Assessment of Personal and Community-Level Exposures to Particulate Matter among Children with Asthma in Detroit, Michigan, as Part of Community Action Against Asthma (CAAA)

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We report on the research conducted by the Community Action Against Asthma (CAAA) in Detroit, Michigan, to evaluate personal and community-level exposures to particulate matter (PM) among children with asthma living in an urban environment. CAAA is a community-based participatory research collaboration among academia, health agencies, and community-based organizations. CAAA investigates the effects of environmental exposures on the residents of Detroit through a participatory process that engages participants from the affected communities in all aspects of the design and conduct of the research; disseminates the results to all parties involved; and uses the research results to design, in collaboration with all partners, interventions to reduce the identified environmental exposures. The CAAA PM exposure assessment includes four seasonal measurement campaigns each year that are conducted for a 2-week duration each season. In each seasonal measurement period, daily ambient measurements of $PM_{2.5}$ and PM_{10} (particulate matter with a mass median aerodynamic diameter less than 2.5 μm and 10 μm, respectively) are collected at two elementary schools in the eastside and southwest communities of Detroit. Concurrently, indoor measurements of $PM_{2.5}$ and PM_{10} are made at the schools as well as inside the homes of a subset of 20 children with asthma. Daily personal exposure measurements of PM_{10} are also collected for these 20 children with asthma. Results from the first five seasonal assessment periods reveal that mean personal PM_{10} (68.4 ± 39.2 μg/m^3) and indoor home PM_{10} (52.2 ± 30.6 μg/m^3) exposures are significantly greater ($p < 0.05$) than the outdoor PM_{10} concentrations (25.8 ± 11.8 μg/m^3). The same was also found for $PM_{2.5}$ (indoor $PM_{2.5}$ = 34.4 ± 21.7 μg/m^3; outdoor $PM_{2.5}$ = 15.6 ± 8.2 μg/m^3). In addition, significant differences ($p < 0.05$) in community-level exposure to both PM_{10} and $PM_{2.5}$ are observed between the two Detroit communities (southwest PM_{10} = 28.9 ± 14.4 μg/m^3, $PM_{2.5}$ = 17.0 ± 9.3 μg/m^3; eastside PM_{10} = 23.8 ± 12.1 μg/m^3, $PM_{2.5}$ = 15.5 ± 9.0 μg/m^3). The increased levels in the southwest Detroit community are likely due to the proximity to heavy industrial pollutant point sources and interstate motorways. Trace element characterization of filter samples collected over the 2-year period will allow a more complete assessment of the PM components. When combined with other project measures, including concurrent seasonal twice-daily peak expiratory flow and forced expiratory volume at 1 sec and daily asthma symptom and medication dairies for 300 children with asthma living in the two Detroit communities, these data will allow not only investigations into the sources of PM in the Detroit airshed with regard to PM exposure assessment but also the role of air pollutants in exacerbation of childhood asthma. *Key words*: ambient PM, childhood asthma, community-based participatory research, particulate matter, personal exposure, urban air quality. *Environ Health Perspect* 110(suppl 2):173–181 (2002).

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Background on Asthma Prevalence, Causation, and Aggravation

Asthma is the most common chronic disease of childhood in the developed world, affecting approximately 5 million children under 18 years of age in the United States (*1,2*). From 1982 to 1994, the prevalence rate of pediatric asthma (under age 18) in the United States increased by 61% (*1*). The mortality rate from asthma for persons 19 years of age and under increased by 78% from 1980 to 1993 (*1*). Asthma is particularly prevalent among urban populations and minority populations (*3–5*). The national trends in the increase in asthma are visible in Detroit, where a 1993–1994 study found that 17.4% of the 230 children in the sample had a physician diagnosis of asthma (*6*) and where pediatric hospital admissions for asthma among African American children has escalated (from 11.6% of pediatric hospital admissions in 1986 to 17.5% in 1989). Data from the Michigan Department of Community Health show childhood asthma hospitalization rates in Detroit were more than twice the statewide average during the period from 1991 to 1996 (75.5 ± 1.4 per 10,000 children under 18

years of age for Detroit vs. 30.1 ± 0.3 per 10,000 for Michigan). Furthermore, pediatric asthma hospitalization rates, while stable throughout the rest of Michigan, continue to rise in Detroit (84.3 ± 3.3 per 10,000 in Detroit in 1997 vs. 30.7 ± 0.7 per 10,000 in Michigan) (*7*).

The causation and aggravation of pediatric asthma is complex and multifactorial and includes genetic disposition, demographic variables, psychosocial stressors, and environmental exposures (*8–14*). Considerable research evidence suggests

that both indoor and outdoor environmental exposures may be involved in the worldwide increase in asthma (*15–25*). Some of the strongest associations have been found with indoor allergens such as dust mite and cockroach in children sensitized to that particular allergen (*24–32*). Exposure to environmental tobacco smoke, both *in utero* (*15,19*) and during childhood (*17,18,20*), also appears to play an important role in asthma causation and aggravation. Additionally, exposures to indoor sources of fuel combustion have significant associations with exacerbations

of asthma (*33,34*). These may be sources of nitrogen dioxide, which can potentiate airway reactivity in persons with asthma (*20*). Increased ambient levels of respirable particulates (*35–39*) and ozone (*35,40–46*) have been reported to precipitate symptoms of asthma (*35–37,39*) and to increase emergency department visits and hospitalizations for asthma (*38–41,43–46*). Studies in the United States and Europe report an association between increased morbidity and mortality and ambient particulate matter (PM) concentrations at levels currently below the U.S. National Ambient Air Quality Standard (NAAQS) (*47–49*). Highly sensitive subpopulations, including children and persons with asthma, are at increased risk (*50,51*). Exposure to PM and copollutants in the ambient environment may provide the critical factor in increased morbidity and mortality in these individuals in urban centers (*50,51*).

