Understanding Air Pollution in Amager, Copenhagen and its Effects on the School-Aged Population

An Interactive Qualifying Project submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfilment of the requirements for the degree of Bachelor of Science

By: Nour Elmaliki, Muyun He, Connor Mclaughlin, Tom Nurse
October 16, 2020

Report Submitted To:
Professor Gary Pollice and Professor Jefferson Sphar, Worcester Polytechnic Institute
Director Dorte Grastrup-Hansen, Miljøpunkt Amager

Abstract

Air pollution poses a serious threat to children. Our sponsor Miljøpunkt Amager enlisted our help in identifying the health risks of air pollution experienced by children at the Kalvebod Fælled Skole in Copenhagen, Denmark. Our team explored potential strategies for reducing air pollution levels through archival research, data collection, interviews, and surveys. Using this information, we developed a set of recommendations for Miljøpunkt Amager.

Acknowledgements

Our team wishes to thank the various organizations and individuals that helped to make our project possible:

- Our sponsor, Miljøpunkt Amager and Dorte Grastrup-Hansen, for providing our team with the support, resources, and information we needed. Without them this project would not have been possible.
- Gehl Architects for allowing us access to some of their ongoing research.
- Nick Vikander and the other Miljøpunkt Amager volunteers for taking air quality measurements on our behalf.
- Our advisors Professor Gary Pollice and Professor Alex Sphar for providing valuable advice and guidance regarding our project.
- To all survey respondents and interviewees for taking the time to answer our questions and for providing us with valuable input.
    - Dr. Matthew Adams
    - Dr. Ole Hertel
    - Dr. Kåre Press-Kristensen
    - Rasmus Reeh
    - Nick Vikander

The Executive Summary

Project Goal

This project aimed to identify the health risks of air pollution experienced by children at the Kalvebod Fælled Skole in Copenhagen, Denmark and recommend potential courses of action to reduce that risk.

Introduction

Air pollution is a byproduct of various processes which introduce chemicals or compounds into the atmosphere. It kills over 7 million people worldwide every year (Osseiran & Lindmeier, 2018) and causes negative health effects especially in urban environments. Our sponsor, Miljøpunkt Amager, is an environmental organization focused on improving air quality in Copenhagen, Denmark. They have partnered with multiple local organizations including Gehl Architects, Copenhagen Solutions Lab, and the Amager Vest Lokaludvalg (Local Council) to measure and analyze the levels of air pollution in Amager. This project was completed to help Miljøpunkt Amager better understand the extent of air pollution's impacts on first grade students at the Kalvebod Fælled Skole and to identify potential courses of action to help alleviate its effects.

Methodology

Through archival research and data collection, including surveys and interviews, we achieved four goals related to the technical, social, and political aspects of air pollution in Amager.

- Measure children's exposure and air pollution levels around the Kalvebod Fælled Skole in Amager.
- Identify relevant sources of air pollution around the Kalvebod Fælled Skole.
- Evaluate current policies and practices taken to reduce air pollution in Copenhagen.
- Research the human health impacts of air pollution in Amager, focusing primarily on first grade students attending the Kalvebod Fælled Skole.

Key Findings

Based on the analysis of the collected data, we derived our findings below.

Amager Community Awareness & Priorities

We administered two surveys that aimed to collect data about children's or residents' commuting habits, the reasoning behind their chosen method of transportation, and to understand their overall air quality concerns. Miljøpunkt Amager shared one of our surveys in the September issue of their monthly newsletter and on their Facebook page. This survey received a total of 94 responses. Our other survey went out to parents of first graders at the Kalvebod Fælled Skole and received 13 responses.

Finding: While the community of Amager is generally aware of their air quality, they are not aware of the numerous initiatives aimed at improving it.

By analyzing survey data from Miljøpunkt Amager's newsletter, we found that most residents of Amager are generally concerned about their local air quality, with 61% of individuals considering their air quality daily or weekly. However, the majority of people (86%) could not name any ongoing community programs aimed at improving the air quality in Copenhagen.

Finding: Parents are concerned about their child's safety when biking to school, but they value convenience above all else when selecting a form of transportation.

From the survey of Kalvebod Fælled Skole parents, we saw a similar trend to that of the community survey. While fewer respondents think about their air quality when considering transportation methods for their children, 78% of parents noted that their children already walk or bike to school. The most common priority among survey respondents was convenience.

Wood Stoves & Wood Burning

Finding: Wood stoves contribute more to air pollution in Copenhagen than motor vehicles do.

Dr. Kåre Press-Kristensen, our interviewee working with the United Nations, cited wood stoves as the most prominent source of air pollution in Copenhagen. Each year wood stoves in Copenhagen contribute twice as much pollution as all the motor vehicles in Copenhagen combined, despite only being in use for around 4 months a year. There are roughly 15,000 wood stoves in Copenhagen, 2,700 of which reside in Amager (D. Grastrup-Hansen, personal communication, 2020). A reduction in wood stove usage by half would therefore result in a reduction in pollution equivalent to banning all motor vehicles in the city.

Impact of Student Drop-off at Kalvebod Fælled Skole

On September 24, Miljøpunkt Amager volunteers used a P-Trak device to collect data on the amount of ultrafine particles in the air around the drop-off area at the Kalvebod Fælled Skole and near the intersection of Hannemanns Alle and Ørestads Boulevard. The weather conditions were excellent as it was clear and dry all morning.

Finding: Motor vehicle traffic has a minor temporary impact on ultrafine particle concentrations.

When analyzing these measurements, we discovered that while there were occasionally small increases, or peaks, in the ultrafine particle concentrations when heavy vehicles, especially trucks, appeared or passed by, the concentrations remained mostly consistent over time. Nearly every spike returned to baseline levels within a minute or two. Furthermore, idling cars and the distance between traffic and the P-Trak device did not appear to have obvious impacts on ultrafine particle concentrations. However, when comparing ultrafine particle concentrations from the drop-off area with a nearby intersection, the concentrations at the intersection were 22% higher.

Airport-Related Findings

Finding: The nearby Copenhagen airport likely contributes to the air pollution in the Kalvebod Fælled Skole area.

Using data from a monitoring station on HC Andersen Boulevard, along with public wind data, we determined that pollutants from Copenhagen Airport could reach the Kalvebod Fælled Skole. We found that average $PM_{2.5}$ concentrations when downwind of the airport were 5.61 $\mu g/m^3$ higher than average levels; an 11.7% increase. When upwind of the airport, $PM_{2.5}$ concentrations were 9.75 $\mu g/m^3$ lower than average; a 20% decrease. T-test scores from the linear regression model showed statistical significance of wind direction, with $p < 0.001$. Based on our findings, we hypothesize that the wind carries pollution from the airport or other sources in southeast Copenhagen, and this phenomenon may similarly impact the Kalvebod Fælled Skole area.

Pollution from Construction

Finding: Nearby construction could have an impact on the air quality, once operations resume.

Dr. Matthew Adams mentioned that dust would likely be the primary pollutant coming from construction zones. Additionally, unfiltered heavy machinery emits ultrafine particulate matter. At the time of this study, nearby construction projects were inactive, however we hypothesize that they will have a greater impact on the air quality once they resume normal activity.

Recommendations

Youth Education & Wood Burning Outreach

One way to reduce the impact of wood stoves and school bonfires is to educate the community and youth of Amager through community outreach events. By teaching families about the health effects of wood burning, we may encourage a reduction in wood stove usage, which would have a significant impact on pollution levels. These families may also petition to stop the practice of bonfire burnings. This outreach would likely have to take place in the scope of Amager, as Ørestad is a relatively new development and does not have many wood stoves in residential buildings.

Extending the Low Emission Zone into Ørestad

We recommend assessing the viability of extending the borders of the Low Emissions Zone (LEZ) to include the school. Our research shows that the low emission zone in Copenhagen reduced exhaust-particle emissions by 60% and NOx (nitrogen oxide compounds) by 25% in 2011. However, the experts we interviewed expressed dissatisfaction with the effectiveness of the LEZ as it is currently under-enforced. Furthermore, the LEZ only demands an open filter rather than more effective closed filters. Despite these limitations, LEZs still provide benefits that could improve the health of the students at the school.

Continued Investigation of Copenhagen Airport

We also recommend that Miljøpunkt Amager consider the airport as a source of pollution and conduct an additional investigation. Our findings suggest that pollution from the airport can travel upwards of 6.5 km, depending on the wind direction. The Kalvebod Fælled Skole is closer to the airport than the monitoring station and is therefore likely at a higher risk of receiving wind-carried pollution. As a result, it would be worth following up with the municipality of Tårnby, who is currently investigating the spread of pollution from the airport. Additionally, we recommend connecting with the citizens group CPH Uden Udvidelse, which is protesting plans to expand the airport.

Continued Investigation of Traffic

Our investigation identified motor vehicle traffic as a notable source of air pollution near the school. However, due to limitations imposed by the Coronavirus pandemic, we cannot determine the full extent of its impact on air pollution. Our sample consisted of only one morning of ultrafine particulate matter measurements. For future investigation, we propose collecting measurements before, during, and after the drop-off/pick-up periods for several weeks. Additionally, fine particulate matter and NO_2 should also be measured, as they are the primary outputs of motor vehicle exhaust and would provide a more accurate estimate of the impact of traffic near the school.

Mapping Cleaner Air Routes

The city of London has created an interactive air quality map which helps citizens find clean air routes between any two points in the city. We believe that a similar map could be a valuable tool in Copenhagen as well. Combining the data from the Google Air Quality project, once it is released, with real time information from monitoring stations across Copenhagen could help generate accurate suggestions for the cleanest and fastest routes to work or school.

Authorship

Abstract: He, Nurse
Executive Summary: Elmaliki, He
Introduction: Elmaliki, He, Mclaughlin, Nurse
Background: Elmaliki, He, Mclaughlin, Nurse
Methodology: Elmaliki, He, Mclaughlin, Nurse
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1. Introduction

Air pollution kills over 7 million people worldwide every year (Osseiran & Lindmeier, 2018). It has more negative effects in urban environments, where there is a higher density of pollution sources, such as vehicle emissions. Even cities with the best air quality have concerns about their residents' health. In Copenhagen, Denmark's capital, an estimated 800 - 1,100 residents perish every year as a result of complications arising from air pollution exposure (Press-Kristensen, 2014). Fortunately, the city is already taking steps to improve their air quality and plans to be carbon-neutral by 2025 (City of Copenhagen, 2012).

One of the most common sources of air pollution is the exhaust from diesel engines, which are in wide use among motor vehicles in Europe. The World Health Organization has classified diesel exhaust as a dangerous carcinogen (Press-Kristensen, 2014). While the city of Copenhagen has implemented regulations on heavy vehicles that primarily use diesel, they have not yet placed restrictions on lighter passenger vehicles. Vehicle traffic regulation is particularly important around schools and playgrounds as air pollution affects children disproportionately (Salvi, 2007).

One organization focused on improving air quality in Amager, is our sponsor, Miljøpunkt Amager. They are currently working to understand and reduce its effects on children attending the Kalvebod Fælled Skole in Ørestad. They have partnered with multiple local organizations including Gehl Architects, Copenhagen Solutions Lab, and the Amager Vest Lokaludvalg (Local Council) to measure and analyze the levels of air pollution in Amager. Miljøpunkt Amager has enlisted our help to better understand the extent of air pollution's impact on children and to identify potential courses of action to help alleviate its effects.

Through data collection and analysis, we completed four main objectives: identify the key sources and health impacts of air pollution, assess the local air quality, evaluate current policies and practices, and determine potential courses of action for reducing air pollution in Amager. We conducted interviews and surveys to develop a better understanding of the technical, social, and political aspects involved in reducing air pollution and to provide support for possible future action.

2. Background

In this chapter, we discuss various types of air pollution and its corresponding health effects, review specific solutions implemented in other countries, and evaluate what has already been done in Amager. This information will provide the foundations for our research objectives defined in our methodology.

2.1 What is air pollution?

Air pollution is a byproduct of various processes which introduce chemicals or compounds into the atmosphere. Common sources of air pollution include emissions from motor vehicles, wood stoves, and the burning of fossil fuels. Scientists often classify gaseous air pollution, such as Nitrogen Dioxide (NO_2), by its chemical composition. Solid particle pollution, known as particulate matter, is classified by size. Particulate matter spans the sizes between 10 and 2.5 micrometers (PM_{10}), 2.5 and 0.1 micrometers (fine particulate matter, $PM_{2.5}$), and 0.1 micrometers or smaller (ultrafine particulate matter or UFP, $PM_{0.1}$). Ultrafine particles are the most dangerous, due to their small size. They can easily pass through membranes of the lungs and enter the bloodstream damaging other organs (Belleudi et al, 2010). Particulate matter is the primary focus of this paper as it is among the most impactful forms of air pollution in Copenhagen. Table 1 summarizes the most common sources and major health impacts associated with these pollutants.

