Evaluation of the Levels of Diesel-related Pollutants from School Buses While Transporting Children

New Brunswick Lung Association

In partnership with:

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Abbreviations and Acronyms

AGM – Alexander Gibson Memorial Elementary School
BC – Black carbon
BTX – Benzene-toluene-xylene
CARB – California Air Resource Board
CI – Confidence interval
CFB – Canadian Forces Base
CNG – Compressed natural gas
COPD – Chronic Obstructive Pulmonary Disease
DE – Diesel exhaust
EPA – Environmental Protection Agency
G – Gesner Street Elementary School
Gmean – Geometrical mean
HVOC – Halogenated volatile organic compounds
MVI – Management Vehicle Inspection
N – Number
NB – New Brunswick
NESCAUM – Northeastern States for Coordinated Air Use Management
NM – New Maryland Elementary School
NMHC – Non-methane hydrocarbons
NO_x – Nitrogen oxides
PAH – Polycyclic aromatic hydrocarbons
PCV – Positive crankcase ventilation
PM – Particulate matter
PPM – Parts per million
Q – Quartile
SAE – Society of Automotive Engineers
SD – Standard deviation
TSI – Thermo Systems Incorporated
TWA – Time weighted average
UV – Ultraviolet
VOC – Volatile organic compound

Executive Summary

A project by the New Brunswick Lung Association, Health Canada, Environment Canada and Environment and Human Health, Inc. (EHHI), with support from the New Brunswick Department of Education and the staff and children of the New Brunswick School Districts.

Diesel emissions are a complex mixture of hazardous particles, gases and vapours. Diesel gaseous emissions contain carbon monoxide (CO), carbon dioxide (CO2), oxides of nitrogen (NOx), sulphur dioxide (SO2) and volatile organic compounds (VOC), specifically non-methane hydrocarbons, carbonyl compounds such as aldehydes, and polycyclic aromatic hydrocarbons (PAH). Diesel particulate emissions consist of carbonaceous material, usually 75% elemental carbon known as “char” or “soot” and 20% organic carbon. These percentages vary widely depending on engine technology and the type of exhaust technology present. A small fraction of the particulate matter (PM) mass consists of inorganic compounds such as sulphate, water bound to the sulphate and various trace elements (metal oxides) originating from diesel oil and engine material.

Several governmental and scientific agencies have ascertained that diesel exhaust is a probable human carcinogen. Recent studies have also shown a relationship between lung diseases such as asthma and exposure to emissions from diesel engines. There is evidence to suggest that children are especially vulnerable to these effects. School bus rides have been indicated as a potentially important source of exposure to diesel emissions. Levels of diesel-related pollutants on school buses have been investigated in several studies in the United States, which reported a high bus-to-bus variability with the highest concentrations of measured pollutants found in conventional diesel buses. However, most of these studies have used few buses and have measured pollutant levels without passengers on board. In Canada, little information about the characteristics of these exposures is available for school-day conditions that students typically experience.

The New Brunswick Lung Association, the New Brunswick Department of Education, Health Canada, Environment Canada and Environment and Human Health, Inc. were interested in determining the potential levels of exposure of New Brunswick children to diesel exhaust while commuting to and from school. The geography and population density of New Brunswick communities require a large number of students to travel to school by bus each day. Approximately 95,000, or 77% of all enrolled students, rely on school bus transportation. The objective of this study was to measure actual levels of diesel exhaust pollutants in New Brunswick school buses during children’s daily commutes to and from school, relative to the age of the bus, the length of the bus route, the school region, the bus fuel injection system, weather variables (temperature and humidity) and ambient $PM_{2.5}$ levels. The ultimate goal of this study is to help develop policy recommendations aimed at reducing the exposure level of schoolchildren to diesel exhaust originating from school buses.

For the purpose of this report, the term “exposure” is defined as the measure of pollutants on buses with children on board. Exposure is not in this context representative of the exposure of one individual child on one individual bus.

Methods

The study was conducted in the province of New Brunswick, Canada, in two school districts. Children from Kindergarten up to Grade 5 were selected for participation in this study and ranged in age from 5 to 11 years. The air was sampled for children on 63 school days from April 24 to June 19, 2003. Forty-one buses were used, the average age of a bus being 6.6 years (standard deviation [SD] = 4.4 years). Most buses were smoke opacity[1] tested and all passed testing standards. All buses tested in the study were diesel fuelled, with a sulphur content for March of 436 ppm, for April of 427 ppm and for May of 433 ppm.

Air sampling technicians carried the scientific measuring instrumentation and accompanied the children throughout the school day, including the period of walking or riding to school. Although measurements were taken for the entire day, only exposure values collected during commute time were investigated in the analysis. Buses and sampling days were randomly selected, and a sufficiently large number of bus rides were tested to be representative of the conditions in the community. A different bus route was followed for 63 typical school days of a child; thus 63 days of sampling were completed. Exposure measurements were also collected for 11 days of walking routes. Air sampling technicians kept log sheets to record any factors that could have influenced exposure.

Particulate matter with aerodynamic diameter less than 2.5 µm ($PM_{2.5}$) was measured using a Dust Trak® ($PM_{0.1–2.5}$ µm), and PM with diameter less than 1.0 µm ($PM_{1.0}$) was measured using a P-Trak® ($PM_{0.02–1.0}$ µm). Concentrations of black carbon (BC) and ultraviolet (UV) absorbing aromatic organic materials were measured using a portable, fully automatic Aethalometer™. SUMMA canisters were used to collect air samples for VOC, which were analyzed using cryogenic pre-concentration high-resolution gas chromatography and a quadruple mass-selective detection (GC-MSD) method. The sampling was usually carried out at children's breathing zone. Meteorological data, including hourly temperature, relative humidity, wind speed and direction, and cloud cover were collected at Fredericton airport by Environment Canada. Ambient air quality data including $PM_{2.5}$, NOx, ozone (O_3) and carbon monoxide (CO) were obtained from Environment Canada, monitored at a fixed site in Fredericton, New Brunswick.

The University of New Brunswick Ethics Committee approved the study.

Major findings

The average ride was 26 minutes (95% confidence interval [CI] 24–29 minutes). Thus, over a typical school day nearly one hour was spent riding a bus. During the study period, mean temperature was 12°C and the relative humidity was 60%; these were used as cut-off points to separate temperature and humidity into binary variables. The mean level of ambient $PM_{2.5}$ during

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[1] Exhaust opacity testing is a measure of the amount of light that is blocked by particulate matter emitted by diesel engines. The opacity measurement increases as the exhaust fumes become darker.

commute times recorded for the entire study period was 5.0 μg/m^3. In-bus average level of $PM_{2.5}$ was 32.1 μg/m^3 (95% CI 28.2–36.5), while the exposure level during walking was 9.7 μg/m^3 (95% CI 7.4–12.7). In-bus concentrations of other air pollutants were 10,786 counts/m^3 (95% CI 8,521–13,656) for $PM_{1.0}$, 0.7 μg/m^3 (95% CI 0.5–0.9) for BC and 775 ng/m^3 (95% CI 593–1,019) for UV absorbing aromatic organic materials. The exposure levels for walking were about one third of those for in-bus concentrations. However, the comparison between the exposure level of pollutants measured in buses and during walking commutes must be done with caution, as the measurements for buses and during walking commutes were not carried out at the same time, for the same length of time and did not follow identical routes.

For $PM_{2.5}$, the values during both walking and bus commutes exceeded the levels found in ambient air. Ambient $PM_{2.5}$ values were based on the hourly average, which corresponded to the commute time. It should be noted that ambient pollution data were collected from a single monitoring site in Fredericton, which may not necessarily represent personal exposure levels at the time. A comparison among levels of air pollutants in ambient air, on buses and while walking must be made with caution. The age of the buses (<6 years vs. ≥6 years) did not significantly affect in-bus levels of air pollutants and neither did temperature (<12°C vs. ≥12°C), although there was a trend that air pollutant levels appeared to be higher during colder days.

Using multivariate linear regression analyses, we further analyzed the impact of factors (weather, bus age, commute duration, ambient particulate concentration) on air pollution levels in buses and when walking. Factors were ranked by importance; those associated with the levels of pollutants measured on the buses and while walking were ambient levels of $PM_{2.5}$, humidity, temperature and duration of the bus ride (not ranked in order of importance). Other factors—which possibly affected commuting exposures—are the number of bus stops, traffic around the bus, configuration of the windows (open windows tend to have higher levels on short rides and lower levels on long rides), and to a lesser degree mechanical characteristics of the bus. The project was not designed to test for the influence of these latter factors. These factors should be analyzed in a subsequent study, because unlike ambient air quality, humidity and temperature , the number of stops, stops near traffic and window configuration can be modified as possible policy measures.

Bus idling, believed to be an important factor, was not a common practice for the buses in this study, and therefore the impact of idling could not be assessed in the results. It is also important to note that these buses were well maintained and met the standard tests for smoke opacity. Although the statistical analyses were conducted using univariate models, data were stratified into various categories of weather conditions and bus age, in an attempt to control for the confounding factors.

The majority of VOC tested for were above the detection limit. Benzene is of particular concern because it is carcinogenic. The results show that the average benzene levels measured on buses were within the range of average levels found at typical urban locations between 1989 and 1998 (1.8–3.6 μg/m^3). This implies that exposure levels are similar to those experienced by pedestrians in urban sites.

Some bus routes and buses tended to be either consistently low or high in exposure. The reason for these observations is not yet clear. The sample size was too small to make any conclusions. It is possible that engine temperature, degree of load, temperature and local traffic density may have added to this variability. This observation may suggest that it is possible to reduce exposures on commutes by implementing changes to the conditions under which the bus ride and routes occur. Further work will be directed toward determining which management changes are most effective.

Although the technologies used in these engines did not make a significant difference on exposure levels, engines with electronically controlled fuel injection systems seemed to be on average cleaner with respect to $PM_{2.5}$, BC and UV absorbing organic material than those with mechanically controlled fuel injection systems. Cumulative exposure results show a significantly higher level of $PM_{2.5}$ with mechanical injection than electronic injection, when humidity conditions were restricted to less than 70%.

The present study is one of the largest and most extensive studies of diesel exposure during actual school bus commutes performed to date. This rich dataset allows for the analysis of the relationships between bus emissions and children's exposure to a variety of compounds. Overall, the study found that children's levels of exposure to air pollutants on school buses were lower than those found in other studies, such as the ones conducted in Los Angeles and in 15 towns in Connecticut. Buses remain a good transportation option because they are safe and cut down on the number of vehicles on the road, resulting in decreased overall air pollution levels.

Limitations and uncertainties

Several limitations and uncertainties in this study need to be acknowledged to accurately interpret the results.

As noted above, the exposure monitoring for buses and during walking were not carried out at the same time, for the same length of time, or for an identical route. Therefore, when comparing the exposure levels of air pollutants in buses and during walking, bias may be introduced, and the results may be misinterpreted. No definitive conclusion should be drawn from this comparison.

Ambient pollution data were collected from a single monitoring site in Fredericton, which may not necessarily represent personal exposure levels in a neighbourhood during commuting time. Exposure misclassification may be introduced if one compares ambient air pollutant levels with exposure levels in a bus and during walking. An interpretation of the results must be made with caution.

Many factors may influence the exposure levels in a bus, such as weather conditions, bus conditions, idling, windows open or closed, number of times opening the doors, surrounding traffic density and the type of vehicles. Some of the factors may confound the results. Our statistical analyses are largely univariate analyses, which did not take into account all confounding factors. However, data were stratified into various categories according to weather conditions, bus age and the length of bus rides, in an attempt to control for these confounding factors. Additionally, a multivariate regression analysis was conducted on pollutants to test the contributions of factors to in-bus pollutant levels.

Although in this study the exposure levels in a school bus were postulated to be largely attributable to the diesel bus emissions, with the exception of BC, none of the exposure measures is considered to be an accurate surrogate measure of diesel exhaust due to the presence of numerous other common sources. Even BC can have sources other than diesel exhaust. Several variables that could affect exposure levels in a school bus (e.g. seasons, self-pollution, surrounding traffic counts and types, roadside pollutant concentrations) were not analyzed in this study, as the information necessary was either not available or not collected. This study is more of a commuter exposure study than a bus diesel exhaust exposure study.

It is important to note that "afternoon" commutes did not always occur at the same times. Pick-up times ranged from 12:00 to 15:00, and on some days the same buses picked up the students at noon, 14:00 and/or 15:00 on the same day. It is therefore possible that contaminants from previous rides were present during the later ride. The impact of surrounding traffic pollution would also be smaller during noon hour than in the afternoon after rush hour has started.

This study sampled a large number of buses and measured the exposure level of many children on different days. Under realistic conditions, day-to-day pollutant levels in buses varied markedly.

During the various categories of comparison, each category had a different sample size (i.e. a different number of buses in each group), which may have introduced some uncertainties in the analysis when the sample size was too small (e.g. $PM_{2.5}$ concentrations were sampled 4 times during walking commutes in cold weather).

Although parallel measurements were taken on several days, the variability between duplicate samplers was not assessed, which could limit our ability to determine how much of the differences in the exposure measurements were due to variability between monitors.

Although the study participants were chosen randomly, the study was also based on which children followed the most convenient routes to get a representative sample. The schools referred the children to the researchers, and selection bias could have occurred when selecting children.

Recommendations

1. Eliminate bus idling. Although bus idling is not a major issue in this study, an anti-idling policy for schools is strongly recommended by several organizations, including the United States Environmental Protection Agency (Clean School Bus USA: http://www.epa.gov/otaq/schoolbus/anti idling.htm). It recommends this policy not only to reduce the levels of exposure to diesel exhaust, but also to reduce fuel wastage and engine wear and tear. Bus drivers should also undergo periodical training to understand the issues pertaining to idling. There should also be a no-idling policy in effect for all other vehicles on the school grounds.

2. For short bus routes, consider reducing the number of stops or relocating stops to areas with lower traffic density. Frequent stopping and opening/closing of doors allow for greater contribution from outside sources (i.e. surrounding traffic) to the levels of air pollutants in the bus.

3. To avoid self-pollution, consider re-engineering bus exhaust pipes to extend to the left rear-end of the bus, so that exhaust will not be emitted on the same side of the bus as the doors. An even better location to release exhaust is from a stack above the back of the bus, as the vacuum created at the back of the bus when in motion draws exhaust from lower pipes back toward the bus. Crankcase exhaust should be released from the same location.

4. Investigation of alternative methods of the ventilation of the bus cabin is needed and air-filtering systems should be considered. In the literature, there is a discrepancy in the pollutant levels between public transit buses, which usually have air conditioning, and school buses, which usually do not. All efforts should be made to minimize exposure levels, keeping in mind that the World Health Organization states that there is no safe threshold for the health effects of diesel exhaust.

5. It is strongly recommended that retrofitting of buses be given high priority to reduce emissions. Retrofit measures include pollution control devices such as diesel oxidation catalysts and diesel PM filters. Low sulphur diesel to be introduced in 2006 is necessary to introduce this retrofit technology. This study shows that the engines with electronically controlled fuel injection systems appear to be on average cleaner with regard to $PM_{2.5}$, BC and UV absorbing organic material than those with mechanically controlled fuel injection systems. Further investigation is warranted to confirm these findings.

6. In the future, whenever a new bus is purchased or contracted, only low-emission vehicles should be chosen.

7. Avoid caravanning. Buses leaving school in the afternoon should leave at staggered departure times to avoid tailgating. Bus drivers should be instructed to avoid other diesel school buses whenever possible.

Future work

1. Results from this school bus exposure study have suggested several issues that deserve more attention in future work.

2. Data on traffic density, the type of vehicles on the road with school buses, and roadside and ambient pollutant data within the community need to be collected to differentiate the sources of pollutants in a school bus and better represent the driving conditions of the school buses.

3. The exposure levels experienced by children in this study need to be placed in context with the levels they might experience during the rest of their school day. Future work to be completed using this dataset includes investigating all day exposure concentrations compared with on-bus exposure levels. Preliminary results show that in-class exposure levels of $PM_{2.5}$ can reach levels comparable to on-bus exposures, which suggests that important indoor sources exist.

4. In future exposure studies, additional modes of transportation may be included for comparison to bus and walking routes. Commutes by car and use of public buses could be introduced as comparison groups, as well as buses that run on different types of fuel (e.g. natural gas, bio-diesel). To compare cars with school buses, it must be kept in mind that if school buses

were to be replaced more private cars would be required, which may result in higher levels of pollutants emitted to ambient air, although in-car pollutant levels may be low because the driver does not need to open the doors often.

5. To provide a more controlled environment, scripted exposure studies may be carried out to assess the levels of exposure to school bus exhaust that children experience. The use of specific commuting routes under set conditions would increase comparability of the routes and eliminate much of the bias present from confounding factors.

6. The relative contribution of self-pollution originating from both crankcase emissions and tail pipe exhaust to pollutant levels in a bus needs to be assessed.

7. This school bus study should be repeated in different seasons (winter, fall, summer) to determine if there are changes in exposure levels with changes in ambient conditions.

8 Panel epidemiological studies may be designed to investigate the health impact of exposure to air pollutants in a school bus.

1. Introduction

Many studies, including this one, were inspired by a common concern for our children's health. This study was a collaborative effort between the New Brunswick Department of Education, Health Canada, Environment Canada, Environment and Human Health, Inc. and the New Brunswick Lung Association, with input from the Research and Productivity Council, New Brunswick. A healthy population starts with healthy children, and both are considered a priority by the Canadian and New Brunswick governments. An important determinant of children's health is a healthy environment, one of its components being clean air. Air pollution affects us all and vulnerable populations, especially children.

1.1 Air pollution and health

It has been shown that cases of respiratory diseases have increased in North America over the past decades and are becoming one of the leading causes of death (Statistics Canada, 1997). Air pollution plays an important role in the development of several respiratory conditions, including infections such as bronchitis and pneumonia, exacerbation of symptoms of chronic obstructive lung disease and asthma, decreased lung function and lung growth, and is a factor in the development of lung cancer (Schwartz et al., 1993; Peters et al., 1999; Avol et al., 2001; Brunekreef & Holgate, 2002; Pope III et al., 2002; U.S. Environmental Protection Agency [EPA] 2002; Gent et al., 2003). It is therefore not surprising that air pollution has become a leading issue in the past two decades, and that governments, organizations and industries are changing their policies and creating measures to protect human health.

Symptoms most often associated with diesel exhaust exposure are irritation of the eyes and nose, bronchoconstriction, cough and signs of laboured breathing, chest tightness and wheezing. Long-term studies point toward chronic inflammation and fibrosis of the lungs (Gamble et al., 1987a;1987b; Ulfvarson, 1987; Rudell 1996; U.S. EPA, 2002).

Asthma accounts for one quarter of school absenteeism and is the most common chronic disease plaguing children. In 2000-01, 8.7% of Canadians 4 years of age or older suffered from asthma. Between 1995 and 1999, the prevalence of asthma increased by 14% among children between ages 4 and 11. It occurs currently in approximately 7% to 10% of children (Health Canada, 2002; Canadian Lung Association, 2004). In New Brunswick, 54,569 people over the age of 12 years were diagnosed with asthma in the year 2000-01, and there were 8652 young people between the ages of 12 and 19 suffering from asthma (Statistics Canada, 2001). Studies have shown an association between traffic congestion, diesel exhaust and asthma (Ciccone et al., 1998; English et al., 1999; Masayuki et al., 2002; Wargo et al., 2002). Observations suggest that exposure to motor vehicle traffic and diesel fumes can contribute to asthma exacerbations and increase the rate of asthmatic attacks.

1.2 Diesel emission characterization

Diesel emissions can be generally categorized as tailpipe emissions and running loss emissions. Tailpipe emissions result directly from fuel combustion and are those products of fuel combustion (gases and particles) from the engine that are collected in the exhaust manifold and emitted at the tailpipe. Running loss emissions can include exhaust gases (those gases not collected in the exhaust manifold and emitted at the tailpipe), such as crankcase vent gases or engine leakage, and also fuel vapours. Fuel vapours are not usually a significant emission from diesel vehicles (Seinfeld, 1986).

Diesel emissions are a complex mixture of hazardous particles, gases and vapours that can cause adverse effects on the human respiratory system (Hoek et al., 2002; U.S. EPA, 2002; Weir, 2002; Yin et al., 2002). Several governmental and scientific agencies have ascertained that diesel exhaust is a probable human carcinogen. As early as 1988, the American National Institute for Occupational Safety and Health (NIOSH) designated diesel exhaust as a potential occupational carcinogen, as did the California Air Resources Board (CARB) in 1998 (Kagawa, 2002; Decker et al., 2003). The World Health Organization (WHO) proclaimed it a probable human carcinogen in 1996, and the U.S. Environmental Protection Agency (EPA) a likely human carcinogen in 2002 (Decker et al., 2003).

Diesel gaseous emissions contain carbon monoxide (CO), carbon dioxide (CO2, oxides of nitrogen (NOx, specifically nitric oxide and nitrogen dioxide), sulphur dioxide (SO2) and volatile organic compounds (VOC), specifically non-methane hydrocarbons, carbonyl compounds (such as aldehydes) and polyaromatic hydrocarbons (Brauer et al., 2000; Lloyd & Cackette, 2001; Ayala et al., 2002; Grosjean & Grosjean, 2002; U.S. EPA, 2002, 2003).

Diesel particulate emissions consist of carbonaceous material, usually 75% elemental carbon known as “char” or “soot,” and 20% organic carbon. These percentages vary widely depending on engine technology and the type of exhaust technology present. A small fraction of the PM mass consists of inorganic compounds such as sulphate, water bound to the sulphate and various trace elements (metal oxides) originating from diesel oil and engine material (Ayala et al., 2002; U.S. EPA, 2003).

Diesel engines are not as large a source of CO or VOC emissions compared with gasoline engines (Jo & Yu, 2001; U.S. EPA, 2002). Nonetheless, some of the most harmful components to health, which are present in diesel exhaust are benzene, 1,3-butadiene, toluene and m,p-xylene among hydrocarbons, and aldehydes and polycyclic aromatic hydrocarbons (PAH). Benzene and 1,3-butadiene are human carcinogens, and aldehydes are human carcinogens as well as mucous membrane irritants. This is one reason that diesel exhaust likely causes respiratory irritation and has been hypothesized as a likely trigger for asthmatics (Ormstad et al., 1998; Lipsett and Campleman, 1999; Pandya et al., 2002). Past studies focused mostly on the amount of VOC (Chan et al., 1993; 1994; Jo & Yu, 2001; Szaniszlo & Ungvary, 2001; Kuusimäki et al., 2003, 2004), but in recent years the composition of diesel particles has been examined more closely (Gee & Raper, 1999; Levy et al., 2001; Kelly et al., 2003).