Air quality fluctuates considerably in the city of Detroit. Given that areas of Wayne County, including portions of Detroit, have been designated as nonattainment areas under the NAAQS for PM_{10} as recently as 1995, there is reason to believe that residents of these communities may be exposed to levels of respirable particulates that can exacerbate respiratory illnesses. Although the Wayne County area was redesignated as being in attainment for the PM_{10} (particulate matter with a mass median aerodynamic diameter less than 10 μm) standard in October 1996, more recent data suggest that local levels of $PM_{2.5}$ (particulate matter with a mass median aerodynamic diameter less than 2.5 μm) may exceed the proposed 1997 U.S. Environmental Protection Agency (U.S. EPA) standards for PM of that size (*52*).

Background on Environmental Justice and Community-Based Participatory Research

Environmental justice is defined as "the fair treatment and meaningful involvement of all people regardless of race, ethnicity, income, and national origin or educational level with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" (*53*) and is based on the increasing number of findings that environmental stressors (e.g., air, water, and land pollution) are disproportionately distributed among communities of color and low-income communities (*54–57*). For example, Wernette and Nieves (*58*) found that the percentage of persons living in nonattainment air quality areas is considerably higher for Hispanic and African American populations than for White populations, with the

greatest percentage being for Hispanic populations. Furthermore, the worst air pollution problems in the United States are most often found in urban areas in which a large number of communities of color reside (*59*). Because of this growing empirical evidence, the Committee on Environmental Justice (*60*) has made three recommendations for environmental and public health research: *a*) improve the knowledge base through the conduct of research, using improved methodologies for examining environmental etiologies of disease; *b*) engage participants from the affected communities in all aspects of the design and conduct of the research; and *c*) disseminate the results of the research to all parties involved. In addition to these developments in the environmental justice field, there have been increasing calls for more participatory and comprehensive approaches to research and public health practice (*61*) to address the social and environmental determinants of health and disease, most visible in the health disparities between rich and poor, White and non-White, urban and nonurban (*55,62–65*). One such approach, community-based participatory research (CBPR), emphasizes the participation, influence, and control of nonacademic researchers in the process of creating knowledge and change (*61*). CBPR is a collaborative research approach that equitably involves all partners in contributing their expertise and sharing ownership and responsibilities to enhance understanding of a given phenomenon, and to translate the knowledge gained into interventions and policies to improve the health and quality of life of community members (*61*).

Environmental Exposure Assessment: Community Action Against Asthma

All exposure assessment data collection for this project takes place through Community Action Against Asthma (CAAA), a field-based CBPR project. The overall goal of CAAA is to gain an increased understanding of the environmental and psychosocial triggers for asthma in children's homes and neighborhoods and to reduce those triggers through household- and neighborhood-level interventions. CAAA conducts research that follows suggested guidelines of the Committee on Environmental Justice (*60*). That is, CAAA conducts research on the effects of environmental exposures among the residents of Detroit through a participatory process that engages participants from the affected communities in all aspects of the design and conduct of the research; disseminates the results to all parties involved; and uses the research results to design, in collaboration with all partners, interventions to

reduce the identified environmental exposures. To ensure this happens, all strategies and plans for data collection and intervention activities are carried out in accordance with the principles of CBPR (*61*) and are thus formulated and approved by the CAAA Steering Committee. The committee comprises representatives from the Michigan Center for the Environment and Children'ns Health (MCECH). The center was established in 1998 and is a community-based participatory research initiative investigating the influence of environmental factors on childhood asthma. MCECH involves collaboration among the University of Michigan Schools of Public Health and Medicine, the Detroit Health Department, the Michigan Department of Agriculture, Plant and Pest Management Division, and nine community-based organizations in Detroit (Butzel Family Center, Community Health and Social Services Center, Detroiters Working for Environmental Justice, Detroit Hispanic Development Corporation, Friends of Parkside, Kettering/Butzel Health Initiative, Latino Family Services, United Community Housing Coalition, and Warren/Conner Development Coalition), and Henry Ford Health System.

The CAAA project is being conducted in neighborhoods on the east side and in the southwest portion of Detroit. The two areas were selected initially as part of the Detroit Community–Academic Urban Research Center (*66*), with which the MCECH is affiliated, on the basis of statistics highly relevant to general child and family health (e.g., high infant mortality rates, high proportion of households living below the poverty level); evidence of community strengths and efforts to address health problems; and preexisting relationships among some of the partners involved. The east side of Detroit is predominantly African American (more than 90%) (*67*), has a large number of single-family dwellings, and contains a major interstate highway and some manufacturing plants. Southwest Detroit is the part of the city where the largest percentage of Latinos reside [approximately 40% Latino, 50% African American, and 10% White (*67*)] and has historically contained most of the industrial facilities of Detroit. This industry, including iron/steel manufacturing, coke ovens, chemical plants, refineries, sewage sludge incineration, and coal-fired utilities, is located in and around Zug Island, an industrial complex along the Detroit River (Figure 1). In addition, southwest Detroit experiences heavy car and truck traffic because of both the presence of two major interstates and the entrance/exit of the Ambassador Bridge, the international border crossing that connects Detroit to Windsor, Canada.

