Children's Exposure to Diesel Exhaust on School Buses

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Children's Exposure to Diesel Exhaust on School Buses

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Abstract

In the United States nearly 600,000 school buses transport 24 million students to school daily. Each year buses travel 4.3 billion miles as children take nearly 10 billion school bus rides. In Connecticut, 387,000 students ride to school each day on 6,100 buses. If rides average 30 minutes in each direction, students will spend 180 hours on buses each year. Collectively, U.S. children spend 3 billion hours on school buses each year. Connecticut children annually spend more than 50 million hours on school buses.[1]

Most U.S. school buses are powered by diesel fuel. Diesel exhaust is comprised of very fine particles of carbon and a mixture of toxic gases. Federal agencies have classified diesel exhaust as a probable human carcinogen. Benzene, an important component of the fuel and exhaust, is designated to be a known human carcinogen. Components of diesel exhaust are genotoxic, mutagenic, and can produce symptoms of allergy, including inflammation and irritation of airways. There is no known safe level of exposure to diesel exhaust for children, especially those with respiratory illness.

The Centers for Disease Control and Prevention (CDC) estimates that 4.5 million U.S. children have asthma. This figure includes nearly 44,500 school-aged children in Connecticut diagnosed with the illness. Diesel exhaust can adversely affect children with underlying respiratory illnesses such as asthma, bronchitis, and infections. Diesel emissions may enhance the effects of some allergens among sensitive individuals. Children's airways are not yet fully developed and have a smaller diameter than those of adults. If airways are inflamed or constricted by asthma, allergies or infections, diesel exhaust may make breathing more difficult.

Fine particulate concentrations ($PM_{2.5}$) *measured on buses in this study were often 5-10 times higher than average levels measured at the 13 fixed-site* $PM_{2.5}$ *monitoring stations in Connecticut. Levels of fine particles were often higher under certain circumstances: when buses were idling with windows opened, when buses ran through their routes with windows closed, when buses moved through intense traffic, and especially when buses were queued to load or unload students while idling.*

This study concludes that the laws intended to control air pollution in the U.S. and Connecticut must be strengthened to protect the health of children in several important respects. First, fixed monitoring facilities do not capture the variability in air pollution experienced by children. Second, air quality indoors and within vehicles is not regulated by EPA or the State of Connecticut, while Americans spend on average between 80-90% of their time indoors. Third, tougher diesel regulations adopted by EPA last year are insufficient to protect health. Under the new provisions, they will be phased in between 2006-2010. This delay means that children may be exposed to increasing levels of diesel exhaust for nearly a decade, as truck and bus traffic are likely to continue their steady rate of increase. Fourth, Connecticut is already beyond compliance with federal air quality standards for ozone, which may exacerbate respiratory illnesses. Given the limited monitoring facilities and extended averaging periods allowed by current law, state "compliance" with federal standards offers little assurance of sufficient health protection. Fifth, routine emissions testing for school buses is not required by federal law, and school buses are specifically exempted from testing in Connecticut. Sixth, Connecticut adopted idling regulations, limiting idling time to 3 minutes, however, few know of the restriction, and it is neither monitored nor enforced.

It is possible to reduce children's exposure to diesel emissions immediately. We suggest prohibition of bus idling, especially while loading and unloading students. Exposures could also be reduced by limiting the amount of time students spend on buses. The dirtiest buses should be identified by testing emissions and air quality within passenger compartments. The cleanest buses could then be assigned to the longest routes.

These interventions would provide some relief, but additional steps are needed to protect the respiratory health of children, and provide the "adequate margin of safety" required by the Clean Air Act. The current fleet of diesel-powered buses should soon be retrofitted with interior air filters, particle traps, catalytic converters, and be powered by ultra low sulfur fuels. These strategies, if adopted together, would substantially reduce pollution levels in the air students breathe on their way to and from school.

CONTENTS

Abstract 5

1. Summary of Findings 9

2. Recommendations 14

3. Introduction and Overview 16

3.1 Background Burden of Respiratory Illness 16

3.2 Background Burden of Air Pollution 17

3.3 Diesel Emissions 19

3.4 Children's Susceptibility to Air Pollution 22

3.5 Health Effects of Diesel Exhaust 23

3.6 Carcinogenicity of Diesel Exhaust 24

3.7 Asthma and Particulates 26

3.8 Health Effects of Short-Term Exposures to Air Pollution 28

3.9 Children's Exposure: Time on the Bus 30

3.10 Regulating Diesel Exhaust 33

4. Research Methods 36

5. Detailed Research Findings 38

6. Recommendations By Level of Government 67

7. References 70

LIST OF FIGURES

Figure 1: Diesel $PM_{2.5}$ Chemical Composition
Figure 2: U.S. Trends in Diesel Fuel Consumption
Figure 3: Toxic Chemicals in Diesel Exhaust
Figure 4: Millions of Hours Spent on School Buses by U.S. Children
Figure 5: Hours Spent on School Buses
Figure 6: Student Rides on School Buses in U.S. Daily and Annual Estimates
Figure 7: Student Exposure to PM_{10} (ug/m^3)
Figure 8: PM_{10} Levels in Southeastern Connecticut Town
Figure 9: PM_{10} Levels in Northeastern Connecticut Town
Figure 10: PM_{10} Levels in Central Urban Connecticut Town
Figure 11: 5 Students' Exposure to Particulates
Figure 12: Particulate Matter on School Buses: Range of Detected $PM_{2.5}$
Figure 13: $PM_{2.5}$ on Connecticut School Buses: Distributions of $PM_{2.5}$
Figure 14: Black Carbon in Moving Buses: Percentile Comparison
Figure 15: Black Carbon Levels in Moving Buses: Boxplot Comparison
Figure 16: $PM_{2.5}$ in Moving Buses (ug/m^3)
Figures 17 & 18: Bus Stops Increase Interior $PM_{2.5}$
Figures 19 & 20: Bus Idling Accumulation and Ventilation of $PM_{2.5}$
Figure 21: Idling Effect: $PM_{2.5}$ Accumulation and Ventilation
Figure 22: Changing Concentrations During Bus Trip
Figure 23: $PM_{2.5}$, Idling vs. Moving School Buses
Figure 24: Black Carbon, Idling vs. Moving School Buses: Percentile Comparison
Figure 25 & 26: $PM_{2.5}$ Idling vs. Moving
Figure 27: Mean Idling Concentrations: Black Carbon
Figure 28: Carbon Levels in Idling Buses
Figure 29: Mean Daily Black Carbon Levels
Figure 30: Percent Carbon Reduction: Natural Gas vs. Diesel
Figure 31: Black Carbon Levels in Moving Buses: Front vs. Back of Bus
Figure 32: Range of Particulate Concentrations: Grouped by Bus-Day
Figure 33: 1999 $PM_{2.5}$ Levels at Connecticut Monitoring Sites
Figure 34: Average Daily Norwich Background + Estimated Bus $PM_{2.5}$
Figure 35: Average Daily New Haven Background + Estimated Bus $PM_{2.5}$
Figure 36: Average Daily Bridgeport Background + Estimated Bus $PM_{2.5}$
Figure 37: Average Daily Westport Background + Estimated Bus $PM_{2.5}$
Figure 38: 6 Ways to Report the Same Data

1. SUMMARY OF FINDINGS

1. ***Diesel Buses:*** Each day, nearly 600,000 school buses transport 24 million students to schools in the U.S. Within Connecticut, nearly 387,000 children ride 6,100 school buses, and most are powered by diesel fuel.

2. ***Children's Time on Buses:*** The time spent on buses by individual students varies between 20 minutes and several hours per day. For one child, a half-hour ride to school, and a half-hour ride home each day amounts to 180 hours per school year—90 full 24-hour-days over 12 years of school. Annually, U.S. children spend 3 billion hours on school buses. Connecticut children spend 50 million hours on buses each year.

3. ***Background Particulates:*** Connecticut background fine particulate matter levels ($PM_{2.5}$) are near or above national standards, when averaged over 24 hours. Children's exposure to diesel exhaust from school buses constitutes an additional exposure beyond background levels of particulates reported from current monitoring efforts.

4. ***Background Ozone:*** Connecticut is not in compliance with current federal ozone standards. In 2001, portions of the state exceeded the 8-hour limit on 26 days, and the 1-hour limit was exceeded on 9 days. Ozone is known to exacerbate asthma, and is normally highest in the afternoon, when children's exposure to diesel particulates from school bus rides is also likely to be high. NO_x precursors to ozone have increased over the past 10 years. In 2001, nearly 109 million people lived in 272 counties where federal ozone limits were exceeded.[2]

5. ***Carcinogenicity of Diesel Exhaust:*** Diesel exhaust is classified as a probable human carcinogen by many governmental authorities, including the International Agency for Research on Cancer (WHO), the U.S. National Toxicology Program, the U.S. Environmental Protection Agency, and as a known carcinogen by the State of California. The California South Coast Air Quality Management District recently estimated that nearly 71% of the cancer risk from air pollutants in the area is associated with diesel emissions. Diesel exhaust includes benzene, 1,3-butadiene, and soot, all classified as known human carcinogens. Nearly 33 studies have explored the association between diesel exhaust exposure and bladder cancer. A recent meta analysis of this literature found increased risk between 18-76%. These findings are based primarily upon studies of truck drivers, railroad workers, bus drivers and shipyard workers.[3]

6. ***Diesel Exhaust Contains 40 Hazardous Air Pollutants:*** In addition, diesel exhaust contains both carbon particulates and 40 chemicals that are classified as "hazardous air pollutants" under the Clean Air Act.

7. ***Particulates and Respiratory Diseases:*** Exposure to particulates has been associated with: increased mortality among those with cardiopulmonary diseases; exacerbation of symptoms for asthma, bronchitis, and pneumonia; decreased lung function; and retarded lung development. It has also been correlated with increased hospital admissions and emergency room visits for respiratory illnesses.

8. ***Children's Susceptibility:*** Children may be especially susceptible to adverse respiratory effects following exposure to fine-diameter particulate matter ($PM_{2.5}$) emitted from diesel engines. Nearly 94% of diesel particulates have diameters less than 2.5 micrometers (um).[4] The average diameter of diesel particulates is 0.2 micrometers. Smaller particles are able to penetrate children's narrower airways reaching deeply within the lung, where they are more likely to be retained. Higher rates of respiration among children may lead to their higher exposure, when measured per unit of their bodyweight.

9. ***No Known Safe Exposure to Diesel Exhaust:*** There is no known safe exposure to diesel exhaust for children, especially those with asthma or other chronic respiratory disease. There is no single standard for acceptable cancer risk from diesel exhaust in the U.S.

10. ***Asthma Prevalence:*** Nationally, 4.8 million children have asthma. More than 44,500 Connecticut school children have the disease.

11. ***Asthma Costs:*** Asthma costs an average of $500 per child per year for medications, physician care, and hospital treatment. Annual direct medical costs are estimated to be nearly $22 million for Connecticut school students alone. This estimate does not account for other costs that often include school absenteeism, lost parental work while caring for ill children, psychological effects, and abnormal social development.

12. ***Children's Exposure to Particulates on Buses:*** Children were exposed to airborne particulate concentrations in tested buses that were sometimes 5-15 times higher than background levels of $PM_{2.5}$.

13. ***Variability Within Buses:*** Particulate and black carbon levels vary within individual buses over time. The most important influences on variability include: bus idling behavior, queuing practices, bus ventilation via windows, and outdoor concentrations on bus routes. Particulate and carbon concentrations did not vary by sampling location within diesel buses, e.g., front vs. rear. Engine model, age of engine, number of miles since last overhaul, maintenance cycles, location of bus engine (front, next to driver, or rear), elevation change, passenger load, and climate may all influence levels of interior pollutants and children's exposure.

14. ***Exhaust From Other Traffic:*** The intensity and type of traffic along bus routes significantly affects air quality on buses. Buses following diesel-powered vehicles, *including other buses,* have increased levels of carbon and particulate concentrations within passenger compartments. Particulate levels rose rapidly within the passenger cabin when buses pulled behind other diesel vehicles in traffic. No buses tested had air filtration equipment capable of removing the fine particles detected in the buses.

15. ***Idling Buses:*** Idling buses tested had higher concentrations of particulates and carbon than moving buses. Higher concentrations occurred when idling buses had open windows when compared with buses with closed windows. There is a current Connecticut Department of Environmental Protection (DEP) regulation, DEP 22a-174-18 (a)(5), that limits idling time to 3 minutes, yet it is neither monitored nor enforced.

16. ***Queued Idling Buses:*** Queued idling buses had the highest levels of particulates and black carbon measured. Idling buses tend to accumulate diesel exhaust which may be retained during the ride, depending upon bus ventilation rates. Particulate and carbon concentrations rise rapidly once idling begins.

17. ***Length of Bus Route:*** The length of bus routes affects the magnitude of children's exposure to air pollutants in the interior compartment. Time in transit between home and school spent by Connecticut students varied between 20-180 minutes per day in the towns sampled. The longest routes may occur in the rural parts of the state, especially in large regional school districts.

18. ***Lower Emissions From Natural Gas Buses:*** Natural gas buses studied emitted 60-98% less carbon than diesel-powered buses.

19. ***Findings Are Likely to Underestimate Exposure:*** Exposures to carbon and particulates found in this study were measured in environments with exceptionally low traffic and few other sources of pollution. Most children are exposed to additional pollution from traffic and other residential, commercial and industrial activities. These findings therefore are likely to underestimate levels of fine particulates and carbon found in more urban areas and routes with higher traffic intensity.

20. ***Additional Sources of Particulate Exposure Threaten Children:*** Residential use of tobacco products, wood stoves, candles, kerosene heaters, and poorly ventilated cooking stoves are for many children additional sources of exposure to carbon-based particulates and organic gases that result from combustion. Federal and state monitoring efforts fail to account for these exposures despite the fact that most people spend more than 80% of their time indoors. Most epidemiological studies that associate PM_{10} levels with adverse respiratory health effects consider particles measured by outdoor stationary monitoring facilities, neglecting indoor air exposures.

21. ***School Buses Are Exempt From Emissions Testing:*** School buses are currently exempt from routine emissions testing in Connecticut.[5] There is no federal requirement that all state governments monitor school bus emissions, although some states require testing.

22. ***Federal Particulate Standards Exceeded:*** EPA estimates that in 2000, 11 million U.S. children lived in areas that exceeded one or more federal air quality standard. Nearly 3.5 million children lived in areas where the particulate standards were exceeded in 1998. Within Connecticut, bus exposures when combined with background outdoor particulate levels may elevate children's average daily exposure beyond the current federal 24-hour $PM_{2.5}$ standard.

23. ***Absence of Passenger Cabin Air Quality Standards:*** Current law does not regulate air quality within buses.

24. ***Federal Monitoring vs. Personal Monitoring:*** Federal law and regulation permit the testing of air quality by means of fixed monitors. In Connecticut, 13 fixed monitors measure $PM_{2.5}$. This sampling design fails to capture the local variability and severity of air pollution in the state. National standards permit averaging particulates over 24-hour periods. These practices ensure that shorter episodes of intense pollution—such as those experienced in bus rides—are neither recognized nor regulated by the state or federal government.

25. ***Tougher Federal Diesel Standards Delayed Until 2006:*** Tougher new diesel emissions standards will not be phased in until 2006. This delay poses respiratory health threats to Connecticut citizens, who now experience air pollution at levels above acceptable federal standards for ozone. Compliance with current standards does not ensure health protection. EPA estimated that the new standards would result in 8,300 fewer premature deaths, 17,600 fewer cases of childhood acute bronchitis, and 360,000 fewer asthma attacks. These estimates demonstrate the scale of respiratory health threat EPA believes exist under current conditions.

26. ***Federal Particulate Standards:*** The exposures identified in this study will not be affected by the tougher federal PM standards adopted in 1997 (which are different from the diesel standards described in 26 above), since monitoring to determine compliance with the PM standards is done outdoors.

27. ***Bus Parking Yards:*** Bus parking and maintenance facilities have the potential to create localized particulate air pollution that far exceeds ambient outdoor levels reported from State monitoring efforts. Pollution may routinely migrate to adjacent properties, as buses are left idling, or during periods of peak use—early mornings and afternoons. If vehicles are parked near schools, both outdoor and indoor school air quality may be diminished.

28. ***Bus Drivers:*** Bus drivers' exposure to motor vehicle and diesel exhaust is significantly higher than children's, due to longer periods of time spent on buses.

2. RECOMMENDATIONS

1. ***Prohibit Bus Idling:*** Drivers should be required to turn off bus engines immediately upon reaching their destinations. Buses should not be turned on until fully loaded. This is especially important when buses are queued while loading and unloading at schools and transfer stations. Exceptions should include conditions that would compromise passenger safety—e.g., extreme weather conditions, idling in traffic. In cases where engine operation is necessary to activate safety equipment such as flashing lights, buses should be retrofitted to permit battery operation. Idling restrictions should be defined by state statute and include clear and substantial enforcement power, instead of the present Department of Environmental Protection regulation 22a-174-18 (a)(5).

2. ***Retrofit Diesel Buses to Lower Emissions:*** Diesel school buses should be refitted with particle traps and catalytic converters designed to reduce emissions. Retrofit of the existing fleet should be completed by 2003.

3. ***Require School Buses to Use Ultra Low Sulfur Fuels:*** Ultra low sulfur diesel fuel (<15 ppm) should be required for all school buses. Acid aerosols, ozone precursors, and fine particulate emissions would be substantially reduced in the vicinity of children.

4. ***Replace Bus Fleet With Low Emission Vehicles:*** Existing diesel fleets should eventually be replaced with new low emission vehicles.

5. ***Allocate the Cleanest Buses to the Longest Routes:*** Bus companies and towns should allocate buses with the lowest emissions to the longest routes. Meeting this recommendation requires emissions testing to distinguish between clean and dirty buses.

6. ***Set Priorities:*** Priority for replacement with low emission vehicles, retrofit technologies, and filtration equipment should be assigned to communities with the highest ambient pollution levels, and to bus routes with the highest traffic intensity within communities.

7. ***Limit Ride Duration:*** School districts should reduce students' exposure to air pollution by limiting time spent on buses. This is already regulated by some town policies. Limiting ride duration would reduce exposure to pollution generated by diesel buses, and by other traffic.

8. ***Require Routine Maintenance:*** Buses should be monitored and maintained to ensure that emissions remain at their lowest possible level. Special care should be taken to ensure that exhaust systems are fully intact and secure, and that engine compartments are completely sealed from interior passenger space.

9. ***Test Tailpipe Emissions:*** Tailpipe emissions should be routinely tested on all school buses. This should be required by federal regulation, and implemented by the State.

10. ***Establish Passenger Cabin Air Quality Standards:*** The federal government should establish standards for air quality within vehicles that provide assurance of health protection for children.

11. ***Require Filtration Equipment:*** The federal government should require the installation of air filtration equipment on school buses. Equipment should be capable of removing vehicle exhaust from air entering the passenger cabin. This is especially important when buses travel in areas with high traffic intensity, or high outdoor background concentrations of pollutants.

12. ***Adjust Federal Air Quality Standards to Account for Indoor and Vehicle Exposures:*** EPA should adjust outdoor air quality standards to better account for probable indoor and within-vehicle exposures to air pollution. The Clean Air Act demands that standards be set to provide "an adequate margin of safety," however governments' neglect of particulate levels within homes, schools, and vehicles make it impossible to conclude that standards protect health.

13. ***Expand $PM_{2.5}$ Monitoring Network:*** The State of Connecticut should expand its monitoring network to more fully capture the local variability of air pollutants.

3. INTRODUCTION AND OVERVIEW

3.1 The Background Burden of Respiratory Illness

- Asthma is now the most prevalent chronic disease among U.S. children.[6]
- Nearly 4.8 million children between the ages of 0-18 have asthma in the nation.[7] This number represents about 7% of all children in the U.S.
- Although children make up 25% of the U.S. population, 40% of all asthma cases occur in children.[8]
- Between 1980 and 1995, the asthma prevalence rate for children ages 5-14 increased 74%.[9]
- Asthma related death rates for children 19 years and younger increased by 78% between 1980 and 1993.[10]

- Nearly 160,000 children in the U.S. are hospitalized for asthma annually.[11] Asthma prevalence is highest among urban children[12,13] and is the primary cause for childhood hospitalization in urban areas.[14] Background ambient outdoor pollution is most concentrated in urban areas.
- Since the mid-1980s, asthma rates in the U.S. have grown rapidly, increasing among all races, both sexes, all age groups, and in all regions of the U.S.
- These changes have occurred too quickly to be the result of genetic changes in the population, and most likely reflect varying patterns in exposure to chemical, physical and biological substances in their environment.

