



Challenges and Opportunities for Indoor Air Quality in a World of Energy Efficiency and Climate Change

Jeffrey Siegel, jeffrey.siegel@utoronto.ca



Civil & Mineral Engineering
UNIVERSITY OF TORONTO

How do we improve indoor air quality?

1. **Keep it Dry**
2. Source Control
3. Ventilation
4. Air Cleaning

Leviticus 14:33-53 New International Version (NIV)

³³ The LORD said to Moses and Aaron, ³⁴ “When you enter the land of Canaan, which I am giving you as your possession, and I put a spreading mold in a house in that land, ³⁵ the owner of the house must go and tell the priest, ‘I have seen something that looks like a defiling mold in my house.’ ³⁶ The priest is to order the house to be emptied before he goes in to examine the mold, so that nothing in the house will be pronounced unclean. After this the priest is to go in and inspect the house. ³⁷ He is to examine the mold on the walls, and if it has greenish or reddish depressions that appear to be deeper than the surface of the wall, ³⁸ the priest shall go out the doorway of the house and close it up for seven days. ³⁹ On the seventh day the priest shall return to inspect the house. If the mold has spread on the walls, ⁴⁰ he is to order that the contaminated stones be torn out and thrown into an unclean place outside the town. ⁴¹ He must have all the inside walls of the house scraped and the material that is scraped off dumped into an unclean place outside the town. ⁴² Then they are to take other stones to replace these and take new clay and plaster the house.

⁴³ “If the defiling mold reappears in the house after the stones have been torn out and the house scraped and plastered, ⁴⁴ the priest is to go and examine it and, if the mold has spread in the house, it is a persistent defiling mold; the house is unclean. ⁴⁵ It must be torn down—its stones, timbers and all the plaster—and taken out of the town to an unclean place.

How do we improve indoor air quality?

1. Keep it Dry
- 2. Source Control**
3. Ventilation
4. Air Cleaning

“If there is a pile of manure in a space, do not try to remove the odor by ventilation. Remove the pile of manure.”

~ *Max von Pettenkofer, 1858*



How do we improve indoor air quality?

1. Keep it dry
2. Source Control
3. Ventilation
4. Air Cleaning

III.
A HEALTHFUL HOME.
Household murder—Poisoning and starvation the inevitable result of bad air in public halls and private homes—Good air as needful as good food—Structure and operations of the lungs and their capillaries and air-cells—How people in a confined room will deprive the air of oxygen and overload it with refuse carbonic acid—Starvation of the living body deprived of oxygen—The skin and its twenty-eight miles of perspiratory tubes—Reciprocal action of plants and animals—Historical examples of foul-air poisoning—Outward effects of habitual breathing of bad air—Quotations from scientific authorities.—Pages 43-58.

IV.
SCIENTIFIC DOMESTIC VENTILATION.
An open fireplace secures due ventilation—Evils of substituting air-tight stoves and furnace heating—Tendency of warm air to rise and of cool air to sink—Ventilation of mines—Ignorance of architects—Poor ventilation in most houses—Mode of ventilating laboratories—Creation of a current of warm air in a flue open at top and bottom of the room—Flue to be built into chimney: method of utilizing it.—Pages 59-65.

V.



Beecher CE, Stowe H B. 1869. *The American Woman's Home*. New York: J.B. Ford and Company.

“When ‘the wise women buildeth her house,’ the first consideration will be to the health of the inmates. The first and most indispensable requisite for health is pure air, both by day and by night.”

“A learned physician also thus wrote to the author of this chapter: “The subject of the ventilation of our dwelling-houses is one of the most important questions of our times. How many thousands are victims to a slow suicide and murder, the chief instrument of which is want of ventilation!”

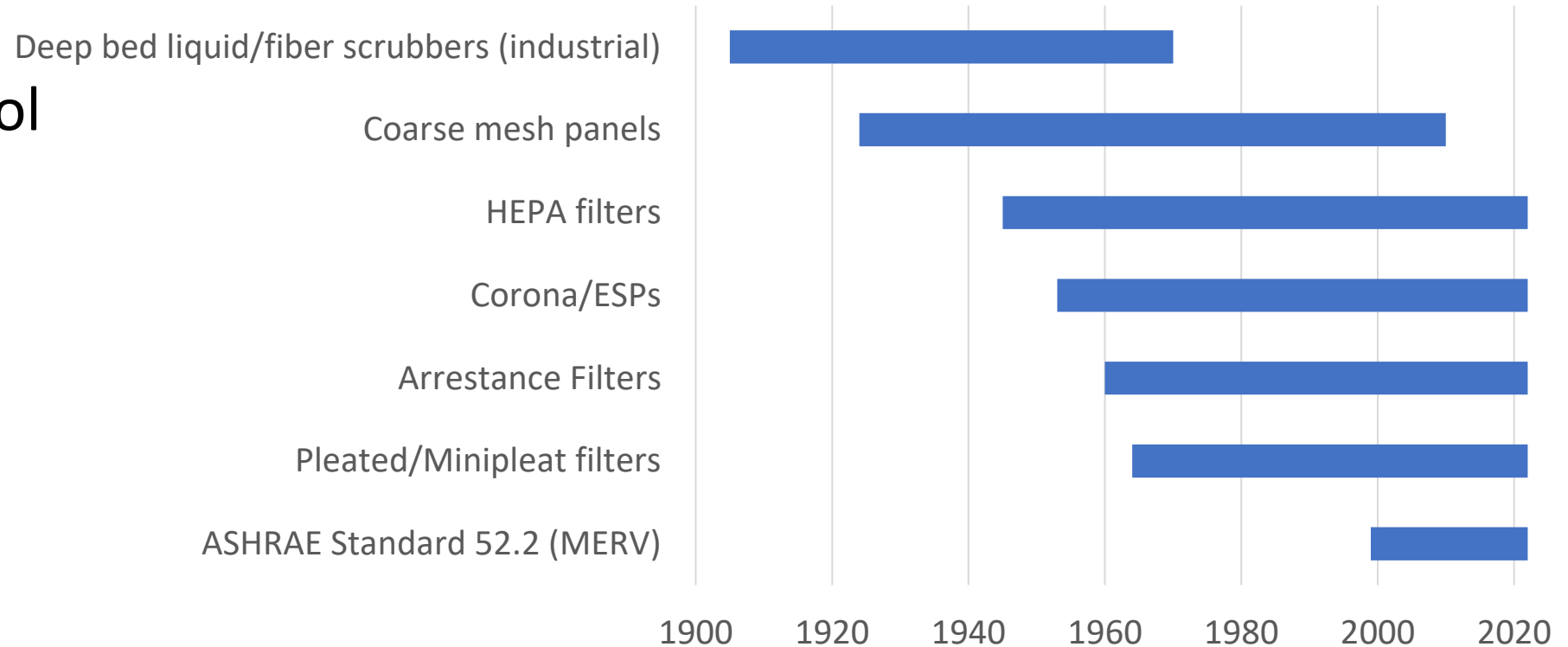
How do we improve indoor air quality?

1. Keep it Dry

2. Source Control

3. Ventilation

4. **Air Cleaning**



We all (should) know Indoor Air Quality (IAQ) is Important

- We spent most of our time in buildings
- There are unique indoor sources
- Even exposure to outdoor pollutants happens mostly inside
- We have all just lived through a pandemic
- Increasingly we see wildfires, ambient air pollution events, more shared air

Example Myth 1: Use Green Building Materials

- Classic answer: Low-VOC paint
 - Less odor, less VOCs, dries faster
 - Increased emission of specific VOCs of concern, inclusion of SVOCs, increased acetic acid, poor ventilation recommendations Schieweck & Bock (2015) *Bldg. Environ.*
- “Green” answer: No-VOC paint
 - Linseed oil (or similar) base Knudsen et al. (2003) *Indoor Air*
 - “the SOA concentrations generated at modest O_3 concentrations approach or exceed current guideline levels for $PM_{2.5}$ established by the US EPA and the World Health Organization”
Toftum et al. (2008) *Atmos. Environ.*



Right answers (my opinion):
Ordinary latex paint and wait
before occupancy, use
surfaces that don't need to be
painted



Example Myth 2: Integrate Plants



Ref: <http://www.davidsuzuki.org/what-you-can-do/queen-of-green/faqs/cleaning/can-indoor-plants-improve-air-quality-inside-my-home/>

What you can do » Queen of Green » FAQs » Cleaning

Can indoor plants improve air quality?

Believe it or not, [NASA created a list of the best air-filtering plants!](#)

The plants listed below are some of the most popular house plants, so they'll be easy to find, and they're also easy to care for.

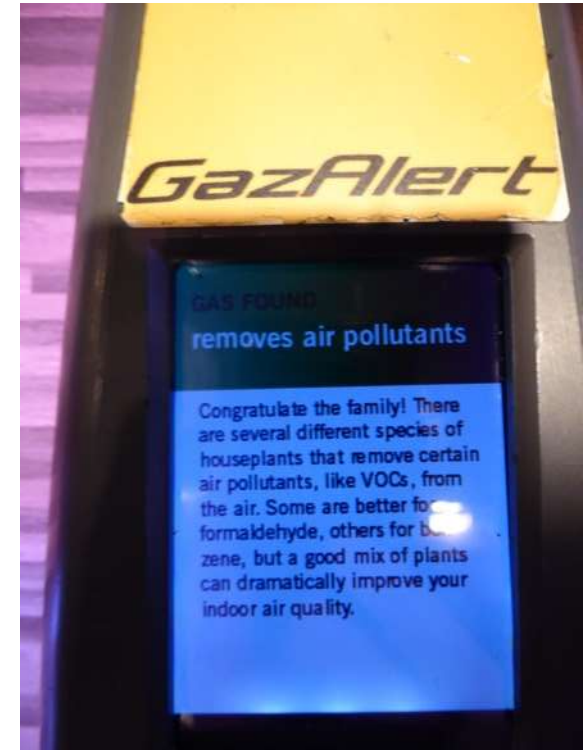
Decorate your home or office with a combination of indoor plants

- Spider plants
- Peace lilies
- Snake plants (aka mother-in-law's tongue)
- Elephant ears
- Weeping figs
- Rubber plants
- Bamboo palms (aka reed palm)

Back in the 1980s, NASA did a study to look at which plants were best able to filter the air of the space station! And if it's good enough for the space station...

You don't have to be an astronaut to know that plants produce oxygen. But what you might not realize is that indoor plants can also absorb contaminants like benzene and formaldehyde (a known carcinogen). Dr. B.C. Wolverton's research also showed that plant-filtered rooms have 50 to 60 per cent less airborne microbes, like mold spores and bacteria.

Get rid of any fake, silk plants—they only collect dust—and harness the environment's natural ability to clean itself. You can also check the library for a more exhaustive list in Dr. B. C. Wolverton's book, *How to Grow Fresh Air: 50 houseplants that purify your home or office*.

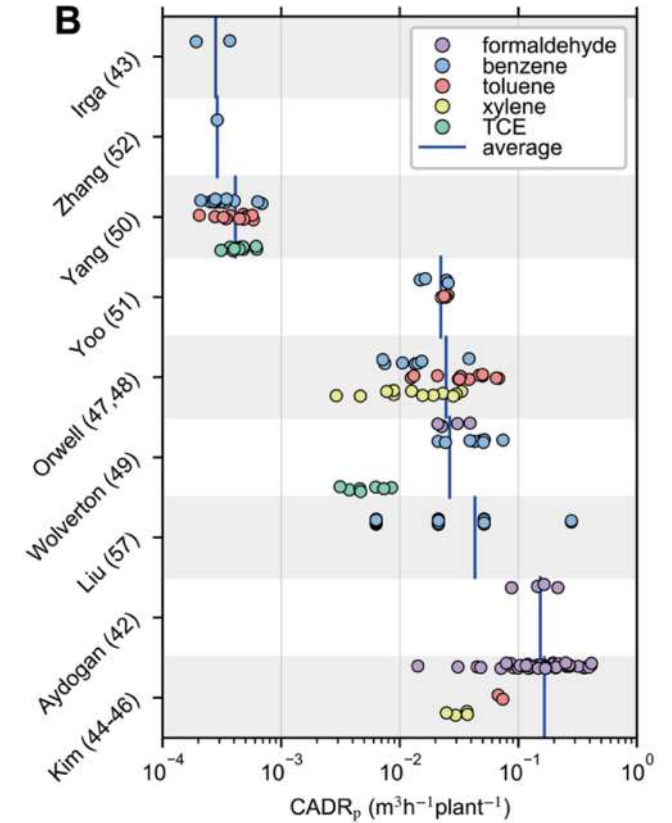
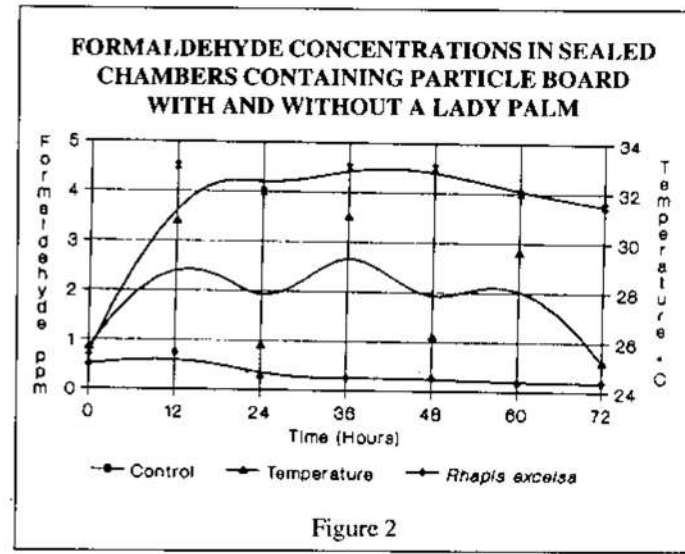
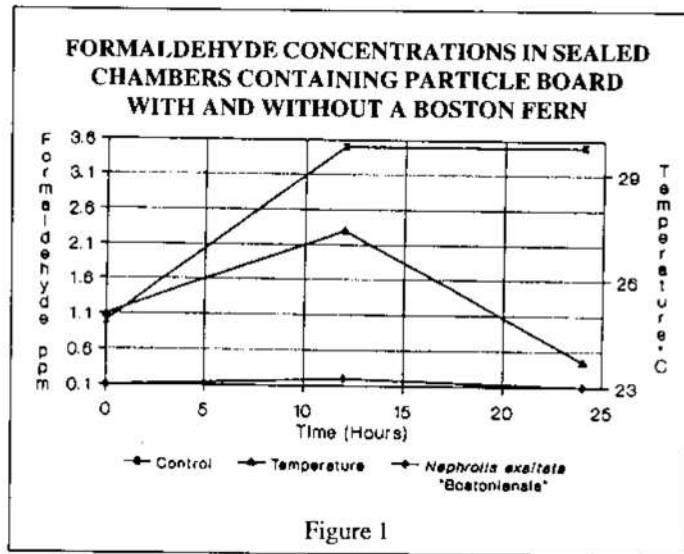


Images courtesy Sandra Dedesko

Plants And Soil Microorganisms: Removal of Formaldehyde, Xylene, and Ammonia from the Indoor Environment

B. C. Wolverton and John D. Wolverton
Wolverton Environmental Services
514 Pine Grove Road
Picayune, Mississippi 39466

Journal of Mississippi Academy of Sciences (1993)



Potted plants do not improve indoor air quality: a review and analysis of reported VOC removal efficiencies

Bryan E. Cummings¹ · Michael S. Waring¹

Journal of Exposure Science & Environmental Epidemiology (2020) 30:253–261
<https://doi.org/10.1038/s41370-019-0175-9>

a serious mycotic hazard to the immunosuppressed patient.

