WORKING TOGETHER TO IMPROVE DETROIT'S AIR

COMMUNITY ACTION TO PROMOTE HEALTHY ENVIRONMENTS

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7.2 INDOOR AIR FILTERS FOR SCHOOL, HOME, & COMMERCIAL USES

2016

This work is made possible by National Institute of Health and Environmental Sciences, RO1ES022616, and the Fred A. and Barbara M. Erb Family Foundation. Additional support was provided by the Michigan Center on Lifestage Environmental Exposures and Disease (M-LEEaD), #P30ES017885.

Table of Contents

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Tables

Figures

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7.2 INDOOR AIR FILTERS FOR SCHOOL, HOME, AND COMMERCIAL USES

7.2.1 What are indoor air filters?

Indoor air filters are devices that remove can certain air pollutants from air that is passed through them. Most air filters remove particles, including dust, small particles (including much $PM_{2.5}$), pollen, allergens, animal dander, and fibers. Some filters can remove gases, such as sulfur dioxide (SO_2), odors, and volatile organic compounds. When designed and used appropriately, air filters can reduce indoor exposure to harmful air pollutants, like $PM_{2.5}$.

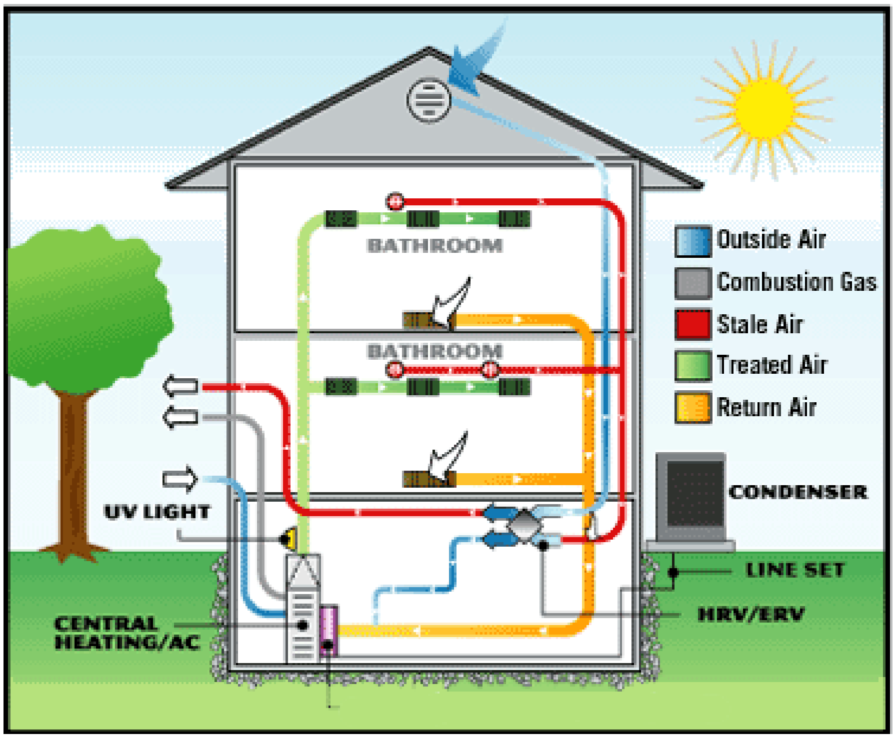

Figure 7.2-1: Illustration of a residential forced-air HVAC system. All such systems have a central heating system where filters can be installed, and vents for treated and return air. This system has several features that are not typical of most systems, including UV disinfection, and an air-to-air heat exchanger in the basement with controlled makeup (intake) and exhaust air (arrows to left of house) to improve efficiency and increase air exchange rates.[1]

[1] Green Living Ideas. The Basics of HVAC. Available: http://greenlivingideas.com/2014/09/26/the-basics-of-hvac/ [accessed 9-13-16].

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7.2.2 What types of air filters can be used, and where can they be used?

Many types of air filters can be installed in homes, businesses and schools. One type of filter is installed in forced-air heating, ventilation, and air conditioning systems (HVAC, see Figure 7.2-1). These can clean air throughout the house (or the space ventilated by the HVAC system) when the system is operating. While all forced air systems are supposed to have filters, which are often called "furnace filters," generic filters are very low quality and remove very little $PM_{2.5}$. Sometimes the filter is missing, and often it has not been changed for a long period. Frequently, furnace filters can be upgraded with a more effective filter that fits in the same space. Changing filters each season is needed to maintain their effectiveness.

A second type of device is a free standing or portable filter unit. These can be installed anywhere there is an electrical power outlet. These portable units clean the air in a single room (and help to clean air in nearby rooms). These filters can operate year round, including times when a forced air system is not being used (e.g., when heating or cooling is not being used.) This type of filter is also useful when a house or building does not have a forced air system, for examples, in houses with steam radiators or baseboard heat.

Figure 7.2-2: HEPA air filter/purifier, an example of a free-standing air filter.[2]

There are also many types of filters that can be used in forced air systems or portable filters, including paper-like, fabric/cloth, fiberglass, and others. Filters are typically rated using the minimum efficiency rating value (*MERV*). You should select a MERV value of at least 11 or 13. Filters need to be replaced each season as they

[2] HEPA Air Filter Example. Available: http://www.air-purifiers-america.com/products/alen-t500-hepa-air-purifier-w-hepa-odorcell-filter?variant=948368571&gclid=CJfplam97coCFYIBaQodXUUFjA [accessed 9-13-16].

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lose effectiveness, even though they may appear to be clean. One type of filter, called a HEPA filter (for high efficiency particle arrestance), can capture over 99% of particles. However, this particular type of filter is expensive and generally cannot be used in forced air systems. Fortunately, less expensive air filters can be very effective.

