Clearing the air: impacts of plants on air particulates in passive ventilation

Elise Braun[1], Thomas Cooper[1], Marsie Surguine[1]

[1]University of Oregon, Portland, OR

ABSTRACT: The presence of air contaminants, such as fine particulate matter generated by transportation and other outdoor sources is linked to adverse effects on human health such as asthma, headaches, and irritation in the eyes (Kluizenaar, et al. 2016). To improve the health and wellbeing of its employees and inform its professional practice, the architecture firm Opsis engaged with University of Oregon architecture students to study the presence and low-cost interventions to reduce air contaminants in their passively ventilated office space. The study consisted of a multi-phased experiment in the open office, testing the effect of plants on air particulates derived from outdoor sources measured at PM2.5 and PM10. The objectives of the study were to determine if there was a reduction in the number of air particulate levels measured after the intervention of plants. However, our experiments showed that plants were not able to significantly reduce particle counts through natural ventilation. Our data did support that increasing the plant density for the Sanseveria robusta (Snake plants), as well as combining both the Sanseveria robusta (Snake plants) and the Dracaena Marginata Colorama (Dracena) together, did have a slight impact on particle count reduction. The study also revealed other findings. One finding is that interior pollutants were more prevalent than exterior pollutants, indicating interior sources of pollutants and the recommendation for future testing to location the interior sources. Data collected from the exterior alludes to wind direction playing a role in the intake of outdoor pollutants into the indoors, but further study, especially by season, is recommended. In a lab test, moistening plants reduced particle counts more than dry plants, but scalability and practicality at an office scale is questionable. Overall, the data shows the average particulate counts are within acceptable EPA ranges. But, research literature indicates limits may not be low enough as health is impacted at levels lower than EPA limits. A final take-away is that we should continue to explore ways to improve outdoor air quality.

KEYWORDS: Indoor air quality, indoor plants, natural ventilation, sustainability

INTRODUCTION

As we try to find new ways to reduce our consumption and contributions to climate change, we must develop and understand more environmentally friendly architecture. This interest includes passive design which has multiplied the implementation of natural ventilation systems in buildings, relying on operable windows and wind to refresh the air within a space. Unfortunately, these strategies assume that outdoor air is fresh air and free of pollutants. Developed outdoor environments often have poor air quality from sources including roadways, construction, and other human activity, and the use of natural ventilation without filtration can introduce these outdoor pollutants into the occupied spaces of our 'green' architecture. This is quite concerning considering that "about 200,000 Americans are thought to die from air pollution each year" (Holden, 2019). Furthermore, the presence of air contaminants is linked to adverse human health effects including discomfort, eye irritation, increased susceptibility to asthma, sickness, absence, and risk of deteriorating work performance (Carrer, et al. 2018). In our quest for an architecture that is better for the environment, we must ensure that we are not crafting an architecture that is adverse to the health of its occupants.

Figure 1: Exterior rooftop close-up of black particles collected in puddles. Source: (Marsie Surguine 2019)

For this study, we worked with Opsis Architecture. Opsis is an architecture firm that has implemented the sustainable practices it recommends for its clients, within its own office. A key part of their indoor environmental quality strategy includes a natural ventilation system. So, to improve the health and wellbeing of their employees, and to pursue research informing their professional practice, Opsis wants to study the presence and reduction of air contaminants within their own passively ventilated office. They have become concerned because, over time, the city has developed around them and air quality has seemed poor with the American Lung Association scoring Multnomah county a "C" on a "A" to "F" scale for the particle pollution 24-hour rating (2019). The highway that is a block away, the construction down the street, or the taxi business on the ground floor, are all potential contributors to poor air quality. A recent study of the air around Harriet Tubman Middle School, whose property also abuts a large highway in the Portland metro, showed a significantly elevated presence of a wide variety of toxic chemicals in the air more than 200ft from the roadway (Gall, et al. 2019). As the Opsis building falls within a 200ft range from I-405, it is therefore highly susceptible to the chemicals and particles released on the high traffic roadway. One visit to the office's roof (Figure 1) clearly demonstrates the presence of air pollution because of the many black particles that have settled on it, and just below these blackened puddles, is one of the north facing windows ventilating the interior of Opsis. At the same time, the firm has been growing, the increased cooling demand has led the Opsis to open the windows more often bringing increased urgency to the concerns of pollution infiltration.

Since natural ventilation is typically associated with the desire for a healthier environment, we wanted to explore a natural filtration system to address the poor exterior air quality without resorting to mechanical systems. In traditional air systems, indoor air filtration and purifiers do not always remove all potential pollutants and sometimes make air quality worse (Claudio, 2011). Plant matter has been noted to successfully remove particulates (Ramasubramanian, et al. 2019), and the study of the highway adjacent middle school found that 15-60 percent of the pollutants from the highway could be reduced with vegetation and/or sound barriers (Gall, et al. 2018). What is less clear, is the effectiveness on a small scale of a regularly potted plants. Some studies argue that for a significant removal of particulate matter, the root system must be exposed to the polluted air (Zhang, et al. 2010). Our study attempts to test the effectiveness of normally potted plants as filtration in an actively occupied space.

HYPOTHESIS

1. Plants in the direct airflow path of passive ventilation openings will reduce the levels of PM 2.5 and PM 10 air particles coming indoors.
2. For the controlled chamber testing, the more plants in the direct airflow, the lower the number of air particles measuring at PM2.5 and PM10.

METHODS

Study overview
For our study, we did a multi-step experiment at the Opsis Architecture office testing the effects of plants on air quality. An additional component to our study was testing the plants in an air-controlled chamber in the University of Oregon Energy Studies in Building Laboratory, testing air particles with and without plants, to both supplement the data collect at Opsis as well as provide a comparison control for the Opsis collected data.

Baseline data
Baseline data, including interior air flow, temperature, PM 2.5 and PM 10, and site weather data, was collected for four days before implementing the intervention. The Dylos Logger DC1700 (v2.08cy) is a particle counter used to measure air quality. The Kestrel 5400 Heat Stress Tracker (0854LVCORA) is a device that tracks air flow and temperature, used with the intention to understand air flow within the space. We paired the Kestrels and Dylos devices together, placing each near an operable window along the north and west exterior walls and near the center of the open office space (Figures 6-11). The open office space features cubicles with human occupants (employees), machines (primarily computers and printers), papers, books, journals, and other office supplies. The deployment of initial equipment, Dylos and Kestrels, was based on the suspected airflow patterns.

Independent variables
Distance of house plants to air intake(s), changing for each phase of data collection.

Dependent variables
Air particle count (PM 2.5 and PM 10), heat levels (degrees Fahrenheit).

Controls
Similar ventilation opening on the same north-facing façade without any plants

Research setting
Opsis Architecture office, 920 NW 17th Ave, Portland, OR 97209

Initial site visit
Prior to testing, we made a site visit to the Opsis office on October 7th, 2019, documenting the existing conditions and determining specific locations for setting up testing equipment to collect both baseline data and considered locations for potential intervention tests. We selected both interior and exterior locations for data collection, with the intention to run comparison tests between the interior and exterior conditions.

During the initial visit, we observed how the main working office area is a shared open space (see Figure 2). The open office space features cubicles with human occupants (employees), machines (primarily computers and printers), Running the perimeter of the open office space are a series of operable windows along the west and north walls. Examples of the operable windows can be seen in Figure 2. A plan of the operable windows is shown in Figure 6. For the windows along the north and west exterior walls, the uppers are connected a direct digital control sensor system separated in zones, triggering the windows to be open at high temperature and CO_2 threshold levels. The windows on the east exterior wall are fixed.

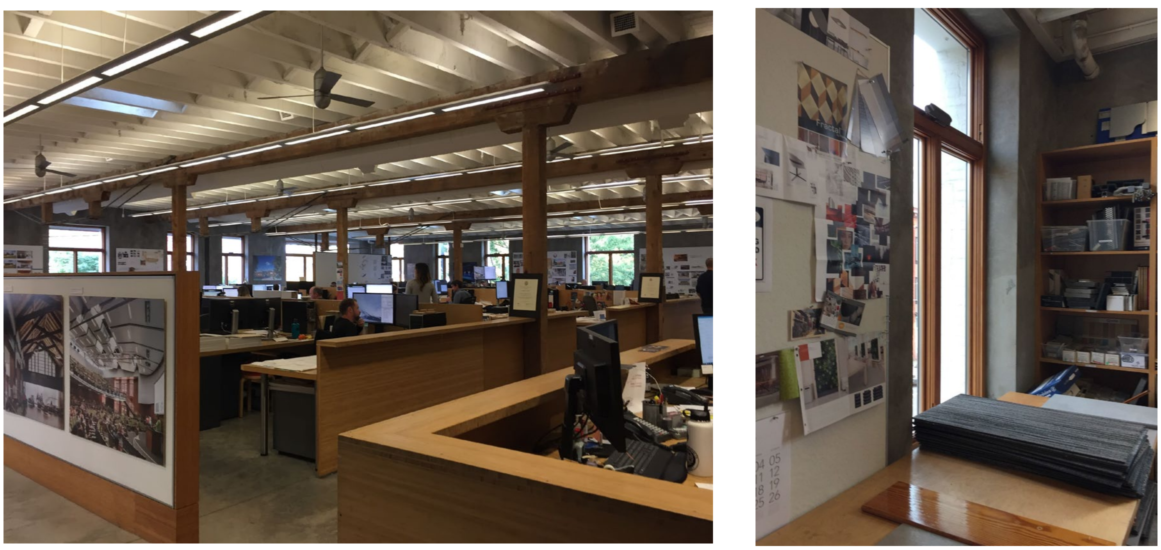

Figure 2: Office open space (left) and north facing material library window (right). Source: (Marsie Surguine, 2019)

