Use of low-cost air quality sensors in childcare and long-term care facilities in BC and impacts of wildfire smoke on indoor air quality

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NCCEH

Vancouver, BC

June 11, 2024

BC Centre for Disease Control

Health Canada Santé Canada

AGENDA

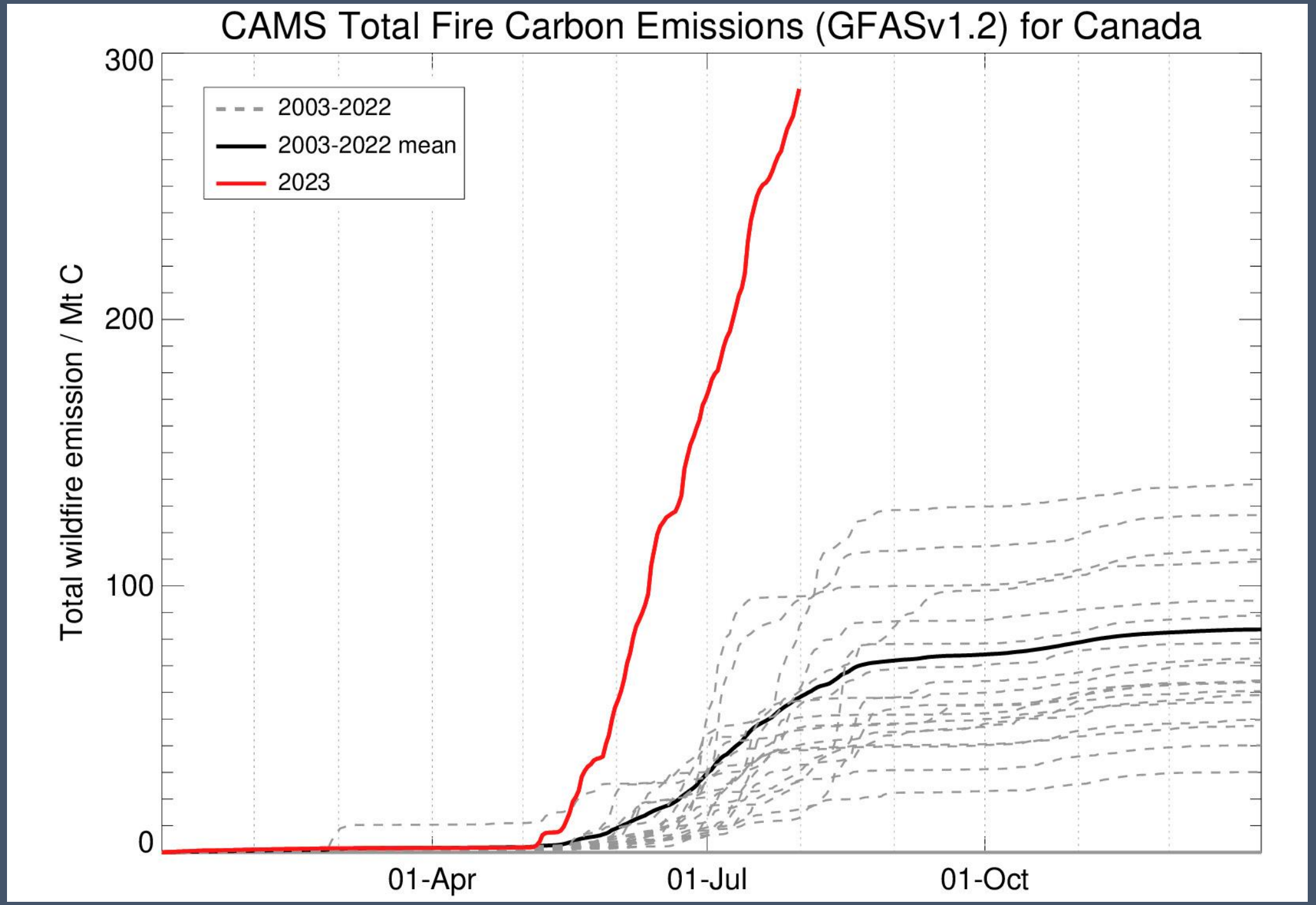
- Wildfire smoke and indoor air quality
- Low-cost air quality sensors
- Indoor air quality at childcare and long-term care facilities