Table 1. Types, Sources, and Major Human Impacts of Air Pollution

Type of Air Pollution	Most Common Sources	Major Human Impacts
Black Carbon	Transportation (Diesel)	Respiratory, and Cardiovascular Disease, Cancer, Birth Defects, Death
Ultrafine Particles	Transportation	Respiratory, and Cardiovascular Disease, Cancer, Birth Defects, Death
Particulate Matter	Transportation, Power Plants, Industry, Households	Respiratory, and Cardiovascular Issues, Death
Ozone	Transportation, Industry, Power Plants	Respiratory Issues (airway Inflammation, reduction in lung function,) Death
Sulphur Dioxide	Power Plants, Industry	Respiratory Issues (many cases of asthma)
Nitrogen Dioxide	Transportation	Respiratory Issues (reduces capacity of lungs)
Ammonia	Agriculture, Mining Operations	Respiratory Issues (severe inflammation of airways)
Carbon Monoxide	Transportation, Power Plants, Industry	Unconsciousness, Death

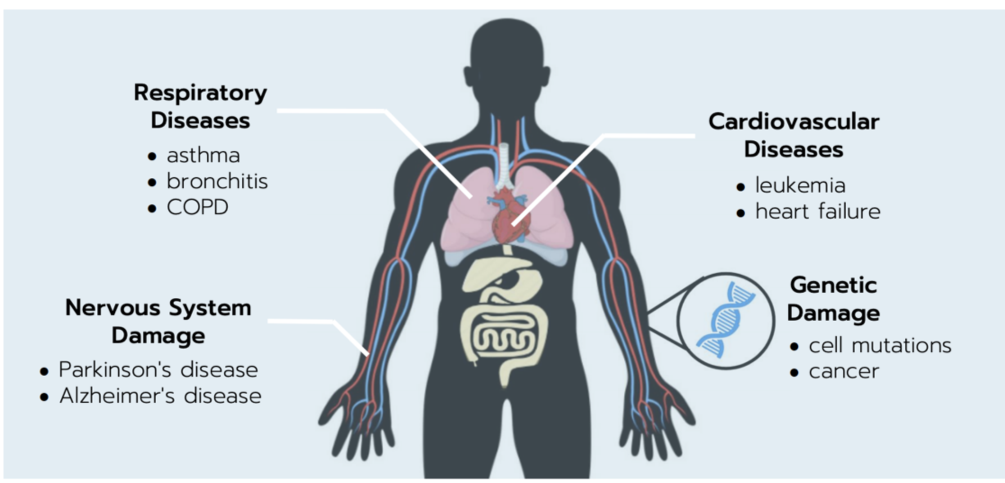
Source: The Danish Centre for Environment and Energy, 2013

2.2 Health Effects of Air Pollution

Air pollution has greatly affected human health since the Industrial Revolution. The World Health Organization classifies “air pollution, both ambient (outdoor) and household (indoor), [as] a public health emergency” (Isaifan, 2020). Exposure to air pollution can lead to stroke, heart disease, lung cancer, and other chronic respiratory diseases. In 2016, air pollution accounted for 7.6% of all deaths worldwide.

The respiratory system is at the greatest risk of damage by air pollution, regardless of the exposure level. Common pollutants include carbon monoxide, ozone, sulfur dioxide, nitrogen dioxide, and particulate matter. According to the World Health Organization (2017), when coming into contact with the lungs, carbon monoxide attaches to the blood, making it impossible for the rest of the body to receive oxygen. When the human body is in a state of exercising and exposed to increased levels of ozone, oxygen intake declines. Ambient ozone exposure causes higher occurrences of asthma, more frequent asthma attacks, short term respiratory inflammation, and chest pain. Exposure to sulfur dioxide causes the body to react similarly: irritation in the nose, throat, and airways. Furthermore, exposure to nitrogen dioxide causes a deficiency in lung function and can lead to the development of respiratory diseases such as Chronic Obstructive Pulmonary Disease (COPD) — an obstruction of airflow from the lungs (Zhang, 2018). Finally, particulate matter also causes a range of health problems, some of which are detailed in Figure 1.

Figure 1: Health Effects of Particulate Pollution



Source: Victor et al., 2019

Air pollution also impacts the cardiovascular system as it is interconnected with the respiratory system. With decreased access to oxygen, the different organs of the body, especially the heart, begin to operate deficiently. Inflammation caused by air pollution affects the body’s ability to coagulate blood, which can obstruct blood vessels (Kampa & Castanas, 2008). These obstructions can lead to dangerous and potentially fatal heart conditions. Air pollution can also cause coronary artery disease and is associated with hospital admissions for arrhythmia (Link & Dockery, 2010).

The World Health Organization has created safety guidelines concerning particulate matter and fine particulate matter exposure. The guidelines are based on two statistics: the annual mean and the 24-hour mean. The annual mean represents the average level of year-long exposure to particulate matter and the 24-hour mean represents the average short term exposure for a given 24 hour period (Table 2).

Table 2. WHO guidelines on safe levels of particulate matter

Pollutant Type	Annual Mean Guideline	24-Hour Mean Guideline
Fine Particulate Matter (PM2.5)	10 µg/m3	25 µg/m3
Coarse Particulate Matter (PM10)	20 µg/m3	50 µg/m3

Source: WHO Report for ambient outdoor air pollution, 2018

Ultrafine particulate matter concentrations are measured by the number of particles per cubic centimeter (pt/cc) and are generally measured on the scale of thousands of pt/cc. Unlike the other types of particulate matter, there are no established limits for healthy levels of ultrafine particles.

Health Effects of Air Pollution on Children

Air pollution tends to have more severe health impacts on children. Higher levels of air pollution lead to higher mortality rates and life-long conditions among children. A mother exposed to air pollution during pregnancy may deliver a child susceptible to growth retardation, low birth weight, preterm birth and increased perinatal morbidity (Salvi, 2007). Children are highly susceptible to the harmful effects of air pollution, as the lining within the lungs is more permeable at a young age. This leads to an increased risk for pulmonary growth defects.

Air pollution can also have adverse effects on mental development and on behavioral functions of the very young. These include a reduced IQ, a decrease in memory and academic performance, a higher prevalence of Attention Deficit Hyperactivity Disorder (De Prado Bert et al., 2018) and a higher risk for developing Autism Spectrum Disorder (Just et al., 2015). In trials, chronic exposure to pollution at a young age produced depression-like symptoms and permanently impaired memory and spatial learning (Fonken et al., 2011).

Children exposed to particulate matter develop more covert brain infarcts (areas of dead brain tissue) than those who are not exposed. There have also been traces of white matter depletion when in contact with higher concentrations of particulate matter, which has been linked to mental impairment, as previously mentioned (De Prado Bert et al., 2018). Furthermore, particulate matter is linked with shortened telomere length, which indicates premature aging and a higher risk of developing cancers (Zhao et al., 2018). Secondhand smoke also worsens the effects of particulate matter (Xu et al., 2020). It can linger in the air for several hours, even after the smoker has finished smoking, and increases one's risk of developing lung cancer or heart disease (National Cancer Institute, 2020).

2.3 Global Phenomena

Air pollution kills approximately 6-7 million people around the world annually (Pozzer, 2015). At least 4 million of those deaths result from ambient (outdoor) air pollution, while the rest are caused by inhaling dangerous chemicals indoors; often while cooking or heating a home (World Health Organization, 2018). This global problem causes permanent lung deficiency in children in California, kills hundreds of thousands of people in China yearly, and reduces the life expectancy in Europe by as much as two years (Gauderman et al., 2004). The problem is the worst in India where 1.8 million people died from air pollution related illnesses in 2015 alone (Suharsono et al., 2019). According to Suharsono et al., health-related costs resulting from air pollution account for 3% of India's GDP and unlike other countries, India's government heavily subsidizes the coal industry and doesn't enforce many environmental regulations. This lack of regulation allows coal plants in India to be the single largest producer of air pollution in the world. While India has been increasing subsidies for renewable energy, their actions are not enough to make a drastic change anytime soon. This is not just a problem in countries like India, as most large metropolitan areas around the world also produce unhealthy amounts of air pollution.

Global Actions Taken to Combat Air Pollution

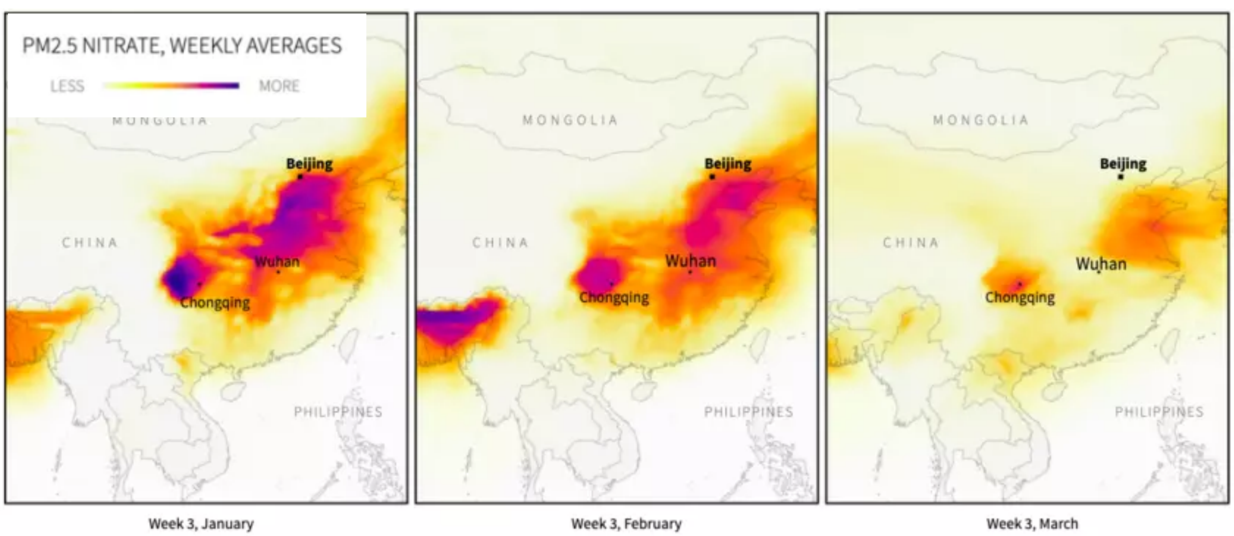
In the late 20th century, environmental issues became mainstream within the scientific community. As a result, many international entities began making attempts to diminish the air pollution problem. One of the premier initiatives created to combat air pollution is Agenda 21, which was established in 1992 by the United Nations to foster global sustainable development (United Nations, 1992). By shifting the focus towards more sustainable efforts, the UN hopes to foster better access to basic needs and improve the quality of life globally.

In addition to Agenda 21, the European Union (EU) has set forth goals to eliminate different forms of air pollutants. The EU Commission, an independent branch of the European Union, collaborates with EU member states to create European air quality regulations. Member states must then agree to abide by these limits by the specified dates. One of the more ambitious goals is for every EU member to be carbon-neutral by the calendar year 2050 (European Council, 2020). Copenhagen has taken this one step further and plans to be carbon-neutral by 2025. This will require a drastic reduction in the use of fossil fuels and a shift towards renewable resources within transportation, construction, and energy creation. If they are successful, Copenhagen would be the first capital in the world to do this (Nikel, 2019).

Meeting these goals is not impossible. When communities take radical action air pollution levels can decrease rapidly. One example of this is Beijing's attempts to improve air quality leading up to the 2008 Olympics. The Chinese Government wanted to clean up the air within a timespan of several months. To this day it is the largest directed effort to reduce air pollution in recorded history. The government halved the number of cars permitted on the road on any given day, banned high pollution vehicles, halted construction, and shut down 100 factories and 56 power plants (Stewart, 2008). As a result of their efforts, fine particle air pollution decreased by an estimated 31%, and medium to large size particle pollution by 42% (Simonich et al., 2009). While the results were promising, soon after the Olympics, China rescinded all of their new policies and the air quality returned to its previous unhealthy levels. By some estimates, if China complied with the least strict WHO air regulations, it would save 200,000 lives a year in China alone (Ma et al., 2013). This case study provides an example of the widespread impact of air pollution and the impact of drastic intervention on public health.

The global shutdowns imposed by the Coronavirus (COVID-19) pandemic provide another example of how drastically our air quality can change. National Aeronautics and Space Administration (NASA) satellites reported a sharp drop of pollutants in major metropolitan areas as a result of lockdown restrictions. Figure 2 shows levels of $PM_{2.5}$ in China from January to March 2020. China saw major changes in air quality, noticeably around Wuhan. The time period captured by the satellites coincides with a total lockdown of the city that started the 3rd week of January (Gan, 2020). The lockdown lasted until April 8th (Campbell, 2020), and the affected area largely cleared up within those two months. Although entirely shutting down all business and travel is an unsustainable environmental policy, the lockdown illustrates that controlling the environmental impact of commerce and transportation is possible.

