National Collaborating Centre for Environmental Health

Centre de collaboration nationale en santé environnementale

JANUARY 2015

Effective Indoor Air Interventions

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Summary

- Interventions that target multi-pollutants and involve multiple intervention measures are more effective in reducing asthma morbidity burden than those that address a single pollutant or source.
- Home-based education and visits by community health workers can provide cost-effective interventions via behavioural changes that improve indoor air quality.
- Policy interventions, such as smoke-free policies, reduced children's exposure to second-hand smoke (SHS) in homes and improved their respiratory health.
- Public education campaigns targeting SHS could be beneficial in Canada in further reducing exposure, particularly in First Nations Communities with high prevalence of smoking.
- Evidence from recent studies on room air cleaners with high-efficiency particle filtration supports their effectiveness in reducing indoor air particles and respiratory and cardiovascular morbidity. However, source removal, such as indoor smoking, remains the first and foremost priority.
- For highly sensitive populations, such as asthmatic and allergic patients, particle filtration in the sleep-breathing zone can improve their respiratory symptoms and quality-of-life.
- Simple non-structural remediation measures such as sealing cracks to remove pest access into homes, changing behaviour, including proper storage of food, and laundering bed covers with hot water can be effective in reducing exposure to allergens from house dust mites and pests.
- More intervention studies in non-home settings (e.g., schools and public buildings) are needed, as the general population is likely to be exposed to indoor air pollutants in other indoor spaces.
- Cost-benefit analyses would enable translation of evidence from intervention studies into program and policy development.

Introduction

Canadians spend approximately 90% of their time indoors, including homes, offices, schools, and daycare centres.[1] "Tighter" sealed homes combined with the presence of indoor emission sources can worsen indoor air quality compared with outdoors,[2-4] which can have major influences on health, learning, and productivity of occupants.[5]

Exposure to indoor air pollutants is associated with a multitude of respiratory and systemic illnesses. This includes development and exacerbation of asthma, airway irritation, and inflammation, as well as non-respiratory symptoms, such as headaches, fatigue, and eye irritation.[6,7] Long-term or acute exposures to high levels of indoor pollutants can lead to lung cancer and premature death.[6]

In Canada, chronic lung diseases cost the economy $12 billion in 2010 in direct and indirect health-care costs, through premature death and long-term disability, primarily from lung cancer,

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asthma, and chronic obstructive pulmonary disease.[8] Poor indoor air quality (IAQ) is important in the etiology of acute and chronic respiratory illnesses. An earlier economic assessment of poor indoor air quality in the U.S. estimated tens of billions of dollars a year in costs incurred from exacerbation of respiratory illnesses, asthma, allergic symptoms, and lost productivity.[9]

Indoor air pollutants and sources

Indoor air pollutants can be categorized into biological and chemical agents. Biological agents include mould, house dust mites, bacteria, viruses, pests (cockroaches, rats) and dander or hair from pets. Chemical agents commonly found in indoor environments are second-hand smoke (SHS), asbestos, lead, pesticides, inhalable particles (particulate matter: PM), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone, and volatile organic compounds (VOCs), such as formaldehyde.

Combustion related indoor air pollutants, such as PM, NO_2, and CO, can be emitted from smoking, incense candles, gas or kerosene space heaters, fireplaces, and wood and gas stoves. Non-combustion sources of household chemical pollutants include cleaning, disinfecting, and degreasing products, insecticides, paint, varnish, pressed wood products (particleboard, fiberboard, and plywood), and furniture, which can off-gas and emit VOCs, particularly if they are new.

In addition to indoor sources, building conditions and outdoor sources also influence IAQ. Cracks in walls and ceilings serve as access points for cockroaches and rats. Standing water also supports infestation of these pests, whose feces, saliva, and skin cells are allergens to sensitized and asthmatic individuals. Poorly maintained heating and ventilation systems, air purifiers, and humidifiers can harbour allergens and become pollutant sources.[5,10] Water leaks and condensation contribute to a damp moist environment favouring house dust mites and mould and bacterial growth. Excessive indoor moisture can initiate chemical emissions from building materials and furnishings.[11] Human occupants can also emit biological contaminants in an indoor environment spreading airborne infectious agents and communicable disease.[12] Climate change is likely to worsen IAQ as a result of mitigation or adaptation measures taken in response to extreme weather events.[5] For example, increased use of air conditioning and weatherization can lower air-exchange rates, resulting in build-up of indoor pollutants. Major indoor air pollutants, sources, and their health impacts are summarized in *Appendix 1, Table A1*.

Objective

The purpose of this evidence review is to assess interventions applicable to a Canadian setting that are undertaken to improve IAQ and health. "Effectiveness" of an intervention was based on demonstrated reductions in both indoor air pollutants and improvements in human health. Studies that assessed both indoor air contaminants as well as IAQ parameters, such as temperature, relative humidity, and CO_2, and health outcomes were included in the review.

Methods

Pubmed, Google Scholar, and Web of Science, as well as references in identified articles were searched for relevant literature. Only English language literature was reviewed. Articles were restricted to interventions in residences and public buildings, including schools, daycares, and offices. Hospitals and industrial workplaces were excluded because they are governed under different regulations and standards. Laboratory tests are not covered in the review. Inclusion criteria for studies were that it should evaluate both environmental and health measures. For example, a study must assess indoor air contaminants or IAQ parameters, as well as health measures, either self-reported or objectively measured.

The NCCEH has published evidence reviews on IAQ interventions, such as air cleaners,[13] integrated pest management,[14] and most recently on mould. Mould remediation is not included in this document, as this was covered in a recent NCCEH review.[15]

Radon was excluded from this review because remediation technologies have been extensively published elsewhere including at the NCCEH and Health Canada.[16,17]

Literature searches were restricted to interventions implemented in Canada and the US, and from other developed countries. Indoor air issues are likely to be similar among these countries due to similar economic development, built environment, and emission sources. Search terms and databases used are provided in *Appendix 1, Table A2*.

Results and Discussion

Indoor air quality interventions reviewed can be categorised into two levels: population (including policies) and community. Interventions implemented at the population level include policies, public-sector regulations, and mass media campaigns. Community-level interventions address issues common in a group (community) of individuals who share similar characteristics (practices, socioeconomic status, culture, etc.) or a common geographic area.[18]

Population-level interventions

In Canada, 4.5% of children below the age of 17 continue to be regularly exposed to SHS in homes.[19] This percentage is likely to be higher in First Nations communities due to high prevalence of smoking; 43% of First Nations adults are daily smokers compared to 17% of the general Canadian population.[20] An indoor air quality intervention study in a First Nations community found 73% of the participants were exposed to SHS in the home.[21]

A smoke-free policy is a population-level intervention that can ban smoking in indoor public spaces, workplaces, and nearby public building entrances. Smoke-free policies have been credited with improving the respiratory and cardiovascular health of occupationally exposed workers in the hospitality sector,[22-24] and also, in the general population.[25,26] Initial fears that public bans may displace smoking activities from public places to homes and cars, and therefore increase SHS exposure among children, has not been supported by scientific evidence.[27] Rather, smoke-free policies may contribute to reduced prevalence of smoking in homes via increased awareness and changing social norms.[27] A study in Scotland found reduced hospital admissions for asthma in children aged under 15 after implementation of a public smoke ban.[28]

A review by the International Agency for Research on Cancer evaluating effectiveness of smoke-free policies concluded that smoke-free policies and associated public education campaigns are more effective and sustainable in reducing SHS exposure for children in homes than interventions targeted at individuals and homes where parents smoke.[27] Given that smoke-free policies have been implemented in Canada's provinces and territories, public education campaigns to promote smoke-free homes may further reduce SHS exposure in homes.

Community-level interventions

Community-level interventions on IAQ often involve environmental remediation measures as a major component that may be combined with an educational component.[29] Environmental remediation can be categorized into non-structural and structural activities as defined in Croker's review.[29] Non-structural remediation activities include using allergen-impermeable bedding covers, patching holes in walls, and installing air filters. Structural remediation involves major changes to the home or building structure, such as installation of ventilation units and extensive repairs to floors. An increasing number of community-level interventions emphasize education to empower residents to adopt or modify behaviour to eliminate or reduce exposures.

