Assessing Particulate Pollution in the Østerbro District of Copenhagen

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WPI

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ØSTERBRO

Assessing Particulate Pollution in the Østerbro District of Copenhagen

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In Cooperation With
Miljøpunkt Østerbro

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ABSTRACT

Ultrafine particulate (UFP) pollution causes 500 premature deaths annually in Copenhagen, Denmark. This project, in conjunction with Miljøpunkt Østerbro, measured UFP using a P-Trak Ultrafine Particle Counter, near various schools and a large park in Østerbro district, chosen because children are at the greatest risk of developing long-term complications. Final measurements and analysis showed a strong correlation between the number of diesel engines and high concentrations of UFP, that UFP dissipates over distance, and solid noise barriers decrease the concentration in the immediate area. Using this data and additional observations, the team created a list of suggestions for businesses to reduce UFP emissions and strategies for individuals to avoid high UFP concentrations.

EXECUTIVE SUMMARY

Background

Denmark has taken a progressive stance with regards to environmentalism and expressed their interest with a series of long term plans that aim to reduce climate change and pollution. Recent plans include the 2050 plan, a plan to make Denmark fossil fuel free by 2050; eco-metropolis, a plan to make Copenhagen the "world's best city for cyclists" by 2015; and Cityringen, a plan to construct additional metro lines and stops by 2018 to increase public transit use and decrease vehicle use (The Danish Government, 2011; City of Copenhagen, 2008; Cityringen, 2014). The residents of Copenhagen consider air pollution to be the most important environmental issue their city faces in regards to public health.

Air pollution causes 2.4 million deaths per year, globally (Guilford, 2013). The health effects of air pollution are most common in the respiratory and cardiovascular systems especially in at risk individuals such as children and the elderly. Immediate respiratory effects from inhalation of vehicular emissions are wheezing, dizziness, and irritation of airways. More severe effects include but are not limited to oxidative stress and increased inflammatory response (Brook, 2008; Douglas, Haldane, & Haldane, 1912; Mills et al., 2008). Oxidative stress and increased inflammatory response are linked to cancer, Parkinson's disease, and Alzheimer's disease (Brook, 2008; Douglas, Haldane, & Haldane, 1912; Mills et al., 2008). Ultrafine particulates, particulates less than 0.1 μm in diameter, are the most harmful particulates in regards to human health because they are small enough to enter the blood stream, travel systemically through the body and directly damage organs and cells (Oberdorster, G., 2000; R. D. Brook et al., 2002). Children are high risk and high priority individuals concerning air pollution because they are developing, active, and often breathe through the mouth as opposed to the nose (Clark, Demers, & Brauer, 2010; Burtscher, Schuepp, 2012).

Østerbro, one of the ten districts of Copenhagen, is a residential district with 16 grade schools. Located northeast of downtown Copenhagen, Østerbro is surrounded by large roads, the O2 and Helsingørmotorvejen, and has four construction sites related to Cityringen. Diesel vehicles, such as those used in construction, are associated with higher concentrations of ultrafine particulates (Peya, Querola, Alastueya, Rodriguez, Van Dingenend, 2014). While the Danish government has plans that will reduce future air pollution concentrations, such as expansion of mass transit, the construction required to implement these plans increases current air pollution concentrations. Currently there is no data for ultrafine particulate concentrations in the Østerbro district. Østerbro residents are concerned about air pollution concentrations and the health risks posed to their children.

Miljøpunkt Østerbro, the sponsor of this project, is a non-governmental organization that focuses on sustainability in Østerbro. They are particularly concerned about air pollution and the resulting negative health effects because of the large at-risk population in Østerbro, composed of elderly and young children (Lene Midtgaard, personal communication, 2014). In previous projects, Miljøpunkt Østerbro focused on the impact of pollutants on children and provided remedies to avoid or reduce exposure to pollutants. Due to the lack of ultrafine particulate data in Østerbro, the team's sponsor wanted to assess the risk these particulates posed to children.

Mission Statement and Objectives

The goal of this project was to help Miljøpunkt Østerbro provide information to residents in order to increase awareness of air pollution in the district, especially regarding children. The team took samples from various locations at different times to determine and plot ultrafine particulate concentrations.

The objectives of this project were to:

1. Record ultrafine particle (UFP) concentrations in conjunction with observations of:
   a. Weather
   b. Traffic events
   c. Other potential data anomalies
2. Arrange the air pollution data in chart form
   a. Remove outlying data with observations 1.a-1.c
   b. Compare pollution concentrations against time and distance
3. Use analyzed data to:
   a. Support advocacy for better habits and emission regulations in Copenhagen
   b. Provide suggestions on how to avoid high concentrations of UFP
4. Display information for public view, using an article released by Miljøpunkt Østerbro

Methodology I: Traffic Measurement

The team measured ultrafine particulates in the Østerbro district near schools and high congestion areas during rush hour and non-rush hour times. Miljøpunkt Østerbro used the measurements, analysis, and suggestions to provide information to residents about ultrafine particulate concentrations and solutions to better protect the health of at-risk individuals.

Miljøpunkt Østerbro provided a map of Østerbro indicating the specific focus locations, including schools and high congestion areas. The team took measurements using the P-Trak Ultrafine Particle Counter and determined taking multiple 20-minute measurements instead of fewer longer measurements limited variables, such as weather from skewing the data. The team recorded all necessary observational data in a notebook along with the date, location, and time. These observations were key in the analysis phase when the team determined if there was a correlation between particulate concentrations and the presence of traffic.

Analysis I: Traffic Data

After the team measured and analyzed the first set of locations, the data showed minimal correlation between high traffic and high concentrations of ultrafine particulates. The team expected Trianglen, an area congested with traffic, to show the greatest correlation between increased concentration and increased traffic. The team found minimal correlation between increased traffic and increased ultrafine particulate concentrations. During further analysis of the data, the team reviewed the observational data collected at the time of measurement. The team noticed that areas near construction had higher averages and larger spikes.

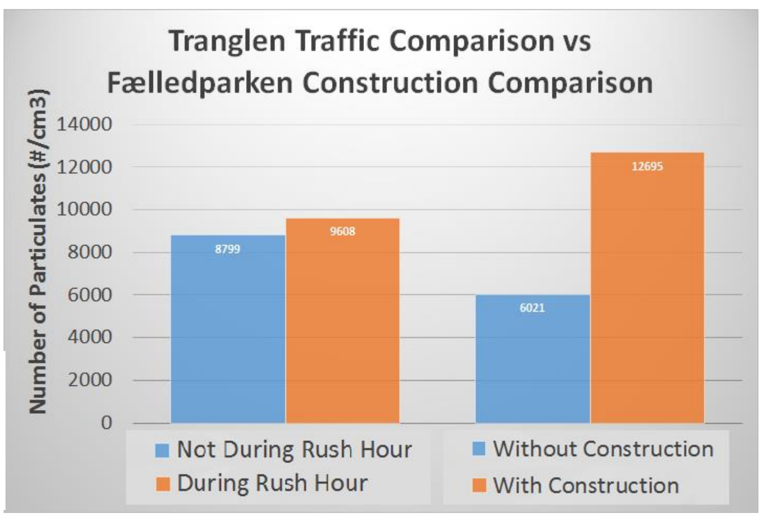

Figure 1. Comparison graph of traffic and construction averages.

Methodology II: Construction Measurement

The team selected a new set of locations, with and without construction, from the original list of schools and locations. The primary criteria for selecting locations were the proximity to schools; size of the construction site; whether barriers surrounded a site; and a lack of potential interference, such as diesel vehicles. Using these criteria, the team reduced the number of locations from the 24 schools and high congestion areas selected during preliminary measurements to five. The five locations included two schools in close proximity to construction, two schools with no nearby construction, and Fælledparken because the site had barriers. The team took measurements at construction locations similar to those described in Methodology I.

Analysis II: Construction Data

The team used several graphs for each construction site to display data including: the average number of particulates over a 20-minute period versus distance from the construction site; the average number of particulates each minute for 20 minutes at each distance versus time; and the number of pollution spikes at each distance. A spike is any second above the acceptable baseline of 10,000 particulates per cubic centimeter presented to the team by the Danish ECO Council representative, Kåre Press-Kristensen.

The graphs in combination with observational data showed that ultrafine particulate concentrations near construction sites dissipate over distance and noise barriers decrease concentrations in the immediate area. Both Vibenhus Skole and Langelinieskolen, the schools with construction, showed a negative correlation as distance increases from the construction site. There is a safe distance from a construction site but it will vary due to weather and site size. A distance of 50 meters is safe for construction sites of similar size to the ones near Vibenhus Skole and Langelinieskolen. The average value at 50 meters was below the baseline and the number of spikes at each site were insignificant when at or beyond 50 meters. The team used the schools without construction for comparison, to see if construction adds a significant amount of pollution and to determine if schools fall below the baseline provided by Kåre Press-Kristensen. The averages the team measured at the schools without construction were below the baseline value.

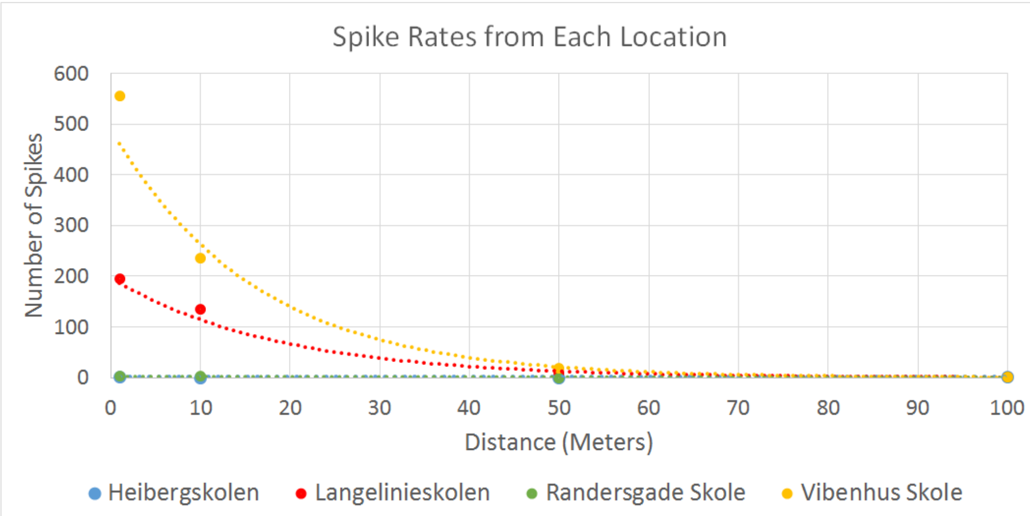

Figure 2. Graph of number of spikes at each distance for all achools.

Suggestions

Using the results from the data and analysis, the team created a list of suggestions for construction companies and the general public. Miljøpunkt Østerbro used the data and suggestions to propose habit changes to construction companies to decrease the amount of and exposure to ultrafine particulates.

The team determined that at a distance of approximately 50 meters from a construction site, ultrafine particulate concentrations are close to normal background values and are considered safe. If it is not possible to be 50 meters away from a site, it is best to stay as far away as possible because the concentration of particulates decreases exponentially except in one important case: the presence of solid noise barriers. If barriers are present, and it is not possible to be 50 meters away, then it is best to maintain a distance of one meter from the barrier. The area one meter or less from the barrier has a much lower concentration of ultrafine particulates compared to a distance of 10 meters. These suggestions of distance to construction site apply to the sites of similar size in the Østerbro district, as well as the city of Copenhagen.

In addition to avoidance of high concentrations of ultrafine particulates, it is possible to reduce the output of these particulates. Suggestions are turning off diesel vehicles; reducing idling time; installing diesel particulate filters; installing solid barriers around all construction sites; and, when near schools, turning off diesel engines half an hour before and after school hours. The team makes these suggestions aiming to reduce exposure to high ultrafine particulate concentrations from construction sites. The team believes that further research into the health effects and the implications of construction is necessary to protect the health of city residents.

ACKNOWLEDGEMENTS

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- The project's advisors, Professor Robert Kinicki and Professor Steve Taylor, for their guidance and advice throughout the duration of the project.
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- The Danish ECO Council for providing the team with valuable information on ultrafine particulates and operation of the P-Trak device.

AUTHORSHIP PAGE

Each member of the team contributed equally to the production of this report and to the project's overall completion, which includes, but is not limited to, the collection, processing, and analysis of data and information.

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CHAPTER 1 - INTRODUCTION

Air pollution causes 2.4 million deaths per year, globally (Guilford, 2013). Of anthropogenic pollutants, those created by humans, 13% are from mobile sources (Intergovernmental Panel on Climate Change, 2007). Health issues that arise from air pollution are often seen in and around urban areas because of the high concentrations of vehicular emissions. The main health issues resulting from high pollution concentrations occur in the respiratory system, most noticeably affecting the elderly and young children (Davies, Vlaanderen, Henderson, & Brauer, 2009).

Many Danish citizens believe that air pollution is the most important environmental issue and the Danish government reflects this concern ("Clean Air," 2012). The Danish government created several long-term plans to reduce pollution and its negative effect on the environment and the negative health effects posed to Danish citizens. The plans included many mass transit options designed to remove vehicles from the roads ("Clean Air," 2012). Although the majority of Danish roadways have low pollution concentrations, some are above standards set by the World Health Organization (WHO) and the European Union (European Environmental Agency, 2010). As of 2010, an estimated 3,400 Danes per year die prematurely because of current city air quality (European Environmental Agency, 2010).

Miljøpunkt Østerbro, the team's sponsor, is a non-governmental organization that focuses on sustainability in Østerbro. Miljøpunkt Østerbro is particularly concerned about air pollution and the resulting negative health effects because of the large at-risk population (Lene Midtgaard, personal communication, 2014). In previous projects, the sponsor focused on the impact of pollutants on children and provided remedies to avoid or reduce exposure to pollutants. Due to the lack of ultrafine particulate data in Østerbro, the sponsor wanted to assess the risk these particulates posed to children at schools.

Similar to Miljøpunkt Østerbro, many companies in Copenhagen aim to reduce the amount of air pollution in the city. Copenhagen is currently expanding its metro system to include two new lines dubbed "Cityringen." Cityringen aims to reduce air pollution concentrations by encouraging more residents and commuters to use public transport as opposed to personal vehicles. However, pollutant concentrations may be increasing and negatively affecting residents due to the construction of Cityringen, especially in Østerbro where there are multiple construction sites. The planned construction related to the metro will continue until 2018 at the earliest.

The amount and length of time for the Cityringen construction and its proximity to schools may negatively affect the health of children and residents.

The main objective of this project was to collect ultrafine particulate data at schools. To achieve this, the team measured pollutant concentrations near schools to assess the health risks to children and other residents posed by ultrafine particulates. The team expected vehicular emissions and construction related pollution to be the major contributing factors to ultrafine particulate concentrations in the Østerbro district. With the data and subsequent analysis, Miljøpunkt Østerbro provided information to Østerbro residents about ultrafine particulate concentrations at schools and solutions to protect the health of at-risk individuals.

CHAPTER 2 - LITERATURE REVIEW

In Denmark, there is a focus on environmentalism and the effects of air pollution on human health. The chapter presents Denmark's progressive attitude towards environmental issues and the history of pollution in Copenhagen and introduces Østerbro's concern with health effects from air pollution. As discussed in Chapter 1, air pollution causes millions of deaths per year globally. Health issues related to air pollution often occur in urban areas because of a high amount of vehicular emissions. The chapter also provides a detailed explanation of the short and long-term negative health effects of exposure to particulate matter (PM). To provide context of the pollutants measured in the project, the chapter explains the different sources of air pollution, and influences on air pollution distribution.

2.1 - Progressive Environmental Policies in Denmark

Denmark has taken a progressive stance on environmental issues. During the 1960s, traffic overran many of Denmark's cities ("How Denmark became a cycling nation," 2014). In response to increasing traffic and the emissions they produce, the Danish Government created the Ministry of the Environment. After the Ministry's establishment in 1971 many conflicts arose surrounding car and bicycle interests in the cities, resulting in increased bicycle lanes and space for pedestrians (Ministry of the Environment, 2014). In recent years, the public's focus is climate change and the health effects associated with pollution ("How Denmark became a cycling nation," 2014).

Denmark's focus on climate change and health effects spurred a series of initiatives and plans at both the national and municipal level. The most well-known plan, and first of its kind, is the Energy Strategy 2050, also known as the 2050 Plan. The 2050 Plan aims to make Denmark fossil fuel free by 2050 (The Danish Government, 2011). To keep the plan on track, at least 35% of Denmark's total energy need must be comprised of renewable sources by the year 2020 (Lidegaard, 2012). If successful, the 2050 Plan will reduce pollution concentrations and set an example for other countries.

At a municipal level, Copenhagen has several strategies to increase bicycle use and improve the health of its residents. In 2008, Copenhagen politicians unanimously decided to make Copenhagen an eco-metropolis (The City of Denmark Traffic Department, 2014). This initiative focuses on making Copenhagen the "world's best city for cyclists" and includes goals to create a cleaner, healthier and more environmentally friendly city ("Copenhagen's Bicycle Strategy & Policies," 2014). In order to reach this goal, Copenhagen plans to improve upon both national and international standards of harmful air pollutant concentrations by the year 2015 (City of Copenhagen, 2008). The eco-metropolis vision aims to increase the number of cyclists and pedestrians in order to reduce the number of cars and concentration of air pollution.

2.1.1 Pollution in Copenhagen

The 2050 Plan states, "the air should be so clean that Copenhageners health will not be damaged [by 2015]" ("Clean Air," 2012). Residents of Copenhagen believe air pollution is the most important environmental issue that their city faces in regards to public health. The city aimed to decrease the air pollutant concentrations by managing traffic and continued promotion of cycling ("Clean Air," 2012). H.C. Andersens Boulevard, a road in downtown Copenhagen, is a quintessential example of the goals set by the 2050 Plan. The concentration of particulate matter less than 10 micrometers in size (PM_{10}) on H.C Andersens Boulevard has decreased by 50% between 2002 and 2010, as well as consistently staying under the new European Union (EU) limit of 25 µg/m^3 for particulate matter less than 2.5 micrometers in size ($PM_{2.5}$) since 2007 ("Clean Air," 2012). The yearly average pollution concentrations of H.C. Andersens Boulevard are shown in Figures 2.1.a and 2.1.b. Though the average concentrations are below health standards, high amounts of traffic and construction in the city can produce spikes in particulate concentration that are harmful to city residents.

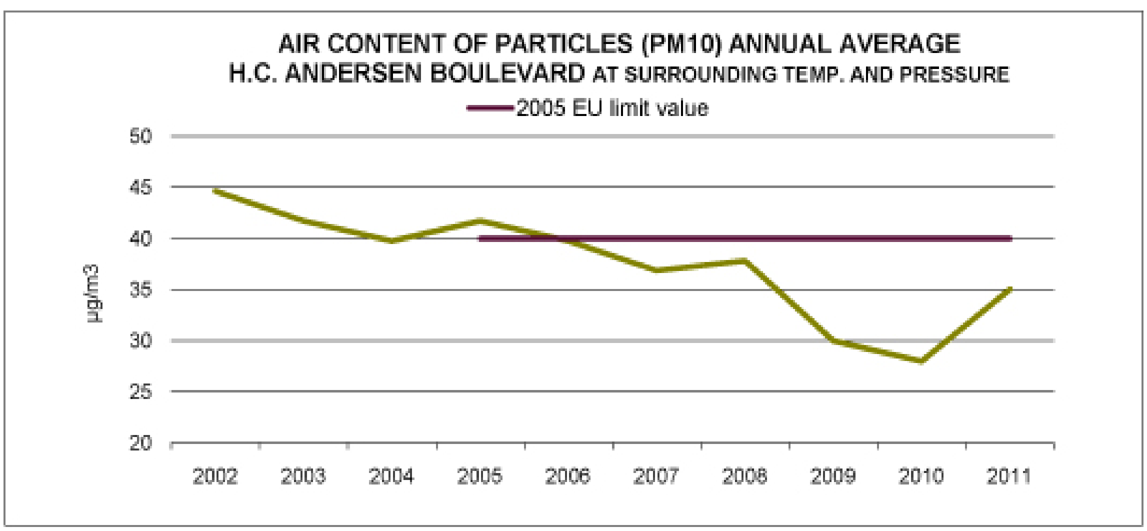


Figure 2.1.a: Average of PM_{10} on H.C. Andersen Boulevard ("Clean Air," 2012)

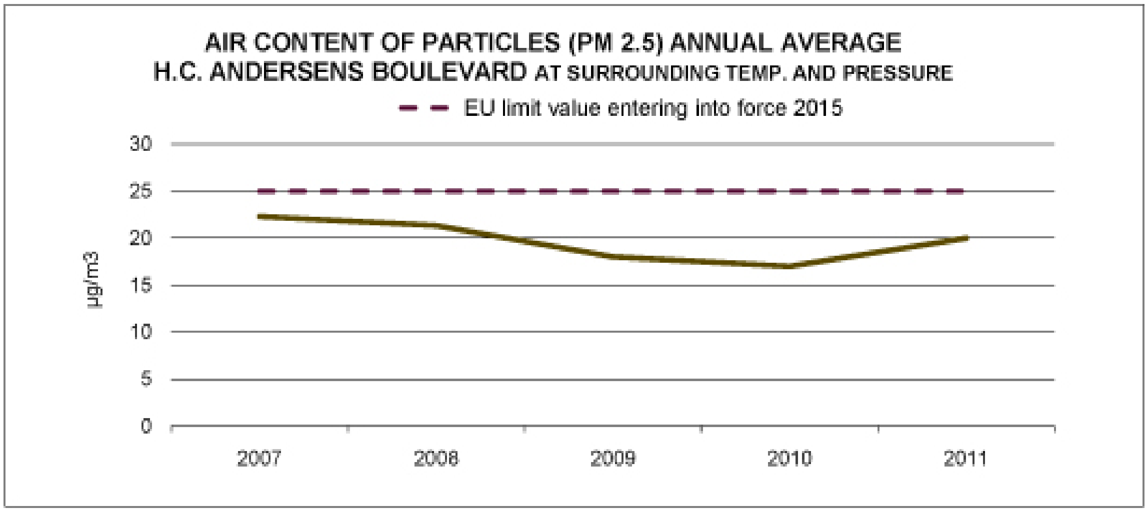


Figure 2.1.b: Average of $PM_{2.5}$ on H.C. Andersen Boulevard ("Clean Air," 2012)

Copenhagen is currently undergoing an expansion of its Metro system, including 17 new stations and two new lines, see Figure 2.1.c. The Cityringen project began in 2010, with renovation of the city utility grid costing around one billion DKK ("Cityringen", 2014). The tunnel and station construction began once grid renovation was complete ("Cityringen", 2014). Metroselskabet (English: the Metro Company) will completely build the M3 and M4 metro lines by early 2018 and open the lines for commercial operation in late 2018 ("Copenhagen Metro" 2014). The ongoing Cityringen construction caused a number of complaints about noise pollution from residents throughout the city ("Expansion of Copenhagen Metro" 2014). The complaints are largely due to extended working hours during evenings and nights. The Metro Company predicts that if it cannot continue with extended hours of operation, completion of the Cityringen could be delayed up to six years and cost nine billion DKK more than expected ("Expansion of Copenhagen Metro" 2014). To ensure on time construction completion, the Metro Company is providing compensation to residents that are exposed to high noise levels that is "sufficient for [the resident] to find alternate accommodation during the period when noise exceeds [acceptable] levels ("Expansion of Copenhagen Metro" 2014)." Noise pollution is a nuisance to the surrounding areas, while air pollution caused by the construction is an invisible strain that may have a much greater impact than noise pollution on the health of those living near the construction areas.

