MAKING THE INVISIBLE VISIBLE

Using hyperlocal air monitoring to engage residents and activate change

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Submitted To:
Dorte Grastrup-Hansen

Making the Invisible Visible:
Using Hyperlocal Air Monitoring to Engage Residents and Activate Change

An Interactive Qualifying Project
submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
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degree of Bachelor of Science

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Report Submitted to:

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ABSTRACT

Air pollution exposure poses a significant and often invisible health risk. In collaboration with Miljøpunkt Amager, we evaluated how best practices in mapping hyperlocal air quality data can be used to activate change and community engagement. We conducted pilot tests collecting local air quality using sensors to map air quality across an urban and commuting environment. Based on the insights, we recommended strategies for public engagement and emphasized the integration of real-time air quality monitoring systems to empower community decision-making.

ACKNOWLEDGMENTS

We extend our deepest gratitude to all those who have supported us throughout our project. We are particularly thankful to our sponsor, Dorte Gastrup-Hansen, for her invaluable assistance and expert knowledge in air pollution, which significantly contributed to our research and project guidance.

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Our heartfelt appreciation goes to the staff at Miljøpunkt Amager. Your warm welcome made the office space feel like a second home to us, fostering an environment where creativity and productivity thrived.

We also extend our thanks to the Copenhagen Police Officers, who, after a brief mix-up where they mistook us for bridge activists, kindly wished us good luck with our project.

Lastly, we owe a profound debt of gratitude to our advisors, Professor Ingrid Shockey and Professor Robert Hersh. Your thorough guidance, unwavering support, and enthusiasm for our project have been instrumental during the entire 14-week Interactive Qualifying Project process. Thank you for steering us through this educational journey with such dedication.

AUTHORSHIP

This report is the result of a comprehensive collaborative effort by all the members of our team. Each team member has contributed ensuring their insights and expertise are reflected throughout the report. The process involved equal participation in the research, analysis, and writing phase demonstrating our collective commitment to producing a thorough and accurate report.

This work is original to the project authors and study participants and was not generated or assisted using ChatGPT or AI tools. Grammarly was used for editing.

MEET THE TEAM

AILI BRAY

I AM A JUNIOR AT WPI STUDYING CHEMICAL ENGINEERING WITH A BIOLOGICAL FOCUS. I AM FROM CENTRAL MASSACHUSETTS. THIS PROJECT HAS BEEN A LOT OF FUN, COLLECTING AIR QUALITY DATA AND INTERACTING WITH THE COMMUNITY.

SAMUEL FORERO

I AM A JUNIOR AT WPI STUDYING ELECTRICAL AND COMPUTER ENGINEERING. I AM FROM BOGOTA, COLOMBIA. THIS PROJECT HAS BEEN VERY INTERESTING. I'VE ENJOYED LEARNING FROM EVERYONE AROUND ME.

MEET THE TEAM

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RISHI PATEL

I AM A JUNIOR AT WPI STUDYING COMPUTER SCIENCE. I'M FROM NASHUA, NH. I DEEPLY ENJOYED INTERACTING WITH THE COMMUNITY IN COPENHAGEN, AND UNDERSTANDING CITIZEN APTITUDE WITH AIR QUALITY DATA

MEET THE TEAM

EXECUTIVE SUMMARY

Background:

Fine particulate matter from vehicle emissions, wood burning stoves, and other sources can have serious adverse effects on the health of populations exposed to elevated levels of air pollution. Our sponsor, Miljøpunkt Amager (MPA), is a non-profit organization that focuses on sustainability initiatives within the Amager community of Ørestad, emphasizing education about best environmental practices and collaborations with local entities. The city is undergoing rapid urban development leading to increased environmental changes, and MPA is promoting mitigation efforts to reduce the adverse health effects.

Our project aimed to evaluate how mapping hyperlocal air quality data can be used to activate change and citizen engagement in Amager. To meet this goal, our team developed a series of objectives: 1. Identify best practices for leveraging hyperlocal air quality data to engage citizens on citizen science projects; 2. Collect air quality samples in Ørestad to support a hyperlocal dataset; 3. Identify strategies to use hyperlocal data to support local interest in air pollution mitigation. Through these approaches, our team gave a full list of recommendations to MPA.

The case studies we analyzed to leverage urban planning and community decision-making still provided valuable information. From them, we were able to conclude that compressing cities and adding more green spaces will dramatically improve air quality.

Approach:

To accomplish our first objective, we gathered information on various approaches to engage citizens collecting and communicating hyperlocal urban air pollution data. To realize our second objective, we conducted a site assessment. We then gathered and mapped air quality data using Atmotube Air Quality sensors and Testo DiSCmini ultrafine particle sensors. Data was gathered on a pedestrian bridge above the E20 motorway and in a nearby park. We also simulated a commuting route on the motorway to measure and record the factors affecting air quality within the cars cabin. Our third objective identified opportunities to integrate hyperlocal air quality considerations into a science communication and citizen engagement

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initiative. We conducted a survey via MPA's social media platform to gather information on residents' commuting habits, their reasons for choosing certain commuting options, and their awareness of air quality in their community.

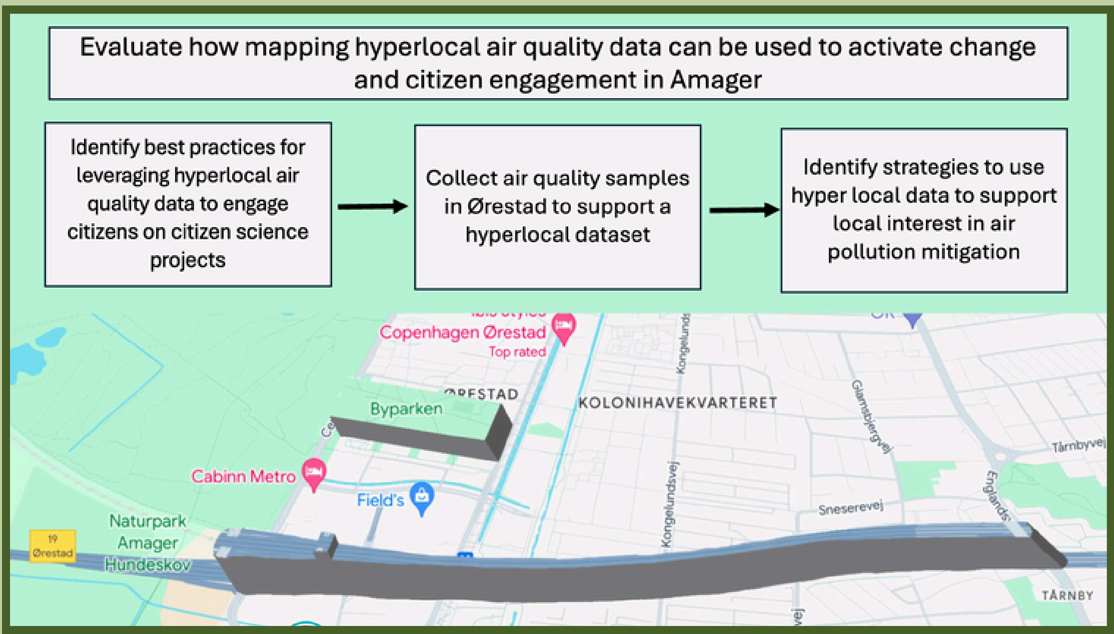

Figure A: Flow chart of the goal and objectives with map of our site (Google Maps, 2024).

Results:

Our case studies proved the importance of citizen science projects in improving air quality monitoring and awareness. Engaging the public helps to both educate residents and potentially improve policies around air pollution.

Our findings from the air quality assessments in Ørestad provided insightful implications for understanding urban air pollution and its management. Through hyperlocal air quality measurements conducted at various points—including a bridge over the E20 motorway, a nearby park, and inside a vehicle—our study reveals several key aspects of air quality dynamics in urban settings influenced by architecture and traffic. We found that, while the air quality is generally good on the bridge, staying below EU standards, it could be improved.

From our surveys and interviews, we discovered that the community is ready to be engaged with air quality data; however, they do not know where or how to access hyperlocal air quality information. This shows a major gap between organizations that are collecting data and communities they are collecting in.

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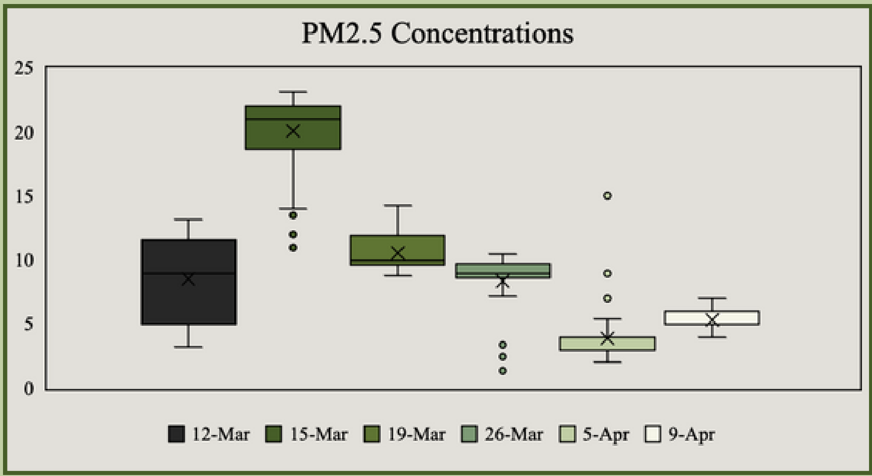

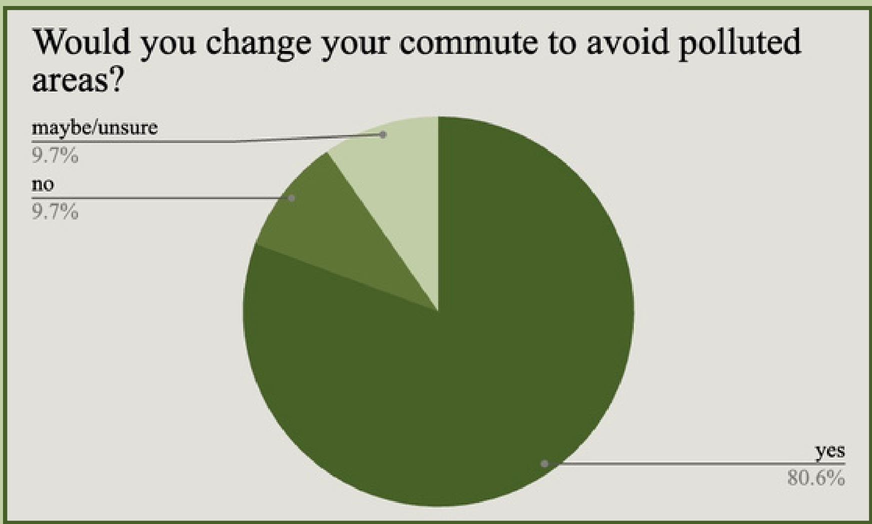

Figure B: (top) Graph of PM 2.5 concentrations for each measurement day. (bottom) Graph of survey results.

Recommendations:

Our first recommendation is the launch of a two-phased citizen science initiative. The first phase involves placing fixed air quality sensors at three metro stops along the E20 highway in Ørestad. The second phase is giving sensors to residents to carry with them during their commutes. This will allow for an abundance of air quality data.

Our second recommendation is the development of the "Awair App" This app will provide real-time air quality data, making use of sensors posted and data collected in the previous recommendation. This will empower residents with timely information about their air quality, allowing them to avoid areas with high pollution.

Our third recommendation is continuing the collection of in-cabin air quality. By continuing to collect and analyze data on the air quality inside cars, MPA can better understand exposure levels during commutes and advocate for reduced car use.

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CHAPTER 1: INTRODUCTION

Fine particulate matter from vehicle emissions, wood-burning stoves, and other sources can have serious adverse effects on the health of populations exposed to elevated levels of air pollution. The European Environmental Agency considers air pollution the "biggest environmental health risk in Europe" (Castro, 2022). Exposure has been linked to lung cancer, COPD, depression, anxiety, ADHD, and autism. In 2016, a study estimated that 1,800 deaths in Denmark (3.4% of the total) were related to air pollution (Brønnum-Hansen, 2018).

In 2021, a project called "Thrive Zone Amager" led by Miljøpunkt Amager (MPA) engaged residents in air pollution monitoring, which helped create a more informed community. MPA has continued to focus on similar initiatives within the community, emphasizing education about best environmental health practices and participating in collaborations with local entities. Its approach to education fosters data-driven projects and encourages innovative urban designs that could improve air quality and therefore improve the safety of public spaces. The organization understands that sound strategies and accessible data must be readily available for decision-makers, including residents who want actionable recommendations to protect their health.

This project worked with Miljøpunkt Amager to evaluate how mapping hyperlocal air quality data can be used to activate change and citizen engagement in Ørestad. To meet this goal, our team developed a series of objectives: 1. Identify best practices for leveraging hyperlocal air quality data to engage citizens on citizen science projects; 2. Collect air quality samples in Ørestad to support a hyperlocal air quality dataset; 3. Identify strategies to use hyperlocal data to support local interest in air pollution mitigation. These objectives generated insight that informed our list of recommendations to MPA.

CHAPTER 2: LITERATURE REVIEW

This chapter explains the rapid urban development in Ørestad and how that contributed to air pollution. First, we begin with an introduction to Ørestad and its rapid urban development. We highlight citywide environmental accomplishments and outline the European Union standards for air quality. Finally, we review the potential air quality pollutants in Copenhagen and investigate their impacts on the health of residents who commute and live in neighborhoods with potentially unhealthy air quality readings.

2.1 –Piloting Ørestad as a case study for residential exposure

Ørestad is situated on the Amager Island in Copenhagen, Denmark's metropolitan area as shown below in red (see Figure 1). The urban population of Ørestad has reached 21,000 residents and is experiencing a rapid expansion in both residential and commercial sectors (Livexirno, 2021). Since 2010, the number of housing units has seen a threefold increase from 5,000 to over 15,000. With urban growth, there is a rise in transit, with the number of commuters just traveling through Ørestad estimated at 40,000 daily (Livexirno, 2021). A significant contributor to this volume is the E20, a motorway that accounts for a substantial part of the vehicular flow as shown in Figure 2. Given the recent development of the area, a convergence of vehicular traffic, bicycle lanes, and pedestrian pathways has given rise to considerable air and noise pollution, becoming a concern for the residents.