Filters are also available that remove gases like sulfur dioxide (SO_2), ozone (O_3), volatile organic compounds (VOCs), and odors. These filters are much bigger and heavier than the typical filter, and they are only rarely found in homes or commercial buildings. They can work well, but they are relatively expensive and require regular replacement. Some are sold as freestanding or portable devices.

Several types of filters are sold that should not be used because they are not effective or they produce dangerous byproducts, including ozone. These include products sold as "*ionizers*" and "*electronic air cleaners*" (which use electrostatic precipitators).

Most filters are relatively inexpensive. For example, you can replace an ineffective $2 furnace filter with a high quality filter that costs about $15 to $20. Filters should be changed every season to ensure that they remain effective. Freestanding filters can cost roughly $100 to $300 and consume $5 to $10 of electricity each month.

Both HVAC and free-standing filters are effective in reducing PM levels only when windows and outside doors are closed. Pollutants in air blowing in through windows and doors generally overwhelms the filter's cleaning ability.

7.2.3 Why is this important?

The average person spends over 90% of their time indoors.[3] Air pollution found indoors arises from indoor sources, such as cooking, smoking and vacuuming, as well as outdoor sources, such as traffic and power plants. Outdoor pollutants enter building via the ventilation system, windows, doors, and other openings in the building. Indoor air filters can significantly reduce the amount of both indoor and outdoor PM pollution you breathe. As a result, using filters to improve or maintain air quality can reduce your exposure from both outdoor and indoor sources of particulate matter. Among the mitigation strategies considered, filters are unusual in this regard.

Indoor air quality is important in schools, where children spend much of their day during the school week. Many of Detroit's schools are old buildings that suffer from mold, ventilation problems, and heating and cooling issues.[4] Detroit children also suffer from high rates of asthma, which can be exacerbated by some school's conditions.

[3] Klepeis NE, Nelson WC, Ott WR, Robinson JP, Tsang AM, Switzer P, et al. 2001. The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. Journal of exposure analysis and environmental epidemiology 11:231-52.

[4] Detroit Free Press. 2016. Trying to teach in DPS amid decay: It's a travesty. Available: http://www.freep.com/story/news/local/michigan/detroit/2016/01/14/detroit-schools-problems/78804118/ [accessed 11 February 2016].

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Section 7.2.8 quantifies the benefit of using filters in Detroit, and includes an analysis of using filters in schools and in homes.

7.2.4 Which pollutants are affected by using air filters?

Indoor air filters can remove or reduce the concentrations of $PM_{2.5}$, PM_{10}, pet allergens, tobacco smoke, some respiratory viruses, dusts, and other particles.[5,6,7]

As mentioned above, some filters can remove gases like sulfur dioxide (SO_2), ozone (O_3), volatile organic compounds (VOCs) and odors. These filters are uncommon. They are found in some special environments, for example, cleanrooms, certain manufacturing facilities, and buildings and shelters that might be exposed to high concentrations of hazardous chemicals (e.g., industrial and chemical warfare agents).

7.2.5 What health effects can be mitigated?

Indoor air filters can lower concentrations and exposures to $PM_{2.5}$ and PM_{10}. This can reduce the incidence of respiratory diseases (such as asthma), decrease respiratory inflammation and irritation, and lessen irritation of the nose, throat, and lungs. Lower $PM_{2.5}$ levels are associated with fewer premature mortalities; reduced incidence of heart attacks, hypertension, and adverse birth effects; and reduced risk of cancer.[8] Section 7.2.8 quantifies the benefit of using filters in Detroit, and includes an analysis of using filters in schools and in homes.

7.2.6 What is happening in and around Detroit?

Filters in schools. As a result of 2015 litigation by the US Department of Justice and the Michigan Department of Environmental Quality, AK Steel agreed to install air filters in the Salina Elementary and Salina Intermediate Schools. This was negotiated as a *Supplemental Environmental Project* (SEP),[9] a part of a larger settlement (fines totaled $1.35 million) to resolve 42 violation notices from the Michigan Department of Environmental Quality.[10]

Using HEPA filters in Homes**.**

In 2012-13, Community Action Against Asthma provided 89 households with freestanding HEPA air filters. Filters were placed in the child's bedroom or sleeping area. Monitoring for nearly a year showed that when used,

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[5] CARB (California Air Resources Board). Research Projects. Available: http://www.arb.ca.gov/research/single-project.php?row_id=64797 [accessed 12 February 2016].

[6] Du L, Batterman S, Parker E, Godwin C, Chin JY, O'Toole A, et al. 2011. Particle concentrations and effectiveness of free-standing air filters in bedrooms of children with asthma in Detroit, Michigan. Building and Environment 46: 2303-2313.

[7] Brown KW, Minegishi T, Allen JG, McCarthy JF, Spengler JD, MacIntosh DL. 2014. Reducing patients' exposures to asthma and allergy triggers in their homes: an evaluation of effectiveness of grades of forced air ventilation filters. Journal of Asthma 51:585-94.

[8] EPA (Environmental Protection Agency). Integrated Science Assessments (ISAs). Available: https://www.epa.gov/isa [accessed 29 February 2016].

[9] The United States Department of Justice. 2015. United States of America and the Michigan Department of Environmental Quality v. AK Steel Corporation. Available: http://www.justice.gov/sites/default/files/enrd/pages/attachments/2015/05/19/env_enforcement-2523241-v1-ak_steel_lodged_decree.pdf [accessed 11 February 2016].

[10] The Detroit News. 2015. AK Steel to pay $1.35M fine, install filters at schools. Available: http://www.detroitnews.com/story/business/2015/05/20/ak-steel-fine-install-filters-schools/27658285/ [accessed 11 February 2016].

