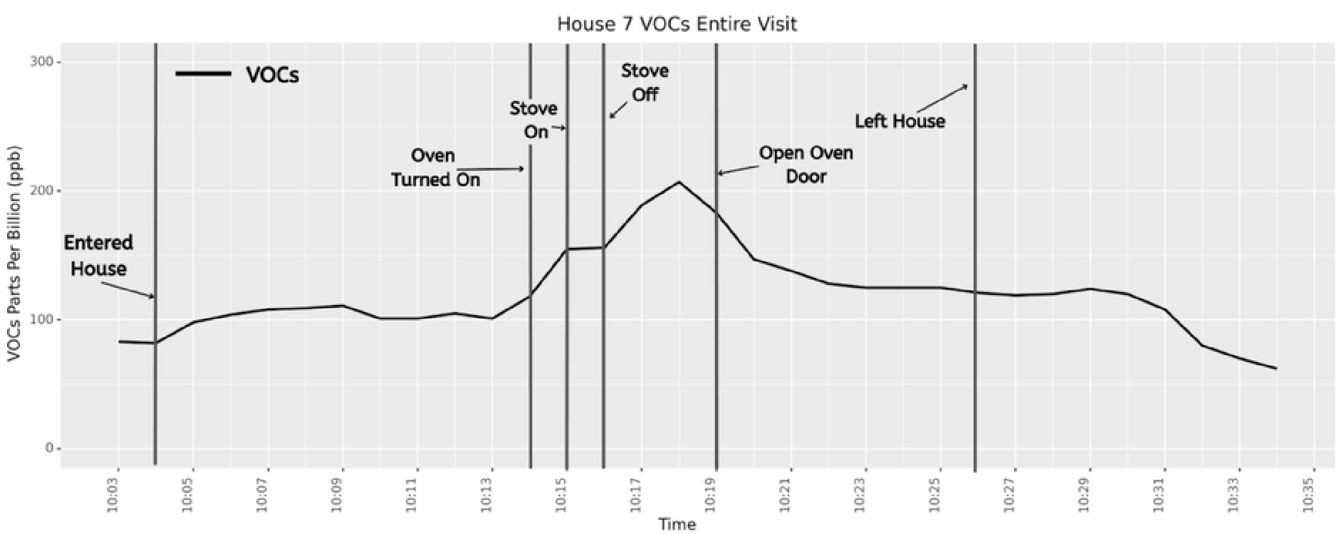
NO2 & VOCS IN HOUSE 7

The Flow 2 Air monitor was used and placed on the kitchen countertop to monitor NO2 and VOCs at house 7. At 10:14 the oven was turned on quickly followed by the stove at 10:15. NO2 rose from 21 PAQI (Yellow- unsafe for vulnerable groups over long periods of time) to 409 PAQI (Purple- hazardous for everyone. Leave the area if possible). This was the highest value recorded over our study, and could be due to the house's very small kitchen size and lack of ventilation. Additionally, this resident also had the burner on for the longest because they were fascinated by the camera footage. VOCs also rose rapidly from 155 ppb to peak at 207 ppb at 10:18 before slowly plateauing out at an elevated level from the starting background and decreasing after exiting the house.

FIGURE. 12.

Graphing the rise in NO2 and TVOC levels during House 7 visit.





SUMMARY

Gaseous plumes of hydrocarbons, VOCs, NO2, and other pollutants were made visible by footage taken with the FLIR camera in HSM and Auto Mode. These gasses are the result of incomplete combustion of methane gas. The majority of ventilation systems ineffectively captured gasses, allowing pollutants to circulate inside the kitchen air without being vented to the outside. The results of the FLIR camera visualizations were consistent between all thirteen participants' houses.

FLOW 2 results varied. All houses observed an increase above background levels in NO2 ranging from 2 ppb to 409 ppb. The Plume AQI scale was used to correlate ppb measurements with health standards recommended by WHO (Figure 8). Similarly, all houses also experienced an increase in VOCs above background levels. The VOC increases ranged from 7 ppb to 127 ppb. Due to a device malfunction, VOC data from one house was disqualified.

DISCUSSION

FLOW 2 AIR POLLUTANTS

During our visits six out of the total thirteen houses experienced a NO2 spike of at least 15 ppb, which Lin et al. (2013) and Li et al. (2006) cite as substantial enough to exacerbate symptoms for children with asthma. Nine of the thirteen houses had NO2 levels increase by at least 5 ppb over initial backgrounds of at least 6 ppb, which Belanger et al. (2014) cited as a condition for increased asthma symptoms among children.

Five of thirteen houses recorded NO2 concentrations that reached levels WHO recommends keeping exposure limited to an hour. All of those houses had gas ovens. Three of those five reached levels beyond the hourly exposure recommendation, which WHO advises people of all health conditions to avoid. One of those five houses reached a threshold WHO recommends leaving the area if possible and minimizing all physical exertion that requires additional breathing. The house in question had a small, closed kitchen with no ventilation.

The increase in VOCs when using gas appliances is concerning but difficult to analyze without more advanced equipment. More precise methods such as capturing air samples and using chemical laboratories to analyze the content of air in gas kitchens would be required in order to determine the health implications of chronic exposures to gas stove VOCs in residential homes.

