Brett Stinson
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Hello there. My name is Brett Stinson and I am a mechanical engineering student working out of the Healthy Buildings Research Laboratory with Dr. Elliott Gall. Today I'm going to be sharing with you the project I have been working on for the last 9 months or so, which is titled: *"Modeling Airflows and VOC Source Strengths to an Occupied School."*

To begin, let's briefly talk about VOCs—which is short for volatile organic compounds—and try to understand why they are considered to be so important. They are emitted from thousands of consumer products, as well as from human metabolism and internal combustion engines in vehicles, both sources that will prove to be important for the purposes of my study. Long-term exposure to VOCs can cause impaired cognition as well as detrimental health effects in humans, and their presence outdoors can meaningfully degrade urban air quality.

My study had two purposes: First, I aimed to quantify per-person VOC emission rates, concentrating primarily on compounds associated with human metabolism or human activity. Second, I focused on a group of compounds linked to traffic-related air pollution—from here on out known as TRAP. These were called BTEX compounds, and sustained exposure to them can lead to health issues as well. One of their primary sources is exhaust from vehicles, and as you'll see, the field site at which the study took place was uniquely suited to explore the implications of exposure to this group of VOCs.

Harriet Tubman Middle School is an institution built in close proximity to I-5. Exposure to TRAP is especially harmful to vulnerable populations such as children, and the school is located a mere 25-125 meters from the roadway.

So, in Fall 2018, after having been closed since 2012, the school was reopened with a renovated HVAC system. Portland Public Schools selected PSU to investigate the air-handling system's effectiveness over the course of three, six-week long phases—the majority of the data used in my analysis was extracted from the final phase.

Air was monitored at three locations in relation to the air-handler: Return air is representative of indoor air present throughout the school, outdoor air is representative of the air before it is taken in from outside and cleaned, and supply air is composed of return and outdoor air after it passes through the air-handler for cleaning.

VOC sampling was conducted using a proton-transfer-reaction mass spectrometry (PTR-MS) instrument. VOC concentrations were sampled by use of a switching valve, which alternated between return, outdoor, and supply air in regular, ten-minute intervals.

As the Portland Public Schools campaign took place before I was a student at Portland State University, the majority of my portion of the work revolved around data analyzation.

The first step I took was to analyze the outdoor air exchange rate, and to verify that outdoor air was being taken in and pushed through the school at rates consistent with those told to us by the building's mechanical contractor.

In order to do this, a tracer decay test was implemented using CO_2, whose concentration data was examined between April 19 and June 19, 2019. CO_2 concentrations were plotted against time each day, the most pronounced decay period was selected, and a linear regression was performed in MATLAB to extract the air exchange rate in air changes per hour.

After performing both a KS and student t-test, it was determined that the data was normal and that the weekday and weekend data was statistically, significantly different.

Still, due to the uncertainty associated with weekend decay periods, which were difficult to dig into due to a lack of occupancy, the focus of the study was narrowed to two days. May 27, 2019, a holiday in which the air-handler was operating but the school was mostly vacant, and May 28, 2019, a weekday in which the air-handler was on and the school was fully occupied.

The outdoor air exchange rate for May 28th was found to be 0.8457 air changes per hour.

Several calculations in this study required a stable occupancy period to be determined—a phenomenon that can be observed when the CO_2 concentration in return air has reached a stable level for a prolonged period of time.

After creating plots in MATLAB of return air CO_2 concentration vs. time, the data cursor tool was used to identify the beginning and ending points of a consistently stable period on May 28th, the occupied day.

As the school was vacant on May 27th, the same timeframe selected for May 28th was applied: 10:12 A.M. – 12:04 P.M.

Though Portland Public Schools reported that 472 students and 33 faculty members were enrolled or employed at the school in 2019, deviation from these numbers on any given day was expected for reasons such as absenteeism and janitorial work. Thus, a refined calculation of N—or the number of people present during the stable occupancy period—was carried out.

Table 4 of Persily, 2016, which is considered to be an authoritative work on the subject, provided CO_2 generation rates for humans based on their age, gender, and level of physical activity. As you can see in the table at the bottom of the slide, ages and MET levels were decided on, calculations were made, and a CO_2 generation rate was arrived at for the school: $2.35\ \frac{L}{s}$.