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filters dramatically reduced particle concentrations.[11] Filters were often used improperly, possibly to reduce electricity costs or due to noise and drafts.[12]

7.2.7 What are the best practices?

Schools buildings

Improve HVAC system filters. In schools near a major highway in Las Vegas, enhanced filters in the school's HVAC system decreased children's exposure to particle concentrations (including diesel exhaust) by 74-97%.[11] These filters were installed as a *Supplemental Environmental Project* associated with the widening of the interstate highway.

Utilize the guidance in US Environmental Protection Agency's *Indoor Air Quality Tools for Schools*.[12] This includes guidance on selecting and using filters, and many other topics.

Require new construction or renovations to improve indoor environmental quality. New and renovated buildings should incorporate enhanced filters, low emission materials[13] and other measures to improve indoor environmental quality. A "green design" rating program for buildings, called LEED (Leadership in Energy and Environmental Design), utilize points for air quality. LEED certification provides independent verification of a building or neighborhood's green feature, allowing the design, construction, operations and maintenance of resource-efficient, high-performing, healthy, cost-effective buildings.[14] This certification is a good indication of a "green" building, but does not necessarily ensure that high performance filters are installed or properly maintained.

Use air filter management programs or filter committees. The Thames Valley District School Board in Canada used an air filter management program to bring together an air filter company, school officials, and school personnel (from purchasing, maintenance, and health and safety departments) for quarterly meetings to

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[11] Du L, Batterman S, Parker E, Godwin C, Chin JY, O'Toole A, et al. 2011. Particle concentrations and effectiveness of free-standing air filters in bedrooms of children with asthma in Detroit, Michigan. Building and Environment 46: 2303-2313.

[12] Batterman S, Du L, Parker E, Robins T, Lewis T, Mukherjee B, et al. 2013. Use of free-standing filters in an asthma intervention study. Air Quality, Atmosphere and Health 6:759-767.

[11] McCarthy MC, Ludwig JF, Brown SG, Vaughn DL, Roberts PT. 2012. Filtration effectiveness of HVAC systems at near-roadway schools. Indoor Air 23:196-207.

[12] EPA (Environmental Protection Agency). Indoor Air Quality Tools for Schools Action Kit. Available: http://www.epa.gov/iaq-schools/indoor-air-quality-tools-schools-action-kit [accessed 2 March 2016].

[13] For more information about low emissions materials, see LEED (Leadership in Energy and Environmental Design). 2016. Lo emitting materials. Available: http://www.usgbc.org/credits/schools-new-construction-healthcare/v4-draft/eqc2 [accessed 4 April 2016].

[14] USCBC (U.S. Green Building Council). 2016. LEED. Available: http://www.usgbc.org/leed [accessed 22 February 2016].

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monitor filter change schedules and to troubleshoot problems, resulting in improved maintenance and air quality in the schools.[15]

Form school-community partnerships. Public schools in Hartford, Connecticut created a district-wide wellness program to address rising rates of asthma, which used school teams, and health and environmental organizations, and US EPA's *Indoor Air Quality Tools for Schools*[16] material to engage and train teachers, staff and parents on indoor air quality risks and what they can do about them. The district saw a decrease in asthma-related visits to school-based care providers.[17]

Improve preventive maintenance. The Hartford initiative described above incorporated a preventive maintenance program, which included quarterly cleaning and filter change-out, repairing roof leaks, a comprehensive “Green Clean” janitorial cleaning program with environmentally-friendly material, and established guidelines for renovation projects (e.g., controlling emissions during construction and using low emitting materials).[18]

Legislation addressing air quality. In 2003, Connecticut enacted Public Act No. 03-220 that required school districts to adopt and implement an indoor air quality program that "provides for ongoing maintenance and facility reviews necessary for the maintenance and improvement of the indoor air”. It also allows boards of education to establish an indoor air quality committee to increase staff and student awareness. [19]

Homes

Use high-performing filters in homes with forced air systems. Homes in Atlanta and Chicago using high efficiency filters (rated MERV 12 or above) reduced levels of asthma triggers, such as cat dander and $PM_{2.5}$, by over 50%.[20]

When using high-performing filters in forced air systems, run the forced air system continuously. With high performing filters, you can continuously run your forced air system by using "fan" mode, which will filter air even if you are not heating or cooling your home. This can further reduce $PM_{2.5}$ levels. This strategy should be used only if the windows are closed.

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[15] NAFA (National Air Filtration Association). 2016. Air Filtration for Schools. Available: https://www.nafahq.org/air-filtration-for-schools/ [accessed 12 February 2016].

[16] EPA (Environmental Protection Agency). Indoor Air Quality Tools for Schools Action Kit. Available: http://www.epa.gov/iaq-schools/indoor-air-quality-tools-schools-action-kit [accessed 3-2-16].

[17] EPA (Environmental Protection Agency). 2014. Hartford Public Schools: Using IAQ Management to Address Asthma in an Urban District. Available: http://www2.epa.gov/sites/production/files/2014-08/documents/Hartford.pdf [accessed 11 February 2016].

[18] East Hartford Public Schools. Indoor Air Quality Tools for Schools (TFS) IAQ Program. Available: http://www.easthartford.org/page.cfm?p=7588 [accessed 12 February 2016].

[19] East Hartford Public Schools. Indoor Air Quality Tools for Schools (TFS) IAQ Program. Available: http://www.easthartford.org/page.cfm?p=7588 [accessed 12 February 2016].

[20] Brown KW, Minegishi T, Allen JG, McCarthy JF, Spengler JD, Macintosh DL. 2014. Reducing patients’ exposures to asthma and allergy triggers in their homes: an evaluation of effectiveness of grades of forced air ventilation filters. Journal of Asthma 51:585-94.