The emissions, in terms of particle number, from diesel-powered vehicles are much greater than those from gasoline-fuelled vehicles (U.S. EPA, 2002), and include health-aggravating particles in the range of 0.0–0.1µm (ultrafine PM) and 1.0–2.5 µm (fine PM). About 98% of the number of particles emitted from diesel engines belong to the ultra-fine particle size range and are 0.005–0.05 µm in diameter (Solomon et al., 2001; Kittelson et al., 1998, cited in U.S. EPA, 2002; U.S. EPA, 2002). Most of the mass, however, is made up of particles in the size range of fine particles

(0.05–1.0 μm), with ultrafines accounting for only 1%–20% of the total mass of particles. Exposure to PM, especially fine and ultra-fine ($PM_{2.5}$ and $PM_{0.1}$, respectively) even for very brief periods or at low levels, has been associated with cardiovascular effects, reduced respiratory function and increased mortality because of their ability to penetrate deep into the lung tissue (Salvi & Holgate, 1999; Blomberg, 2000; Pope III et al., 2002; Vrang et al., 2002). Other studies demonstrate the link between fine particles found in diesel exhaust and asthma (Pandya et al., 2002). Crankcase emissions are composed of diesel exhaust gases and a fine mist of lubricating oil. Crankcase emissions can be significant and generally increase with the age of the engine. Total PAH concentrations in lube oils can range from 2 to 200 ppm, depending on the brand and the age of the oil. Test data cited by the U.S. EPA in its 1997 regulatory analysis supporting the 2004 on-road diesel emission standards indicate that crankcase emission can range from 0.2% to 4% of current tailpipe hydrocarbon emission standards, 0.01% to 0.1% of NOx emission standards and 0.9% to 2.9% of PM emission standards (U.S. EPA, 1997c). Current diesel engine regulations in Canada require only naturally aspirated engines to have some kind of positive crankcase ventilation (PCV) system. PCV systems have been required on gasoline engines since the 1970s. Turbocharged/supercharged diesel engines are not required to have a PCV system, because it causes durability problems with the turbocharger and after-cooler systems.

1.3 Residential area exposure studies

Several studies have assessed levels of traffic-related pollutants (PM, BC, PAH, VOC) in residential areas and examined the correlation between local traffic density and these pollutant levels. Kinney et al. (2000) measured $PM_{2.5}$ and elemental carbon (EC) (used as a marker for diesel exhaust) on sidewalks in Harlem, New York City and found that higher levels of EC were associated with elevated bus and traffic counts on adjacent streets and with the presence of a bus depot. A similar pattern was found by measuring $PM_{2.5}$ and PAH within a 1-mile radius of a bus terminal in Roxburry, Massachusetts. It was found that PAH were significantly higher close to the bus terminal ($p<0.05$) (Levy et al., 2001). This study also found that both $PM_{2.5}$ and PAH levels in Roxburry were higher during morning rush hour and on weekdays, which is consistent with the higher levels of passing traffic during these times (Kinney et al., 2000; Levy et al., 2001).

1.4 Occupational exposures

A range of studies have examined occupational exposure levels to diesel exhaust for employees using or in close proximity to diesel engines. These studies have implications for drivers of school buses and their passengers. All studies have found elevated exposure levels for diesel-exposed workers when compared to an unexposed reference group. In a study by Kuusimaki et al. (2002), exposure to 15 PAH were measured via personal sampling for garbage truck drivers in Finland. They were found to be exposed to significantly higher levels of diesel-derived PAH than maintenance workers in both summer ($p=0.0022$) and winter ($p=<0.001$) (Kuusimaki et al., 2002). The same 15 PAH were measured in five breathing zone samples collected for 22 bus garage workers, also in Finland. Statistically higher PAH levels were observed for bus garage workers when compared to the control group of unexposed workers ($p<0.001$) (Kuusimaki et al., 2003). A survey of forklift truck drivers showed similar results, with this occupational group demonstrating the highest exposure to diesel-derived pollutants when compared to other occupational groups. Their mean (geometrical mean) levels of exposure to EC from personal monitoring results were 122 μg/m^3 compared with 31 μg/m^3 for bus/garage repair workers (Groves & Cain et al., 2000). Biological indicators for the high exposure levels to diesel exhaust experienced by bus drivers were assessed in Denmark, by measuring the amount of 1-hydroxypyrene (a biomarker for exposure to PAH) and level of mutagenic activity in their urine (Hansen et al., 2004). Investigators found that these bus drivers had higher levels of 1-hydroxypyrene in their urine than mail carriers and this correlates with an increased occupational exposure to PAH and mutagens.

Exposure to diesel exhaust on buses consistently has been found to be significantly higher than other modes of transportation. Gee and Raper (1999) found that the exposure of people on buses to respirable $PM_{4.0}$ varied, but was 5 to 7 times higher than levels experienced by bicyclists. The wide fluctuation was thought to reflect traffic conditions and limited ventilation on buses.

1.5 School bus exposure studies

School buses represent an important source of exposure to diesel exhaust, whether for the driver or for commuting children. Exposure to diesel exhaust for schoolchildren has been investigated in numerous studies (Solomon et al., 2001; Wargo et al., 2002; Weir, 2002).

Several school bus studies have been completed in the United States, with results somewhat relevant to a Canadian context, because bus fleets in both countries are similar. There is a policy of alignment between Canada and the United States with regards to bus technology and fuel regulations (Environment Canada: www.ec.gc.ca/energ/fuels/reports). Many of the Canadian school bus safety regulations also follow the federal motor vehicle standards in the United States and were developed by the National Highways Traffic Safety Administration (School transportation in Canada: www.http://www.stnonline.com /stn/government/Canadafed govt /index.htm).

In March 2001, the Environmental Health Section of the Fairfax County (Virginia) Public Schools Office of Security and Risk Management Services, Department of General Services, conducted a study on 12 buses (O'Neil & Tistadt, 2001). It measured integrated samples of respirable particulates (PM_{10}), elemental and organic carbon. None showed elevated levels above the Occupational Safety and Health Administration (OSHA) occupational threshold for respirable particulates for an 8-h time weighted average (TWA). They found no age-related differences in pollutant levels between school buses and no correlation between odour and respirable particulate, organic carbon and elemental carbon (O'Neil & Tistadt, 2001). Fairfax county school buses were found to pose no health risk for students and staff in the community.

One significant Canadian school bus study was completed by Brauer et al. in 2000. They collected random air samples to investigate several potential air contaminants inside school buses during normal operation. Measurements were conducted on 25 school buses from Abbotsford, British Columbia, between November and December 1999. Air pollutants measured were CO, CO2, nitrogen dioxide (NO2) and hydrocarbons. The authors noted that except for periodic elevations of CO, perhaps due to infiltration from surrounding traffic, and of CO2, likely due to high passenger occupancy of the buses, none of the other pollutants showed elevated levels

(Brauer et al., 2000). These results were not surprising because diesel engines are not large emitters of either VOC or of CO (U.S. EPA, 2002).

Although these studies do not show an increase in certain pollutants on school buses, several other studies demonstrate elevated levels of $PM_{2.5}$, BC, VOC and other pollutants associated with diesel emissions. In January 2001, the American Natural Resources Defence Council and the Coalition for Clean Air released the report *No Breathing in the Aisles: Diesel Exhaust Inside School Buses* (Solomon et al., 2001). Measurements were taken on four buses while driving on actual elementary school bus routes without the children on board. The report measured BC and $PM_{2.5}$ and found that both were significantly elevated inside the school buses as compared to outside. The levels of total diesel exhaust particulate (i.e. BC was adjusted to represent estimates of total diesel exhaust particles) were highest in the back of the bus when the windows were closed. A child, commuting in such a bus, would inhale 4 times the amount of diesel pollutants compared with a child riding in a passenger car (Solomon et al., 2001). However, this study considered only repeated measurements on four buses with no children aboard. The few number of buses does not give representative information of the levels experienced for an entire bus fleet under typical conditions.

In February 2002, a U.S. non-profit organization, Environment and Human Health, Inc., and researchers from Yale University released a report entitled *Children's Exposure to Diesel Exhaust on School Buses*. This study was used as a model for our school bus study in Fredericton, as it is one of the most extensive to date. Fifteen Connecticut schoolchildren were monitored, each for an entire school day, and their exposures to fine particles ($PM_{2.5}$), BC and VOC were estimated (Wargo et al., 2002). Researchers calculated the average exposure of each school child and accounted for the duration of the bus ride, measured idling times and waiting queues, and compared ambient state-wide pollutant levels and meteorological variables. They found that average PM levels during commute times were 5 to 10 times higher in diesel-fuelled school buses compared with 24-h averages for the community. They also found higher concentrations when buses idled and that pollutants were retained longer if the windows on the bus were closed.

In October 2003, the California Air Resource Board published a report on the range of children's pollutant exposure during school bus commutes in which it examined pollutant concentrations on board seven buses; five were old diesel school buses, one was a diesel school bus retrofitted with a particulate trap, and one was a compressed natural gas-powered bus (Fitz et al., 2003). Pollutants measured were BC, particle-bound PAH, NO2, particle count and $PM_{2.5}$. Results showed that children commuting on school buses in Los Angeles are exposed to significantly higher concentrations of vehicle-related pollutants than those exposed to ambient air or to concentrations measured on roadways. A tracer gas added to each bus's exhaust demonstrated that pollution from the bus itself contributed to these high exposure levels, as did other traffic sources (Behrentz et al., 2004). Older buses showed higher levels of exhaust intrusion. For most routes, the concentrations of pollutants were higher with the windows closed. Formaldehyde levels were higher for buses fuelled with clean natural gas (CNG). Bus-to-bus variability was high, but the conventional diesel bus had the highest concentrations of measured pollutants.

1.6 Measures to reduce school bus exposure

Measures such as low emission technology and low sulphur diesel can be implemented to reduce children's exposure to diesel exhaust-related pollutants on board school buses. Studies have been undertaken to assess the effectiveness of these measures and most prove that these measures are justified.

In fall 2003, North-Eastern States for Coordinated Air Use Management (NESCAUM) began conducting a study of children's exposure to diesel-derived air pollutants on school buses and tailpipe emissions from school buses (NESCAUM, 2003). The final report is currently being prepared, but indicates that retrofitting of school buses and reducing the sulphur content of diesel fuel substantially reduce the on-board exposure levels (NESCAUM, personal communication).

The Union of Concerned Scientists, a non-profit U.S. organization, released the *Pollution Report Card: Grading America's School Bus Fleets*, which examined the buses, surveyed them in terms of age, model year, fuel type and their contribution to general air pollution. They graded each U.S. state fleet. Only six states and one district were ranked above average when compared with emission standards and the rest received a medium rank, and more than one third of the states had school buses that did poorly or failed. The organization also compared standard diesel bus emissions with those from retrofit buses and buses with alternative technologies and concluded that natural gas buses are the cleanest, but that retrofit low-emission diesel buses would have comparable emission rates (Monahan et al., 2002).

In November 2002, the International Truck and Engine Corporation and Conoco Phillips International conducted a study comparing exhaust emissions from school buses with compressed natural gas, low-emitting diesel and conventional diesel. The study found that low-emitting diesel technology provides the lowest emissions for most criteria pollutants and toxic air contaminants (Lapin, 2002).

2. Background/Rationale

The geography and population density of New Brunswick communities require a large number of students to travel to school by bus each day. Approximately 95,000, or 77% of all enrolled students, rely on school bus transportation. The ratio of school bus users in New Brunswick will likely increase, considering current housing trends in the province. Approximately 80% of new developments between 1991 and 1996 occurred in unincorporated areas. New Brunswick's long winter season also encourages many school bus drivers to keep their buses idling for longer periods of time when not transporting children. While this practice is being discouraged at local levels, it has yet to be regulated on a province-wide basis. Given the prevailing housing and transportation trends in the province, and that all school buses after 1988 (93% of buses in the fleet) are diesel buses, it is important to examine the level of air pollutants inside N.B. school buses.

The New Brunswick Lung Association, the New Brunswick Department of Education with New Brunswick schools, Health Canada, Environment Canada and Environment and Human Health, Inc. were interested in determining the potential exposure of N.B. schoolchildren to diesel exhaust-related air pollutants while commuting to and from school. It was important to conduct a study of this kind in Fredericton, New Brunswick to broaden the database for school bus exposures in Canada, while improving on the methodology used to date. Compared with previously published studies, the present study used a larger number of buses, with children on board, and samples were taken at several locations over an extended period of time.

The Connecticut study in the United States in 2001-02 demonstrated that schoolchildren are often exposed to elevated levels of diesel exhaust inside school buses, even after the ambient pollutant levels and meteorological data were taken into account (Wargo et al., 2002). Considering the similarities between Canadian and American provincial and state school jurisdictions and regulations of emissions (for bus technology, and fuel and safety regulations), we felt it important to evaluate, using a larger sample, whether N.B. schoolchildren are exposed to levels of diesel emissions similar to those in the Connecticut study. The findings would be beneficial in the development of transportation policies and guidelines that aim to reduce schoolchildren's exposure to diesel-derived air pollutants on school buses.

For this study, we chose two school districts of the province, school districts 17 and 18, which cover Fredericton and nearby communities (Appendix 1, Map 1 and Map 2). The city of Fredericton has approximately 40,000 inhabitants. It is the capital of the province of New Brunswick. The Saint John River divides the city into north and south sides. Fredericton has two universities and extensive governmental offices, and lies adjacent to the four-lane Trans-Canada Highway, which has steady but not heavy traffic. Several highways lead into Fredericton from various parts of the province, but there is usually only light traffic congestion during "rush hour."

The adjacent village south of Fredericton is New Maryland, with a population of 4400. The village consolidated recently from several residential neighbourhoods along a rural highway, Route 101. The town of Oromocto, 15 km east of Fredericton along the Trans-Canada Highway, has a population of around 10,000. It is located next to an army base (Canadian Forces Base, Gagetown) and houses many military families. Fredericton and its greater area is a typical mix of rural, semi-rural and urban life, with no major factories or power plants located within it in either of the two school districts. Facilities in the area regulated by Environment New Brunswick for air pollution emissions include various heating plants for major institutions in the area (the universities, Oromocto High School, hospitals, governmental buildings, research facilities), and small industrial operations including a food-processing plant, several furniture manufacturers, an asphalt- and cement-making plant, and several crematoriums. Except for the universities' heating plants, which fall under Class 1, all other 19 facilities belong under Class 2-4 Air Industrial Approvals regulations (NB Department of Environment, 2003). The three elementary schools (schools housing grades from Kindergarten to Grade 5) chosen for the study were located in Fredericton, New Maryland and Oromocto.

Alexander Gibson Memorial Elementary School, also known as Marysville Elementary, is located in Marysville, in the northern part of Fredericton. It was built in 1957, modified following a fire in 1977, and has at present a student population of around 400 with a staff of 24 teachers. The school is heated by an oil furnace. It lies close to a moderately busy city bus route, which turns into Highway 8. It is also close to a bridge, which connects the area to another major highway. Constant and sometimes heavy truck traffic occurs about 100 m away from the school. About a block away from it are two gas stations. The school serves Marysville and other greater Fredericton area settlements: Durham Bridge, Taymouth (not shown on Map 2, Appendix 1), Penniac, and Nashwaak village. It lies within School District 18, as does New Maryland Elementary School.

The New Maryland school was built in 1994 in the village of New Maryland, has a student population of around 650 and 44 staff, and is located in a residential neighbourhood next to an outdoor summer sport field and woods, several blocks removed from Route 101. It is electrically heated. This school serves New Maryland, Beaver Dam, Nasonworth, Charters Settlement and part of the Rusagonis area. There are three gas stations in New Maryland, all several blocks away from the school.

Gesner Street Elementary School is in School District 17, in the town of Oromocto. It was built in 1958, and is a few blocks removed from two major rural roads. It has a student population of around 320 and a staff of 23. This school is heated by a gas furnace. The school serves the central area of Oromocto, the rural area of Rusagonis, and the area of Burton from the North Gate of CFB Gagetown to Goan's on Route 102. It lies across a field from a fire station and gas station, and is a block away from Oromocto High School, which has oil heating regulated by the Department of the Environment (Class 2-4 Air Industrial Approvals).

The objective of this study was to determine the levels of diesel emission-related pollutants on school buses during the transport of children. The data were extracted from a larger dataset in which information on air pollution exposure for a child's entire day was collected. The goal of the present study was to improve our understanding of the exposure of N.B. schoolchildren to diesel exhaust relative to the age of the bus, the length of the bus route, the school region, the bus fuel injection system, weather variables (temperature, humidity) and ambient $PM_{2.5}$ levels. Air pollution levels during walking commutes were also collected for a set of children. This study measured levels of $PM_{1.0}$, $PM_{2.5}$, BC, UV absorbing organic material and specific VOC on the school buses. The study included smoke opacity testing for buses involved in sampling as a measure of their level of maintenance. Results from this study are ultimately intended to help inform policy recommendations aimed at reducing the exposure level of schoolchildren to diesel exhaust.

3. Methods/Study Protocol

3.1 Study objectives

The objective of this study was to measure actual levels of diesel-related pollutants in N.B. school buses during children's daily commutes to and from school, relative to the age of the bus, the length of the bus route, the school region, the bus fuel injection system, weather variables (temperature, humidity) and ambient $PM_{2.5}$ levels. The primary goal, agreed upon by Health Canada in conjunction with the New Brunswick Lung Association, was to obtain baseline PM ($PM_{2.5}$ and $PM_{1.0}$), BC, UV absorbing aromatic organic material and VOC exposure levels for children commuting to school, by school bus, and to consider the effect of certain variables on these exposure levels (Table 3, under Statistical Methods).

3.2 Project design

The study was conducted in the province of New Brunswick, Canada, in school districts 17 and 18 (Appendix 1, Map 1). The elementary schools assigned to the study by the New Brunswick Department of Education were selected based on their accessibility, sufficient number of buses, bus route lengths and their urban, suburban and rural location. The schools involved in the study were Gesner Street Elementary School (G) in District 17 in Oromocto, and New Maryland Elementary School (NM) in New Maryland, a village south of Fredericton, and Alexander Gibson Memorial Elementary School (AGM) in Marysville, a suburb on the north side of Fredericton, both from District 18 (Appendix 1, Map 2). Gesner Street Elementary School was located close to rural routes. Alexander Gibson Memorial Elementary School was located close to heavy traffic, while NM school lies on the outskirts of quiet, typically residential neighbourhoods. There was a “no idling” policy in effect in School District 18, but not in School District 17. The students always waited for the afternoon buses inside the school. A small proportion of the students in all three schools travelled from remote rural locations. Exact starting locations and walking routes from home were provided by the schools, which allowed us to follow the route of a typical child. Children from Kindergarden up to Grade 5 were selected for participation in this study and ranged in age from 5 to 11 years.

The study was approved by the University of New Brunswick Ethics Committee (Appendix 2).

A table summarizing the characteristics of the schools and buses used in our study follows.

3.3 Air sampling

During the study, four hired adult research assistants conducted the air sampling. To be able to work in schools, the research assistants successfully went through a security clearance through the local police department. Parents, teachers, children and bus drivers were informed of the study and could contact the New Brunswick Lung Association with further questions at any time.

The air was sampled for children on 63 school days from April 24 to June 19, 2003, and exposure levels during the commute period only were considered in our analysis. Sampling days were on weekdays and were not consecutive. Rain and high humidity conditions prevented

Table 1: Characteristics of schools and buses used for air sampling

School	**School district**	**# Buses (N=41)**	**# Children (N=74)**	**Bus model**	**Opacity testing (N=37)**	**Bus idling policy***
Gesner Street School (G)	District 17 Longest rural routes	20	30 (6 of whom walked)	8=International 4=Ford 6=freightliners 2=Thomas	19 out of 20 buses tested. All buses PASS	No
New Maryland School (NM)	District 18 Suburb	12 (3 of these was a spare bus)	24 (4 of whom walked)	9=International 2=Chevrolet 2=Freightliner	9 out of 12 buses tested All buses PASS	Yes
Alexander Gibson Memorial School (AGM)	District 18 Close to heavy traffic	9 (1 of these was a spare bus**)	20 (1 of whom walked)	6=International 1=GMC 1=Ford 1=Freightliner	9 out of 10 buses tested All buses PASS	Yes

* Indicates if school has a policy in place, which forbids buses from idling outside school property while waiting to pick up children.

** Spare buses do not service a particular school. They are used when needed.

reliable measurements; hence, sampling could not be done on such days. Each day, the research assistant simulated the entire school day of a different child. The technician carried the equipment that recorded air quality from the time a child waited for the school bus or started walking to the participating school until that child returned home after school. The sampling typically started after 06:50 and ended at the latest by 16:45 on regular days. On half-days, with the school time finishing at 12 noon, the afternoon sampling ended by 12:45. In District 18, the half-day was Wednesday and in District 17 it was Friday. On each of the 52 days, the research assistants were riding buses to school with the children, each from a different bus stop. They returned, often by a different bus, to the same location in the afternoon. On 11 days, technicians walked as the child would from a residential neighbourhood to the participating school and back. The exposure levels for walking routes were measured only for schools AGM and G. The study monitored as many different buses as possible and included longer and shorter bus rides.

The P-Trak® ($PM_{0.02–0.1}$ µm) and Dust Trak® ($PM_{0.1–2.5}$ µm) instruments (described in sections 3.4.1 and 3.4.2) were worn in a front pack on the researcher's chest so that the sampling hoses were at the level of an elementary child's head. The assistant wore low-dust emitting clothes (e.g. no fleece or flannel materials). The SUMMA Canister was in a pouch slung over the shoulder, with the opening of the flow restrictor at the head level of a child. During the bus ride, the Aethalometer™ was carried at waist height or positioned on a bus seat; in a classroom or outdoors it was usually on a table, bench, or occasionally on the floor, with the sampling hose opening just above the instrument. Thus, the sampling hose was usually elevated at least 35 cm off the ground, at an elementary child's breathing level. The research assistants recorded all relevant events in a log for each entire day, describing the waiting period, the bus ride or walking route, classroom or playground environment, the child's school activities and any other variables that might have affected the levels of air pollutants.

Two of each type of PM monitor (P-Trak® and Dust Trak®), one Aethalometer™ and 10 Summa Canisters were used. For PM with diameter 0.02 to 0.1 µm (P-Trak) samples were taken on 63 days, providing a maximum of 126 commute exposure estimates.

The two sets of PM monitors enabled monitoring of air quality in two locations on many of the sampling days, or dual monitoring in the same school on seven days to compare their recordings. On two of those seven days, research assistants rode the same bus to and from the school and stayed in the same locations in the school. On one day, they walked to and from the school together and again stayed in the same classrooms throughout the day. On four of those seven days, the assistants were in the same school in different locations and rode different buses to and from the school, except for one afternoon bus ride, which they monitored together.

Analysis of paired samples (i.e. on the three days when sampling was done in identical locations with the same type of equipment) revealed little significant difference between samplers, and the difference was not adjusted for in the results. Appendix 17 shows the results of testing for significant differences between paired samples when either the two Dust-Traks® or two P-Traks® were sampling side by side during the same commutes.

The following table summarizes the equipment used and the number of exposure measurements obtained using each one, on bus and walking routes. A more detailed description of each piece of equipment is described in section 3.3.

