

**Northeast States for Coordinated Air Use Management
Indoor/Outdoor School Air Monitoring Pilot Project**

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EXECUTIVE SUMMARY

Northeast States for Coordinated Air Use Management Indoor/Outdoor School Air Monitoring Pilot Project

For over thirty years, the Northeast States for Coordinated Air Use Management (NESCAUM) has been working in the field of air quality control with its members, who include air quality management officials from the New England states, New York and New Jersey. The top priority of state air quality management officials is to protect the public from exposure to unhealthy levels of air pollutants. NESCAUM's greatest concerns in the Northeast are outdoor levels of ozone, particulates, and hazardous air pollutants. More recently, awareness has grown of the importance of indoor air quality, when considering exposure and public health impacts, and of the need for better understanding of the influence of outdoor air pollution on indoor air quality.

This report describes the results of a pilot air quality monitoring project conducted by NESCAUM in nine elementary and middle schools across New England during the summer and fall of 2001. The intent of the pilot project was to develop methods to characterize the impact of ambient air pollution and human activity on the indoor air quality in a variety of schools in the Northeast. The main goal for this study was to use these methods to determine whether ambient air pollution concentrations penetrate indoor environments to establish a baseline of exposure for individuals in these specific environments. A secondary goal was to investigate whether urban areas and areas near heavy roadway traffic have higher indoor concentrations of the targeted ambient air pollutants.

The study focused on schools because of recent attention to the health effects of air pollution on sensitive populations, one of which is children. According to recent reports by the Centers for Disease Control, children have experienced a dramatic increase in asthma, which is exacerbated by air pollution. Consequently, the impact of outdoor air pollution on an indoor environment where children spend time became the subject of this report. Besides their own homes, where studies of this type have been conducted, children spend a vast majority of their time in schools.

The nine schools in the study constitute a diverse set in terms of ambient pollution sources, geographic location, population density, motor vehicle traffic patterns, and building construction types. Given the schools' widely different characteristics, the limited number of monitoring days, and the small sample size, any results should be viewed as a data set targeted to investigate the stated goals and to explore the effectiveness of the monitoring strategy. These data are also expected to be useful to structure future studies. Results from a single school should not be viewed as a conclusive representation of "healthy" or "unhealthy" conditions.

In order to test the hypotheses of this pilot project, it was important to characterize the variability in ambient and indoor pollutant concentrations between urban and rural (or

rural-near roadway) schools. To this end, the methods that were used and developed in this project measured the concentrations of fine respirable particulate matter and several other air pollutants.¹ These pollutants are characterized as lung irritants, which are believed to trigger asthma attacks at moderate to high exposures, and are potential cancer-causing agents, associated with a potential increased risk of certain forms of cancer, following long-term exposures to relatively low concentrations. Fossil fuel combustion, particularly from motor vehicles, is a primary outdoor emissions source of these pollutants.

This project had two phases. Phase One consisted of monitoring during the summer of 2001 to obtain baseline measurements when schools were not in session (referred to as “summer monitoring” throughout this report), in order to minimize the impact of student/faculty occupancy and emissions from school buses. Phase Two involved monitoring during the fall of 2001 when schools were in session (referred to as “fall monitoring” in this report). Summer pollutant concentrations serve as a baseline that was compared with measurements taken during normal building occupancy during the fall.

In this pilot study, NESCAUM employed the ACCESS air monitoring system to evaluate changes in carbon dioxide, criteria air pollutants and meteorology. The ACCESS system senses and records information for each criteria every minute, providing real-time data. NESCAUM was interested in obtaining real-time data because short-term, episodic exposures to a number of air pollutants may be very important when considering non-cancer health effects, and a time-averaged, integrated sample would not provide an adequate level of resolution. For this study, NESCAUM was particularly interested in real-time measurements for carbon dioxide and fine particulate matter (PM_{2.5}). Tracking minute-to-minute variations in these two compounds is instrumental to the aims of this and future studies since: 1) measurement of the indoor carbon dioxide concentration is an indicator of the rate of air exchange in the school buildings which will aid in understanding the amount of outdoor air infiltration, and 2) short-term episodic exposures to fine particulate matter (PM_{2.5}) are important to characterize because of the potential adverse impact on asthmatics or other individuals susceptible to respiratory irritation. The ACCESS system was used in this pilot study because these multi-pollutant monitoring systems have been used effectively in past NESCAUM projects to provide qualitative evidence of the real-time variations of these and other compounds.

The real-time monitoring techniques were sensitive enough to detect variability in concentrations of pollutants including carbon monoxide, carbon dioxide, sulfur dioxide, nitrogen dioxide, ozone, and particulate matter throughout the monitoring day. The sensitivity and accuracy of the ACCESS monitoring system was not sufficient in many cases to make quantitative conclusions (see Appendix D for details). Despite the limitations of the ACCESS system, data collected during the pilot project demonstrate that specific outside pollutant sources (e.g., carbon monoxide generated by an idling delivery truck) can affect indoor air concentrations if prevailing wind patterns carry

¹ Fine respirable particulate matter has an aerodynamic diameter of less than 2.5 microns. Criteria pollutants and several hazardous air pollutants were measured including a suite of fifteen carbonyls and twenty-eight volatile organic compounds.

pollutants from the sources toward schools. Since the initiation of the pilot project, more accurate and sensitive real-time monitoring systems are now available to NESCAUM for these types of projects. NESCAUM will focus on carbon dioxide and particulate matter monitoring with more state-of-the-art technology in all future work.

NESCAUM also measured carbonyls using Gilian personal sampling pumps, which draw air through an absorbent tube at a constant rate for a specified amount of time. Testing for volatile organic compounds was performed using Summa canisters. Summa canisters are evacuated stainless steel canisters, which were fitted with an orifice calibrated to draw in one liter of air over a period of seven to eight hours. NESCAUM believes these methods collected reliable data. In the body of the report, the strengths and limitations of each of these methods are described in greater detail. The results from the carbonyl and volatile organic compound monitoring are described below.

The pilot project monitoring data suggest that outdoor air concentrations and indoor air concentrations of several pollutants are related. This is most evident when comparing indoor and outdoor concentrations of selected volatile organic compounds, such as benzene, with the degrees of urbanization around the school. The pilot project monitoring data illustrate that the greater the ambient concentration of selected pollutants, in most instances, the greater the indoor concentration. Existing air pollution literature supports this observation and indicates that outdoor and indoor concentrations are indeed related to one another, with urbanized regions demonstrating the highest concentrations. This larger body of evidence also suggests that the infiltration of outdoor concentrations of persistent, low reactivity volatile organic compounds like benzene, often approaches 100%, but varies by conditions during the day of monitoring and the pollutant. The understanding of the impact of ambient concentrations and the infiltration of more reactive compounds, such as acetaldehyde and formaldehyde, is more complicated since the atmospheric formation and destruction of these compounds and their persistence during infiltration into indoor environments is less well understood. Additionally, the indoor concentration of these pollutants is often dominated by indoor sources and activity levels, which makes it difficult to ascertain the degree of ambient infiltration directly.

When considering our primary research interest regarding ambient air infiltration, our limited data suggest that during the summer months of the pilot project, the median indoor concentration of low reactivity volatile organic compounds (such as acetone, benzene, methyl ethyl ketone, and toluene) range from approximately 65% to 90% of the outdoor concentrations. Fall monitoring data indicate median indoor concentrations of these same pollutants range from 130% to 500% of outdoor concentrations, respectively. When considering more reactive pollutants, the summer monitoring data suggest that the median indoor concentrations of acetaldehyde and formaldehyde range from approximately 130% to 375% of the outdoor concentrations, respectively. During the fall, the range of median values for these pollutants increased to approximately 150% to 430%, respectively.

This observation that indoor concentrations of volatile organic compounds and carbonyls often track outdoor concentrations is consistent with studies by other researchers. These

studies underscore the importance of considering seasonality and of the potential contribution of indoor emissions sources and activities when attempting to evaluate infiltration. Further analysis of air exchange rates is needed to more thoroughly investigate infiltration by these pollutants. Additionally, a more detailed survey of indoor sources and their contribution as well as a comprehensive outdoor emissions inventory would help in characterizing the impact of ambient air on indoor air quality.

When considering our secondary research interest regarding the impact of urbanization and motor vehicle traffic on the concentrations of these pollutants, these preliminary data suggest that concentrations of pollutants primarily generated by motor vehicle fuel combustion or evaporation (e.g., benzene and toluene), are higher in urban areas and in areas in close proximity (< 500 meters) to roadways with higher vehicle density. For instance, the highest benzene concentrations were recorded for schools located near roadways with high traffic counts. Importantly, despite the limited data set, this study suggests that rural, near-roadway schools have airborne concentrations of benzene and toluene similar to urban schools. However, the potential association between population density and ambient or indoor concentrations of pollutants generated primarily by industrial sources or personal products such as acetone and methyl ethyl ketone is less clear. For instance, there was no clear association between population density and the levels of acetone or methyl ethyl ketone, unlike the observations for benzene and toluene described above.

NESCAUM's observations of higher concentrations of these pollutants in more urban environments in this pilot are consistent with previous monitoring results in numerous locations across the northeast region.² State ambient air monitoring results have consistently shown a substantial difference between urban and rural concentrations for motor vehicle-related pollutants.

The preliminary findings provide initial support for our operating hypotheses and confirm that our study design and methods are generally sound. However, NESCAUM's ability to interpret these data more thoroughly is limited by the degree of variability between sites, the lack of information regarding air exchange rates, and the incomplete emissions inventory inside and outside each of the monitored schools which confound a quantitative assessment at this time. Future studies will need to include more comprehensive emissions inventories for participating schools. Indoor air sources for a number of the compounds evaluated must be more thoroughly characterized in order appropriately interpret the data and to suggest activities to minimize if exposure reduction is warranted. For this pilot project, the research team sought to track product use and the presence of building materials known to emit any of the target compounds. This was a difficult task and additional work is needed in this area.

² <http://www.nescaum.org/committees/CEPmay99/regnlsumm2.html>

NEXT STEPS:

This pilot project demonstrates that it is possible to use available occupational or environmental monitoring methods to evaluate ambient and indoor air concentrations of a number of important air pollutants. With the exception of the ACCESS air monitoring system that was used to monitor for real-time criteria air pollutants, NESCAUM recommends the use of the same monitoring methods for future studies. Instead of the ACCESS system, NESCAUM suggests using other real-time monitoring methods focusing on particulates (PM_{2.5}) and carbon dioxide that offer greater reliability and accuracy.

NESCAUM will be completing a follow up study to this pilot in the fall of 2002. The central and secondary hypotheses will be the same: that ambient pollutants penetrate indoor environments to establish a baseline of exposure for individuals in the indoor environment, and that urban areas and areas near heavy roadway traffic have higher indoor concentrations of the targeted pollutants. However, building on our experience with the monitoring equipment and the interpretation of the monitoring results from the pilot project, we will monitor fewer schools using more exhaustive inventory characterization and more comprehensive monitoring strategies. Variability within the dataset will be reduced by:

- Limiting the variability between sites by choosing schools near roadways in distinctly urban vs. rural environments;
- Measuring air exchange rates to help ascertain and verify whether pollutant sources originate outside or inside the building;
- Documenting a comprehensive emissions inventory inside and outside of the monitored schools; and
- Choosing schools near state air monitoring stations that sample for hazardous air pollutants to help verify our monitoring data.

The results of this follow up study will be used to understand and document the infiltration of mobile source pollutants into the indoor environment and the potential public health impact nationwide when considering the combustion of fossil fuel products. It is anticipated that these and other data will help support more effective and appropriately targeted national and regional policy development regarding mobile source pollution.

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This report is structured to provide a regional overview of project results and additional resources for interested parties, while maintaining confidentiality for participating schools. It includes a discussion of the impact of ambient and indoor air pollutants on health and a brief overview of the current state of knowledge in this field. The report also provides a general description of sampling and analytical methods used.

BACKGROUND: AMBIENT AIR QUALITY AND PUBLIC HEALTH

The U.S. Environmental Protection Agency (EPA) established a program to control six key air pollutants: ozone, carbon monoxide, lead, sulfur dioxide, nitrogen dioxides and particulate matter over 30 years ago. EPA set standards for ambient (outdoor) air quality and established limits on air emissions from power plants, industries and motor vehicles to protect public health. It targeted these six “criteria pollutants” because scientific evidence showed that adverse health effects, such as heart and lung disease, resulted from exposure to them.³

Recently, EPA and the public health community have paid special attention to particulate matter. When the air program began in the 1970s, EPA regulated coarse particulates, or PM₁₀.⁴ These particles reach the bronchiolar region of the lung (mid-lung) and have been associated with adverse effects on the lungs for decades by health scientists. The agency developed a new fine particulate, or PM_{2.5},⁵ standard in 1997, in response to a growing body of evidence suggesting that these smaller particles – which reach the alveolar (deep-

³ For more detailed information regarding health effects associated with these pollutants, see Appendix A.

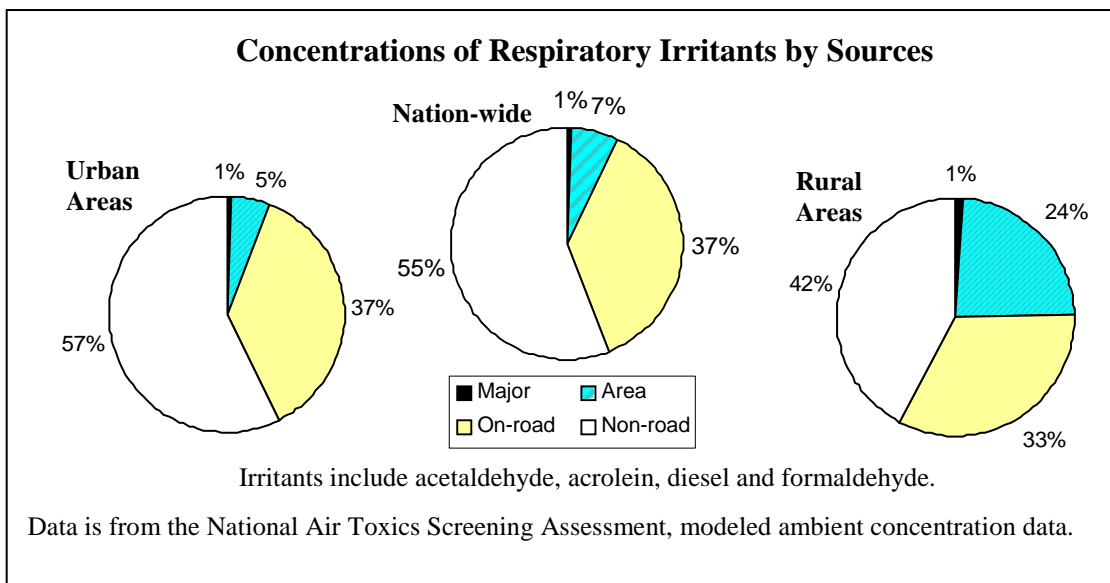
⁴ Particulate matter with an aerodynamic diameter of 10 microns (µm) or less.

⁵ Particulate matter with an aerodynamic diameter of 2.5µm or less.

lung) region – might be even more toxic than larger particles. A recent review of past studies by Samet *et. al* supports a linkage cited by EPA between increased mortality and PM_{2.5} and PM₁₀ levels in 20 major U.S. cities, underscoring the importance of reducing public exposure to particulate matter (Samet, 2000). Additional studies have also suggested that increased levels of particulates may exacerbate asthma symptoms (Pearson, 2000; Kinney, 2000; Yu, 2000; and Freidman, 2001).

In addition to regulating the six criteria pollutants described above, the Northeast states have been controlling emissions of hazardous air pollutants from industrial sources since the early 1980s. Since 1990, EPA has been developing federal regulations to control the emissions of 188 compounds referred to as hazardous air pollutants (HAPs) under the Clean Air Act. Like the toxic air pollutants regulated through state programs, the federal HAPs are targeted because they are associated with adverse health effects, including cancer and respiratory disease. HAPs present in ambient air originate from a variety of sources, including on-road sources such as motor vehicles, non-road vehicles such as construction equipment, “major” industrial sources such as electric utilities and factories, and “area” sources including dry cleaners, gasoline stations, and use of architectural coatings and paints. Control programs focused on HAPs are designed to reduce emissions from this full range of sources. Figure 1 illustrates evidence from a recent national air quality assessment, which identifies on-road and non-road vehicle emissions as a dominant emission source for a number of respiratory irritants.⁶

Figure 1. Important emission sources of potent hazardous air pollutants nationwide.



In 1998, the Northeast states reviewed air pollution data and identified a subset of ten HAPs from the federal list of 188 that are presently detectable in the region at levels above thresholds set to protect public health (NESCAUM, 1999b).⁷ These ten HAPs are

⁶ Please see <http://www.epa.gov/ttn/atw/nata>

⁷ The thresholds or health benchmarks for these pollutants are described in greater detail in Appendix B.

benzene, 1,3-butadiene, formaldehyde, carbon tetrachloride, chloroform, ethylene dibromide, ethylene dichloride, methyl chloride, chromium, and acrolein. Concurrent analyses by the EPA have demonstrated that this subset of HAPs is also present in similar amounts in the ambient air nationwide (Woodruff, 1998). These ten HAPs primarily exceed the benchmark levels for cancer risks. However, acrolein – one of the most potent respiratory irritants currently present in ambient air – has been estimated to exceed health protective thresholds for respiratory irritation in all areas of the country in these assessments (Woodruff, 1998; Caldwell, 1998).