Figure 2. $PM_{2.5}$ Nitrate, weekly averages in China



Source: Reuters Graphics, 2020

2.4 Policies and Solutions

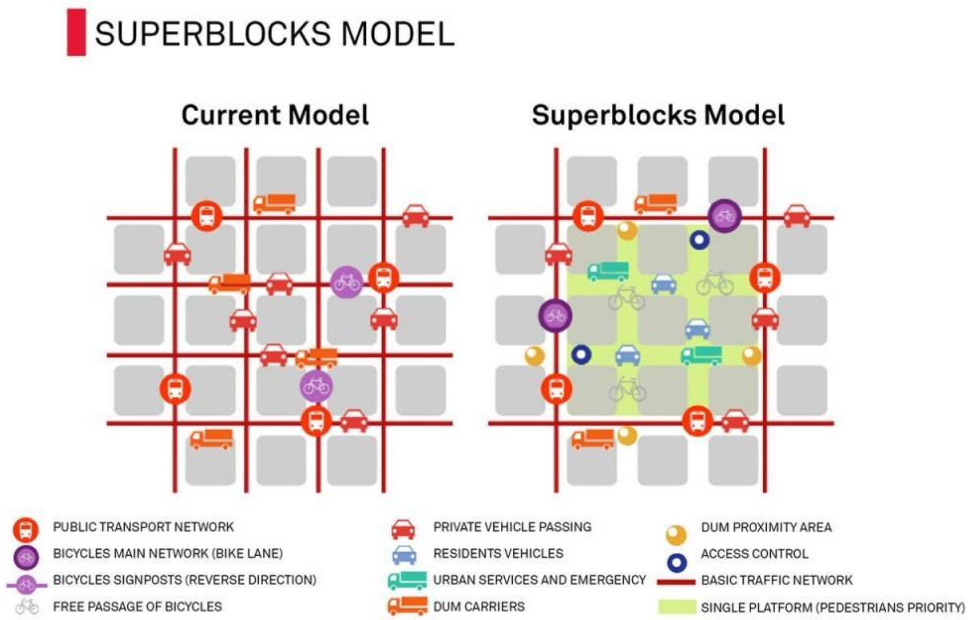
Many cities and regions worldwide have enacted their own solutions to reduce air pollution concentrations. One popular solution is to implement Low Emission Zones (LEZs), which are areas where regulations impose limits on what vehicles may travel through them. Typically, only vehicles with relatively low emissions may travel in a LEZ. According to a 2013 study of a LEZ currently in place in Munich, Germany, particulate matter pollution resulting from traffic-related sources decreased by approximately 60% after the LEZ was implemented (Qadir et al., 2013).

Governments have also experimented with other forms of traffic regulations aimed at reducing motor vehicle emissions. For instance, Titos et al. (2015) compared two different approaches aimed at improving public transportation systems and evaluated their impact on the air quality. In Ljubljana, Slovenia, the city experimented with restricting a major street to just public transportation, while in Granada, Spain, they reduced bus schedule overlap and introduced new emission-efficient buses. Both solutions resulted in significant reductions in concentrations of particulate matter in the immediate area, most notably in black carbon. In Slovenia there was a 72% reduction in black carbon concentrations while in Spain there was a more than 30% reduction in both black carbon and PM_{10} concentrations. A few other cities, such as London and Stockholm, have implemented congestion charges or "road pricing" in an effort to reduce traffic in certain areas (Press-Kristensen, 2014). However, road pricing can be expensive and challenging to implement. Additionally, Press-Kristensen points out that these extra taxes would mostly affect passenger vehicles, as businesses can often pass those charges on to their customers.

Another form of air pollution reduction policy are no-idling laws. Idling is a known source of air pollution that occurs when vehicles are stationary with their engines running for an extended period of time. These laws seek to limit how long cars can be left running while stationary. Electric vehicles can also help reduce emissions from idling. In 2020, Denmark implemented new legislation which could make purchasing new hybrid or fully electric vehicles more affordable (Balzhäuser, 2020).

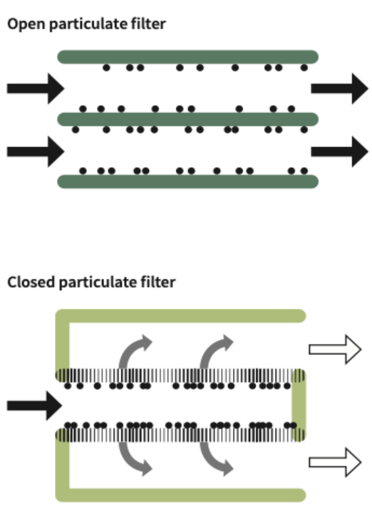
In Barcelona, politicians are experimenting with the superblocks model as a long-term solution for air pollution (see Figure 3). Superblocks are reimagined city blocks with reduced traffic access and greater access to green spaces (Barcelona Architecture Walks, 2016). They encourage active forms of transportation, such as biking or walking, and limit private vehicle traffic to residents alone (Mueller et al., 2020). The blocks have separate bus lanes to allow for faster public transport options and the speed limit is set at around 20 km/h (about 12.5 mph). Mueller et al. (2020) estimates that the implementation of these superblocks in Barcelona could prevent 667 premature deaths annually, increase life expectancies by almost 200 days, and save the city 1.7 billion Euros.

Figure 3. Superblock model in Barcelona, Spain



Source: Barcelona Architecture Walks and Tours, 2020

Figure 4. Open particle filter vs closed particle filter



Source: Press-Kristensen 2014

Technical solutions also exist which can help reduce harmful emissions. Filters, for instance, can be applied to a wide range of polluting machinery to limit their emissions. Closed particulate filters installed along the exhaust line of road vehicles can remove upwards of 99% of the pollution particles (Press-Kristensen, 2014). Cheaper open filters are also available; however, they typically only remove up to 30% of the larger particles and their effectiveness with ultrafine particles is not well known (see Figure 4). Press-Kristensen also discusses Selective Catalytic Reduction systems or SCRs, which are designed to remove more than 80% of the nitrogen oxides found in exhaust. These systems, typically meant for diesel trucks, use ammonia to convert nitrogen oxides into nitrogen gas and water, which are both harmless when released. These solutions have an overall positive impact on the air quality, and therefore, reduce harmful exposure to children.

While the benefits of closed filtration units are enormous, the cost is often the largest barrier to their installation. When it comes to consumer vehicles, installing a closed particle filter costs twice as much as an open one (Press-Kristensen, 2014). Unfortunately, this means that most people would opt for the latter, even though closed particle filters are 3-5 times more efficient. SCRs face a similar reality. Newer combined SCR and filter solutions typically cost around 16.650 euro (just over $18,000 USD) and last for roughly 5 years. This is one of the primary reasons many vehicle owners have not chosen to install them.

Filters can be applied to more than just vehicles. Filtration units have also been applied to factory equipment and even wood stoves. In a recent study from the US, researchers analyzed indoor $PM_{2.5}$ concentrations after installing filtration units in wood stoves and compared the results to a control group (Ward et al., 2015). The researchers discovered that homes that utilized the filters saw $PM_{2.5}$ concentrations reduced by more than 50%. The same study also evaluated whether the replacement of old, inefficient wood stoves with newer models would make an impact but concluded that it was not significant enough.

Another long-term solution that helps reduce air pollution is to plant more trees. Studies in the United States have estimated that trees have removed 711,000 metric tons of air pollution per year in 55 cities across the country (Nowak, 2006). Trees improve air quality through photosynthesis as they remove carbon dioxide from the air. They also pick up particulate matter which often gets deposited onto leaves and branches; some of which even gets absorbed by the plant. A similar study conducted in Canada demonstrated how green roofs and walls can have a positive impact on the air quality (Currie & Bass, 2008) and found that shrubbery was nearly as effective as trees in the removal of PM_{10} from the atmosphere.

Eliminating the burning of fossil fuels remains one of the most effective ways to reduce air pollution in the long term. To do this, companies are increasingly working on renewable energy solutions such as solar panels, wind farms, and nuclear energy. Furthermore, green vehicles such as electric cars, buses, and trains are gaining popularity. This will have an enormous impact on air pollution levels, although many of these solutions do come at a cost and will take time to implement.

2.5 Air Pollution in Copenhagen

Air pollution is one of the foremost health concerns in Copenhagen. In 2013, the city experienced an estimated 800-1,100 premature deaths as a result of fine particle and ultrafine particle pollution (Press-Kristensen, 2014) (see Table 3 for distribution and sources). On average, these premature deaths shorten the affected Danes' lifespan by 10 years.

Table 3. Causes of Premature Death in Copenhagen

	Deaths
Fine particulate matter	500-600
(Fine particulate matter from within the city)	65-70
Ultrafine particulate matter (soot)	300-500
All particulate matter	800-1100

Source: The National Institute for Public Health and the Danish Centre for Environment and Energy, 2013

According to Press-Kristensen (2014), 80-90% of the deaths caused by fine particle pollution in Copenhagen result from particulate matter that originates from outside the city or even the country. Fine particulate matter can remain in the atmosphere for 7-10 days, assuming there is no rain event, and can travel for 1000s of kilometers (O. Hertel, personal communication, October 1, 2020). Air pollution produced within Copenhagen is responsible for the remaining 10-20% of deaths. Press-Kristensen states that "300-500 deaths among residents alongside roads with heavy traffic in the city is [...] believed to be associated with ultrafine soot particles from local traffic exhaust." Table 4 outlines common sources of these pollutants in Copenhagen.

Table 4. Sources of Pollution in Copenhagen (2013)

	PM10	PM2.5	NO2
Power plants	0.2	0.2	8.3
Residential wood burning	4.6	6.7	1.5
Road transport	2.3	2.6	25.8
Train transport	0.1	0.1	1.2
Construction equipment	0.2	0.3	2.2
Shipping traffic in Oresund	0.1	0.1	3.6
Other sources	92.5	90.0	57.4
Total	100	100	00

Source: The Danish Centre for Environment and Energy, 2013.

While levels of ultrafine particles in Copenhagen are not as high as in other European cities (see Table 5), they are still responsible for the deaths of hundreds of Danes each year (European Environmental Agency, 2019). The World Health Organization acknowledges ultrafine particles as dangerous carcinogens. However, Denmark and the European Union (EU) have yet to pass any regulations on this specific type of air pollution. The EU Air Quality Directive is a set of guidelines, much like the WHO guidelines in section 2.2, which regulates healthy levels of air pollution exposure, however the EU limit is much less strict. While Denmark is currently under the EU Air Quality Directive limit for fine particle pollution, this limit is not stringent enough to adequately protect Europeans from premature pollution-related deaths. For example, the maximum average yearly mean for the EU is 25 $\mu g/m^3$ of fine particulate matter, while the corresponding WHO maximum is 10 $\mu g/m^3$ (Environment Directorate General of the European Commission, 2019). Despite lax EU limits, Denmark still has some of the lowest levels of air pollution in the European Union (Table 5).

Table 5. Denmark and EU levels of $PM_{2.5}$, NO_2

	Annual Mean (PM2.5) µg/m3	Annual Mean (NO2) µg/m3
Denmark	9.2	10.4
EU-28	12.93	10.42
EEA-33	14.42	16.28
WHO Guidelines	10	40

Source: Adapted from European Environmental Agency, 2019 and World Health Organization, 2018

Denmark showcases lower than average levels of fine particle pollution across all 28 EU member states (EU-28) and much lower levels when including the 5 related countries that are not full members (EEA-33). However, while Danish levels of NO_2 are in line with the EU-28 average, they are significantly lower than the EEA-33 average. EU regulation limits NO_2 exposure to a yearly average of 40 $\mu g/m^3$ and Denmark was in violation of this limit from 2010 to 2017 (Press-Kristensen, 2014). Denmark has since met the yearly limit, but again, the EU limit may not be stringent enough to protect at-risk populations from NO_2 - most notably the elderly and children.

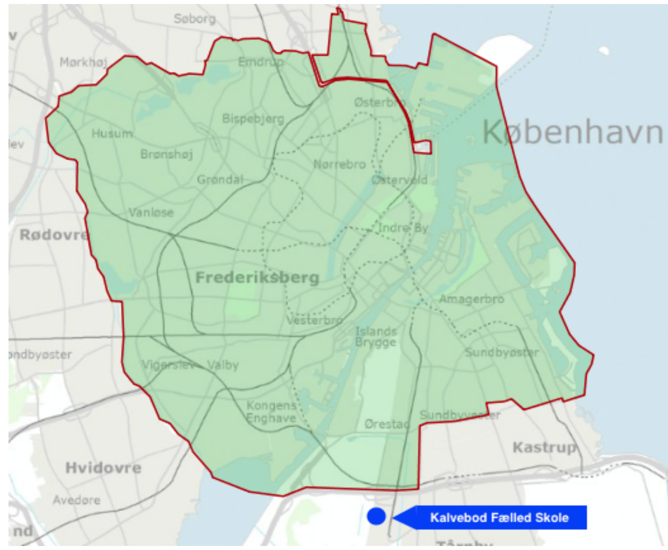
Local Organizations and Movements

Non-Governmental Organizations (NGOs) and other community organizations play a valuable role in clean air initiatives. For instance, Amager Vest Lokaludvalg (Amager West Local Committee) is a local community group which supports community projects and serves as a liaison between the local community and the city government (Amager Vest Lokaludvalg, 2020). Furthermore, the Copenhagen city government has established the Copenhagen Solutions Lab, which works with industry partners and local organizations to support urban development efforts (Copenhagen Solutions Lab, 2020). The Copenhagen Solutions Lab recently partnered with Google to collect air quality data using a fleet of cars equipped with air quality sensors. Another organization working closely with our sponsor is Gehl Architects, a Copenhagen-based, world-renowned nonprofit, that helps local municipalities create eco-friendly infrastructure. For a brief overview of one of Gehl's more recent projects concerning better air quality for young children, see Appendix I. Through these organizations, Copenhagen's leaders are working towards a greener future.