Non-Structural Remediation

Control of House Dust Mites (HDM)

Reductions in HDM exposure can be achieved via a combination of non-structural remediation measures, such as use of allergen-impermeable pillow and mattress covers, washing of bedding in hot water, removal of carpets, and application of acaricides.[30-34] A multi-faceted study on primary prevention of asthma implemented a combination of methods to reduce HDM and other asthma triggers that included allergen impermeable covers, weekly washing of bedding in hot water, high-efficiency vacuum cleaners, and the replacement of carpets with hard floors. The intervention was associated with significant reduction in HDM concentrations in mattress dust by up to 95%, with sustained reductions observed through one year of follow-up.[32] Associated health benefits were significant reductions in severe wheeze, prescription of medication for the treatment of wheezy attacks, and wheezing after vigorous playing, crying, or exertion during the first year of life.[33]

The use of impermeable bedcovers as a solo intervention is insufficient in providing clinical benefits.[35-37] Effectiveness of chemicals alone in reducing HDM exposure is inconclusive,[30,36,38] and there are concerns about their proper use and potential toxic exposure to household members.

Integrated Pest Management

Integrated pest management employs a combination of strategies to prevent, manage, and treat pest infestations as well as eliminate use of toxic pesticides. Integrated pest management can improve IAQ by reducing indoor levels of mouse, rat and cockroach allergens, and exposure to pesticides. A previous NCCEH review on reducing indoor pesticide exposure using integrated pest management can be found in Appendix 3: Additional Resources.

Three studies cited in the previous review had evaluated health outcomes from integrated pest management interventions on paediatric asthmatic populations.[39-41] An integrated pest management intervention in the homes of asthmatic children sensitized to mouse allergen consisted of filling holes and cracks to remove rodent access points; placing traps throughout the home; educating the family about kitchen cleaning and food storage; and use of high efficiency particulate air (HEPA) vacuum cleaner and HEPA air filter in the child's bedroom. The intervention found significant reductions in mouse allergens, which was associated with reductions in missed school days, child sleep disruption, and caretaker burden but did not reduce asthma symptoms or medical utilization.[40] A similar intervention, but without HEPA filtration, in the homes of asthmatic children who were sensitized to mice found a significant reduction in mouse allergens in dust samples from kitchen, living room, and bedrooms. However, the intervention was not associated with improved asthma symptoms or lung function.[39] A third study found a significant reduction in roach allergens, and improved respiratory symptoms and quality-of-life, using an integrated pest management approach, but the study design was limited by lack of a control population.[41]

Air Filtration

High efficiency particulate air filters can improve IAQ by reducing particles present in an indoor environment. Given that there is currently no indoor $PM_{2.5}$ standard nor recognized threshold of health effects for $PM_{2.5}$, Health Canada has recommended that indoor $PM_{2.5}$ levels be kept lower than outdoor levels.[42] Canadian ambient (outdoor) air quality standards for annual exposure to $PM_{2.5}$ will be set at 10 μg/m^3 beginning in 2015.

The NCCEH has reviewed residential air cleaners and their effectiveness in improving IAQ and health[13]: http://www.ncceh.ca/sites/default/files/Air_Cleaners_Oct_2010.pdf. The section below summarizes evidence from articles published after the NCCEH 2010 review as well as expands upon the effects of filtration types, and on additional intervention settings (i.e., schools and office buildings).

Indoor particle exposure can be reduced via three types of filtration: 1) whole house filtration that is particle filtration provided through heating, ventilation, and air conditioning (HVAC) system; 2) portable room air cleaners; and 3) filtration in the sleep breathing zone. Only one recent study included whole house filtration as one of the interventions.[43] The study provided one or a combination of the following three intervention types: HVAC servicing with installation of high-efficiency furnace filter; room air cleaners in children's bedrooms; and basement dehumidifiers. Mould removal and repairs to remove moisture sources were also conducted when the problem was detected. Total allergen load was reduced in 61% of homes but due to skewed allergen levels in some homes, the reductions were not significant, except in homes with basement dehumidifiers. Significant reductions in breathing problems and allergy attacks were seen in homes that implemented either one or all interventions types (HVAC servicing, room air cleaners, and dehumidifiers).[43]

Four recent portable room air cleaner (PRAC) interventions were conducted in communities with strong indoor polluting sources of indoor smoking,[21,44,45] or residential wood combustion.[46] Two interventions targeting SHS used HEPA air cleaner units with activated carbon filters for capturing gas-phase contaminants,[44,45] while one study employed electrostatic filters.[21] All three filtration studies on SHS found significant reduction in particles of various sizes, including >0.3 micrometer (μm) and <0.5 μm,[45] $PM_{1,}$[21] $PM_{2.5,}$[21,44] and $PM_{10.}$[21,44] These reductions were associated with improved lung function[21] and symptom-free days,[44] and reduced unscheduled asthma-related visits to a health care provider.[45] Activated carbon filters were ineffective in reducing gaseous nicotine levels; however, the improvements in respiratory health nevertheless suggested that non-nicotine bound particles of SHS were responsible for asthma exacerbation and respiratory illnesses.[44,45] The electrostatic filter intervention was not associated with improvements in blood pressure or blood vessel health. The authors noted this may be due to high prevalence of indoor smoking in the First Nations Community, underscoring the importance of source removal (e.g., cessation of smoking).[21]

A HEPA filter intervention study[46] in a Northern British Columbia community affected by residential wood combustion showed significant reduction in indoor $PM_{2.5}$ concentrations. This was associated with improved microvascular function (a measure of blood vessel health) and reduced markers of systematic inflammation, both of which play a role in cardiovascular related illnesses.

The delivery of HEPA-filtered air in an individual's sleep breathing zone can be effective in reducing respiratory symptoms for asthmatic or allergic patients. Two such studies[47,48] found reductions in allergen-sized particles >0.3 μm in breathing zones of asthmatic or allergic patients, and improved markers of airway inflammation, asthma and allergic symptoms, and quality of life scores, despite the small sample sizes.

Fisk (2013)[49] reviewed three intervention studies in offices and classrooms which were considered rigorously designed based on the presence of a control arm, randomization, crossovers, placebo filters, and objective health measures.[49] One study reported significant reductions (94%) in particle sizes 0.3-0.5 μm in diameter, but did not find reduced symptom severity among its 396 respondents.[50] The other two studies that installed electrostatic precipitators in offices[51] and classrooms[52] found significant reductions in particles of varying sizes ranging from ultrafine (0.02–0.1 μm) to larger than 15 μm in diameter. The office intervention provided health benefits for those with airway symptoms (reduced nasal congestion and increased peak expiratory flow),[51] whereas the classroom intervention had no effect on symptoms associated with sick building syndrome.[52] Previous evidence reviews of electrostatic precipitators suggest they may produce ozone and, therefore, pose potential health concerns.[13] The authors in both studies claimed the electrostatic precipitators used in the interventions did not produce ozone or were modified to remove the pollutant.[51,52]

Structural Remediation

Efficient Heaters

A few studies on the replacement of inefficient heating units with more efficient units in homes[53] and schools[54] show improvements in asthma morbidity. A study in New Zealand installed 131 heat pumps, 39 wood pellet burners, and five flued gas heaters combined with retrofit insulation in intervention homes with asthmatic children to reduce NO_2 exposure.[53] The intervention was associated with lower levels of NO_2, increased temperatures, and significant reduction in asthma symptoms, days off school, and fewer visits to a doctor or pharmacist compared to control homes. The study did not assess health outcomes by heater type. A similar intervention involved replacing unflued gas heaters with flued gas or electric heaters in schools to reduce NO_2 exposure.[54] The interventions were associated with reduced NO_2, and asthma-related symptoms among school children. Neither of the heater replacement interventions was associated with improved lung function or reduced bronchial hyperresponsiveness.[53,54]

Multi-faceted Interventions

Multi-faceted interventions are defined as those that target multiple pollutants or triggers and employ a variety of strategies to remove or reduce pollutants, including structural and non-structural remediation. An example of a multi-faceted intervention in a home involves removal of carpets, use of allergen-impermeable bedding covers, high-efficiency particle filtration and smoking cessation initiatives.

An increasing body of literature supports that multi-faceted interventions are effective in reducing respiratory illnesses particularly for asthmatic children. Crocker (2011) reviewed 23 home-based, multi-faceted intervention studies to evaluate their effectiveness in reducing asthma morbidity.[29] The most commonly targeted indoor pollutants were house dust mites, cockroaches, mould, and mouse, cat, and dog allergens. Two studies measured NO_2, PM_{10}, and $PM_{2.5}$. Summary statistics combining the results of twenty studies of multi-faceted interventions involving children and adolescents found reductions in symptom days by 0.8 days per two weeks (range: 0.6 to 2.3); missed school days by 12.3 days per year (range: 3.4 to 31.2); and asthma acute care visits by 0.57 visits per year (interquartile interval: 0.33 to 1.71). Outcomes for the adult population were inconclusive due to inconsistent results from the limited number of studies.