To date, review of available outdoor air monitoring data demonstrates that urban areas and traffic corridors typically have the highest concentrations of these pollutants. Primary sources include motor vehicles, construction equipment and small area sources of air emissions, such as dry cleaners, personal product use, and gasoline stations (NESCAUM, 1999b).

CONNECTIONS BETWEEN OUTDOOR AND INDOOR AIR QUALITY

It is estimated that people spend over 90% of their time indoors.⁸ Recent policy development in various offices of the EPA has suggested that assessing ambient air concentrations for many pollutants is insignificant when considering public health impacts, since any exposure will be dwarfed by indoor microenvironmental exposures to these same compounds.⁹ NESCAUM and others have argued that ambient pollutant concentrations may, in some cases, establish the baseline for total exposure. As such, indoor emission sources or human activities only add to this baseline when considering total exposure. It should be noted that this baseline is only applicable to pollutants that are generated outdoors, as there are many indoor pollutants that do not have an outdoor baseline.

A review of peer-reviewed published literature and some indoor residential monitoring surveys conducted in rural areas of the Northeast region indicate that ambient concentrations of some volatile organic compounds such as benzene and toluene exhibit infiltration ratios ranging from 0.2 to greater than 1 when considering indoor vs. outdoor concentrations (Lewis, 1991; Gilli, 1996; Wallace, 1996; Lewis, 1992). At a one-to-one ratio, ambient concentrations would establish a baseline for continuous exposure in indoor microenvironments. Indoor concentrations of other HAPs, such as acetaldehyde and formaldehyde, are typically measured at higher concentrations indoors than outdoors, this is likely due to individual residential activities supplementing the airborne concentration. However, it may be due to other factors including nearby outdoor sources. Further characterization of the relative contributions of indoor vs. outdoor sources of these pollutants is fundamental to a thorough understanding of the impact of ambient air on indoor air quality.

⁸ <http://www.epa.gov/iaq/>

⁹ public presentation by EPA staff on 202(1) rulemaking and the 2002 National Scale Assessment activities

In addition to the target compounds assessed during this pilot project, a number of other air pollutants can have significant adverse health effects in exposed populations. One of the most significant indoor air quality concerns involves biological agents such as fungus, bacteria, and plant and animal products. These materials, in addition to some of the chemical compounds identified in this study, are known to serve as respiratory irritants and potential triggers for asthma attacks. Testing for biological contaminants was beyond the scope of this pilot project. However, in an effort to evaluate the potential for biological agent exposure in the schools, the project team attempted to identify and record the presence of water damage or visible mold or mildew during the monitoring days at each facility.¹⁰

INTRODUCTION TO THE PILOT PROJECT

NESCAUM conducted the Indoor/Outdoor School Air Monitoring Pilot Project to develop methods to characterize the impact of ambient air pollution and human activity on the indoor air quality in a variety of schools in the Northeast. The pollutants targeted by this project include particulate matter, other criteria pollutants, and hazardous air pollutants (HAPs). NESCAUM's primary research interest for this pilot study was in pollutants from motor vehicle fuel combustion. Gasoline and diesel powered vehicles and non-road machines emit up to one-half of smog forming volatile organic compounds (VOCs), particulate matter, and oxides of nitrogen (NO_x) in the Northeast. Furthermore, Northeast regional ambient monitoring and emissions inventory data have concluded that about half of the public health risk from exposure to HAPs (i.e. acetaldehyde, benzene, formaldehyde) is associated with automobile emissions (NESCAUM, 1999a). Thus, the study focused on the aforementioned HAPs, criteria pollutants (particulate matter, ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide), and volatile organic compounds.

The nine schools studied constitute a diverse set in terms of ambient pollution sources, geographic locations, population density, motor vehicle traffic patterns, and building construction types. The first aim of the pilot project was to determine whether federally approved occupational or environmental monitoring techniques¹¹ could be used to monitor daylong exposures to ambient and indoor air pollutants. The second aim was to test two central hypotheses: (1) ambient air pollution concentrations penetrate indoor environments to establish or contribute to a baseline of exposure for individuals in the indoor environment; and (2) urban areas and areas near heavy roadway traffic have higher outdoor and indoor concentrations of the targeted pollutants than other areas. The study will not provide a definitive estimate of potential health impacts given its limited scope and sample size.

Given the widely varying characteristics of schools included in this pilot project, the limited number of monitoring days, and the small sample size, these initial data alone can

¹⁰ More detailed information and resources available to assist schools in identifying and addressing indoor air quality concerns may be found in Appendix C and E.

¹¹ The ACCESS system, which measures criteria pollutants in real-time, is not a federally approved monitoring technique.

neither confirm nor reject the central or secondary hypotheses. These data are expected to be useful in refining our central and secondary hypotheses, in method development, and to structure future studies, but not as a conclusive representation of “healthy” or “unhealthy” conditions at any particular school.

Numerous studies analyzing exposure to these pollutants in the outdoor (ambient) environment have been used to support EPA rulemaking activities. Some researchers have sought to evaluate both the outdoor and indoor (home, workplace, school) concentration of pollutants (Woodruff, 1998; Caldwell, 1998; NESCAUM, 1999b; Lewis, 1991; and Gilli, 1996). This pilot project explored the feasibility of methods that combine these past approaches in an effort to more accurately characterize total exposure. Doing so requires consideration of both ambient concentrations and indoor concentrations of these pollutants in selected environments. This juxtaposition illustrates how outdoor pollutant concentrations impact indoor environments, and provides a more complete picture of total exposure for individuals living and working in both indoor and outdoor environments. This study considered daylong exposures, typically eight-hour,¹² in contrast to the 24-hour averages of many previous studies. The purpose for monitoring eight-hour exposure in this pilot project was to assess the typical exposure window for students and teachers in the nine schools studied.

This study focused on characterizing a single microenvironment: schools. NESCAUM thought it was appropriate to look at the impact of outdoor air pollution on an indoor environment where children spend time. Besides their homes, where studies of this type have been conducted, children spend a vast majority of their time in schools. We focused on children because of the recent reports in the dramatic increase in childhood asthma. The Center for Disease Control and Prevention (CDC) has documented that between 1980 and 1994, the prevalence of asthma increased 74% among children 5 to 14 years of age. According to the CDC, asthma now affects nearly 5 million Americans younger than 18 years of age.¹³ Children and a majority of adults have been shown to be susceptible to lung irritants that exacerbate asthma symptoms. These lung irritants, mentioned above, are the target compounds monitored in our study.

This project had two phases. The intent of Phase One was to monitor during the summer of 2001 to obtain baseline measurements when schools were not in session (referred to as “summer monitoring” throughout this report), in order to minimize the impact of student/faculty traffic and emissions from school buses. However, summertime maintenance and cleaning activities may have introduced pollutants. Phase Two involved monitoring during the fall of 2001 when schools were in session (referred to as “fall monitoring” in this report), to contrast summer baselines against fall pollutant concentrations measured with heating and ventilation systems operating, normal building occupancy levels, and buses and other vehicular traffic.

¹² Four-hour samples were also collected for some pollutants in an effort to understand whether short-episodic peak exposures were occurring that might be minimized if averaged over an eight-hour sampling duration.

¹³ <http://www.cdc.gov/nceh/airpollution/asthma/children.htm>

The nine schools studied were selected based on their accessibility, availability, and willingness to participate, as well as their different geographic and demographic characteristics. The schools are characterized and referred to as Schools A through I, moving from urban to rural.¹⁴ Information used to make this characterization is presented in Table 1 below.

Schools A, B and C are all located in a Northeastern inland city. It is a busy commercial and manufacturing center, with a nearby airport, surrounding highways and congested city streets. Students' homes are close to these schools, so most students walk instead of taking the bus. However, nearby traffic from the rest of the city is heavier in this area than it is near rural or suburban schools. School A is located in a commercial area of the city next to a large intersection, so School A's estimated vehicle traffic is higher than Schools B and C, while School A's population density is lower than B and C. School B is located in a mixed residential and commercial area where streets are less busy. School C is located on smaller roads in a mostly residential part of the city and so has less truck and bus traffic.

School D is located in a coastal city in the Northeast, which is generally upwind of a city larger than the town surrounding Schools A, B and C. The school is located in a residential part of the city. There are large city streets near the school, but immediately surrounding the school are smaller streets, houses and a golf course. School E is located inland in a moderately sized city. The school is located on the edge of a residential area, but is also very close to the largest downtown intersection, which is often congested. The city is also located in a valley, which can lead to the potential inversion of pollution (increased concentration and atmospheric residency) under certain meteorological conditions.

School F is located in a coastal town about half a mile from a large interstate highway. Many buses serve this school because students come from a large residential area. School G is also in a coastal town and is only a few yards from a large interstate highway. The area surrounding the school is farmland and largely unsettled. School H is located in a northern inland town that is sparsely settled, although it is only a mile or two from a large interstate highway. The closest city is about 30 miles away, with a population near 35,000. School I is also located in an inland town and its closest large street is a small state highway. The closest urban center is located about 15 miles away from School I, with a population of 22,000.

¹⁴ Urban to rural for this purpose is defined in terms of population density, with the exception of School A, which has a lower population density than Schools B and C, but is much more "urban" in terms of vehicle traffic and is placed ahead of those schools in this ranking.

Table 1. Characterization of Schools A-I

School	City/Town Population*	Population Density (people/sq mile)	Vehicle Count**	Geographic Characteristics
School A	100,000+	4124-6443	41,500	Inland, urban, commercial
School B	100,000+	12840-20257	10,000	Inland, urban, commercial/residential
School C	100,000+	12840-20257	10,000	Inland, urban, residential
School D	50,000	2300-3940	10,000	Coastal, urban, residential
School E	22,000	701-711	26,000	Inland, valley, small urban center
School F	7,500	216-342	2,000	Coastal, Residential
School G	3,500	149-219	25,000	Coastal, rural open space, next to highway
School H	2,400	66	3,500	Inland, very rural, farmland
School I	2,100	45	2,300	Inland, small rural town

* Rounded from Census 2000 to maintain the anonymity of the schools.

** Annual Average Daily Traffic estimates of local school area, from state Department of Transportation offices. (see Appendix G for calculation details)

METHODS AND LIMITATIONS

This study was designed to monitor criteria pollutants, carbonyls, and volatile organic compounds, and also to qualitatively assess the indoor environment by implementing a walkthrough assessment. As mentioned previously, one of the primary sources of these pollutants in the outdoor environment is fossil fuel combustion, particularly from motor vehicles. The methods used for this pilot study include real-time monitoring, four and eight-hour sampling and instantaneous sampling. Except for the real-time monitoring equipment, these are all adapted from standard methods used in ambient monitoring and industrial hygiene practice. Equipment and methods for monitoring each pollutant category are described below, along with limitations of the methods and equipment that were experienced by the monitoring team.

- **Criteria Pollutant Monitoring**

Methods:

The ACCESS air monitoring system was used to monitor criteria pollutants and other atmospheric indicators.¹⁵ The system senses and records information from each sensor every minute, providing real-time data. NESCAUM was interested in obtaining real-time data for selected pollutants since short-term, episodic exposures to a number of air pollutants may be very important when considering non-cancer health effects. For this study, NESCAUM was particularly interested in real-time measurements for carbon dioxide and fine particulate matter (PM_{2.5}). Tracking minute-to-minute variations in these two compounds is instrumental to the aims of this and future studies since: 1) measurement of the indoor carbon dioxide concentration indicates the amount of fresh air exchange in the school buildings which aids in understanding the amount of air infiltration and 2) short-term episodic exposures to fine particulate matter (PM_{2.5}), are important to characterize because of the potential adverse impact on asthmatics or other individuals susceptible to respiratory irritation. In addition to sensors for carbon dioxide (CO₂) and PM_{2.5}, the ACCESS system has been used effectively by NESCAUM in the past to monitor for carbon monoxide (CO), nitrogen dioxide (NO₂), ozone (O₃), and sulfur dioxide (SO₂). In addition to these compounds, the ACCESS system tracks temporal variation in barometric pressure, temperature, and relative humidity. Concentrations of the pollutants measured with the ACCESS system appear to be well within the limits of detection for the different sensors.¹⁶ However, operational limitations and sensor interferences described in more detail in Appendix D will affect the quantitative accuracy of this equipment.

Real-time data provides an important source of information on minute-by-minute fluctuations of pollutants. Because pollutants that are lung irritants can produce acute health effects from high-concentration exposures over very short durations, real-time data is an important component of a multi-pollutant analysis. Without this information, short-term spikes in pollutant levels are obscured when data is collected and averaged over several hours. Accordingly, this study examines real-time data in conjunction with average values from four and eight-hour samples of carbonyls and volatile organic compounds (VOCs).

In schools where two ACCESS systems were available, one system was placed outside and the other system was placed 50 feet inside the main hallway. In cases where the ACCESS system could not be placed outside, one system was placed immediately inside the doorway, and the other was placed approximately fifty feet down the hall. These placements were designed to measure the difference between ambient air and indoor air, and also to track detectable movements of pollution as it traveled into and down the hall.

¹⁵ For details on the ACCESS system, see Appendix D.

¹⁶ For example, O₃, NO₂, and SO₂ accuracy is ± 20 ppb and CO sensor accuracy is ± 2 ppb.

Strengths and Limitations:

The main problems experienced in monitoring criteria pollutants with the ACCESS system were variations in placement in each school, differences in the actual machines that were used, and limitations with individual sensors on the machines. Placement issues stemmed from logistical difficulties (such as outlet location, length of power cord, weather conditions and student traffic) and difficulties defining the “main entrance” at some schools: at urban schools such as A, B, and C, a majority of students walked to school, so the small number of buses did not always have a drop-off area at an identified “entrance” for each school. Some other schools had a number of entrances from the bus stop area. In each case, the most commonly used entrance was monitored, but this did not represent all foot traffic entering the school or vehicle traffic near the school. These discrepancies between locations from school to school make it difficult to compare schools, but outside (or immediately inside) measurements and indoor measurements can be compared to each other for a given monitoring day at a single location.¹⁷

Another factor contributing to the uncertainty of ACCESS monitoring results is the fact that different ACCESS systems were used during summer and fall monitoring. ACCESS systems used during the fall were upgraded and recalibrated by the manufacturer prior to the beginning of fall monitoring. However, despite these upgrades, some problems were experienced with the new equipment. For instance, one system lost part of the computer code, which resulted in difficulties with calibration, datalogging and downloading results. Also, one of the newly installed particulate sensors became temporarily clogged with debris during a monitoring study at one of the project sites. The change in monitoring equipment between the summer and fall monitoring undermines the direct comparison of results between monitoring phases. The ACCESS system results are quantitative in nature only within operational limitations and sensor accuracy, and are most effective when used to track events at a given school during a given time period.¹⁸

Notwithstanding these issues, however, the ACCESS systems provided a valuable tool during this pilot study. The systems were relatively reliable, and provided excellent qualitative data, as well as quantitative measures within the operational limits of the system. Because levels of uncertainty are relatively constant for specific monitoring periods, trends throughout a day of monitoring are still valid. The primary purpose of real-time monitoring was to track movement and relative trends of criteria pollutants inside and outside of schools. When specific sensors recorded erroneous data, it was evident and that portion of the data was not included during our data analyses efforts, recognizing the effect these outliers may have on our analyses.

¹⁷ The specific locations of the ACCESS systems are specified in each school’s attached individual data.

¹⁸ Please review Appendix D, part I, for more information

- Carbonyls

Methods:

Carbonyls were measured with Gilian personal sampling pumps, which draw air through an absorbent tube at a constant rate for a specified amount of time.¹⁹ Each cartridge was analyzed by an EPA approved laboratory for the presence of a suite of fifteen carbonyls, of which the primary compounds of interest for our pilot study were formaldehyde, acetaldehyde and acetone. Acetaldehyde and formaldehyde are of particular concern to air quality and public health professionals of the NESCAUM region due to exceedances of the highly conservative health benchmarks for cancer risks across the nation. These health benchmarks have been used historically in all NESCAUM states to target emissions control efforts through state air toxic control programs. These compounds are also known to be present in certain types of building materials used in schools, such as carpeting (particularly the adhesive that holds the carpeting down) and some pressed plywood.

Samples were taken over four- to eight-hour periods; the results show average pollutant concentrations for the given time period. Eight-hour samples are typically collected in occupational exposure studies and are appropriate for recording average, long-term exposures. Most of the long-term samples taken were from six to eight hours in length. Some four-hour samples were taken to determine whether short-term peaks (which would be diluted in an eight-hour sample volume) could be measured. Short-term peaks are of interest because they are likely to contribute to respiratory irritation. Although the sample volume collected was greater than the minimum required under the monitoring methods selected, the total concentration of carbonyls collected in four hours in the schools during the summer was below the detection level for the analytical method. As a result, during the fall, all samples were collected over six- to eight-hour periods.

