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The Air We Breathe: Understanding Individual Exposure to Air Pollution

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Abstract

Every day, people are exposed to air pollution. But not all people experience the same levels of exposure. Human exposure to ambient air pollution is commonly represented by the concentration of pollutants in the air outside, but this is not accurate in revealing the complex and individual experience that is pollution exposure. This paper reevaluates how we represent exposure to ambient pollution and presents data from an ongoing study to broaden our understanding of the role of indoor air quality. Chapter one uses quantitative data to describe the relationship between humans and ambient air pollution and explain why the current measure of human exposure to these pollutants is inadequate. Chapter two introduces the history of air pollution and its health effects and how government policies throughout different time periods have impacted the way society interacts with pollution. Chapter three describes the issues of architecture and urban planning in relation to ambient pollution exposure, and the types of solutions that are being proposed in terms of infrastructure. Chapter four investigates the relationship between indoor and outdoor air quality by utilizing an ongoing study which measures indoor air quality in various classrooms at Fordham University as well as different types of housing on and near campus, and compares these indoor pollutant concentrations to the outdoor pollution and weather patterns that are collected in the same area. Finally, chapter five explains the necessary policies regarding city infrastructure and air filtration in housing and work places in order to protect people from the outcomes of weather events and pollution exposure.

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Introduction: Asthma and The Bronx

Asthma is the leading cause of childhood hospitalizations and absences from school in the Bronx, New York (Warman, et al. 2009). The Bronx has some of the highest rates of childhood asthma in the country, and studies have shown that ambient, or outdoor, air pollution not only exacerbates existing asthma symptoms but also may cause the development of asthma in children (Almetwally et al 2020). When comparing the rates of childhood asthma in the Bronx versus Manhattan, a study conducted by the National Library of Medicine found that 15.5% of children living in the Bronx were diagnosed with asthma compared to 9.2% in Manhattan (Warman, et al. 2009). According to this disparity, it would make sense that the ambient pollution concentrations must be higher in the Bronx compared to the levels in Manhattan. Higher levels of harmful pollutants in the air in the Bronx must be causing the high rates of asthma which aren't as extreme in Manhattan. In reality, Manhattan has been found to have higher concentrations of ambient pollution (Perera et al. 2021; King et al. 2014). If Manhattan has higher outdoor concentrations of air pollution, then why is a higher percentage of children in the Bronx suffering the health effects of ambient pollutants?

This begs the question: Is the outdoor concentration of pollution in a borough or city the same as the exposure that an individual in that city experiences on a day-to-today basis? Do all individuals in a city experience the same levels of exposure? Most likely, no. The way in which policymakers currently measure people's exposure to ambient pollutants is most often by measuring an area's outdoor air quality. Evidently, this leaves out the experience of individuals. According to this reasoning, a policymaker may assume that a child in the Bronx is at less of a risk of respiratory issues like asthma in comparison to a child in Manhattan, but this is not true. This paper will investigate what human exposure to ambient pollutants really entails, and more accurate ways to measure it. This involves understanding the role that indoor air quality may play, as well as architectural and urban planning influences.

Chapter one will describe the role that clean air plays in earth's ecosystems in relation to humans, and the health impacts that different ambient air pollutants have on human health. Further, it will break down the manner in which human exposure to these pollutants is measured, and discuss the difference between concentration and exposure. Chapter two will examine the history of people's relationship to poor air quality and how the United State's understanding of exposure has developed over time and impacted public health policies. Chapter three will evaluate the role that city infrastructure and building architecture play in reinforcing the disparities that different populations face in terms of pollution exposure. Chapter four will introduce an ongoing study which I have worked on during my time at Fordham, which aims to understand the relationship between outdoor air quality and indoor air quality. It will present relevant weather and air quality data and analyze the relationship between these two variables, and discuss this relationship in the context of climate change and air quality policies. Finally, chapter five will utilize the discussion from the first four chapters and present suitable policies for the issues discussed. This paper will discuss air quality exposure inequalities specifically experienced in New York City, with data from the United States as a whole and other areas of the world for context on the issues.

Chapter One: Human Health and Air Quality

This chapter will examine the issue of ambient pollution, how air quality relates to basic ecosystem services, and the problems involved in current methods of estimating air pollution exposure. Air quality is a basic necessity of human life, and as the depletion of air-regulating ecosystems and the growth of industrial development work together to decrease the availability of clean air, less and less people have access to this resource. Air pollution is not distributed equally, though, and many different environmental and anthropogenic factors impact the exposure an individual person may be exposed to on a daily basis. According to current measures of air quality levels and standards, the assumption is made that people's exposure to ambient pollutants, or air pollutants originating from outdoor sources, is only when they are outdoors, and is relatively equal throughout different parts of a city. Due to what studies have shown about human activity, it is not likely that the majority of people's exposure to deadly pollution is fully explained by time spent outdoors, nor is it likely that people of different demographics experience the same exposure to these pollutants. This chapter will investigate this complex relationship between people and air pollution and introduce this paper's reevaluation of measuring human exposure to ambient pollutants.

Air Quality Regulation as an Ecosystem Service: Air is vital to survival, and this is a renewable resource that may seem like it is not going anywhere. The quality of the air, though, is the most important factor in ensuring human health as well as environmental survival. Earth's ecosystems have evolved to create complex and balanced processes to maintain regulating services as basic as cleaning the atmosphere's air, such as trees sequestering carbon dioxide. There are three other types of ecosystem services in addition to regulating services, and these include provisioning services, cultural services, and supporting services (Millennium 2005, 7).

Human life is only possible due to the different ecosystem services that fall under these four categories, and each service provides a distinct support. Provisioning services relate to the useful products that humans obtain from ecosystems, such as fish from aquatic environments or timber from forest environments. Cultural services relate to the educational, art-inspiring, or recreational services that human culture depends on and is inspired by every day. Supporting services are the basis for all ecosystems, and relate to the natural cycles that are constantly circulating resources such as water, and allowing for various species to inhabit the same habitats in harmony. Finally, and most closely related to air quality, are regulating services, which maintain the quality of different resources and processes, such as carbon sequestration, waste decomposition, and pollination. Regulating services can often be taken for granted by humans, because they relate to complex processes that can be impossible to notice on a daily basis, yet allow for us to enjoy basic needs such as food, air, and water without dealing with our own wastes. While air regulation primarily falls under the category of regulating services, it also is very connected to cultural ecosystem services because the physical and mental health of a community is a vital aspect to the health of its culture. So, while air regulation may not appear to be a visible focus of people's everyday lives, an environment's ability to regulate air quality is woven into every aspect of life and culture.

The more humans take ecosystem services for granted, the more we prioritize human development, and eventually, the more severely the ecosystems supplying these services are degraded. Forests and aquatic environments are examples of incredibly powerful systems which sequester the carbon that humans release and naturally convert this into oxygen. Old-growth forests, which are undisturbed forests that are at least 120-150 years old, are especially valuable for this service. In fact, a study focused on Northeast maple-beech-maple forests found that a 25-year-old forest sequestered 1,760lbs of CO_2 per acre per year, while a 120-year-old forest sequestered 3,909lbs of CO_2 per acre per year (Toochi 2018). Unfortunately, as fossil fuel combustion increases the rates of carbon output and agricultural and urban development destroy the ecosystems which provide these air-quality regulating services, these systems become less and less effective. In the most basic interaction between producers and human beings, this exchange between carbon dioxide and oxygen occurs, in which most of our natural carbon output is able to be absorbed. Yet, as human industrialization has grown, our output of carbon has grown immensely, and led to irreversible species-killing effects of climate change. According to the UN Intergovernmental Panel on Climate Change, the intense heating of the globe has led to hundreds of species lost, including a great amount of producers which are necessary for clean air. In addition to issues related to carbon dioxide, air pollution today is much more complex in its composition and scale.

Thankfully, trees have also evolved to filter other dangerous pollutants like particulate matter, or PM, which is a fine mixture of different types of particles in the air, due to natural sources like volcanic eruptions and forest fires that have emitted these pollutants in all types of ecosystems (Dzierżanowski et. al 2011). This is why greenspace is so vital to the cause of decreasing our atmospheric pollution, because we have living systems which already work to clean our air and only become more productive as time goes on. A study conducted at the Warsaw University of Life Sciences showed that “trees planted at road sites are able to improve the air by capturing particles and depositing them on leaves,” and that “there are significant differences in effectiveness between tested species” of trees (Dzierżanowski et. al 2011). The study describes the way in which tree leaves are able to capture PM depending on different characteristics like trichomes, or leaf hair, as well as the thickness and composition of their wax layers (Dzierżanowski et. al 2011). Trees are especially efficient at this job when compared to other plants, because they have a higher ratio of leaf surface area to the total amount of space they take up (Dzierżanowski et. al 2011). In fact, the study mentions that “planting trees on one fourth of available urban area may reduce PM_{10} concentration by 2-20% (Dzierżanowski et. al 2011). Evidently, the relationship between greenspace and decreased air pollution has been proven to be very strong, and protection and increase of greenspace should be understood as a priority in the effort to improve global air quality. Human health depends on environmental health, and the effects of environmental degradation have become increasingly apparent in the scope of people's reactions to lack of clean air.

Human Exposure to Pollution: Clearly, access to clean air is one of the most important elements of human life, so it is important to understand the impacts of pollution exposure on humans, and how exactly this exposure is measured. In general, certain levels of exposure to air pollution have been linked to serious health issues like asthma, cardiovascular disease, diabetes, and epilepsy, as well as a general decrease in productivity and happiness (Almetwally et al 2020). These different health conditions can both be caused by and exacerbated by poor air quality and span a wide range of severities. While all of these various health conditions are relevant in the discussion of air pollution, the health impacts of pollution-related childhood asthma will be explored in-depth, due to this paper's motivation relating to the high rates of childhood asthma in NYC. There is a widespread amount of air pollutants which are dangerous for human exposure, spanning from various sources such as indoor and outdoor, and this paper will primarily focus on the relationship between specific ambient pollutants that are related to the research study in chapter 4.

The six principal pollutants that are most heavily monitored nationally are carbon monoxide, lead, nitrogen dioxide, ozone, particle pollution (PM), and sulfur dioxide. These pollutants all originate from various sources, and are monitored to protect both the health of sensitive populations as well as general welfare protection, as well as "protection against decreased visibility and damage to animals, crops, vegetation, and buildings" (nyc.gov 2023). For each of these common pollutants, there are different national standards which measure the concentrations which can be harmful to human health. These standards are required by the Clean Air Act, which will be discussed further in Chapter 2, and are called the National Ambient Air Quality Standards (NAAQS) (nyc.gov 2023). For example, the NAAQS note that a person should not be exposed to over 150 µg/m3 of PM_{10} over the span of 24 hours (nyc.gov 2023). These standards help calculate the Air Quality Index, or the AQI, which is calculated real-time by the Environmental Protection Agency so citizens are able to know if the daily air quality may pose a risk to their health (nyc.gov 2023). According to the EPA, New York City's AQI is measured by 11 outdoor monitors throughout different rooftops in the city (nyc.gov 2023). People all over NYC with access to the internet are able to view live levels of ambient pollutants they are being exposed to daily, and they are given warnings by the EPA when the AQI is especially dangerous. For example, in June 2023 when the Canadian wildfires brought intense smoke pollution to NYC, New Yorkers were encouraged to stay indoors in order to stay safe from the high levels of PM, CO, and CO_2. This is a very helpful resource, yet it operates under the assumption that people's indoor air quality is, in fact, a shelter with safe air quality. This measurement system is also a dangerous generalization of what pollution individuals are truly being exposed to daily.