The environmental exposure assessment portion of CAAA has as its primary objectives *a*) to provide ambient (community-level), microenvironmental (inside schools and homes), and personal monitoring data needed for the investigatation of the relationships between exposure metrics and activity patterns of children with asthma living in an urban community; *b*) to investigate whether seasonal and daily fluctuations in ambient air pollution and indoor air contaminants are predictive of fluctuations in asthma disease status; *c*) to identify the components of outdoor and indoor air that are associated with increased risk for asthma in the urban communities involved; and *d*) to provide data needed for the investigation of the relationship of specific interventions at the household and neighborhood level with measurable decreases in exposure to contaminants and associated improvements in disease status. CAAA is somewhat unique in its focus on exploring the combined effects of ambient indoor and outdoor air contaminants on fluctuations in asthma, and by doing so, uses a CBPR approach that follows suggested guidelines of the Committee on Environmental Justice (*60*). The PM exposure assessment measures and methodologies for CAAA, described in detail in the following sections, include measures of both indoor and outdoor air quality, primarily PM and ozone. Our objectives here are to describe the exposure assessment methodologies of CAAA and to present results and preliminary findings from PM exposure assessment for the first year of data collection. Because the exposure assessment activities of CAAA are tightly linked to the intervention activities of the project, the need for credible scientific data specific to achieve cleaner environments for children with asthma cannot be understated. The data collected in the urban neighborhoods must stand up to rigorous and critical review by the scientific community before it can be used to evaluate environmental risks. The collection of quality measurement data with partner involvement leads to more relevant exposure data for the study of children in urban neighborhoods and provides immediate knowledge and understanding of the outcomes and results of the combined environmental health analysis to the communities.

Methods

Assessment of Personal Exposures to Indoor and Outdoor Air Pollutants

The implementation of this study was made possible by the CBPR approach used in the assessment of environmental exposures of children with asthma living in two communities in Detroit. The CAAA Steering Committee played an active role in the

Figure 1. Map of Detroit, Michigan, illustrating community boundaries and air monitoring sites (filled circles) used for CAAA.

implementation decisions for the exposure assessment aspects of the project. They actively participated in the identification, hiring, and training of community outreach workers, called Community Environmental Specialists (CES), who performed the household assessments and the personal exposure monitoring activities. A Steering Committee hiring subcommittee was formed to oversee the selection of the CES, including development of job descriptions, interviewing, and ultimate hiring of the four CES. The Steering Committee also approved the content and format of the CES training curriculum, and some Steering Committee members participated as trainers in some of the CES training sessions. In addition, as described below, the Steering Committee participated in the design of the recruitment process for the families participating in the intensive exposure assessment aspects of the research.

The CAAA project includes participation of 300 children, 7–11 years of age, who were diagnosed with moderate to severe asthma through a mailed screening questionnaire. These families reside in one of two Detroit communities, eastside or southwest (Figure 1). As part of a community-level environmental exposure assessment, air quality measurements are performed at fixed monitoring locations within each of the communities. Four times each year, a 2-week seasonal field intensive data collection is conducted so that investigators can assess both levels of exposure as well as asthma health status of all 300 participants. Twice-daily measures of pulmonary function include peak expiratory flow (PEF) and forced expiratory volume at 1 sec (FEV_1). Additional measures of the children's health status include diaries of daily asthma symptoms and medications. During the seasonal

assessments, daily measures of $PM_{2.5}$, PM_{10}, and ozone are made at each of the two community locations on the rooftops of two elementary schools. In addition, daily measures of $PM_{2.5}$ and PM_{10} are also made indoors in school classrooms to characterize indoor penetration of outdoor pollutants.

Indoor levels of $PM_{2.5}$ and PM_{10} are also monitored daily in the homes of 20 study participants during each seasonal assessment. As mentioned previously, the Steering Committee was actively involved in the recruitment process for these 20 households. The original recruitment process proposed by the academic partners involved contacting these potential 20 households via telephone and letter to ask them to participate. On the basis of input from the community members on the Steering Committee, the recruitment process was redesigned to include visits to the potential families by a community member of the Steering Committee, who volunteered to visit each of the 20 households. During these visits, the member further explained the purpose of the exposure assessment equipment (including photographs of the equipment) to the families so they would better understand what their participation in the intensive household exposure monitoring would entail.

In addition to indoor measurements in their home, these children also wear a personal exposure monitor (PEM) each day for characterization of their exposure to PM_{10}. The rationale for this seasonal measurement approach considered the expected daily variability in PM exposure as well as issues related to retention and participation of families. It was determined that a seasonal assessment period of 2 weeks, taking into account the synoptic meteorology of southeast Michigan and regional air pollution transport

patterns, would be of sufficient duration to introduce and characterize variation in PM exposure for analysis with health outcome measures. At the same time, a seasonal assessment period of 2 weeks (in each season for 2 years) was determined to be the maximum duration for obtaining adequate retention of and participation by the 300 CAAA families involved.

Community-level exposure assessment. Ambient air quality measurements are performed at two sampling locations established for this study. Community-level exposure measurements are made on the rooftops (inlet heights approximately 5–6 m above ground) of Keith and Maybury Elementary Schools, located in the eastside and southwest Detroit communities, respectively (monitoring sites denoted by filled circles in Figure 1). Filter-based measurements of $PM_{2.5}$ and PM_{10} are made daily during seasonal exposure assessment field intensives (each 2 weeks in duration) at each sampling location. All PM samples collected are nominally 24 hr in duration. Measurements are made using both 2-µm pore, 47-mm Teflon (PTFE) membrane filters (Pall, Ann Arbor, MI) and prebaked 47-mm quartz fiber filters (Pall). Vacuum pump systems are used to draw air through the sample at a nominal flow rate of 16.7 L/min using Teflon-coated aluminum cyclone inlets (University Research Glassware, Chapel Hill, NC). The volume of air drawn through each sampling train is determined using a dry test meter (DTM; Schlumberger, Owenton, KY) placed inline between the vacuum pump and the sample. The DTMs are calibrated both before and after being deployed into the field against a laboratory spirometer (Warren E. Collins, Inc., Boston, MA), which is a primary calibration standard. In addition, flow determinations are made at the beginning and end of each sampling period using a calibrated rotameter (Matheson Inc., Montgomeryville, PA) to ensure that the flow rate is set correctly.