- Asthma is the primary cause of school absenteeism from chronic illness, and results in 10 million lost school days per year.[15]
- In 1999 Environment and Human Health, Inc. conducted a survey of asthma prevalence in Connecticut schools and demonstrated the illness to be more prevalent than earlier believed.[16]
- Among 543,475 children who attended Connecticut public schools in 1999, 44,571 were reported by school nurses to have prescribed medication for asthma. This rate, 1 out of 11, or 8.7%, is higher than CDC or EPA earlier estimated.
- Rates were highest for Connecticut middle school students, and these findings were consistent among urban, suburban and rural school districts. However, reported rates are likely lower than real prevalence, as high school students are less likely to report medications to school health officials.
- Districts with the highest socioeconomic status had the lowest prevalence rates (5.5%) while those with the lowest status had the highest prevalence rates (mean=9%).
- Prevalence among school districts ranged between 3 and 14%, while some individual schools had rates as high as 20%.

3.2 The Background Burden of Air Pollution

- U.S. industry emits nearly 200 *billion* pounds of air pollutants annually.[17]
- Nearly 500 million pounds of particulates are released from motor vehicles each year.
- In 1998, 25% of all U.S. children lived in parts of the U.S. that did not meet at least one of the federal standards for air quality.[18]
- EPA estimates that in 2000, 11 million U.S. children lived in areas that exceeded one or more federal air quality standards; 9 million children lived in areas where ozone standards were exceeded; 3.5 million children lived in areas where the particulate standards were exceeded, 2.8 million children lived in counties where the carbon monoxide standard was exceeded, and 1.4 million children lived in counties where the standard for lead was exceeded.[19]

- Severe asthma occurs more commonly than mild asthma among children living in areas that exceed federal air quality standards.[20]

- Living in areas that meet federal air quality standards does not ensure health protection, since only a limited number of pollutants are monitored at a limited number of sites. In addition, many hazardous chemicals remain unregulated.

- Diesel exhaust contributes significant amounts of NO_x to the atmosphere. Ozone is generated by photochemical reactions of ultraviolet light with nitrogen oxides and volatile organic compounds from hydrocarbon combustion. Ground-level ozone is the principle component of urban smog.

- The entire state of Connecticut has been designated by EPA to be a "*severe or serious ozone non-attainment area*," meaning that the ozone levels in the state are well above federal standards.

- In 2001, Connecticut exceeded the 8-hour ozone standard (85 ppb) for 26 days. The 1-hour ozone standard (124 ppb) was exceeded for 9 days.[21]

- The association between ambient ozone and increased asthma-related emergency room visits for children is well documented.[22, 23, 24, 25, 26]

- Experimental studies have shown that ozone can interact with allergens, amplifying airway reactions.[27]

- "PM_{10}" is defined as coarse particles with aerodynamic diameters between 2.5 and 10 micrometers. Sources of PM_{10} include crushing or grinding operations, and dust from paved or unpaved roads. These particles can aggravate asthma.[28]

- "$PM_{2.5}$" is defined as fine particles with aerodynamic diameters less than 2.5 micrometers. These result from fossil fuel combustion (motor vehicles, power plants, and wood burning), some industrial processes, and incineration. The chemical composition of PM_{10} varies considerably from that of $PM_{2.5}$.

- Although the U.S. has several decades of data available to understand the distribution of PM_{10}, $PM_{2.5}$ data have been less commonly collected.

- U.S. particulate sampling methods have relied upon fixed sampling sites to estimate variability rather than mobile or personal sampling designs.

- The California Air Resources Board estimated that indoor concentrations of particulates from diesel emissions were 1.5 ug/m^3 in 1995. The average outdoor level of diesel PM_{10} in Southern California was estimated to be 3.6 ug/m^3 in 1990.[29] In 2000, the average levels for California were estimated at 1.8 ug/m^3.

- Ozone, particulate matter, sulfur dioxide, and nitrogen oxides can worsen asthma in predisposed children. All of these pollutants are emitted as vehicle exhaust, or formed as a result of their interaction with other chemicals in the atmosphere.

3.3 Diesel Emissions

- Nearly 300 billion gallons of gasoline and diesel fuel are consumed each year.[30]

- Approximately 7 million heavy trucks drive nearly 200 billion miles annually in the U.S.[31] Heavy trucks emit approximately 1.5 grams of total carbon per mile traveled.[32]

- Nearly 500 million pounds of particulates are released from motor vehicles each year, and roughly 60% of this weight is emitted from diesel engines.[33] This results in emissions of 300 million pounds annually of PM_{10} and 268 million pounds annually of $PM_{2.5}$ from diesel powered vehicles.[34]

- Diesel exhaust is a complex mixture of particles and hazardous volatile chemicals. Emissions include gases formed from combustion (nitrogen, oxygen, carbon dioxide and water vapor), and from incomplete combustion (benzene, formaldehyde, 1,3-butadiene, and polycyclic aromatic hydrocarbons).

- Diesel emissions contain a far higher concentration of particulates—especially those of small diameter—than gasoline emissions. Nearly all diesel exhaust particles are less than 10 micrometers in diameter, while almost 94% are less than 2.5 micrometers, and 92% are less than 1 micrometer. These fine particles penetrate most deeply into the lungs of children, who have especially small airways.[35]

- These fine and ultrafine particles provide the delivery system to the lung for hazardous particles and gases. Hazardous organic compounds include: carbon monoxide, formaldehyde, sulfur and nitrogen oxides and PAH's (polycyclic aromatic hydrocarbons).[36]
- Recent advances in diesel engine technology have resulted in a decline in the total weight of emissions. However, some research suggests that newer engines may produce a higher number of small diameter particles, especially threatening the health of children with smaller airways.[37]
- The composition of diesel exhaust varies by engine type (heavy vs. light duty), engine age, fuel used (low vs. high sulfur), operating conditions (acceleration, deceleration, idling, uphill and downhill runs) and vehicle load.
- Diesel particulate matter (DPM) ranges between 1-20 ug/m^3 in ambient air, depending upon location of sampling and measurement methods.[38]
- Within-vehicle concentrations of black carbon were measured in Sacramento (0-10 ug/m^3), and Los Angeles (3-40 ug/m^3).[39]
- Black carbon within vehicles was detected at 5 ug/m^3 in background Los Angeles air; at 15 ug/m^3 when following a diesel vehicle with a high exhaust pipe; at 50 ug/m^3 when following a truck with a low exhaust pipe; and at 130 ug/m^3 when following an urban transit bus (windows were closed for all readings).[40]
- The California Air Resources Board (CARB) conducted a study of air contaminants within cars in 1998. They found levels of benzene, formaldehyde, carbon monoxide, toluene, and other pollutants that were often 2-10 times higher than levels measured at a nearby fixed monitoring site.
- CARB also found pollution levels within vehicles increased as traffic became more congested, and that pollution levels quickly doubled when following diesel powered trucks and buses.[41]
- The International Center for Technology Assessment reviewed 20 reports on in-vehicle air contamination and found that pollution levels within vehicles were normally significantly higher than levels found along roadsides.[42]
- Almost 94% of diesel particulate matter is comprised of elemental and organic carbon.

FIGURE 1: DIESEL $PM_{2.5}$ CHEMICAL COMPOSITION[43]

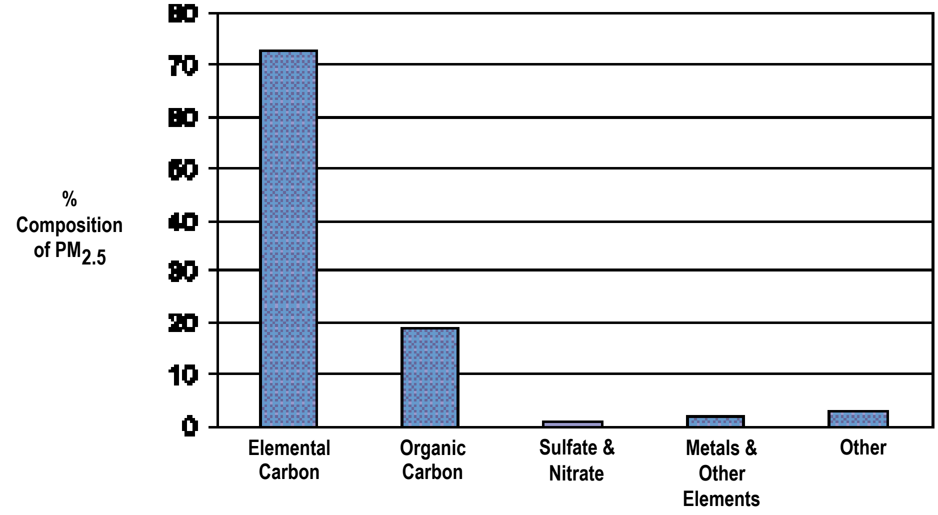


FIGURE 2: U.S. TRENDS IN DIESEL FUEL CONSUMPTION
30 BILLION GALLONS PER YEAR[44]

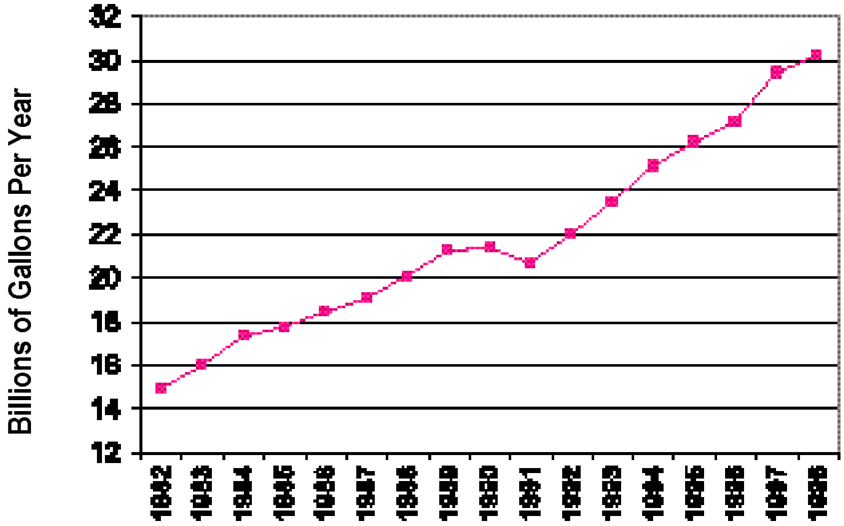


Figure 2 demonstrates a 45% increase in diesel fuel consumption in the U.S. over the past decade. As newer diesel engines emit less pollution, total pollution may still increase in response to increasing numbers of vehicles on the highway, and increasing miles driven by diesel vehicles.

3.4 Children's Susceptibility

- Some individuals are more susceptible to adverse health effects from exposure to air pollution than others. Children, those with respiratory disease, and the elderly are often the most susceptible.

- Lung function grows rapidly during adolescence. Increases in lung function level off during late teenage years for females, and early 20's for males.[45, 46]

- The branching of airways is a gradual process that continues to develop through early childhood. Respiratory development involves more than 40 different types of cells that evolve or "differentiate" from primitive lung cells in the developing fetus. Rapid rates of cell differentiation, cell division, and airway branching make the period between conception and young adulthood one of unusual susceptibility to adverse effects from toxic air pollutants.

- When lungs are fully developed, several hundred million tiny sacs (alveoli) deep within the lungs replenish blood with oxygen, while removing carbon dioxide; 80% of the alveoli develop following birth, when children are often exposed to diverse air pollutants.

- Children are normally more exposed to environmental hazards than adults. Pound for pound, children breathe nearly 50% more air than is inhaled by adults. During strenuous exercise and intensive play, respiration rates increase rapidly, increasing the inhaled dose of any air pollutant.[47]

- Breathing fine particulate matter has been associated with increased use of medications, hospital admissions, emergency room visits, and premature mortality.

- Children's rapid growth and development make them especially sensitive to chemicals that may affect cell reproduction and differentiation. This has been demonstrated for tobacco smoke, alcohol, some drugs, and some pesticides in animal and human studies.

3.5 Health Effects of Diesel Exhaust

- Diesel exhaust contains more than 40 chemicals listed as Hazardous Air Pollutants under the Clean Air Act.

- Diesel exhaust is a mixture of many gases and inorganic substances that individually are hazardous to human health.
- Diesel exhaust has been associated with premature mortality, increased risk of lung cancer among truck drivers, immunological reactions including inflammation of the airways, airway constriction, chronic bronchitis, reductions in pulmonary function, chronic cough, phlegm, chest tightness, wheezing, and increased susceptibility to infections.[48]
- Diesel exhaust has been found to induce genetic damage in both animal and human cells, including chromosomal aberrations, aneuploidy, and sister chromatid exchange.
- 1,3-butadiene, a component of diesel fuel and its exhaust, was recently found to be both cytotoxic and genotoxic to human bronchial epithelial cells. It is also classified as a "known human carcinogen" by the U.S. National Toxicology Program.[49]
- Polycyclic aromatic hydrocarbons (PAH's) found in diesel emissions are among the most potent carcinogens and mutagens known.
- Benzene levels were associated with increased childhood visits to emergency rooms for asthma in Belfast, Ireland. Benzene is a component of vehicle exhaust and fuels.[50]

Figure 3: Chemicals in Diesel Exhaust Listed by the California Air Resources Board as Toxic Air Contaminants[51]

acetaldehyde
acrolein
aniline
antimony compounds
arsenic
benzene
beryllium compounds
biphenyl
bis[2-ethylhexyl]phthalate
1,3-butadiene
cadmium
chlorine
chlorobenzene
chromium compounds
cobalt compounds
cresol isomers
cyanide compounds
dioxins and dibenzofurans
dibutylphthalate
ethyl benzene
formaldehyde
hexane
inorganic lead
manganese compounds
mercury compounds
methanol
methyl ethyl ketone
naphthalene
nickel
4-nitrobiphenyl
phenol
phosphorus
Polycyclic Aromatic Hydrocarbons
propionaldehyde
selenium compounds
styrene
toluene
xylene isomers and mixtures
o-xylenes
m-xylenes
p-xylenes

3.6 Carcinogenicity Of Diesel Exhaust

- Fine particulates deliver several known and probable carcinogens to human lungs. These include: benzene[52, 53], 1,3-butadiene, soot, formaldehyde[54], PAH's, and nitroarenes.[55]

- The U.S. Department of Health and Human Services National Toxicology Program classified diesel exhaust as *Reasonably Anticipated to Be a Human Carcinogen* in 2000. This choice was based upon an increased risk of lung cancer of 30%, with higher risks found among more heavily exposed groups in occupational settings.[56]

- Diesel exhaust was recently classified as the 6th most potent carcinogenic substance reviewed by the State of California's Scientific Review Panel, following dioxins, chromium IV, inorganic arsenic and benzo(a)pyrene. The panel reviewed 30 human epidemiological studies, and found that cancer risks increased 40 percent among those exposed to diesel exhaust over long periods of time, an association "unlikely to be due to chance" and strongly suggesting "a causal relationship between diesel exhaust exposure and lung cancer."[57]

- The International Agency for Research on Cancer (IARC) classified diesel exhaust as a probable human carcinogen in 1989.[58]

- The State of California classified diesel exhaust as "*known to the State of California to cause cancer*" in 1990.

- The State of California Scientific Review Panel on Diesel Exhaust concluded: "A level of diesel exhaust exposure below which no carcinogenic effects are anticipated has not been identified."[59]

- In Southern California, the South Coast Air Quality Management District estimated that 71% of cancer risk from air pollution is derived from diesel exhaust, finding the excess cancer risk to be 1.4 per 1,000 associated with diesel concentrations in outdoor air.[60]

- Diesel bus drivers in Copenhagen and garage mechanics were found to have higher levels of PAH adducts in their lymphocyte DNA, demonstrating exposure to genotoxic substances most likely from vehicle emissions.[61]

3.7 Asthma and Particulates

- Asthma is a chronic inflammatory disorder of the airways. Airways may become highly responsive to a variety of physical, chemical and biological contaminants in the air. Asthma causes breathing difficulties by constricting muscles surrounding the airways, and inflaming them. Both of these processes reduce air flow to the alveoli.[62]

- Children and the elderly are commonly more susceptible to asthma than adults; and some children are more susceptible to chronic airway sensitization and restriction than other children.

- A variety of factors can trigger asthma in predisposed individuals: household dust mites, indoor or outdoor air contaminants, allergens, food, exercise, respiratory infections, and cold weather may set off an attack. These triggers may act independently or together.

- Air pollution may induce asthma attacks and increase their severity. Breathing wood smoke, tobacco smoke, volatile substances, motor vehicle exhaust, exhaust fumes from heating and cooking appliances, pesticides, paint fumes and synthetic fragrances may diminish respiratory health.

- Air pollution has been associated with asthma in many studies and is considered by many researchers to be an important factor in the increasing incidence and severity of asthma.[63, 64, 65]

- Recent studies suggest that pollutants such as diesel exhaust, ozone, sulfur dioxide, and nitrogen dioxide, together with allergens and susceptible genes are likely to promote IgE production, allergic reactions and airway constriction.[66]

- Children with asthma are 40% more likely to have an attack on high outdoor pollution days.[67]

- Particle deposition and retention has been shown to be higher among severely asthmatic children when compared with mildly asthmatic children. Thus the delivered dose of particulates and associated toxic air pollutants may be higher among severely asthmatic children.[68]

- Ozone, particulate matter, sulfur dioxide, and nitrogen dioxide can adversely affect lung function in asthmatics. [69, 70, 71, 72]

- Experimental studies have also shown that some pollutants, such as ozone or diesel exhaust particles, can interact with allergens, amplifying allergic reactions.[73]

- Environmental factors—including pollution, dust mites, pet dander, molds, pollen, cockroaches, viruses, and bacteria—may increase the severity and prevalence of the disease, even though they do not cause the disease.[74]

- As concentrations of particulate matter rise, prevalence and severity of asthma increase. Children experienced increased severity of asthmatic symptoms and increased use of medications following short term increases in particulates (PM_{10}). One-hour maximum PM_{10} levels were more strongly associated with increased symptoms than 24-hour mean levels.[75]

- High particulate concentrations have been associated with asthma attacks and deaths due to asthma.[76]

- Ultrafine carbon particles may become more deeply embedded in lung tissue than coarse particles. Higher concentrations of carbon have been found in lungs of those living in areas of higher concentration of PM_{10}.[77] Most of the particles are less than 0.1 micrometers and are classified as "*ultrafine*."[78] Particulate size is inversely associated with increasing severity of symptoms and prevalence of asthma.[79]

- EPA estimated in 1999 that several tens of thousands of premature deaths are caused annually by outdoor, fine-diameter (<2.5 micrometers) particulate matter.[80]

- Children living near high traffic flows are more likely than those residing near lower traffic flows to have more medical care visits per year for asthma[81] and a higher prevalence of most respiratory symptoms.[82, 83]

- Traffic related air pollution in Austria, France, and Switzerland is estimated to be responsible for 290,000 episodes of bronchitis in children; and 0.5 million asthma attacks.[84]

- Children living in areas with higher ambient or background levels of PM_{10} had lower rates of annual lung function growth.[85]

- The Children's Health Study at the University of Southern California recently found that children who moved to areas with lower PM_{10} levels had increased lung function growth rates, while those moving to areas with higher PM_{10} levels had reduced lung function growth rates.[86]

3.8 Health Effects of Short-Term Exposure To Air Pollution

- The federal government averages particulates from a limited number of monitoring sites over 3 years to judge compliance with PM standards. Adverse respiratory health effects among asthmatics may occur following shorter duration exposures to some pollutants. Evidence that short-term exposures may be associated with adverse respiratory health effects is growing rapidly and is briefly summarized below.