In addition to asthma symptom reductions, two large-scale prospective randomized trials suggest multi-faceted interventions can reduce asthma prevalence.[31,33] The Canadian Childhood Asthma Primary Prevention Study assigned 545 high-risk infants into a control and intervention group prenatally. The intervention group received measures for dust mite control (vapor-impermeable bedding covers, weekly hot water washing of all bedding, and application of acaricide), as well as avoidance of SHS and pets. The intervention made little difference to pet allergen levels and parental smoking but significantly reduced dust mite levels compared to the control,[55] and was associated with significantly lower prevalence of asthma and asthma symptoms in children at seven years of age.[56]

Home-based, multi-faceted interventions can be delivered by medical or trained personnel, such as a nurse, physician, social worker, or community health worker (CHW).[29] A systematic review found CHW-delivered interventions were more effective in reducing indoor environmental triggers with associated improvements in pediatric asthma symptoms, daytime activity limitations, and healthcare utilization.[57] CHWs are often peers from communities they serve who share similar cultural and social experiences to their clients, and as such, CHWs are more readily welcomed into the home[58] and may be more successful in promoting sustained behavioral changes.[59-61]

Evidence from one study suggests the level of CHW involvement is also key for delivering effective results, which may apply generally to the benefits of intensive follow-up. A Seattle-King County Healthy Homes Project compared intervention outcomes from a low-intensity treatment that included a single CHW visit, to a high-intensity treatment which provided seven CHW visits, and individualized action plans and social support. The high-intensity group reported positive behavioral changes such as increased actions to reduce dust and consistent use of bedding encasements. The high-intensity group had higher caregiver's quality-of-life and reduced asthma-related urgent health services utilization compared to the low-intensity group.[58,62]

Although multi-faceted interventions may be more effective in reducing morbidity, implementing them may not be practical or acceptable for many asthmatic patients within the context of primary care.[63] Home-based multi-faceted environmental interventions may be impractical and costly, contributing to poor compliance and maintaining interventions over time.[29,64] Other factors reported for failing to comply with intervention protocol include patient or parental stress, lack of time, feelings by parents of neglecting their child in order to comply with protocols, disagreements between partners about housework or other aspects of allergen avoidance, lack of confidence in the intervention, and complacency.[35]

Strengths and Limitations

Many of the earlier indoor environmental intervention studies were criticized for weak designs, including limited sample size, lack of control population, and blinding.[36,49,65,66] An increasing number of IAQ intervention studies are being implemented with more rigorous designs, including treatment randomization, double-blinding, placebo-controlled, cross-over treatment, and objective health measures to help minimize bias and confounding.[21,46,47,49,59] However, exposure misclassification is a remaining concern in intervention studies and has been regarded as one of the reasons behind modest effect estimates.[35] Intervention studies may introduce errors in exposure measurement, for example if house dust mite levels in mattress dust are the only exposure measure used, when study participants may be exposed to dust mites in other locations inside and outside the home environment (i.e., schools). Authors of a multi-faceted intervention that reduced airborne PM and indoor allergens levels but only found a modest effect on asthma morbidity questioned whether further reductions in participants' homes are feasible. Reducing exposure in other indoor spaces such as schools or friends' homes, where the child spends time, may be necessary to see significant health benefits.[67] Finally, researchers are unable to assess sustained compliance to an intervention due to limited follow-up time windows ranging from a few weeks to a year.

Only a few intervention studies provide cost-benefit or cost-effectiveness analyses. When economic measures are provided, they suggest substantial returns on dollars invested in interventions to improve IAQ. A systematic review assessed the economic efficiency of home-based, multi-faceted interventions in reducing asthma morbidity.[68] Three studies reported cost-benefit ratios which found that for every dollar invested on interventions, benefits ranged in monetary value from $5.30–$14.00 (in 2007 US dollars). Another three studies reported cost-effectiveness ratios which found that an additional symptom–free day on average can be obtained for net savings ranging from $12–$57 (in 2007 US dollars).[68]

Not all interventions may be feasible to implement at a wider population level despite health benefits. The heater replacement study in New Zealand found capital costs of new heaters high for a population-based intervention despite benefits of reduced asthma symptoms and health care utilization.[53] The intervention was made possible by funding from public and private sectors.

Gaps in Research, Policy and Knowledge

- Many IAQ interventions target allergic and asthmatic populations, rather than a healthy general population. In addition to the potential for improved health and associated cost-savings in treatment, the limited sample size of many intervention studies requires selecting more responsive subjects, such as asthmatics, to achieve sufficient statistical power to detect a significant effect size. Some of the more intense intervention measures, such as multi-faceted interventions, may not be practical for the general population.

- More evidence is needed on the effectiveness of interventions in reducing health impacts for occupants in non-home settings, such as schools and public buildings.
- No studies to date have assessed ventilation and air filtration interventions for control of infectious biological agents in non-hospital settings such as homes, schools, and offices.
- Only a few studies include cost-benefit analyses or provide sufficient information to allow for an analysis of interventions; this limits translation of evidence into policy and program development.

Conclusion

Canadians spend a majority of their time indoors where air pollutants can build up and pose health risks to occupants. Effective interventions ranging from policies to simple or structural home-based remediation measures can be implemented to improve IAQ and health. Economic analyses from studies suggest substantial benefits and cost savings as a result of improved health, quality-of-life, and reduced health care utilization.

Acknowledgements

We would like to thank Luisa Giles, MSc, PhD, Helen Ward, MSc, PhD, and Michael Brauer, ScD, BA for their invaluable input and review of this document.

Table 1: Indoor Air Intervention Studies

Author	Study Design (number in intervention group/control)	Subjects	Intervention	Outcomes	
				Environmental Hazard/ Exposure	Health
House Dust Mite Control (HDM) Measures					
Wright et al. (2009)[69]	Randomized double-blind, placebo-controlled parallel group trial (54/47) Follow-up: 12 months	HDM sensitized asthmatic adults	Mechanical heat recovery ventilation system (MHRV); steam cleaning carpets; and bedding covers	(▼) Indoor RH (—) HDM, cat and dog dander allergens, endotoxin in dust	(—) Morning PEF (▲) Evening PEF
Dharmage et al. (2006)[37]	Randomized double-blind, placebo-controlled parallel group trial (32) Follow-up: 6 months	HDM sensitized asthmatic adults	Impermeable bed covers	(▼) HDM allergens in mattress dust	(—) Lung function (—) Bronchial reactivity (—) Asthma symptoms (—) Medication use (—) QOL
Nishioka et al. (2006)[70]	Randomized controlled (24/12) Follow-up: 12 months	Asthmatic children only sensitized to HDM	Intervention: monthly home visit counselling (>60 minutes) on: washing bedding encasement in room temperature more than once a week; cleaning the children's mattresses, quilts, as well as the bedroom and living room with a powerful (>900 watts) vacuum cleaner more than once a week; removal of stuffed dolls, soft toys, furred pets from home; and removal of carpets. Control: regular clinical guidance (10 min/patient)	(▼) HDM allergens in beds, and living room and bedroom floor	(—) Asthma attacks (—) Theophylline dosages
Integrated Pest Management (IPM)					
Pongracic et al. (2008)[40]	RCT (150/155) Follow-up: 2 years	Asthma children	(1) HEPA vacuum cleaner and HEPA air filter in child's bedroom, (2) fill rodent access points and traps throughout home, and (3) educate family about kitchen cleaning and proper food storage	(▼) Mouse allergen levels	(▼) Missed school days, child sleep disruption, and caretaker burden (—) Asthma symptoms and medical utilization

