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Design and Construction of a Filter Bank Assembly for Low Volume Air Sampling

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by

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Abstract

Maintaining indoor air quality that supports human health is a primary objective of the built environment. While outdoor air is commonly thought of as having more pollutants, it has been shown that indoor air quality (IAQ) can be more polluted with VOCs and particulate matter. In order to better understand IAQ, we must understand the types of compounds present in the air that we are filtering into our buildings. One method for doing this is by analyzing the intake air and the filters in HVAC (heating, ventilation, and air conditioning) systems. These filters are specifically designed to collect dust, pollen, and other particulate matter; however, prior research has shown that on green roofs, microbes and dirt from the surrounding vegetation can accumulate onto these filters. Oxidation reactions with ozone and the particulate matter can result in the byproduct formation and the emissions of unidentified VOCs. In order to analyze these emissions, we need to collect the filter particulates; however, we don’t know the amount of exposure they are receiving due to fluctuations in the wind speed and direction. This thesis reviews the design and fabrication of a filter bank assembly (FBA), which will enable further research for the impact of biogenic particulate matter loading onto typical HVAC filters depending on the direction of wind.

Acknowledgements

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1 Introduction

As cities continue to expand, air pollution increases, the urban heat island effect becomes more prominent, and stormwater becomes more difficult to manage [1]. Air quality, in particular, has been shown to have adverse effects on human health, resulting in various conditions of cardiovascular and respiratory diseases [2]. Previous literature has demonstrated that green infrastructure has the potential to positively affect urban air quality [3]. For green roofs in particular, the sedum produces oxygen and can remove carbon dioxide, ozone, and volatile organic compounds (VOCs). Additionally, green roofs can also reduce the heat and runoff from stormwater in urban areas.

Several cities are beginning to implement green roofs into their infrastructure, not only for aesthetics, but for other various environmental benefits. As of July 2018, Portland, Oregon passed a new law that mandates eco-roofs for buildings in the Central City that are more than 20,000 square feet. This will be a much more sustainable option for Portland as it continues to grow. The Green Building Research Lab (GBRL), part of the Mechanical Engineering Department at Portland State University, studies indoor air quality by analyzing the VOCs and other indoor air pollutants. One way of investigating the link between indoor and outdoor air pollution is to analyze VOCs emitted from the filters on HVAC (heating, ventilation, and air conditioning) systems, which are located on the roofs for commercial buildings in urban areas. The indoor air is supplied from the outdoor intake of these ventilation systems. Because of this, the intake air from green roofs may differ from standard white membrane roofs, resulting in different indoor air quality.

VOCs are gases that may originate from a wide variety of sources, including solids and liquids that tend to vaporize at room temperature. While not all VOCs are bad, some are concerning because they can cause various health effects based on the level of toxicity. Some of these health issues include eye, nose and throat irritation, headaches, nausea, and can also damage the liver, kidney and central nervous system [4]. Compounds such as benzene and formaldehyde are particularly hazardous and can even be potential causes for cancer. These types of VOCs, found both indoors and outdoors, can come from fossil fuels and various household products such as paints, disinfectants, building materials and anything else that contains organic solvents.

This project explores the design and construction of a low-cost, filter bank assembly (FBA) that is used to sample particle resuspension from green roofs and white membrane roofs. Ultimately, this will allow the distinction between particulate matter and microbial volatile organic compounds that originate from the green roof surface versus other surfaces, in this case a white membrane roof, when loading onto the filter samples. This device is specifically designed for the green roof research site located on the Hayden Meadows Walmart in North Portland, as shown in Figure 1. Approximately 50% of the roof is covered in vegetation, and the other 50% is covered with a low-albedo white membrane “cool” roof. Because the roof contains both roof types, the types of particles loading onto the filters strongly depend on the direction of the wind. The Air Handling Units (AHU) throughout the roof have the potential to collect particulate matter on both the green roof and white membrane roof. This FBA also reduces error and any contamination when handling the filter samples for analysis and data collection with the VOC analysis used subsequently, a proton-transfer-reaction - mass spectrometer (PTR-MS). While most research looks at urban air quality, I am investigating the potential for vegetation to have local effects, including those on building environmental systems like AHUs and the filters present in those AHUs.

Figure 1 Hayden Meadows Walmart Eco-Roof

2 Background & Motivation

According to the Environmental Protection Agency (EPA), we spend approximately 90% of our time indoors [4]. Because so much of our time is spent indoors, we need to understand the quality of our indoor air that we are breathing in every day and the types of compounds we are filtering inside through our HVAC systems. While HVAC filters prevent small, airborne particles from entering your heating and cooling system, microbes and other particulate matter can build up, ultimately creating the potential for filters a potential source of harmful VOCs. We hypothesize that re-suspended green roof matter may present a rich source of VOCs that may emanate from filter deposits to the indoor environment.

