



How well do buildings protect occupants during wildfire smoke episodes?

Ryan D. Huff, MSc, PhD

July 9, 2026

NCCEH Webinar Series



Overview

- Background, purpose, and methods
- Indoor air pollutants during smoke episodes
- General building characteristics
- Interventions/mitigation
- Overall summary

February 2026



Wildfire smoke: What is the relationship between outdoor and indoor air pollutants?

By Ryan D. Huff

National Collaborating Centre for Environmental Health



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Wildfire smoke

- Communities in North America frequently experience periods of **high air pollution** due to drifting **wildfire smoke**
- Wildfire smoke poses significant **health risks**





British Columbia

B.C.'s major wildfires remain out of control, despite calmer day of wind

Lower temperatures, higher humidity and lack of wind are all expected to calm Kiskatinaw River fire

[Lauren Vanderdeen](#) · CBC News · Posted: Jun 10, 2025 5:15 PM PDT | Last Updated: June 10, 2025

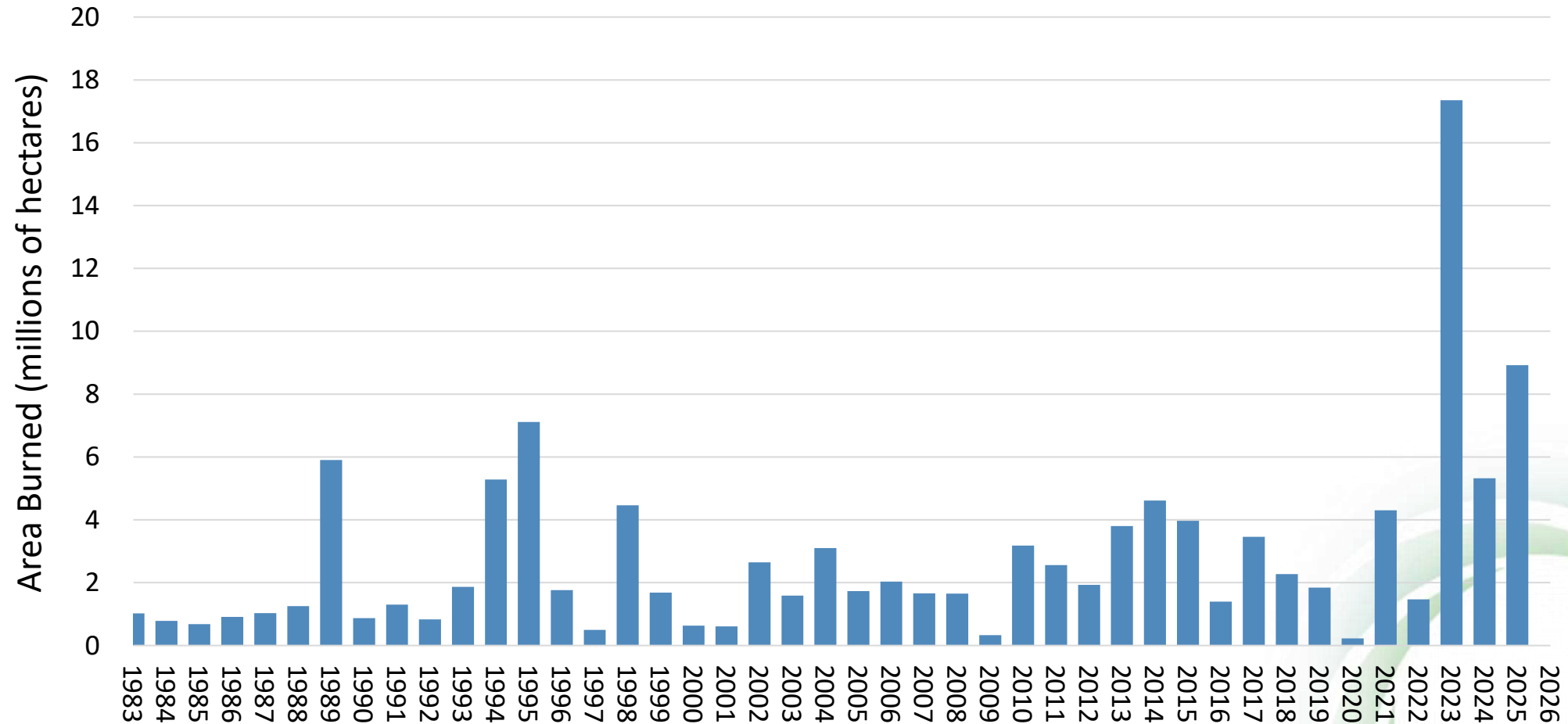


Smoke fills the sky above the Kiskatinaw River wildfire on June 8. The fire has moved east from B.C. and crossed into Alberta, triggering a string of evacuation notices. (B.C. Wildfire Service)



