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Particle concentrations and effectiveness of free-standing air filters in bedrooms of children with asthma in Detroit, Michigan

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ABSTRACT

Asthma can be exacerbated by environmental factors including airborne particulate matter (PM) and environmental tobacco smoke (ETS). We report on a study designed to characterize PM levels and the effectiveness of filters on pollutant exposures of children with asthma. 126 households with an asthmatic child in Detroit, Michigan, were recruited and randomized into control or treatment groups. Both groups received asthma education; the latter also received a free-standing high efficiency air filter placed in the child's bedroom. Information regarding the home, emission sources, and occupant activities was obtained using surveys administered to the child's caregiver and a household inspection. Over a one week period, we measured PM, carbon dioxide (CO_2), environmental tobacco smoke (ETS) tracers, and air exchange rates (AERs). Filters were installed at midweek. Before filter installation, PM concentrations averaged 28 $\mu g\ m^{-3}$, number concentrations averaged 70,777 and 1471 L^{-1} in 0.3–1.0 and 1–5 μm size ranges, respectively, and the median CO_2 concentration was 1018 ppm. ETS tracers were detected in 23 of 38 homes where smoking was unrestricted and occupants included smokers and, when detected, PM concentrations were elevated by an average of 15 $\mu g\ m^{-3}$. Filter use reduced PM concentrations by an average of 69–80%. Simulation models representing location conditions show that filter air flow, room volume and AERs are the key parameters affecting PM removal, however, filters can achieve substantial removal in even "worst" case applications. While PM levels in homes with asthmatic children can be high, levels can be dramatically reduced using filters.

1. Introduction

Airborne particulate matter (PM) is an environmental trigger of asthma [1–3] and has been linked to adverse health impacts including aggravation of respiratory conditions and premature death [4,5]. Often, attention focuses on the PM fraction that is small enough to enter deep into the respiratory tract, e.g., $PM_{2.5}$ consisting of particles smaller than 2.5 μm dia [6,7]. Exposure to environmental tobacco smoke (ETS), to which a large fraction (60%) of asthmatic children in the U.S. is exposed [8], is associated with increased frequency and severity of asthma attacks, prolonged duration of symptoms, and decreased lung function [9,10]. Children in urban areas are especially exposed to elevated levels of allergens and indoor air pollutants, including $PM_{2.5}$ [7].

Indoor environments dominate exposures of many pollutants, including PM, because most people spend the bulk of their time indoors, e.g., U.S. adults and children respectively are indoors 87 and 85% of the time [11]. Indoor PM concentrations are determined by both indoor emission sources, e.g., tobacco smoke, gas stoves, cooking, vacuuming, and outdoor (ambient) sources, e.g., suspended soils, pollen and traffic exhaust [12–14]. Ambient $PM_{2.5}$ can easily penetrate building envelopes [7,18–20] and it represents an important component of indoor exposure [15]. ETS is an important source of PM as well as gaseous pollutants [9,16]. In addition to the types and strengths of indoor and outdoor sources [14,17], indoor concentrations are affected by building characteristics [17,18], air exchange rates (AER) [19], air mixing characteristics [20,21], heating/cooling system type [22], and the presence, if any, of PM filters [19,23–25].

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1.1. Application and evaluation of air filters

Air filters can substantially reduce indoor concentrations and exposures to PM, as demonstrated in both modeling [23,25] and field studies [19,22,26–31]. Free-standing (semi-portable or "room") filters are low in cost and easily installed in spaces where people spend large amounts of time. Both high-efficiency particle arrestor (HEPA) filters, which are rated for a minimum removal of 99.97% for particles 0.3 μm dia [25], as well as conventional low efficiency filters can provide effective PM removal since air makes multiple passes over the filter. Several studies have suggested that such filters can reduce asthma symptoms of children and adults [3,18,22–24,27–29,32–35].

In practice, filter performance is affected by many factors. First, filter performance decreases as AERs increases, since a smaller fraction of air in the space will be treated by the filter. AERs can increase due to opened windows, large indoor-outdoor temperature gradients, high wind speeds [36,37], and coupling to other building zones. Unfortunately, few filter studies have measured AERs. Second, indoor emission rates can be highly variable and are rarely measured or controlled, which can confound performance evaluations [38,39]. Third, filter performance can decrease if filters become loaded and air flow rates decrease. Filter performance can also be affected by the quality of ventilation air, the placement of the filter, and mixing of air in the room and building.