One of these principal air pollutants that originates from both indoor and outdoor pollutants is particulate matter, or PM, and can be categorized into PM_1, $PM_{2.5}$, or PM_{10}, depending on the size of the particles measured in microns. According to The World Health Organization, "particulate matter (PM) air pollution contributes to approximately 800,000 premature deaths each year, ranking it the 13th leading cause of mortality worldwide" (Anderson et al 2012). These deadly impacts most often relate to cardiovascular and respiratory issues, both due to short-term and long-term exposure. In fact, ambient pollution is very closely related to higher rates of asthma, and associations have been found between $PM_{2.5}$ increases and asthma-related school absences in asthmatic youth populations (Anderson et. al 2012). Thus, exposure to particulate matter can not only impact people's health, but can make access to education and work more difficult. Other examples of ambient air pollutants are sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon dioxide (CO_2), and ozone (O_3). Nitrogen oxide concentrations have recently been found to be associated with cardiovascular and respiratory diseases, and mortality, especially for sensitive populations (Almetwally et al 2020).

The issue of asthma is especially relevant to the discussion of air pollution in NYC, because the disparities experienced by marginalized populations relating to air pollution exposure are highlighted clearly by the unequal distribution of childhood asthma rates across the city's different boroughs. Asthma is a long-term respiratory disease that causes inflammation and swelling of the airways and impacts about 27 million people in the United States, making it one of the most common and costly diseases in the country ("Asthma - Asthma Facts" 2024). Ambient air pollution has been found to be a serious danger to individuals with acute and chronic asthma, and there are seven main adverse effects that result from air pollution on this population. These effects include "pulmonary function decrements, increased bronchial hyperresponsiveness, visits to emergency departments and hospital admissions, increased medication use and symptom reporting, inflammatory changes, interactions between air pollution and allergen challenges, and immune system changes" (Koenig 1999). So, not only does increased pollution impact the wellness of asthmatic populations in real time, but it also can impact their long-term health, as well as congest emergency rooms and risk the safety of other patients in need of care.

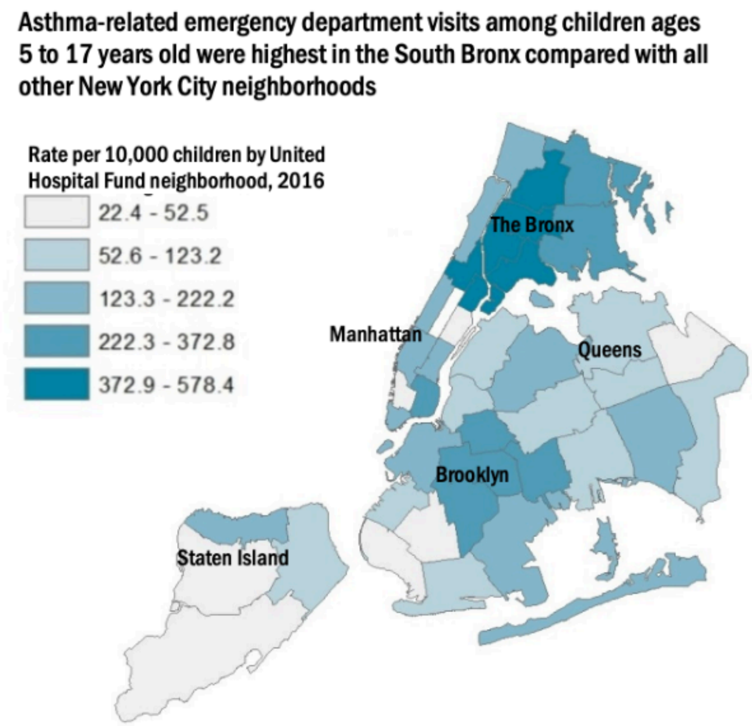

Figure 1: Asthma-related emergency visits in NYC, (NYC Health 2021).

When compared to other boroughs and the rest of the country, The Bronx proves to have some of the highest rates of childhood asthma as well as hospitalizations related to asthma. In fact, the asthma death rate in the Bronx is double that of New York City (Maantay 2008). These disparities are evidence of the environmental injustice experienced, which can be defined as "inequitable exposure of poor and minority populations to environmental hazards such as air pollution" (NYC Health 2021). The relationship between pollution sources and residents is very complicated in the Bronx, because of the prevalence of stationary sources, like industrial facilities, as well as mobile sources, such as highways, in addition to the insufficiency of protective spaces, such as clean indoor spaces. In addition, 30% or more of the population live below the Federal Poverty Level (FPL) in 4 out of 7 Bronx neighborhoods (NYC Health 2021). Due to these reasons and more, residents of the Bronx are especially vulnerable to air pollution. Not only can these vulnerabilities lead to asthma flare ups for sensitive populations with the disease, but also cause the initial development of asthma in all age groups, especially children (NYC Health 2021). “In 2016, the rate of asthma-related emergency department (ED) visits among children ages 5 to 17 years was more than six times higher in very high poverty NYC neighborhoods,” proving how especially harmful the issue of air pollution can be for children living in poverty. These cases can be very serious, too, as 10-11% of asthma-related emergency room visits in impoverished NYC neighborhoods resulted in hospitalizations (NYC Health 2021). The Bronx in the context of NYC is a very clear example of urban environmental injustice as well as the severity of the complex issue of air pollution.

Concentration vs. Exposure: As Kennedy et al. write in their book *Air Pollution, the Automobile, and Public Health,* “There is an important distinction between concentration and exposure. Concentration is a physical characteristic of the environment at a certain place and time, whereas strictly speaking, exposure describes an interaction between the environment and a living subject” (Kennedy et al. 1988). While this book was published 35 years ago, our current measures of pollution exposure which aim to help Americans still tend to neglect this critical distinction. These two terms are often used interchangeably, and while the difference between them may seem insignificant, the use of pollution concentration to represent individuals’ exposure, and therefore the data which public health policies are based on, has led to heightened disparities in pollution-related health problems. This section will highlight a few of the key components which must be considered when calculating exposure, a more accurate measure of individuals’ experiences with varying levels of air quality.

Recent studies published by the Public Library of Science have shown that people in the United States spend about 90% of their time indoors (Seguel et al. 2017, Ji et al. 2015). So, why are our national public health policies based on the pollution levels outside when the vast majority of people's time is spent inside? Outdoor concentrations of these ambient pollutants do not accurately represent the environments in which people are being exposed to them. In fact, one study found that "indoor PM [particulate matter] pollution of outdoor origin is a cause of considerable mortality, accounting for 81% to 89% of the total increase in mortality associated with exposure to outdoor PM pollution" (Ji et al. 2015). People are being exposed to deadly levels of ambient pollution while they are indoors, so the AQI, which is measured by outdoor concentrations, must not accurately reflect the individual experience that is pollution exposure. This suggests that indoor air quality may play a bigger role in ambient pollution exposure than the current exposure measures indicate. Chapter 4 will utilize an ongoing research study investigating this role.

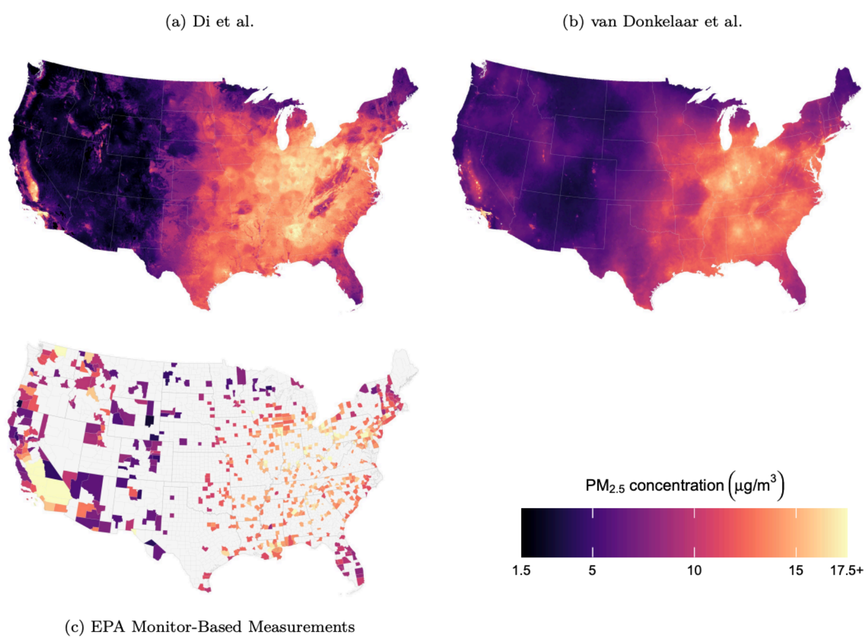

Figure 2: PM Concentrations via EPA vs Satellites (Fowlie et. al 2019).

In addition to understanding the importance of indoor air quality, there are a few more elements of the current exposure-estimating methods which must be examined. First, the distribution of ambient pollutants is not equal throughout a city, due to many factors. Proximity to highways versus greenspaces can impact an area's pollution concentration immensely, and this is not reflected in citywide averages of the EPA's AQI (Fowlie et al. 2019). A large percent of the counties in the United States do not contain a $PM_{2.5}$ monitor, leading to significant gaps in our knowledge in local pollution distribution, and these gaps can be seen across the map in Figure 2 (Fowlie et al 2019). These measures result in policies which aim to give welfare to individuals who are experiencing the most exposure to pollution, but one study done by Fowlie et al. found that these monitor readings do not necessarily result in welfare-improving policies (Fowlie et al. 2019). In fact, through satellite-monitored estimations of air pollution compared to EPA readings of the same neighborhoods, these researchers found that some populations who were exposed to acceptable concentrations according to NAAQS standards received welfare benefits, while populations exposed to unacceptable levels did not (Fowlie et al. 2019). Although satellite measurements still solely record outdoor air quality, they give a more complete representation of the country's ambient concentrations than the EPA's monitor system which clearly has many flaws in the way that it intends to support the populations that need it. Evidently, there is a clear disconnect between the true relationship between people and air pollution and the way in which we measure it, and one explanation for this could be discrimination in the monitoring process.

A study done by Corbett Grainger and Andrew Schreiber examined the process of installing the EPA's outdoor monitors to investigate if they are strategically placed in attainment areas in order to reduce the likelihood of costly reductions in pollution output. Attainment areas are parts of the country that comply with the NAAQS levels, and nonattainment (or "maintenance") areas are parts that exceed at least one of the levels of the NAAQS (EPA.gov). While these pollution standards are set at a national level, the installment of monitors and measurement of ambient concentrations are done by local regulators (Grainger et. al 2019).

While the federal outlines for the monitoring network suggest that new monitors are installed in the most polluted areas of a neighborhood so that they can be addressed at the highest priority, this study found that this is not always the case. In fact, it found that new monitors are placed in areas that are, "on average, relatively clean compared to the surrounding area" (Grainger et. al 2019). Due to possible political pressure from influential individuals and firms which may bear the costs if an attainment county is designated a nonattainment county due to high pollution levels, local regulators have been found to avoid pollution hotspots, especially so in poor areas (Grainger et. al 2019). In addition, they found that race may play a role in these local siting processes, making it much less likely for low-income and populations of color to have their neighborhoods monitored by this network (Grainger et. al 2019). This evidence suggests a huge flaw in the EPA's air quality monitoring strategy, proving that the gaps in information not only exist, but also are evidence of and may heavily contribute to the environmental justice issues that specifically target minority and low-income Americans. While there are obvious strides to make in the country's air pollution regulations, it is necessary to understand the history of all these policies and the improvements they have made so far. Chapter two will discuss the history of air pollution regulation, especially focusing on the origins and developments of the Clean Air Act.