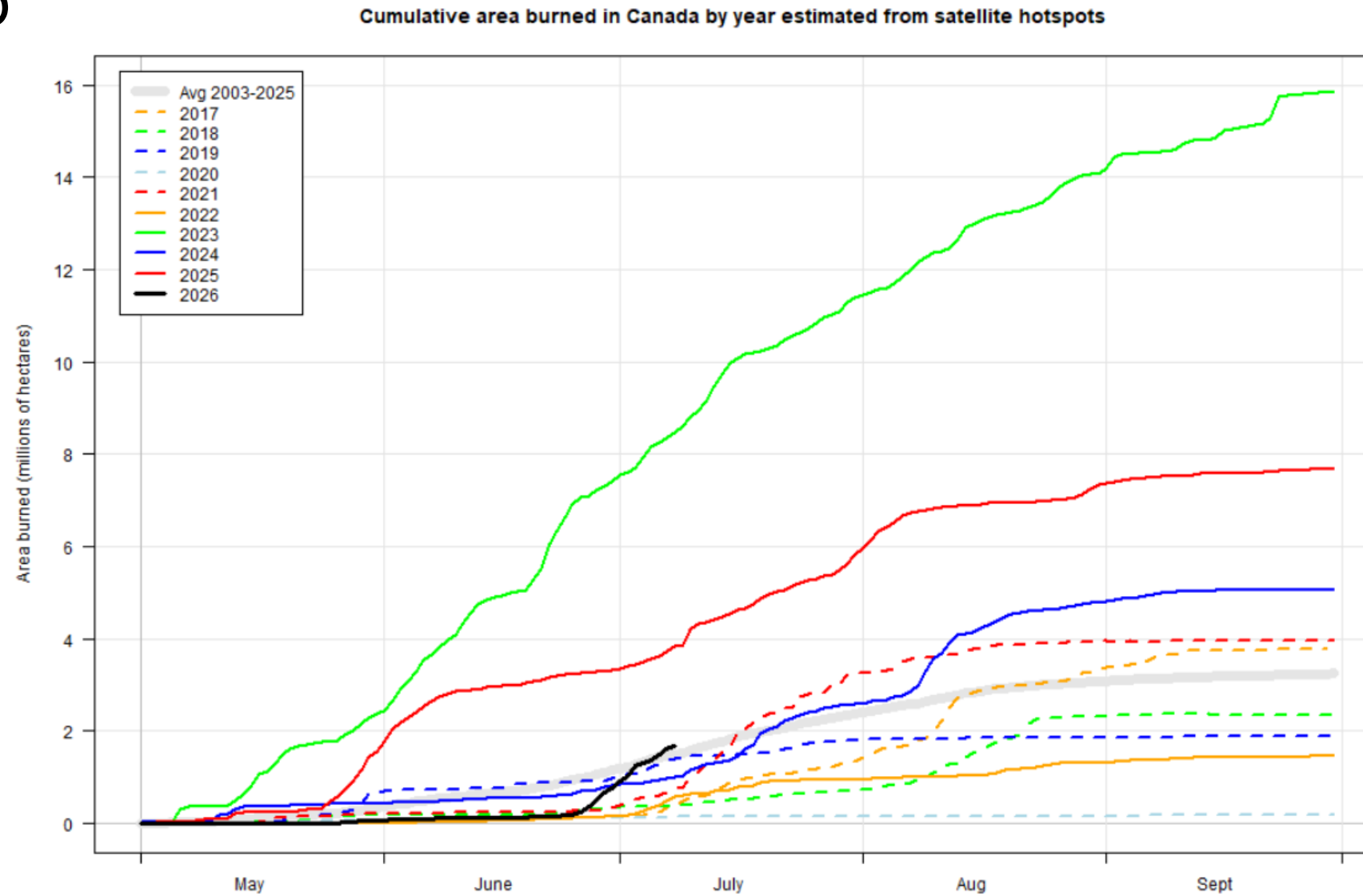
Halifax, NS, Canada - August 12, 2025

2025: Canada's second-worst wildfire season



Source: Canadian Interagency Forest Fire Centre

2026



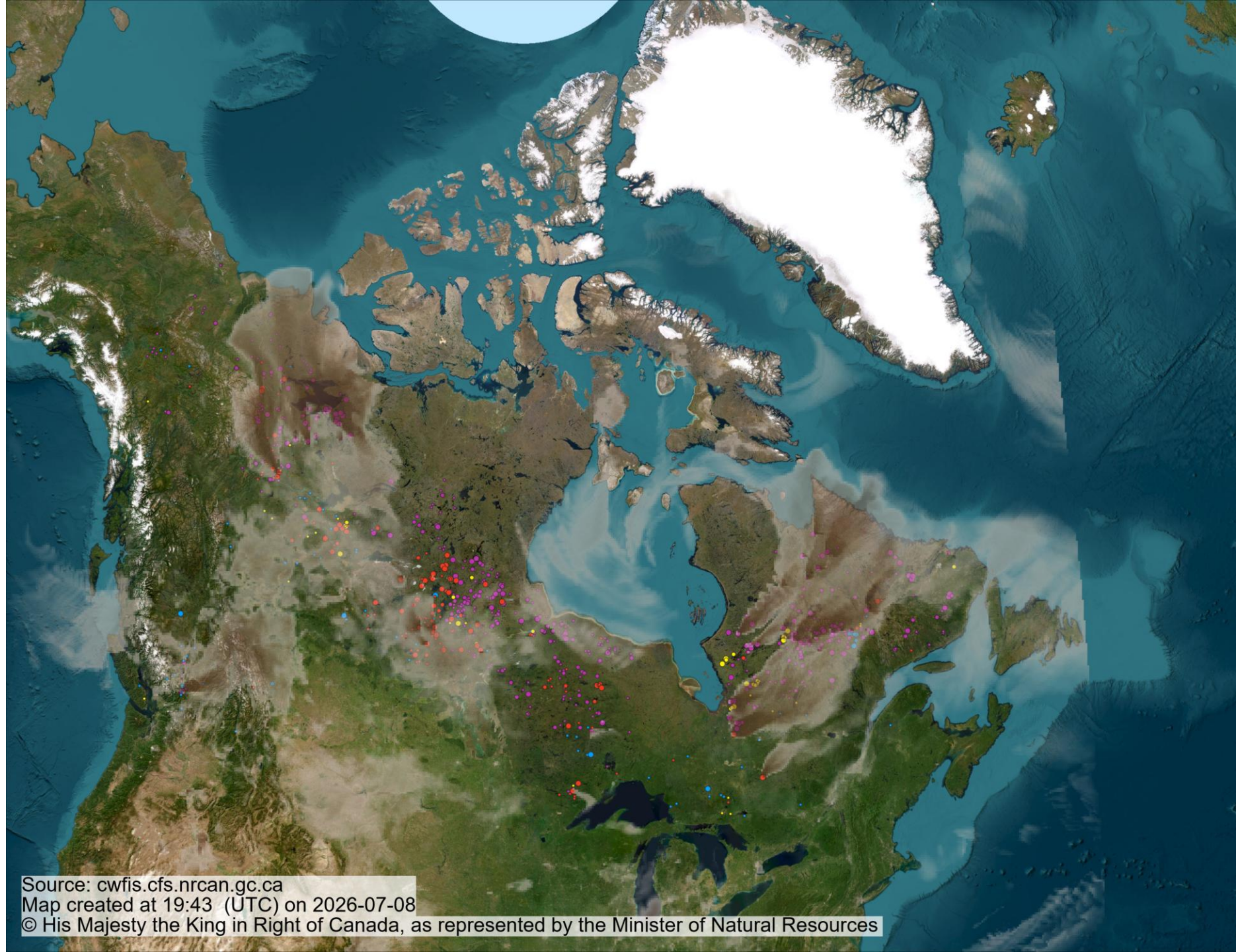
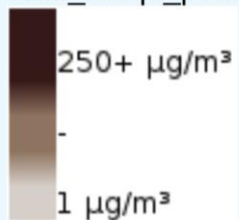
Source: Canadian Wildland Fire Information System

July 8 2026

cwfif_national_activefires
Stage of Control

- Out of Control
- Being Held
- Under Control
- Out of Control (Monitored)

cwfif_rdaqa_peaksмоke



Source: cwfis.cfs.nrcan.gc.ca

Map created at 19:43 (UTC) on 2026-07-08

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HEALTH EFFECTS OF WILDFIRE SMOKE

Respiratory effects

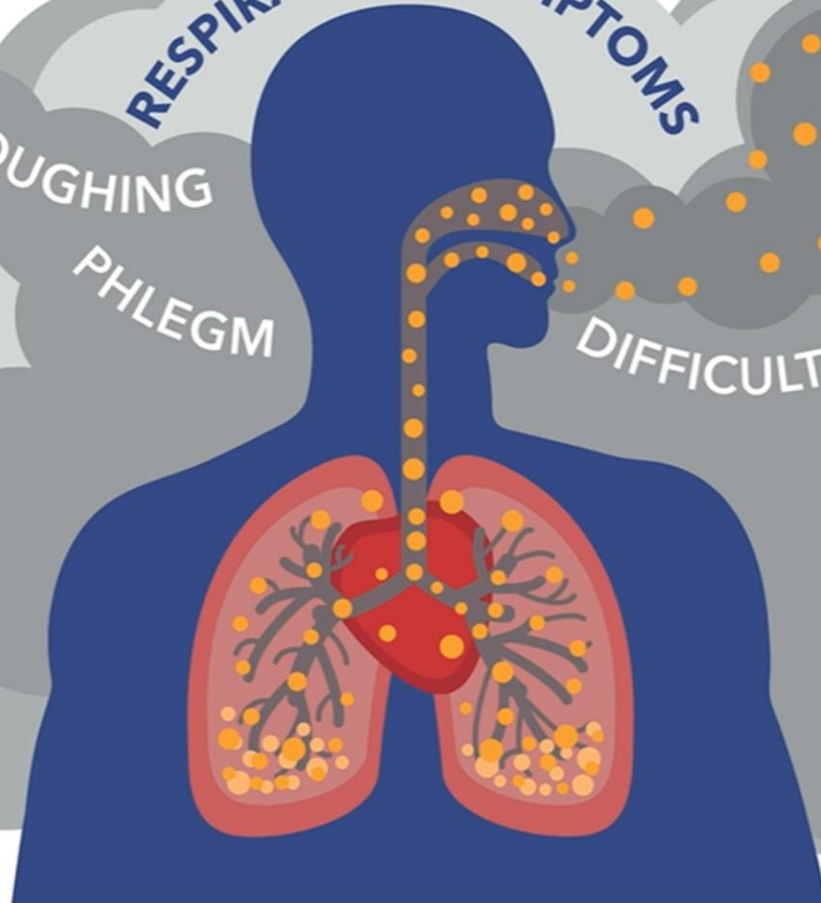
- Bronchitis
- Reduced lung function
- Asthma & other lung diseases aggravated
- Emergency room visits & hospital admissions



BAY AREA AIR QUALITY
MANAGEMENT DISTRICT

RESPIRATORY SYMPTOMS

COUGHING
PHLEGM



DIFFICULTY BREATHING
WHEEZING

Cardiovascular effects

- Heart failure
- Heart attack
- Stroke
- Emergency room visits & hospital admissions

WHAT'S IN WILDFIRE SMOKE?

WILDFIRE SMOKE EMISSIONS



FINE PARTICULATE MATTER (PM_{2.5})

Greatest public health concern in smoke; can reach deep into lungs and enter the bloodstream.



VOLATILE ORGANIC COMPOUNDS (VOCs)

Gaseous pollutants that cause eye, nose, throat irritation.



CARBON MONOXIDE (CO)

A poisonous gas from incomplete combustion; rare general public risk, dangerous close to fire.



POLYCYCLIC AROMATIC HYDROCARBONS (PAHs)

Toxic compounds formed during incomplete burning; many are suspected or known carcinogens.



NITROGEN DIOXIDE (NO₂)

Highly reactive gas that irritates airways and aggravates respiratory diseases, like asthma.



SULPHUR DIOXIDE (SO₂)

Gaseous oxide that can harm human respiratory system, make breathing difficult.



METHANE (CH₄)

A non-toxic gas but can displace oxygen in closed spaces; also a precursor to harmful ground-level ozone.