Introduction

The increasing importance in recent years of opportunistic fungal infections in immunocompromised patients [57] has led to a search for sources of fungal contamination within the hospital environment [85]. Important sources of infection include catheterization in the case of yeast

conidia have been shown to include cellulose fireproofing materials [1] and dust collect within false ceilings [4, 15].

A number of studies by F. Staib and coworkers have shown in addition that the soils of cultivated indoor plants may be significant reservoirs of conidia of certain pathogenic *Aspergillus* species within hospitals [71, 76, 77]. This has been co

As a result of the investigation of potentially pathogenic species were isolated, including *Aspergillus fumigatus* at up to 53.5 colony-forming units (CFU) per gram dry soil and *Scedosporium apiospermum* (*Pseudallescheria boydii*) at up to 97.0 CFU/g. Other common species included *Phialophora verrucosa* and *Fusarium solani*. *Scedosporium inflatum*, a recently described emerging pathogen, is reported for the first time from an environmental source. The results of this study, in combination with previous

Childhood hypersensitivity pneumonitis associated with fungal contamination of indoor hydroponics

Steffen Engelhart^{a,*}, Ernst Rietschel^b, Martin Exner^a, Lars Lange^b

^aInstitut für Hygiene und Öffentliche Gesundheit, Universität Bonn, Sigmund-Freud-Straße 25, 53105 Bonn, Germany

^bKlinik und Poliklinik für Allgemeine Kinderheilkunde, Universität Köln, Germany

We describe a case of HP associated with indoor hydroponics in a 14-year-old girl.

symptoms following the removal of hydroponics from the home. We conclude that hydroponics should be considered as potential sources of fungal contaminants when checking for indoor health complaints.

International Journal
of Hygiene and
Environmental Health

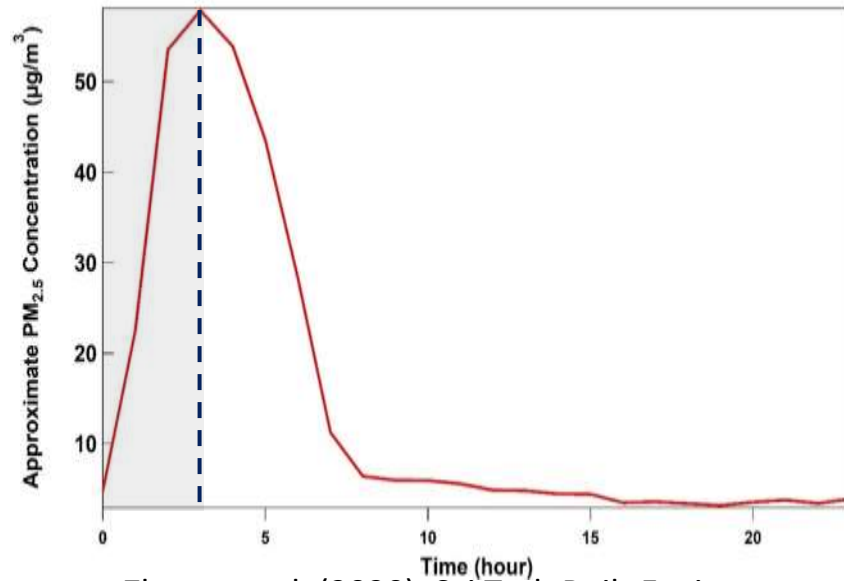
www.elsevier.de/ijheh

Int. J. Hyg. Environ. Health 212 (2009) 18–20

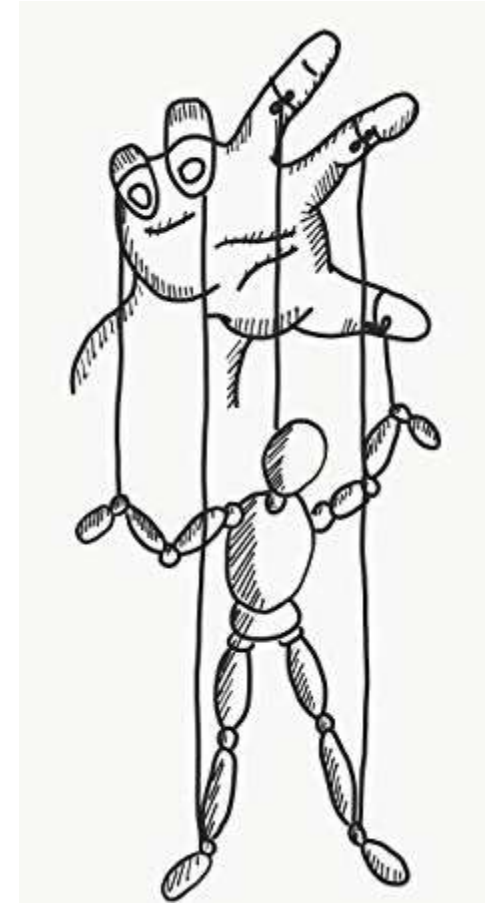
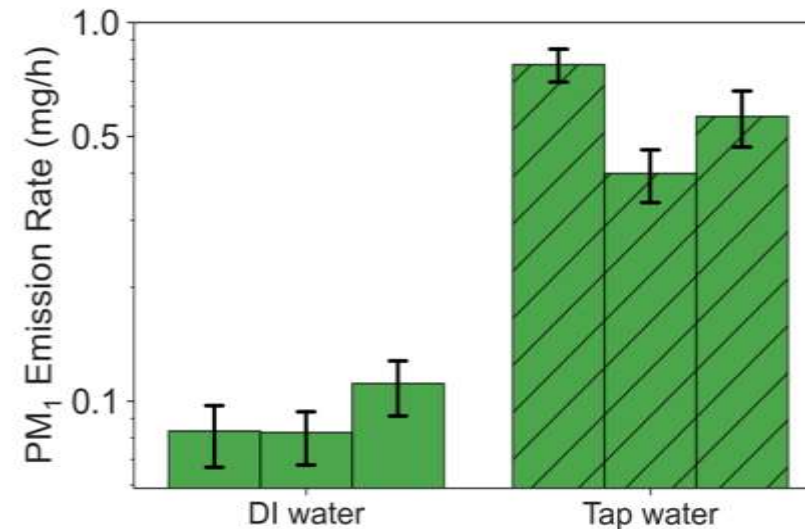
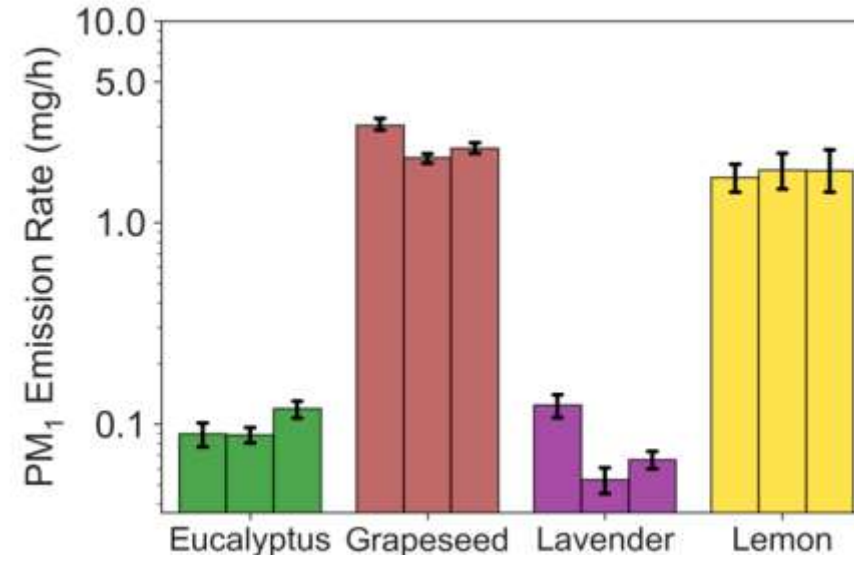
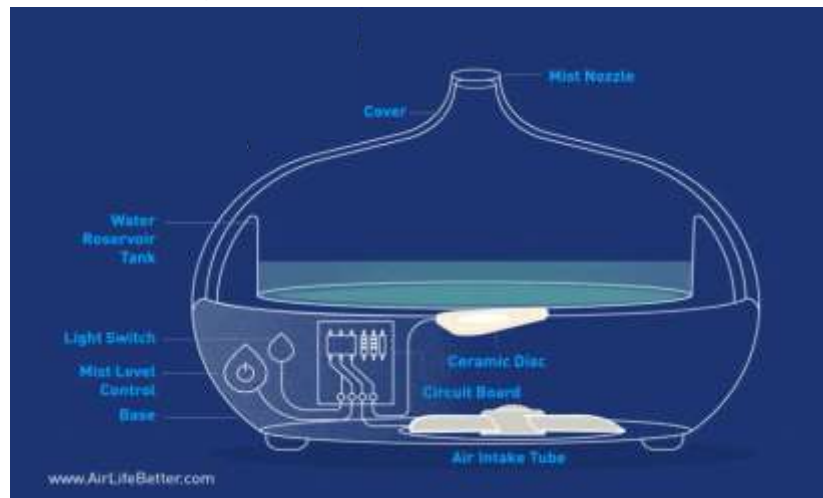


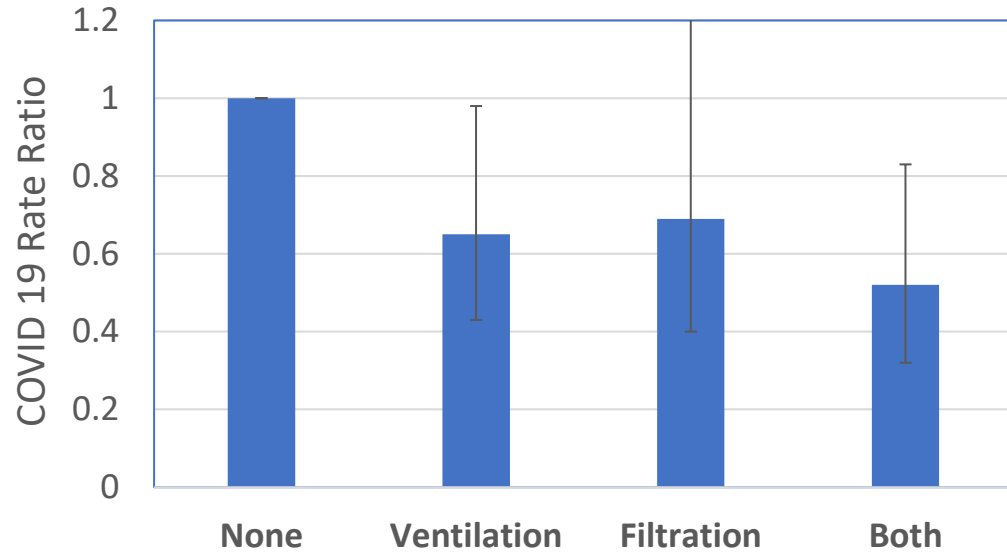
<https://dsai.ca/news/living-wall-biofilter-turns-10/>