It is important to note that turning on a burner for 1-5 minutes is only the initial activity a person would do when cooking. A few minutes is just enough time to heat up a pan to begin cooking. Typically, a resident would have their burner on for many more minutes, potentially hours depending on the recipe.

A similar scenario would occur in regards to ovens. Heating an oven to 350°F is, typically, the minimum requirement for baking. Many recipes call for higher temperatures, and gas is burned continually to maintain an oven temperature during the time it takes to warm-up, bake or broil food. Every time heat is lost by opening an oven door, the temperature inside the oven drops, causing more gas to be used to return the oven to the set cooking temperature, more pollutants are released and a continuing build-up of harmful chemicals fills the kitchen space.

VENTILATION

The camera footage, as well as scientific research, indicate that the type and quality of kitchen ventilation matter. Larger catchment basins, a design that is parallel to the cook top, higher air flows, and broader range coverages all increase the effectiveness of ventilation. However, the households participating in this study rarely had adequate ventilation, if any at all. Six kitchens had common consumer-grade flat ventilation systems which were insufficient to capture pollutants. Two kitchens had no ventilation at all, and owners cited the high cost of renovation as a hindrance to install hoods. Three kitchens had commercial grade ventilation systems, two of which were able to capture and vent gasses generated from turning on the gas stove and/or oven.

Scientific literature enhances our understanding of the patterns the FLIR camera visualized. One study found that fan speed, hood size, and kitchen size all contribute to variations in NO2 concentrations in residential households. Smaller kitchens often lead to higher NO2 concentrations, presumably because air pollutants accumulate in the small area. Similar to our camera findings, the study notes that small hood catchment areas and hoods that don't cover all burners are less effective at reducing pollutants. Scientists also found that higher vent speeds cleared air pollution more effectively, which is something not measured in this study.

Another study tested 7 different models of ventilation and found they captured as low as under 15% of pollutants and as high as 96% depending on the kitchen setup and model attributes (Delp & Singer, 2012). Even senior officials of the American Gas Association cautioned against the idea that range hoods would fully solve the problem of exposure to pollution from gas stoves (Leber, 2023).

Sun and Wallace (2021) note a substantial gap in data collection between residential cooking and consistent use of ventilation. Upon setting out on their own study in Canada, the authors found hoods were only used for 12% of cooking events. Windows were used for 15% of cooking events. Residents employed a combination of a hood and an open window to create an effective path of ventilation for pollutants in only 2% of cooking events. Cross ventilation created by opening a window was the only means of increasing the effectiveness of flat, typical household ventilation hoods. Neglecting to use a range ventilation hood when cooking with a gas range is dangerous due to the continuous emissions of harmful air toxics.

One study compared three intervention methods in unvented gas appliance kitchens to determine which was most effective to reduce NO2 levels. Researchers randomly selected participants to install a ventilation system, or a portable air filter, or replace their gas stoves with induction burners. Results showed that the air filter and induction stoves led to statistically significant decreases in NO2 levels throughout the house, while households with newly installed ventilation hoods actually showed an increase in NO2 levels, although not statistically significant. The researchers cited a few potential reasons for this discrepancy. Firstly, most vents do not operate at the airflow that manufacturers purport they do (Paulin et al., 2014), which makes sense given Delp's and Singer's (2012) findings.

Secondly, the study had no means of ensuring that residents used the vents. Therefore, it is unsurprising that vents were not effective in reducing NO2 levels in practice (Paulin et al., 2014).

Finally, it should be pointed out that using a gas stove with an effective ventilation system including adequate size, airflow, range coverage, and the ability to vent outdoors would simply transfer indoor air pollution to outdoors, contributing to smog, ground-level ozone, toxic air and climate warming. Thus, the problem of gas stove pollution would not be solved, but merely relocated.

PARTICIPANT REACTIONS

FLIR cameras are used by the oil and gas industry to detect leaks and other emission problems. Footage of gaseous emissions while turning on a gas burner or gas oven as captured by the FLIR camera inside homes was shocking to residents. They were incredulous to see plumes of gas emerging from their stoves, something they have never seen with the naked eye and had never suspected was occuring. A few participants asked, "Is this normal!?" Others exclaimed, "Wow, that is scary!" Many talked about the hours they spend cooking and wondered about the cumulative effects of breathing in these chemicals while standing over a stove to stir a pot or opening the oven door to remove a casserole or cake.

Every resident asked those of us visiting something to the effect of "How can I make my home safer?" The solutions and recommendations will detail several solutions including how to increase kitchen ventilation, which air purifiers reduce NO2, and how to utilize existing rebates and loans to finance making the switch to electric stoves.

LIMITATIONS

As one of the first studies to focus on visualizing methane gas air pollutants through a gas imaging camera in a home setting, there are certain circumstances based on the study design that impact our results.

MEASUREMENTS TIMELINE, STUDY DESIGN, AND PROTOCOLS

The FLIR camera was only available for a short period of time and was rented for less than a week due to the high cost. It was not possible to extend the period of testing. Normal cooking activities were not replicated, which likely would involve using more than one gas burner and having the oven running for more than the time allocated to preheat the oven to 350°F and possibly at higher temperatures. No necessary protocols were established for choosing the exact placement of the Flow 2 monitor to take the background pollutant measurements.