On each day of monitoring a total of four to seven samples were taken in various locations around the school. One pump was placed outside to obtain an ambient baseline measurement. A second pump was placed inside and down the main hallway approximately 50 feet inside the entrance. The remaining indoor pumps were placed in “problem” classrooms (as identified by schools and teachers), in classrooms with carpeting, or in rooms close to roadways or bus stops in an effort to characterize the potential range in airborne concentrations in a given school.

Strengths and Limitations:

The main methodological problem experienced in carbonyl monitoring was faulting [i.e. the pumps stopped working] by the Gilian pumps. Faulting is a common problem when using the Sep-pak collection media and the Gilian pumps that were used for this project. Faulting occurs because the pressure drop across the sample bed becomes too extreme with elevated airborne concentrations or high atmospheric humidity, which saturates the absorbent media during sampling. Faulting occurred less frequently during fall

¹⁹ For more detailed information, see Appendix D, part II.

monitoring due to lower humidity levels and because of the use of two Gilian low-flow pumps. These low-low pumps sample for longer duration more reliably because they sample at a significantly slower airflow rate and are less affected by the pressure drop across the Sep-pak cartridges.

- **Volatile Organic Compounds**

Methods:

Testing for volatile organic compounds was performed using Summa canisters. Summa canisters are evacuated stainless steel canisters, which were fitted with an orifice calibrated to draw in one liter of air over a period of seven to eight hours.²⁰ The sampling duration was set at eight hours in order to provide data for the risk associated with long-term health effects and a comparison with the carbonyl sampling described previously. For each day of monitoring, canisters were co-located with the ACCESS system, with one evacuated canister placed outside near the main entrance and one canister with the ACCESS system inside the school. The canisters were elevated a few feet when possible to more accurately sample the breathing zone for school children. These locations were selected to evaluate relative concentrations of these chemicals in ambient air and in the school environment.

Twenty-eight VOCs were reported by the laboratory that analyzed the samples, including benzene, toluene, and methyl ethyl ketone, which are targeted HAPs under the Clean Air Act. Importantly for this pilot study, benzene and toluene are known to be present in large percentages in evaporating fuel or as fuel combustion products. In addition, methyl ethyl ketone, benzene, and toluene are all emitted by a number of other sources, such as industrial solvents, personal care products, and chemicals used by schools for cleaning, such as floor strippers and waxing products. Because they are emitted from multiple sources, it is difficult to associate ambient or indoor concentrations with a single activity.

These chemicals do not have known acute health effects. However, benzene is a known human carcinogen and toluene and methyl ethyl ketone, although low in potency, may cause other adverse non-cancer health effects such as central nervous system depression and liver damage following long-term exposure.

Strengths and Limitations:

Summa canister monitoring is widely used, is very reliable, and indicates clearly when a full sample has not been collected. The limitations experienced with the Summa cans were due to difficult attachment of the orifices, which only happened on a few occasions. During summer monitoring, two different styles of orifices were used. The two styles varied slightly in design and in ease of use, but both styles facilitated collection of a seven- to eight-hour sample at each school. During fall monitoring, five- to seven-minute grab samples were collected for five schools, and seven to eight-hour samples were

²⁰ See Appendix D, part III, for more information.

collected for the remaining four schools.²¹ Grab samples had to substitute for the seven-eight-hour samples because the calibrated orifices for the Summa canisters were not available on those monitoring days. These grab samples provide a “snapshot” of the ambient air concentration as they do not integrate a sample over a full eight-hour sampling period.

- **Indoor Air Walkthrough Assessment**

As part of this study, NESCAUM developed a walkthrough assessment, partially adapting EPA’s Tools for Schools Indoor Air Quality Checklist (see Appendix E), and integrating questions about building layout and surrounding areas.²² The purpose of the checklist is to identify and describe potential sources of pollution in and around schools that may result in poor indoor air quality. One of the most important topics on the checklist is moisture sources in buildings, which can enhance mold growth. Water infiltration is indicated by evidence of leaks in roofs or pipes, water stains on ceiling or floor tiles, and observable condensation. Available sources of moisture and nutrition create an environment that supports the growth of mold, a common respiratory allergen and irritant. Details such as the number and location of water stains, the number of tiles affected, and musty odors were noted.

Effective ventilation is another important factor in maintaining healthy levels of fresh air in buildings. Thorough inspections of the inner workings of ventilation systems was beyond the scope of this study, but the checklist includes a section that addresses some central aspects of ventilation, including the type of system; areas in which it operates; and the presence of sealed windows and blocked vents. The effectiveness of ventilation systems was also characterized in most schools with instantaneous sampling of carbon dioxide (CO₂) levels, which indicate the amount of fresh air in buildings. A high CO₂ concentration may indicate that the air exchange rate is low or nonexistent, either because only a small amount of fresh air entering the building or due to a high occupancy rate.²³

When equipment for grab sampling was available, samples were taken outside, at main entrances, and in many rooms within schools, some of which had been identified as possible problem areas by teachers. Samples of CO₂ were taken during summer and fall in order to compare unoccupied and occupied schools. Samples were taken with a Dräger CMS handheld monitor.²⁴ CO₂ samples were taken in occupied and unoccupied spaces and were collected at different times throughout the day in an effort to qualify the degree of fresh air intake and distribution in schools.

Walkthroughs also attempted to characterize some potentially important indoor pollution sources, such as chemicals used for cleaning and use of photocopiers. Additionally,

²¹ Data is presented in Appendix H.

²² See Appendix E for EPA’s Tools for Schools checklist and Appendix F for the NESCAUM checklist.

²³ These are all comfort criteria; there are no health effects associated with levels of CO₂ which are expected to be found in a school building.

²⁴ See Appendix D, part IV for more information.

walkthroughs identified whether exhaust hoods and fans were present above combustion appliances and if so, whether they were free of soot and discoloration. The general condition and cleanliness of buildings was also recorded, since dust exposure is known to result in respiratory irritation. Temperature and humidity levels were observed, since these factors often influence the comfort level of buildings, as well as growth of biogenic pollutants such as molds. Outside of buildings the air intake locations, water drainage patterns, and characteristics of surrounding areas were also noted.

FINDINGS

• Criteria Pollutant Monitoring

Real-time monitoring results for respirable particulate matter²⁵ carbon monoxide, carbon dioxide, sulfur dioxide, nitrogen dioxide, and ozone are shown in Figure 2, panels A – H. Figure 2 presents eight panels of representative data (one for each monitoring criteria) from schools in this study. To illustrate temporal variation in target compounds, monitoring results are shown for an entire day. Further, data from a variety of schools is shown to best illustrate the qualitative importance of real-time monitoring. The operational limits of the ACCESS system prevent quantitative interpretation (see Appendix D for details).

In some instances, it is possible to correlate variations in measured concentrations with indoor or outdoor events. In these cases, we have attempted to identify potential sources of the observed variation in measured values as detailed below. These data represent quantitative results only within the operational limitations for the individual sensors.²⁶ Future NESCAUM analyses will track real-time carbon dioxide and PM_{2.5} concentrations with more sensitive and accurate monitoring equipment now available to researchers.

In the few instances where the ACCESS system recorded levels above EPA standards, they are not definitive exceedances because of the margin of error present in each sensor. Additionally, the standards for criteria pollutants are for 24-hour averages of ambient pollutants, which is very different from episodic peaks recorded by the ACCESS system.

Panel A shows carbon dioxide (CO₂) levels in a school's main entrance and 50 feet down the hallway. Carbon dioxide was measured because it is an indicator of ventilation effectiveness and air exchange rates for buildings. It is not a criteria pollutant and is not associated with any health effect at levels found in schools. At the school shown in Panel A, CO₂ levels at the entry were lower than in the hallway for the entire day. This difference may illustrate the smaller number of occupants in the entrance or a higher rate of ventilation given proximity to an exterior door used throughout the day. The measurements in the two locations changed together: both levels increased when students arrived (around 9:00 a.m.), and then again when they entered the hallway for

²⁵ The Access System was calibrated to selectively measure particulate matter with a mean aerodynamic diameter of 2.5 micrometers or less (PM_{2.5}).

²⁶ See Appendix D for more detail.

dismissal (2:30 p.m.). Other smaller spikes throughout the day likely due to indoor activity patterns. The results in Panel A are representative of most carbon dioxide levels recorded at schools during the fall. There was typically some variation during the day due to movement and activity in hallways. Levels in hallways at some schools were slightly higher than those seen in Panel A.

Panel B displays PM_{2.5} levels at a school's entrance and 50 feet down the hallway. The measurements indicate fluctuations occurring throughout the day ranging between 0 - 25 $\mu\text{g}/\text{m}^3$. Fluctuations in the two locations coincide or closely follow each other, indicating that they may be influenced by the same events, such as movement of students throughout the school (which may re-entrain dust and small particles within the school and which may be reported as PM_{2.5} by the ACCESS system). The additional 10 $\mu\text{g}/\text{m}^3$ found in entryway versus hallway measurements may be due to calibration of the ACCESS system and not to concentration differences, since the margin of error for the particulate monitor is greater than 10 $\mu\text{g}/\text{m}^3$. The concentrations of PM_{2.5} shown in Panel B are typical results for schools monitored during the fall, which all varied with the movement of people around the school. Some schools experienced spikes higher than those seen in Panel B during periods of high activity in the hallways. These spikes may be attributed to differences in PM_{2.5} concentrations or measurement artifact from dusts generated by disruption of floor material, school cleaning practices, or calibration and operational limitations of the sensors.

The level of carbon monoxide (CO) detected in one school during the summer is shown in Panel C. Measurements were taken at the main entrance and 50 feet down the hallway. These concentrations varied throughout the day and demonstrate an apparent relationship between outside activity and inside concentrations. The spike around 8:00 a.m. correlates with the observation of the arrival and idling of a delivery truck outside the main entrance of the school during this time. Peak CO levels 50 feet down the hallway occur a few minutes after the peak at the entrance, marking the potential migration of the pollutant into the school. CO levels recorded by the ACCESS monitor 50 feet down the hallway are higher than those at the main entrance. However, this is likely an artifact of differences in zeroing of the sensors or simply a variance within the accuracy of the CO sensor itself. At some other schools, low levels of carbon monoxide were also measured in the building, possibly from the infiltration of carbon monoxide from idling school buses or other traffic in the local area or due to low level release of indoor combustion sources (i.e. a heating system boiler).

Ozone levels detected outside and inside a school during the summer is shown in Panel D. The graph indicates that the levels of ozone outside were higher than the levels detected inside. This is expected during the summer when outdoor ozone is at its highest, due to atmospheric residence. Additionally, one would expect a lower ozone concentration inside a microenvironment because it is a highly reactive, relatively short-lived pollutant indoors. Also ambient ozone typically peaks in the afternoon, around 1:30 p.m. Therefore, the peak of indoor ozone at the same time suggests that the indoor detection may be attributable to the infiltration of ambient ozone. Ozone was detected at many schools over the summer, due in large part to elevated ambient summertime

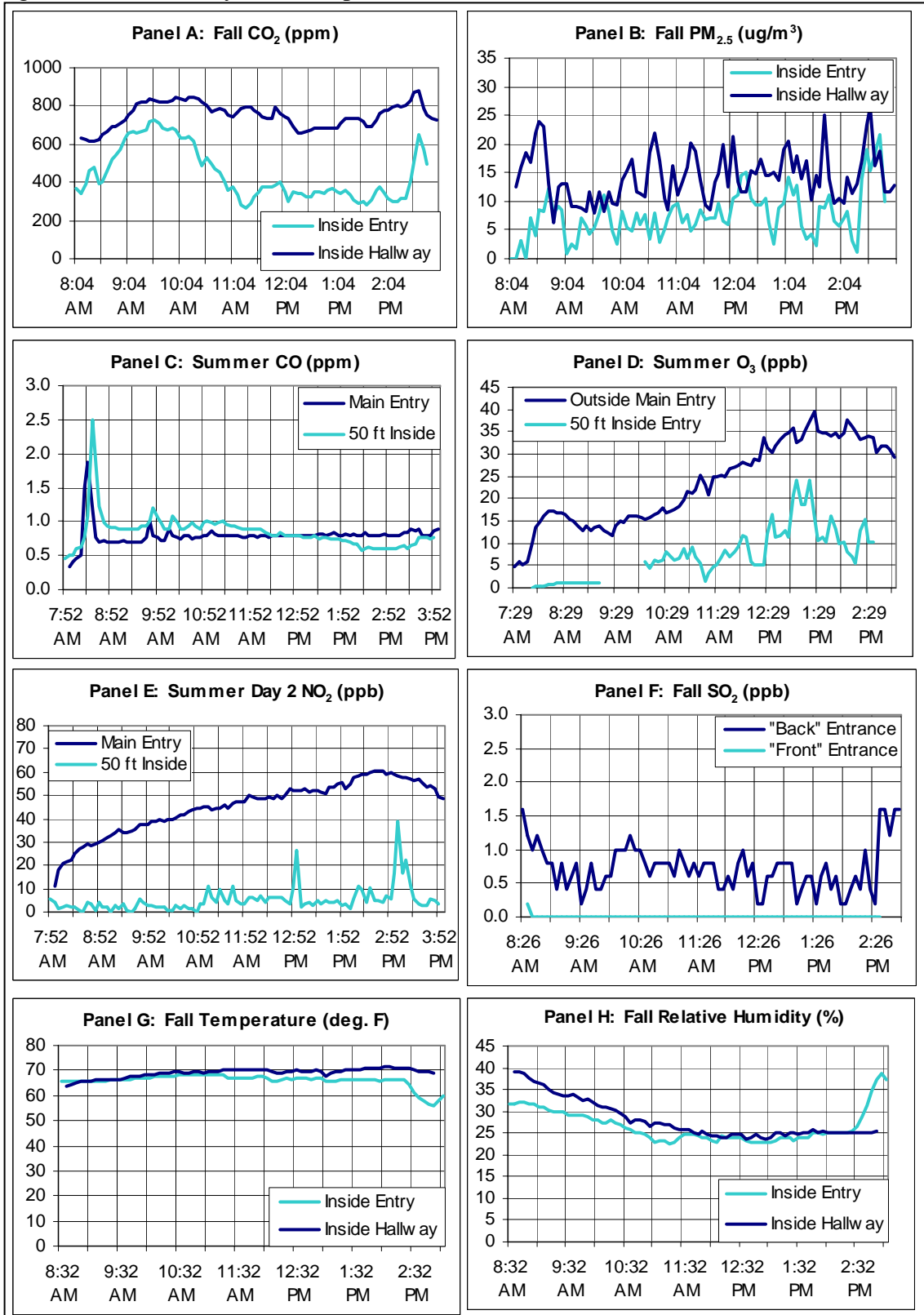
concentrations. In addition, when monitoring was done at the end of the summer while schools were preparing for the start of classes, sources of indoor ozone, such as copiers and printers, may have been detected.

Panel E shows NO₂ concentrations detected at the entrance to a school and 50 feet inside the entrance. Indoor concentrations fluctuated between 0 and 10 ppb, with two spikes of up to 45 ppb during the day. The ACCESS sensor located outside recorded a steady increase from 10 ppb to 60 ppb around 2:45 p.m., with a small decline by the end of the monitoring day. This steady increase may be due to ambient sources or local traffic. At other schools NO₂ was sometimes seen in the fall, but no consistent pattern emerged.

SO₂ concentrations at the “front” and “back” entrance of a school are shown in Panel F. There was almost no detection at the “front” entrance except at the start of monitoring. The fluctuation in the “back” entrance represents a small level of SO₂, which may be due to the fact that this entrance is only a few feet away from a street, and is located near the bus stop.

Temperatures and relative humidity levels at each school were recorded on every day of monitoring to help explain the behavior of pollutants and of sensors on the ACCESS system. The temperature levels shown in Panel G are representative of temperatures seen in most schools during the fall. The humidity levels shown in Panel H are from the same school and same day of monitoring as Panel G and are also representative of levels seen at other schools during the fall.

Figure 2. ACCESS System Composite Data



- **Carbonyls**

Of the suite of fifteen carbonyls monitored during this project, three target compounds for this pilot project – acetaldehyde, formaldehyde, and acetone – were found most consistently and in the highest concentrations. Other peer-reviewed EPA monitoring and modeling studies for hazardous air pollutants have shown these pollutants to be present in high concentrations in ambient air. Thus, the detection of these same compounds in our pilot study lends credibility to our concern over indoor exposure. Also, acetaldehyde and formaldehyde were target compounds for this project due to our focus on fossil fuel combustion, particularly from motor vehicles.

The summary data in Tables 2 - 4 indicate that concentrations of acetaldehyde, formaldehyde and acetone outside schools, 50 feet inside main entrances, and in rooms inside the schools appear to increase as one moves toward the interior of school buildings. Note that where the sample was below the analytical limit of detection, one-half the minimum detection limit was substituted in the calculations for these samples (a total of 13 samples during the entire project). These tables also illustrate that for the most part, concentrations during summer were higher than in fall both inside and outside. This could be due to atmospheric conditions on monitoring days, or to summertime atmospheric conditions that tend to result in greater formation, transport, and residency of these compounds in ambient air, or due to additional, unconsidered variables. Higher ambient concentrations may then have directly influenced indoor concentrations in the schools that were monitored. Additionally, indoor human activity and emission sources such as carpeting may play a critical role in increasing detected concentrations for compounds like formaldehyde.

