



A novel approach and apparatus for monitoring air quality for pulmonary health

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Abstract

The quality of the air we breathe is of pivotal importance for our health and wellbeing. Aside from the oxygen needed for our survival and other inert natural gases, the air nowadays is made also of toxic components coming mostly from human processes. Depending on the place where we live and the locations where we spend most of our time, the air quality can be substantially different. Man-made activities can impact negatively what we take into our lungs and therefore our body. In order to improve our quality of life by improving the air we breathe; we need to be aware of the dangers around us. In this project we designed and developed a simple instrumentation for the measuring and monitoring of air quality that can be easily operated and transported. This instrumentation was used to measure the presence and levels of different air pollutants in different locations, demonstrating the considerable differences in air quality from an indoor suburban house to a main road with heavy traffic. This study demonstrates the importance of monitoring the quality of the air in the places we frequent the most in order to be able to take informed decisions regarding our daily habits and possibly influence local policies regarding infrastructure and regulations.

Keywords: Air quality, environment, pollution, respiratory diseases

Introduction

The air we breathe has a lot to do with our health. As we breathe in fresh air, our lungs absorb oxygen from the air and pass it into our blood stream so it can be transported throughout our bodies. Oxygen is important for our whole body to have the energy it needs to survive. But the air we breathe is not made only of oxygen; aside from other naturally occurring gases like nitrogen and carbon dioxide, there are a number of other gases and very small particles floating around. Some of these components can be toxic to life and many of those are the direct byproduct of human activities. People living in industrial areas are more likely to develop asthma. Years and years of breathing particles of tar and smoke can cause the lung tissue to develop cancer and can even cause death.

The World Health Organization (WHO) reported that 92% of the world population suffers from poor air quality and many industrial countries struggle to reduce air pollution for their citizens

The Clean Air Act requires EPA to set National Ambient Air Quality Standards (NAAQS) for six common air pollutants^[1]. These pollutants are particulate matter, photochemical oxidants (including ozone), carbon monoxide, sulfur oxide, nitrogen oxides and lead. They can harm your health and the environment, and cause property damage^[2].

Ozone in the air we breathe can harm our health, especially on hot sunny days when ozone can reach unhealthy levels. Even relatively low levels of ozone can cause health effects. People most at risk from breathing air containing ozone include people with asthma, children, older adults, and people who are active outdoors, especially outdoor workers. In addition, people with certain genetic characteristics, and people with reduced intake of certain nutrients, such as

vitamins C and E, are at greater risk from ozone exposure^[3].

Particulate matter (PM) is the term for a mixture of solid particles and liquid droplets found in the air. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye^[4]. Others are so small they can only be detected using an electron microscope. Particle pollution includes:

- **PM10:** inhalable particles, with diameters that are generally 10 micrometers and smaller.
- **PM2.5:** fine inhalable particles, with diameters that are generally 2.5 micrometers and smaller.

These particles can be made up of hundreds of different chemicals. Some are emitted directly from a source, such as construction sites, unpaved roads, fields, smokestacks, or fires. Most particles form in the atmosphere as a result of complex reactions of chemicals such as sulfur dioxide and nitrogen oxides, which are pollutants emitted from power plants, industries and automobiles^[4]. Exposure to such particles can affect both your lungs and your heart. Numerous scientific studies have linked particle pollution exposure to a variety of problems, including premature death in people with heart or

Table 1: Environmental conditions at the locations during testing.

Location	Air temperature (°C)	Humidity (%)	Wind speed (Km/h)
Outdoor – back yard	18.3	50	12.5
Indoor - house	20.6	50	0
Outdoor - city street	6.1	30	14.5
Outdoor - Forest	3.9	28	17.7
Indoor - School	22.2	50	0
Outdoor - gas station	7.8	33	22.5

lung disease, nonfatal heart attacks, irregular heartbeat, aggravated asthma, decreased lung function, increased respiratory symptoms, such as irritation of the airways, coughing or difficulty breathing. People with heart or lung diseases, children, and older adults are the most likely to be affected by particle pollution exposure ^[5].