Table 2: Description of air sampling equipment and commute information

Sampling equipment	**Pollutant measured**	**Where located**	**Total number of commutes**
P-Trak	PM 0.02–0.1 μm	Carried by volunteer at waist level in front pack	126 (2 commutes per day for 63 days)
Dust Trak	PM 0.1–2.5 μm	Same as above	126 (2 commutes per day for 63 days)
Aethalometer	BC	Carried at waist-level height or positioned on a bus seat	60 (2 commutes per day for 30 days)
	UV absorbing organic material	Same as above	60 (2 commutes per day for 30 days)
Summa canister	VOC	Carried by volunteer in a pouch slung over shoulder	41 samples

3.4 Material/Methods

3.4.1 Fine particulate matter ($PM_{2.5}$)

For monitoring of $PM_{2.5}$, two Model 8520 personal real-time Dust Trak® Aerosol Monitors (Thermo Systems Inc. [TSI], Shoreview, Minn.) were used. A 2.5-μm inlet nozzle and impactor plate were employed to attain the necessary particle size cut and isolate $PM_{2.5}$. The Dust Trak® measured particles in the size range of 0.1 to 2.5 μm, and provided real-time mass concentration in units of mg/m^3. The sample flow rate was maintained at 1.7 L/min. An averaging time and logging interval of 1 min were used. Calibration of the Dust Trak® was performed yearly by TSI Inc. This was done using a standard ISO Test Dust and the Dust Trak® was assigned a calibration factor of 1.0 to this dust. Data logged into the instrument memory were downloaded and processed with TrakPro (TSI Inc.) and Microsoft Office software (TSI 2000; 2002).

3.4.2 Ultra-fine and fine particulate matter ($PM_{1.0}$)

A combination of fine and ultrafine PM was measured by two Model 8525 P-Trak® Ultra-fine Particle Counters (TSI Inc.). The P-Trak® counts particles optically, after they are "grown" by condensation of isopropyl alcohol. Thus, there is a lower limit on the size of particles that are seen. The P-Trak® is able to detect particles in the range of 0.02 to 1.0 µm and the term "PM1.0" in this context refers to this size range. This range includes particles in the fine range (0.1–2.5 µm) and ultrafine range (<0.1 µm). A real-time particle count in units of particles per cubic centimetre (pt/cc) is provided. The sampling was performed through the inlet screen and sample tube. An averaging time and logging interval of 1 min were used. Data logged into the instrument memory were downloaded and processed with TrakPro (TSI Inc.) and Microsoft Windows software (TSI, 2001, 2002).

3.4.3 Black carbon and ultraviolet absorbing aromatic organic material

Black carbon aerosol concentrations were measured using a portable, fully automatic Aethalometer™, an extended spectrum model AE-21, manufactured by Magee Scientific Instruments, with dual-wavelength optical analysis for BC and UV absorbing Paromatic organic material (AE-21 Dual Channel UV-BC Aethalometer™). The 880-nm absorption yields measures of carbonaceous particles (i.e. BC), while 370 nm absorption (UV channel) is an indicator of all material that absorbs UV light at this wavelength. Diesel emissions and tobacco smoke are two aerosols that give a measurable response; polycyclic aromatic hydrocarbons (PAH) are one class of compounds present in these aerosols that contribute to this measured response. Since only one Aethalometer™ was available, measurements were recorded on approximately half of the routes (i.e. on 29 days). The instrument draws sample air through a 0.5 cm^2 opening onto a quartz fibre filter tape. The attenuation of the light is proportional to the amount of elemental carbon. The instrument's response to the change in light transmittance is recorded on BC and UV channels. The instrument's sample flow rate, controlled by an internal vacuum pump, was maintained at 4 L/min. The instrument determined the concentration of BC in units of mass of BC per volume of air (ng/m^3) from the flow rate and change in light transmittance data. Real-time data were recorded at 1-min intervals to a 3.5" floppy diskette with a COM-port digital stream output. Data from the Data RAM and Aethalometer™ were downloaded onto an IBM-compatible computer and processed (Hansen et al., 1984; Magee Scientific Company, n.d.). Comparison between Aethalometer™ data and Dust Trak® and P-Trak® data allows us to evaluate PM levels as originating from combustion sources.

3.4.4 Volatile organic compounds

The canisters used for collecting the air samples for volatile organic compounds (VOC) analysis were 1.8-L stainless steel pre-cleaned and evacuated SUMMA Canisters from Pacwill Environmental (MC400/1000, Elecropolished Passive Sampler Canisters). The vacuum created in the SUMMA Canister draws the sample air into the canister. A restrictive orifice was used at the inlet of the canister to adjust the flow to 5.6 mL/min, 12.0 mL/min or 18.2 mL/min. The appropriate flow restrictor was chosen based on the time anticipated for sampling. As mentioned, SUMMA Canisters were used only to sample air for VOC analysis while waiting for and during the bus rides or while walking to and from school. The SUMMA Canister was manually opened while waiting for the school bus and was closed upon entering the school or upon reaching the child's house. The times during which the canister was open were recorded on the log.

The Environmental Technology Centre Emissions Research and Measurement Division (ERMD) of Environment Canada performed the analysis of air samples for VOC in ambient air. The samples were analyzed using a cryogenic pre-concentration high-resolution gas chromatography and quadrupole mass-selective detection (GC-MSD) method developed in-house, based on the TO-14A and TO-15 methods (U.S. EPA, 1997a,b; Graham, 2003). Appendix 3 provides a list of substances for which the air samples were analyzed. Approximately 190 non-methane hydrocarbons (NMHC) and 30 halogenated VOC (HVOC) were determined.

3.5 Meteorological data

Meteorological data were obtained through Environment Canada from its fixed, 24-h manned weather station, located at the Fredericton airport. Hourly temperature and relative humidity were recorded for each day. Wind speed and direction, as well as cloud cover were recorded, but were not used in the analysis.

3.6 Ambient air quality data

Ambient air quality data, reported as hourly averages, were collected and recorded by Environment Canada in Fredericton, New Brunswick. The air quality monitoring station is located on Aberdeen Street and continuously samples the air for $PM_{2.5}$, nitrogen oxides (NO, NO_2), ozone (O_3) and carbon monoxide (CO).

3.7 Buses

Forty-one buses were registered for the study, 20 serving School District 17 and 21 serving School District 18. Samples were collected on 40 buses; one additional bus was opacity tested, but this bus was not otherwise used in the study. Buses were sampled repeatedly over several days, at different times of day (i.e. morning and afternoon). Of the 40 buses, 20 served Gesner Street Elementary School (School District 17), 9 New Maryland School and 9 Alexander Gibson Memorial Elementary School. Two buses were replacement buses used in School District 18 (Appendix 4). (Bus number 35 with a 1997 Ford engine which also serves AGM was not tested either for smoke opacity of the exhaust or for air pollution for lack of time, and is therefore not listed in the tables).

The buses used in the study ranged in age from 1 to 15 years, manufactured from 1988 to 2002 (Appendix 4). The average age of a bus was 6.6 (standard deviation [SD = 4.4]) years, 6.5 (SD = 3.5) years in District 17 and 6.7 (SD = 5.1) years in School District 18. All buses were full size. Two buses in School District 17 had a carrying capacity of 84 passengers (bus number 51 and 68); all other buses had a carrying capacity of 72 passengers. The buses made in 1997 or before had mechanically controlled fuel injection systems on their engines and were classified in this study as older buses. The number of "old" buses servicing each school was approximately evenly distributed with 2 old buses for each of AGM and NM schools and 3 for school G. Most of the buses manufactured in and after the year 1998 had electronically controlled fuel injection systems on the engines and were categorized as newer buses. All buses, except 2, had the engine at the front of the bus. In 2 buses the engine was in the rear. These were bus number 68 (engine made in 1989) and bus number 51 (engine made in 1997), both in School District 17 and serving school G. All engines were four-stroke, with the crankcase ventilation tube exiting out the middle of the engine and into the ambient air under the bus, typically slightly to the left of the driver.

All buses tested in the study were diesel fuelled. The diesel was supplied by Irving Oil Ltd. Its sulphur content for March 2003 was 436 ppm, for April 427 ppm, and for May 433 ppm. Data for June are not available. The average sulphur content for the first quarter of 2003 was 436 ppm (personal communication, Irving Oil). All buses had exhaust pipes exiting at the right rear end out the back of the bus, just clearing the rear bumper. They all conformed to the standard school bus safety regulations used in the province, Regulation School Buses, Standard D 250-03.

3.7.1 Maintenance of buses

Under the supervision of the New Brunswick Department of Transportation, with the help of the Vehicle Management Agency, all fleet school buses, including those in the study, underwent regular motor vehicle inspection and maintenance checks at a minimum of twice a year. The first of these two inspections was the motor vehicle inspection, followed by a Preventive Maintenance “B” Inspection session six months later, conforming to the “Vehicle Management Agency Policy and Procedure Manual,” Section 4006. Engine efficiency, tires, brakes, exhaust, looseness and other technical details were checked and repaired. If additional checks or maintenance were needed, each individual bus returned for inspection and repairs. Depending on the condition of the bus and its mileage, the inspections could occur more frequently. Five buses used in the study were contracted buses (bus number 4, 5 and 44 in School District 17 and bus number 55 and 56 in School District 18), which followed a similar schedule of maintenance. Buses often had additional smaller inspections once every one or two months. To ensure that school buses were always in prime working condition, the Commercial Vehicle Enforcement Group - Public Safety, together with the Department of Education, conducts random check inspections and reports on any deficiencies.

All drivers and vehicles contracted by the Province of New Brunswick that convey students to and from school must have met the standard requirements set out under the Pupil Transportation Regulation (Regulation 2001-51) by the Department of Education. Every day before the bus run, each bus underwent a 20- to 30-minute pre-trip vehicle inspection. The content and the type of inspection were established under Policy 504 - School Vehicle Inspections and Maintenance of School Vehicles (New Brunswick Department of Education, 2003). The individual bus driver walked around the bus and checked wheels and tires, mirrors, lights, inspected the engine, wipers and all fluids, battery, the undercarriage (exhaust, transmission), windows, emergency door, doors, steps, etc. After the engine was started, the driver also checked oil pressure, all gauges, all controls and engine-related parameters, light system and air brake system.

All drivers were made aware of the issues or concerns associated with idling diesel engines. All drivers of diesel-powered units were required to start the engines, check all gauges and then set the idle up to 1200 to 1400 rpm to warm up. One of the benefits of this procedure was that the engine would run at a more efficient heat rating than at a base idle of 700 to 800 rpm. Additionally, if the unit was left idling for any period during the day the drivers were instructed to set the fast idle. Stickers were displayed in most units outlining this procedure. This information was communicated to the drivers via information sessions.

3.7.2 Smoke opacity test of bus exhaust

Opacity testing of bus exhaust smoke was performed on 37 buses involved in the study. The measurement of smoke opacity was conducted according to the Society of Automotive Engineers (SAE) J 1667 Snap Acceleration Smoke Test Procedure for Heavy-Duty Powered Vehicles, published in February 1996 (Society of Automotive Engineers , 1996). The test, which is a non-moving vehicle test, is endorsed by the California Air Resource Board and is commonly known as the California Snap-Idle Test Procedure (Society of Automotive Engineers, Inc., 1996). The method consists of a snap-acceleration test procedure, which simulates on-the-road acceleration. The inspector places the probe from a smoke sensing meter in the vehicle's exhaust pipe. With the vehicle in neutral gear, the driver is instructed to rapidly depress the accelerator and hold at the maximum governed speed for a few seconds, then return to idle. The meter measures the opacity of the smoke emitted while the driver repeats the snap-acceleration test a number of times.

The exhaust smoke level is measured in terms of percentage (%) opacity. As the amount of PM in the exhaust increases, the opacity of the exhaust also increases. Current maximum smoke opacity limit for engines made prior to and in 1990 is 55%, and for engines made in 1991 and later the limit is 40% (Diesel Technology Forum: <www.dieselforum.org/factsheet/map.html>).

3.8 Statistical methods

Air pollutant monitoring was conducted on 63 days during a 3-month period from mid-April to mid-June 2003, as described above. Although children were followed throughout the school day, only their exposure resulting from commutes to and from school, on school buses or while walking was considered in our analysis. Commutes refer to both walking and bus routes unless otherwise specified. The volunteers accompanying the children on the school bus or while walking recorded air pollutant levels; thus, the exposure during these times could be distinguished from levels recorded at other times during the school day. All values recorded in this study, including zero values and extreme values, were used in our analysis. In the case of zero values, to be able to calculate their logarithm, zero was replaced by half of the detection limit.

In this study, the unit of observation was school bus ride or walking commute rather than the individual students. For each commute, a series of recorded (available) measurements was taken and logarithms for each measurement were calculated. Data were logarithmically transformed so that the impact of extreme measurements was reduced and the values obtained assumed a normal distribution necessary for further statistical analysis.

The data available for $PM_{2.5}$ and $PM_{1.0}$ were provided by the 1-min logging intervals recorded by the Dust Trak® and P-Trak®, respectively. For BC and UV absorbing aromatic organic material, the data were also provided as 1-min logging intervals. The arithmetic mean of these logarithmic numbers was computed and used to represent the exposure observed for a single commute. The distribution of arithmetic means, which represent exposure on school buses, showed a close-to-normal distribution, which was required for subsequent statistical tests for significance. Using these logarithmic values and back transformation to original measurement, geometric means (Gmean) and their 95% confidence intervals (95% CI) were calculated. Medians, minimum (min), maximum (max) and third maximum (3rd max), and standard deviation (SD) values for exposures were also calculated. Standard deviation values were calculated for logarithmic values of measurements. The 3rd max was shown because it is less affected by equipment characteristics and is less likely to be an outlying value.

In addition to calculating the logarithm of measurements of BC and UV absorbing aromatic organic material measurements, we applied a smoothing process to remove the negative values present in the datasets for these two pollutants (www.mageesci.com). Negative values were obtained due to the scaling system used by the Aethalometer™, and they are a normal occurrence in data produced by this instrument. Smoothing is used to reduce irregularities in time series data and to provide a clearer view of the underlying trend in the data. The procedure used to smooth the data was recommended and provided by Magee Scientific in the form of an Excel spreadsheet with an incorporated smoothing equation. This ensured a standardized company-provided method. Numerical values (i.e. 0, 1, 2…), which represent the degree of smoothing, were inputted into the smoothing equation for a greater or lesser degree of smoothing. For our study, we input the values 1, 3 and 5, and smoothing degree of order 3 was selected to obtain measurements for school bus exposure. Some raw values were negative, but after applying the smoothing process with parameter 3, all mean values were positive (www.mageesci.com).

As a reference, the exposure of students who walked to and from school was also measured. We calculated an arithmetic mean of exposure and the cumulative exposure, as was done for data from bus commutes. Although the bus and walking commutes were of different average length and covered different routes, the difference in exposure between the two groups represents that found under realistic conditions undergone by schoolchildren. Categories of comparison analyzed in our data are listed in Table 3.

Two components of meteorological conditions were considered in our analysis; temperature measured in degrees Celsius (°C) and relative humidity (percentage %). The values corresponding to our bus route times were matched for dates and times with meteorological data. Temperature and humidity were divided into binary groups for analysis of variance (ANOVA).

Ambient $PM_{2.5}$ concentrations were monitored and used to investigate their contribution to school bus and walking route exposures. The ambient $PM_{2.5}$ pollution values were divided into four classes determined by quartiles. These quartile values were then applied to categorize $PM_{2.5}$ exposure on the school bus into four groups. All statistical analysis was completed using Statistica software (StatSoft Inc., 2003). Tests for significance were done using the ANOVA method. Multivariate regression analysis was conducted to show the influence of factors to air pollutant levels during commutes.

Table 3: List of variables considered in analysis

- Commuting by walking or taking the bus
- Length of bus ride (Short/Long)
- Age of bus (New/Old)
- Fuel injection system (Mechanically/Electronically)
- Time of bus ride (Morning/Afternoon)
- Region (A/G/N)
- Ambient temperature (Low/High)
- Ambient Humidity (Low/High)
- Ambient PM2.5 (quartile ranges: Q1–Q4)

4. Results

4.1 Preliminary information

4.1.1 Sample size (completeness of data)

The total number of successfully sampled commutes was 111 (21 walk commutes, 90 bus commutes) with the P-Trak®. For the Dust Trak® (PM1.0–2.5), the total number of commutes were 106 (20 walk commutes, 86 bus commutes). For VOC (SUMMA canisters), 41 samples were collected and 32 viable samples were analyzed. The Aethalometer™ was employed for 30 days spanning the 4-month study period. A total of 57 commutes were sampled for BC (11 walk commutes, 46 bus commutes).

4.1.2 Buses

The most notable bus characteristics, age and duration of bus route are listed in Table 1, section 3.1. The median duration of a single trip commute was 25 min. For the purposes of the analysis of this report, the bus rides under 25 min were considered short and the bus rides of 25 min duration or above were considered long. Figure 1 shows the distribution of the duration of the school bus rides. The most frequent bus ride duration was 15 min. The mean duration of a single bus ride was 26.2 min, and the mean age of school buses was 7.4 years when bus rides and not the bus itself were considered the sampling unit. Most buses were used more than once, and the age of buses used for all 86 bus rides contributed to the average age. Old buses were considered those made before and not including 1998. Appendix 5 illustrates the ranking of all buses based on the average concentrations of $PM_{1.0}$, $PM_{2.5}$, BC and UV absorbing aromatic material of all commutes that each bus made. Note the negative sign in the Appendices means that the bus used an electronic injection system, while the absence of a sign in front of the bus number indicates a mechanical injection system. Zero indicates walking.

Table 4: Average age of buses in service, including all bus rides and average duration of bus ride (min)

Variable	**Number of buses**	**Mean**	**95% CI**	**Min**	**Max**
Bus age (year)	86	7.4	7.1–9.4	2.0	16.0
Commute duration (minutes)	86	26.2	28.9–23.9	8.0	76.0

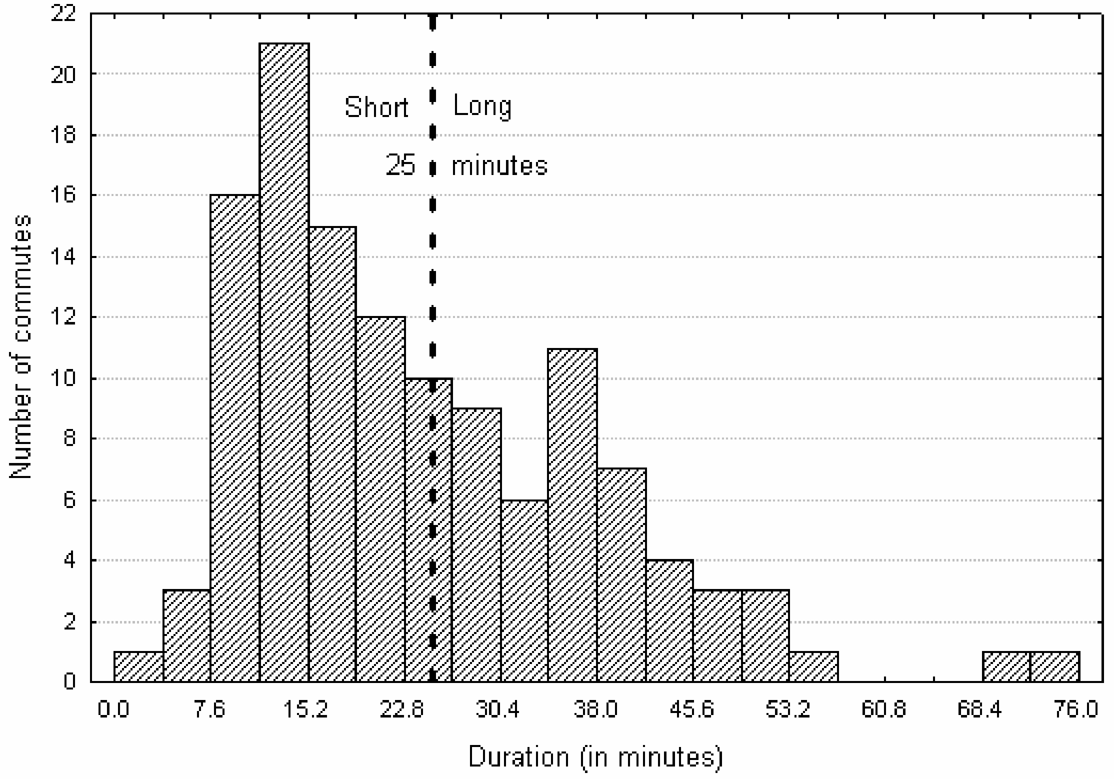


Fig. 1 Distribution of Duration on commutes

4.1.3 Average time of highest exposure

We investigated at which point during a child's commute that he or she was likely to receive most air pollutants. Figures A through D of Appendix 6 show the frequency distribution of duration of commutes when cumulative pollutant concentration of a commute reaches 50% of the total cumulative concentration. Time is expressed as a percentage of the total commute time. Most pollutants measured are markedly elevated at the mid-point of the commute, whereas BC, usually considered a marker of diesel combustion (U.S. EPA, 2002), shows high concentrations throughout the entire duration of the commute. While it is possible that BC could come from other sources such as wood smoke or gasoline, in this study it is noted that the most proximate source of combustion is diesel exhaust. Possible sources of diesel exhaust are from traffic surrounding the bus or diesel exhaust from the bus itself (resulting in self-pollution). The contribution of sources to the in-bus concentration of air pollutants was not quantified in the present study.

4.2 Environmental data

4.2.1 Meteorological data

From the ambient dry bulb temperatures provided by Environment Canada, the minimum and maximum temperatures recorded during commute times (bus and walking) were 10.7°C and 26.7°C, respectively. The mean value for the temperature distribution was 12°C and this was used as a cut-off point to compare low temperature and high temperature conditions. A similar method was used to categorize the humidity data, with the mean value of the humidity data distribution being the cut-off point to divide the air pollution data into high and low categories. For relative humidity, 60% humidity was used as the cut-off point dividing the two comparison groups. The minimum recorded humidity level was 22% and the maximum 93%. Wind speed varied from 0 to 30 km/h on the days of measurements (Table 5). (For details of the wind speed and other meteorological variables, see Appendix 7.)

4.2.2 Ambient $PM_{2.5}$

To account for background levels of exposure, we used ambient levels of $PM_{2.5}$ which matched the bus and walking commute times. The minimum ambient $PM_{2.5}$ value recorded was 0 µg/m^3 (which was below the level of sensitivity for the instrument) and the maximum was 22.1 µg/m^3. The mean level of ambient $PM_{2.5}$ during commute times recorded for the entire study period was 5.0 µg/m^3. (Table 5)

Table 5: Table of means, minimums and maximum values for environmental variables

Variable	**Mean**	**Minimum**	**Maximum**
Temperature (ºC)	12	-10.7	26.7
Humidity (%)	60	22	93
Wind speed (km/h)_	-	0	30
Ambient $PM_{2.5}$ (µg/m^3)	5.0	0	22.1

4.3 Personal exposure profiles

Several patterns of exposure become apparent when looking at commuting profiles for the individual children. These patterns are described qualitatively in Figures 2 to 5. These specific commutes were chosen to represent a variety of scenarios; they are from complete datasets, with no outliers.