Chapter two: The History of Air Pollution Regulation

Humanity's relationship with air pollution has been documented throughout history since 2000 B.C., and the issue has been understood and dealt with in numerous ways over the course of those thousands of years (Heidorn 1978, 1589). As the sources of anthropogenic air pollution have evolved, so have people's understanding of air quality, and not until very recently have governments intervened with measuring people's exposure and controlling the sources which emit the harmful pollutants. Centering in on the United States, the majority of the country's history was without government action until states began to individually implement their own regulations (Stern 2012, 44). The slow introduction of government's role within air quality concerns began a timeline of laws and regulations which eventually led up to one of the most significant moments in US environmental history: the creation of the EPA and the Clean Air Act of 1970 (EPA 2023). This chapter will discuss the history of air quality regulation pre-1970, highlighting the ways in which people began to measure air pollution and approach different modes of regulation. It will then examine the events that led up to the creation of the Clean Air Act and the elements of the act that are most relevant to the discussion of air pollution exposure. Finally, it will relate these principal elements of the EPA and its Clean Air Act to recent government measures of ambient air pollution exposure, including the ways in which it is adequate, yet focusing on its shortfalls in accurately measuring and limiting individual exposure.

The First Responses to Air Pollution: With the existence of human civilization, comes air pollution. First documented by Biblical and historical figures such as Abraham and Hippocrates, people have associated cities with smoke, odor, and contamination (Heidorn 1978, 1589). In 1170, philosopher Maimonides wrote about the conditions of rome, and noted that "The relation between city air and country air may be compared to the relation between grossly contaminated, filthy air, and its clear, lucid counterpart (Heidorn 1978, 1589). Even before written documentation of environmental pollution, there is proof that early homosapiens suffered the health consequences of smoke production inside confined spaces (László 2014). In fact, "Histological assessment of the lungs of ancient human mummies has shown that anthracosis (accumulation of carbon in the lungs caused by inhaled smoke or coal dust) was a regular disorder in many ancient societies due to long exposure to the smoke of domestic fires" (László 2014). Materials such as animal and vegetable oils were burned to supply light, and wood and other animal wastes were burned to supply heat. These materials emit dangerous levels of smoke and toxins when burned, and this was especially lethal due to the fact that they were often burned in enclosed spaces (László 2014). There is no doubt that the relationship between humans and anthropogenic pollution has been long-running and significant throughout time. Yet, a drastic shift occurred in human history that changed the state of the atmosphere and environment in a way it had never been affected before. Around the 1760s, the start of the First Industrial Revolution coincided with the birth of the United States, and the sources of anthropogenic air pollution shifted to become incredibly more numerous and powerful. Since this boom of production and power, large-scale industry and the United States have become a large source of the earth's air pollution and complicated humanity's relationship with the atmosphere.

The mid-to-late 20th century in the US was a marking period for the development of the Clean Air Act and modern air quality standards in the United States, and an increasing amount of government action has occurred since then. But there were 200 years of American history before this time, and it is important to review the ways in which Americans came to understand and deal with the issue of air pollution in this pre-EPA era. During the early years of the United States, all issues regarding air pollution were resolved privately between parties, often labeled as "private nuisances" or "trespasses," and little government intervention was ever involved (Stern 2012, 44). So, because they were private nuisances, individual citizens and institutions were responsible for settling any issues between themselves, allowing more powerful sources to emit unlimited volumes of pollution and collatorally cause harm to endless recipients, without being held accountable by the law. The first ever official legislation regarding air quality in 1881 was enacted to finally declare that emitting smoke was a public nuisance, meaning that producing pollution affects a group of people or the general public, a much more apt characterization of the issue (Stern 2012, 44). This was followed by decisions to place limits on the amount of acceptable emissions, and this shifted the focus of air regulation onto the importance of reducing emissions from using abatements after the fact (Stern 2012, 44). This was a vital step in the evolution of air pollution regulation, because creating these limits both gave the public an understanding of their relationship with pollutants as well as reduced the pollution at the origin. As these government regulations continued, it became imperative to create a ranking system of smoke density and standards for these levels, thus the Ringelmann chart was created (Stern 2012, 45).

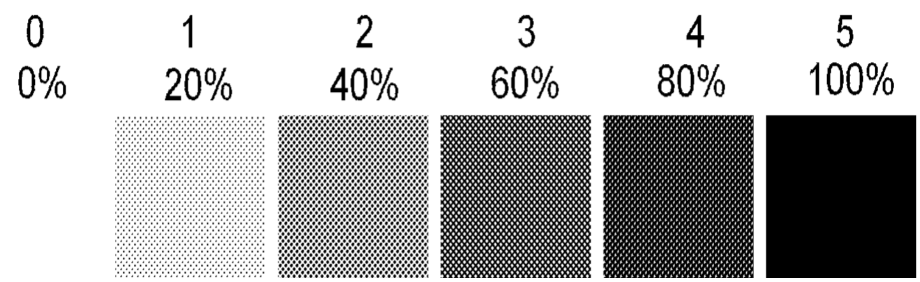

Figure 3: The Ringelmann Chart (Soliftec 2020)

As seen in Figure 3, this chart provided a visual scale of different smoke opacities ranging from 1 to 5, in which number 3, or at least 60% opacity, was prohibited from being emitted in almost all communities (Stern 2012, 45). This system was obviously not very precise, but it was a necessary introduction of basic air quality standards as industrial black smoke became so dense in some American cities that it could “barely float in the air” (Rosen 353). At this point, the focus of air quality regulations was very surface level, and mostly related to reducing the general amount of pollution in the atmosphere. Individual exposure to air pollution was not heavily considered or measured, as Americans were just beginning to understand the economic, environmental, and health impacts of the smoke they were encountering.

The Creation of the Clean Air Act: As the twentieth century progressed, various county and city regulations trickled into action, including limits on the emission of different types of particulate matter and controls on the type of coal being burned (Stern 2012, 47). Yet, many scientists and citizens felt as though this state-based approach was not adequate, so the federal government finally took action with the Air Pollution Act of 1955, which funded and authorized research programs centered around air pollution (EPA, 2023). Around the country and world, the topic of pollution was at the forefront of many people's minds, due to a few separate events. For starters, the publication of Rachel Carson's *Silent Spring* brought nationwide attention to environmental issues that had not been addressed so directly in the media before (Stern 2012, 51). This book criticized the use of pesticides and the ways in which human-made chemicals impact both human health as well as environmental health. In addition, the London Smog Disaster of 1962 and the drastically polluted conditions of both Birmingham, Alabama and Los Angeles, California brought global attention to the horrors of air pollution and the lack of regulation that existed to address the problems (Stern 2012, 51). A severe smog event in 1953 occurred in NYC that closed two airports, caused respiratory reactions for residents all over the city, and was eventually linked to almost 200 deaths (Umich n.d.). With all this attention on air quality and intense bipartisan demand for pollution solutions, the United States passed the Clean Air Act of 1963, which made history as the country's first ever federal legislation which involved direct control of air quality (EPA 2023). An essential part of this act was the establishment of research programs and authorized the research of new air quality measurement and controlling techniques (EPA 2023).

By 1970, the Environmental Protection Agency (EPA) was formed and the Clean Air Act of 1970 was created. These both act as foundations for the air pollution regulations that we still see today, so it is important to understand where our current measures and controls of air quality have come from. The EPA was not a new agency created from the ground up with new abilities or resources that did not exist before in the government, it was rather a reorganization of various departments by President Nixon (Andrews 2010, 227). For this reason, the main focus of the EPA was to create and maintain standards of different pollutants, from air and water pollution to hazardous waste (Andrews 2010, 229). Maintaining these standards worked hand-in-hand with the establishment of the Clean Air Act, which consisted of four principal regulatory programs. First, as mentioned in the first chapter, the National Ambient Air Quality Standards (NAAQS) were created to set standards for the certain concentrations and time spans of exposure that should not be exceeded for six different pollutants in order to preserve public health (EPA 2023). The act also implemented State Implementation Plans (SIPs), New Source Performance Standards (NSPS), and National Emission Standards for Hazardous Air Pollutants (NESHAPs) (EPA 2023). These programs hold state governments accountable for maintaining the standards for NAAQS and for hazardous pollutants in particular, as well as require them to set standards for any new stationary sources of air pollution (EPA 2023). So, the basic duties of the EPA and the Clean Air Act of 1970 involved creating nationwide standards for specific pollutants and holding companies and governments responsible for keeping people safe by maintaining these standards.

The six “criteria” air pollutants which are included in the NAAQS table can be found all over the United States and are harmful to human health and the environment, and include Carbon Monoxide, Lead, Nitrogen Dioxide, Ozone, Particle Pollution, and Sulfur Dioxide (EPA 2023). The standards for these pollutants are very specific, and they are important in keeping the public informed on the gasses and pollutants which can cause them harm. In order to implement these standards, it is vital to accurately understand and measure the pollutants which individuals are actually being exposed to. These standards have created a tremendous foundation for a system that measures exposure and protects people from dangerous levels of pollution, but there are still ways to go to make this system a reality.

The Clean Air Act and Measuring Exposure: In order to keep track of the levels of pollution in the air, the EPA began publicly measuring the country's ambient air quality with outdoor monitors in the 1980s, starting with ozone and, a few years later, with measurements of PM10 and PM2.5 (EPA 2023). According to the EPA today, approximately 1,000 out of 3,000 counties in the country are included in their air monitoring data, because their resources are only able to cover a certain amount of space, and they prioritize the areas where communities are "most impacted" (EPA 2023). This includes prioritizing urban areas over rural areas that may not experience as much direct exposure. This system may seem sufficient on a macro level, but when it comes down to individual communities and people, there is a lot of information in terms of air pollution exposure that is missing. Firstly, each person experiences different air quality conditions in their homes, on their commute to work or school, inside and around their workplace, and all of the time in between. In addition, a lot of the differences between these factors are related to demographic differences such as income, race, and gender, strengthening the disparities that exist between the experiences of specific groups of people. Because the EPA measuring system is relatively one-dimensional and does not address these complex differences between individuals and communities, the people who need the most support are not able to receive it.

The Clean Air Act has not gone without positive changes, though, and it is actually set up to require the EPA to review the NAAQS every five years to decide if the standards should be revised. The most recent change since 2012 was announced on February 7th, 2024 to require a more stringent control on fine particulate matter, or $PM_{2.5}$ (EPA 2024). The EPA revised the accepted level of $PM_{2.5}$ from 12 µg/m3 to 9 µg/m3, stating that scientific evidence proved the old standard to not adequately "protect public health with an adequate margin of safety" (EPA 2024). Thousands of studies regarding the adverse effects of $PM_{2.5}$ exposure impacted the agency's adjustment, many of which supported "a causal relationship between long- and short-term exposures to PM2.5 and cardiovascular effects, respiratory effects, nervous system effects, and cancer" (EPA 2024). It is estimated that this revision will result in reducing as many as 4,500 deaths as well as 290,000 missed workdays in 2032 (EPA 2024). This will not only improve public health, but also benefit the economy by improving quality of life and productivity for millions of workers and families. Further, this ruling mentions that the EPA is finalizing revisions on other aspects of the PM NAAQS standards, focusing on enhancing monitoring and protection of at-risk communities who suffer from environmental injustices (EPA 2024). Hopefully this will address the issues relating to discriminatory siting of monitors, which will make the CAA one step closer to effectively protecting individuals from air pollution.