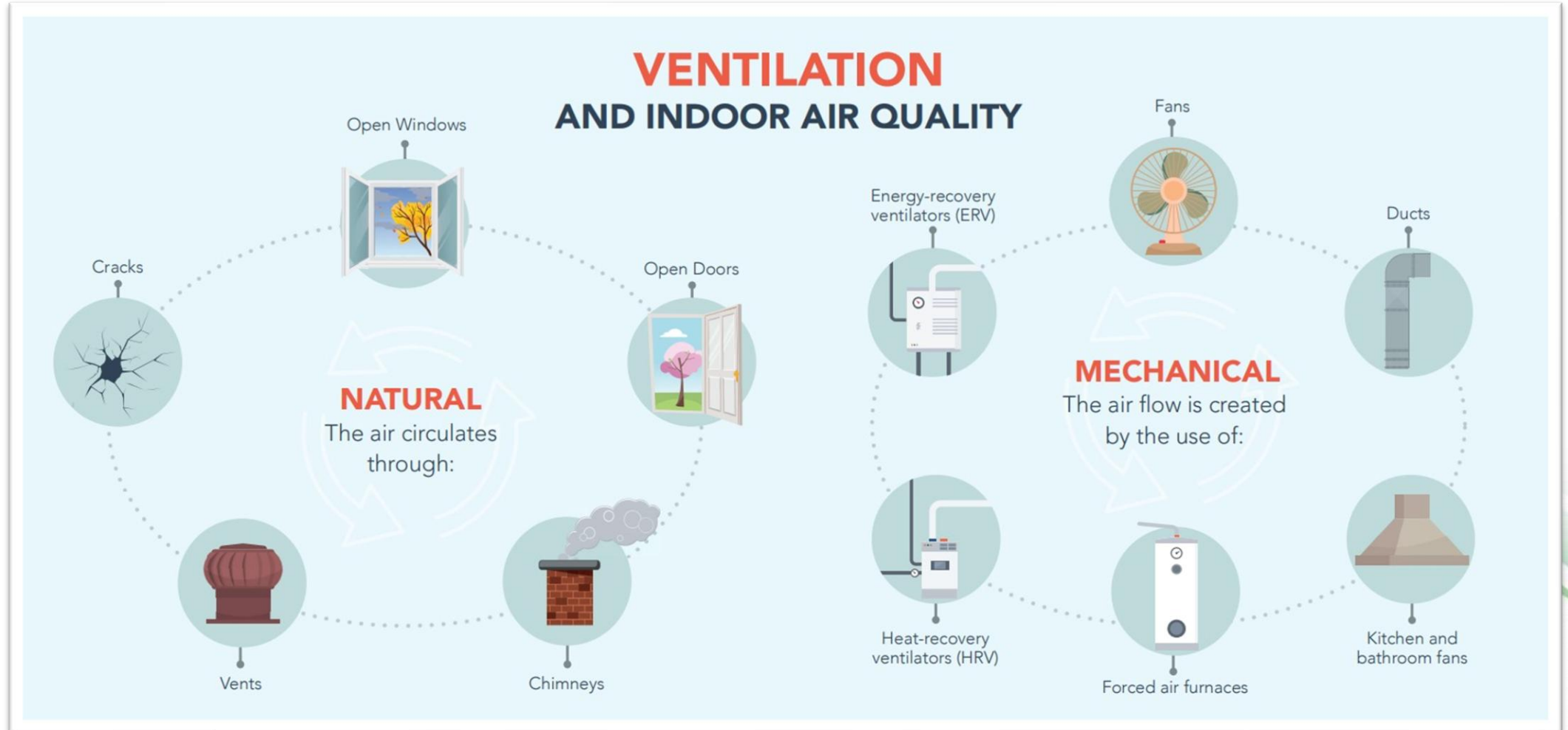
OZONE (O₃)

Ground-level ozone forms downwind from complex reactions between smoke gases in sunlight; a major smog component.

Indoor Air Quality



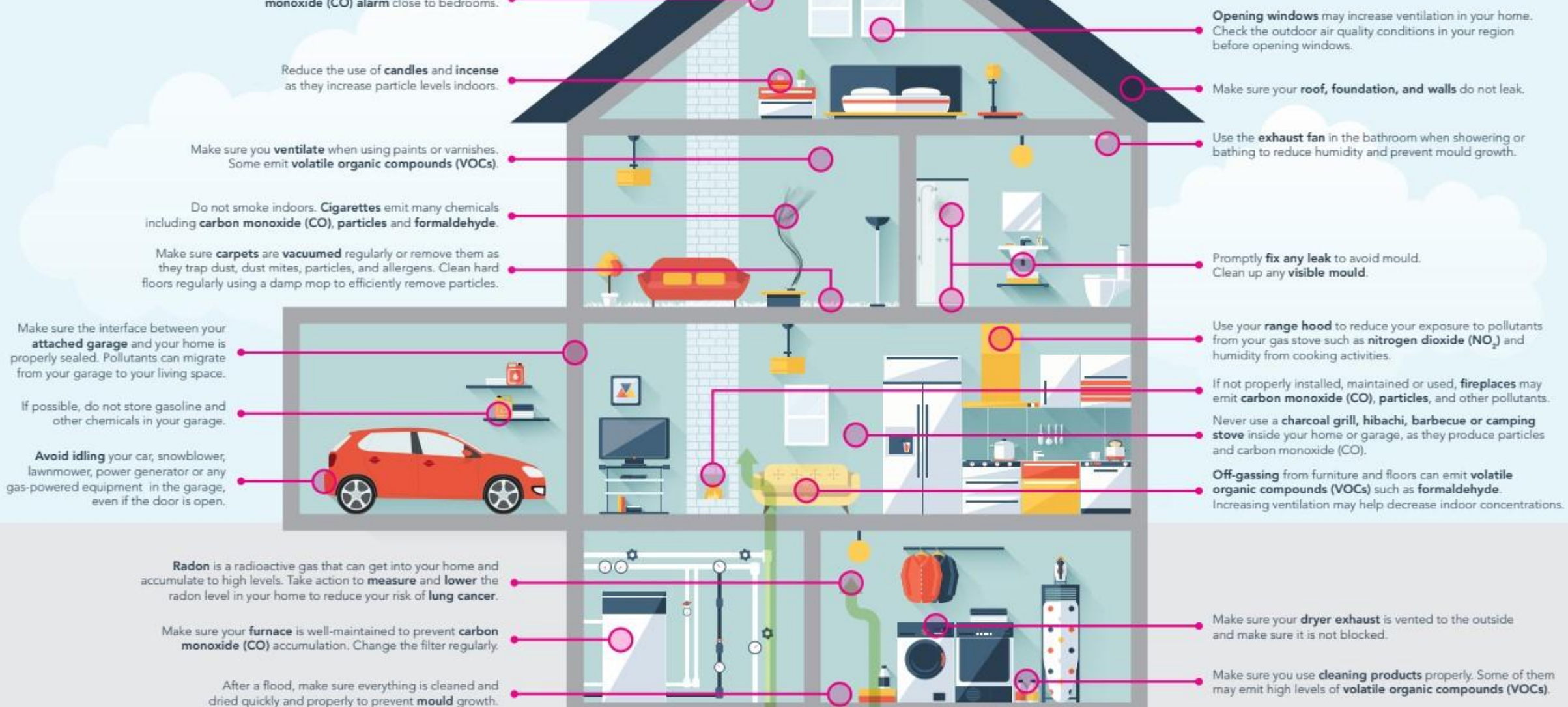
Indoor Air Quality



MAINTAIN AND IMPROVE INDOOR AIR QUALITY

Healthycanadians.gc.ca/IndoorAir

HC.air.SC@canada.ca



Indoor Outdoor (I/O) Ratio

Ratio between indoor and outdoor pollutant concentrations, with values above 1 indicating air pollutants are higher indoors than outdoors

Infiltration Factor (F_{inf})

Similar to I/O ratio, but removes indoor pollutant spikes that do not correspond to an outdoor spike

properly sealed. Pollutants can migrate from your garage to your living space.

If possible, do not store gasoline and other chemicals in your garage.

Avoid idling your car, snowblower, lawnmower, power generator or any gas-powered equipment in the garage, even if the door is open.

Radon is a radioactive gas that can get into your home and accumulate to high levels. Take action to **measure** and **lower** the radon level in your home to reduce your risk of **lung cancer**.

Make sure your **furnace** is well-maintained to prevent **carbon monoxide (CO)** accumulation. Change the filter regularly.

After a flood, make sure everything is cleaned and dried quickly and properly to prevent **mould** growth.

MAINTAIN AND IMPROVE INDOOR AIR QUALITY

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Opening windows may increase ventilation in your home. Check the outdoor air quality conditions in your region before opening windows.

Make sure your **roof, foundation, and walls** do not leak.

Use the **exhaust fan** in the bathroom when showering or bathing to reduce humidity and prevent mould growth.

Promptly **fix any leak** to avoid mould. Clean up any **visible mould**.

Use your **range hood** to reduce your exposure to pollutants from your gas stove such as **nitrogen dioxide (NO_2)** and humidity from cooking activities.

If not properly installed, maintained or used, **fireplaces** may emit **carbon monoxide (CO)**, **particles**, and other pollutants.

Never use a **charcoal grill, hibachi, barbecue or camping stove** inside your home or garage, as they produce particles and carbon monoxide (CO).

Off-gassing from furniture and floors can emit **volatile organic compounds (VOCs)** such as **formaldehyde**. Increasing ventilation may help decrease indoor concentrations.