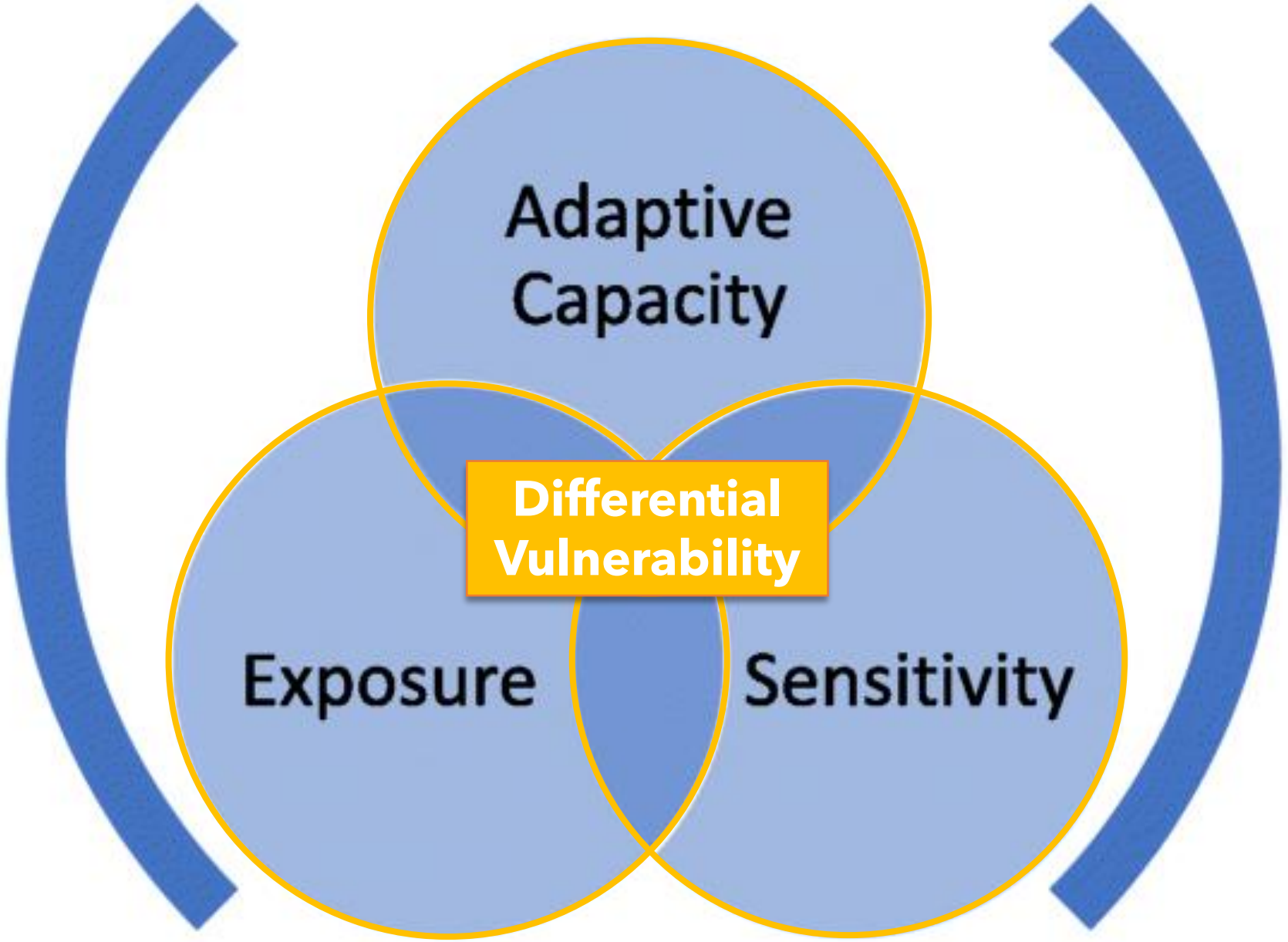
The 2023 report of the *Lancet* Countdown on health and climate change: the imperative for a health-centred response in a world facing irreversible harms