- One-hour and 8-hour maximum PM_{10} levels were found to have a larger effect in inducing asthma symptoms among children ages 9-17 than 24-hour average levels, and the effects were strongest among children who frequently were more symptomatic.[87]

- Single episode exposures to nitrogen dioxide emitted from gas cooking stoves induced immediate airflow limitation in a study of 16 adult women with mild to severe persistent asthma.[88]

- A study of 133 Seattle children found an association between short-term particulate and CO levels and the occurrence of asthmatic symptoms. The odds of experiencing symptoms increased by 18% for a 10 ug/m^3 increase in the very finest particles ($PM_{1.0}$), while symptoms increased 11% for a 10 ug/m^3 increase in PM_{10}. The authors concluded: "there is an association between change in short-term air pollution levels, as indexed by PM and CO, and the occurrence of asthma symptoms among children in Seattle.[89]

- 29 volunteers with mild allergic asthma were exposed to vehicle exhaust in a car within a Stockholm road tunnel for 20 minutes. Subjects exposed to $PM_{2.5}$ at levels above 100 ug/m^3 had an increased reaction to an allergen administered 4 hours after the tunnel exposure. The authors concluded: "Exposure to air pollution in road tunnels may significantly enhance asthmatic reactions to subsequently-inhaled allergens." [90]

- A German study of asthmatic children concluded: "Exposure to traffic flow and in particular, truck traffic and diesel exhaust leads to significant increases in respiratory symptoms and decreases in lung function." [91]

- Lung function among children in the Netherlands was associated with intensity of truck traffic near residences and schools. "Cough, wheeze, runny nose, and doctor-diagnosed asthma were significantly more often reported for children living within 100 m from the freeway. Truck traffic intensity and the concentration of black smoke measured in schools were found to be significantly associated with chronic respiratory symptoms." [92]

- Ten-minute SO_2 exposures >0.5 ppm when combined with intensive exercise produced short-term asthma symptoms of higher intensity than those usually experienced. Sulfur is a component of diesel fuel and exhaust. [93]

- A study of 89 asthmatic children in the Czech Republic found that the effects of air pollution on asthmatic children with respiratory infections may be greater than on those without infections. Children experienced declines in peak respiratory flow associated with exposure to fine particulates during air pollution episodes. [94]

- Exposure to NO_2 for 30 minutes increased airway responsiveness to hyperventilation among 14 mild asthmatics. [95]

- EPA concluded in 2000 that short-term exposures to diesel particulate matter can produce allergenic effects, caused by both the carbon core of particles, and adsorbed gaseous compounds. [96]

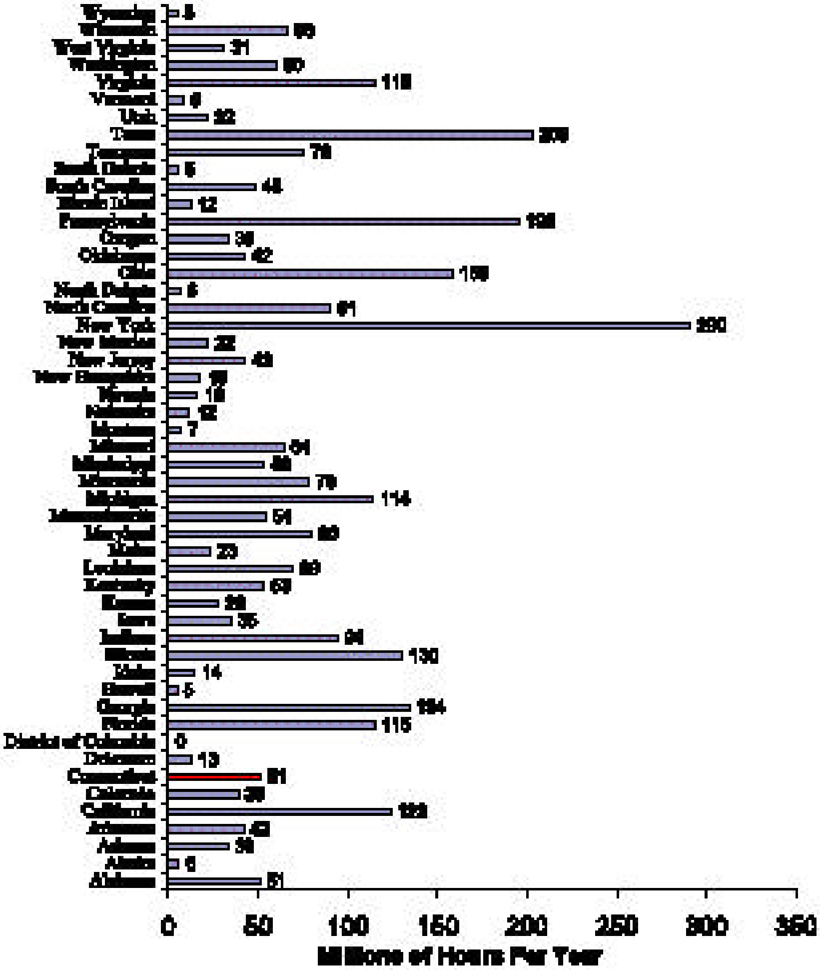
- Human volunteers exposed to diesel exhaust for 1 hour experienced airway resistance and irritation of the eyes and nose. [97]

3.9 Children's Exposure: Time on the Bus

- Nearly 600,000 school buses transport 24 million students to school each day in the U.S. These children travel nearly 4 billion miles on buses each year.[98]
- More than 10 billion rides are taken on school buses by America's children each year.
- Connecticut children spend nearly 50 million hours on school buses each year:[99]
  - In Connecticut, 592,000 students are enrolled in kindergarten through 12th grade, including public and private schools.
  - Nearly 387,000 students ride nearly 6,100 buses to school each day in the State.[100]

  - School buses in Connecticut in 1998 each consumed an estimated 1600 gallons of diesel fuel on average for a total of 9.8 million gallons.[101]
  - Assume student time on the school bus averages 1 hour per day, over 180 days per year, for 13 years (K-12). This would constitute 2,340 hours of bus time for each child—almost 90 complete 24-hour days, or 2% of their childhood between the ages of 5-17. Transit time per student varied between 20 minutes and 3 hours among the towns studied.

Figure 4: Millions of Hours Spent on School Buses by U.S. Children[102]



Total: 3 Billion Hours Per Year Assuming 40 Minutes/Child-Day

Figure 5: Hours Spent on School Buses

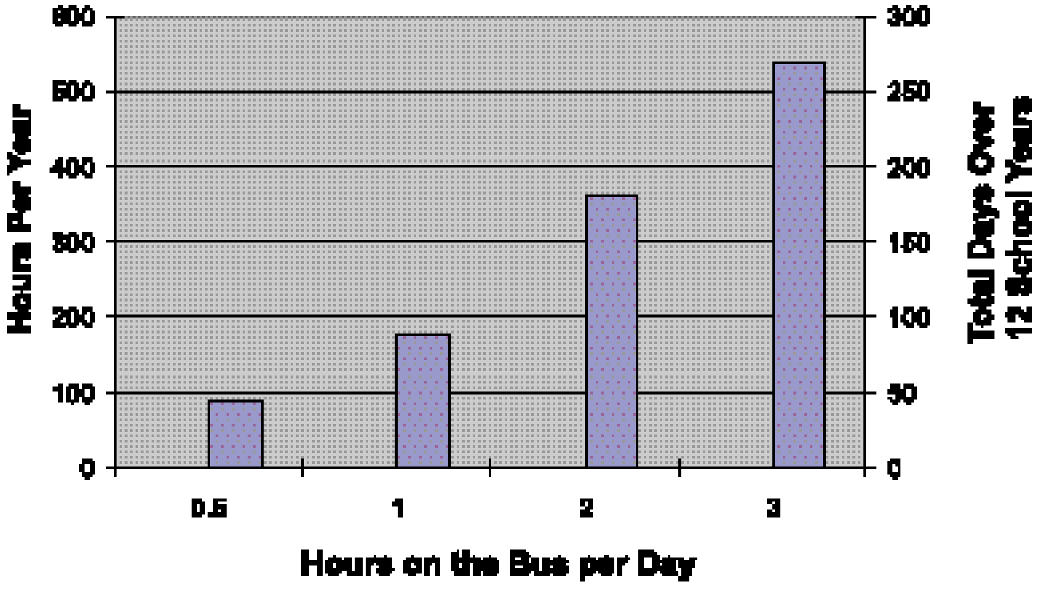


Figure 6: Student Rides on School Buses in U.S.[103]

RIDES PER DAY	52.8 Million
RIDES PER SCHOOLYEAR (X 180)	9.5 Billion
RIDES DURING SUMMER	1.0 Billion
TOTALSTUDENT RIDES PER YEAR	10.5 Billion

- Although the average bus ride duration in towns studied was approximately 30 minutes, in some large rural communities, transit time for students was nearly 3 hours per day, including bus transfers. Variability in the length of ride will lead to variability in exposure to pollution levels within buses.

- Background concentrations of particulate matter and various organic compounds emitted by motor vehicles often contribute to the concentrations found within buses. This is especially the case in urban areas, near heavily used roads and highways, and in proximity to "non-road" sources of diesel emissions—e.g., construction sites, rail lines, and ports.

- Although this study was designed initially to understand student exposure to air pollution, bus drivers are obviously more heavily exposed to higher levels of the motor vehicle exhaust, due to the longer duration of their daily exposures. Figure 5 could be used to estimate bus driver exposure, i.e., 5 hours per day would be equivalent to 900 hours of exposure per year.

3.10 Regulating Diesel Exhaust

- Air quality law in the U.S. regulates three types of outdoor pollutants:

    - "*Primary Pollutants*" also known as "*Criteria Pollutants*" include: lead, carbon monoxide, sulfur dioxide, nitrogen oxides, ozone and particulate matter.

    - "*Hazardous Air Pollutants*": 189 chemicals to which "maximum achievable control technology" standards must be applied.

    - "*Mobile Source Emissions*": primarily cars and trucks, and their fuels.

- Diesel emissions have been regulated primarily under federal "mobile source" rules. Diesel exhaust however includes both "criteria" particulates and "hazardous air pollutants."

- Indoor air quality remains largely unregulated in the U.S., with the exception of some chemicals in some occupational settings, some pesticides, and tobacco smoke in some public and private settings.

- Air pollution within motor vehicles remains unregulated in the U.S. and permissible exposure limits have not been set for diesel emissions in occupational settings.

- Tailpipe emissions testing of buses or trucks is not required by federal law, but may be adopted by individual states. Routine emissions testing is not required of school buses or trucks in Connecticut.

- The Connecticut Department of Environmental Protection established a regulation to limit vehicle idling to 3 minutes, yet this is neither monitored nor enforced.[104]

- Delays in air quality regulation are routine. The American Lung Association sued EPA in 1994, arguing that the particulate standard then in place was not health protective. At that time, 12 years had passed since EPA's first reassessment of its scientific analysis, and 7 years had passed since EPA had replaced the TSP standard with the PM_{10} limits. The court demanded that EPA complete its review of the scientific literature and propose any changes to the standards by 1997.[105]

- EPA issued new particulate and ozone standards in 1997.[106, 107] EPA focused their health concerns on mortality studies, and concluded that on average, a 4% increase in daily mortality occurred with a 50 ug/m^3 increase in average daily levels of PM_{10}. A $PM_{2.5}$ standard was added to the PM_{10} standard to control the finer particulate matter then believed to pose a special threat to respiratory health of children. The 1997 standard restricts $PM_{2.5}$ to 15 ug/m^3 when data are averaged daily over a 3 year period. It also sets a daily maximum daily average of 65 ug/m^3, calculated as the average of daily 98th percentile values, again averaged over 3 years.

- EPA, in 2000, adopted new emissions standards for heavy-duty diesel engines.[108] Sulfur content of fuel will be reduced from 500 to 15 ppm, and refiners and retailer will be required to produce and provide 15 ppm sulfur fuel by July 15, 2006. Use of the fuel will be phased in between 2006 and 2010. EPA estimated that the cost of sulfur reduction will eventually result in a 4-5 cent increase in the price per gallon, and an increase in the costs of new vehicles of $1,200-$1,900.[109]

- Trucks and buses, beginning in model-year 2007, must have engines that produce 90% fewer particulate emissions than current models. By 2010, nitrogen oxide emissions must be reduced by 95% from current levels.[110]

- EPA estimated that the new standards, *when fully implemented in 2010*, would result in 8,300 fewer premature deaths, 17,600 fewer cases of childhood acute bronchitis, and 360,000 fewer asthma attacks.[111]

- The U.S. Supreme Court in *Whitman v. American Trucking Associations, Inc., No. 99-1257,* ruled that the Clean Air Act unambiguously bars cost considerations from the standard-setting process. It requires EPA to set standards "allowing an adequate margin of safety...requisite to protect the public health."[112]

4. Research Methods

1. ***School Day Personal Monitoring:*** 15 students were followed through their school day—both outdoors and indoors—using personal monitors to measure airborne particles (PM_{10} and $PM_{2.5}$). Each student was monitored for an average of 7 hours.[113] Air samples were collected using gas canisters and absorbent cartridges to measure 105 different volatile compounds, including benzene, formaldehyde, 1,3-butadiene, and MTBE. Children were personally accompanied by a research assistant and monitored from the time each left their home in the morning to the time each returned to their home in the afternoon. Students carried a particulate meter, personal sampling pump, and VOC canister throughout the day. A research assistant monitored equipment function and placement, and recorded the child's behavior and movement as well as environmental conditions on a log.

Student with monitoring equipment.

2. ***Experimental Monitoring:*** Black carbon and particulates ($PM_{2.5}$) were measured on buses as they idled and drove along a route in Storrs, CT. No students were on the buses, yet 4 or 8 stops were made for 30 second intervals as the bus moved through each run to simulate normal child entry or exit. Eight runs of diesel buses were conducted per day for 4 days to test the effects of a) windows being opened, and b) the location of monitoring equipment on the bus. Two window conditions were compared, one with all windows opened, and the second with all windows closed. Two locations within the buses were compared, one with the equipment in the first seat behind the driver, and one with the equipment in the last seat. A natural gas-powered bus was also tested.

3. ***Experimental Control:*** To better understand the contribution of the tested buses to detected levels of carbon and particles, we monitored carbon and particles for 3 days, following an established bus route with 20 stops in a rural Connecticut town. The runs were conducted without students on a rural route during midday to minimize additional sources of particulates and carbon. Three bus types were compared—a diesel-powered bus with the engine next to the driver, a second diesel powered rear engine bus, and a natural gas powered bus. Additional traffic was logged.

4. ***Black Carbon Monitoring Equipment:*** We used an aethalometer (Magee Scientific Instruments) to measure carbon. It produces readings of black carbon particles by collecting a continuous sample on a quartz fiber filter and this sample is compared with a reference segment of the tape.[114] Specifications are further reported by Hanson et al.[115] Results are reported at 1-minute intervals. Air flow was controlled by an internal vacuum pump, and operated at 4 liters per minute. Power was supplied by a 12 volt battery. The instrument recorded background measurements similar to levels of BC reported elsewhere (<0.3 ug/m^3), and was responsive to visible changes in diesel traffic intensity.[116]

5. ***Particulate Monitoring Equipment:*** We used two *personalDataRAM* monitors, model pDR-1200, manufactured by MIE, Inc., Bedford, Mass., to measure both PM_{10} and $PM_{2.5}$. One instrument was assembled with a cyclone and air pump (flow rate 1.5 L/min) to measure $PM_{2.5}$. The meter measures light scatter from particles, and takes real time readings at 1-second intervals, reported as 10-second averages.[117] The meters reported background outdoor levels of $PM_{2.5}$ and PM_{10} within the range of levels reported by State monitoring equipment. The instruments were immediately responsive to visible changes in traffic intensity.

6. ***Sampling and Chemical Analysis:*** Sampling and chemical analyses were conducted by the University of Connecticut Environmental Research Institute (ERI). ERI staff contacted potential student subjects, obtained school and parental permissions, supervised personal sampling and monitored equipment, and conducted analyses on gas samples.

7. ***Study Limitations:*** This study did not capture the full range of vehicle emissions likely to be experienced by Connecticut children while on school buses. Given our efforts to conduct tests in rural settings, with low traffic volume and few additional sources of nearby combustion, these findings are likely to *underestimate* Connecticut children's upper levels of particulate and black carbon exposure from vehicle exhaust. The sample size of buses tested, consistency in patterns of detected levels of particles and carbon, knowledge of associated bus idling, queuing and running practices, together provide a basis for reasonable estimates of children's exposure to vehicle emissions while moving between homes and schools on buses in Connecticut. Our use of 10-second averaged data also produced underestimates of the upper levels that existed on tested buses.

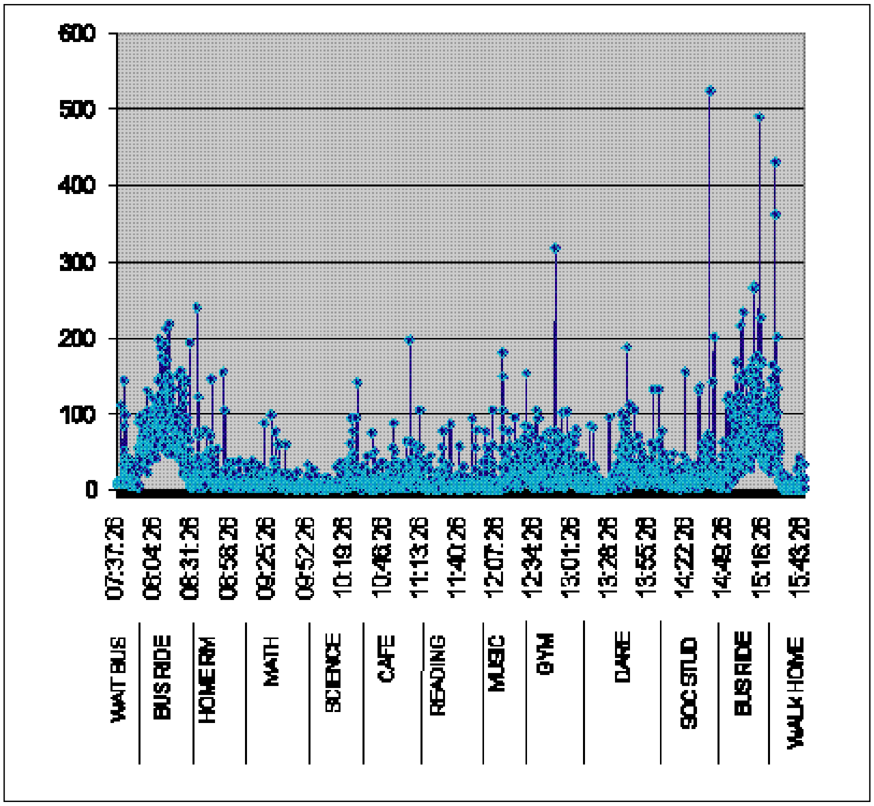
5. Detailed Research Findings

Finding 1: Variability In Daily Personal Exposure

- Highest outdoor concentrations of particulates were found within or near school buses, or when walking along routes with high traffic volumes. Detected levels of PM_{10} exceeded 150 ug/m^3 for short periods. Highest indoor levels were associated with intense activity, such as movement from class to class, recreational periods in gymnasiums or playgrounds, and some class activities.
- Figure 7 demonstrates one child's exposure through the school day, including a pattern of concentrated exposure to particulate matter (PM_{10}) in early morning and late afternoon surrounding bus transport.
- The chart also demonstrates that children are exposed to levels of PM_{10} occasionally exceeding 100 ug/m^3 within the school itself.

Figure 7: Student Exposure to PM_{10} (ug/m^3)

Each data point represents a 10-second average of recorded data. Unless otherwise noted in the analyses and charts that follow, summary statistics and distributions for particulates are presented for data averaged over 10-second intervals.



- Figures 8, 9 and 10 demonstrate that monitored children were exposed to PM_{10} at levels several times higher than experienced before entering or after leaving buses. Arrow points indicate the beginning and end of rides.

- In all three of these cases, levels of PM_{10} increased immediately as the student entered the bus. Concentrations decline following exit from the bus, however, when students walked past other idling buses the decline was sometimes delayed until the student entered the school.

- The levels of PM_{10} measured before and after the bus ride were within the range of PM_{10} reported by State of Connecticut background monitors. While on buses, levels were 5-10 times higher than averages reported by State monitoring efforts.