Example Myth 3: Essential Oil Diffusers

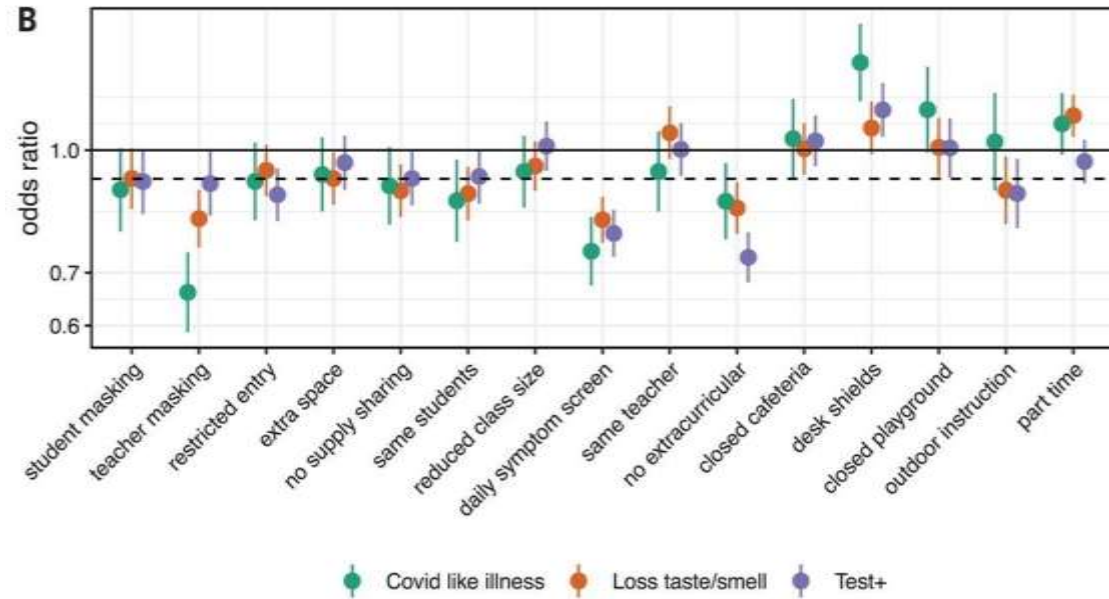


Zhang, et al. (2020). Sci Tech Built Environ

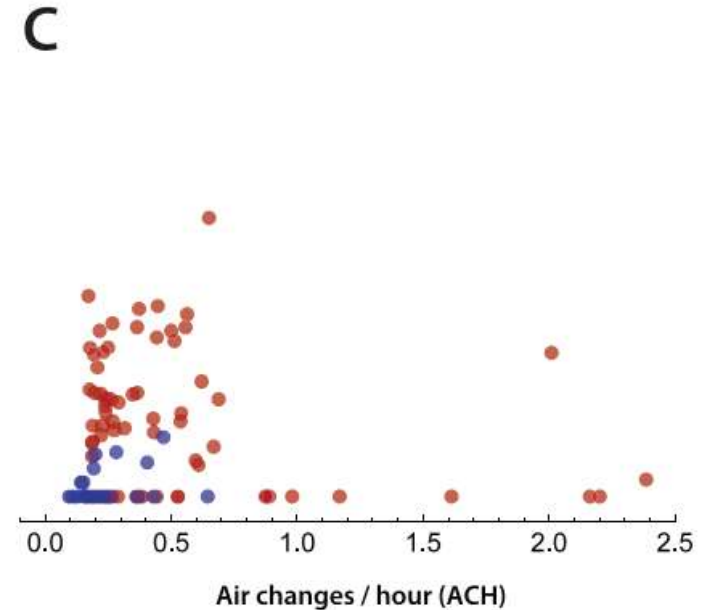
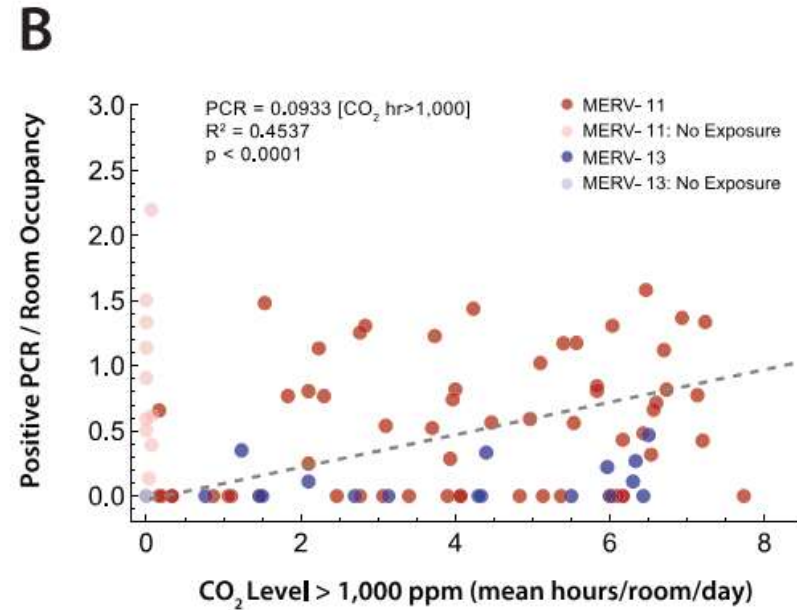
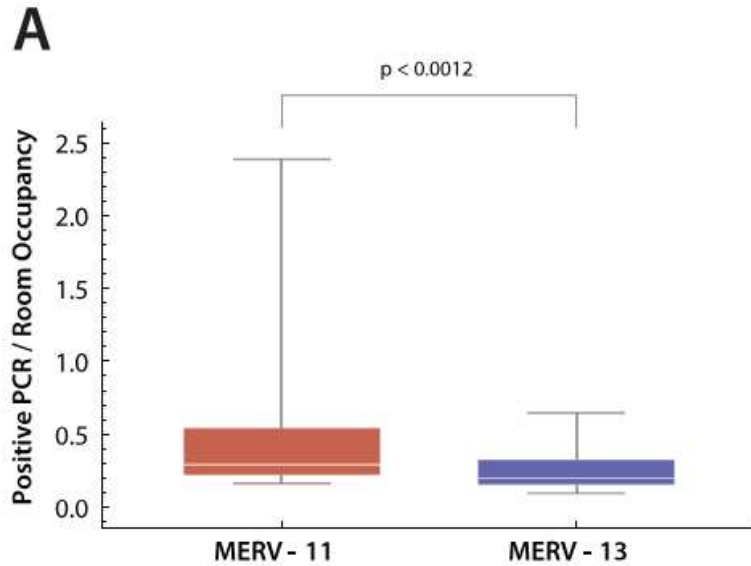




Data from Gettings et al. (2021) *MMWR*



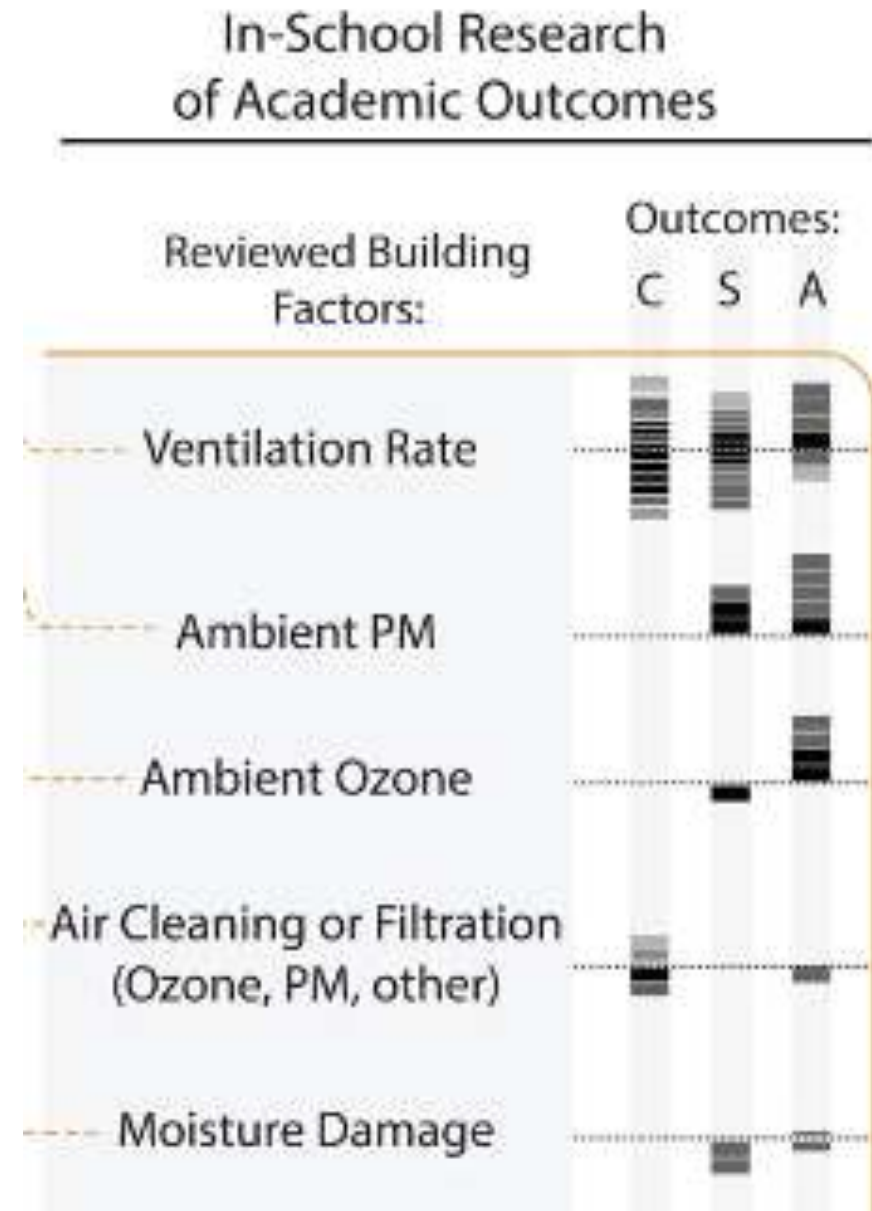
<https://www.cbc.ca/news/health/plexiglass-covid-19-ventilation-1.6259887>

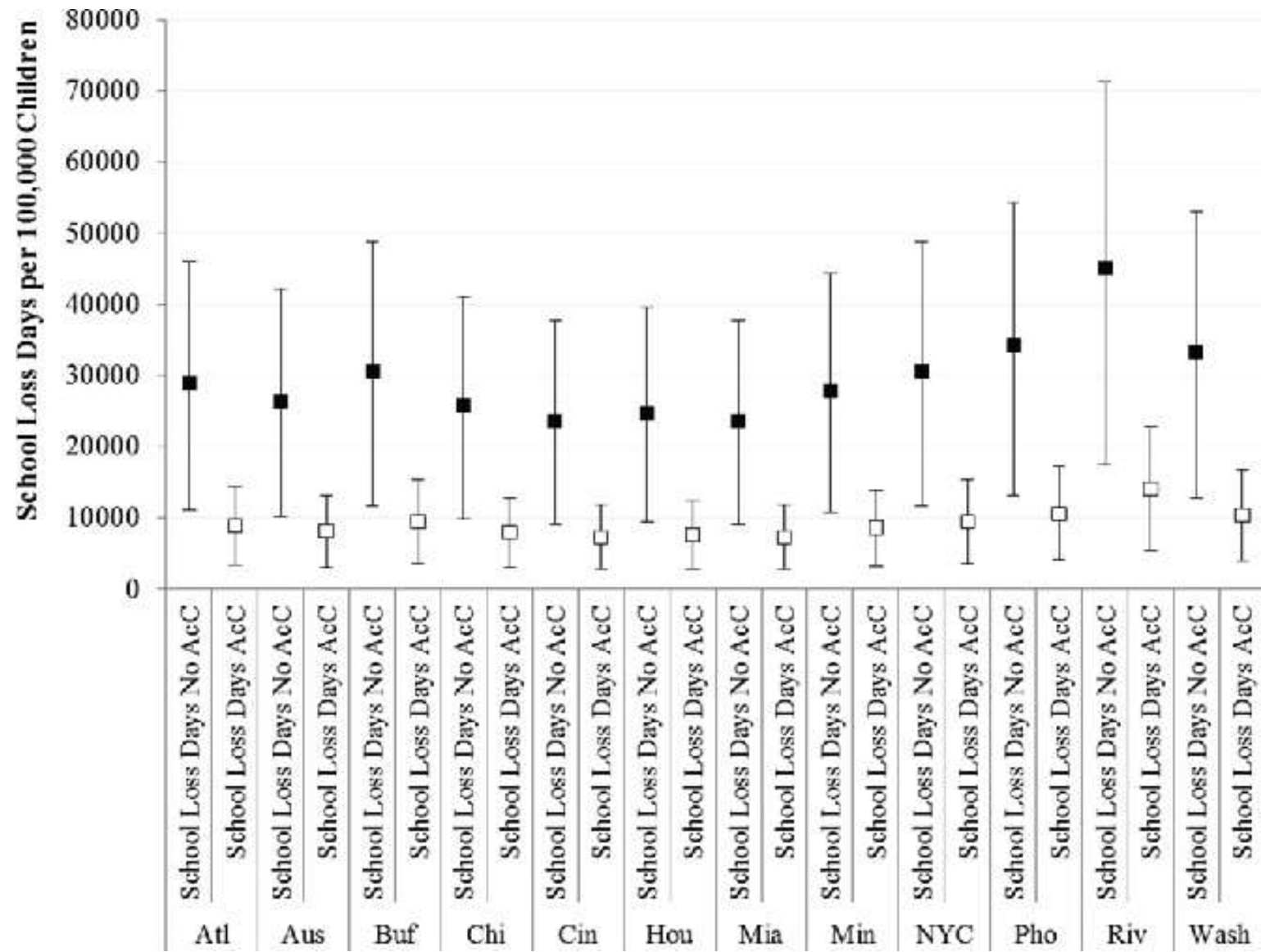


Zand et al. (2024) PLoS ONE doi: 10.1371/journal.pone.0291840.g008

- Healthy indoor environments:
 - Improve cognitive performance and learning
 - Increase productivity
 - Improve performance on standardized tests
 - Reduce absenteeism from school and work
 - Reduce asthma frequency and severity
 - Cause students to have higher salaries when they graduate
 - Lower healthcare costs

e.g., Fisk and Rosenfeld (2004) *Indoor Air*





ASHRAE believes that indoor air quality and will remain the single most important health issue...

Unacceptable indoor air quality can impair our health, affect our sense of well-being and affect our productivity...

Today, we might not always want to bring in unfiltered uncontrolled outside air...

The way we live today, spending more than 90% of our time indoors, creates the need for a better knowledge of what contaminants are present in the indoor environment and their effect on people....

The issue of indoor air quality is a sleeping giant whose time has come...

COMMENTS OF DONALD R. BAHNFLETH, PRESIDENT
AMERICAN SOCIETY OF HEATING, REFRIGERATING
AND AIR-CONDITIONING ENGINEERS

IAQ 86 OPENING SESSION
APRIL 20, 1986

Good afternoon, and thank you for joining us for this very important conference on Managing Indoor Air for Health and Energy Conservation. During the next four days, we will hear from experts in indoor air quality. A diverse group of talented men and women from around the world will present us with the latest findings in virtually every aspect of the issue.

More than 100 authors will present papers, either orally during the 12 sessions or in poster sessions on Monday and Tuesday. They represent government, corporations, universities and colleges, private laboratories. All of them have worked for months to gather the data for their presentations and they have done it for one purpose: because they believe it important to provide solutions to indoor air quality problems.

ASHRAE has organized and is co-sponsoring with the Department of Energy and the Environmental Protection Agency this conference for the same reason. Because indoor air quality is an important issue. In fact, ASHRAE believes that indoor air quality is and will remain the single most important health issue facing us in the 1980's. Unacceptable indoor air quality can impair our health, affect our sense of well-being, and affect our productivity in terms of both lost time and loss of productive effort. *Make any ASHRAE sponsored conference*

Years ago, whenever there was a problem regarding the indoor air, we usually tried what I call "granny's solution." We just threw open the door or the window and brought in outside air. Today, we might not always want to bring in unfiltered uncontrolled outside air. In some cities, what's outside could be worse than what's inside. Large amounts of outside air also require expending large amounts of energy for heating and cooling. Concern for the IAQ issue is still growing.

The way we live today, spending more than 90 percent of our time indoors, creates the need for a better knowledge of what contaminants are present in the indoor environment and their effect on people. The issue of indoor air quality is a sleeping giant whose time has come. The total number of serious health effects related to IAQ in non-industrial buildings have been miniscule compared to the total building stock. But there have been enough to indicate that a problem exists. Fortunately, addressing the situation this early gives us time to move rationally. The issue does not need to be sensationalized. We do not need knee-jerk reactions.

Why haven't we moved the needle on IAQ on as much as on other issues?

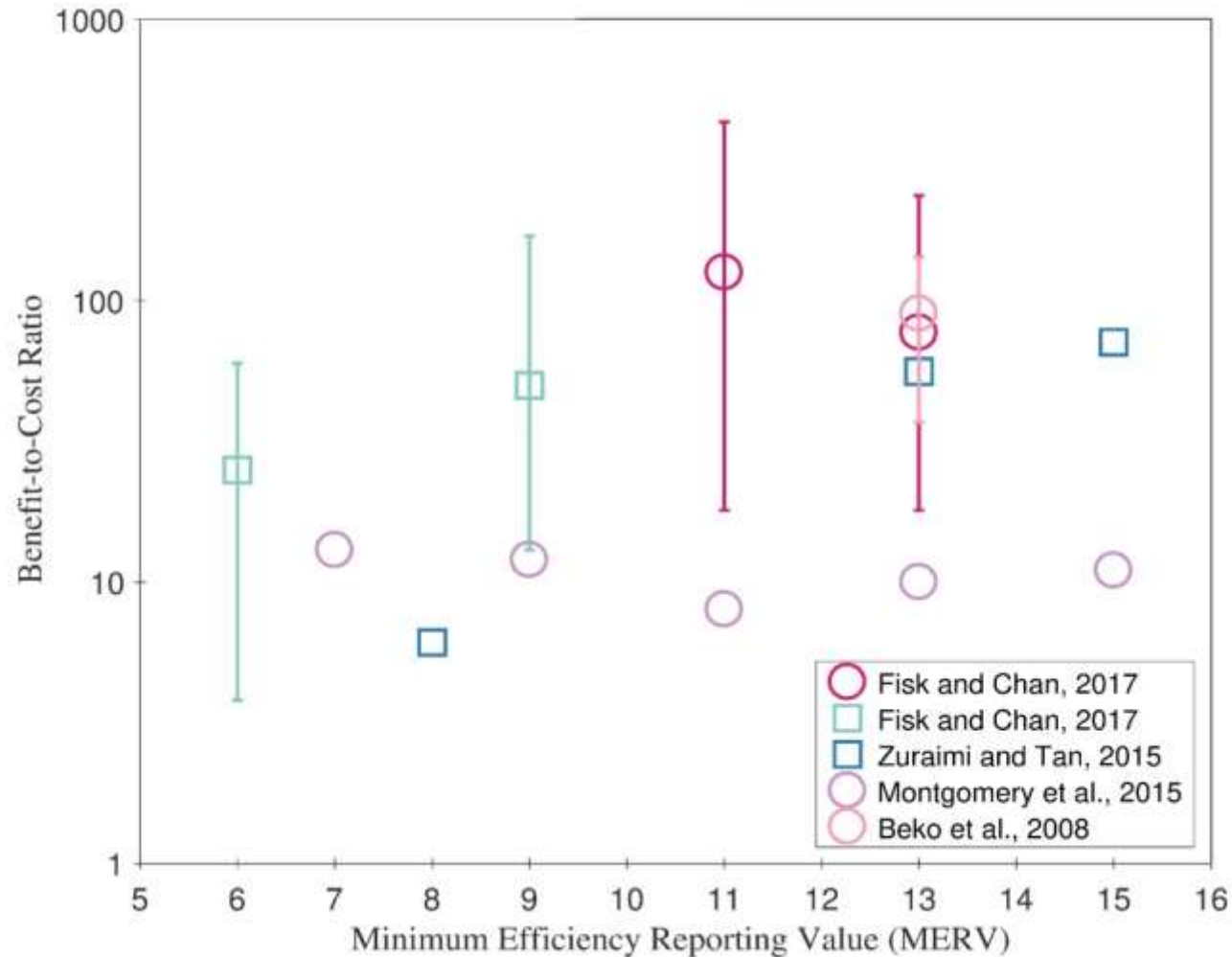
1. We need to do a better job in assessing the benefits of improved IAQ.
2. We need to be able to demonstrate how well IAQ measures actually work in real buildings.
3. We need to get better at communicating information about IAQ.
4. We need to integrate IAQ with other goals (climate, equity, housing).