Teflon filters are also collected daily during seasonal measurement intensives using a dichotomous sequential air sampler, Partisol-Plus Model 2025 (Rupprecht and Patashnick, Inc., Albany, NY), for subsequent chemical and elemental characterization of fine and coarse particles. As opposed to the standard cyclone inlets, which collect all particles less than the defined size cut, the dichotomous configuration permits the differentiated mass determination and chemical composition of the fine (<2.5 µm aerodynamic diameter) and coarse (2.5–10 µm) particles contained in PM_{10}, which can aid in further source identification. The sequential dichotomous sampler also maintains sampling flow rates of 16.7 L/min using integrated volumetric flow controllers.

Semicontinuous PM determinations are made at each of the fixed ambient monitoring locations using a tapered element oscillating microbalance (TEOM) ambient particulate monitor Series 1400a (Rupprecht and Patashnick, Inc.) operated at 40ºC and equipped with a sharp-cut cyclone (SCC) inlet (BGI Inc., Waltham, MA). These inlets provide a sharper particle size cut at 2.5 µm relative to standard cyclone inlets. Similar to the dichotomous sequential samplers described above, the TEOM also operates at a sampling flow rate of 16.7 L/min while incorporating volumetric flow control. In contrast to the standard filter-based measures described above, which provide a sample media suitable for subsequent chemical characterization, the primary function of the TEOM is to determine PM mass. The great advantage of the TEOM is its ability to characterize PM concentrations in near real time (30-min intervals for this study), as opposed to the 24-hr integrated values obtained using the standard filter-based methods. The 30-min fine-mass data provided by the TEOM allow one to better assess short-term pollutant episodes and to determine contributions from local sources, which can impact the community on very short time frames. In contrast to the daily PM measurements performed only during the seasonal assessment periods, the TEOMs operate continuously year-round.

Additional ambient measurements made at each of the community monitoring sites include ozone and meteorological variables. Ozone, identified in previous studies to be a lung irritant, is monitored continuously at each of the sites and is logged as 30-min average values (Dasibi Environmental, Glendale, CA). Because ozone is a secondary pollutant typically present in Michigan at high levels only during the warm months, ozone measurements are made from April through October during each year of the study. Standard U.S. EPA protocols are used for calibration of all continuous instruments deployed in the field for this study. Standard meteorological variables including temperature, atmospheric pressure, relative humidity, wind speed, and wind direction (R. M. Young Co., Traverse, City, MI) are recorded in 30-min intervals at each of the sites. Meteorological variables are collected at a height of 4 m above the school rooftop, and all pollutant inlets are at a height of approximately 2 m above the rooftop.

Indoor and personal pollutant exposure assessment. Indoor PM levels are measured inside classrooms at the two elementary schools that serve as fixed outdoor monitoring sites, as well as inside the homes of 20 Detroit families participating in CAAA. Indoor measurements of $PM_{2.5}$ and PM_{10}

are made concurrently with the outdoor measures on a daily basis during each seasonal assessment to provide a measure of indoor penetration of outdoor pollutants as well as provide insight into indoor sources of PM. Similar to the outdoor sample collection methodologies, indoor PM measurements are made with both Teflon and prebaked quartz filter media and use Teflon-coated aluminum cyclone sample inlets at a nominal flow rate of 16.7 L/min. Sample flow rates are set using calibrated rotameters as described above. Indoor sample inlets are set at an approximate height of 1 m, a typical height of the breathing zone of children 7–11 years of age. Indoor samples are collected using pump systems designed and fabricated at the University of Michigan Air Quality Laboratory (UMAQL). These pump systems use linear, free-piston vacuum pumps, needle valves, and timers to provide accurately regulated air flow for PM sample collection. Acoustically insulated wood cases, designed for operation in the classroom and home environments, house the pumps, thus minimizing pump noise during sampling periods. Special attention was given to details such as noise and size of the equipment through close communication with our community partners and participating families.

Of the 300 total participants, 20 children who have indoor PM exposure measurements performed in their homes also participate in personal exposure monitoring for PM_{10}. PEMs (MSP Corp., Minneapolis, MN) are worn by 10 children during the first week of each seasonal assessment, then by 10 other children during the second week. The PEM system includes a small battery-powered pump (Gilian Inc., West Cladwell, NJ). The commercially available nickel-cadmium rechargeable batteries typically used with these pumps can provide only enough power for an 8-hr sampling duration (for workplace exposure applications). However, because the CAAA wanted to quantify PM exposure for full 24-hr sample periods, the UMAQL developed a custom battery pack using AA-size alkaline batteries that ensured pump power for sample durations of 24 hr or more. Sample flow rates for the PEMs are set at 2 L/min using a built-in rotameter calibrated with a Gilian Gilibrator (Gilian Inc.). The personal samples are collected using 2-µm pore, 37-mm Teflon (PTFE) membrane filters (Pall) in a PM_{10} filter inlet cassette. The pump and battery pack assembly is carried in a small child's backpack, while the inlet is connected via a short piece of Tygon tubing to the child's breathing zone. The PEM is carried with the child throughout the course of each day both indoors and outdoors, including

home, school, auto. While the child sleeps the PEM is placed on a nearby nightstand or equivalent. The child also records hourly activities in a daily activity log kept during all sample collection periods.

Laboratory analyses. All filters collected as part of CAAA for PM characterization are prepared and analyzed at the UMAQL. All gravimetric determinations of Teflon filters are made using a microbalance (Mettler MT-5; Mettler Toledo, Columbus, OH) in a temperature/humidity-controlled environment. All sample handling, processing, and analysis takes place in a Class 100 ultra-clean laboratory uniquely suited for ultra-trace element analysis with an emphasis on environmental determinations. Measures including field blanks, filter-lot blanks, laboratory blanks, replicate analyses, and externally certified standard weights are incorporated into all gravimetric analyses for quality assurance (QA) and quality control (QC) purposes. The detection limit for mass determination, calculated as 3 times the standard deviation of seven replicate filter measures, is 5.1 μg. This corresponds to a concentration detection limit of 1.8 μg/m^3 for a 24-hr personal sample collected at 2 L/min.