Figures 2 to 5 depict the patterns of exposures to $PM_{2.5}$ during the first or last 2 h of the child's school day. Five-minute moving averages were used to partially smooth the data. These include (1) typical exposure while walking, (2) typical exposure during a long bus ride, and (3) typical exposure during a short bus ride. It should be noted that these figures are for illustration purposes only; no data synthesis and statistical analysis were undertaken.

Legend for Figures 2 to 5:

🟨 = Commute period
B= Bus stop (children get off/on)
S= Stop sign/Stop light
C= Classroom

R= Rest/Stop during walk
H= Hall
G= Gymnasium
O= Outside (school yard)
W= Waiting bus (bus off

Note: The time axis on the following graphs have different scales.

4.3.1 PM$_{2.5}$ levels while walking to and from school

Figure 2A: Walk to school in the morning of May 26, 2003. Student walked near traffic from 07:50 to 08:14. At 08:00, the ambient PM$_{2.5}$ was 4.0 µg/m^3, wind speed 7 km/h, temperature 10ºC, humidity 80%. Traffic density was medium.

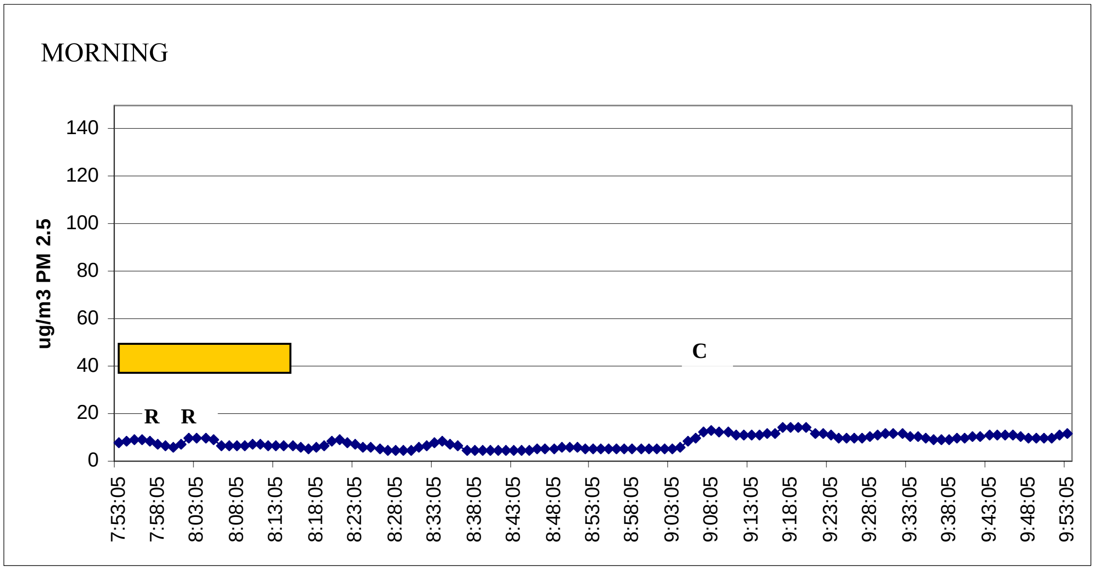
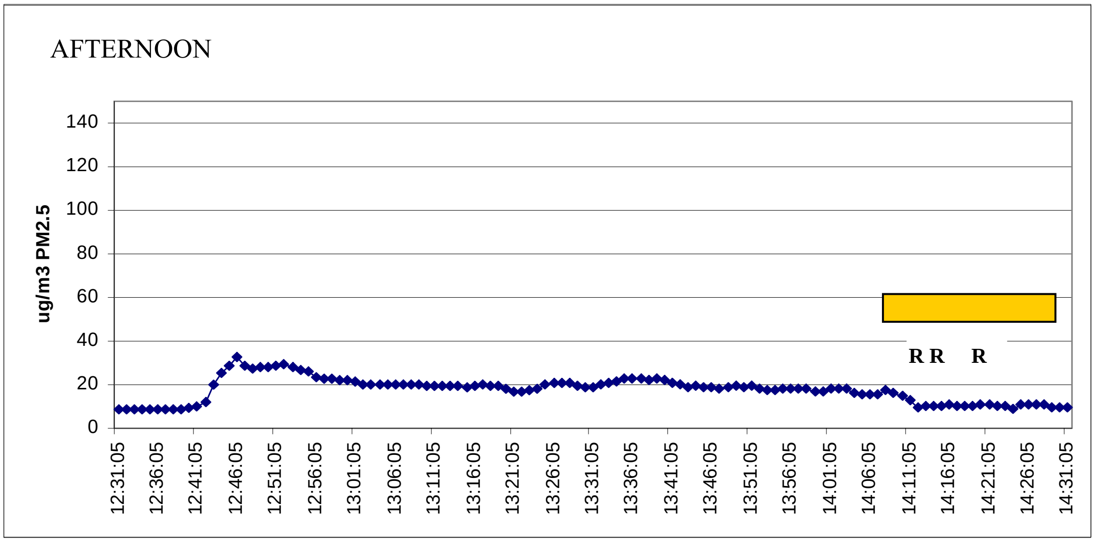


Figure 2B: Walk home from school in the afternoon of May 26, 2003. Student walked near traffic between 14:07 and 14:27. At 14:00, the ambient PM$_{2.5}$ was 3.3 µg/m^3, wind speed 20 km/h, temperature 18.6 ºC, humidity 51%. Traffic density was medium.



4.3.2 Long bus rides (over 25 min) $PM_{2.5}$ (μg/m^3)

Figure 3A: Bus commute to school in the morning of April 22, 2003. Bus ride was from 07:05 to 07:55, a 50-minute ride with windows closed. There were 20 pick-up stops on the way. At 08:00, the ambient $PM_{2.5}$ was 4.2 μg/m^3, wind speed 13 km/h, temperature 6.5ºC, humidity 92%. Traffic density was low. At 14:00, the ambient $PM_{2.5}$ was 6 μg/m^3, wind speed 6 km/h, temperature 13.2ºC, humidity 71%.

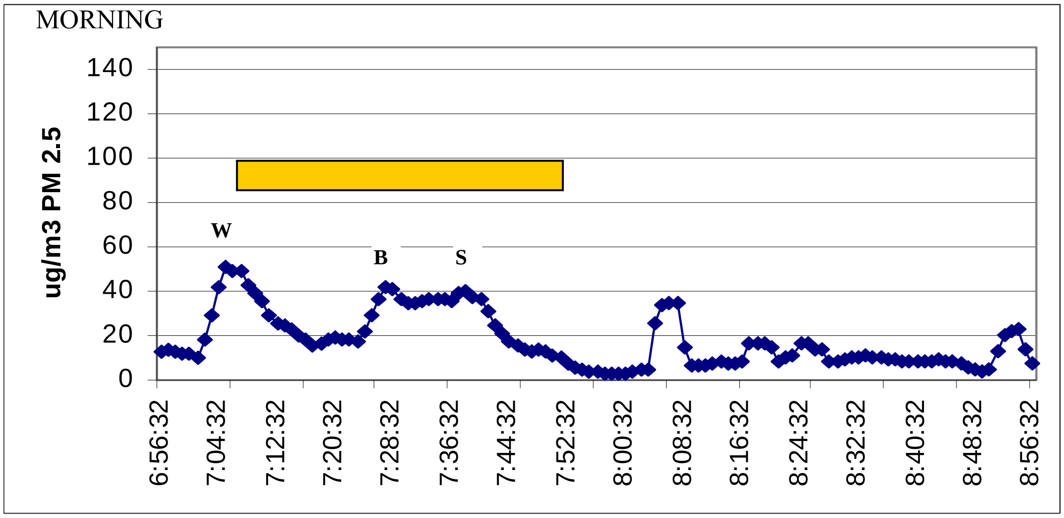
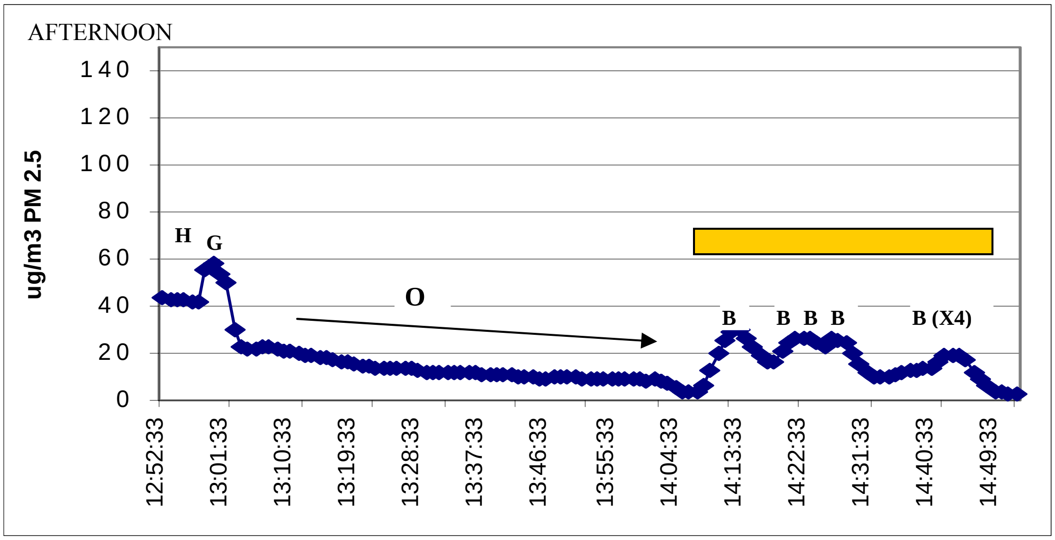


Figure 3B: Bus commute from school in the afternoon of May 8, 2003. Bus ride was from 14:08 to 14:47, a 38-minute ride with 5 windows half-way open. There were 18 drop-off stops on the way. At 14:00, the ambient $PM_{2.5}$ was 0.7 μg/m^3, wind speed 13 km/h, temperature 16.1ºC, humidity 40%. Traffic density was low.



4.3.3 Short bus rides (less than 25 min) $PM_{2.5}$ ($\mu g/m^3$)

Figure 4A: Bus commute to school in the morning of May 23, 2003. Bus ride was from 07:27 to 07:40, a 13-minute ride with windows closed. There was little or no traffic passing by. At 08:00, the ambient $PM_{2.5}$ was 6.8 $\mu g/m^3$, wind speed 9 km/h, temperature 6.6ºC, humidity 81%.

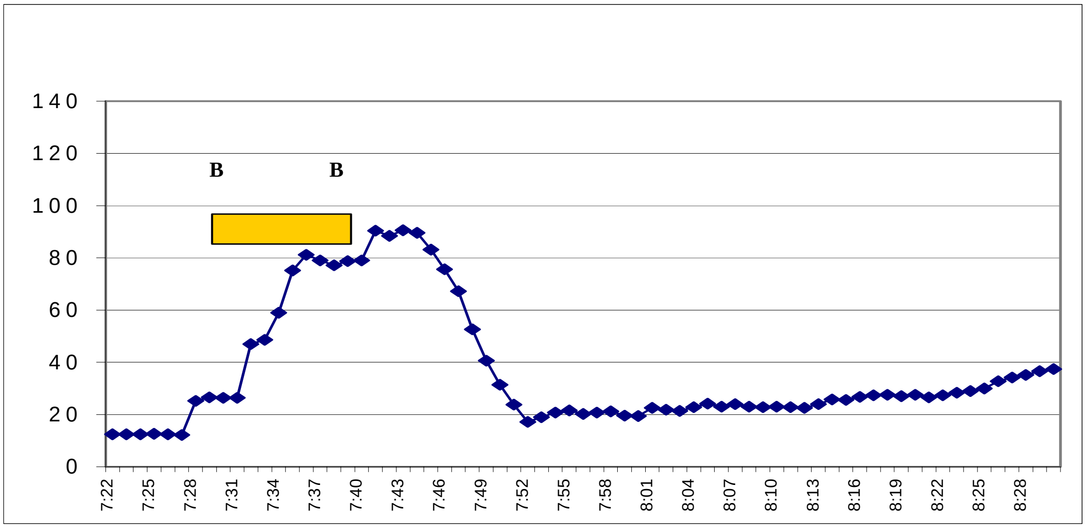
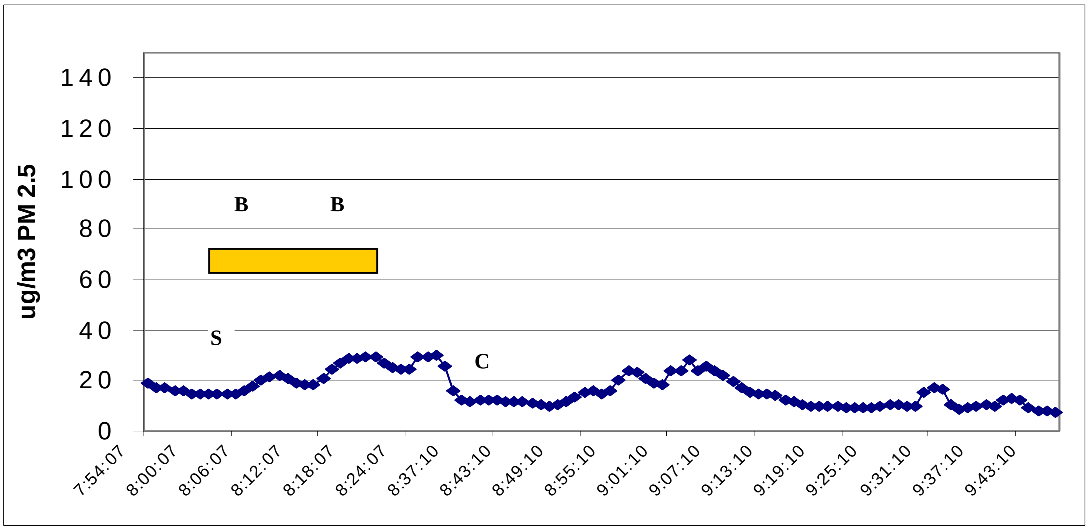


Figure 4B: Bus commute on a short bus ride in the morning of May 16, 2003, from 08:05 to 08:21. Ten windows opened a crack. There were 7 pick-up stops on the way. At 08:00, the ambient $PM_{2.5}$ was 3.7 $\mu g/m^3$, wind speed 11 km, temperature 4.2ºC, humidity 67%. Traffic was heavy (i.e. constant flow of vehicles). At 12 noon, the ambient $PM_{2.5}$ was 5 $\mu g/m^3$, wind speed 7 km/h, temperature 10.5ºC, humidity 45%.



4.3.4. PM$_{2.5}$, PM$_{1.0}$ and BC during a Long Bus Ride

Figure 5A–C: Bus commute from school, afternoon of May 23, 2003. Bus ride from 12:04 to 12:45 (41-minutes with windows closed on a 1999 bus). There were 20 drop-off stops. Traffic density was low. At 14:00, ambient PM$_{2.5}$ was 10.5 μg/m^3, wind speed 6 km/h, temperature 14.4ºC, humidity 61%.

Figure 5A: PM$_{1.0}$ (pt/cm3)

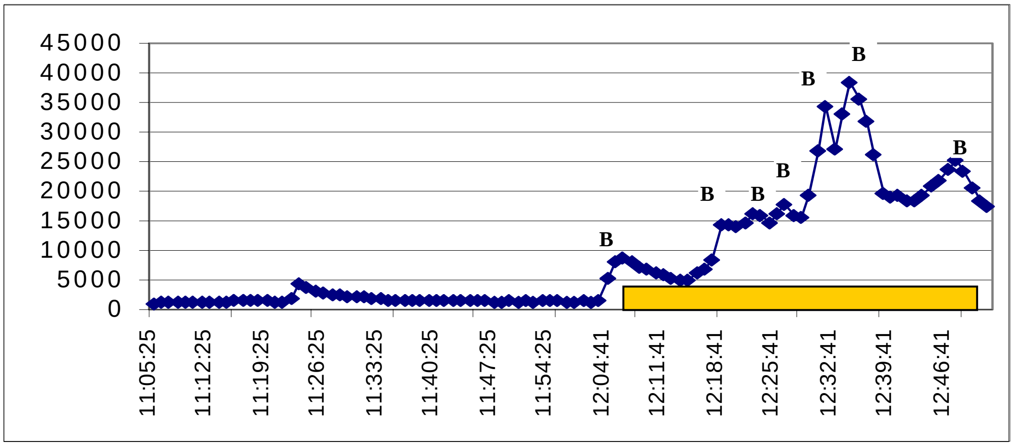


Figure 5B: Black carbon (ng/m3)

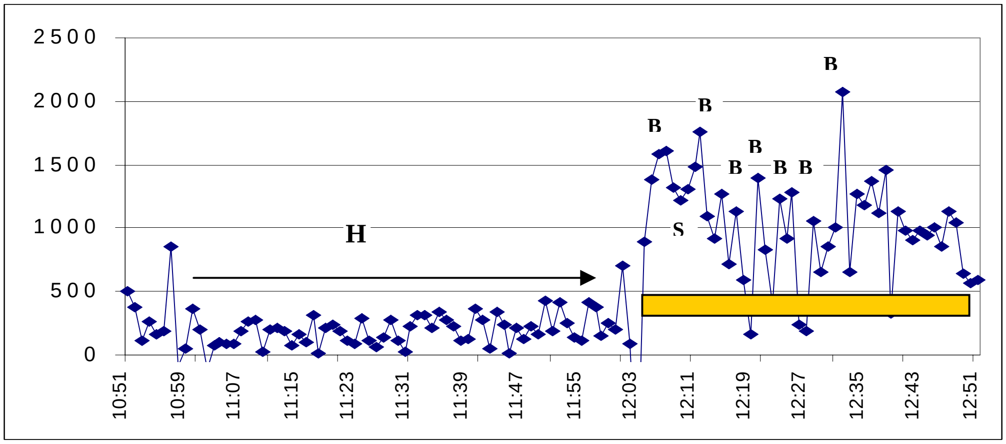
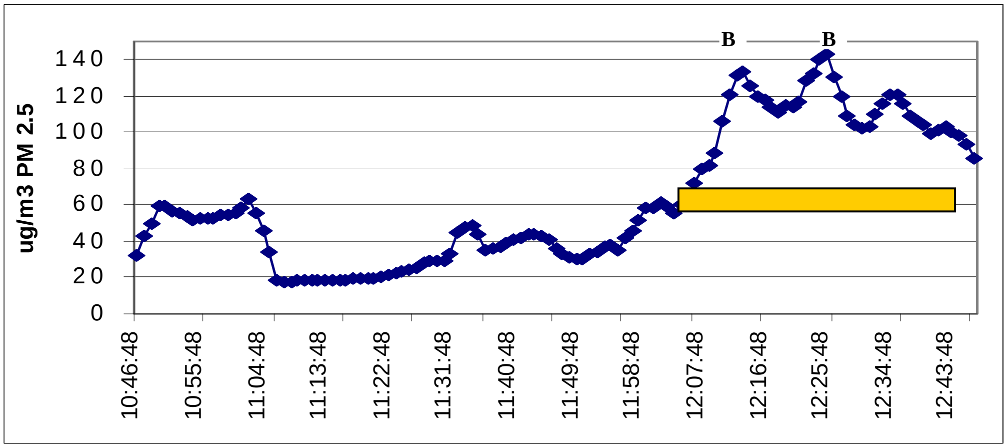


Figure 5C: PM$_{2.5}$



The student exposures to $PM_{2.5}$, illustrated in Figures 2 to 5, show that the exposure during the bus ride was among the highest levels experienced during the day. The example in Figure 2 shows elevated $PM_{2.5}$ levels above ambient levels. Notice that the 5-min averaging procedure may shift the time of actual exposures slightly. Also note that the ambient $PM_{2.5}$ was monitored at a central station in Fredericton, which may not reflect the $PM_{2.5}$ levels along this bus route.

Figure 3 shows that during long bus rides the levels of $PM_{2.5}$ were elevated during the period when students were on the bus, compared with exposure levels before and after commute times. The higher levels of $PM_{2.5}$ recorded during commutes could be influenced by factors such as window configuration, number of bus stops, presence of strong or weak cross winds, the degree that the bus is “labouring” in stop-and-go traffic or in hill climbing, the actual temperature of the engine and the exhaust. Like Figure 2, these figures show that the concentrations of $PM_{2.5}$ in the bus were relatively higher compared with the ambient levels. Figure 3A shows $PM_{2.5}$ peaked 1 min before the commute period when the bus was turned off and waiting for the child, presumably a contribution from surrounding traffic.

Figure 4B shows that the levels of $PM_{2.5}$ were elevated during the period when students were on the bus during the shorter rides compared with the waiting period and the period in school. Note that for a short ride the 5-min averaging time appears to distort the position of the commute period (yellow figure). The PM appears to increase before the student had entered the bus, but this likely was an artefact of the calculation. Short rides tend to have more stops during which the bus doors are opened and this could have caused the increase. Figure 4B suggests that open widows reduced the intensity of the exposure. This trend is consistent with results from other studies where window configuration was tested (Solomon et al., 2001; Fitz et al., 2003; Sabin et al., 2005) and with the overall trend observed in Figures 3 to 5.

An example comparing $PM_{1.0}$, BC and $PM_{2.5}$ is shown in Figure 5. All three were elevated during the bus ride but the patterns are not identical. From Figures 5A–C, the $PM_{1.0}$ levels increased with the time the student spent on the bus. The BC is considered to be the more reliable marker to quantify the diesel exhaust content in the air (Solomon et al., 2001). Black carbon levels in Figure 5B show definite peaks at bus stops, an observation similar to those made by Fitz et al. (2003). These increases were presumably caused by the exhaust plume of the bus being carried forward by wind, which entered through open windows or the open bus door.

4.4 Air pollution results

The following sections present detailed results for $PM_{1.0}$, $PM_{2.5}$, BC, UV absorbing aromatic organic material and VOC concentrations collected during commutes. Pollutant levels varied depending on outdoor conditions, such as temperature and humidity, school bus conditions, the school (region) to which the bus was commuting and variability in the bus ride itself (length, time of day, age of engine, etc.).

4.4.1 Fine particulate matter (<2.5 µm)

There are a total of 106 bus and walking routes for which $PM_{2.5}$ was measured for commutes either to or from school. These were for 20 walking routes and 86 bus routes. $PM_{2.5}$ levels tend to be higher on shorter routes, on newer buses, during morning rides, at lower temperatures and at humidity conditions above 60%, compared with opposite conditions. AGM, the school closest to heavy traffic, recorded the highest levels of $PM_{2.5}$ exposure. Using ANOVA testing, none of the differences in geometrical means among the different categories was statistically significant, except when comparing short bus rides with long bus rides. Although walking had significantly lower $PM_{2.5}$ levels than bus commuting, the air sampling for buses and during walking were not carried out at the same time, for the same length of time and did not follow identical routes. Direct comparisons on pollutant levels between bus and walking commutes should not be made.