Figure 8: PM_{10} Levels

Southeastern Connecticut

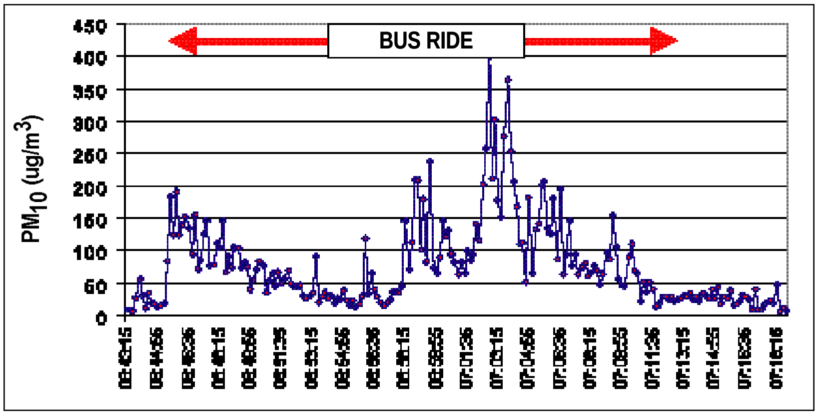


Figure 9: PM_{10} Levels

Northeastern Connecticut

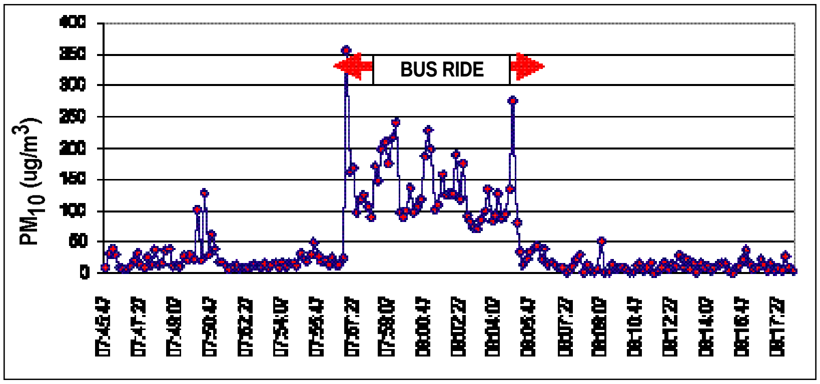
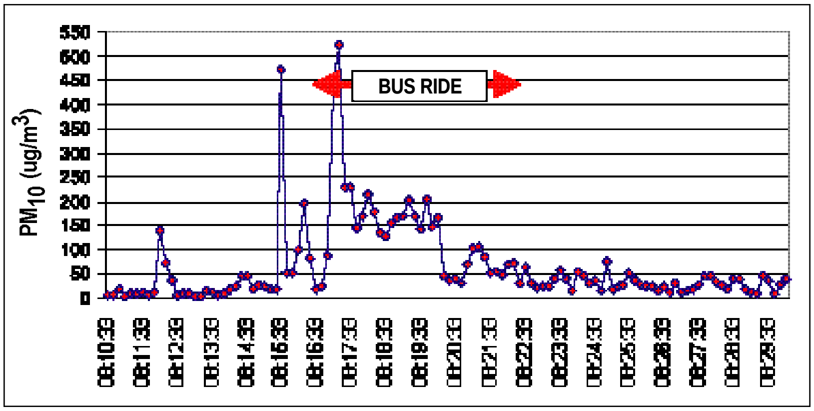


Figure 10: PM_{10} Levels

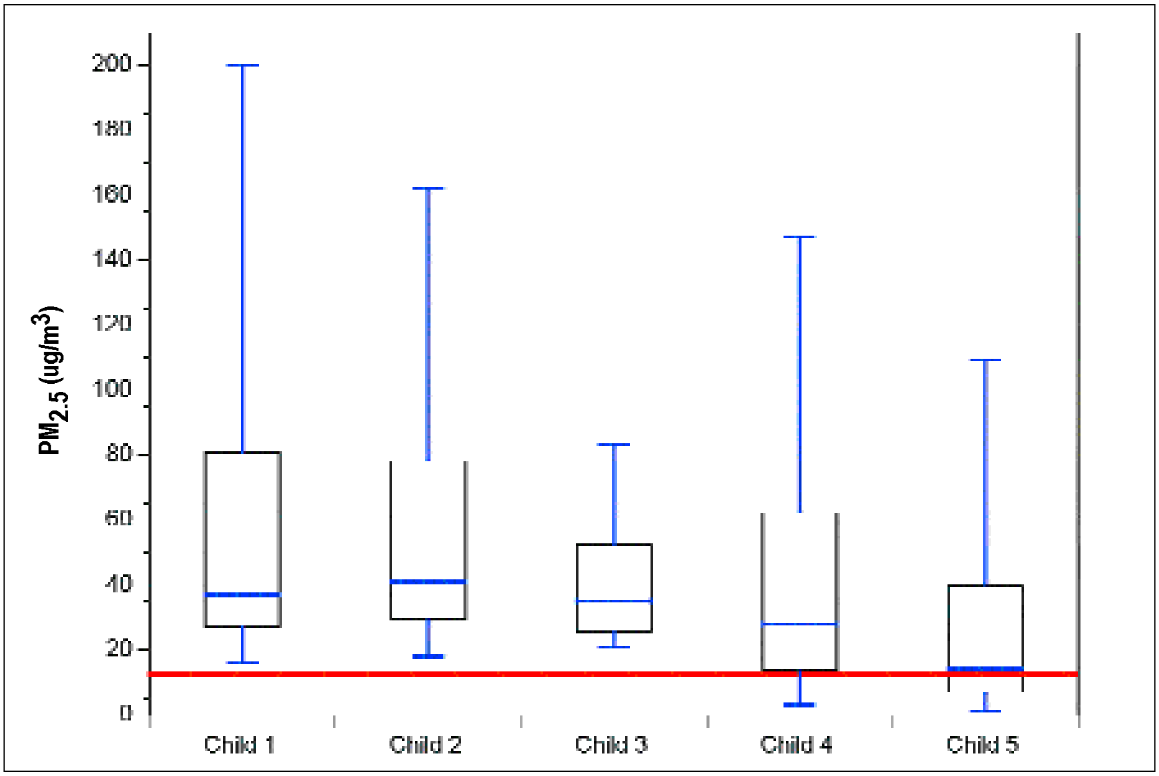
Central Urban Connecticut



- Figure 11 below demonstrates that school day exposures for individual children are sometimes higher than levels estimated by the State's estimates, derived by averaging data obtained from fixed monitors.

- The average levels of $PM_{2.5}$ detected near Child 1 during the school day were nearly 3 times higher than the average daily readings for outdoor air in that community. In this case the State's monitoring facility lies at the school we sampled. Child 1 and Child 2 walked to school on a route adjacent to Interstate 95 with nearby construction activity. These boxplots represent the distribution of detected $PM_{2.5}$ (maximum, 75th %, mean, 25th %, and minimum values).

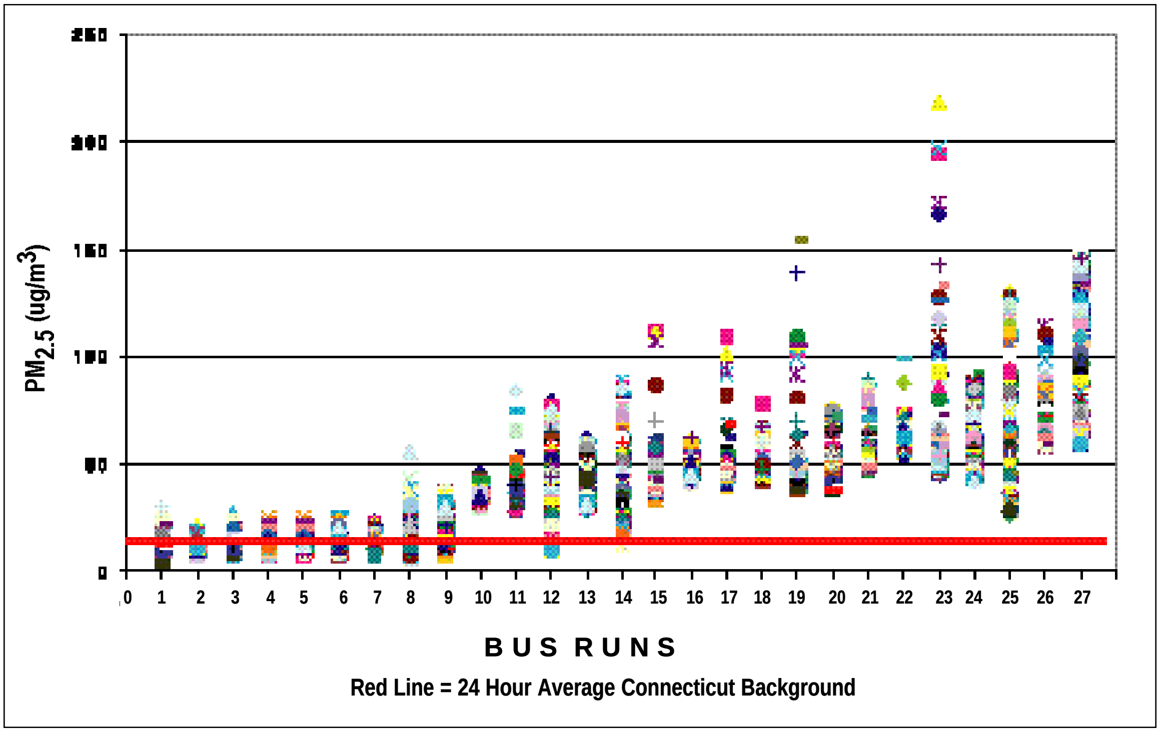
Figure 11: 5 Students' Exposure to Particulates ($PM_{2.5}$ ug/m^3)



Red Line Locates Average Daily Connecticut $PM_{2.5}$.

Finding 2: Children's Exposure to Particulates on Buses

Figure 12: Particulate Matter on School Buses
Range of Detected PM$_{2.5}$



Red Line = 24 Hour Average Connecticut Background

Particulate levels detected in 27 different bus runs along the experimental route are presented in Figure 12. Each bar represents a separate bus run, arrayed from lowest to highest concentration by run.

- Highest concentrations detected within buses exceeded these background levels by nearly a factor of 10, exceeding 100 ug/m^3 during 7 bus runs.

- Short-term exposures on school buses were sometimes 5-10 times higher than State of Connecticut estimates of average 24-hour concentrations for the community.

Figure 13: $PM_{2.5}$ on Connecticut School Buses

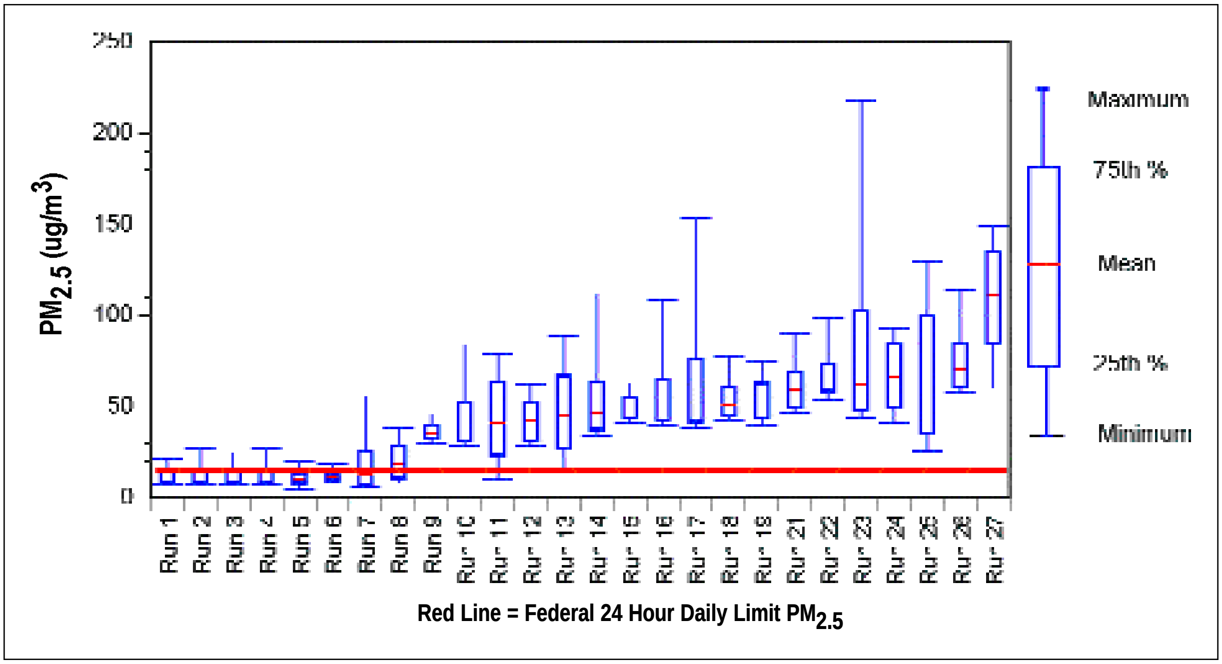


Figure 13 demonstrates the range of detected $PM_{2.5}$ *on 27 bus runs. Maximum, 75th%, mean, 25th% and minimum values are shown.*

Finding 3: Carbon and Particulates Within Moving Buses

- In the buses studied, exhaust often entered bus interiors when buses stopped. Exhaust entered through opened doors and windows. The change in concentration may have been influenced by wind direction, window configuration, exhaust pipe location, ambient concentrations, and traffic.

- This effect was recognized by the monitors, by sight (visible smoke entering some buses) and by smell.

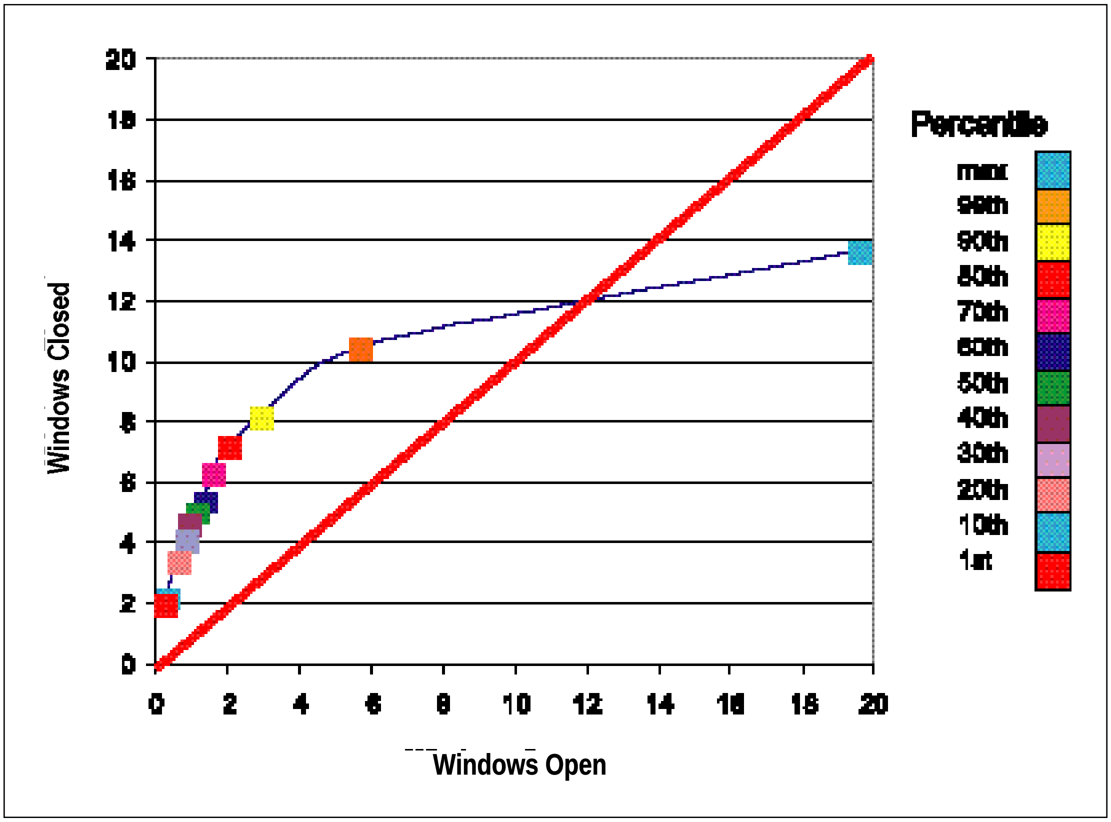
- When the buses moved through the route with the windows closed, carbon levels often increased at stops. Exhaust is emitted from the rear tailpipe, and some portion appears to be pulled along behind the bus, depending upon wind and traffic conditions. When buses stop and the door is opened, some exhaust may enter the bus along with the children. When windows were closed, carbon levels increased with stops. When windows were open, carbon and particulate reduction was more rapid than when windows were closed.

- Buses traveling closely behind other diesel vehicles had higher concentrations of interior particulates than buses on routes with no diesel traffic. This effect was found in several California studies cited above. Diesel exhaust may enter the bus interior in several ways. It may enter from unsealed engine compartments, leaking exhaust systems, through windows and through doors, and unfiltered air and heating vents.

- Figure 14 demonstrates that mean detected levels of black carbon were significantly different when bus runs are grouped by window configuration. When windows were closed, carbon levels increased. When opened, black carbon tended to be ventilated rapidly.

Figure 14: Black Carbon in Moving Buses (ug/m^3)

Percentile Comparison: Closed vs. Opened Windows



If black carbon levels in moving buses were identical when windows were open and closed, the percentile levels depicted by the colored blocks would fall on the red line of equivalence. Instead, concentrations were higher when windows were closed. When the percentile levels were compared between the two window scenarios—for example, the 90th percentile level among runs when windows were open compared with the 90th percentile value when windows were closed—all fall above the line of equivalence.

- As shown in figures 14, 15 and 16, managing interior pollution levels by opening and closing windows is clearly a possibility, but is neither a reliable nor practical option.

Figure 15: Black Carbon in Moving Buses (ug/m^3)

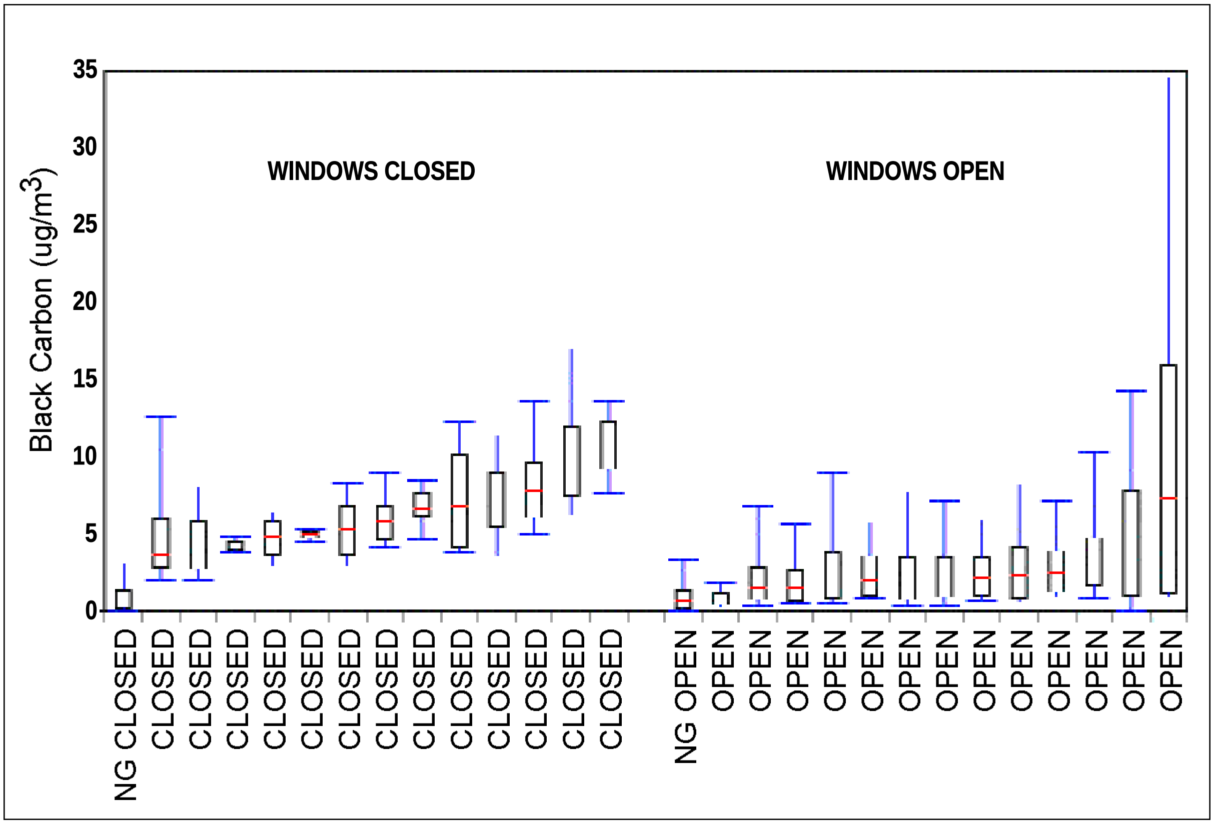


Figure 15 demonstrates that concentrations of black carbon were higher on moving buses when windows were closed, when compared to runs when windows were opened. Natural gas-powered bus concentrations of carbon (NG) were among the lowest levels detected in the study, with the exception of one diesel bus tested when windows were open.