2.1 HVAC Filters on Green Roofs

On green roofs, there is an abundance of vegetation, such as sedum, surrounding these HVAC systems. Through the process of photosynthesis, plants have the ability to transform the CO_2 (carbon dioxide) present in the ambient air into oxygen, as well as remove levels of O_3 (ozone) [5]. From a study done by Li et al. [6], green roofs have specifically been shown to have a higher removal efficiency of compounds such as CO_2 and O_3. However, other studies demonstrate that the microbes, from the vegetation on green roofs, accumulate on the HVAC filters. It has been shown that these microbes can chemically react with other VOCs, such as ozone, and create byproducts [7]. While the microbiome on the filters was not analyzed, a study done by Destaillats et al. [8] found that when ozone reacts with the various types of used HVAC filters on standard rooftops, harmful secondary byproducts were formed. Similarly, a study done by Schleibinger and Ruden [9] revealed significant levels of formaldehyde and acetone, potentially due to microbial growth on the filters themselves, even without the presence of vegetation. However, on green roofs, where large amounts of microbes are present due to the surrounding vegetation and soil, we propose that high levels of VOCs such as formaldehyde and acetone on the HVAC filters may emanate from the filter to the indoor space.

2.2 Microbial Volatile Organic Compounds (mVOCs)

Microbial volatile organic compounds (mVOCs), which are produced by the metabolism of fungi and bacteria usually found in soil, can also be emitted into the air. Microbes are significant to the biodiversity and health of plants because they provide nutrients, promote plant growth, and help resist diseases. On green roofs, these microbes can become airborne and enter the airstream. Over time, the mVOCs, microbes, and other particulate matter accumulate on the filter media; however, it is difficult to predict the types of byproducts that will be formed due to the fact that there is a high diversity of mVOCs depending on several environmental factors. In a previous study done in New York, the types of soil fungal communities on green roofs were compared to those found in parks [10]. On the green roofs, the most prominent types of fungi were glomus and rhizophagus. Despite the fact that fungal communities depend on the type of vegetation and surrounding environmental conditions, we might expect to see similar fungi on green roofs in Portland. Furthermore, another study suggests that trace gases are produced and consumed by reactions in microorganisms from soils [11]. However, there are a lack of studies that analyze these different interactions and relationships between harmful gases and microbes found in the soil.

2.3 Scope of Project

My thesis stems from the work done by Abbass et al. [12]. In this study done in Portland, Oregon, the ozone removal efficiency was analyzed on filters from a green roof versus a white membrane roof. This study concluded that the HVAC filters on green roofs had a higher O_3 removal efficiency; however, they also observed that there was a higher accumulation of biogenic particulate matter on the filters from the green roof, possibly due to the surrounding vegetation. Chemical reactions with this biogenic particulate matter and ozone may result in the formation of byproducts and unidentified VOCs. These byproducts have the potential to reverse the positive effects of green roofs in terms of air quality. I will be developing a tool that will sample filters from the same HVAC systems of a Walmart roof in order to isolate the source of particulate matter on the green roof filters versus the white membrane roof filters, which will be done with the filter bank assembly. This paper will explain the design and fabrication of this device and discuss future steps in order to deploy the FBA on the Walmart rooftop for further research.

3 Methods and Materials

This custom filter bank assembly consists of many components that are controlled with an Arduino microcontroller. The main components include a wind vane, an anemometer, two vacuum pumps, and a bank of filter cassette holders. Additionally, to provide more information about the surrounding environmental factors, the system also includes a temperature sensor, relative humidity sensor, real time clock module, and a SD card to log the data. This product is similar to the TE-WILBUR Low Volume Federal Reference Method Sampler and a Relaxed Eddy Accumulator (REA), which are both currently on the market. However, this device provides a slightly different purpose and was made at a much lower cost by utilizing off the shelf products and sensors. This section will review the materials selected and the challenges regarding wiring and programming.