Challenge # 1: It costs too much to improve IAQ

- Example: Cooking is an important source of indoor air pollution
 1. Have (and use) a good rangehood fan (and use it well)
 2. Switch to electric

These are expensive, not attainable for much of the population, and are just presented as costs.

Opportunity: Accurately compare costs and benefits



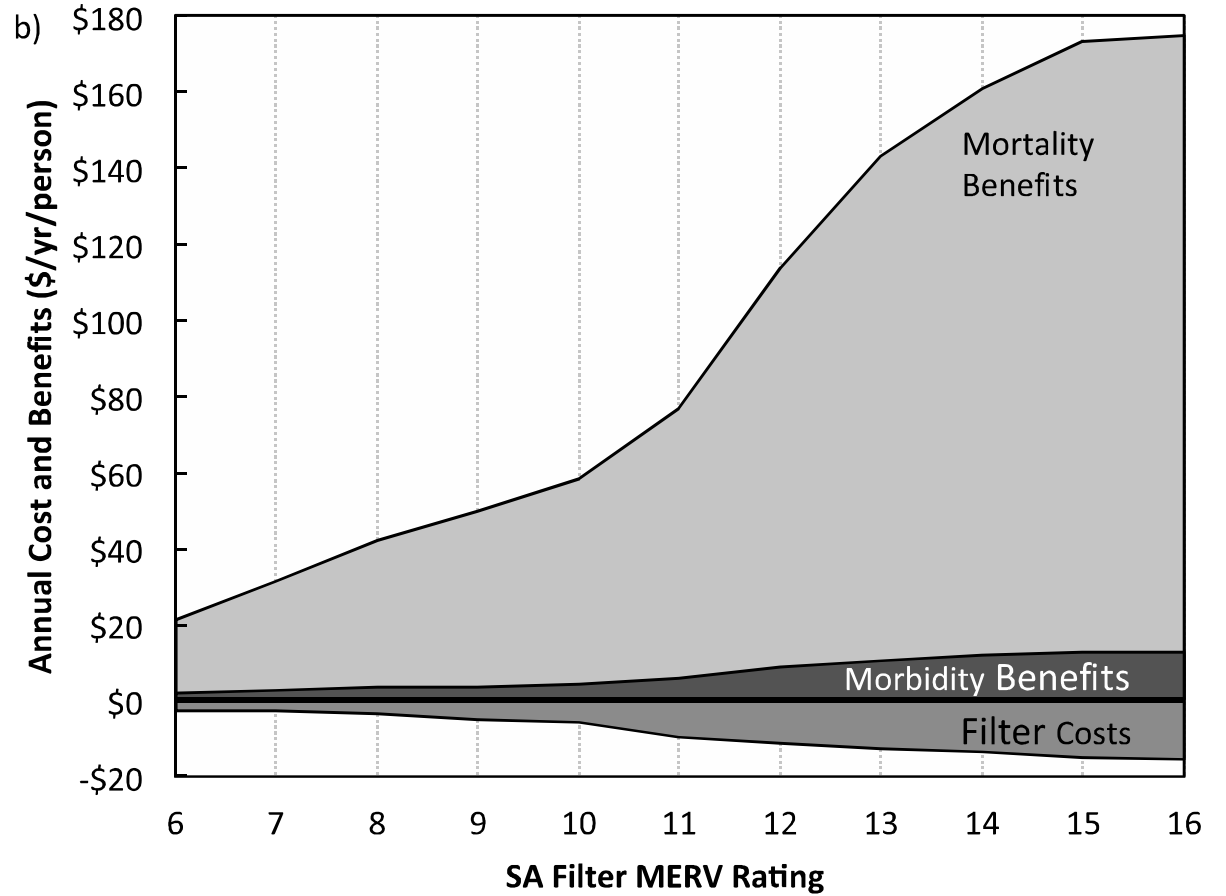
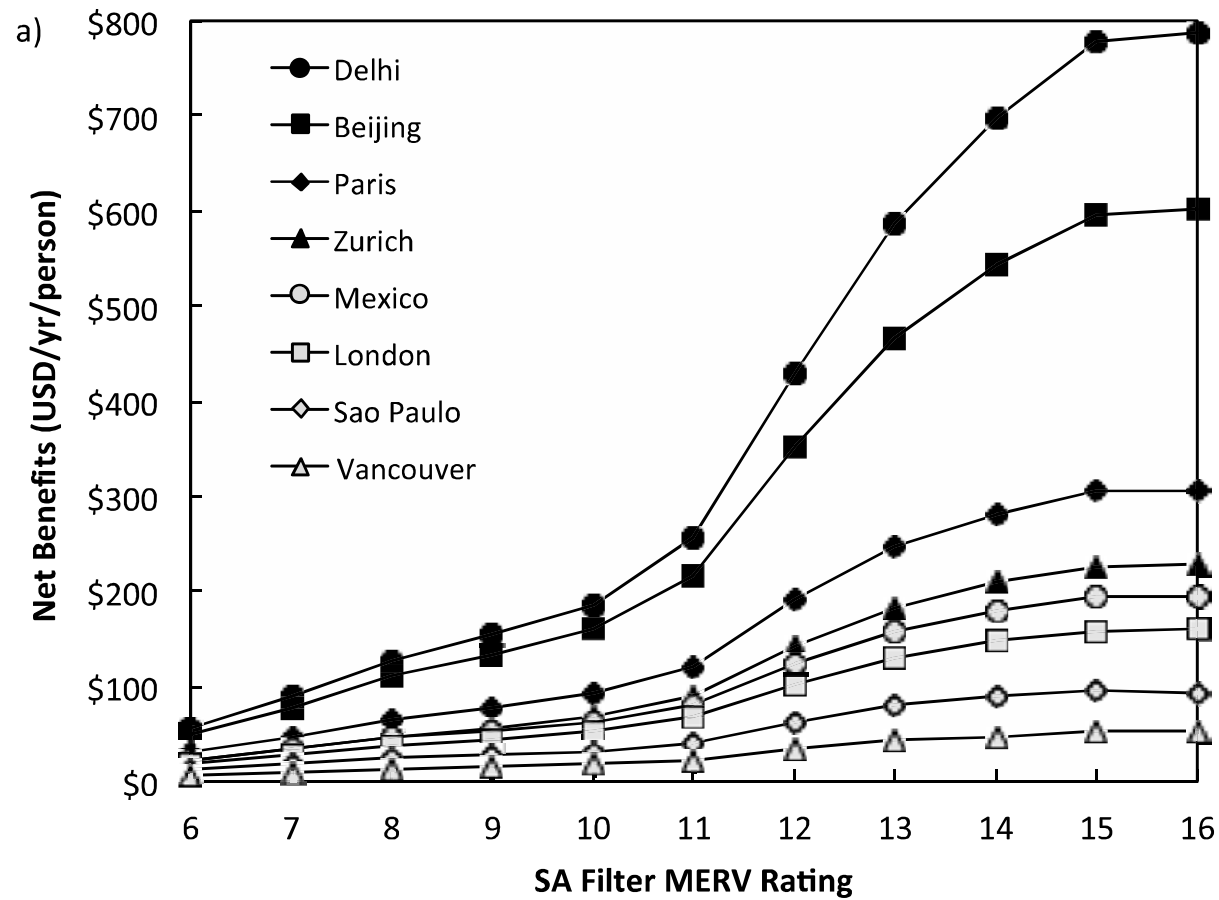
Opportunity: Value Benefits Completely

Dec 16, 2021 by Anthony Fong

Inuit communities bracing for return of RSV in babies

<https://healthydebate.ca/2021/12/topic/inuit-communities-rsv-outbreak/>

- Economic costs: Medical transport, medical treatment & pharmaceutical treatment, housing families, diminished income for parents
- Social costs: Disrupted schooling and communities



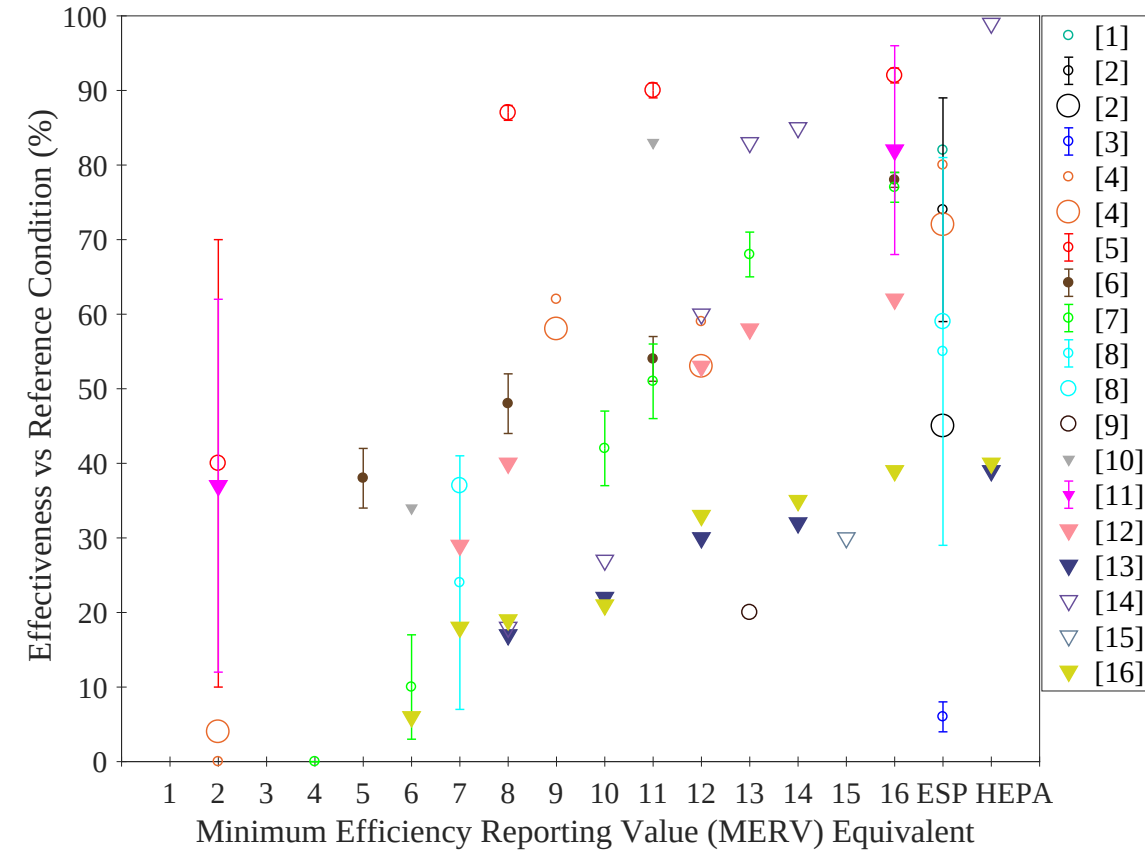
Montgomery et al (2015) *Bldg Environ*

Opportunity: Value New Benefits

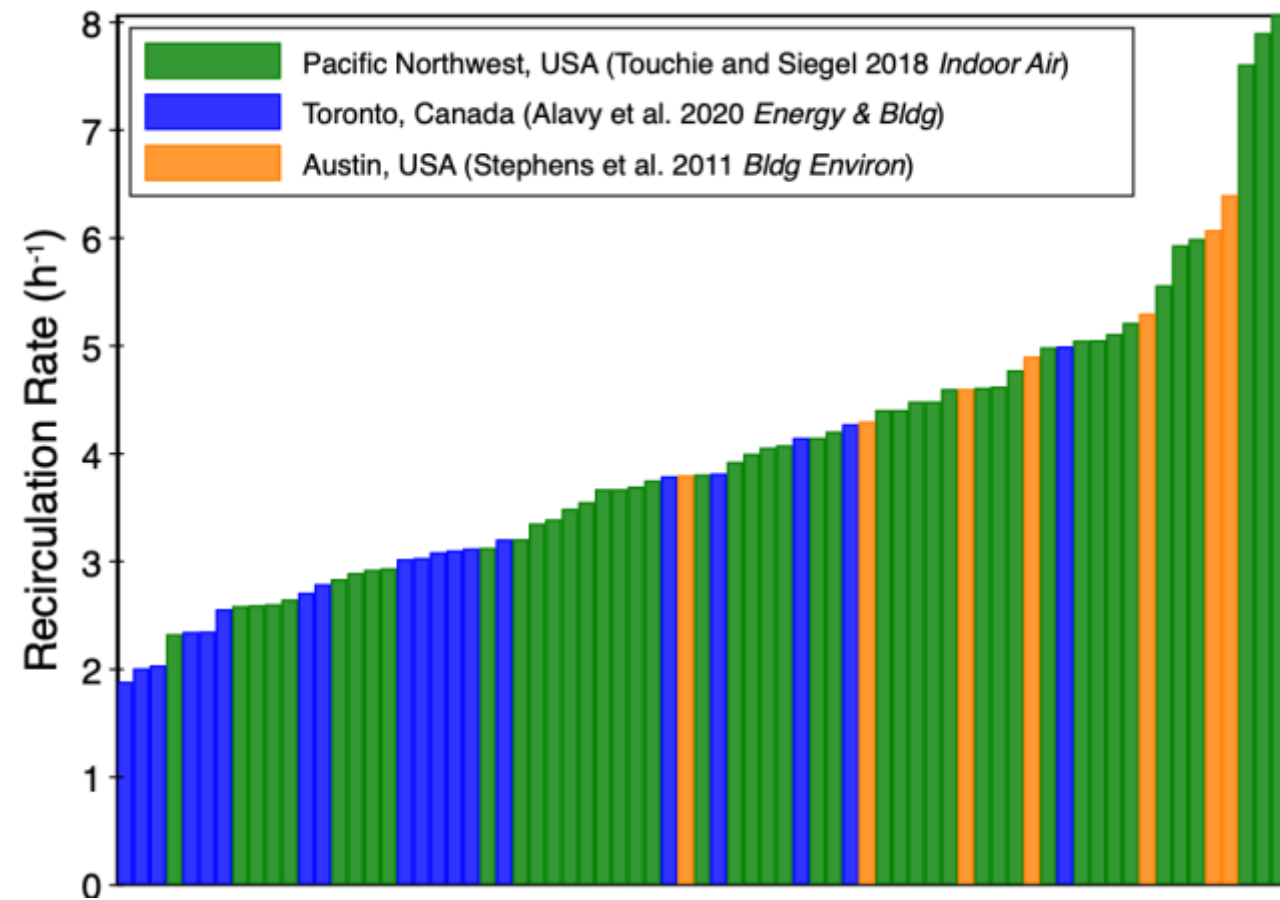
Invest in indoor air to improve cognitive function. Use benefits to pay for improvements. Chronic health outcome improvement are a “side” benefit.