Upon completion of gravimetric analysis, PM samples collected on Teflon filters are analyzed for trace element composition. Teflon sample filters are wetted with 150 μL ethanol before extraction in 20 mL 10% HNO_3 and sonication for 48 hr in an ultrasonic bath. Samples are then diluted with Milli-Q water (Millipore, Bedford, MA) to 4% volume/volume solutions prior to passive acid digestion for 1 month. The extracts are then analyzed for a suite of elements by high-resolution inductively coupled plasma–mass spectrometry (ICP–MS; Finnigan MAT ELEMENT2 (Thermo Finnigan, San Jose, CA) similar to that previously described (*68,69*). This analysis

method also incorporates daily QA/QC measures such as field blanks, acid blanks, laboratory blanks, replicate analyses, and external standards certified by the National Institute of Standards and Technology (NIST) (e.g., NIST SRM 1643c).

PM samples collected on quartz filters are analyzed for carbonaceous aerosols at the UMAQL using a thermal-optical analyzer (Sunset Labs, Forest Grove, OR). The speciation of organic carbon (OC) and elemental carbon (EC) is accomplished through gradient heating and continuous monitoring of filter transmittance with flame ionization detection. This method has been previously described (*70,71*) and also includes the equivalent QA/QC measures described above for gravimetric and trace element determinations.

Results

Method Comparisons for Particulate Matter Collection: Samplers and Inlets

Automated samplers for ambient PM collection, although ideally suited to fixed-site outdoor air monitoring efforts, tend to be prohibitively large, costly, and immobile for indoor home and personal exposure monitoring. To circumvent these problems, customized manual sampling techniques were developed for CAAA that allow these types of exposure monitoring to be conducted. Because it is necessary to use different sampling systems and approaches to quantify PM levels in each of the microenvironments (i.e., indoor, outdoor, personal), a sampler methods comparison is performed to characterize any inherent differences in sampler performance for PM collection. This is essential because different sampler inlets and monitors are used in each of the microenvironments sampled. Results are presented below for sampler intercomparisons

conducted during the first year of CAAA exposure assessment.

Personal exposure monitors versus standard cyclone inlets for PM_{10}. Differences in particle collection efficiency for PM_{10} measured with the PEMs and standard cyclone inlets were investigated over two seasonal assessment periods in each of the indoor classroom sampling locations. These filters were collected concurrently each day for 2 weeks during each seasonal assessment. Figure 2 shows the results of this method intercomparison. Regression of the PEM data against the cyclone data yields a slope of 1.05, with r^2 of 0.91 (n = 18). Figure 2 illustrates that the two methods are very comparable for collection of PM_{10} over a wide concentration range (5–75 μg/m^3), as the mean percent difference between the two methods is 17.1%.

Standard cyclone inlets versus sequential dichotomous samplers for PM_{2.5} and PM_{10}. The collection efficiency for $PM_{2.5}$ and PM_{10} was investigated by side-by-side measurements performed daily with the standard cyclone inlets and the sequential dichotomous samplers over three seasonal assessment periods at each of the community monitoring sites. Figure 3 illustrates that the two methods are not statistically different from each other for collection of PM_{10} (fine and coarse filter combined for dichotomous sampler) over a range of 5–50 μg/m^3. The mean percent difference between the two methods was 10.6% (n = 56). However, differences in particle collection efficiency for fine and coarse fraction determinations were observed between the two methods, as illustrated in Figures 4 and 5. For determination of $PM_{2.5}$, the standard cyclone inlets resulted in significantly higher concentrations (p < 0.05 average of 19.0% higher) than the dichotomous sampler, as seen in Figure 4. This difference is likely due to the sharper
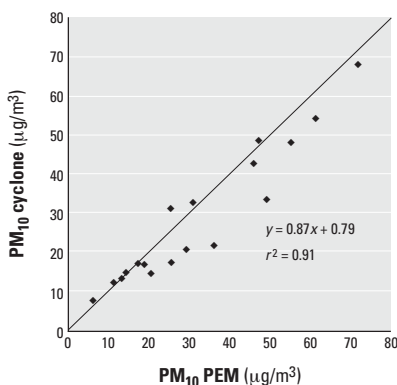

Figure 2. Sample inlet method intercomparison between PEM inlets and standard cyclone inlets for PM_{10} conducted inside community school classrooms (n = 18).

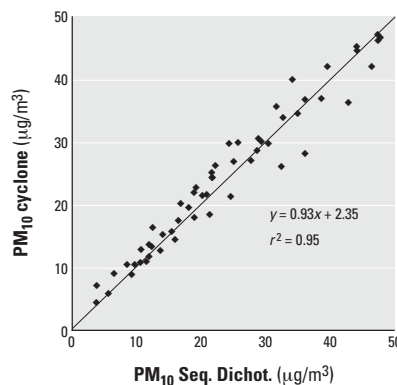**Figure 3.** Sample inlet method intercomparison between sequential dichotomous samplers and standard cyclone inlets for PM_{10} conducted at ambient community monitoring sites (n = 56).
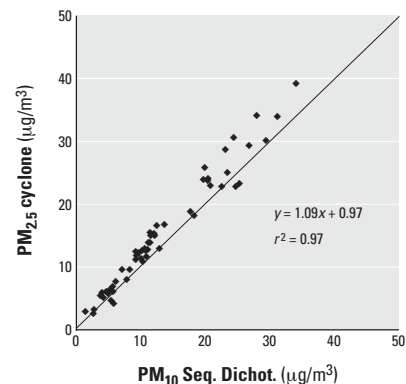
Figure 4. Sample inlet method intercomparison between sequential dichotomous samplers and standard cyclone inlets for fine fraction particulate ($PM_{2.5}$) conducted at ambient community monitoring sites (n = 56).

particle size cut at 2.5 μm provided by the dichotomous sampler inlet. In contrast, the standard cyclone inlets were found to be significantly lower ($p < 0.05$ average of 28.3% lower) than the dichotomous samplers for determination of the coarse particle fraction ($PM_{2.5-10}$), as seen in Figure 5. This, again, is due to the sharper size cut at 2.5 μm provided by the dichotomous sampler, as the coarse particle fraction for the standard cyclones is determined by subtracting the $PM_{2.5}$ sampler value from the PM_{10} sampler value. These characterized methodological differences will be of paramount importance in ultimately gaining a quantitative understanding of true differences in personal exposures among the various microenvironments.