Figure 3: Exterior rooftop views: facing east (left) and facing south, showing roof vent and mechanical system (right). Source: (Marsie Surguine 2019)

We were able to access the roof during our initial visit (Figure 3). On the roof, we observed black particles collected in puddles (Figure 1). The presence of the particles at the exterior made us curious to learn how many particles are entering the interior office spaces, especially when the windows are open. From the rooftop, we were able to observe the surrounding site context. Adjacent to the Opsis office building are multiple sources of pollutants, including an open-air parking and the I-405 highway to the east, a construction site to the west, and a cab business to the south (Figures 4, 5). Per the United States Environmental Protection Agency, fossil fuel-based gasoline and diesel releases carbon dioxide into the atmosphere, which, in combination with other greenhouse gases, is causing the Earth's atmosphere to warm and result in changes in the climate (EPA, 2019). Not only is CO_2 harmful for the atmosphere, an increase in CO_2 results in lessening of air quality and environmental comfort (Parhizkar et al., 2017 p. 1151). Recognizing exterior pollutant sources means for a better understanding on how many particulates are entering the interior office space and if interventions like plants can reduce the number of particulates would be valuable information for Opsis.

Figure 4: Exterior pollutant sources include an adjacent parking lot and the I-405. Source: (Elise Braun 2019)

Figure 5: Nearby the Opsis office (shown in blue) is a construction site to the west, cab business to the south, and highway I-405 to the east. Source: (Google Maps 2019, diagram by Thomas Cooper)

Baseline testing

To establish a baseline and understand the conditions of the Opsis office, we set up testing equipment at both the exterior and interior of the building. For the interior space, we wanted to measure air flow and current airborne particulate matter (PM) to help us understand the path of ventilation and establish a baseline to compare particles counts with our results after our plant intervention. Two common particulate matter sizes will be measured: 2.5μm/m^3 (PM 2.5) and 10μm/m^3 (PM 10). PM shows adverse health effects at exposure levels experienced by urban populations (World, 9), and is the standard metric used to create Air Quality Indexes. Additionally, particulates smaller than PM 2.5 are more likely to be inhaled by an individual. Two prominent organizations provide short-term (24 hour) and long-term (annual) guidelines on particulates: The Environmental Protection Agency (EPA) and World Health Organization (WHO). EPA guidelines do not provide an absolute maximum, instead focusing on an average volume over time. Guidelines can be a useful tool to compare to our collected PM data, however, the Journal of the American Medical Association reported 99% of deaths in locations linked to illness from air pollution were below EPA guidelines. The Dylos Logger DC1700 (v2.08cy) is a particle counter used to measure air quality. The Kestrel 5400 Heat Stress Tracker (0854LVCORA) is a device that tracks air flow and temperature, used with the intention to understand air flow within the space. We paired the Kestrels and Dylos devices together, placing each near an operable window along the north and west exterior walls and near the center of the open office space (Figures 6-11). The open office space features cubicles with human occupants (employees), machines (primarily computers and printers), papers, books, journals, and other office supplies. The deployment of initial equipment, Dylos and Kestrels, was based on the suspected airflow patterns.

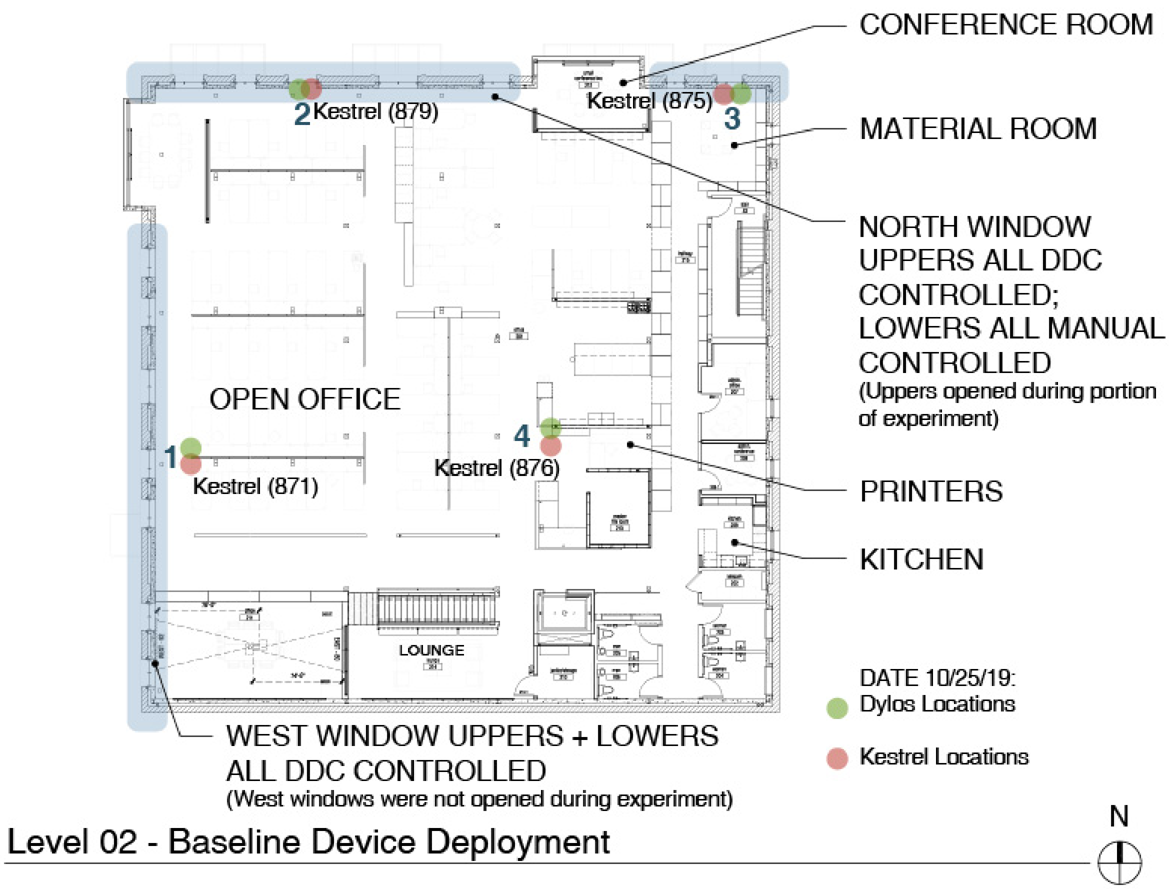

Figure 6: Interior equipment deployment, Opsis office. Source: (base map Opsis, diagram Marsie Surguine 2019)

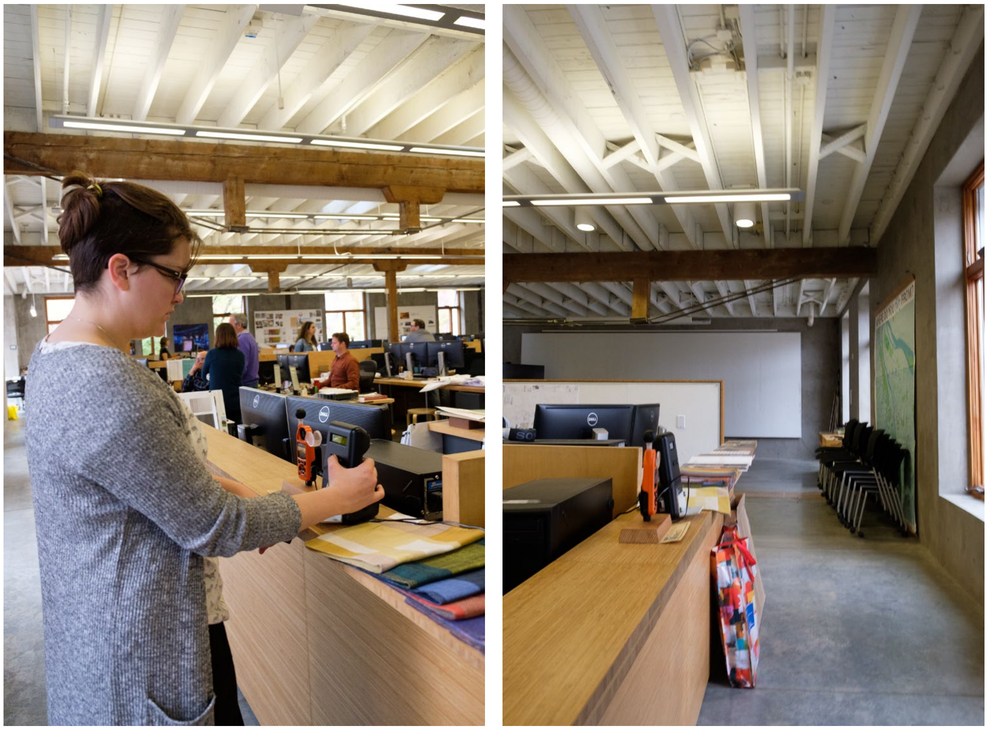

Figure 7: Interior Dylos and Kestrel location 1, near the west facing windows. Source: (Marsie Surguine 2019)