AIR MONITORING EQUIPMENT

Flow 2 monitor was chosen for its affordability and efficient portability. Recommendations from Plume Labs were followed for calibration including powering on the device weeks in advance of the study and calibrating the AI every day by syncing the Flow with the Plume Labs app (Plume Labs, nd). That being said, Plume notes that Flow 2's have an accuracy of about 90-95% of static reference monitors. This means our results could be 5-10% off (Plume Labs, nd). The FLIR camera was calibrated prior to shipping to Beyond Toxics.

CONTEXTUAL LIMITS OF AIR MONITORING FINDINGS

Our experiment recorded ambient air quality in a variety of different kitchens with varying ages, brands, and models of gas appliances. Our study did not control for the size of the kitchen, open vs closed kitchen floor plans, the rate or efficiency at that different stoves burn gas and the effectiveness of varying ventilation models. No burners and ovens were turned on for the same amount of time in each house because we were largely interested in the participants' experience of viewing their stoves through the camera. It is understood that the findings are contextualized within these conditions.

SOLUTIONS AND RECOMMENDATIONS

Many participants expressed their shock and dismay upon viewing their gas stoves and ovens through the FLIR camera and visualizing the amount of pollution emitted to their living space from the combustion of fossil fuels inside their homes. Our findings add to an already robust literature problematizing the public health implications of gas appliances in regard to climate change and public health. Some folks have the resources to electrify, but for many, shifting to electric or induction stoves is not an immediate option.

The following section provides a list of precautionary steps to lower long-term exposure to NO2 and VOCS; and support shifting away from burning fossil fuels to home electrification.

ELECTRIFICATION OF NEW CONSTRUCTION

There are many public health benefits to electrifying newly constructed homes, but the question arises if building an all-electric home is cheaper than the cost of installing natural gas infrastructure and appliances. A 2020 RMI study analyzed all-electric, single-family homes in seven different cities across the country (McKenna et al., 2020), and found constructing all-electric homes to be less expensive than mixed gas and electric homes across all seven cities. An expanded RMI cost analysis found that an all-electric home in Eugene would save $1,600 in initial construction costs, **due primarily to the savings from eliminating household gas infrastructure** (Lacey et al., 2021). Electrifying a home originally constructed to run on mixed-gas infrastructure is expensive, which is why it's crucial to get out ahead of the problem and prevent the construction of gas infrastructure in new housing. This will save homeowners renovation costs in the future and prevent investing in likely soon to be stranded infrastructure.

FIGURE. 13.

RMI Costs for Constructing Mixed Fuel vs All-Electric Homes in Eugene

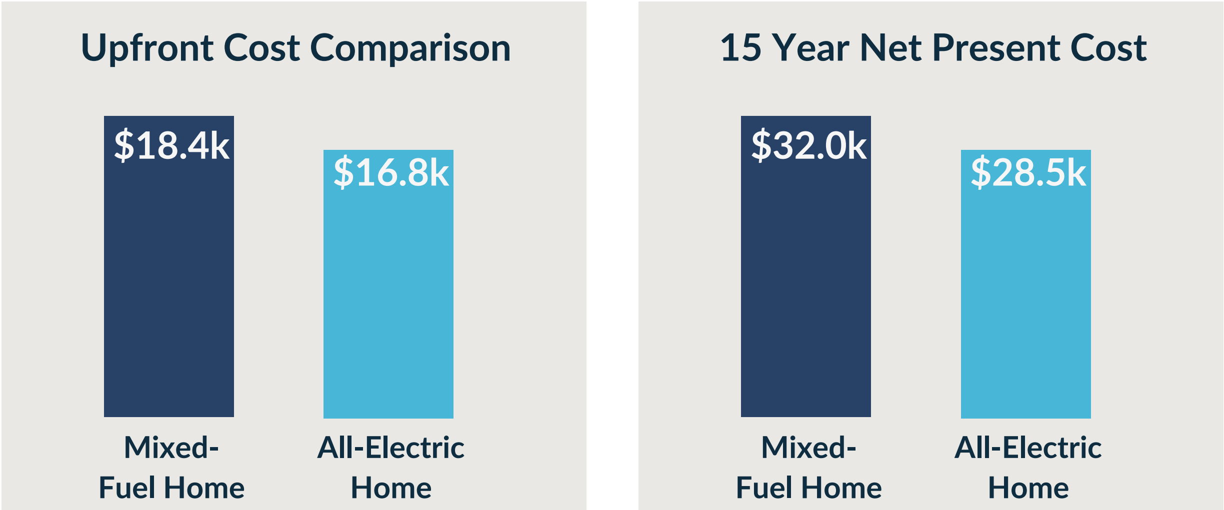


Figure. 13. This graph shows the upfront and 15 year net costs for Mixed Fuel (dark blue) vs All electric homes (light blue). Original graphic made by RMI (Kocher, 2022)

GHG EMISSIONS SAVINGS

Using the Eugene Water Electric Board's 2021 published emissions intensity, the emissions reduction for an all-electric home was 74%, a reduction of 30 metric tons of CO2 over a 15-year period (Kocher, 2022).