CO is a colorless, odorless gas that can be harmful when inhaled in large amounts. CO is released when something is burned. The greatest sources of CO to outdoor air are cars, trucks and other vehicles or machinery that burn fossil fuels. A variety of items in your home such as unvented kerosene and gas space heaters, leaking chimneys and furnaces, and gas stoves also release CO and can affect air quality indoors. Breathing air with a high concentration of CO reduces the amount of oxygen that can be transported in the blood stream to critical organs like the heart and brain. At very high levels, which are possible indoors or in other enclosed environments, CO can cause dizziness, confusion, unconsciousness and death ^[6].

Sources of lead emissions vary from one area to another. At the national level, major sources of lead in the air are ore and metals processing and piston-engine aircraft operating on leaded aviation fuel. Other sources are waste incinerators, utilities, and lead-acid battery manufacturers. The highest air concentrations of lead are usually found near lead smelters. As a result of EPA's regulatory efforts including the removal of lead from motor vehicle gasoline, levels of lead in the air decreased by 98 percent between 1980 and 2014 ^[7]. Once taken into the body, lead distributes throughout the body in the blood and is accumulated in the bones. Depending on the level of exposure, lead can adversely affect the nervous system, kidney function, immune system, reproductive and developmental systems, and the cardiovascular system. Infants and young children are especially sensitive to lead exposures, which may contribute to behavioral problems, learning deficits and lowered IQ ^[8].

The largest source of sulfur dioxide (SO₂) in the atmosphere is the burning of fossil fuels by power plants and other industrial facilities ^[9]. Short-term exposures to SO₂ can harm the human respiratory system and make breathing difficult. People with asthma, particularly children, are sensitive to these effects of SO₂. SO₂ emissions that lead to high concentrations of SO₂ in the air generally also lead to the formation of other sulfur oxides (SO_x). SO_x can react with other compounds in the atmosphere to form small particles. These particles contribute to particulate matter pollution ^[9].

Nitrogen Dioxide (NO₂) is one of a group of highly reactive gases known as nitrogen oxides (NO_x), such as nitrous acid and nitric acid. NO₂ is used as the indicator for the larger group of nitrogen oxides. NO₂ primarily gets in the air from the burning of fuel. NO₂ forms from emissions from cars, trucks and buses, power plants, and off-road equipment ^[10]. Breathing air with a high concentration of NO₂ can irritate airways in the human respiratory system. Such exposures over short periods can aggravate respiratory diseases, particularly asthma, leading to respiratory symptoms (such as coughing, wheezing or difficulty breathing), hospital admissions and visits to emergency rooms. Longer

exposures to elevated concentrations of NO₂ may contribute to the development of asthma and potentially increase susceptibility to respiratory infections. NO₂ along with other NO_x reacts with other chemicals in the air to form both particulate matter and ozone ^[10].

Air pollution is a major environmental risk to health. By reducing air pollution levels, we can reduce the burden of disease from stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma. But first it is necessary to be aware of the presence of these chemicals in the air and if they are above dangerous levels. In this study we built a system of sensors and data collection using inexpensive off-the-shelf parts for the monitoring of different air pollutants in the environment. The device was used to record the presence of these pollutants in different locations and the results were compared and reported in this paper.

Materials and Methods

Instrument assembly

The materials that were part of this study are Arduino UNO Controller, Breadboard, Connection wires, Air quality sensors, Battery 9V, Arduino Sketch for coding, Laptop for data collection and Daily weather for temp and humidity. Four different kind of air quality sensors that measures different chemicals in the air.

The procedure of my experiment included researching on the chemical components in the air as per EPA guidelines for the Air Quality Index, assembly if the 4 sensors and the Arduino components, code to measure and collect the data. Here are the chemicals that the sensors can measure.