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Use freestanding filters. These filters can significantly reduce $PM_{2.5}$ concentrations in portions of your home such as bedrooms and living areas. These filters can be used in homes with or without a forced air system.

Eliminate or reduce indoor sources of pollutants, such as smoking.

Commercial buildings

Require new construction or renovations to improve indoor environmental quality. New and renovated buildings should incorporate enhanced filters, low emission materials, and other measures to improve indoor environmental quality. "Green" buildings, designed according to LEED or other criteria, explicitly consider indoor air quality in their design, construction and use. [21]

Use tax credits for HVAC improvements. Section 179d of the US tax code, popularly known as the green building tax deduction, offers up to $1.80 per square foot to businesses for installing heating, cooling and ventilation systems (HVAC). Qualifying systems must reduce the building's total energy and power cost by at least 50%.[22]

7.2.8 What is the benefit of using air filters in Detroit?

Air filters can be used in many buildings, including schools, homes, and commercial locations. Homes and businesses using improved air filters would especially benefit children and individuals with allergies and/or asthma. In 2014, approximately 178,000 children under the age of 18 lived in Detroit.[13] Between 2012 and 2014, 11.3% of Detroit children and 15.5% of Detroit adults had asthma.[14]

Detroit has many older homes (most were built between 1939 and 1951), many of which use steam or hot water heat. Stand-alone filters can be used in these homes. Often, when these homes are renovated, forced-air systems are installed, which permits the use of enhanced HVAC filters.

Filter strategies evaluated

The remainder of this section estimates the health benefits of using enhanced air filters at homes and schools in the Detroit area. Three strategies are considered where filters could be installed and used:

- Schools (K-12) located near major roads, major industrial sources and construction sites. This strategy prioritizes the application of filters where outdoor PM concentrations are higher. This strategy focuses on schools within 200 m of major roads, and estimates effects on children's health.

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[21] LEED (Leadership in Energy and Environmental Design). Available: http://www.usgbc.org/leed [accessed 3-2-16].

[22] Poplar Network. Available: http://www.poplarnetwork.com/news/5-green-building-tax-incentives-2015 [accessed 2-11-16].

[13] US Census Bureau. Demographic and housing estimates- 2010-2014 American Community Survey 5-Year Estimates. Available: https://www.census.gov/acs/www/data/data-tables-and-tools/data-profiles/2014/. [accessed 04.15.16]

[14] DeGuire, P., Cao, B., Wisnieski, L., Strane, D., Wahl, R., Lyon-Callo, S., Garcia, E., 2016. Detroit: The current status of the asthma burden. Michigan Department of Health and Human Services.

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- All schools (K-12). Because PM is broadly distributed spatially, there are potentially significant benefits using filters at all schools. This analysis is otherwise similar to the first.
- All homes. Children and adults spend between 60 and 80% of each day indoors at home[15], so there are potentially significant benefits for using filters at home. This strategy estimates health benefits for both children and adults.

Analysis methods

This analysis considered Detroit and several nearby communities affected by PM from local emission sources. The study area, highlighted in Figure 7.2-3, has a population of 1,010,956 and included 392 schools with a K-12 enrollment in 2014-2015 of 145,593.[16] Of these 392 schools, 309 had an enrollment of greater than 0. (For comparison, K-12 school enrollment was 91,771 in Detroit, and 275,544 in Wayne County.) These students, as well as teachers and staff, could benefit from high performance filters placed in school buildings.[24] Figure 7.2-3 shows the locations of the schools, as well as the air quality monitoring sites from which ambient $PM_{2.5}$ measurements are used.

Schools near roads were determined using road network data from the Michigan Center for Geographic Information, geocoding school locations, and identifying schools within 200 m of freeways and state highways. Of the 392 schools, 75 schools are considered "near road" schools, and 58 showed enrollment (greater than 0) for the 2014-2015 year. An estimated 24,490 children attended the near-road schools.

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[15] U.S. EPA. Exposure Factors Handbook 2011 Edition (Final). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/052F, 2011.

[16] Michigan School Data, https://www.mischooldata.org/DistrictSchoolProfiles/EntitySummary/Summary.aspx, accessed 2/1/2016.

[24] Shaughnessy RJ, Haverinen-Shaughnessy U, Nevalainen A, Moschandreas D. 2006. A preliminary study on the association between ventilation rates in classrooms and student performance. Indoor Air 16:465-8.