Exposure to wildfire smoke increased 220% over the past 20 years in Canada

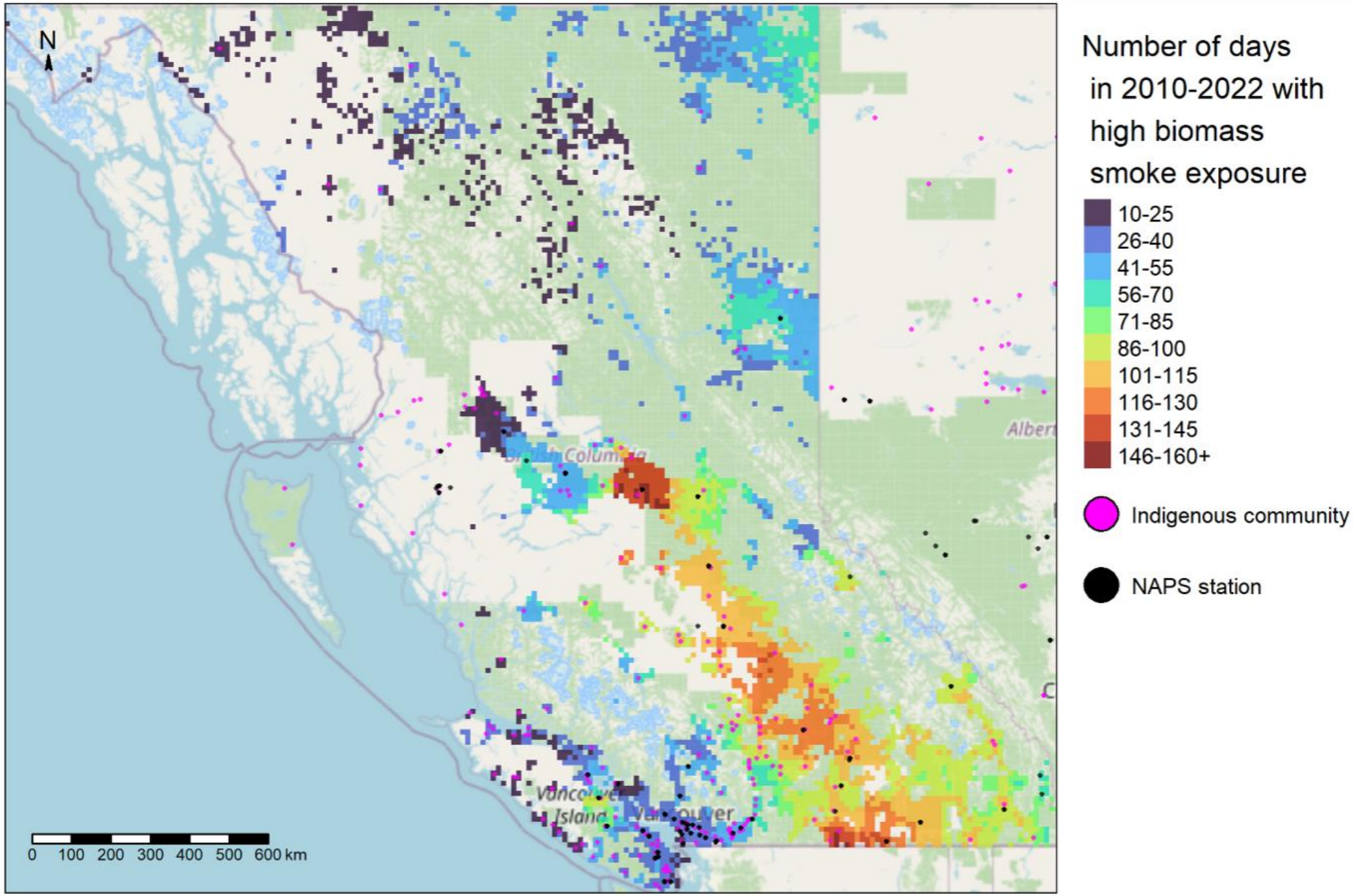
Between 2018 to 2022, Canadians were exposed to two days of "very high or extremely high wildfire danger"

New report estimates a 76% increase in deaths in the US from wildfire smoke by 2050

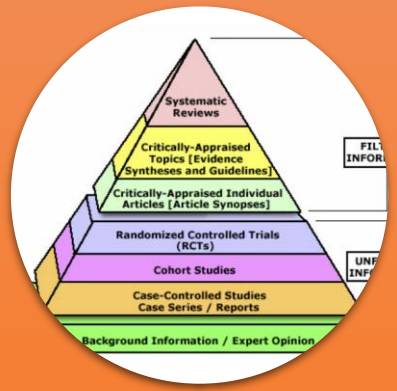

CAMS Total Fire Carbon Emissions (GFASv1.2) for Canada
2003-2022
2003-2022 mean
2023
Total wildfire emission / Mt C
300
200
100
0
01-Apr
01-Jul
01-Oct