- Sensor 1 measures Ammonia, Sulfide, Benzene
- Sensor 2 measures carbon monoxide
- Sensor 3 measures butane, propane, methane and gasoline
- Sensor 4 measures smoke, alcohol and air dust

The measured data from all sensors and trials were based on location. For each trial Temperature, Humidity, location and time were collected.

Data Collection and Analysis

Values collected for each trial and pollutant were analyzed with MS Excel. Average and standard deviations were calculated. One-way ANOVA statistical analysis was used to calculate the significant differences for each pollutant between baseline and the different locations. A p-value below 0.05 was considered as statistically significant. The p-value is the probability of obtaining test results at least as extreme as the result actually observed, under the assumption that the null hypothesis is correct. A very small p-value means that such an extreme observed outcome would be very unlikely under the null hypothesis ^[11].

Results

Background research

In person interviews were conducted with a medical doctor specialized in respiratory illnesses and with an environmental scientist specialized in pollution management. The interviews' results were as follow

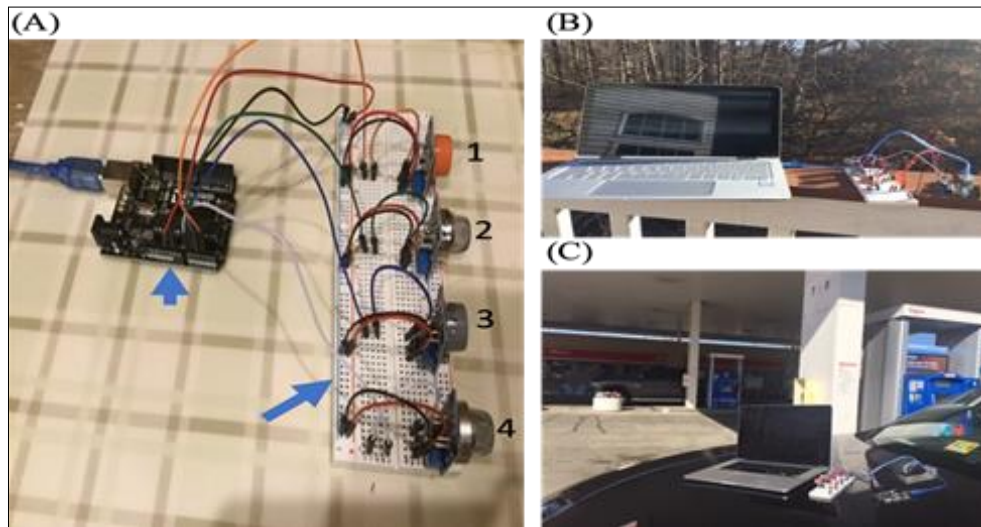


Fig 1: Systema layout and use. (A) Construction of the sensors and control board. Sensor for the detection of ammonia sulfide and benzene (1); sensor for the detection of carbon monoxide (2); sensor for the detection of butane, propane, methane and gasoline (3); sensor for the detection of smoke, alcohol and dust (4). The sensors are connected to a bread board (arrow) which is itself connected to an Arduino controller (arrowhead). (B) The system depicted in (A) collecting data in a residential backyard to be used as baseline for subsequent trials. (C) The system described in (A) collecting data at a gas station.

1. What are the health impacts of air pollution?

The long-term health effects can include chronic respiratory disease, lung cancer, heart disease, and even damage to the brain, nerves, liver, or kidneys. Continual exposure to air pollution affects the lungs of growing children and may aggravate medical conditions in the elderly.

2. How do you prevent these health impacts?

There are many ways, including, reducing personal exposure to air pollution, clean indoor air, reduce the effect of inhaled air pollutants and exposure to microenvironments near sources such as traffic, leverage personal respiratory equipment.

3. What kinds of chemicals and components can cause unhealthy air pollution?

Environmental Protection Agency (EPA) has named the six most common air pollutants, which are found all over the United States. These pollutants are ozone, particulate matter, carbon monoxide, nitrogen oxides, sulfur dioxide and lead. Additionally, gasoline and alcohol-based chemicals are also unhealthy.

