Characterization and Source Apportionment of Indoor Air Pollutants in an Urban Environment

Americans spend approximately 90% of their time indoors[1], and by 2050 over two-thirds of the global population will live in urban environments[2]. Studies have shown that human exposure to pollutants indoors is orders of magnitude higher than the exposure experienced outdoors[3]. Focusing air quality research on the places occupied by the most people and where pollutant exposure is highest is important in preventing negative health outcomes. It is paramount to understand the chemical, physical, and societal processes of the interface between urban and indoor air quality.

Volatile organic compounds (VOCs) are emitted into the atmosphere from both anthropogenic and biogenic sources, including industrial and transportation activity, biomass burning, and vegetation. Indoor VOCs accumulate both from outdoor sources permeating into indoor spaces and from indoor activities such as cooking, cleaning, and off-gassing of furniture. Besides these gaseous VOCs, other semi-volatile organic compounds (SVOCs) exist both in the gaseous and condensed phase due to their lower vapor pressure and higher boiling points. When VOCs and SVOCs react with sunlight and oxidants such as ozone and nitrogen oxides (NO_x), secondary organic aerosols (SOA) are produced, particles with known hazards to human health.

While there have been mobile, real-time measurements of air pollutants such as $PM_{2.5}$[4] (particles less than 2.5 microns in diameter), there have been limitations to similar VOC measurement campaigns: the measurement's location was stationary[5], the hour-long sampling time made it difficult to locate pollution "hot spots"[6], or the instruments used could not measure compounds made possible by current technology[7,8]. Prior to recent advances in VOC mass spectrometry, it had been difficult to measure VOCs and SVOCs at (a) sensitivities that allow identification of compounds and measurement of accurate concentrations and (b) mobile, real-time temporal scales to link concentrations to specific sources.

Recent technological advances have made it possible to overcome such limitations. The newest generation proton transfer reaction time-of-flight mass spectrometer, the Vocus 2R PTR-ToF-MS from Aerodyne, Inc., has world-leading real-time mass resolution and sensitivity. The new mass spectrometer measures concentrations of more than 1600 chemical compounds every second, including many high-molecular-weight molecules considered semi-volatile. It can detect concentrations at part per trillion levels with 1-second measurements and even part per quadrillion scales at 1-minute averaging for certain compounds, allowing us to explore the frontier of trace – and very toxic – air pollutants. Using the most advanced mass spectrometer for this project will lead to the reporting of both SVOC molecules and trace VOCs that past mass spectrometers did not have the sensitivity to detect. The new Vocus Inlet for Aerosol (VIA, Aerodyne, Inc.) gives us the novel ability to measure the time-resolved chemical composition of SOA and other particles found indoors and outdoors, which is important for quantifying human exposures.

Research Objective

As the first study to investigate the interface in VOC and SOA concentration between urban outdoor and indoor environments using world-leading measurement capabilities, this project aims to:

(1) Quantify **concentrations and human exposure** to air pollutants that have been previously unidentifiable due to technological limitations.

(2) Identify and apportion the **major sources of VOCs and SOA** found indoors and in urban areas.

Task 1: In controlled experiments, we will characterize indoor concentrations of VOCs and SVOCs such as benzenoids, siloxanes, and hydrocarbons. In UT-Austin's environmental chambers and UTest House – a full-scale house on UT-Austin's research campus outfitted with an array of sensors – experiments will simulate common household events such as cooking and cleaning; VOC, SVOC, and particle concentrations will be measured. To supplement our work, we will also use past datasets of the HOMEChem measurement campaign, which used the UTest House to characterize typical household activities[9]. Due to the increased sensitivity and precision of our novel mass spectrometer, **we hypothesize that we will make novel characterizations of SVOCs** that previous instruments were insensitive to and that past research campaigns did not report.