3.1 Existing Products

This product is custom made for ongoing research on the Hayden Meadows Walmart roof; however, there are products on the market that serve similar functions. This includes a Te-Wilbur Low Volume Federal Reference Method (FRM) Sampler (Figure 2) and a Relaxed Eddy Accumulator (Figure 3). The Te-Wilbur device from Tisch Environmental is a very advanced low volume air sampler for flow rates between 1-25 LPM. It has the ability to sample ambient air and separate particulate matter from PM2.5 to PM10 onto separate filters. The purpose of this device is to accurately monitor the air pollutants in specific areas to ensure they are compliant with the National Ambient Air Quality Standards (NAAQS) [13]. Basic operation of the device includes weighing each of the filters before and after to determine the amount of particulate matter accumulated over a period of time. Additionally, the Te-Wilbur records various parameters such as temperature, pressure, and flow rate. In comparison, a Relaxed Eddy Accumulator (REA) is a device that is also used for evaluating VOCs; however, this method is specifically used for measuring vertical fluxes of trace gases within atmospheric boundary layers. The REA operates at a constant sampling rate with a high frequency, allowing it to measure compounds at very low levels. As seen in Figure 3, an eddy covariance tower was implemented in Vancouver, Canada to measure the carbon fluxes and water exchange between the forest and the atmosphere. While these methods are similar to the FBA, they serve different purposes. The FBA specifically focuses on the accumulation of particle resuspension onto HVAC filters on green roofs versus white membrane roofs.

Figure 2 Te-Wilbur Low Volume Federal Reference Method Sampler

Figure 3 Eddy Covariance device used to measure carbon fluxes

3.2 Device Specifications

A list of materials used for building the FBA are shown in the Bill of Materials (BOM) in Appendix A. Arduino, which is an open-source, C++ based microcontroller, was used in this project to control and integrate each of the electrical components. For this device, a weather station assembly, purchased from SparkFun Electronics and shown in Figure 4, was implemented for its ability to measure wind speed and direction, as well as measure the amount of rainfall. In order to collect more data about the environmental conditions, the Adafruit SHT31-D temperature and humidity sensor, as shown in Figure 5, was implemented. This device was chosen for its ability to make precise measurements with high accuracy. Furthermore, a microSD breakout board was used for data logging of the various sensors. The ChronoDot Ultra-precise Real Time Clock (RTC) module was also added to record the date and time to ensure that each recorded data value is associated with a timestamp.

The system includes two 12V DC vacuum pumps, one from KNF Neuberger and the other from an unknown source. Ideally, the final product would have two similar pumps; however, this is what was available at the time. Each pump was wired to a Single Pole-Double Throw (SPDT) relay, which can be controlled via the microcontroller based on the average wind direction for a given period of time.

The current state of the filter bank assembly does not have any housing components due to time constraints; however, parts for the filter bank have already been selected and purchased. Each of the filter samples will be contained in a polypropylene cassette with a diameter of 37mm. Each of these cassettes will be connected in-line with ¼" tygon tubing using PVC luer adapters. Two separate filter banks will be implemented, one for sampling of the green roof and the other for sampling of the white membrane roof. Each of the cassettes, for a specified roof, will be connected to a vacuum pump, which will be controlled based on the wind direction readings. A waterproof enclosure will also contain all of the electrical components in order to protect it from harsh weather conditions. Further work of the FBA will include this fabrication of the housing for the filter bank and the electrical components.

Figure 4 Weather Station Assembly from SparkFun Electronics

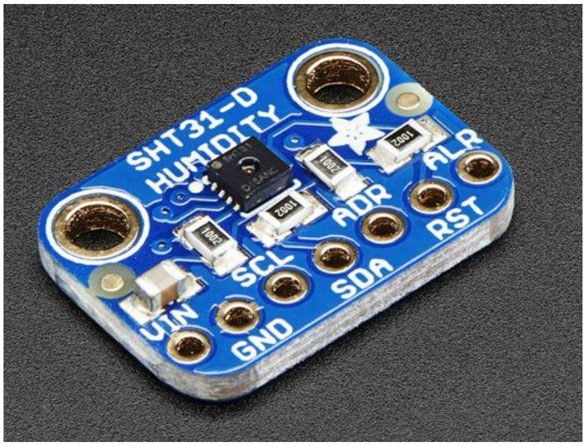

Figure 5 SHT31-D Temperature and Humidity Sensor

3.3 Relevant Calculations

Based on the studies done by Abbass et al. [12] and Destaillats et al. [8], the target face velocity for each of the filter samples was approximately 1.1-1.3 cm s^{-1}. This range also stems from a field study conducted by Zaatari et al. [14], where the face velocity was correlated to the filter pressure drops in 15 rooftop units. One of the vacuum pumps used in this device has an air flow rate of 3 LPM (50 cm^3s^{-1}) at atmospheric pressure; however, the specifications for the other pump is unknown. Each of the cassette holders, shown in Figure 7, have a diameter of 37 mm, which results in a surface area of 10.75 cm^2 for the filter sample. For the desired number of filter cassette holders per pump, these parameters can be calculated to achieve the desired face velocity for each filter. Equation 1 shows the relationship of the volumetric flow rate (Q) to the face velocity and the area of the filter sample.