Table 2: P-values of each location compared to the baseline.

Location	S1	S2	S3	S4
Indoor - house	1.093E-01	4.058E-01	4.226E-09	4.906E-55
Outdoor - city street	1.214E-59	1.504E-34	2.413E-59	7.517E-47
Outdoor - Forest	1.022E-25	3.245E-06	5.576E-03	6.369E-68
Indoor - School	4.484E-03	1.513E-09	1.945E-02	1.334E-06
Outdoor - gas station	2.991E-02	3.651E-06	2.005E-24	6.407E-04
p-values ≥ 0.05 are marked with a double underline.				

4. What means do we have to manage air pollution?

We first need to start by measuring these chemicals, including sources, in air and then prepare a management plan. The air quality index (AQI) is an index for reporting daily air quality. It tells you how clean or polluted your air is, and what associated health effects might be a concern for you. The AQI focuses on health effects that might be experienced within a few hours or days after breathing polluted air.

Based on the interviews with experts, the first step to improve air quality and mitigate the health effects that air pollutants can have on people is to know that such pollutants are present in the air and in what quantity. For this scope, a system composed of different sensors capable of detecting air pollutants, a control board for the control of the sensors and a personal computer for data collection and analysis was developed (Figure 1). To assemble a system that would be user-friendly, scalable and low cost, off-the-shelf parts were used and installed as described in Materials and Methods.

Field research

When considering air quality and the amount of pollutant in the air we breathe, a number of variables need to be taken into consideration that can affect the final measurements. Such variables include temperature, humidity, wind speed and direction and time of the day and time during the year. These variables cannot be directly controlled by the operator. What can be controlled are the variables that can be tested by the detection system.

The system created for this project was tested in different locations representative of the different environments experienced in everyday life for the average American person. In each location several measurements for each pollutant were taken over a period of time and analyzed compared to a reference location.

The first location (Trial 0) was a house backyard in a suburban neighborhood in Herndon, VA. The readings from this first location were then used as comparison for all the other locations tested. This measure was used as a reference based on the initial assumption that the air quality would be among the less polluted during this study. After gathering the baseline data from the house backyard, the first location tested (Trial 1) was the indoor of a house in a suburban area in Herndon, VA. The second location (Trial 2) was a busy street in the city of Herndon, VA. The third location (Trial 3) was in the woods north of Hendon, VA and the fourth location (Trial 4) was inside a school. Finally, the fifth location tested (Trial 5) was outside a gas station.