Figure 2.1.c: Copenhagen Metro, M3 and M4 currently under construction ("Cityringen" 2014)

2.1.2 Why Østerbro?

Miljøpunkt Østerbro is located in Østerbro, one of the ten districts of Copenhagen. Østerbro is a residential district located northeast of downtown Copenhagen, shown in Figure 2.1.d. The district has 16 schools, four of which have construction nearby. Construction near schools is concerning because children are most prone to negative health effects, as discussed in Section 2.3.3. The lack of pollution data in the district concerns Miljøpunkt Østerbro because children are exposed to unknown concentrations of pollution (Nielsen & Jensen, 2010).

Figure 2.1.d: A map of Copenhagen, the district of Østerbro is green. (Copenhagen Districts, 2008)

Construction of the Cityringen metro expansion has introduced four station construction sites and one major tunnel-drilling site into the Østerbro district, shown in Figure 2.1.f. The metro construction is causing increased noise and particulate pollution in the district. The purpose of the largest construction site, located at the north end of Sortedams Sø, is the insertion of tunnel digging equipment. Increased metro construction and construction near schools poses negative health risks associated with ultrafine particulates to the children and residents of Østerbro.

Figure 2.1.e: Close up of Østerbro. The Metro construction sites are marked by colored circles (Cityringen, 2014)

2.2 - Distribution of Air Pollution

Human activity does not create the majority of airborne pollution; in fact, only approximately 10% of all aerosols are anthropogenic (Voiland, 2010). Despite being only one-tenth of global atmospheric aerosols, anthropogenic aerosols have higher concentrations than natural aerosols in urban and industrial areas (Voiland, 2010). Stationary or mobile sources produce these pollutants and have varying health effects depending on their location. Stationary sources--industry, agriculture, forestry, waste and wastewater, commercial and residential buildings, and energy supply-- comprise 87% of anthropogenic greenhouse gas production globally, as seen in Figure 2.2.a. The mobile sources, or transportation, comprise the remaining 13%.

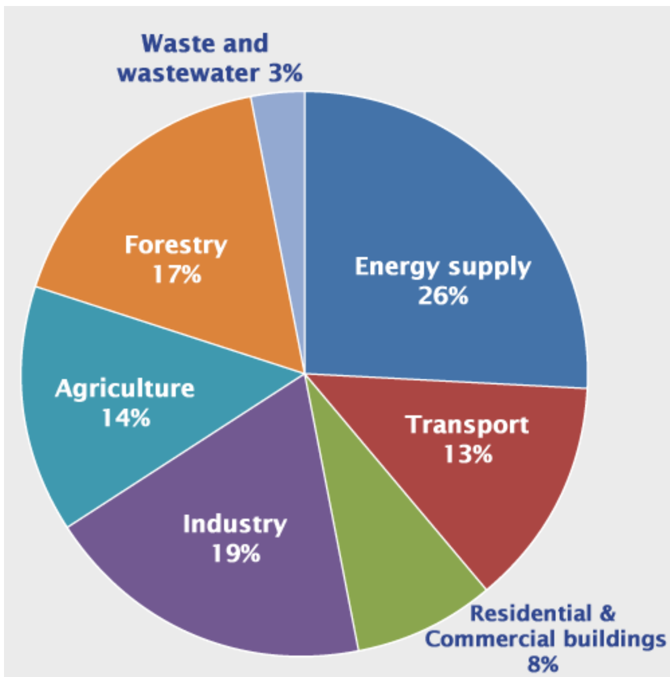


Figure 2.2.a: Greenhouse gas emissions by economic sector globally in 2011 (Intergovernmental Panel on Climate Change, 2007).

2.2.1 Stationary Sources

Stationary pollution includes natural sources of air pollution and human sources. The most visible natural causes of pollution are volcanic eruptions and dust storms. Other natural causes of pollution are as simple as respiration in animals, or as complex as creation of radon gas from the decay of radium in the Earth's crust. The majority of anthropogenic stationary-source pollutants are from power plants and industry (Environmental Protection Agency, 2013). These anthropogenic sources have varying effects on the global ecosystem (Environmental Protection Agency, 2013).

Any source of pollution increases the concentration of pollutants in the immediate area; therefore, city planners purposely position many anthropogenic stationary pollution sources outside of city limits to have the least impact on residents. Though stationary sources are often positioned outside a city, their effect establishes a background pollution concentration within the area. While this concentration may change due to weather and other natural events, it is remains consistent ("Factors Affecting Air Quality," 2014). Since the background is consistent from day to day, the stationary pollution sources will have a constant effect on the health of local residents. Air pollution created by stationary sources is largely unavoidable and will not be the focus of this project.

2.2.2 Mobile Sources

Mobile sources can be located within the city, in close proximity to children and pedestrian commuters, directly exposing them to hazardous pollutants. Mobile sources directly produce carbon monoxide, carbon dioxide, nitrogen monoxide, hydrocarbons, sulfur dioxide and particulates; whereas, ozone, nitrogen dioxide, and acid vapors are created secondarily, through chemical reactions of the primary vehicle emissions with outside elements (Brunekreef & Holgate, 2002). Mobile sources can further be broken down into road and nonroad sources. Cars, trucks, and other street vehicles are road sources, while construction vehicles and generators are nonroad sources. The Danish Government does not regulate nonroad sources as strictly as road sources because they are used less than road sources ("Nonroad Diesel Engines" 2014). Diesel vehicles are associated with higher concentrations of fine and ultrafine particulates (Peya, Querola, Alastueya, Rodriguez, Van Dingenend, 2014). The construction equipment in use in Copenhagen is mostly composed of nonroad diesel sources ("Cityringen" 2014).

2.2.3 Construction Equipment

The Cityringen construction sites all use heavy lifting and digging machinery, powered by large diesel engines. Many construction vehicles idle when not in use, increasing pollutant production, wasting fuel, and causing unnecessary wear on the engine ("Idle Reduction" 2014). Depending on the year of manufacture of the machinery used, it may comply with different emissions standards as seen in Table 2.2.a. Although 80% of construction vehicles for Cityringen use diesel particulate filters (DPFs), the larger vehicles that consume 50% of the diesel fuel do not have these filters (The Danish ECO Council, 2012). Older machines can be grandfathered in, remaining in use even though they produce more particulate pollutants and do not comply with new emissions standards.

Stage	Year	PM emissions (g/kWh)
I	1999	0.54
II	2002	0.2
III	2006	0.2
IV	2014	0.025

Table 2.2.a: European Union nonroad diesel emissions standards for PM ("Nonroad Diesel Engines" 2014)

An analysis completed by the United States Environmental Protection Agency (US EPA) discovered that retrofitting of old diesel engines with diesel particulate filters is a cost effective mechanism, compared to updating to modern machinery, to immediately reduce particulate matter pollution by up to 99% ("Diesel Retrofit Technology" 2014). The outlined solutions' costs range from $1,900 to $87,600 per ton of PM produced, depending on equipment activity, emission rate, and engine upgrade cost ("Diesel Retrofit Technology" 2014). Retrofitting of old equipment with DPFs at the Cityringen sites could prove to be the best strategy for reducing harmful particulate pollutants.

2.2.4 Meteorology Effects on Pollution

Weather has many effects on air pollution, which are important to consider when attempting to measure air pollution concentrations. The main factors affecting air quality are wind, temperature, and humidity (Environmental Protection Authority, 2013). Each of these factors has its own set of hindrances, which compound when considering multiple variables at once.

Wind, when combined with a valley-like structure, much like the buildings surrounding a city street, can create a recirculation effect as seen in Figure 2.2.b (Wang, van den Bosc, & Kuffer, 2008). When a crosswind is blowing, the buildings trap air and recirculate it, which prevents dispersal of the pollutants. This creates an imbalance of pollution concentration on the street level, where walking on the leeward side of the street exposes pedestrians to much higher concentrations of pollution than the windward side. On especially windy days, pedestrians often opt to take the leeward side of the road, which exposes residents to much higher pollutant concentrations (Wang, van den Bosch, & Kuffer, 2008).

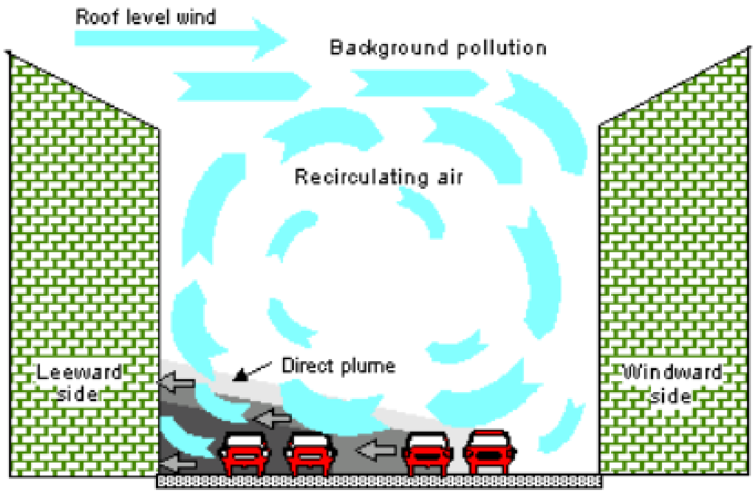


Figure 2.2.b: Wind flow in a street canyon (Berkowicz, 2000)

Temperature inversion primarily occurs in valleys, when a pocket of cold air is trapped below warmer, ambient air ("Factors Affecting Air Quality," 2014). The cool air is denser and does mix well with the warmer, less dense air above it. The lack of mixing will trap any pollutants at the street level. Temperature inversion most often happens overnight ("Factors Affecting Air Quality," 2014). The combination of the recirculation effect and temperature inversion traps pollutants on the street level for extended periods. This exposes many children and residents to unnecessarily high concentrations of pollution.

Rain suppresses dust and other pollutants in the air (Agency, 2013). The rain absorbs pollutants and deposits them on the ground, decreasing the concentration of pollutants in the air. Rain also affects the ability of pollutant measurement devices to function, potentially damaging them; measurement on days with precipitation is inadvisable due to this fact. Since rain reduces the amount of airborne pollution exposure to residents, the inability to measure on rainy days should have minimal impact on the data.

2.2.5 Summary of Pollution Distribution

The distribution of air pollutants has a range of implications when attempting to measure the concentrations of pollutants in a city. There are many contributing factors to the distribution of air pollutants, including the type of source, the emission control of the source, distance from source, and the meteorology effects once the source releases the pollutant. The distribution of pollution will affect the ability of people to limit the health effects caused by these pollutants. The possible health effects of particulate pollutants are discussed in Section 2.3.

2.3 - Health Effects

From the 1970's to 1990's, there was a transition from petrol-driven to diesel-driven vehicles throughout Europe (Dockery & Pope, 1994). This switch has negatively affected global climate change, in addition to increasing air pollution concentrations to alarming levels in many European locations (Dockery & Pope, 1994). Mobile source emissions and their subsequent secondary products described in Section 2.2.2 are becoming more prevalent and affecting people in subtle but life-threatening ways.

Those at higher risk to develop complications from direct exposure to particulate matter are children, elderly, and those with preexisting conditions (Commission, 2007). Particulate matter affects children developmentally, particularly concerning lung function, while elderly suffer intense immediate effects such as dizziness, wheezing, and irritation of airways (Davies, Vlaanderen, Henderson, & Brauer, 2009).

2.3.1 Air Quality Baseline

The World Health Organization (WHO) has set up an Air Quality Index for Europe regarding a variety of different particulates and chemical compounds to reduce negative health effects ("Air quality guidelines," 2005). The Air Quality Index (AQI) is a set of tested and established guidelines based on the amounts and the duration of time a person can be exposed to a certain compound, while still being considered healthy. When conditions exceed these guidelines, exposed persons may experience short-term side effects as well as develop long-term conditions. The concentration of an air pollutant is given in micrograms per cubic meter air or $\mu g/m^3$. While there are no established guidelines for ultrafine particulate concentrations, high concentrations correlate with negative health effects. Thus, lower concentrations will be safest and cause least problems for citizens and children in Østerbro.

Particulate pollutants, the focus of this project, can be broken down into three categories: coarse, fine and ultrafine. Coarse particles are defined as PM_{10}; fine particles are defined as $PM_{2.5}$; ultrafine particles are defined as $PM_{0.1}$, with a diameter of less than 0.1 micrometers (Brunekreef, 2002).

Particulate size	**Annual mean**	**24-hour mean**
<10 µm	20 $\mu g/m^3$	50 $\mu g/m^3$
<2.5 µm	10 $\mu g/m^3$	25 $\mu g/m^3$
<0.1 µm	Not Established	Not Established

Table 2.3.a: WHO guidelines concerning different sizes of particulate matter ("Air quality guidelines," 2005)

2.3.2 Cardiovascular and Respiratory Effects

The most common immediate respiratory effects from inhalation of vehicular emissions are wheezing, dizziness, and irritation of airways. Long-term cardiovascular and respiratory effects largely depend on the size of particulate matter. Three general biological pathways shown in Figure 2.3.a, account for the majority of cardiovascular complications associated with inhalation of particulate matter.

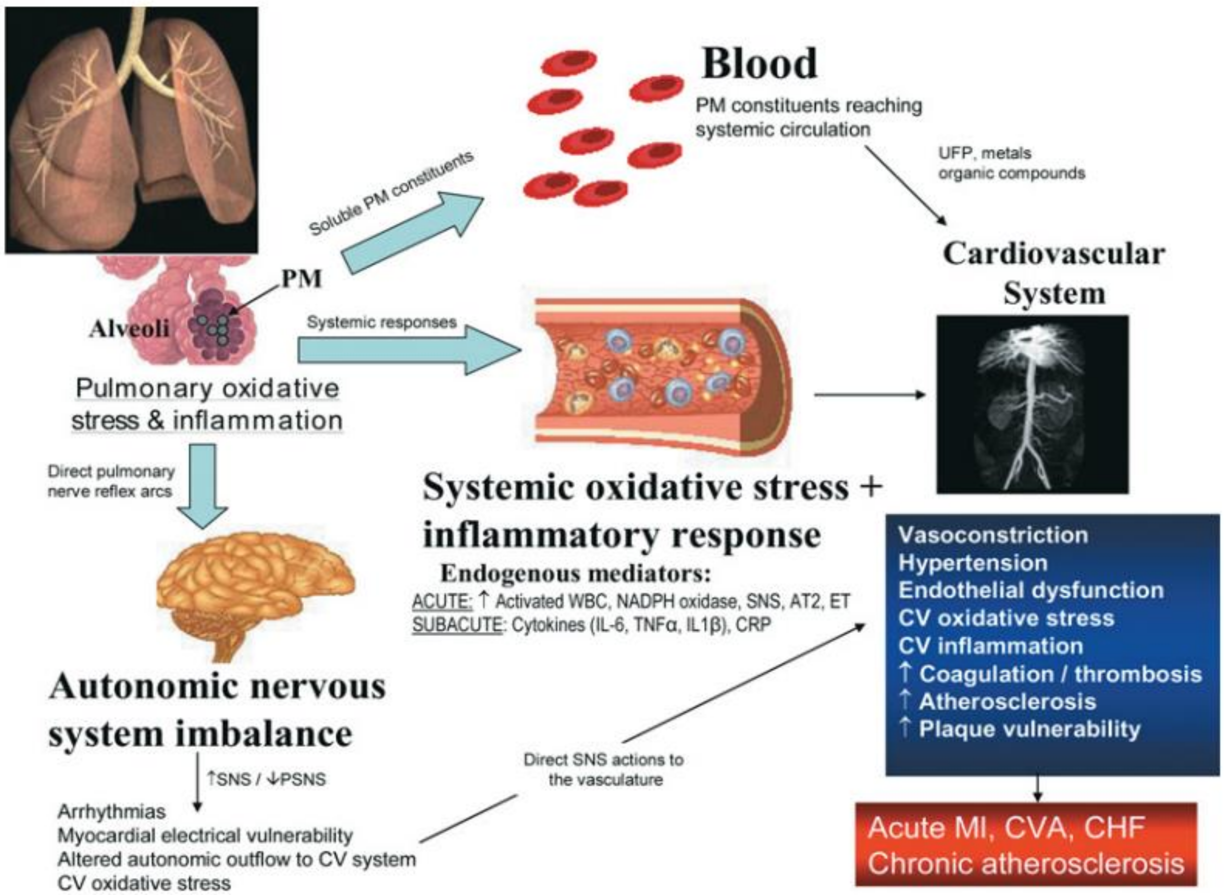


Figure 2.3.a: PM causing CV events via biological pathways (Brook, 2008). AT2, (angiotensin II); CVA, (cerebrovascular accident); CHF, (congestive heart failure); ET, (endo-thelins); MI, (myocardial infarction); ROS, (reactive oxygen species); UFP, (ultra-fine particles); WBC, (white blood cells)

$PM_{0.1}$ are small enough to enter the bloodstream when inhaled and circulate throughout the body systemically shown in the top pathway (denoted by the topmost shaded arrow) of Figure 2.3.a. Systemic circulation gives $PM_{0.1}$ direct contact with the body's vital support systems including the brain and can alter their functions even on a subcellular level; electron microscopy determined subcellular penetration and mitochondrial damage (Li et al., 2003, Burtscher, 2005). The damage to these cells can result in inheritable mutations (Burtscher, 2005).

The middle pathway of Figure 2.3.a shows systemic responses of particulate matter that is not small enough to enter the bloodstream. Coarse, fine, and ultrafine particulate matter cause systemic oxidative stress and inflammatory response in the body (Brook, 2008; Douglas, Haldane, & Haldane, 1912; Mills et al., 2008). Researchers link oxidative stress to diseases including cancer, Parkinson's disease, and Alzheimer's disease (Brook, 2008; Douglas, Haldane, &

Haldane, 1912; Mills et al., 2008). When the body exhibits an inflammatory response, white blood cell count increases to fight against the infection or irritation. High white blood cell count can result in hypercoagulability causing shorter prothrombin time (Barron et al., 2001). Prothrombin time, or PT, is the amount of time measured for blood to clot. Higher concentrations of PM_{10} have been associated with shorter PT (Baccarelli et al., 2007; Douglas et al., 1912). Shorter PT from hypercoagulability may lead to increased risk for blood clots to form in blood vessels called thrombosis (Bick & Ucar, 1992). Depending on the size and location of these blood clots, thrombosis can result in a wide range of complications including stroke, pulmonary embolism (blockage of lung artery), and may even require surgery to remove the clot (Decousus et al., 1998). As PM_{10} concentrations increase by 1 $\mu g/m^3$, hospital admissions for cardiovascular disease increase by 0.5% (Brunekreef & Holgate, 2002).

Particulate matter inhaled from vehicular emissions can damage small tissues and nerves of the lungs, affecting the autonomic nervous system, as indicated from the bottom pathway of Figure 2.3.a. The autonomic nervous system controls the body in many ways including the sympathetic nervous system (SNS) and parasympathetic nervous system (PSNS). PSNS activates when the body is at rest by keeping heart rate and blood pressure low. When SNS activates, the body prepares to fight by increasing heart rate and blood pressure ("Nervous and Endocrine Systems," 2008). If SNS triggers unnecessarily, it creates an imbalance of the PSNS and SNS states. The damage from particulate matter triggers SNS and causes cardiovascular conditions such as arrhythmia, vasoconstriction, and hypertension (Brook, 2008).

$PM_{0.1}$ has the strongest correlation between exposure and respiratory complications than any other particulate matter size (Toxicology in Ultrafine, 2000; Pope et al., 2004). Short-term exposure at urban levels to $PM_{0.1}$ causes acute artery vasoconstriction (Toxicology in Ultrafine, 2000; R. D. Brook et al., 2002). This directly results in acute cardiac events and demonstrates the severity of complications that can arise from exposure to these particulates, even for a short duration of time (R. D. Brook et al., 2002). Systemically affecting the human body and directly damaging other organs as well as lungs and heart makes $PM_{0.1}$ the most concerning particulate size in regards to human exposure.

2.3.3 Why are Children High Risk Individuals?

Children are high priority and high-risk individuals concerning air pollution. A study conducted in Southern California analyzed the association between long-term exposure to ambient air pollution and the growth in lung function over an eight-year period. The study found a strong correlation between $PM_{2.5}$ inhalation and a clinically low forced expiratory volume in the first second (FEV1) as well as an increased risk of respiratory conditions that can cause complications and death later in adulthood (Gauderman et al., 2004). All three types of particulate matter are associated with a decline in morning pulmonary expiratory flow (PEF). Short-term increases in ambient air pollution increase mortality and morbidity in adults, children, and fetuses.