Figure 8: Interior Dylos and Kestrel location 2, near the north facing windows. Source: (Marsie Surguine 2019)

Figure 9: Interior Dylos and Kestrel at location 2 (left) and at location 3 (right). Source: (Marsie Surguine 2019)

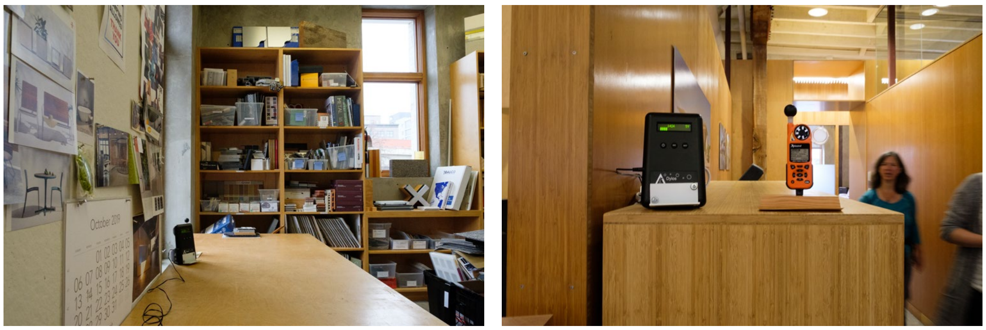

Figure 10: Interior Dylos and Kestrel location 3 (left) and location 4 (right). Source: (Marsie Surguine 2019)

Figure 11: Interior Dylos and Kestrel location 4. Source: (Marsie Surguine 2019)

For the exterior, we wanted to determine conditions outside the building that may impact the interior environment, especially when the office windows are open. For baseline exterior data collection, we selected a weather station (make and model number) to measure the outdoor conditions, air flow, and wind direction, as well as a Dylos Logger to capture particle counts in order to measure air quality. The weather station selected location was the center of the Opsis office roof, with the sensors oriented north as was instructed. (Figures 12-14).

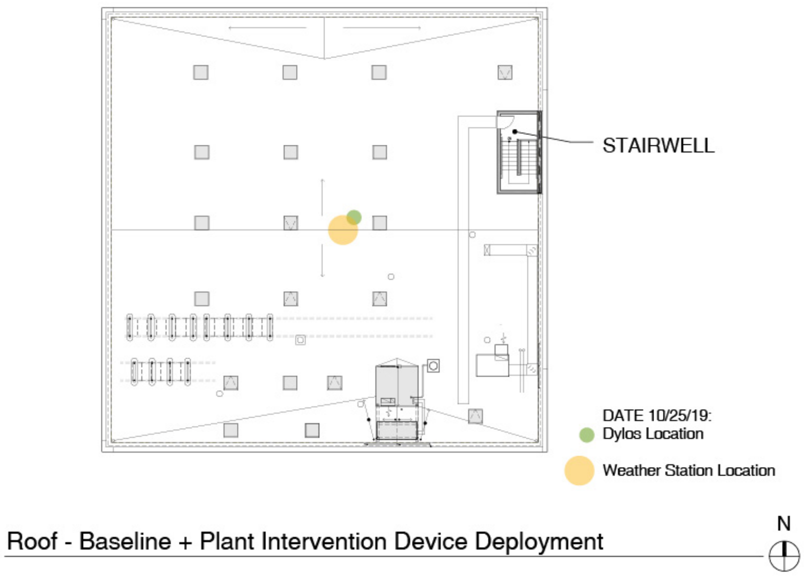

Figure 12: Exterior equipment deployment, Opsis Architecture office. Source: (base map Opsis, diagram Marsie Surguine 2019)

Figure 13: Exterior roof weather station and Dylos set-up. Source: (Marsie Surguine 2019)

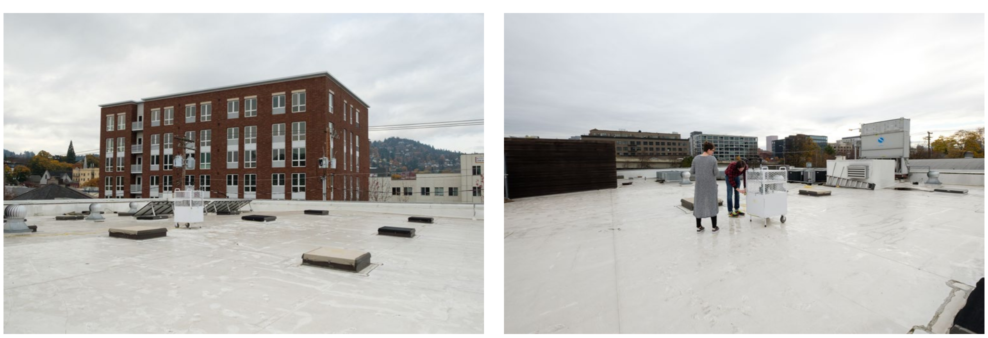

Figure 14: Exterior roof weather station and Dylos set-up. Source: (Marsie Surguine 2019)

Intervention testing

While the baseline data was being collected, we built a simple lumber assembly to function as a plant shelf. We also researched, determined, and procured the plants for our intervention testing, selecting the

Dracaena Marginata Colorama – also known as the corn plant or dragon tree – and the Sanseveria Robusta – snake plant and mother-in-law tongue – both plants are marketed by the Portland Nursery as "plants for cleaner air" (Portland Nursery).

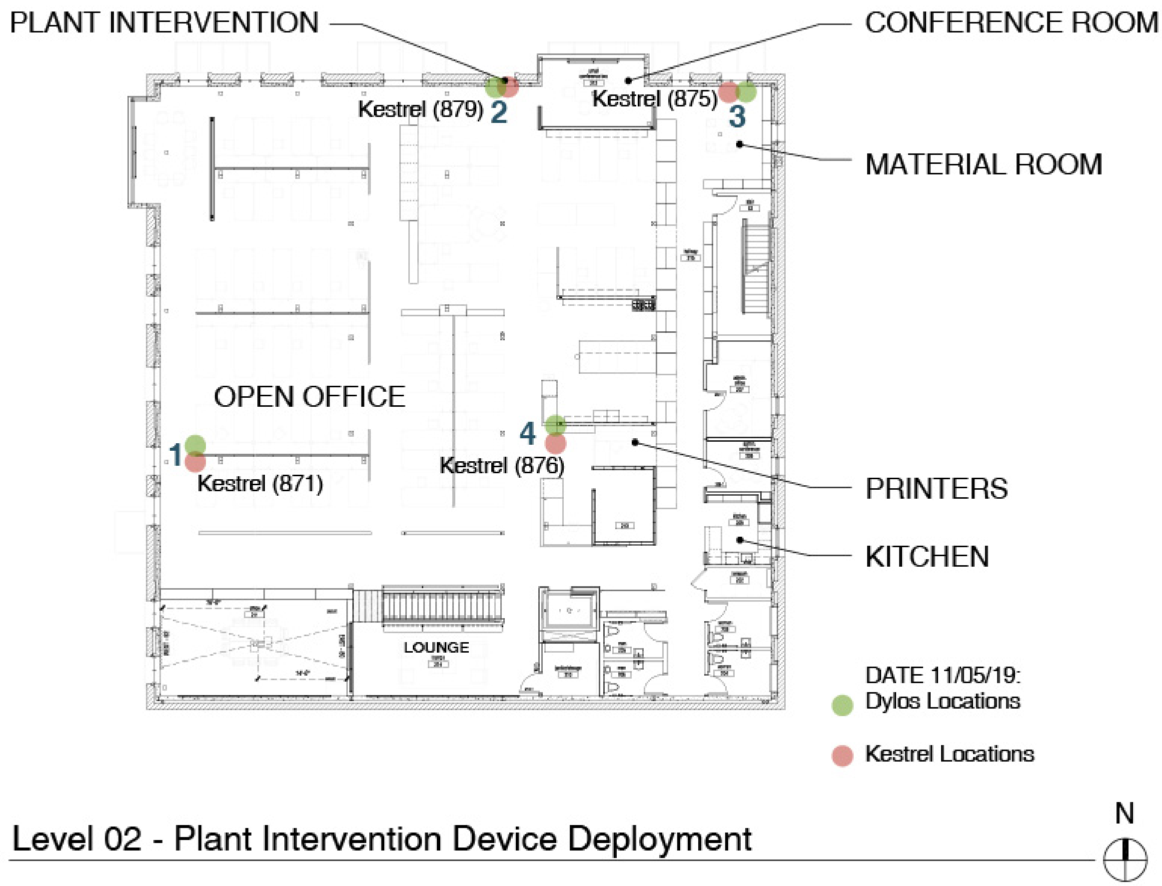

Figure 15: Interior equipment deployment, Opsis Architecture office. Source: (base map Opsis, diagram Marsie Surguine 2019)