FIGURE. 14.
Emissions Savings for an All-Electric Home vs Mixed-Fuel Home in Eugene

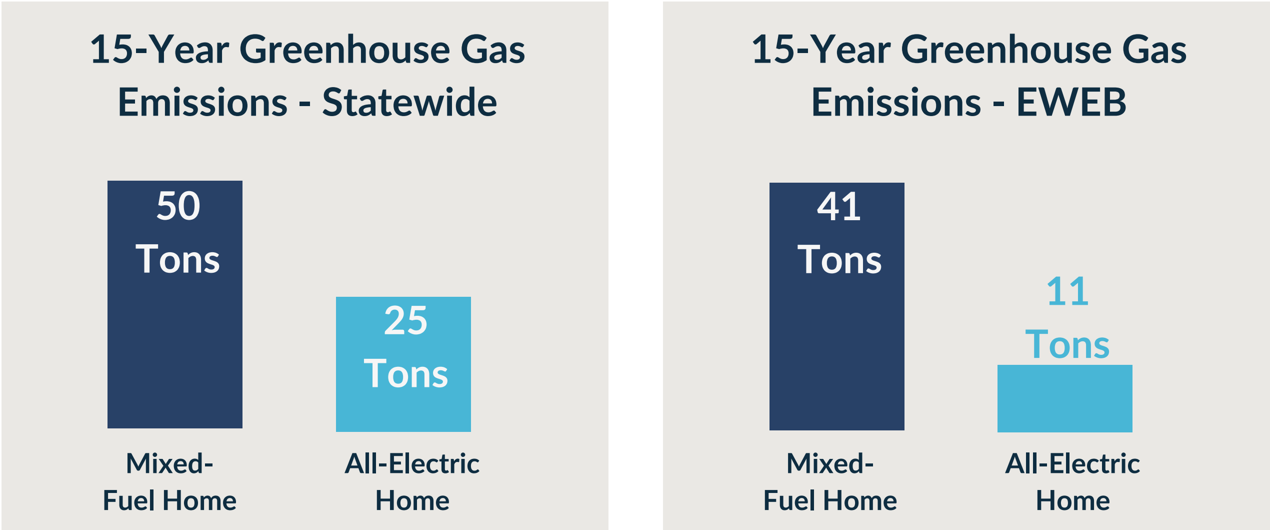


Figure. 14. This graph shows the 15 year carbon emissions for Mixed Fuel (dark blue) vs All electric homes (light blue). The left shows Oregon wide average emissions while the left shows average emissions for Eugene Water and Electric Board Customers. Original graphic made by RMI (Kocher, 2022).

Our recommendations include taking advantage of the inherent carbon reduction and cost savings of all-electric construction. Given this, switching from fossil fuels to electricity in our homes can help reduce carbon emissions, lower health risks from methane, and save upfront construction costs.

ELECTRIFYING YOUR EXISTING HOME

Residents may want to replace their gas cooking and heating equipment with high-efficiency electric systems as they near the time for a replacement or when the equipment breaks down. They can use government incentives from the Inflation Reduction Act, local governments, and utilities to lower the cost. If you or anyone in your household has or is prone to respiratory diseases such as asthma or chronic bronchitis, you will want to replace your gas stove sooner if possible and/or increase ventilation.

MONEY AVAILABLE FROM THE GOVERNMENT FOR SWITCHING FROM GAS TO ELECTRIC

The Inflation Reduction Act (IRA) has rebates of up to $14,000 available for low and moderate-income households to help electrify home heating systems, increase insulation, and lower power bills, including an $840 rebate available to switch gas stoves to an all-electric alternative. For home heating systems, the IRA has incentives for heat pumps to heat and cool the air and incentives for heat pump water heaters to replace older heat waters. Heat Pumps and Heat Pump Water Heaters are super efficient which makes them cheaper to run than gas or traditional electric heating systems and can save people significant amounts of money on energy bills. The IRA also includes rebates for a new electric panel and wiring to install electric appliances, such as adding 240 V outlets that high-energy appliances like electric stoves and clothes dryers use. See additional Resources on page 34.

CONSIDER INDUCTION COOKING WHEN SWITCHING FROM GAS

When upgrading from gas to electric cooking systems, consider trying an induction oven or cooktop. New induction ovens and cooktops boil water in half the time of traditional gas and electric cooktops by using magnets to heat the pot or pan while using less energy. Induction cooktops are also available as countertop units that use a traditional wall outlet, so they don’t need a 240 V outlet which requires a licensed electrician to install. These countertop units are relatively inexpensive and can be used to supplement or replace gas cooking (without needing to remove the old appliance).

FOR RENTERS

Renters may be concerned about buying new electric appliances because they may want to invest only in an appliance they can take with them if they should leave their current rental. Furthermore, it may be difficult to get a landlord's permission to install new electric appliances. However, there are all-electric alternatives that are good investments for renters and can travel with them to other locations and don’t require a landlord to approve new wiring or renovations. For cooking, there are new countertop induction cooktops that run on a traditional wall outlet and can be taken with you if and when moving. There are also new heat pumps available for heating and cooling that can fit in a window and run off a traditional outlet, so you can take the units with you when you move.

FIGURE. 15.
Portable Electric Appliance Options

Window Heat Pump (left) and a Countertop Induction Cooktop (right)

INCREASE KITCHEN VENTILATION

If you have a ventilation hood, get in the habit of using it. Start by using the back burners which are usually in a better position under the hood to take advantage of the exhaust capture. Immediately turn on the hood vent when using any burner as opposed to waiting for part way through cooking the meal (many folks wait until they smell cooking odors or see smoke before turning on the fan, and that is too late). Keep the vent on for a few minutes after cooking to capture any slower-moving particles. Opening a window can create a more effective airflow for moving pollutants into a hood.