Yu et al., 2021
https://link.springer.com/article/10.1186/s12940-021-00708-z/figures/2


N
0 100 200 300 400 500 600 km
Number of days in 2010-2022 with high biomass smoke exposure
10-25
26-40
41-55
56-70
71-85
86-100
101-115
116-130
131-145
146-160+
Indigenous community
NAPS station

KEY INGREDIENTS FOR PUBLIC HEALTH MEASURES



Evidence-based

- **Accurate and reliable** data
- Up-to-date and emerging
- Informed by community input

Targeted

- Sensitive populations
- Vulnerable communities
- Optimal timing

Communication

- Key stakeholders
- Consistent and timely
- Culturally and socially appropriate

Public Resources and Support

- Programs and policies
- Clear guidance
- Funding/workforce
- Monitoring and Evaluation

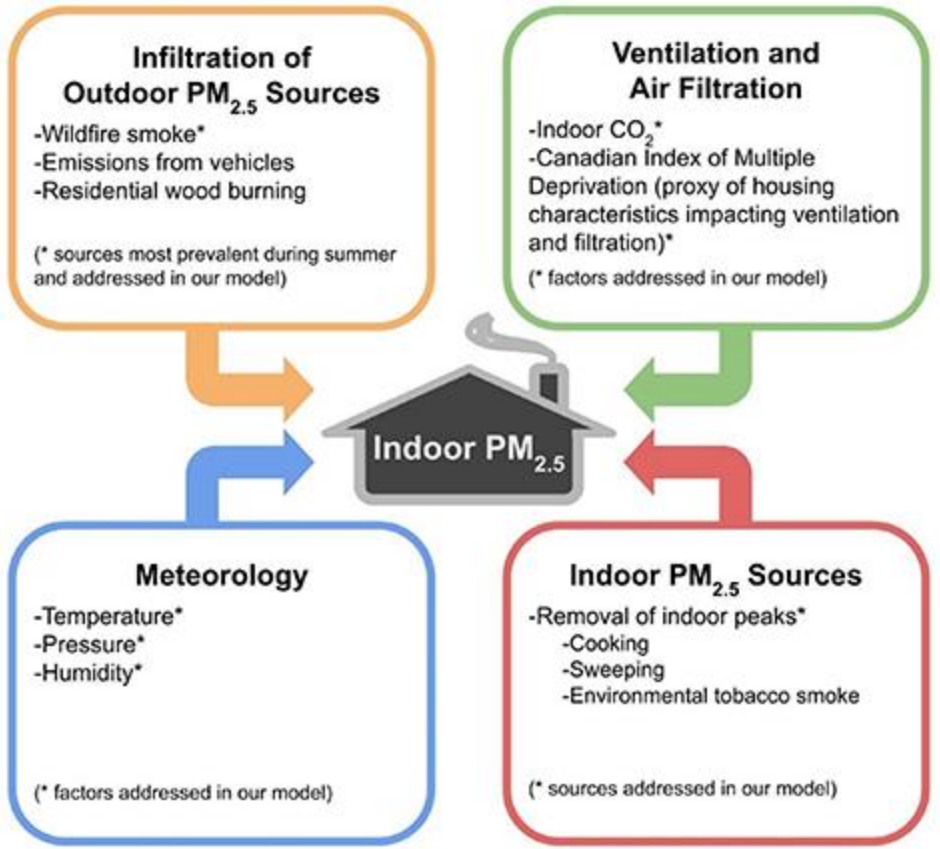
Partnerships

- Coordination
- Inter-agency
- Public-private
- Equitable community partnerships

INDOOR AIR QUALITY

Canadians ~90% of their time indoors

- Home, work, school, or care settings
- Fine particulate matter ($PM_{2.5}$) from wildfire smoke can enter (or infiltrate) the indoor environment
  - Sharp increases of $PM_{2.5}$ outdoors has an almost immediate impact on indoor air quality
- Multiple factors influence indoor $PM_{2.5}$ beyond outdoor air pollution
  - Indoor emissions (e.g., cooking), ventilation (bringing in “fresh” air), air filtration
  - Meteorological factors



DURING A WILDFIRE – PROTECT YOURSELF

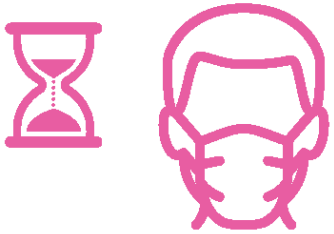
IF YOU SMELL SMOKE OR SEE ASH DUE TO A WILDFIRE, HERE ARE WAYS TO LIMIT YOUR EXPOSURE:

Remain indoors with windows and doors closed or seek alternate shelter.