For each ambient $PM_{2.5}$ quartile range, the corresponding mean exposure of school bus $PM_{2.5}$ level is listed. There is an increasing trend in $PM_{2.5}$ levels on the school bus as ambient $PM_{2.5}$ increases. Several factors, such as contribution of traffic emissions to ambient air pollutant levels, might be involved in this apparent association.

The $PM_{2.5}$ levels during commutes are also reported as a cumulative value to represent the total concentration of traffic-related pollutants that children are exposed to during a bus ride. Cumulative exposure is dependent on time; therefore, the level of cumulative exposure is expected to be higher than average $PM_{2.5}$ values for long commutes compared with shorter ones.

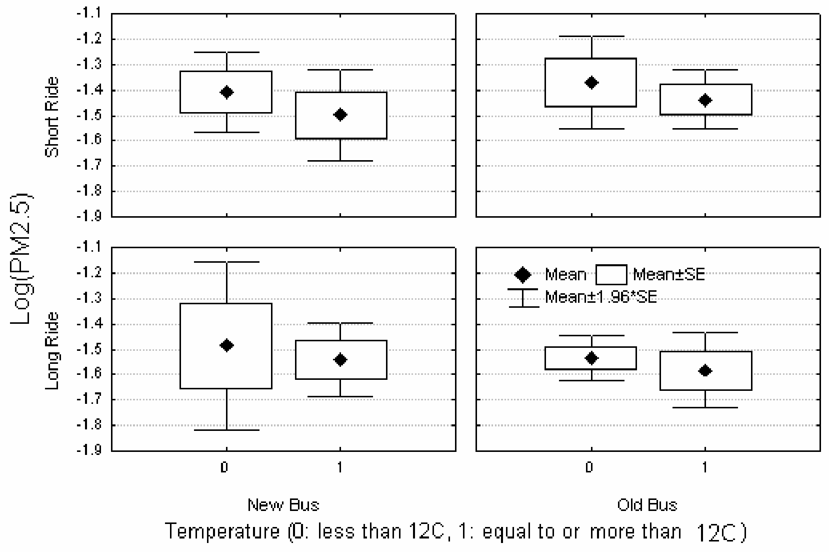
Figure 6 shows the relationship between mean $PM_{2.5}$ (in mg/m^3) levels for long and short bus ride and new and old buses when compared in terms of high and low temperature. The category with the highest mean level of $PM_{2.5}$ appears to be for old buses, on short commutes and in conditions of low ambient temperature. The lowest mean exposure occurred on old buses on long commutes and at high temperatures. None of these differences was statistically significant.

The Mann-Whitney U test, a non-parametric test for non-normal distributions to compare rank sums instead of means, was used to test the statistical differences of cumulative levels of $PM_{2.5}$ (Table 6b) in various categories. Results show that longer routes had significantly higher cumulative exposures than shorter routes ($p<0.01$). Region AGM was lower than region G ($p<0.01$) and region NM was higher than region G ($p=0.01$). There was a marginally significant difference in $PM_{2.5}$ concentrations for mechanical injection systems compared with electrical systems ($p=0.08$), low temperature compared with high temperature ($p=0.09$), and region NM compared with region AGM ($p=0.09$). In all categories, the increase in $PM_{2.5}$ levels is relatively equal in the 1st and 2nd half of the bus ride.

.**Table 6a:** $PM_{2.5}$ concentrations on school **BUS** and **WALKING** routes. Results presented are geometric mean (Gmean), 95% confidence interval (95% CI), median, minimum (min), maximum (max), 3rd maximum (3rd max.) and standard deviation (SD) of exposure in µg/m^3, for all humidity conditions

Category (Sample Size)	Gmean	95% CI	Median	Min	Max	3rd Max	SD of Gmean
ALL (Bus+Walk) (106)	26	22–30	27	3	160	102	0.3
WALK (Students) (20)	10	7–13	11	3	33	16	0.3
BUS RIDE (86)	32	28–37	30	5	158	102	0.3
Short (<25min) (41)	37	30–44	30	13	158	97	0.3
Long (≥25min) (45)	29	24–34	30	5	102	64	0.3
New (>1997) (38)	32	26–40	31	5	158	97	0.3
Old (≤1997) (48)	32	27–38	30	9	111	91	0.2
Mechanically controlled injection (55)	32	28–37	30	9	111	91	0.2
Electronically controlled injection (31)	33	25–42	30	5	158	97	0.3
Morning ride (41)	33	28–39	32	5	91	87	0.3
Afternoon ride (45)	31	25–38	30	9	158	102	0.3
Region AGM (31)	33	26–42	29	9	158	97	0.3
Region G (30)	33	27–41	34	9	102	66	0.2
Region NM (25)	30	23–38	30	5	91	63	0.3
Low temp (<12˚C) (35)	35	28–42	34	7	104	83	0.3
High temp (≥12˚C) (51)	30	26–36	29	9	158	102	0.3
Low humidity (<60%) (39)	28	24–34	31	9	102	66	0.2
High humidity (≥60%) (47)	36	29–43	38	5	158	97	0.3
Ambient $PM_{2.5}$ Quartiles							
$PM_{2.5}$: Q1 (<1.95) (22)	24	19–32	22	9	97	55	0.3
$PM_{2.5}$: Q2 (1.95–3.80) (22)	31	26–37	32	9	63	50	0.2
$PM_{2.5}$: Q3 (3.90–6.9) (16)	37	29–47	31	21	87	64	0.2
$PM_{2.5}$: Q4 (>6.95) (26)	39	29–52	34	5	158	102	0.3

Fig.6 Exposure to PM2.5 (mg/m3) on school buses categorised by long vs. short ride, new vs. old bus and temp., high vs. low.



Note: The values graphed are the original exposure measurements in mg/m^3 recorded by the Dust Trak® which were log-transformed.

Table 6b: Cumulative concentrations of $PM_{2.5}$ ($\mu g/m^3$) during school **BUS** commutes. Results presented are Median and Mean Cumulative Exposures to $PM_{2.5}$ ($\mu g/m^3$) on school bus commutes. Results presented are CUM1 (median cumulative exposure in 1st half of commute), CUM2 (median cumulative exposure in 2nd half of commute), CUMT (median of total cumulative exposure) and CUMT 25%–75% (median of total cumulative exposure in 1st or 3rd quartile), mean T (mean of total cumulative exposure) and standard deviation (SD) of exposure.

Category (Sample Size)	**CUM1**	**CUM2**	**CUMT**	**CUMR 25%–75%**	**Mean T**	**SD**
BUS RIDE (Total): (86)	360	490	750	460–1,150	970	800
Short (<25min) (41)	230	260	530	340–760	630	430
Long (≥25min) (45)	540	550	990	730–1,540	1,280	920
New (>1997) (38)	290	390	720	390–1,240	1,020	1,010
Old (≤1997) (48)	390	360	780	510–1,150	930	580
Mechanically controlled injection (55)	390	380	800	520–1,150	990	700
Electronically controlled injection (31)	260	310	610	290–1,240	930	960
Morning ride (45)	300	380	750	490–1,120	910	630
Afternoon ride (41)	390	360	760	430–1,150	1,030	950
Region AGM (31)	240	260	530	410–700	590	330
Region G (30)	540	640	1,140	750–1,730	1,400	920
Region NM (25)	360	310	8000	340–1,050	920	820
Low temp (<12˚C) (35)	400	420	820	600–1,270	1,090	830
High temp (≥12˚C) (51)	300	360	660	410–1,120	880	770
Low humidity (<60%) (39)	390	260	760	410–1,120	940	830
High humidity (≥60%) (47)	330	400	750	500–1,250	990	780
Ambient $PM_{2.5}$ Quartiles						
$PM_{2.5}$: Q1 (<1.95) (22)	240	260	620	410–820	680	430
$PM_{2.5}$: Q2 (1.95–3.80) (22)	370	380	740	400–1,120	890	800
$PM_{2.5}$: Q3 (3.90–6.94) (16)	360	380	700	520–1,430	950	650
$PM_{2.5}$: Q4 (>6.95) (26)	520	550	1,000	500–1,630	1,280	1,010

Cumulative PM$_{2.5}$ concentrations on walking routes show the same trends as for average levels measured. Note that the average PM$_{2.5}$ results were not broken down into categories as was done here for cumulative exposure during walking commutes.

Non-parametric testing for a significant difference for cumulative measurements indicates that afternoon PM$_{2.5}$ levels were higher than morning levels ($p=0.07$). There is a significantly higher cumulative exposure in the third quartile range of ambient PM$_{2.5}$ than in the first quartile range ($p=0.02$).

Table 6c: PM$_{2.5}$ concentrations (μg/m^3) during **WALKING** commutes. Results presented are Median and Mean Cumulative Exposures to PM$_{2.5}$ (μg/m^3) on walking commutes. Results presented are CUM1 (median cumulative exposure in 1st half of commute), CUM2 (median cumulative exposure in 2nd half of commute), CUMT (median of total cumulative exposure) and CUMT 25%–75% (median of total cumulative exposure in 1st or 3rd quartile), mean T (mean of total cumulative exposure) and standard deviation (SD) of exposure. Measurements taken during all humidity conditions are included here.

Category (Sample Size)	**CUM1**	**CUM2**	**CUMT**	**CUMT 25%–75%**	**Mean T**	**SD**
Walk (Total): (20)	65	39	114	73–179	132	83
Morning walk (9)	46	43	83	39–224	94	56
Afternoon walk (11)	98	36	135	84 –155	163	90
Region AGM (8)	49	35	90	745–133	120	71
Region G (12)	80	72	145	67–203	146	89
Region NM (0)	--	--	--	--	--	--
Low temp (<12°C) (9)	52	28	80	40–155	113	99
High temp (≥12°C) (11)	68	52	125	85–220	147	67
Low humidity (<60%) (12)	72	35	132	76–204	136	74.
High humidity (≥60%) (8)	49	47	90	60–165	125	99
Ambient PM2.5 Quartiles						
PM$_{2.5}$: Q1 (<1.95) (6)	46	27	73	54–96	96	82
PM$_{2.5}$: Q2 (1.95–3.80) (3)	89	79	168	85–224	160	70
PM$_{2.5}$: Q3 (3.90–6.94)(10)	72	59	132	83–161	136	87
PM$_{2.5}$: Q4 (>6.95) (1)	111	110	220	220–220	220	0

Aerosol mass is increased due to water absorption from humidity conditions in the environment, and when humidity reaches 60% to 80% the Dust Trak® measurements can be increased (TSI, 2003). Thus, some measurements taken under conditions of high humidity are inaccurate. To verify the values obtained for this study, we re-analyzed the measurements obtained for $PM_{2.5}$, excluding all measurements for bus rides and walking routes where humidity was higher than 70%. These results are shown in Table 7a.

The number of walking routes included for this analysis was 12, and there are 42 bus routes. The geometric mean for all exposure routes decreased from 25.6 $\mu g/m^3$ when all humidity conditions were considered, to 23.2 $\mu g/m^3$ when only conditions below 70% were included. All other relationships are similar to Table 6a except for the disparity between electronically and mechanically controlled fuel injection systems. Mechanical injection recorded slightly higher $PM_{2.5}$ exposure levels, although this relationship is not significant.

Table 7a: $PM_{2.5}$ concentrations on school **BUS** and **WALKING** routes. Results presented are geometric mean (Gmean), 95% confidence interval (95% CI), median, minimum (min), maximum (max), 3rd maximum (3rd max) and standard deviation (SD) of exposure in $\mu g/m^3$, for results restricted to those collected when humidity conditions were <70%.

Category (Sample Size)	Gmean	95% CI	Median	Min	Max	3rd Max	SD of Gmean
ALL (Bus + Walk) (54)	23	19–29	234	3	158	87	0.3
WALK (Students) (12)	9	6–14	11	3	18	14	0.3
BUS RIDE: (42)	30	25–36	29	9	158	87	0.3
Short (<25min) (18)	32	24–43	28	13	158	53	0.3
Long (≥25) (24)	29	22–37	30	9	102	63	0.3
New (21)	31	23–42	28	11	158	63	0.3
Old (21)	29	23–36	29	9	87	50	0.2
Mechanically controlled injection (25)	31	25–38	31	9	87	63	0.2
Electronically controlled injection (17)	29	20–42	23	11	158	59	0.3
Morning ride (8)	32	18–54	29	11	87	43	0.3
Afternoon ride (34)	30	24–36	29	9	158	66	0.3
Region AGM (15)	28	19–41	24	9	158	40	0.3
Region G (17)	35	26–47	35	11	102	66	0.2
Region NM (10)	26	19–36	23	13	63	32	0.2
Low temp (<12°C) (9)	31	22–45	24	17	63	42	0.2
High temp (≥12°C) (33)	30	24–37	28	9	158	87	0.3

Table 7b summarizes the cumulative levels of $PM_{2.5}$ on the bus when measurements were restricted to those measured only when humidity conditions were less than 70%. As expected, we see higher exposure levels for longer bus commutes than shorter ones.

The results from testing for significance when $PM_{2.5}$ values are limited to <70% humidity are similar to those for the unrestricted dataset. Long commutes have significantly higher cumulative $PM_{2.5}$ concentrations than short commutes ($p<0.01$), mechanical injection has higher cumulative $PM_{2.5}$ concentrations than electrical injection ($p=0.02$) and region G is higher than region AGM ($p<0.01$).

Table 7b: $PM_{2.5}$ concentrations ($\mu g/m^3$) during school **BUS** commutes. Results presented are Median and Mean Cumulative levels of $PM_{2.5}$ ($\mu g/m^3$) on school bus commutes. Results presented are CUM1 (median cumulative exposure in 1st half of commute), CUM2 (median cumulative exposure in 2nd half of commute), CUMT (median of total cumulative exposure) and CUMT 25%–75% (median of total cumulative exposure in 1st or 3rd quartile), mean T (mean of total cumulative exposure) and standard deviation (SD) of exposure. Measurements taken during conditions below 70% humidity are included here.

Category (Sample Size)	**CUM1**	**CUM2**	**CUMT**	**CUMT 25%–75%**	**Mean T**	**SD**
BUS RIDE (Total): (42)	410	490	760	430–1,140	1,020	940
Short (<25min) (18)	250	190	450	290–700	570	440
Long (≥25min) (24)	540	490	1,040	750–1,500	1,360	1,070
New (>1997) (21)	330	280	700	290–1,110	1,080	1,230
Old (≤1997) (21)	530	370	820	530–1,140	960	540
Mechanically controlled injection (25)	530	400	910	660–1,150	1,110	800
Electronically controlled injection (17)	250	240	490	290–800	890	1,130
Morning ride (8)	390	330	760	430–120	810	510
Afternoon ride (34)	410	330	740	410–1,150	1,070	1,010
Region AGM (15)	310	210	530	400–760	590	350
Region G (17)	520	590	1,110	730–1,720	1,390	1,040
Region NM (10)	470	220	820	290–1,140	1,050	1,150
Low temp (<12°C) (9)	570	400	820	730–990	1,170	1,120
High temp (≥12°C) (33)	390	280	710	410–1,140	980	900
Ambient PM2.5 Quartiles						
$PM_{2.5}$: Q1 (<1.95) (11)	440	190	660	410–940	740	550
$PM_{2.5}$: Q2 (1.95–3.80) (15)	380	400	770	530–1,120	1,020	920
$PM_{2.5}$: Q3 (3.90–6.94) (7)	330	280	610	240–1,720	980	830
$PM_{2.5}$: Q4 (>6.95) (9)	520	590	1,090	390–1,550	1,400	1,370

The results for testing for significance between categories of cumulative $PM_{2.5}$ concentrations during walking commutes (Table 7c) showed only a significant difference between morning and afternoon exposures (p=0.06).

Table 7c: $PM_{2.5}$ concentrations ($\mu g/m^3$) during **WALKING** commutes. Results presented are Median and Mean Cumulative concentrations of $PM_{2.5}$ ($\mu g/m^3$) on school walking commutes. Results presented are CUM1 (median cumulative exposure in 1st half of commute), CUM2 (median cumulative exposure in 2nd half of commute), CUMT (median of total cumulative exposure) and CUMT 25%–75% (median of total cumulative exposure in 1st or 3rd quartile), mean T (mean of total cumulative exposure) and standard deviation (SD) of exposure. Exposure measurements taken during conditions below 70% humidity are included here.

Category (Sample Size)	CUM1	CUM2	CUMT	CUMT 25%–75%	Mean T	SD
WALK (Total): (54)	72	35	132	76–204	136	74
Morning walk (2)	44	46	132	26–155	90	92
Afternoon walk (10)	83	35	90	85–220	145	72
Region AGM (5)	52	33	85	67–96	106	88
Region G (7)	98	77	155	130–220	158	60
Region NM (0)	--	--	--	--	--	--
Low temp (<12°C) (4)	57	24	92	40–143	91	61
High temp (≥12°C) (8)	89	51	162	90–222	159	73
Ambient PM2.5 Quartiles						
$PM_{2.5}$: Q1 (<1.95) (5)	40	27	67	54–96	99	91
$PM_{2.5}$: Q2 (1.95–3.80) (2)	87	68	154	85–224	154	99
$PM_{2.5}$: Q3 (3.90–6.94) (4)	87	72	145	132–172	152	27
$PM_{2.5}$: Q4 (>6.95) (1)	111	109	220	220–220	220	0

Further analysis completed for $PM_{2.5}$ exposure can be found in Appendices 8 and 9.

Figure II (Appendix 8) shows the overall average exposure to $PM_{2.5}$ for each time point over the entire school day. This was calculated by averaging all available measurements for each time period shown in Figure III (Appendix 9).

4.4.2 Ultra-fine and fine particulate matter (<1.0 μm)

Concentrations of $PM_{1.0}$ were measured using the P-Trak®, which measures particle number rather than mass (Table 8a). There are a total of 111 bus and walking routes for which related $PM_{1.0}$ was measured. Ninety of these were bus routes and 21 were walking routes. Unlike the Dust Trak®, the P-Trak® is not affected by humidity; therefore, measurements for all ambient conditions of humidity are considered in our analysis and presented together. Similarly as for $PM_{2.5}$, $PM_{1.0}$ concentrations were approximately 3 times higher for bus rides than walking routes (p<0.001). There was also a significantly higher concentration of $PM_{1.0}$ when ambient temperature was lower than 12ºC, and in the morning compared with warmer days and in the afternoon. $PM_{1.0}$ concentrations tend to be higher for longer routes than shorter routes, for newer buses than older ones, and for electronically controlled injection systems than mechanically controlled injection systems. These differences were not statistically significant. Table 8b presents bus-only data

Table 8a: Concentrations of PM$_{1.0}$ on school **BUS** and **WALKING** routes. Results presented are geometric mean (Gmean), 95% confidence interval (95% CI), median, minimum (min), maximum (max), 3rd maximum (3rd max) and standard deviation (SD) of particle counts per cm^3.

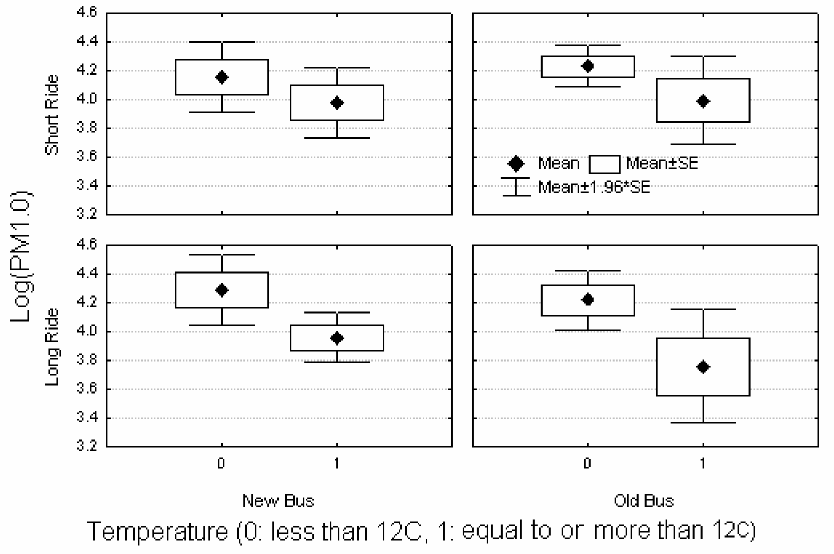
Category (Sample Size)	**Gmean**	**95% CI**	**Median**	**Min**	**Max**	**3rd Max**	**SD**
ALL (Bus+Walk) (111)	9,000	7,300–11,000	9,300	30	134,300	58,000	0.5
WALK (Students) (21)	4,00	3,000–5,500	4,200	930	11,700	9,000	0.3
BUS RIDE: (90)	10,80	8,500–13,700	11,800	30	134,300	58,000	0.5
Short (<25min) (44)	11,700	8,500–17,000	11,600	1,600	134,300	48,900	0.4
Long (≥25min) (46)	10,000	7,000–14,400	11,800	30	69,800	39,200	0.5
New (>1997) (45)	11,400	9,000–15,000	11,300	3,100	58,000	33,000	0.4
Old (≤1997) (45)	10,200	7,000–15,200	12,900	30	134,300	27,500	0.6
Mechanically controlled injection (53)	9,400	6,700–13,200	10,700	30	134,300	45,400	0.5
Electronically controlled injection (37)	13,200	9,800–17,900	13,100	3,100	58,000	47,500	0.4
Morning ride (48)	18,100	14,300–23,000	18,200	2,800	134,300	58,000	0.4
Afternoon ride (42)	6,000	4,200–8,500	5,600	30	39,200	26,100	0.5
Region AGM (31)	7,700	4,600–12,900	6,80	30	58,000	47,500	0.6
Region G (30)	13,500	9,400–19,400	13,300	1,600	134,300	45,400	0.4
Region N (29)	12,300	8,800–12,100	12,00	3,100	46,900	34,200	0.4
Low temp. (<12˚C) (33)	16,600	13,000–21,300	18,200	3,900	69,800	39,000	0.3
High temp (≥12˚C) (57)	8,400	6,000–11,700	7,500	30	134,300	48,900	0.5
Humidity <60% (45)	8,400	5,600–12,500	6,600	30	134,300	47,500	0.6
Humidity ≥60% (45)	13,900	11,000–17,700	13,400	2,700	69,800	41,900	0.3
Ambient PM2.5 Quartiles							
PM$_{2.5}$: Q1 (<1.95) (20)	8,800	6,200–12,500	7,000	3,300	34,200	30,000	0.3
PM$_{2.5}$: Q2 (1.95–3.80) (28)	9,300	6,500–13,300	9,300	2,300	69,800	33,000	0.4
PM$_{2.5}$: Q3 (3.90–6.9) (17)	10,900	5,800–20,700	11,300	1,600	134,300	39,200	0.5
PM$_{2.5}$: Q4 (>6.95) (25)	14,800	8,000–27,000	18,000	30	48,900	45,300	0.6

Table 8b: Concentrations of $PM_{1.0}$ (particles/cm^3) during school bus commutes. Median and Mean Cumulative concentrations. Results presented are CUM1 (median cumulative exposure in 1st half of commute), CUM2 (median cumulative exposure in 2nd half of commute), CUMT (median of total cumulative exposure) and CUMT 25%–75% (median of total cumulative exposure in 1st or 3rd quartile), mean T (mean of total cumulative exposure) and standard deviation (SD) of exposure.