Author	Study Design (number in intervention group/control)	Subjects	Intervention	Outcomes	
				Environmental Hazard/ Exposure	Health
Levy et al. (2006)[41]	Longitudinal community-based participatory research study (50) Follow-up: 3-10 months	Asthmatic children	IPM, support from trained community health advocates; one-time intensive cleaning; in-home education about pest reduction; provision of new mattresses with microfiber technology; and asthma education	(▼) Roach allergen in house dust	(▼) Respiratory symptoms (frequency of wheeze/cough, slowing down or stopping play; and waking at night) (▲) Asthma-related QOL
Phipatanakul et al. (2004)[39]	RCT (12/6) Follow-up: 5-months	Asthmatic children with positive mouse allergen skin test	IPM: filling holes and cracks with copper mesh and caulk sealant; use of HEPA vacuum cleaner; cleaning surfaces with detergents; use of low-toxicity pesticides and traps; and educating on pest control measures	(▼) Mouse allergen levels	(—) Lung function (—) Asthma symptoms
Air Cleaners (home intervention studies published in or after 2010)					
Karottki et al. (2013)[71]	Randomized double-blind cross-over (48) Follow-up: 2 weeks	Non-smoking adults between ages of 51-81 years	HEPA filters in living room and bedroom of each home	(▼) $PM_{2.5}$ (46% ↓) (▼) Particle number concentrations (average diameter 0.01-0.3 μm) (30% ↓) (▼) BC (46% ↓) (▼) PAH (48% ↓)	(—) BP (—) Systematic inflammation biomarkers (—) MVF* (—) FEV_1, FVC **Improvements in MVF were seen in homes where $PM_{2.5}$ levels were actually reduced, and with participants with no pre-existing disease or are taking* vasoactive *drugs.*
Weichenthal et al. (2013)[21]	Randomized double-blind cross-over (37 residents in 20 homes)	First Nation Community participants. Mean age (range) = 32 (11 to 64)	Electrostatic air filters (1 week), washout period (1 week), placebo air filter (1 week)	(▼) PM_{10}, $PM_{2.5}$, and PM_1	(▲) FEV_1 (—) BP (—) RHI
Butz et al. (2011)[44]	RCT single-blind (41/41/44) Follow-up: 6 months	Asthmatic children residing with a smoker	Group 1 – Air cleaner only group: two HEPA air cleaners with activated carbon in child's bedroom and living room/television room. Four asthma education sessions.	(▼) $PM_{2.5}$ and PM_{10} in Group 1 and 2. (—) Air nicotine (—) Urine cotinine	(▲) Symptom free days in Group 1 and 2. (—) Slowed-activity days (—) Symptom free nights

Author	Study Design (number in intervention group/control)	Subjects	Intervention	Outcomes: Environmental Hazard/ Exposure	Outcomes: Health
			Group 2 – Air cleaner and behavioural intervention group: two HEPA air cleaners with activated carbon and four health coach (nurse) home visits Group 3: Control		
Lanphear (2011)[45]	RCT double-blind (105/111) Follow-up: 12 months	Asthmatic children residing with a smoker	Two HEPA air cleaners with activated carbon in child's bedroom and main activity room	(▼) Particle $\geq$ 0.3 μm levels (—) Particle > 0.5 μm levels (—) Air nicotine (—) Cotinine in hair and serum	(▼) Unscheduled asthma-related visits to health care provider (—) Asthma symptoms (—) Exhaled NO (—) Medication use
Allen et al. (2011)[46]	Randomized cross-over placebo trial (25 homes) Follow-up: 2 weeks	45 "healthy" adults in communities affected by wood smoke	HEPA air cleaners in participant's bedroom and main activity room	(▼) $PM_{2.5}$	(▲) RHI (▼) Inflammation biomarkers (C-reactive protein) (—) Oxidative stress biomarkers
Lin et al. (2011)[72]	Single-blinded panel study (60) Follow-up: 1.5 months	Healthy adults	3M filtrete filters in air conditioning system	(▼) $PM_{2.5}$ (—) Total VOCs	(▼) BP (▼) Heart rate
Johnson et al. (2009)[43]	Pre-post single-blind (186 homes) Follow-up: 6 months	219 asthmatic children	Asthma education; removal of visible mould; repair of water intrusion sources; and one or combination of the following interventions: HVAC servicing and installation of pleated Allergy Zone furnace filter; basement dehumidifiers; and room air cleaners.	(▼) Dust allergen load (with dehumidifiers only) (▼) Nonviable mould spore counts (all interventions)	(▼) Cough (with HVAC and dehumidifiers) (—) Wheeze and shortness of breath (▼) Breathing problems (with all interventions individually or combined) (▼) Allergy attacks (with all interventions individually or combined) (—) Asthma QOL

Author	Study Design (number in intervention group/control)	Subjects	Intervention	Outcomes	
				Environmental Hazard/ Exposure	Health
Sleep breathing zone (SBZ)					
Boyle et al. (2012)[47]	Randomised, double-blind, placebo-controlled, parallel-group (166/79) Follow-up: 12 months	Asthmatic adults and children with persistent atopic asthma	Delivery of HEPA filtered, temperature controlled laminar air flow in SBZ	(▼) Median count of particle $\geq$ 0.5 µm in breathing zone (limited measurements) (—) Dust mite and cat allergen in mattress	(▲) Asthma QOL score (▼) Exhaled NO (—) Systemic allergy (blood eosinophil counts and IgE levels) (—) Asthma medication (—) Asthma exacerbation (—)FEV, PEF
Stillerman et al. (2010)[48]	Randomized cross-over trial (35) Follow-up: 12 weeks	Adults with perennial allergic rhinocon-junctivitis (sensitized to dust mite, dog, or cat allergens)	HEPA-filtered air supplied to special pillow system	(▼) Particles $\geq$ 0.3 µm in breathing zone (limited measurements)	(▼) Nasal and ocular allergy total symptom score (▲) QOL
Non-residential Settings (Offices and Classrooms)					
Wargocki et al. (2008)[52]	Single-blind cross-over (90 children from 5 public schools) trial Follow-up: 1-4 weeks	Children in elementary schools	Electrostatic filters in classrooms (laboratory tests showed no ozone production)	(▼) Particle counts of sizes ranging: >0.75, >1, >2, >3.5, >5, >7.5, >10, and >15 µm (▼) Settled dust (% covering a glass plate) (—) Temp (—) RH (—) CO_2 (▲) Perceived air quality rating by a sensory panel (acceptability, odor intensity; freshness; and dryness of classroom air)	(—) Schoolwork performance (—) Reported symptoms intensity (nose congestion, nose throat, lips and skin dryness, hunger, fatigue, and headache)

Author	Study Design (number in intervention group/control)	Subjects	Intervention	Outcomes	
				Environmental Hazard/ Exposure	Health
Skulberg et al. (2005)[51]	Randomized (group level matching by gender, symptom level and allergy status), double-blind (41/39) Follow-up: 3 weeks	Adults with airway symptoms from six companies	Electrostatic air cleaners in office (contain carbon filter for removing ozone)	(▼) Total airborne dust (▬) Particles <5 μm, 5–10 μm, >10 μm	(▬) Reported symptoms (relating to skin, mucosal membrane, and general (fatigue, heavy headed, headache, nausea or concentration problems) (▲) Nasal dimensions (▲) PEF
Mendell et al. (2002)[50]	Randomized, double-blind, cross-over (135/261) Follow-up: 4 weeks repeated measures	Office workers	Installation of highly efficient particle filters in the ventilation systems in two office floors within a large office building (1900 m^2)	(▼) Particles 0.3-0.5 μm (94% reduction) (▼) Particles 0.5-2 μm (>50% reduction)	(▬) Symptoms associated with sick building syndrome (▼) Negative mental state (confusion*, fatigue, less productive) (▼) Environmental dissatisfaction (stuffy*, dusty, dry) **Changes associated with filtration. Other changes were after adjusting for temperature*
Heating Units					
Howden-Chapman et al. (2008)[53]	RCT (175/174) Follow-up: 1-year	Asthmatic children	Efficient heating units (heat pump, wood pellet burner, or flued gas) replacement in homes	(▼) NO_2 (▲) Temp	(▼) Asthma symptoms, and days off school school, visits to doctor and pharmacist for asthma (▬) PEF (▬) FEV_1
Pilotto et al. (2004)[54]	Cluster RCT blinded (8/10 schools; 45/68 children). Follow-up: 12-week	Asthmatic children	Unflued gas heaters in schools replaced with flued gas or electric heaters	(▼) NO_2	(▼) Reported asthma symptoms (▬) FEV_1 (▬) Bronchial hyperresponsive-ness