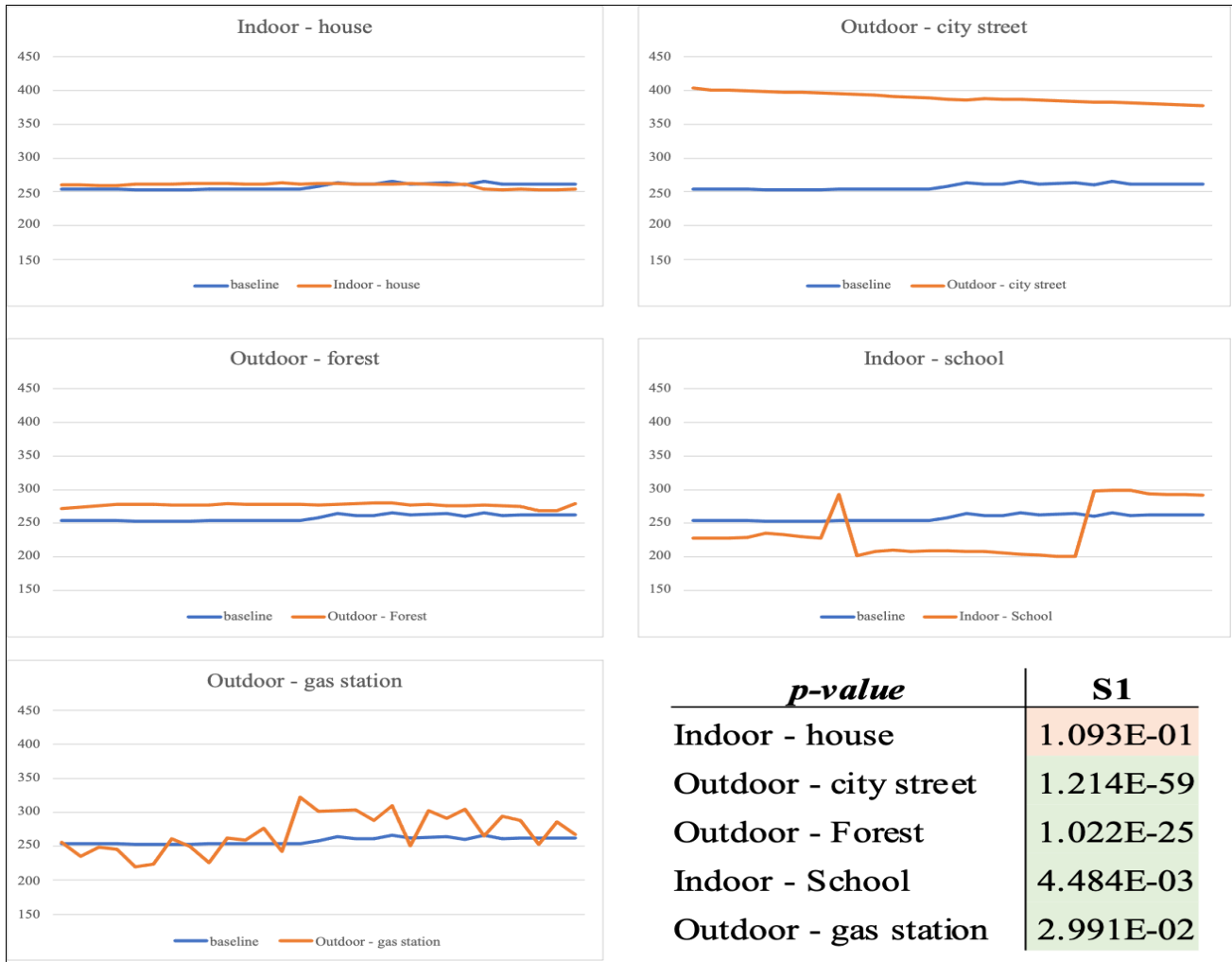


Fig 2: Plot data of the measurements recorded for ammonia, sulfide and benzene at the different locations tested. X-axes represent the different measurements taken over time at that specific location. Y-axes represents the parts per million detected by the sensor. The table shows the p-values for each location compared to baseline. P-values ≥ 0.05 are considered non-significant and are highlighted in red; p-values < 0.05 are considered significant and are highlighted in green.

Table 3: Averages for the different sensors at each location.

location	S1	S2	S3	S4
baseline	258	298	351	179
Indoor - house	260	302	359	237
Outdoor - city street	390	398	420	272
Outdoor - Forest	277	315	348	244
Indoor - School	237	344	344	254
Outdoor - gas station	270	416	430	207

As can be seen in Figure 2, the levels in the amounts of ammonia, sulfide and benzene measured in the air outside (backyard) or inside the house are similar, with no relevant differences between the two environments. As can be expected, the levels of these pollutants are considerably elevated near a busy street due to the exhaust gas emitted by the passing vehicles with internal combustion engines. Interestingly, the levels of these pollutants are slightly increased, compared to the baseline, in the air inside the forest visited for this study. Significant differences can also be detected in the air tested inside a school building, even though in this case the levels of these pollutants are lower than the baseline (Figure 6 and Table 3). The levels measured are significantly higher, even though maybe not as much as could be expected, at a gas station.