Standard cyclone inlets versus continuous TEOM instruments with sharp-cut cyclones for $PM_{2.5}$. Differences in $PM_{2.5}$ concentrations measured with the standard cyclone inlets and the continuous TEOM instruments equipped with SCC were investigated. Data from both outdoor community
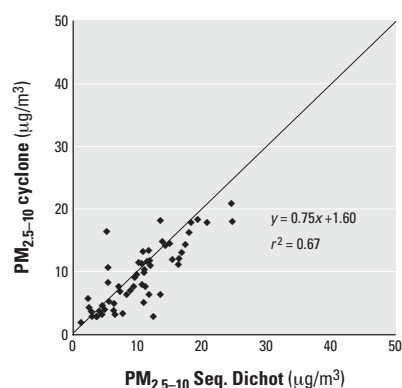

Figure 5. Sample inlet method intercomparison between sequential dichotomous samplers and standard cyclone inlets for coarse fraction particulate ($PM_{2.5-10}$) conducted at ambient community monitoring sites ($n = 56$).

monitoring sites collected during the four seasonal assessment periods were used. These data expand upon the results previously presented for the first two seasonal assessment periods (*71*). The standard cyclone inlets resulted in significantly higher $PM_{2.5}$ ($p < 0.05$ average of 14.1% higher, $n = 104$) than the $PM_{2.5}$ measured with the TEOM equipped with SCC inlet at the two monitoring sites for the autumn, spring, and summer assessment periods. This is likely because of the sharper particle size cut obtained with the SCC inlet, as previous characterization studies using the standard cyclones and the TEOM equipped with a standard cyclone show the two methods to be in good agreement (*72*). The effects of the SCC inlet are relatively consistent in the spring, summer, and autumn seasonal assessment data. However, the TEOM $PM_{2.5}$ is much lower on average (27%, $n = 19$) than the standard cyclones $PM_{2.5}$ during the winter assessment. This relatively large difference during the winter season is primarily driven by TEOM sampling bias encountered during the winter season related to the instrument's internal filter temperature set point with regard to loss of semivolatile nitrate and organic compounds from the filter, as previously discussed by Dvonch et al. (*72*). Novel approaches to modify the TEOM monitor and characterize the performance of this instrument have recently been reported (*73*).

Particulate Matter Exposure Assessment

Particulate matter characterization at community schools. Meteorological measurements of wind speed, wind direction, temperature, pressure, and relative humidity were performed at each school. Table 1 provides an overview of the meteorological results for the first year of data collection and

provides other air quality indicators measured at the sites. The meteorological conditions observed during the intensive assessment periods fell within the climatological norms for Detroit for year 1 of the study, except winter 2000, which was on average slightly above the climatological mean temperature. Included in the table are the mean and maximum 1-hr ozone concentration, the maximum 1-hr $PM_{2.5}$ concentration measured with the TEOM, the maximum daily PM concentrations measured during each season, and the mean concentrations measured both indoors and outdoors at the two community schools in each season. Results from the first five seasonal campaigns (October 1999–October 2000) indicate daily $PM_{2.5}$ levels averaged 17.0 ± 9.3 μg/m^3 and 15.5 ± 9.0 μg/m^3 at the southwest Detroit and east Detroit sites, respectively. Daily PM_{10} for the same measurement periods resulted in 28.9 ± 14.4 μg/m^3 and 23.8 ± 12.1 μg/m^3 at the two sites, respectively. Levels of both $PM_{2.5}$ and PM_{10} are significantly higher at the southwest Detroit site relative to the east Detroit site. Although levels of both PM_{10} and $PM_{2.5}$ had large daily variability in both communities, even larger variations (over 100 μg/m^3) in $PM_{2.5}$ were observed with the TEOM on shorter temporal scales (30 min) (Figure 6).

Indoor PM levels are very sensitive to infiltration rates that tend to be higher for smaller particles. Both the community schools studied, Keith and Maybury, have no air conditioning, and the levels of PM indoors varied dramatically and proportionately with the outdoor levels when the school windows were opened. As seen in Table 1, the indoor classroom PM levels more closely follow the outdoor PM levels during the spring, summer, and fall seasons when the outdoor temperatures are generally higher. In

Table 1. Seasonal summary statistics for meteorological and pollutant measures at the two ambient community monitoring sites for year 1 (October 1999–October 2000) data collection of CAAA. Data represent mean ± standard deviation of daily values by season.