Author	Study Design (number in intervention group/control)	Subjects	Intervention	Outcomes	
				Environmental Hazard/ Exposure	Health
Multi-faceted Interventions					
Bryant-Stephens et al. (2009)[59]	Randomized cross-over (144/120) Follow-up: 6-months	Asthmatic children	Five visits by community health workers (lay health educators) providing education and assisting families on avoidance measures for dust, pests, pets, and smoke; bedding covers; roach bait; mice traps; cleaning aids; shades to replace curtains; tiles to replace carpet; and storage bins	(▼) Pest presence (rodents) (▼) Dust mite allergens	(▼) Night time wheezing (—) Albuterol use (▼) Healthcare utilization
Parker et al. (2008)[56]	RCT (116/111) Follow-up: 3 months-1 year	Asthmatic children	Community environmental specialists (mean=9 home visits, range= 1-17); HEPA vacuum cleaner; allergen-impermeable bedding covers; household cleaning supplies; education on dangers of ETS and strategies for exposure reduction; and integrated pest management.	(▼) Dog allergen in child bedroom's dust (—) Cockroach, dust mite and cat in child bedroom's dust (—) Self-reported smoking in home	(▲) FEV1 (▲) PEF (▼) Symptoms (cough and cough with exercise) (▼) Unscheduled healthcare utilization (▼) Inadequate medication use (▼) Caregiver depressive symptoms (▲) Self-reported trigger-reducing behaviour (vacuuming, cleaning, washing sheets, use of allergen covers)
Williams et al. (2006)[73]	RCT (84/77) Follow-up: 12 months	Asthmatic urban children	Health education on ETS, food handling practices; proper washing and drying of fabrics, bedding covers, carpets, curtains; allergen impermeable bedding covers; professional house cleaning, and placement of roach bait.	(▼) Dust mite allergens from bed surface dust (at 8 and 12 months) (▼) Roach allergens from kitchen floor dust (at 4 and 8 months only)	(▲) Functional severity (wheeze frequency, night time awakening symptoms, severe asthma attack, and limited home and sports activities) (—) Healthcare utilization (—) Medication use

Author	Study Design (number in intervention group/control)	Subjects	Intervention	Outcomes	
				Environmental Hazard/ Exposure	Health
Krieger et al. (2005)[58]	RCT (138/136) Follow-up: 1 year	Asthmatic children	Low intensity: single visit by community health workers for initial assessment, home action plan, limited education, and bedding encasements. High intensity: 7 visits by community health workers providing individualized action plans, education and social support, materials to reduce exposures (i.e., bedding encasements), roach and rodent eradication, and advocacy for improved housing conditions	(▼) Floor dust loading	(▲) Asthma caregiver QOL (▼) Healthcare utilization
Eggleston et al. (2005)[67]	RCT (50/50) Follow-up: 1 year	Asthmatic urban children	Home-based education, integrated pest management for cockroach and rodent extermination, bedding covers, and HEPA air cleaner	(▼) PM_{10} and $PM_{2.5}$ (▼) Cockroach allergen in floor dust (p-value = 0.08)	(▼) Daytime asthma symptoms (—) Night-time symptoms (—) QOL (—) FEV_1 (—) Healthcare utilization
Klinnert (2005)[74]	RCT (90/91) Follow-up: 1 year	Wheezing infants aged 9 to 24 months at risk of childhood asthma	Home visits (median=15 visits, lasting on average 53 minutes) by nurses over 12 month period focused on 1) Allergen and SHS reduction (SHS avoidance, smoking cessation counseling, cleaning materials and traps in homes with high roach allergens levels, and vacuum cleaners if homes did not own one); 2) health promotion and parent-child Interaction; and 3) caregiver mental health	(▼) Cockroach allergens in house dust (—) Dog and cat dander (▼) Urine cotinine	(—) Reported symptoms (—) Healthcare utilization (emergency department visits) (▲) Caregiver QOL (foreign-born) (▲) Corticosteroid use
Morgan et al. (2004)[60]	RCT (469/468) Follow-up: 2 years	Asthmatic urban children	Tailored interventions to child's sensitization: education, allergen-impermeable bedding cover, vacuum cleaner with HEPA air filters, HEPA air purifier, and professional pest control for children sensitive to cockroach allergen.	(▼) Cockroach allergen on floor (▼) Dust mite in bed and floor	(▼) Asthma symptom days (▼) Disruption of caretakers' plans, caretakers' and children's lost sleep, and missed school days (▼) Unscheduled visits to emergency department and clinic (—) FEV_1, FVC, PEF

Author	Study Design (number in intervention group/control)	Subjects	Intervention	Outcomes	
				Environmental Hazard/ Exposure	Health
Chan-Yeung et al. (2002)[30]; Chan-Yeung et al. (2005)[31]	RCT (266/279) Follow-up: 7 years plus	High-risk infants (family history of asthma and allergies)	Vapour-impermeable bedding covers; weekly hot water wash of all bedding; application of acaricides to carpets and upholstered furniture; pet and SHS avoidance measures; and encouragement of breast-feeding	(▼) HDM allergens in mattress dust (measures at 12 and 24 months) (**—**) HDM allergens in carpets and upholstered furniture where acaricides was applied (measures at 12 and 24 months)	(▼) Pediatric allergist–diagnosed asthma prevalence and symptoms (**—**) Allergic rhinitis, atopic dermatitis, atopy, bronchial hyperresponsiveness
Carter et al. (2001)[75]	RCT single-blinded, 3 arms (35/35/34) Follow-up: 12 months	Asthmatic urban children	Active group: allergen-impermeable bedding covers; cockroach bait; and instructions about cleaning, i.e. weekly washing of bedding covers with hot water; 4 home visits Placebo: allergen-permeable bedding covers; ineffective roach traps; and instructions to continue normal practice of washing the bedding in cool or cold water; 4 home visits Control: continued routine medical care provided at the clinic; no discussion on allergen-control measures in the home; no home visits until end of study	(▼) Mite and cockroach allergen levels (32-41% of homes in active and placebo groups had >70% reduction in cockroach and dust mite allergens in house dust compared to baseline); no difference between active and placebo groups.	(▼) Unscheduled healthcare utilization (compared to control; no difference between active and placebo groups)

*Symbols: (▼) Significant decrease from baseline or compared to control group; (▲) significant increase from baseline or compared to control group; (**—**) no significant change or improvement from baseline or compared to control group.*

BHR = Bronchial hyperresponsiveness; BP= Blood pressure; EBC = Exhaled breath condensate (measure of pulmonary inflammation), Exhaled NO = Exhaled nitric oxide (inflammation indicator); *FEV_1= forced expiratory volume in 1 second; MVF = Microvascular function; PEF = Peak expiratory flow; QOL = Quality of Life; symptoms grouped under sick building syndrome include: eye, nose, and throat irritation, headache and fatigue, dry or irritated skin, and breathing problems; RCT=Randomized Clinical Trial RH = Relative humidity, RHI = Reactive hyperemia index (measure of microvascular endothelial function for cardiovascular effect); VOCs = Volatile organic compounds.*

References

1. Matz CJ, Stieb DM, Davis K, Egyed M, Rose A, Chou B, et al. Effects of age, season, gender and urban-rural status on time-activity: CanadianHuman Activity Pattern Survey 2 (CHAPS 2). Int J Environ Res Public Health. 2014 Feb;11(2):2108-24.

2. Franklin PJ. Indoor air quality and respiratory health of children. Paediatr Respir Rev. 2007 Dec;8(4):281-6.

3. Montgomery DD, Kalman DA. Indoor/Outdoor air quality: reference pollutant concentrations in complaint-free residences. Appl Ind Hyg. 1989 1989/01/01;4(1):17-20.

4. Wallace LA, Mitchell H, O'Connor GT, Neas L, Lippmann M, Kattan M, et al. Particle concentrations in inner-city homes of children with asthma: the effect of smoking, cooking, and outdoor pollution. Environ Health Perspect. 2003 Jul;111(9):1265-72.

5. Institute of Medicine, Effect of Climate Change on Indoor Air Quality and Public Health. Climate change, the indoor environment, and health. Washington, DC: National Academies Press; 2011. Available from: http://www.nap.edu/catalog/13115/climate-change-the-indoor-environment-and-health.

6. U.S. Environmental Protection Agency. Indoor air pollution: an introduction for health professionals. Washington, DC: EPA, Consumer Product Safety Commission and the American Lung Association. Available from: http://www.epa.gov/iaq/pubs/hpguide.html.

7. Health Canada. Residential indoor air quality guidelines - Moulds. Ottawa, ON: Health Canada, Environmental and Workplace Health; 2007 Available from: http://www.hc-sc.gc.ca/ewh-semt/pubs/air/mould-moisissure-eng.php.

8. Conference Board of Canada. Lung disease imposes major costs on Canada's economy. Ottawa, ON: Conference Board of Canada; 2012. Available from: http://www.conferenceboard.ca/e-library/abstract.aspx?did=4585.

9. Fisk WJ, Rosenfeld AH. Estimates of improved productivity and health from better indoor environments. Indoor Air. 1997;7(3):158-72.

10. Krieger J, Jacobs DE, Ashley PJ, Baeder A, Chew GL, Dearborn D, et al. Housing interventions and control of asthma-related indoor biologic agents: a review of the evidence. J Public Health Manag Pract. 2010;16(5 Suppl):S11-S20.