Category (Sample Size)	**CUM1**	**CUM2**	**CUMT**	**CUMT25%–75%**	**Mean T**	**SD**
BUS RIDE (Total): (90)	126,600	141,600	279,800	133,300–585,200	471,400	513,600
Short (<25min) (44)	72,400	98,200	174,30	57,000–460,000	319,800	450,300
Long (≥25min) (46)	176,800	221,300	405,000	210,700–917,900	616,400	532,900
New (>1997) (45)	146,000	150,700	296,800	133,300–671,800	478,100	475,000
Old (≤1997) (45)	107,000	139,000	266,300	139,000–559,600	464,700	554,900
Mechanically controlled injection (53)	100,100	135,100	251,800	130,900–529,300	435,300	533,200
Electronically controlled injection (37)	183,000	180,800	407,400	141,700–731,700	523,200	486,600
Morning ride (42)	224,500	217,000	453,500	201,800–886,900	635,900	594,600
Afternoon ride (48)	67,600	99,200	176,200	74,300–312,900	283,400	315,500
Region AGM (31)	56,400	101,100	178,200	63,000–284,200	221,600	190,600
Region G (30)	220,700	230,800	493,100	275,400–975,600	731,900	651,000
Region NM (29)	114,400	141,000	316,900	82,200–691,100	469,000	467,700
Low temp (<12˚C) (33)	222,600	180,800	434,000	192,900–813,000	583,800	529,900
High temp (≥12˚C) (57)	90,200	135,100	246,400	117,700–521,200	406,300	497,000
Low humidity (<60%) (45)	97,100	142,100	246,600	111,600–731,700	488,200	585,200
High humidity (≥60%) (45)	164,700	141,000	316,900	170,400–579,700	454,600	436,500
Ambient PM2.5 Quartiles						
$PM_{2.5}$: Q1 (<1.95) (20)	103,400	150,147	259,000	187,500–406,300	355,500	296,900
$PM_{2.5}$: Q2 (1.95–3.80)(28)	75,800	116,426	192,200	87,300–552,200	404,300	499,000
$PM_{2.5}$: Q3 (3.90–6.94)(17)	79,300	111,585	178,200	70,000–572,600	533,700	727,000
$PM_{2.5}$: Q4 (>6.95) (25)	214,800	263,808	485,900	246,400–917,900	596,900	490,200

Figure 7 shows the relationship between mean $PM_{1.0}$ levels for long and short bus rides and new and old buses when compared in terms of high and low temperature. The category with the highest mean level of $PM_{1.0}$ is for old buses, on short commutes and in conditions of low ambient temperature. The lowest mean exposure occurred on old buses on long commutes and at high temperatures.

Fig.7 Exposure to PM1.0 (pt/cm3) on school buses, categorised by long vs. short rides, old vs. new buses and temp., high vs. low.



Note: The values graphed are the original exposure measurements in particles per cm^3 recorded by the P-Trak® and then log-transformed.

The cumulative levels of $PM_{1.0}$ while walking (Table 8c) were also compared using a non-parametric test for significance (Mann-Whitney U test). Results for walking commutes show that cumulative levels during morning rides were significantly higher than in the afternoon (p=0.04). Cumulative exposure levels were also higher at higher humidity than during lower humidity conditions (p=0.01).

Table 8c: Cumulative $PM_{1.0}$ concentrations (particles/cm^3) during **WALKING** commutes. Results presented are Median and Mean Cumulative levels of $PM_{1.0}$ (particle/cm^3) on walking commutes. Results presented are CUM1 (median cumulative exposure in 1st half of commute), CUM2 (median cumulative exposure in 2nd half of commute), CUMT (median of total cumulative exposure) and CUMT 25%–75% (median of total cumulative exposure in 1st or 3rd quartile), mean T (mean of total cumulative exposure) and standard deviation (SD)

Category (Sample Size)	**CUM1**	**CUM2**	**CUMT**	**CUMT 25%–75%**	**Mean T**	**SD**
Walk (Total): (21)	17,400	173,200	45,400	25,100–66,600	51,900	37,600
Morning Walk (10)	27,000	25,900	64,700	34,900– 107,1300	67,300	39,500
Afternoon Walk (11)	11,700	16,300	30,500	14,600–53,400	37,900	31,200
Region AGM (8)	19,400	19,100	46,700	23,700–86,800	55,300	38,800
Region G (11)	12,700	16,400	34,900	10,800–56,400	42,000	32,100
Region NM (2)	59,000	33,000	92,100	53,400–130,900	92,100	54,800
Low temp (<12˚C) (10)	17,500	23,600	49,400	33,800–67,500	58,200	38,900
High temp (≥12˚C) (11)	14,300	16,300	30,500	14,600–66,600	46,100	37,300
Low humidity (<60%) (12)	14,200	16,400	32,200	18,400–49,400	33,000	18,400
High humidity (≥60%) (9)	27,900	30,000	67,500	53,400–113,700	77,000	42,800
Ambient PM2.5 Quartiles						
$PM_{2.5}$: Q1 (<1.95) (7)	31,000	22,300	45,400	22,200–62,900	41,600	21,000
$PM_{2.5}$: Q2 (1.9–3.8) (3)	44,700	16,300	30,500	7,800–66,600	34,900	29,600
$PM_{2.5}$: Q3 (3.9–6.9) (10)	26,000	16,900	44,200	25,200–107,100	56,300	41,900
$PM_{2.5}$: Q4 (>6.9) (1)	87,000	--	--	--	--	--

4.4.3 Black carbon

Concentration of BC was measured using an Aethalometer™. Data were smoothed to remove negative values (statistical methods section). Exposure was measured for 11 walking trips and 46 bus trips. Exposure to BC on the school bus is more than three times greater when compared with walking (Gmean = 0.7 vs. 0.2 μg/m^3, $p<0.001$). The level of BC recorded for bus rides was significantly higher on shorter routes and on older buses than on longer routes and newer buses. Buses with mechanically controlled injection systems recorded higher BC levels than buses with electronically controlled injection systems. No other significant differences were observed for any categories of comparison except for walking when compared with school bus exposure (Table 9a).

Table 9a: Concentrations of BC on school **BUS** and **WALKING** routes. Results presented are geometric mean (Gmean), 95% confidence interval (95% CI), median, minimum (min), maximum (max), 3rd maximum (3rd max) and standard deviation (SD) in μg/m^3

Category (Sample Size)	Gmean	95% CI	Median	Min	Max	3rd Max	SD of Gmean
ALL (Bus+Walk) (57)	0.5	0.4–0.7	0.6	0.03	15.3	4.6	0.6
WALK (Students) (11)	0.2	0.1–0.4	0.2	0.03	0.7	0.4	0.8
BUS Ride (46)	0.7	0.5–0.9	0.7	0.1	15.3	4.6	0.5
Short (<25min) (13)	0.8	0.4–1.4	0.7	0.2	5.5	1.7	0.4
Long (≥25min) (33)	0.7	0.5–1.0	0.7	0.1	15.3	3.0	0.5
New (>1997) (20)	0.5	0.4–0.7	0.5	0.1	1.9	1.1	0.3
Old (≤1997) (26)	0.9	0.6–1.4	0.8	0.1	15.3	4.6	0.5
Mechanically controlled injection (33)	0.8	0.5–1.2	0.7	0.1	15.3	4.6	0.5
Electronically controlled injection (13)	0.5	0.3–0.8	0.6	0.1	1.9	1.0	0.3
Morning ride (23)	0.9	0.7–1.3	0.9	0.3	5.5	2.2	0.3
Afternoon ride (23)	0.5	0.3–0.9	0.4	0.1	15.3	1.7	0.5
Region AGM (8)	0.5	0.2–1.2	0.5	0.1	1.9	1.2	0.4
Region G (26)	0.8	0.6–1.3	0.7	0.1	15.3	4.6	0.5
Region NM (12)	0.5	0.3–1.0	0.6	0.1	2.2	1.3	0.5
Low temp (<12˚C) (16)	0.8	0.5–1.2	0.7	0.1	15.3	1.7	0.4
High temp (≥12˚C) (30)	0.5	0.3–0.8	0.6	1.2	1.9	3.0	0.5
Humidity <60% (22)	0.5	0.3–0.8	0.5	0.1	5.5	1.6	0.5
Humidity ≥60% (24)	1.0	0.7-1.4	0.8	0.3	15.3	2.2	0.4
Ambient PM2.5 Quartiles							
$PM_{2.5}$: Q1 (<1.95) (12)	0.6	0.3–1.4	0.7	0.1	4.6	1.9	0.5
$PM_{2.5}$: Q2 (1.95–3.80) (12)	0.4	0.3–0.7	0.4	0.2	1.3	1.0	0.3
$PM_{2.5}$: Q3 (3.90) (9)	1.3	0.5–3.6	1.0	0.3	15.3	2.2	0.6
$PM_{2.5}$: Q4 (>6.95) (13)	0.8	0.6–1.1	0.9	0.3	1.6	1.3	0.2

The cumulative BC levels during bus commutes are presented in Table 9b. Tests for significance were performed to compare cumulative exposures for each category in this table. Significant differences were found for long bus rides compared with short bus ($p=0.05$), morning rides compared with afternoon rides ($p=0.02$) and region G compared with region AGM ($p<0.01$). Marginal significance was found for high humidity ($p=0.07$) and region G compared with NM ($p=0.07$).

Table 9b: BC concentrations (μg/m^3) during school **BUS** commutes. Results presented are Median and Mean Cumulative Exposures to BC (μg/m^3) on school bus commutes. Results presented are CUM1 (median cumulative exposure in 1st half of commute), CUM2 (median cumulative exposure in 2nd half of commute), CUMT (median of total cumulative exposure) and CUMT 25%–75% (median of total cumulative exposure in 1st or 3rd quartile), mean T (mean of total cumulative concentrations) and standard deviation (SD).

Category (Sample Size)	CUM1	CUM2	CUMT	CUMT 25–75%	Mean T	SD
BUS RIDE (Total): (46)	10.3	9.4	21.4	10.0–33.8	34.0	47.4
Short (<25min) (13)	6.5	7.4	18.1	5.8–23.1	22.0	31.1
Long (≥25min) (33)	11.2	9.6	24.8	12.7–35.6	38.7	52.1
New (>1997) (20)	7.7	6.2	18.4	8.5–24.8	19.0	11.8
Old (≤1997) (26)	12.1	12.2	25.5	11.0–48.5	45.5	60.2
Mechanically controlled injection (33)	10.5	11.3	21.8	11.0–34.1	39.4	54.7
Electronically controlled injection (13)	10.1	5.0	20.9	9.9–24.8	20.1	12.6
Morning ride (23)	10.6	14.4	26.4	18.0–34.1	37.2	39.9
Afternoon ride (23)	6.5	5.7	12.7	5.4–24.8	30.7	54.7
Region AGM (8)	2.9	4.1	5.8	5.2–21.8	12.6	10.6
Region G (26)	12.8	14.6	26.8	16.1–42.0	46.6	5.9
Region NM (12)	6.6	8.3	17.1	8.5–25.5	20.8	18.4
Low temp (<12˚C) (16)	11.4	12.7	25.5	14.5–32.2	34.9	43.0
High temp (≥12˚C) (30)	7.9	6.4	20.7	6.9–33.8	33.5	50.3
Low humidity (<60%) (22)	7.1	5.9	13.1	5.4–35.6	25.9	30.8
High humidity(≥60%) (24)	10.9	12.6	24.7	17.1–32.3	41.3	58.4
Ambient PM2.5 Quartiles						
PM$_{2.5}$: Q1 (<1.95) (12)	10.9	7.5	22.5	11.5–27.5	36.8	50.5
PM$_{2.5}$: Q2 (1.95–3.80) (12)	7.0	5.9	11.9	5.4–24.5	15.0	11.8
PM$_{2.5}$: Q3 (3.90–6.94) (9)	10.6	14.1	20.6	12.7–70.1	612.0	83.6
PM$_{2.5}$: Q4 (>6.95) (13)	10.5	14.3	26.4	20.4–33.8	29.4	18.0

Table 9c also shows cumulative BC concentrations for walking commutes. Significant differences between means of cumulative concentrations were found for morning commutes compared with afternoon commutes ($p<0.01$) and commutes during high humidity conditions ($p=0.01$).

Table 9c: BC concentrations (μg/m^3) during **WALKING** commutes. Results presented are Median and Mean Cumulative Exposures to BC (μg/m^3) on walking commutes. Results presented are CUM1 (median cumulative exposure in 1st half of commute), CUM2 (median cumulative exposure in 2nd half of commute), CUMT (median of total cumulative exposure) and CUMT 25%–75% (median of total cumulative exposure in 1st or 3rd quartile), mean T (mean of total cumulative concentrations) and standard deviation (SD)

Category (Sample Size)	CUM1	CUM2	CUMT	CUMT 25–75%	Mean T	SD
Walk (Total): (11)	0.9	1.6	2.5	0.8–7.1	3.5	3.2
Morning walk (5)	3.9	2.2	7.1	4.5–7.5	6.4	2.3
Afternoon walk (6)	0.6	1.0	1.1	0.8–1.8	1.1	1.1
Region AGM (4)	2.3	1.1	3.9	0.02–7.3	3.7	4.2
Region G (7)	0.9	1.6	2.5	1.4–4.5	3.4	2.8
Region NM (0)	-	-	-	-	-	-
Low temp (<12˚C) (4)	2.1	1.9	4.0	3.0–6.9	4.9	3.0
High temp (≥12˚C) (7)	0.7	1.3	1.4	0.8–7.1	2.7	3.3
Low humidity (<60%) (7)	0.7	1.3	1.5	0.8–2.5	1.6	1.6
High humidity (≥60%) (4)	4.0	2.8	7.3	5.3–8.4	6.8	2.4
$PM_{2.5}$: Q1 (<1.95) (4)	0.8	0.9	1.6	0.02–3.0	1.5	1.9
$PM_{2.5}$: Q2 (1.95–3.80) (2)	2.3	1.7	3.9	0.8–7.1	3.9	4.4
$PM_{2.5}$: Q3 (3.90–6.95) (5)	2.4	2.2	4.5	1.8–7.5	4.9	3.4
$PM_{2.5}$: Q4 (>6.95) (0)	--	--	--	--	--	--

4.4.4 Ultraviolet absorbing aromatic organic material

In addition to measuring BC, the Aethalometer™ also measures non-black, UV absorbing aromatic organic filterable material at a wavelength of 370 nm. This measure of UV absorbing material includes mostly PAH. The same number of routes was measured for both UV absorbing aromatic organic material and BC, as they were measured simultaneously (Table 10a). An identical smoothing technique as that used for BC was applied to these measurements (statistical methods section). No significant difference was observed for any category of comparison, except for walking when compared with school bus commutes ($p<0.001$). Compared with walking, the mean concentration of BC in school buses is approximately 3 times greater.

Table 10a: Concentrations of UV absorbing aromatic organic material on school **BUS** and **WALKING** routes. Results presented are geometric mean (Gmean), 95% confidence interval (95% CI), median, minimum (min), maximum (max), 3rd maximum (3rd max) and standard deviation (SD) in ng/m^3.

Category (Sample Size)	Gmean	95% CI	Median	Min	Max	3rd Max	SD of Gmean
ALL (Bus+Walk) (57)	630.4	490.6–809.9	681.9	129.8	14516.8	2560.8	0.4
WALK (Students) (11)	265.4	180.7–389.7	241.4	131.9	761.8	358.9	0.3
BUS RIDE (46)	775.3	593.4–1012.9	748.1	129.8	4516.8	2560.8	0.4
Short (<25min) (13)	942.2	593.9–1494.9	759.0	337.4	4981.5	1903.7	0.4
Long (≥25min) (33)	717.9	512.9–1003.9	736.5	129.8	14516.8	1946.4	0.4
New (>1997) (20)	603.2	438.0–830.7	648.7	181.6	2114.7	1222.1	0.3
Old (≤1997) (26)	940.4	563.6–1412.4	807.9	129.8	14516.8	2560.8	0.4
Mechanically controlled injection (33)	82.5	631.9–1232.5	759.0	129.8	14516.8	2560.8	0.4
Electronically controlled injection (13)	557.9	362.5–858.7	522.6	181.6	1978.2	1008.5	0.3
Morning ride (23)	947.3	696.1–1289.2	953.4	318.4	4981.5	1946.4	0.3
Afternoon ride (23)	634.4	406.0–991.5	636.7	129.8	14516.8	1903.7	0.5
Region AGM (8)	638.6	314.5–1296.6	632.8	129.8	1978.2	989.3	0.4
Region G (26)	860.2	575.0–1287.0	754.5	181.6	14516.8	2560.8	0.4
Region NM (12)	704.3	442.4–1121.0	801.0	206.9	2114.7	1222.1	0.3
Low temp (<12˚C) (16)	719.2	505.7–1022.8	761.4	187.8	1332.7	1332.7	0.3
High temp (≥12˚C) (30)	635.4	432.6–933.2	549.6	81.9	2560.8	2560.8	0.5
Humidity <60% (22)	605.1	407.1–899.3	576.8	129.8	4981.5	1594.7	0.4
Humidity ≥60% (24)	973.0	676.0–1400.5	863.8	318.4	14516.8	1946.4	0.4
Ambient PM2.5 Quartiles							
$PM_{2.5}$: Q1 (<1.95) (12)	555.6	288.5–1070.0	595.7	81.9	1332.7	1332.7	0.5
$PM_{2.5}$: Q2 (1.95–3.80) (12)	447.5	294.2680.7	388.5	144.2	978.8	978.7	0.3
$PM_{2.5}$: Q3 (3.90–6.94) (9)	1233.3	473.13214.9	740.3	309/6	1946.4	1946.4	0.5
$PM_{2.5}$: Q4 (>6.95) (13)	731.4	549.1974.2	801.2	334.7	1008.5	1008.5	0.2

A comparison of cumulative levels of UV absorbing organic material on the bus (Table 10b) showed similar trends to other pollutants. Old buses' exposure had marginally significantly higher cumulative levels than newer buses (p=0.078). On-bus concentration was significantly higher in the third quartile of ambient $PM_{2.5}$ than the first quartile (p=0.04).

Table 10b: Concentrations of UV absorbing material (ng/m^3) during school **BUS** commutes. Results presented are Median and Mean Cumulative levels of UV absorbing material (ng/m^3) on school bus commutes. Results presented are CUM1 (median cumulative exposure in 1st half of commute), CUM2 (median cumulative exposure in 2nd half of commute), CUMT (median of total cumulative exposure) and CUMT 25%–75% (median of total cumulative exposure in 1st or 3rd quartile), mean T (mean of total cumulative concentration) and standard deviation (SD).

Category (Sample Size)	CUM1	CUM2	CUMT	CUMT 25–75%	Mean T	SD
BUS RIDE (Total): (46)	10,000	8,500	21,200	12,000–33,100	34,100	44,600
Short (<25min) (13)	6,800	7,900	18,200	6,700–23,800	22,300	27,400
Long (≥25min) (33)	11,800	8,500	24,100	13,100–36,200	38,700	49,400
New (>1997) (20)	9,300	7,500	18,000	12,400–26,900	20,900	11,600
Old (≤1997) (26)	11,3007	10,700	23,000	10,200–50,500	44,200	56,900
Mechanically controlled injection (33)	10,000	9,900	22,100	13,100–35,000	39,100	51,400
Electronically controlled injection (13)	11,600	5,700	18,800	12,000–27,400	21,300	13,100
Morning ride (23)	8,600	6,400	15,300	8,400–26,400	32,000	51,800
Afternoon ride (23)	10,700	14,200	26,000	18,200–35,000	36,200	37,100
Region AGM (8)	4,900	6,200	10,100	6,200–21,000	13,500	9,000
Region G (26)	13,200	14,000	26,200	15,400–48,600	45,800	55,800
Region NM (12)	8,800	8,500	18,700	13,300–26,400	22,500	15,600
Low temp (<12˚C) (16)	11,300	12,000	24,700	16,000–33,000	35,300	40,000
High temp (≥12˚C) (30)	9,000	7,900	18,500	10,200–35,000	33,500	47,500
Low humidity (<60%) (22)	9,000	6,600	16,200	8,400–35,000	27,000	28,500
High humidity(≥60%) (24)	10,500	11,800	24,700	16,800–33,000	40,600	55,300
$PM_{2.5}$: Q1 (<1.95) (12)	11,700	7,400	22,100	12,000–30,200	37,200	48,000
$PM_{2.5}$: Q2 (1.95–3.80) (12)	7,000	6,600	13,200	8,400–24,100	16,600	10,300
$PM_{2.5}$: Q3 (3.90–6.94) (9)	10,700	15,100	25,400	15,300–64,100	59,600	78,200
$PM_{2.5}$: Q4 (>6.95) (13)	10,000	13,800	24,100	18,200–36,200	29,900	19,000

The cumulative concentrations of UV absorbing organic material for walking commutes (Table 10c) also showed significant differences between morning and afternoon exposure levels (p=0.003). When humidity was high, cumulative exposure levels were significantly elevated (p=0.085). Cumulative exposure was significantly affected by ambient $PM_{2.5}$ and the cumulative levels were higher for walking students when ambient $PM_{2.5}$ levels were in the third quartile range when compared with the first quartile (p=0.049).

Table 10c: Concentrations of UV absorbing material (ng/m^3) during **WALKING** commutes. Results presented are Median and Mean Cumulative levels of UV absorbing material (ng/m^3) during walking commutes. Results presented are CUM1 (median cumulative exposure in 1st half of commute), CUM2 (median cumulative exposure in 2nd half of commute), CUMT (median of total cumulative exposure) and CUMT 25%–75% (median of total cumulative exposure in 1st or 3rd quartile), mean T (mean of total cumulative levels) and standard deviation (SD).