Figure 1: Map of Copenhagen with Ørestad and Amager highlighted (Google Maps, 2024).

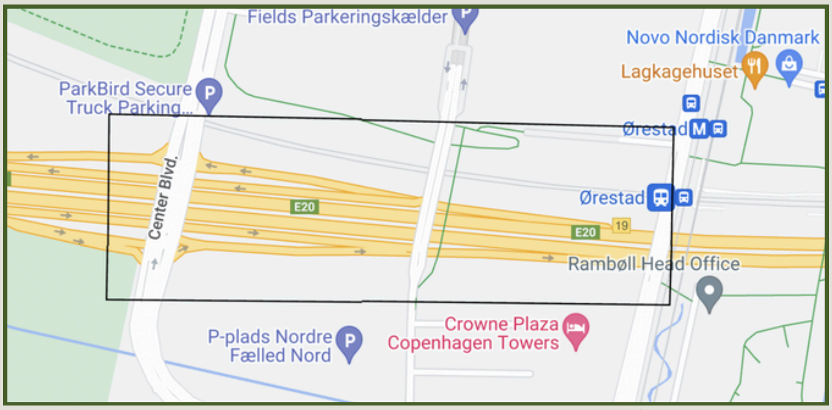


Figure 2: Map of the E20 through Ørestad, outlined in black (Google Maps, 2024).

2.2 –Air Pollution Monitoring in Copenhagen

Copenhagen has been tackling air pollution despite its status as a clean city, with local activists recognizing its role in premature deaths and various illnesses. They found that traditional static sensors provided only a general view of air quality, lacking detailed, dynamic data (Copenhagen: Rethinking, 2021) . A solution was found when Google equipped Street View cars with air quality sensors to measure pollutants at a granular level throughout Copenhagen (see Figure 3). This approach enabled the mapping of air pollution with high spatial accuracy, revealing evidence of the impact of human activities and infrastructure on air quality (Copenhagen: Rethinking , 2021) . The results included a publicly accessible, detailed map of air quality in Copenhagen, highlighting pollution hotspots and aiding in urban planning. This initiative, particularly The Thrive Zone project, aimed at reducing unhealthy exposures, especially for vulnerable groups, by redesigning urban spaces and promoting behavioral changes (Copenhagen: Rethinking , 2021) .

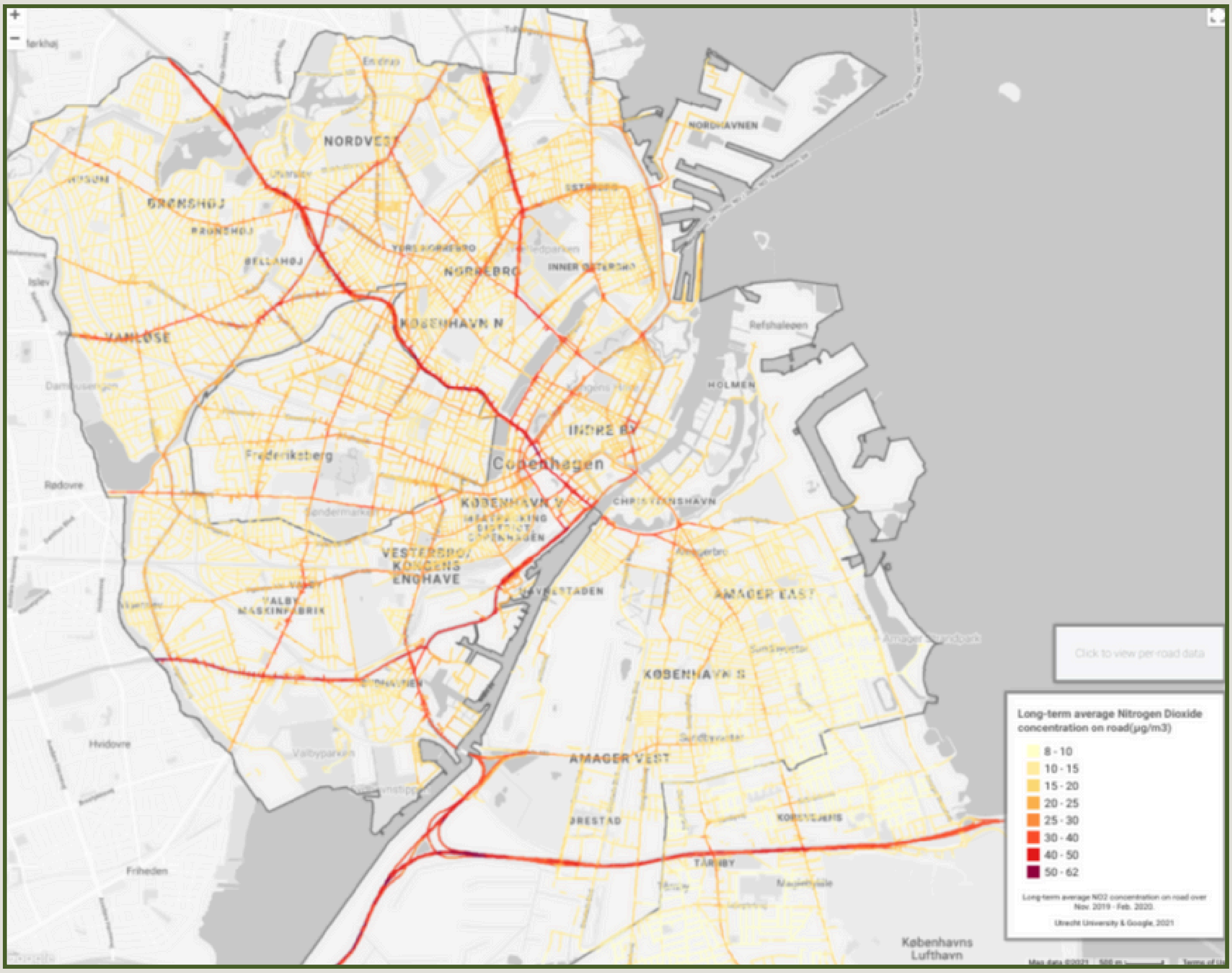


Figure 3: Sample street map showing air pollution ranges in Copenhagen Copenhagen: Rethinking, 2021). .

While Copenhagen builds awareness, the greater context of the European Union has seen a plan to reduce all pollution levels by 2050. The Zero Pollution Action plan has six objectives that have targeted 2030 and 2050 goals that are meant to speed up the process of reducing pollution in general. Their first objective, holding the greatest relevance to this project, promises “Improving air quality to reduce the number of premature deaths caused by air pollution by 55%” (Zero pollution action plan, 2024). To achieve this objective, the EU created air quality standards for PM 2.5 and PM 10 based on yearlong monitoring, as well as the permitted exceedances for each of them, as noted below.

Pollutant	Concentration	Averaging period	Legal nature	Permitted exceedences each year
Fine particles ($PM_{2.5}$)	20 µg/m^3	1 year	Stage 2 limit value to be met as of 1.1.2020 ***	n/a
Particulate matter (PM_{10})	50 µg/m^3	24 hours	Limit value to be met as of 1.1.2005 **	35
Particulate matter (PM_{10})	40 µg/m^3	1 year	Limit value to be met as of 1.1.2005 **	n/a

Figure 4: European Union standards for PM10 and PM2.5. Taken from the European Commission "EU Air Quality Standards"

We used these standards to assess our air quality data and to rank Ørestad's progress with the EU goals as a baseline.

2.3 – Tracing the exposure pathways of Urban Pollutants

The focus on Particulate Matter (PM2.5) is important, since these invisible fine particles are responsible for the most detrimental human health conditions. The largest source of PM2.5 in Denmark between 1997 to 2007 came from combustion plants (Hossy Hjelgaard, 2024). Since then, new regulations have reduced the amount of wood that can be burned in these plants. While legislation was able to reduce PM levels generated through wood burning, other source of PMs originates from the transportation sector. These sources have not yet been significantly targeted for official action.

Air pollution exposure to (PM2.5) causes health issues in humans. Particulate matter can track deeply into the lungs and bloodstream (Sofia et al., 2020). Increased levels of exposure can raise the risk of respiratory illnesses, heart disease, neuronal issues, and cancers (WHO, 2019). Individuals facing higher risk include children, the elderly, and those with pre-existing health conditions (WHO, 2019). These exposures also have short- and long-term health effects (Sofia et al., 2020). Short-term effects include headaches, coughing, viral infections, and increased anxiety. Long-term health issues can range from arrhythmia to heart failure. Research also shows that children with asthma exposed to increased levels of air pollution are more likely to develop bronchitis (NIEHS, 2024). Short-term respiratory infections are also more common in children, which has led to more absences from school (NIEHS, 2024). Children living near busier roads are more likely to develop asthma (NIEHS, 2024). Research shows that major cardiovascular and respiratory problems arise when living close to elevated concentrations of ultrafine particles, black carbon, nitrogen oxides, and volatile organic compounds. These pollutants are even more common in urban or congested areas.

While avoiding congested areas can reduce exposures, there are indications that air quality can be exacerbated even inside vehicles that are in the commuting zone. Vehicle internal air quality (VIAQ) is often different than the air outside the car cabin, however VIAQ is affected by many environmental factors. All the factors that influence outside air quality will influence the cabin air (weather, temperature, traffic conditions, etc.). In addition, the car can affect air quality, particularly regarding VOC concentration. The car's age, type, and composition all impact the VIAQ. The reading will change depending on whether the car is moving or stationary and its ventilation mode (AC, heat, pulling in outside air, recirculating cabin air, windows open, etc.) (Faber, 2016). All these confounding variables make testing air quality of for commuters. The variables also make transferring data gained in one study in particular conditions to another with different conditions inaccurate. Because of this, only general conclusions can be made from the data.

2.4 – Summary of Key Points

Ørestad faces challenges related to poor air quality exposure due to high levels of commuter traffic. Innovative monitoring methods, like air quality sensors on Google Street View cars, can provide new insights into localized pollution levels, which can help the city meet the EU's Zero Pollution Action Plan. We also learned that the complexities of vehicle interior air quality (VIAQ) are influenced by both external environmental conditions and vehicle-specific factors.

CHAPTER 3: METHODOLOGY

The goal of our project was to evaluate how mapping hyperlocal air quality data can be used to activate change and citizen engagement. To complete this goal, we designed three objectives: 1. Identify best practices for leveraging hyperlocal air quality data to engage citizens on citizen science projects; 2. Collect air quality samples in Ørestad to support a hyperlocal dataset; 3. Identify strategies to use hyperlocal data to support local interest in air pollution mitigation.

To accomplish our first objective, we gathered information on various approaches to engage citizens in collecting and communicating hyperlocal urban air pollution data. We analyzed the case studies to see what methods were effective, the outcomes from the initiatives, and what strategies and communication platforms could be replicated in Amager.

To accomplish our second objective, we conducted a site assessment. We then gathered and mapped air quality data using Atmotube Air Quality sensors. We placed the sensors on the pedestrian bridge above the E20 motorway during the morning rush hour (around 8:30 to 9:30) on Tuesdays and Fridays between March 12 th and April 12 th , 2024. Data was gathered on seven different days in this period. One sensor was placed above each of the motorway's directions to gather data as specifically as possible. Air quality data was also gathered in a nearby park. To connect the data gathered on the bridge and the data in the nearby park, we collected data on the walk from the bridge to the park. In addition to the Atmotube sensors, we used a more sensitive ultra-fine particle sensor (Testo DiSCmini sensor) to record slight changes in air composition. Using the same equipment, we created a field experiment of a commuting route on the motorway to measure and record the factors affecting air quality within the car's cabin. We tested this route using a variety of ventilation modes two times in the car, once on March 19th and once on April 3rd.

Our third objective identified opportunities to integrate hyperlocal air quality considerations into a science communication and citizen engagement initiative. We conducted a survey via MPA's social media platform to gather information about residents' commuting habits, their reasons for choosing certain commuting options, and their awareness of air quality in their community. This survey contained a question allowing people to fill in their emails if they were willing to do a follow - up interview with us. In addition to four follow-up interviews, we conducted three interviews in the park. Interview guides and the survey can be found in Appendices A-C.

A visual representation of our data was designed as a mockup for an app that could be used to encourage awareness and to spark interest in air quality data and to inform decision making about commuting choices. Based on the case studies we found and the community's response to our surveys and interviews, we designed a two-phase citizen engagement air quality collection project to contribute to the effort to inform residents about hyperlocal air quality.