Another study assessed in utero exposure to air pollutants and found that early childhood exposure plays a role in the development of asthma (Clark, Demers, & Brauer, 2010). The environment in which a child develops influences their growth. In addition to experiencing the adverse effects listed in Section 2.3.2, children are also more susceptible to developing long-term effects than adults. Children are more active than adults and often mouth breathe as opposed to nose breathing (Burtscher, Schuepp, 2012). Breathing through the nose filters the air and decreases the amount of particles deposited in the lungs. Children's increased breathing rate in combination with mouth breathing deposits particles more frequently and deeper in the respiratory system than adults (Burtscher, Schuepp, 2012). Limiting a child's exposure to these particulates benefits their growth by promoting a healthier and longer life.

2.3.4 Summary of Health Effects

There are many possible health effects caused by particulate pollutants, focused in the cardiovascular and respiratory systems. Children are at highest risk of developing long term effects from extended exposure to high concentrations of particulates, and elderly are more likely to experience aggravation of existing conditions. There are currently no guidelines for ultrafine particulates and minimal advice on how to avoid exposure. The information presented in this section explains the importance of researching ultrafine particulate concentrations and finding better ways to avoid contact with these pollutants.

2.4 - Summary

Danes consider air pollution to be the most important environmental issue. While the Danish government has plans that will ultimately reduce air pollution concentrations caused by vehicular emissions, the construction required to implement these plans will increase air pollution concentrations. Østerbro is one of the main areas in the construction phase of the Cityringen plan. Due to the large population of children in Østerbro, residents are concerned about air pollution concentrations in the district and the health risks posed to the children. When compared to other particulate pollutants, ultrafine particulates pose the greatest adverse health effects, especially for at-risk individuals, such as children. Currently there is no data for ultrafine particulate concentrations in Østerbro. The team aimed to provide information about particulate concentrations near schools to Miljøpunkt Østerbro.

CHAPTER 3 - GENERAL METHODOLOGY

The project, a collaborative effort between Worcester Polytechnic Institute and Miljøpunkt Østerbro, helped minimize negative health effects caused by exposure to ultrafine particulates by increasing awareness of air pollution in the Østerbro district. The team achieved this goal by completing the following objectives:

1. Record ultrafine particle (UFP) concentrations in conjunction with observations of:
    a. Weather
    b. Traffic events
    c. Other potential data anomalies
2. Arrange the air pollution data in chart form
    a. Compare pollution concentrations against time and distance
    b. Explain outlying data with observations 1.a-1.c
3. Use analyzed data to:
    a. Support advocacy for better habits and emission regulations in Copenhagen
    b. Provide suggestions on how to avoid high concentrations of UFP
    c. Provide all suggestions to Miljøpunkt Østerbro
4. Display information for public view, using an article released by Miljøpunkt Østerbro

3.1 - Measurement of Pollution

The Miljøpunkt Indre provided the P-Trak Ultrafine Particle Counter (UPC) to the team, shown in Figure 3.1.a. The device measures the average concentration of ultrafine particulates every second. For increased data integrity, the team estimated each measurement would take 20 minutes to limit variables, such as weather, from skewing the data. This created 1,200 data points per session, allowing for a maximum of 24 measurements in an eight-hour period. The P-Trak device is unable to measure for more than eight consecutive hours and re-

Figure 3.1.a: P-Trak UPC (TSI Incorporated, 2013)

quires two hours to recharge the alcohol cartridge before taking further measurements (TSI Incorporated, 2013).

The two main roles in the observation and measurement process were the device manager and the observer. The device manager prepared the device for measurements, kept the device at a constant height of one meter above the ground during measurement, and announced measurement extremes on the readout to the observer. Preparation of the device included several steps. The P-Trak device uses 99% isopropyl alcohol to allow its enclosed laser to measure the ultrafine particulates. Before use, the device manager transferred the alcohol cartridge from the holding capsule to the device. The device manager checked the battery level, set the device to measure one-second averages and waited 60 seconds before recording measurements. A measuring tape was unavailable during the measurement process so the team used the device case, approximately one meter in length, to maintain a constant height. To estimate the distance from the location the team used a pace count. One team member knew their pace count before the project, the process of calculating pace count is available in Appendix L. The team designated one team member to measure the distances for every location to limit variability. The P-Trak device has a real-time readout on its screen. Anytime a measurement exceeded the background average of 10,000 particulates/cm^3, the device manager told the observer. The typical background average in Copenhagen is 10,000 particulates/cm^3. The Danish ECO Council representative presented this information to the team.

The observer role, comprised of one to three team members, managed the time and recorded relevant observations. Weather observations included humidity, wind speed, and temperature. The team recorded these observations to explore trends and minimize variables between data sets with similar weather conditions. The team also recorded smokers, cars, and construction. All observational data included the time and location to allow for comparison with the UPC data, and made it possible to explain spikes in pollutant concentration. For proper analysis, it was important to understand the reason for extremes in pollutant concentration, as well as determine any possible trends.

3.2 - Analysis of Data

The team recovered the data from the P-Trak device after each measurement by transferring the information from the device to a computer. The software output the measurements in a Microsoft Excel spreadsheet. The spreadsheet organized the data with the location name, time, date, and average number of particulates per second. One team member removed explainable anomalies unrelated to the measurement focus, such as cigarette smoke. The team member also calculated the average for every minute of measurement to reduce the number of data points for display and calculated the overall average across the 20 minute time period.

CHAPTER 4 - METHODOLOGY I: TRAFFIC MEASUREMENT

Upon arrival in Copenhagen, the project focused on traffic and the avoidance of air pollution. The project planned to provide a comprehensive map of the pollutant concentrations throughout the district, allowing commuters to choose routes with lower pollutant concentrations, thereby limiting the health effects they experience. Before the initial measurements, it became clear that the amount of data required to sufficiently display safe routes through Østerbro was infeasible during the allotted time for the project. Miljøpunkt Østerbro instead suggested focusing on traffic near schools and children as opposed to commuters, reducing the required amount of data. The team measured near schools with the intention of showing the effect of rush hour traffic on the concentration of ultrafine particulates when students arrive to school.

4.1 - Areas of Data Collection

Miljøpunkt Østerbro is concerned with negative health effects to children caused by exposure to air pollutants. As discussed in Chapter 2, children are high-risk individuals and are more susceptible to developing long-term complications. Miljøpunkt Østerbro provided a list of grade schools, gymnasiums, and high congestion areas and their corresponding addresses. The team created a map of Østerbro with the locations using Google Maps, as shown in Figure 4.1.a. The common names of the locations and naming scheme are presented in Table 4.1.a. The singular letter in Figure 4.1.a marks the exact location.

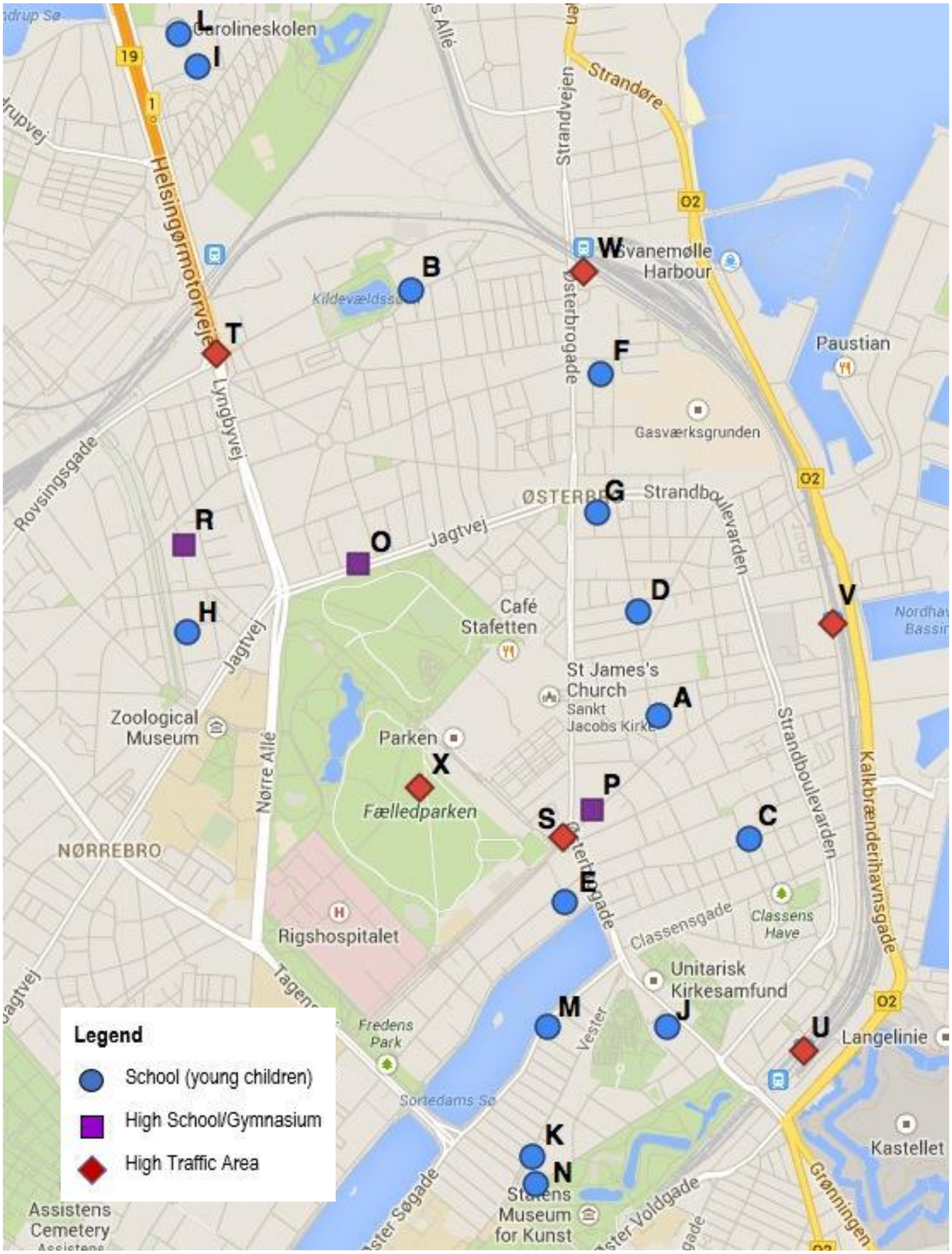


Figure 4.1.a: Map of Measurement Locations

Point	Name of Location
A	Heibergskolen
B	Kildevældskolen
C	Langelinieskolen
C	Skolen på Strandboulevarden
D	Randersgades Skole
E	Sortedamskolen
F	Strandvejsskolen
G	Vibenshus Skole
H	Nørre Fælled Skole
I	Bjørns Internationale Skole,
I	Østerbro lilleskole
J	Institut Sankt Joseph
K	Øbro friskole

Point	Name of Location
L	Carolineskolen
M	Bordings friskole
N	Krebs' skole
O	Niels Stensens Gymnasuium
P	Ingrid Jespersens Gymnasieskole
R	Københavns Private Gymnasium
S	Trianglen
T	Lyngbyvejen
U	Østerport station
V	Nordhavn station
W	Svanemøllen station
X	Fælledparken

Table 4.1.a: Names of locations and corresponding letter

4.1.1 Schools

The primary focus of pollutant concentration measurements was schools. The team's initial plan was to take measurements at 16 grade schools and three gymnasiums in various areas of Østerbro on both major and minor roadways. The grade schools begin at 8:00 and many students arrive by car (Lene Midtgaard, personal communication, 2014). The cars around this time, as well as rush hour traffic in the area, create a negative environment for student health. Miljøpunkt Østerbro wanted to display the concentration of pollutants that the students are exposed to when arriving at school. To ensure there were no misunderstandings, the team acquired permission to measure on the grounds of each school prior to taking measurements.

4.1.2 High Congestion Areas

The second focus area of the project was major roadways because they experience the greatest increase in vehicular traffic during rush hour times. The largest roadway in Østerbro is Helsingørmotorvejen, a three-lane highway leading into Østerbro from the north (Lene Midtgaard, personal communication, 2014). The Helsingørmotorvejen was a point of interest when measuring pollutant concentrations because of the high amount of traffic it brings into the district. The team focused on the Trianglen area for similar reasons. Trianglen has six bus stops and vehicular traffic, the combination of buses and vehicular traffic causes congestion and increases pollution concentrations, exposing bicycle and pedestrian commuters to high concentrations of pollution concentration (Lene Midtgaard, personal communication, 2014). Families frequent Fælledparken, a centrally located park in Østerbro. The team took measurements at Fælledparken because of the high level of human congestion. Fælledparken also served as a basis for background pollution concentrations in Østerbro, as it was the most removed from pollutant sources. By measuring at Helsingørmotorvejen, Trianglen, and Faelledparken, the team planned to assess the severity of the health effects experienced by the residents and commuters in the Østerbro district.

4.1.3 Train Stations

The final areas of interest were train stations, specifically the S-Tog. The area in and around the stations experience high levels of commuter congestion and vehicular traffic. All of the stations in Østerbro were at the intersection of large, heavy traffic roads. The team placed focus on the Østerport, Nordhavn, and Svanemøllen stations because they were the largest stations in Østerbro.

4.2 - Times of Data Collection

As stated in Section 3.1, each measurement took 20 minutes. The team used this number to estimate the number of measurements possible. To estimate the total time available to measure, team considered rush hour length, rain days and Danish holidays. Copenhagen rush hour traffic occurs at approximately 7:00-9:00 and 15:00-17:00, Monday through Friday allowing four hours of rush hour measurements per weekday (Lene Midtgaard, personal communication, 2014). The P-Trak device is unable to take measurement in the rain so the team estimated one rainy day per week based upon past weather in Copenhagen. In the planned four-week measurement period, the team estimated 18 days where it was possible to measure rush hour pollution. Miljøpunkt Østerbro's request to measure when student arrive at school limited school measurements to the morning. To maximize the total number of measurements the team took measurements at schools in the morning and the remainder of the locations in the afternoon. The number of schools in combination with the projects allotted time prevented multiple measurements at each school. The remainder of the locations did not have a measurement time restriction and the team planned to measure each location a maximum of three times over the four-week period.

The team took measurements at off peak times to establish a baseline of air pollution concentrations in Østerbro, the locations are outlined in Figure 4.1.a. The team compared baseline data to average and peak rush hour concentrations, and used it to establish the relative severity of possible health effects caused by traveling in rush hour traffic.

	MON	TUES	WED	THURS	FRI
MARCH	24	25	26	27	28
	8: L/I 11: L/I 13-15: R/T/O 15-17: R/T/O	8: B 11: B 13-15: U/V/W 15-17: U/V/W	8: F 11: F 13-15: X/S/P 15-17: X/S/P	8: H 11: H 13-15: R/T/O 15-17: R/T/O	8: G/D 11: G/D 13-15: U/V/W 15-17: U/V/W
APRIL	31	1	2	3	4
	8: A/C 11: A/C 13: X/S/P 15-17: X/S/P	8: E 11:E 13: U/V/W 15-17: U/V/W	8: M 11: M 13: X/S/P 15-17: X/S/P	8: J 11:J 13: R/T/O 15-17: R/T/O	8: K/N 11: K/N 13: U/V/W 15-17: U/V/W
	7	8	9	10	11
	13: R/T/O 15-17: R/T/O	13: X/S/P 15-17: X/S/P	13: U/V/W 15-17: U/V/W	13: R/T/O 15-17: R/T/O	13: X/S/P 15-17: X/S/P

Table 4.2.a: Schedule of tentative measurement times and locations

The schedule in Table 4.2.a outlines the tentative measurement times and locations. Letters in Table 4.2.a are locations corresponding to Table 4.1.a and Figure 4.1.a. The team excluded Saturdays and Sundays from the schedule because schools were closed and rush hour on the weekends was not as consistent. The team grouped locations in close proximity to ensure the maximum amount of measurements could be taken during rush hour. The team planned to take measurements from March 24th to April 4th, with the week of April 7th set aside for rain days. If time allowed, and the team did not use rain days, the team planned to take additional measurements at the high congestion locations. The data collected from these measurements is analyzed in Chapter 5.

CHAPTER 5 - ANALYSIS I: TRAFFIC DATA

The team followed the schedule outlined in Table 4.2.a for the first week of measurement and measured at Kildeværdskolen, Nørre Fælled Skole, Østerbro Lilleskole, Trianglen, Lyngbyvejen, and Fælledparken. Unexpected issues, such as receiving the device late and numerous rain days, caused the team to not to measure as often as the schedule suggests. The team's unexpected results discussed in this chapter ultimately changed the focus of the project.

5.1 - Correlation of Traffic and Pollutant Concentration

Early measurements were consistently inconclusive in relating traffic to the number of ultrafine particulates in the air, as seen in Figure 5.1.a. Figure 5.1.a shows the average number of particulates at both rush hour and non-rush hour times at Trianlgen. The observed measurements are below the baseline value and do not show a significant difference in measured concentrations. Though there were more spikes during rush hour times, there was a minimal increase in the average concentration of UFP. Since sustained exposure to particulates causes harmful health effects, the average value is the most important. This data was largely inconclusive from a traffic standpoint, as there was negligible difference in average pollutant concentration between the two times.

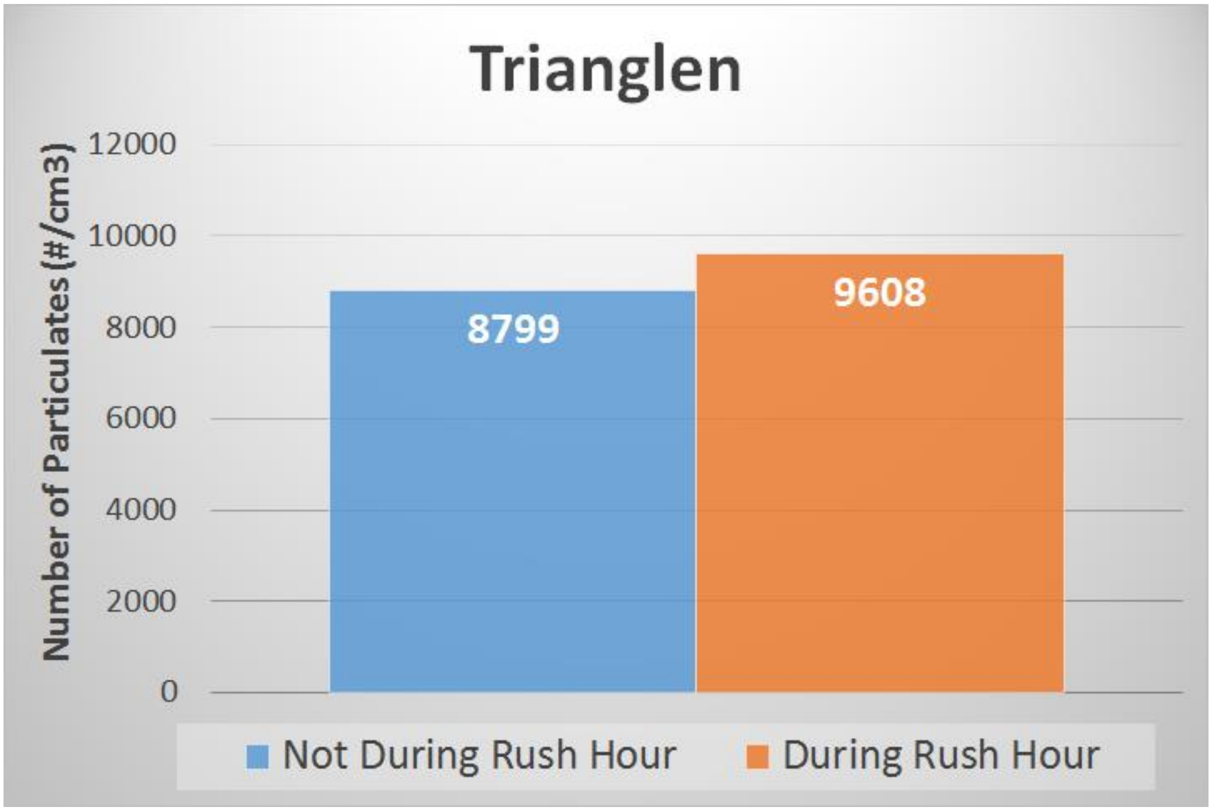


Figure 5.1.a: Graph showing the average number of particulates versus time for rush hour and non-rush hour times at Trianglen

The team reviewed the graphs and compared them to the observational data. This review connected locations near construction sites with higher average concentrations of ultrafine particulates than locations without. Figure 5.1.b shows that the Trianglen metro construction site in Fælledparken (location S, Figure 4.1.a) had an average number of particulates more than double the average number of particulates of in Fælledparken (location X, Figure 4.1.a) without construction. The team's examination of observational data showed that several schools were near construction sites and the construction vehicles idled when students arrived at school. The team compared the graphs in Figures 5.1.a and 5.1.b and concluded that the difference between rush and non-rush hour times is not significant but the difference between construction and non-construction is significant.