11. Institute of Medicine, Committee on Damp Indoor Spaces and Health. Damp indoor spaces and health. Washington, DC: National Academies Press; 2004. Available from: http://www.nap.edu/openbook.php?isbn=0309091934.

12. Li Y, Leung GM, Tang JW, Yang X, Chao CY, Lin JZ, et al. Role of ventilation in airborne transmission of infectious agents in the built environment - a multidisciplinary systematic review. Indoor Air. 2007 Feb;17(1):2-18.

13. Barn P. Residential air cleaner use to improve indoor air quality and health: a review of the evidence. Vancouver, BC: National Collaborating Centre for Environmental Health; 2010 Oct. Available from: http://www.ncceh.ca/documents/evidence-review/residential-air-cleaner-use-improve-indoor-air-quality-and-health-review.

14. van Balen E, Shum M, Ward H. Reducing residential indoor exposure to pesticides: A toolkit for practitioners. Vancouver, BC: National Collaborating Centre for Environmental Health; 2011 Oct. Available from: http://www.ncceh.ca/documents/guide/reducing-residential-indoor-exposure-pesticides-toolkit-practitioners.

15. Palaty C, Shum M. Mould assessment recommendations. Vancouver, BC: National Collaborating Centre for Environmental Health; 2014 Mar. Available from: http://www.ncceh.ca/documents/guide/mould-assessment-recommendations-revised.

16. National Collaborating Centre for Environmental Health. Effective interventions to reduce indoor radon levels. Vancouver, BC2008 Dec. Available from: http://www.ncceh.ca/sites/default/files/Radon_Interventions_Dec_2008.pdf.

17. Health Canada. Radon. Ottawa ON: Health Canada, Environmental & Workplace Health; [cited 2015 Feb 27]; Available from: http://www.hc-sc.gc.ca/ewh-semt/radiation/radon/index-eng.php.

18. Centers for Disease Control and Protection. Community-level interventions eligibility criteria. Atlanta, GA: U.S. Department of Health and Human Services; 2013.

19. Health Canada. Canadian Tobacco Use Monitoring Survey, Household component, February - December 2012. Table 9. Exposure of children at home to Environmental Tobacco Smoke (ETS), by province and age group, Canada 2012. Ottawa, ON: Health Canada; 2012. Available from: http://www.hc-sc.gc.ca/hc-ps/tobac-tabac/research-recherche/stat/_ctums-esutc_2012/ann-eng.php#t9.

20. First Nations Information Governance Centre. Regional Health Survey Phase 2 (2008/10) National results. [cited 2015 Mar 1]; Available from: http://fnigc.ca/our-work/regional-health-survey/rhs-phase-2-national-results.html.

21. Weichenthal S, Mallach G, Kulka R, Black A, Wheeler A, You H, et al. A randomized double-blind crossover study of indoor air filtration and acute changes in cardiorespiratory health in a First Nations community. Indoor Air. 2013 Jun;23(3):175-84.

22. Menzies D, Nair A, Williamson PA, Schembri S, Al-Khairalla MZ, Barnes M, et al. Respiratory symptoms, pulmonary function, and markers of inflammation among bar workers before and after a legislative ban on smoking in public places. JAMA. 2006 Oct 11;296(14):1742-8.

23. Fernandez E, Fu M, Pascual JA, Lopez MJ, Perez-Rios M, Schiaffino A, et al. Impact of the Spanish smoking law on exposure to second-hand smoke and respiratory health in hospitality workers: a cohort study. PLoS ONE. 2009;4(1):e4244.

24. Goodman P, Agnew M, McCaffrey M, Paul G, Clancy L. Effects of the Irish smoking ban on respiratory health of bar workers and air quality in Dublin pubs. Am J Respir Crit Care Med. 2007 Apr 15;175(8):840-5.

25. Lin H, Wang H, Wu W, Lang L, Wang Q, Tian L. The effects of smoke-free legislation on acute myocardial infarction: a systematic review and meta-analysis. BMC Public Health. 2013;13:529.

26. Tan CE, Glantz SA. Association between smoke-free legislation and hospitalizations for cardiac, cerebrovascular, and respiratory diseases: a meta-analysis. Circulation. 2012 October 30, 2012;126(18):2177-83.

27. International Agency for Research on Cancer. IARC Handbooks of Cancer Prevention, Tobacco Control, Volume 13: Evaluating the effectiveness of smoke-free policies. Lyon, France: International Agency for Research on Cancer; 2009. Available from: http://www.iarc.fr/en/publications/pdfs-online/prev/handbook13/handbook13-0.pdf.

28. Mackay D, Haw S, Ayres JG, Fischbacher C, Pell JP. Smoke-free legislation and hospitalizations for childhood asthma. N Engl J Med. 2010 Sep 16;363(12):1139-45.

29. Crocker DD, Kinyota S, Dumitru GG, Ligon CB, Herman EJ, Ferdinands JM, et al. Effectiveness of home-based, multi-trigger, multicomponent interventions with an environmental focus for reducing asthma morbidity: a community guide systematic review. Am J Prev Med. 2011 Aug;41(2 Suppl 1):S5-32.

30. Chan-Yeung M, Ferguson A, Dimich-Ward H, Watson W, Manfreda J, Becker A. Effectiveness of and compliance to intervention measures in reducing house dust and cat allergen levels. Ann Allergy Asthma Immunol. 2002;88(1):52-8.

31. Chan-Yeung M, Ferguson A, Watson W, Dimich-Ward H, Rousseau R, Lilley M, et al. The Canadian Childhood Asthma Primary Prevention Study: outcomes at 7 years of age. J Allergy Clin Immunol. 2005 Jul;116(1):49-55.

32. Custovic A, Simpson BM, Simpson A, Hallam C, Craven M, Brutsche M, et al. Manchester Asthma and Allergy Study: low-allergen environment can be achieved and maintained during pregnancy and in early life. J Allergy Clin Immunol. 2000 Feb;105(2 Pt 1):252-8.

33. Custovic A, Simpson BM, Simpson A, Kissen P, Woodcock A, Asthma NACM, et al. Effect of environmental manipulation in pregnancy and early life on respiratory symptoms and atopy during first year of life: a randomised trial. Lancet. 2001 Jul 21;358(9277):188-93.

34. Htut T, Higenbottam TW, Gill GW, Darwin R, Anderson PB, Syed N. Eradication of house dust mite from homes of atopic asthmatic subjects: a double-blind trial. J Allergy Clin Immunol. 2001 Jan;107(1):55-60.

35. Recer GM. A review of the effects of impermeable bedding encasements on dust-mite allergen exposure and bronchial hyper-responsiveness in dust-mite-sensitized patients. Clin Exp Allergy. 2004 Feb;34(2):268-75.

36. Nurmatov U, van Schayck CP, Hurwitz B, Sheikh A. House dust mite avoidance measures for perennial allergic rhinitis: an updated Cochrane systematic review. Allergy. 2012 Feb;67(2):158-65.

37. Dharmage S, Walters EH, Thien F, Bailey M, Raven J, Wharton C, et al. Encasement of bedding does not improve asthma in atopic adult asthmatics. Int Arch Allergy Immunol. 2006;139(2):132-8.

38. El-Ghitany EM, Abd El-Salam MM. Environmental intervention for house dust mite control in childhood bronchial asthma. Environ Health Prev Med. 2012;17(5):377-84.

39. Phipatanakul W, Cronin B, Wood RA, Eggleston PA, Shih MC, Song L, et al. Effect of environmental intervention on mouse allergen levels in homes of inner-city Boston children with asthma. Ann Allergy Asthma Immunol. 2004 APR;92(4):420-5.

40. Pongracic JA, Visness CM, Gruchalla RS, Evans R, 3rd, Mitchell HE. Effect of mouse allergen and rodent environmental intervention on asthma in inner-city children. Ann Allergy Asthma Immunol. 2008 Jul;101(1):35-41.

41. Levy JI, Brugge D, Peters JL, Clougherty JE, Saddler SS. A community-based participatory research study of multifaceted in-home environmental interventions for pediatric asthmatics in public housing. Soc Sci Med. 2006 Oct;63(8):2191-203.

42. Health Canada. Guidance for fine particulate matter (PM2.5) in residential indoor air Ottawa, ON: Healthy Environments and Consumer Safety Branch, Safe Environments Programme, Water, Air and Climate Change Bureau, Air Health Effects Division; 2012. Available from: http://www.hc-sc.gc.ca/ewh-semt/pubs/air/particul-eng.php.