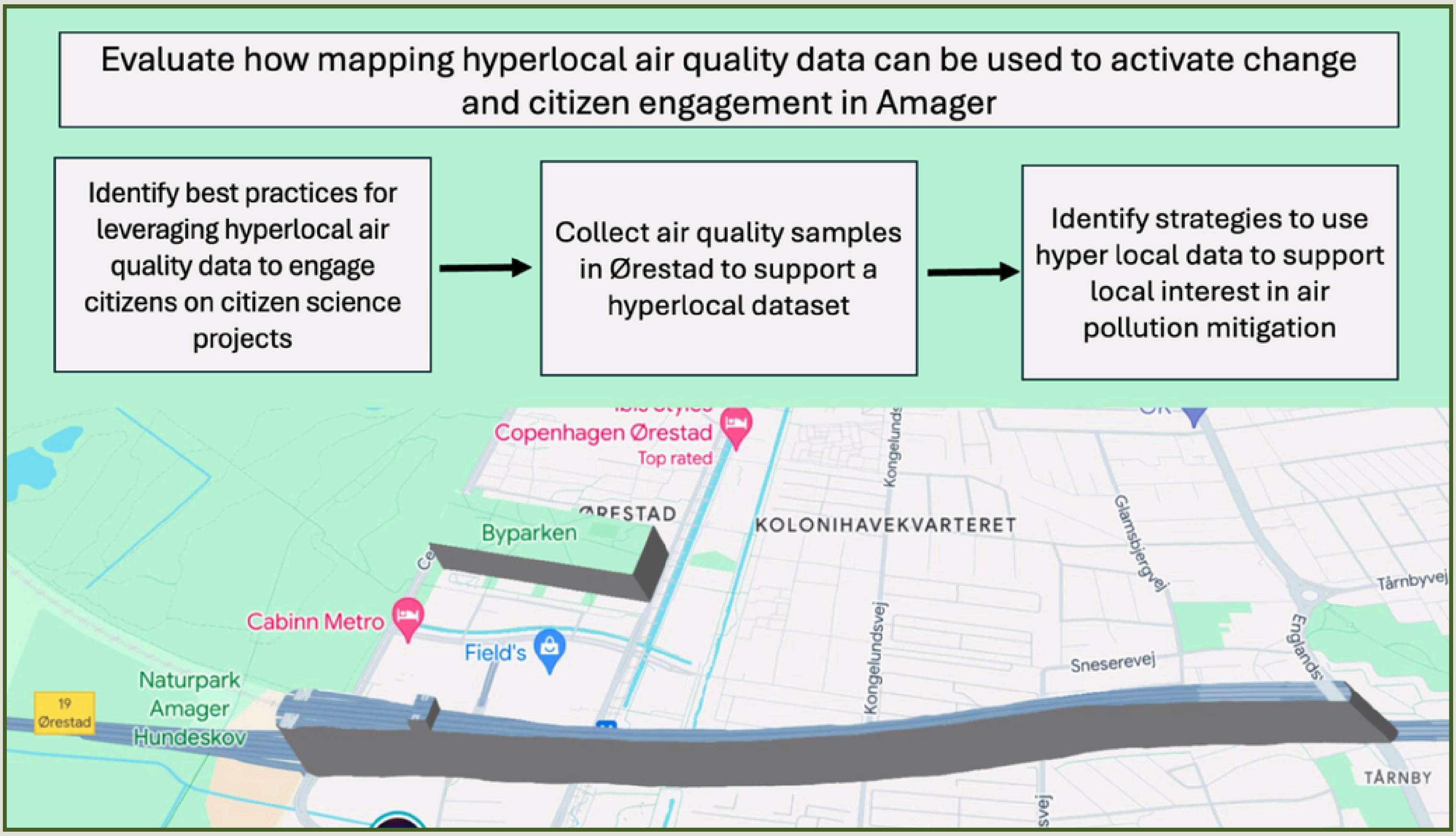


Figure 5: Flow chart of goal and objectives with map of our site (Google Maps, 2024).

CHAPTER 4: RESULTS

This chapter delves into our findings, highlighting the importance of community engagement, the variability in air quality across Amager, and the implications for fostering a healthier, well-informed community.

4.1 - Objective 1. Identify best practices for leveraging hyperlocal air quality data to engage citizens on citizen science projects

Citizen science initiatives have been shown to effectively increase public knowledge about the sources of air pollution. They help to identify hyperlocal pollution sources, which strengthens actions against violations of environmental regulations. A paper by Elizabeth Moses identifies six strategic pathways through which citizen science achieves impactful outcomes: educating communities about pollution sources and health impacts, engaging policymakers to influence environmental policies, mobilizing communities to collect more data and research, spurring targeted regulatory enforcement, enhancing pollution models to identify new emission sources, and influencing behavior changes based on new pollution insights (Moses, 2022).

Challenges with citizen science initiatives are complex, nonetheless. First, pinpointing specific sources of particulate matter and gaseous pollutants is incredibly complex due to the nature of these contaminants. They originate emissions and point sources, such as vehicle exhaust, industrial emissions, and natural sources. This makes it difficult to trace back to a specific origin. Additionally, the variability of air pollution due to factors like unstable weather conditions and traffic patterns, adds another layer of complexity to this issue. Secondly, difficulties in linking pollution data to its source are often due to the lack of precise professional-grade instruments. This leads to data that is too general to pinpoint specific sources; this is especially harmful in urban environments where pollution sources are densely packed and mixed. Lastly, community frustrations are a consistent challenge due to a disconnect between the collection of data and actual policy action. Even with increased awareness and documentation of pollution sources, the community can feel disappointed if new research does not lead to immediate or effective changes in public health and environmental policies. This challenge highlights the need for robust mechanisms that translate citizen-collected data into policy reforms and enforcement actions that are visible and meaningful to the community suffering with air pollution.

HackAIR is a method for quality monitoring that combines data with information contributed by citizens offering a thorough and accessible view of air pollution. Participants use sensors and phones to collect data, which is then emerged with readings from monitoring stations. This information is displayed on an online platform, which enables citizens to actively monitor their environment. HackAIR fosters togetherness in the community, informed decision-making, and proactive policy development to improve urban air quality across Europe (How citizen science helps, 2023). The initiative Eurocities promotes the significant role of citizen science in combating air pollution. It highlights how over 37,000 devices deployed by citizens across Europe are used to measure air quality, providing essential data that complements official monitoring systems. This data helps to identify discrepancies in air quality and empowers residents to actively participate in environmental advocacy, potentially influencing policy changes (The power of people, 2022).

Citizen science initiatives play a crucial role in both improving air quality models and raising public awareness about air pollution issues. By actively engaging citizens in data collection and monitoring efforts, these initiatives not only provide valuable data but also encourage informed behavioral change, such as through reducing car usage, which contributes to improved air quality (European Environment Agency, 2019). However, it is essential to recognize the limitations of their methods and how this can impact their data. Looking ahead, the report suggests that the growing number of citizen science initiatives and digitalized approaches could revolutionize air quality monitoring practices. By integrating a large network of low-cost sensors and advanced techniques, there is potential to enhance the reliability and real-time availability of air quality information. This approach could represent a significant shift in monitoring strategies, offering more comprehensive and timely insights into air quality conditions across Europe (European Environment Agency, 2022).

Finally, a study conducted in Pittsburg, Pennsylvania, USA emphasized the effect of a mobile reporting app used to build awareness and empower the community towards action. The app known as Smell Pittsburg was developed to allow citizens to report air quality odors around the community. The app uses GPS location tracking to record the reported location and allow users to describe the smell and symptoms they experienced (Hsu, 2022). This information is combined with air quality data from monitoring stations in the area. Maps are created using this data so users can see air quality hotspots in the area. Using the data gathered from users and monitoring stations, they can also use machine learning to predict pollution in the area. They found that notifying users of potential future smells increases user engagement with the app (Hsu, 2022). By allowing citizens to be more engaged with air quality data collection, they can increase knowledge in the community and gather more air quality data.

4.2 - Objective 2. Collect air quality samples in Ørestad to support a hyperlocal dataset

We conducted a site assessment in a plot in Ørestad that ranged from the motorway to a nearby park. The development in this area is relatively new. Many of the structures are large, tall, glass buildings that do not share similar architectural styles or have many similarities to other parts of Copenhagen. Some of these large buildings flank each side of the highway creating an intense wind tunnel along the route. Another main road runs perpendicular to the highway with the metro line over it. This roadway is also lined with tall buildings that create another wind tunnel in that direction. The park is a 5–10-minute walk from the pedestrian bridge over the highway. This is a small green area sectioned by two main roads and featuring apartment complexes on two sides. The park has small playgrounds, an artificial turf football field, and a few pathways for walking. A few small trees dot the park. Other shrubs are being planted too to encourage greenery.

Figure 6: Photograph taken from our bridge looking at the referenced metro line and tall buildings (photo credit: Aili Bray, April 9, 2024).

Figure 7: Photograph of the team at bridge where we took our measurements (photo credit: Ingrid Shockey, March 19, 2024).

Figure 8: Photograph of the park in Ørestad (photo credit: Bella Kirby, April 15, 2024).

Our air quality data was conducted within this rectangular plot, from various locations capturing bridge and pedestrian exposure. When looking at the data recorded on the bridge over the highway, we can see that the overall air quality meets EU air quality standards, however we have noticed some trends. We found that the side of the motorway with traffic traveling west is busier compared to the side with traffic traveling east. We counted an average of 1000 cars going west compared to the 900 headed in the opposite direction over 30 minutes. The air quality measurements suggest that the air quality is worse on the side of the road that has the most cars and is worse around the middle of the measurement period, which would be around 8:45-9:00. Each of the different PM sizes fluctuate together. A clear increase around the middle of the measurement period can be seen in our data. The PM 2.5 data we collected only exceeds the EU standard, 20 μg/m^3 , on one day, March 15th . None of the collected PM 10 data exceeds the EU standard of 40 μg/m^3 . The cause of the spike seen in the PM graphs on April 15 th is unknown. Nothing significant was noted during that time that could have caused the spike. These findings can be seen below in Figures 9 and 10.

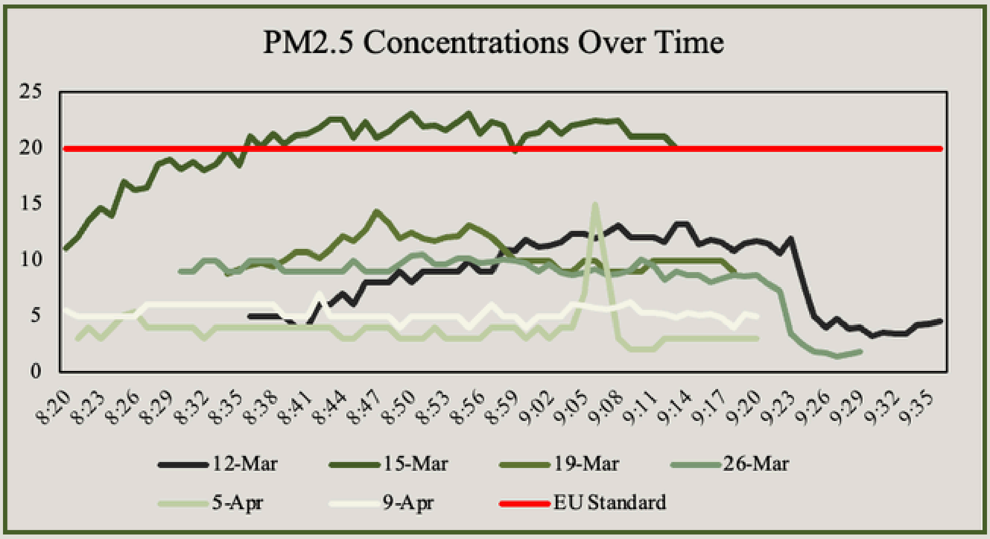


Figure 9: Graph of PM 2.5 concentrations over time for each measurement day.

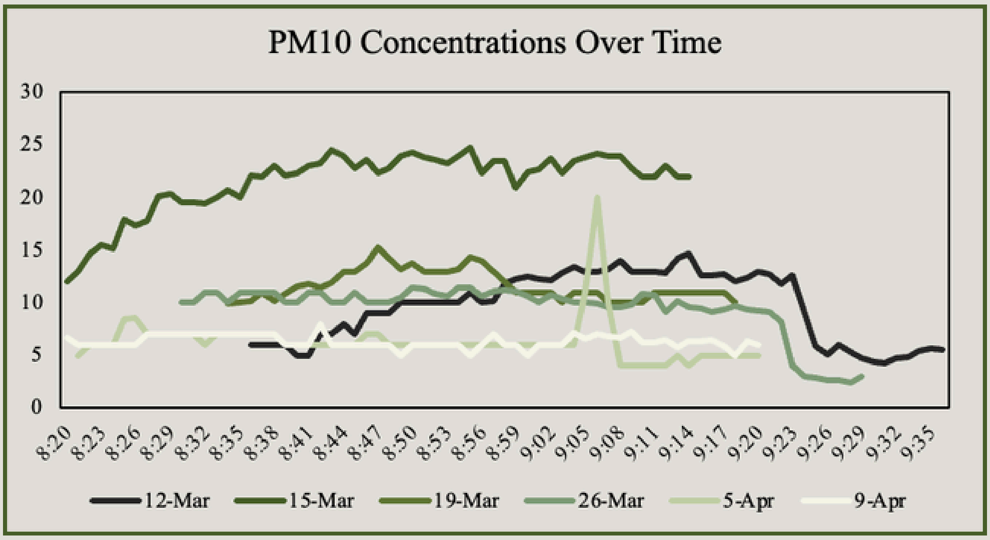


Figure 10: Graph of the PM10 concentrations recorded over time on each measurement day. EU standard is at 40 μg/m3, significantly above what we measured

From our measurements, the air quality in the park is not significantly different than the air quality on the bridge. We walked from the bridge to the park to monitor air quality change in route. We used a direct route along another busy road. We found no major difference in the air quality on the bridge, walking to the park, and within the park. These findings can be seen in Figures 11 and 12.

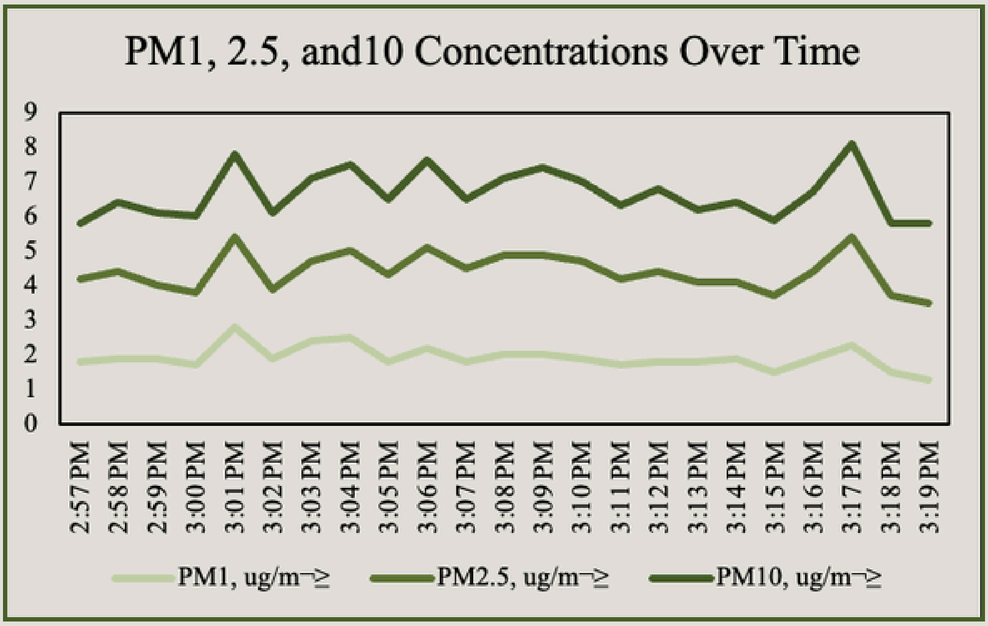


Figure 11: Graph of the PM1, PM2.5, and PM10 concentration when walking from the bridge to the park.