Make sure your **dryer exhaust** is vented to the outside and make sure it is not blocked.

Make sure you use **cleaning products** properly. Some of them may emit high levels of **volatile organic compounds (VOCs)**.

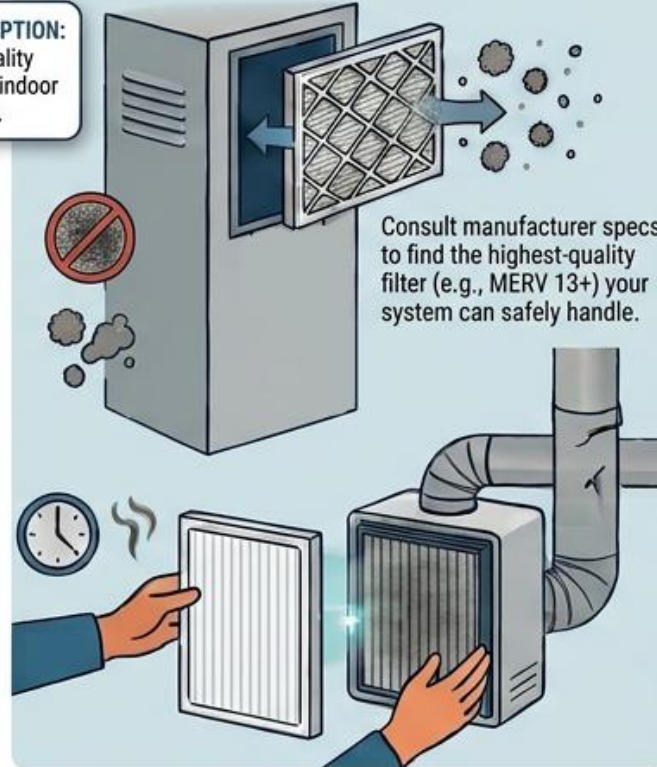
PROTECT YOUR INDOOR AIR FROM WILDFIRE SMOKE

1 KEEP WINDOWS & DOORS CLOSED



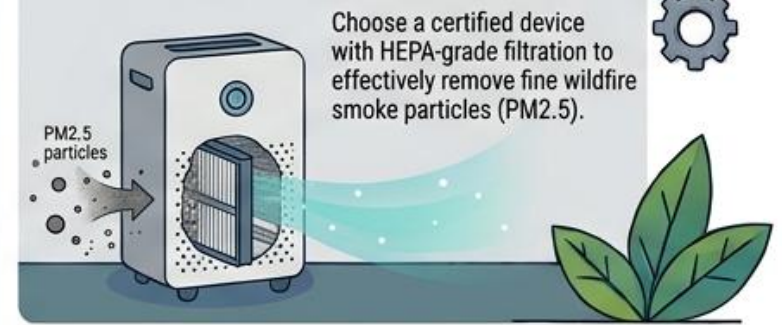
SPECIAL EXTREME HEAT EXCEPTION: Prioritize cooling if poor air quality and high heat coincide. A cool indoor temperature is a safety priority.

2 UPGRADE VENTILATION FILTER



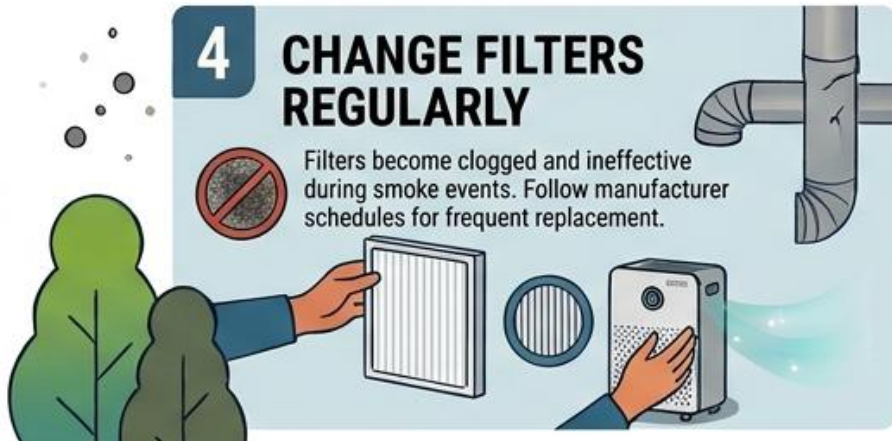
Consult manufacturer specs to find the highest-quality filter (e.g., MERV 13+) your system can safely handle.

3 USE A CERTIFIED PORTABLE AIR CLEANER



Choose a certified device with HEPA-grade filtration to effectively remove fine wildfire smoke particles (PM2.5).

4 CHANGE FILTERS REGULARLY



Filters become clogged and ineffective during smoke events. Follow manufacturer schedules for frequent replacement.

5 LIMIT EXHAUST FAN USE



Restrict operation of bathroom and kitchen exhaust fans, as they can draw smoky air indoors through gaps.

Review: Research questions

Research Questions:

1. What is the **relationship between outdoor and indoor air** pollutant concentrations during smoke episodes?
2. What is the **impact of closing windows and doors** on indoor air pollutant concentrations during smoke episodes?
3. What is the **impact of using portable air cleaners (PACs)** on indoor air pollutant concentrations during smoke episodes?
4. How do **building features** impact the relationship between indoor and outdoor air pollutant concentrations during smoke episodes?



Overview of studies

Comprehensive search of the peer-reviewed literature and manual searches of relevant special issues over the last 20 years identified 41 studies of moderate to high quality



Combustion Event

- Wildfire (n = 16)
- Residential wood smoke (n = 7)
- Wildfire/ residential wood smoke (n = 2)
- Haze (n = 5)
- Biomass (n = 2)
- Landfill fire (n = 1)

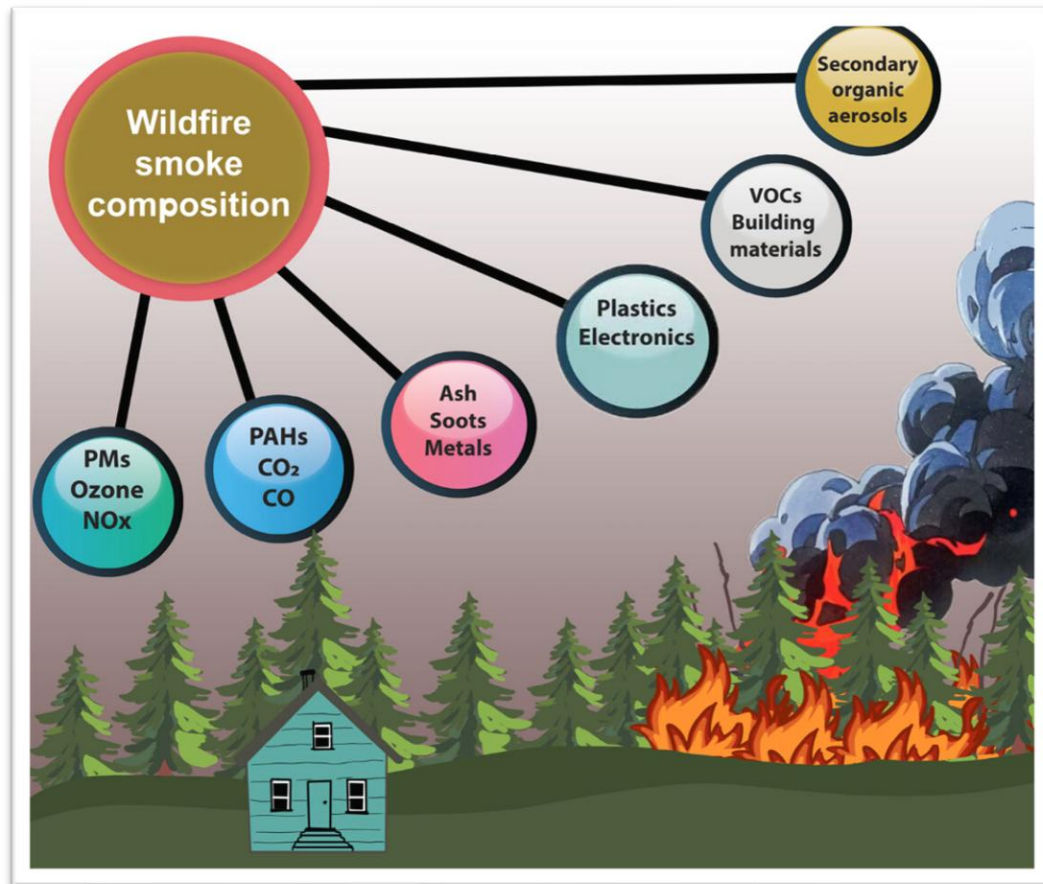
Setting

- Residential detached homes (n = 21; 51%)
- Apartment buildings (n = 5; 12%)
- Public buildings (n = 12) i.e., schools, university buildings, a public library, assisted living or skilled nursing facilities, churches, fitness centres, childcare centres, museums, community centres, a fire station, and a homeless shelter



What is the relationship between outdoor and indoor air pollutant concentrations during smoke episodes?