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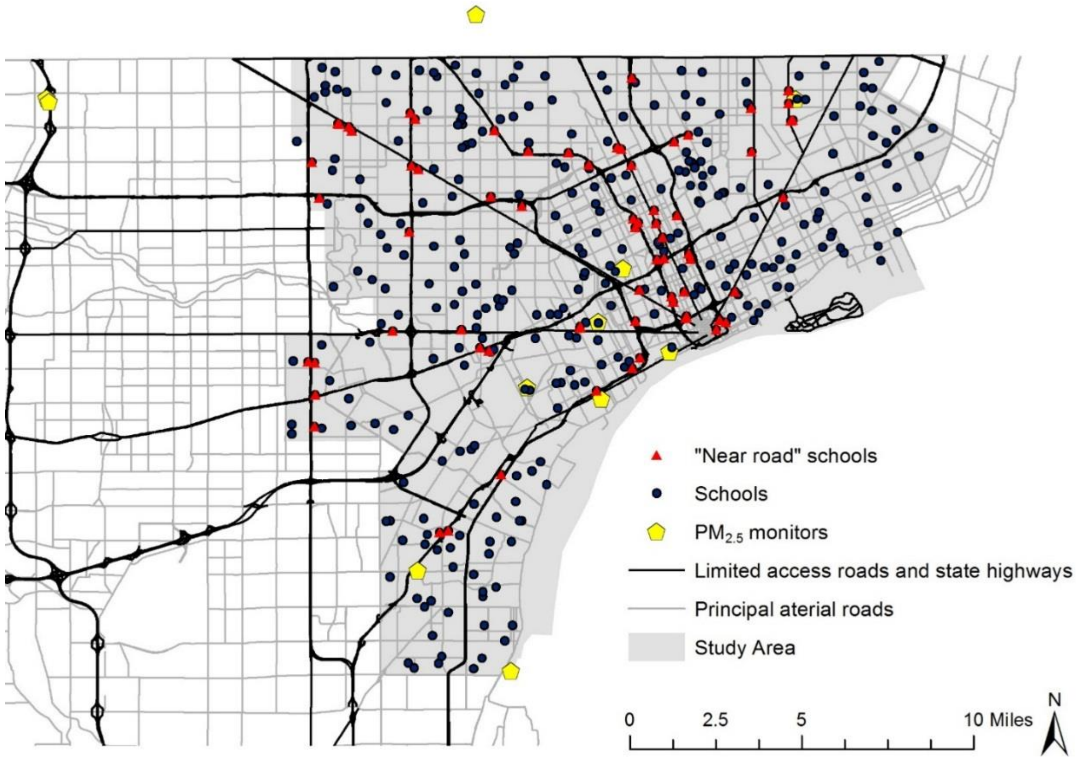
Figure 7.2-3. Locations of schools and air quality monitoring stations. One monitor (Ypsilanti, MI) not shown.



Many factors affect filter effectiveness, including the type of filter, filter air flow, air flow circulation, use schedule (e.g., full-time or intermittent), room and building size, air exchange rate and penetration of outdoor pollutants indoors, the nature of indoor particle sources, the outdoor PM concentration. To account for these factors, a range of indoor particle removal efficiencies is considered (25, 50 and 75%), with the most likely value being about 50% for HVAC type filters. Indoor PM sources were not considered. Particle penetration of 100% was considered, that is, without a filter, indoor and outdoor PM concentrations are equal. Estimates assume near-full-time operation of filters in both homes and schools. These assumptions are discussed later.

Monitored $PM_{2.5}$ concentrations at 12 Detroit area monitoring sites over the 2012-2014 period (using high quality Federal Reference Method monitors) were used to estimate exposures and health impacts. "School year" exposures use PM data for only those days that fell within the school year (weekends and weekdays in summer were excluded). "All year" exposures do not exclude any monitoring days. Exposures estimates, including the effect of utilizing filters, accounted for the amount of time students spend in schools (7 hours per day, 177 days per year) or at indoors at home (approximately 15 hours per day, 365 days per year). For schools near major roads or other larger pollution sources, daily PM concentrations were estimated using the highest daily concentration in the monitoring network (average school day concentration of 12.2 $\mu g/m^3$). For schools not near major roads or industry and all homes, $PM_{2.5}$ concentrations used typical concentration in the

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monitoring network (10.1 μg /m^3 for school days and 10.4 μg/m^3 for all days). Again, health benefits of using filters were estimated by reducing the indoor concentrations by 25%, 50% and 75%. The analysis assumes none of the schools or homes currently use effective air filters.

Health impacts for children from filter use

For children, the following health outcomes were considered: asthma exacerbations (as cough, wheeze, or shortness of breath) among children ages 6-14; ED visits for asthma among children ages 6-18; and asthma hospitalizations among children ages 6-18. Baseline rates for exacerbations used the NEXUS study,[17] which were applied to all schools in the analysis; and baseline rates for asthma ED visits and hospitalizations used ZIP code level data for schools in Detroit and county level data for schools outside of Detroit.[18,19] Health impact functions giving the $PM_{2.5}$ concentration-response relationship used the epidemiological literature,[20] which was assumed to be linear given the small range of exposure concentrations used. Enrollment in grades K to 8 was used to estimate the schools' age 6-14 population; the total enrollment at each school was used to estimate the population under the age of 18. The asthma prevalence of children in Detroit (11.3%,[21]) was used to estimate how many children were at risk of asthma exacerbations.

Table 7.2-1 summarizes the "baseline" or current asthma incidence and outcomes for children in the study area, and estimates outcomes and impacts attributable to $PM_{2.5}$ exposure at both homes and schools, assuming homes and schools do not currently use filters. Currently, asthma causes 659 hospitalizations for asthma, 7,166 ED visits for asthma, 2 million days with cough, and a total annual monetized impact of $245 million, for example. Asthma outcomes due to $PM_{2.5}$ exposure at schools (school days only) and at home (all year), account for 0.75 and 1.89%, respectively, of the overall asthma health burden (applies to hospitalizations, ED visits, and exacerbations). This estimate applies across the study area, and impacts will depend on where the child lives or goes to school. The incidence estimates in Table 7.2-1 are slightly higher than the incidence data reported in the most recent asthma surveillance report for Detroit, MI, which reported 440 hospitalizations and 4,600 ED visits for asthma among Detroit children covered by Medicaid,[22] largely because Table 7.2-1 consider a larger

[17] Batterman, S., et al., SO2 Exposures and Health Effects on Children with Asthma in Detroit, manuscript in development, 2016.

[18] DeGuire, P., Cao, B., Wisnieski, L., Strane, D., Wahl, R., Lyon-Callo, S., Garcia, E., 2016. Detroit: The current status of the asthma burden. Michigan Department of Health and Human Services.

[19] Michigan Department of Health and Human Services [MDHHS], 2016. Michigan Asthma Surveillance, Data and Reports [WWW Document]. URL http://www.michigan.gov/mdhhs/0,5885,7-339-71550_5104_5279-213824--,00.html (accessed 2.8.16).