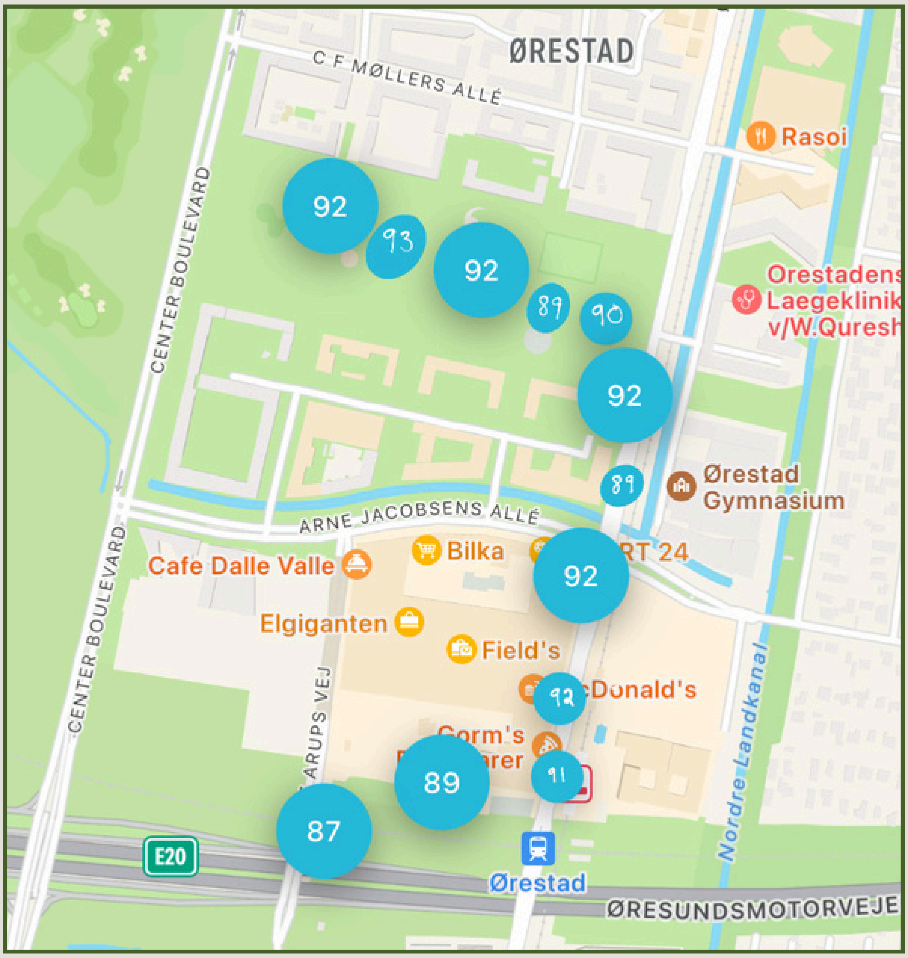
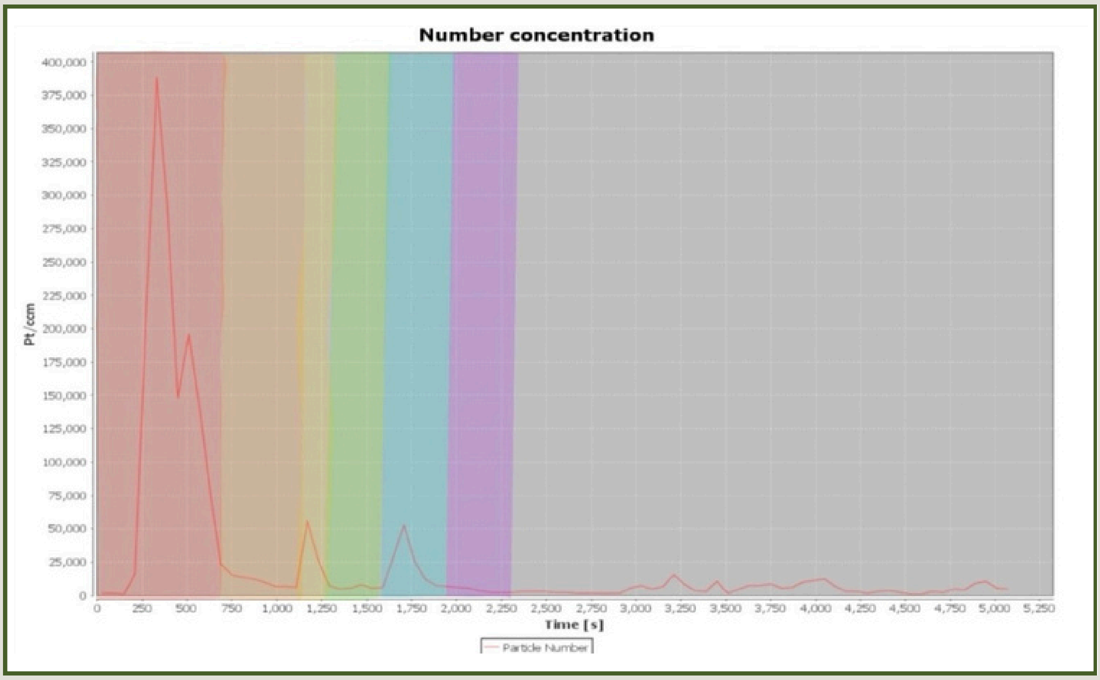


Figure 12: Map generated by the Atmotube sensor showing the AQS (Air Quality Score which is an Atmotube generated score on a scale of 0-100, 0 being the worst and 100 being the best) through the walk from the bridge to the park. The numbers highlighted in the image make it seem as though the AQS improved as we approached the park; however, the air quality was fluctuating between the high 80s and low 90s throughout the whole walk.

Finally, the data collected from the cabin of a car clearly shows how air quality inside a car is affected by many environmental factors including the vehicle's ventilation mode, traffic conditions, and weather conditions. Test run protocols are indicated in Table 1 and the readings collected for these ventilation modes are seen in the graphs (Figure 13). The number of particles measured in the car stayed more consistent than the fluctuating numbers measured on the bridge. However, different ventilation modes affected the levels recorded by the monitors. The beginning of the graph corresponds to AC on, pulling in outside air. The large spike in the beginning happened when the car was following behind a large diesel truck. Once the ventilation mode was switched to recirculating instead of pulling in outside air, a clear decrease in particle number was seen. The next spike on the graph corresponds to when the windows open. Then, the ventilation was changed to heat on while recirculating cabin air. This caused the particle number to decrease again. Then the ventilation was changed to heat on while pulling in outside air. This caused another spike in the measured particle number. The last ventilation mode used was with the AC and heat off with the windows closed. Low numbers were recorded again. After the highlighted parts of the graph, the ventilation was switched back to low heat, pulling in outside air. The car then drove around smaller streets in the Amager area. Small spikes were occasionally recorded, but none as significant as on the busier highway. We found that the primary area of polluted air quality is on the highway and in the surrounding area.

Table 1. Ventilation modes used while measuring ultrafine particles during the six runs inside the car cabin.

Run Number	Climate Control	Air Source
1	AC	Recirculating
2	AC	Pulling in outside air
3	Off	Windows open
4	Heat	Recirculating
5	Heat	Pulling in outside air
6	Off	Windows closed



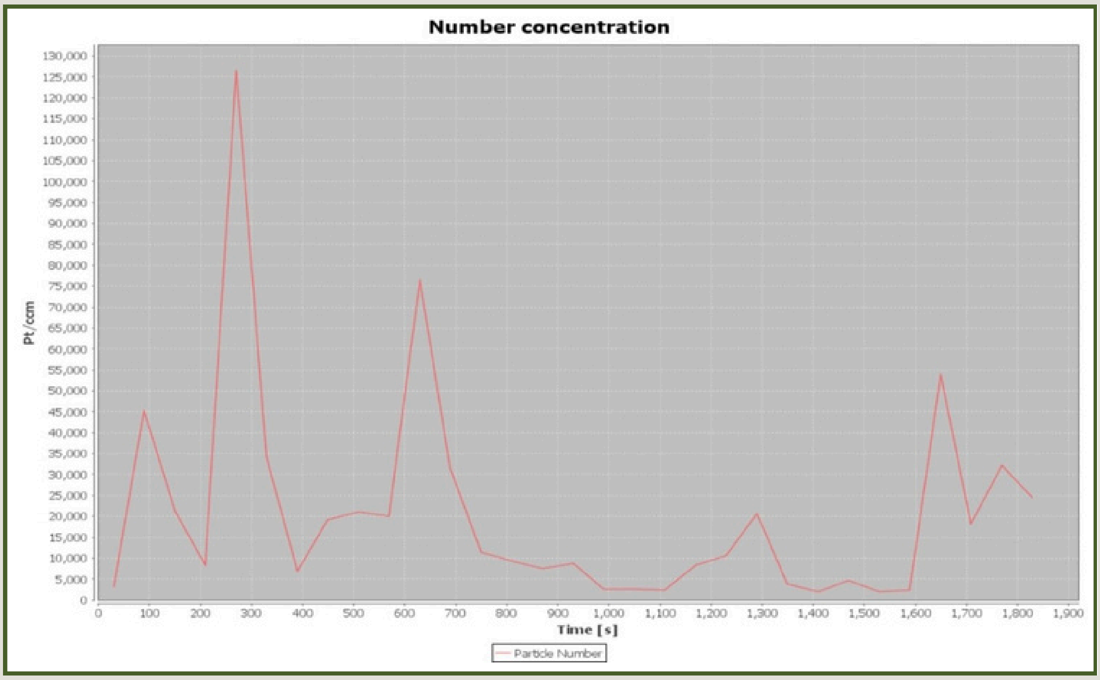


Figure 13: Graphs made from the Testo DiSCmini ultrafine particle sensors: (top) Graph Data collected in the cabin of a car. The different ventilation modes are highlighted in distinct colors. The red was AC on pulling in outside air. Orange is AC on recirculating cabin air. Yellow is AC and heat off with the windows open. Green is heat on pulling in outside air. Blue is heat on recirculating cabin air. Purple is AC and heat off with the windows closed. The data on the rest of the graph was from driving around through Amager with the heat slightly on, pulling in outside air. (bottom) Graph contains data collected on the bridge overlooking the motorway (E20) gathered while the data was collected in the car. There was less data collected on the bridge than in the car because the car run was much longer.

During our measurement trials, we encountered some challenges and limitations. Some days we were not able to take measurements because of the rain. Some data from the Atmotube sensors has been lost due to malfunctions with the devices recording abilities. However, each time this happened, data from the other sensor was able to compensate. A record of the data from the first round of measurements inside a car cabin was also lost due to device malfunctions, but we had some backup photos of the live data feed to confirm readings. We were able to fix the device to collect data during the second round. Another weather limitation came from a dust cloud moving over Europe from the Sahara Desert starting about two thirds of the way through our measurement period (Le Monde, 2024). The dust cloud affected more southern areas of Europe; however, it may have skewed some of our measurements.

4.3 - Objective 3. Identify strategies to use hyperlocal data to support local interest in air pollution mitigation

In the United States, weather apps have a feature to check air quality in your area. It is commonly used to alert about the effects of nearby wildfires and other causes of air quality deterioration. In Copenhagen, such a feature doesn't exist. We researched what information was available about air quality in Copenhagen which resulted in some interesting findings. There are ways to find air quality information in Copenhagen, like Google Maps' layer for air quality as well as other independent websites that show you the data and where they got it from. The concerning finding was related to how little weather stations were being used to measure air quality. Three are in Zealand and one is in the north of Amager. Even though they provide air quality information for the entire city there is a lack of transparency referring to how the information is processed and how inaccessible it is for citizens. Because of this, we decided to survey the residents of Amager to identify strategies to support pollution mitigation.

The lack of transparency in air quality data processing and the limited number of weather stations in Copenhagen led us to survey the residents individually. To identify strategies, we first surveyed to gather baseline values and behaviors. When asked about the preferred method of commuting, our 31 survey responses reveal several themes regarding practices in the choice of commuting methods. Speed and efficiency are highly valued, with many opting for the quickest route to their destinations. Residents preferred commuting methods that had health benefits, which meant those that involve physical activity and less exposure to pollution. Environmental considerations are evident, with a focus on eco-friendly transportation options. Additionally, when asked about commuting methods, convenience and economic factors were significantly important, influencing commuters to select methods that integrate seamlessly into their daily routines and are cost-effective. Personal lifestyle choices, such as avoiding car ownership in densely populated areas and enjoying the outdoor aspects of commuting, were influential factors for choosing sustainable and active transportation modes.

Not surprisingly in Copenhagen, when comparing preferred methods of commuting, biking was the most popular mode of transportation, followed by public transport and walking. Commuting by car using petrol is less common, while electric car usage was noted as the least preferred method among our respondents. The data suggests a strong inclination towards environmentally friendly and active modes of transportation within the community.

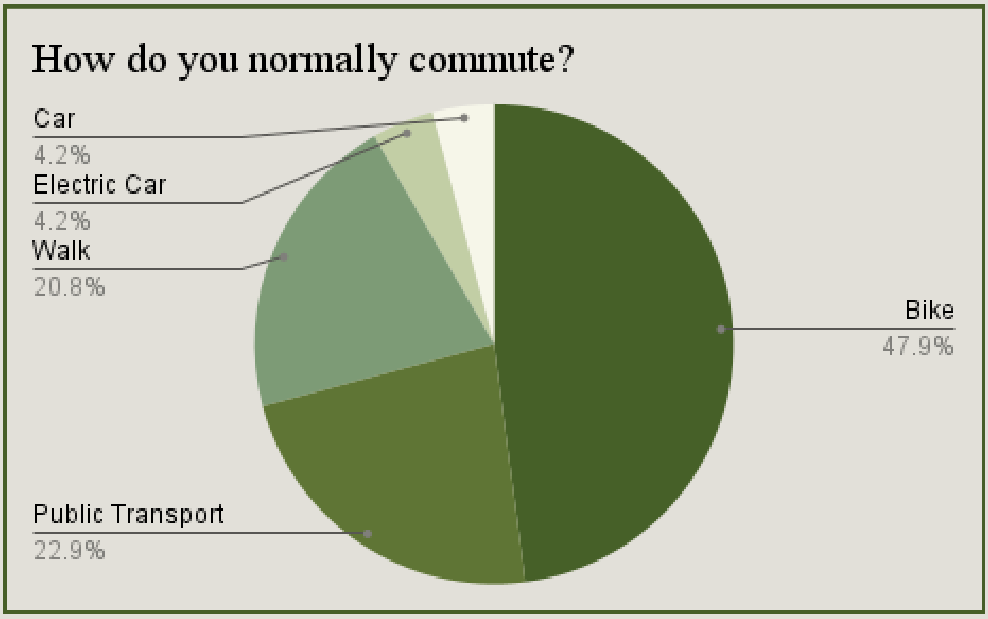


Figure 14: Comparing the Commute Methods Chosen by the Ørestad Community (n= 31).