Results: What was measured?



- PAHs (n = 3; 7%)
- Trace metals, ions, and minerals (n = 3; 7%)
- Black carbon (BC) (n = 3; 7%)
- Inorganic gases (n = 4; 10%)
- Levoglucosan (n = 4; 10%)
- PM number concentrations (n = 6; 15%)
- PM_{2.5} mass concentrations (n = 31; 76%)

Results: Overview of non-PM pollutants

- **Indoor PAHs** were increased by up to **10-fold** when comparing non-smoke and smoke episodes
- Indoor concentrations of **ions** (e.g., nitrate or ammonium) and **trace metals** (e.g., iron or potassium) **doubled** during smoke episodes
- **Indoor CO₂ and NO₂** were generally **not elevated** during smoke episodes but were associated with indoor combustion sources
- **CO** was **elevated** in one study during a smoke episode, with concentrations below health-based exposure limits



Results: PAHs

Wildfire Impact on Indoor and Outdoor PAH Air Quality

Christine C. Ghetu, Diana Rohlman, Brian W. Smith, Richard P. Scott, Kaley A. Adams, Peter D. Hoffman, and Kim A. Anderson*

Study Details

- Washington, Oregon, California, and Idaho, USA
- Residential detached homes (n = 15)
- Air sampling period 3–4 weeks through study duration, Aug–Nov, 2018–2020

Results

- Average indoor vapour-phase HMW PAH concentrations 6x higher during wildfires
- Cancer and noncancer inhalation risk from PAHs: Indoor risk 3x higher, while outdoor risk 36x higher during wildfires

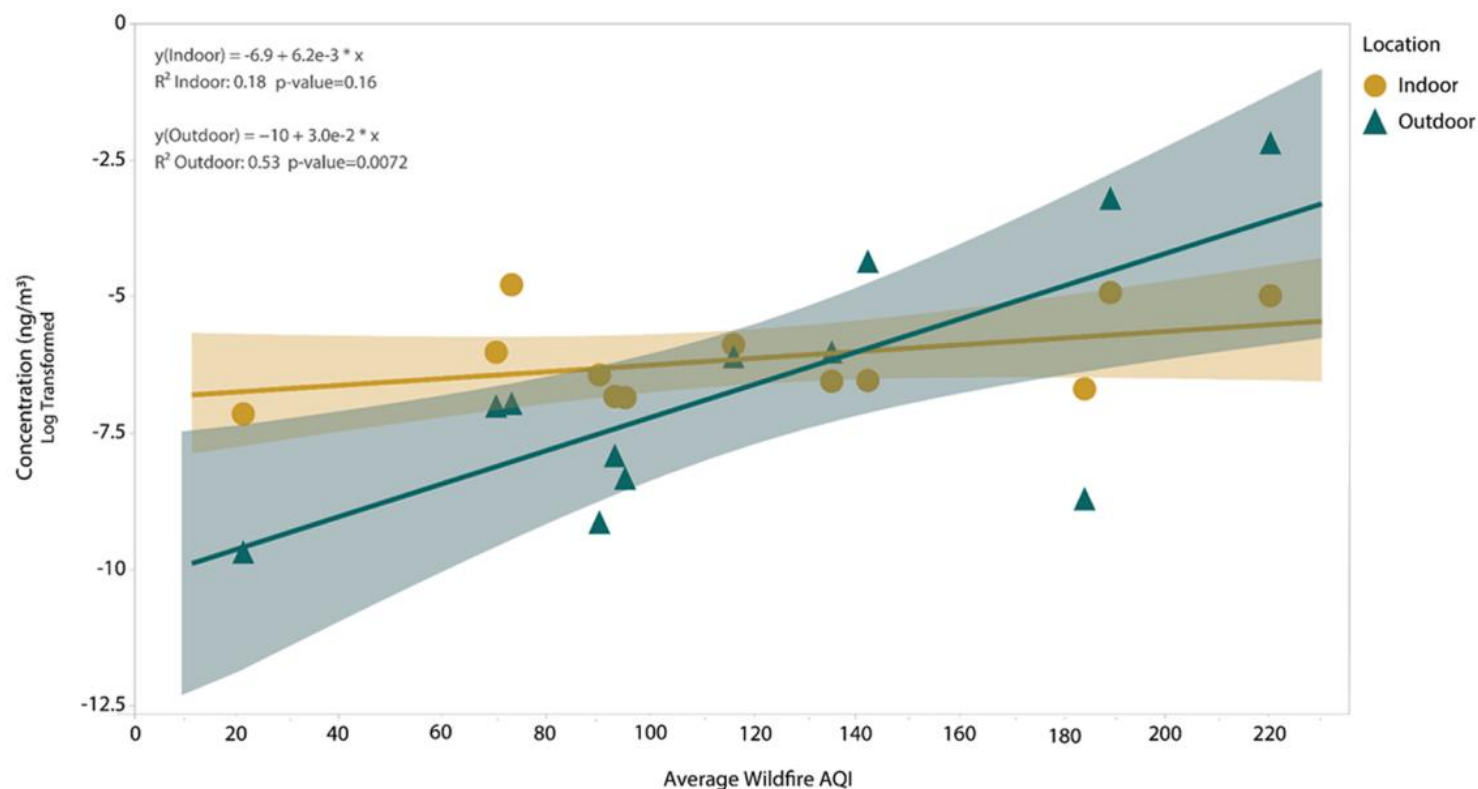
Results: PAHs

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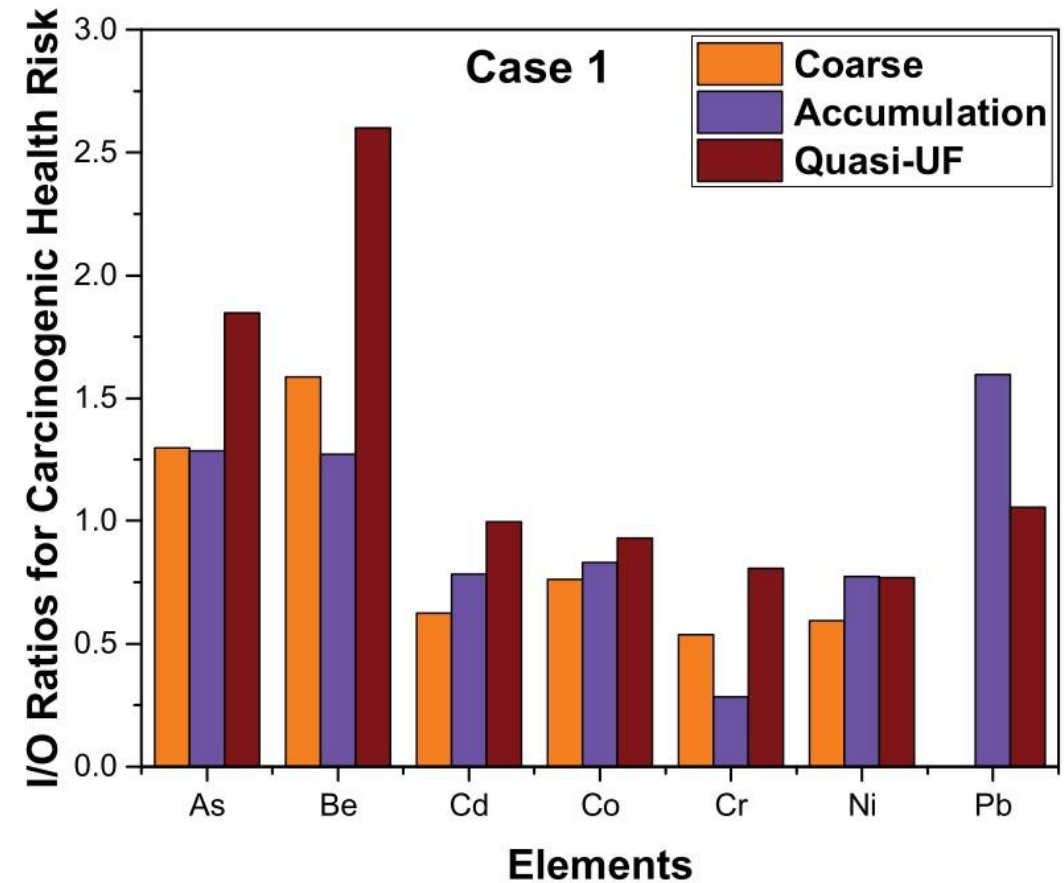
Study Details

- Washington, Oregon, California, and Idaho, USA
- Residential detached homes (n = 15)
- Air sampling period 3–4 weeks through study duration, Aug–Nov, 2018–2020