Table 2. Acetaldehyde Statistics in $\mu\text{g}/\text{m}^3$ (all samples, separated by sampling location)

	Median Value		75th Percentile		Minimum/Maximum	
	Summer	Fall	Summer	Fall	Summer	Fall
Outside	0.19	0.27	0.37	0.36	0.04/0.90	0.14/0.47
Entry	0.30	0.36	0.49	0.44	0.04/0.69	0.04/0.69
Inside	0.45	0.46	0.63	0.61	0.04/1.16	0.04/1.11

Table 3. Formaldehyde Statistics in $\mu\text{g}/\text{m}^3$ (all samples, separated by sampling location)

	Median Value		75th Percentile		Minimum/Maximum	
	Summer	Fall	Summer	Fall	Summer	Fall
Outside	0.13	0.21	0.41	0.36	0.03/4.51	0.05/0.51
Entry	1.27	0.60	1.60	0.81	0.36/2.92	0.23/1.51
Inside	1.75	0.91	2.15	1.23	0.03/5.60	0.03/2.71

Table 4. Acetone Statistics in $\mu\text{g}/\text{m}^3$ (all samples, separated by sampling location)

	Median Value		75th Percentile		Minimum/Maximum	
	Summer	Fall	Summer	Fall	Summer	Fall
Outside	0.55	0.47	0.86	0.72	0.07/2.24	0.26/0.87
Entry	1.25	1.05	1.60	1.85	0.50/78.58	0.65/4.24
Inside	1.45	1.43	2.19	2.16	0.07/39.24	0.21/4.24

Figures 3, 4 and 5 show the ratio by percentage of indoor to outdoor carbonyl concentrations measured at schools over two days of monitoring in the summer and two days in the fall. Note that each percentage figure is a ratio of an indoor to an outdoor concentration. A percentage infiltration above 100% indicates that a higher concentration of the compound was measured indoors. At each school, NESCAUM monitored for carbonyl compounds in two to five indoor locations. As a result between two and five ratios per school per day could be generated (a total of 36 – 90 ratios). Where the samples were below the analytical limit of detection, indoor to outdoor ratios were not calculated or plotted in Figures 3 - 5.

During the summer a total of 52 indoor samples were collected. The total number of monitoring sample site ratios calculated for acetaldehyde, formaldehyde and acetone during the summer was 31, 34, and 36 respectively. This reduction in sample population was due to 5 monitoring days during the summer when no outdoor sample was taken to derive a ratio (loss of 15 potential ratios), and due to no detectable concentration reported for 1 acetone, 3 acetaldehyde, 6 formaldehyde indoor samples.

During the fall, 70 indoor samples were taken at the schools. A total of 59, 60, and 61 ratios were calculated for acetaldehyde, formaldehyde, and acetone respectively. The fall reduction in indoor to outdoor ratios was due to one day with no outdoor measurement at a single school and due to non-detected indoor concentrations of acetaldehyde (2 samples) and formaldehyde (1 sample) during the fall monitoring study.

These Figures suggest a number of interesting relationships. First, indoor to outdoor concentration percentages generally exceed 100% for all three pollutants (acetaldehyde ratios sometimes are at or below 100%); hence, indoor levels of these pollutants were greater than outdoor concentrations at most schools on most of the days that we monitored. Second, ratios varied considerably depending on the day when monitoring took place. For example, in Figures 3 - 5, in the summer at School A on day 1, carbonyl ratios ranged from over 200% to over 1200%, while on day 2, all three carbonyl ratios clustered between just under 100% and 200%. Finally, ratios for the three carbonyls were different. Acetaldehyde percentages were generally between 50 and 300% in summer and 50 and 375% in fall. Acetone ratios ranged between 0 and 300% in summer and 0 and 800% in fall. Ratios for formaldehyde in both summer and fall were more varied than the other two carbonyls and ranged from near 0 to approximately 800% and in some cases, over 2000%.

The higher inside concentrations of carbonyls indicated in Tables 2 - 4 and Figures 3 - 5 may suggest that carbonyls accumulate over the course of the day when air exchange is minimal. Alternatively, they may indicate the presence of critically important indoor sources of these carbonyls, which would supplement the concentration of infiltrating outdoor carbonyls. A more complete assessment is needed to account for building residency, air exchange rates, and interior emission sources in order to determine the actual contribution of ambient pollution to indoor concentrations. In addition, further ambient emissions characterization and monitoring is necessary to adequately evaluate these observations. Typical indoor building materials such as carpeting, modular panel

walls, indoor combustion sources, and some cleaning products have been identified as important indoor sources, particularly for carbonyls like formaldehyde. In this case, carpeting does not appear to be a distinguishing factor among schools.²⁷

Figure 3. Acetaldehyde Summer and Fall Inside/Outside Concentrations by Percentage²⁸
(line indicates the median value of all 31 and 59 values on the summer and fall charts, respectively)

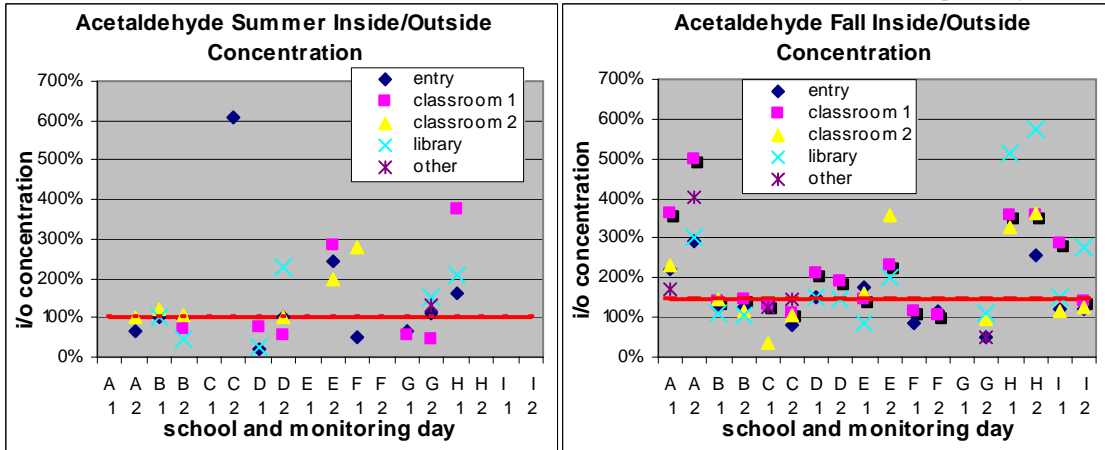
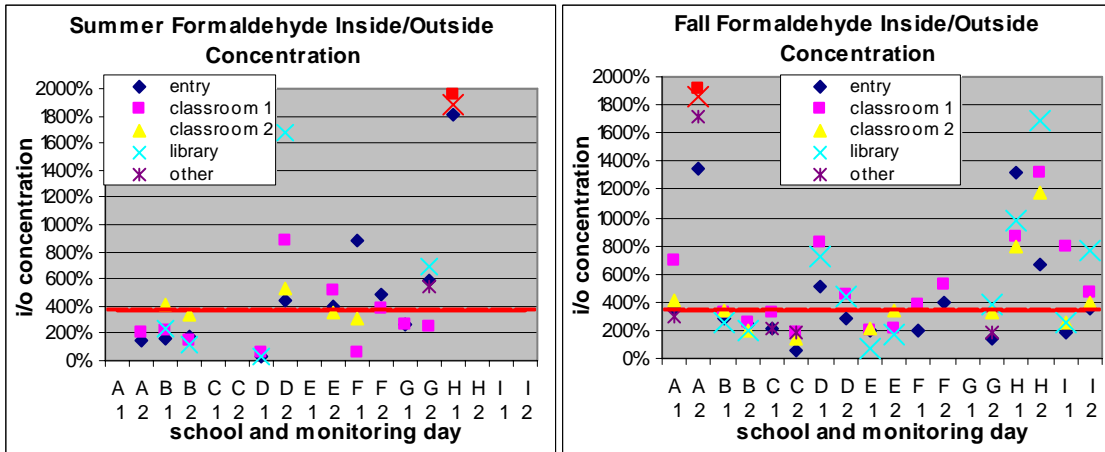


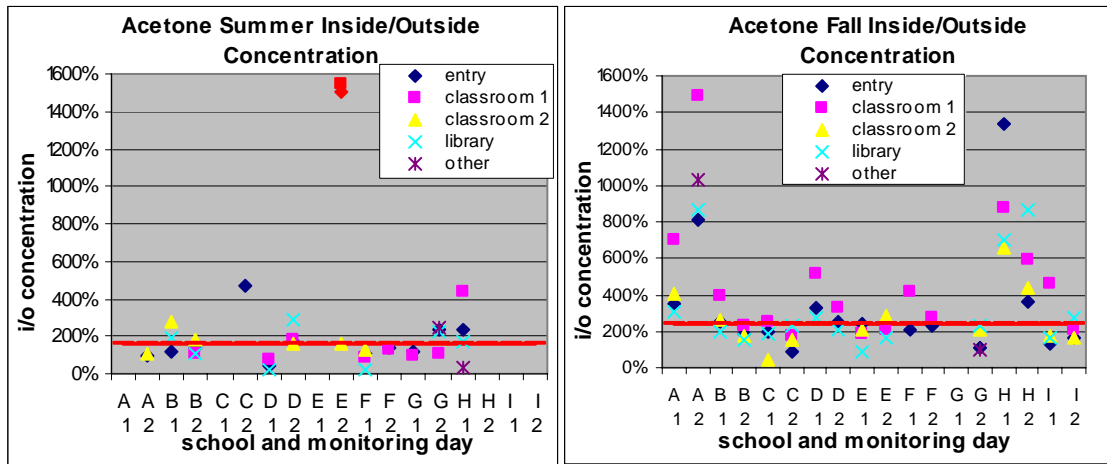
Figure 4. Formaldehyde Summer and Fall Inside/Outside Concentrations by Percentage
(line indicates the median value of all 34 and 60 values on the summer and fall charts, respectively)
(red data points – classroom 1 and library values for Summer School H Day 1 and Fall School A Day 2 – have been reduced to fit on the chart)



²⁷ Please see Appendix H for further analyses of subsets of carbonyl samples.

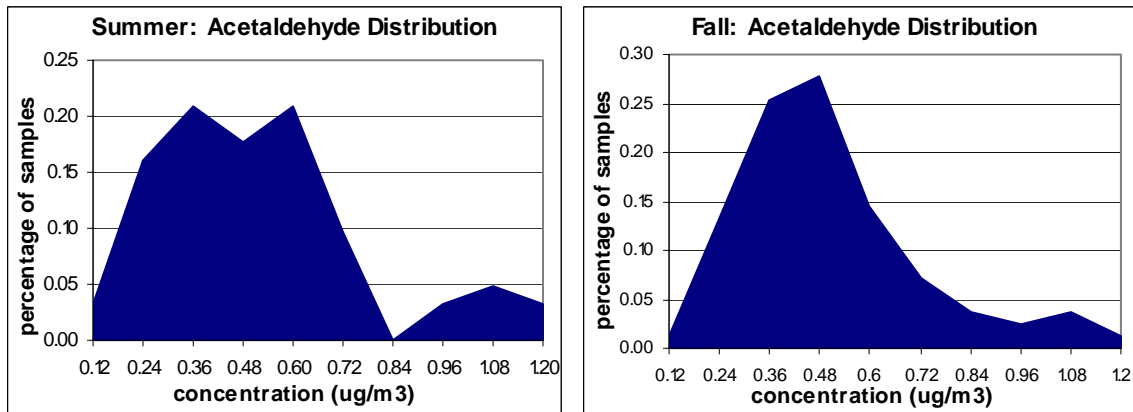
²⁸ For example, a ratio above 100% demonstrates a higher concentration inside, and a ratio below 100% demonstrates a higher concentration outside.

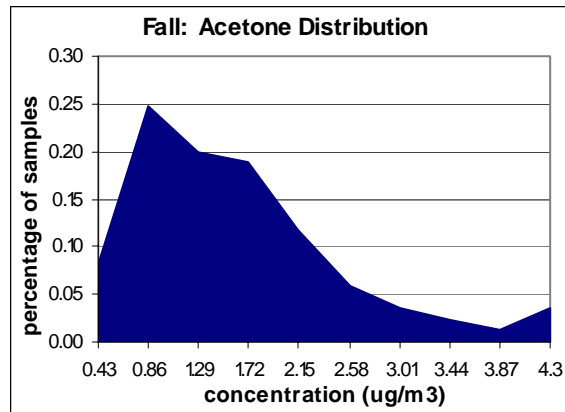
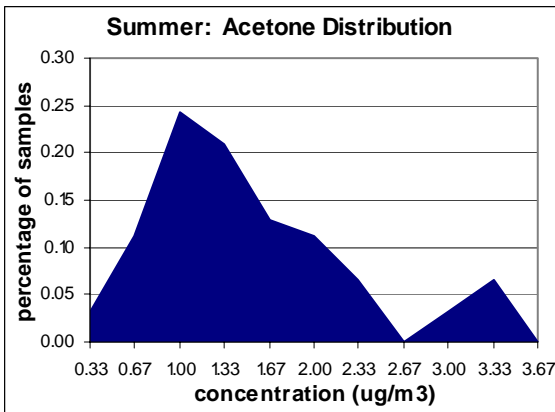
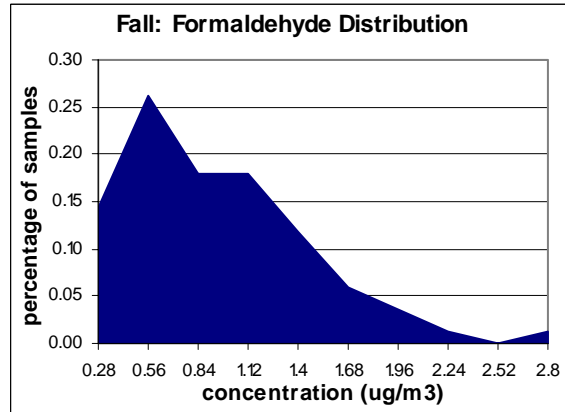
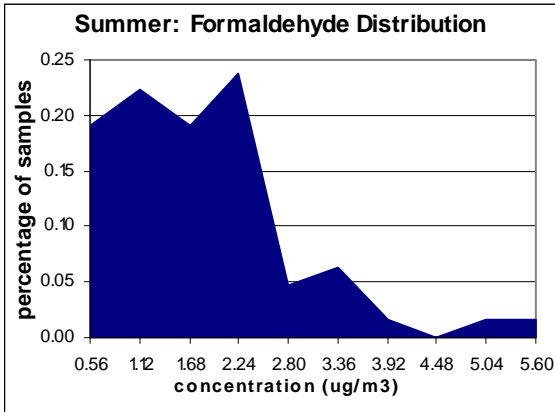
Figure 5. Acetone Summer and Fall Inside/Outside Concentrations by Percentage
 (line indicates the median value of all 36 and 61 values on the summer and fall charts, respectively)
 (red data points – entry and classroom 1 values for Summer School E Day 2 – have been reduced to fit on the chart)



The graphs in Figure 6 below illustrate the distribution of acetaldehyde, formaldehyde and acetone for all carbonyl samples collected. The graphs indicate that carbonyl concentrations inside the school environment do not follow a normal distribution. In fact, a few of the pollutants appear to follow a somewhat biphasic distribution in the summer (where some results cluster around a lower range of concentrations while other results cluster around a higher range of concentrations). The inconsistency and abnormality of the distribution indicate that a number of factors must be considered to appropriately explain the concentrations of pollutants. In future studies it will be important to more carefully track weather conditions, monitoring location within the school building, traffic volume near the school, industrial emissions, and the presence of indoor pollutants that influence concentrations, in order to better interpret the data. However, given the pilot nature of this study, the limited sample size, the number of potential variables, and the range of monitoring conditions, these data are useful to illustrate the wide variability and range of findings across the various locations within a school or between schools participating in the study.

Figure 6. Distribution of All Carbonyl Samples, by the percentage of samples with a given concentration in $\mu\text{g}/\text{m}^3$





The problem of pumps faulting during sample collection occurred with 30% of our summer samples and 20% of samples during the fall. In some instances, the pumps stopped working when the field monitoring team was not present to note the fault. This pump error (typically due to excessive pressure across the sampling media) results in an uncertain total sample volume. In each of these cases, the time the fault was noted and the potential shortest and longest run time was recorded. We assumed longest possible sample duration, which is the laboratories routine practice, and in each we had adequate sample volume for a positive detection (therefore not less than the limit of analytical detection). Assuming our actual sample duration was between the shortest and longest possible sample period, the ambient concentration could have been greater than that reported by the laboratory. We conducted an analysis to determine the range of potential error in the concentration for these faulted samples, as shown in Appendix I. The potential errors of the faulted samples range from 4 to 56%, with a median value of 21%.