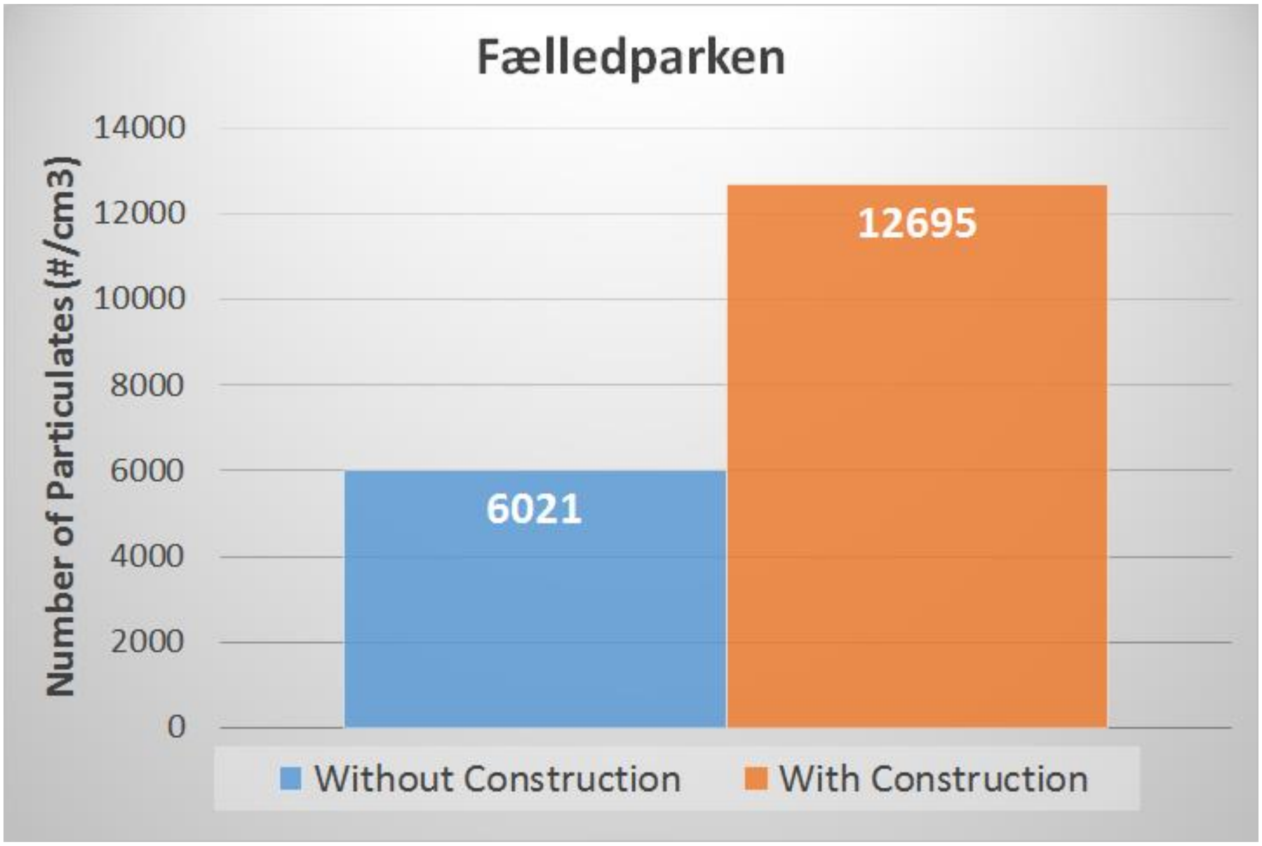


Figure 5.1.b: Graph showing the average number of particulates versus time for construction area and no construction area in Fælledparken

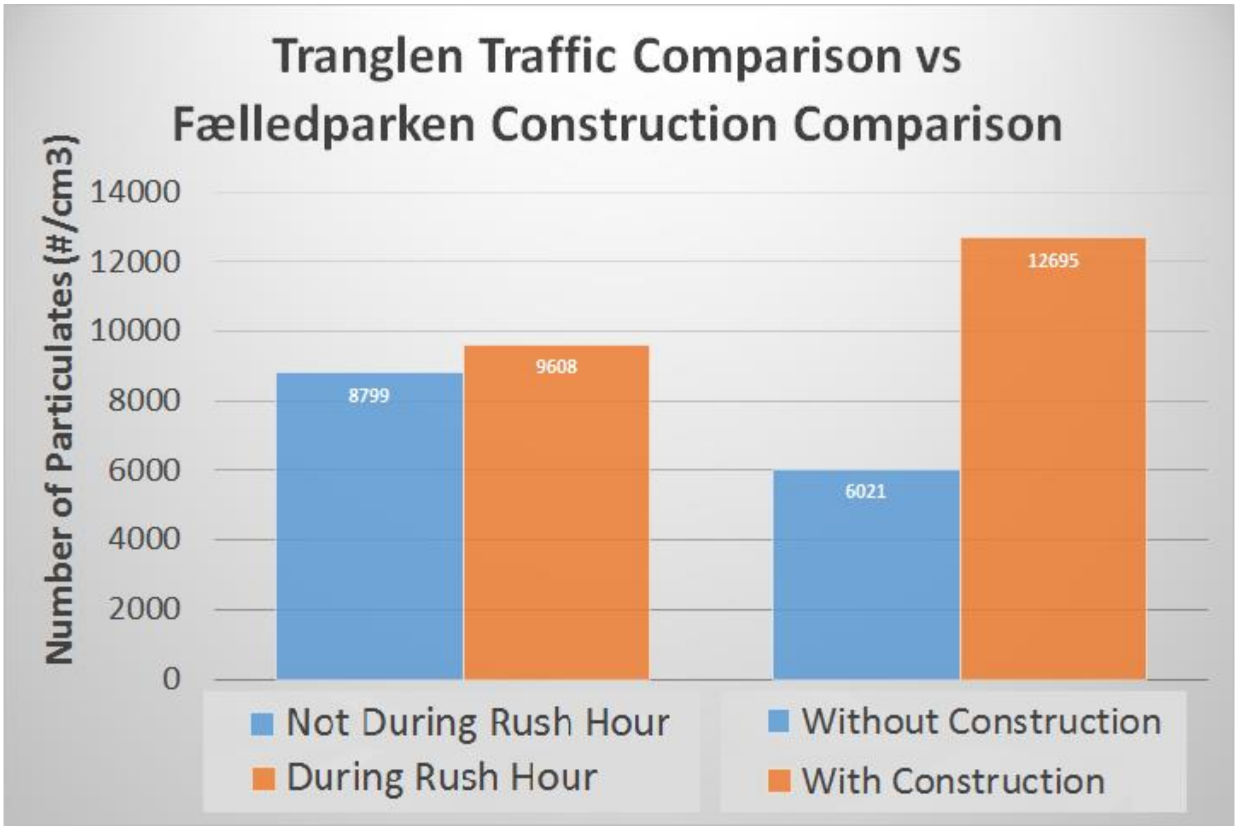


Figure 5.1.c: Graph showing the average number of particulates versus time for construction area and non-construction areas in Fælledparken and rush hour and non-rush hour time at Trianglen.

5.2 - Conclusion

The team's analysis of initial traffic measurements presented a reason to shift the project's focus from traffic to construction. The traffic data analysis showed no significant correlation between high traffic and high concentrations of pollutant. The data also showed higher concentrations of ultrafine particulates near construction sites and idling construction vehicles when students arrived at school.

CHAPTER 6 - METHODOLOGY II: CONSTRUCTION MEASUREMENT

The team brought the information seen in Chapter 5 to the attention of Miljøpunkt Østerbro with the suggestion of moving the project's focus away from traffic to construction sites. The team created the following hypotheses:

1. Areas near construction sites consistently have a higher average UFP concentration than areas without
2. Increasing distance from construction sites correlates with an exponential decay of UFP concentration
3. Solid barriers encompassing a construction site drastically decrease UFP concentration in close proximity to the site and moderately decrease overall

The majority of the reasoning behind the hypotheses derived from research and the team's traffic measurements. The team hypothesized that areas near construction sites would have a higher average UFP concentration than areas without because the measured concentrations near Fælledparken construction were twice that away from construction. The team wanted to know if this was true for other construction sites. The team based their final hypotheses off research. Provided a constant rate of production of particulates, and a constant rate of removal from the atmosphere, then the concentration as distance increases will fall off exponentially to an equilibrium value (Stern, 1976). This reinforced hypothesis two. The team based their final hypothesis off the wind canyon in a street phenomenon discussed in Chapter 2.

6.1 - Areas of Data Collection

The team selected a new set of measurement locations after initial analysis, described in Chapter 5. The primary criteria for selecting locations were:

1. The sites' proximity to schools.
2. The size of the construction site
3. The existence of barriers around a site
4. A lack of potential interference, such as diesel vehicles

The purpose of the construction site size criterion was to limit the variability of the number of construction vehicles at each construction site ensuring more consistent data between locations. The barrier criterion was the result of the hypothesis that encompassing barriers will decrease ultrafine particle concentrations in close proximity to the construction site. The team based this hypothesis with the idea that the solid barrier would provide a similar environment to that in a street canyon, where the barrier is the windward side. This phenomenon states that air pollution concentrations on the leeward side of the street exposes pedestrians to much higher concentrations of pollution than the windward side. The barriers are solid and intentionally constructed to reduce noise pollution. The interference criterion was the result of diesel vehicles skewing the data, as seen in Section 5.1. The school criteria was at the request of Miljøpunkt Østerbro to understand the impact of air pollution on school children.

Two team members went to each location and recorded the school name and which criteria it followed. The team used these observations to reduce the number of locations from the 24 schools and high traffic areas selected during preliminary measurements to five, shown in Figure 4.1.a and 6.1.a respectively. The five locations included two schools in close proximity to construction, two schools without, and Fælledparken the site had barriers. The team created a map of Østerbro with the locations of the schools and the park using Google Maps, see Figure 6.1.a. The names of the locations are presented in Table 6.1.a. The team chose five measurement locations to maximize the remainder of the project's allotted time.

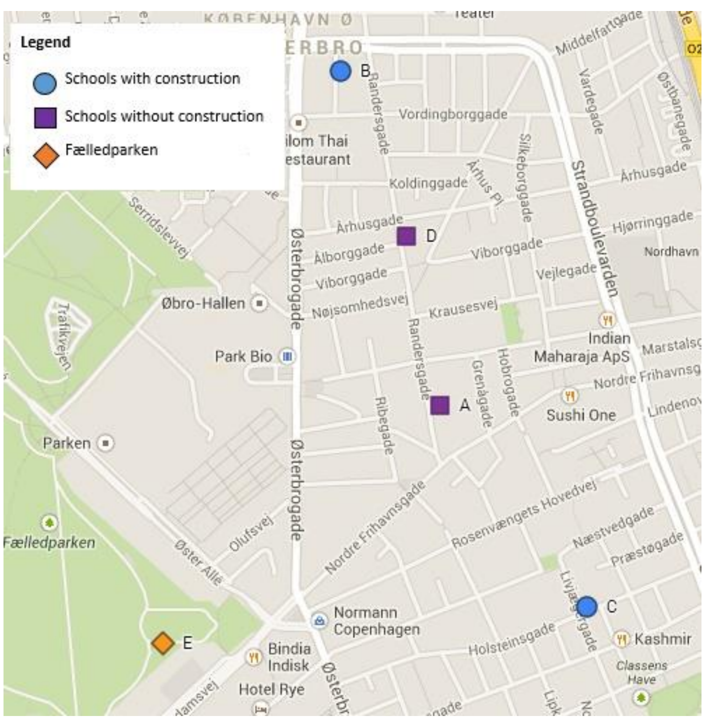


Figure 6.1.a: Map of Construction Measurement Locations

Point	Name of Location
A	Heibergskolen
B	Vibenshus Skole
C	Langelinieskolen
D	Randersgades Skole
E	Fælledparken (Construction)

Table 6.1.a: Names of Measurement Locations

6.1.1 Schools

Vibenshus Skole and Langelinieskolen, locations B and C from Table 6.1.a respectively, had active construction sites next to the school. Vibenshus Skole had fencing surrounding the construction site while Langelinieskolen did not have barriers or fencing, shown in Figures 6.1.b and 6.1.c. The team selected sites because of their similarly sized construction sites. Heiberg-skolen and Randersgades Skole, locations A and D respectively, did not have construction near-by, shown in Figures 6.1.d and 6.1.e. The team chose sites with and without construction in order to best support the hypothesis, which related construction to higher concentrations of ultrafine particulates.

Figure 6.1.b: Vibenhus Skole, partial view of construction in far right corner

Figure 6.1.c: Langelinieskolen with visible, active construction next to school

Figure 6.1.d: Heibergskolen, no construction

Figure 6.1.e: Randersgade Skole, no construction

6.1.2 Fælledparken

The final area of interest was Fælledparken. This park had an active construction site located at one end of the park near Trianglen. The construction site was larger than those near the schools and surrounded by a solid barrier. Fælledparken also had areas far from roads and construction, ideal for taking measurements with minimal variables. The team measured at the south end of Fælledparken to provide a measurement of a construction site with solid barriers, shown as E in Figure 6.1.a.

The team used measurements near the construction site to determine if barriers had an effect on the concentration of ultrafine particulates, see Figures 6.1.f and 6.1.g. The team measured at 1, 10, 50 and 100 meters to determine the distance which the barriers had a negligible effect. The data and analysis collected from these measurements are discussed in Chapter 7.

Figure 6.1.f: Faelledparken, location E, construction site with barriers

Figure 6.1.g: Faelledparken, location E, construction site barrier close up

6.2 - Time of Data Collection

The standard working hours for construction sites are 7:00 to 18:00 (Jensen, Personal Communication, 2014). The estimated measurement schedule, shown in Figure 6.2.a, explains when the team planned to take measurements; letters correspond with the locations in Figure 6.1.a and Table 6.1.a. The team took measurements from 9:00 to 17:00, with a two-hour break from 12:00-14:00 to allow the device to rest. To minimize travel time and maximize measurement time the team designated one day for each location. The maximum number of 20-minute measurements for each location was 12, three for each distance. The team scheduled rain days for the final week of measurements, from April 21st to April 25st, based on weather in March. Measurement times were more flexible than the times described in Chapter 4 because the measurements were not limited to rush hour.

	MON	TUES	WED	THIRS	FRI
MARCH	24	25	26	27	28
	Traffic Measurements				
APRIL	31	1	2	3	4
	No Device				
	7	8	9	10	11
	A	B	C	D	E
	14	15	16	17	18
	Easter Break				
	21	22	23	24	25
	Easter Break	Rain Days			Return Device

Figure 6.2.a. Estimated schedule of construction measurements

CHAPTER 7 - ANALYSIS II: TRAFFIC DATA

This chapter presents the results of the team's analysis of the ultrafine particulate concentrations related to construction in the Østerbro district. Section 7.1 reports the results of the measurements taken at each location and corresponding observations, including a discussion and comparison of the various measurements. Section 7.2 includes the team's suggestions based on the measurements and research that Miljøpunkt Østerbro will use.

7.1 - Graphical Representation of Data

The team used several graphs for each construction site to display data including: the average number of particulates over a 20-minute period versus distance from the construction site; the average number of particulates each minute for 20 minutes at each distance versus time; and the number of pollution spikes at each distance. A spike is any second above the acceptable baseline of 10,000 particulates/cm^3. The Danish ECO Council representative, Kåre Press-Kristensen, provided the team with an acceptable baseline of 10,000 particulates/cm^3. Pollution blown in from other Scandinavian countries causes baseline values to range between 6,000 and 10,000 particulates/cm^3 in baseline measurements.

The device manager downloaded the data for the graphs from the P-trak measurement device and exported it into Microsoft Excel, roughly 1,200 data points for each 20-minute measurement. As described in Chapter 3, the team removed explainable anomalies in the data before they processed it for graphical display. The team modified the remaining data for each 20-minute measurement in Microsoft Excel by taking the:

1. Average of all 1,200 data points
2. Average for every 60 data points, condensing the 1,200 points down to 20
3. Count of every point greater than 10,000 particulates.

Initial data and graphs displayed the data in a format that was difficult to read, see Appendix A-H. The team took averages to simplify and examine trends in the data, and used the modified data to create the graphs described in the following sections.

7.1.1 Minute Average versus Time

The team used the first set of graphs, one for each location, to approximate the shape of the data. These graphs provide 20 one-minute averages for each measurement and show the general shape of the data as well as any significant pollution spikes. The spikes are muted compared to the raw data and some smaller spikes are missed but these graphs provide a general representation of the overall data, and demonstrate the variability within the measurements.

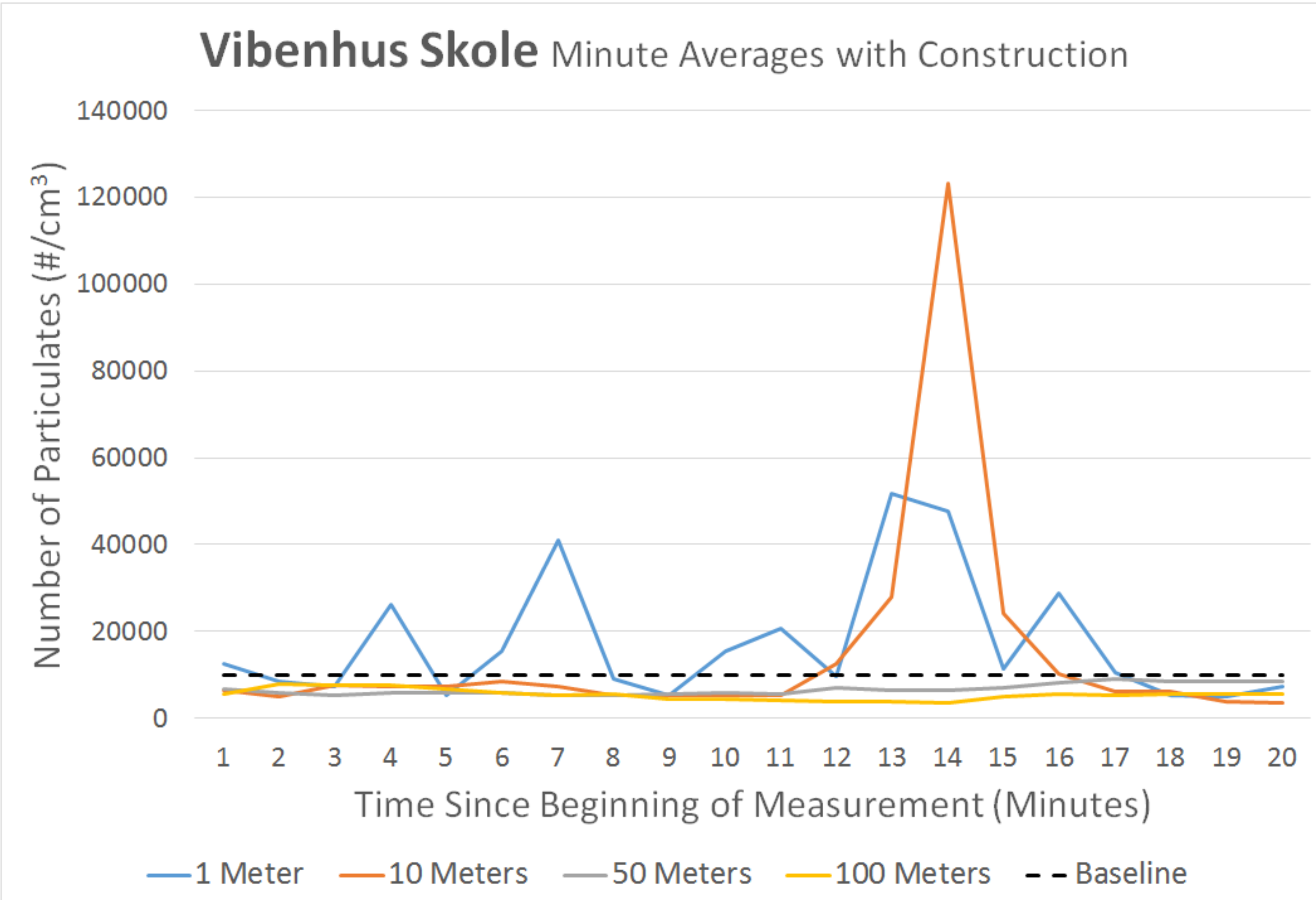


Figure 7.1.a: Graph showing the minute average versus time for each distance at Vibenhus Skole. For the table showing all minute averages for Viebnhus Skole, see Appendix A. For the graph of the second averages for 20 minutes, see Appendix B.

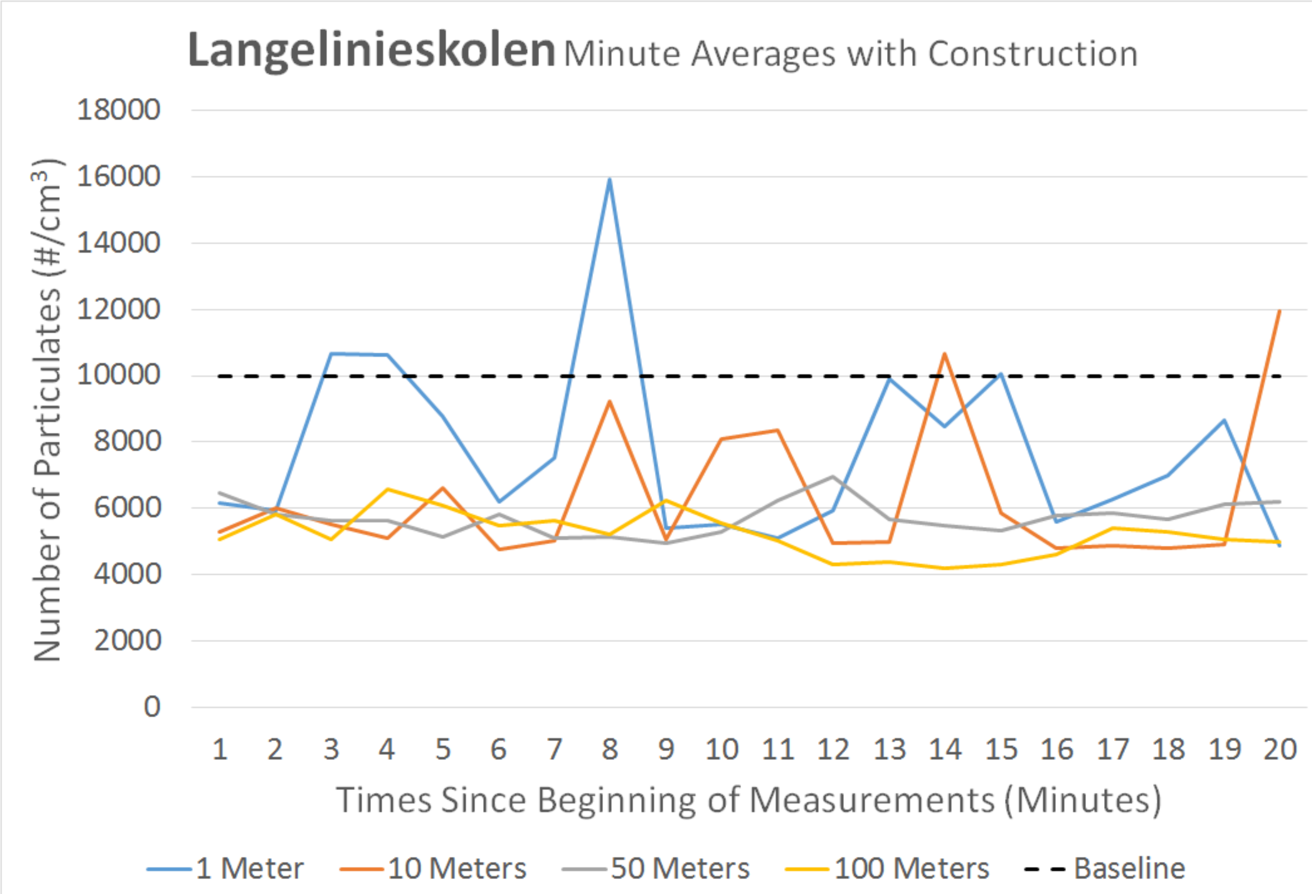


Figure 7.1.b: Graph showing the minute average versus time for each distance at Langelinieskolen. For the table showing all minute averages for Viebnhus Skole, see Appendix C. For the graph of the second averages for 20 minutes, see Appendix D.