Results: Trace metals

- PM_{2.5} total ions increased from 8.77 to 14.98 µg/m³ (Tran et al. 2021)
- PM_{2.5} water-soluble trace metals increased from 0.75 to 1.53 µg/m³ (Tran et al. 2021)
- Elevated lifetime cancer risk values of 5.67×10^{-6} for naturally vented conditions (Sharma et al. 2017)

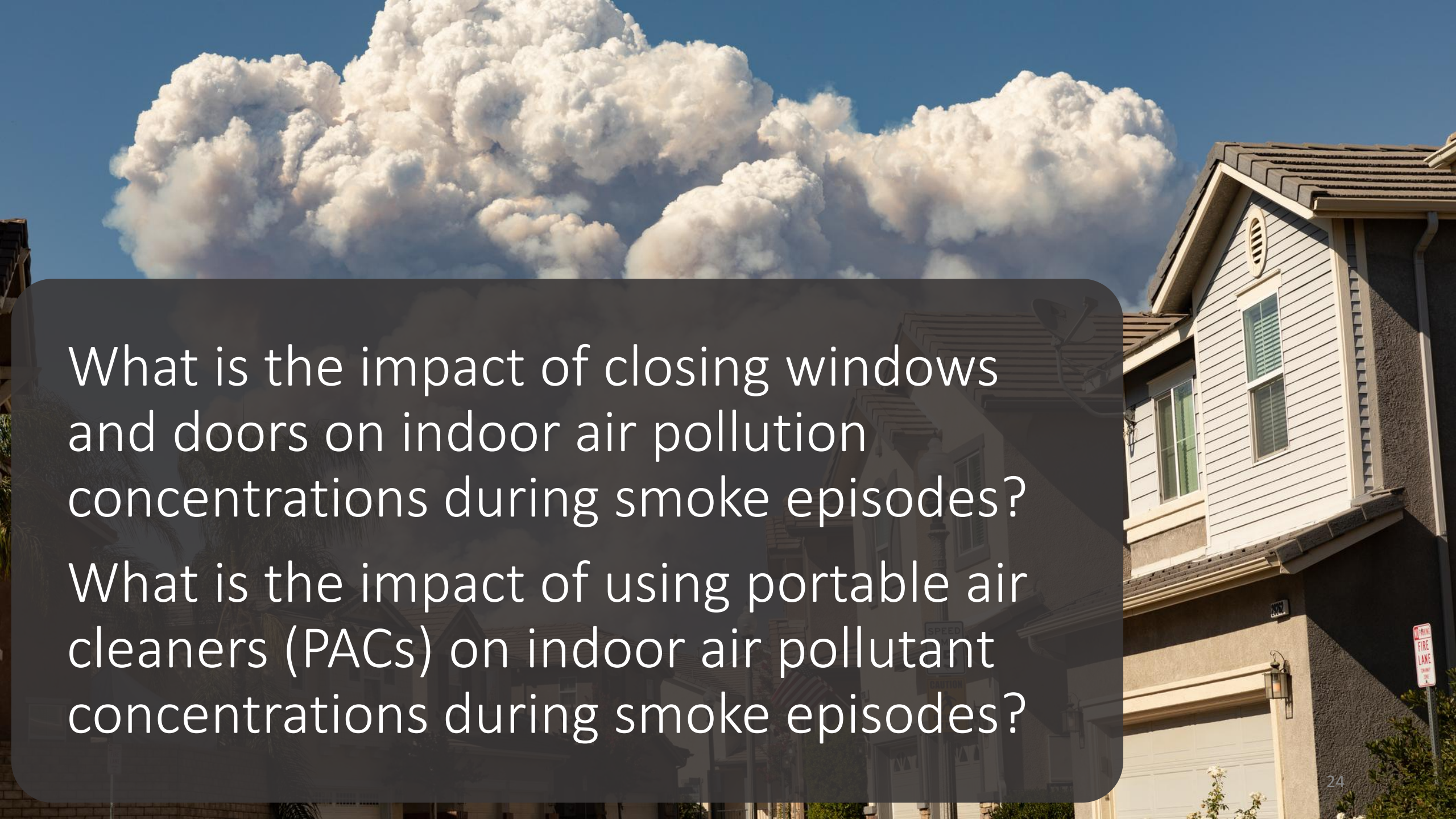


Sharma R, Balasubramanian R. Environ Res Lett. 2017;12(11)



Results: PM

- **Outdoor** median (range) outdoor PM_{2.5} mass concentration
 - Smoke episodes = **37.4 (3.9–157.0)** µg/m³ (20 studies)
 - Non-smoke episodes = **4.6 (2.0–9.1)** µg/m³ (4 studies)
- **Indoor** median (range) outdoor PM_{2.5} mass concentration
 - Smoke episodes = **31.5 (5.2–98.0)** µg/m³ (20 studies)
 - Non-smoke episodes = **4.7 (1.3–7.5)** µg/m³ (4 studies)
- **Indoor/outdoor (I/O)** median (range) PM_{2.5} mass concentration ratios
 - Smoke episodes = **0.74 (0.31–1.3)** µg/m³ (12 studies)
- **Infiltration factor (F_{inf})** median (range) PM_{2.5} mass concentration
 - Smoke episodes = **0.45 (0.20–0.70)** µg/m³ (9 studies)



What is the impact of closing windows and doors on indoor air pollution concentrations during smoke episodes?

What is the impact of using portable air cleaners (PACs) on indoor air pollutant concentrations during smoke episodes?

Mitigation: Closing windows

- Closing windows reduces indoor air pollutant concentrations during smoke-episodes
- **PM_{2.5} I/O ratios** median (range, n):
 - **0.76** (0.41-1.3, n = 6) when windows open
 - **0.62** (0.41-0.92, n = 7) when windows closed
- PM_{2.5} increased by 11.4% per every 10% increase in days with windows/doors open (95% CI: 6.4, 16.7) across 20 homes in Montana (Walker et al. 2023)
- I/O ratios were reduced for **ions (1.00 to 0.71)** and **trace metals (0.79 to 0.42)** in one study