$$Q = V * A \ [cm^3/s] \quad (1)$$

$$\dot{m}_{in} = \dot{m}_{out} \ [kg/s] \quad (2)$$

$$\dot{m} = \rho * Q \ [kg/s] \quad (3)$$

The conservation of mass can be simplified to Equation 2, where $\dot{m}_{in}$ and $\dot{m}_{out}$ are the mass flow rates entering and exiting the system respectively. This demonstrates that $\dot{m}_{in}$ must be equivalent to $\dot{m}_{out}$, which can each be calculated with Equation 3 using the density for air at a specific temperature and pressure. While these equations can be used to determine the face velocity for a given number of cassette holders, the filter media and air pressure must also be considered. Due to the resistance of the filter media, this will create a pressure drop, which is inversely related to the air velocity through the system and can result in a lower pump efficiency.

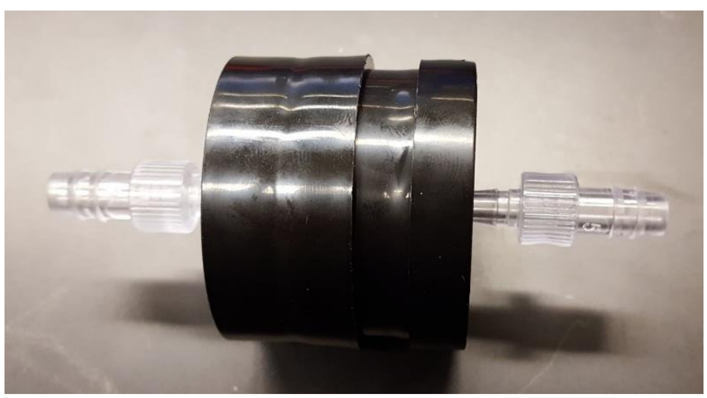

Figure 6 37mm Polypropylene Cassette Blank

The wind vane required complex code in order to determine the average wind direction over a specific period of time. The wind vane is composed of a magnet and eight reed switches, each connected to resistors of various values. This magnet closes the reed switches as the wind rotates the vane, with the capability of closing two switches at once. The results in a total of 16 different positions mounted radially at 22.5 degrees, as shown in Figure 7. With the analog-to-digital converter, the reading outputs a voltage value that corresponds with a value in degrees and radians, as shown in Table 1.

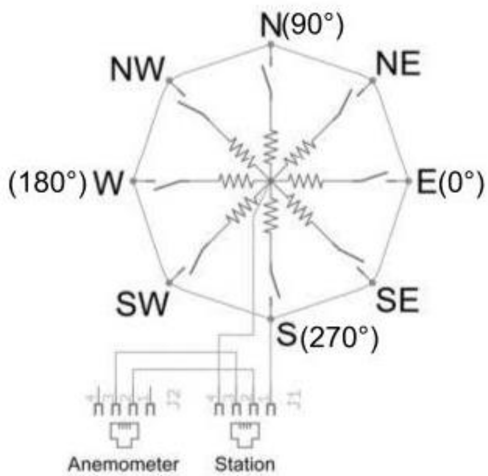

Figure 7 Diagram of Wind Vane Positions

Table 1 Corresponding resistance and voltages values for cardinal directions

Cardinal Directions	Direction (degrees)	Direction (radians)	Resistance Value (Ω)	Voltage (V=5V, R=10kΩ)
N	90	1.57	33k	3.84v
N-NE	67.5	1.18	6.57k	1.98v
NE	45	0.79	8.2k	2.25v
NE-E	22.5	0.39	891	0.41v
E	0	0	1k	0.45v
E-SE	337.5	5.89	688	0.32v
SE	315	5.5	2.2	0.90v
SE-S	292.5	5.12	1.41k	0.62v
S	270	4.71	3.9k	1.40v

Table 1 Continued

S-SW	247.5	4.32	3.14k	1.19v
SW	225	3.93	16k	3.08v
SW-W	202.5	3.53	14.12k	2.93v
W	180	3.14	120k	4.62v
W-NW	157.5	2.75	42.12k	4.04v
NW	135	2.36	64.9k	4.33v
NW-N	112.5	1.96	21.88k	3.43v

As shown in Figure 8, the FBA will be placed in the middle of the Walmart Eco-roof, where each pump will be sampling from its designated rooftop type. The specified sampling directions for each rooftop were calculated using an aerial image of the roof from Google Maps, as seen in Figure 8. For example, the distances from the FBA location to the corners of the green roof side were measured with Google Maps, which allows you to measure exact distances. Based on this, I calculated the resulting angle of sampling to be approximately 72° for the green roof and 78° for the white membrane roof; however, both of these values were rounded to 90° due to the limitations of the wind vane.