If you don't have a ventilation system in your house, consider setting up two box fans in a window during temperate months. One box fan should be set up to bring in fresh, outdoor air, and the other should be set up to move indoor air outdoors. This will help cycle the pollution outside of your house. Additionally, HEPA and Carbon filter-equipped air purifiers have been found to reduce NO_2 and other air pollutants from gas stoves (Paulin et al., 2014).

ADDITIONAL RESOURCES FOR FINANCIAL INCENTIVES FOR ELECTRIC UPGRADES

See a list of electric stoves for less than $840 that lower-income households can get for free here:

Electric Stoves You Can Get for Free With the IRA Rebate (lifehacker.com)

See the full list of Inflation Reduction Act Incentives and find out which you may be eligible for here:

How much money can you get with the Inflation Reduction Act? — Rewiring America

You may also be eligible for incentives from your local utility that can be combined with Inflation Reduction Act Incentives to maximize benefits for your household. Work with contractors that can help connect you with these local and Federal Incentives. See local incentives from the Eugene Water and Electric Board here:

https://www.eweb.org/residential-customers/rebates-loans-and-conservation

Example: Incentives are available from the Inflation Reduction Act and the Eugene Water and Electric Board for low-income customers. These incentives could potentially be combined to pay for higher-cost upgrades or to pay for a greater percentage of the total costs of upgrades, potentially making the upgrades free for low-income customers.

You can learn more about how to combine local and federal incentives for maximum benefit, by visiting Beyond Toxic's upcoming report on how local and Federal incentives can be combined to electrify low-income and moderate-income households, allowing for whole home retrofits to be completed for free for low-income households and for no upfront costs for moderate-income households in some cases.

Table. 3. Incentives available from the Inflation Reduction Act and the Eugene Water and Electric Board for low-income customers. These incentives could potentially be combined.

Device	Federal Inflation Reduction Act Rebates (<80% Area Median Income)	EWEB Incentives for Low-Income Customers (<200% Federal Poverty Level)
Heat Pump	$8000	$3800 (ductless)
Heat Pump Water Heater	$1750	$800
Heat Pump Dryer	$840	N/A
Weatherization	$1600	100% of insulation costs, some of windows and doors
Wiring	$2500	N/A
Electric Panel	$4000	$5000
Electric Stove	$840	N/A
Total	up to $14000	$9600

REFERENCES

Alberts, W. M. (1994). Indoor air pollution: NO, NO2, CO, and CO2. Journal of Allergy and Clinical Immunology, 94(2), 289–295. https://doi.org/10.1053/ai.1994.v94.a56007.

American Lung Association. "Nitrogen Dioxide | American Lung Association." American Lung Association, n.d. https://www.lung.org/clean-air/outdoors/what-makes-air-unhealthy/nitrogen-dioxide. Accessed 3 Apr. 2023.

Anderson, D. A. "Natural Gas Transmission Pipelines: Risks and Remedies for Host Communities." Energies, vol. 13, no. 8, 2020, https://doi.org/10.3390/en13081873.

Atkinson, Richard W., et al. "Long-term Concentrations of Nitrogen Dioxide and Mortality: A Meta-analysis of Cohort Studies." Epidemiology, vol. 29, no. 4, 2018, pp. 460-472. https://doi.org/10.1097/EDE.0000000000000847.

Belanger, K., et al. "Household Levels of Nitrogen Dioxide and Pediatric Asthma Severity." Epidemiology, vol. 24, no. 2, 2013, pp. 320-330. https://doi.org/10.1097/EDE.0b013e318280e2ac.

Bodor, K., Szép, R., and Bodor, Z. "Time Series Analysis of the Air Pollution around Ploiesti Oil Refining Complex, One of the Most Polluted Regions in Romania." Scientific Reports, vol. 12, no. 1, 2022, article 11817. https://doi.org/10.1038/s41598-022-16015-7.

Boyle, E., et al. "Assessment of Exposure to VOCs among Pregnant Women in the National Children's Study." International Journal of Environmental Research and Public Health, vol. 13, no. 4, 2016, article 376. https://doi.org/10.3390/ijerph13040376.

Brady, Anne Seals and Andy Krasner. "Health Effects From Gas Stove Pollution." Rocky Mountain Institute, Physicians For Social Responsibility, Mothers Out Front, and Sierra Club, 2020.

Buonanno, Giorgio, Lidia Morawska, and Luca Stabile. "Particle Emission Factors During Cooking Activities." Atmospheric Environment, vol. 43, no. 20, 2009, pp. 3235-3242. https://doi.org/10.1016/j.atmosenv.2009.03.044.

Chen, Bingheng, and Haidong Kan. "Air Pollution and Population Health: A Global Challenge." Environmental Health and Preventive Medicine, vol. 13, no. 2, 2008, pp. 94-101. https://doi.org/10.1007/s12199-007-0018-5.

Chin, Jennifer-Ann Y., Cora Godwin, Evan Parker, Thomas Robins, Todd Lewis, Peggy Harbin, and Stuart Batterman. "Levels and Sources of Volatile Organic Compounds in Homes of Children with Asthma." Indoor Air, vol. 24, no. 4, 2014, pp. 403-415. https://doi.org/10.1111/ina.12086.