We found that the public's desire for hyperlocal air quality data is apparent, with one participant saying, "It would be nice to know the air quality from street to street" (stated in an interview on 4/15/24). However, out of 31 survey respondents, 23 respondents do not know where to access air quality data in the first place.

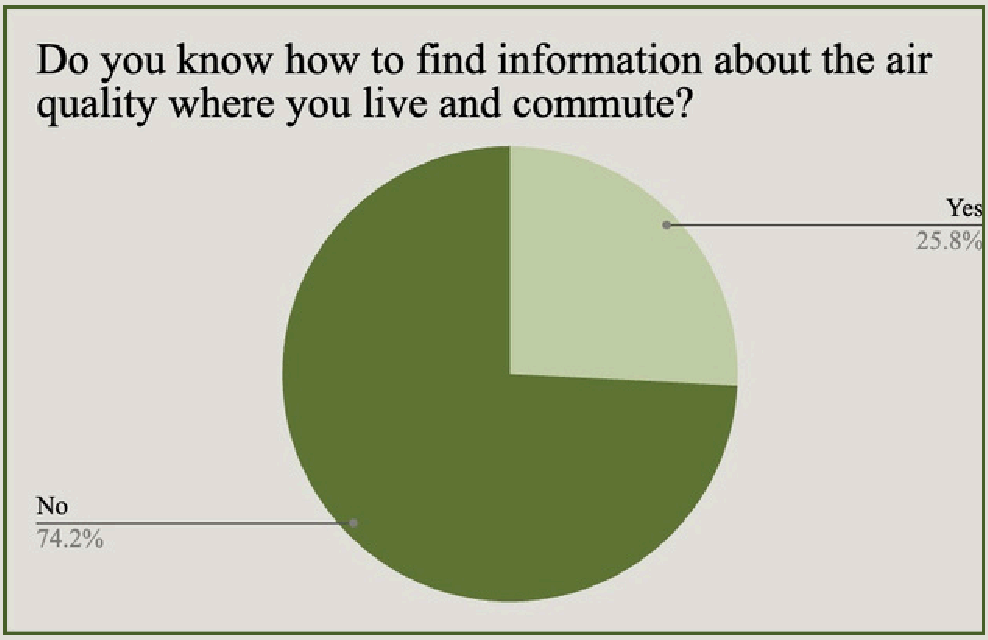
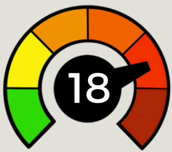


Figure 15: Survey results asking if people know how to find air quality information (n=31).



It was encouraging to find that most people are willing to change their commute pattern. However, a huge gap is apparent when three-quarters of the respondents do not know how to find air quality data. To bridge that gap, during follow-up interviews, we asked, "What would it take to make air quality data easily accessible and comprehensible?" Our Interviewee responded, "In Copenhagen, everyone is checking the weather, all the time. An integrated air quality feature in the Weather App would be the best".

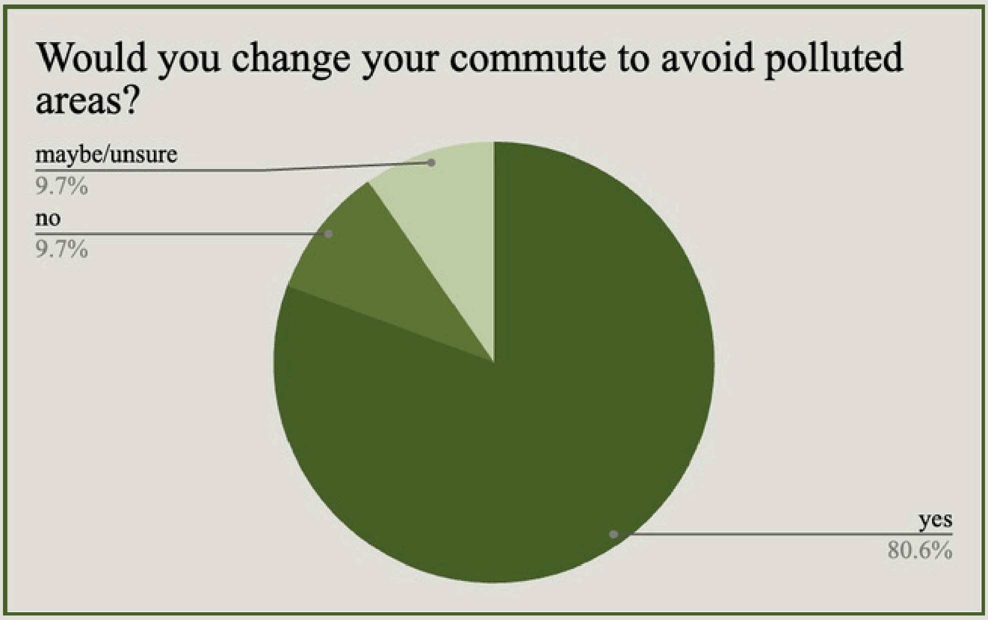


Figure 16: Survey results asking if people would change their commute to avoid polluted areas (n=31).

When conducting interviews in the park area, we only spoke to 3 individuals: a worker fixing the flower arrangements in the park, a worker from the coffee shop, and a resident of Copenhagen that works in Ørestad. Out of three interviews, only one respondent knew where and how to access air quality data. The other two reinforced the idea of an app to communicate air quality data to the public. One confirmed, "In Copenhagen, everyone's checking the weather, all the time. An integrated air quality feature in the Weather App would be the best" (stated in an interview conducted on 4/16/24). This encapsulates the idea of the desire for an accessible mobile application, displaying air quality data. Some feedback identified features in a prospective app such as real-time monitoring, hyperlocal data, and comprehensive monitoring that might include metrics such as PM1, PM2.5, PM10, VOCs, AQS, and AQI. Customizable alerts were also mentioned, "It would be nice for users to set alerts for when air quality when pollutants break a threshold" (stated in an interview conducted on 4/12/24).

During our study, we had a few site limitations. We observed that many local people use the park to get from one place to another faster. We did not observe many who were using the park and its infrastructure for recreation. This limited the number of individuals that we were able to meet. Many individuals who did use the park were unsupervised minors who were using the park for games or the soccer field. They were ineligible for our study. Finally, we recognize that there were limitations related to the weather conditions, which included high winds and cloudy weather.

4.5 - Discussion

Our findings show that the residents of Amager are interested in air quality data that can improve their decision-making related to their own health as well as suggesting the use of the residents themselves for air quality monitoring. This approach will empower residents to act upon air quality and the issues it brings to improve their environment. Our collected data shows that frequent visitors as well as residents of Ørestad are concerned about air quality but lack access to air quality data, very important especially for the people who spend most of their time outdoors, like most of our respondents who choose to commute by bike. Most of them also rate air quality very highly when choosing a commuting route and are willing to change if data shows that a healthier route exists. This highlights a gap in communication and shows a need for methods of communicating air quality data effectively, with the suggestion of a mobile app being frequently mentioned by our interviewees.

The need for an effective way of communicating air quality data is evident. While air quality communication platforms do exist, they don't meet the needs of the Ørestad community. They offer data that lacks the hyperlocal factor that is necessary for the residents to make decisions about their health. On the other hand, they can be too complicated to be used by the public. These difficulties show the importance of developing a tool for improved air quality monitoring with better communication strategies, vital for residents to make better decisions about their health.

CHAPTER 5: RECOMMENDATIONS AND CONCLUSION

Based on our findings, we have developed a set of recommendations for Miljøpunkt Amager moving forward in its goal to improve the air quality in Amager. Our three recommendations propose a two-phase initiative to encourage citizen involvement in the collection of hyperlocal air quality data around the city.

Recommendation 1: Collect air quality data with the community

Based on data we collected from air quality collection, a survey, and our interview findings, we recommend the launch of a two-phased citizen science initiative.

Why: Enhancing local knowledge through community-based air quality awareness.

Air quality has serious impacts on health and quality of life. Copenhagen is an environmentally committed city, which means that understanding air quality and the distribution of its data around the city is crucial for residents' decision-making. Because of this, empowering residents to contribute to measuring and sharing air quality measurements with their community will raise awareness and inspire others to do the same. This approach will further engage citizens with Copenhagen's green city initiatives as well as improve residents' abilities to make better decisions when it comes to their daily travel based on real-time data.

What: A two-phase project to deploy air quality monitoring in the Amager Island.

Phase 1: In the first phase of our citizen engagement initiative, we propose the installation of fixed air quality monitors at key stations along the E20 highway. Initially, three monitors will be deployed on the metro stops that go along the E20 highway to establish a baseline of air quality data surrounding this major road. The stations selected are the Ørestad metro stop, Tårnby station, and the Copenhagen Airport metro stop. A map of sensor placement at these stations can be seen in Figure 18. These monitors will measure particulate matter (PM1, PM2.5, and PM10) and volatile organic compounds (VOCs), the same data we collected for this study. The sensors will contribute data on air quality experienced by daily commuters. This air quality data can be then handed off to a university for the data analysis aspect. After the data is analyzed, it can be shown on the Aw-Air app discussed in recommendation two, or a previously developed air quality website.

Figure 17: Map of the 3 metro stations that could host sensors.

Phase 2: This phase requires the participation of residents. It will incorporate them into a citizen science project where they will be the ones collecting air quality data. They will have access to portable sensors like the Atmotubes, designed for personal monitoring of air pollutants. The atmotubes allow for mobility in the data collection process without compromising on ease of use and accuracy. Participants will be guided to keep the sensors in non-obstructed areas as well as recording their location when capturing the air quality data.

The data from the Atmotubes should be communicated to the organization hosting the project. MPA could hand off this project to a local university as a continuous research project. This institution should facilitate the real-time data analysis tool, in the form of a simple JavaScript program, developed by the selected university as well. This program should be handed back to MPA for its distribution. This enables citizens to actively contribute with real-time and reliable air quality data, improving our understanding of hyperlocal environmental conditions. Ideally, a constantly updating map like the one shown in Figure 12 will be the result.

How: Collaboration is the key

Phase 1 requires the installation of fixed air quality monitors along the E20 highway, able to record all the air pollutants previously mentioned. This requires collaboration between MPA and the local transportation agency, to ensure not only their installation but their maintenance.

Phase 2 will equip volunteers with Atmotubes, distributed through local organizations, who should also host workshops on how to use them. Volunteers will be instructed to keep the sensors in places where they won't be obstructed to ensure data accuracy. The data from both the static and dynamic sensors should be compiled and processed using a JavaScript program that can digest the information for easy consumption. This information should later be relayed to the public, enabling them to make informed decisions based on their environmental conditions.

Recommendation 2: Aw-Air app: Making the invisible visible

Why: Addressing community needs for air quality information

Our interviews with the Ørestad community show the need for a way to access real-time and accurate air quality data. Such information is either very incomplete or nonexistent, leaving citizens unable to inform themselves about their environmental conditions. Community members have shown interest in a digital solution to fulfill this need.

What: Proposal for a dedicated air quality app

To meet the community's preferences, we recommend that Miljøpunkt Amager collaborates with a team to develop an app called "Aw-Air." This app would provide real-time air quality data, accessible anytime and anywhere, directly to the users' mobile devices. The app will better inform residents and their decision making about their daily activities, especially those who are concerned about health and environmental exposures.

How: Development and features of the Aw-Air app

Development steps:

1. Integration with existing infrastructure: The app will integrate with current air quality sensors in Ørestad and include additional sensors if necessary. Installing air quality monitors with GPS trackers on city-rentable bikes which would be powered by the motion of pedaling to ensure continuous operation can be a realistic way to add sensors into existing infrastructure.
2. Software development: For effective use of the app, developing the app interface and backend systems to process and display air quality data would be beneficial.

Key features:

1. Real-time air quality data: In a users' immediate surroundings, they will be able to see real time air quality data.
2. Hyperlocal data: Sensors will be placed throughout Ørestad to provide local readings.
3. Comprehensive monitoring: The app will measure key data points such as PM1, PM2.5, PM10, and volatile organic compounds (VOCs).
4. Air quality index (AQI) and air quality score (AQS): To help users understand health implications, these values will be displayed for the current levels.
5. GPS integration: To provide relevant data, the app will use the device's location to show data from the nearest sensor.
6. Customizable alerts: To be aware of the air quality levels, users will be able to set alerts for when air quality score rises below or above a set threshold.
7. Community engagement: There will be options to report local air quality issues and share experiences with the local community.
8. Historical data: Users will have access to past air quality data to observe trends and changes over time.
9. Educational resources: Users will have access to tips and resources to help users reduce exposure to pollutants.
10. Integration with weather apps: This air quality data can be integrated into existing weather applications to increase accessibility.

Figure 18: Aw-Air (Design concept)- weather app concept to better communicate air quality.

By following these steps and incorporating these features, the "Aw-Air" app will not only meet the expressed needs of the community but also foster a more engaged and environmentally aware population in Ørestad.

Recommendation 3: Assess in-cabin air quality for healthier commutes

Why: Monitoring cabin air quality

During our project, we conducted a few trials collecting air quality data inside the cabin of a car. We wanted to gather data to determine if being inside a car protects the driver and passengers from the polluted air of the highway outside the car or if they are exposed to the same or higher levels of pollution.

What: A focus on car cabin air quality research

Our data and research show that being inside a car can expose people to more polluted air. The research highlights how car commuters are exposed to the pollutants from traffic, emission from their car, and VOCs given off by materials inside the car. Reducing the number of people who commute by car could be a focus for Miljøpunkt Amager. Reducing car commuters would decrease air pollution from cars traveling on highways and reduce the rate of exposure to poor air quality inside cars. Our survey and interview data provided preliminary data suggesting residents would be willing to change their commute to avoid polluted air. Miljøpunkt Amager could amplify this data in a campaign against commuting in a car.