One of the most noteworthy green movements in Copenhagen emphasizes pollution free transport in the form of cycling. Around 75% of people living in Copenhagen (and roughly 60% of school children) use a bicycle as their primary method of transport, which largely decreases the number of polluting vehicles on the road (Press-Kristensen, 2014). Local Copenhagen organization Cyklistforbundet organizes a yearly campaign called Alle Børn Cykler (ABC) with over 100,000 students to encourage cycling to school. Studies show that most Danish children are not getting the daily exercise recommended by the World Health Organization (Cyklistforbundet, 2020). Additionally, a Copenhagen study found that commuting by bike actually results in lower exposure to air pollutants than commuting by car as biking improves respiratory strength and resistance to air-pollution related ailments (Rank, 2001). Another study conducted in Canada found that typical drop-off procedures, where vehicles line up one after another to approach a single drop-off location, led to significantly higher concentrations of dangerous air pollutants in the area around the drop-off zone (Adams, 2017). If more students and teachers biked to school instead of driving, these dangerous pollution hot spots would likely vanish.

A few other green initiatives in Copenhagen include the introduction of low-emission zones and requirements for closed-filter vehicles. In 2006, the Danish Parliament passed an act to introduce low emission zones in the four largest cities in Denmark, including Copenhagen (Danish Environmental Protection Agency, 2020). The policy asked owners of diesel-powered lorries, buses and vans to install a particle filter before entering the low emission zones. In 2011, researchers found that exhaust-particle emissions were reduced by 60% and NOx (nitrogen oxide compounds) by 25% (European Commission, 2012). Unfortunately, the LEZ does not encompass the entire city and its regulations are not strictly enforced. The Kalvebod Fælled Skole, for instance, is located just south of the LEZ.

Figure 5. Low Emission Zone in Copenhagen



Source: Miljøzoner, 2020

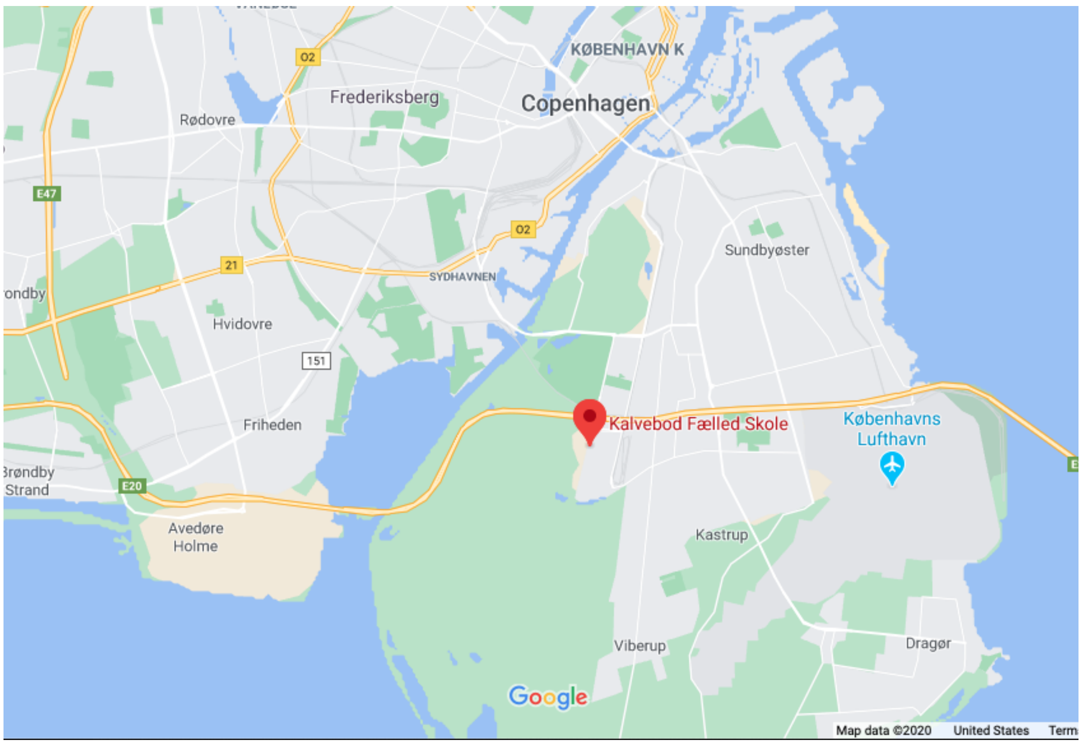
Fortunately, in terms of the limited enforcement, some progress has been made. After July 1, 2020, the government set up cameras to read license plates and starting October 1, owners will receive a fine for driving unqualified cars in low emission zones (Miljøzoner, 2020).

Copenhagen is a C40 city, meaning it has joined an international network of cities working towards addressing climate change. Specifically, “mayors of the C40 cities are committed to delivering on the most ambitious goals of the Paris Agreement at the local level, as well as to cleaning the air we breathe” (C40 Group, 2020). Copenhagen consistently stands out among the greenest cities in the world and was awarded C40’s “Adaption In Action” award in 2016. As a result of Copenhagen’s green initiatives, the city has the second-best air quality among major European cities (Anderson, 2015).

2.6 Our Purpose

Along with our partners, we measured air pollution around the Kalvebod Fælled Skole in Amager and evaluated potential methods of reducing that pollution. Our research focuses primarily on first grade students attending the Kalvebod Fælled Skole in Ørestad - part of Amager Vest (Figure 6). The school opened in the spring of 2018 and currently provides instruction for around 450 students (Kalvebod Fælled Skole, 2020). Students in Grades 0 - 9 attend classes at the school during the day, while in the evenings the school serves as a community center. The Kalvebod Fælled Skole places a major focus on living an active lifestyle through sports and other activities.

Figure 6. Location of the Kalvebod Fælled Skole in Copenhagen



Source: Google Maps, 2020

The location of the Kalvebod Fælled Skole is unique in that it exists on the edge between nature and Copenhagen's expanding urban environment. The school borders an area of reclaimed seabed and marshlands called the Kalvebod Fælled (Naturstyrelsen, 2020). The area is largely undeveloped and features wide open spaces and an abundance of wildlife. On the other hand, the school is also situated within a rapidly developing residential area with a lot of ongoing construction. Furthermore, it is located only 0.4 km from the high-traffic E20 highway (the highway that crosses over the Øresund Bridge) and about 3.7 km from Copenhagen Airport.

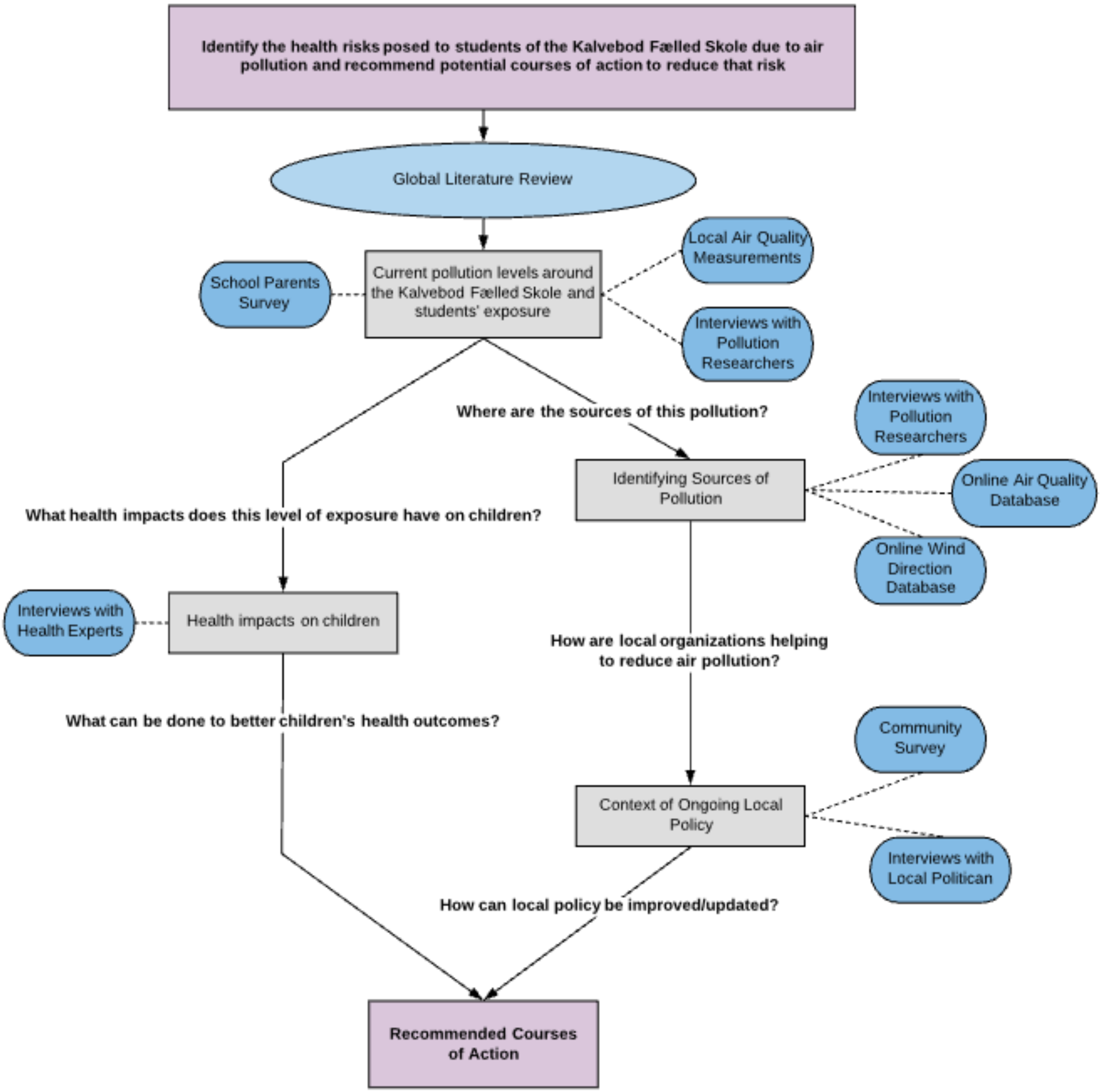
3 Methodology

The goal of our project was to identify the health risks posed to children in Amager as a result of air pollution and recommend potential courses of action to reduce that risk. To achieve this goal, we defined the following objectives:

- Measure children's exposure and air pollution levels around the Kalvebod Fælled Skole in Amager
- Identify relevant sources of air pollution around the Kalvebod Fælled Skole
- Evaluate current policies and practices taken to reduce air pollution in Copenhagen
- Research the human health impacts of air pollution in Amager, focusing primarily on first grade students attending the Kalvebod Fælled Skole

By addressing these objectives through archival research, data collection, data analysis, and interviews with experts, we gained an understanding of the technical, social, and political aspects of the issue. From there, we were better equipped to develop a more comprehensive set of recommendations for further action. Our process for completing these objectives can be seen in Figure 7.