Assessment period	Temperature (°C)	Relative humidity (%)	O_3 (ppb)	Max 1-hr O_3 (ppb)	Max 1-hr $PM_{2.5}$ (μg/m³)	Ambient $PM_{2.5}$ (μg/m³)	Ambient PM_{10} (μg/m³)	Max 24-hr $PM_{2.5}$ (μg/m³)	Max 24-hr PM_{10} (μg/m³)	Classroom $PM_{2.5}$ (μg/m³)	Classroom PM_{10} (μg/m³)
Fall 1999 (26 Oct–7 Nov)											
Southwest	–	–	–	–	69.6	19.7 ± 13.0	34.2 ± 22.2	45.7	77.0	13.6 ± 8.9	31.6 ± 15.4
Eastside	–	–	–	–	48.1	19.5 ± 12.3	25.2 ± 16.4	42.8	59.4	8.4 ± 5.8	11.6 ± 6.5
Winter 2000 (12–26 Feb)											
Southwest	2.6 ± 6.5	78 ± 11	–	–	36.9[a]	20.6 ± 8.1	30.8 ± 12.3	29.7	54.3	11.1 ± 4.5	21.5 ± 12.2
Eastside	2.5 ± 6.8	77 ± 11	–	–	31.9[a]	16.2 ± 6.0	24.3 ± 8.9	24.2	41.2	6.5 ± 2.5	8.7 ± 3.1
Spring 2000 (6–21 May)											
Southwest	17.3± 5.3	69 ± 14	24 ± 10	63	49.7	16.6 ± 7.6	28.8 ± 11.8	29.6	49.2	13.1 ± 6.4	33.3 ± 18.9
Eastside	16.7± 5.8	69 ± 15	33 ± 8	73	49.1	14.2 ± 7.0	25.2 ± 11.3	28.3	45.7	10.3 ± 8.5	12.0 ± 7.9
Summer 2000 (15–29 July)											
Southwest	21.9 ± 2.2	71 ± 11	30 ± 9	78	61.7	17.2 ± 9.7	28.0 ± 11.0	34.2	47.5	16.4 ± 9.6	30.4 ± 20.0
[b]East side	22.1 ± 2.3	76 ± 10	48 ± 18	93	53.4	18.4 ± 12.5	27.8 ± 10.7	38.0	42.2	–[c]	–[c]
Fall 2000 (23 Sept–7 Oct)											
Southwest	15.0 ± 4.5	76 ± 8	14 ± 11	70	95.8	13.3 ± 7.6	24.9 ± 13.4	26.1	48.5	8.0 ± 5.1	18.0 ± 10.6
East side	14.8 ± 4.8	75 ± 9	23 ± 10	92	32.9	11.6 ± 7.3	18.3 ± 11.7	24.5	42.2	9.3 ± 5.7	17.1 ± 7.5

[a]Winter TEOM effect minimizes peak. [b]Only 1 week of data collected because of nearby construction. [c]No classes in session.

contrast, classroom PM levels are well below ambient during the winter season.

Personal and home indoor particulate matter characterization. The most difficult measurement to perform is the personal exposure measurement. Many studies have been performed that have attempted to characterize the personal exposure of people using various sampling techniques. Table 2 shows the average PM_{10} concentrations by season measured with the PEMs worn by the 20 children with asthma participating in this portion of the study. On average, for all four seasons in collection year 2000, personal exposures to PM_{10} were 68.4 ± 39.2 µg/m^3, or 2.7 times higher than the levels of PM_{10} measured outdoors at the community level for the same periods (25.8 ± 11.8 µg/m^3). However, personal PM_{10} levels were not significantly higher than indoor PM_{10} levels measured in homes during the same periods (52.2 ± 30.6 µg/m^3). The PM levels in this study are similar in magnitude to levels of indoor home $PM_{2.5}$ and PM_{10} and personal PM_{10} measured in previous studies for children in urban locations (*74–77*). Although children living in homes with at least one smoker tended to have higher PM exposures than children living in nonsmoking homes, this was not always the case. Personal exposures for individual children were 2–3 times higher than the indoor or outdoor concentrations measured concurrently, regardless of their household smoking status. However, indoor levels of PM (both PM_{10} and $PM_{2.5}$) in homes of children with asthma living in a smoking household were statistically higher than indoor levels of PM in nonsmoking households. As seen in Table 2, the levels of PM were, on average, about twice as high in the smoking homes compared with those in the nonsmoking homes.

Discussion and Future Work

The first year results suggest that the levels of fine PM in the two Detroit communities will exceed the proposed annual NAAQS for $PM_{2.5}$ of 15 µg/m^3. The influence of local sources on both $PM_{2.5}$ and PM_{10} was clearly observed in the year 1 data. Outdoor levels of PM in both size fractions were found to be significantly greater in the southwest community than in the eastside community and also appear to drive the indoor PM levels in both the schools and homes to be higher as well. The increased levels in southwest Detroit, where the coarse particle fraction ($PM_{2.5–10}$) makes up nearly 40% of the total PM_{10}, are likely due to the proximity of the southwest community to the heavy industry on and around Zug Island, as well as the proximity to interstate motorways and the entrance to the Ambassador Bridge leading to Windsor, Canada (Figure 1). The bridge from Detroit to Windsor is the most traveled international border crossing between the two countries. Because of local traffic patterns, truck routes take all bridge-bound traffic through the southwest Detroit community. This results in a continuous queue of diesel truck traffic through the community. Preliminary analysis of data collected during the summer of 2000 at Maybury Elementary School suggests that traffic contributes a significant fraction of the PM measured at this site with a majority of the measured PM in the submicron size range.

While outdoor PM levels across the city may not meet the new NAAQS for $PM_{2.5}$, indoor levels of PM in nonsmoking homes are typically 1.5–2 times higher than the outdoor PM levels. Smoking continues to be a major contributor to the PM levels measured indoors, as well as contributing to the personal PM exposures of children with asthma. Whereas a child's exposure to secondhand smoke can voluntarily be reduced through education and intervention, exposure to such things as diesel emissions and other industrial emissions can only be remedied through effective policy decisions and through emissions control programs. Previous studies have attempted to find associations of higher incidences of asthma with specific sources such as traffic patterns and density. One study found evidence that children with asthma living near busy roads may have an increased risk of repeated medical care visits, compared with children with asthma living near lower traffic densities (*78*). Thus, identifying the sources of the PM exposure must be a high priority for children living in industrialized urban areas like Detroit.

Comprehensive elemental characterization (trace metals, EC, OC) of all filter samples over the 2-year collection period will provide a more complete assessment of the PM components. A detailed source apportionment of the elevated PM exposures measured for the children with asthma in each microenvironment can then be
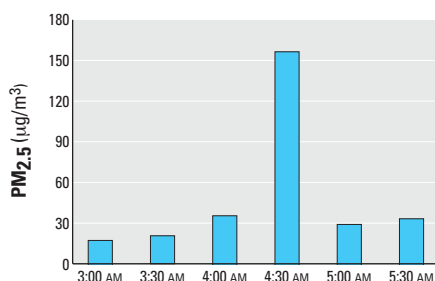

Figure 6. Continuous (30-min integrated) $PM_{2.5}$ measured with a TEOM at the southwest Detroit ambient community monitoring site on 23 September 2000.