Results: Closing windows and running PACs

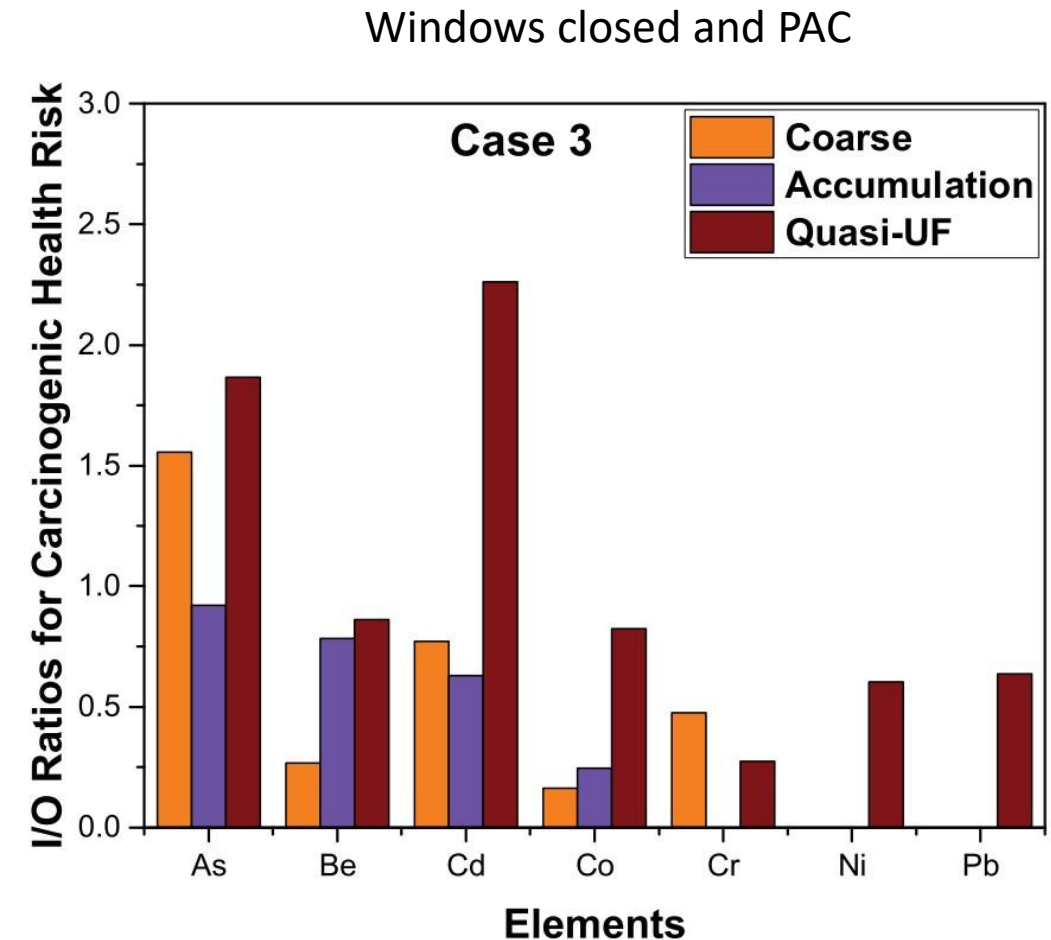
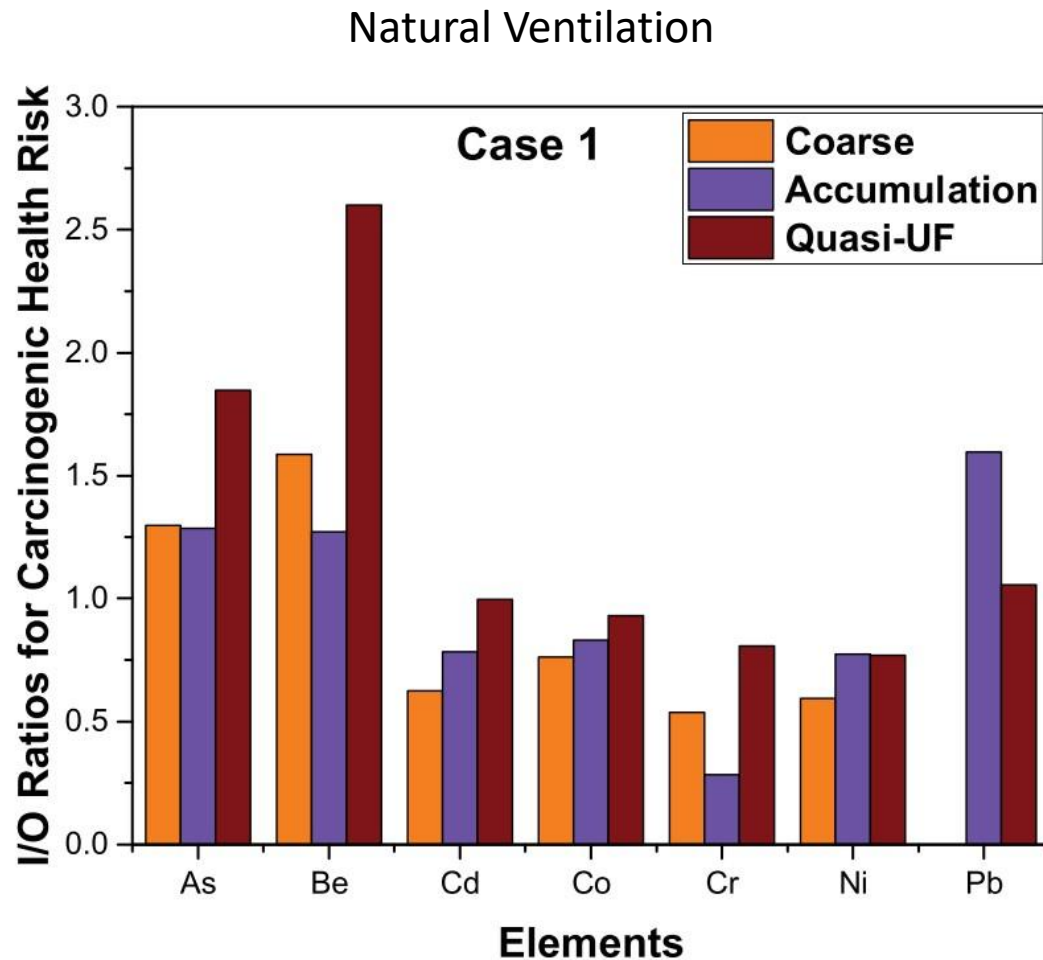
Windows closed studies:

- Indoor median (range, n) PM_{2.5} mass concentrations
 - Baseline = **29.2** (5.2–98) µg/m³ (7 studies)
 - PAC = **8.51** (0.4-30.7) µg/m³ (7 studies)
- Median (range) I/O ratios
 - Baseline = **0.74** (0.31–0.93) µg/m³ (5 studies)
 - PAC = to **0.25** (0.003–0.72) (5 studies)

Summary:

- Windows closed = 71% (18–99%) [PM_{2.5}] reduction with PAC
- Windows open = 37% (25–59%) [PM_{2.5}] reduction with PAC

Results: Closing windows and running PACs



How do building features impact the relationship between indoor and outdoor air pollutant concentrations during smoke episodes?



BUILDING ENVELOPE

THE TOTAL EXTERIOR SHIELD OF YOUR HOME



Results: Building characteristics

Construction methods influence smoke infiltration

- Tighter building envelopes reduced $PM_{2.5}$ infiltration by 68% vs. 31% in leakier envelopes (Wheeler et al. 2024)
- Post-1975 buildings had lower $PM_{2.5}$ infiltration ($F_{inf}=0.27$) than older buildings ($F_{inf}=0.41$) (Walker et al. 2023)
- Energy efficient homes $PM_{0.5-2.5}$ I/O ratios (Shrestha et al. 2019)
 - Traditional builds: 0.66
 - Energy efficient retrofitted: 0.57
 - Certified built green: 1.02



Results: Building characteristics

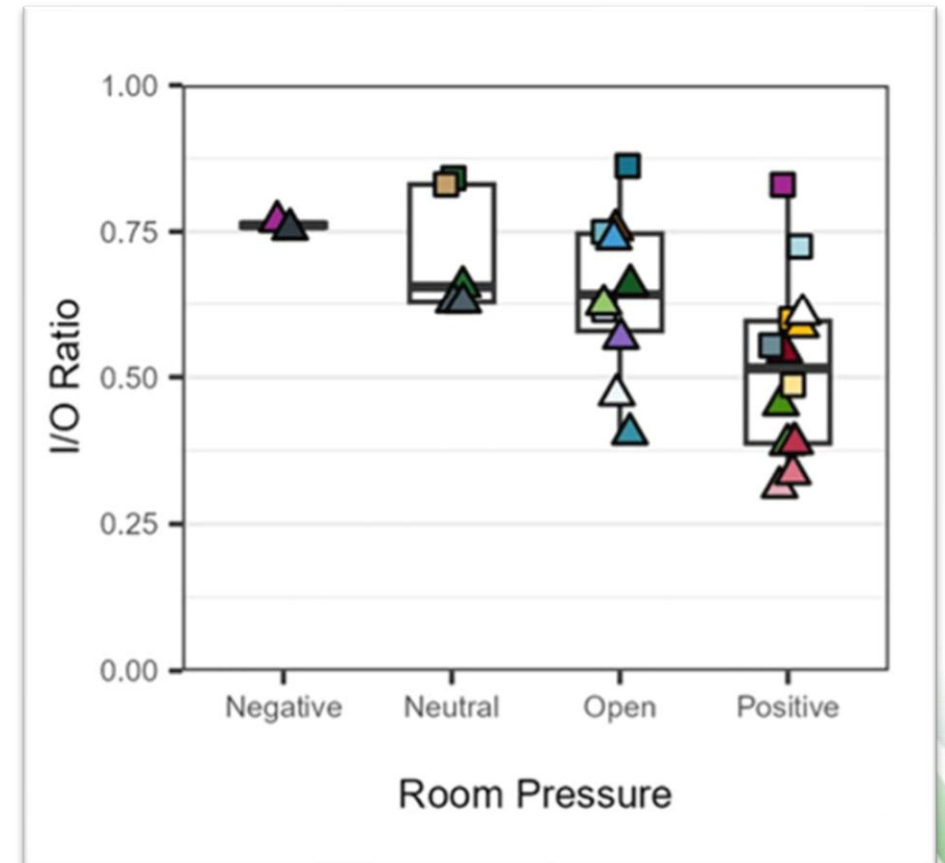
HVAC systems

- $\text{PM}_{0.5-2.5}$ particle number and black carbon F_{inf} values were significantly higher by 18% and 4%, respectively, when mechanical ventilation was present in residential homes (Shrestha et al. 2019)
- $\text{PM}_{2.5}$ F_{inf} of 0.29 (95% CI: 0.28, 0.30) on non-wildfire days and 0.59 (95% CI: 0.49, 0.71) on wildfire days in skilled nursing facilities that had HVAC systems with MERV 13 filters (Montrose et al. 2022)