Challenge #2: Real-World Performance is variable

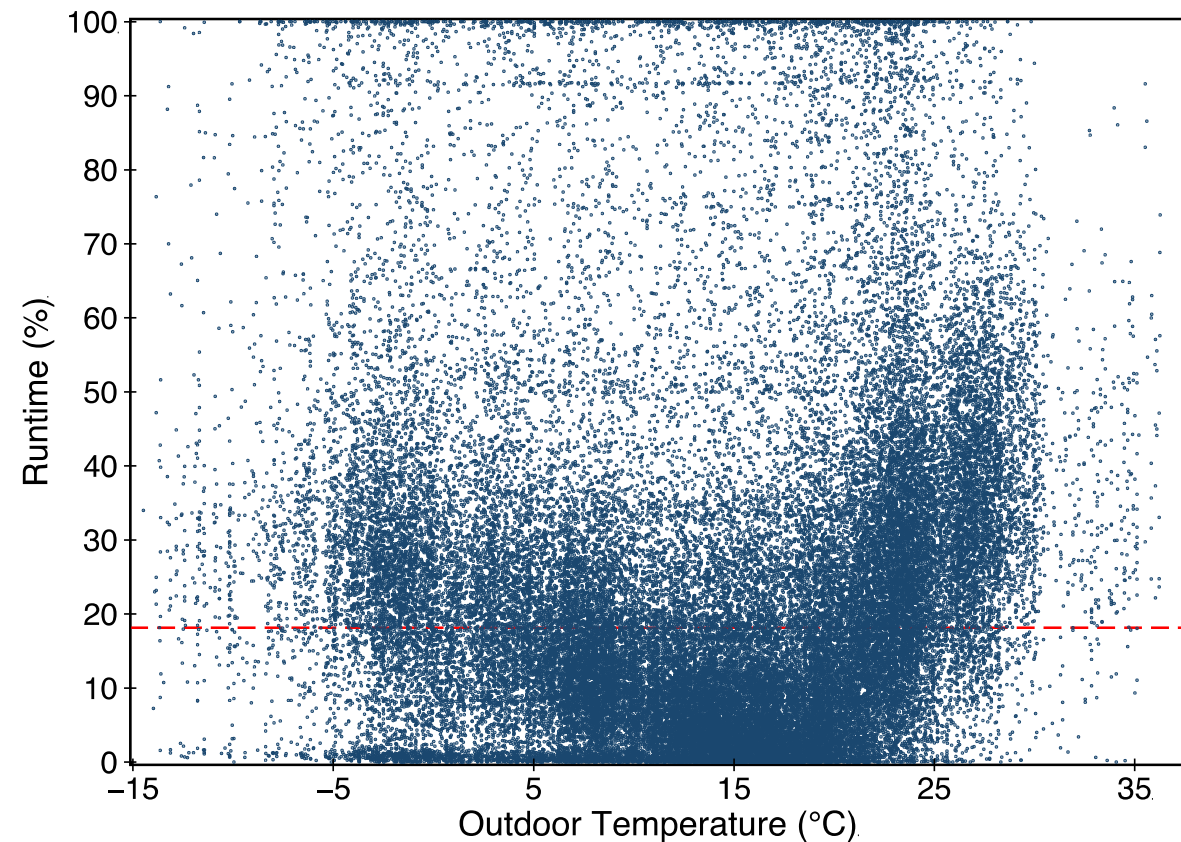
- Filters and air cleaners are evaluated by standardized tests (eg, ASHRAE Standard 52.2, AHAM AC1)
- Actual performance is function of the filter, the building, the HVAC system, the use, and lots of other things



Alavy and Siegel (2019) *Sci Tech. Built Environ.*



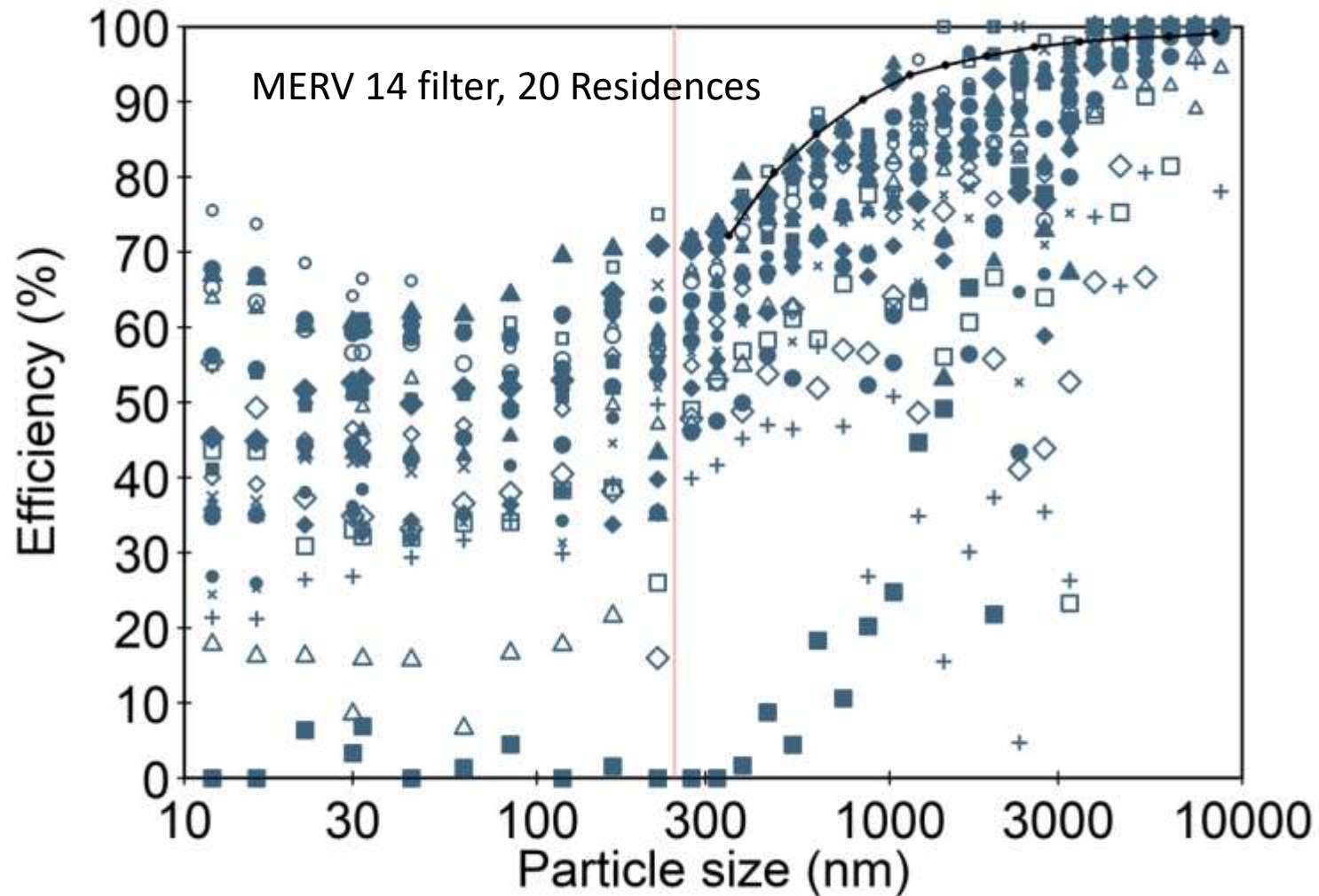
Recirculation: home volumes that pass through filter when system operates



Data from: Touchie and Siegel (2018) *Indoor Air*

Runtime: Fraction of time that system operates

Lab Efficiency is Not In-situ Efficiency



Li and Siegel (2020) *Indoor Air*



Image: Courtesy Geoffroy Allard

Efficiency: Filter Aging

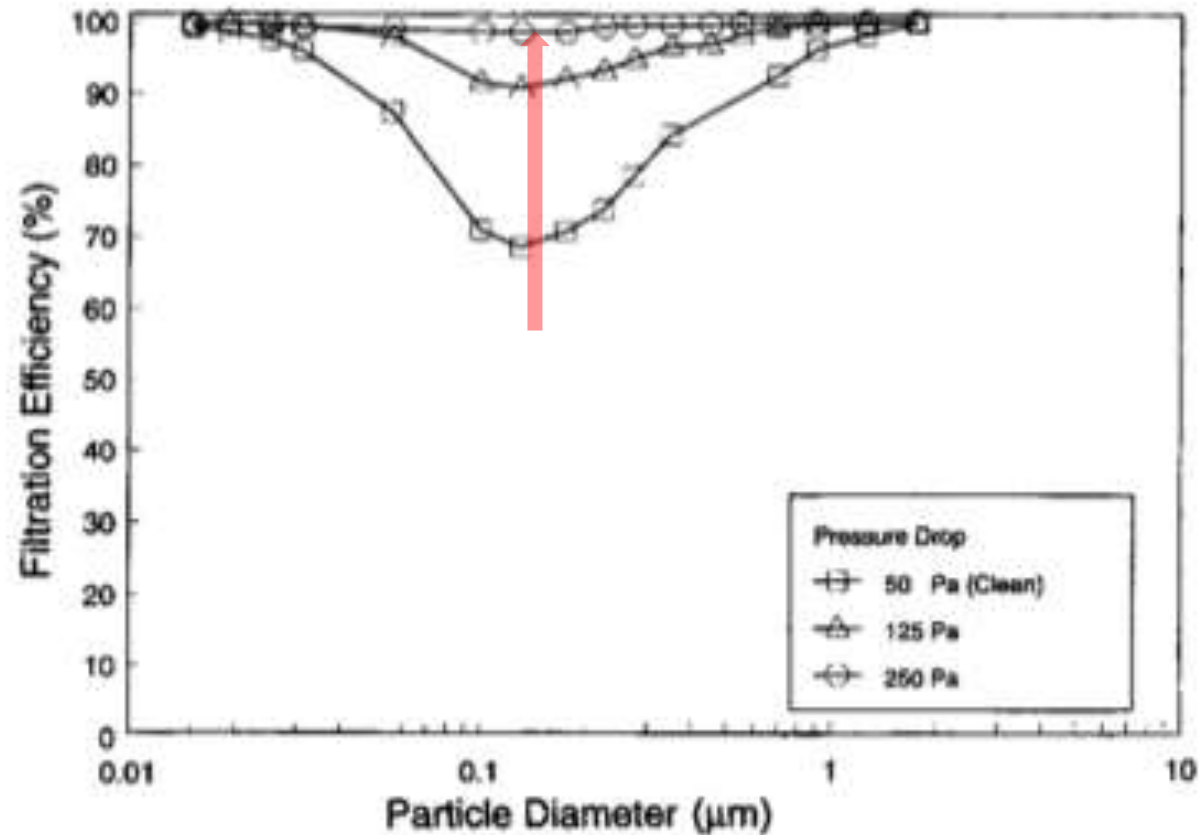


Fig. 6 The effect of dust load on the fractional filtration efficiency of a pocket filter of non-woven fiber media at 1.3 m/s

Refs: Hanley et al. (1994) *Indoor Air*, Lehtimäki et al. (2002) ASHRAE RP-1189 Report

Efficiency: Filter Aging

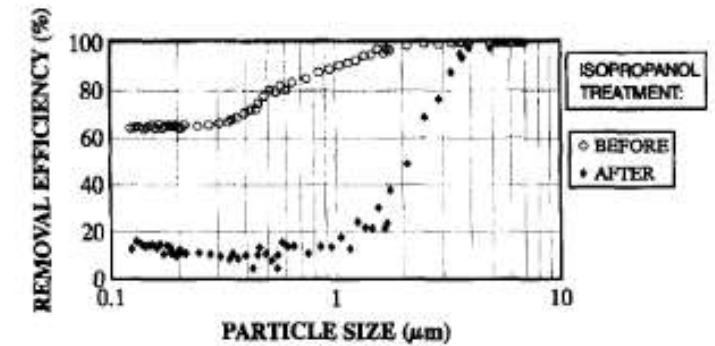
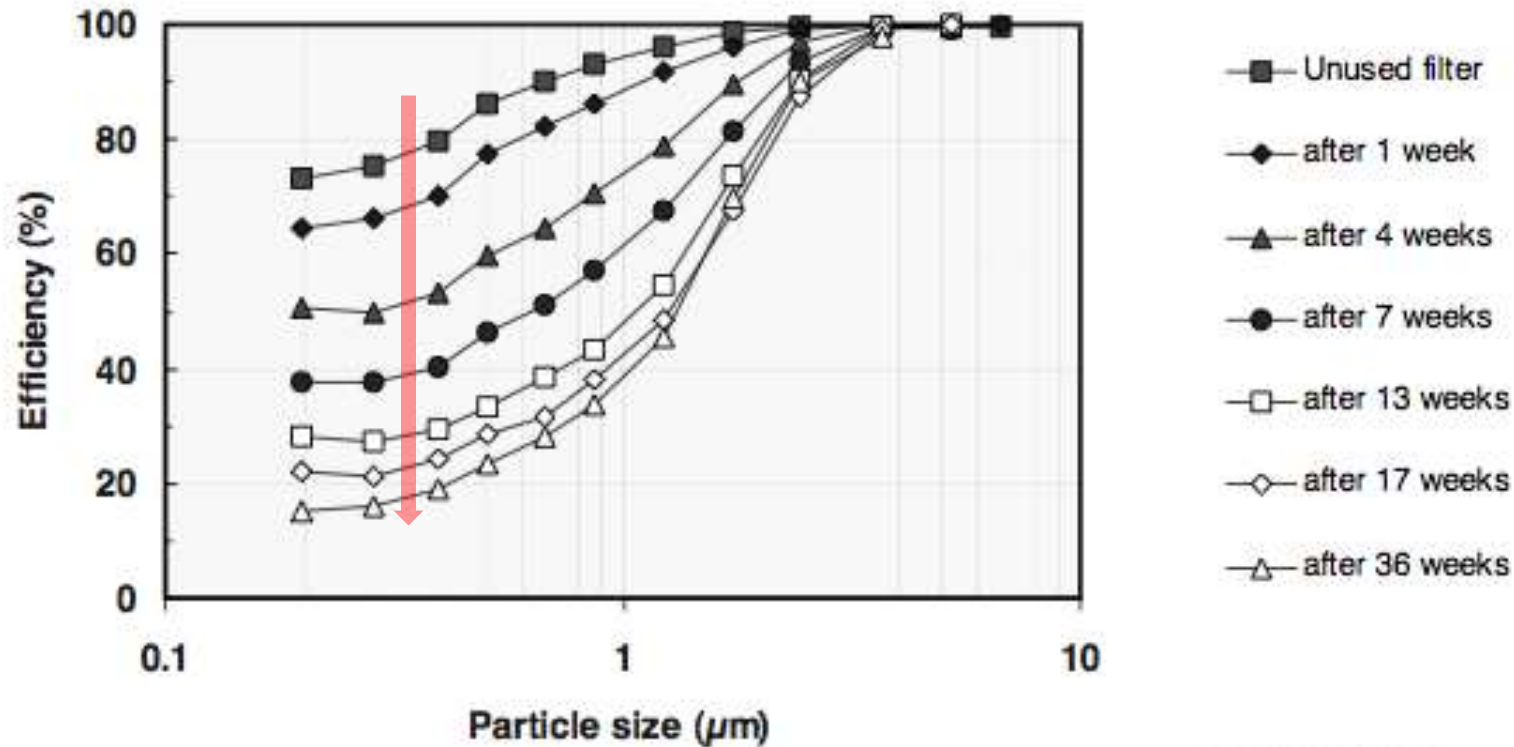


Fig. 2. Effect of isopropanol treatment on the removal efficiency of an "EU7" electret filter, flow velocity 0.33 m/s.