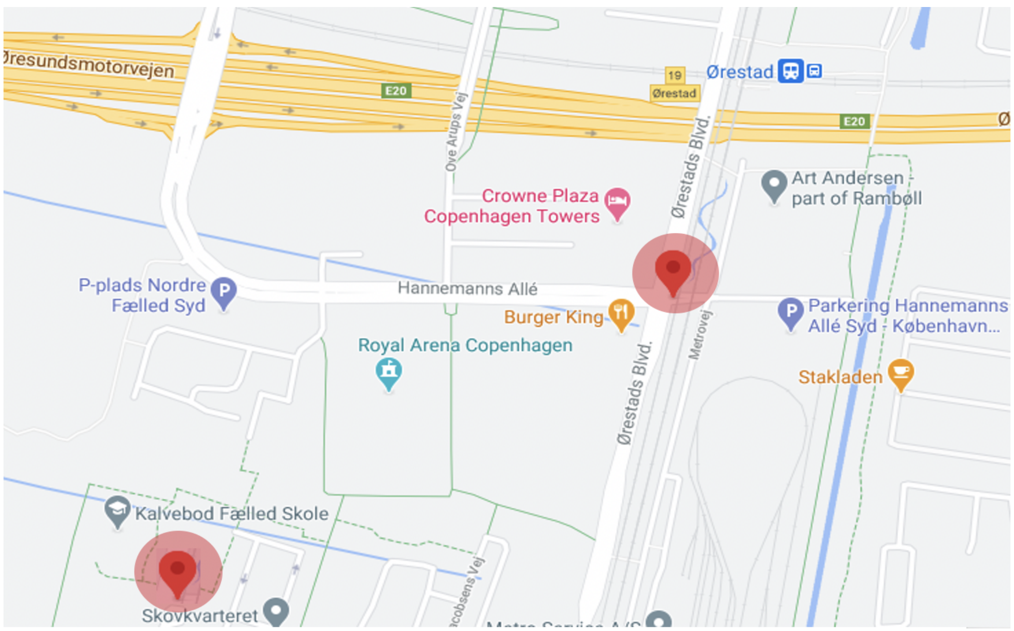
Figure 7. Methodology Flowchart



3.1 Air Pollution in Amager

To ascertain the levels of air pollution throughout Amager, we integrated air pollution measurements from various sources. We interviewed Dr. Matthew Adams, an air pollution researcher at the University of Toronto, to learn about the best way to gather air quality data. A full list of questions can be seen in Appendix D. We also utilized data from a P-Trak device (model 8525), to collect information on ultrafine particle pollution levels close to the school. A volunteer took readings in the early morning of September 24 near the school's drop-off area and at the intersection of Hannemanns Alle and Ørestads Boulevard (shown in red in Figure 8). Examining this data allowed us to identify when and where ultrafine particulate matter concentrations were higher.

Figure 8. Locations for P-Trak data collection



Source: Google Maps, 2020

To complement the quantitative datasets, we observed how students commute to school and how personal vehicles idling in front of the school may impact the air quality. Furthermore, we surveyed 13 parents of first grade students at the Kalvebod Fælled Skole and asked them about their child's commuting habits and their reasoning behind the chosen method of transportation (see Appendix A). We also surveyed 94 residents of Amager through Miljøpunkt Amager's monthly newsletter to understand their commuting habits and overall air quality concerns (see Appendix B). This information helped us better understand the air quality concerns of the local population and determine which sources of air pollution were considered the most critical.

3.2 Sources of Pollution in Amager

To better understand where most of the air pollution comes from in Ørestad, we analyzed a number of possible sources. We investigated the dangers associated with airports, vehicle traffic, construction sites, and wood burning by interviewing air quality experts and discussing their impact with local community leaders. We also collected air quality data for the last 6 years from a sensor located on H.C. Andersens Boulevard. To complement this data, we accessed aggregate wind speed and direction data from the same time frame to determine if pollution could travel from the airport. We identified the major sources of air pollution in Ørestad and examined current practices and policies based on those sources. We focused primarily on the current policies, or lack thereof, that address the most significant sources of air pollution.

3.3 Current Practices and Policies

To make comprehensive recommendations that focus on reducing emissions, we first explored what initiatives were already in place or in development in Copenhagen. We interviewed local community organization leaders who work to reduce air pollution and surveyed local community members about their habits and awareness of ongoing green initiatives. In our interview with Nick Vikander, a local representative from the Amager Vest Lokaludvalg, we focused on the council's outreach activities and interactions with the government. A full list of questions can be found in Appendix G. We also spoke with Dr. Kåre Press-Kristensen from the Danish Ecocouncil and Rasmus Reeh from the Copenhagen Solutions Lab about the policies already in place in Copenhagen - namely Low Emissions Zones and vehicle filter requirements. A full list of questions from those interviews can be found in Appendix E and Appendix F, respectively. To investigate the health impacts of air pollution, we interviewed Dr. Ole Hertel, an air pollution health expert at Aarhus university. The interview provided insight into the severity of health-related problems posed to children and what causes them. A full list of questions from Dr. Hertel's interview can be found in Appendix C.

3.4 Limitations

The team's largest limitation was a result of the ongoing Coronavirus pandemic. We were not able to travel to Copenhagen, so we adjusted our aforementioned methods to work remotely. Surveys were sent digitally, and interviews were conducted through online video calls. Data collection was conducted by local volunteers, when possible. The pandemic has also delayed the public release of Google's Air Quality Data for Copenhagen, which meant we only had access to their preliminary findings.

4 Analysis and Findings

We derived our findings from an analysis of the data sources described in our methodology. We have compressed our findings down to six key claims:

- While the community of Amager is generally aware of their air quality, they are not aware of the numerous initiatives aimed at improving it.
- Parents are generally concerned about their child's safety when biking to school, however most value convenience above all else when selecting a form of transportation.
- Wood stoves contribute more to air pollution in Copenhagen than motor vehicles do.
- Motor vehicle traffic has a minor temporary impact on ultrafine particle concentrations.
- The nearby Copenhagen airport likely contributes to the air pollution in the Kalvebod Fælled Skole area.
- Nearby construction could have an impact on the air quality once operations resume.

4.1 Amager Community Awareness & Priorities

Miljøpunkt Amager included one of our surveys in the September issue of their monthly newsletter and received 94 responses. The other survey went out to parents of first graders at the Kalvebod Fælled Skole and received 13 responses. By analyzing survey data from Miljøpunkt Amager's newsletter, we found that most residents of Amager are generally concerned about their local air quality, with 61% of individuals considering their air quality daily or weekly. Despite this, 86% of people were unable to name any ongoing community programs aimed at improving the air quality in Copenhagen. While unaware of green initiatives, most participants reported primarily using a green method of transport, with 80% of individuals walking or biking to work. The most common priority in choosing a commuting method was convenience, followed by environmental concerns.

From the survey of Kalvebod Fælled Skole parents, we saw a similar trend to that of the community survey. While fewer respondents think about their air quality when considering transportation methods for their children, 78% of parents reported that their children already walk or bike to school. The most common priorities were convenience and safety.

Figure 9. Students participating in the Alle Børn Cykler program at the Kalvebod Fælled Skole

Some respondents indicated they would be more willing to let their children bike to school if the bike paths were safer and crossed fewer intersections. The Amager Vest Lokaludvalg and Cyklistforbundet are already working towards creating a safer biking environment by encouraging more people to bike. This is the first year that students at the Kalvebod Fælled Skole have participated in Cyklistforbundet's Alle Børn Cykler program (Figure 9) and it appears to have already had a positive impact. While it is still too early to tell how effective the program will ultimately be, Nick Vikander remarks that he has received a lot of positive praise from parents. According to Dr. Kåre Press-Kristensen, these types of programs will bring a compounding effect. As more people bike everywhere, the community will perceive it to be safer. This phenomenon is known as the *Network Effect*.

4.2 Wood Stoves & Wood Burning

Dr. Kåre Press-Kristensen cited wood stoves as the most prominent source of air pollution in Copenhagen. There are roughly 15,000 wood stoves in Copenhagen, 2,700 of which are in Amager (D. Grastrup-Hansen, personal communication, 2020). Each year wood stoves in Copenhagen contribute twice as much pollution as all the motor vehicles in Copenhagen combined, despite only being in use for around 4 months a year. A reduction in wood stove usage by half would therefore result in a reduction in pollution equivalent to banning all motor vehicles in the city.

A ban on wood stove usage is unlikely to be introduced anytime soon, according to Press-Kristensen, as Danish politicians are hesitant to introduce laws intruding into the home. While the mayor of Copenhagen is in favor of a ban, legislation is required at the national level, according to Nick Vikander. Fortunately, some progress has been made in recent years. Denmark has offered programs in the past which provide a grant to citizens who upgrade or remove their older wood stoves and recently imposed stricter emissions standards on the installation of new ones. However, the Danish Environmental Protection Agency estimates that this new legislation will only reduce pollution by about 2% since it will only limit the re-sale of older stoves (Press-Kristensen, 2016). Wood stoves have a long lifetime and can last for more than 30 years so greater action is needed to make an impact anytime soon.

4.3 Health Impacts

According to Ole Hertel, individuals exposed to higher levels of air pollution are at a greater risk of contracting and dying from the novel Coronavirus (COVID-19). A recent preprint Harvard study suggests that an increase of just $1 \mu g/m^3$ in $PM_{2.5}$ corresponded with an 8% increase in the COVID-19 death rate (Wu et al., 2020). This may explain why so-called fringe communities, located closer to industrial areas and featuring lower income housing, have a greater number of COVID-19 cases.

Hertel also claimed that the effects of air pollution go well beyond the respiratory system. Air pollution can increase one's risk of developing lung or colon cancers as well as diabetes. Furthermore, while scientists are already aware that air pollution can make asthma worse, recent studies suggest that air pollution exposure may actually play a role in its development as well. Additionally, Hay Fever, a mild form of asthma, has become more common. In Denmark, just over 20% of the population is now affected.

Hertel suggests that the health impacts associated with air pollution may have more to do with the actual substances themselves rather than their size. For example, the same amount of $PM_{2.5}$ from a wood stove may have a different effect on the human body than $PM_{2.5}$ from motor vehicles.

4.4 Status of Air Quality Regulation and Policies

Dr. Kåre Press-Kristensen noted that it is unlikely the Air Quality Commission will introduce new legislation. If the commission opens the current reforms, member countries may veto any new proposed regulations, and may instead vote to lessen existing regulations. For Danish politicians to pass national regulations, it is often necessary to sue the state over specific infractions to EU limits. Although Denmark consistently reaches only half of the EU limit value for $PM_{2.5}$, an estimated 15% of Denmark's annual deaths can still be attributed to air pollution (European Environment Agency, 2019). This suggests that stricter national regulations would save lives, however there is currently no movement to develop any.

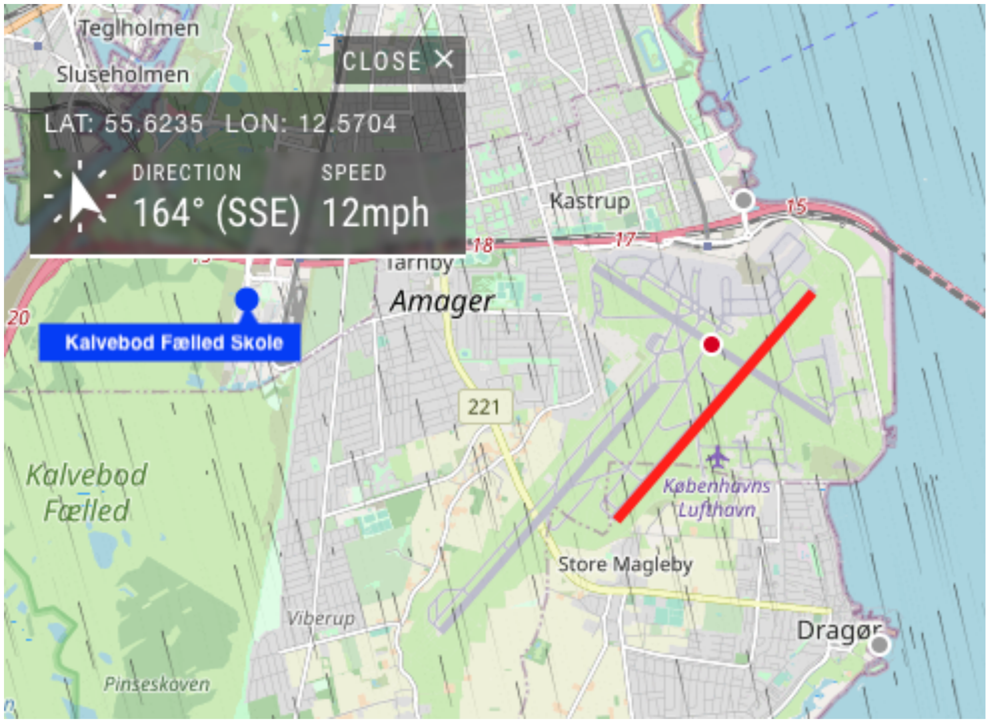
One prominent local policy is the Copenhagen Low Emission Zone (LEZ). While in 2011, it reduced exhaust-particle emissions by 60% and Nitrogen Oxide compounds by 25%, the Copenhagen LEZ has been less successful than implementations in other European cities. Rasmus Reeh also indicated that these zones are not consistently enforced. For this reason, Copenhagen instituted a license plate scanning program in 2020 to automatically detect infractions. Ole Hertel added that political factors have lessened the impacts of the LEZ, and Nick Vikander mentioned that some traffic regulations, such as changing speed limits, rely on approval from unwilling police departments. Furthermore, the LEZ only requires open particle filters, which are significantly less effective than closed filters. These issues might be particularly difficult to change, as the LEZ regulation is dictated at the national level.

Copenhagen's plan to be carbon-neutral by 2030 will include the electrification of all of their public transportation. Copenhagen recently received five electric ferries which the manufacturer claims will "make significant strides towards a zero emission service, reducing Copenhagen's public transport NO_X emissions by 2.5%, CO_2 emissions by 10% and particulate emissions by 66%" (Danigelis, 2020). According to Rasmus Reeh, buses are also being converted and the city aims to have their entire fleet become fully electric within the next decade.