[20] The health impact assessment uses the same health impact functions as a previous case study of $PM_{2.}$ health impacts in Wayne County, MI. See Martenies, S.E., Wilkins, D., Batterman, S.A., 2015. Health impact metrics for air pollution management strategies. Environment International 85, 84–95.

[21] DeGuire, P., Cao, B., Wisnieski, L., Strane, D., Wahl, R., Lyon-Callo, S., Garcia, E., 2016. Detroit: The current status of the asthma burden. Michigan Department of Health and Human Services.

[22] DeGuire, P., Cao, B., Wisnieski, L., Strane, D., Wahl, R., Lyon-Callo, S., Garcia, E., 2016. Detroit: The current status of the asthma burden. Michigan Department of Health and Human Services.

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study population, e.g., Detroit and the surrounding communities, and estimates include all children, not just those children covered by Medicaid.

Table 7.2-1. Current (baseline) asthma-related impacts for children in study area. Shows total impacts and impacts attributable to $PM_{2.5}$ exposures at schools and homes during the school year (weekdays from September 1 to June 15) and at homes during the full year. Baseline case (no filters).

		Number of PM2.5 attributable health impacts			% Attributable	
Outcome (age group)	Estimated Incidence (per yr)	School Exposures (1) (per school yr)	Home Exposures (1) (per school yr)	Home Exposures (per yr)	School Exposures (school year) (%)	Home Exposures (all year) (%)
Asthma hospitalization, cases (6-18)	659	2	7	14	0.37	1.00
Asthma ED visits (6-18)	7166	46	119	252	0.64	1.65
Asthma exacerbations (as cough, 6-14)	1,778,282	25,735	65,242	138,782	1.45	3.67
Asthma exacerbations (as wheeze, 6-14)	1,130,220	2,061	5,217	11,115	0.18	0.46
Asthma exacerbations (as SOB, 6-14)	1,073,190	2,613	6,617	14,096	0.24	0.62
DALYs (years)	1,956	34	85	181	1.71	4.34
Monetized impacts (million 2010$)	244.57	1.82	4.63	9.84	0.75	1.89

Abbreviations: DALYs: disability-adjusted life years; ED: emergency department; SOB: shortness of breath

Note (1): Considers only 177 days during the school year.

Table 7.2-2 summarizes the potential health benefits for children (as the number of avoided health impacts) of reducing $PM_{2.5}$ exposures for the three air filter strategies (using filters at schools near highways, in all schools and in all homes). Of the estimates in Table 7.2-2, filters installed in schools are likely to reduce PM exposure by about 50%. Filters installed at homes would likely reduce exposures by a lower fraction, likely by 25%. (Higher rates are technically possible but unlikely in practice.)

- The greatest benefits are installing filters in all homes, since children spend most of their time indoors at home.[23] This represents approximately 9,000 homes to be equipped with filters (based on asthma incidence and 81,000 households with children under the age of 18 in Detroit[24]).
- Using filters in the 309 schools where enrollment is >0 obtains benefits that are 39% of those obtained from installing filters in all homes. This represents a significant efficiency, since each filter system benefits all the children in the school (an average of 471 children attend each of the schools in the analysis).

[23] U.S. EPA. Exposure Factors Handbook 2011 Edition (Final). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/052F, 2011.

[24] US Census Bureau. Selected social characteristics in the United States- 2010-2014 American Community Survey 5-Year Estimates. Available: https://www.census.gov/acs/www/data/data-tables-and-tools/data-profiles/2014/. (accessed 04.15.16)

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- Using filters in the 58 schools near major roads is about 20% more effective (in terms of reducing adverse impacts) than installing filters at schools not near major roads since PM exposure is about 20% higher. However, the 58 schools near roads tended to have lower enrollments, on average than other schools in the analysis (e.g., 422 students per near-road school compared to 482 students per non-near road school), which diminished the estimated health impacts. However, these schools experience higher overall exposures to $PM_{2.5}$, and potentially rates of asthma incidence are higher at these schools, thus, the analysis may underestimate the benefit of filters.

Table 7.2-2. Health benefits for children of using air filters in schools and homes of children with asthma. Outcomes show the number of avoided health impacts during the school year, September 1 to June 15, and for all year. Does not consider exposure at home during non-school days. Most likely case is highlighted.

Avoided health impacts per year	Filters installed at all schools (during the school year)			Filters installed at near-road schools only (during the school year)			Filters installed at all homes (operating all year)		
	% $PM_{2.5}$ removed by Filter								
	25%	**50%**	75%	25%	**50%**	75%	**25%**	50%	75%
Asthma hospitalization (6-18)	1	**1**	2	0	**0**	0	**3**	7	10
Asthma ED visit (6-18)	11	**22**	34	2	**5**	8	**61**	124	187
Asthma exacerbation (as cough, 6-14)	6196	**12,556**	19,072	1,031	**2,094**	3,188	**33,406**	67,701	102,843
Asthma exacerbation (as wheeze, 6-14)	512	**1,026**	1,543	86	**173**	260	**2,763**	5,537	8,320
Asthma exacerbation (as SOB, 6-14)	648	**1,300**	1,955	109	**219**	329	**3,497**	7,012	10,545
DALYs (years)	8	**16**	25	1	**3**	4	**43.7**	88.5	134.2
Monetized impacts (million 2010$)	0.44	**0.89**	1.35	0.07	**0.15**	0.23	**2.38**	4.82	7.31

Abbreviations: DALYs: disability-adjusted life years; ED: emergency department; SOB: shortness of breath

