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Reducing indoor air pollutants with air filtration units in wood stove homes

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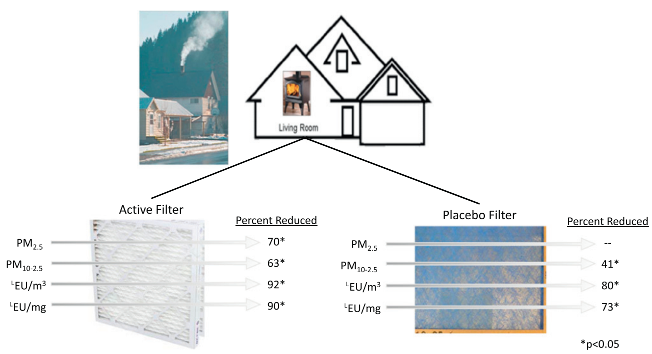
HIGHLIGHTS

- High and low efficiency filters are evaluated.
- Fine particles are significantly reduced using high efficiency air filters.
- Larger particles and airborne endotoxin are reduced with high and low efficiency filters.
- Constant filter unit use not required for pollutant reduction.

GRAPHICAL ABSTRACT



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ABSTRACT

Background: Biomass burning has been shown to be a major source of poor indoor air quality (IAQ) in developing and higher income countries across the world. Specifically, wood burning for cooking and heating contributes to high indoor concentrations of fine (particles with aerodynamic diameters < 2.5 μm; $PM_{2.5}$) and coarse (particles with aerodynamic diameters <10 μm and >2.5 μm; PMc) particulate matter. Endotoxin, predominantly found within the coarse fraction of airborne particulate matter, is associated with proinflammatory effects and adverse outcomes among susceptible populations. The aim of this study was to assess the efficacy of air filter interventions in reducing indoor $PM_{2.5}$, PMc, and PMc-associated endotoxin concentrations in homes using a wood stove for primary heating.

Results: Homes ($n = 48$) were randomized to receive in-room air filtration units with either a high efficiency filter (i.e. active) or a lower efficiency fiberglass filter (i.e., placebo). The active filter intervention showed a 66% reduction in indoor $PM_{2.5}$ concentrations (95% CI: 42.2% to 79.7% reduction) relative to the placebo intervention. Both the active and the placebo filters were effective in substantially reducing indoor concentrations of PMc (63.3% and 40.6% average reduction for active and placebo filters, respectively) and PMc-associated endotoxin concentrations (91.8% and 80.4% average reductions, respectively).

Conclusions: These findings support the use of high efficiency air filtration units for reducing indoor $PM_{2.5}$ in

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homes using a wood stove for primary heating. We also discovered that using lower efficiency, lower cost filter alternatives can be effective for reducing PMc and airborne endotoxin in homes burning biomass fuel.

1. Introduction

Exposure to particulate matter is known to exacerbate existing respiratory conditions (van Berlo et al., 2012) with size fraction playing an important role in the toxicity of the particles (Tong et al., 2010). Epidemiological evidence indicates that coarse particulate matter (particles with aerodynamic diameters <10 μm and >2.5 μm; PMc) has an acute effect on respiratory health, particularly among susceptible populations (Brunekreef and Forsberg, 2005). Further, the biological component of the coarse fraction including endotoxin, a component of the cell wall of Gram-negative bacteria, has long been known to trigger asthma symptoms (van Berlo et al., 2012) and severity in children (Liu, 2004).

People spend a majority of their time indoors, averaging 86–87% of time for the general population and 89–90% for children (Klepeis et al., 2001). The home environment is ideal for health-based interventions because it can be altered with fewer resources and fewer barriers than the outdoor environment. It has been estimated that for every dollar spent on home-based multicomponent interventions designed to reduce asthma morbidity, the monetary value of the resulting benefits, such as averted medical costs, was $5.30–$14.00 (Nurmagambetov et al., 2011). Air filters have been shown to significantly reduce breathing problems, asthma symptoms and allergy attacks (Eick and Richardson, 2011; Fisk, 2013; Johnson et al., 2009; McDonald et al., 2002). These results are likely achieved because air filters can reduce exposure to asthma triggers such as airborne pet allergen (van der Heide et al., 1999) and particulate matter.