McKenna, Claire, Amar Shah, and Leah Louis-Prescott. "The New Economics of Electrifying Buildings." Rocky Mountain Institute, 2020. https://rmi.org/insight/the-new-economics-of-electrifying-buildings?submitted=1983dhtw8.

Coker, E. S., Smit, E., Harding, A. K., Molitor, J., & Kile, M. L. (2015). A cross sectional analysis of behaviors related to operating gas stoves and pneumonia in U.S. children under the age of 5. BMC Public Health, 15(1), 77. https://doi.org/10.1186/s12889-015-1425-y.

Delp, W. W., & Singer, B. C. (2012). Performance Assessment of U.S. Residential Cooking Exhaust Hoods. Environmental Science & Technology, 46(11), 6167–6173. https://doi.org/10.1021/es3001079.

Dirgawati, M., Hinwood, A., Nedkoff, L., Hankey, G. J., Yeap, B. B., Flicker, L., Nieuwenhuijsen, M., Brunekreef, B., & Heyworth, J. (2019). Long-term Exposure to Low Air Pollutant Concentrations and the Relationship with All-Cause Mortality and Stroke in Older Men. Epidemiology, 30, S82–S89. https://doi.org/10.1097/EDE.0000000000001034.

Donaldson, K., & MacNee, W. (2001). Potential mechanisms of adverse pulmonary and cardiovascular effects of particulate air pollution (PM10). International Journal of Hygiene and Environmental Health, 203(5–6), 411–415. https://doi.org/10.1078/1438-4639-00059.

"Gas Leaks." Gas Stoves Are Dangerous and We've Known It for Decades. 23 Jan. 2023. Gas Leaks. https://www.gasleaks.org/gas-stoves-are-dangerous-and-weve-known-it-for-decades.

Gruenwald, T., Seals, B. A., Knibbs, L. D., & Hosgood, H. D. (2022). Population Attributable Fraction of Gas Stoves and Childhood Asthma in the United States. International Journal of Environmental Research and Public Health, 20(1), 75. https://doi.org/10.3390/ijerph20010075.

Guo, H., Kwok, N. H., Cheng, H. R., Lee, S. C., Hung, W. T., & Li, Y. S. (2009). Formaldehyde and volatile organic compounds in Hong Kong homes: Concentrations and impact factors. Indoor Air, 19(3), 206–217. https://doi.org/10.1111/j.1600-0668.2008.00580.x

Hasselblad, V., Eddy, D. M., & Kotchmar, D. J. (1992). Synthesis of Environmental Evidence: Nitrogen Dioxide Epidemiology Studies. Journal of the Air & Waste Management Association, 42(5), 662–671. https://doi.org/10.1080/10473289.1992.10467018.

Chin, J.-Y., Godwin, C., Parker, E., Robins, T., Lewis, T., Harbin, P., & Batterman, S. (2014). Levels and sources of volatile organic compounds in homes of children with asthma. Indoor Air, 24(4), 403–415. https://doi.org/10.1111/ina.12086.

Hendrick, M. F., Ackley, R., Sanaie-Movahed, B., Tang, X., & Phillips, N. G. (2016). Fugitive methane emissions from leak-prone natural gas distribution infrastructure in urban environments. Environmental Pollution, 213, 710–716. https://doi.org/10.1016/j.envpol.2016.01.094.

Holloway, M. D. (2013). Fracking: The operations and environmental consequences of hydraulic fracturing. Wiley Scrivener Publishing.

Hu, T., Singer, B. C., & Logue, J. M. (2012). Compilation of Published PM2.5 Emission Rates for Cooking, Candles and Incense for Use in Modeling of Exposures in Residences (LBNL--5890E, 1172959; p. LBNL--5890E, 1172959). https://doi.org/10.2172/1172959.

Huangfu, P., & Atkinson, R. (2020). Long-term exposure to NO2 and O3 and all-cause and respiratory mortality: A systematic review and meta-analysis. Environment International, 144, 105998. https://doi.org/10.1016/j.envint.2020.105998.

Kile, Molly L., et al. "A cross-sectional study of the association between ventilation of gas stoves and chronic respiratory illness in U.S. children enrolled in NHANES III." Environmental Health, vol. 13, no. 1, 2014, p. 71. https://doi.org/10.1186/1476-069X-13-71.

Kocher, Jonny. "RMI Economic and Energy Analysis of All-Electric New Construction in Eugene." 7 Apr. 2022, Unpublished Memo.

Lebel, E. D., Finnegan, C. J., Ouyang, Z., & Jackson, R. B. "Methane and NOx Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes." Environmental Science & Technology, vol. 56, no. 4, 2022, pp. 2529-2539. https://doi.org/10.1021/acs.est.1c04707.

Lebel, E. D., Michanowicz, D. R., Bilsback, K. R., Hill, L. A. L., Goldman, J. S. W., Domen, J. K., Jaeger, J. M., Ruiz, A., & Shonkoff, S. B. C. "Composition, Emissions, and Air Quality Impacts of Hazardous Air Pollutants in Unburned Natural Gas from Residential Stoves in California." Environmental Science & Technology, vol. 56, no. 22, 2022, pp. 15828-15838. https://doi.org/10.1021/acs.est.2c02581.

Li, R., Weller, E., Dockery, D. W., Neas, L. M., & Spiegelman, D. "Association of indoor nitrogen dioxide with respiratory symptoms in children: Application of measurement error correction techniques to utilize data from multiple surrogates." Journal of Exposure Science & Environmental Epidemiology, vol. 16, no. 4, 2006, pp. 342-350. https://doi.org/10.1038/sj.jes.7500468.