We collected the baseline data and installed the plant shelf assembly using provided existing anchor bolts. For the office intervention testing, we selected one north-facing operable window to have the plant intervention and another north-facing window, along the same wall, to have no plant intervention as a comparison control (Figure 16). A pair of Kestrel and Dylos Logger devices was placed at both window locations. We also continued to collect data from the other existing baseline Kestrel/Dylos Logger interior locations (Figure 16) and the exterior rooftop weather station and Dylos Logger. Six plants, three each of the Dracaena Marginata Colorama and Sanseveria Robusta, were placed at the window for the plant intervention. Before placing the plants, we wiped down the foliage and made sure the plants were adequately watered.

Figure 16: Interior plant intervention set-up at Opsis Architecture office. The two plant types used were the Dracaena Marginata Colorama and Sanseveria Robusta. Source: (Marsie Surguine 2019)

Figure 17: Interior plant intervention set-up office context. Source: (Marsie Surguine 2019)

Controlled chamber testing

After the onsite office plant intervention tests, we ran control tests in the University of Oregon Energy Studies in Building Laboratory. The idea was to test the plants in an air-controlled chamber, testing air particles with and without plants. The goal of the controlled chamber testing was to both supplement the data we collected at Opsis as well as provide a comparison control for the analysis of the Opsis collected data. The controlled chamber was a series of connected air-sealed ductwork with a motorized fan to simulate air flow (Figure 18). The particulate source was pulled directly from the exterior, by locating the intake aperture at an open doorway. A pair of a Kestrel and Dylos Logger were placed in the interior of the chamber, the placement near the intake source and before the spot reserved for plants. Another Dylos Logger was located after the plant spot and a Kestrel was placed at the air outtake location (Figures 19, 20)

Figure 18: Ductwork serving as the chamber for the control experiment. Source: (Marsie Surguine 2019)

Figure 19: Controlled chamber testing set-up. Source: (Marsie Surguine 2019)

A baseline test was conducted, with no plants placed in the controlled chamber. After the baseline test was conducted, we placed one Sanseveria Robusta into the chamber and collected data (Figure 20). We then added a second plant and ran the same test before adding the third plant for another round of data collection (Figure 21). After the Sanseveria Robusta, we conducted the same additive series of testing on the Dracaena Marginata Colorama (Figures 20-21). We then collected data when all six of the Dracaena Marginata Colorama and Sanseveria Robusta plants were in the chamber (Figure 21). As an additional test, we removed the dry plants, spraying the leaves with water until moistened, and placed the six plants back in the chamber for another round of data collection.

Figure 20: Controlled chamber testing with a single Sanseveria Robusta (left) and Dracaena Marginata Colorama (right) Source: (Marsie Surguine 2019)

Figure 21: Controlled chamber testing with multiple Sanseveria Robustas (left) and a combination of Sanseveria Robustas and Dracaena Marginata Coloramas (right) Source: (Marsie Surguine 2019)

RESULTS

The data collection analysis is broken into the following categories: baseline data collection, intervention data collection, and controlled chamber data collection. The baseline data refers to the data collected at the Opsis office before the plant intervention, between the dates of October 25 and November 5, 2019. The intervention data refers to the data collected after the plants were installed at the office from November 5 thru the 12th. The controlled chamber data refers to the data collected in the controlled chamber at the University of Oregon Energy Studies in Building Laboratory.

Baseline testing results

Our findings defied our expectations in many ways. When we observed indoor particles without any intervention on our part, we found generally stable low particle counts throughout the office (Figure 22). When the windows were open, the particles were higher at the windows, as expected. However, we did not see as much pollution infiltration as we anticipated. The particles entering the space often did not come close to the quantity of particles we were seeing on the roof and did not come close to recommended limits. In fact, we saw higher particle counts from events occurring at the interior of the space, and these events hit much higher levels than those we saw at the open windows.

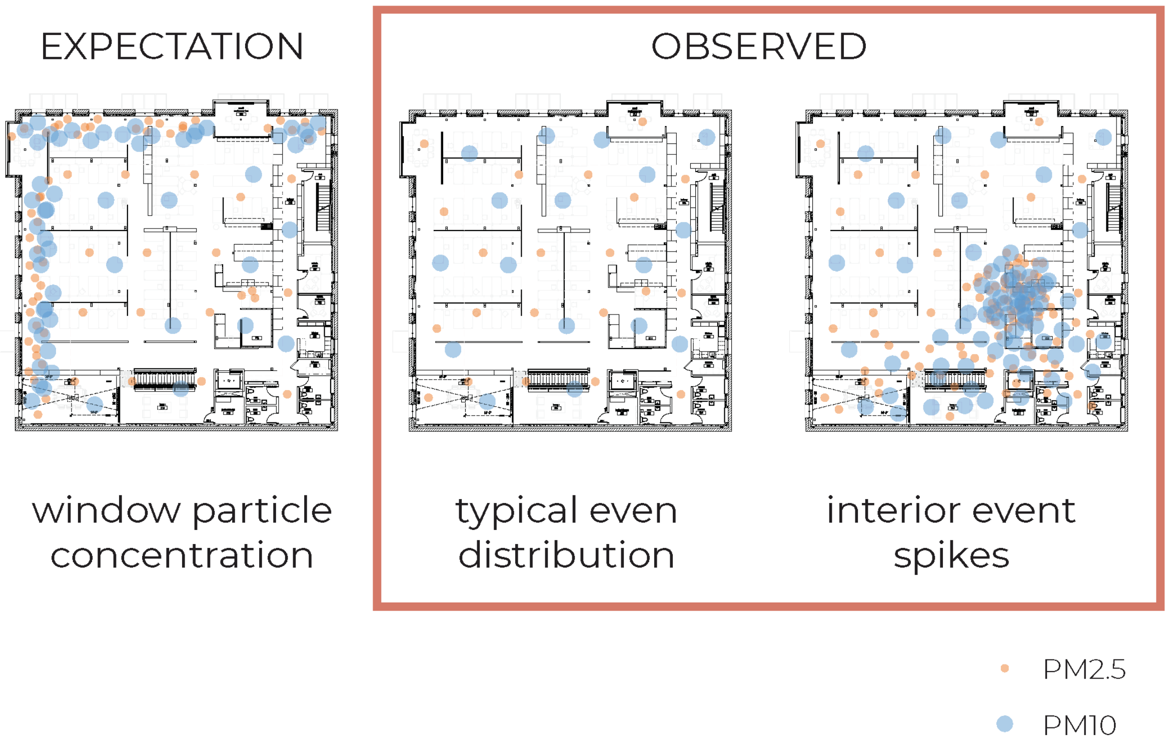

Figure 22: Diagrammatic plans showing expected versus observed to see particle concentrations within the office space. Source: (base plan Opsis, diagram Marsie Surguine)

At the exterior of the building, there was not consistent levels or patterns in the quantity of particles. There were no corresponding spikes at commuter hours from the adjacent highway, nor levels associated with day and night. The wind came most frequently from the Northwest. Figure 23 shows NW direction also saw the highest particle counts but didn't seem to correlate to any of the sources of pollution that we were concerned about. There were plenty of winds from the east, coming off the highway and often with a higher wind speed, but the average quantity of particles was much lower. In the end, the exterior air quality varied wildly, and as a result, it cannot be declared acceptable or unacceptable for use of natural ventilation. Rather, exterior conditions should be monitored to determine if opening windows will bring in acceptable air quality.