The second sensor present in the system assembled for this study measures the levels of carbon monoxide in the air. This is an important pollutant to be monitored, especially in closed environments since it is odorless and highly poisonous. Indeed, hundreds of people die every year in the USA alone due to carbon monoxide poisoning [12]. Levels of carbon monoxide measured in the different locations tested in this study are represented in Figure 3. All locations tested, except for the indoor house, have significantly elevated levels of carbon monoxide compared to the baseline reference, albeit to different degrees (Figure 6 and Table 3). In particular, the trafficked street and the gas station showed the highest levels of carbon monoxide among the locations tested (Figure 3, Figure 6 and Table 3). The third sensor used in our system measures the levels in the air of different hydrocarbons (see Materials and Methods). The data collected using this sensor is summarized in Figure 4. The levels measured were particularly high in the city street and at the gas station as it could be predicted due to the high traffic of ICE vehicles in the former and the presence of gasoline vapor in the latter (Figure 4). Even though the difference were statistically significant when measured by one-way ANOVA, the levels of hydrocarbons were only slightly higher inside the urban

house compared to the baseline (Figure 4, Figure 6 and Table 3). Similarly, the levels of hydrocarbons measured inside the school and in the forest were only mildly lower than the baseline (Figure 4, Figure 6 and Table 3). Finally, the fourth sensor allowed the measurements of levels of smoke, alcohol and air dust present in the different environments analyzed in this study. As can be seen in Figure 5, all the locations tested shower higher levels of smoke, alcohol and air dust compared to the baseline. The differences were more accentuated in the city street, forest and inside the school (Figure 5, Figure 6 and Table 3).

Discussion
Trial Observations

Table 3: Averages for the different sensors at each location.

location	S1	S2	S3	S4
baseline	258	298	351	179
Indoor - house	260	302	359	237
Outdoor - city street	390	398	420	272
Outdoor - Forest	277	315	348	244
Indoor - School	237	344	344	254
Outdoor - gas station	270	416	430	207



Fig 4: Plot data of the measurements recorded for carbon monoxide at the different locations tested. X-axes represent the different measurements taken over time at that specific location. Y-axes represents the parts per million of carbon monoxide detected by the sensor. The table shows the p-values for each location compared to baseline. P-values ≥ 0.05 are considered non-significant and are highlighted in red; p-values < 0.05 are considered significant and are highlighted in green.

Considering the results collected during this project, it is evident that the different compounds detected by the sensors build into the device are present in different amount depending on the environment considered. Interestingly, some chemicals are present in higher amounts in places that are otherwise considered the safest and less pollutes. For instance, the levels of hydrocarbons measured by the sensor S4 were slightly higher inside the urban house compared to the baseline (Figure 4). This could be due to the use of house cleaning products or the use of a gas stove for cooking or the furnace for ambient heating. On the other hand, these chemicals were significantly (albeit slightly) inside the school building, maybe suggesting of an efficient air circulation system in the building (Figure 4).

Other pollutants that were significantly higher in the air of all the places considered are smoke, alcohol and air dust. The presence of alcohols in safe and well-kept places such as inside the urban house and the school building might be indicative of the ubiquitous use of such chemicals in everyday consumables such as cleaning products. While smoke and dust are a byproduct of common activities such as cooking or the work of furnaces for heating. It is not a surprise that the most polluted air was found at gas station and near a busy trafficked road. The presence of a high number of cars with running engines and the need to provide fuels to make them run is clearly of serious detriment for the health of people leaving near or passing through such places.



Fig 3: Plot data of the measurements recorded for butane, propane, methane, and gasoline at the different locations tested. X-axes represent the different measurements taken over time at that specific location. Y-axes represents the parts per million of hydrocarbons detected by the sensor. The table shows the p-values for each location compared to baseline. P-values ≥ 0.05 are considered non-significant and are highlighted in red; p-values < 0.05 are considered significant and are highlighted in green.