How: Specifics of the study

Enlisting volunteers from the community and equipping them with less sophisticated sensors like the Atmotubes would allow for a wide range of data to be gathered. However, residents on their daily commute may not be able to keep track of all the variables that could affect the measurements. To get more accurate data, we recommend that MPA find research partners that can perform more sophisticated tests using more sensitive sensors like the ultrafine particle sensors. A research team will record the environmental factors to get the most useful and accurate data possible.

While conducting research and during our preliminary tests, we discovered how complicated it is to gather air quality data in a car. There are many variables that need to be accounted for, all of which can influence collected data, such as weather conditions and amount of traffic. When performing more tests, MPA needs to ensure that these variables are recognized. Some variables are easier to control. Data should be collected inside cars of the same model and age (ideally only one car would be used so that data can be more easily compared; however, this limits that sample size of the project). Ensure that the cars' make, and model are noted. Before beginning tests, measure the air quality in the car when it is parked and turned off. This will establish a baseline for the pollutants from the car. When performing the tests variables like weather and traffic conditions are harder to control. MPA should try to run tests under the same weather conditions at the same time so that traffic patterns can be more consistent. The ventilation mode of the car during the test is one of the most important variables. It is also where some of the biggest differences in recorded data can be seen. While testing, ensure that all ventilation modes (AC, heat, recirculation of air, pulling in outside air, windows open, no ventilation, etc.) are tested. Ultimately, ensure that all the variables and conditions are noted while performing tests including weather, changing ventilation modes, if the car is idling, when passing a large truck, and any other environmental factors that may influence the data. While performing the tests, fixed monitors should be posted along the route to gather data from outside the vehicle. This can be compared to the data inside the car.

In this chapter, we propose three recommendations for MPA. Adding air quality monitors throughout Ørestad and involving the citizens in collecting data will allow a wealth of air quality data to be collected. Making this data available to the public through our proposed "Aw-Air" app will give the residents the real-time, hyperlocal data they have been wanting. Our last recommendation will help MPA move forward in studying car cabin air quality to help residents plan their commutes. We hope these recommendations will help MPA move forward to improve the community's knowledge about and engagement with air quality.

Conclusion

In this chapter, we propose three recommendations for MPA. Adding air quality monitors throughout Ørestad and involving the citizens in collecting data will allow a wealth of air quality data to be collected. Making this data available to the public through our proposed "Aw-Air" app will give the residents the real-time, hyperlocal data they have been wanting. Our last recommendation will help MPA move forward in studying car cabin air quality to help residents plan their commutes. We hope these recommendations will help MPA move forward to improve the community's knowledge about and engagement with air quality. Conclusion Our project started with air quality data collection in the area of Ørestad to understand the current pollutants present and get our own baseline of the air quality. To get a better understanding of what other cities are doing to help mitigate air pollution while involving citizens, we investigated case studies and determined their best practices. As our project progressed new data collection methods were introduced to get a wide range of air quality data on and around the E20 highway. Through our surveys and interviews we learned that residents want access to real time data to help them inform them about their commuting routes and where to spend time outdoors. Our proposed mobile app is one of, if not the most important recommendation we make. It would hopefully satisfy the community's' desire for real time, hyperlocal air quality data, which was abundantly clear in our surveys and interviews. In the broader scope of our project, we hope the collected data and increasing resident engagement with air quality will eventually lead to policy changes. These changes would include better regulations for new developments in Copenhagen to reduce pollution hotspots and improve the overall air quality.

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APPENDIX

Appendix A: Survey (on MPA's social media)

Our team of WPI students working with Miljøpunkt Amager will use your response to better understand the community's knowledge and concerns about air quality in your daily life. Thank you for your input! (If a question does not apply to you, please write N/A)

1. What is your gender?
2. How old are you?
3. Do you live in/near the Ørestad area?
4. What is your relationship to the area? (I live here, I go to school/study here, I work here, I have friends/family here, I spend free time here)
5. Do you have small children under the age of 10?
6. How do you normally commute (bike, public transport, car, walk, other)?
7. Why have you chosen this commuting method?
8. If you drive, do you often drive on the Ørestad motorway (E20)?
9. How important is ambient air quality exposure to you while commuting?
10. If you drive, do you think the air quality inside a car is better, worse, or no different than the outside air?
11. Would you consider changing your commuting route or method to avoid high pollution areas?
12. What would make you spend more time outside in Ørestad (more city life, more green, better protection against bad weather, less noise, more safe places, better lighting)
13. Have air quality concerns affected your daily life?
14. Do you know how to find information about the air quality where you live and commute?
15. Please provide your email if you are willing to be asked further questions

Appendix B: In person park interviews

1. Do you live in/near Ørestad?
2. Do you believe your health is impacted by air quality?
3. What are the most effective methods for educating the public about air pollution? (if they have trouble producing an idea, we will guide them by giving them these options: app/website, billboard with real time data, infographic)
4. What would be good features and metrics to include for the (insert answer from Q3 here)?
5. What would it take to provide the best method of communicating air pollution data?
6. Is there anything else you would like to make a note of?

Appendix C: Zoom and in person interviews

1. What makes you passionate about understanding air quality?
2. Do you think your health has been impacted by air pollutants?
3. What would it take to make air quality data easily accessible and comprehensible?
4. What are the most effective methods for educating the public about air pollution (app/website, billboard with real time data, infographic)?
5. Is there anything else you want to tell us?

Appendix D: Graphs of collected data and survey results

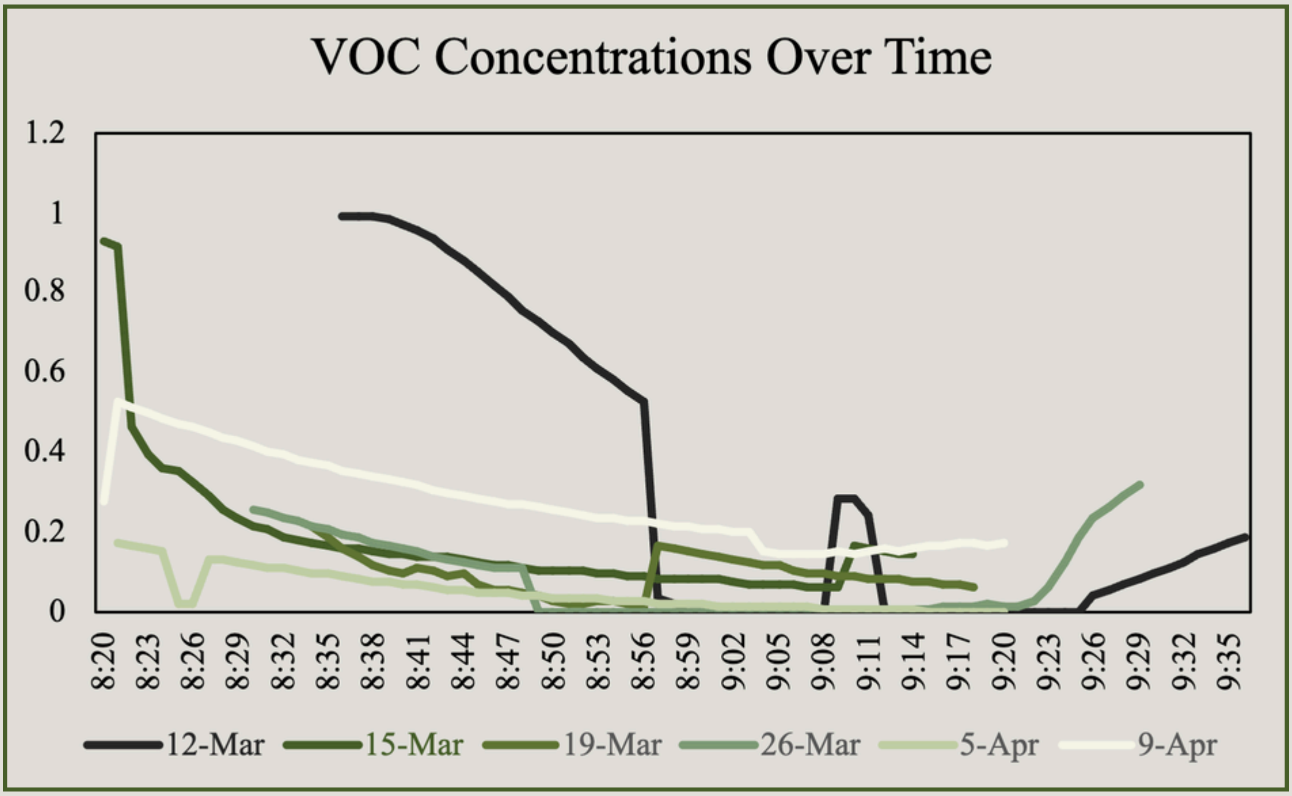

Figure 19: Graph of the VOC concentrations over time on each measurement day.

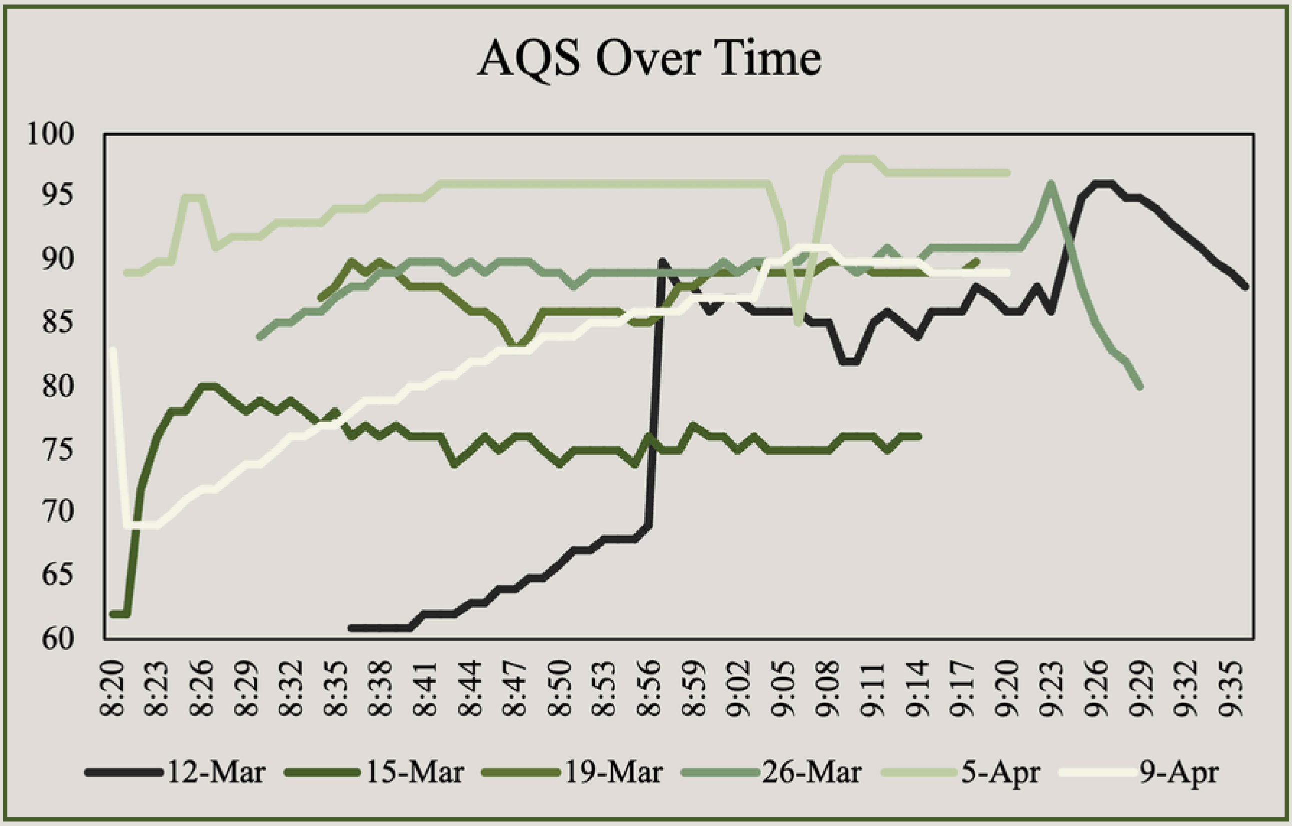

Figure 20: Graph of AQS over time on each measurement day.

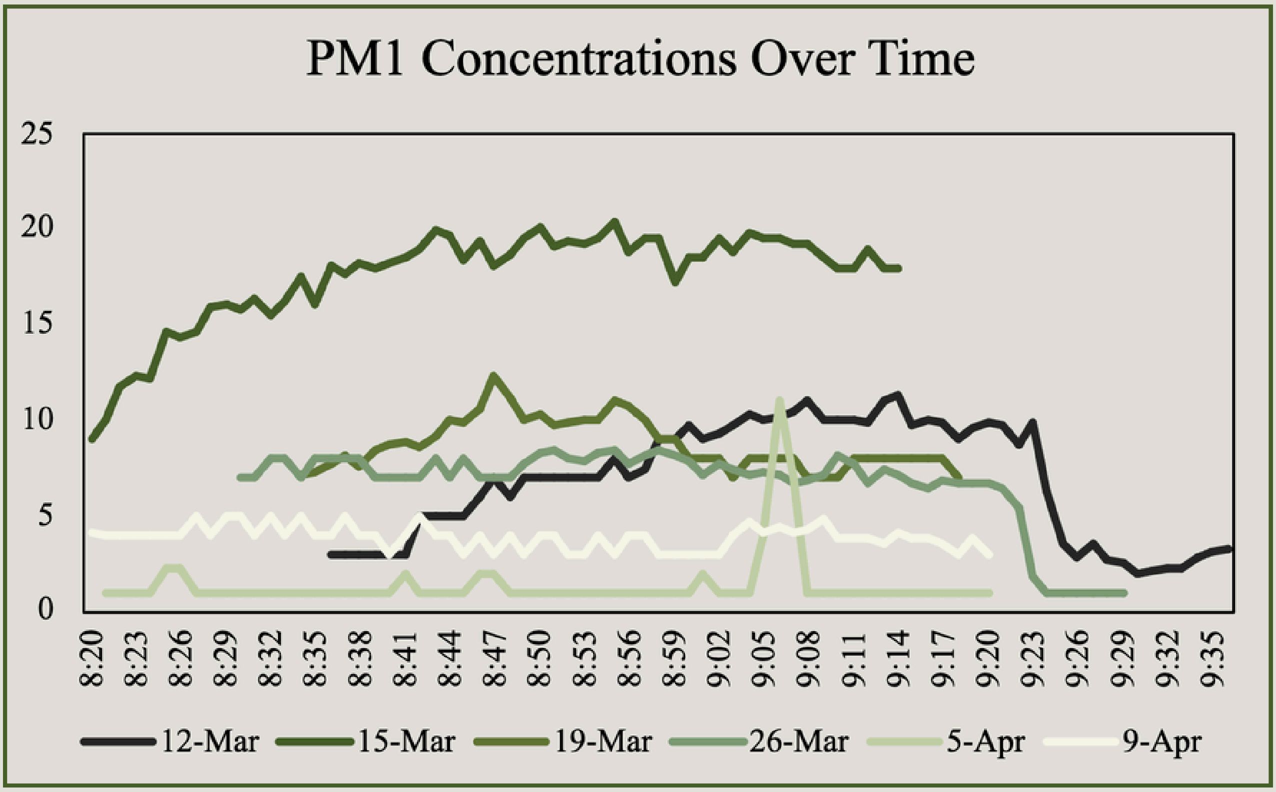

Figure 21: Graph of the PM1 concentrations over time for each measurement day.