Figure 16: PM $_{2.5}$ in Moving Buses (ug/m^3)

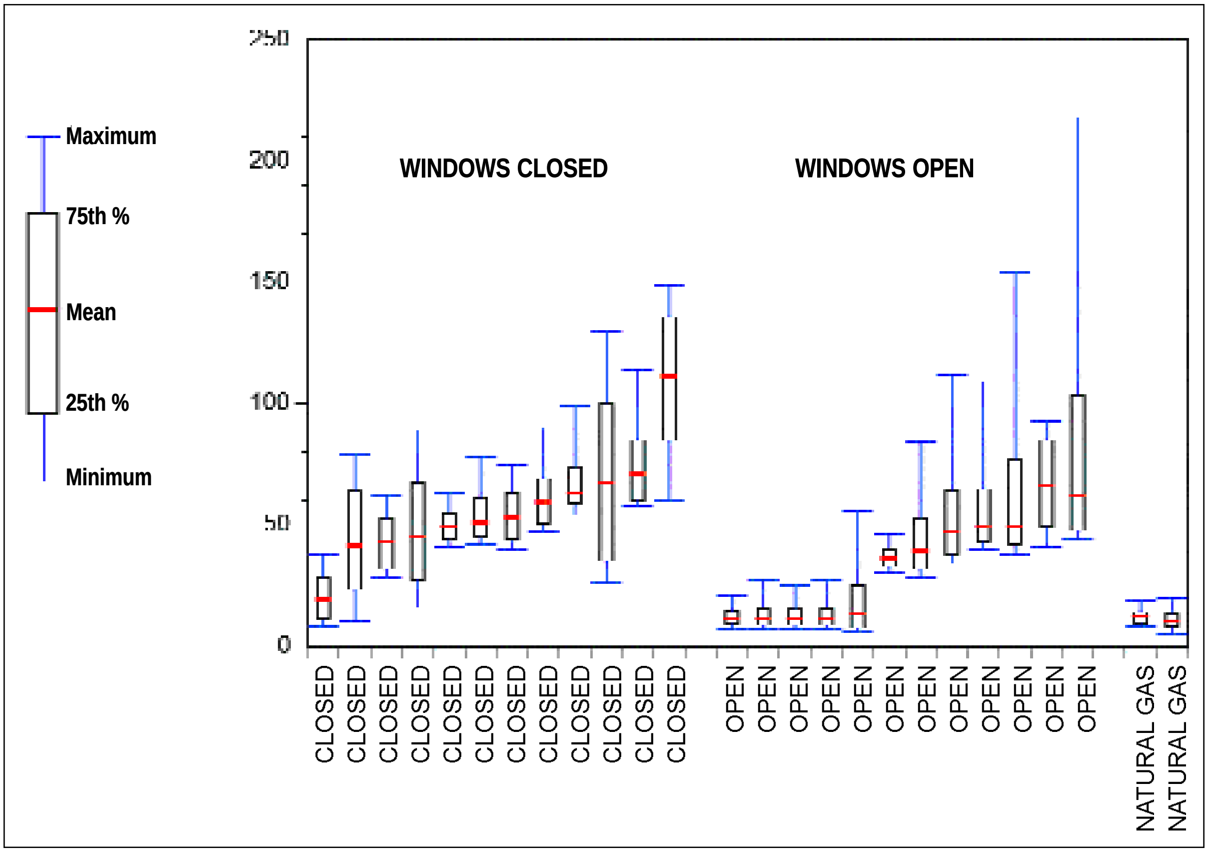


Figure 16 demonstrates that concentrations of PM$_{2.5}$ were also higher when windows were closed. Figures 15 and 16 each demonstrate runs with wider variability with opened windows, possibly due to exhaust blowing in and out of windows. If windows were closed, exhaust most likely entered through the door, even though it was opened for an average of only 30 seconds for each stop.

- Figures 17 and 18 below provide examples of individual bus runs. Peaks often occurred at or near stops recorded in our logs. Interior levels of PM$_{2.5}$ increased at bus stops as exhaust and outdoor air entered buses through opened windows and doors.

Figure 17: Bus Stops Increase Interior PM$_{2.5}$

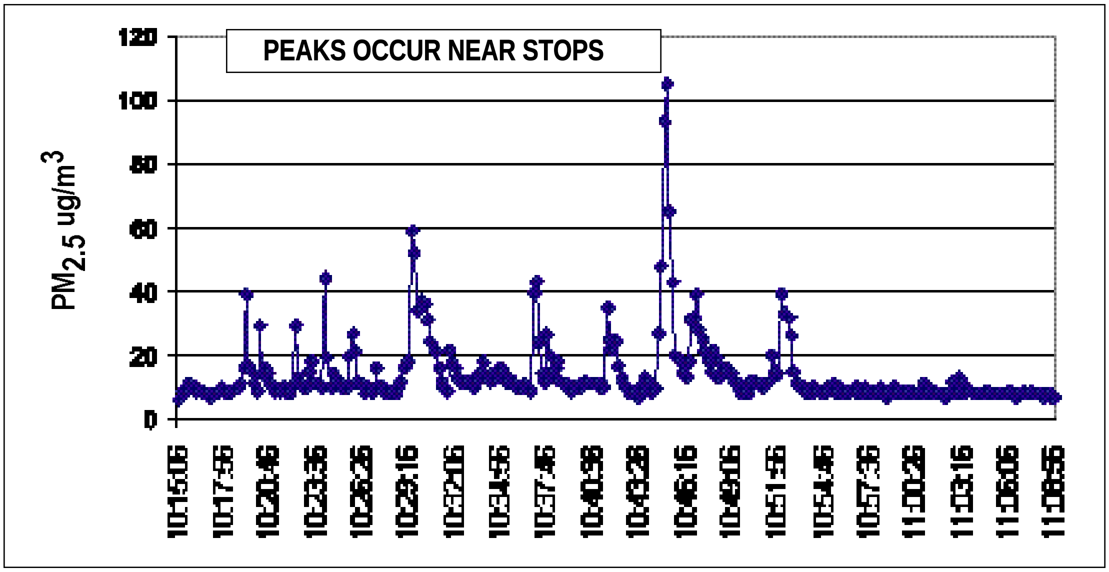
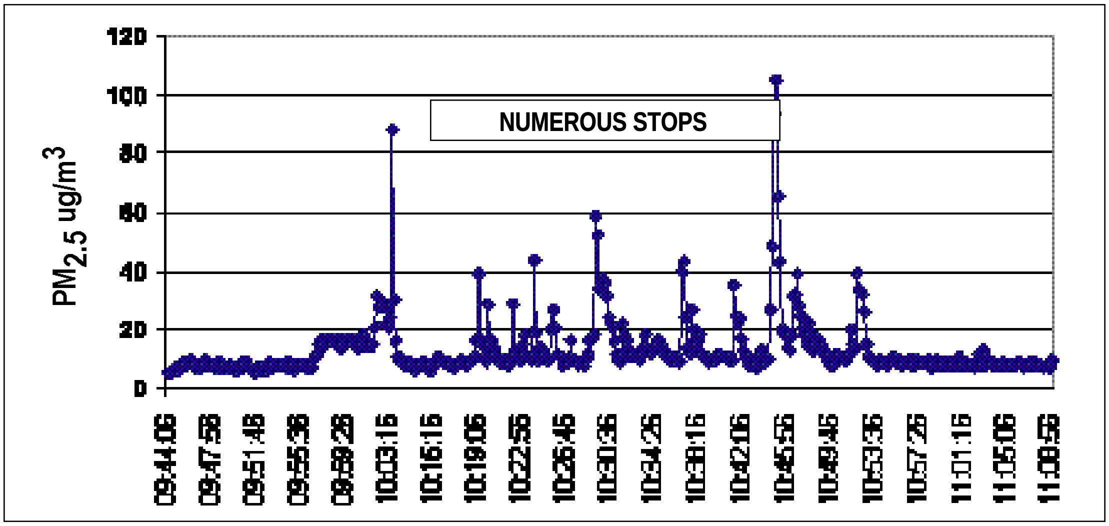


Figure 18: Bus Stops Increase Interior PM$_{2.5}$



- Each of the runs plotted in Figures 17 and 18 on the preceding page were made within very rural environments with few identifiable additional sources of carbon or $PM_{2.5}$. The relatively flat readings at the beginning and end of each run demonstrate the effect of a moving bus, with open windows, causing particulate levels to fall rapidly to background levels.

Finding 4: Bus Idling and Air Quality

- Bus idling practices affected concentrations of both particles and carbon within bus passenger compartments.

Particulate levels were especially high when buses idled and were queued at schools.

- When buses line up to pick students up, drop them off, or wait for students to transfer among buses, interior particulate levels rise quickly, often within a minute of arrival. In some cases they were found to be 10-15 times higher than background levels recorded by State monitoring efforts.

- When buses line up and leave engines running, exhaust from one bus is emitted within 6 feet of open doors on adjacent buses.

- The following charts demonstrate accumulation and ventilation of two buses, neither of which were queued with other vehicles.

Figure 19: Bus Idling Accumulation and Ventilation of PM $_{2.5}$

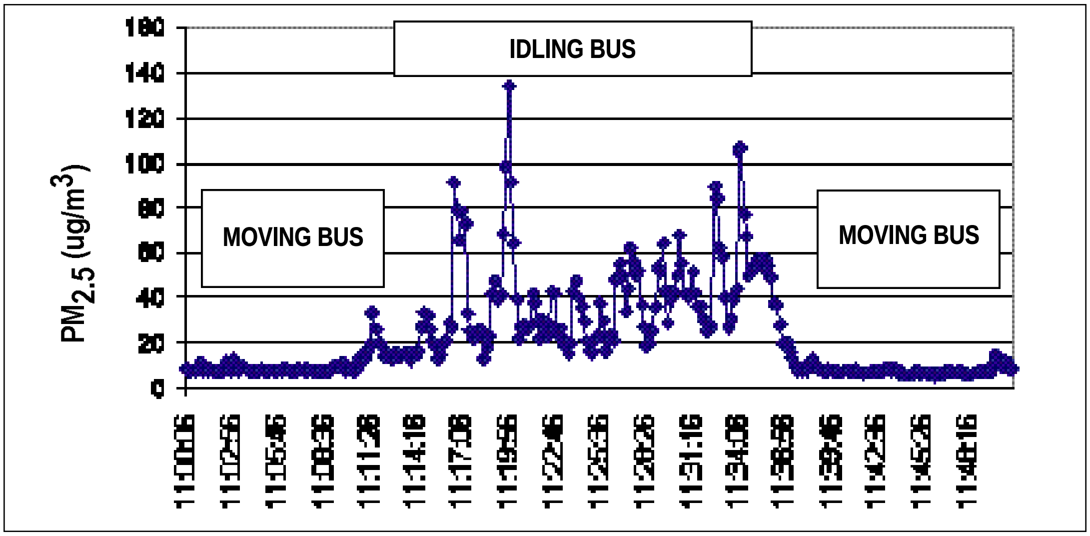


Figure 20: Bus Idling Accumulation and Ventilation of PM $_{2.5}$

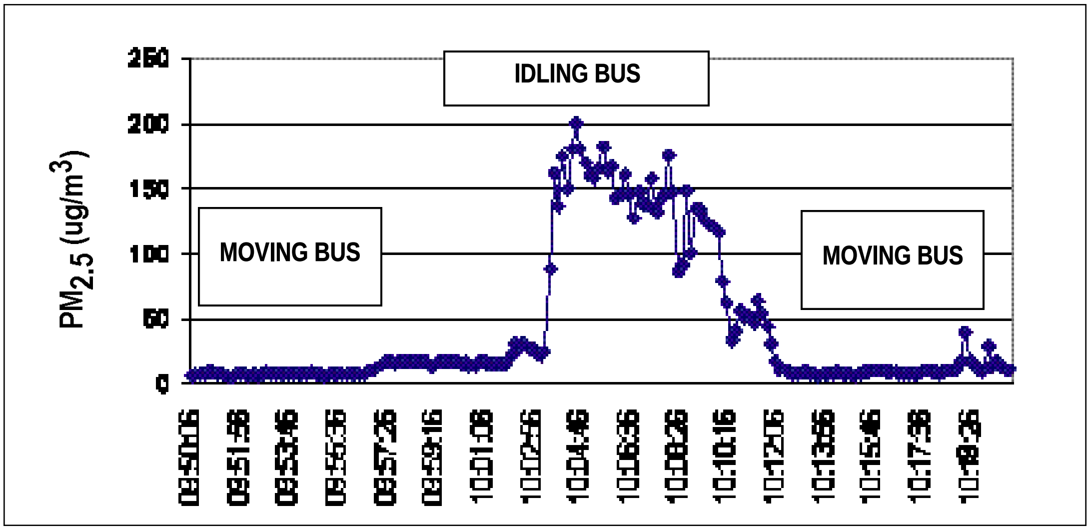
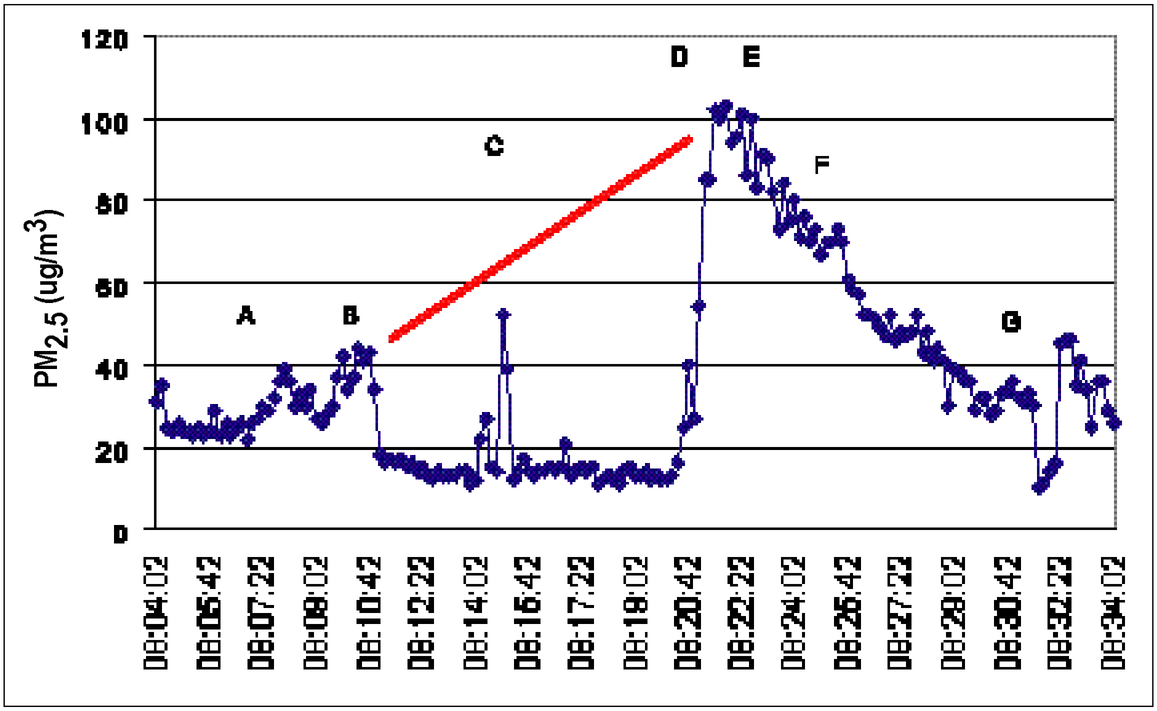


Figure 21: Idling Effect: $PM_{2.5}$ Accumulation and Ventilation



A: Bus Arrives at School Transfer Station and Begins Idling

B: Student Exits Bus with Personal Monitor and Waits to Re-enter (BD)

C: Presumed Increase in $PM_{2.5}$ Concentrations Within Bus

D: Student Reenters Bus 10 Minutes Later With $PM_{2.5}$ Higher by 5X.