Lim, C. C., Hayes, R. B., Ahn, J., Shao, Y., Silverman, D. T., Jones, R. R., Garcia, C., Bell, M. L., & Thurston, G. D. "Long-Term Exposure to Ozone and Cause-Specific Mortality Risk in the United States." American Journal of Respiratory and Critical Care Medicine, vol. 200, no. 8, 2019, pp. 1022-1031. https://doi.org/10.1164/rccm.201806-1161OC.

Lin, W., Brunekreef, B., & Gehring, U. "Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children." International Journal of Epidemiology, vol. 42, no. 6, 2013, pp. 1724-1737. https://doi.org/10.1093/ije/dyt150.

Liu, Z., & Little, J. C. "Materials responsible for formaldehyde and volatile organic compound (VOC) emissions." Toxicity of Building Materials, edited by F. Pacheco-Torgal, S. Jalali, & A. Fucic, Woodhead Publishing, 2012, pp. 76-121. https://doi.org/10.1533/9780857096357.76.

Melia, R. J., Florey, C. D., Altman, D. G., & Swan, A. V. "Association between gas cooking and respiratory disease in children." BMJ, vol. 2, no. 6080, 1977, pp. 149-152. https://doi.org/10.1136/bmj.2.6080.149.

Meng, Q., & Ashby, S. "Distance: A critical aspect for environmental impact assessment of hydraulic fracking." The Extractive Industries and Society, vol. 1, no. 2, 2014, pp. 124-126. https://doi.org/10.1016/j.exis.2014.07.004.

Michanowicz, D. R., Dayalu, A., Nordgaard, C. L., Buonocore, J. J., Fairchild, M. W., Ackley, R., Schiff, J. E., Liu, A., Phillips, N. G., Schulman, A., Magavi, Z., & Spengler, J. D. "Home is Where the Pipeline Ends: Characterization of Volatile Organic Compounds Present in Natural Gas at the Point of the Residential End User." Environmental Science & Technology, vol. 56, no. 14, 2022, pp. 10258-10268. https://doi.org/10.1021/acs.est.1c08298.

Mullen, N. A., Li, J., & Singer, B. C. "Participant Assisted Data Collection Methods in the California Healthy Homes Indoor Air Quality Study of 2011-13." LBNL--6374E, 1221052, Lawrence Berkeley National Laboratory, 2013. https://doi.org/10.2172/1221052.

Multnomah County Health Department. "A Review of the Evidence: Public Health and Gas Stoves." Multnomah County Health Department, 2022. https://www.opb.org/pdf/Multnomah%20County%20Health%20Department%20Gas%20Stoves%20Health%20Risk%20Report%202022_1668121151633.pdf.

National Cancer Institute. "Definition of Hydrocarbon - NCI Dictionary of Cancer Terms." NCI, n.d. https://www.cancer.gov/publications/dictionaries/cancer-terms/def/hydrocarbon. Accessed 30 March 2023.

National Cancer Institute. "Formaldehyde and Cancer Risk - NCI." NCI, 10 June 2011. https://www.cancer.gov/about-cancer/causes-prevention/risk/substances/formaldehyde/formaldehyde-fact-sheet. Accessed 30 March 2023.

Paulin, Laura M., et al. "Home Interventions Are Effective at Decreasing Indoor Nitrogen Dioxide Concentrations." Indoor Air, vol. 24, no. 4, 2014, pp. 416-424. https://doi.org/10.1111/ina.12085.

Plume Labs. "Flow, by Plume Labs: The First Smart Air Quality Tracker." PlumeLabs By AccuWeather. N.p., n.d. Web. 3 Apr. 2023. https://plumelabs.com/en/flow.

Plume Labs. "How Accurate is Flow?" Plume Labs, n.d. Web. https://plumelabs.zendesk.com/hc/en-us/articles/360025092554-How-Accurate-is-Flow.

Pope, C. A., & Dockery, D. W. "Acute Health Effects of PM10 Pollution on Symptomatic and Asymptomatic Children." American Review of Respiratory Disease, vol. 145, no. 5, 1992, pp. 1123–1128. https://doi.org/10.1164/ajrccm/145.5.1123.

Poppendieck, Dustin, and Gong, Mengyan. "Simmering Sauces! Elevated Formaldehyde Concentrations from Gas Stove Burners." International Society of Indoor Air Quality and Climate, 2018. https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=926006.

Qian, Yunzhao et al. "Long-Term Exposure to Low-Level NO2 and Mortality among the Elderly Population in the Southeastern United States." Environmental Health Perspectives, vol. 129, no. 12, 2021, p. 127009. https://doi.org/10.1289/EHP9044.

Leber, Rebecca. "The Gas Stove Wars Are Far from Over." Vox, 21 March 2023, https://www.vox.com/policy/2023/3/21/23593644/gas-stove-pollution-science-health-risks.

Rocky Mountain Institute. "2019 Nonresidential New Construction Reach Code Cost Effectiveness Study." 2020. https://localenergycodes.com/download/74/file_path/fieldList/2019%20NR%20NC%20Cost%20Effectiveness%20Report.