Avoid using a whole-house fan or a swamp cooler with an outside air intake.

Avoid vigorous physical activity.

If you must be outdoors in smoky conditions, keep it brief, and use a disposable respirator (N-95 or P-100).



Run your A/C if you have one, change your filter often (MERV 13 +), or run a portable HEPA purifier.

Avoid using indoor or outdoor wood-burning appliances, including fireplaces, and combustion sources like candles and incense.

https://www.aqmd.gov/images/default-source/Publications-Library/wildfire/protect-yourself.png?sfvrsn=6

Aerosol and Air Quality Research

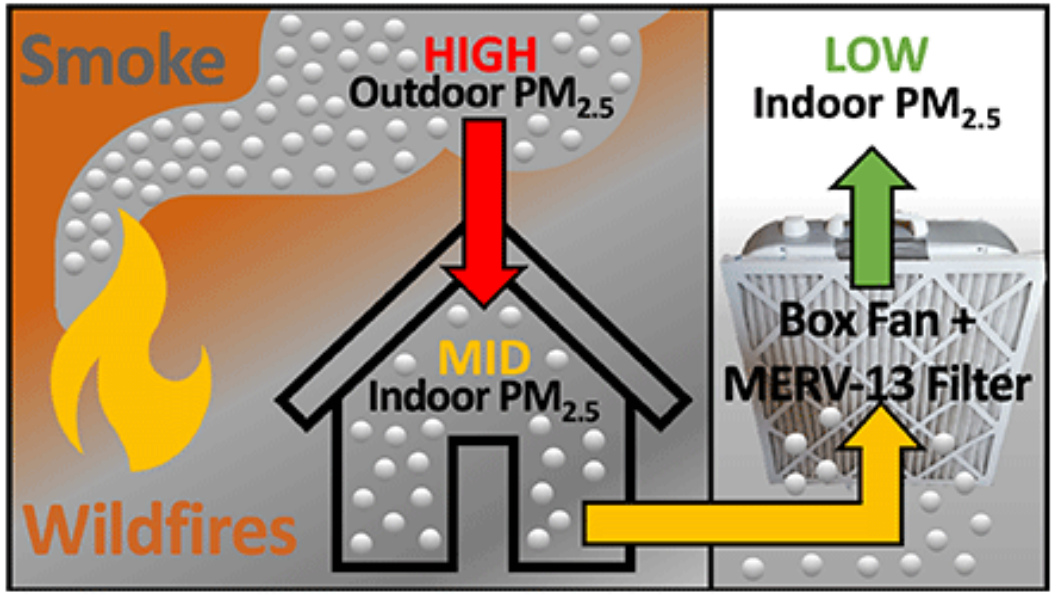
TECHNICAL NOTE
https://doi.org/10.4209/aaqr.210046