E: Bus Leaves Transfer Station

F. Steady Ventilation and Reduction of $PM_{2.5}$ En Route to School

G: Student Exits Bus At School, Walking Past Idling Buses

Red Line from B to D = Presumed Rate of Increase in Bus Interior $PM_{2.5}$

Figure 22: Changing Concentrations During Bus Trip

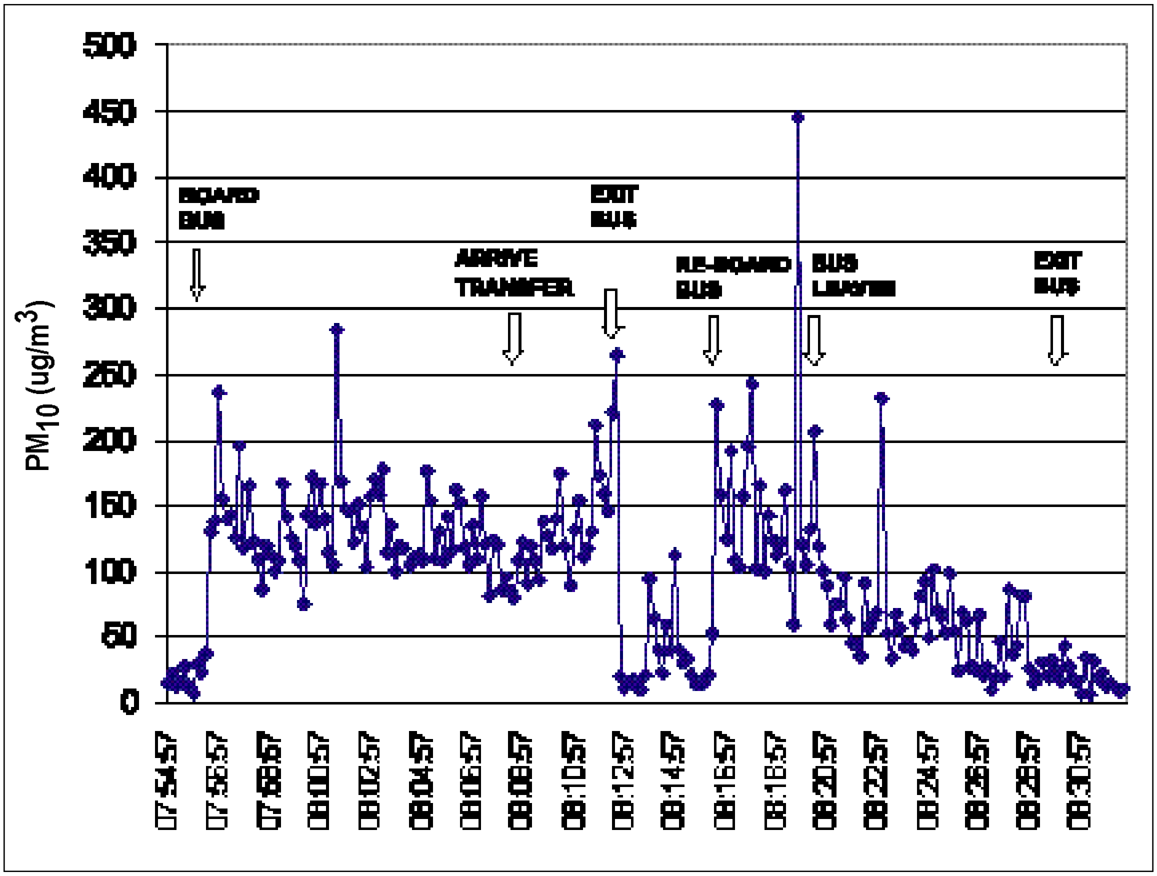
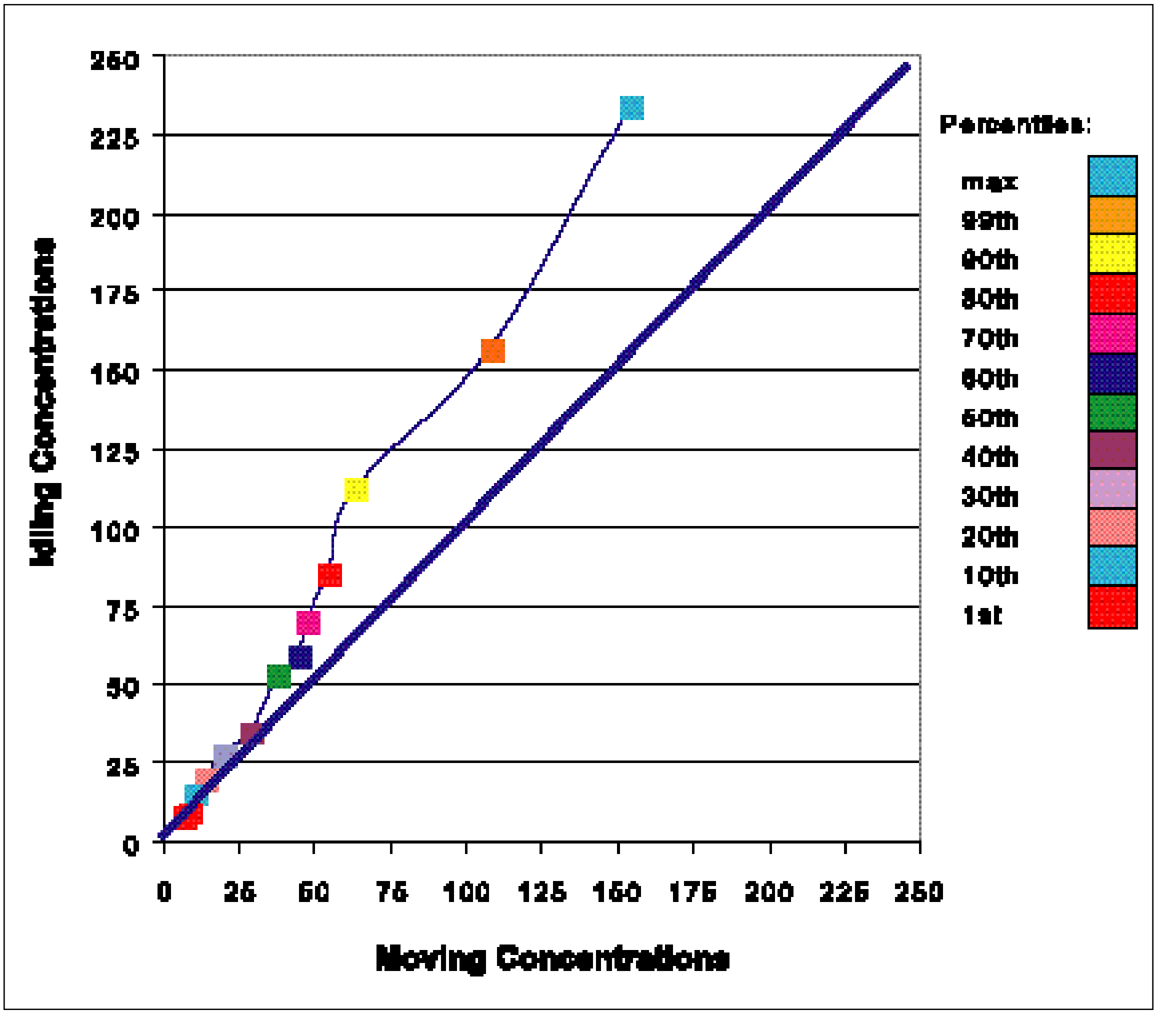


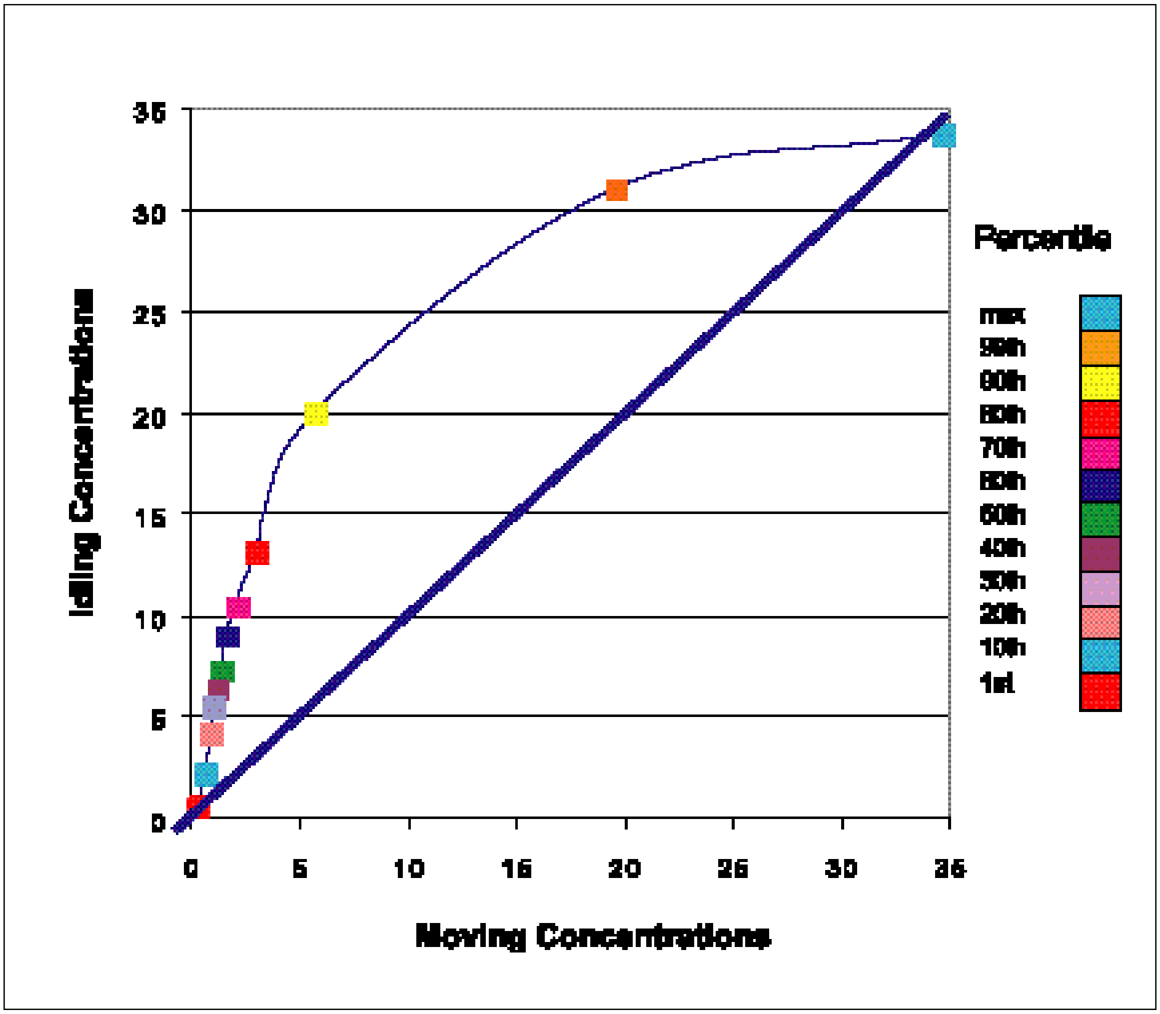
Figure 22 (PM_{10}) monitors the same bus run, but on a different day from that presented in Figure 21 ($PM_{2.5}$). Note the periodic spikes in PM_{10} at bus stops between 7:56 and 8:08, a dramatic reduction in levels when the student exited the bus at a transfer station, a dramatic increase when the student boarded another bus. Lowest levels detected across the 35-minute period were recorded prior to boarding the bus, at 7:55, and after exiting the bus at 8:30.

Figure 23: $PM_{2.5}$ (ug/m^3): Idling vs. Moving Buses



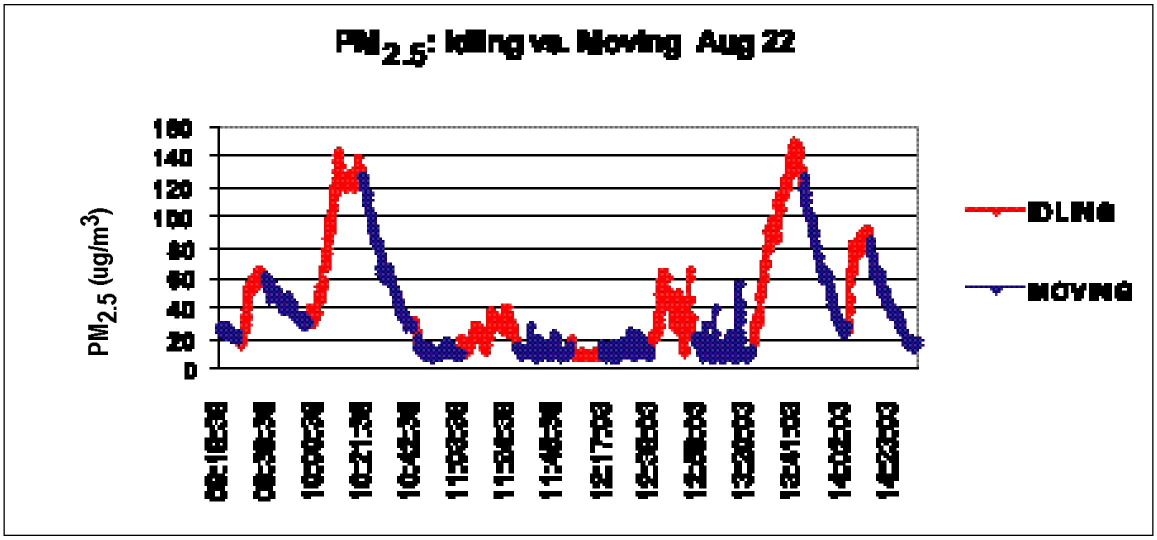
If $PM_{2.5}$ levels detected in idling buses were identical to those measured in moving buses, the colored blocks depicting the percentile levels would lie on the blue line of equivalence. Instead, idling concentrations of $PM_{2.5}$ consistently exceeded concentrations measured in moving buses.

Figure 24: Black Carbon (ug/m^3): Idling vs. Moving Buses

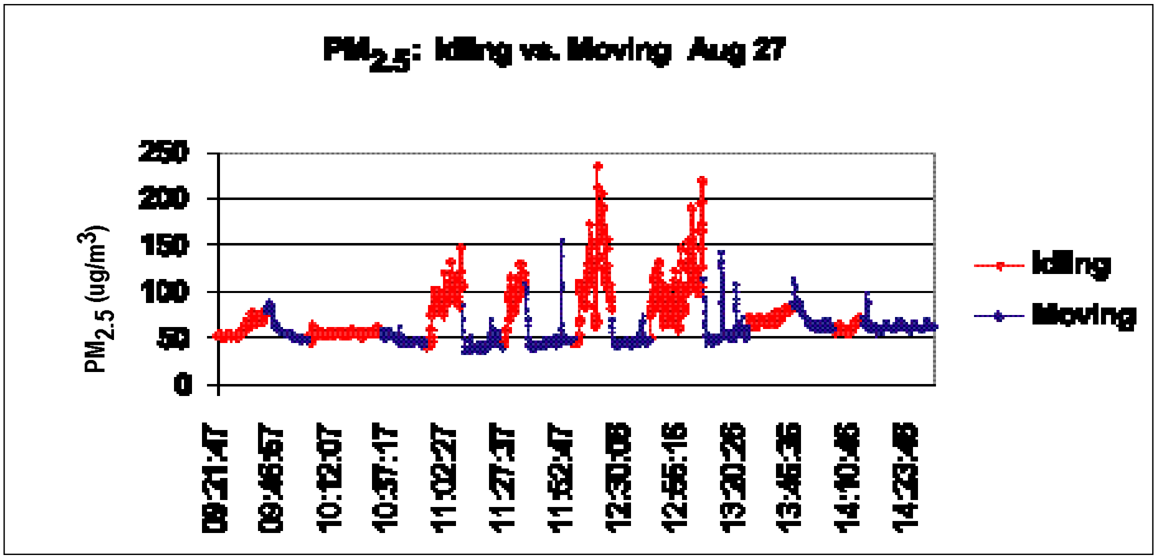


If carbon levels in idling buses were identical to those detected in moving buses, the colored blocks depicting the percentile levels would lie on the blue line of equivalence. Instead, idling concentrations consistently exceeded concentrations measured in moving buses for each percentile—except the maximum and 1st or lowest percentiles, which were nearly equivalent.

Figures 25: PM$_{2.5}$ Idling vs. Moving



Figures 26: PM$_{2.5}$ Idling vs. Moving



Cabin pollution rose during idling (red), and declined during bus runs (blue). Levels of jet fuel fumes in aircraft—detectable by human senses while idling—may follow a similar pattern when compared with airborne levels, when fresh air ventilation occurs.

Finding 4 (Continued): Bus Idling and Air Quality

- When windows were open while buses were idling, interior particulates and carbon levels increased rapidly.

- Mean concentrations of both black carbon and particulates are higher in idling buses when windows are open.

Queued Buses: Proximity of Doors to Tailpipes

- Idling creates a legacy effect of particulate and carbon pollution in bus interiors that lingers during bus runs. The duration of the legacy appears to depend upon the length of the idling period, the window configuration once the bus is underway, and it is likely to be affected by traffic type and intensity.

Figure 27: Mean Idling Concentrations of Black Carbon

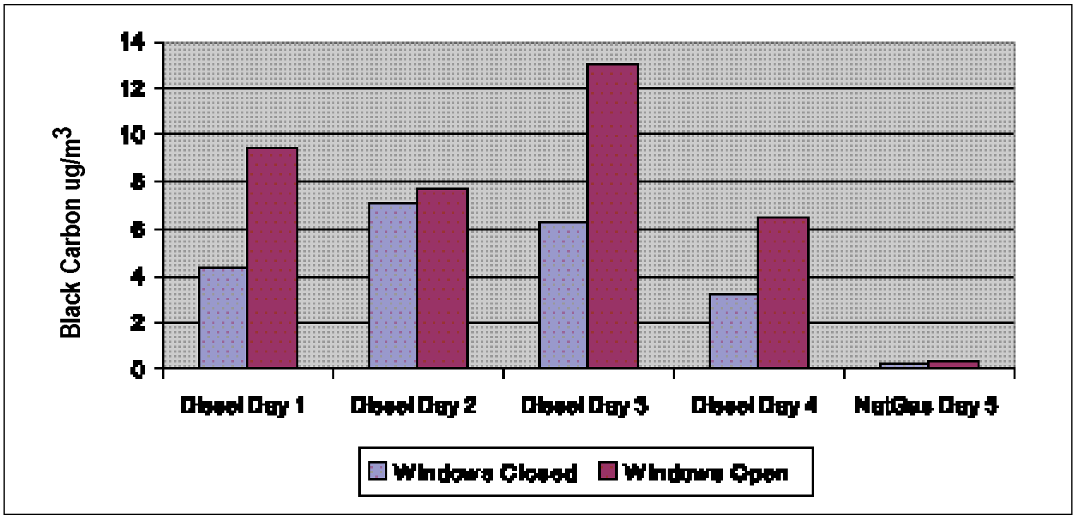


Figure 27 demonstrates that mean levels in idling buses with open windows exceed mean levels when windows are closed.

- The effect of idling on interior carbon concentrations was tested among 22 bus runs on an experimental bus run in rural Connecticut. Following 4 days of monitoring, we averaged carbon levels detected when idling, and compared these levels to moving buses. Average daily results are demonstrated in Figures 27 and 28: the first shows average results, and the second distribution of carbon levels.

Figure 28: Carbon Levels in Idling Buses

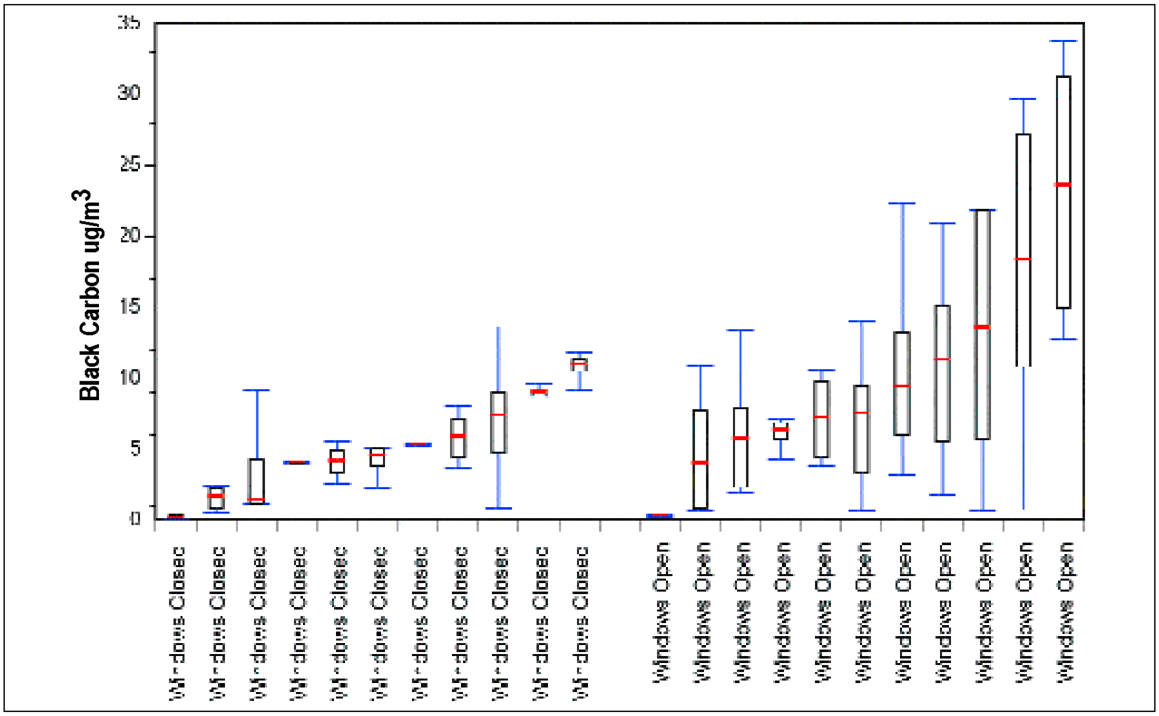


Figure 28 demonstrates separate bus runs with windows closed or opened. If windows of idling buses were open, then variability in interior concentrations was usually higher than if windows were closed. This might be explained as exhaust both enters and exits the bus through the windows and doors. Readings were reported as 1-minute averages, indicating some persistence of the pollutants once they entered the buses. This effect is the opposite of that found in moving buses, where open windows were associated with lower levels of particle and carbon concentrations.

- Several school administrators and teachers complained that bus queuing and idling practices often resulted in high levels of detectable diesel odor within schools. These emissions may enter schools from open doors and windows, or from air intake vents located near bus loading zones. If indoor air is contaminated by diesel emissions, ventilation may be far slower than rates detected on moving buses, with higher outdoor-interior exchange rates.

Finding 5: Natural Gas Emissions

- We tested several school buses powered by natural gas, and found the levels of particulates and carbon to be far lower than those found on diesel buses operated on the same routes.

- Natural gas bus emissions of particulates were tested both within and outside of buses. *Particulate emissions (PM$_{2.5}$) within 1 foot of the tailpipe were lower than levels found in the interior of many of the diesel buses tested.*

- Interior concentrations of PM$_{2.5}$ within natural gas-powered buses were essentially the same as average background levels (11-13 ug/m^3 of PM$_{2.5}$) reported from State of Connecticut monitors.