In addition, it is important to recognize the positive impact that the Clean Air Act has had on the United States so far, not only in creating a strong foundation for future regulations, but for the actual atmospheric and public health improvements that it has accomplished. In 2023, the EPA released a 40-year-anniversary report highlighting the progress it has made in Americans' lives since the original Clean Air Act of 1970. In the year 1990 alone, the CAA had led to the prevention of 205,000 premature deaths, 672,000 cases of chronic bronchitis, 843,000 asthma attacks, and 189,000 cardiovascular hospitalizations (EPA 2023). In children specifically, it was estimated to prevent 10.4 million lost I.Q. points, due to the impact of lead reductions, and 18 million child respiratory illnesses (EPA 2024). This report also details that from 1990 to 2008, emissions of the six NAAQS pollutants went down 41%, while domestic gross product had risen 64% (EPA 2024). Improvements in vehicle models and heating systems, guided by the rules implemented by the CAA, have also significantly reduced the concentrations of deadly pollutants in the atmosphere (EPA 2024). In fact, when it is fully implemented in 2030, the EPA's vehicle and fuel rules will produce $186 billion in air quality and health benefits, only having cost $11 billion to implement (EPA 2024).

Another aspect of New York City's government which has contributed to a more complete network of air quality monitoring is the New York City Community Air Survey (NYCCAS) which was started by the Health Department and Queens College in 2008 (NYCCAS 2024). This network records data from about 100 different locations in the city each season, which is much more spatially dense than the EPA's outdoor monitors. These monitors do not collect live readings of pollution, though, they collect pollution over the course of a two-week period, and later analyzed in a laboratory (NYCCAS 2024). This makes it impossible for this network to accurately report the everyday fluctuations in ambient air pollution which are impacting the residents in various neighborhoods.

Evidently, since the start of the United States and especially after the environmental crises of the 20th century, there has been a gradual increase of government attention on the issue of air quality regulation. Apart from the various aspects of the EPA's ambient monitoring that must be improved, one of the most obvious shortcomings of this history report is the absence of indoor air quality (IAQ) regulation. This is due to the fact that the EPA has yet to engage legally with the issue of indoor air quality. Not only is there a lack of indoor monitoring to more accurately measure people's experiences with air pollution, but there is a complete lack of regulation involving indoor air quality. For about 100 years starting during the hygienic revolution in the mid 1800s, indoor air quality was at the forefront of public health relating to the environment, with one New York doctor John Griscom in 1850 stating that "deficient ventilation … (is) more fatal than all other causes put together" (Sundell 2004). Yet, as described earlier in this chapter, the mid 1900s brought a complete transformation in the public understanding of the environment and the human relationship to it. While public statements like Silent Spring brought awareness to the issues of the ambient environment and led to a remarkable surge in understanding and action related to the outside world, they also changed the idea of "environment" from all environments (with a specific focus on IAQ) to exclusively outdoor nature (Sundell 2004). We still see today that the word "environment" is synonymous with outdoor environments, and while this is appropriate for addressing issues related to the atmosphere and outdoor ecosystems, it inhibits our ability to address one of the deadliest environmental issues relating to human health. In developing countries, the IAQ issues resemble those discussed in the early human history section, such as burning biomass in unvented spaces (Sundell 2004). In 2004, due to these issues in less developed parts of the world, over 2,000,000 deaths occured yearly, mostly with women and children (Sundell 2004). In developed parts of the world, IAQ issues are less severe but still contribute to a significant amount of illnesses, allergies and deaths yearly (Sundell 2004).

Factors such as dampness, ventilation, building materials, and outdoor air quality are some of the main factors that contribute to the quality of air indoors. Some of the most common indoor-originating air pollutants include asbestos, carbon monoxide, formaldehyde, lead, and nitrogen dioxide (EPA 2024). In addition, volatile organic compounds, or VOCs, are a pollutant that are much more common indoors than outdoors, due to the nature of their sources, such as paints, wood preservatives, aerosols, and dry-cleaned clothing (Namieśnik 1992). "In the 1970s a sharp increase in nonspecific complaints by office workers and school children was noted in several countries. As the symptoms seemed to result from exposure in schools or office buildings, the term 'sick building syndrome' [SBS] was applied to them" (Namieśnik 1992). As more cases of SBS were reported, with people experiencing wide-ranging symptoms like fatigue, sore throat, and depression, more attention was brought to building conditions and pollutants like VOCs (Namieśnik 1992). In 1980, the EPA published a VOC national ambient database to compile as much information as possible on the pollutant, and this helped with the understanding of its varying chemical properties and concentrations in different sites (Namieśnik 1992). While the EPA has never set any regulations on indoor air pollution, it does offer educational information on the ways in which people can improve their indoor air quality (epa.gov). Unlike the NAAQS, there are no national standards for indoor pollutants despite all of the research that has proven that there are deadly levels of specific chemicals and pollutants. The history of the government's role in indoor air quality regulation proves to be brief if not non-existent, and this is one of the most significant fault's of the EPA's role in air quality regulation. There are many factors which play into the complex issue of individual exposure, and chapters three through five will address the infrastructural and meteorological impacts of exposure, as well as the policies which should be put in place to more thoroughly keep the public safe from air pollution.

Chapter 3: The Impact of Infrastructure

The ways in which cities are designed and maintained make a great impact on their inhabitants' access to clean air. Environmental infrastructure refers to the architecture and urban plan systems within cities that safeguard environmental quality while also providing their citizens with necessary shelter, resources, and protection from outside hazards (Nathanson 2023).

In terms of different people's daily proximity to pollution sources, access to greenspace, and the quality of the structures that people are spending their time in, there are multiple levels of urban infrastructure which can either reduce or exacerbate the inequalities that exist within the web of exposure to air pollution. This chapter will review the different sources of air pollution in New York City as well as analyze the role of these sources in relation to housing and infrastructure. It will also discuss the role of greenspaces in NYC and provide examples of the benefits they are providing in terms of air pollution levels. Finally, this chapter will examine the role of architecture in protecting people from air pollution and the different levels of air filtration that are needed for human safety.

Proximity to Sources: One feature of urban environments which heavily impacts the way we understand environmental infrastructure is the presence of air pollution sources and their relationship to residents. There are a wide variety of local air pollution sources in NYC which are constantly being supplemented by outside sources, such as coal burning plants which are located upwind of the city, some as far as the Midwest (Lall 2006). Some of the most powerful local sources include highways, outdated heating systems, waste transfer stations, and other industrial facilities (Hiciano 2022). The locations of these sources in relation to housing, schools, and workplaces in different neighborhoods play a critical role in individual exposure to pollutants.

The New York City Community Air Survey report 2008-2021 informs the public on the impacts of many different infrastructural conditions on the amount of ambient air pollution in a given area. This survey reports that air quality greatly varies by location in the city, not just in overall concentration levels but also in the types of pollutants that contribute to the varying air quality (nyc.gov). In addition, it notes that overall levels of pollution have decreased since 2009, but there are specific types of areas that continue to have higher levels of pollution, and this says a lot about the placement of sources. For example, $PM_{2.5}$, NO, NO_2, and black carbon are highest in “areas with higher density of commercial cooking grills and charbroilers, industrial areas (specifically areas with higher density of warehouses), areas of higher traffic density, and areas with higher building density” (EPA 2024). In the past, “industrial land use” has been the main indicator of high pollution, this survey found that the “density of warehouses with loading docks” is a better indicator of recent trends in pollution between neighborhoods in the city (EPA 2024). So, the areas in which industrial trucks are constantly loading and unloading cargo at warehouses have high levels of ambient pollution. The neighborhoods with a high concentration of these warehouses include Newtown Creek area in Brooklyn and Queens, the area surrounding JFK airport, and Hunts Point in the Bronx (EPA 2024). These impacts disproportionately impact communities of color, as well as those with lower income due to policies like redlining.

Redlining historically refers to the discriminatory policies from the 1930s and 1940s in which the federal government created the Home Owners’ Loan Corporation (HOLC) to determine the levels of risk of housing loans to encourage banks to give loans to middle-class families and support the economy (Kraus 2024). Neighborhoods were labeled either green, blue, yellow, or red, with each color relating to an increasingly “risky” neighborhood to fund (Kraus 2024). During this time, the HOLC “explicitly cited the lack of Black individuals or immigrants as a reason for marking an area green,” and cited the presence of Black residents of various income classes as a reason for marking an area red, hence the term “redlining”(Kraus). This racist policy has led to decades of loan practices which tend to favor populations with higher concentrations of high-income and white individuals (Kraus 2024). “When moving from zone A to zones B, C, and D, there is progressively less green space, forest cover, and open land, and progressively more developed urban land, brownfields, Superfund sites, and industrial sites," and this disproportionately affects low-income individuals and people of color" (Kraus 2024). So, there are systemically racist patterns in the ways in which pollution sources like industrial warehouses are placed in cities, as well as the placement of pollution sinks like parks and trees (Kraus 2024).

As mentioned earlier, the case study of the South Bronx is essential to this discussion of addressing environmental racism, where residents disproportionately suffer the consequences of some of the most harmful pollution sources with very little access to defensive measures. These infrastructure policy trends include redlining but also urban renewal, in which there is a prioritization of protecting and updating high-income and white neighborhoods over low-income neighborhoods where minorities live (Hiciano 2022). This has resulted in neighborhoods like Hunts Point in the South Bronx, which houses mostly Hispanic and Black residents, to bear the burdens of an intense concentration of various pollution sources (Hiciano 2022). These specific sources include "four intersecting highways, old building heating systems, a Fresh Direct warehouse and a private waste transfer station and large industries (including Hunts Point Market)" (Hiciano 2022). With children in Hunts Point being 1.3 times more likely to visit the emergency room due to particulate matter exposure than the overall rate in the Bronx and 13.7 times more likely than the rates in Greenwich-village, it is clear that this neighborhood bears the burden of the discriminatory trends in NYC's city planning and infrastructure (Hiciano 2022).

Lack of policies addressing the locations of highways is also an issue that must be addressed in the conversation of pollution sources. Some members of NYC go to schools and workplaces which border main highways, and therefore spend the majority of their day in dangerous proximity to constant fuel combustion releases. In fact, the NYCLU found that about one third of students in New York go to school within 500 feet of a major highway with a daily volume of at least 30,000 cars (NYCLU). About 80% of these students are people of color and 66% are a part of low income families (NYCLU). Clearly, there are systemic mechanisms which make it much more likely for low income and people of color to suffer the dangers of local air pollution, and it can come right down to the placement of neighborhoods and schools. In response to the lack of regulation regarding school proximity to major roadways, the NY government attempted to enact the "Schools Impacted by Gross Highways" act, or SIGH Act, which would prohibit the construction of any new schools within 500 feet of a highway, unless it is determined that there are no other possible locations for the school (NYCLU). This is a necessary step in the direction towards environmental justice for future children and schools, but it does not address the existing 375 New York schools that are located within 500 feet of a highway (NYCLU). While it may seem like an ambitious plan to address the locations of all of these schools, it is quite astonishing that New York has allowed such a large percentage of children to be educated in such dangerous environmental conditions daily. On the other hand, there are defensive measures which can be used in these high-risk locations to protect individuals in the meantime, and these will be discussed later in this chapter.

Access to Green Space: In addition to the presence of pollution sources, an important factor in air pollution exposure is an individual's proximity and access to greenspace. It is no secret that plants and forests are great natural air filtration systems, and it is also clear that greenspaces are especially rare in urban settings. A study conducted in Zhengzhou, China, investigated the relationship between greenspace and PM_{10} concentrations, and found that there was a very significant decrease in PM_{10} levels where there was some form of greenspace, and also concluded that "increasing the contact area between the edge of greenspace patches and the surrounding urban area… could reduce PM_{10} concentrations significantly" (Lei et al. 2021) Not only does the presence of a greenspace make a difference in the quality of air, but its size and orientation in relation to the surrounding urban area matters as well. Increased contact between plants and people's living and working spaces is essential to increasing the wellbeing of the urban atmosphere and the population's public health. This is vital information to consider when constructing and updating urban infrastructure, because air pollution is inevitable in current cities, and greenspaces can provide self-sustaining systems which clean increasingly more air as they grow.