43. Johnson L, Ciaccio C, Barnes CS, Kennedy K, Forrest E, Gard LC, et al. Low-cost interventions improve indoor air quality and children's health. Allergy Asthma Proc. 2009 Jul-Aug;30(4):377-85.

44. Butz AM, Matsui EC, Breysse P, et al. A randomized trial of air cleaners and a health coach to improve indoor air quality for inner-city children with asthma and secondhand smoke exposure. Arch Pediatr Adolesc Med. 2011;165(8):741-8.

45. Lanphear BP, Hornung RW, Khoury J, Yolton K, Lierl M, Kalkbrenner A. Effects of HEPA air cleaners on unscheduled asthma visits and asthma symptoms for children exposed to secondhand tobacco smoke. Pediatrics. 2011 Jan;127(1):93-101.

46. Allen RW, Carlsten C, Karlen B, Leckie S, Eeden Sv, Vedal S, et al. An air filter intervention study of endothelial function among healthy adults in a woodsmoke-impacted community. Am J Respir Crit Care Med. 2011 May 1, 2011;183(9):1222-30.

47. Boyle RJ, Pedroletti C, Wickman M, Bjermer L, Valovirta E, Dahl R, et al. Nocturnal temperature controlled laminar airflow for treating atopic asthma: a randomised controlled trial. Thorax. 2012 Mar;67(3):215-21.

48. Stillerman A, Nachtsheim C, Li W, Albrecht M, Waldman J. Efficacy of a novel air filtration pillow for avoidance of perennial allergens in symptomatic adults. Ann Allergy Asthma Immunol. 2010 May;104(5):440-9.

49. Fisk WJ. Health benefits of particle filtration. Indoor Air. 2013 Oct;23(5):357-68.

50. Mendell MJ, Fisk WJ, Petersen MR, Hines CJ, Dong M, Faulkner D, et al. Indoor particles and symptoms among office workers: results from a double-blind cross-over study. Epidemiology. 2002 May;13(3):296-304.

51. Skulberg KR, Skyberg K, Kruse K, Eduard W, Levy F, Kongerud J, et al. The effects of intervention with local electrostatic air cleaners on airborne dust and the health of office employees. Indoor Air. 2005 Jun;15(3):152-9.

52. Wargocki P, Wyon DP, Lynge-Jensen K, Bornehag CG. The effects of electrostatic particle filtration and supply-air filter condition in classrooms on the performance of schoolwork by children (RP-1257). HVAC & R Res. 2008;14(3):327-44.

53. Howden-Chapman P, Pierse N, Nicholls S, Gillespie-Bennett J, Viggers H, Cunningham M, et al. Effects of improved home heating on asthma in community dwelling children: randomised controlled trial. BMJ. 2008;337:a1411.

54. Pilotto LS, Nitschke M, Smith BJ, Pisaniello D, Ruffin RE, McElroy HJ, et al. Randomized controlled trial of unflued gas heater replacement on respiratory health of asthmatic schoolchildren. Int J Epidemiol. 2004 Feb;33(1):208-14.

55. Lin LY, Lin CY, Lin YC, Chuang KJ. The effects of indoor particles on blood pressure and heart rate among young adults in Taipei, Taiwan. Indoor Air. 2009;19(6):482-8.

56. Parker EA, Israel BA, Robins TG, Mentz G, Xihong L, Brakefield-Caldwell W, et al. Evaluation of Community Action Against Asthma: a community health worker intervention to improve children's asthma-related health by reducing household environmental triggers for asthma. Health Educ Behav. 2008 Jun;35(3):376-95.

57. Postma J, Karr C, Kieckhefer G. Community health workers and environmental interventions for children with asthma: A systematic review. J Asthma. 2009 Aug;46(6):564-76.

58. Krieger JW, Takaro TK, Song L, Weaver M. The Seattle-King County Healthy Homes Project: a randomized, controlled trial of a community health worker intervention to decrease exposure to indoor asthma triggers. Am J Public Health. 2005 Apr;95(4):652-9.

59. Bryant-Stephens T, Kurian C, Guo R, Zhao H. Impact of a household environmental intervention delivered by lay health workers on asthma symptom control in urban, disadvantaged children with asthma. Am J Public Health. 2009 Nov;99 Suppl 3:S657-65.

60. Morgan WJ, Crain EF, Gruchalla RS, O'Connor GT, Kattan M, Evans R, 3rd, et al. Results of a home-based environmental intervention among urban children with asthma. N Engl J Med. 2004 Sep 9;351(11):1068-80.

61. Krieger J, Takaro TK, Song L, Beaudet N, Edwards K. A randomized controlled trial of asthma self-management support comparing clinic-based nurses and in-home community health workers: the Seattle-King County Healthy Homes II Project. Arch Pediatr Adolesc Med. 2009 Feb;163(2):141-9.

62. Krieger JK, Takaro TK, Allen C, Song L, Weaver M, Chai S, et al. The Seattle-King County Healthy Homes Project: implementation of a comprehensive approach to improving indoor environmental quality for low-income children with asthma. Environ Health Perspect. 2002 Apr;110 Suppl 2:311-22.

63. Woodcock A, Forster L, Matthews E, Martin J, Letley L, Vickers M, et al. Control of exposure to mite allergen and allergen-impermeable bed covers for adults with asthma. N Engl J Med. 2003 Jul 17;349(3):225-36.

64. Eggleston PA. Methods and effectiveness of indoor environmental control. Ann Allergy Asthma Immunol. 2001 Dec;87(6 Suppl 3):44-7.

65. Gøtzsche PC, Johansen HK. House dust mite control measures for asthma: systematic review. Allergy. 2008;63(6):646-59.

66. Wood RA. Air filtration devices in the control of indoor allergens. Curr Allergy Asthma Rep. 2002 Sep;2(5):397-400.

67. Eggleston PA, Butz A, Rand C, Curtin-Brosnan J, Kanchanaraksa S, Swartz L, et al. Home environmental intervention in inner-city asthma: a

randomized controlled clinical trial. Ann Allergy Asthma Immunol. 2005;95(6):518-24.

68. Nurmagambetov TA, Barnett SB, Jacob V, Chattopadhyay SK, Hopkins DP, Crocker DD, et al. Economic value of home-based, multi-trigger, multicomponent interventions with an environmental focus for reducing asthma morbidity a community guide systematic review. Am J Prev Med. 2011 Aug;41(2 Suppl 1):S33-47.

69. Wright GR, Howieson S, McSharry C, McMahon AD, Chaudhuri R, Thompson J, et al. Effect of improved home ventilation on asthma control and house dust mite allergen levels. Allergy. 2009 Nov;64(11):1671-80.

70. Nishioka K, Saito A, Akiyama K, Yasueda H. Effect of home environment control on children with atopic or non-atopic asthma. Allergol Int. 2006 Jun;55(2):141-8.

71. Karottki DG, Spilak M, Frederiksen M, Gunnarsen L, Brauner EV, Kolarik B, et al. An indoor air filtration study in homes of elderly: cardiovascular and respiratory effects of exposure to particulate matter. Environ Health. 2013;12:116.

72. Lin L-Y, Chen H-W, Su T-L, Hong G-B, Huang L-C, Chuang K-J. The effects of indoor particle exposure on blood pressure and heart rate among young adults: An air filtration-based intervention study. Atmos Environ. 2011 10//;45(31):5540-4.

73. Williams SG, Brown CM, Falter KH, Alverson CJ, Gotway-Crawford C, Homa D, et al. Does a multifaceted environmental intervention alter the impact of asthma on inner-city children? J Natl Med Assoc. 2006 Feb;98(2):249-60.

74. Klinnert MD, Liu AH, Pearson MR, Tong S, Strand M, Luckow A, et al. Outcome of a randomized multifaceted intervention with low-income families of wheezing infants. Arch Pediatr Adolesc Med. 2007 Aug;161(8):783-90.

75. Carter MC, Perzanowski MS, Raymond A, Platts-Mills TA. Home intervention in the treatment of asthma among inner-city children. J Allergy Clin Immunol. 2001 Nov;108(5):732-7.