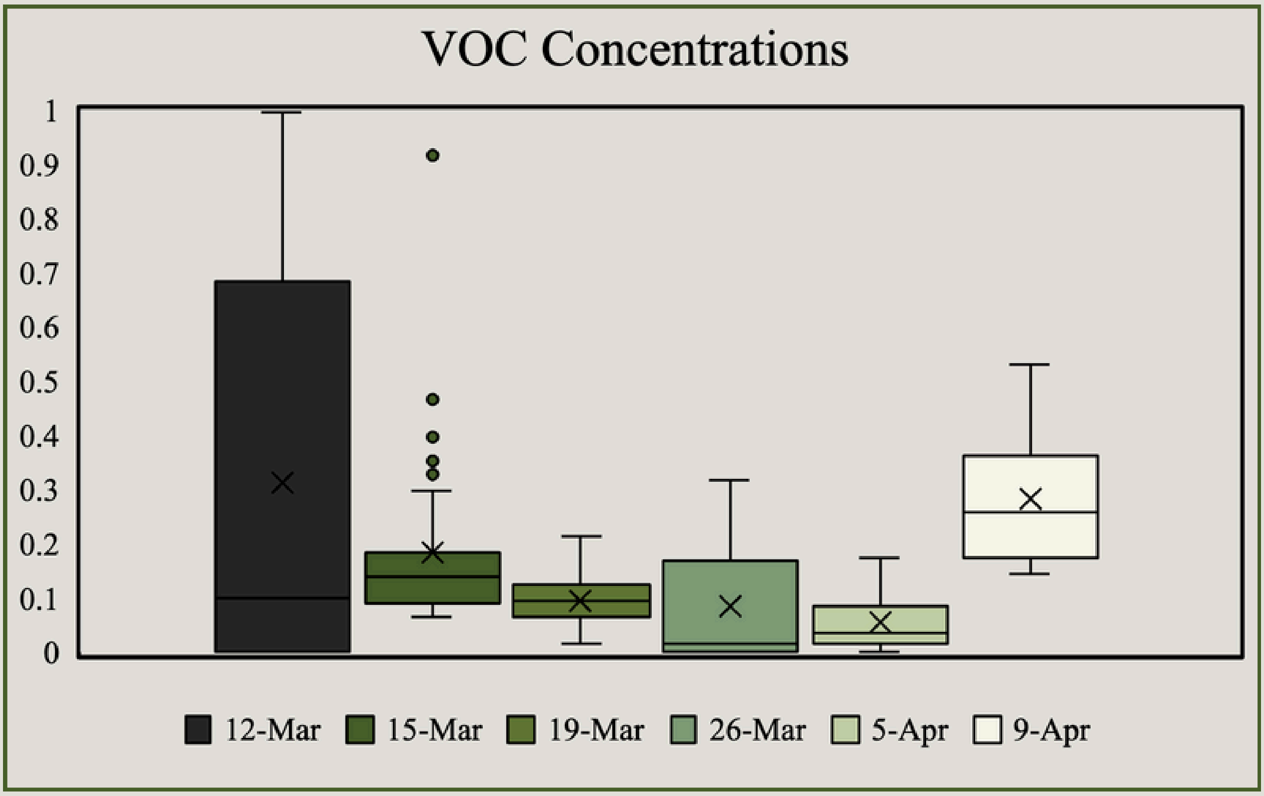

Figure 22: Box and whisker plot of the VOC concentrations on each measurement day.

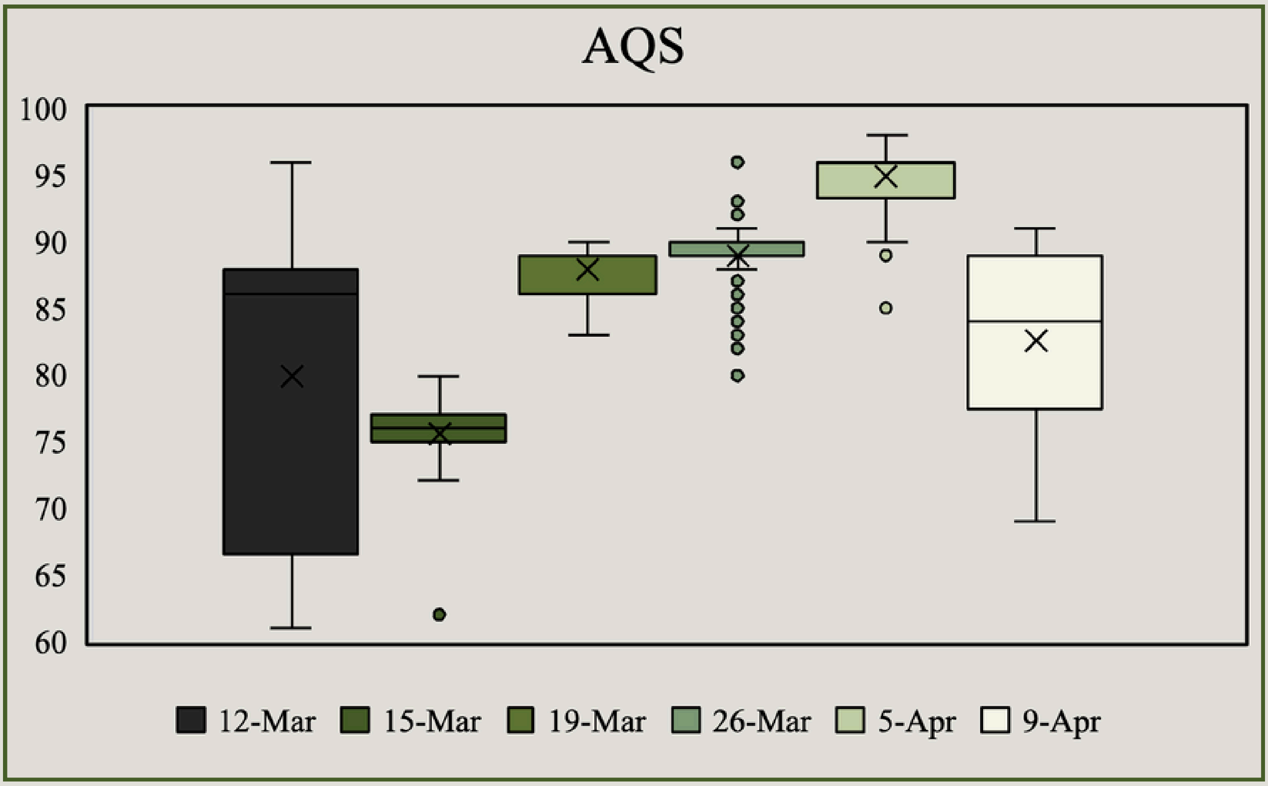

Figure 23: Box and whisker plot of the AQS on each measurement day.

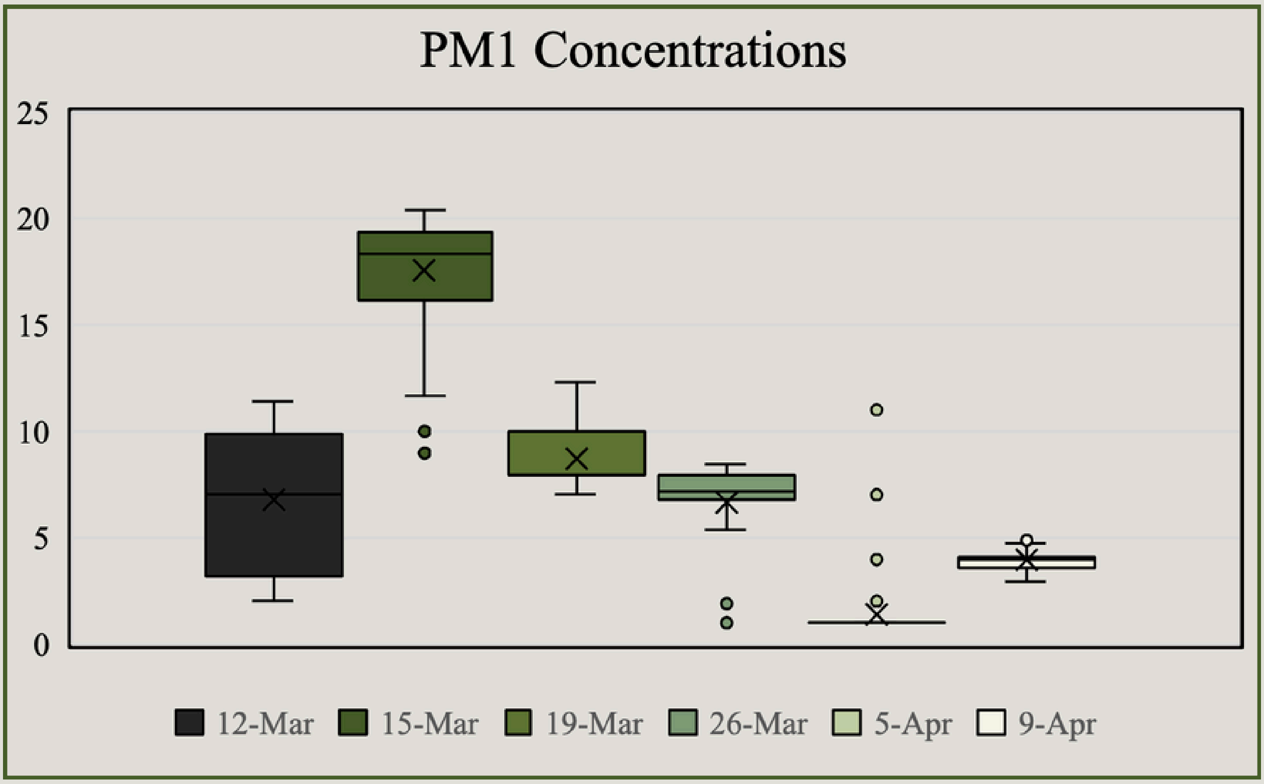

Figure 24: Box and whisker plot of the PM1 concentrations on each measurement day.

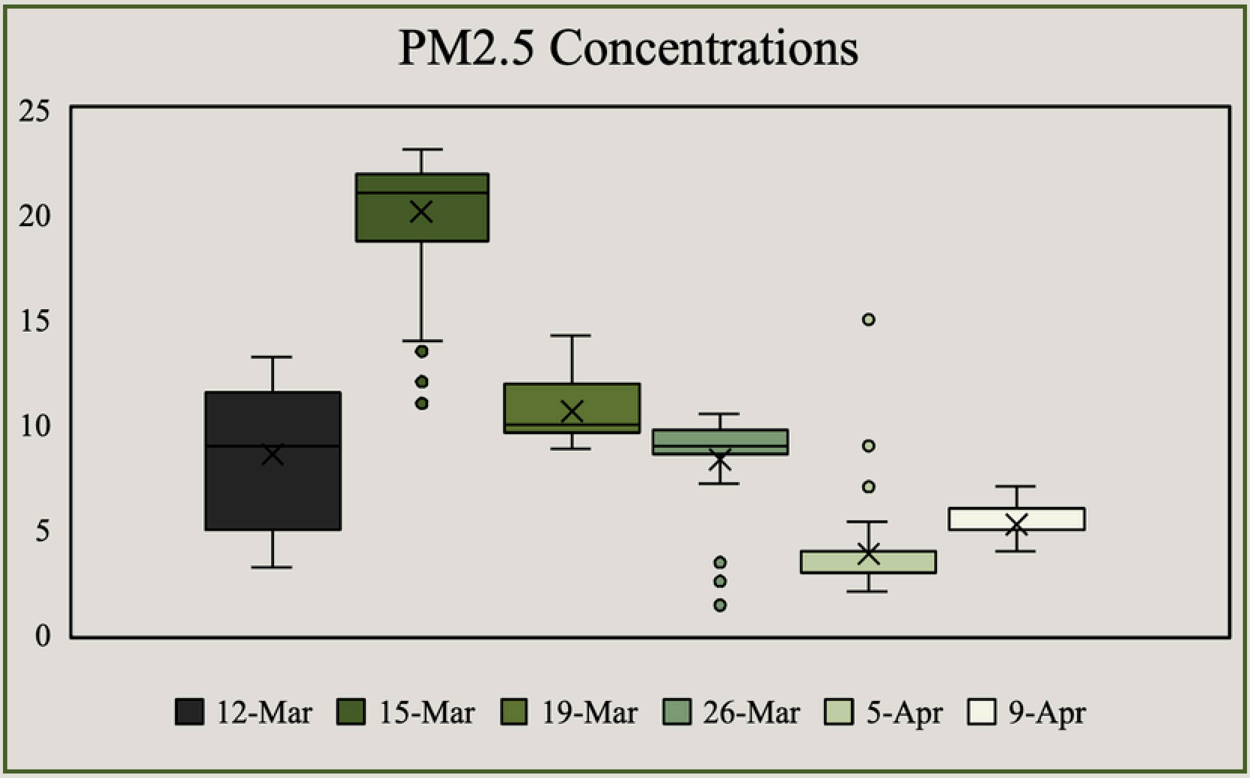

Figure 25: Box and whisker plot of the PM2.5 concentrations on each measurement day.