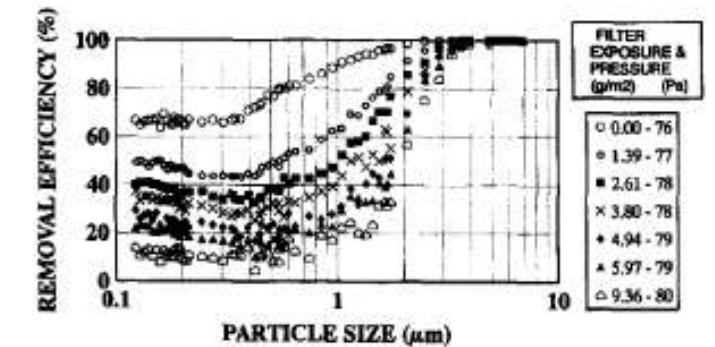


Fig. 3. Effect of diesel fume aerosol on the removal efficiency of an "EU7" electret filter, flow velocity 0.33 m/s.

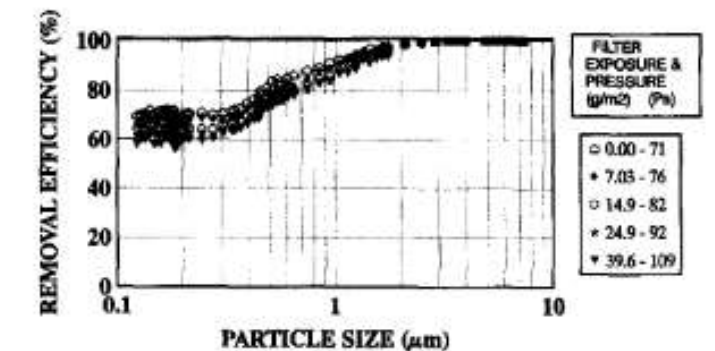


Fig. 4. Effect of Arizona road dust loading on the removal efficiency of an "EU7" electret filter, flow velocity 0.33 m/s.

Refs: Hanley et al. (1994) *Indoor Air*, Lehtimäki et al. (2002) ASHRAE RP-1189 Report

Important Point: Filtration Can and Does Work

- Scientific evidence
 - 55+ papers that measure a health effect associated with filtration
 - Consistent message: Filtration improves health outcomes with some variation
 - Benefit is strongest in locations with high ambient fine PM
 - Almost all are short-term studies
 - Context is often not measured

“The very big picture of this literature is that there is clear evidence that air cleaning is an effective mitigation measure for fine PM. However, there is also considerable variation in findings between studies and within studies for multiple health outcomes.”

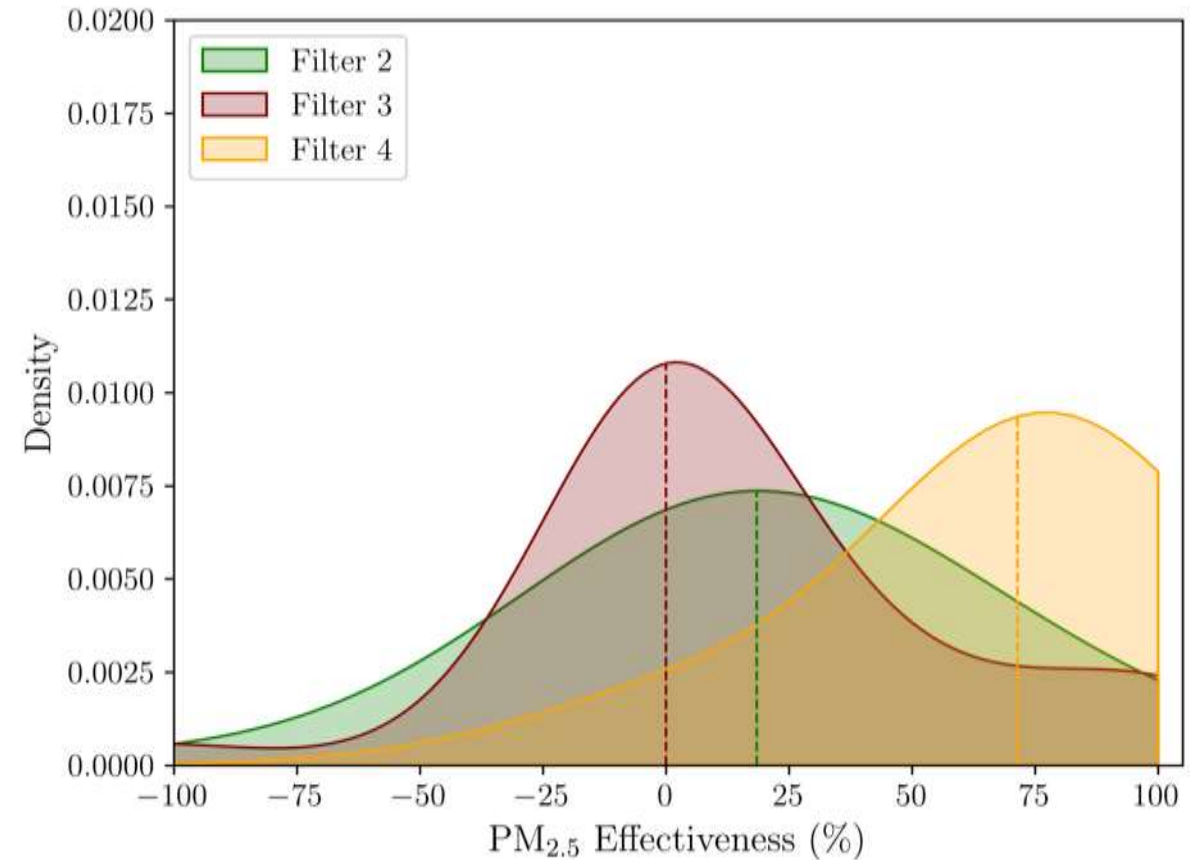
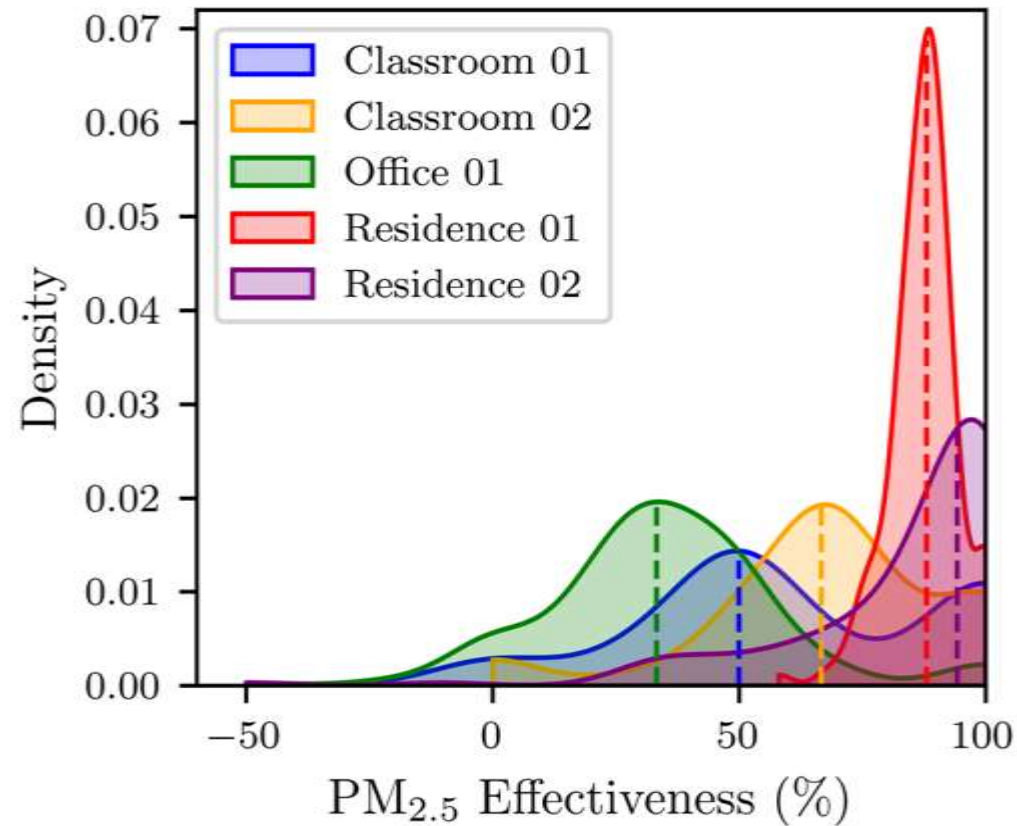
<https://nap.nationalacademies.org/catalog/27341/health-risks-of-indoor-exposure-to-fine-particulate-matter-and-practical-mitigation-solutions>



Opportunity: Teach Users How to Use Filters

Install a good filter/air cleaner properly, make sure lots of air goes through it, change it frequently, and verify performance.

Opportunity: Verify Performance



Air Cleaner

Placebo

Air Cleaner

Placebo

Opportunity: Integrate IAQ Monitoring

- Last decade – proliferation of low-cost IAQ monitoring devices
- Double-edged sword
 - As absolute monitors, they are not very accurate
 - As relative monitors (different rooms in the same building, same environment over time) they are very instructive
- Opportunity: Invest resources in interpretation (and data presentation)

Challenge #3. Absence of good information/Abundance of Misinformation

- IAQ is (largely) unregulated
- People don't want to hear that
 1. Their homes and buildings are not sanctuaries
 2. Their choices can negatively impact indoor air quality
- No government agency has a complete/coordinated mandate
- We have an incomplete picture of the science

Miscommunication By Air Cleaner Manufacturers

- Very long history of manufacturers making claims about “alternative” air cleaners
- Examples
 - Very low flow rates (high efficiencies)
 - Very small volume testing chambers
 - Bogus metrics
- Lawsuits
 - Sharper Image (early 2000s)
 - GPS vs. Dr. Zaatari & Bud Offermann
 - GPS vs. Elsevier



GPS Air® Files a Motion to Amend Complaint Against Elsevier, Seeking Damages in Excess of \$1.8 billion

<https://www.prnewswire.com/>

Air Cleaning Claims

This is a suitable place to give
a most earnest warning
against the use of so-called
secret remedies and patent
medicines.... Pettenkofer (1883)

- Many types of additive technologies (ions, plasma, ozone, hydroxyl radicals, etc.)
- Central paradox for additive technologies
 1. Emitting enough into the air to make a difference and there is risk of harm
 - “Our findings suggest that negative ions, possibly along with their reaction products with the room air constituents, adversely affect health.” Liu et al (2021) *Indoor Air*
 2. Not emitting enough into the air to make a difference
 - Cleaning power is small

Opportunity: Counter Misinformation



Systematically omitting indoor air quality: sub-standard guidance for shelters, group homes and long-term care in Ontario during the COVID-19 pandemic

Amy Katz, Tianyuan Li, LLana James, Jeffrey Siegel & Patricia O'Campo
Received 25 Oct 2022, Accepted 19 Sep 2023, Published online: 13 Oct 2023

Cite this article: <https://doi.org/10.1080/09581596.2023.2262736> Check for updates

Table 1. Selection of evidence and guidance related to the use of portable air filters in reducing transmission of airborne diseases.

Type	Reference
Studies demonstrating that portable air filters (PAFs) remove particles that are the same size as respiratory particles from the air.	Derk et al. 2023; Fennelly et al. 2023; Buising et al. 2022; Dellweg et al. 2022; Lee et al. 2022; Coyle et al. 2021; Curtius, Granzin, and Schrod 2021; Duill et al. 2021; Lindsley et al. 2021; Boswell and Fox 2006; Miller-Leiden et al. 1996; Rutala, Weber, and Jones 1995; Offermann et al. 1985
Studies demonstrating that PAFs help to reduce transmission of COVID-19 by reducing concentrations of SARS-CoV-2 RNA copies in the air.	Morris et al. 2022; Myers et al. 2022; Thuresson et al. 2022; Ueki et al. 2022; Rodríguez et al. 2021
Studies demonstrating that portable HEPA filtration has been a standard practice in hospital infection prevention and control.	Curtis 2008; Eckmanns, Rüden, and Gastmeier 2006; Hahn et al. 2002; Davis, McCray, and Simone 1997; Loo et al. 1996; Nicas et al. 1993; Sherertz et al. 1987
Engineering guidance documents recommending the use of PAFs to reduce transmission of airborne diseases.	Centers for Disease Control and Prevention 2023; ASHRAE 2023; OSPE 2022; ASHRAE 2021
Examples of high-quality guidance for PAFs use and do-it-yourself PAFs.	Li, Katz, and Siegel 2022; CleanAirCrew 2021
Studies and guidance to aid in selecting PAFs that do not use unproven technologies or generate harmful by-products.	Siegel 2016; ASHRAE et al. 2015; Waring and Siegel 2011

Li et al. In Review

Rapid response to wildfire smoke

Checklist/plain language guidance

Office Hours for community organizations to ask questions about reducing disease transmission/IAQ,
Grant-writing consulting

Sharing practical information about indoor air quality with community spaces

COVID-19 | Work and Health

Improvements to indoor air quality can help limit transmission of COVID-19 and other respiratory diseases. We're working with researchers with expertise in engineering, indoor air quality, epidemiology, public health and knowledge translation to help share practical information about improving indoor air quality with community spaces in Toronto and beyond.