Most studies investigating PM removals using free-standing filters have focused on symptom outcomes [25,27–29,35] or have employed small sample sizes and thus may not be representative of either local or global conditions. Few studies have assessed PM removal rates, filter usage, and factors affecting filter performance. Previous tests of HEPA filters in 4 cigarette smoker's homes showed that PM concentrations decreased by 30–70% depending on size fraction and occupant activities [19]. Several larger filter studies have been conducted that have focused on specific allergens, but have not evaluated PM removal. In the Netherlands, HEPA filters were provided to 15 of 45 homes studied, and filters were dismantled after 6 months to quantify dust and house dust mite allergen loadings [33], however, airborne PM measurements were not collected. In seven U.S. cities, allergens in bed and surface dust sampled in 425 homes equipped with filters in the child's bedroom were compared to levels in 444 control homes [35]. Unfortunately, information regarding filter size and use is unavailable, and again, PM was not measured. In a study of 35 cat-allergic adults, half received HEPA filters placed in their bedrooms (including a timer to document use), and 1-h monitoring conducted monthly over a season showed gradual reductions (up to 40%) of airborne levels of Fel d1 compared to the placebo group, but again, PM was not measured [29].In Buffalo, NY and Hagerstown, MD, HEPA room filters were placed in bedrooms of 32 adults with symptoms of perennial rhinitis, and particle number counts (PNCs) showed reductions in most (85%) homes, with an overall reduction of 73% for >0.3 μm PNCs [28]. This study was conducted in winter; short-term measurements (duration unspecified) were utilized; and homes where active smoking took place were omitted. In a study of 93 asthmatic children living in mostly row homes in Baltimore, MD, HEPA filters were placed in half of the children's bedrooms, and $PM_{2.5}$ and PM_{10} concentrations in the bedrooms decreased by about 39%; comparable reductions were seen for some allergens [27]. In upstate New York, a system integrating a HEPA filter, air conditioner and energy recovery ventilator reduced 0.5–10 μm PM by 72% in bedrooms of 30 children with asthma [22]. This system was sophisticated, and the tests were designed to boost AERs, isolate and positively pressurize the bedroom. Overall, evaluations of stand-alone filters have been modest in scope and limited by incompletely known or controlled variables including, most importantly, indoor emissions, outdoor concentrations, and AERs.

1.2. Objectives

The objectives of this study are to characterize PM and ETS exposures of children with asthma in Detroit city homes, and to evaluate the effectiveness of stand-alone filters in reducing PM concentrations. In this intervention study, HEPA filters were placed in the bedrooms of children with asthma, one of the "microenvironments" where children spend considerable time. Our approach and sample size were designed to obtain representative and robust results. This study was motivated by the need to understand pollutant exposures of children, and to recognize the significance of the time spent at home. It was conducted as community-based participatory research by the Community Action Against Asthma (CAAA) partnership, which includes community-based organizations, health and human service organizations, and university researchers.

2. Materials and methods

2.1. Participant recruitment and schedule

The study sample consisted of households recruited to participate in a study investigating the effect of providing HEPA filters and asthma education provided by community health workers on symptoms and lung function of asthmatic children. Households in Detroit, Michigan with a child between the age of 6–12 and identified as having persistent asthma were eligible. Detroit is a city of about 900,000 that contains numerous industrial facilities, rail yards and highways. The study area is predominantly African American and Latino, a large fraction of households have low incomes, and asthma hospitalization rates are moderately high to very high [40].

A short screening questionnaire was distributed to caregivers of Detroit children ages 6–12 through recruitment activities at community-based organizations, schools, community fairs and other venues. Households were deemed initially eligible if they had at least one child who reported symptoms or medication use consistent with persistent asthma. Exclusion criteria were: participation in a previous CAAA intervention study; living outside of Detroit; intention to move in the next 6 months; family monolingual in a language other than English or Spanish; and child with physical or mental handicap that would preclude successful spirometry measurements.

Our final sample included 126 households that were randomized to one of three groups: a control group receiving only community health worker (CHW) home education visits ($n = 37$); the standard intervention group receiving a filter and CHW visits ($n = 47$); and an enhanced intervention group receiving the filter, the CHW visits, plus an air conditioner ($n = 42$). Households entered the study on a rolling basis, and baseline monitoring and filter deployment occurred between March, 2009 and February, 2010. Table 1 shows the number of households completing initial visits by season. Following the baseline visit, two or three follow-up

Table 1
Number of baseline visits by season in the three groups. "CHW" = control; "AF" = CHW + air filter; "AF/AC" = CHW + air filter + air conditioner; "Total" includes sum of three groups.

Season	CHW	AF	AF/AC	Total
Spring (Mar–May)	6	5	6	17
Summer (Jun–Aug)	14	3	3	20
Fall (Sep–Nov)	6	21	15	42
Winter (Dec–Feb)	11	18	18	47
Total	37	47	42	126