4.5 Airport-Related Findings

The Kalvebod Fælled Skole may receive pollutants from the Copenhagen Airport. Air pollution from airports is primarily a result of take-off and landing activities, with pollution mostly traveling downwind. Hudda et al (2014) suggests that ultrafine particulate matter concentrations more than double 16 kilometers downwind of the runway. The same study found that concentrations increased nearly 10-fold within about 3.2 kilometers. In Amager, when wind comes from the southeast, it could potentially carry ultrafine particles over the school. While the school is not located directly underneath any approach paths, it is only about 4 kilometers from the nearest runway (Figure 10). Though the prevailing winds generally blow in the opposite direction (southwest), our observations show that the winds change direction frequently throughout the day.

Figure 10. Wind conditions in Amager on September 24, 2020

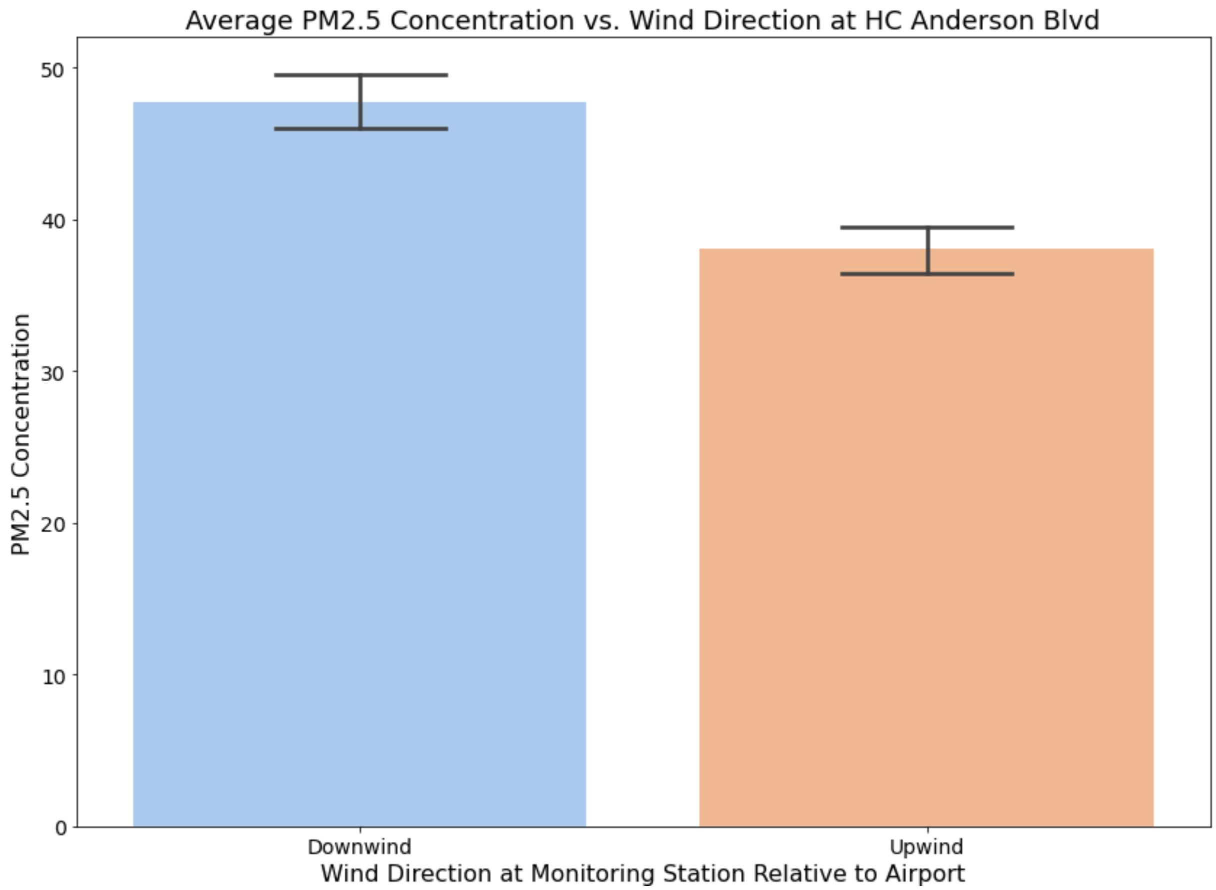


Source: Windfinder.com, 2020

Using data from the monitoring station on HC Andersen Boulevard, along with historical wind data provided by worldweatheronline.com, we determined that pollutants from Copenhagen Airport could reach the Kalvebod Fælled Skole. This dataset contained average levels of $PM_{2.5}$ and wind direction since 2014, measured from a monitoring station 6.5 km northwest of the airport. We first aggregated the data by wind direction at the monitoring station, relative to the airport, and classified it as either downwind (Southeast) or upwind (Northwest). We then compared average $PM_{2.5}$ concentration levels for each of these wind direction groups, shown in Figure 11. Using a linear regression model with wind direction as a predictor of $PM_{2.5}$, we obtained coefficient confidence intervals and t-test scores for the pollution levels between the two groups.

We found that average $PM_{2.5}$ concentrations when downwind of the airport were 9.75 µg/m^3 higher than upwind pollution levels; a 20% increase. T-test scores from the linear regression model showed statistical significance of wind direction, with $p < 0.001$. Despite the significant effect of wind direction on pollution levels, the direct source of pollution is still unknown. Our hypothesis is that the wind carried pollution from the airport, but it may also come from other sources in the southeast, either within Copenhagen or from other countries.

Figure 11. Average Pollution by Wind Direction



Source: Generated using from aqicn.org and worldweatheronline.com

4.6 Pollution from Construction

Dr. Matthew Adams mentioned that dust would likely be the primary pollutant coming from construction zones. Most of the heavy machinery used in construction zones throughout Copenhagen run on diesel power and are required to have filters installed, reducing their impact significantly. Particulate matter from construction zones largely consists of dirt, sawdust, and other waste particles that would be classified as PM_{10} or larger; which is less harmful to human health than fine or ultrafine particles. Regardless, more research is required to understand the severity of construction zone pollution. It is also worth noting that at the time of this study, several nearby construction projects were inactive.

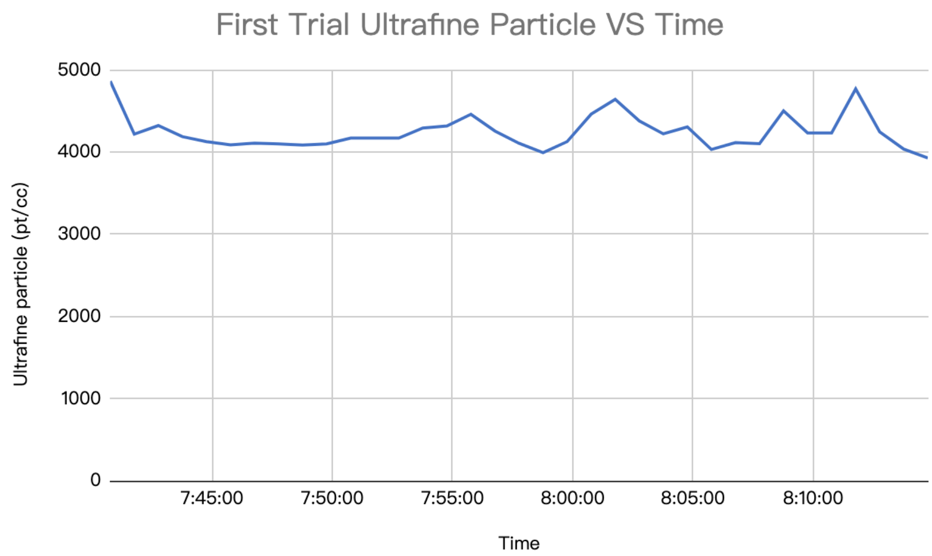
4.7 Impact of Student Drop-off at Kalvebod Fælled Skole

On September 24, Miljøpunkt Amager collected data both near the intersection of Hannemanns Alle and Ørestads Boulevard and at the drop-off zone at the Kalvebod Fælled Skole (Figure 12). For both locations, volunteers used a P-Trak device to get reliable data on the number of ultrafine particles in the air between 7:38 AM and 9:05 AM. The weather conditions were excellent as it was clear and dry all morning.

Figure 12. Vehicles at Kalvebod Fælled Skole Drop-Off on September 24, 2020

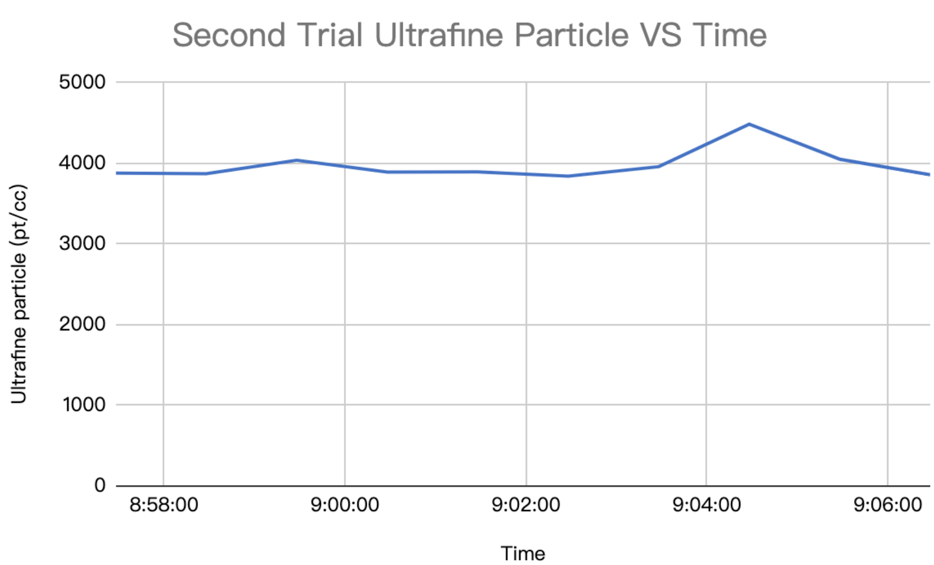
The first trial at the Kalvebod Fælled Skole measured ultrafine particle concentrations while parents dropped their children off at school. The range of ultrafine particle concentrations was mostly between 4000 particles per cubic centimeter (pt/cc) and 5000 pt/cc (Figure 13); averaging 4243 pt/cc. The ultrafine particle concentrations remained fairly consistent, although small spikes did occur. For instance, when a bus started its engine around 8:00 AM, the ultrafine particle concentration increased by 514 pt/cc. At the time there were also quite a few cars in the roundabout. Occasional gusts of wind also appear to coincide with some of the spikes. At 8:14 AM, there was a decrease in ultrafine particle concentrations to 3929 pt/cc as few cars remained in the roundabout. During this trial, there were no peaks observed when cars were idling or when the P-Track device was moved closer to the traffic. Thus, idling cars and the distance between the traffic and the P-Trak device do not appear to have obvious impacts on ultrafine particle concentrations.

Figure 13. First trial ultrafine particles vs time



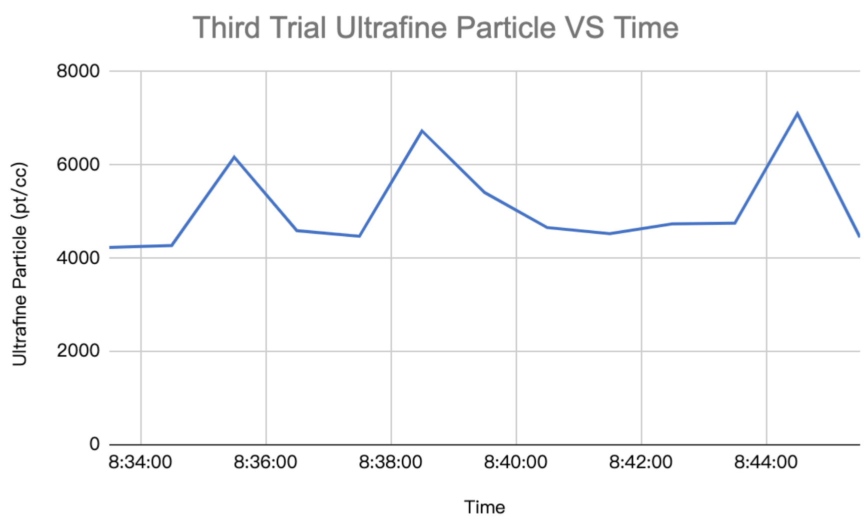
The second trial also occurred at the Kalvebod Fælled Skole to measure ultrafine particle concentrations in the air during the school day rather than during the drop-off period. At that time, far less traffic was on the road. The range of ultrafine particle concentrations was between 3900 pt/cc and 4500 pt/cc (Figure 14). The trend was mostly flat except for one increase around 9:04 AM. The average ultrafine particle concentration for the second trial was 3977 pt/cc. Compared to the first trial, the average ultrafine particle concentration was 266 pt/cc lower, suggesting that traffic may have an impact on ultrafine particle concentrations.