Table 2. Seasonal summary statistics for PM_{10} and $PM_{2.5}$ measures of personal exposure and in-home exposure among children with asthma by community for year 1 (2000) data collection of CAAA. Values represent mean (µg/m^3) ± standard deviation of collective daily averages by season.

	Eastside Detroit		Southwest Detroit		Both communities	
	Smoking (*n*)	Nonsmoking (*n*)	Smoking (*n*)	Nonsmoking (*n*)	Smoking (*n*)	Nonsmoking (*n*)
Indoor PM_{10}						
Winter	65.0 ± 26.2 (43)	30.9 ± 17.0 (29)	72.8 ± 63.4 (19)	27.1 ± 5.3 (7)	68.8 ± 47.0 (62)	29.6 ± 14.2 (36)
Spring	55.4 ± 15.9 (54)	56.7 ± 33.0 (26)	64.2 ± 14.3 (23)	39.4 ± 4.7 (5)	59.5 ± 15.5 (77)	52.4 ± 29.4 (31)
Summer	53.0 ± 12.2 (42)	35.9 ± 18.7 (22)	57.3 ± 20.3 (10)	38.2 ± 8.0 (2)	54.2 ± 14.3 (52)	36.2 ± 17.5 (24)
Fall	55.4 ± 30.8 (30)	36.6 ± 28.1 (30)	67.0 ± 40.8 (10)	55.9 ± 26.1 (11)	60.7 ± 35.3 (40)	45.4 ± 28.3 (41)
						Annual average: 52.2 ± 30.6 (363)
Indoor $PM_{2.5}$						
Winter	51.4 ± 25.1 (44)	19.4 ± 9.7 (29)	36.6 ± 14.4 (19)	15.0 ± 7.5 (7)	44.6 ± 21.8 (63)	17.9 ± 9.1 (36)
Spring	41.2 ± 14.4 (55)	37.6 ± 24.3 (26)	50.8 ± 19.1 (20)	15.3 ± 6.0 (5)	45.6 ± 17.1 (75)	32.0 ± 23.2 (31)
Summer	34.2 ± 11.0 (43)	20.6 ± 15.4 (22)	33.9 ± 13.7 (11)	28.8 ± 5.8 (2)	34.1 ± 11.4 (54)	21.7 ± 14.6 (24)
Fall	40.8 ± 26.5 (30)	26.0 ± 23.4 (30)	51.1 ± 30.3 (10)	21.5 ± 11.1 (9)	45.5 ± 28.1 (40)	24.1 ± 19.1 (39)
						Annual average: 34.4 ± 21.7 (362)
Personal PM_{10}						
Winter	52.1 ± 23.0 (34)	35.7 ± 14.0 (10)	47.0 ± 43.1 (7)	76.2 ± 27.6 (2)	50.7 ± 28.3 (41)	43.8 ± 23.0 (12)
Spring	66.5 ± 19.4 (39)	74.2 ± 58.4 (19)	45.1 ± 35.7 (6)	NA	60.4 ± 26.1 (45)	74.2 ± 58.4 (19)
Summer	62.8 ± 15.7 (33)	89.6 ± 50.9 (17)	59.7 ± 24.8 (7)	76.1 ± 52.6 (3)	62.1 ± 17.5 (40)	87.1 ± 49.7 (20)
Fall	90.9 ± 44.5 (31)	61.9 ± 31.1 (28)	80.6 ± 47.9 (9)	83.0 ± 32.4 (7)	86.7 ± 45.1 (40)	69.3 ± 32.4 (35)
						Annual average: 68.4 ± 39.2 (252)

performed. For example, tracer species of specific source types can be used within a receptor-modeling framework to identify the major sources contributing to PM in each community. Furthermore, daily diaries and activity patterns will be linked with the exposure metrics to determine the relationship between children's exposure to PM and their daily activities and to determine the effects of these exposures on their respiratory health.

The second-year data collection activities will expand upon the measurements performed in year 1 by making microenvironmental measurements only when the children are present in the microenvironment, e.g., 8 A.M. to 4 P.M. for measurements in the school classrooms. Additional measurements will be made to more fully characterize the size distributions of the ambient PM, including the ultrafine particles, as well as provide for a more complete chemical characterization of the PM to which the children with asthma living in these communities are exposed. Furthermore, continuous EC measurements, using an aethalometer, will be performed in the southwest community to specifically address exposure to diesel emissions. When combined with other project metrics including twice-daily seasonal PEF and FEV_1 measurements and daily asthma symptom and medication dairies for 300 children with asthma, and daily characterization of PM personal exposure and PM indoor home exposure for a subset of 20 of the children, the chemical and elemental data will allow investigations not only into the sources of PM in the Detroit airshed with regard to PM exposure assessment but also into the role of air pollutants in exacerbation of childhood asthma.

There is considerable research evidence indicating an association between indoor and outdoor environmental exposures and childhood asthma (15–25) and that such exposures are particularly concentrated in urban, low-income communities of color (50,51,54–59). The results presented here are consistent with these findings and point to the need to better understand and address the sources of both indoor and outdoor pollutants. In keeping with the recommendations of the Committee on Environmental Justice (60), the CAAA project is involving community partners in collecting, analyzing, interpreting, and disseminating the results of this research as well as in developing, implementing, and evaluating household-, community-, and policy-level strategies aimed at reducing these exposures and improving the health of children and their families in Detroit. Interventions to reduce exposures based upon sound scientific data and relevant exposure metrics is a key to the CAAA approach for implementing these strategies.

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