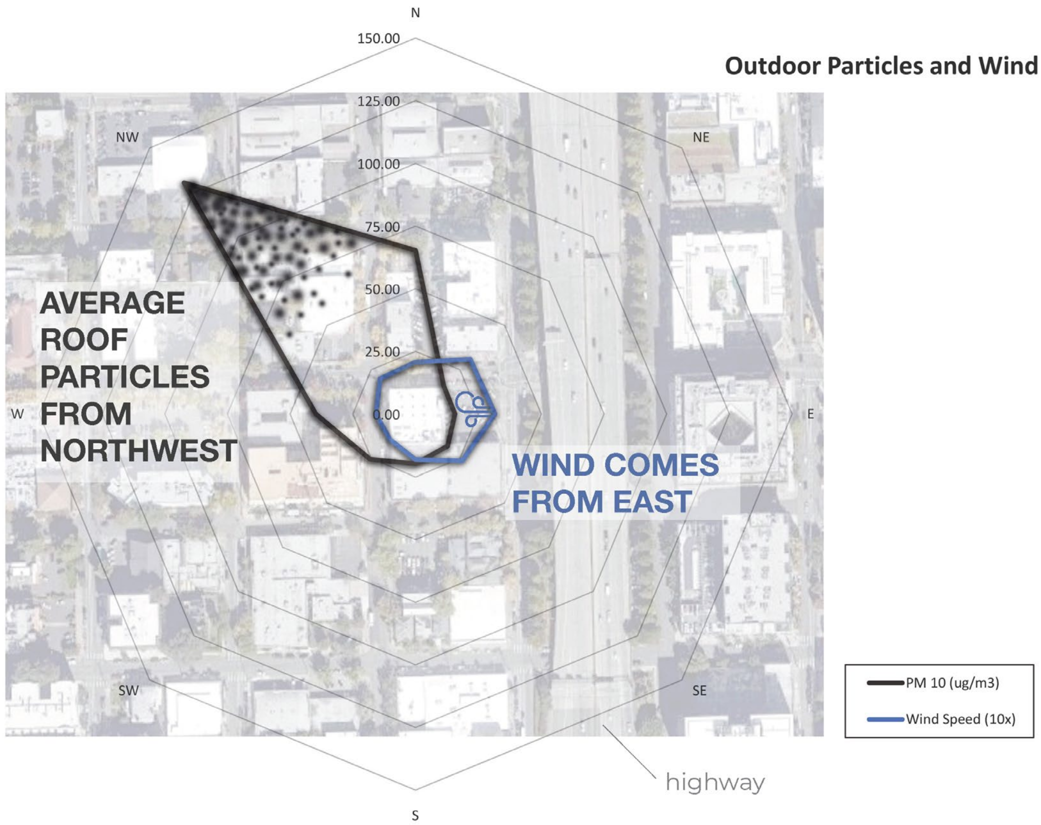

Figure 23: Average PM 10 counts by Wind direction with an exaggeration of Wind Speed in contrast. Source: (Elise Braun)

Despite the even distribution of air particles within the space, there was no correlation to quantities outside the building. Granted most of our study the windows were closed, but this also demonstrates that particles are not infiltrating the space through other paths. When graphed against one another in Figure 24 there are even times that the interior particle counts exceed those at the exterior. Looking at longer term trends, there is frequently a spike on particles stemming from an interior source in the evenings on weekdays. These events sent particle counts soaring into concerning levels, that fade away before morning. We suppose these spikes are associated with the time the space is cleaned.

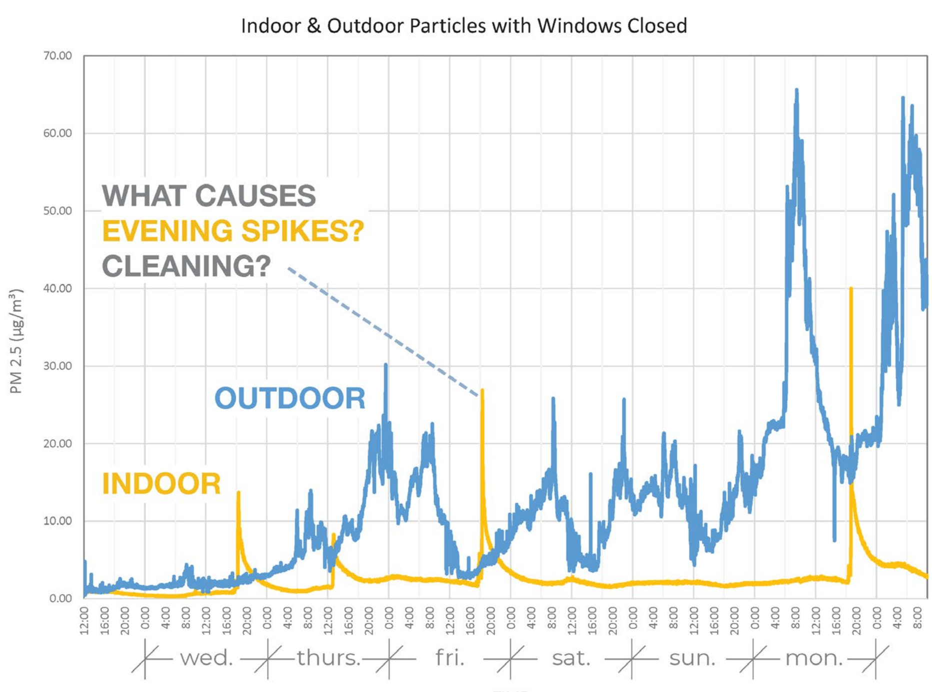

Figure 24: Comparing Particle Counts within and outside of our space. Source: (chart Elise Braun additional graphics Marsie Surguine)

To ensure we are capturing the conditions caused by natural ventilation, we had to be certain of window operations. In discussion with Opsis about the state of the automatic window ventilations, we discovered that our study was more limited than planned. Though the original design of the space have the West Windows as operable, the system is presently non-functional which left us with one orientation of operable windows. Then within our timeframe of testing the operation of the North Windows went out of commission temporarily. Even when the system was operational, the weather brought quite cold exterior temperatures, so the system never reached a point when it was appropriate to open the windows. Thus, the windows were not open frequently during our testing, and we had to pinpoint when the windows were open. By comparing temperature at the windows with the interior of the space in figure 25, we could identify the times when the temperate at the operable windows was significantly lower than the center of the space due to the flow of cool outdoor air and isolate the times the windows were open.

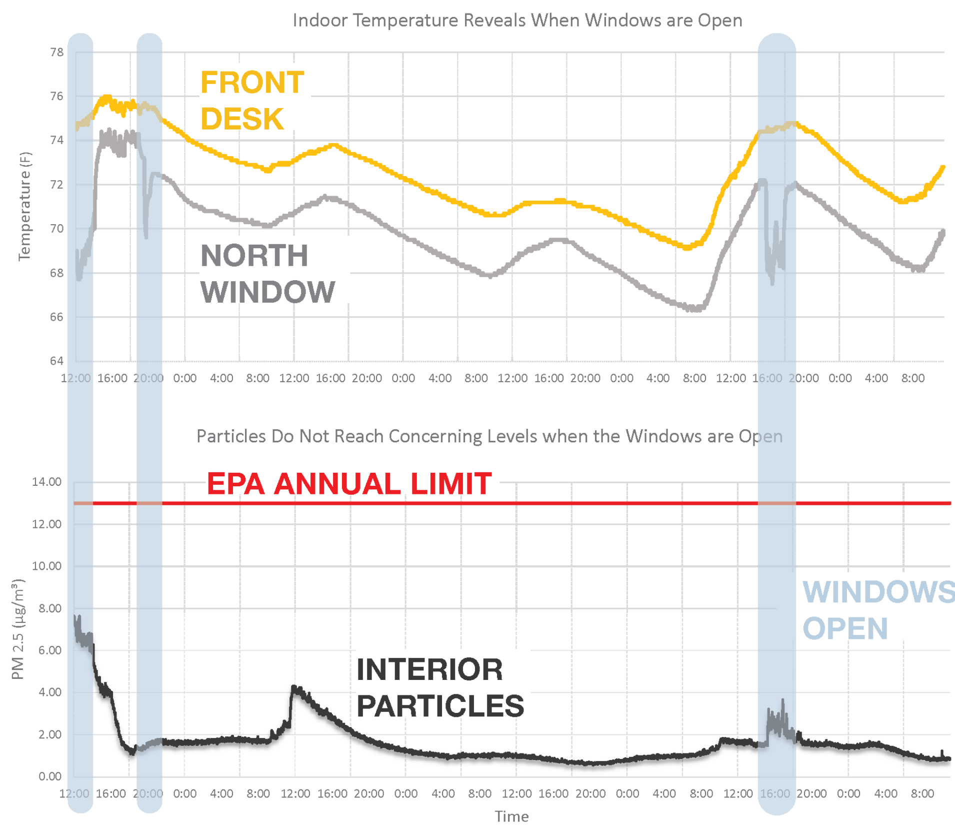

Figure 25: The charts highlight how when a significant indoor temperature drop correlates to when windows were opened. Source: (chart Elise Braun additional graphics Marsie Surguine)

If we isolate when the windows were open during our study, we may not have seen concerning levels of particulates, but that does not mean the interior never reached concerning levels. When the windows open, there is a definite uptick in particles within the space, however in the few cases we must reference, they do not reach concerning levels. In fact, in figure 25, we can see that while outdoor particles climb, the number entering the office remain relatively constant. Thus, we should simultaneously recognize that not everything that is in the air around the office will enter through open windows, and that if the outdoor quality is poor enough it could infiltrate and affect the interior space. In figure 26, we do see interior particulate levels really exceeding recommended limits for several hours. This is one instance of the regular workday evening spike that hits shocking levels and indicates that greater care is needed to address internal pollution sources.