In reducing concentrations of indoor PM, two in-room air cleaner technologies are typically utilized: systems that operate on the principle of electrostatic precipitation, and air cleaners using filtration technologies. Both systems are widely available, economical, and simple to use. As it has been estimated that 4.8 million susceptible individuals live in homes with significant exposures to residential wood smoke (Noonan et al., 2015), evaluating interventions that reduce these indoor exposures is important when considering the potential corresponding improvements to human health. To this end, our team has evaluated high efficiency air filtration technologies in wood burning homes, and have observed consistent reductions (~60%) in indoor wood smoke PM across multiple locations (Hart et al., 2011a; Ward et al., 2015). We have not, however, investigated the impact of lower efficiency filtration units on reductions in PM, or how filtration influences changes in indoor, airborne endotoxin.

The present study examined the efficacy of two classifications of air filters in the reduction of $PM_{2.5}$, PMc, and endotoxin within homes using wood stoves for residential heating. Homes were randomized to receive high efficiency "active" or lower efficiency "placebo" filters that looked similar in order to blind participants to their intervention. "Active" filters had a Minimum Efficiency Reporting Value (MERV) rating of 13, meeting specifications for capturing >90% of particles 1–3 μm with a dust-spot efficiency of 80–90% with typical application in hospital laboratories while "placebo" filters had a MERV rating of 2 and are typically used to protect residential furnaces from the buildup of unwanted materials and are not commonly used for direct indoor air quality reasons (EPA, 2013).

2. Materials and methods

2.1. Study design

This study utilizes a subset of homes from the Asthma Randomized Trial of Indoor Wood Smoke (ARTIS) study. ARTIS is an intervention-based study designed to improve the quality of life of children with asthma living in wood stove homes by reducing in-home levels of $PM_{2.5}$ (Noonan and Ward, 2012). Use of a non-EPA certified, older model wood stove as the primary heating source in the home was required for inclusion in the ARTIS study. The ARTIS study involved four separate 48-hour sampling visits over two consecutive winters - a baseline winter and post-intervention winter. After baseline sampling was completed homes were randomized into three treatment arms: 1) homes receiving an active, in-room filtration unit, 2) homes receiving a placebo in-room air filtration unit, and 3) homes receiving a new high-efficiency wood stove to replace their older model. Interim analysis showed that the wood stove changeouts were not efficacious in reducing indoor $PM_{2.5}$ (Ward et al., 2015). As a result, this intervention arm was discontinued and homes assigned to the wood stove changeout were excluded from the results presented here. The active air filter and placebo air filter are designed to appear similar to household members, thereby blinding them to treatment status. This single-blind control arm was an essential feature of a randomized controlled trial evaluating asthma health outcomes.

In this study we present baseline and post-intervention measures from a subset of 48 homes. Indoor PMc and endotoxin levels were collected for baseline and post-intervention winters. Among these, 25 homes were assigned to the active filtration arm and 23 homes were assigned to the placebo arm. During each of two winters (baseline and post-intervention), exposure sampling consisted of two 48-hour monitoring events. At each sampling event homeowners reported descriptive characteristics of their residence, including number of full-time residents (adults and children), number of pets (furry animals only, i.e., dogs and cats) and square footage.

As previously described (Noonan and Ward, 2012), following the baseline winter all homes received two in-room stand alone air filtration units. One large (20 ft. × 18 ft) air filtration unit (Filtrete Ultra Clean Air Purifiers, 3 M, St. Paul, MN, USA) designed for a 360 ft^2 space was placed in the same room as the wood stove, typically the main living room. Within the child's bedroom, an in-room air filtration unit designed for 170 ft^2 was placed. Participants were instructed to operate the units on the "high" setting throughout the duration of the winter. Homes were randomly assigned filters with a MERV value of 13 or 2 for installation in the air filtration units, with a higher MERV indicating higher efficiency. Units were taped closed to ensure there was no human interference with the filters.

To assess compliance with continuous usage, each air filtration unit was fitted with a data logging kilowatt meter (KWM). The KWM monitored on/off status and logged the amount of kilowatt-hours used by the filtration units. Laboratory tests of the air filtration units determined a predicted kilowatt-hour usage of 3.13 per day for the large units and 1.90 per day for the small units running continuously on "high". KWM values were recorded at each sampling visit, and this value was divided by the predicted value to estimate filter use compliance.

2.2. Data collection

2.2.1. Indoor air sampling

The 48 wood burning homes participating in this study were located in the following regions: 1) a 100-mile radius surrounding Missoula in western Montana; 2) the Nez Perce Indian Reservation in Idaho; 3) Butte, Montana; and 4) Fairbanks, Alaska. Indoor air sampling took place during consecutive baseline and post-intervention winter periods (typically November 1 through March 15). Samplers were collocated in each home in the common living area on a table 3–5 ft off the ground