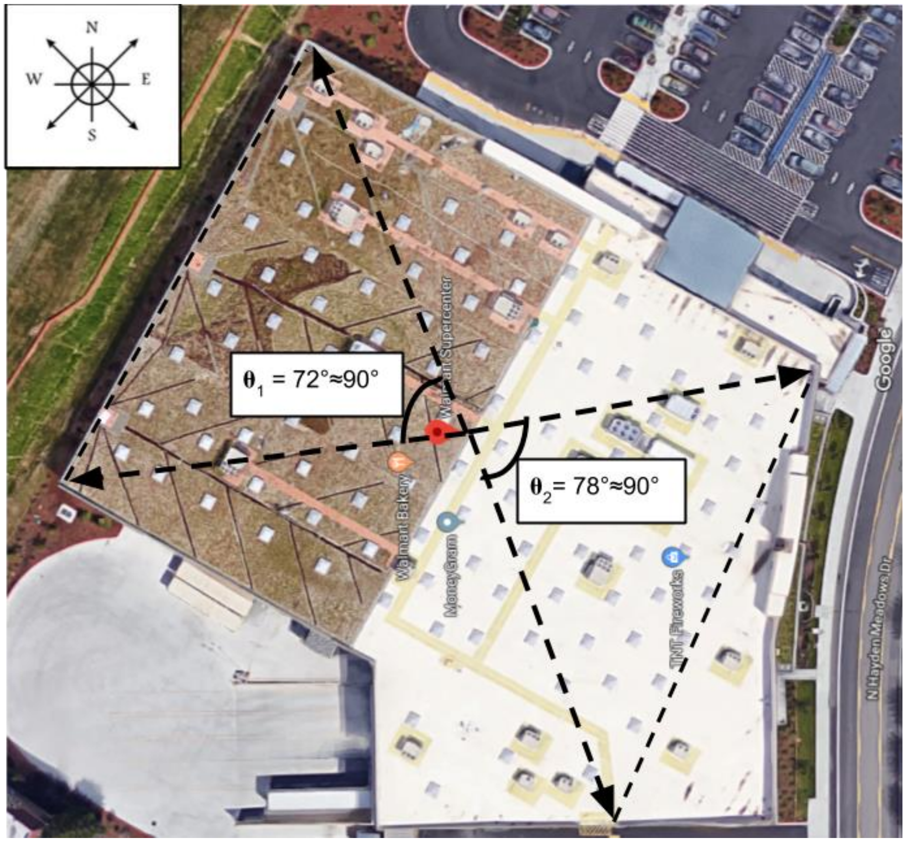

Figure 8 Google Maps Aerial View of Walmart Eco-Roof

The sampling algorithm consists of averaging 100 readings, from the wind vane, over a period of 20 seconds. In order to average the wind directions, the x and y vectors were taken in radians using Equations 4 and 5. Both vectors were averaged for 100 readings and the resultant angle was found using Equation 6, where the signs of both the x and y arguments were used to find the quadrant of the resultant angle, $\theta_{resultant}$. Therefore, when the wind vane calculates an average wind direction that lies between West and North over a period of 20 seconds, one of the pumps will turn on for 60 seconds to sample from the green roof area. Similarly, the when the wind vane outputs an average wind direction ranging from East to South, the other pump will sample air on the white membrane roof area for 60 seconds until the next reading. The average wind directions in degrees are stored on the microSD card, along with what state each pump is in.

$$x = \cos(\theta) \tag{4}$$

$$y = \sin(\theta) \tag{5}$$

$$\theta_{resultant} = \operatorname{atan2}(y,x) \tag{6}$$

4 Results

Currently, the filter bank assembly is fully functional; however due to time constraints, it is not yet ready for deployment on the Walmart Eco-roof and improvements can be made. Each of the main parts used for this device are shown in Table 3. All of the electrical components, shown in Figure 9, are wired, but the pins have loose contact with the breadboard and microcontroller. This causes some components and sensors to occasionally fail due to the bad connections. In order to fix this problem, wires should be soldered or a PCB could be constructed for a more solid, condensed product. Additionally, the sampling frequency is inconsistent due to the differences in the time it takes to average the wind directions compared to the amount of time a pump is on if the wind is coming from the specified direction. Ideally, the data logger should have a constant sampling rate. In order to achieve this, the data logger should record every 20 seconds, independent of the current state of the pump. If one of the pumps is on for 60 seconds, the SD card should continue to record data.