Figure 14. Second trial ultrafine particles vs time



Measurements for the third trial represent ultrafine particle concentrations at the intersection of Hannemanns Alle and Ørestads Boulevard. The range of ultrafine particle concentrations was between 4000 pt/cc and 6000 pt/cc; the average was 5085 pt/cc (Figure 15). There are three distinct peaks in the data. At 8:34 AM, the ultrafine particle concentration increased rapidly from 4273 pt/cc to 6166 pt/cc as a garbage truck passed by. We were not able to definitively determine the cause of the other two peaks. Based on the traffic conditions, we hypothesize that ultrafine particulate matter may have come from the nearby E20 highway, which is only about 165 meters (about 541 feet) away.

Figure 15. Third trial ultrafine particles vs time



When comparing these trials to the data collected through the Google Air Quality Project, we see that the ultrafine particle concentrations are generally lower now than the city-wide median nearly a year ago. Our third trial came the closest to the Google data with an average concentration of 5085 pt/cc, compared with the city-wide median of 7039 pt/cc in 2019. This is particularly interesting considering that ultrafine particulate matter concentrations in this area were generally higher than the city-wide median in 2019 (Figure 16). Construction, along with roadwork centered around the installation of new fiber cables may have increased the ultrafine particulate matter concentrations in Google's data. Furthermore, we hypothesize that the shutdowns imposed by the Coronavirus crisis, which significantly reduced motor vehicle traffic and construction activities, ultimately caused the low levels of ultrafine particulate matter we recorded.

Figure 16. Ultrafine particulate matter concentrations near the Kalvebod Fælled Skole

Source: Utrecht University and Google, 2019

With the three trials, we concluded that motor vehicle traffic does not appear to have a significant impact on ultrafine particle concentrations during student drop-off. When compared with data from Hannemanns Alle and Ørestads Boulevard, the spikes at the busy intersection were much more significant. Furthermore, these spikes did not last very long and often returned to previous levels within a few minutes. Idling and the location of the P-Trak device did not significantly affect the measurements either. However, considering the limitation that we only received data for a single morning, it is difficult to make any further conclusions with much certainty.

4.8 Limitations

Overall, one of the biggest limitations to our project was the lack of sufficient quantitative data. The Coronavirus pandemic delayed the official release of Google air quality data and prevented us from conducting our own measurements. New practices due to the pandemic, such as social distancing, have also altered normal behaviors. For instance, during school drop-off, families now arrive during scheduled time slots, rather than all at once. It is not yet known if this change has a significant impact on the air quality.

5 Conclusions and Recommendations

We have developed five recommendations based on our findings. There are several ways to further incentivize green travel and educate residents on the dangers of wood stoves, for instance. However, due to the limitations of our project further investigation is the primary focus of our recommendations. We have compressed our recommendations down to 5 key points:

1. Educate the community and youth of Amager through community outreach events
2. Consider extending the Low Emission Zone into Ørestad
3. Further investigate the impact of the Copenhagen Airport
4. Continue to evaluate the impact of motor vehicle traffic on school zones once the Coronavirus pandemic has concluded
5. Create an interactive clean air route map based on data from the Google Air Quality project and real time monitoring stations

5.1 Summary of Findings

Based on our investigation, we gained insight on public opinion in Amager and identified several potential sources of air pollution affecting the Kalvebod Fælled Skole. From the P-Trak data, we discovered that motor vehicle traffic does have a minor short-term impact on ultrafine particle concentrations, but we did not observe any significant changes in its impact during the drop-off period or from idling. Wood stoves are a significant contributor to pollution throughout Denmark and have already become a political issue at the federal level. Copenhagen Airport contributes notable levels of particle pollution, some of which is likely ending up near the school. Despite initiatives like Alle Børn Cykler, some families are still reluctant to let their children bike to school as they feel it is not safe enough. Traffic is a common source of air pollution in any metropolitan area, however Amager is already taking steps to reduce that as much as possible. The city could expand the borders of the Copenhagen low emission zone (LEZ) to include the school. Although currently the LEZ is under reinforced and of limited effectiveness.

5.2 Youth Education & Wood Burning Outreach

One solution for the issues of wood burning, for both wood stoves and school bonfires, is to educate the community and youth of Amager through community outreach events. Through teaching families about the health effects of wood burning, we may encourage a reduction in wood stove usage, which would have a significant impact on air pollution levels. These families may also petition to stop the practice of kindergarten bonfires. This outreach would likely have to take place in the scope of Amager, as Ørestad is a relatively new development and does not have many wood stoves in residential buildings.

5.3 Extending the Low Emission Zone into Ørestad

We recommend assessing the viability of extending the borders of the LEZ to include the school. Our research shows that the low emission zone in Copenhagen reduced exhaust-particle emissions by 60% and NOx (nitrogen oxide compounds) by 25% in 2011. However, the experts we interviewed expressed dissatisfaction with the impact of the LEZ. The LEZ is under-enforced, though there are currently plans in motion to make it easier for police by implementing stricter punishments. Furthermore, the LEZ only demands that vehicle owners install an open filter rather than more effective closed filters. Despite these limitations, the LEZ still provides benefits that could improve the health of the students at the school.

5.4 Continued Investigation of Copenhagen Airport

We also recommend that Miljøpunkt Amager further investigate the airport as a source of air pollution. Our findings show that fine particle pollution from the airport can travel over 6.5 km, based on wind direction. This is further supported by previous studies that have shown that particle concentrations can increase 2-fold upwards of 16 km from the airport (Hudda et al., 2014). The Kalvebod Fælled Skole is closer to the airport than the monitoring station, and therefore at a similar to increased risk of exposure to the airport's pollution. As a result, it would be worth following up with the municipality of Tårnby, who may have more experience investigating the spread of pollution from the airport, to learn more about their plans to evaluate the impact of pollution from the airport. We suggest continuing these investigations in collaboration with the Amager citizens group CPH Uden Udvidelse, who are currently protesting plans to expand the airport.

5.5 Continued Investigation of Traffic

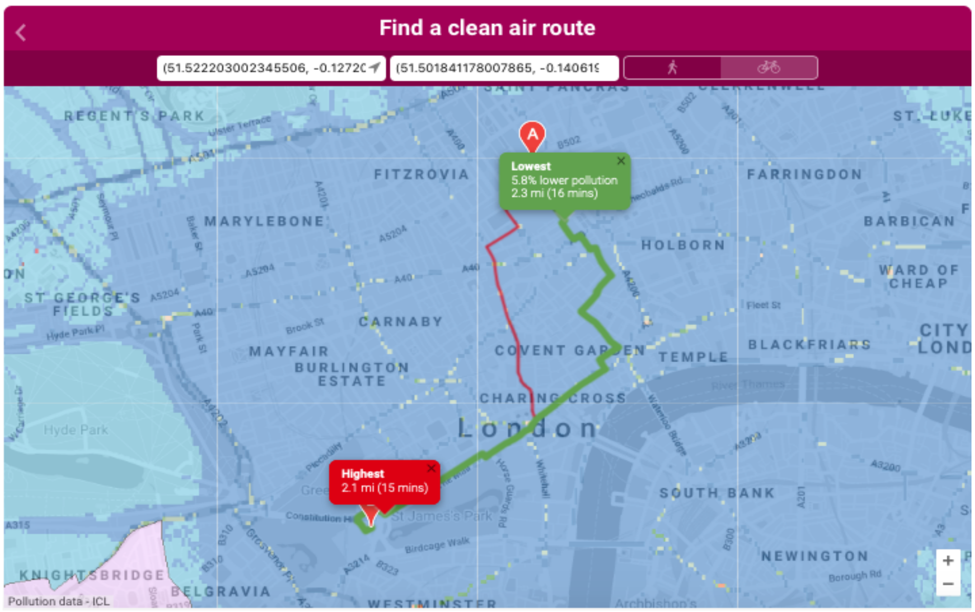
Our investigation identified motor vehicle traffic as a potential cause of air pollution near the school. However, due to limitations imposed by the Coronavirus pandemic, we cannot determine the full extent of its impact. Therefore, we recommend that Miljøpunkt Amager continue to investigate the impact of motor vehicle traffic on school zones.

Our extremely limited measurements indicated that commuting to work or school in private vehicles does contribute to ultrafine particle pollution. Unfortunately, our sample was only collected on a single morning and therefore is not statistically significant. For future investigation, we propose collecting measurements before, during, and after the drop-off/pick-up period for several weeks to account for variations in the weather. Additionally, concentrations of fine particulate matter and NO_2 should also be measured, as they are the primary outputs of motor vehicle exhaust and provide a better metric for the impact of traffic than ultrafine particulate concentrations.

5.6 Mapping Cleaner Air Routes

The city of London has created an interactive air quality map (Figure 17) which helps citizens find clean air routes between any two points in the city. We believe that a similar map could be a valuable tool in Copenhagen as well. Combining the data from the Google Air Quality project, once it is released, with real time information from monitoring stations across Copenhagen could help generate accurate suggestions for the cleanest and fastest routes to work or school.

Figure 17. London's interactive city map for locating clean air routes



Source: Mayor of London, 2019

5.7 Future Work

Our research focused mainly on ambient air pollution. However indoor air pollution also has a significant impact on human health. According to the United States Environmental Protection Agency (2018), concentrations of indoor air pollutants are often two to five times greater than outdoor concentrations. Considering we spend 90% of our time indoors (O. Hertel, personal communication, October 1, 2020), further research into how indoor air pollution impacts health, especially as it relates to children, would be incredibly valuable.

Our project focused primarily on the Kalvebod Fælled Skole and therefore did not represent the conditions around all schools in Amager. We recommend conducting additional studies in more communities across Amager as key pollution sources and conditions are likely to differ. For instance, Ørestad has very few wood stoves as the community itself is relatively new, however other parts of the island may have thousands.

Therefore, in these communities, emissions from wood stoves would likely have a greater impact on air pollution levels than they do in Ørestad.

In our interview with Dr. Hertel, the issue of noise pollution from the airport was also mentioned. In fact, Hertel stated that the noise from the airport is likely the biggest concern for the health of the students rather than the particulate matter concentrations. Loud noises, especially those that are not continuous, are especially dangerous and have been linked with a range of sleep and cardiovascular problems. We believe that future studies should try to evaluate the impact of noise pollution from the airport on children's health and determine if anything can be done to reduce its effects.

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Appendix

Appendix A: Survey for School Parents

Purpose:

This survey informed us about students' commuting habits and the reasons why parents choose different commuting methods. Our team enlisted a volunteer to observe morning drop-off activities and we cross referenced that data with these survey responses. The survey was intended for parents of students attending the Kalvebod Fælled Skole.

Questions:

1. What form of transportation does your child take most often to school?
   a. Walking
   b. Biking
   c. Driving
   d. Public Transport
   e. Other
2. Why do you use the option you chose above? Please rank the importance of each of the following factors on a scale from 1-5 (1-high priority, 5-low priority). If any of the options below do not apply to you, then feel free to leave it blank.
   a. Cost
   b. Convenience
   c. Safety
   d. Distance from School
   e. Environmental Concerns
3. How often do you consider the local air quality when choosing a particular form of transportation?
   a. All of the time
   b. Most of the time
   c. Some of the time
   d. Not at all
4. If you would be concerned about your child's safety while walking or biking to school, please list your concerns:
5. If you would like to include any additional comments regarding your child's commuting habits or air quality concerns, please include them below.

Appendix B: Survey for Amager Residents

Purpose:

This survey helped us better understand the air quality concerns of the local population, understand their commuting habits, and determine which sources of air pollution were the most critical.

Questions:

1. How do you feel about the air quality in your community?
    a. Very Bad
    b. Poor
    c. Okay
    d. Good
    e. Very Good
2. On average, how often do you think about your local air quality?
    a. Daily
    b. Weekly
    c. Monthly
    d. Yearly
    e. Never
3. Are you aware of any community programs or initiatives to improve air quality in Amager?
    a. Yes
    b. No
4. If yes, please list them, with the most effective to least effective.
5. What form of transportation do you take to work / school?
    a. Walking
    b. Biking
    c. Driving
    d. Public Transportation
    e. Other
6. Why did you choose this form of transportation? Please rank the importance of each of the following factors on a scale from 1-5 (1-high priority, 5-low priority). If any options do not apply, then leave them blank.
    a. Cost
    b. Convenience
    c. Safety
    d. Distance from work
    e. Environmental Concerns
    f. Other

Appendix C: Medical Researcher Interview

Purpose:

The purpose of this interview was to determine what health risks are associated with exposure to air pollution in Amager. The interviewee was a researcher investigating the health effects of air pollution. They elaborated on the developmental complications that children undergo when exposed to air pollution.