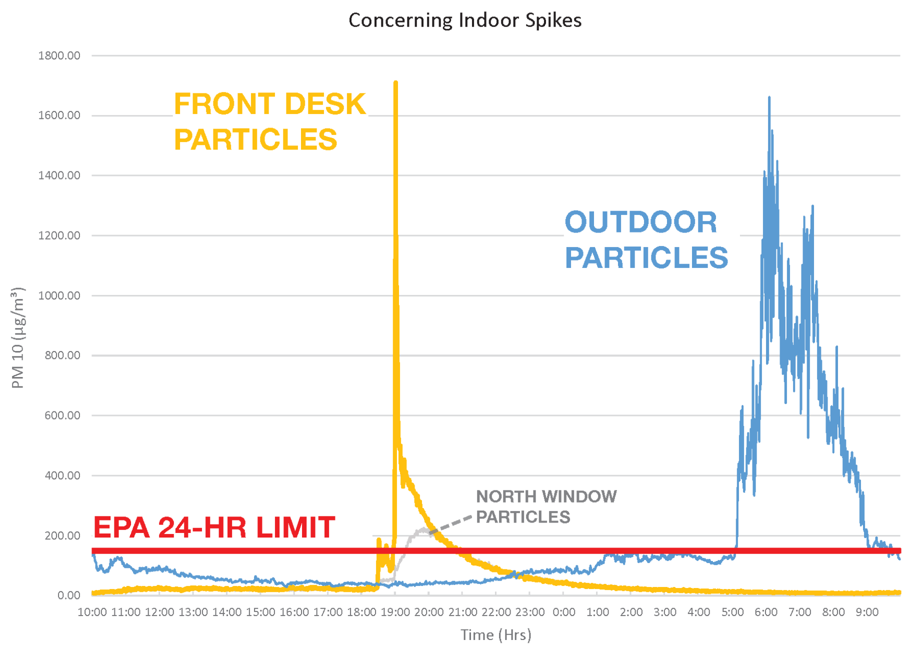

Figure 26: One day of Particles showing the most concerning particle levels in our data. Source: (Elise Braun).

Intervention experiment results
The plant intervention within the Opsis office involved more focused study. Two North-facing operable windows were compared, only one had our plant intervention of six plants: wiped, watered, and situated in the path of air flow. The result revealed no correlation between plants and improved air quality. As shown in figure 27, when the window was open, there was no significant particle reduction at the window with the plant installation compared to the window with no alteration. Furthermore, there was not any evidence that the plants were able to reduce particles in standard conditions nor during the interior spike events.

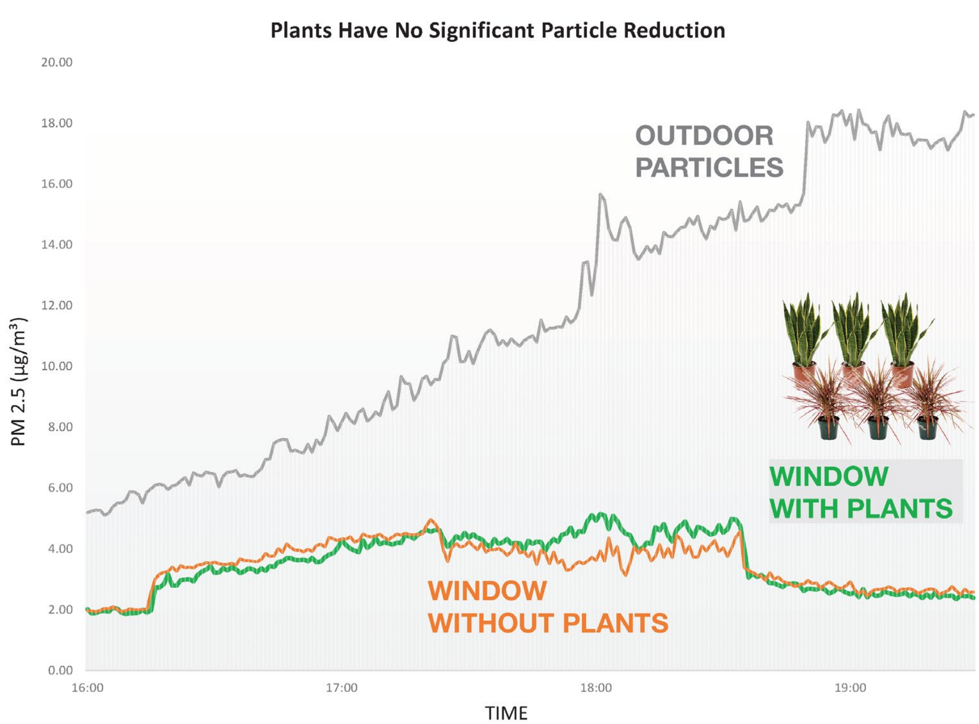

Figure 27: North window and outdoor particle count comparison during plant intervention when windows were open. Source: (chart Elise Braun, additional graphics Marsie Surguine)

Controlled chamber experiment results
For both a comparison study and to verify our findings at Opsis, we did a controlled chamber study at the lab placing plants directly in an air stream, testing the impact of plants on particle counts by changing the quantity and subsequently the density of plants, as well as testing if wet plants behaved differently than dry plants. The results show that increasing plant density could reduce particle counts, depending on the plant type. The Snake plants did show a decrease, whereas the Dracena plants generally showed an increase in particle counts. However, the particle count reduction was not dramatic, indicating that effective changes in occupied space would require a huge volume of plants. The greatest particle count difference occurred when we Wet the plants.

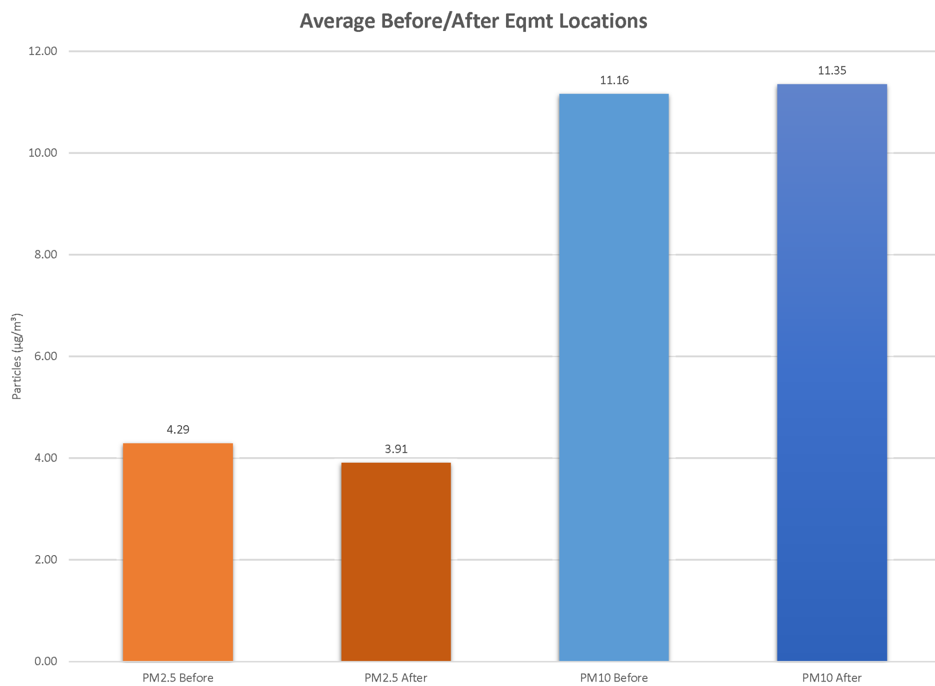

Figure 28: The chamber-controlled plant study baseline tests show that the Dylos equipment was reading PM 2.5 particle count drops from the different sides of the chamber. Source: (Marsie Surguine)

Controlled chamber baseline tests
The baseline test, where no plants were placed in the controlled chamber, demonstrated that there were particle count fluctuations from one end of the control chamber to the other (Figure 29). The PM 2.5 particles had an average drop of 0.38 µg/m³, whereas the average particles counts for PM 10 particles had an increase of 0.19 µg/m³.

These initial fluctuations brought on their own questions. The equipment might not be sensitive enough, calibrated accurately to each other, or the baseline testing window was not long enough to see the broader trends in particle counts. We must also recognize that small particle changes during the plant permutations may fall within the margins of error in these readings.

Sanseveria robusta (Snake plants)

After the baseline test was conducted, we placed one Sanseveria Robusta (snake plant) into the chamber and collected data (Figure 20). We then added a second plant and ran the same test before adding the third plant for another round of data collection (Figure 20).