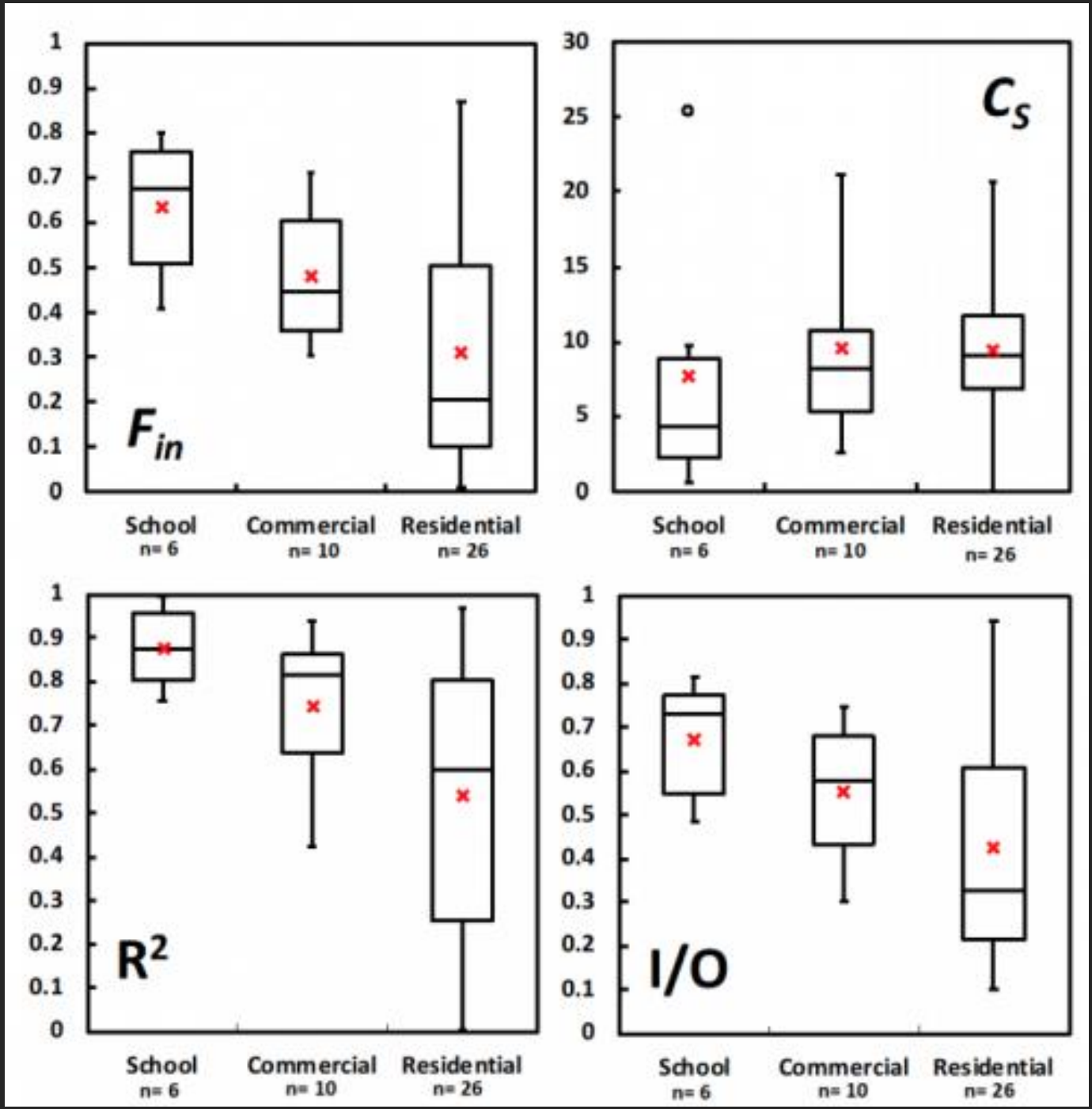
Impact of Wildfire Smoke Events on Indoor Air Quality and Evaluation of a Low-cost Filtration Method

Nathaniel W. May[1*], Clara Dixon[1], Daniel A. Jaffe[1,2]

[1] University of Washington Bothell, Bothell, WA 98011, USA
[2] University of Washington, Seattle, WA 98195, USA