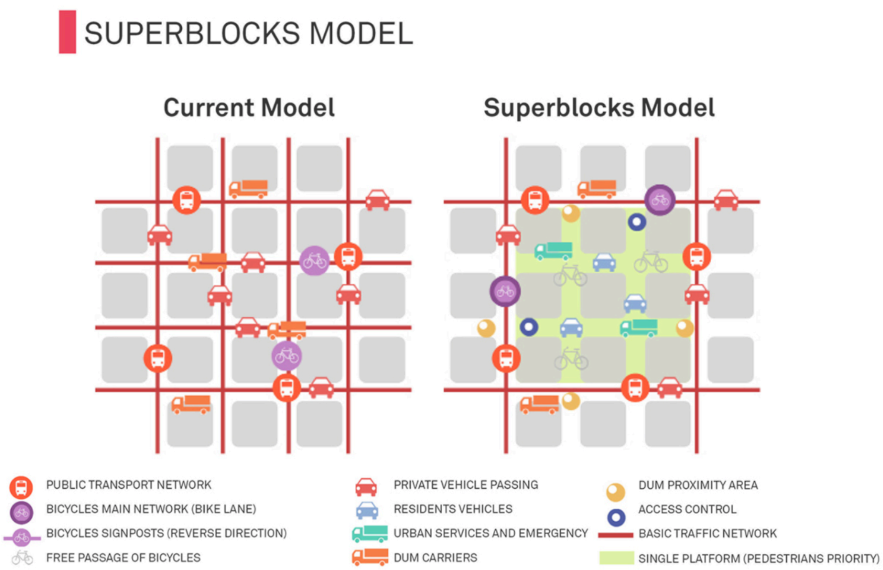

Figure 4: Superblock Model Example (BAW 2016)

One concept in new urban models which increase greenspace and provide numerous benefits is called a Superblock, which can be seen in Figure 4. This model was created by urban planner Rueda, and is created by closing four junctions in a grid of nine to reduce motorized traffic and "provide space for people, active travel, and greenspace" (Nieuwenhuijsen 2021). Barcelona has over 500 Superblocks planned, and has begun to implement them in order to reduce city noise, heat island effect (in which cities experience higher temperatures than surrounding rural areas), and most importantly, air pollution (Nieuwenhuijsen 2021). These plans are estimated to reduce nearly 700 premature deaths per year in Barcelona, with the primary cause of these prevented deaths originating from air pollution (Nieuwenhuijsen 2021). This model prioritizes the surface area of greenspace and reduces the surface area of traffic, which works in more ways than one to reduce ambient pollutants from the air. This plan could be applicable to New York City, because of the city's street grid and successful public transportation system. With smaller streets dedicated to greenspace and active transportation, citizens of New York would be able to more heavily rely on the existing public transportation system and dedicate more main streets to automobile use. In turn, this decrease in traffic would significantly lower the amount of fuel emissions and dependency on energy consumption, as well as increase the spread of greenspace, which would more effectively absorb the existing air pollution. An implementation of some form of the Superblock plan in New York City would begin a powerful transformation prioritizing public and environmental health.

So far, the closest version of this plan which has become increasingly popular in NYC has been the formation of "Open Streets," or streets which are deemed car-free on specific days of the week for certain periods of time, often associated with community partners like schools or organizations (nyc.gov). The New York City Department of Transportation website has an open application system for community organizations to apply for varying levels of closure on specific streets, as well as a map showing the closures across the city (nyc.gov). This not only encourages community engagement in the most common public spaces which are streets, but it also reduces the output of traffic pollution from these streets, and discourages transportation by car in these neighborhoods. They have been a great success so far, and if these open streets were implemented more permanently, then the addition of greenspaces would be much more attainable. Not only would the planting of more trees and creation of more greenspaces reduce the amount of pollution in the air, but it would reduce the impacts of the heat-island effect, which was mentioned earlier. In urban areas, structures like buildings and streets absorb and reemit the sun's heat much more effectively than natural landscapes, causing the areas to become "heat islands," or spaces in which the temperatures rise much higher than the surrounding areas. (nyc.gov). In heat islands, daytime temperatures can rise 1-7°F, and nighttime temperatures can rise 2-5°F (nyc.gov). The re-introduction of vegetation into these settings, like trees that form canopies over roads, green roofs, and the planting of native plants, can make a significant reduction in these temperatures. This is a simple way to target the neighborhoods that need air pollution relief the most and grant them access to the recreational, aesthetic, and health benefits of open roads and greenery.

Architecture and Filtration: Finally, the architecture of buildings in cities and their ability to filter out ambient pollutants in order to create safe indoor environments is one of the most important factors in individual pollution exposure. As mentioned earlier in this paper, people in the United States spend about 90% of their time indoors, so the quality of the air inside of homes, schools and workplaces is arguably the most important air to preserve, in terms of supporting human health. In low-income areas of New York City where buildings and air conditioning systems tend to be updated less often, it is more likely for the filtration systems to fail at keeping their residents safe. Most experts agree that centralized air systems provide the most protection from ambient pollution, and this is only effective when filters are changed regularly (Clark 2023).

A simple yet overlooked example of infrastructural defensive behavior is the existence of effective air filtration and purification systems. Due to the fact that about 75% of residential buildings in New York City were built before central air conditioning systems became standard in the 1960s, there is a lack of central air in the majority of the city (nyc.gov). The alternative form of air conditioning, a window unit, can be less thorough in cleaning the air because of the gaps that often form between the units and the window (nyc.gov). Both of these systems require regular maintenance every few months with the switching of filters, making renters in NYC reliant on their landlords to maintain the quality of their air. According to a study conducted by CUNY, low-income tenants of color are more prone to health violations which are not addressed by strong regulations or landlords, such as pest infestations and unsafe mold and pollution levels (Jungermann 2020). These minorities are taken advantage of as renters, and don't have the same freedom that homeowners do in affording to install and maintain air filtration measures. So, while utilizing measures like air conditioning systems to maintain a healthy IAQ may seem simple, it is much more difficult for populations who rely on landlords, especially for those whose homes have additional sources of pollution, like mold or pest waste.

Air purification systems are another form of defensive behavior which can improve indoor air quality. During the Summer of 2020, due to concerns about air-borne spread of COVID-19, New York City implemented the installation of 2 Intellipure air purifiers per classroom of every public school (Akpan et. al 2021). These purifiers are able to filter the size of particles that carry COVID-19, but do not have the qualifications to filter smaller particles which are harmful to student health, like $PM_{2.5}$ (Akpan et. al 2021). Over the past 2 years working as a research assistant for a project that studies indoor air quality in NYC schools, I have personal experience seeing how numerous public schools interact with these purifiers. Although each classroom does often have two of these Intellipure devices, it is very rare that both classroom's purifiers are plugged in and continuously running, which is the only way that they actually succeed in cleaning the air. Due to the fact that there is not an effective system to ensure these purifiers are constantly running during school hours as well as their inability to control certain pollutants, these purifiers have likely not contributed enough defense to improve these students' conditions. There are more effective purifiers, though, such as ones that use High-Efficiency Particulate Air (HEPA) filters (Dubey et. al 2021). The use of HEPA-certified purifiers in schools, homes, and other indoor spaces could greatly improve the conditions that people are living in, but only if they are used regularly or always.

Another infrastructural advancement which has provided great guidance for maintaining healthy indoor air quality is the creation of the Leadership in Energy and Environmental Design, or LEED certification. The United States Green Building Council created this certification to award environmentally-conscious building performance based on seven areas: "indoor environmental quality, sustainable sites, water efficiency, energy and atmosphere, materials and resources, innovation, and regional priority credits" (Phillips et. al 2020). Based on these criteria, green buildings are given a score and awarded one of the certification levels: Certified, Silver, Gold, or Platinum (Phillips et. al 2020). A very important factor in scoring a high value in the indoor environmental quality section is the type of ventilation in the building. LEED-certified buildings with ventilation systems that supply outdoor air into occupied spaces must contain particle filters, ensuring that the outdoor PM does not enter the building (Phillips et. al 2020.)

At the University of Utah, all new buildings costing over $2.5 million are required to achieve at least a Silver rating, and a study published in 2020 investigated the impact that the campus' LEED buildings had on indoor PM levels in comparison to its non-LEED buildings

(Phillips et. al 2020). The PM pollution concentrations in 12 different LEED buildings of varying certification levels were monitored and compared to those in 12 different non-LEED buildings, and researchers found that there were statistically significantly lower concentrations in the LEED buildings (Phillips et. al 2020). This is a very valuable finding, because it proves that these certified structures not only reduce the impact that they have on the environment around them, but have been proven to make a substantial improvement for the indoor conditions when compared to structures in the same environment which were not constructed considering the same factors. The LEED certification, or at least the air quality factors, should be considered for the construction of all buildings, because clean air is a basic human right. In terms of New York, projects which cost over 2 million dollars are required to achieve a LEED gold standard or higher (nyc.gov 2023). This is a huge step for the future of the city's infrastructure, and proves that environmental initiatives have been taken seriously since regulations in NY involving LEED began in 2005 (nyc.gov 2023). One point which should be addressed in future regulations is the improvement of existing buildings in areas of the city where people suffer disproportionately from indoor air pollution. This would work to address the considerable disparity in air pollution exposure that certain neighborhoods and demographics face daily.

Chapter 4: Environmental Economics and Indoor Air Quality

Environmental economics is a very important discipline in environmental studies, and it studies the complex and quantitative issues of the environment and translates them to the systems of the market economy. The production and consumption of goods in our economy often generate a negative externality, or a third-party effect, relating to the dangers of pollution on the public. One might assume that the answer to air pollution concerns would be to ban all emissions, but environmental economists consider the tradeoffs of the costs and damages involved with the externalities like pollution. It costs more money for firms to reduce their emissions of pollution, but as we know, it causes more damage to the environment and public health to reduce these costs and increase their emissions of pollution. Economists estimate optimal emission levels in order to best reduce the costs while simultaneously reducing the pollution in the most efficient manner.

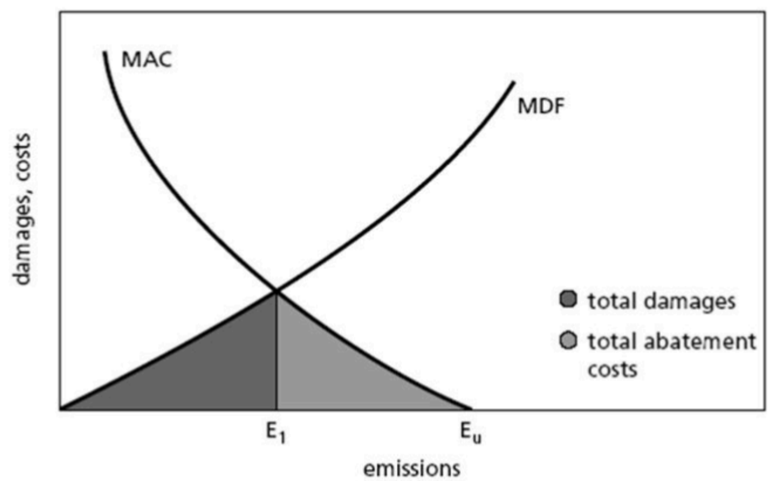

Figure 5: Optimal Emissions Graph (Fleming n.d.)