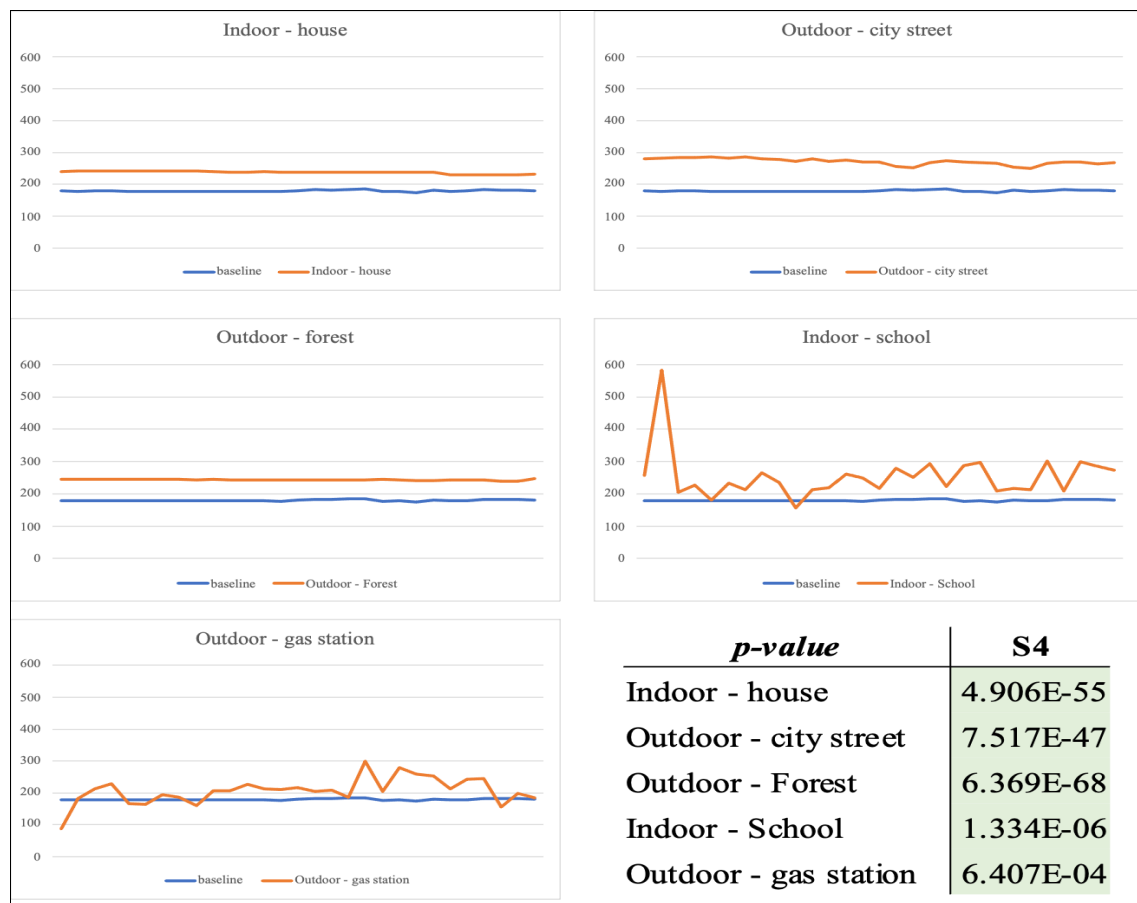


Fig 5: Plot data of the measurements recorded for smoke, alcohol and air dust at the different locations tested. X-axes represent the different measurements taken over time at that specific location. Y-axes represents the parts per million of all the compounds detected by the sensor. The table shows the p-values for each location compared to baseline. P-values ≥ 0.05 are considered non-significant and are highlighted in red; p-values < 0.05 are considered significant and are highlighted in green.