Table 2 List of main components

Item	Part No.	Component Name	Description	Quantity	Unit Cost	Total Cost
1	DEV-13975	SparkFun RedBoard w/ Arduino	ATmega328 microcontroller with Optiboot (UNO) Bootloader	1	$19.95	$19.95
2	80422	Weather Meter	Wind Vane/Anemometer/Rain Gauge	1	$76.95	$76.95
3	2857	Temp/RH Sensor	Adafruit Sensirion SHT31-D - Temperature & Humidity Sensor	1	$13.95	$13.95
4	BOB-00544	microSD Card Module	SparkFun microSD Transflash Breakout	1	$4.50	$4.50
5	225	RTC module	ChronoDot - Ultra-precise Real Time Clock - v2.1	1	$17.50	$17.50
6	COM-00100	Relay	JZC-11F - Relay SPDT Sealed	2	$1.95	$3.90
7	NMP830KNDC	Vacuum Pump	12V DC Vacuum Pump 3 L/min at atm. Pressure	2	$188.33	$376.66

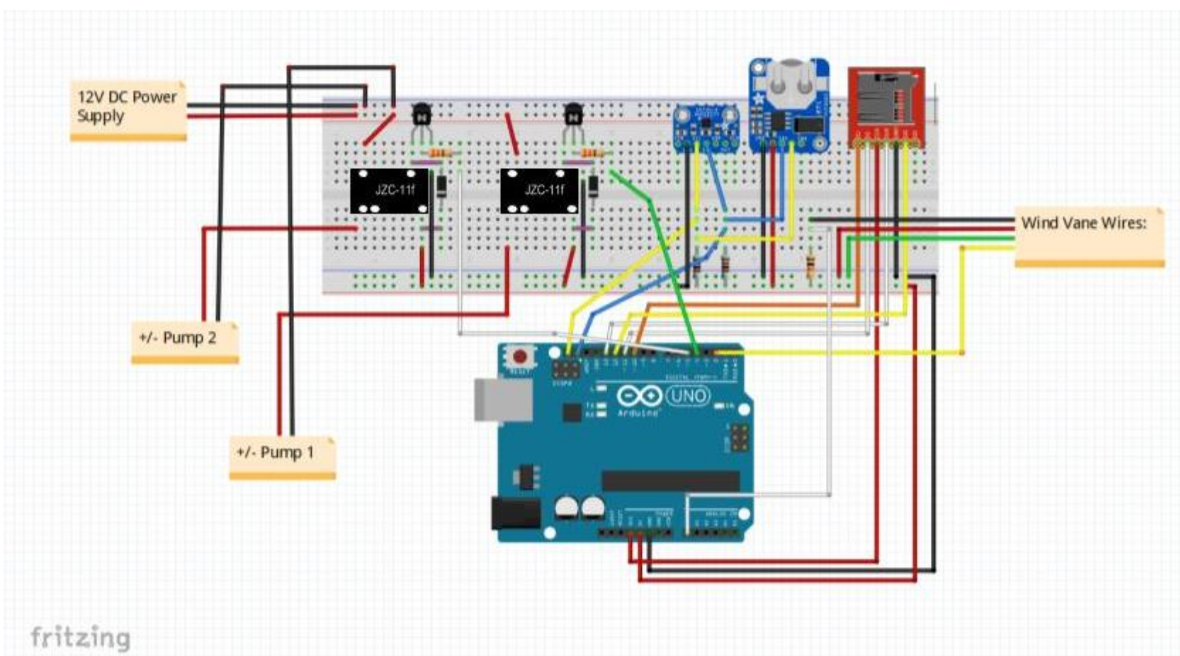

Figure 9 Fritzing Schematic of Circuitry

4.1 Next Steps

As previously stated, there are still improvements that can be made to the current FBA, shown in Figure 10, such as the wiring and sampling frequency. Further steps for the FBA will also include selection of new pumps, implementing the rain gauge, and the housing for the final product. Depending on the desired number of filter cassette holders that will be deployed in the field, the system might require a pump with a higher flow rate. Additionally, it would be better to have the two pumps be the same in order to simplify the system. The weather station assembly that contains the wind vane and anemometer also includes a rain gauge. This component is already attached to the assembly but has not yet been programmed to function. The rain gauge is a self-tipping bucket that can be recorded from the momentary contact closure when 0.011 inches of rain is collected. Lastly, the housing needs to be fabricated for the final product. This will consist of a waterproof enclosure for the electrical components and an enclosure for both filter banks. Each filter bank will consist of the desired number of filter cassette holders, in-line with the tygon tubing. A new tripod must also be selected to better support the weather station assembly.