- **Volatile Organic Compounds**

Of the suite of 27 volatile organic compounds monitored during this project, the data presented below show findings for four of the most pervasive and/or potent volatile organic compounds (VOCs): benzene, methyl ethyl ketone (MEK), acetone (also classified and reported as a carbonyl²⁹) and toluene. These data represent a limited sample size (a maximum of four days at each school), however, so pollutant levels do not necessarily represent typical conditions at each site.

VOC data are plotted to address the applicability of the methods to explore our central and secondary hypotheses: 1) ambient air pollution concentrations penetrate indoor environments and 2) urban areas or areas near heavy roadway traffic have higher ambient and indoor concentrations of the pollutants.

Figures 7 and 8 examine the ratio of indoor to outdoor pollutants and do not indicate any conclusive relationship. Figures 9 – 13 suggest the range of relative VOC concentrations across the region varying with the level of urbanization and proximity to motor vehicle traffic at each school.

Figure 7 shows the ratio of indoor to outdoor VOC concentrations, as a percentage, measured at schools on both days of monitoring in the summer. In Figure 7, we excluded data from 3 out of 9 schools because the samples were analyzed using a different method and were not comparable. The fall data is shown in Figure 8 using data from four schools. The remainder of the data was excluded in this study because it came from grab samples collected with the Summa canisters rather than eight-hour integrated samples collected during the summer. Additionally, where a data point is missing, VOCs were not detected in either the indoor or outdoor sample, so a ratio could not be calculated.

²⁹ Acetone is reported as a carbonyl and a volatile organic compound because it is detected under both the sampling and analytical methods employed for this project. However, the accuracy and sensitivity in detection for this compound will differ between these methods, therefore, the results are not directly comparable.

Figure 7. Summer VOCs Inside/Outside (i/o) Concentration Presented as Percentage (line on graph indicates median value)

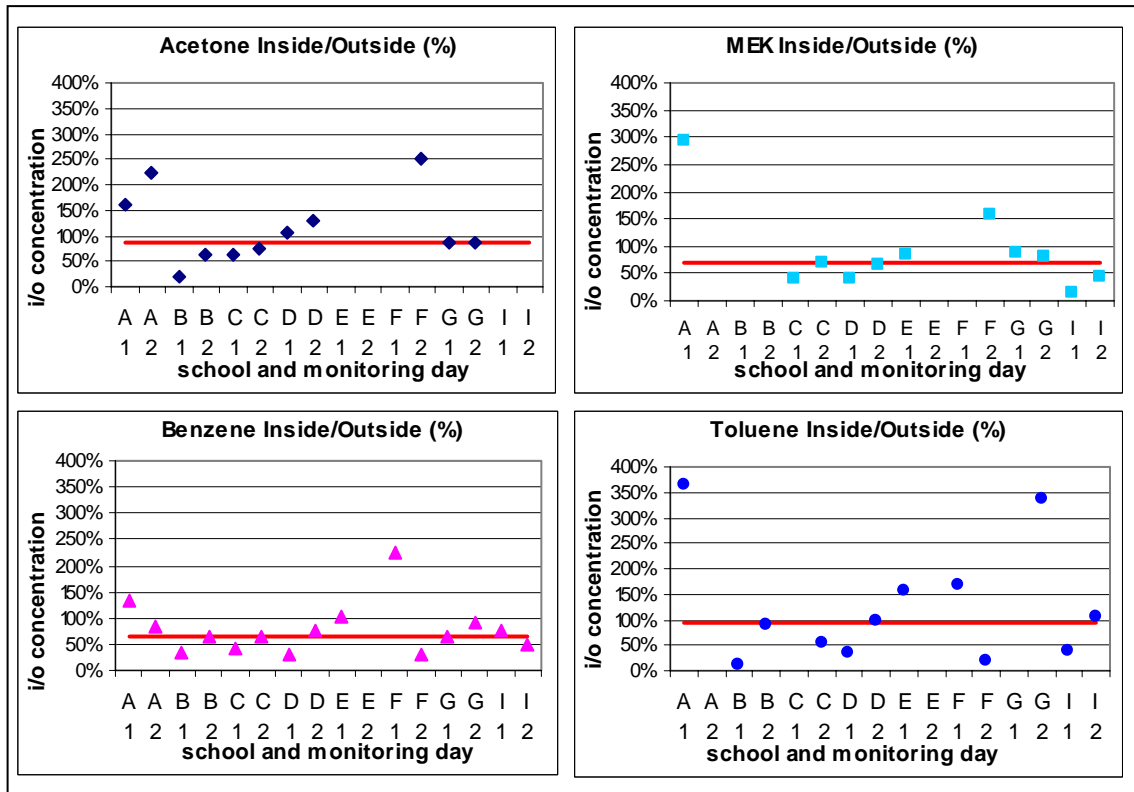
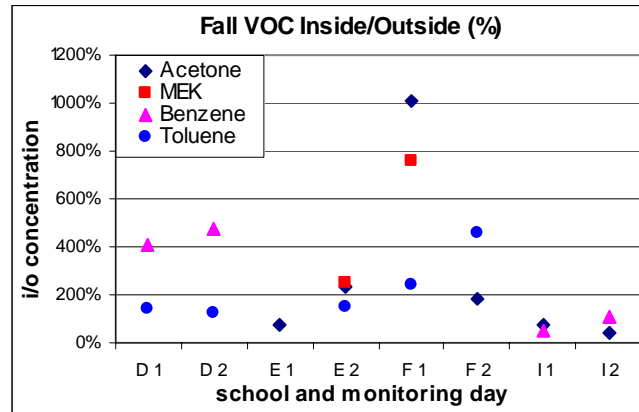


Figure 8. Fall VOCs Inside/Outside (i/o) Concentrations Presented as Percentages



In an attempt to better understand the variability in indoor to outdoor ratios in our sample population, we calculated the average and median percentage infiltration for all nine schools.³⁰ During the summer months of this study the median indoor concentrations of acetone, benzene, methyl ethyl ketone, and toluene ranged from approximately 60 to 90 % of the outdoor concentrations, respectively. Fall monitoring data for the much smaller integrated sample population (n= 8) suggest a median indoor concentration of these same

³⁰ This represents a sample size of eighteen samples.

pollutants ranging from approximately 130% to 500% of outdoor concentrations, respectively. Creating these types of comparisons with our pilot project data is illustrative, supports the investigation of our central and secondary hypotheses, and assists us when reviewing our methodology. The sample size is very small, which limits any rigorous statistical analyses of the data at this time.

However, as described previously in this report, these observations are consistent with those made by other researchers previously and underscore the importance of season and of the potential contribution of indoor emissions sources and activities when attempting to evaluate infiltration. Future analyses will aim to more carefully characterize indoor sources and activities in an effort to more appropriately evaluate whether important mobile source pollutants (i.e. benzene and toluene) will infiltrate indoor microenvironments in a manner that approaches 100% to establish a “baseline” of exposure.

Figure 9 examines the influence of urbanization levels on concentrations of VOCs. Figure 9 is a scatter plot of relative inside and outside summer concentrations for the four compounds discussed above, with schools arranged from urban to rural (A to I, as described in Table 1) from left to right along the x-axis.³¹ The diagram suggests a general trend of decreasing pollutant concentrations from urban to rural areas. This is most apparent for acetone and benzene, but also occurs to some degree with MEK and toluene.

A high degree of variation is evident, and may be explained by meteorological effects, varying either with the seasons or with individual days picked for sampling. In addition, benzene, toluene, acetone and MEK are emitted from numerous sources, including cleaning products. These emissions may be higher in the intense summer cleaning period at schools. Further testing is needed in order to determine the exact nature of these potential impacts.

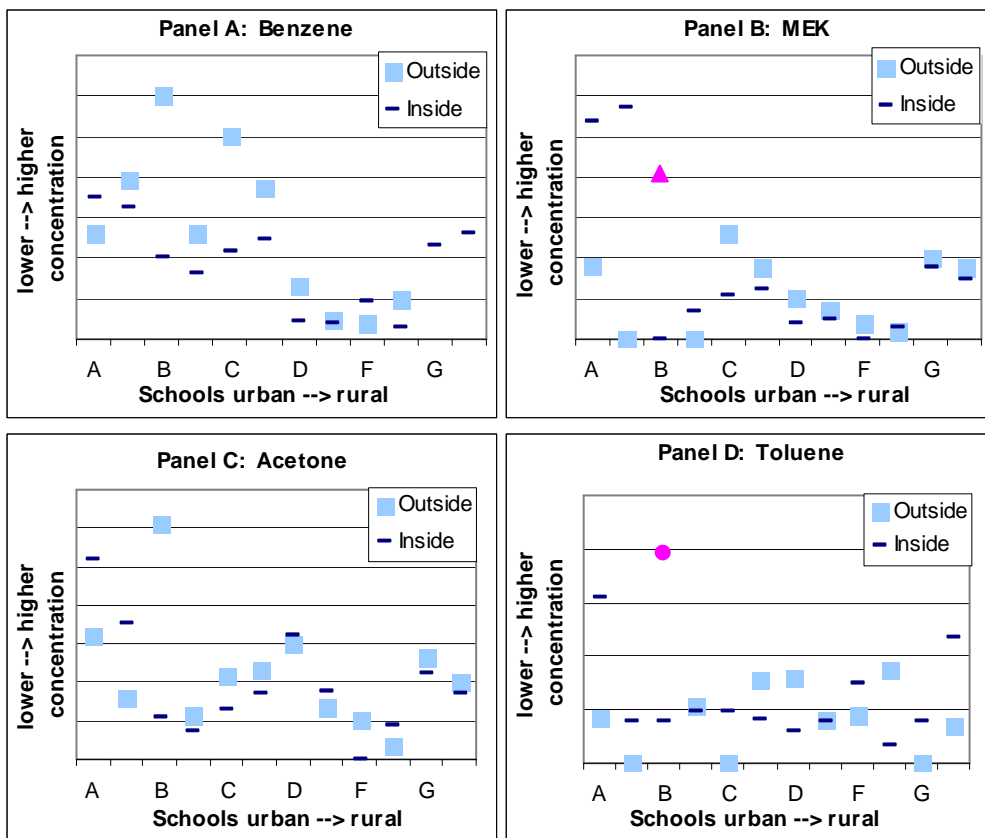
Another interesting observation is the higher concentration of benzene at school G relative to the other rural schools, D and F. This may be because School G, the most rural school presented in this figure, is located near a road with very heavy traffic volume, and benzene is largely a fuel-related constituent.

³¹ Schools E, H and I were not included in these graphs. Data for School H was not available at the time of publication of this report, and the data for Schools E and I were not comparable to the other six schools due to alternate analytical techniques.

Figure 9. Scatter Plots of Relative Inside and Outside Concentrations of VOCs by School

* Triangle in Panel B represents School B Outside concentration divided by 10

* Circle in Panel D represents School B Outside concentration divided by 100, to incorporate these data points on the same graph



Figures 10 through 13 present relative data correlating ambient and indoor concentrations with population density and traffic volume. Figures 10 and 11 illustrate that concentrations of benzene and toluene, which are primarily generated by motor vehicle fuel combustion or evaporation, are relatively higher in areas located in close proximity (< 500 meters) to roadways with higher traffic volume. Note, however, that the relationships between traffic volume and these two pollutants were stronger for inside measurements than for outside measurements.

Relative concentrations for schools B and C in Figure 10A suggest the importance of urban environments as additional considerations to traffic volume.³² Essentially, these schools are located in the most urbanized environment of our sample population; as a result, we hypothesize that the general ambient “background” concentration for some of the traffic-related pollutants are higher than other less urban locations. These schools were the sites of the highest measured benzene concentrations even though they are located near only moderately trafficked roads. This apparent confounding observation, is

³² Schools are ranked from most to least urban, with School A being the most urban and School G the least.

probably because traffic volume in the surrounding area (>500 meters from the school) contributed to an elevated benzene baseline for these schools.

In Figures 12 and 13, associations with population density and ambient or indoor concentrations are less clear. Acetone and methyl ethyl ketone are pollutants typically associated with industrial sources or personal product use rather than fuel combustion or evaporation. Accordingly, we graphed relative concentrations of these pollutants in comparison with the broader criterion of population density. No close association is seen in these graphs, likely due to the many potential emission sources of these pollutants and the variability between sampling sites in this study. In Figure 12, levels of MEK measured outside correlate more closely with population density than those measured inside. This same relationship does not hold true for acetone measurements in Figures 13A and B.³³

Our ability to interpret these data more thoroughly was limited by laboratory error,³⁴ and a lack of a comprehensive outdoor or indoor emissions inventory during pilot monitoring. Although they represent a limited sample size, these data provide interesting insights for future study design, particularly with respect to sample site selection.

Figure 14 shows the distribution of all VOC measurements collected during summer monitoring. These graphs also suggest the variability and multiphasic nature of the data. As with the carbonyl distributions shown in Figure 6 above, biphasic or multiphasic distributions imply that a number of factors may explain concentrations of pollutants rather than one overriding factor. Thus in a future study it will be important to carefully track weather conditions, location within the school building, traffic volume near the school, industrial emissions, and the presence of indoor pollutants that influence the concentrations in order to interpret the data more comprehensively. A more complete emissions characterization and monitoring program will be necessary to better understand the biphasic nature of the pollutant concentrations. However, given the pilot nature of this study, the limited sample size, the number of potential variables, and the range of monitoring conditions, these data are useful to illustrate the range of findings across the region.

For two pollutants, benzene and formaldehyde, many of the levels found in the pilot study are above the cancer risk thresholds set by the U.S. Environmental Protection Agency. This finding is consistent with recent regional and national studies that have found that **all** locations in the country exceed the conservative thresholds for these pollutants. At this time there is a vigorous public debate regarding scientifically justifiable use of health risk assessment practices for air pollution policy at the regional and national level. The observation that all locations are recording concentrations above the risk thresholds underscores the need for federal consideration of policy changes. It is

³³ The strength of the association of each set of inside and outside data with population density and traffic volume was evaluated statistically; results are shown in the table in Appendix H. Note: the power of these statistical analyses is limited by the small sample size.

³⁴ The laboratory error produced samples that are relative to each other, but they cannot be analyzed as definitive concentrations.

anticipated that improved public education and public policy will be forthcoming to address the real or potential health risk associated with environmental exposure to widespread pollutants such as benzene and formaldehyde. For further information on how the U.S. EPA establishes these thresholds or ongoing regional and national assessments, see Appendix B.

Figure 10. Benzene Relative to Traffic Data

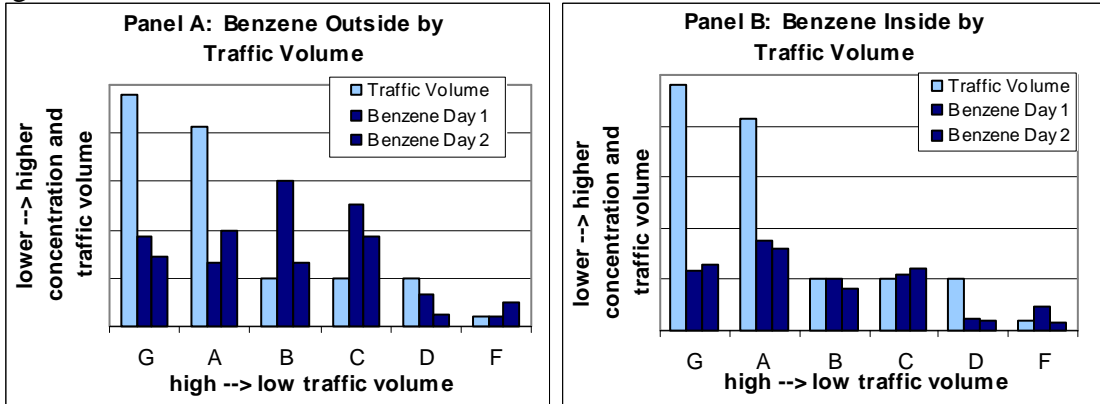
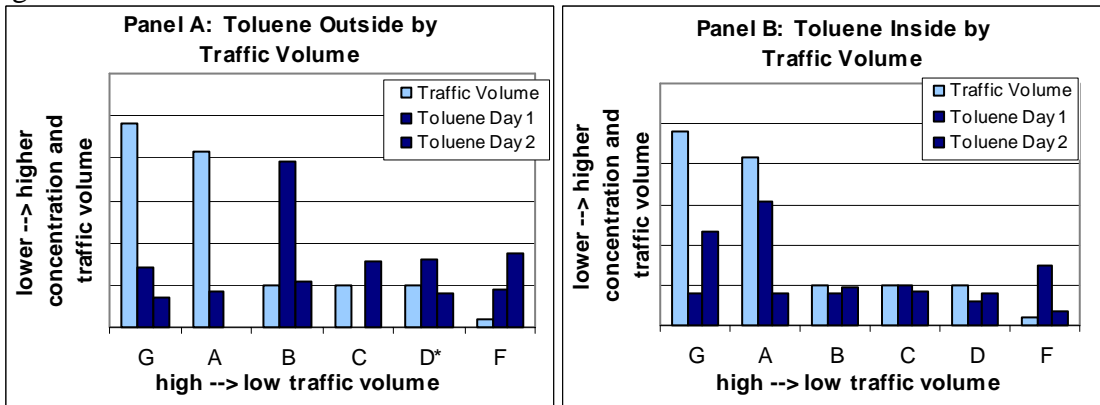
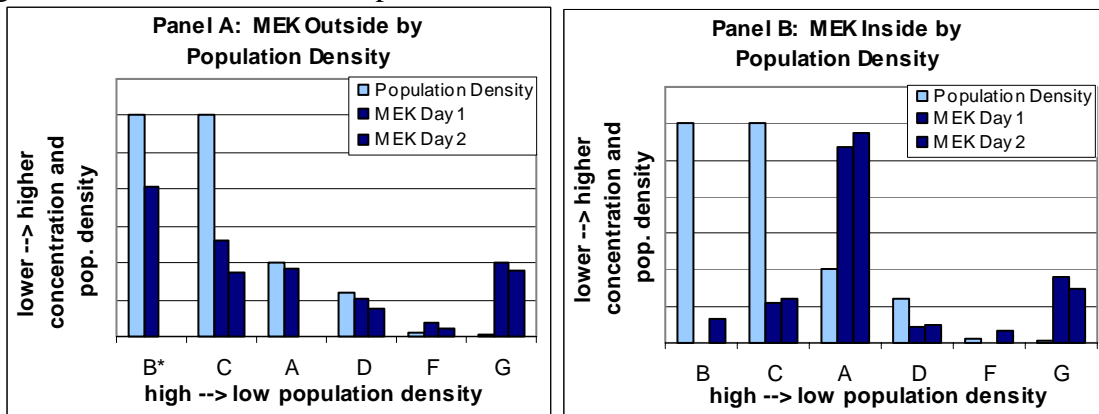