These results were promising as most permutations saw a decrease in particles as we increased the plants. For the PM 2.5 particle counts, one, two, and three Snake plants showed a particle count drop. The PM 2.5 particle count drop difference for snake plants was: 0.76 µg/m³ for one plant, was 0.83 µg/m³ for two plants, and 1.25 µg/m³ for three plants. For the PM 10 particle counts, both the one and three Snake plants showed a particle count drop, whereas the two Snake plants had an increase. The PM 10 particle count difference was 3.05 µg/m³ (drop) for one plant, a 1.64 µg/m³ (increase) for two plants, and 0.68 µg/m³ (drop) for three plants.

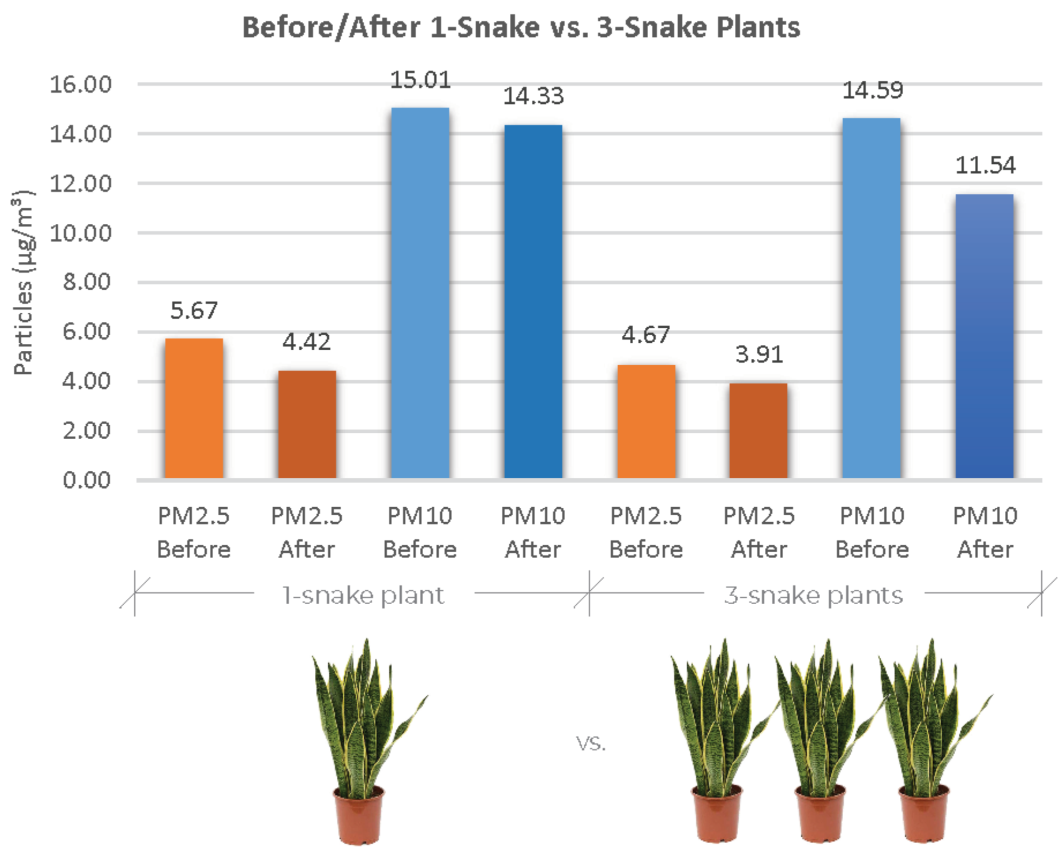

Figure 29: Charts show the average before and after particle counts for 3-Snake plants and 3-Dracenas plants and how particle counts went down for the snake plants and up for the Dracenas. Source: (Marsie Surguine)

Dracaena Marginata Colorama (Dracena plants)
After the Sanseveria Robusta, we conducted the same additive series of testing on the Dracaena Marginata Colorama (Figures 20, 21) This test had distinctly fewer promising results. Generally, the particle counts after going through the Dracena plants showed an increase in particle counts for both PM 2.5 and PM 10. The PM 2.5 particle count difference for the Dracena plants was: 0.20 µg/m³ (drop) for one plant, was 0.41 µg/m³ (increase) for two plants, and 0.47 µg/m³ (increase) for three plants. For the PM 10 particle counts, all three permutations with the Dracena plants showed a particle count increase. The PM 10 particle count difference was 0.56 µg/m³ (increase) for one plant, a 1.56 µg/m³ (increase) for two plants, and 1.23 µg/m³ (drop) for three plants.

Figure 30 shows the three Dracena plants and their increase in particle counts compared to the three Snake plants having a decrease in particle counts. We suspect that the narrower Dracenas leaves are not able to capture as many of the air particles in comparison to broader leaves on the Snake plants.

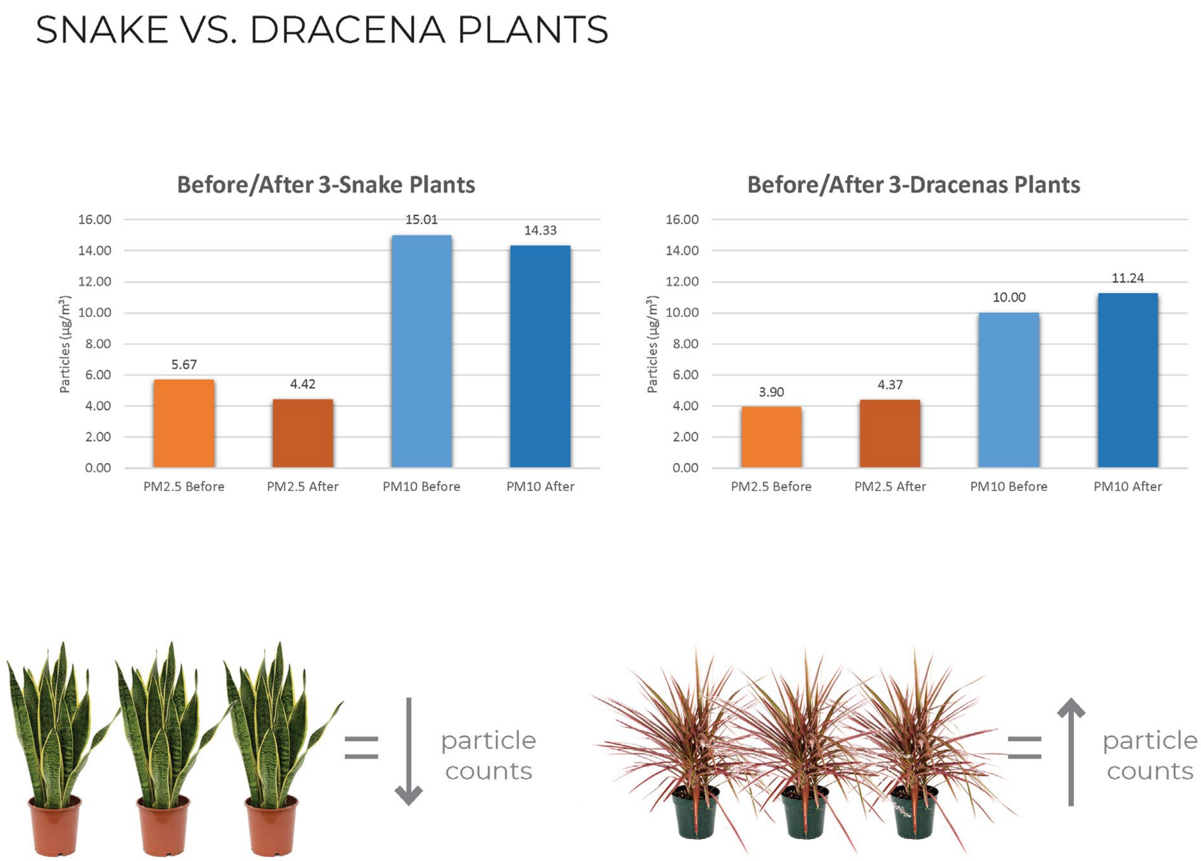

Figure 30: Charts show the average before and after particle counts for 3-snake plants and 3-dracenas plants and how particle counts went down for the snake plants and up for the dracenas. Source: (Marsie Surguine)

Combining both plants, dry and wet results

We then combined all the plants together in the chamber and collected data (Figure 21). We test the plants both in a dry state and a wet one, by spraying the leaves with water until moistened, and then repositioning them in the chamber.

Both the dry and wet plant tests show a reduction in the PM 2.5 and PM 10 particle counts; however, the moistened plants show a greater reduction than the dry plants. Because of water's "stickiness," or molecular bonding, we suspect the water is able to trap more particles than the dry particles. For the dry combined testing, the PM 2.5 particle counts dropped by 0.05 µg/m³ and the PM 10 particle counts dropped by 1.45 µg/m³. For the wet combined testing, the PM 2.5 particle counts dropped by 0.06 µg/m³ and the PM 10 particle counts dropped by 4.07 µg/m³, the largest particle count difference for the entire controlled chamber testing.