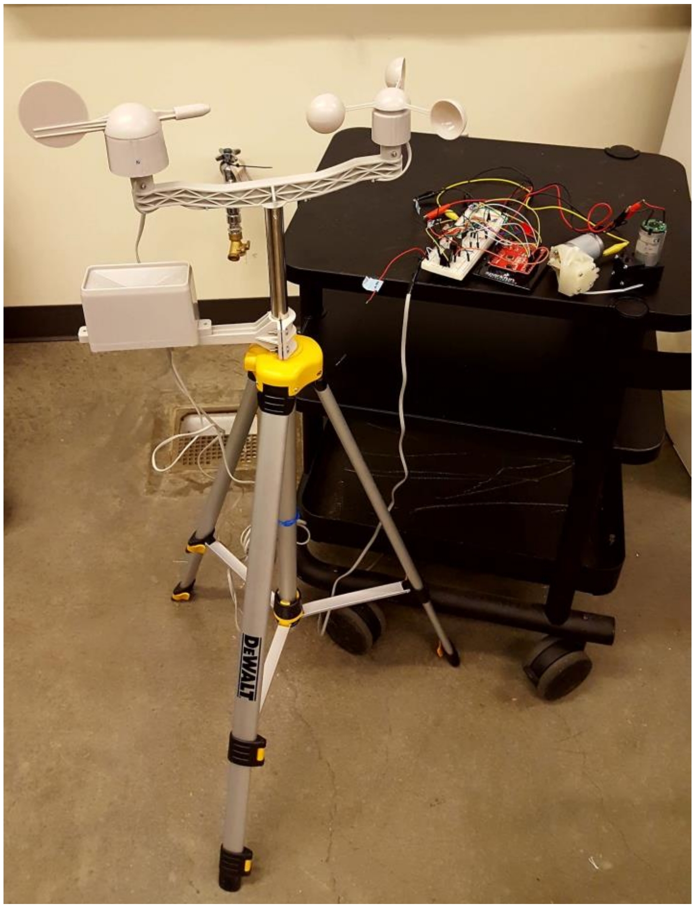

Figure 10 Current Assembly of FBA

4.2 Data Logger Output

The final product of the FBA would ideally be deployed on the roof for 1 week, seasonally. An example of what the data logger looks like is shown in Table 3. The microSD card stores the date and time stamps, ambient temperature in Celsius, the relative humidity, wind speed in mph, wind direction in degrees, and whether the pumps are on or off. After the FBA is deployed for a period of 1 week, the SD card will have this stored in order to provide information about the filter samples.

Table 3 Sample output of the data stored on the microSD card

Date	Time	Temperature (ºC)	RH(%)	WindSpeed (MPH)	WindDirection (degrees)	Pump
5/6/2019	13:54:04	21.97	42.27	0	315.13	Pump2:ON
5/6/2019	13:54:37	21.99	42.39	3.93	315.13	Pump2:ON
5/6/2019	13:55:37	22.03	42.34	2.93	135.22	Pump1:ON
5/6/2019	13:55:57	21.93	41.98	0	135.22	Pump1:ON
5/6/2019	13:56:48	21.99	42.27	0.49	135.22	Pump1:ON
5/6/2019	13:57:48	21.99	42.31	0	135.22	Pump1:ON
5/6/2019	13:58:08	21.99	42.17	11.28	89.95	Pump1:ON
5/6/2019	13:58:59	21.97	42.19	12.76	225.17	Pump:OFF
5/6/2019	13:59:19	21.97	42.12	1.96	225.17	Pump:OFF
5/6/2019	13:59:40	21.96	42.23	1.98	225.17	Pump:OFF
5/6/2019	14:00:00	21.97	42.26	1.96	225.17	Pump:OFF
5/6/2019	14:00:20	21.97	42.1	1.67	225.17	Pump:OFF
5/6/2019	14:00:41	21.97	42.16	0	225.17	Pump:OFF
5/6/2019	14:01:01	21.96	42.14	0	225.17	Pump:OFF
5/6/2019	14:01:22	21.97	42.04	1.96	225.17	Pump:OFF
5/6/2019	14:01:42	21.96	42.1	1.98	225.17	Pump:OFF
5/6/2019	14:02:03	21.97	42.23	1.96	225.17	Pump:OFF
5/6/2019	14:02:23	21.99	42.13	1.67	225.17	Pump:OFF
5/6/2019	14:02:44	22	42.02	5.32	225.17	Pump:OFF
5/6/2019	14:03:04	21.99	42.3	10.24	225.17	Pump:OFF
5/6/2019	14:03:25	21.99	42.15	0	135.22	Pump1:ON
5/6/2019	14:04:20	22.04	42.3	0	315.13	Pump2:ON
5/6/2019	14:04:41	22.03	42.26	0	315.13	Pump2:ON
5/6/2019	14:05:31	22.07	42.12	0.98	315.13	Pump2:ON