Vibenhus Skole and Langelinieskolen have considerable spikes in particulate concentration and concentrations consistently above the acceptable background concentration of 10,000 particulates/cm^3, see Figure 7.1.a and 7.1.b. Construction sites had higher average values as distance decreases but they also had periods in which shorter distances have equal or lesser concentrations then further distances. Figure 7.1.a has a spike of 120,000 particulate/cm^3 from the baseline seen at minute 14, ten meters from the construction site. At that time and location, a large construction vehicle as seen in Figure 7.1.c drove directly past the P-Trak device, increasing readings to 350,000 particulates/cm^3 at its peak, see Appendix B. The large vehicle remained at its new location for the remainder of the measurement with the wind blowing the exhaust toward the device. Although these graphs show no distinct relation between concentration and time, the data for both locations supported the hypothesis that near construction sites, concentrations decrease as distance increases. Particulate concentrations versus distance for each location are further discussed in Section 7.1.2.

Figure 7.1.c: Large construction vehicle at Vibenhus Skole.

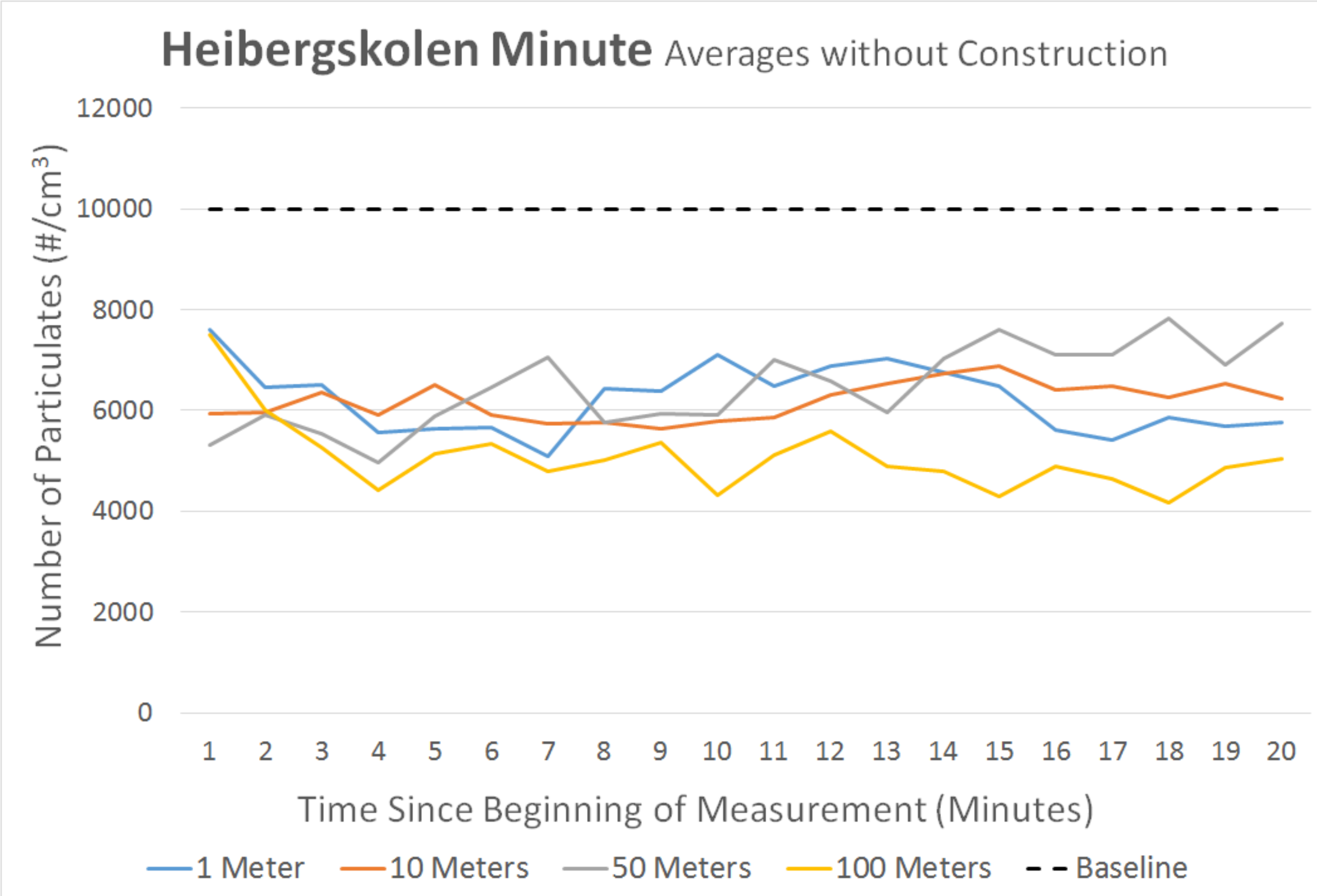


Figure 7.1.d: Graph showing the minute average versus time for each distance at Heibergskolen. For the table showing all minute averages for Heibergskolen, see Appendix E. For the graph of the second averages for 20 minutes, see Appendix F.

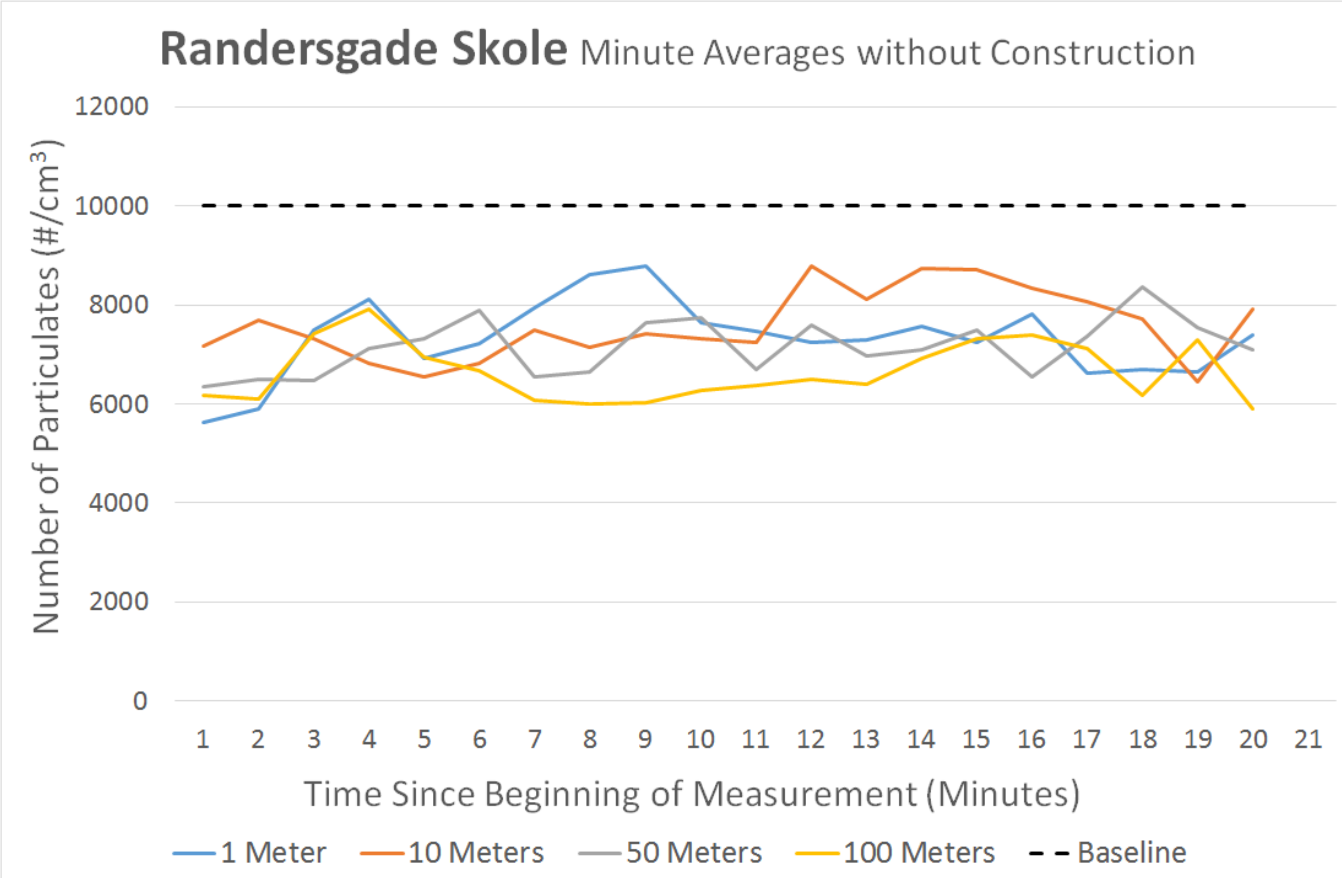


Figure 7.1.e: Graph showing the minute average versus time for each distance at Randersgade Skole. For the table showing all minute averages for Randersgade Skole, see Appendix G. For the graph of the second averages for 20 minutes, see Appendix H.

Figures 7.1.d and 7.1.e are graphs for Heibergskolen and Randersgade Skole, locations without construction. Unlike the schools with construction, Heibergskolen and Randersgade Skole had consistent concentrations across time and distance with no spikes exceeding 9,000 particulates/cm^3, see Figures 7.1.d and 7.1.e. The team used these graphs to check that ultrafine particulate concentrations at schools without construction fall below the baseline. There was no clear relation between distance and concentration of particulates, see Figures 7.1.d and 7.1.e. The relation between distance and particulate concentration is explored in Section 7.1.2.

The graphs presented in this section provided the general shape of the data and allowed for simple comparisons between measurement locations. The team used this information to understand the effect of construction on UFP concentrations and realized the importance of spikes in the data. The graphs and data in the following sections provided further analysis focusing on trends at each site or significant differences between sites.

7.1.2 Average Number of Particulates versus Distance

The team used the second set of graphs, one for each location, to compare the total average number of particulates against each distance. The graphs in this section showed the decrease in particulate concentration as distance from a construction site increases, and that there was no correlation between the distance from a school without construction and concentrations of particulates.

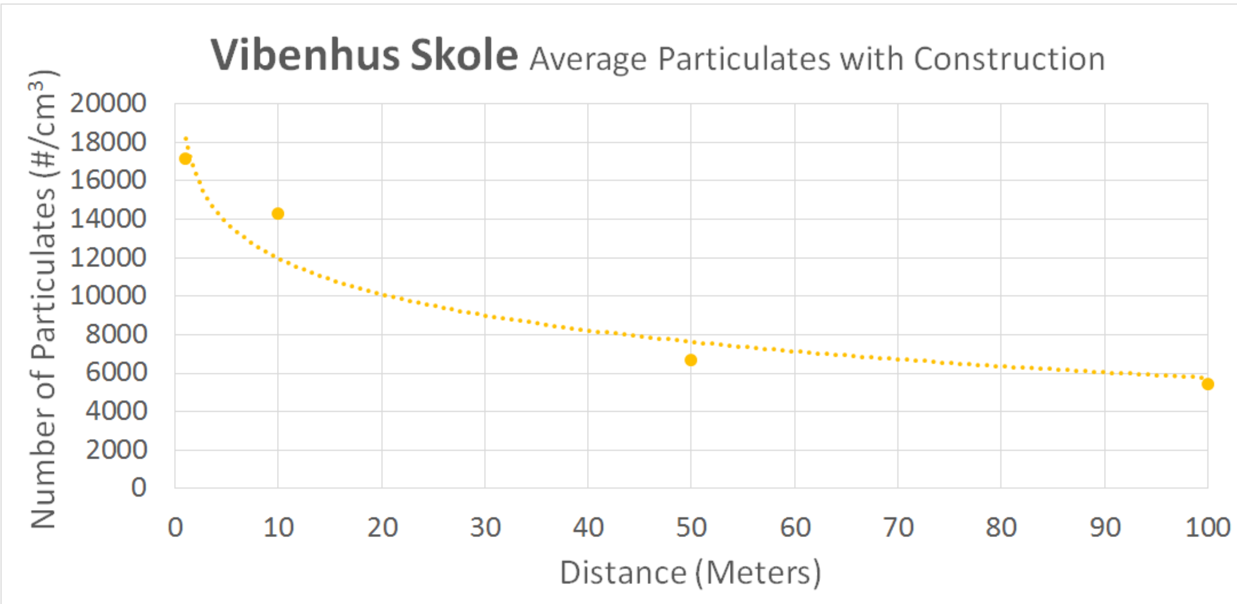


Figure 7.1.f: Graph comparing the average number of particulates for each distance at Vibenhus Skole.

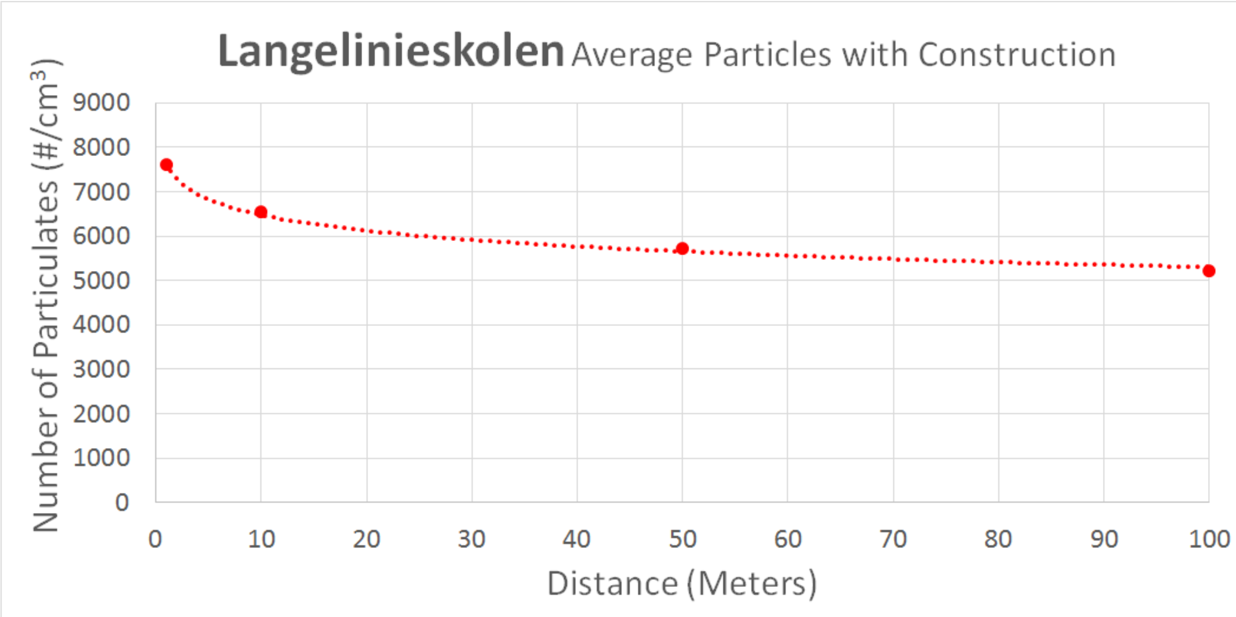


Figure 7.1.g: Graph comparing the average number of particulates for each distance at Langelinieskolen.

There was a clear decrease in average number of particulates as distance increases from the construction site, shown by the trends in Figures 7.1.f and 7.1.g. The team best modeled both figures as an exponential decay, which was consistent with the hypothesis that distance from a construction site would have a negative correlation to ultrafine particulate concentrations. The measurements indicated there was a safe distance from the construction site, see Figure 7.1.f. Ultrafine particulate concentrations do not have an established safe level and have significant negative health effects as concentrations increase, as explained in Chapter 2. For the purposes of this project, the team decided safe concentrations were less than or equal to the baseline. Averages for Vibenhus Skole, Figure 7.1.f, were 4,000 to 8,000 particulates/cm^3 above the baseline at one and ten meters while averages at 50 and 100 meters were below the baseline. This showed that a minimum safe distance from the site is 50 meters. The minimum distance will vary due to weather and site size.

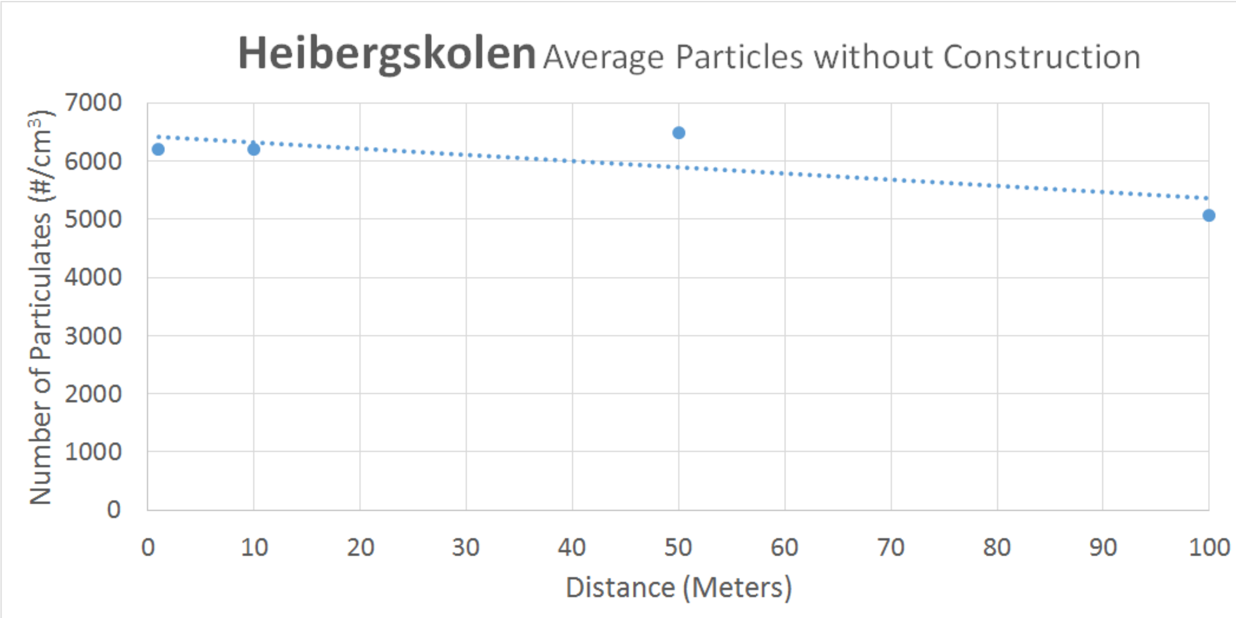


Figure 7.1.h: Graph comparing the average number of particulates for each distance at Heibergskolen.

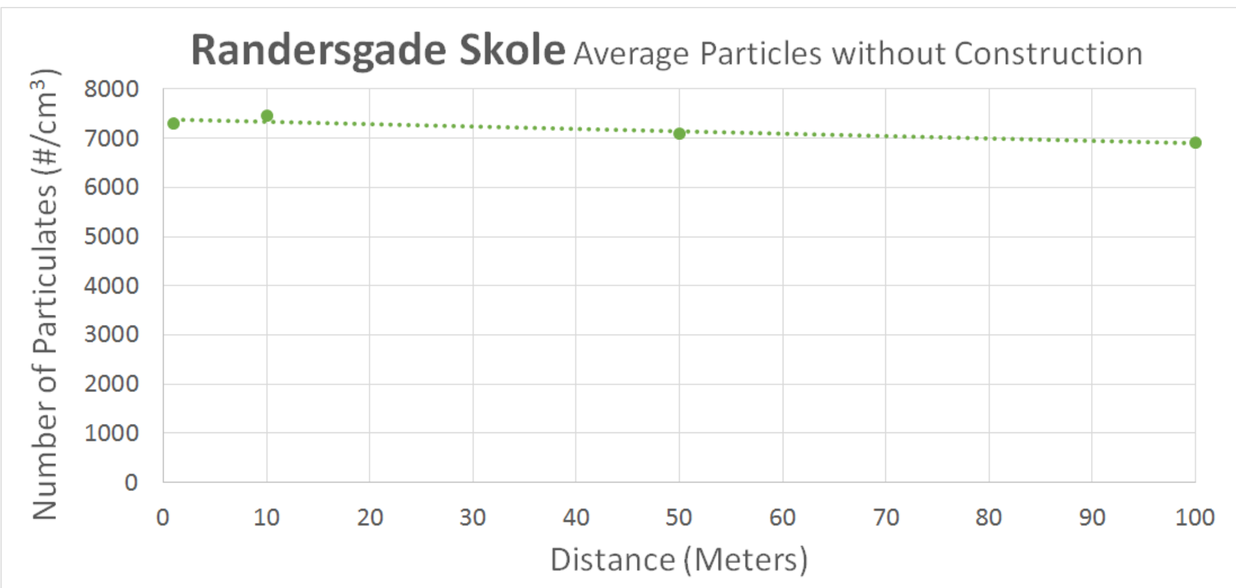


Figure 7.1.i: Graph comparing the average number of particulates for each distance at Randersgade Skole.

The average number of particulates was relatively consistent when there was no nearby construction, shown in Figures 7.1.h and 7.1.i. Higher concentrations of vehicles in different areas of the district, inaccuracy in the measurement device, or the meteorological effects discussed in Section 2.2.4 caused site-to-site variability. These variables caused the team to focus on trends.