The emission level at which the marginal abatement costs (MAC), or the costs that result from pollution abatement, equal the marginal damages of pollution (MDF), equals the optimal pollution level, which is shown as E_1 in Figure 5. Evidently, the costs of pollution abatement are already understood with monetary values, therefore applicable to an economist's understanding and estimation of this optimal level. The damages associated with pollution are much more complex and nuanced, like the ways in which ecosystems can be contaminated or humans can go to the hospital from asthma-related illnesses. In order to estimate the most efficient amount of pollution, the damages related to pollution must be translated into dollar terms. Here is where the importance of measuring individual exposure comes into play. If the pollution damages relating to public health are being miscalculated by ambient concentrations, then the true complexity of experience with air pollution is simplified, and economists are not able to estimate an accurate balance between abatement costs and pollutant damages. Overall, we must accurately understand the mechanisms and measurements involved in pollution damages in order to assign them a monetary value, translate them to the economic market, and effectively create policies. This is necessary in order to bring justice to the communities which continue to suffer from environmental issues in silence.

Research at Fordham: During my time at Fordham, I have worked with professor and environmental economist Marc Conte on a study which investigates the role of air pollution exposure in high schools, including the determinants and the impacts of indoor air pollution. Thanks to Professor Conte's guidance and the receipt of two undergraduate research grant programs at Fordham, I have been able to lead my own portion of the project on the Rose Hill campus, which utilizes data from air pollution monitors inside of classrooms in Dealy Hall, as well as an outdoor air pollution monitor and a weather station. In addition, I have installed air quality monitors in four different types of student housing, on and off campus. The primary focus of my study is to investigate the relationships between meteorological changes and particulate matter pollution concentrations inside and outside the classroom. I also aim to investigate the impact that different types of buildings within the same neighborhood, which experience similar outdoor conditions, have on the conditions of indoor air quality.

Motivations: As climate change progresses and weather patterns become increasingly intense and unpredictable, it is important to understand the relationship between meteorological changes and the concentrations of indoor air quality. Extreme weather events may bring outdoor conditions unlike ever before, and it will be vital for people to recognize the mechanisms that drive fluctuations in indoor pollution levels in order to protect themselves as well as create infrastructural regulations in order to protect all members of the public. For example, in June of 2023, severe wildfires in Canada produced tremendous amounts of smoke and pollution that were swept by southbound winds toward New York City. These wind patterns essentially resulted in an extreme weather event in the city, in which many residents experienced health emergencies due to the poor air quality (Lin et. al 2023). A study by the Yale School of Public Health found a "stark association between Canadian wildfire smoke and increases in the number of people being seen for asthma-related symptoms in New York City emergency departments" (Lin et. al 2023). While there are usually about 162 asthma-related emergency department visits across New York City per day, the week with heavy wildfire pollution was recorded to have 261 asthma-related visits each day (Lin et. al 2023). This event brought a lot of attention to the scale of the impacts that wildfires can have, not only within the areas of the fires, but also extending to population centers hundreds of miles away. Local news stations and weather advisories cautioned residents of NYC and the surrounding area to stay indoors, especially if they were a part of sensitive groups that could be more prone to hospitalization due to smoke. Indoor spaces in NYC were not necessarily exempt from the impacts of these fires though. In fact, the air monitors that I installed inside Dealy Hall's classrooms on campus recorded incredibly high levels of indoor particulate matter during those few days.

Clearly, ambient pollution sources have an impact on indoor air quality levels, and meteorological variables such as wind direction play a large role in controlling the conditions of indoor spaces like classrooms. This event motivated my interest in investigating the relationship between indoor air quality and weather characteristics, which is not only relevant during extreme events, but also in understanding a local environment.

The characteristics of the area surrounding Fordham's Rose Hill campus vary significantly in each direction, from major roadways and interstate railways to an old growth forest. So, the local wind directions bringing in air from these various areas on a day-to-day basis may have an influence on the indoor conditions, in much the same way that far-away winds from the Northwest had on New York during the wildfires. I am interested in understanding if there are any patterns connected to winds originating from pollution sources versus pollution sinks and the fluctuations of indoor pollution levels. In chapter 3, the issue of urban infrastructure and the significance of pollution sources and greenspaces on individual pollution exposure were discussed. This study aims to provide more data and evidence on how weather patterns and indoor air quality play a part in this equation, making it easier for policymakers and urban planners to understand the complex mechanisms involved in pollution exposure.

A final issue that has motivated my research is the variance in air quality that different indoor spaces within the same neighborhood experience. This is why I am interested in studying the differences in air quality fluctuations between student apartments in different types of buildings on and off Fordham's campus. According to our country's current measure of air pollution, it is sufficient to measure a community's air pollution with one outdoor monitor and estimate the damages of pollution for all members of the community based on that data. Yet, as presented earlier in this paper, evidence proves that Americans spend the majority of their time indoors and trends show that certain people bear disproportionate burdens associated with air pollution exposure. So, my hypothesis is not only that indoor concentrations are different from outdoor concentrations, but also that indoor concentrations in different spaces vary between each other, even if those spaces are located in the same neighborhood. Considering these motivating factors, this study on campus investigates the following questions: first, is there a causal relationship between certain wind directions recorded in the Fordham area and indoor air quality in Dealy Hall? And second, are indoor pollution concentrations relatively consistent with the concentrations outdoors, or do they vary significantly between different buildings?

Project Description and Data Collection: In order to answer these questions, there are a few different types of data that I have collected on and around Fordham's campus. First, to represent the wind and other meteorological variables, I routinely collected data from a weather station which was installed on the roof of Freeman Hall. This station is called a Vantage Pro weather station by Davis Instruments, and the station records temperature, precipitation, wind, humidity, barometric pressure, and a few other components of weather patterns. It has been recording hourly data since January of 2023, and I have collected a full year's worth of this data. To represent the air pollution variable on campus, there are 10 air quality monitors collecting data, with 1 installed outdoors and the rest installed in 9 different classrooms in Dealy Hall. These monitors are called PurpleAir monitors, which detect concentrations of PM_1, $PM_{2.5}$, and PM_{10}, as well as relative humidity, temperature, and pressure. I installed these monitors in Dealy with a research team in the Summer of 2022 for a larger project, and I have periodically collected and organized this data since then. Finally, in order to examine the variance in PM concentrations within different types of housing, I installed 4 PurpleAir monitors in four separate student apartments. One of these monitors is recording data in Walsh Hall on campus, and the other three are in different styles of apartments, all within a 2,000 foot radius of each other. The actual installation of these monitors is very simple and temporary, making it easy to fix them in a setting like a classroom or apartment and remove them without damaging the setting. I used zip ties to fix the monitors to beams or pipes on the wall at least 5 feet above the ground to allow for air flow. Although I ran into occasional problems with the monitors' power chords being unplugged by students in the classrooms and apartments, I generally found these to be a perfect device in recording constant PM data.

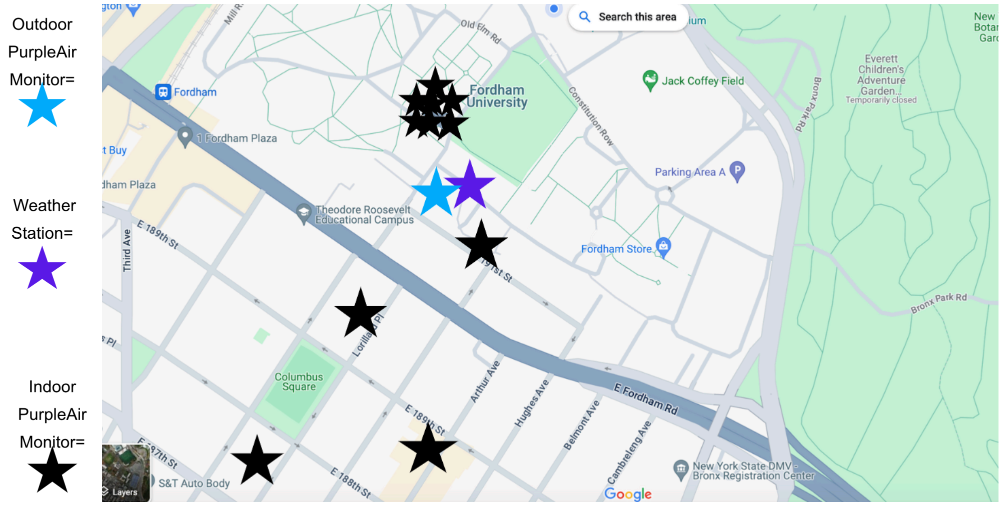

Figure 6: Map of Devices in Relation to Rose Hill Campus

Data Analysis: In order to analyze the relationships between the various types of data I collected, I have learned to work with a few different software programs. With the help of Excel, as well as two statistical analysis software packages, R and Stata, I have been able to organize and write code to organize and compile datasets in order to prepare them for regression analysis. Regressions are a form of statistical analysis that estimate the relationships between a dependent variable and one or more independent variables. A basic linear regression equation is where Y represents the dependent variable, X represents the independent variable, β represents the coefficient, or the average linear relationship between X and Y, and ε represents the unobserved variables that affect Y and are assumed to be unrelated to X. The program which I have used for my final analysis, Stata, estimates what the coefficient is between variables, and determines if the relationship is statistically significant. For example, in understanding the relationship between indoor air quality and weather characteristics, I estimated regressions of the form:

$$Y_{it} = \text{Wind}\beta_1 + X\beta_2 + \varepsilon_{\text{unobserved}}$$

Here, the independent variable is indoor air quality in Dealy Hall, as recorded by each of the 9 classrooms' hourly $PM_{2.5}$ concentrations. The independent variables include 16 different wind directions, including north (N), south (S), west (W), east (E), northwest (NW), northeast (NE), southwest (SW), southeast (SE), north-northwest (NNW), west-northwest (WNW), north-northeast (NNE) east-northeast (ENE), east-southeast (ESE), south-southeast (SSE), west-southwest (WSW), and south-southwest (SSW). I controlled for several additional variables that may be related to the Y variable, including outdoor conditions such as outdoor $PM_{2.5}$ concentrations, wind speed, temperature, as well as indoor conditions such as floor number of the classroom, orientation of the room in Dealy Hall (whether or not it is facing Fordham Rd), temperature, and humidity. The unobserved variables include factors which have not been measured, but are assumed to be unrelated to wind and my vector of controls, making it possible for me to estimate the causal relationship between wind direction and indoor pollutant concentration.