Safer indoor air: Recommendations on wildfire smoke for community spaces and public health authorities

A guide for public health authorities and settings such as shelters, group homes, drop-ins, community centers, and community clinics with plain language information about reducing exposure to wildfire smoke.

[Read the guide here](#)

Reducing transmission of COVID-19 through improvements to indoor air quality: a checklist for community spaces

A plain language, step-by-step guide outlining how community spaces can use indoor air quality measures to help reduce transmission of COVID-19. The latest revision of this checklist was Oct 26, 2022. Please see the summary of revisions [2022].

[Read the guide here](#)

Indoor air office hours

Do you work at a community space or aggregate setting (like a shelter or a group home)? Would you like advice about reducing transmission of COVID-19 through indoor air quality measures (like ventilation and filtration)? Here's your chance! You can ask questions about HVAC systems, portable air filters, UV disinfection, and more! You can ask questions about particular rooms—like bathrooms, choir's or singing groups—or your whole building. These sessions are open to anyone working in community spaces including facility managers, people responsible for infection prevention and control, and workers who have questions about how indoor air quality measures can help make workplaces safer for everyone. For more information and to schedule an appointment, please see our flyer [here](#).

Resources

- Recommendations on Wildfire Smoke for Community Spaces and Public Health Authorities
- Reducing Transmission of COVID-19 Through Improvements to Indoor Air Quality

Investigators

Dr. Patricia O'Campo
Amy Katz
Dr. Amy (Tianyuan) Li
Dr. Jeff Siegel
Lana James
Jo Ann Chai (Team Research Fellow)

Staff

Pearl Bukarwala

Funders

School of Cities at the University of Toronto
Canadian Institutes of Health Research

Contact Info

Amy Katz
Amy.katz@maphealth.ca

Related Events

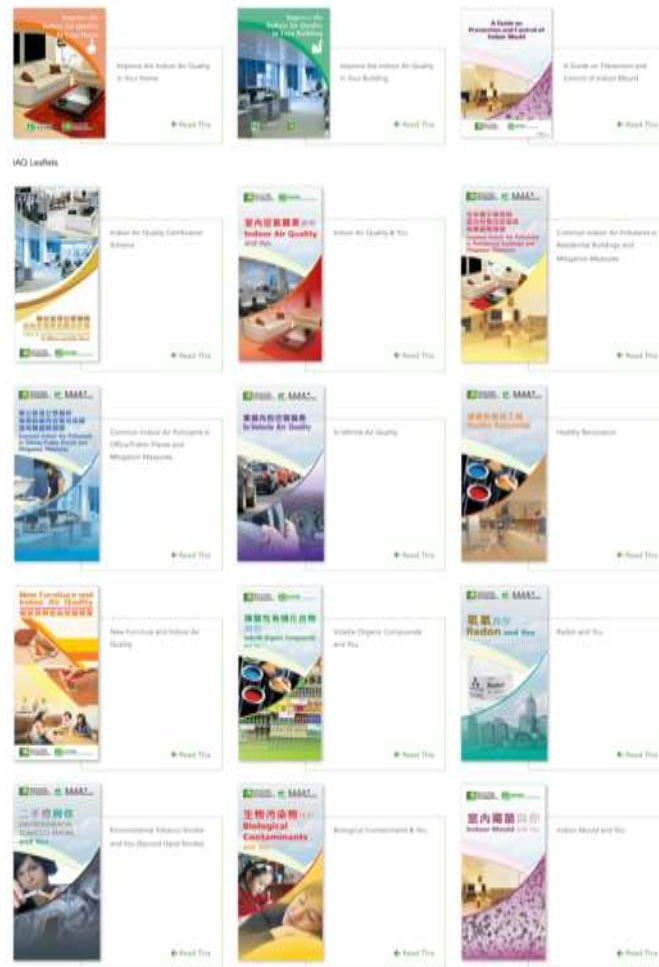
On-COVID Conversations: Critical concepts in ventilation & viral evolution
December 14, 2022

Indoor air quality, public health and COVID-19: a new guide for community spaces
October 19, 2022

Launch of "Safer COVID-19 and indoor air quality" – how community spaces can reduce transmission using ventilation, filtration and ultra-violet disinfection
April 5, 2022

<https://maphealth.ca/ventilation/>

Opportunity: Provide Good Information



Opportunity: Improve IAQ in Schools

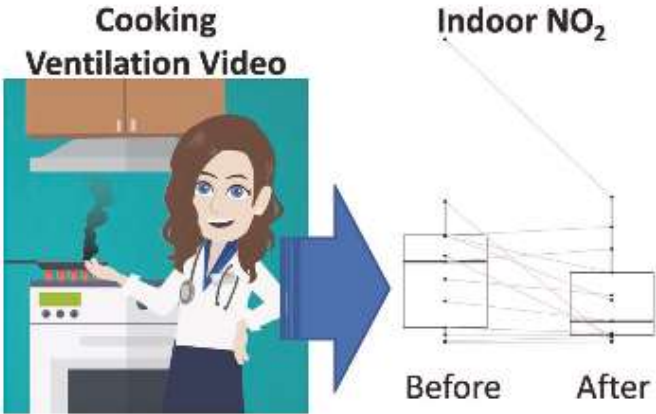
- <https://www.usgbc.org/resources/school-iaq-fact-sheets-entire-series>
- <https://www.epa.gov/iaq-schools/reference-guide-indoor-air-quality-schools>
- <https://www.lung.org/clean-air/indoor-air/building-type-air-resources/at-school/iaq-guide>
- <https://publications.gc.ca/site/eng/9.648748/publication.html>

How information is provided is as important as the information itself

Measured air quality impacts after teaching parents about cooking ventilation with a video: a pilot study

Stephanie M. Holm^{1,2,3}, Brett C. Singer⁴, Mi-Suk Kang Dufour^{3,5}, Woody Delp⁴, James E. S. Nolan^{1,2,3}, P. Jacob Bueno de Mesquita^{4,6}, Bailey Ward³, Yahna Williamson³, O'Philia Le³, Marion L. Russell⁴, Kim G. Harley³ and John R. Balmes^{1,3}

Holm et al. (2024) *JESEE*



Emergency Knowledge Translation, COVID-19 and indoor air: evaluating a virtual ventilation and filtration consultation program for community spaces in Ontario

Amy Katz[✉], Tianyuan Li, LLana James, Pearl Buhariwala, Jo-Ann Osei-Twum, Jeffrey Siegel & Patricia O'Campo

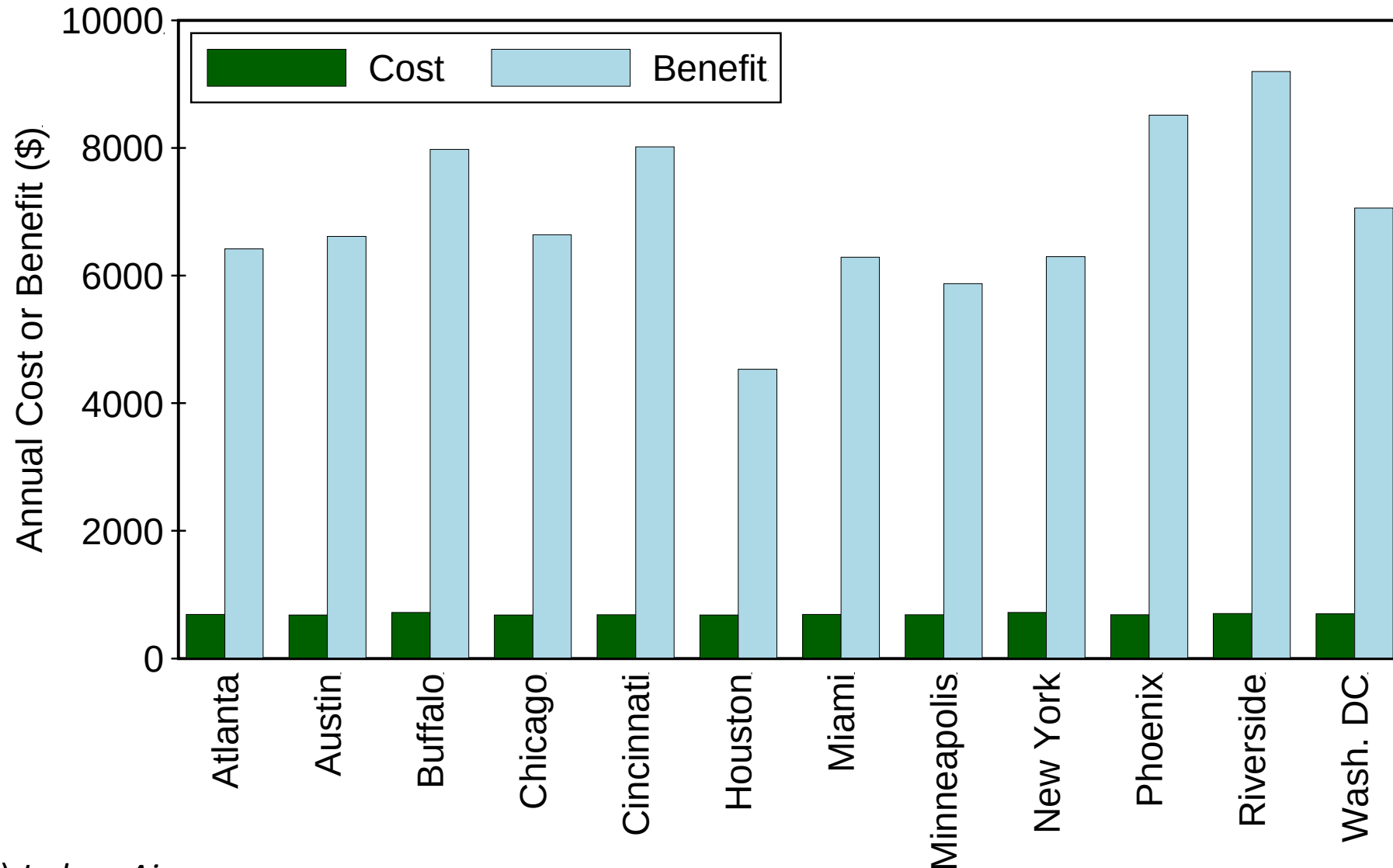
Katz et al. (2024) *BMC Pub Hlth*

Evidence-based interventions to reduce risk of airborne transmission of COVID-19 ^a	Concrete actions undertaken ^b	Number of survey participants who took this action (11 participants in total took part in the survey)
Portable air filters	Purchased additional portable air filters	55% (6)
	Increased use of portable air filters (i.e. used more often, or on a higher setting)	45% (5)
	Change in maintenance of portable air filters (e.g., wearing PPE while changing filters; checking the status of the filters regularly)	36% (4)
	Change in use of portable air filters (e.g., bringing several into a meeting room while a big meeting is going on; positioning portable air filters differently; running multiple on lower settings to reduce noise)	27% (3)

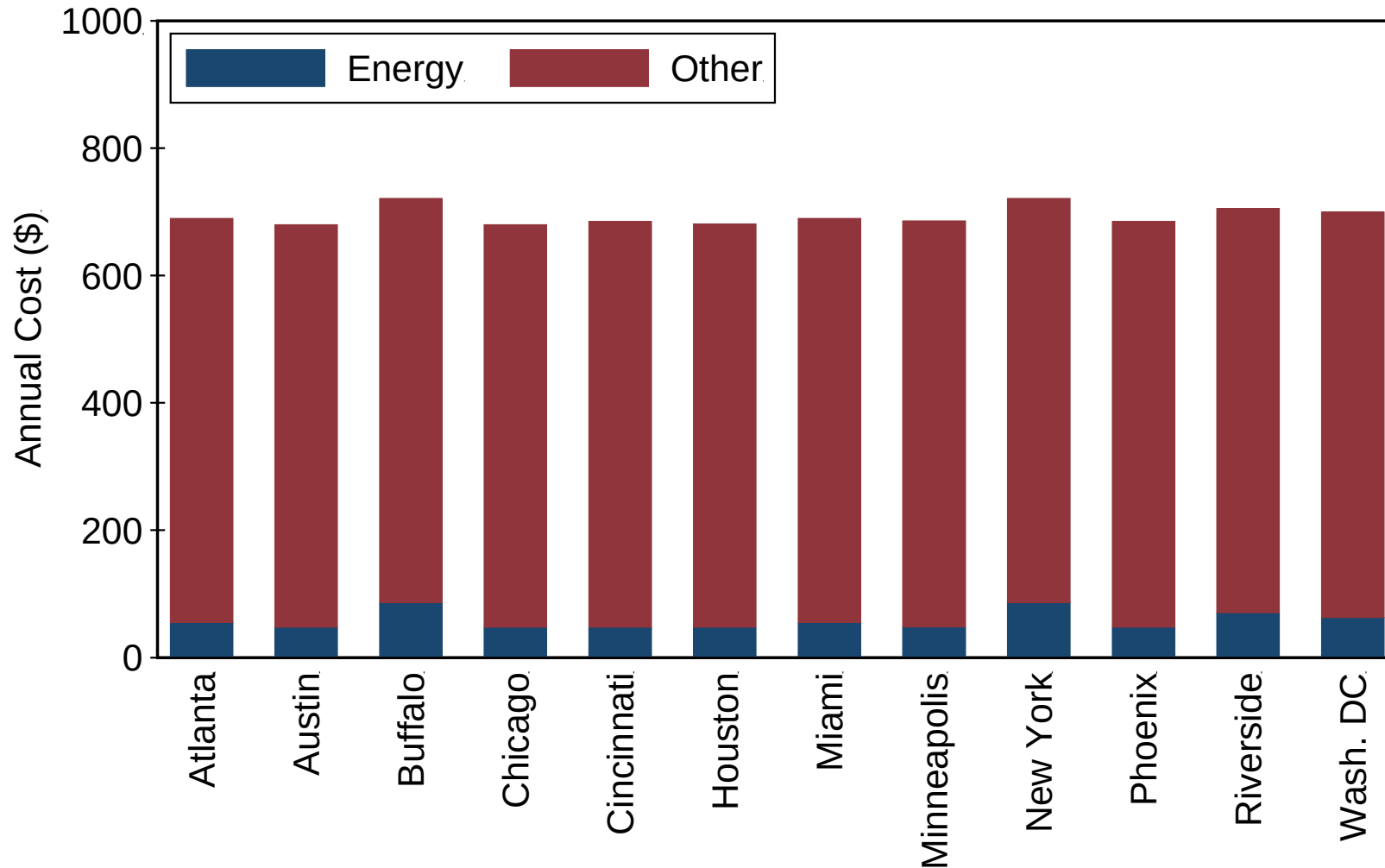
Challenge #4: Perception that IAQ goals oppose Energy, Climate, and Equity goals

- Common comments
 - IAQ improvement is expensive
 - IAQ improvement wastes energy
 - IAQ improvement furthers health disparities