Appendix 1

Table A1: Commonly Found Indoor Air Pollutants, Sources, and Health Effects

Air pollutant/Hazard (Location most prevalent)	Location/ Sources/Conditions	Health effect
I. Biological Agents		
Mould (Residence/Public buildings)	Moisture/damp environment, high relative humidity Moulds can be concealed behind walls	Asthma exacerbation; respiratory ailments: cough, wheeze, shortness of breath, bronchitis, sore throat, conjunctivitis, allergic rhinitis, nasal congestion; and eczema
House dust mite (Residence)	High humid environments	Asthma exacerbation; allergic rhinitis; and eczema
Pet dander/allergens (Residence/Public buildings)	Indoor cats and dogs	Asthma exacerbation; upper and lower respiratory tract symptoms (congestion, sneezing, runny nose, chest tightness and wheezing); itching; watery eyes; and eczema
Pest allergens (cockroach, rats) (Residence/Public buildings)	Improper food storage or cleaning; cracks in walls, and humid environments	Asthma exacerbation and development; allergies; wheezing and coughing, eczema, and allergies
II. Chemical Agents		
Asbestos (Residence/Public buildings)	Building materials (attic and wall insulation; vinyl floor tiles and the backing on vinyl sheet flooring and adhesives; roofing and siding shingles, textured paint and patching compounds on wall and ceilings; walls and floors around wood-burning stoves); hot water and steam pipes, and oil and coal furnaces and door gaskets. No significant health risks if asbestos fibres are enclosed or tightly bound in a product. Exposure generally occurs from disturbance of asbestos-containing material during product use, demolition work, building or home maintenance, repair, and remodeling.	Lung cancer, mesothelioma, asbestosis
Lead (Residence/Public buildings - particularly a concern for houses built before 1960. One out of 4 Canadian dwellings built prior to 1960)	Lead-based paints; toys and consumer products (jewellery, solder); contaminated soil and dust tracked indoor Outdoor ambient air (leaded gasoline prior to 1990)	Neurodevelopmental, behavioural, neurodegenerative, cardiovascular, renal, and reproductive effects
Pesticides (Residence/Public buildings)	Household products	Neurodevelopmental; behavioural; neurodegenerative
Secondhand smoke (SHS) (Residence/Public buildings)	Smoking	Lung cancer; lower respiratory tract infections; asthma; acute coronary events (e.g. heart attack); eye and nasal irritation; ear infection; low birth weight; and greater risk for sudden infant death syndrome.

Air pollutant/Hazard (Location most prevalent)	**Location/ Sources/Conditions**	**Health effect**
Particulate Matter (PM) less than 10 µm or 2.5 µm in aerodynamic diameter (PM_{10}, $PM_{2.5}$) and black carbon (Residence/Public buildings)	Indoor sources: smoking; fuel-burning appliances, incense burning Outdoor sources: Traffic; forest fires	Respiratory illnesses (aggravated asthma; decreased lung function; irritation and inflammation of airways) and deaths; lung cancer. Cardiovascular illnesses and death (myocardial infarction, ischemic heart disease, stroke, heart failure, arrhythmias).
Nitrogen dioxide (Residence)	Indoor sources: Gas stoves; furnaces; fireplaces; and space heaters Outdoor sources: vehicles	Impairs lung function; airway inflammation; increase respiratory infection; eye, nose, and throat irritation; and respiratory symptoms in asthmatic population; increased emergency and hospital visits.
Carbon monoxide (Residence)	Indoor sources: smoking; fuel-burning appliances; and incense burning Outdoor sources: vehicles in attached garage, and from busy road	Low levels: headaches; tiredness; shortness of breath; and impaired motor functions. High levels or low levels for long periods of time: dizziness; chest pain; tiredness; disorientation; poor vision; and difficulty thinking. Acute exposures at very high levels: convulsions; coma; and death.
Ozone (Residence/Public buildings)	Indoor sources: ozone generators used as air cleaners. Outdoor sources: vehicles	Coughing; chest discomfort; reduced lung function; shortness of breath; irritation of the eyes, nose and throat; asthma; and chronic obstructive pulmonary disease.
Volatile organic compounds (Residence/Public buildings especially new buildings/furnishings)	Paint; varnish; wax; cleaning, disinfecting, cosmetic, and degreasing products; products containing particle board and plywood; air fresheners; and hobby products	Threat of sensitization; cancer; eye, nose and throat irritation; headaches; nausea; damage to the liver, kidneys, and central nervous system.
Formaldehyde (Residence/Public buildings)	Off-gassing: building materials and furnishings, in particular those made from pressed-wood products with formaldehyde-based adhesives; carpets; varnishes; paints; drapes; and curtains. By-product of combustion, such as smoking; vehicle exhaust; wood-burning fireplaces and stoves; and improperly vented gas or oil burning appliances.	Short-term effects: eye, nose and throat irritant; and burning sensation. Long-term effects: breathing problems especially for children with asthma. Known carcinogen. High levels found in occupational settings have been associated with cancer. Levels found in residential homes are not as high, and are not a concern.

Appendix 2: Search Terms and Databases

Search engines used were Pubmed and Google Scholar as well as references in identified articles. Only English language literature was reviewed. Articles were restricted to interventions in residences and public buildings, including schools, daycares, and offices.

Search terms were divided into three concept categories. First category includes terms, such as "health effect," "clinical effect," and "intervention." Second category includes terms such as "indoor air pollut*," and specific pollutants, such as "mould," "particulates." The "intervention" concept was also paired with "effective*," "efficacy," "cost," "feasibility," and "adoption." The third category of concept relates to location/settings, population, and intervention type, such as "public building," "home," "school," "asthma*," "elderly," and "policy." The details of the search terms are provided in *Table A2.*

Table A2: Search Terms

Concept 1	**Concept 2**	**Concept 3**
Source	Indoor air pollut*	Public building
Health/clinical effect	Pollutant* *Substitute with mould, bacteria, allergens, particulates/PM, black carbon, radon, carbon monoxide, ozone, volatile organic compounds, i.e., formaldehyde	Office
	Mould or dampness, damp, “water damage,” moisture, humidity, fungi, fungus, mold, mould, bacteria, or microorganisms	
Intervention	Indoor air	School
	Indoor air quality	Day care
	Effective*	House/home/ residence
	Efficacy	Dwelling
	Cost	Apartment
	Feasibility	Building (public)
	Adoption	
		Sensitive/vulnerable population (children, elderly, pregnant women, pre-existing disease/illness)
		Asthma*
		Policy
		Behaviour
		Engineering control
		Source control

Appendix 3: Additional Resources

1. **Canadian government guidelines and recommendations**
   - Exposure Guidelines for Residential Indoor Air Quality: http://www.hc-sc.gc.ca/ewh-semt/air/in/res-in/index-eng.php
   - Mould:
   - Addressing Moisture and Mould in Your Homes: http://www.hc-sc.gc.ca/ewh-semt/pubs/air/mould-home-moisissure-maison-eng.php
   - Fungal Contamination in Public Buildings: Health Effects and Investigation Methods: http://www.hc-sc.gc.ca/ewh-semt/pubs/air/fungal-fongique/index-eng.php (Archived on June 24, 2013)
   - Naphthalene in Indoor Air: http://www.hc-sc.gc.ca/ewh-semt/pubs/air/naphthalene_fs-fi/index-eng.php
   - Benzene in Indoor Air: http://www.hc-sc.gc.ca/ewh-semt/pubs/air/benzene_fs-fi/index-eng.php
   - Indoor Air Quality - Tools for Schools Action Kit for Canadian Schools: http://www.hc-sc.gc.ca/ewh-semt/pubs/air/tools_school-outils_ecoles/index-eng.php (Archived on June 24, 2013)

2. **National Collaborating Center for Environmental Health (NCCEH) Reports:**
   - Mould Remediation Recommendations (Revised March 2014): http://ncceh.ca/sites/default/files/Mould_Remediation_Evidence_Review_March_2014.pdf
   - Reducing Residential Indoor Exposure to Pesticides: a Toolkit for Practitioners (October 2011): http://ncceh.ca/sites/default/files/Residential_Exposure_to_Pesticides_Toolkit_Oct_2011.pdf
   - Residential Air Cleaner Use to Improve Indoor Air Quality and Health: A Review of the Evidence (October 2010): http://www.ncceh.ca/sites/default/files/Air_Cleaners_Oct_2010.pdf

3. **US Environmental Protection Agency (US EPA) Reports**
   - Care for Your Air: A Guide to Indoor Air Quality. Understand Indoor Air in Homes, Schools and Offices: http://www.epa.gov/iaq/pubs/careforyourair.html
   - US EPA IAQ Action Kit for Schools: http://www.epa.gov/iaq/schools/actionkit.html
   - Residential Air Cleaners (Second Edition): A Summary of Available Information 2009: http://www.epa.gov/iaq/pubs/residair.html

This document was produced by the National Collaborating Centre for Environmental Health at the British Columbia Centre for Disease Control, January 2015.

Production of this document has been made possible through a financial contribution from the Public Health Agency of Canada through the National Collaborating Centre for Environmental Health.

ISBN: 978-1-926933-77-1

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