Category (Sample Size)	CUM1	CUM2	CUMT	CUMT 25–75%	Mean T	SD
BUS RIDE (Total): (46)	10,000	8,500	21,200	12,000–33,100	34,100	44,600
Short (<25min) (13)	6,800	7,900	18,200	6,700–23,800	22,300	27,400
Long (≥25min) (33)	11,800	8,500	24,100	13,100–36,200	38,700	49,400
New (>1997) (20)	9,300	7,500	18,000	12,400–26,900	20,900	11,600
Old (≤1997) (26)	11,3007	10,700	23,000	10,200–50,500	44,200	56,900
Mechanically controlled injection (33)	10,000	9,900	22,100	13,100–35,000	39,100	51,400
Electronically controlled injection (13)	11,600	5,700	18,800	12,000–27,400	21,300	13,100
Morning ride (23)	8,600	6,400	15,300	8,400–26,400	32,000	51,800
Afternoon ride (23)	10,700	14,200	26,000	18,200–35,000	36,200	37,100
Region AGM (8)	4,900	6,200	10,100	6,200–21,000	13,500	9,000
Region G (26)	13,200	14,000	26,200	15,400–48,600	45,800	55,800
Region NM (12)	8,800	8,500	18,700	13,300–26,400	22,500	15,600
Low temp (<12˚C) (16)	11,300	12,000	24,700	16,000–33,000	35,300	40,000
High temp (≥12˚C) (30)	9,000	7,900	18,500	10,200–35,000	33,500	47,500
Low humidity (<60%) (22)	9,000	6,600	16,200	8,400–35,000	27,000	28,500
High humidity(≥60%) (24)	10,500	11,800	24,700	16,800–33,000	40,600	55,300
$PM_{2.5}$: Q1 (<1.95) (12)	11,700	7,400	22,100	12,000–30,200	37,200	48,000
$PM_{2.5}$: Q2 (1.95–3.80) (12)	7,000	6,600	13,200	8,400–24,100	16,600	10,300
$PM_{2.5}$: Q3 (3.90–6.94) (9)	10,700	15,100	25,400	15,300–64,100	59,600	78,200
$PM_{2.5}$: Q4 (>6.95) (13)	10,000	13,800	24,100	18,200–36,200	29,900	19,000

4.4.5 Ranking factors

In the present analysis of pollutant levels, we also provided a ranking of the importance of each factor that may influence the concentrations of $PM_{2.5}$, $PM_{1.0}$, BC and UV absorbing material. Using multivariate linear regression, we ranked age of bus, duration of bus and walk commutes, ambient temperature, ambient humidity and ambient $PM_{2.5}$ according to regression coefficients. These values can be found in Table 11. The regression coefficients that are significant are indicated in letter “s”. For $PM_{1.0}$, temperature has the greatest effect on exposure in the bus. Low temperature corresponds to significantly higher levels of $PM_{1.0}$ on the bus. For $PM_{2.5}$, ambient $PM_{2.5}$ levels, followed by duration of bus ride, have the greatest effect on the concentrations in the bus. Note that the bus commute duration was negatively associated with $PM_{2.5}$ concentrations, indicating that longer duration had lower $PM_{2.5}$ concentrations. One interpretation for this negative association may be that during a long bus ride, the bus travelled mostly in rural areas and did not stop and open the door frequently, whereas a short bus ride took place usually near the city centre with higher traffic and stopped frequently to pick up students. This may have resulted in the difference in $PM_{2.5}$ levels in a bus with different commute durations. Ambient $PM_{2.5}$ had a significant impact on the level of $PM_{2.5}$ during walking commutes. In increasing order, humidity, duration and ambient $PM_{2.5}$ have a significant effect on exposure during walking commutes for BC and UV absorbing organic material.

Table 11: Impact of explanatory variables on pollutant levels while commuting. Regression coefficients are shown here, and factors that have a significant impact on exposure are marked.

Variable	**$PM_{1.0}$**		**$PM_{2.5}$**		**BC**		**UV absorbing aromatic material**	
	Bus	**Walk**	**Bus**	**Walk**	**Bus**	**Walk**	**Bus**	**Walk**
Bus age	-247	N/A	3X10-4	N/A	87	N/A	77	N/A
Duration of commute	-184	-161	**-5X10-4 (s)**	-4X10-4	-18	**-16 (s)**	-18	**-17 (s)**
Temperature	**-710 (s)**	-37	-2X10-4	3X10-4	31	-0.1	35	5
Relative humidity	48	51	6X10-5	6X10-5	18	**10 (s)**	18	**9 (s)**
Ambient $PM_{2.5}$	464	439	**1X10-3 (s)**	**1X10-3 (s)**	-21	**32 (s)**	-24	**41 (s)**

N/A: Not applicable to walking

Note: Factors that have a significant impact on exposure are marked in letter “s”. A negative sign in front of the coefficient indicates that the variable significantly reduces exposures whereas a positive sign indicates that exposure is significantly increased.

4.4.6 Volatile organic compounds

Volatile organic compounds were measured using SUMMA canisters with flow controllers. A total of 50 VOC samples were collected and 41 of those yielded results, which were analyzed (Graham, 2003). Thirty-seven of these samples represented school bus exposure and four represented walking routes. The VOC samples were collected only during commute periods and not throughout the entire day as was done for other pollutants.

VOC results reflect integrated samples and are not categorized by morning and afternoon ride, but by frequency of occurrence of the specific VOC of concern in the samples. All the VOC, which were analyzed, are listed in Appendix 3. Appendix 10 indicates those VOC that were detected at least once in samples analyzed from all bus routes, and they are listed by order of occurrence as a percentage of the total number of samples (i.e. from most commonly detected VOC to least commonly detected). Those VOC, which are most important either due to their carcinogenicity (1,3-butadiene, benzene) or because they suggest exposure to vehicle emissions (toluene, ethyl-benzene) are emphasized in bold. The mean levels of these key VOC measured on bus commutes can be found in Table 12.

The majority of VOC levels were measured above the detection limit in the SUMMA canister samples collected on buses. The number of VOC found in samples collected from students who walked to school was comparatively smaller (Appendix 11).

No major differences in the types of VOC detected in each region were noted (Appendices 12, 13 and 14).

Table 12: The arithmetic means (minimum, maximum) of key VOC in ng/L, by region

Carcinogenic VOC	**Alexander Gibson Memorial**	**Gesner Street**	**New Maryland**
1,3-butadiene	0.4 (0.4–0.4)	0.6 (0.4–0.8)	Below detection limit
Benzene	1.6 (0.8–1.9)	1.4 (0.7–2.8)	2.4 (0.8–5.5)
Traffic Exhaust Markers			
Toluene	6.1 (2.6–14.1)	5.2 (2.1–15.7)	17.0 (2.5–123.8)
E-benzene	0.9 (0.4–1.3)	1.1 (0.3–3.3)	2.0 (0.3–8.0)

Three categories often used to assess automotive emissions in the air are non-methane hydrocarbons, benzene-toluene-xylene (BTX) and the California Air Resource Board (CARB) grouping, which includes ethyl-benzene, 1,3-butadiene and styrene. The BTX group and the CARB as a percentage of the total non-methane hydrocarbon were calculated to determine the relative compositions of the different mixtures sampled. The BTX portion ranged from 1.5% to 26.4% of the sample. The CARB grouping showed a similar wide variation ranging from 1.76% to 27.6%. The samples from the walking groups are less than 9.2% and 10.15% for the BTX and CARB groups, respectively. This suggests that walking is generally associated with lower exposures, but riding has a wider range of exposure. With respect to VOC, neither the duration of the ride nor the schools and location appear to be significantly associated with the level of VOC. The BTX for AGM ranged from 4.2% to 20.0%, for G it ranged from 1.76% to 27.67% and for NM it ranged from 7.8% to 23.24%.

For the window configuration, the values ranged from 3.27% to 15.12% for all closed, 1.76% to 27.6% for slightly open, 9.06% to 23.2% for moderate number opened and 10.52% to 21.48% for nearly fully opened. These distributions show a tendency toward higher percentages of BTX with the windows open, but on longer rides the open windows tended to lower the overall amounts of the materials on the bus.

When non-methane hydrocarbons (NMHC) are calculated as a measure of total VOC levels, the amount ranged from a low of 25.69 $\mu g/m^3$ to a high of 1730.83 $\mu g/m^3$. When the highest seven sample days were compared with the lowest seven sample days based on NMHC, the proportion of traffic- and diesel-generated BTX was not different. This suggests that mechanical conditions, ventilation on the bus or route factors are playing a more dominant role in the higher concentrations. However, two sampling days of VOC indicate a disproportionate level of organic alkenes or halogenated aliphatic compounds. The sources of these compounds are not known.

5. Discussion

5.1 Conditions of measurements

The analysis in this report identified and described the key factors involved as determinates of the exposures during the commutes (i.e. bus rides and walking to and from three schools in two school districts (17 and 18) in New Brunswick [Appendix 1, Map 1]). Data on particles, BC and VOC were obtained during the bus ride or while walking. Conditions recorded include activities on the bus, number of bus stops, window configuration of the bus, weather and ambient air $PM_{2.5}$. Bus drivers followed the normal practices with respect to student pick-up and drop-off locations and idling. Two schools have specified policies to limit idling; one does not. With the exception of the VOC measurements, the sampling and data logs continued for the entire school day, but only the exposure levels during the commute periods were analyzed. No unusual events occurred during the period of testing. Thus, we believe that this dataset represents the typical conditions during commutes to and from school experienced by New Brunswick elementary schoolchildren for the period between April and June 2003.

5.1.1 Participating buses and routes

Table 1, as well as Appendix 4, show all buses involved in the study. The fleets of the two school districts tested did not differ greatly for any of the parameters listed in the tables, and we believe them to be a representative sample of the New Brunswick school bus fleets. The average age of buses was 6 to 7 y, ranging from 1 to 15 y. All buses tested passed the smoke opacity test of their exhaust (Appendix 15). These and further results show that the buses tested are very well maintained. The New Brunswick Vehicle Management Agency follows Section 4006 of its Policy and Procedure Manual, which outlines the preventive maintenance policy for fleet buses. The program is completed annually, and schedules are formulated based upon the elapsed time from the last service interval. The current Management Vehicle Inspection (MVI) regulation requires the bus to be inspected every 6 months. Nevertheless, each time the bus is in the shop (MVI and/or repairs), the unit is checked extensively.

Table 4 shows the duration of the bus rides. The duration of the rides varied from 8 min to 76 min, which could affect the accumulation of emissions in the bus. Six different models of bus were involved in the study, which further emphasizes the representative nature of the investigation. It is important to note that the study did not attempt to compare the different models of bus but to record the pollutant concentrations for typical bus rides. Each operates under different conditions on each day. The study did, however, provide a realistic measure of the different levels of pollutants that were occurring on bus rides in the districts.

5.1.2 Factors affecting the measurements of diesel exhaust

Varying equipment specifications may have limited our ability to measure diesel exhaust specifically. The P-Trak® counts particles optically and detects particles in the range of 0.02 to 1.0 µm. The Dust Trak® also uses optical counting and detects particles in the range from 0.1 to 2.5 µm. The BC measurement is a filter-based method and therefore sees all particles that are trapped on the filter. The smallest particles are likely not efficiently collected. Approximately 90% of the number of diesel emission particles are less than 0.1 μm in diameter (Kittelson et al., 1999) so some may not be seen by the Dust Trak® instrument. Gasoline particles are generally smaller than diesel particles and are less than 0.06 to 0.08 μm in diameter. The Dust Trak® measurements may be more indicative of aerosols that are transported into the region (background aerosol), of local aerosol that has aged, or of the fine particle fraction of resuspended road dust. Based on these facts, the $PM_{1.0}$ counts when correlated with BC are a good indication of combustion emissions.

The VOC determined equally affected our measurement of diesel exhaust as none of the VOC was a specific marker for diesel emissions. Toluene and ethyl-benzene emissions are higher from gasoline vehicles than from diesel vehicles, especially when morning cold start and afternoon evaporative emissions are considered. Some of these compounds, often originating from other sources, can also be the markers of vehicle emissions in general.

It is also well known that vehicle emissions, especially gasoline vehicle emissions, are significantly higher in cold weather (Joumard & Sérié, 1999; Kelly et al., 2003; Kuusimaki et al., 2003; Cadle et al., 2004). Diesel emissions are less sensitive to temperature, but still do increase slightly with decreasing temperature. For gasoline vehicles, in the cold mornings, cold start emissions (the first 5 min or less) can account for well over 80% of the emissions of the vehicle's short trip. This happens because extra fuel is injected into the engine to start it in cold weather and because the catalyst takes longer to reach operating temperature. During that time, gasoline vehicles emit most of their BC. Diesel vehicles do not undergo fuel enrichment at start because the engine operation is different. Typically, the hydrocarbon emissions are very low in diesel engines because they run very lean (with a large amount of extra oxygen), and thus the combustion is more complete. Gasoline engines run very close to stoichiometric combustion (i.e. just enough oxygen to react with the carbon in the fuel).

5.1.3 Selected examples of measurements taken during bus rides and walking commutes

Several bus rides and walking commutes were demonstrated in Figures 2 to 5. These trips were chosen because they had the complete dataset. Typical sample measurements show that the (morning and afternoon) bus rides are important sources of exposures to motor vehicle emissions, including diesel for children on buses. The levels of $PM_{2.5}$ illustrated in Figures 2 to 5 show that the bus ride tends to be the period of higher $PM_{2.5}$ concentrations experienced throughout the school day, with morning exposure levels typically higher than afternoon levels. This was confirmed by the diagram of generic relative and average $PM_{2.5}$ concentrations on buses (Appendix 8, Figure II).

Even during walking commutes, increased exposures are encountered. Figure 2A shows that the levels of $PM_{2.5}$ fluctuate during walking to school. The afternoon tracing (Figure 2B) suggests a possible exposure from passing traffic. Note that because a 5-min moving averaging procedure is used the exposure time shown on the diagrams may be slightly shifted from the time of the actual exposure.

Figures 3 to 5 show that the levels of $PM_{2.5}$ are periodically substantially elevated when students are on the bus during commutes. The window configuration and the number of pick-ups and drop-offs occurring during a bus route potentially affect the levels of $PM_{2.5}$. For both examples of long and short bus rides, closed windows were more frequently associated with higher exposure levels in the personal exposure profiles. An explanation may be that opening windows tends to ventilate the bus and reduce in-bus exposure levels. Other possible factors that could alter $PM_{2.5}$ levels on the bus are the number of bus stops, presence of strong or weak cross winds, the degree to which the bus is "labouring" in stop-and-go traffic or in hill climbing, the actual temperature of the engine, and the exhaust. These figures show that there are periods when the concentrations of $PM_{2.5}$ in the bus can be relatively elevated compared with the ambient levels. They also show that the levels of $PM_{2.5}$ are substantially elevated during periods when students are on the bus during shorter rides compared with the waiting period and the time in school.

Other air pollutants act similarly to $PM_{2.5}$. A comparison among $PM_{1.0}$, BC and $PM_{2.5}$ is shown in Figure 5. All three are elevated during the bus ride but the patterns in the tracings are not identical. Different aspects of the engine exhaust are measured by each of these elements. Black carbon primarily measures the elemental carbon portion of the diesel exhaust, while $PM_{1.0}$ measures some organic material with the particulate and $PM_{2.5}$ measures the mass of the particulate emission in the range of 2.5 μm or less (U.S. EPA, 2002).

The findings in Figure 5C and Appendix 6, Figures A, B and C, suggest that the characteristics of exhaust change as the ride continues, with an increase of organic materials later in the bus ride. It seems from the figures that the BC concentrations increased more rapidly than the mass of $PM_{2.5}$ and the $PM_{1.0}$ number counts, which contain organic compounds. Black carbon shows a high level throughout the trip while the other figures suggest an increase in total concentration of particles as the trip continues. Note that Figure 5 presents a single ride, whereas figures in Appendix 6 present aggregated values.

One possible explanation for the trend seen may be that fresh diesel exhaust, which appears early in the ride and consists of smaller particles, remains trapped inside the closed system of the bus cabin and ages. Coagulation of particles and other processes occur and cause the particles to grow larger, but reduce in number, which explains the increase in mass in the late stages of the commutes. Fresh injection of exhaust from opening and closing of doors and windows causes changes to the total number of particles, thus explaining the consistently high levels of particles seen for BC.

The $PM_{2.5}$ levels shown are consistent with other reports (Wargo et al., 2002; Fitz et al., 2003). Although this report is focused on exposures during the trip to and from school, preliminary analysis of exposure levels for the entire day demonstrates that typically the in-school $PM_{2.5}$ levels are close to ambient air $PM_{2.5}$ levels, with occasional high peaks. Further, the tracings during the bus rides indicate that there are sporadic periods of very high $PM_{2.5}$ levels during stopping and starting. Statistical analysis of congregated data needs to be done before a conclusion can be drawn. The health significance of such elevations may also need to be examined.

5.2 Variability of pollutant levels

We observed substantial variability between commutes, whether expressed as average levels or cumulative values. We expressed the geometrical mean values of logged sampling measurements because they are is not influenced by occasional extreme values as much as the arithmetic mean.

5.2.1 Fine particulate matter (<2.5 μm)

Riding or walking

Comparison of rows 2 and 3 in Table 6a shows that there are significantly higher average $PM_{2.5}$ concentrations during bus riding than during walking to and from school. With respect to the maximum level, the difference between walking and riding is even larger. Riding the bus appears to expose children to 3 to 5 times higher concentrations of $PM_{2.5}$ than walking. $PM_{2.5}$ levels range from 5 $\mu m/m^3$ to 158 $\mu g/m^3$ and are consistent with Figures 2 to 5. However, it must be kept in mind that the exposure monitoring for buses and during walking were not carried out during the same time, for the same length of time, or for an identical route. Therefore, when the exposure levels of air pollutants in buses and during walking are compared, errors may be introduced and the results may be misinterpreted. No conclusion should be drawn from this comparison.

Short or long rides

When short rides are compared with long rides, the short rides have a higher geometrical mean and higher maximum and third maximum exposure level than the long bus rides. This could reflect a more frequent closing and opening of the door on short rides. Shorter rides also covered routes closer to the schools and generally required more inner-city driving where traffic density was higher and driving speed was slower. The bus stops during shorter bus rides would mean that doors were opening and closing in more traffic-dense areas, allowing higher levels of traffic-related pollutants to enter the bus. The difference in exposure levels between short and long commutes is not only related to their duration, but also might be due to the geographical areas they cover and to the number of bus stops in traffic-dense areas.

As expected, cumulative exposure results showed higher levels on longer rides compared with shorter ones, as this value is directly proportional to the length of the bus ride.

Old or new buses

There is no trend of higher exposure on old versus new buses, and it appears that the type of engine also did not have a significant effect. Our findings suggest that age of bus engine did not markedly affect the exposure. Mechanically versus electronically controlled fuel injections systems were marginally significantly different; thus, the conclusion about which fuel injection system may result in higher exposure levels needs to be drawn with caution. It appears that mileage of these well-maintained buses did not greatly affect the $PM_{2.5}$ concentrations measured.

Morning or afternoon rides

There was no significant difference in the $PM_{2.5}$ levels in the morning and afternoon rides, although the maximum levels tended to be higher in the afternoon. This could have been related to humidity because the measures tend to be higher during periods of high humidity. Table 6 shows that humidity did not appear as an important factor in morning or afternoon differences in exposures. When Table 6 is compared with Table 7, removing the values recorded during humidity above 70% led to lower geometric means for almost all categories, yet none of the decreases was statistically significant. For example, the geometric mean of a bus ride fell from 32.1 to 30 $\mu g/m^3$ when high humidity days were removed. This likely reflects an analytical issue in which the instrument had a tendency to report higher values at higher humidity.

Low or high temperature

The days with low temperatures (below 12°C) tend to have higher average concentrations of $PM_{2.5}$ in a bus. These data suggest that weather would be a factor in a child's exposure to $PM_{2.5}$. Figure 6 shows a great variability in $PM_{2.5}$ on long bus rides on newer buses under colder temperatures. One possible explanation for this pattern is that on cold days windows are more likely to be kept closed, which could lead to higher concentrations of $PM_{2.5}$ being trapped in the bus cabin. Weather in this case affects ventilation patterns on the bus. Alternatively, on cold days the engine performance may not be as efficient as on warm days.

Ambient $PM_{2.5}$ and weather relationships

Differences in ambient $PM_{2.5}$ shown in the last four rows of Table 6a indicate that the geometric mean levels of in-bus $PM_{2.5}$ increase from 24.4 $\mu g/m^3$ (95% CI 18.7–31.9) to 38.5 $\mu g/m^3$ (95% CI 28.6–51.8) from the first quartile (<19.5) to the fourth quartile (>69.5) of ambient $PM_{2.5}$ concentrations, although this increase is not statistically significant. However, a multivariate regression analysis shows that ambient $PM_{2.5}$ contributed significantly to the in-bus $PM_{2.5}$ levels (Table 11). Ambient $PM_{2.5}$ may contribute to the amount of $PM_{2.5}$ measured during the ride to and from school. Average ambient $PM_{2.5}$ during the sampling period was 5 $\mu g/m^3$, which seems to indicate that the children on the bus were exposed from 2 to 4 times higher concentrations of $PM_{2.5}$ than if exposed to ambient levels. However, it must be noted that ambient pollution data were collected from a single monitoring site in Fredericton, which may not necessarily represent roadside pollution levels in a neighborhood during commuting time. If one compares ambient air pollutant levels with exposure levels in a bus, potential exposure misclassification may be introduced. At this stage, it is difficult to determine how much ambient $PM_{2.5}$ contributed to in-bus concentrations.

Temperature and humidity impact all measurements, including the measurements on the bus and on the walking routes. Measurements were done in the spring months of April, May and June, when the ambient temperature started rising. Our results suggest that the exposure could be higher if sampling had been conducted during the winter when the average ambient temperature in New Brunswick, as measured and calculated by Environment Canada for the greater Fredericton area, is lower, around minus 6.8°C. The normal temperature for our sampling period of April, May and June is 10.5°C (Environment Canada, 2003).

It is important to note that removing measurements sampled during the days with high humidity causes a downward trend of all values, but the variability of data and trends remain. Therefore, the data from Table 7a indicate that the differences found between conditions described in Table 6a were not fully attributable to humidity. Limitations of the Dust Trak® at high humidity conditions likely resulted in exaggerated measurements, but controlling for this did not remove the original relationships.

5.2.2 Ultra-fine and fine particulate matter (<1.0 μm)

Particulate matter in the size range of 0.02 to 1.0 μm represents an additional component of motor vehicle emissions, including diesel. The factors discussed above in section 5.2.1, including walking versus riding a bus, commute duration, bus age and the time of commute, appear to have effects on $PM_{1.0}$ similar to those seen for $PM_{2.5}$ (Table 5).

$PM_{1.0}$ count information was collected using P-Trak® for real-time continuous recording of the number of particles (size 0.02–1.0 μm) per air volume (shown in Table 5). Trends similar to $PM_{2.5}$ were observed for $PM_{1.0}$ particles. Again, significantly higher values of $PM_{1.0}$ on bus rides compared with walking were noticed. The same caution as that discussed in section 5.2.1 must be taken when making such comparison and data interpretation.

No significant difference was apparent between the mean number of particles on a short as opposed to a long bus ride, although the maximums were slightly higher on shorter rides. Whereas the new and old buses did not differ in levels of exposure to $PM_{1.0}$ particles, a somewhat higher number of particles was detected on the rides on buses with electronically controlled fuel injection systems on their engines compared with mechanically controlled ones. Although the difference is not statistically significant or apparent in extreme values, this is suggestive of an area for further study, since the type of controls is important in the development of diesel bus engines and may be related to operating temperatures. This suggestion is supported by morning and afternoon observations. Engine operating temperature reportedly affects the quantity and quality of exhaust emissions (Kelly et al., 2003).