Figure 29: Mean Daily Black Carbon Levels

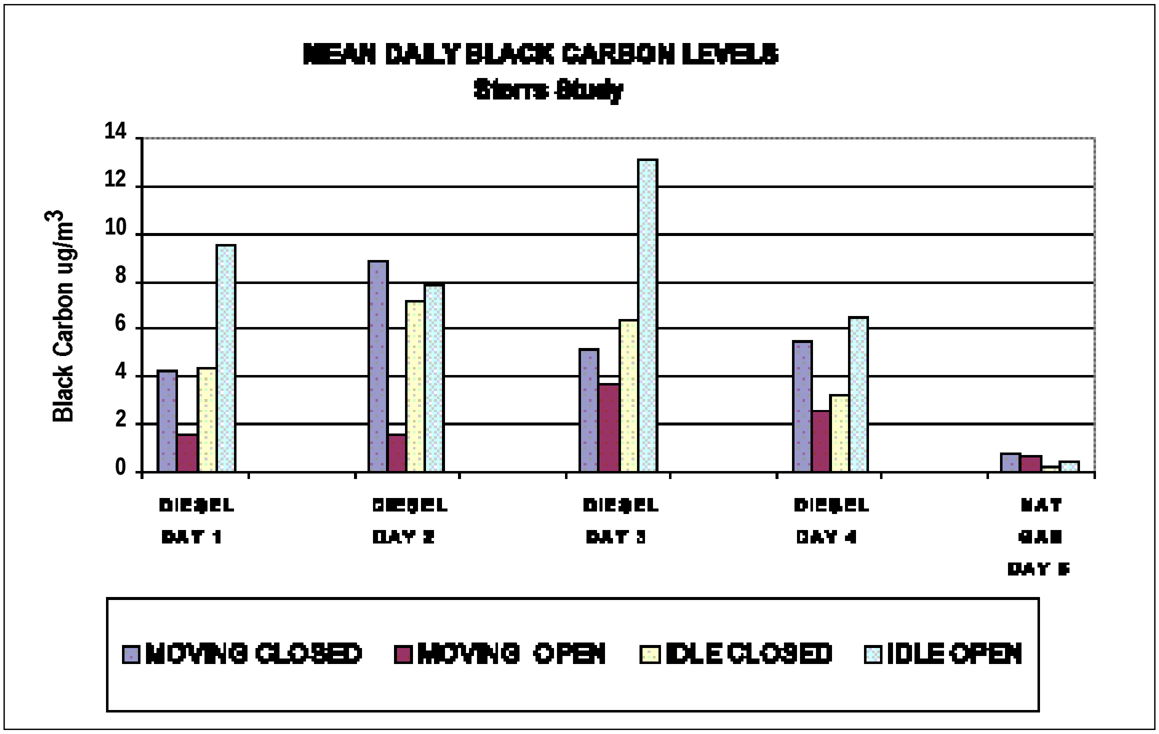
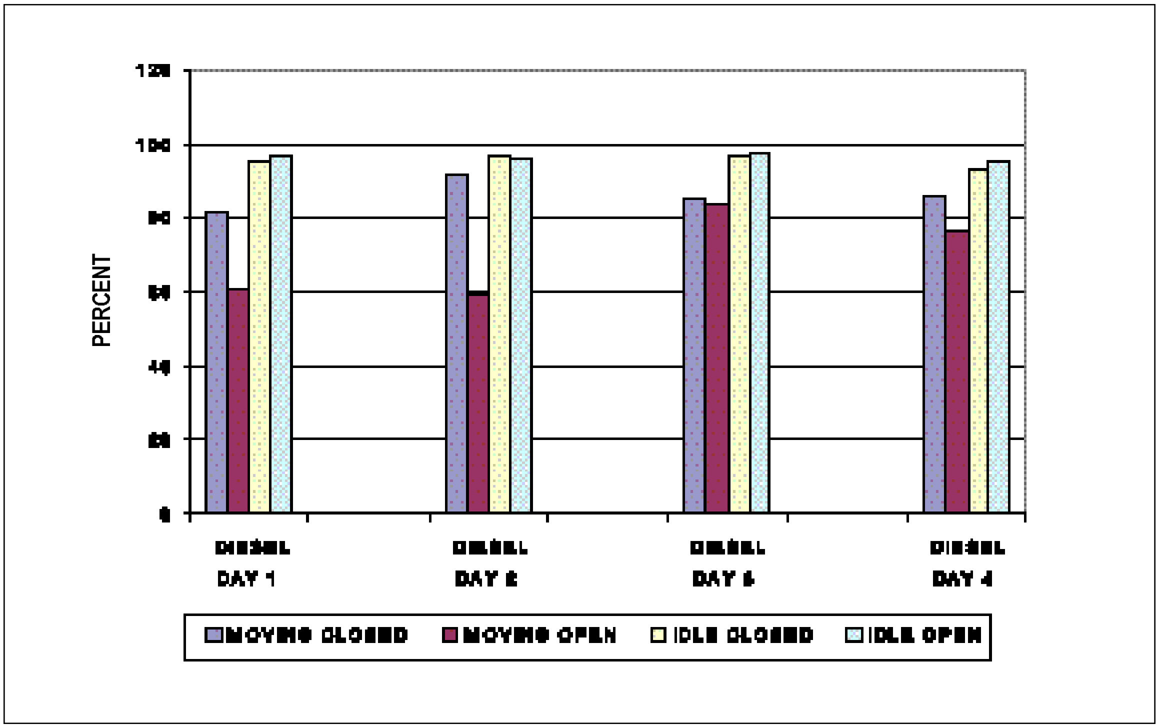


**Figure 30: PERCENT CARBON REDUCTION
NATURAL GAS COMPARED WITH DIESEL**



Carbon levels detected in natural gas buses were less than 5% of carbon levels found in idling diesel buses, and less than 20% of carbon levels found in moving diesel buses, when windows were closed. The percent reduction was least for moving buses (maroon) as concentrations were also lowest in diesel buses when sampled while moving through bus runs—unless windows were closed.

Finding 6: Variability in Pollution Levels Within Individual Buses

- We found no significant differences in carbon or particulate levels when our monitoring equipment was placed in the front seat versus the rear seat of the bus.

Figure 31: Black Carbon Levels in Moving Buses
Front vs. Back of Bus

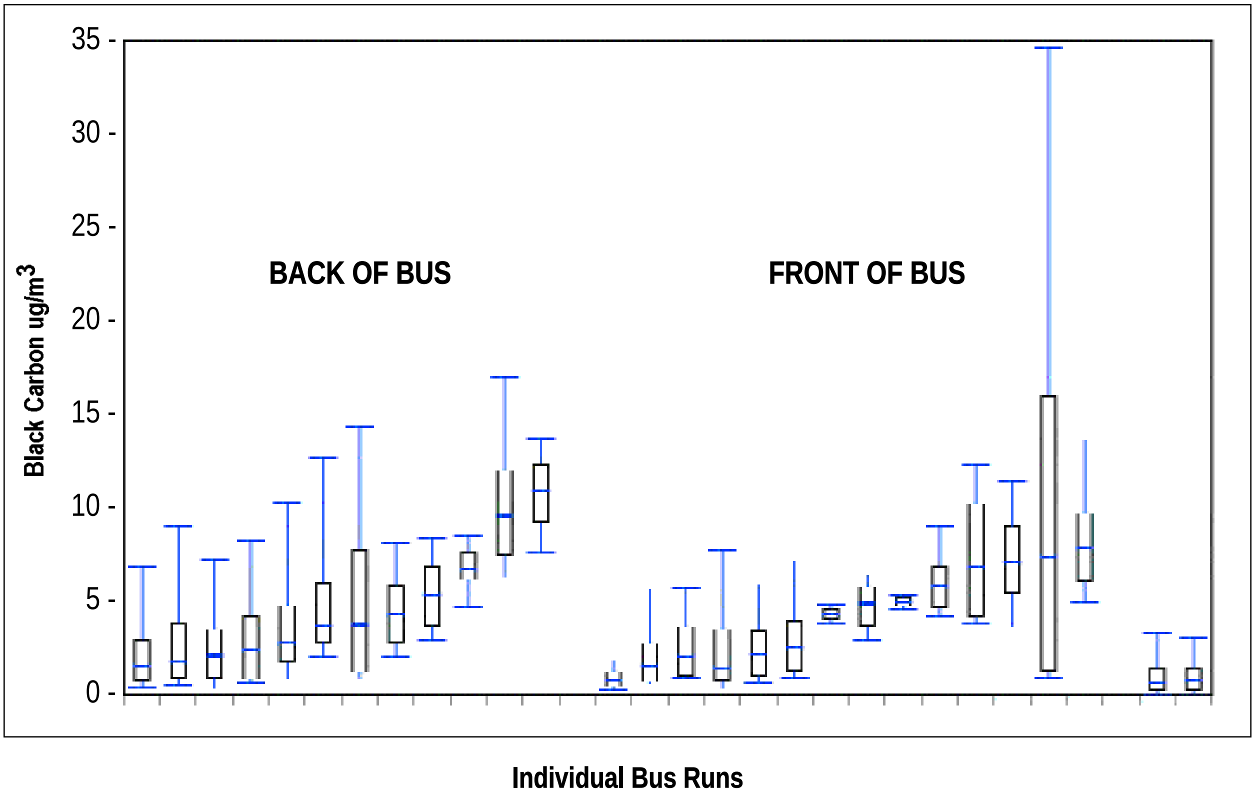


Figure 32: Range of Particulate Concentrations

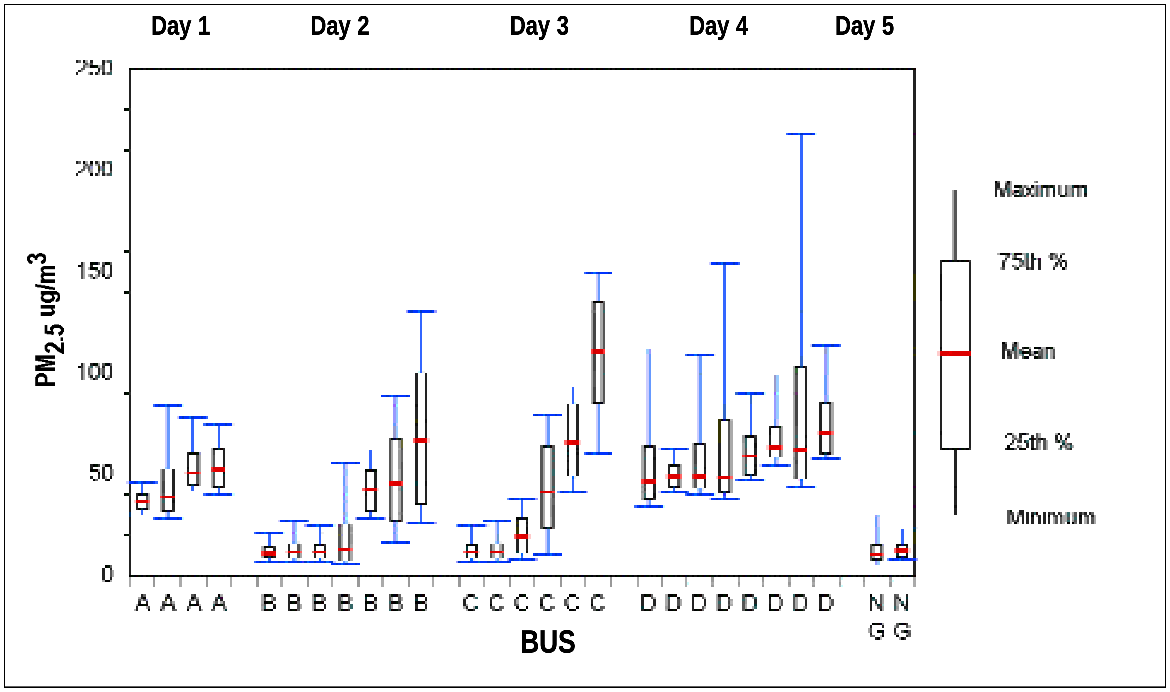


Figure 32 demonstrates variability in detected $PM_{2.5}$ *levels within the same bus when different runs are compared. Mean levels differ significantly within the same bus, but on different runs, on days 2 and 3 (buses B and C). The same bus may have clean and dirty runs on the same day. This could be explained by differing window configurations, load conditions, weather conditions, ambient outdoor concentrations, or traffic intensity.*

Factors that may affect variability in particulate concentrations on buses:

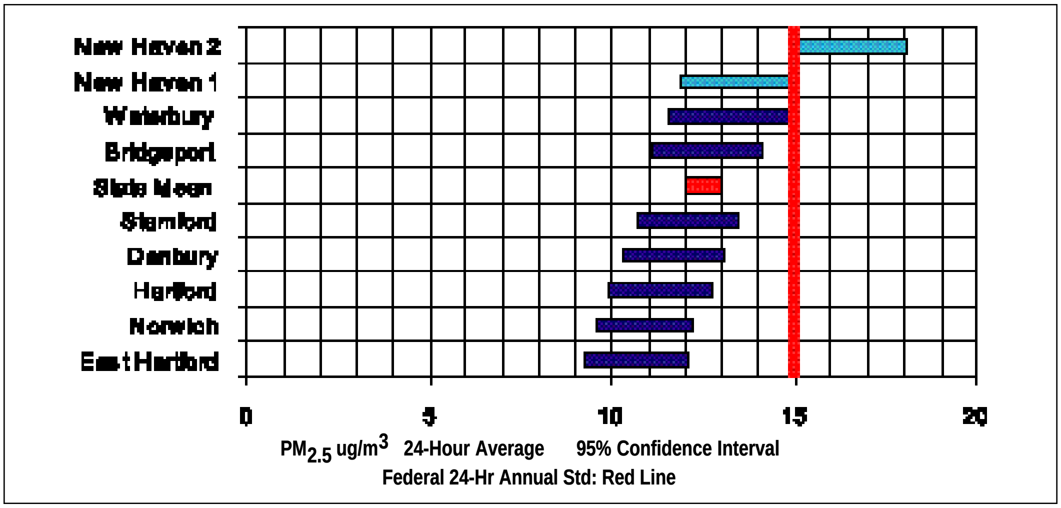
- Window configuration: open vs. closed
- Idling practices
- Queuing practices
- Sampling location on the bus
- Route: length, elevation change, stops
- Traffic intensity
- Ambient outdoor air quality
- Engine type
- Condition of exhaust system
- Exhaust pipe location (left or right rear)
- Heating and ventilation: fans, filters
- Fuel Type: sulfur content
- Temperature, humidity, and wind
- Passenger load and student movement
- Engine maintenance
- Engine age

Finding 7: Connecticut Background Particulate Levels

- Connecticut created a monitoring network to measure fine airborne particulate matter (less than 2.5 micrometers in diameter) in response to regulations adopted by EPA in 1997. The standard was designed to provide additional protection for children, the elderly and others with respiratory problems.

Figure 33: 1999 $PM_{2.5}$ Levels at Connecticut Monitoring Sites[118]

95th% Confidence Interval of Average Daily Levels



The turquoise bars in Figure 33 demonstrate the levels of $PM_{2.5}$ at two monitoring stations in New Haven. The location of monitoring stations may influence judgments regarding compliance with federal standards. In this case, the State could simply move the monitoring facility to an area removed from traffic, industrial activity or areas of known fuel or waste combustion and the full state would be judged to be compliant.

- The new standard restricts $PM_{2.5}$ to 15 ug/m^3 (24-hour arithmetic means are again averaged over 3 years); and to 65 ug/m^3 as a maximum allowable average over any single day (calculated as the 98^{th} percentile daily levels, averaged over 3 years.) Sufficient data (3 years) have not yet been collected to judge compliance.
- Particulate levels ($PM_{2.5}$) in Connecticut average between 10.8 and 17.9 ug/m^3, with the highest levels recorded in urban areas of the state near highway corridors. The highest average level was recorded in New Haven, and the lowest in East Hartford. $PM_{2.5}$ is measured at 13 fixed stations in the State.

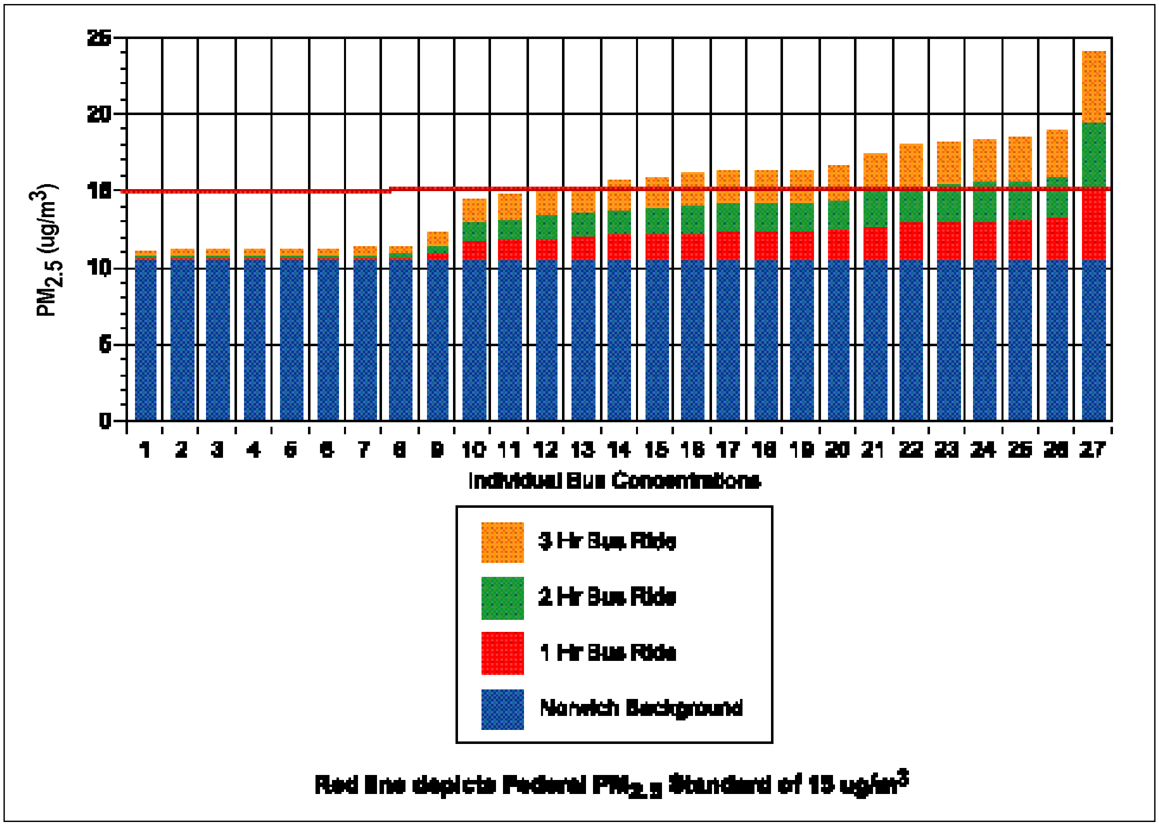
- Other researchers have concluded that ambient particulate levels are uniformly distributed across space, providing justification for a limited fixed monitoring system.[119] These findings suggest instead, that personal and vehicle monitoring will demonstrate significant variability across space and time.

Finding 8: Cumulative Particulate Exposure

- The following four charts (Figures 34, 35, 36 and 37) demonstrate the addition of school bus exposures to average background levels of $PM_{2.5}$ detected in 4 Connecticut communities. The school bus exposures presented are average levels detected during the experimental bus runs conducted in Storrs, reported above.