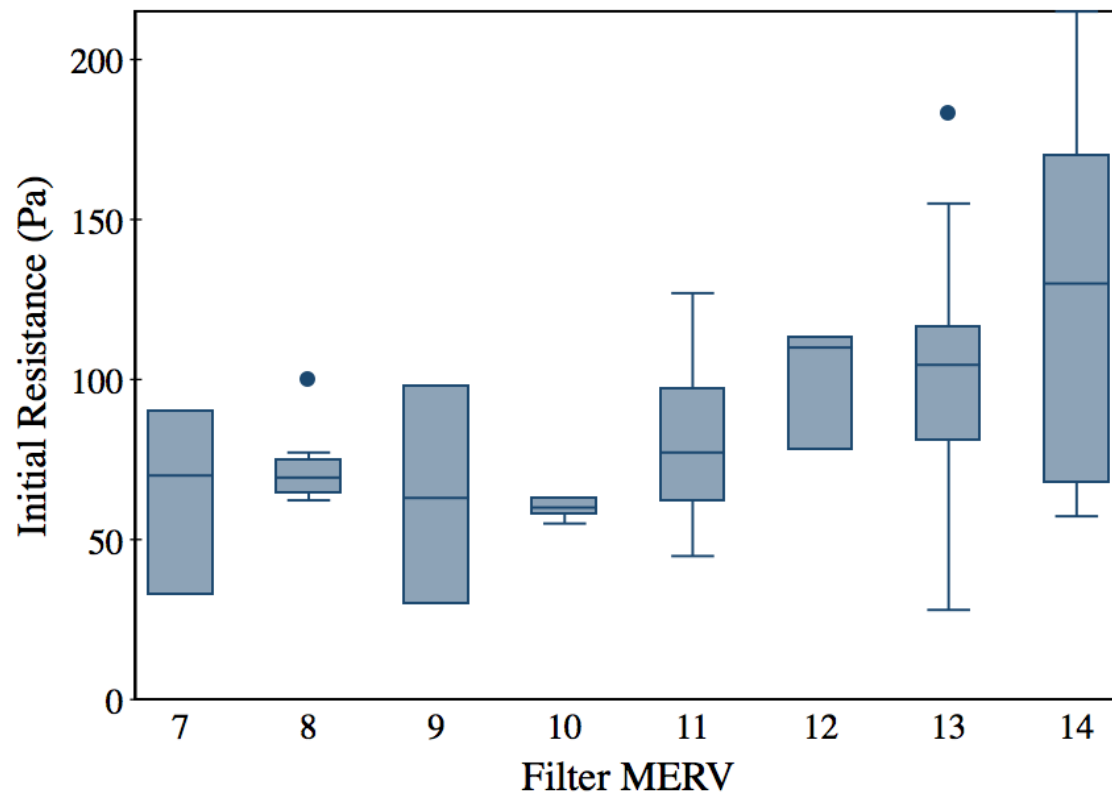
Opportunity : Completely show cost and Benefit



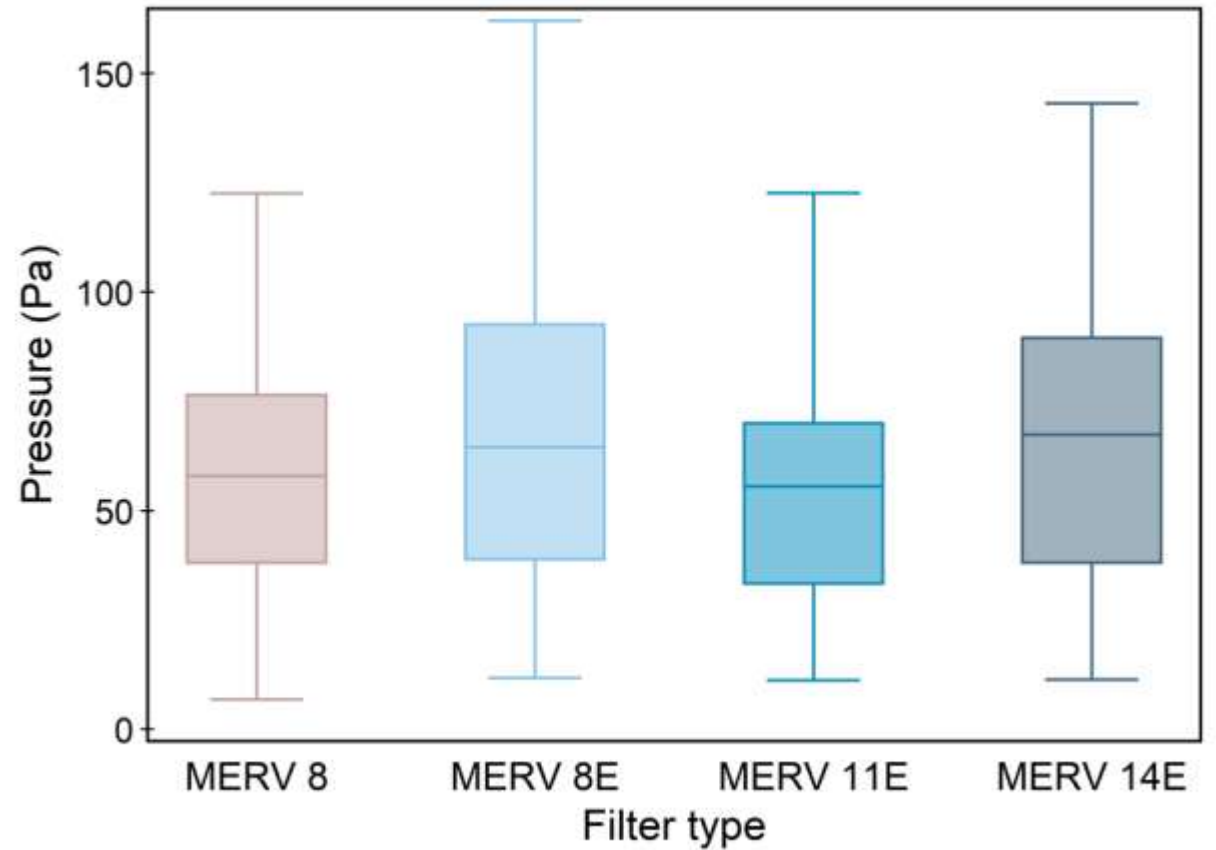
Opportunity: Include Energy



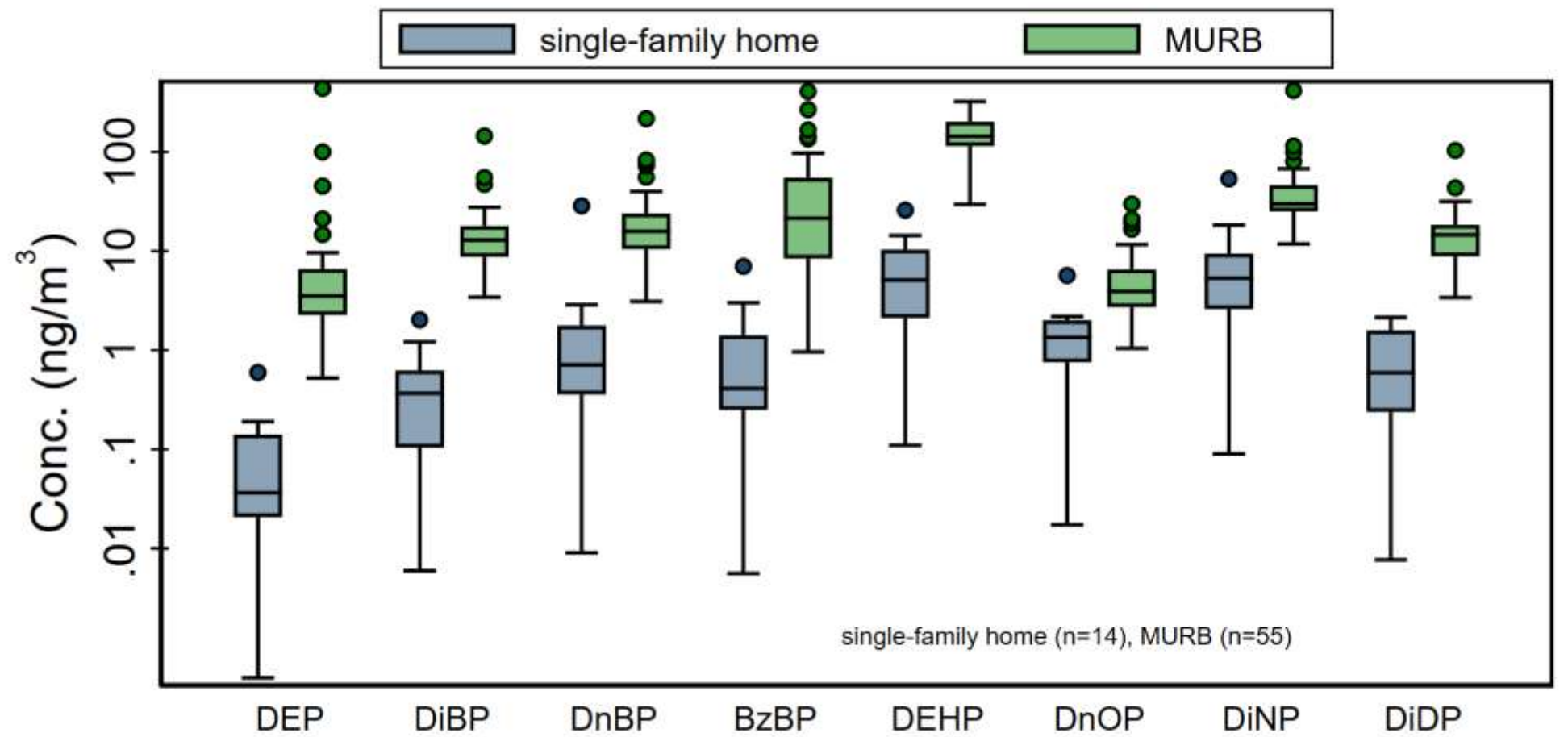
Opportunity: Measure/Show Energy



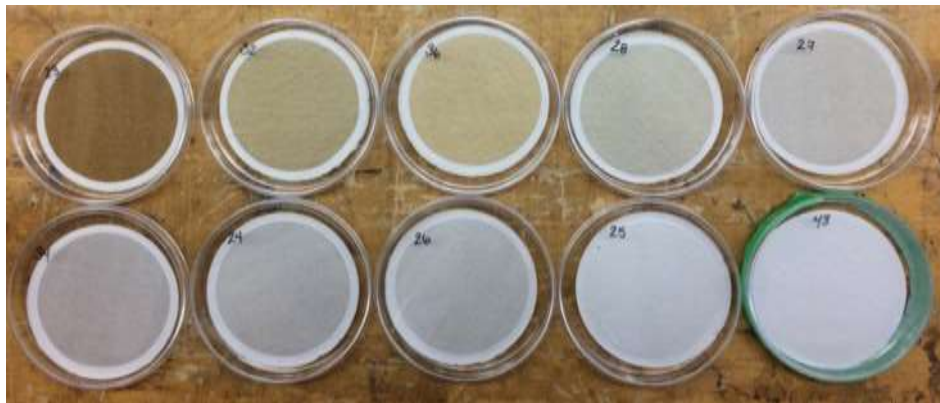
Ref: Zaatari (2014), Rivers and Murphy (1999) *ASHRAE RP-675*



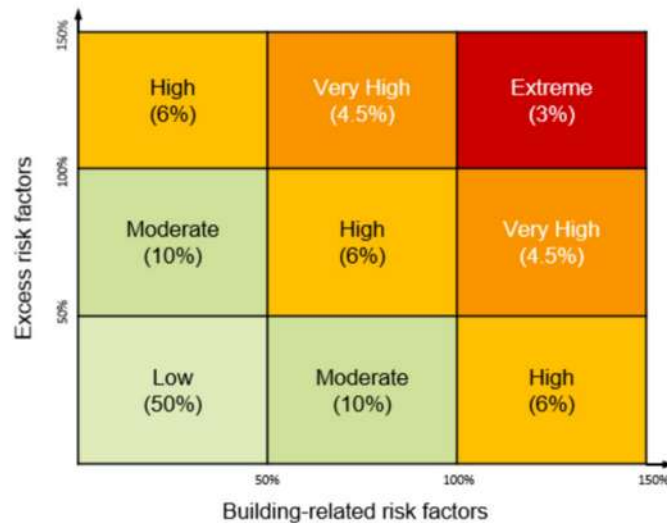
Data From Alavy et al. (2020) *Energy Bldg*



Li et al. (2024 *Bldg Environ*)



Opportunity: Target IAQ Approaches



Dymond et al. (2021) *Int. J. Environ. Res. Public Health*

		Upfront cost of intervention (per dwelling)										
		£0.00	£25.00	£50.00	£75.00	£100.00	£125.00	£150.00	£175.00	£200.00	£225.00	£250.00
Relative reduction in asthma associated symptoms due to intervention	0%	£0	£3,549,465	£7,098,930	£10,648,394	£14,197,859	£17,747,324	£21,296,789	£24,846,253	£28,395,718	£31,945,183	£35,494,648
	1%	-£4,607,942	-£1,058,477	£2,490,987	£6,040,452	£9,589,917	£13,139,382	£16,688,846	£20,238,311	£23,787,776	£27,337,241	£30,886,705
	2%	-£9,215,884	-£5,666,420	-£2,116,955	£1,432,510	£4,981,975	£8,531,439	£12,080,904	£15,630,369	£19,179,834	£22,729,298	£26,278,763
	3%	-£13,823,827	-£10,274,362	-£6,724,897	-£3,175,432	£374,032	£3,923,497	£7,472,962	£11,022,427	£14,571,891	£18,121,356	£21,670,821
	4%	-£18,431,769	-£14,882,304	-£11,332,839	-£7,783,375	-£4,233,910	-£684,445	£2,865,020	£6,414,484	£9,963,949	£13,513,414	£17,062,879
	5%	-£23,039,711	-£19,490,246	-£15,940,782	-£12,391,317	-£8,841,852	-£5,292,387	-£1,742,923	£1,806,542	£5,356,007	£8,905,472	£12,454,937
	6%	-£27,647,653	-£24,098,189	-£20,548,724	-£16,999,259	-£13,449,794	-£9,900,329	-£6,350,865	-£2,801,400	£748,065	£4,297,530	£7,846,994
	7%	-£32,255,595	-£28,706,131	-£25,156,666	-£21,607,201	-£18,057,736	-£14,508,272	-£10,958,807	-£7,409,342	-£3,859,877	-£310,413	£3,239,052
	8%	-£36,863,538	-£33,314,073	-£29,764,608	-£26,215,143	-£22,665,679	-£19,116,214	-£15,566,749	-£12,017,284	-£8,467,820	-£4,918,355	-£1,368,890
	9%	-£41,471,480	-£37,922,015	-£34,372,550	-£30,823,086	-£27,273,621	-£23,724,156	-£20,174,691	-£16,625,227	-£13,075,762	-£9,526,297	-£5,976,832
	10%	-£46,079,422	-£42,529,957	-£38,980,493	-£35,431,028	-£31,881,563	-£28,332,098	-£24,782,634	-£21,233,169	-£17,683,704	-£14,134,239	-£10,584,775

Figure 3. Incremental total cost varying the effectiveness and cost of the intervention across England over five years; extreme risk; 100% implementation rate; non-decent homes (asthma).

Summary

- Benefits of investing in IAQ far outweighs costs
- We face implementation challenges
- We need to get better at overcoming barriers
 - Political, economic, contextual, informational
- Many opportunities for positive change