Task 2: Using citizen science pathways already established from past research campaigns[10], we will recruit 20 volunteer homes of diverse economic and geographical locations around Austin, Texas to take

2 air samples of ambient air twice per day for 2 weeks, one inside their home and one directly outside of it. The air samples will be taken off-site for evaluation by our Vocus mass spectrometer to find VOC and SVOC concentrations across both temporal and spatial scales in urban and suburban environments. We expect that VOC concentrations will vary widely from home to home due to individual differences in ventilation, personal care product usage, and cooking routines; **however, we hypothesize that homes within a neighborhood will have similarities due to proximity to vehicle and industrial emissions.**
Task 3: Concurrently with the citizen science measurement, we will drive the Vocus mass spectrometer around Austin to measure VOC concentrations found on Austin's roads at 1 Hz time scales. Pairing the VOC data with GPS data will be vital in finding point sources and pollution "hotspots". Every other day we will measure with and without the VIA aerosol inlet, collecting data on both the gaseous concentrations and chemical composition of particles. **We hypothesize that many pollution "hotspots" will be from sources usually overlooked** as key polluters. Due to the complex chemical and physical processes that impact air quality, it is important to measure other air pollutants, not just VOCs and SVOCs. We will also measure mobile concentrations of ozone, NO_x, and $PM_{2.5}$ – all interdependent on the presence of VOCs – as well as meteorological data such as wind speed, temperature, and humidity. To add to our data set, we will use the Texas Commission on Environmental Quality's (TCEQ) 6 Austin-area monitoring stations as supporting data for wind speed, temperature, $PM_{2.5}$, ozone, NO_x, and sulfur oxides.
Task 4: Combining the mobile air pollutant data with citizen science air samples and environmental parameters will produce a rich dataset across temporal and spatial scales. Using source apportionment and multivariate analysis methods – for example, positive matrix factorization (PMF) and principal component analysis (PCA) – we will identify major sources of urban and indoor VOCs. **We hypothesize that our analysis will reveal unknown, as well as verify known emissions** from indoor sources – such as cleaning or cooking – **but will also quantify indoor exposure** to pollutants penetrated from outdoors.

Broader Impact

Due to the breadth of samples we will collect during Tasks 2 and 3, I will recruit at least 2 undergraduate students from both UT-Austin and Huston-Tillotson University (an H.B.C.U. located in East Austin) to help with the collection of the citizen air samples. To introduce them to air quality research, I will train them in off-line VOC analysis and data processing.

By conducting this campaign in actual homes and roads in addition to a laboratory setting, our findings can be used quickly for recommendations in homes and residential developments in Austin and other cities. By utilizing citizen science, **this research will increase public awareness of the pollutants** that residents are inhaling. The papers published from this campaign will be used as recommendations for urban planners, environmental regulators, and, perhaps most importantly, the general public. By measuring around Austin, we will also report on the accuracy of the TCEQ stations and how each station's neighborhood-scale measurements differ from precise ground-level measurements.

Intellectual Merit

While several studies have measured air quality across urban areas, this will be the first study to do so by measuring a wide range of VOCs (with atomic mass units from 30 to 500) in real-time using new mass spectrometry technology. It will also be the first campaign to use such a wide-ranging dataset – the controlled studies in the UTest House, the citizen science household air samples, TCEQ station measurements, and the mobile dataset – to better understand the urban and indoor air quality system. By focusing on air pollutants that are not well-understood due to past technological limitations, we will also report on exposures that have been overlooked.

Works Cited

[1] Klepeis et al. (2001), *J Expo Anal Environ Epidem.*, 11(3), 231-252; **[2]** UN World Urban. Proj.: The 2018 Revision (2018), pg. 10; **[3]** Nazaroff (2008), *Build. and Env.*, **43(3)**, 269-277; **[4]** Apte et al. (2017) *Environ. Sci. Tech.,* **51(12)**, 6999–7008; **[5]** Deng et al. (2018), *Aero. Air Qual. Research*, **18**, 3025-3034; **[6]** Zheng et al. (2020), *Sci. Total Environ*, **703**, #135505; **[7]** Maji, Beig and Yadav (2020), *Environ. Pollution*, **258**, #113651; **[8]** Crippa et al. (2013), *Atmos. Chem. Phys.*, **13**, 8411–8426; **[9]** Farmer et al. (2019) *Environ. Sci: Proc. Imp.*, **21**, 1280-1300; **[10]** Bi et al. (2018), *Environ. Inter.*, **121(1)**, 916-930