Roda, C., et al. "Formaldehyde Exposure and Lower Respiratory Infections in Infants: Findings from the PARIS Cohort Study." Environmental Health Perspectives, vol. 119, no. 11, 2011, pp. 1653-1658. https://doi.org/10.1289/ehp.1003222.

Beall, Ross. "In 2020, Most U.S. Households Prepared at Least One Hot Meal a Day at Home." U.S. Energy Information Administration, n.d. https://www.eia.gov/todayinenergy/detail.php?id=53439#. Accessed 7 April 2023.

Royte, Elizabeth. "Fracking Our Food Supply." The Nation, 28 November 2012. https://www.thenation.com/article/archive/fracking-our-food-supply/. Accessed 7 April 2023.

Samet, Jonathan M., Marbury, Mackenzie C., and Spengler, John D. "Health Effects and Sources of Indoor Air Pollution. Part I." American Review of Respiratory Disease, vol. 136, no. 6, 1987, pp. 1486-1508. https://doi.org/10.1164/ajrccm/136.6.1486.

Sharma, Shubham, Chandra, Madhuri, and Kota, Sunil H. "Health Effects Associated with PM2.5: A Systematic Review." Current Pollution Reports, vol. 6, no. 4, 2020, pp. 345-367. https://doi.org/10.1007/s40726-020-00155-3.

Simkhovich, Boris Z., Kleinman, Michael T., and Kloner, Robert A. "Air Pollution and Cardiovascular Injury." Journal of the American College of Cardiology, vol. 52, no. 9, 2008, pp. 719-726. https://doi.org/10.1016/j.jacc.2008.05.029.

Singer, Brett C., et al. "Pollutant concentrations and emission rates from natural gas cooking burners without and with range hood exhaust in nine California homes." Building and Environment, vol. 122, 2017, pp. 215-229. https://doi.org/10.1016/j.buildenv.2017.06.021.

Spiegel, Simon J. "Fossil fuel violence and visual practices on Indigenous land: Watching, witnessing and resisting settler-colonial injustices." Energy Research & Social Science, vol. 79, 2021, article 102189. https://doi.org/10.1016/j.erss.2021.102189.

Sun, Lixiao and Wallace, Lance A. "Residential cooking and use of kitchen ventilation: The impact on exposure." Journal of the Air & Waste Management Association, vol. 71, no. 7, 2021, pp. 830-843. https://doi.org/10.1080/10962247.2020.1823525.

Sundell, J., Anderson, B., Anderson, K., & Lindvall, T. "Volatile Organic Compounds in Ventilating Air in Buildings at Different Sampling Points in the Buildings and their Relationship with the Prevalence of Occupant Symptoms." Indoor Air, vol. 3, no. 2, 1993, pp. 82-93. DOI: 10.1111/j.1600-0668.1993.t01-2-00003.x.

Roda, C., Kousignian, I., Guihenneuc-Jouyaux, C., Dassonville, C., Nicolis, I., Just, J., & Momas, I. "Formaldehyde Exposure and Lower Respiratory Infections in Infants: Findings from the PARIS Cohort Study." Environmental Health Perspectives, vol. 119, no. 11, 2011, pp. 1653-1658. DOI: 10.1289/ehp.1003222.

Tan Lacey, et al " The Economics of Electrifying Buildings: Residential New Construction: Electrifying Homes to Save Energy, Money, and Carbon." https://rmi.org/insight/the-economics-of-electrifying-buildings-residential-new-construction. Retrieved April 10, 2023.

Teledyne FLIR. "FLIR GF320 Infrared Camera for Methane and VOC Detection" .https://www.flir.com/products/gf320/?vertical=optical+gas&segment=solutions. Accessed: April 3, 2023

United Nations Environment Programme. "Gas Fracking: Can We Safely Squeeze the Rocks? - UNEP Global Environmental Alert Service (GEAS) November 2012." UNEP, 2012, https://wedocs.unep.org/20.500.11822/40939.

U.S. EPA. "Natural Gas Combustion." U.S. EPA, 2020, https://www.epa.gov/sites/default/files/2020-09/documents/1.4_natural_gas_combustion.pdf.

U.S. EPA Office of Air and Radiation. "Air Quality Guide for Nitrogen Dioxide." U.S. EPA, 2010, https://www.airnow.gov/sites/default/files/2018-06/no2.pdf.

WHO. "Climate Change and Health." WHO, October 2021, https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health.

Wi, S., Kim, M.-G., Myung, S.-W., Baik, Y. K., Lee, K.-B., Song, H.-S., Kwak, M.-J., & Kim, S. (2020). Evaluation and analysis of volatile organic compounds and formaldehyde emission of building products in accordance with legal standards: A statistical experimental study. Journal of Hazardous Materials, 393, 122381. https://doi.org/10.1016/j.jhazmat.2020.122381.

Winters, Joseph. "A gas utility's astroturf campaign threatens Oregon's first electrification ordinance." Grist, n.d. https://grist.org/accountability/a-gas-utilitys-astroturf-campaign-threatens-oregons-first-electrification-ordinance/. Accessed 9 April 2023.

Zhang, Q., Gangupomu, R. H., Ramirez, D., & Zhu, Y. (2010). Measurement of Ultrafine Particles and Other Air Pollutants Emitted by Cooking Activities. International Journal of Environmental Research and Public Health, 7(4), 1744–1759. https://doi.org/10.3390/ijerph7041744.