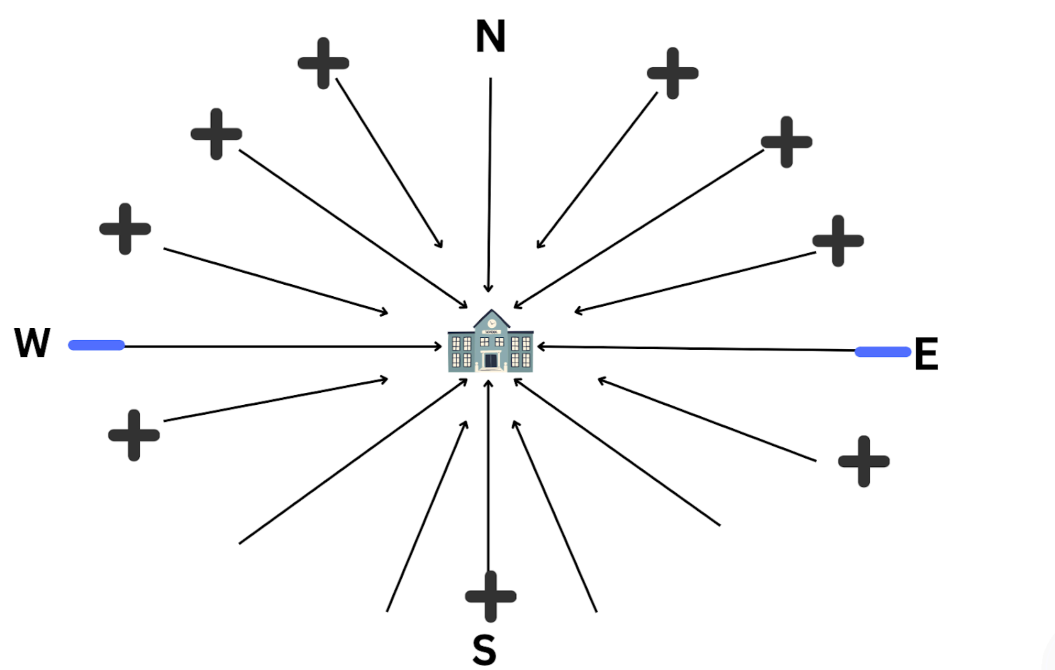

Figure 7: Wind Directions relative to indoor $PM_{2.5}$

When running this regression, I found the majority of the wind directions to be statistically significant with a P-value of 0.00, meaning that the null hypothesis is rejected for these variables. In statistics, the null hypothesis predicts that there is no relationship between the observed X variable and the Y variable. So, there are significant relationships found between the majority of the wind directions recorded and the fluctuations in indoor $PM_{2.5}$. As seen in Figure 7, which highlights the coefficients of various directions which were statistically significant, some wind directions were found to have a positive correlation with increases in indoor $PM_{2.5}$, and some with a negative correlation. The directions with no signs represent the directions which did not have a statistically significant relationship with the indoor pollution measured. The black plus signs represent the wind directions which were found to have this positive correlation, meaning that wind directions such as NNW, NW, WNW, NE, ENE, NNE, WSW, ESE, and S cause an increase in indoor $PM_{2.5}$ in Dealy Hall. On the other hand, wind directions including E and W were found to decrease indoor $PM_{2.5}$ concentrations in Dealy Hall. Some of the highest positive coefficients included the following: NNW had a coefficient of 1.109, NW had a coefficient of 1.1, NE had a coefficient of 1.35, and S had a coefficient of 1.65. These numbers represent the slope, or the relationship between the X and Y, so it is interesting to see values at this level, each with statistical significance.

I made sure to control for the time period in which the Canada wildfires occurred, because this time was a unique event in which there was a strong correlation between North-originating winds and increased indoor pollution, making this graphic more concise in its representation of everyday conditions. Figure 7 shows a pattern with the coefficients that doesn't tell a clear story, but I have hypothesized that due to the various sources surrounding Fordham, there are many winds coming from various directions and sources which contribute to indoor increases in pollution. These sources include the metro north railway, i-87, the Mosholu Parkway, and the Henry Hudson Parkway, and the Bronx River Parkway. Overall, this data presents interesting findings which prove that there are, in fact, very strong relationships between the changing meteorological conditions outdoors and the indoor conditions in locations where we spend much of our time. I find it imperative that we continue to investigate relationships like these, because just as measuring indoor air quality is important, so is understanding its role within the context of its changing surroundings.

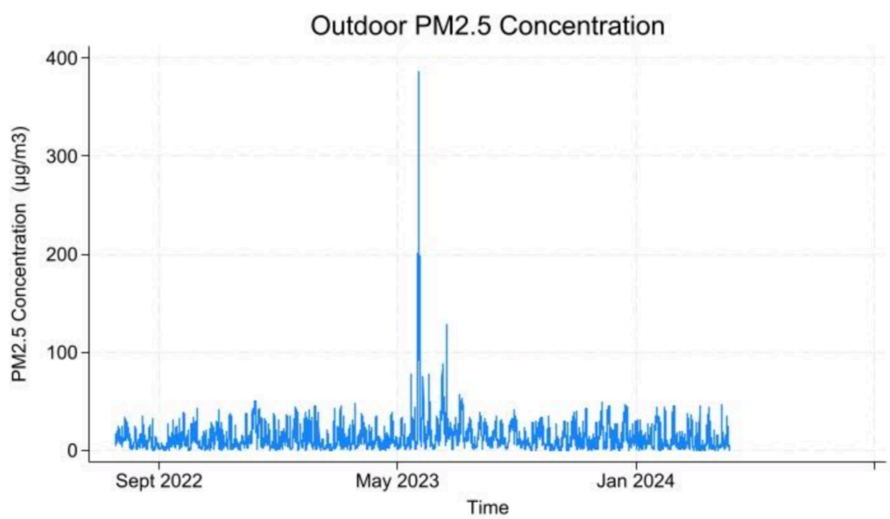

Figure 8: Outdoor $PM_{2.5}$ levels recorded at Fordham

In order to understand the outdoor PM conditions at Fordham University and in the Belmont area, I collected data from the PurpleAir monitor installed outside of Freeman Hall and created this graph. For context, as mentioned earlier, the EPA recently revised the primary acceptable levels of $PM_{2.5}$ which people can be exposed to safely, from 12 $\mu g/m^3$ to 9 $\mu g/m^3$, and the 24-hour standard to be 35$\mu g/m^3$. As seen in Figure 8, from August 2022 until April 2024, it is clear to see that the everyday fluctuations in particulate matter tend to remain below 50 μg/m^3, often wavering in the 10s, 20s, and 30s. A very obvious feature of this graph is the tremendous spike, reaching nearly 400μg/m^3 during the Summer of 2023. This, of course, represents the extremely high concentrations of pollution in early June, during the events following the Canadian wildfires. So, in theory, if this outdoor monitor was a part of the EPA's outdoor monitoring network, these levels would be representing the community of Fordham, and likely many neighborhoods around it. While there are levels higher than the NAAQS which could be investigated further by the EPA, this one graph may be a generalization of the variance that occurs in each community member's experience with PM exposure.

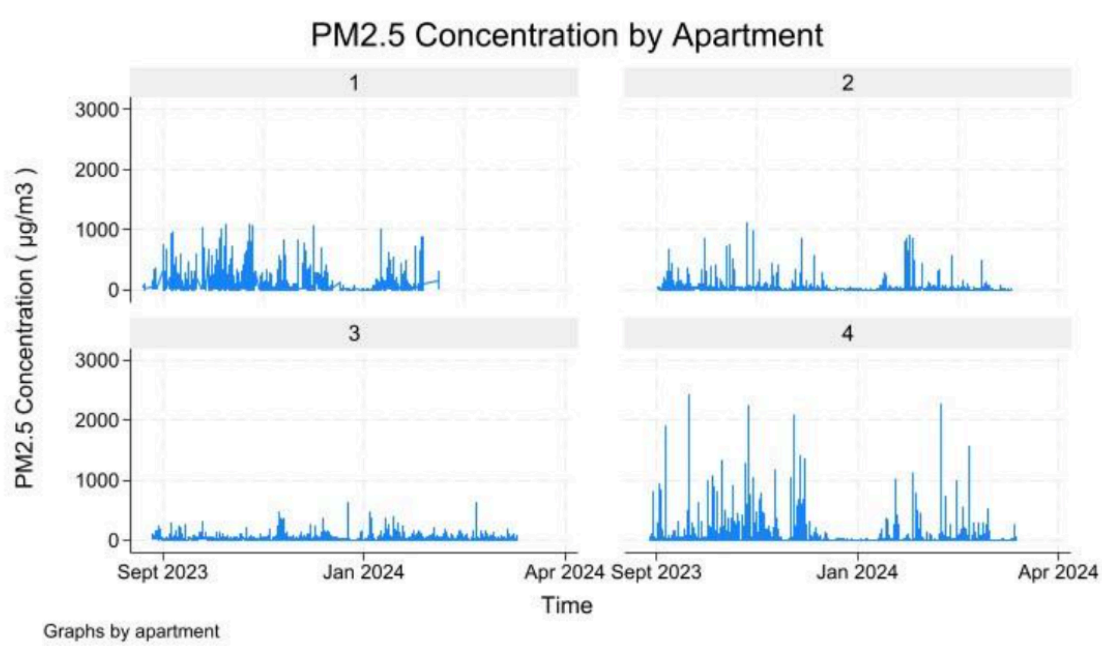

Figure 9: Indoor $PM_{2.5}$ levels recorded in four apartments

This series of graphs displays each apartment's $PM_{2.5}$ concentrations over the course of the 2023-2024 school year, spanning from September to March. These graphs most likely show a more accurate representation than the outdoor monitor on campus of the pollution which students are exposed to during the majority of their day. First off, a very important aspect of these graphs to notice is the difference in scale compared to the outdoor monitor. The scale of these indoor concentrations is alarmingly high, with some spikes from monitor 4 reaching above 2000 $\mu g/m^3$. Not only is the scale much different between indoor spaces and the outdoor readings, but there is also a considerate amount of variance between each of these indoor spaces. A basic comparison of the outdoor graph and the indoor graphs proves that recording outdoor concentrations on campus are highly inaccurate in measuring the pollution exposure that students are experiencing in their daily lives.

There are some possible explanations for why these indoor spaces have such high PM concentrations, and most of them have to do with the pollutant sources that exist in small apartments like these. Each of these apartments has a similar setup including 2-4 bedrooms, 1-2 bathrooms, a kitchen area, and a living area, all on one floor. Apartments 1 and 4 both housed four tenants, while apartment 3 housed three tenants, and apartment 2 housed two tenants. Pollution originating from cooking most likely contributes to a large percentage of these levels, as "cooking-generated particles have been considered as the most remarkable indoor particle pollutants," whether due to actual steam or smoke from food, or from stoves if they are gas (Liu et. al 2022). While family households sharing one kitchen most likely cook meals together, college students living together are most likely cooking separate meals in the same kitchen, increasing the volume of pollution emitted, as well as the length that a mealtime lasts.

In addition, many of the students living in these apartments do not prioritize ventilation while cooking via fans, windows, or purifiers, because the issue of IAQ is not well known. For example, the monitor in apartment 1 regularly saw spikes up into the 200s-300s during the 2-3 hour blocks in which all four tenants were cooking meals, mostly with lunch and dinner. Another source of particulate matter in student housing is the type of heating system, which often varies between electric furnaces and natural gas powered furnaces. Other possible air pollution sources include cleaning activities (vacuuming, sweeping), combustion of candles or smoking/vaping products, and biological contaminants (mold spores, dust mites, plants) (Liu et. al 2022). Finally, many students leave their windows open for temperature control, making these indoor spaces susceptible to outdoor-originating traffic pollution, from nearby busy streets like Fordham Road, Arthur Ave, and Lorillard Place. In the students' experiences, there is no engagement with university facility services and apartment landlords to conduct regular indoor air quality inspections, and landlord-provided AC units are rarely given new filters. One pattern in figure 9 that is interesting to note is the dip in concentrations in three of the apartments during December and January. During this time, the majority of these students were on Winter break not living in these apartments, therefore not contributing to the sources mentioned above. A final pattern which is important to note is the remarkably lower levels recorded in apartment 3 when compared to the rest of the apartments. These three roommates reported to keep their stove fan on at all times in order to maintain constant white noise, and I have hypothesized that this continuous source of ventilation may have tamed any possible spikes of PM during cooking or other activities.

Overall, the data presented above brings about a valuable discussion regarding both of my research questions. First, in regards to my data involving the relationship between wind direction and indoor $PM_{2.5}$, we are able to understand that the role of indoor air quality is very connected to the outside world. The significant relationships between wind originating from specific directions and spikes in indoor PM may not reveal a clear understanding of the exact mechanisms involved in these atmospheres, but they do reveal that there are mechanisms to be studied. I find this topic to be very important because it allows us to connect our experiences with the systems that work around us, some that may be hundreds of thousands of miles away. Not only in a time where there is an increasing prevalence of extreme weather events due to climate change, but also in a time where we must realize that the way in which we plan our cities and shape our living spaces is vital to equity in our communities as well as overall wellness.