Figure 11. Toluene Relative to Traffic Data



*School D Day 1, concentration divided by 20

Figure 12. MEK Relative to Population Data



*School B Day 1, concentration divided by 10

Figure 13. Acetone Relative to Population Data

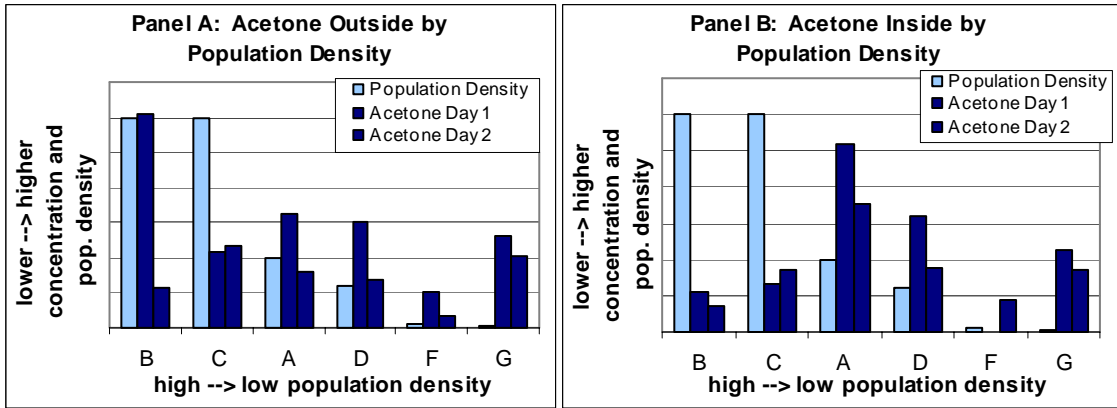
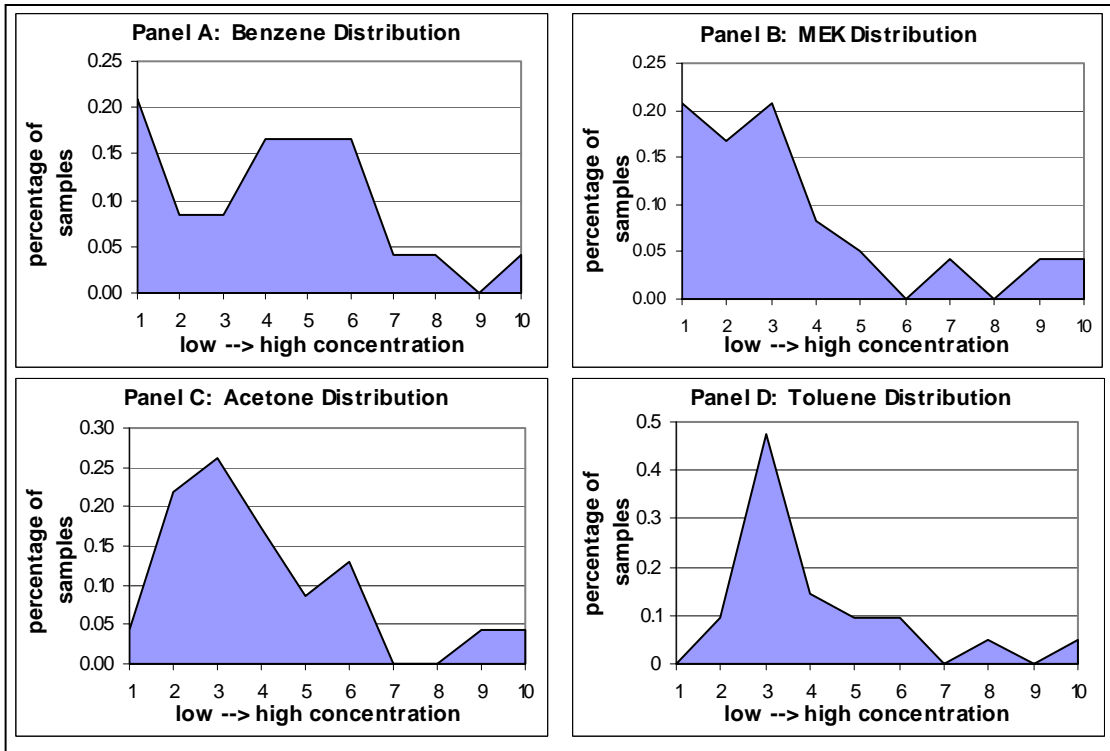


Figure 14. VOC Relative Distribution Graphs



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APPENDIX A: Health Effects of Criteria Pollutants

The federally regulated criteria pollutants are carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide, particulate matter and lead. Lead is not included in this appendix because it is beyond the scope of this report. Additionally, this section addresses carbon dioxide, which is an indicator of indoor air quality but not a criteria pollutant.

Carbon Monoxide (CO)

Sources:

CO is a product of fossil fuel combustion, predominantly generated by vehicle emissions. Additional sources include other modes of transportation, as well as wood-burning stoves, incinerators, and industrial sources. The presence of CO in a school indicates the infiltration of vehicle emissions or other outdoor sources, or an inefficient heating system.

Standards and Health Effects:

The EPA's National Ambient Air Quality Standard (NAAQS) for CO is 9 ppm for an eight-hour average and 35 ppm for a one-hour period. Low levels of exposure to CO are thought to contribute to heart disease by reducing the amount of oxygen delivered to the body's organs and tissues. At extremely high concentrations (which are not expected to be found in schools), CO can be lethal.

Nitrogen Dioxide (NO₂)

Sources:

NO₂ is a brownish, highly reactive gas produced when fossil fuels are burned at high temperatures. Sources include transportation vehicles such as diesel buses and trucks, power generating facilities and industrial boilers. Cooking can also be a particularly large contributor in schools.

Standards and Health Effects:

The outdoor annual standard for NO₂ is 50 ppb; there is no indoor standard. NO₂ exposure irritates the lungs, and can aggravate bronchitis and lower resistance to respiratory infections.

Ozone (O₃)

Sources:

O₃ is a highly reactive gas that is the major component of smog. It is not directly emitted into the outside air, but instead is formed through chemical reactions between nitrogen oxides and volatile organic compounds. These two precursors are primarily emitted by transportation and industrial sources. Inside, photocopiers and other office equipment can produce ozone.

Standards and Health Effects:

Ozone can damage the lungs and reduce their function when it is inhaled because of its reactivity. At relatively low levels exposure for several hours can significantly reduce lung function and induce inflammation in healthy people during exercise. The EPA's NAAQS is 120 ppb for a maximum hourly exposure to ozone, and 80 ppb for 8 hours.

Sulfur Dioxide (SO₂)

Sources:

SO₂ is emitted by stationary sources such as coal and oil combustion, steel mills, refineries, and pulp and paper mills. SO₂ is also a contributor to acid rain, and along with particulate matter contributes to decreased visibility.

Standards and Health Effects:

SO₂ can affect breathing and aggravate existing respiratory conditions at high concentrations. EPA's NAAQS for SO₂ is 140 ppb for a 24-hour period, and 500 ppb for a 3-hour period, and the annual mean for SO₂ should not exceed 30 ppb. We would not expect to find high levels of SO₂ in schools.

Particulate Matter (PM_{2.5})

Sources:

Particulate Matter includes dust, dirt, soot, smoke, and liquid droplets. Sources of PM include diesel school buses, factories, power plants, cars, construction vehicles and activity, fires, natural dust and condensation.

Standards and Health Effects:

PM is of interest because as it is inhaled it becomes a lung irritant and causes breathing problems, aggravates existing respiratory and cardiovascular disease, and can damage lung tissue. The smaller the PM, the deeper it is thought to travel into the lungs and contribute to many types of bronchitis. PM is also of concern because toxic substances can collect on the surface of the particulate matter and be absorbed into our bodies after particles are inhaled. EPA's NAAQS for particulate matter with an aerodynamic diameter of less than or equal to 2.5 μm (PM_{2.5}) is a maximum 24 hour concentration of 65 μg/m³, and an annual concentration less than 15 μg/m³.

Carbon Dioxide (CO₂)

Sources:

CO₂ is a major component of air. It is the respiration product exhaled by animals and is taken up by plants. High levels of CO₂ in buildings indicate poor ventilation, because they signal that there is not enough fresh air entering the area, or that there are more people (and more exhalation product) in a given area than the ventilation system is able to accommodate.

Standards and Health Effects:

CO₂ is an essential gas that usually has an ambient outdoor concentration around 300 - 350 ppm. When CO₂ concentrations exceed 700 ppm above the ambient concentration, according to the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) standard, occupants of the affected area can experience drowsiness and fatigue. At levels of 2500 ppm and above (which are not expected to be found in school buildings), the resulting low oxygen levels can cause headaches and sometimes more serious symptoms.

APPENDIX B: Benchmark Concentrations for Hazardous Air Pollutants (HAPs)

Benchmarks

The following chart contains a list of 188 hazardous air pollutants (HAPs) identified under the Clean Air Act because of serious adverse health effects associated with exposure, including but not limited to cancer in multiple organ systems and non-cancer effects such as liver damage, respiratory damage, and central nervous system effects. Many of these compounds are target analytes of concern in the pilot project, including acetaldehyde, benzene, and formaldehyde, while several other compounds reported during the pilot monitoring project are not listed under the federal program, including acetone, butyraldehyde, and propionaldehyde.³⁵ Table 5 below includes concentrations or benchmarks that are estimated to be protective of the public health for cancer, non-cancer (short-term), and non-cancer (long-term) effects. The benchmarks are not necessarily "safe" or no risk levels. Rather, they represent concentrations below which there is believed to be little risk to the population.

Unlike other air pollutants like ozone, carbon monoxide and particulate matter described in Appendix A, less detailed information is available about potential health effects of HAPs. This is largely due to a lack of adequate exposure data and scientific study evaluating human health effects of these pollutants. The likelihood of these pollutants to cause cancer or non-cancer effects has been characterized in animal studies or occupational exposure studies. However, these types of studies involve higher levels of exposure than commonly found in the environment and thus may not be directly relevant. Consequently, the regulatory approach taken by EPA for HAPs relies on extrapolation from higher doses to lower doses to estimate hazards.

For non-cancer effects, this approach uses findings of "no effect" concentrations from relatively high dose animal studies to predict a "no effect" in a low-dose concentration with a safety factor included. This "no effect" level is a concentration to which humans could be safely exposed in the environment throughout a lifetime. The scientific standard for non-cancer benchmarks is that "the concentration represents the value likely to present no appreciable risk of deleterious non-cancer effect during a lifetime of continuous inhalation." For cancer effects, the benchmarks used by EPA reflect the assumption that there is no concentration below which there is no risk (e.g. no threshold). Concentrations that are assumed to present a potential public health concern are derived by estimating a risk concentration for humans from observed tumor incidence in animals. For cancer risk, the scientific standard for the benchmarks denotes "the concentration of a known, probable, or possible human carcinogen that will result in one in a million risk of contracting cancer over a lifetime of exposure."

In addition to the limitations above, most regulatory efforts have addressed a single pollutant at a time. In the atmosphere, many pollutants co-exist, which may significantly alter the potential health effect(s) following exposure to chemical combinations. It is

³⁵ The latter compounds are typically low-potency materials that are not believed to represent risks to public health at environmental concentrations, and therefore are not currently covered by the federal program.

extremely difficult to predict the effect of multiple pollutant exposures in human populations, but research continues to assist federal, state, and local agencies in developing appropriate regulatory programs to address air pollution concerns.

Table 5 below displays the health effect benchmark concentrations for many of the federally regulated HAPs (Caldwell, 1998). A benchmark concentration represents the atmospheric concentration of a pollutant above which there may be potential public health concerns. Benchmark values essentially serve as "yardsticks" to assess potential threats to public health posed by HAPs. These values represent the current state of scientific understanding about the health effects of pollutants of concern. The benchmarks are a compilation of values used by EPA, the International Agency for Research on Cancer, the National Toxicology Program, the California Environmental Protection Agency, and the Agency for Toxic Substances and Disease Registry when recommending regulatory limits or public health advisory limits. The concentrations shown in the table below are generally similar to the health-based regulatory standards developed by health agencies in the Northeast states.

Benchmarks for short-term exposure are included in the table for comparative purposes. These benchmarks were calculated by dividing the Level of Concern (LOC) values developed for EPA's Superfund program by a safety factor of 1000. The LOC is indicative of levels of airborne concentrations of chemicals for which no serious irreversible health effects are expected to occur after exposure of thirty minutes to the pollutant.

The benchmarks shown here are meant to serve as general indicators of air quality presenting potential risk to public health. It is important to recognize that these values cannot necessarily be used to predict the likelihood of a particular cancer or non-cancer effect.

Table 5. Benchmark Concentrations for Hazardous Air Pollutants (HAPs)

<i>Benchmark values published in Caldwell et al. Toxicology and Industrial Health, Vol 14, No.3, 1998, pp 429-454 .</i>				
Published Benchmark Concentrations ($\mu\text{g}/\text{m}^3$)				
ChemName	CAS Number	Chronic Toxicity	Acute Toxicity	Carcinogenicity
Acetaldehyde	75-07-0	9	.	0.45
Acetamide	60-35-5	.	.	0.05
Acetonitrile	75-05-8	50	.	.
Acetophenone		.	.	.
Acrolein	107-02-8	0.02	1.2	**
Acrylamide	79-06-1	0.7	.	0.00077
Acrylic acid	79-10-7	1	.	.
Acrylonitrile	107-13-1	2	.	0.015
Allyl chloride	107-05-1	1	.	0.17
Aniline	62-53-3	1	.	0.63
Anisidine	90-04-0	.	.	0.025
Antimony compounds		*	*	*
Arsenic compounds		0.5	.	0.00023

Benzene	71-43-2	71	.	0.12
Benzotrichloride	98-07-7	.	0.7	0.00028
Benzyl chloride	100-44-7	12	5.2	0.02
Beryllium compounds		0.0048	.	0.00042
Biphenyl		.	.	.
Bis(2-ethylhexyl)phthalate	117-81-7	71	.	0.25
Bis(chloromethyl)ether	542-88-1	.	.	0.000016
Bromoform	75-25-2	.	.	0.91
1,3-butadiene	106-99-0	8	.	0.0036
Cadmium compounds		3.5	*	0.00056
Calcium cyanamide		.	.	.
Captan	133-06-2	.	.	1
Carbaryl		.	.	.
Carbon disulfide	75-15-0	700	.	.
Carbon tetrachloride	56-23-5	2.4	.	0.067
Carbonyl sulfide		.	.	.
Catechol		.	.	.
Chloramben		.	.	.
Chlordane	57-74-9	0.018	.	0.0027
Chloroacetic acid	79-11-8	.	1.8	.
Chlorobenzene	108-90-7	70	.	.
Chloroform	67-66-3	35	.	0.043
Chloromethyl methyl ether	107-30-2	.	1.8	0.0014
Chloroprene	126-99-8	1	.	**
Chromium Compounds	18540-29-9	0.002	0.05	0.000083
Cobalt and Compounds	7440-48-4	*	.	.
Cresol		180	.	**
Cumene	98-82-8	.	.	.
Cyanide compounds		*	*	*
D(2,4)		.	.	.
Dibutylphthalate		.	.	.
Dichlorobenzidene(3,3')	91-94-1	.	.	0.0078
Dichloroethyl ether	111-44-4	.	.	0.003
1,3-dichloropropene	542-75-6	20	.	0.027
Dichlorvos	62-73-7	0.5	.	0.012
Diethanolamine		.	.	.
Diethyl sulfate	64-67-5	.	.	**
Dimethoxybenzidine(3,3')	119-90-4	.	.	0.0067
Dimethyl formamide	68-12-2	30	.	**
Dimethyl hydrazine(1,1)	57-14-7	0.022	.	0.0004
Dimethyl phthalate		.	.	.
Dimethyl sulfate	131-11-3	.	5	**
dinitro-o-cresol(4,6)	534-52-1	.	0.5	.
Dinitrophenol(2,4)		.	.	.
Dinitrotoluene(2,4)	121-14-2	7	.	0.0091
dioxane(1,4)	123-91-1	400	.	0.32
Epichlorohydrin	106-89-8	1	.	0.83
Epoxybutane(1,2)	106-88-7	20	.	.
Ethyl acrylate	140-88-5	48	.	0.073
Ethyl carbamate	51-79-6	.	.	0.036
Ethyl benzene	100-41-4	1,000	.	**