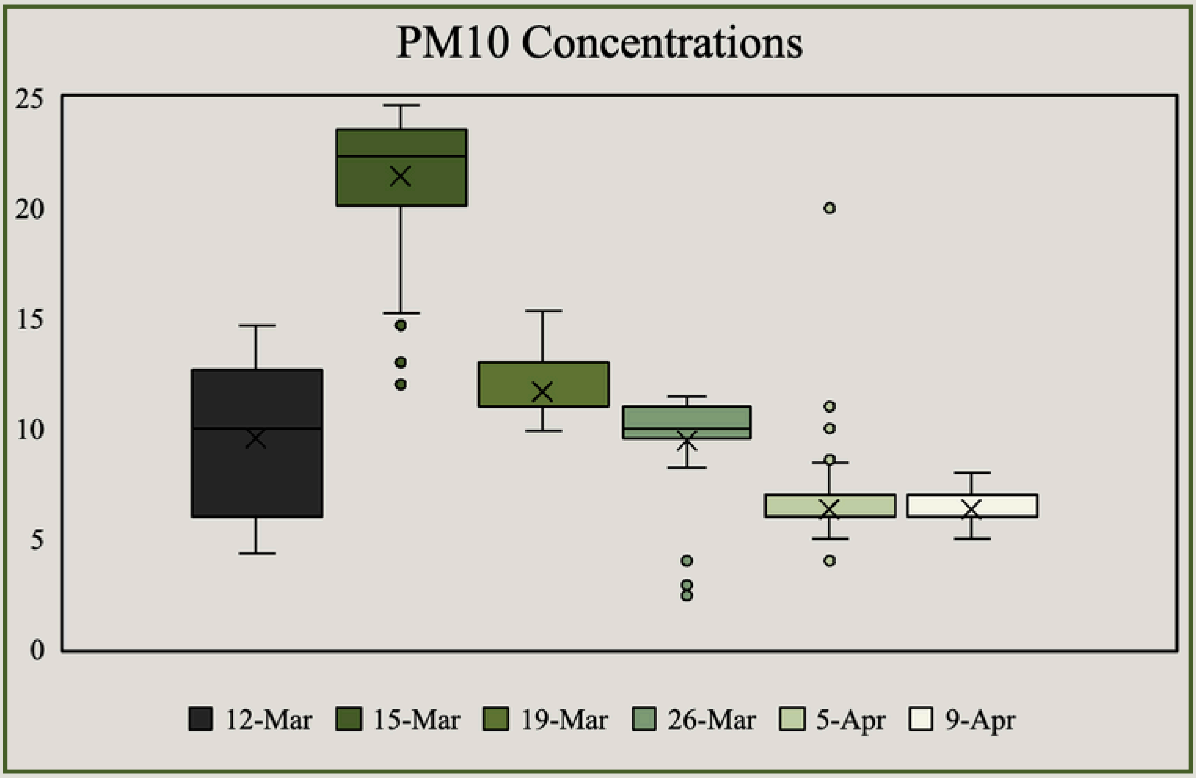

Figure 26: Box and whisker plot of the PM10 concentrations on each measurement day.

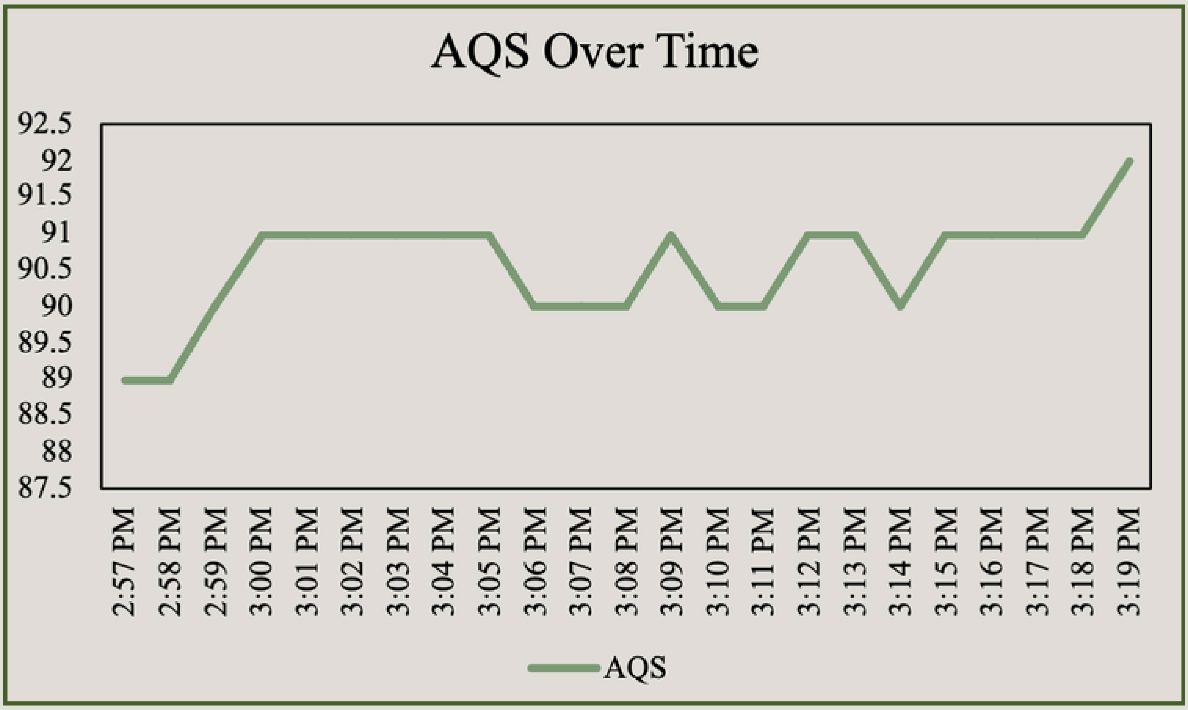

Figure 27: Graph of the VOC concentration when walking from the bridge to the park.

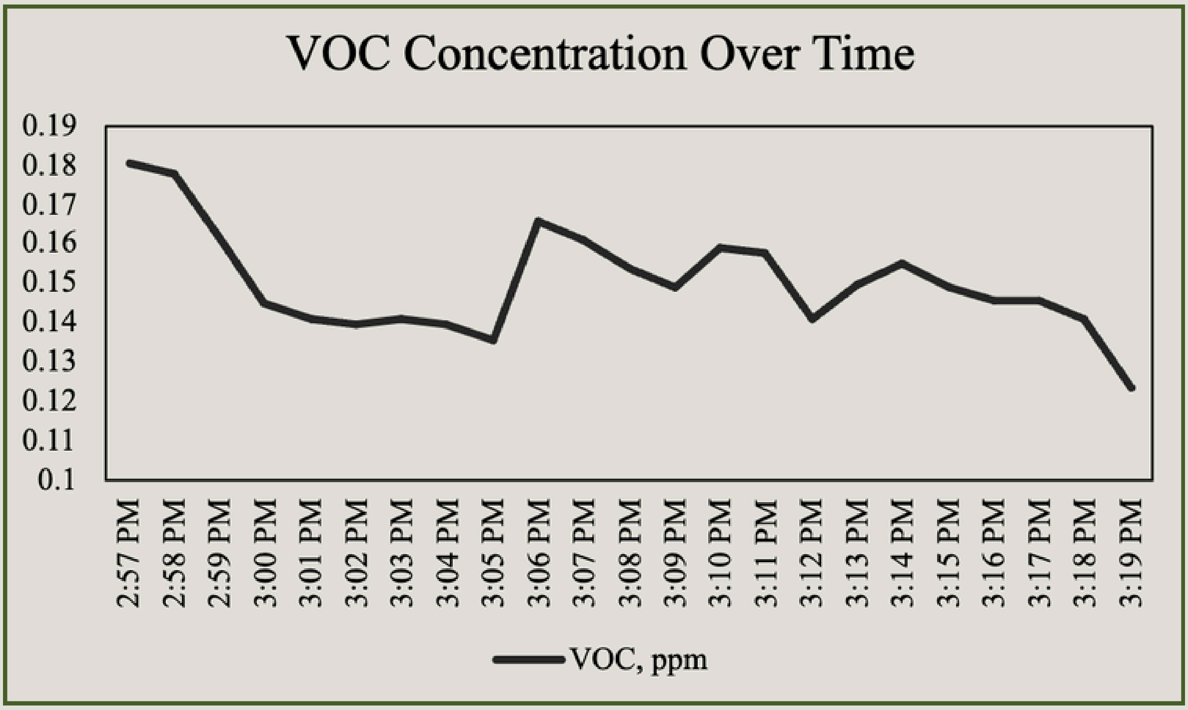

Figure 28: Graph of the AQS when walking from the bridge to the park.

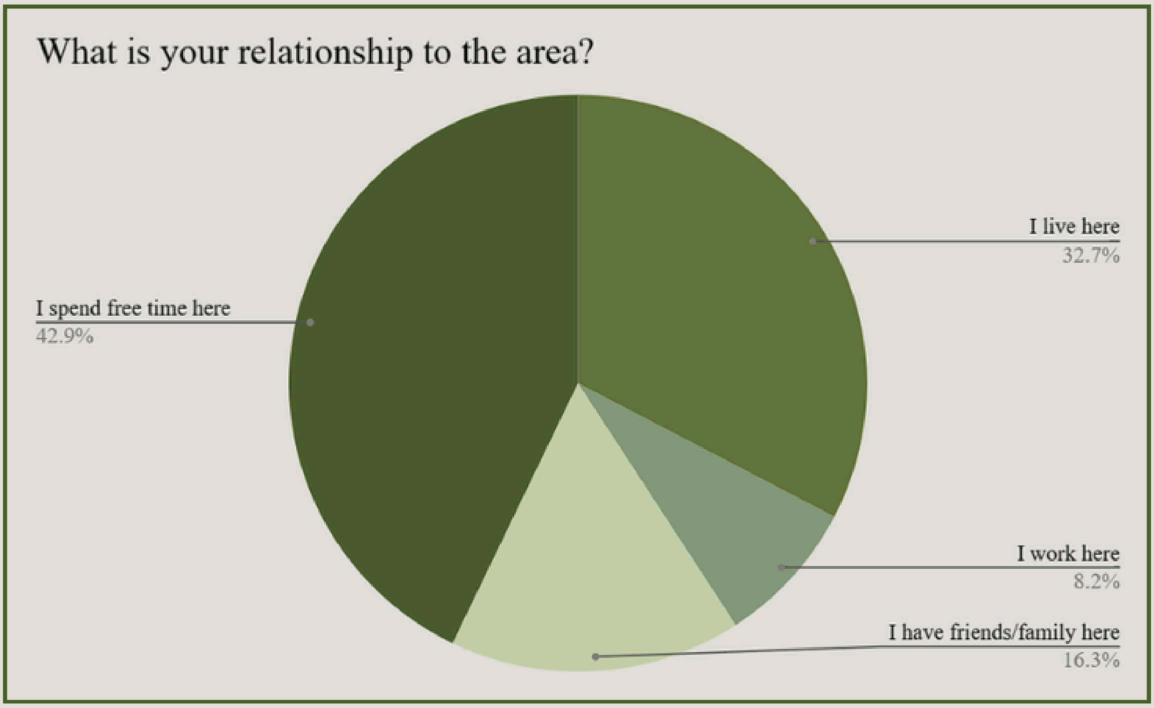

Figure 29: Reasons why people go into Ørestad taken from the survey data.

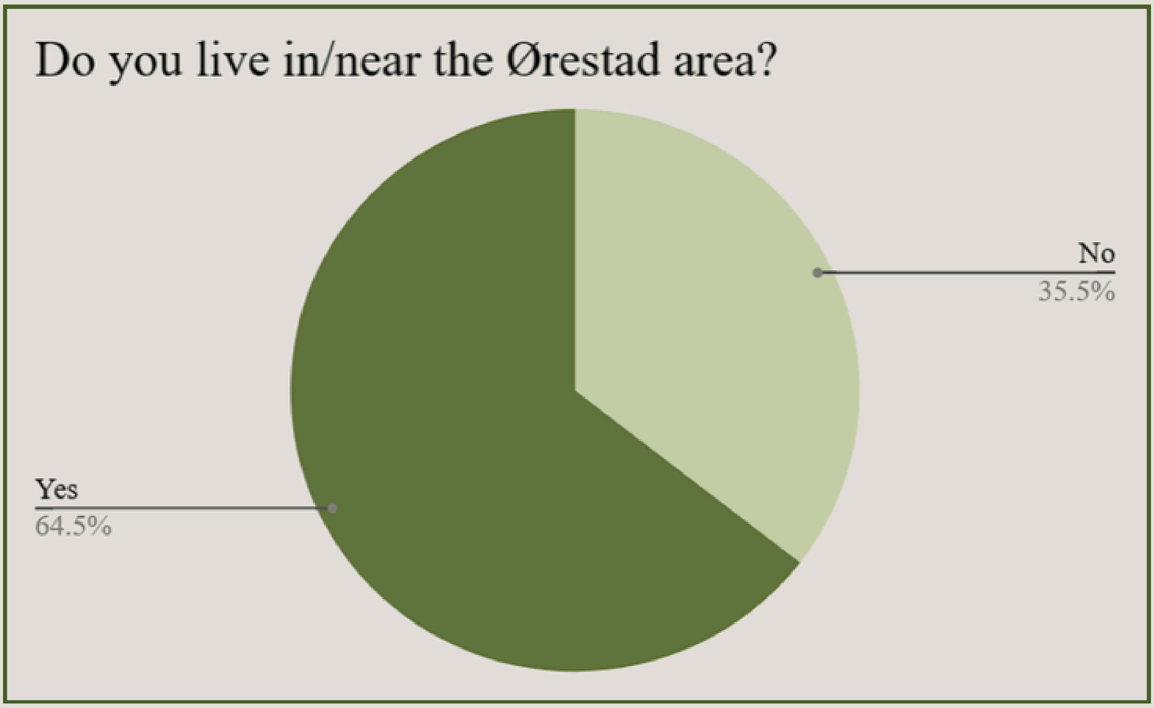

Figure 30: Percentage of people who live in the Ørestad area taken from survey data.