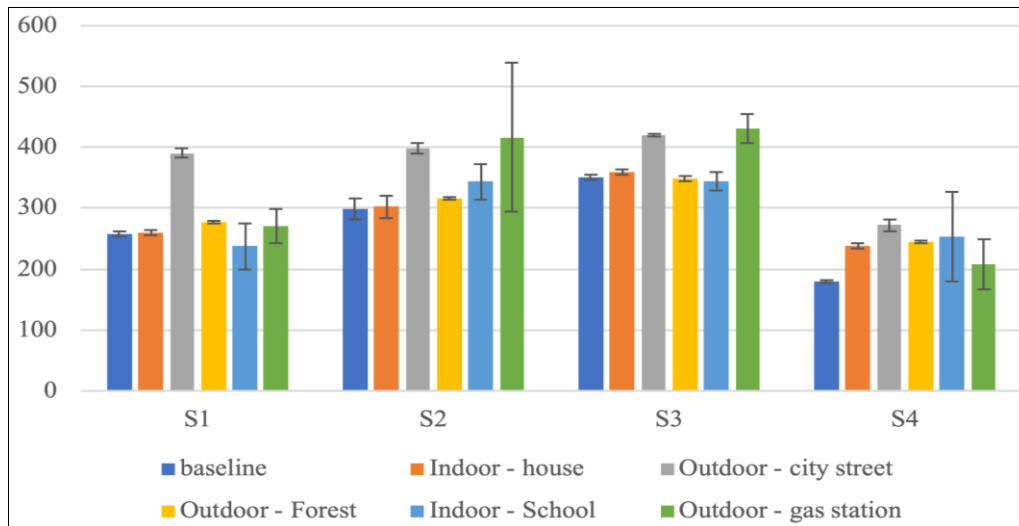


Fig 6: Concentration of different pollutants in the air at different locations. Represented in the histograms are the average values ($n = 29$) of the readings for each sensor at the different locations tested during this study. Error bars represent standard deviation. S1, sensor for ammonia, sulfide and benzene; S2, sensor for carbon monoxide; S3, sensor for butane, propane, methane and gasoline; S4, sensor for smoke, alcohol and air dust.

Conclusions

Particulate matter (PM) air pollution in urban areas is a major public health concern. Burning solid fuels indoors for heating, light and cooking, and burning liquid fuels outdoors to power vehicle engines, results in a complex mix of gases and particulate matter (PM) [13].

In the last few decades, Indoor Air Quality (IAQ) has received increasing attention from the international scientific community, political institutions, and environmental governances for improving the comfort, health, and wellbeing of building occupants [14]. Indoor environments represent a mix of outdoor pollutants prevalently associated with vehicular traffic and industrial activities, which can enter by infiltrations and/or through natural and mechanical ventilation systems, as well as indoor contaminants, which originate inside the building, from combustion sources (such as burning fuels, coal, and wood; tobacco products; and candles), emissions from building materials and furnishings, central heating and cooling systems, humidification devices, moisture processes, electronic equipment, products for household cleaning, pets, and the behavior of building occupants (i.e., smoking, painting, etc.).

The impact of traffic-related pollution around schools on student health has attracted increased attention in recent years. As students are exposed to pollutants around schools during their daily commute, the effect of pollutant exposure on students is substantial [15]. To reduce the effect of traffic-related pollution on student health, some mitigation measures can be implemented. Suitable transport routes and walking routes to and from school should be planned based on the pollution levels around the school. Trees and hedges could be set up on the roads around the school to prevent the diffusion of PM. The influence of street form and building layout on pollutant diffusion should be considered in urban planning. In heavily polluted areas, pollutant filters can be used to clean the air. The government should actively reduce the number of vehicles near schools, strengthen infrastructure construction, and reduce congestion. At the social level, idle running time should be reduced [15].

But first, in order to properly implement effective measured to improve the air quality of the environments where we

live, it is necessary to have an effective way to monitor the quality of the air. The device described in this study can easily be commercialized in a format that is easy to use, required minimal space and can be upgraded with the ability to connect to the cloud to share the data collected in time and space.

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