Figure 34: Average Daily Concentrations During School Year

Norwich Background + School Bus $PM_{2.5}$ Levels

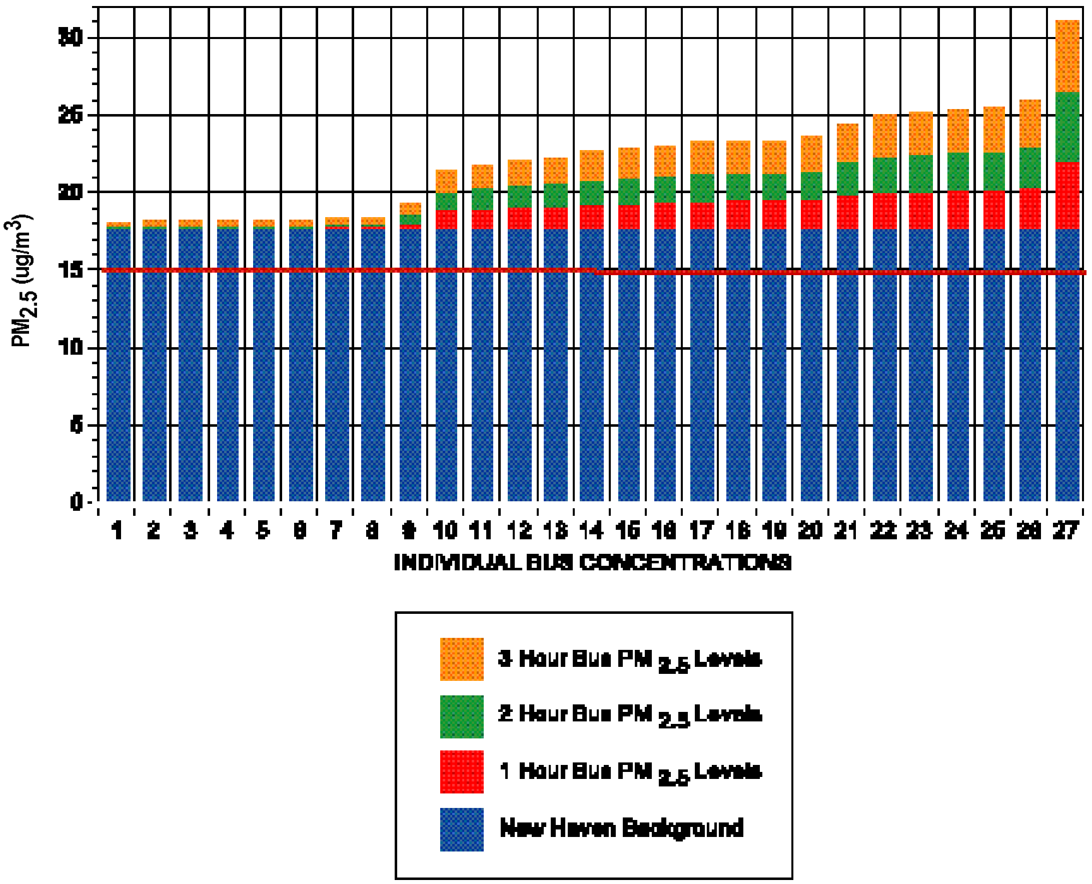


Red line depicts Federal $PM_{2.5}$ Standard of 15 ug/m^3

- New Haven background levels would exceed the federal standard—using data from the Stiles St. monitoring station, if current trends continue—thus any additional school bus exposure would push average daily concentrations further from compliance. In the worst case, assuming the longest duration ride of 3 hours per day, the average daily concentrations would be nearly double the federal standard.

Figure 35: Average Daily Concentrations During School Year

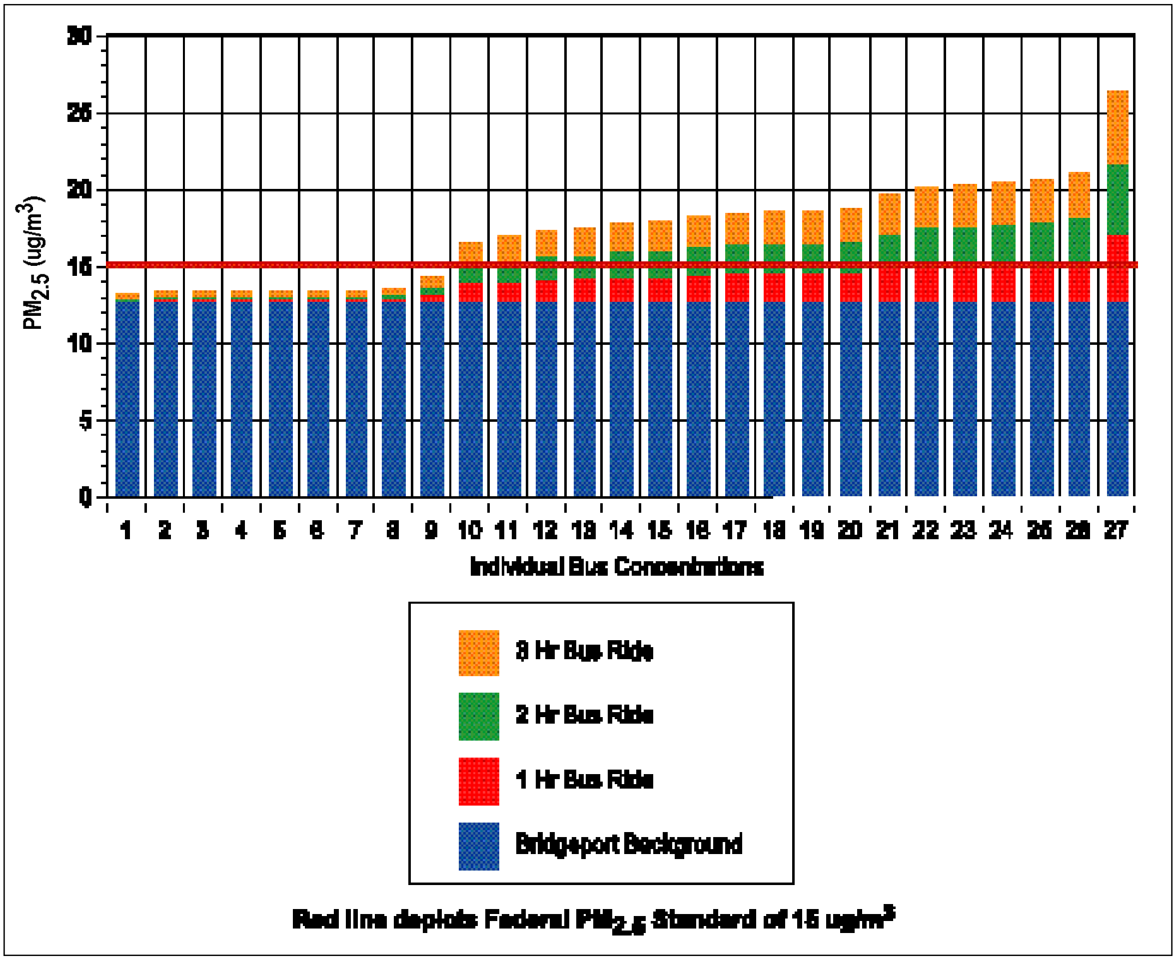
New Haven Background + School Bus PM$_{2.5}$ Levels



Red line depicts Federal PM$_{2.5}$ Standard of 15 ug/m^3

Figure 36: Average Daily Concentrations During School Year

Bridgeport, CT Background + Bus $PM_{2.5}$ Levels

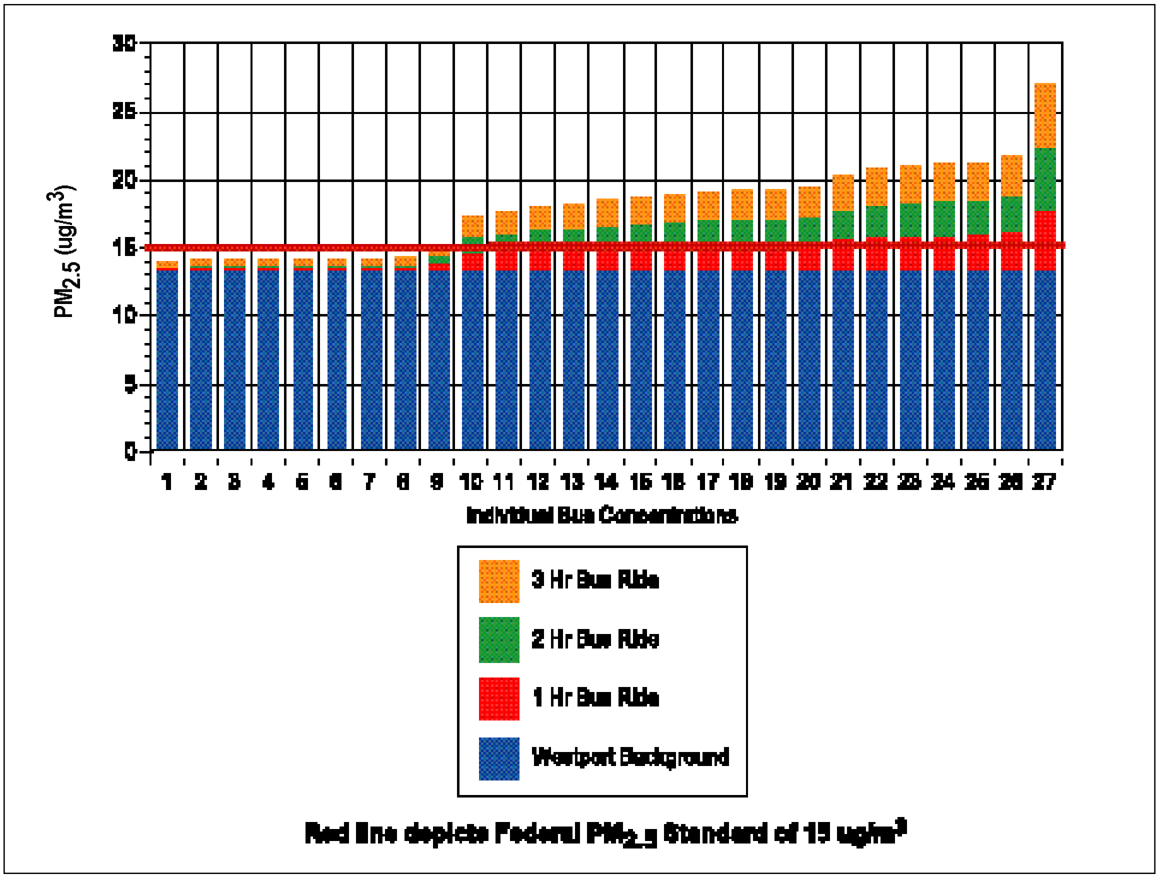


Red line depicts Federal $PM_{2.5}$ Standard of 15 ug/m^3

These charts demonstrate how exposures to particulates might accumulate from outdoor, vehicular and indoor sources. Average daily community levels of $PM_{2.5}$ are held constant. School bus concentrations were time-weighted and added to background levels. Color differences represent the effects of bus routes of different durations. These data demonstrate the close proximity of background levels to the federal standard. Note: the federal standard is calculated by averaging 24-hour levels over 3 years, while students are in school for only 180 days per year. Thus, the bars represent the range of cumulative $PM_{2.5}$ concentrations averaged daily during the school year.

Figure 37: Average Daily Concentrations
During School Year

Westport, CT Background + Bus $PM_{2.5}$ Levels



Finding 9: Averaging Away the Diesel Exhaust Problem

- Levels of $PM_{2.5}$ found within diesel-powered school buses are far higher than those detected by State of Connecticut’s fixed monitoring facilities. State detected levels are beneath the national $PM_{2.5}$ standard of 15 ug/m^3 per day (24 hour average) with the exception of one site in New Haven. Differences between state averages and our findings may be explained in part by the location of sampling equipment. Also, the State averages its findings over 24 hours for 365 days, over three years (when complete data are available). This ensures that nights and weekends (when traffic and industrial activity are minimal) will reduce reported levels of particulates.

- Averaging air pollution over long periods of time will normally reduce reported levels of pollution. This is well demonstrated by the following chart. As the averaging period increases, reported concentrations diminish. The bursts of particulate and carbon concentrations within school buses found in this study—depicted by the blue peaks in the chart—are reported by state and federal regulatory agencies as negligible—depicted by the red line.

- It is important to measure and report detected levels of air pollution at a frequency relevant to respiratory health problems that may be caused or exacerbated by the air pollutants.

Figure 38: 6 Ways to Report the Same Data: Averaged Over Different Periods of Time

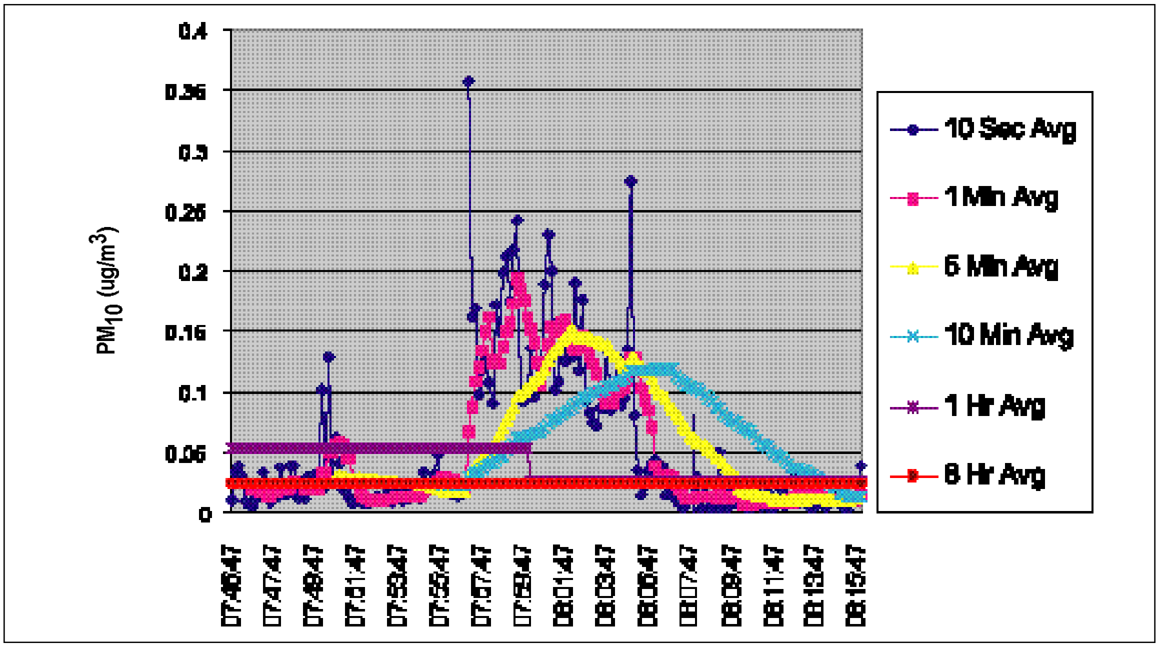


Figure 38 above demonstrates the effect of averaging the same PM_{10} data over different periods of time. Short-term high exposure events, such as those experienced by children on school buses, are neglected by current monitoring and reporting practices. PM levels are now reported from a limited number of fixed monitoring stations. Both the daily averages, and the 98^{th} percentile levels of the daily averages are again averaged over 3 years. High exposure events of short-duration remain unrecognized. The underlying presumption of current practice is that intense short duration exposures are irrelevant to respiratory health.

6. Recommendations By Level of GovernmenT

RECOMMENDATIONS FOR THE FEDERAL GOVERNMENT

1. ***Retrofit Diesel Buses To Lower Emissions:*** The federal government should require the retrofit of existing school buses with particle traps and catalytic converters designed to reduce emissions. Retrofit of the existing fleet should be completed by 2003.
2. ***Require Buses to Use Ultra Low Sulfur Fuels:*** The federal government should require the use of ultra low sulfur diesel fuel (<15 ppm) on school buses. The effect would be to substantially reduce acid aerosols, ozone precursors, and fine particulate emissions in the immediate vicinity of children.
3. ***Replace Bus Fleet With Low Emission Vehicles:*** The federal government should require and provide financial support for eventual replacement of existing diesel fleets with low emission vehicles, especially in areas of the country beyond compliance with current federal pollution standards.
4. ***Test Tailpipe Emissions:*** The federal government should require periodic tailpipe emissions testing of all school buses, unless they have been retrofitted with particulate traps and converters, and use ultra low sulfur fuels.
5. ***Set Passenger Cabin Air Quality Standards:*** The federal government should establish health protective standards for air quality within vehicles. Standards should provide an ample margin of safety for children.
6. ***Require School Bus Air Filtration Equipment:*** The federal government should require the design and installation of air filtration equipment capable of removing vehicle exhaust from air entering bus passenger cabins. This is especially important when buses travel in areas with high traffic intensity, or high outdoor background concentrations of pollutants such as urban environments.
7. ***Federal Standards Should Assume Indoor and Vehicular Exposures:*** EPA should adjust outdoor air quality standards to account for probable indoor and within-vehicle exposures to air pollution. The Clean Air Act demands that standards be set to provide "an adequate margin of safety," yet governments' neglect of particulate levels within homes, schools, and vehicles makes it impossible to conclude that current standards protect health.
8. ***Expand Air Quality Monitoring Network:*** The federal government should require states to develop air quality monitoring programs that capture variability in regulated air pollutants. The existing stationary monitoring network should be supplemented with both additional stationary sources, and with personal monitoring data collection to better understand variability in exposure, especially among susceptible populations.

RECOMMENDATIONS FOR STATE GOVERNMENTS

1. ***Prohibit School Bus Idling:*** Idling should be restricted by State law. Bus drivers should be required to turn off bus engines immediately upon reaching their destinations. Buses should not be turned on until fully loaded. This is especially important when buses are queued while loading and unloading at schools and transfer stations. Exceptions should include conditions that would compromise passenger safety—e.g., extreme weather conditions, idling in traffic. In cases where engine operation is necessary to activate safety equipment such as flashing lights, buses should be retrofitted to permit battery operation. Idling restrictions should be defined by state statute and include enforcement power, rather than by the present DEP regulation 22a-174-18 (a)(5).
2. ***Retrofit Diesel Buses To Lower Emissions:*** The State should plan and implement a school bus retrofit program to ensure that buses are refitted with particle traps and catalytic converters designed to reduce emissions. Retrofit of the existing fleet should be completed by 2003.
3. ***Require School Buses to Use Ultra Low Sulfur Fuels:*** The state should facilitate and monitor the suggested federal requirement that school buses use low sulfur diesel fuel (<15 ppm).
4. ***Replace Bus Fleet With Low Emission Vehicles:*** The state should work with federal agencies (EPA, DOE, DOT) to plan for the replacement of the existing diesel fleet with new low-emission and alternative-fueled vehicles.
5. ***Set Priorities to Reduce Emissions and Exposure:*** The State should plan for, guide, and set priorities to retrofit buses and convert to ultra low sulfur fuels. Priority should be assigned to communities with the poorest outdoor air quality. Within communities, priority should be assigned to the routes that have highest traffic intensity.
6. ***Require Routine Maintenance:*** The State should require that routine maintenance be conducted to ensure that emissions remain at their lowest possible level. Special care should be taken to be certain that exhaust systems are fully intact and secure, and that engine compartments are completely sealed from interior passenger space.
7. ***Test Tailpipe Emissions:*** The State should be responsible for periodic tailpipe emissions testing of all school buses.
8. ***Expand $PM_{2.5}$ Monitoring Network:*** The State should substantially expand its monitoring network to more fully capture local variability of air pollutants.

RECOMMENDATIONS FOR LOCAL GOVERNMENTS

1. ***Prohibit Bus Idling:*** Local governments and school districts should immediately adopt policies that require drivers to turn off bus engines upon reaching their destinations. Buses should not be turned on until fully loaded. This is especially important when buses are queued while loading and unloading at schools and transfer stations. Exceptions should include conditions that would compromise passenger safety—e.g., extreme weather conditions, idling in traffic. In cases where engine operation is necessary to activate safety equipment such as flashing lights, buses should be retrofitted to permit battery operation. School districts should inform drivers about the effects of idling on both indoor and outdoor air quality. This idling restriction will improve air quality within buses, and in the vicinity of schools.

2. ***Adjust Contract Provisions to Lease Retrofitted Vehicles and Require Clean Fuels:*** School districts should adjust their contracts with bus service companies and fuel providers to require the use of ultra low sulfur fuels, particle traps and catalytic converters, without waiting for federal or state requirements to take effect.

3. ***Set Priorities:*** School districts and local governments should allocate buses with the lowest emissions to the longest routes.

4. ***Limit Ride Duration:*** School districts should reduce students' exposure to air pollution by limiting time spent on buses. This is already regulated by some town policies. Limiting ride duration would reduce exposure to pollution generated by diesel buses, and by other traffic.

5. ***Require Routine Maintenance:*** Local governments should ensure that buses are monitored and maintained so that emissions remain at their lowest possible level. Special care should be taken to be certain that exhaust systems are fully intact and secure, and that engine compartments are completely sealed from interior passenger space. Maintenance requirements to ensure health protective air quality should become a routine contract provision between bus companies and local governments.

6. ***Reconsider Location of Bus Parking Lots:*** Local governments should consider whether the location of bus parking facilities contribute to routine air pollution in the vicinity of schools, playgrounds, and residential areas. Some relief may be provided by setting limits on bus idling within parking lots.

7. References

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