DRY VS. WET PLANTS

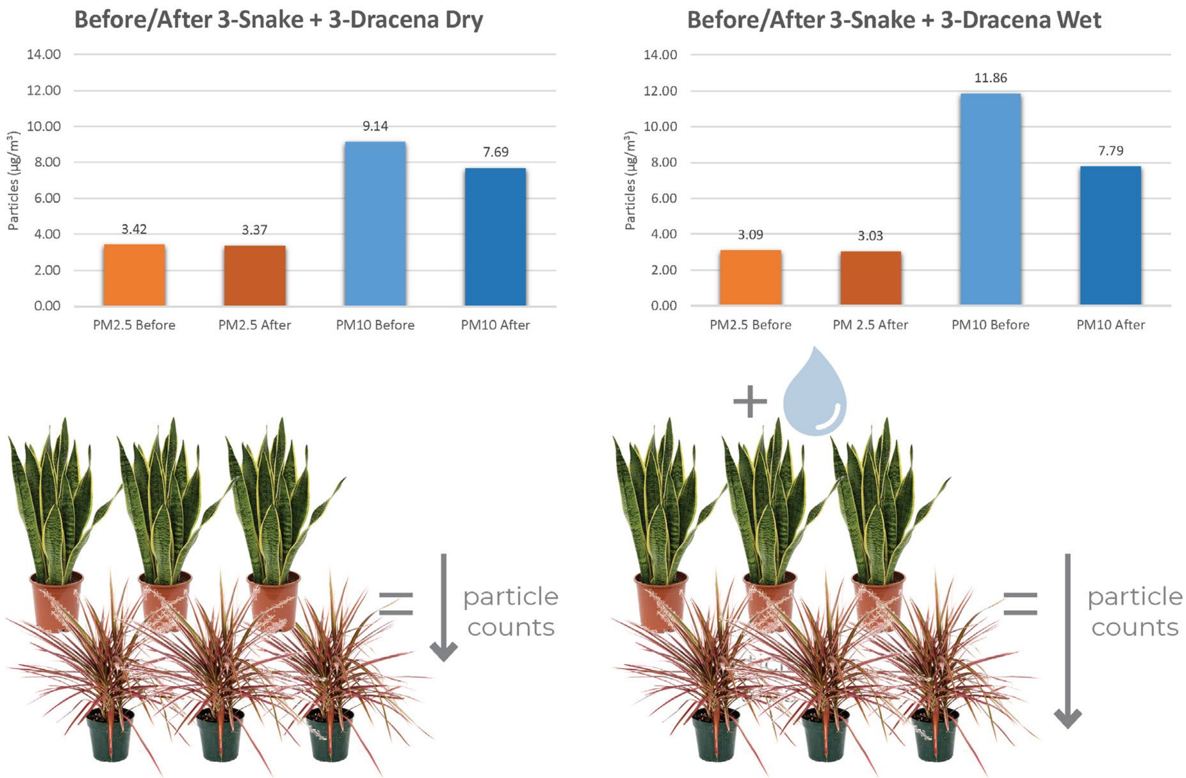

Figure 31: Charts show the average before and after particle counts for 3-snake plants and 3-dracenas plants and how particle counts went down for the snake plants and up for the dracenas. Source: (Marsie Surguine)

CONCLUSION

Process and data summary

In conclusion to both the on-site Opsis study and the lab controlled chamber study, our original hypothesis that plants in the direct airflow path of passive ventilation openings will reduce the levels of PM 2.5 and PM 10 air particles coming indoors was not confirmed, as the data from the on-site plant intervention test showed that plants had no significant impact on particle reduction with the natural filtration.

Regarding our hypothesis for the controlled chamber testing, that the more plants in the direct airflow, the lower the number of air particles measuring at PM2.5 and PM10, our data supports that increasing the plant density for the Sanseveria robusta (Snake plants), as well as combining both the Sanseveria robusta (Snake plants) and the Dracaena Marginata Colorama (Dracena) together, did have a slight impact on particle reduction.

Beyond verifying the validity of our hypotheses, the studies also provided additional findings.

This office's most concerning "pollution" is sourced from activity within the space, and this needs to be addressed. Based on their frequency, we suspect the regular office cleaning may be the culprit. If this is the case, ensuring that clean occurs after hours and the cleaner have proper respiratory protection can begin to address these concerns.

Regarding interior particles and the EPA limits, the data shows that Opsis particle levels do not typically cross the EPA recommended annual limits, even when the windows are open. However, there are times when the indoor particles do cross the EPA threshold, so the office is not entirely in the clear. Additionally, some studies and organizations think the EPA limits are not strict enough, as health is impacted at levels lower than EPA limits. Reinforced by the Air Quality Life Index stating that "Sustained exposure to an additional 10 µg/m3 of PM2.5 reduces life expectancy by 0.98 years." (Greenstone & Qing Fan, 2018).

While we did find a correlation with wind direction and particle counts, we do not necessarily understand what pollution source is creating those particles or what they are. The particle counts direction does not align with the location of the sources we were most concerned with, as the nearby construction site is to the west of the office and the highway and immediately adjacent parking lot is to the east of the office. Nevertheless, wind direction and pollution generates can be variable, and even these results may change over time.

The wind direction may play a role in why the indoor particle counts do not seem impacted by the outdoor particles. We suspect that the indoor air quality is less impacted by outdoor levels when the wind direction is coming from the east, that particles go over the building and bypassing the operable windows (especially the north-facing windows), perhaps creating a leeward negative pressure along the north-facing windows. Future study recommendations is to conduct particle testing during the summer season when the predominant wind direction shifts to coming from the northwest.

The other finding outside of our hypotheses was the dry versus wet plant tests. While both tests showed a reduction in particle counts, the moistened plants showed a larger reduction. This shows potential in the lab test but may be messier to incorporate in the workplace.

Lessons learned

From this study, we hoped to provide Opsis Architecture the following: future practice recommendations, a potential low-cost and low-maintenance solution involving plants, added psychological benefits of plants through the biophilia effect, and other plant benefits that may not be directly measured, such as potential heat reduction and acoustic dampening. Unfortunately, the results were not as promising as we hoped.

We also planned to study air flow in the space, but the equipment we had was not sensitive enough to record the low levels of indoor air. In future research with indoor air movement measurements, more sensitive equipment should be employed. In the end, the space had relatively consistent particle counts, so this may not be as relevant as originally anticipated either.

The implementation of plants for managing air particles is a relatively high maintenance solution for an air system. Typical house plants at a minimum require adequate sunlight, weekly watering, and occasional fertilization. For optimizing the plants ability to filter air particles, the leaves must be dusted regularly. In contrast to an HVAC system requiring less frequent attention than weekly.

Potential Errors

Considering the timeframe and external constraints on the experiments conducted in this study, there are a few sources of potential error. Our research was limited in scope, due to time and cost constraints. Which meant we had very little data with the passive ventilation in action. Since we have so little data we may be susceptible to data irregularities, like low levels of particle influx the three times the window was open. Many windows are also currently in operable. When the West facing windows are restored to operation they may change the dynamics in the space and the intake of particles.

We were also aware of other sources of particulates in the space beyond the outdoor contamination we were attempting to study. Locating and addressing those particulates will help clarify the contributions of natural ventilation to indoor particulate levels.

Another potential source of error is the location of the plant shelf and the window intake location. Because of the location of the existing anchor bolts, which were used to adhere the plant shelf support system, the plants were vertically located in the upper middle of the airflow instead of the lowest point. Having the plants located at the lowest point would have maximized the air passing through the plant foliage.

Future Studies

To continue this research, more studies should be done to understand the conditions of the space year round. Seasons affect wind patterns, outdoor temperatures and particles like pollen. Though we did not get much influx of particles in our study, other outdoor conditions or the frequency at which the windows open, could change those trends. Future studies may also look to attempt a dramatic increase in plants within the office space to manifest the controlled study, in the real world. Work should also be done to pinpoint the indoor pollutant sources and make an effort to mitigate them. We focused on particulates as a proxy for other pollutants. Additional testing should be done to explore smaller particles and more specific pollutants. Ultimately, other ideas for filtration, beyond plants, should also be tested to understand potentially more effective alternatives.

Design Implications

Recommended design implications include continuing the use passive ventilation. Results from our study show that exterior pollutants do not enter the interior of Opsis' workplace in a significant manner. Similar recommendations from PSU's Harriet Tubman Middle School study can also be considered: Keeping air intakes from exterior pollution sources as far away as possible (Gall, et al. 2019 p. 54) When laying out a space, be conscious of wind patterns in relation to operable windows and interior pollutant sources as well. Interior pollutant sources include spaces like kitchens and bathrooms, as well as machinery/plotters like printers and laser cutters. A solution for reducing particulates from these sources would be isolation from workers or better ventilation.

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