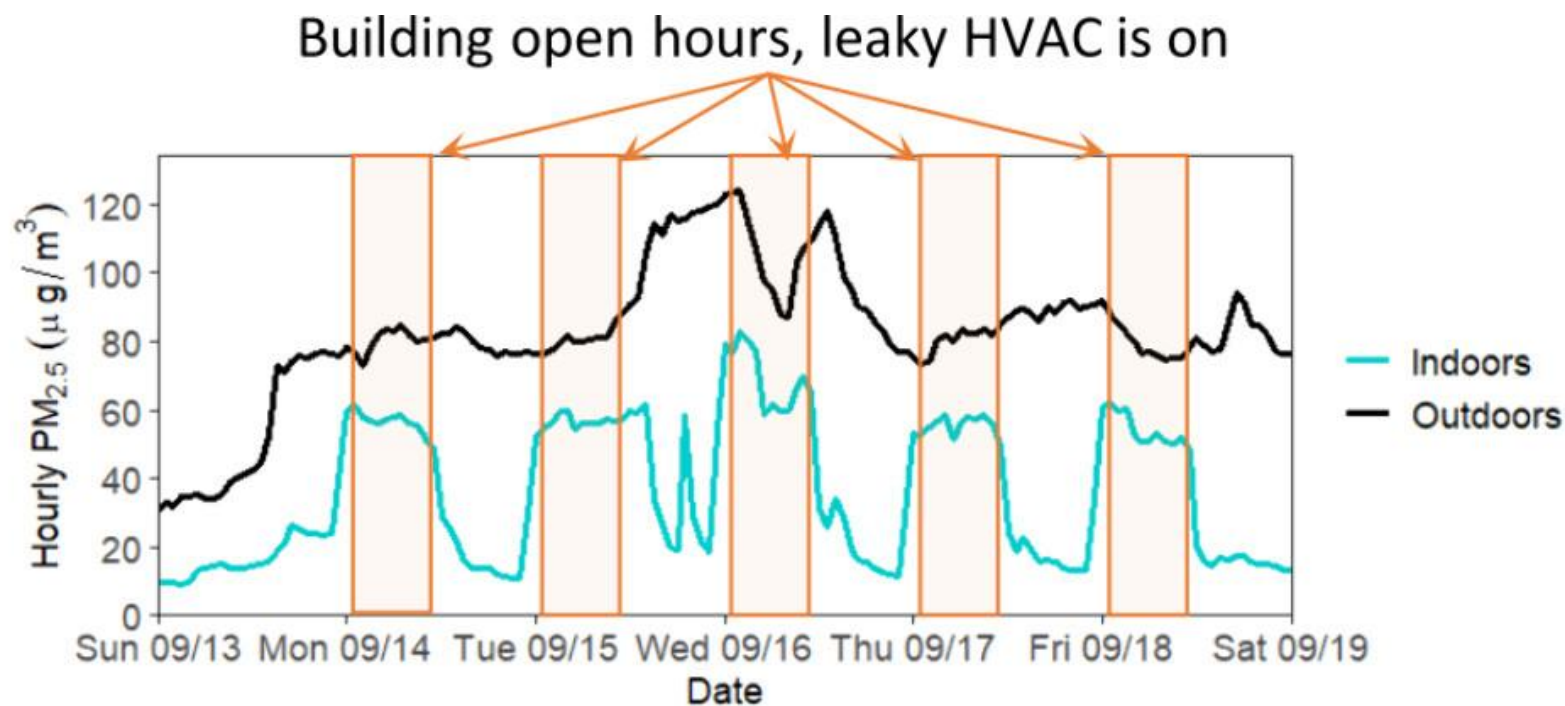


Results: Building characteristics

- Holder et al. examined 23 public buildings during wildfire smoke episodes in Missoula, Montana.
- Factors significantly associated with higher indoor $PM_{2.5}$ during smoke episodes
 - Filter bypass
 - HVAC condition
 - Window type
 - Room pressure.



Results: Building characteristics



Open Indoor/Outdoor $PM_{2.5} = 0.69$

Indoor $PM_{2.5} = 59 \mu g/m^3$

Closed Indoor/Outdoor $PM_{2.5} = 0.31$

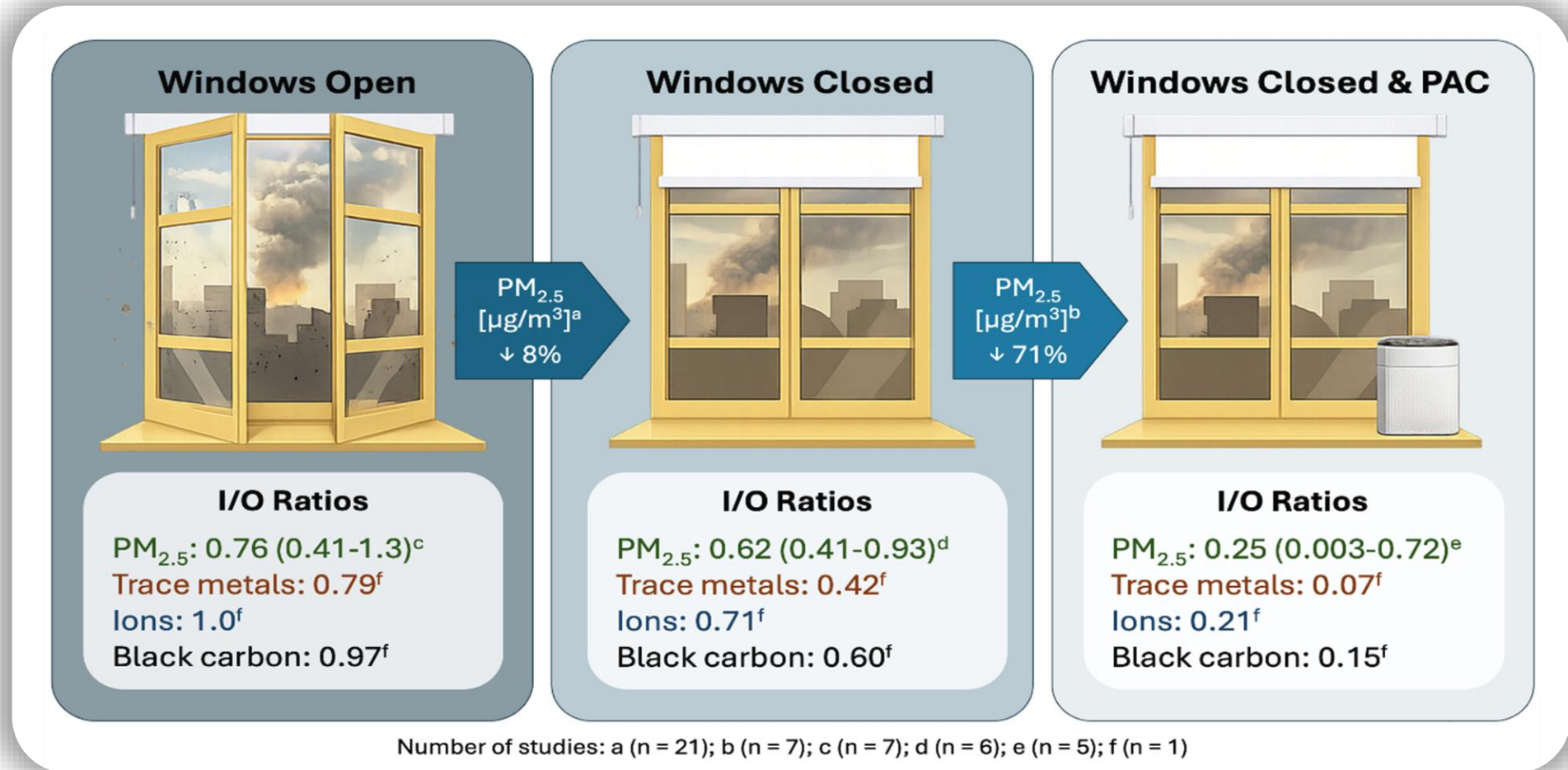
Indoor $PM_{2.5} = 25 \mu g/m^3$



Overall Summary

- Buildings offer meaningful but incomplete protection during smoke episodes
- No two buildings are exactly alike
- Tighter building envelopes reduce smoke infiltration
- Building occupant behaviours influence smoke infiltration
- Combining multiple strategies (closing windows, PACs, HVAC use) provides the best protection

Overall smoke infiltration summary



Overall evidence gaps



- Few studies examining non-PM pollutant infiltration and effective interventions
- Factors influencing infiltration of other smoke pollutants such as PAHs and VOCs are less understood.
- Lack of studies on the impact of exhaust fans specifically during combustion-derived air pollution events.



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for Methods and Tools
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Rapid Review: What effect does indoor air filtration and air cleaning have on concentrations of pollutants and human health endpoints during combustion-derived air pollution episodes?

Prepared by: The National Collaborating Centre for Environmental Health and
The National Collaborating Centre for Methods and Tools

May 27, 2025

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Wiens, M., He
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ISBN: 978-1-9

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Wildfire smoke and portable air cleaners: Improving air quality in schools and child care facilities

Ryan Huff Aug 13, 2025

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School of Nursing



Rapid Review: What effect does public health messaging about wildfire smoke have on behaviours and human health outcomes?

Prepared by: The National Collaborating Centre for Methods and Tools

Date: May

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June 2026

After the wildfire: Indoor smoke residues and cleaning considerations

By Ryan D. Huff
National Collaborating Centre for Environmental Health



Other resources of interest

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Thank you!

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