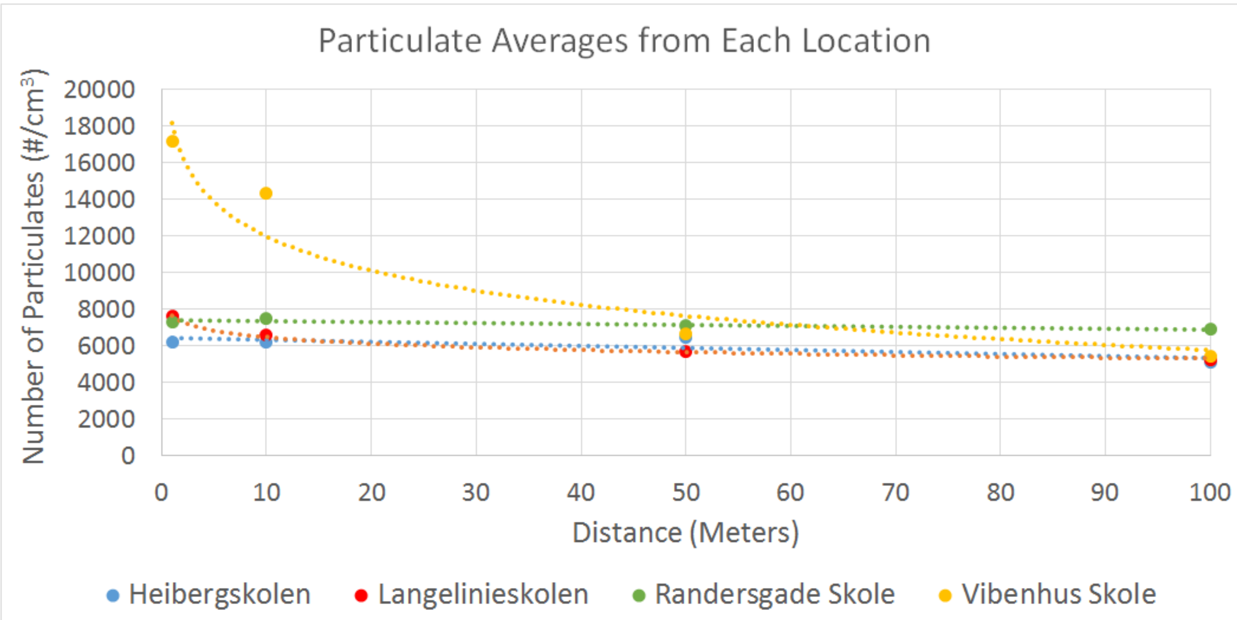


Figure 7.1.j: Graph comparing the average number of particulates for each distance at all schools.

For further comparison between locations, the team created a graph displaying the particulate average over distance for each location. Vibenhus Skole, denoted by the yellow, had a significantly higher average at one and ten meters. The difference in measured concentrations between Vibenhus Skole and Langelinieskolen was the result of more active construction at Vibenhus Skole.

The graphs in the section provided an initial basis to support the first two hypotheses. To further understand and support the first two hypotheses, the team created additional graphs comparing the number of spikes over distance, see Section 7.1.3.

7.1.3 Number of Spikes versus Distance

The next set of graphs compared the number of spikes per distance measured for each location. The team defined spikes as any second when the concentration was above 10,000 particulates/cm^3. The number of spikes indicated the variability of the original data and showed how often a site has concentrations of ultrafine particulates above normal concentrations.

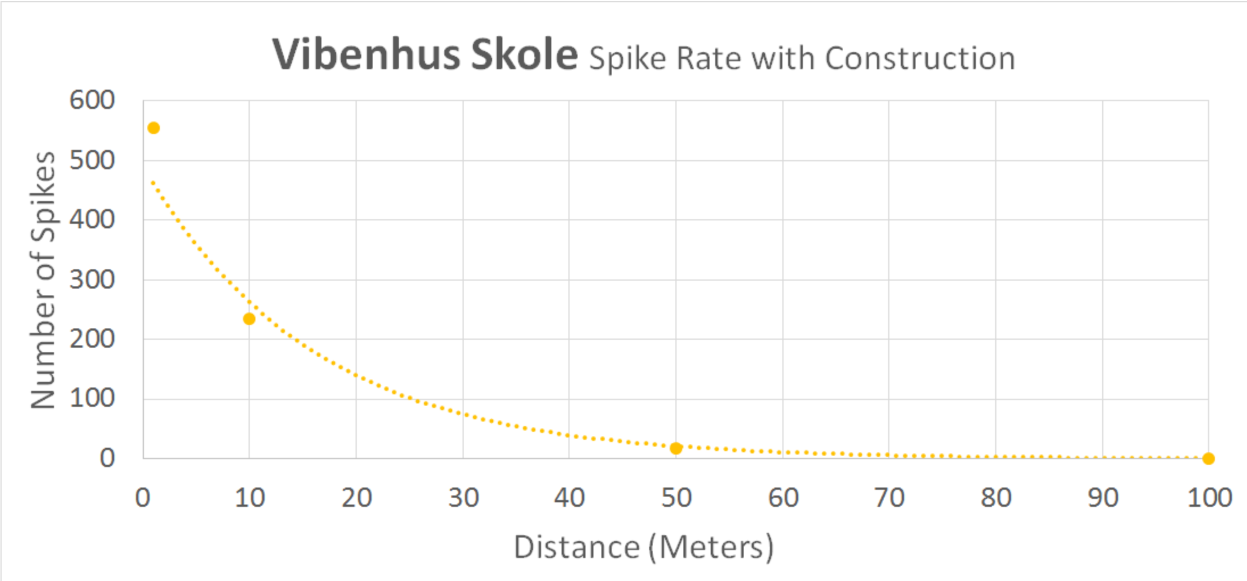


Figure 7.1.k: Graph of the number of spikes for each distance at Vibenhus Skole.

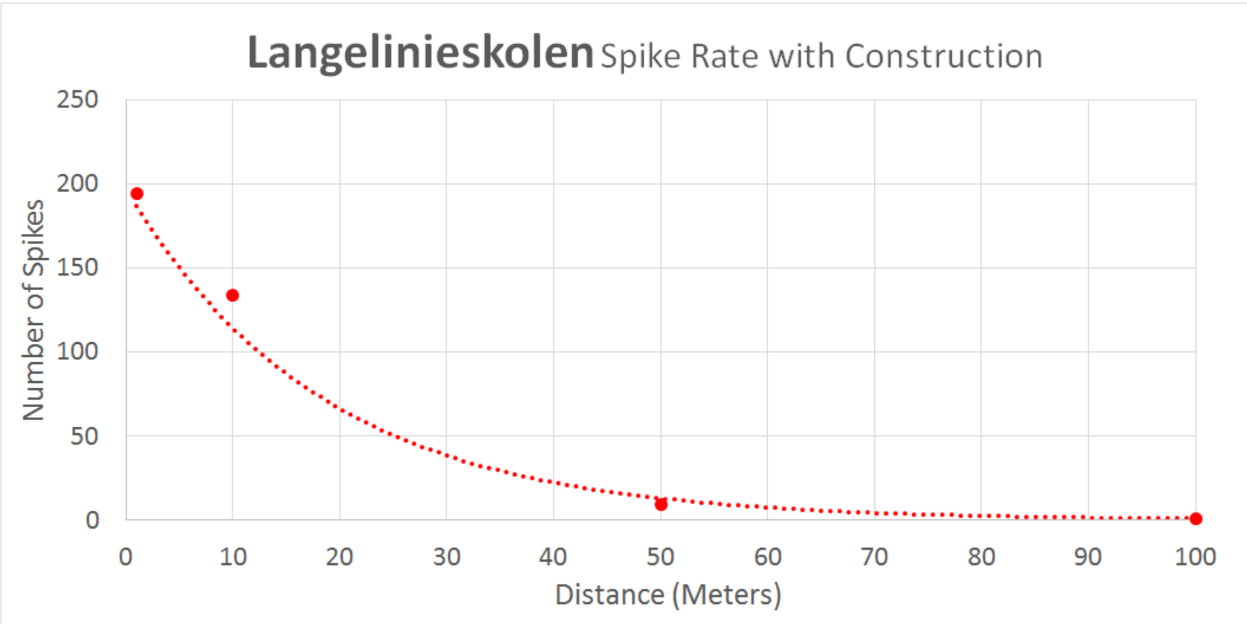


Figure 7.1.l: Graph of the number of spikes for each distance at Langelinieskolen

The schools with construction had a strong correlation between the number of spikes and distance from the site, see Figures 7.1.k and 7.1.l. The best model for the decay in these figures was an exponential decay. The schools with construction had significant decreases in concentration between 1 and 10 meters, and the largest decrease by 50 meters. This supported the hypothesis that the decrease would be exponential and the conclusion that 50 meters is a safe distance from a construction site.

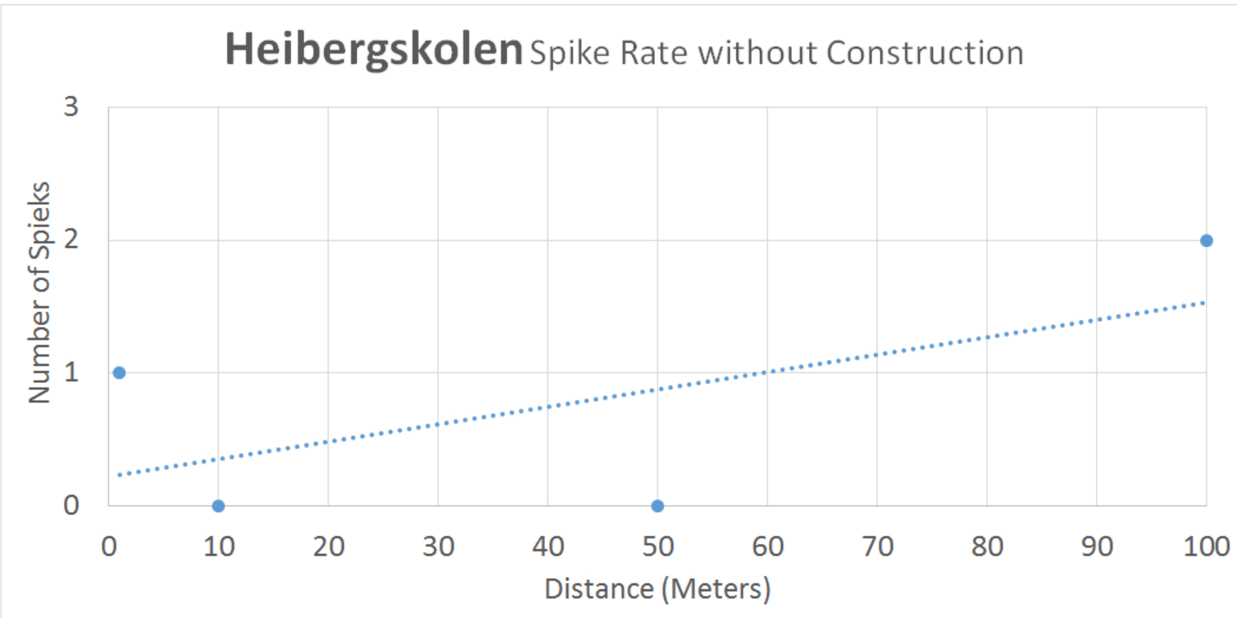


Figure 7.1.m: Graph of the number of spikes for each distance at Heibergskolen.

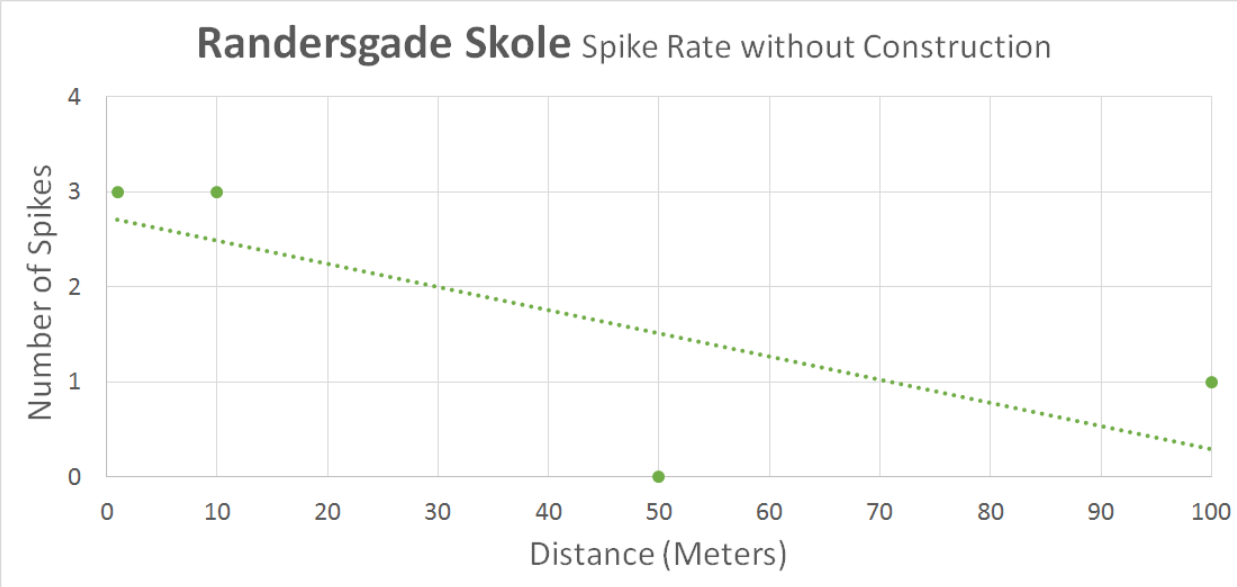


Figure 7.1.n: Graph of the number of spikes for each distance at Randersgade Skole

Heibergskolen and Randersgade Skole had consistently low numbers of spikes, see Figures 7.1.m and 7.1.n. The maximum three spikes for non-construction sites are considerably less than the 600 spikes near construction sites at the same distance. When compared to units of time, Langelinieskolen spent over three of 20 minutes at concentrations above normal background at one meter and Vibenhus Skole spent nearly half of the time above normal concentrations at one meter. This was a drastic difference from the sites without construction where they spent two or three seconds above normal baseline.

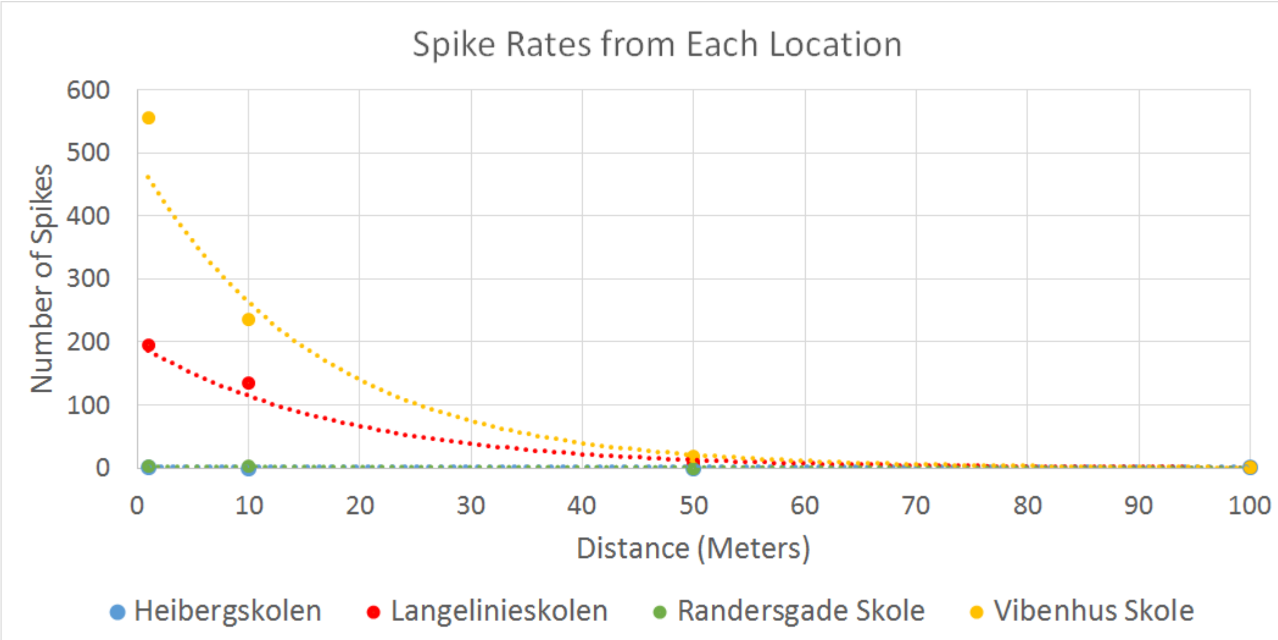


Figure 7.1.o: Graph of the number of spikes for each distance at all schools

The compiled graph of all spikes showed that construction sites have an impact on the surrounding area and individuals should avoid them.

7.1.4 Barrier versus No Barrier

The final graphs showed the average number of particulates at the Faelledparken site versus distance, as well as the number of spikes versus distance. The site had solid barriers seen in Figure 7.1.p. The team chose this site to study the effects of solid barriers on ultrafine particulate concentrations. The barriers reduce noise from the construction site, as well as provide a display of public art.

Figure 7.1.p: Faelledparken Construction Site Barriers

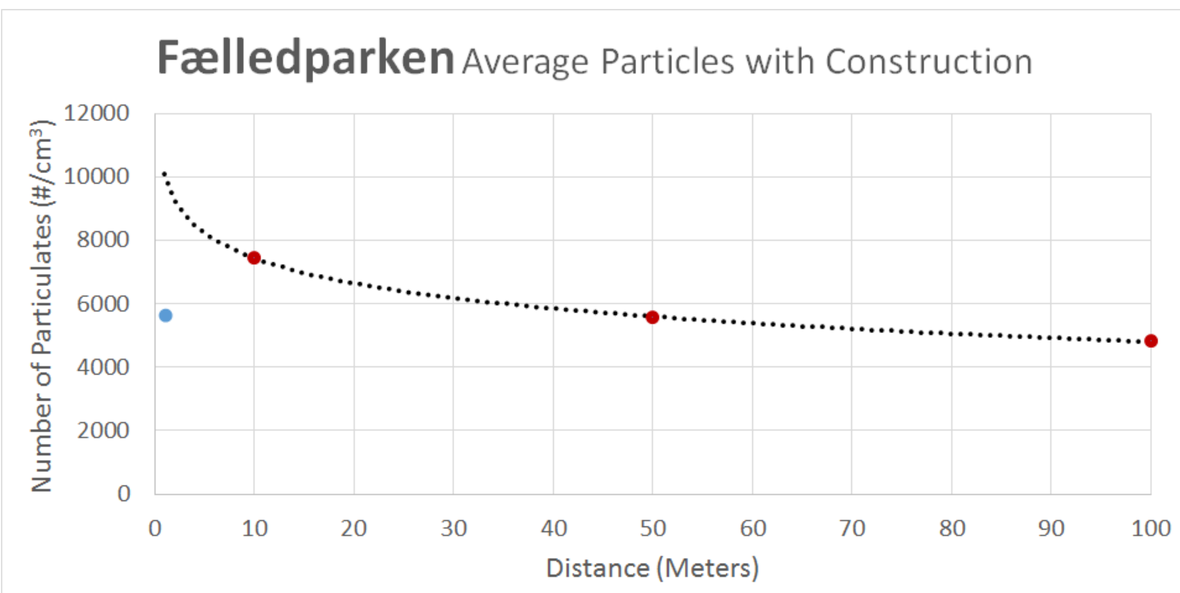


Figure 7.1.q: Graph of the average number of particulates for each distance at Faelledparken

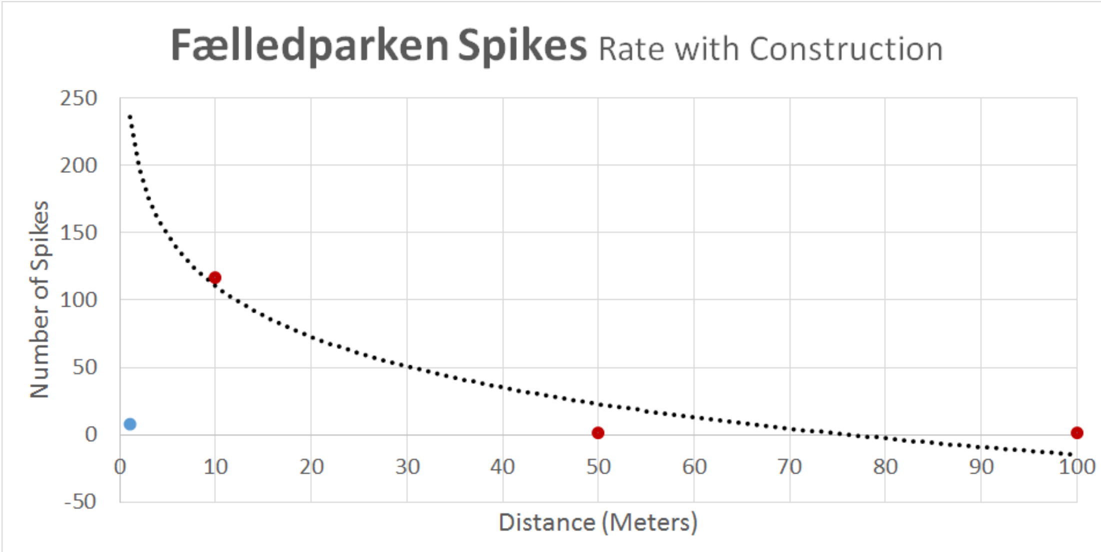


Figure 7.1.r: Graph of the number of spikes for each distance at Faelledparken

At a distance of one meter from the barrier, the average particulate concentration was approximately 6,000 particulates/cm^3 and near the measured concentrations in Fælledparken with no construction, Figure 7.1.q. Measurements at ten meters yielded concentration approximately 150% higher than the other measurements. The number of spikes at each distance shown in Figure 7.1.r supported Figure 7.1.q and showed a drastic increase from one to ten meters. The high variability in concentration at a distance of ten meters and the large number of spikes showed the impact of construction on the surrounding area, see Figure 7.1.r. The trend lines, represented by the dotted lines, seen on the graphs in Figures 7.1.q and 7.1.r did not include the one-meter point to approximate the concentration at one meter without a barrier. Based on the trend lines in Figures 7.1.q and 7.1.r, the concentration at one meter would be higher without barriers than the measured concentration with barriers.