Note: Impacts have been rounded to the nearest whole integer

Health benefits for the total population from filter use

For the total population (children and adults), the following health outcomes were considered in addition to the health outcomes included for children: all-cause mortality in adults older than 29 years; infant mortality for children less than 1 year of age; asthma hospitalizations for persons less than 65 years; hospitalizations for chronic obstructive pulmonary disease (COPD), cardiovascular diseases (CVD) and pneumonia in adults over the age of 64; non-fatal heart attacks in adults over the age of 17; and minor restricted activity days (MRAD) and work loss days in adults ages 18 to 64. Baseline rates come from multiple sources at different spatial scales: mortality rates use ZIP code level data and reported deaths for 2009-2013; asthma hospitalization rates use ZIP

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code level for Detroit[25] and county level data outside of Detroit[26]; rates of COPD, CVD and pneumonia hospitalizations are available at the county level[27]; area-specific rates of non-fatal heart attacks, MRAD and work loss days are unavailable, so nationally representative rates are used.[28,29,30] Health impacts estimates use health impact functions with concentration-response coefficients drawn from the epidemiological literature.[31] Age-stratified populations at the block-level were estimated using block level populations from the 2010 US Census and block group age distribution data from the 2013 5-year American Community Survey.[32,33]

For the total population, exposures consider the amount of time spend indoors at the residence each day, which varies by age.[34] $PM_{2.5}$ exposures for the full year were considered. The area-wide annual mean $PM_{2.5}$ concentration was used to estimate the number of attributable deaths, and daily mean concentrations were used to predict morbidities.

Table 7.2-3 provides an estimate of the current (or baseline case) health impacts attributable to $PM_{2.5}$ exposure among the study population. This analysis does not consider spatial differences in concentration, or weight exposures based on the time spent in different locations. The most common attributable outcomes are the low-severity morbidities, e.g., asthma exacerbations and minor-restricted activity days. The predominant fraction (96%) of the health burden (measured as DALYs) is due to all-cause mortality (adults >29 years) and infant mortality.

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[25] DeGuire, P., Cao, B., Wisnieski, L., Strane, D., Wahl, R., Lyon-Callo, S., Garcia, E., 2016. Detroit: The current status of the asthma burden. Michigan Department of Health and Human Services.

[26] Michigan Department of Health and Human Services [MDHHS], 2016. Michigan Asthma Surveillance, Data and Reports [WWW Document]. URL http://www.michigan.gov/mdhhs/0,5885,7-339-71550_5104_5279-213824--,00.html (accessed 2.8.16).

[27] Michigan Department of Health and Human Services [MDHHS], 2014. Hospitalizations by Selected Diagnosis [WWW Document]. URL http://www.mdch.state.mi.us/pha/osr/CHI/hospdx/frame.html (accessed 2.8.16).

[28] National Hospital Discharge Survey [NHDS], 2007. Number and rate of discharges by first-listed diagnostic categories [WWW Document]. Data Highlights- Selected Tables. URL http://www.cdc.gov/nchs/nhds/nhds_tables.htm#number (accessed 11.24.14).

[29] Ostro, B.D., Rothschild, S., 1989. Air pollution and acute respiratory morbidity: An observational study of multiple pollutants. Environmental Research 50, 238–247. doi:10.1016/S0013-9351(89)80004-0

[30] Ostro, B.D., 1987. Air pollution and morbidity revisited: A specification test. Journal of Environmental Economics and Management 14, 87–98. doi:10.1016/0095-0696(87)90008-8

[31] The health impact assessment uses the same health impact functions as a previous case study of $PM_{2.5}$ health impacts in Wayne County, MI. See Martenies, S.E., Wilkins, D., Batterman, S.A., 2015. Health impact metrics for air pollution management strategies. Environment International 85, 84–95.

[32] US Census Bureau, 2015. TIGER/Line® with Selected Demographic and Economic Data [WWW Document]. URL http://www.census.gov/geo/maps-data/data/tiger-data.html (accessed 7.2.15).

[33] US Census Bureau. American Community Survey 5-year Estimates. URL https://www.census.gov/programs-surveys/acs/ (accessed 2.16.16).

[34] U.S. EPA. Exposure Factors Handbook 2011 Edition (Final). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/052F, 2011.

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Table 7.2-3. Current (baseline) estimates of health impacts among the total population in the study area attributable to $PM_{2.5}$ exposures.

Outcome (age group)	Attributable Impacts per year
All-cause mortality (>29)	554
Infant mortality (0-1)	7
Asthma hospitalization (<65)	107
COPD hospitalization (>65)	21
CVD hospitalization (>65)	130
Pneumonia hospitalization (>65)	58
Non-fatal MI (18+)	25
Asthma ED visit (0-17)	374
Asthma exacerbation (as cough, 6-14)	224,799
Asthma exacerbation (as wheeze, 6-14)	18,003
Asthma exacerbation (as SOB, 6-14)	22,833
Minor restricted activity day (18-64)	365,937
Work loss day (18-64)	64,441
DALYs	10,367
Monetized impacts (million 2010$)	5,449

Abbreviations: COPD: chronic obstructive pulmonary disease; CVD: cardiovascular disease; DALYs: disability-adjusted life years; ED: emergency department; MI: myocardial infarction (heart attack); SOB: shortness of breath

Table 7.2-4 (left side) summarizes health impacts among the total population in the study area attributable to $PM_{2.5}$ exposures at homes, considering the amount of time spent indoors at home each day. The estimates for asthma are the same as shown earlier in Table 7.2-1; estimates for ED visits for asthma are higher because they consider all children under 18 years of age. Health impacts attributable to $PM_{2.5}$ exposures at home for the total study population range from 5 infant deaths to 240,000 minor-restricted activity days, annually, representing 7,457 DALYs and $4.1 billion in monetized impacts per year. Mortality (all-cause adult and infant mortality) accounts for 97% of the DALYs and monetized impacts.