Ethyl chloride	75-00-3	10,000	.	**
Ethylene dibromide	106-93-4	0.2	.	0.0045
Ethylene dichloride	107-06-2	95	.	0.038
Ethylene glycol	107-21-1	.	.	.
Ethylene oxide	75-21-8	600	540	0.043
Ethylene thiourea	96-45-7	3	.	0.032
Ethylidenedichloride	75-34-3	.	.	0.63
Formaldehyde	50-00-0	3.6	.	0.077
Glycol ethers		*	.	.
Heptachlor	76-44-8	.	.	0.00077
Hexachlorobenzene	118-74-1	2.8	.	0.0022
Hexachlorobutadiene	87-63-3	90	.	0.045
Hexachlorocyclopentadiene	77-47-4	0.07	0.02	.
Hexachloroethane	67-72-1	80	.	0.25
Hexane	110-54-3	200	.	.
Hydrazine	302-01-2	0.24	.	0.0002
Hydrochloric acid	7647-01-0	20	.	.
Hydrofluoric acid	7664-39-3	5.9	1.6	.
Hydroquinone	123-31-9	.	.	.
Lead compounds		1.5	*	0.013
Lindane	58-89-9	1	.	0.0026
Maleic anhydride	108-31-6	2.4	.	.
Manganese compounds		0.05	*	.
Methyl ethyl ketone	78-93-3	1000	.	.
Mercury compounds		*	.	*
Methanol	67-56-1	620	.	.
Methoxychlor		.	.	.
Methyl bromide	74-83-9	5	.	.
Methyl chloride	74-87-3	.	.	0.56
Methyl chloroform	71-55-6	320	.	.
Methyl hydrazine	60-34-4	.	0.94	0.0032
Methyl iodide	74-88-4	10	.	**
Methyl isobutyl ketone	108-10-1	.	.	.
Methyl isocyanate	624-83-9	0.36	4.7	.
Methyl methacrylate	80-62-6	980	.	.
Methyl tert-butyl ether	1634-04-4	3000	.	6
4,4-Methylene bis(2-chloroaniline)	101-14-4	.	.	0.011
Methylene chloride	75-09-2	3000	.	2.1
Methylene diphenyl diisocyanate	101-68-8	0.02	.	.
Methylenedianiline(4,4')	101-77-9	1.9	.	0.0022
N,N-diethyl/dimethylaniline		.	.	.
Naphthalene	91-20-3	14	.	.
Nickel and Compounds	7440-02-0	0.24	*	0.0042
Nitrobenzene	98-95-3	1.7	.	.
nitrophenol(4)		.	.	.
nitropropane(2)	79-46-9	20	.	**
o-toluidine	95-53-4	.	.	0.18
p-dichlorobenzene	106-46-7	800	.	0.15
p-phenylenediamine		.	.	.
Parathion	56-38-2	.	2	**
PCDD/PCDFs (used TCDD)	(1746-01-6)	0.0000035	.	0.00000003

Pentachloronitrobenzene	82-68-8	.	.	0.014
Pentachlorophenol	87-86-5	0.2	.	0.033
Phenol	108-95-2	45	.	.
Phosgene	75-44-5	0.3	0.8	.
Phthalic anhydride	85-44-9	120	.	.
Polychlorinated biphenyls	1336-36-3	1.2	.	0.002
Polycyclic organic matter		*	.	.
Propionaldehyde		.	.	.
Propoxur	114-26-1	.	.	0.91
Propylene dichloride	78-87-5	4	.	0.053
Propylene oxide	75-56-9	30	.	0.27
1,2-propyleneimine	75-55-8	.	.	0.00015
Quinoline	91-22-5	.	.	0.00029
Quinone		.	.	.
Selenium compounds		0.5	*	.
Styrene	100-42-5	1000	.	**
Styrene oxide	96-09-3	6	.	0.022
1,1,2,2-tetrachloroethane	79-34-5	.	.	0.017
Tetrachloroethylene	127-18-4	35	.	1.7
Toluene	108-88-3	400	.	.
Toluene diamine(2,4)	95-80-7	.	.	0.0011
2,4-toluene diisocyanate	584-84-9	0.07	7	0.091
Trichlorobenzene(1,2,4)	120-82-1	200	.	.
1,1,2-trichloroethane	79-00-5	400	.	0.063
Trichloroethylene	79-01-6	640	.	0.59
Trichlorophenol(2,4,6)	88-06-2	.	.	0.32
Trifluralin	1582-09-8	.	.	0.45
Trimethylpentane(2,2,4)		.	.	.
Vinyl acetate	108-05-4	200	.	**
Vinyl bromide	59-36-02	3	.	0.031
Vinyl chloride	75-01-4	26	.	0.012
Vinylidene chloride	75-35-4	32	.	0.02
Xylenes (mixed)	1330-20-7	300	.	.
* Benchmark identified; however, given uncertainties in benchmark derivation, a comparison is not advised.				
** Tier III benchmark available				

APPENDIX C: Helpful Suggestions to Manage Indoor Air Quality

These suggestions are based on the EPA's Tools For Schools program.³⁶ Indoor air quality is primarily a function of the effectiveness of ventilation systems and of controls over sources of and exposure to pollutants and bioaerosols. These suggestions are ways to manage indoor air quality. They are intended to help improve indoor air quality in the school, not to fix all possible problems.

- Keep dust and dirt under control in the building
- Use walk-off mats at all entrances, both inside and out
- Be aware of the locations of air intakes and keep the areas surrounding them free of standing water and other sources of pollution (such as dumpsters, fumes from maintenance, and smoking)
- Use cleaning products that do not contain harmful chemicals³⁷
- Only use ventilated areas for chemical storage
- When it is necessary to use a harmful chemical, use the smallest amount possible and use it in a well-ventilated area or under a hood
- Move bus loading and unloading areas away from air intakes and try to minimize the amount of time that doors to schools are open when buses are present
- Minimize the amount of time that buses spend idling near schools
- When deliveries are made to schools, do not allow trucks to idle while being unloaded
- Do not allow parents who pick up their children to idle near the school
- Place printers, copiers, and fax machines in well-ventilated areas
- Ensure that all combustion appliances have clean, working hoods over them
- Inspect and clean ventilation systems regularly (indoors and outside)
- Prevent the blocking of vents
- Fix leaks in floors, roofs and pipes as soon as possible, then remove and replace damaged tiles
- Make sure that the ground around foundations slopes away from buildings, to prevent standing water from accumulating around foundations
- Keep all roof drains and gutters clear so that water can drain away from buildings

³⁶ For further information and references regarding this program see Appendix E.

³⁷ See Appendix E for more information.

APPENDIX D: Detailed Information on Sampling Equipment and Methods

• Part I: ACCESS EMS

The ACCESS Environmental Monitoring system is a single, portable monitoring device comprised of a number of sensors that detect a set of pollutants and register basic meteorology (temperature, barometric pressure, etc.) Carbon monoxide, nitrogen dioxide, ozone, and sulfur dioxide sensors are measured with electrochemical sensors. The particulate sensor uses optical technology. The carbon dioxide sensor is based on infrared technology. The details of these sensors are described below. The temperature sensor is a Type K thermocouple and the relative humidity sensor uses capacitive technology.

All sensors relay data to a specialized computer known as a datalogger, which queries the sensors for current readings every six seconds. The data is averaged over each minute and stored with a date and time stamp for eventual upload to a computer for analysis. For further analysis, data in this study was averaged at five-minute intervals.

An electrochemical sensor uses a chemical reaction between the target gas and a chemical gel in the sensor to detect concentrations of the target gas in the air. When the reaction occurs, it generates a tiny electrical current that is proportional to the concentration. The current is then amplified electronically to a readable level. These sensors can react to other gases, potentially causing the reported value to increase or decrease; this is known as cross-sensitivity. The ACCESS system utilizes the most selective and accurate sensors available. Cross-sensitivity can somewhat affect sensor accuracy. However, each sensor's accuracy is primarily determined by the frequency of calibration and the span gas used to calibrate the sensor. The bottled gas standards used to calibrate the sensor are generally $\pm 10\%$ of the span value. Repeatability is $\pm 2\%$ of span.

Because these sensors are measuring small levels of pollutants in the air, it is critical that they be zeroed before use. This helps to maintain the highest degree of accuracy. No sensor in the system has a perfectly linear response curve. As a result, when the gas sensor is calibrated, it is done over the region of greatest interest to the users. In the cases of O₃, NO₂ and SO₂ this is typically between 0 and 300 ppb. When the sensor is calibrated, the slope and offset of the response curve is determined and stored in the datalogger.

The O₃ sensor on the system has a range of 0-1000 ppb. Its minimum detectable limit is 20 ppb. The expected accuracy of the O₃ sensor is ± 20 ppb. The resolution of the sensor is 1 ppb. It is cross-sensitive to other oxidants such as Cl₂, Br₂, ClO₂ and F₂, and will respond to these gases with a false positive reading. For example, 50 ppb of chlorine will typically cause a reading of 25 ppb ozone. The NO₂ sensor has a range of 0-1000 ppb. Its minimum detectable limit is 10 ppb and the expected accuracy is ± 20 ppb. It is cross-sensitive to other nitrogen oxides such as NO and NO₂. The SO₂ sensor has a range of 0-1000 ppb. Its minimum detectable limit is 10 ppb and the expected accuracy is ± 20 ppb. It is cross-sensitive to other sulfur compounds and NO₂. The CO sensor has a range of 0-

100ppm. Its minimum detectable limit is 1 ppm and the expected accuracy is ± 2 ppm. It does not have any common cross-sensitivities.

The CO₂ sensor is based on infrared technology. It uses a double cell sensor to provide additional signal stability. This sensor has a range of 0-5000ppm. Its minimum detectable limit is 1 ppm and the expected accuracy is ± 20 ppb. It does not have any common cross-sensitivities.

On the ACCESS system, particulates are measured through a nephelometer that is built directly into the system. The nephelometer, an AQ-10, is a passive real-time aerosol monitor that utilizes optical light scattering to continuously sense a population of particles as they transverse the sensing chamber. This nephelometric technique is based on the principles of near forward light scattering, at a 45- to 90-degree angle of electromagnetic radiation in the near infrared. The radiation scattered by airborne particles is detected by means of a silicon photocell and particle concentration is directly proportional to its signal output. Signal processing is performed by lock-in synchronous electronic circuitry that enhances performance by canceling detector noise and drift. All electronic circuitry is housed in a RFI protective case. Power is provided by the ACCESS system. A transformer supplies the main sensor board with 8VDC power. Constructed in lightweight aluminum case, the AQ-10 is able to withstand harsh environments. The absence of moving parts and complete semiconductor design make the AQ-10 largely unaffected by shock, vibration, temperature and humidity.

Calibration of the particulate unit is performed using a representative test dust. When aerosolized to factory calibration standards, the mean mass diameter (mmd) equals 10 microns ± 0.5 microns and a log normal size distribution. The calibration aerosol has a 50% cutpoint at a 10 microns particle aerodynamic diameter, which has applications for both EPA and OSHA particulate air monitoring. The 10 micro-m cutpoint is consistent with the ACGIH Particulate Size-Selective Criteria for Thoracic Particulate Mass (TPH). ACGIH defines TPM as those particles that are likely to be deposited anywhere within the lung airways (tracheobronchial) or gas exchange (alveolar/respirable) region. The 10 microns cutpoint is also consistent with the EPA PM₁₀ reference method for ambient particulate air monitoring. The sensor can also be calibrated to the EPA standard of 2.5 microns. For our pilot study, we used the 2.5 micron calibration.

	Type of sensor	Range	Minimum Detectable Limit	Expected Accuracy	Cross-Sensitivities
CO	Electrochemical	0-100 ppm	1 ppm	± 2 ppm	No
NO ₂	Electrochemical	0-1000 ppb	10 ppb	± 20 ppb	Yes (NO, NO ₂)
SO ₂	Electrochemical	0-1000 ppb	10 ppb	± 20 ppb	Yes (SO _x , NO ₂)
O ₃	Electrochemical	0-1000 ppb	10 ppb	± 20 ppb	Yes (Cl, Br ₂ , ClO ₂ , F ₂)
CO ₂	Infrared	0-5000 ppm	1 ppm	± 20 ppb	No
PM _{2.5}	Nephelometer	0-2000 $\mu\text{g}/\text{m}^3$	10 $\mu\text{g}/\text{m}^3$	± 40 $\mu\text{g}/\text{m}^3$	No

- **Part II: GILIAN PERSONAL SAMPLING PUMPS**

These pumps are designed to measure a four- to eight-hour sample throughout the day for a variety of compounds. They can be calibrated to draw air at different flow rates through a cartridge that reacts with the air being sampled. The cartridge contains different types of media that react and bind to a variety of compounds. Before sampling, each pump in this study was calibrated to 200 ± 20 cc/min so that it would draw through a certain amount of air to create the sample. The Gilian pumps pull air through a filter at a specified rate, gathering particles that react with the filter media, but no air sample is collected. The airflow rate and duration of sampling must be used to calculate the amount of substance present in the air. A dinitrophenyl hydrazine (DNPH) media was used in the cartridges to test specifically for carbonyls. In most cases, ozone scrubbers were used because ozone can interfere with the bond between certain carbonyls and the DNPH media. The sampling media must be kept cool (in the freezer or on ice) before sampling and afterwards as they are shipped to the lab, so that the fragile bonds between the carbonyls and the DNPH are retained. In the laboratory they are analyzed using high-performance liquid chromatography, the details of which are described below.

Throughout the process of monitoring the nine schools, two different types of absorbent tubes (both with DNPH media) were used. The first type used was the sep-pak cartridge. The sep-pak cartridge contains DNPH media and an ozone scrubber was attached. These pumps were calibrated to 200 ± 20 cc/min, and had the problem of becoming saturated, particularly in high humidity conditions. Once saturated, it was difficult for the Gilian pumps to pull through a constant flow rate, causing the pumps to fault before the designated four- or eight- hour sampling period was completed.

This faulting problem led us to try a different type of DNPH cartridge, the SKC tube, in the last few schools we tested. The SKC tubes have the DNPH media and an ozone scrubber together inside a glass tube. The SKC media is not as tightly packed, so the cartridges did not get saturated as easily as the sep-pak cartridges. This was favorable because the samples could be of longer duration and the times recorded were more accurate because the pumps did not fault. These tubes were also able to run at a faster rate (500-700 cc/min), which captured a larger sample, but was also much louder, making it hard to use in a classroom or other quiet areas of a school.

- **Part III: EVACUATED SUMMA CANISTERS**

Summa canisters were used to sample volatile organic compounds over an eight-hour period. These one-liter canisters have been evacuated and fitted with an airflow orifice that controls the rate of airflow into the canister. The orifices were calibrated to draw approximately 15 cc/min, and the airflow would automatically stop after drawing in one liter, which was expected to take seven to eight hours. The canisters could also be sealed prior to collecting a full sample, and by recording a starting and ending pressure the amount of air collected could be determined. When the sample was collected it had to be closed and shipped off to a laboratory to be evacuated and analyzed for the presence of volatile organic compounds. In a few cases during the second phase of testing, during which the orifices were not available, the summa canisters were cracked and a five- to

seven-minute sample was obtained. This will be an estimate of the eight-hour sample, but results may be skewed high or low depending on conditions at that time of day.

- **Part IV: INSTANTANEOUS GRAB SAMPLING**

Grab sampling was performed for CO₂ (and CO) with the Dräger CMS (Chip Monitoring System), a digitized handheld monitor that provides an instantaneous, replicable result. The system works with computerized chips which each contain ten capillaries. The tip of one capillary is broken, it draws in air, and a reading is reported. The pumps are calibrated to draw in a constant mass of air, which automatically adjusts to changes in atmospheric pressure. Each capillary contains a chemical reagent that undergoes a color reaction when the reagent contacts the particular gas being monitored. The extent of the color reaction is measured by a photo-optical system that then returns a digital reading with a repeatable accuracy often at $\pm 5-15\%$.