7.1.5 Variability in Measurements

Analysis of the raw data and observational data suggested that weather and minor changes with the device itself impacted variability. Weather, discussed in Chapter 2.2.4, was fully anticipated. The team did not notice minor changes within the device for the first few measurements. Measurements varied as low as 2000 particulates/cm^3 to as high as 20,000 particulates/cm^3 at locations with low traffic and no construction. The team knew these measurements could not be correct based on the baseline value. Humidity and the time taken to transfer the rod caused the alcohol to evaporate causing the variability. If it was humid, the team had to transfer the rod at a slower rate than if it was not humid. The team improved at taking measurements that were more consistent and recognized when measurements were invalid.

CHAPTER 8 - CONCLUSION

8.1 - Suggestions and Advocacy

Using observational data and the data displayed in the graphs, the team created a set of suggestions for construction companies and schools, Figure 8.1.a. The suggestions aimed to benefit the health of school children through improving the habits of construction workers, and changing the walking habits of children around construction sites.

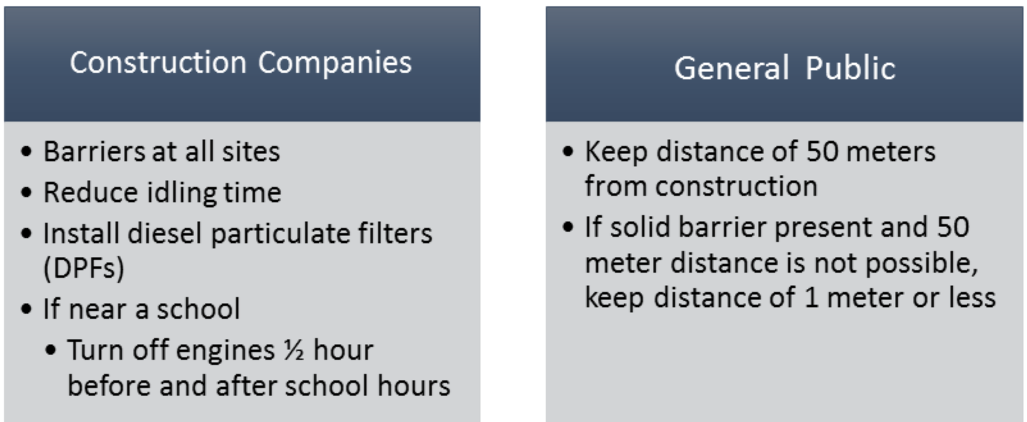


Figure 8.11.a: List of suggestions for construction companies and the general public

Miljøpunkt Østerbro plans to use our data and suggestions to propose habit changes to construction companies to decrease the amount of and exposure to ultrafine particulates. The team determined that at a distance of approximately 50 meters from a construction site, the ultrafine particulate concentration is close enough to normal background values to be considered safe. If it is not possible to be 50 meters away from a site, it is best to stay as far away as possible, as the concentration of particulates decreases exponentially except in one important case: the presence of solid noise barriers. If barriers are present, and it is not possible to be 50 meters away, then being 1 meter from the barrier is best. The area near the barrier has a much lower concentration of ultrafine particulates compared to a distance of 10 meters. These suggestions of distance to construction site apply to the sites in the Østerbro district, as well as other construction sites of similar size throughout the city of Copenhagen.

In addition to avoidance of high concentrations of ultrafine particulates, it is possible to reduce the output of these particulates. The most cost effective way to reduce ultrafine particulate production is to turn off diesel vehicles. A 2003 study conducted by Natural Resources Canada showed that idling for ten seconds uses more fuel and produces more emissions than restarting the engine (Taylor, G., 2003). The study considered fuel savings, overall emissions, and component wear and determined that users should turn off engines if idling for more than 60 seconds (Taylor, G., 2003). Limiting the idling time will reduce ultrafine particulates as well as other harmful emissions. Another way to reduce ultrafine particulate output is to install diesel particulate filters (DFPs). These filters capture up to 99% of particulates, including but not limited to ultrafine particulates and carbon monoxide. Preliminary research of construction companies constructing the metro suggests that they do not have DPFs on all of the construction vehicles in use. Use of DPFs would significantly reduce the amount of UFP near construction sites in Østerbro. The team also suggests building solid barriers around all construction sites. The team's measurements showed that barriers reduced ultrafine particulate concentrations at a distance of one meter or less next to the barrier. This is vital in a city where space is limited and maintaining a distance of 50 meters is difficult. The final suggestion is for construction sites near schools. To reduce ultrafine particulate exposure, especially to children, the team suggests turning off diesel engines half an hour before and after school hours. This will reduce the ultrafine particulate concentration around construction sites near schools before large amounts of children are in the area.

8.2 - Further Research

The constraints of both time and resources prevented the team from fully exploring the topic of ultrafine particulate pollution. As such, the team has further suggestions on new topics of exploration or research.

The team was unable to thoroughly test the impact of solid noise barriers on pollution at varied distances as they lacked sites of similar size with and without barriers. The team suggests controlled tests be taken where a single pollution source can be tested simultaneously with and without barriers. The controlled test should be done on a smaller scale as a proof of concept, with larger scale tests being completed to produce further proof.

The team encountered anomalous data on two occasions that correlated with the passing of a street sweeper. The street sweeper produced the single highest recorded spike in the data, reaching 500,000 particulates/cm^3. More data is required to confirm the dangers of street sweepers, and if confirmed, action should be taken to lessen the impact of street sweepers on ultrafine particulate concentrations.

The team's final suggestion is for the international community on the topic of ultrafine particulate pollution. More research is required to investigate the concentration at which ultrafine particulates no longer negatively affects health of those exposed. Both course and fine particulate pollution have concentrations set by the World Health Organization at which exposure is dangerous. However, there is no information on what concentration of ultrafine particulates is dangerous. In order to bring proper attention to ultrafine particulate pollution, a safe level must be determined. Once a safe level is determined, communities will then be able to take steps to reduce the concentrations of ultrafine particulates to safe levels.

8.3 - Conclusion

Air pollution concentrations have a large, negative impact on the overall health of Østerbro residents. Initially, this project aimed to provide information on ultrafine particulate concentrations resulting from traffic. After initial measurements, observations, and analysis the focus of this project shifted to ultrafine particulate concentrations created by construction sites in the Østerbro district, primarily around parks and schools for young children. The methodology and accompanying background research allowed the team to provide Miljøpunkt Østerbro with information on air pollution concentrations, and suggestions for the general population and construction companies. These suggestions aimed to reduce exposure to ultrafine particulates by providing the general population ways to avoid construction and construction companies to reduce ultrafine particulate emissions.

WORKS CITED

Air Quality Guidelines. (2005) Global Update 2005: World Health Organization.

Baccarelli, A., Zanobetti, A., Martinelli, I., Grillo, P., Hou, L., Giacomini, S., . . . Bertazzi, P. A. (2007). Effects of exposure to air pollution on blood coagulation. Journal of Thrombosis and Haemostasis, 5(2), 252-260.

Barron, H. V., Harr, S. D., Radford, M. J., Wang, Y., & Krumholz, H. M. (2001). The association between white blood cell count and acute myocardial infarction mortality in patients≥ 65 years of age: findings from the cooperative cardiovascular project. Journal of the American College of Cardiology, 38(6), 1654-1661.

Bellman, D. (2007). Electric Generation Efficency.

Belmonte, N. JavaScript InfoVis Toolkit. Web (Ed.).

Berkowicz, R. (2000). A parameterised street pollution model.

Bick, R. L., & Ucar, K. (1992). Hypercoagulability and thrombosis. Hematology/oncology clinics of North America, 6(6), 1421-1431.

Brook, R. (2008). Cardiovascular effects of air pollution. Clinical Science, 115, 175-187.

Brook, R. D., Brook, J. R., Urch, B., Vincent, R., Rajagopalan, S., & Silverman, F. (2002). Inhalation of fine particulate air pollution and ozone causes acute arterial vasoconstriction in healthy adults. Circulation, 105(13), 1534-1536.

Brunekreef, B., & Holgate, S. T. (2002). Air Pollution and Health. Retrieved January 23, 2014, from http://www.sciencedirect.com/science/article/pii/S0140673602112748

Bäck, D., Kuminoff, N. V., Van Buren, E., & Van Buren, S. (2013). National Evidence on Air Pollution Avoidance Behavoir.

Cars, Trucks, & Air Pollution. (2013). Retrieved January 23, 2014, from http://www.ucsusa.org/clean_vehicles/why-clean-cars/air-pollution-and-health/cars-trucks-air-pollution.html

City of Copenhagen. (2008). Eco-metropolis: our vision for Copenhagen 2015. http://www.kk.dk/da/Om-kommunen/Indsatsomraader-og-politikker/Publikationer.aspx?mode=detalje&id=674

The City of Copenhagen Traffic Department. (2008). Bicycle statistics. Retrieved February, 2014, from http://subsite.kk.dk/sitecore/content/Subsites/CityOfCopenhagen/SubsiteFrontpage/LivingInCopenhagen/CityAndTraffic/CityOfCyclists/CycleStatistics.aspx

The City of Copenhagen Traffic Department. (2014a). Cycle tracks and cycle lanes. Retrieved February, 2014, from http://subsite.kk.dk/sitecore/content/Subsites/CityOfCopenhagen/SubsiteFrontpage/LivingInCopenhagen/CityAndTraffic/CityOfCyclists/CycleTracksAndCycleLanes.aspx

The City of Copenhagen Traffic Department. (2014b). Green cycle routes. Retrieved February, 2014, from http://subsite.kk.dk/sitecore/content/Subsites/CityOfCopenhagen/SubsiteFrontpage/LivingInCopenhagen/CityAndTraffic/CityOfCyclists/CycleTracksAndCycleLanes/GreenCycleRoutes.aspx

Clark, N. A., Demers, P. A., & Brauer, M. (2010). Effect of Early Life Exposure to Air Pollution on Development of Childhood Asthma: National Institute of Environmental Health Science.

Clean Air. (2012). Still A Challenge. from https://subsite.kk.dk/sitecore/content/Subsites/CityOfCopenhagen/SubsiteFrontpage/LivingInCopenhagen/ClimateAndEnvironment/CopenhagensGreenAccounts/AirPollution.aspx

Copenhagen's Bicycle Strategy & Policies. (2014). Retrieved February 11, 2014, from http://subsite.kk.dk/sitecore/content/Subsites/CityOfCopenhagen/SubsiteFrontpage/LivingInCopenhagen/CityAndTraffic/CityOfCyclists/CopenhagenCyclePolicy.aspx

Copenhagen Districts. (2008). Retrieved March 1, 2014, from http://wikitravel.org/en/Copenhagen

The Danish Government. (February 2011). Energy Strategy 2050.

Davies, H. W., Vlaanderen, J. J., Henderson, S. B., & Brauer, M. (2009). Correlation between Co-Exposures to Noise and Air Pollution from Traffic Sources. Occupational and Environmental Medicine, 66(5), 347-350. doi: 10.2307/27733130

Decousus, H., Leizorovicz, A., Parent, F., Page, Y., Tardy, B., Girard, P., . . . Barral, F.-G. (1998). A clinical trial of vena caval filters in the prevention of pulmonary embolism in patients with proximal deep-vein thrombosis. New England Journal of Medicine, 338(7), 409-416.

Dockery, D. W., & Pope, C. A. (1994). Acute respiratory effects of particulate air pollution. Annual review of public health, 15(1), 107-132.

Douglas, C. G., Haldane, J., & Haldane, J. B. S. (1912). The laws of combination of haemoglobin with carbon monoxide and oxygen. The Journal of physiology, 44(4), 275-304.

Environmental Commission. (2007). Scientific Committee on Health and Environmental Risks.

Environmental Protection Agency. (2013). National Greenhouse Gas Emissions Data. Retrieved February 9, 2014, from http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html

Environment Protection Authority. (2013). How Weather Affects Air Quality. Retrieved February 30, 2014 from http://epa.tas.gov.au/epa/how-weather-affects-air-quality

European Environmental Agency (2010). Air pollution - State and impacts (Denmark) — European Environmental Agency (EEA).

Factors Affecting Air Quality. Retrieved February 30, 2014, from http://www.bcairquality.ca/101/air-quality-factors.html

Gauderman, W. J., Avol, E., Gilliland, F., Vora, H., Thomas, D., Berhane, K., . . . Peters, J. (2004). The Effect of Air Pollution on Lung Development from 10 to 18 Years of Age: The New England Journal of Medicine.

Government of Japan. (2000). Textbook for Sampling for Environmental Monitoring Analysis Video Series for Environmental Technology Transfer: Overseas Environmental Cooperation Center.

Halliwell, B. (2007). Oxidative stress and cancer: have we moved forward? Biochem. j, 401, 1-11.

Intergovernmental Panel on Climate Change. (2007). *Global Greenhouse Gas Emissions by Source*, Retrieved March 2, 2014 from http://www.ipcc.ch/publications_and_data/ar4/wg3/en/contents.html

Li, N., Sioutas, C., Cho, A., Schmitz, D., Misra, C., Sempf, J., . . . Nel, A. (2003). Ultrafine particulate pollutants induce oxidative stress and mitochondrial damage. Environmental health perspectives, 111(4), 455.

Lidegaard, M. (2012). Accelerating Green Energy Towards 2020. Retrieved Feb 10, 2014, from http://www.ens.dk/sites/ens.dk/files/dokumenter/publikationer/downloads/accelerating_green_energy_towards_2020.pdf

Ministry of the Environment. (2014, 2014-02-20). The Ministry. Retrieved February 26, 2014, from http://www.mim.dk/eng/

Ministry of Foreign Affairs of Denmark. (2014). How Denmark become a cycling nation -The official website of Denmark. Retrieved February 26, 2014, from http://denmark.dk/en/green-living/bicycle-culture/how-denmark-become-a-cycling-nation/

Mills, N. L., Donaldson, K., Hadoke, P. W., Boon, N. A., MacNee, W., Cassee, F. R., . . . Newby, D. E. (2008). Adverse cardiovascular effects of air pollution. Nature Clinical Practice Cardiovascular Medicine, 6(1), 36-44.

Muller, J. G., Dept. of Electr. Eng., T. U. o. D., Lyngby, Denmark, Qiuwei, W., Ostergaard, J., & Nielsen, A. H. (2012). Policies and initiatives for carbon neutrality in nordic heating and transport systems. Paper presented at the IPEC, 2012 Conference on Power & Energy, Ho Chi Mihn City. http://dx.doi.org/

Mygind, O., Rønne, T., Søe, A.-L., Wachmann, C. H., & Ricks, P. (2003). Comparative intervention study among Danish daycare children: the effect on illness of time spent outdoors. Scandinavian journal of public health, 31(6), 439-443.

Neidell, M. (2005). Public information and avoidance behavior: Do people respond to smog alerts? Center for Integrating Statistical and Environmental Science Technical Report(24).

Nervous and Endocrine Systems. (2008).

Østerbro Maps. (2009). Retrieved March 1, 2014, from http://wikitravel.org/en/Copenhagen/%C3%98sterbro

Pekkanen, J., Timonen, K. L., Ruuskanen, J., Reponen, A., & Mirme, A. (1997). Effects of ultrafine and fine particles in urban air on peak expiratory flow among children with asthmatic symptoms. Environmental research, 74(1), 24-33.

Pope, C. A., Burnett, R. T., Thurston, G. D., Thun, M. J., Calle, E. E., Krewski, D., & Godleski, J. J. (2004). Cardiovascular mortality and long-term exposure to particulate air pollution epidemiological evidence of general pathophysiological pathways of disease. Circulation, 109(1), 71-77.

Pucher, J., & Buehler, R. (2008). Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany. http://dx.doi.org/10.1080/01441640701806612. doi: Transport Reviews, Vol. 28, No. 4, July 2008, pp. 495-528

Relocation, S. (2014). The Areas of Copenhagen | Osterbro. Retrieved February 27, 2014, from http://settwell.dk/node/134

Schwarzer, R. (2008). Modeling health behavior change: How to predict and modify the adoption and maintenance of health behaviors. Applied Psychology, 57(1), 1-29.

Shumway, R. H., Azari, A. S., & Pawitan, Y. (1988). Modeling mortality fluctuations in Los Angeles as functions of pollution and weather effects. Environmental Research, 45(2), 224-241.

Stern, C., (1976). Adsorption. *Air Pollution* (3. Ed., p. 349). Orlando [u.s.:Acad. Press]

Taylor, G. W. (2003). Review of the incidence, energy use and costs of passerger vehicle idling. Natural Resources Canada. Retrieved April 30, 2014, from, https://www.nrcan.gc.ca/energy/efficiency/communities-infrastructure/transportation/cars-light-trucks/idling/4415

Valko, M., Leibfritz, D., Moncol, J., Cronin, M. T. D., Mazur, M., & Telser, J. (2007). Free radicals and antioxidants in normal physiological functions and human disease. The international journal of biochemistry & cell biology, 39(1), 44-84.

Voiland, A. (2010). Aerosols: Tiny Particles, Big Impact. 2014, from, http://earthobservatory.nasa.gov/Features/Aerosols/

Wang, G., van den Bosch, F. H. M., & Kuffer, M. (2008). Modelling Urban Traffic Air Pollution Dispersion. International Institute for Geo-Information Science and Earth Observation.

Wantland, D. J., Portillo, C. J., Holzemer, W. L., Slaughter, R., & McGhee, E. M. (2004). The effectiveness of Web-based vs. non-Web-based interventions: a meta-analysis of behavioral change outcomes. Journal of medical Internet research, 6(4).

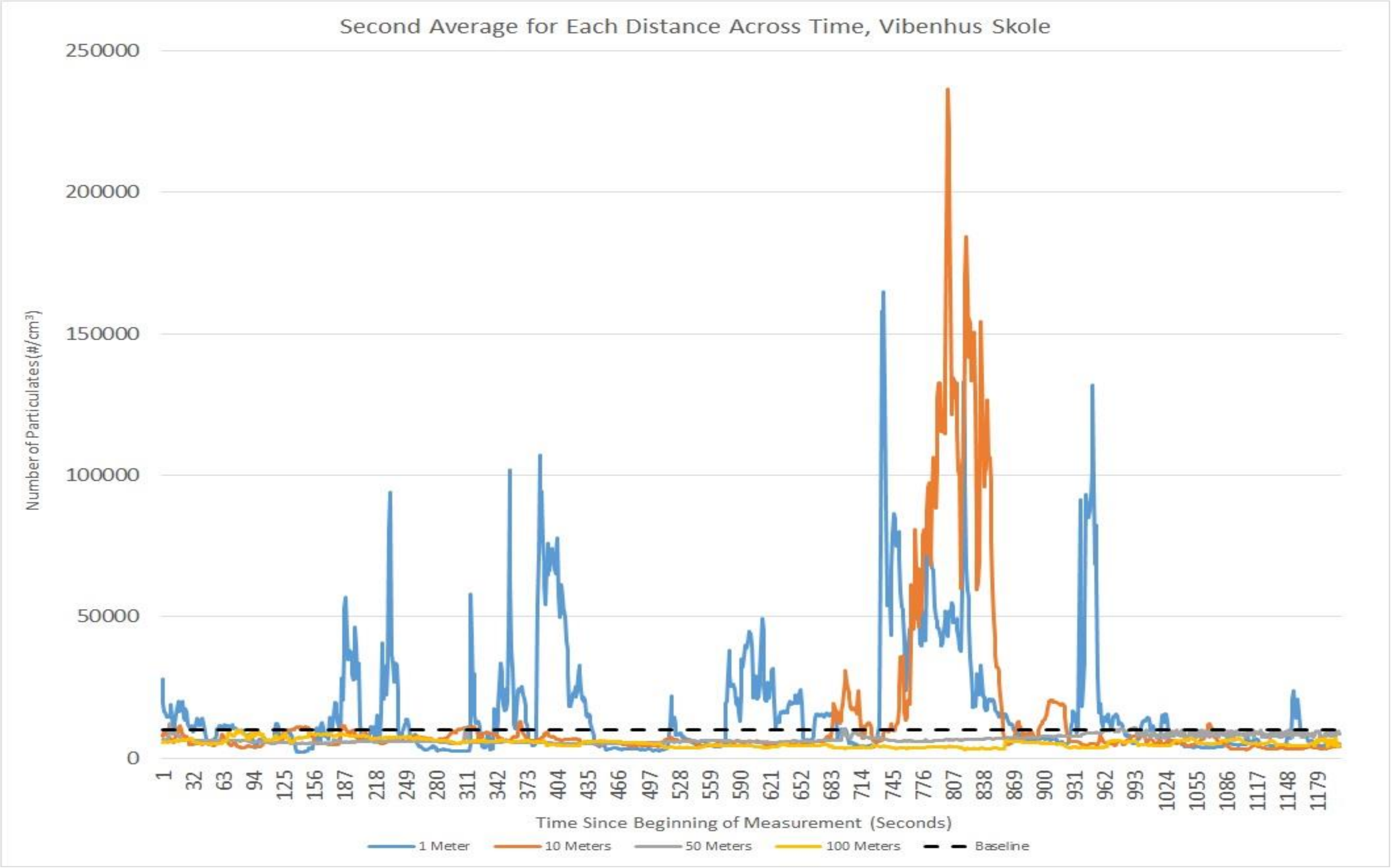
WHO outdoor air quality guidelines. (2014). from http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/policy/who-outdoor-air-quality-guideline

Appendices

Appendix A: Vibenhus Skole, Minute Averages Chart

Minutes	1 Meter	10 Meters	50 Meters	100 Meters
1	12506	6376	6796	5651
2	8356	4936	5812	7749
3	7368	7700	5359	7666
4	26188	7318	5832	7511
5	5372	7333	5739	6622
6	15549	8528	5820	5825
7	41086	7309	5377	5190
8	9071	5338	5160	5586
9	5357	5297	5544	4431
10	15343	5230	5960	4275
11	20587	5140	5701	4195
12	9518	12664	7036	3936
13	51653	27915	6315	3732
14	47725	123131	6379	3641
15	11490	24048	7142	4957
16	28825	10303	8142	5469
17	10465	6123	9149	5368
18	5350	6214	8565	5639
19	5010	3681	8429	5484
20	7427	3534	8548	5606