From here, unit conversions were carried out and a flow balance equation—which can be seen in the bottom left corner—was derived using CO_2 concentrations and the outdoor air exchange rate. Solving for N, it was found that there was a total of approximately 448 people present on May 28, 2019.

Focus was now shifted to calculating the supply air change rate through the school, which would be crucial for subsequent emission rate calculations. In order to accomplish this, the region of pronounced CO_2 accumulation in return air that occurred each morning due to students entering the school had to be analyzed.

Using MATLAB's data cursor tool again, an accumulation period of 09:05 to 10:11 was decided upon, which ran directly into the stable occupancy period—this was intentional.

In order to converge on a number of minutes following the accumulation period to include, Microsoft Excel's Solver was employed several times in intervals of five minutes. This continued until stability with regard to the supply air change rate was realized—which happened after 35 minutes.

With the appropriate time interval in tow, the solver was run and a supply air change rate through the school was returned: 1.965 air changes an hour. The same supply air change rate was applied to the vacant day, as only modest improvements could have been made.

Now that airflows through the school had been modeled, it was time to turn to the study's main objective: determining VOC source strengths. Mass balance equations were taken from the supporting material that accompanied a prior study, Tang 2016, to help develop an approach from a similar investigation.

I will spare you an explanation of the derivations seen here, but in short, equations of total mass were worked up, as well as equations of mass from supply air. These are applied to May 27th, the vacant day, in order to account for non-occupancy sources, and then applied again to the occupied day. The difference between total indoor emission rates on the 28th and vacant emission rates on the 27th, divided by the number of people found earlier, result in per-person VOC emission rates.

I chose to further investigate seven compounds that were associated with human metabolism and human activity, and four that were associated with TRAP, which were the BTEX compounds discussed earlier.

What you're seeing here is a stacked plot of May 28th that shows temperature and relative humidity, along with CO_2, isoprene, monoterpenes, and acetone concentrations. It is clear from the temperature reading that the air handler turns on at 6, and from the CO_2 reading that the school is occupied between 9 A.M. and 4 P.M.

Both isoprene and acetone are present in human breath, and thus their elevated levels between 09:00 and 04:00 are to be expected. As monoterpenes are associated with personal care products, plants, fruits, and cleaning, the mid-day jump could potentially be explained by the commencement of lunch period, and the evening spike could be explained by nightly cleaning activities; an on-site researcher noted that these took place each weekday around 5:00 P.M.

What you're seeing here are the total indoor, supply air, non-occupancy, and per-person VOC source strengths for each of the 11 compounds chosen. I won't dwell too much on this collection of data, but having sources separated like this will make BTEX apportionment possible later on.

There were three major studies that sought to quantify per-person VOC emission rates in public spaces, and I have compiled their results here. I should mention, experimental conditions varied substantially across each study—in terms of both the volumes of the spaces being analyzed and the number of subjects involved.

That being said, you can see that isoprene is relatively constant across each study and that acetone, which is associated with metabolism, agrees closely with Stönner's findings—perhaps because we both focused on children.

Our monoterpenes rates align closely with Tang and Stönner, possibly because similar cleaning protocol was enacted.

The underlying goal of this study, and often air pollution studies in general, is to apportion air pollutants to their sources in order to understand their individual levels of contribution in a space. I was afforded the opportunity to compare VOCs that are thought to be generated by humans to those that are thought to be present due to outdoor pollution—a stark difference in apportionment should have been, and was, apparent.

What you're looking at explains this nicely. On the top, we have three compounds that are associated with humans, and the majority of their presence is due to occupant activity. On the bottom, we have BTEX compounds, and the majority of their presence is due to supply air activity, which does suggest that TRAP is entering the school.

Though Tang, 2016 does not explicitly quantify source apportionment percentages, upon visual inspection, their percentage distributions are quite similar to the ones you see here. As the university where Tang's experiment took place was not near a busy roadway, agreement in source apportionment suggests that the HVAC system recently installed at Harriet Tubman Middle School is reducing exposure to outdoor, gas-phase TRAP.

Moving forward, I intend to expand my dataset to include additional compounds, extend the period of the study to a minimum of two weeks, and possibly try to account for surface partitioning phenomena. In general, there is much work to be done with regard to this subject matter; further contributions are essential to the advancement of building science.

Thank you.