Questions:

1. Could you talk about your current research as it relates to children's health impacts caused by air pollution?
2. Which types of air pollution affect children the most (i.e. fine / ultrafine particulate matter, black carbon, NO_2, etc.)?
3. What are the primary health impacts we see in children?
4. Do you have any suggestions or recommendations for reducing the harm done to children by air pollution?
5. How effective has the Low Emission Zone been in improving health outcomes?
6. How is biking healthier than driving?
7. Have the shutdowns resulting from the COVID-19 pandemic had an overall positive or negative impact on the air quality?
8. What would you say is the impact of pollution coming from the airport?
9. Could you elaborate on any developmental or cognitive effects of air pollution?
10. How much of an impact does smoking have on these health effects?

Appendix D: Air Researchers Interview 1

Purpose:

The researcher, who specializes in air pollution research, provided key information on several research methods. Using the information learned from the researcher, we improved our methods for data collection.

Questions:

1. What work, either current or ongoing, have you been involved in that relates to air pollution?
2. From your experience conducting air pollution research, what are some major lessons you've learned / possible advice you can give?
3. What dangers / pollution sources could potentially present themselves in and around a school setting?
    a. How would you evaluate the severity and impact of each of these sources?
    b. Are you aware of any solutions to help reduce pollution from these sources?
        i. Sources include:
            1. Pollution of personal vehicle vs. public bus
            2. Health of biking vs. additional exposure to pollution
            3. Electric cars
4. Ask about experience from health perspective on air pollution
    a. What level of air quality index (AQI) is actually safe?
    b. Any opinion on current thresholds and regulations?
5. Project-Specific Feedback
    a. Pollution level vs. distance analysis (what should we be concerned about?)
    b. Where best to measure data, what is a typical data collection -> analysis process?
        i. Note that we only have measurement devices for ultrafine pollution (
        ii. How accurate would this device be? Would it work outdoors/is it worth trying?
    c. Air pollution in the time of COVID -- any experiences?

Appendix E: Air Researchers Interview 2

Purpose:

This researcher specializes in air pollution research and the politics of air pollution regulation. They conveyed the results of past studies in Copenhagen and informed us on the political implications of creating and enforcing air pollution regulations. Using the information learned from the researcher, we developed better recommendations based on previous research.

Questions:

1. Could you talk about your current work in regard to air pollution?
2. What lessons have you learned from your work with air pollution? How do green policies get passed in Copenhagen?
3. What new policies would you like to see implemented? How likely are these to happen?
4. Could you give us a comparison between vehicle filters and Low Emissions Zones? What is more effective?
5. What other solutions exist for reducing emissions?
6. What types of emissions are you most concerned about?
7. What sources of air pollution are you most concerned about?

Appendix F: Air Researchers Interview 3

Purpose:

This interviewee is an advisor to an ongoing research project in Copenhagen. They reported the difficulty of conducting research during the Coronavirus pandemic and identified sources of air pollution in Copenhagen. Using the information learned from the researcher, we developed better recommendations to address applicable sources of air pollution.

Questions:

1. Could you talk to us a little bit about how your position at the Copenhagen Solutions Lab relates to air pollution?
2. What could you tell us, if anything, about the data collected by the Google Air Quality project so far?
3. What do you think are the biggest contributors to air pollution in Copenhagen?
4. Do you know of any changes in the trends resulting from the Coronavirus pandemic?
5. Are you familiar with any proposed solutions or policies to reduce air pollution and improve air quality in Copenhagen? If so, which do you feel are likely to be the most effective?
6. Is there a movement in place to reduce emissions from wood stoves?
7. What can you tell us about Copenhagen Airport's attempts to expand from a political or scientific standpoint?

Appendix G: Local Politician Interview

Purpose:

Our local politician was able to provide a local perspective on the successes and failures of green initiatives in the community of Amager. Using the information gathered from this interview, we tailored our recommendations to the concerns of the community.

Questions:

1. To date, what can you tell us about the Lokaludvalg's work with air quality? What work have you been involved with in that regard?
2. Would you say you are more of a bridge between the city government and the Miljøpunkt organizations?
3. What is being done to control the emissions of cars, taxis, buses, etc?
4. Some parents in one of our surveys noted that they have safety concerns, often related to traffic, when letting their children walk or bike to school. What kind of solutions do you think might make it safer or more inviting to walk or ride a bike?
5. How effective would you say Alle Børn Cykler has been in getting students to bike to school?
6. Are you aware of any laws currently in place designed to reduce air pollution around schools (i.e. idling laws)?
7. One solution we've been learning quite a bit about recently is the idea of creating superblocks or "traffic islands" to reduce motor vehicle emissions. Have you heard anything or worked on anything related to superblocks or traffic islands in Copenhagen?
8. What can members of the community do to get involved? How effective would their involvement be in moving things forward?
9. Why would the national government want to hold back on removing wood stoves?
10. Do you think there are any other options for reducing emissions from wood stoves (i.e. filters)?
11. In general, are there a lot of wood stoves in Amager?
12. We have noticed that the Lokaludvalg is made up of a few different working groups, could you tell us a little bit more about those?

Appendix H: Consent Forms

Consent Form: Parent Survey

We are a group of students from the Worcester Polytechnic Institute (WPI) in the United States. We are conducting a survey of parents in Amager to learn more about common practices and conditions in and around your school as it relates to air quality. We believe this research will ultimately help us better understand the sources of air pollution in this environment and will lead to the development of recommendations for reducing its effects on children.

Your participation in this survey is completely voluntary and you may choose to withdraw at any time. The survey should take approximately 5 minutes to complete. Your responses will remain anonymous and we will never ask you to provide any personally identifying information. In the event you do choose to share any personal information with us, it will not appear in any of the project reports or publications and will remain completely confidential.

This is a collaborative project between Miljøpunkt Amager and WPI, and we appreciate your participation. Note that this study will be published, and you have the right to request a copy of our results if you are interested at the conclusion of our study. We are also happy to answer any questions at any time.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact: gr-cleanair-dk_a20@wpi.edu. In addition, feel free to contact the WPI IRB Chair (Professor Kent Rissmiller, Tel. 508-831-5019, Email: kjr@wpi.edu) or the Human Protection Administrator (Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu)

Consent Form: Community Survey

We are a group of students from the Worcester Polytechnic Institute (WPI) in the United States. We are conducting a survey to learn more about your knowledge and concerns regarding air pollution in Amager. We believe this research will ultimately help us better understand the sources of air pollution in this environment and will lead to the development of recommendations for reducing its effects on children.

Your participation in this survey is completely voluntary and you may choose to withdraw at any time. The survey should take approximately 5 minutes to complete. Your responses will remain anonymous and we will never ask you to provide any personally identifying information. In the event you do choose to share any personal information with us, it will not appear in any of the project reports or publications and will remain completely confidential.

This is a collaborative project between Miljøpunkt Amager and WPI, and we appreciate your participation. Note that this study will be published, and you have the right to request a copy of our results if you are interested at the conclusion of our study. We are also happy to answer any questions at any time.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact: gr-cleanair-dk_a20@wpi.edu. In addition, feel free to contact the WPI IRB Chair (Professor Kent Rissmiller, Tel. 508-831-5019, Email: kjr@wpi.edu) or the Human Protection Administrator (Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu)

Consent Form: Health Professional

We are a group of students from the Worcester Polytechnic Institute (WPI) in the United States. We are conducting interviews with health care professionals to learn more about the health effects of air pollution on the human body, particularly in children. We strongly believe this kind of research will ultimately lead to recommendations which lower children's health impacts resulting from air pollution exposure. This will be done by using the information you provide to locate and identify the key health effects on local children.

Your participation in this interview is completely voluntary and you may withdraw at any time. This interview will last between 30-45 minutes. Certain identifying information, including your name, title, and the name of your organization, along with any commentary you provide during the interview may be used in our project reports or publications, unless you choose to remain anonymous. We may also record the interview for later analysis (including video and/or voice), however these recordings will not be published. At the conclusion of our study, the recording(s) will be deleted.

This is a collaborative project between Miljøpunkt Amager and WPI, and we appreciate your participation. Note that this study will be published, and you have the right to request a copy of our results if you are interested at the conclusion of our study. We are also happy to answer any questions at any time.

None of the choices below are required and you may withdraw your consent at any time.

- ❏ I consent to the use of audio/visual recordings from this interview for analysis purposes
- ❏ I consent to the use of my name, title, and/or name of my organization in project reports or publications. I understand that something I say might be directly quoted within said publication.
- ❏ I would like to receive a copy of my responses at the conclusion of this study

__________________________________ _______________
Researcher's name & signature Date

__________________________________ _______________
Interviewee's name & signature Date

For more information about this research or about the rights of research participants, or in case of research-related injury, contact: gr-cleanair-dk_a20@wpi.edu. In addition, feel free to contact the WPI IRB Chair (Professor Kent Rissmiller, Tel. 508-831-5019, Email: kjr@wpi.edu) or the Human Protection Administrator (Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu)

Consent Form: Researcher

We are a group of students from the Worcester Polytechnic Institute (WPI) in the United States. We are conducting interviews with research experts to get a better picture of the current situation in Copenhagen regarding air pollution. We strongly believe this kind of research will ultimately lead to better air quality standards in Amager. Your responses will better our understanding of air quality in Copenhagen.

Your participation in this interview is completely voluntary and you may withdraw at any time. This interview will last between 30-45 minutes. Certain identifying information, including your name, title, and the name of your organization, along with any commentary you provide during the interview may be used in our project reports or publications, unless you choose to remain anonymous. We may also record the interview for later analysis (including video and/or voice), however these recordings will not be published. At the conclusion of our study, the recording(s) will be deleted.

This is a collaborative project between Miljøpunkt Amager and WPI, and we appreciate your participation. Note that this study will be published, and you have the right to request a copy of our results if you are interested at the conclusion of our study. We are also happy to answer any questions at any time.

None of the choices below are required and you may withdraw your consent at any time.

- ❏ I consent to the use of audio/visual recordings from this interview for analysis purposes
- ❏ I consent to the use of my name, title, and/or name of my organization in project reports or publications. I understand that something I say might be directly quoted within said publication.
- ❏ I would like to receive a copy of my responses at the conclusion of this study

________________________________ ______________

Researcher’s name & signature Date

________________________________ ______________

Interviewee’s name & signature Date

For more information about this research or about the rights of research participants, or in case of research-related injury, contact: gr-cleanair-dk_a20@wpi.edu. In addition, feel free to contact the WPI IRB Chair (Professor Kent Rissmiller, Tel. 508-831-5019, Email: kjr@wpi.edu) or the Human Protection Administrator (Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu)

Consent Form: Police Officer/Local Government Employee

We are a group of students from the Worcester Polytechnic Institute (WPI) in the United States. We are conducting interviews with Copenhagen city employees to learn more about the current laws and regulations in place regarding air pollution. We strongly believe this kind of research will ultimately lead to a better air quality standard for young children in the area. Your responses will be used to evaluate current policies and practices.

Your participation in this interview is completely voluntary and you may withdraw at any time. This interview will last between 30-45 minutes. Certain identifying information, including your name, title, and the name of your organization, along with any commentary you provide during the interview may be used in our project reports or publications, unless you choose to remain anonymous. We may also record the interview for later analysis (including video and/or voice), however these recordings will not be published. At the conclusion of our study, the recording(s) will be deleted.

This is a collaborative project between Miljøpunkt Amager and WPI, and we appreciate your participation. Note that this study will be published, and you have the right to request a copy of our results if you are interested at the conclusion of our study. We are also happy to answer any questions at any time.

None of the choices below are required and you may withdraw your consent at any time.

- ❏ I consent to the use of audio/visual recordings from this interview for analysis purposes
- ❏ I consent to the use of my name, title, and/or name of my organization in project reports or publications. I understand that something I say might be directly quoted within said publication.
- ❏ I would like to receive a copy of my responses at the conclusion of this study

________________________________ _______________

Researcher's name & signature Date

________________________________ _______________

Interviewee's name & signature Date

For more information about this research or about the rights of research participants, or in case of research-related injury, contact: gr-cleanair-dk_a20@wpi.edu. In addition, feel free to contact the WPI IRB Chair (Professor Kent Rissmiller, Tel. 508-831-5019, Email: kjr@wpi.edu) or the Human Protection Administrator (Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu)

Appendix I: Gehl Architects

In addition to our own data, we were able to preview a report from Gehl Architects which provides some insight into how the organization plans to improve the local air quality with a particular focus on young children. In one of their recent studies, they observed pedestrian interactions within several spaces within Sundby and compared them to similar spaces within the inner city. They evaluated each of these spaces in terms of what Gehl calls their stickiness - or the space's ability "to invite people passing through to stop and spend time" (Risom et al., 2019, p. 12). Stickier areas often had higher pedestrian counts throughout the day and typically featured better air quality. What they found was that over the course of the day, as the number of pedestrians increased or decreased, the ultrafine particle (UFP) concentrations did the opposite. In fact, in most areas, peak usage occurred when UFP concentrations were the lowest. Based on these findings, Gehl suggests that the air quality in Copenhagen can be improved by focusing on two simple steps: reduce the air pollution in spaces where children spend most of their time, and invite children to spend more time in spaces where the air quality is better (Risom et al., 2019).