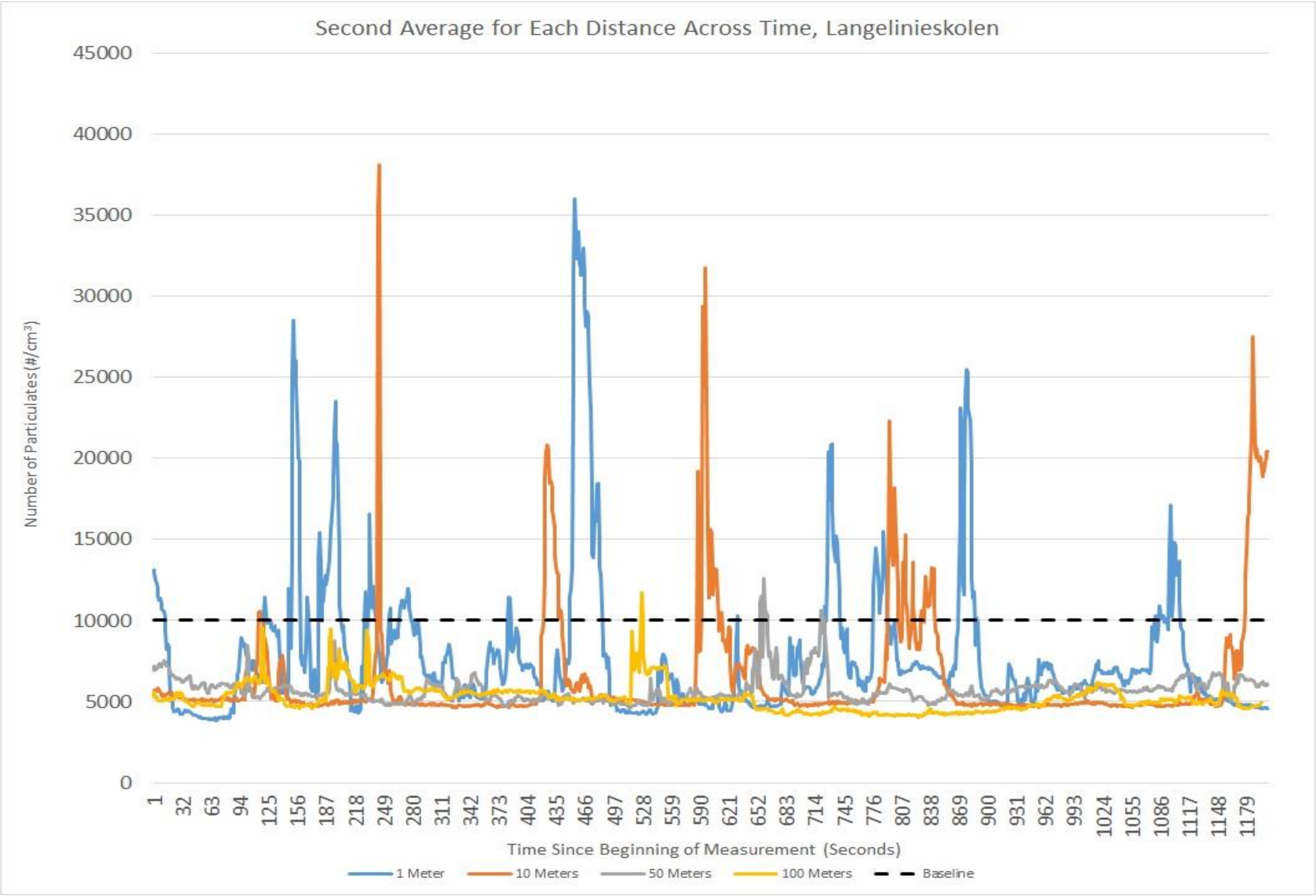
Appendix B: Vibenhus Skole, Second Averages Graph



Appendix C: Langelinieskolen, Minute Averages Chart

Minutes	1 Meter	10 Meters	50 Meters	100 Meters
1	6163	5287	6481	5060
2	5934	6009	5821	5833
3	10669	5530	5617	5060
4	10612	5110	5646	6580
5	8763	6631	5143	6097
6	6187	4779	5821	5476
7	7521	5025	5116	5617
8	15910	9226	5144	5221
9	5405	5068	4967	6247
10	5529	8104	5289	5558
11	5089	8349	6228	5023
12	5952	4958	6961	4311
13	9894	4970	5665	4377
14	8470	10676	5462	4192
15	10063	5840	5335	4303
16	5587	4795	5768	4596
17	6262	4857	5842	5416
18	6984	4790	5680	5276
19	8645	4912	6122	5070
20	4866	11941	6183	4972

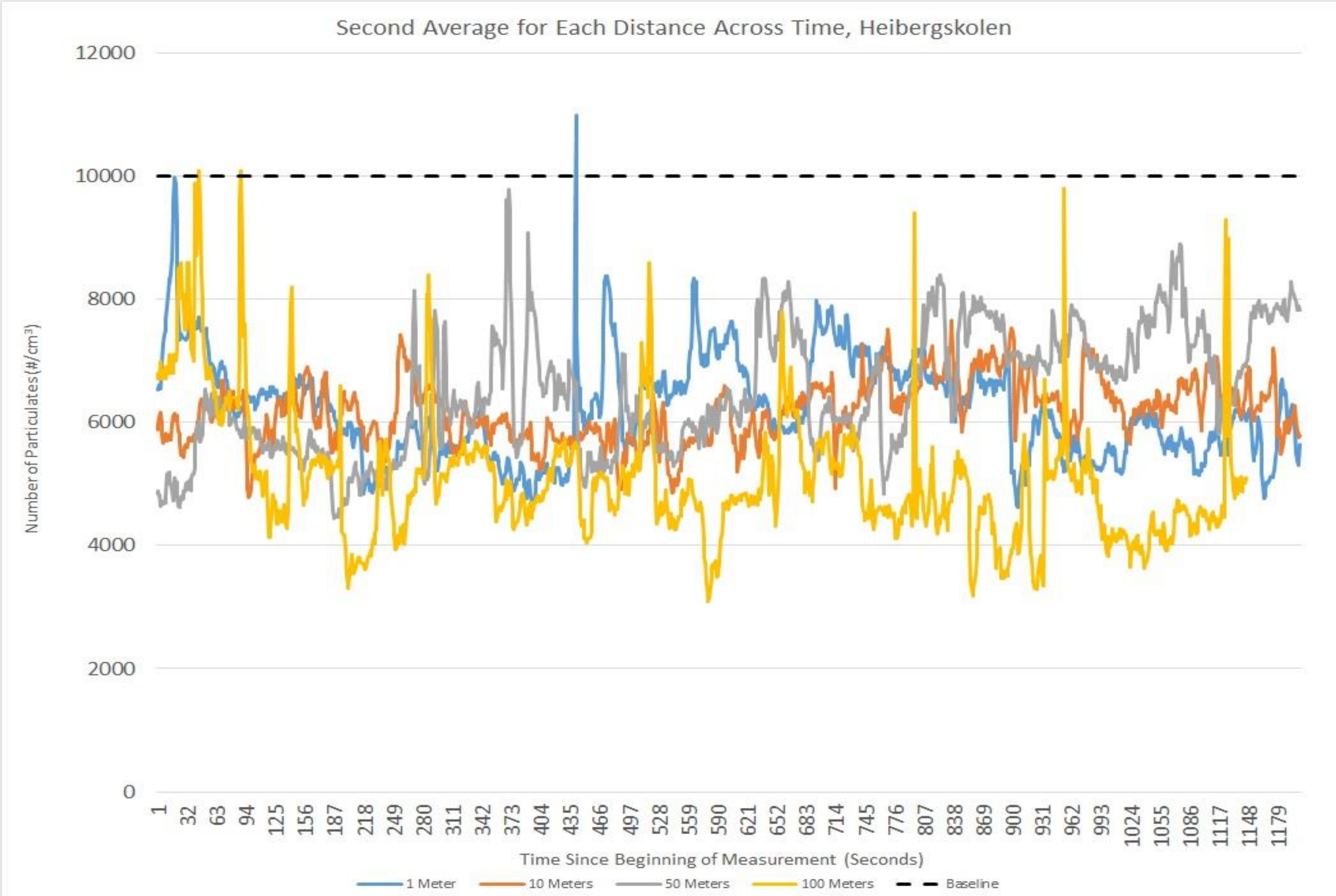
Appendix D: Langelinieskolen, Second Averages Graph



Appendix E: Heibergskolen, Minute Averages Chart

1	7604	5927	5312	7510
2	6448	5957	5906	6009
3	6502	6355	5531	5276
4	5552	5919	4974	4409
5	5645	6505	5893	5150
6	5674	5915	6460	5328
7	5091	5738	7045	4783
8	6427	5763	5769	5016
9	6387	5637	5925	5364
10	7108	5777	5918	4308
11	6494	5871	7011	5125
12	6879	6320	6590	5589
13	7043	6524	5963	4893
14	6753	6746	7031	4797
15	6494	6872	7596	4289
16	5616	6398	7106	4886
17	5408	6492	7099	4640
18	5866	6256	7834	4167
19	5687	6544	6898	4856
20	5761	6235	7729	5038

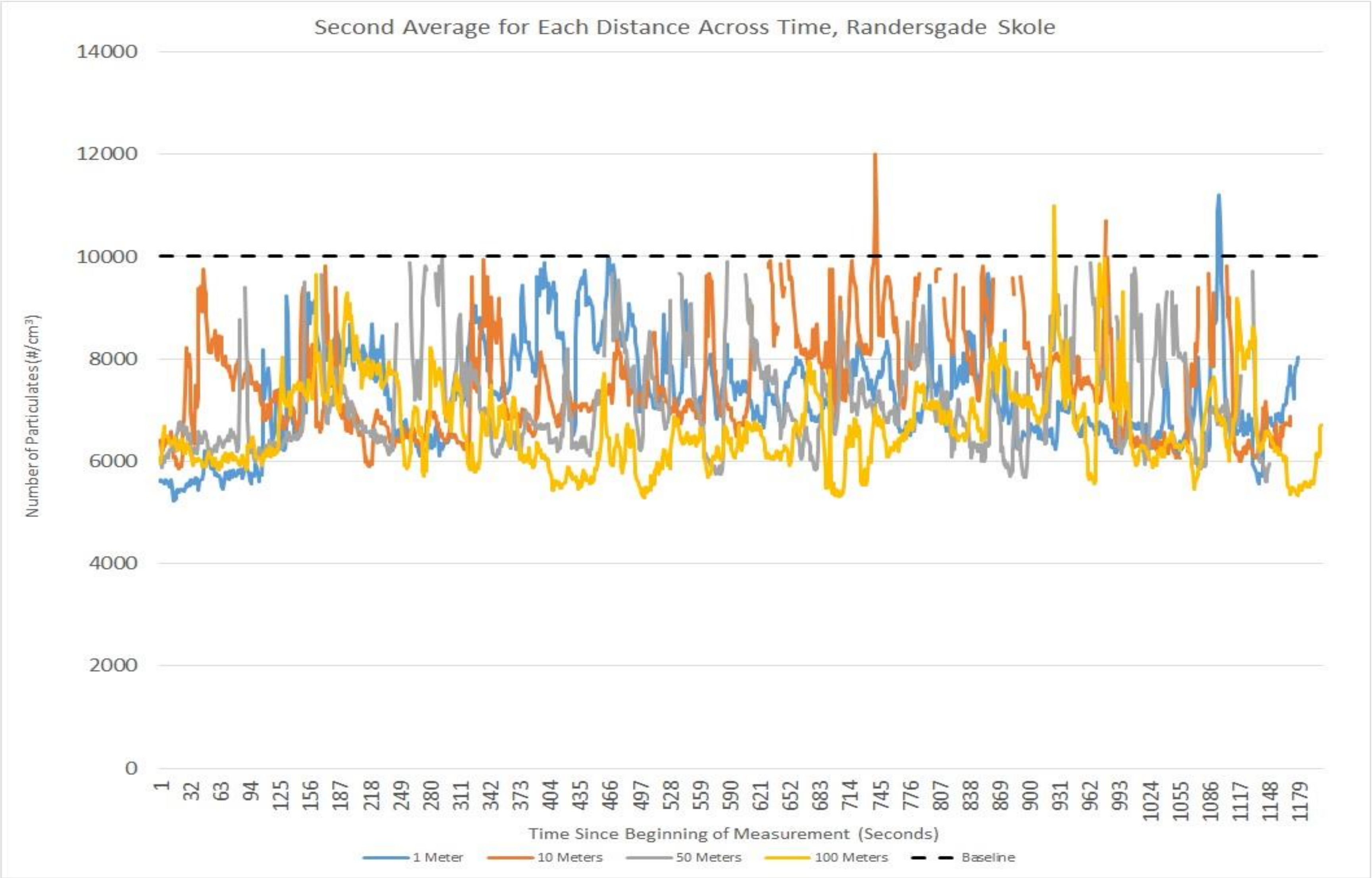
Appendix F: Heibergskolen, Second Averages Graph



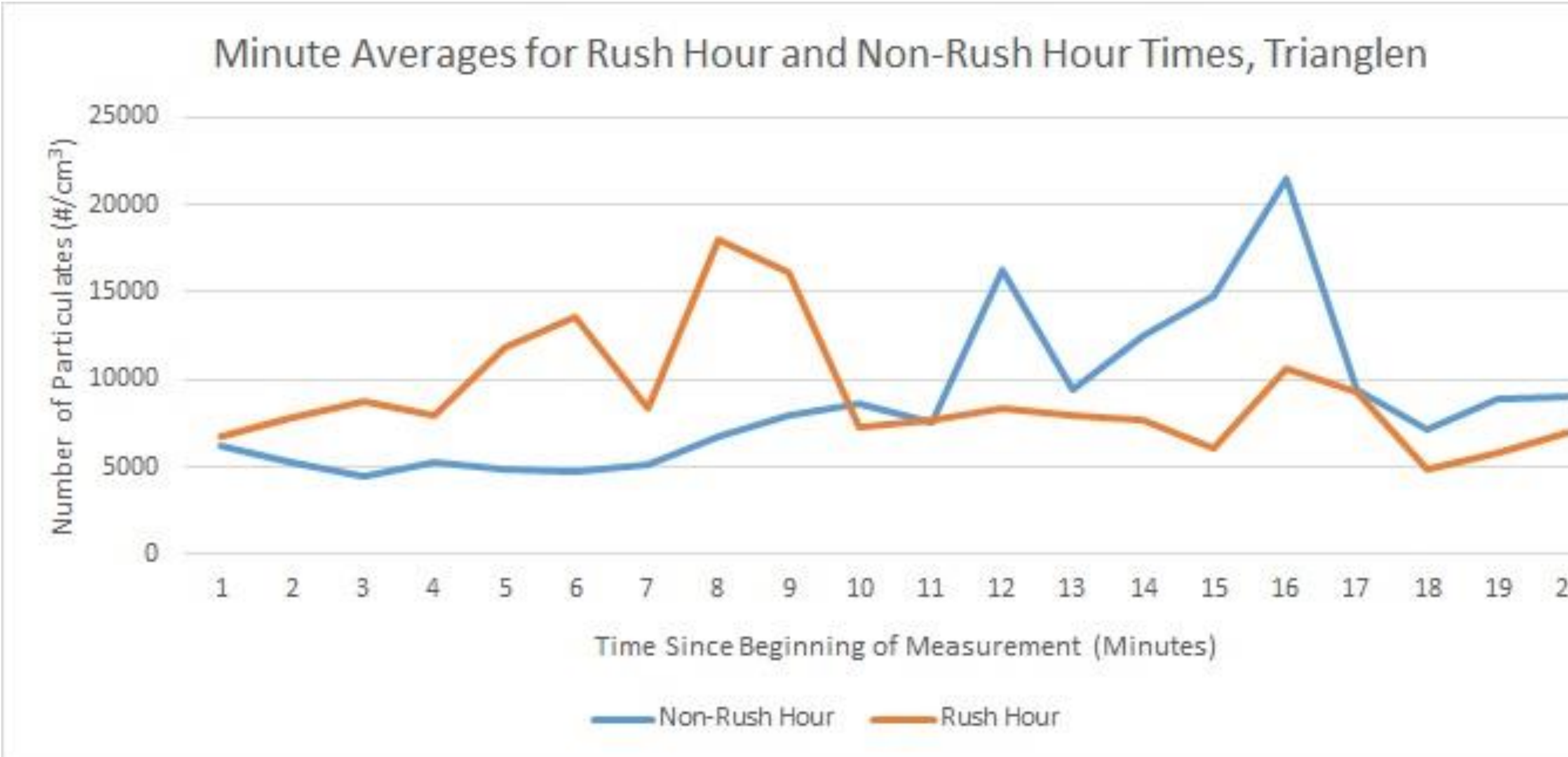
Appendix G: Randersgade Skole, Minute Averages Chart

Minutes	1 Meter	10 Meters	50 Meters	100 Meters
1	5619	7174	6340	6176
2	5891	7703	6499	6089
3	7483	7310	6480	7428
4	8120	6808	7109	7912
5	6911	6541	7324	6935
6	7206	6814	7899	6676
7	7947	7497	6557	6065
8	8617	7150	6638	5999
9	8793	7419	7645	6024
10	7646	7321	7734	6265
11	7464	7243	6702	6368
12	7242	8780	7582	6496
13	7287	8105	6978	6390
14	7563	8737	7103	6918
15	7233	8719	7497	7329
16	7822	8326	6536	7382
17	6627	8055	7365	7114
18	6688	7712	8358	6171
19	6638	6459	7540	7290
20	7387	7905	7099	5903

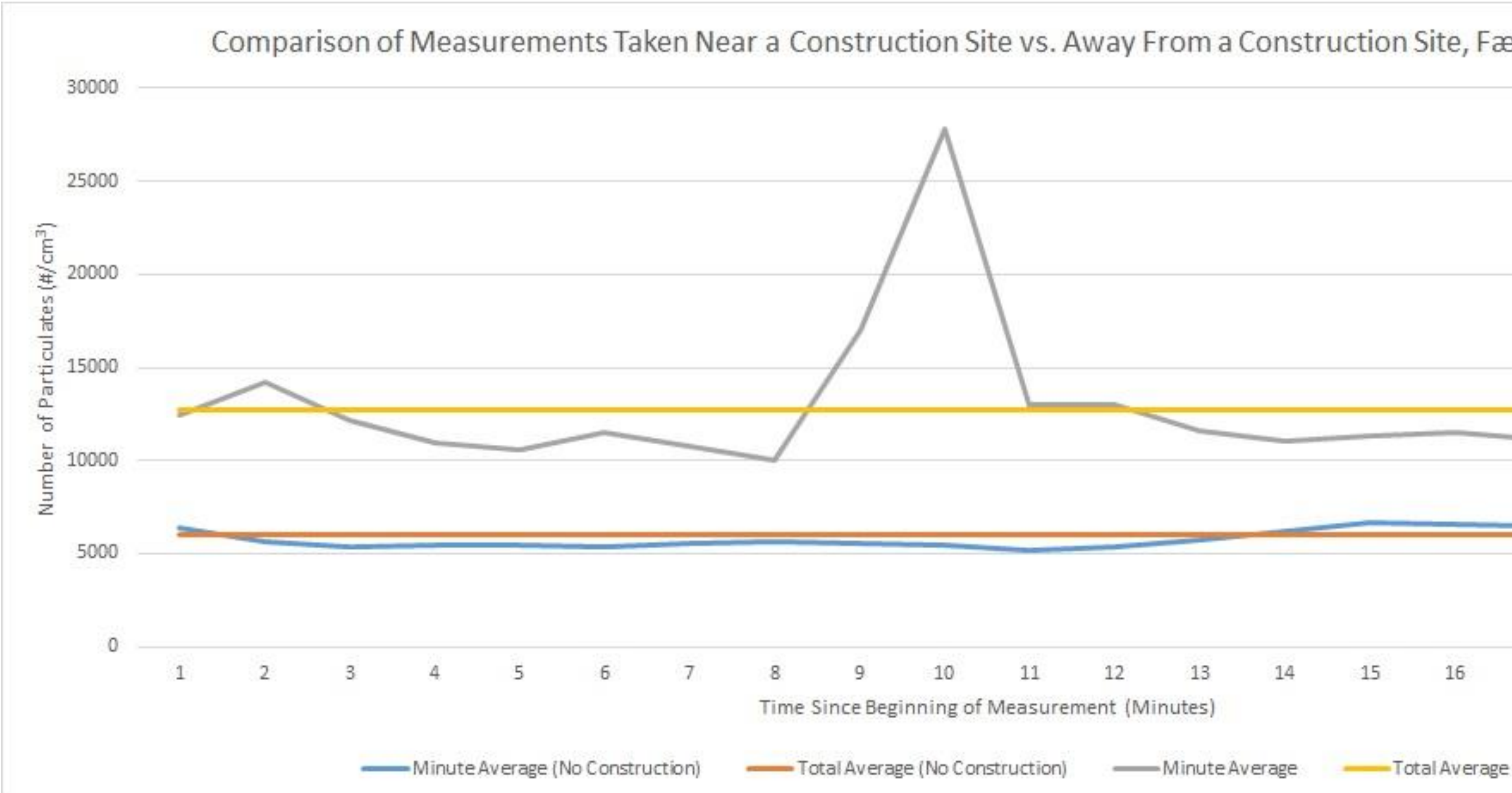
Appendix H: Randersgade Skole, Second Averages Graph



Appendix I: Trianglen Rush Hour and Non-Rush Hour, Minute Averages Chart



Appendix J: Fælledparken Construction and No Construction, Minute Averages Chart



Appendix K: P-Trak Ultrafine Particle Counter Settings

The P-Trak Ultrafine Particle Counter

Model: P-Track

Model Number: 8525

Serial Number: 8525-11100001

Log Interval (mm:ss): 0.01

The full operation and service manual (revised July 2013) is available at:

http://www.tsi.com/uploadedFiles/_Site_Root/Products/Literature/Manuals/Model-8525-P-Trak-1980380.pdf

Additional Information is available at: http://www.tsi.com/p-trak-ultrafine-particle-counter-8525/

Appendix L: Procedure to Calculate Pace Count to Measure Ground Distance

Pace course set-up:

1. Mark start of course.
2. Measured length of course.
    - Length must be at least 100 meters
    - Terrain must be consistent throughout course
3. Mark and end of course.

Pace Count Calculation:

1. Naturally walk the length of the pace course in a straight line.
2. Keep track of paces using a counter.
3. Divide the number of paces by the total number of meters walked