APPENDIX E: Additional Resources for Air Quality Assessment

Indoor air quality problems can be caused by a variety of factors. This project evaluates a specific set of factors that affect indoor air quality, but does not address all of them. The goal of the study was to evaluate the effect of outdoor air pollution on the indoor environment. A thorough assessment of indoor air quality in a building would include inspection and evaluation of many factors that were not evaluated in the study. For example, an inspection of the ventilation system and testing for biological sources (molds and mildews) would be included in a comprehensive evaluation of indoor air quality. The resources listed below can help interested readers to learn more about how to evaluate and improve indoor air quality.

The Indoor Air Quality (IAQ) Tools for Schools Kit

The Environmental Protection Agency (EPA) has designed the *Indoor Air Quality Tools for Schools* kit. This kit is intended to be used by existing staff in schools, and allows schools to construct and implement plans of action to improve their indoor air quality. It includes fact sheets, checklists to help identify problems, an Indoor Air Quality Problem Solving Wheel, and a guide to the use of the system. For more information see the web sites below.

- <http://www.epa.gov/iaq/schools/>
- <http://www.epa.gov/iaq/schools/tools4s2.html>

Indoor Air Quality Information Clearinghouse (IAQ INFO)

EPA created the IAQ INFO to provide a central source of information regarding indoor air quality. It is an excellent resource for EPA publications on all aspects of indoor air quality, from testing to current standards and guidelines. EPA will also refer interested parties to other organizations that may have useful information.

IAQ INFO can be reached toll-free at 1-800-438-4318, from Monday through Friday from 9:00 AM to 5:00 PM EST. During non-business hours voice mail is available. Inquires may also be made via e-mail to the address iaqinfo@aol.com or by fax at 1-(703)-356-5386.

- <http://www.epa.gov/iaq/iaqxline.html>
- Indoor Air Quality Information Clearinghouse
IAQ INFO
P.O. Box 37133
Washington D.C. 20013-7133
Direct line: (703) 356-4020

Moisture Control is the Key to Mold Control [EPA Document Number (EPA 402-K-01-001 March 2001)]

This EPA publication provides a good overview of the impact that mold can have on indoor air quality. It also includes a section detailing methods of mold control. It is available online at <http://www.epa.gov/iaq/molds/toc.html> or can be ordered through the Indoor Air Quality Information Clearinghouse.

Occupational Safety and Health Administration (OSHA)

The OSHA website has many links that lead to excellent resources about indoor air quality. <http://www.osha-slc.gov/SLTC/indoorairquality/index.html>

Consumer Product Safety Commission

The CPSC website has a search engine that allows users to search for information about products that can affect indoor air quality (cleaners, paint strippers, etc.)

- <http://www.cpsc.gov>
- Mailing Address:
U.S. Consumer Product Safety Commission
Washington, D.C. 20207-0001
- Telephone: 1-(301) 504-0990
- Fax: 1-(301) 504-0124 and 1-(301) 504-0025
- E-mail: info@cpsc.gov

American Lung Association

This website has a large amount of information and links about indoor air quality.

- <http://www.lungusa.org>
- Mailing Address:
The American Lung Association
1740 Broadway
NY, NY 10019
- Phone: 1-(212)-315-8700

These Agencies also have information on indoor air quality:

National Institute for Occupational Safety and Health

- <http://www.cdc.gov/niosh/homepage.html>
- Phone: 1-800-35-NIOSH (1-800-356-4674)
- Fax: 1-(513)-533-8573

US Department of Energy

- <http://www.energy.gov/>
- Mailing Address:

U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

- Phone: 1-800-dial-DOE
- Fax: 1-(202)-586-4403

APPENDIX F: NESCAUM Walkthrough Checklist

Name of School:

Location:

Before executing this checklist it is useful to obtain a map of the school and its layout, as well as a small-scale map of the area immediately surrounding the school. If you are unable to obtain these items, draw a map of the building to show problem areas.

Type of Roof: Flat ____ Peaked ____ Combination ____

If the roof is a combination, describe where on the building each type of roofing is used.

Date of original construction:

If the building has had additions, describe the location of the original portion of the building and the location of the additions.

Date(s) of construction of addition(s):

Type(s) of ventilation system(s):

If the building has more than one type of ventilation system, describe which part of the building each system ventilates.

What is the neighborhood like around the school?

Rural ____ Suburban ____ Urban ____

How far away from the road is the school? (If more than one side of the school is adjacent to the road, measure the distance on all sides)

What types of roads are the adjacent roads?

Are the outdoor air intakes obscured? If so, note the locations on a map of the school building.

Where are the outdoor intakes located? If possible, include a diagram of the ventilation system with the intake locations marked.

Are the outdoor air intakes located near any immediate pollution sources? If so, record the locations of the sources in relation to the school building.

Is the roof in good repair? If not, note the damaged locations.

Are there any potential sources of pollution near the building? If yes, note their locations and the type of activity.

Does water drain away from building? If no, note the location of problem areas where water collects.

Are sprinklers in use near the building? If yes, note the location of intake vents that get wet.

Are the outdoor air intakes working? (Use chemical smoke or a small piece of tissue paper to determine if air is moving into the intake vents)

Are there clean walk-off mats at all entrances to the building?

Are there any sign of leaks, mold or mildew growth inside building? If so, please use the following checklists for individual rooms and to document the location and size of the stain.

Room #:

Mold smell: 1 2 3 4 5

Number of wet or stained ceiling tiles:

Please describe:

Carpeting: Yes_____ No_____ Area carpet_____

Fabric walls, fabric chairs: Yes_____ No_____

Evidence of moisture:

Evidence of visible mold:

Ventilation system:

Other comments:

Are there any signs of water damage (e.g, discolored ceiling tiles, or floors)? Use the checklist for individual rooms above to document the location and size of the damaged area.

Have windows that could be important to the airflow system been sealed shut?

Are temperature and humidity levels acceptable?

Is the building generally clean and dust under control?

Have transfer grills between rooms and halls or other rooms been sealed off or blocked?

Does each room have a source of outside air (mechanical or window)?

Have large objects (e.g., blackboards, room partitions) been placed in a position to block airflow in a room?

Have wall vents been covered or blocked by objects (e.g., bookshelves, displays)?

Are the exhaust fans pulling air out of the building?

Do the exhaust fans have enough capacity to cover the area they are designed to exhaust?

Does each bathroom have a working exhaust fan?

Do all drains have traps?

Do trash and chemical storage areas have working exhaust fans?

Are there flumes or exhaust hoods over combustion appliances?

Is there visible soot, leaks, or disconnected flumes or exhaust hoods?

If the building was built before 1980, is there any peeling or flaking paint?

Does the building have chemistry labs? If so, list the chemicals used in the lab.

Does the building have an art room? If so, list the chemicals used in the art area.

Where are the copier machines (or other machines like a fax) located in the building?

Time	Location	Count

Where is the equipment for outdoor maintenance kept? Does it idle near the building?

How is the building heated?

What types of boards are used in the building?

Does the cafeteria cook lunch or defrost prepackaged lunches?

APPENDIX G: Traffic Volume Calculations

Traffic Data was calculated using Annual Average Daily Traffic (AADT) counts from the Department of Transportation of each state in which schools were located. The AADT was calculated by counting the number of cars that pass a particular spot for an entire year, and dividing that number by the number of days in that year. Thus, the AADT value is representative of “a typical day” of traffic for that year. In most cases, the AADT was available for streets bordering schools, and for some of the larger nearby streets as well. The most recent year of data that was available was 2000. In some locations, data was only available from previous years, starting in 1996. Traffic counts of busy streets and major intersections are often calculated every year, but smaller streets are not measured as often.

The traffic counts, shown in Table 1 on page 13, are calculated using the most information available from the most recent years for the area surrounding the school. The area was cut off to a 500m radius, and an approximation was made of the amount of traffic, which is in that area based on the streets for which there was information. For instance, when schools are located near a large intersection, there are typically 4 traffic counts associated with that intersection, one from each direction. Adding these together would overestimate the number of vehicles. Instead, the two points on the same street were averaged to give an estimate of the number of vehicles on that street. Then the traffic counts on the two streets were added to produce a total volume around the intersection. When information was available on a number of streets near the school, the numbers were simply added. However, if there were multiple traffic count numbers on the same street in different locations that were both close to the school, the two were averaged. For schools close to the highway, the total number of cars that passed by was added to the total of smaller streets.

These calculations are imperfect for many reasons, including the fact that the number represents a “typical” 24-hour day. NESCAUM monitoring was representative of four days at each school, which most likely were not “typical” days. The monitoring days also were at most eight hours long, but 24-hour days are used here as a consistent baseline with which to compare the nine schools to each other. When there were other events going on near the school, such as a brush fire or construction, these were noted but not factored into the traffic calculation. Additionally, the difference between the emissions from cars which idle at a stop light, and those which pass by at 70mph on a highway may be significant, but could not be factored into these calculations. Thus, these measurements are only estimates of traffic volume counts. They are not intended to measure the exact quantity of emissions from these vehicles that may be released into the area surrounding the school. Instead, they are intended only to organize the schools according to traffic volume in order to estimate any association with pollutant concentration.

APPENDIX H: Carbonyl Data Summary Information

OUTSIDE MAIN ENTRANCE	SUMMER, 12 samples from 8 schools			FALL, 17 samples from 9 schools		
	Acetaldehyde (ug/m3)	Acetone (ug/m3)	Formaldehyde (ug/m3)	Acetaldehyde (ug/m3)	Acetone (ug/m3)	Formaldehyde (ug/m3)
Minimum Detected	0.11	0.42	0.09	0.14	0.26	0.05
Maximum	0.90	2.24	4.51	0.47	0.87	0.51
Median Value	0.28	0.76	0.33	0.27	0.48	0.22
Average Value	0.34	0.88	0.65	0.30	0.56	0.26
75th Percentile	0.45	1.05	0.49	0.39	0.78	0.41
Standard Dev.	0.24	0.50	1.23	0.12	0.21	0.15
# Non Detects	1	0	1	0	0	0

INSIDE MAIN ENTRANCE	SUMMER, 16 samples from 9 schools			FALL, 19 samples from 9 schools		
	Acetaldehyde (ug/m3)	Acetone (ug/m3)	Formaldehyde (ug/m3)	Acetaldehyde (ug/m3)	Acetone (ug/m3)	Formaldehyde (ug/m3)
Minimum Detected	0.11	0.50	0.36	0.23	0.65	0.23
Maximum	0.69	78.58	2.92	0.69	4.24	1.51
Median Value	0.30	1.25	1.27	0.36	1.05	0.60
Average Value	0.35	6.07	1.26	0.36	1.40	0.69
75th Percentile	0.49	1.60	1.60	0.44	1.85	0.81
Standard Dev.	0.17	19.34	0.65	0.16	0.86	0.36
# Non Detects	1	0	0	2	0	0

ALL INSIDE ROOMS	SUMMER, 36 samples from 9 schools			FALL, 51 samples from 9 schools		
	Acetaldehyde (ug/m3)	Acetone (ug/m3)	Formaldehyde (ug/m3)	Acetaldehyde (ug/m3)	Acetone (ug/m3)	Formaldehyde (ug/m3)
Minimum Detected	0.12	0.23	0.66	0.10	0.21	0.23
Maximum	1.16	39.24	5.60	1.11	4.24	2.71
Median Value	0.45	1.45	1.75	0.46	1.43	0.91
Average Value	0.48	2.73	1.75	0.50	1.69	0.97
75th Percentile	0.63	2.19	2.15	0.61	2.16	1.23
Standard Dev.	0.29	6.37	1.09	0.23	0.94	0.53
# Non Detects	3	1	2	1	0	1

ROOMS WITHOUT CARPET	SUMMER, 16 samples, 6 schools			FALL, 24 samples, 6 schools		
	Acetaldehyde (ug/m3)	Acetone (ug/m3)	Formaldehyde (ug/m3)	Acetaldehyde (ug/m3)	Acetone (ug/m3)	Formaldehyde (ug/m3)
Minimum Detected	0.12	0.23	0.67	0.10	0.21	0.23
Maximum	1.16	6.21	5.60	1.11	4.24	2.71
Median Value	0.48	1.23	1.77	0.49	1.74	0.89
Average Value	0.55	1.90	1.95	0.50	1.89	0.91
75th Percentile	0.69	2.39	2.81	0.65	2.71	1.14
Standard Dev.	0.34	1.55	1.37	0.24	1.07	0.54
# Non Detects	1	0	1	1	0	1

ROOMS WITH CARPET	SUMMER, 20 samples, 7 schools			FALL, 27 samples, 7 schools		
	Acetaldehyde (ug/m3)	Acetone (ug/m3)	Formaldehyde (ug/m3)	Acetaldehyde (ug/m3)	Acetone (ug/m3)	Formaldehyde (ug/m3)
Minimum Detected	0.15	0.22	0.67	0.21	0.38	0.33
Maximum	0.85	39.24	3.39	1.05	4.17	2.09
Median Value	0.41	1.51	1.74	0.45	1.35	0.96
Average Value	0.42	3.40	1.59	0.51	1.51	1.03
75th Percentile	0.63	2.18	2.07	0.56	1.74	1.41
Standard Dev.	0.23	8.48	0.82	0.24	0.80	0.52
# Non Detects	2	1	1	0	0	0

ROOMS NEAR TRAFFIC	SUMMER, 14 samples, 8 schools			FALL, 16 samples, 7 schools		
	Acetaldehyde (ug/m3)	Acetone (ug/m3)	Formaldehyde (ug/m3)	Acetaldehyde (ug/m3)	Acetone (ug/m3)	Formaldehyde (ug/m3)
Minimum Detected	0.12	0.70	0.71	0.29	0.73	0.23
Maximum	0.96	39.24	5.60	0.86	3.87	1.74
Median Value	0.51	2.03	1.75	0.38	1.26	0.91
Average Value	0.53	4.82	2.10	0.49	1.69	0.90
75th Percentile	0.61	2.98	2.45	0.67	2.37	1.10
Standard Dev.	0.22	10.01	1.30	0.19	0.98	0.41
# Non Detects	0	0	0	0	0	0

ROOMS NOT NEAR TRAFFIC	SUMMER, 22 samples, 7 schools			FALL, 35 samples, 8 schools		
	Acetaldehyde (ug/m3)	Acetone (ug/m3)	Formaldehyde (ug/m3)	Acetaldehyde (ug/m3)	Acetone (ug/m3)	Formaldehyde (ug/m3)
Minimum Detected	0.15	0.22	0.66	0.10	0.21	0.33
Maximum	1.16	4.04	3.11	1.11	4.24	2.71
Median Value	0.35	1.19	1.52	0.47	1.43	0.91
Average Value	0.45	1.41	1.53	0.51	1.70	1.00
75th Percentile	0.65	1.73	2.12	0.58	2.08	1.30
Standard Dev.	0.32	0.98	0.91	0.25	0.94	0.57
# Non Detects	3	1	2	1	0	1

Appendix I: Faulted Sample Error Calculation Table

Sample ID	Flow Rate Pre-Cal (ml/min)	Total Sample Volume (m³)- LOW	Total Sample Volume (m³)- High	Formaldehyde Concentration Reported µg/m³	Assuming Low Volume Sampled- Formaldehyde µg/m³	% difference
M-003	196.67	29	58	1.28	0.63	50.68%
F-005	206.73	45	61	1.17	0.87	25.60%
F-004	208.37	45	60	4.51	3.34	25.95%
F-003	192.53	41	56	1.38	1.02	25.86%
F-002	210.02	44	60	2.64	1.95	26.32%
F-003	191.37	35	40	0.13	0.11	11.90%
F-006	211.47	49	55	0.59	0.52	11.49%
F-004	206.87	37	42	1.17	1.03	12.32%
F-005	203.8	45	51	2.21	1.96	11.24%
O-005	204.57	59	65	0.13	0.12	9.40%
O-007	224.4	24	38	2.8	1.80	35.71%
O-003	206.97	42	58	0.48	0.35	28.01%
O-002	204.73	40	55	0.12	0.09	27.78%
2M-003	176.07	61	77	0.6	0.48	20.59%
2B-005	187.8	51	75	0.88	0.59	32.42%
2B-002	205.33	49	74	1.56	1.04	33.33%
2B-003	214.93	82	86	0.73	0.70	3.77%
2B-004	211.7	68	82	0.51	0.42	16.88%
2B-002	210.07	53	75	0.44	0.31	29.49%
2B-004	206.77	77	90	0.56	0.48	13.82%
2C-004	199.83	69	93	1.02	0.76	25.81%
2EM-002	206.4	60	74	0.62	0.51	18.16%
2EM-006	214.97	62	76	0.87	0.71	18.41%
2EM-004	200.67	47	59	1.15	0.91	20.48%
2EM-005	195.37	46	57	0.96	0.76	20.48%
2EM-006	226.33	78	91	1.86	1.58	14.89%
2W-004	208.6	24	54	0.33	0.15	55.77%
2W-005	222.4	37	64	0.93	0.54	41.67%
2W-005	225.6	81	87	0.51	0.48	6.48%
2W-003	203.6	75	84	0.57	0.51	10.92%
2W-002	212.9	70	86	0.73	0.59	18.52%
2W-006	187.03	44	61	0.57	0.41	27.61%
					median %:	20.54%