Table 7.2-4 (right side) presents the potential health benefits for the total population in the study area due to reducing $PM_{2.5}$ exposures using air filters in all homes. As noted earlier, the most likely reduction of $PM_{2.5}$ by filters is likely around 25%. Achieving the benefits in Table 7.2-4 would require installation and full time operation of filters in all households. There are an estimated 254,197 occupied housing units in Detroit, MI.[35]

[35] US Census Bureau. Selected social characteristics in the United States- 2010-2014 American Community Survey 5-Year Estimates. Available: https://www.census.gov/acs/www/data/data-tables-and-tools/data-profiles/2014/. (accessed 04.15.16)

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Filters used in all homes (with 25% effectiveness) would reduce asthma exacerbations by about 225,000 (defined using cough), avoid 1,825 DALYs, and represents a health benefits with a monetized value of $1,015 million, each per year. In comparison, the use of filters at all schools during the school year (with 50% effectiveness) would reduce about 12,000 asthma exacerbations (as cough), avoid 16 DALYs, and represents a total monetized value of $0.89 million (Table 7.2-2). The health benefit of using filters in all homes is much larger, a result of the larger population affected, the greater amount of time spent at home, and the sensitivity of adults to health impacts (including mortality).

Table 7.2-4. Current (baseline) health impacts, impacts attributable to $PM_{2.5}$ exposure, and health benefits from using filters. Considers the total population in the study area and $PM_{2.5}$ exposure at home. Number of avoided health impacts per year. Most likely case is highlighted.

	Baseline health impacts assuming no homes use air filters			Benefits of installing filters in all homes at the number of avoided impacts		
				Percent $PM_{2.5}$ removal		
Outcome (age group)	Estimated Incidence (per yr)	Number of PM2.5 attributable health impacts (per yr)	% Attrib.	**25%**	50%	75%
All-cause mortality (>29)	10,048	422	4.20	**103**	208	314
Infant mortality (0-1)	165	5	3.08	**1**	3	4
Asthma hospitalization (<65)	3,122	71	2.26	**17**	35	53
COPD hospitalization (>65)	1,737	17	1.00	**4**	9	13
CVD hospitalization (>65)	7,896	106	1.35	**26**	53	80
Pneumonia hospitalization (>65)	1,412	47	3.34	**12**	23	35
Non-fatal MI (18+)	1,459	25	1.71	**6**	12	19
Asthma ED visit (0-17)	9,616	374	3.89	**91**	183	278
Asthma exacerbation (as cough, 6-14)	1,778,282	138,782	7.80	**33,406**	67,701	102,843
Asthma exacerbation (as wheeze, 6-14)	1,130,220	11,115	0.98	**2,763**	5,537	8,320
Asthma exacerbation (as SOB, 6-14)	1,073,190	14,096	1.31	**3,497**	7,012	10,545
Minor restricted activity day (18-64)	4,910,560	240,908	4.91	**58,010**	117,467	178,418
Work loss day (18-64)	1,367,402	42,424	3.10	**10,361**	20,884	31,570
DALYs	190,237	7,457	3.92	**1,825**	3,676	5,553
Monetized impacts (million 2010$)	99,520	4,147	4.17	**1,015**	2,044	3,088

Abbreviations: COPD: chronic obstructive pulmonary disease;
CVD: cardiovascular disease;
DALYs: disability-adjusted life years;
ED: emergency department;
MI: myocardial infarction (heart attack);
SOB: shortness of breath
Note: Impacts have been rounded to the nearest whole intege

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Accuracy and uncertainty of results

Many factors affect the accuracy and uncertainty of the health benefits predicted for filter use in schools, homes, and other buildings. The results did not consider the potential health benefits of reducing exposures to $PM_{2.5}$ that originate from indoor sources, which can be very significant, and thus estimated health benefits are conservative. Also, for schools, only children were considered. Teachers and staff in study schools (roughly 14,500 individuals) would also benefit from filter use. On the other hand, the analyses may exaggerate benefits of filters since many homes and school already have filters (though few will have high performance filters); this was one of the reasons why the filter effectiveness at homes was lowered to 25%. The many factors that affect filter effectiveness have been mentioned, e.g., type and use of filter, and thus a range of filter effectiveness was considered. Estimates of most likely conditions were highlighted. The fraction of homes and schools that actually install and use high performance filters was not estimated. Use of high performance filters and continuous use of HVAC systems requires additional electrical energy. In Detroit, much of the energy is generated using coal-fired power plants, thus, some additional pollution will result from filter use, but this was not considered in the analysis, although the incremental increase in electricity consumption due to filter use will be small.

7.2.9 Applicable Strategies for Detroit

Use high performance filters (MERV 11 and above) in homes, schools and commercial buildings. Buildings near major roads, construction sites, and other air pollution sources could be prioritized. The analysis in the preceding section shows significant benefits.

Create multi-stakeholder "Air Filter Management Programs" and/or "Filter Committees" for schools.

Create strategies for businesses to upgrade ventilation and filter systems.

Increase awareness of tax credits for green building.

Use certification systems to encourage green buildings and obtain points for improved air quality in the rating systems.

Create and use regular maintenance schedules for filter replacement, and couple with preventative measures in schools, homes and commercial spaces.

Use the EPA's *Indoor Air Quality Tools for Schools*.[25]

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[25] EPA (Environmental Protection Agency). Indoor Air Quality Tools for Schools Action Kit. Available: http://www.epa.gov/iaq-schools/indoor-air-quality-tools-schools-action-kit [accessed 3-2-16].

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Encourage the City of Detroit and other municipalities to pass ordinances stipulating that schools adopt and implement an air quality and indoor environment program, a preventative maintenance program with appropriate maintenance schedule

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