5 Conclusion

The objective of this project was to create a low-cost sampling mechanism for HVAC filters based on pre-specified wind directions of the Walmart eco-roof. The net cost for this device, not including the enclosures for the filter banks and electronics, is approximately $650, as shown in Appendix A. In comparison, the Te-Wilbur device is significantly more expensive. The price for this commercial product was not listed; however, it can be rented for approximately $1,100 per month. The FBA will allow further research of the types of microbes and VOCs captured on and emitted from the filters in AHUs that potentially end up in our indoor air. Due to the lack of literature on this subject, the device will hopefully assist in providing insights on how green roofs affect, not only our outdoor air quality, but our indoor air quality as well.

5.1 Limitations

While this device is a simple, low cost method for filter sampling, it does have its limitations. Some of these limitations include a low, inconsistent sampling frequency and low pump flow rate. Currently, the device alters between recording data every 20 seconds or 60 seconds, depending on if one of the pumps is on or off. Revisions of the code will need to be made in order for the data logger to consistently record every 20 seconds. Due to time constraints, new pumps have not been selected yet. Further work will include determining the desired number of cassette holders per filter bank in order to select new pumps based on the specified air flow rate.

5.2 Implications

Once the filter bank assembly is improved and ready for deployment, it will sample filters for 1 week. After this period, these samples will be removed and analyzed using a proton-transfer-reaction mass spectrometry (PTR-MS). PTR-MS is an analytical chemistry technique that allows real-time monitoring of VOCs, even at very low concentrations. The PTR-MS can detect molecules and compounds that have a higher proton affinity than water. It will be able to distinguish these types of compounds that are present on the filter, as well as the concentration for each. For example, we might expect to see higher concentrations of formaldehyde and acetone as a result of microbial growth on the green roof filters. This research, which will be done in the Green Building Research Lab, will contribute to the understanding of eco-roofs and their impact to the indoor environment.

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Appendices

Appendix A: Bill of Materials (BOM)

Table A 1 Bill of Materials

Item	Part No.	Component Name	Description	Quantity	Unit Cost	Total Cost	Manufacturer
1	DEV-13975	SparkFun RedBoard w/ Arduino	ATmega328 microcontroller with Optiboot (UNO) Bootloader	1	$19.95	$19.95	SparkFun Electronics
2	80422	Weather Meter	Wind Vane/Anemometer/Rain Gauge	1	$76.95	$76.95	Argent Data Systems
3	2857	Temp/RH Sensor	Adafruit Sensirion SHT31-D - Temperature & Humidity Sensor	1	$13.95	$13.95	Adafruit Industries
4	BOB-00544	microSD Card Module	SparkFun microSD Transflash Breakout	1	$4.50	$4.50	SparkFun Electronics
5	225	RTC module	ChronoDot - Ultra-precise Real Time Clock - v2.1	1	$17.50	$17.50	Adafruit Industries
6	COM-00100	Relay	JZC-11F - Relay SPDT Sealed	2	$1.95	$3.90	SparkFun Electronics
7	COM-13689	P2N2222A Transistor	The BC337 is a drop-in replacement for the P2N2222A Transistor	2	$0.50	$1.00	SparkFun Electronics
8	COM-08588	Diode - 1N4148	Use this for signals up to 200mA of current	2	$0.15	$0.30	SparkFun Electronics
9	COM-11507	330k Resistor	330k Ohm Resistor (20/pck)	1	$0.95	$0.95	SparkFun Electronics
10	COM-11508	10k Resistor	10k Ohm Resistor (20/pck)	1	$0.95	$0.95	SparkFun Electronics
11	R5112KS	12k Resistor	12k Ohm Resistor (20/pck)	2	$0.09	$0.18	Addicore
12	NMP830KNDC	Vacuum Pump	12V DC Vacuum Pump 3 L/min at atm. Pressure	2	$188.33	$376.66	KNF Neuberger
13	225-13-4	Tubing	Tygon Tubing 1/4" ID X 3/8" OD (10 feet)	1	$38.00	$38.00	SKC-West, Inc.
14	225-13-2	PVC Luer Adapters	Luer adapter that connects to 1/4" tubing (pk/10)	3	$13.00	$39.00	SKC-West, Inc.
15	225-308	Cassette Blank	Polypropylene Cassette Blank, 2 sections, 37 mm, black,	1	$54.75	$54.75	SKC-West, Inc.

			conductive (pk/50)				
17	N/A	Tripod	Basic Tripod to prop the weather station (from GBRL)	1		$0.00	
				Net Cost:		**$648.54**	