There is a significant difference in $PM_{1.0}$ numbers between morning and afternoon bus rides. Afternoon rides displayed substantially lower average and maximum levels of $PM_{1.0}$. Changes in temperature and humidity between the morning and afternoon could be a factor. Cold temperatures are believed to lead to higher vehicle emissions, and cold mornings lead to higher cold-start emissions (Joumard & Sérié, 1999; Kelly et al., 2003; Kuusimaki et al., 2003; Cadle et al., 2004). As shown in a multivariate analysis (Table 11), temperature has played an important role in $PM_{1.0}$ concentrations. Heavy traffic during morning rush hour might also contribute to higher levels of $PM_{1.0}$, as afternoon rides often occurred before the rush hour started.

When looking at cumulative exposure values, the longer rides are those with highest exposure levels and the shorter rides have lower total exposure concentrations. When looking at average exposure values, the cleanest bus rides seem to be on long rides with old buses at warm ambient temperatures, but old buses on short commutes tended to display the highest values at low ambient temperatures (Figure 7), which would again indicate some other reason than the age of the bus as a factor responsible for these trends. Perhaps some buses may have chassis/cabins that leak, allowing for greater ventilation at higher speeds, but also greater infiltration at slower speeds and while stopped. Shorter rides may thus be characterized by slower speeds, less ventilation and more infiltration of outside exhaust. The weather exerted the same effect on $PM_{1.0}$ as it did on $PM_{2.5}$: low temperatures and higher humidity were associated with higher $PM_{1.0}$ levels. In-bus $PM_{1.0}$ concentrations seem to be correlated with ambient $PM_{2.5}$ concentrations; however, at this stage it is difficult to quantify the contribution of ambient particles.

5.2.3 Black carbon

A large amount of data on $PM_{2.5}$ was collected during this study. However, $PM_{2.5}$ has a variety of sources in addition to bus diesel exhaust, and thus may not be an accurate surrogate measure of bus exhaust exposures. Black carbon, however, has been considered to be a marker of diesel exhaust emissions.

Average exposure to BC (Table 9a–c) shows very similar trends when compared with $PM_{2.5}$ and $PM_{1.0}$ (i.e. slightly higher values on morning bus rides in colder and more humid weather). Black carbon shows a trend to higher exposure levels for older buses and for those with mechanically controlled fuel injection systems. There was a trend that BC levels during morning rides were higher than during afternoon rides. An interpretation would be that BC concentrations in morning buses could be augmented by higher traffic density during morning rush hour when the temperature was low and relative humidity was high. Further study is warranted to investigate other traffic-related emissions and the impact on the concentrations in school buses.

Local traffic could affect the observed BC concentrations. However, because data on traffic density and roadside air pollution levels were not available, the contribution of local traffic to school buses could not be quantified.

5.2.4 Ultraviolet absorbing aromatic organic material

A pattern similar to that of exposure levels for BC is seen with UV absorbing organic material in Table 10a–c. Absorption in the 370-nm spectrum is not a precise measurement of a single compound. It does reflect a BC component together with the aromatic organic compounds component as, for example, from fresh diesel exhaust. It is a measure of a group of higher molecular weight polyaromatic hydrocarbon compounds that show a pattern similar to that of BC.

The results of UV absorbing organic material measurements show the same trend as other pollutants monitored in the study. They appear to be reflective of the organic material that likely entered the bus from the pollutants caused by burning fuel from surrounding traffic or the bus itself (self-pollution).*5.2.5 Volatile organic compounds*

Volatile organic hydrocarbons represent a diverse group of chemicals found in ambient air as a result of human activity (e.g. cleaning products for buses and for personal use, hair and body washes, perfumes, fuel burning) and, to a lesser degree, natural conditions such as presence of certain plants. The VOC measurements, concurrent with the particulate monitoring on the bus, provided an opportunity to further characterize the exposures and identify sources of the emissions. There are two primary sources: diesel engine emissions and gasoline traffic emissions. Evidence of both is seen in the VOC findings in the study.

To fully understand the VOC information, it will be necessary to analyze the relative findings by bus in future work. However, some general observations could be made from the results in Table 12, which shows levels reported for traffic-related and carcinogenic VOC, and in Appendices 10 to 14 which show a complete list of the VOC. There was a variation of concentrations among bus commutes. Events that could contribute to higher exposures on a bus are driving in heavy traffic, intake of fumes into the bus due to idling with open windows, or frequent stops under certain weather conditions. Although the mean values suggest differences between schools, examination of bus trips in three regions show that the higher exposures for some analytes occurred in all groups, including those who walked to school.

One of the VOC we measured was benzene, which is carcinogenic. This is of concern. The average benzene levels measured on buses in our study were within the range of average levels measured at typical urban site locations from 1989 to 1998 (1.8–3.6 $\mu g/m^3$). This implies that exposure levels are similar to those experienced by pedestrians in urban centres.

The VOC sampled on the buses vary in two respects among bus rides: the average total VOC levels found in the bus and the proportion of different VOC in the mixtures found in each ride or walking commute. The maximum levels found for some compounds indicate that conditions are present in certain buses that lead to accumulation of pollutants. Possible explanations for this are traffic, idling, labouring of the engine, closed windows during frequent stops and local weather conditions. None of these suggestions fully explains the findings in this portion of this study.

5.3 Factors affecting levels of exposures

Although there is quite a wide variation in concentrations of all air pollutants sampled among individual buses, the differences between the older and the newer buses are not statistically significant. The most probable explanation is that the buses are well maintained and that a well-maintained old engine does not emit significantly more exhaust than a newer one. Yanowitz and colleagues (2000) also found no relationship between emissions and mileage in a recent study.

The technologies used in these engines did not show consistent results for pollutant concentrations. Cumulative exposure results show a significantly higher level of $PM_{2.5}$ with mechanical injection than electronic injection, when humidity conditions were restricted to less than 70%. Results from $PM_{1.0}$ did not support this trend.

Drivers in both districts 17 and 18 have been made aware of pollution issues associated with idling diesel engines. To minimize the emissions, drivers of diesel-powered units are required to set the idle up to 1200 to 1400 rpm to warm up the engine after they start it and check all gauges. One of the benefits of this procedure is that the engine will run at a more efficient heat rating than at base idle of 700 to 800 rpm. Also, if the unit is left idling for any period during the day, drivers are instructed to set the fast idle. If idling is done in this manner the emissions are reduced considerably. Stickers outlining this procedure are present in most school buses.

Our results suggest that the factors that most strongly affect average $PM_{2.5}$ measurements are mode of commute (walking or bus), temperature and humidity; there is also a positive correlation between ambient $PM_{2.5}$ and the magnitude of exposure measured in the study.

Walking children had the lowest average exposures to all pollutants. Exposures to $PM_{2.5}$ that children experienced ranged from 2 to 6 times above the ambient $PM_{2.5}$ concentrations, 9.7 $\mu g/m^3$ for walking children and 32.1 $\mu g/m^3$ for pupils riding school buses. Individual recordings of pollutant concentrations (Figures 2–5) showed that some of the highest peaks of exposure during the school day occurred during bus rides and that 50% of exposures experienced by children occurred within the first part of the ride (Appendix 6, Figure A). These differences could be attributable to different times of the day, duration and the routes between bus rides and walking when we monitored air pollution. However, because of the harsh geographic and climate conditions, for a large number of New Brunswick schoolchildren, it may not be feasible for them to walk to school.

The highest average concentrations of $PM_{2.5}$ and $PM_{1.0}$ were found on short bus routes. It seems that frequent stopping and opening the bus doors contributes significantly to the quality of the air inside the bus. Based on the annotated exposure profile presented for individual children during bus rides, the extremes occurred during drop-off and pick-up times of the students. During this time the doors were open. We attribute these increases to self-pollution of the bus interior with exhaust fumes. Whenever the door was opened, the $PM_{2.5}$, $PM_{1.0}$ and BC levels increased sharply. This self-pollution effect is probably aggravated because the exhaust pipe exits on the right side of the back of the bus; that is, on the side where the bus doors are located. It is also possible that the crankcase ventilation tube, which opens underneath the engine at the bottom of the bus, is perhaps contributing to the self-pollution effect by adding some pollutants not originating from incomplete burning but from the engine’s metal parts and oil.

The cumulative values for in-bus $PM_{2.5}$ and $PM_{1.0}$ showed similar trends to those observed for average values; however, there were two main differences. Longer bus rides had higher levels than shorter bus rides and mechanically controlled fuel injection systems had higher values than electronically controlled systems, which was the expected result.

Marked variability of concentrations or number of particles of pollutants collected on diesel vehicles and buses has been observed in other research (Chan et al., 1993; Gee & Raper, 1999; Wargo et al., 2002; Kelly et al., 2003). Most research on buses found very high extreme values and also very low ones, as did our study, with the values for $PM_{2.5}$ ranging from 5 to 158.2 $\mu m/m^3$ and for $PM_{1.0}$ from 26 to 134,285 particles per cm^3. Studies have also shown that higher engine load and cold start of the engine produced high mass concentrations of particles (Kelly et al., 2003). Although these findings were based on off-road diesel engines, it is possible that similar levels would occur in diesel school bus engines.

Similar variations also were observed with VOC collected during bus commutes. There were some regional differences in VOC results; on average the lowest concentrations of VOC pollutants were found in the AGM school area, which has the heaviest traffic. This school was sampled starting at the end of May, with most measurements being done in May and June, when the weather was warmer. Perhaps somewhat lower levels reflect the consumption of some VOC and NOx compounds for ozone formation under the stronger sunlight (U.S. EPA, 2002). Lower concentrations have also been observed under warmer temperatures in other studies (Kuusimaki et al., 2003).

At the time of our measurements, District 17 did not have a “no idling” policy in effect for school buses. Even if bus drivers of all districts had been instructed to perform a high-speed idling technique whenever they needed to warm up the engine and interior of the bus, implementation of an anti-idling policy would still decrease exposure levels further. This study did not test the efficacy of idling policies, but our results indicate that any reduction of exhaust levels would be beneficial.

There are a substantial number of studies that show a clear relationship between childhood asthma and PM, ozone and nitrogen oxides in ambient air. It is therefore important to further investigate their occurrence and levels.

Many questions remain unanswered, and several could be explored with further analysis of our present dataset. VOC data, together with the data on PM and the activity logs, provide a robust data source to investigate the details of these exposures.

5.4 Comparison of our results to other studies

Our study results can be compared with several other school bus studies completed in the United States. The first study was completed by the California Air Resources Board (Fitz et al., 2003).

→ In California, the bus routes were sampled without children on board in urban and rural areas of Los Angeles. Our study did not differentiate between urban and rural routes because many commutes spanned both types of areas.

→ Average levels of BC on urban routes were 10 $\mu g/m^3$ (windows closed), 5.2 $\mu g/m^3$ (windows open) and 2.7 $\mu g/m^3$ for rural routes. These levels were all higher than BC levels in Fredericton, which averaged 0.7 $\mu g/m^3$ for all bus rides.

→ In-cabin benzene concentrations were twice as high in Los Angeles as in New Brunswick school buses (2.9 ppb vs. 1.5 ppb).

A second study for comparison was completed in Connecticut (Wargo et al., 2002).

→The Connecticut study included personal sampling (similar to that in our study), experimental monitoring (to measure the effect of windows open or closed and location of monitoring

equipment on the bus) and experimental control monitoring (to compare three bus types). Levels of $PM_{2.5}$ from personal sampling exceeded 200 μg/m^3 on some bus runs, which is higher than the maximum value of 158 μg/m^3 reported in our study. The routes covered in this study were all in rural low-traffic areas, implying that levels
would have been even higher had urban routes in high-traffic areas been sampled.

→The background $PM_{2.5}$ levels in Connecticut were about twice those in Fredericton (ranged from 10.8 μg/m^3 to 17.9 μg/m^3 in Connecticut vs. 0 to 22.1 μg/m^3 in New Brunswick), and this may have played a role in the higher bus exposure levels observed in Connecticut.

5.5 Limitations of the study

There were several limitations in the present study, which should be acknowledged to accurately interpret our results.

As noted above, the air pollutant monitoring for buses and during walking were not carried out during the same time, for the duration, or for an identical route. Therefore, when comparing the exposure levels of air pollutants in buses and during walking, bias may be introduced and the results may be misinterpreted. Walking commute was used for reference in this study rather than for comparison.

Ambient pollution data were collected from a single monitoring site in Fredericton, which may not necessarily represent personal exposure levels in a neighbourhood during commuting time. Exposure misclassification may be introduced if one compares ambient air pollutant levels with pollutant levels in a bus and during walking. An interpretation of the results must be made with caution.

Many factors might influence the exposure levels in a bus, such as weather conditions, bus conditions, idling, windows open or closed, number of times opening the doors, surrounding traffic density and the type of vehicles. Some of the factors may confound the results. Our statistical analysis (i.e. univariate analysis) did not take into account all confounding factors. However, data were stratified into various categories according to weather conditions, bus age and the length of bus rides, in an attempt to control for these confounding factors. A multivariate regression analysis was conducted to assess the influence of factors on pollutant concentrations monitored during bus or walking commute.

Although in this study the exposure levels in a school bus were postulated to be attributable largely to the diesel bus emissions, with the exception of BC, none of the exposure measures is considered to be an accurate surrogate measure of diesel exhaust due to the presence of numerous other common sources. Even BC can have sources other than diesel exhaust. Several variables that could affect exposure levels in a school bus (e.g. seasons, self-pollution, surrounding traffic counts and types, roadside pollutant concentrations) were not analyzed in this study, as the information necessary was either not available or not collected. This study is more a commuter exposure study than a bus diesel exhaust exposure study.

It is important to note that "afternoon" commutes did not always occur at the same times. Pick-up times ranged from 12:00 to 15:00, and on some days the same buses picked up students at noon, 14:00 and/or 15:00 on the same day. It is possible that contaminants from previous rides were carried over to the later ride. The impact of surrounding traffic pollution would also be smaller during noon hour than in the afternoon after rush hour has started.

This study sampled a large number of buses and measured the exposure level of many children on different days. There is a lack of reproducibility of our results due to the nature of the study, which tries to measure exposure levels under realistic conditions.

During the various categories of comparison, each category had a different sample size (i.e. a different number of buses in each group), which may have introduced some uncertainties in the analysis when the sample size was too small (e.g. $PM_{2.5}$ concentrations were sampled 4 times during walking commutes in cold weather).

Parallel measurements for $PM_{2.5}$ and $PM_{1.0}$ were taken on several days by co-locating samplers side-by-side. The variability between duplicate samplers was found to be small for $PM_{2.5}$ and $PM_{1.0}$. For other pollutants the parallel comparison was not done, which could limit our ability to determine how much of the differences in the exposure measurements was due to variability between monitors.

Although the study participants were chosen randomly, this was also based on which children followed the most convenient routes to get a representative sample. The schools referred the children to the researchers and selection bias could have occurred when selecting children.

6. Conclusions

This study examined levels of diesel-related pollutants on school buses when children were on board in school districts 17 and 18 in New Brunswick, Canada. Air pollutant concentrations were determined during 86 bus rides, with measurements collected over 63 days on 41 school buses between April 24 and June 19, 2003. Exposure measurements were also obtained for 20 walking routes for children commuting to the same elementary schools in these regions. We are not aware of any other study that simultaneously measured PM ($PM_{2.5}$, $PM_{1.0}$), BC, UV absorbing organic materials and VOC. From this study we can conclude the following:

1. There is a wide disparity in the exposure levels observed during the different bus commutes. While overall bus rides tend to have elevated exposures, a portion of rides have low near-ambient levels of $PM_{2.5}$. The rides with lower ambient $PM_{2.5}$ levels are also in the low range for most of the other parameters measured.

2. Results for average air pollutant concentrations during bus commutes did not show significant differences between the buses with mechanically controlled fuel injection systems or electronically controlled systems on their engines. However, results for cumulative exposure did show slightly higher levels of cumulative exposure with mechanical fuel injection systems for $PM_{2.5}$ and BC (under all humidity conditions and when restricted to less than 70%).

3. Weather conditions (relative humidity and temperature) appear to be associated with pollutant levels on the bus in this study. The trend was for higher pollutant levels at low temperatures and high humidity, although only $PM_{2.5}$ was statistically significantly higher at low temperatures.

4. We did not see evidence of extensive idling of buses in our study; thus, there was insufficient evidence to evaluate the effect of anti-idling policies on air pollutant levels. Further work will be directed toward determination of which management changes may be most effective at limiting exposure levels during school bus commutes.

5. A significant difference in exposure levels was found between walking and bus commutes. However, these measurements were not conducted during the same time, for the same length of time, or for an identical route. The routes covered during walking commutes were shorter in duration than bus commutes, and walkers also tended to walk on more residential and less traffic-dense roads, reducing their exposure to traffic-related pollutants.

6. An assessment of cumulative exposures indicated that long bus rides exposed children to higher total amounts of pollutants than short bus rides, whereas average pollutant levels were higher on short bus routes than on long bus routes. Other factors aside from the duration of the bus commute could have influenced these average pollutant concentrations. Shorter rides covered routes closer to the schools and generally required more inner-city driving where traffic density was higher. The number of bus stops in these traffic-dense areas equally plays a role in increasing exposure concentrations on the bus. Longer rides were more likely to cover routes on country roads and bring children from rural areas to their school. In addition, longer rides covered the same suburban and urban area as short rides during the part of the ride closest to the school. Longer rides typically do not have stops near the school and thus buses would not be

opening and closing the doors in the more traffic-dense areas, as they do on short routes. The difference in exposure levels between short and long commutes may be related to the geographical areas they cover, as well as to the duration.

7. Despite the trend observed of increasing levels of ambient $PM_{2.5}$ with increasing $PM_{2.5}$ and PM1.0 concentrations in the bus, this rise was statistically not significant, and no causal relationship can be concluded at this stage. It is difficult to determine the contributions of traffic surrounding the school buses and ambient $PM_{2.5}$ to the pollutant concentrations in school buses at this stage, as data on traffic density and types and roadside air pollution monitoring data would need to be collected.

8. In comparison to other school bus exposure studies completed in the United States, the concentrations of pollutants were generally similar or lower in our study. Differences in methodology may account for some of this difference.

7. General Recommendations

To formulate recommendations to minimize the potential exposure of children to diesel exhaust-related air pollutants on school buses, we have examined our data and results of other studies and have consulted with experts in the field of air pollution and vehicle exhaust. We believe there are several steps that authorities should consider to reduce the exposure levels experienced by children. It should be noted that the majority of these recommendations are not based on the results of this study.

1. *Eliminate bus idling:* Despite the lack of information in our study regarding bus idling, an anti-idling policy for schools is strongly recommended by several organizations including the U.S. EPA (Clean school bus USA: http://www.epa.gov/otaq/schoolbus/anti idling.htm). It recommended this policy not only to reduce the levels of exposure to diesel exhaust, but also to reduce fuel wastage and engine wear and tear. Bus drivers should also undergo periodical training to understand the issues pertaining to idling.

2. *No-idling policy for all vehicles on school grounds:* There should be a no-idling policy in effect also for all other vehicles on the school grounds.

3. *Number of bus stops:* For short bus routes, consider reducing the number of stops or relocating stops to areas with lower traffic density. Frequent opening and closing of doors allow greater contribution from outside sources (i.e. surrounding traffic) to the levels of traffic-related air pollutants on the bus.

4. *Exhaust pipes:* In a study of school buses in California, about 25% of the BC concentration variance on buses was due to self-pollution (Behrentz et al., 2004). To avoid self-pollution, consider re-engineering bus exhaust pipes to extend to the left rear-end of the bus so exhaust will not be emitted on the same side of the bus as the doors. An even better location to release exhaust is from a stack above the back of the bus, as the vacuum created at the back of the bus when in motion draws exhaust from lower pipes back toward the bus. Crankcase exhaust should be released from the same location.

5. *Ventilation*: Investigation of alternate methods of the ventilation of the bus cabin is needed and air-filtering systems should be considered. A discrepancy exists between public transit buses, which usually have air conditioning, and school buses, which usually do not (Behrentz et al., 2004).

6. *Retrofit diesel buses to lower emissions:* It is strongly recommended that retrofitting of buses be given high priority to reduce emissions. Retrofit measures include pollution control devices such as diesel oxidation catalysts and diesel PM filters. Low sulphur diesel to be introduced in 2006 is necessary for the introduction of this retrofit technology (U.S EPA: www.epa.gov/otaq/schoolbus/retrofit.htm). In the present study, a trend is shown that the engines with electronically controlled fuel injection systems seem to be on average cleaner for $PM_{2.5}$, BC and UV absorbing organic material than those with mechanically controlled fuel injection systems. This warrants further investigation to confirm these findings.

7. Future purchasing of buses: When a new bus is being purchased/contracted, only low-emission vehicles should be chosen.

8. Avoid caravanning: Buses leaving school in the afternoon should leave at staggered departure times to avoid tailgating. Bus drivers should be instructed to avoid other diesel school buses whenever possible (Fitz et al., 2003).

9. Reduce in-cabin exposure levels to as low as possible with existing technology: All efforts should be made to minimize exposure levels keeping in mind that the WHO states that there is no safe threshold for the health effects of diesel exhaust (International Program on Chemical Safety, 1996).

8. Future Work

This commuter exposure study was effective in suggesting issues that deserve more attention in future work. Some areas for future consideration are listed below.

1. Data on traffic density, the type of vehicles on road with school buses, and ambient pollutant data within the community need to be collected, to differentiate the sources of pollutants in a school bus and better represent the driving environment of the school buses.

2. The air pollutant levels experienced by children in this study need to be placed in context with regards to levels they might experience during the rest of their school day. Future work to be completed using this dataset includes investigating all day air pollutant concentrations in comparison to on-bus levels. This requires using measurements from the complete dataset as well as those taken during commute times. Preliminary results show that in-class levels of $PM_{2.5}$ can reach concentrations comparable to on-bus levels, which suggests that important indoor sources exist.

3. In future exposure studies, additional modes of transportation may be included for comparison to bus and walking routes. Commuting by car and using public buses could be introduced as a comparison group as well as buses running on different types of fuel (natural gas, bio-diesel, etc.). To compare cars with school buses, it must be kept in mind that to replace school buses more private cars would be required, which may result in higher levels of pollutants emitted to ambient air, although in-car pollutant levels may be low because the driver does not need to open the doors often.

4. To provide a more controlled environment, scripted exposure studies may be undertaken to assess the levels of children's exposure to school bus exhaust. The use of specific commuting routes under set conditions would increase comparability of the routes and eliminate much of the bias present from confounding factors.

5. The relative contribution of on-bus pollutant levels from self-pollution originating both from crankcase emission and from tail pipe exhaust should be assessed. This would be accomplished by employing stronger source apportionment methods, such as using a tracer gas specific for bus exhaust or through correlation analysis of the air pollutants measured.

6. Mulivariate analysis may be conducted to identify the importance of various factors on bus exposure.

7. Finally, this school bus study should be repeated in different seasons (winter, fall, summer) to determine if there are changes in exposure levels with changes in ambient conditions.

9. References

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