Chapter Five: A Cleaner Future

Evidently, there are many concerns that must be addressed in regards to air pollution, and various flaws in the current policies which fail to address the urgency of this issue. The research and findings in chapter 4 have proven that measures of air quality in different indoor spaces are neither uniform nor equivalent to outdoor air quality, proving the importance of measuring and maintaining safe indoor air quality. According to chapter 2, there has been a lot of progress in the country's understanding of the sources of air pollution, measuring air pollution, and the impact that air pollution has on humans. The creation of the Clean Air Act was a historical moment and changed the course of modern federal environmental regulation, especially in shaping our understanding of humans' relationship with the environment around us. Yet, the ways in which the government measures the nation's air pollution exposure, through ambient concentrations, is very flawed and ends up strengthening the inequalities that citizens experience, especially in New York City. This chapter will discuss the importance of federal research involving indoor air quality and closer measurements of exposure. Another aspect of the issue, discussed in chapter 3, are the ways in which NYC infrastructure is constructed and updated, and how this contributes to the inequalities that certain individuals and demographics face. This chapter will present new policies involving urban infrastructure which should be put in place in order to help the cause of public health equality. Finally, the importance of environmental education involving air quality exposure will be discussed and evaluated.

The Role of Government Regulation: The policy which is most important to address in the context of air pollution exposure is the Clean Air Act. As discussed in the second chapter, there has been an ever-changing understanding of air pollution, and the local and federal governments have attempted to follow this knowledge with policies. Because the EPA follows the Clean Air Act guidelines to measure outdoor air quality and apply public health policies accordingly, there are many flaws in the way pollution exposure effects are being addressed. I am proposing a series of amendments that must be applied to the current CAA in order to effectively work towards achieving environmental justice.

Firstly, since the sparseness of the EPA's outdoor monitors inhibits the network to adequately represent the variation of air pollution outdoors, enough funding has to be provided to the agency to work towards a much more spatially-dense system. While the EPA has claimed that they focus on providing AQ measurements for counties which are most susceptible to poor air quality, chapter two proved that it may be more likely that the placement of new monitors tends to be in areas where less correction measures would be needed. This is partly attributed to the fact that the placement of these monitors is done by local regulators who may be influenced by imminent costs resulting from air pollution levels that exceed government standards. Therefore, I am proposing that more funding is allocated to local governments for air quality improvement measures to reduce the influence of costs on monitor placement, as well as ensure there are enough checks and balances in the network of people installing new monitors to remove the influence of discrimination. In addition, more research must be done in order to find the neighborhoods which suffer the worst outdoor AQ levels, because monitors should be required to understand the worst air quality in a county first, in order to ensure that alleviative policies are considerate of all outdoor conditions. In New York in particular, there is so much variation between neighborhoods, so an amendment to the CAA should require in-depth research of the disparities that exist within different counties, or boroughs in NYC.

In addition to more comprehensive measures of outdoor air pollution, the most important aspect of the CAA amendment would include the measurement of indoor air quality. While NYC is at the forefront of this discussion, the federal government must fund the requirement of indoor public spaces being monitored nation-wide in in order to maximize public health benefits. According to the USA 2021 census, nearly 90% of students were enrolled in public schools (census.gov). As children are an especially sensitive population and, on average, spend over 6 hours each day in school, these indoor air monitors should be installed in all public schools. Children in the United States deserve to attend school every day in conditions that they know are safe, and know will not result in asthma flare-ups or other health issues. In other areas of my research experience, I have personally installed air pollution monitors in various high schools across NYC, so I know it is possible to effectively create a network of indoor and outdoor monitors within schools as well as collect and understand this data in the span of a few years. With adequate federal funding, a more spatially outspread as well as dense network in public schools could be created more efficiently. This monitoring can be done without disturbing any educational practices, and has the potential to allow students and staff to understand exactly the conditions they are learning, working, and living in.

In addition, as a large number of families in the United States live in public housing units, these spaces should require indoor air quality monitors. About 9.17 million Americans lived in subsidized public housing in 2021, according to the US Department of Housing and Urban Development (huv). In New York City, 1 in 17 residents live in New York City Housing Authority (NYCHA) housing, which is the nation's largest public housing authority (nycha.gov).

"If NYCHA were a city, it would rank 35th in population size in the United States, and is larger than Sacramento, Atlanta, and Miami," so it is a large percentage of our country's children, workers, and citizens, and must be protected (nycha.gov). In addition, as these residents most likely have low incomes, and therefore may have limited access to healthcare, it is the government's duty to ensure that these people are given access to safe living spaces and reduce the health issues caused by their homes. The measurement of these buildings would increase transparency with the conditions that Americans live in, resulting in accurate air pollution regulations in favor of public health. The measurements of the air pollution inside these public spaces would not only increase the likelihood that their individual conditions could improve, but would also create a comprehensive set of indoor air quality data across the entire country. This would be a monumental step in understanding the various environmental and infrastructural factors which impact indoor air quality. After public schools and housing, I believe that all public spaces, such as community centers and state-owned religious centers, should be regularly monitored and managed in terms of air quality safety. This would hold institutions accountable for proper air ventilation and allow citizens to understand the conditions that they are spending their time in.

The Future of Infrastructure: While the monitoring of air quality is tremendously important, the defensive measures against harmful pollution levels are just as vital in ensuring equal access to a healthy quality of life for all. There are various techniques in combating the issues involved with air pollution exposure, starting with the fact that pollution sources in New York City must be analyzed both in output and location. According to the New York government, Local Law 97 will work to reduce the emissions of buildings of certain sizes using various strategies, including carbon credits, carbon taxes, and renewable energy incentives (nyc.gov 2023). This law was enacted in 2019, and was said to be one of the most ambitious plans to reduce greenhouse gas emissions in the nation, because it focuses on the emissions released by buildings in particular, which account for about two-thirds of GHG emissions in the city (nyc.gov 2023). It specifically targets buildings over a certain square-footage, and demands that they increase their energy efficiency and work to reduce their emissions to reach net zero by 2050 (nyc.gov 2023). This law must be enforced effectively, but should also require all buildings to limit their air pollutant emissions which don't qualify as greenhouse gasses. While a pollutant like PM does not cause the same atmosphere-warming effects like a gas like carbon dioxide in the context of the urgent issue of climate change, it is still clearly a deadly substance in the air which has a direct effect on the health of people exposed to it. A way in which this PM reduction can be achieved has to do with addressing the actual infrastructure of the city's and county's buildings.

Infrastructure: The infrastructure of NYC must be addressed with government policy in order to reduce the disadvantages that certain populations face in terms of air pollution exposure. Electrification of buildings can be a very effective strategy in reducing energy use as well as improving air quality. A study by Flores et. al investigated the environmental impacts of electrification of homes in a disadvantaged community in California, and found that installing electric appliances like heat pump water heaters reduced the community's carbon and pollutant emissions by about 50% (Flores et. al 2024). They stressed the importance that electrification has important and long-term benefits for the cause of improving air quality, but also may require the government to provide incentives that offset the costs of these transitions in order for low-income residents to afford (Flores et. al 2024). It is vital that the government prioritizes projects which not only improve the ways in which buildings are impacting the environment and their residents, but also paying close attention to disadvantaged communities and creating programs which make these safer buildings accessible to all.

As discussed in chapter 3, the placement of pollution sources in relation to schools is an important issue that has been addressed by the SIGH Act. I find it incredibly valuable that the New York government has followed other states in regulating the distances from which schools can be in relation to busy roadways, because learning in safe environments is a human right. Yet, since it only applies to the construction of plans for future schools, I do not find this act to be substantial enough in helping the schools and students of today. Too many students attend schools within 500 feet of highways, and there should be a reform to this act in which all of these schools should eventually be addressed. While the relocation of schools may not be attainable infrastructurally and economically, especially in lower-income school districts, it is necessary that the issues related to proximity to highways are addressed immediately. Aggressive defensive measures should be implemented, in the form of indoor and outdoor air quality monitoring, the most effective forms of quality air filtering, and the use of masks when traveling to and from school.

In terms of the types of air filtration and air conditioning to be installed in indoor spaces, there are a few things to consider. First, while school filtration systems are being considered for defensive purposes, all types of indoor spaces where people congregate or live should be required to have updated and effective air conditioning systems. Considering NYC's ability to act urgently in protecting the spread of COVID-19 with its successful installation of Intellipure air filters in schools during the pandemic, we know that it is possible to utilize government action in efforts to maintain clean classroom atmospheres. I urge cities like New York to understand the dangers of air pollution exposure in a manner which is just as pressing, and install

HEPA-certified filters in schools in order to reduce the impacts of deadly pollution. Further, as the increase in outdoor temperatures has resulted from climate change and the heat island effect, a need for air conditioning systems has increased in NYC, even though not all residents have access to central air conditioning, or even any air conditioning at all. This results in residents opening windows for the use of window units and access to fresh air, which can put many people at risk to the dangerous levels of ambient pollutants outside. I am proposing that NYC prioritizes an initiative to renovate housing in low-income neighborhoods to ensure that indoor air quality can be maintained year-round. The indoor environment requirements in the LEED certification should be followed for the construction and maintenance of all buildings in NYC, because they have been studied and proven to effectively improve indoor conditions. As air pollution worsens, so will the inequalities that low-income communities face, so these protective infrastructure measures are important to be implemented now more than ever.

A final aspect of addressing the role of city infrastructure on air quality is the increase of green spaces and the reduction of traffic-heavy spaces. As explained in chapter 3, there are many benefits to increasing green space and tree cover, including the alleviation of the heat island effect, the promotion of community building, and the reduction of pollution like CO_2 and PM. Because low-income communities often have less access to green spaces and parks, it is vital that local and federal governments allocate funding to disadvantaged urban neighborhoods in order to plan street-lining trees and community gardens and parks. In addition, the impact of community-based organizations which work to plant gardens and foster accessible green spaces must not be underestimated. In the Bronx, organizations like The Bronx Coalition of Parks and Green Spaces and Operation Green Thumb work towards this effort, and I strongly believe that they are capable of increasing the benefits of greenspaces in terms of air quality, especially with direct funding from the NYC government ("Members — Bronx Parks Speak Up." n.d.). With the increase of parks and greenspaces, as well as the use of programs like "Open-streets" described in chapter 3, New York City has the capability to transform into a more sustainable, walkable, and clean city.

Environmental Education: A final measure which I find to be one of the most valuable in terms of improving air quality issues, as well as environmental issues in general, is the expansion of environmental education. This solution is much more motivated by personal experience than the others, due to the fact that I have grown up as a young person and student during a time in which environmental education has become more accessible than ever. As a high schooler, I was introduced to the immense scale of environmental issues through an AP Environmental Science course, which illuminated my passion for understanding climate change and addressing environmental justice. This led to my studies focused on Environmental Studies in undergraduate education at Fordham, and eventually my work in air quality research as a student. While personal research and community engagement have helped to fuel my passion for environmental justice more broadly, my formal education has been the catalyst and motivation behind my research in air pollution, allowing me to understand the profound importance of school in addressing environmental issues.

Throughout the past few years as a research assistant working with high schools, I have also had the opportunity to engage in teaching students about air quality. I have given presentations on my research to AP Environmental Science students and shared my understanding of the environmental justice issues related to air pollution which many of them have experienced firsthand. I have also been able to collaborate with dozens of high schoolers across NYC in collecting vital data for the project which may be able to directly improve their classroom conditions. This has been empowering for the high schoolers, as they have come to find passion in understanding the environments around them, and it has been empowering for me, as I have been able to share that passion. When children grow up in areas like NYC and the Bronx in which issues like asthma cause health complications and school absences every day, it is important for them to be educated on the context of these issues. This type of education could be implemented by the requirement of courses like AP Environmental Science across all high schools, the inclusion of environmental context in all STEM courses, and the use of environmental speakers, like the presentations I have participated in. Education is the most powerful tool, and as we prioritize the environmental education of our youth, we also invest in the individuals and solutions which are increasingly necessary in solving environmental problems like air pollution.

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