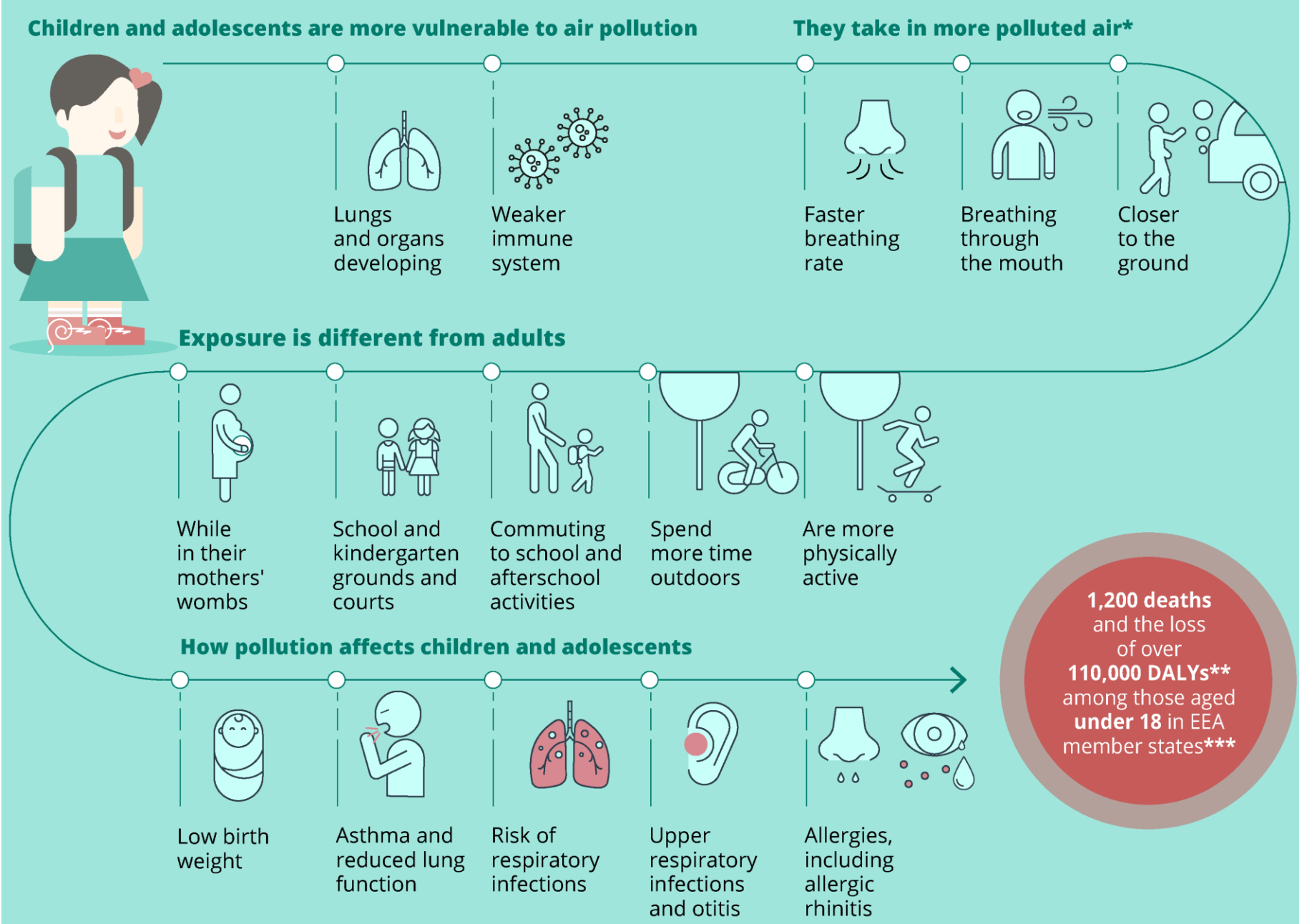
- Analyzed indoor and outdoor fine particulate matter ($PM_{2.5}$) concentrations using low-cost sensors
- Compared infiltration of outdoor $PM_{2.5}$ across different building types
  - Schools, Commercial, Residential
- Evaluated the effectiveness of fan filter units (FFU) to reduce indoor $PM_{2.5}$ in two residential buildings





Impact of Wildfire Smoke Events on Indoor Air Quality and Evaluation of a Low-cost Filtration Method

- Infiltration of outdoor $PM_{2.5}$ from wildfire smoke was highest for school buildings
- Correlation of outdoor $PM_{2.5}$ from wildfire smoke was highest for school buildings


Children and adolescents are more vulnerable to air pollution
They take in more polluted air*
Lungs and organs developing
Weaker immune system
Faster breathing rate
Breathing through the mouth
Closer to the ground
Exposure is different from adults
While in their mothers' wombs
School and kindergarten grounds and courts
Commuting to school and afterschool activities
Spend more time outdoors
Are more physically active
How pollution affects children and adolescents
Low birth weight
Asthma and reduced lung function
Risk of respiratory infections
Upper respiratory infections and otitis
Allergies, including allergic rhinitis
1,200 deaths and the loss of over 110,000 DALYs** among those aged under 18 in EEA member states***
*Per kg of body weight
**DALYs: disability-adjusted life years, a measure of the burden of disease caused by a risk factor
***GBD Collaborative Network, 2020

Health Impacts of Wildfire Smoke on Children and Adolescents: A Systematic Review and Meta-analysis

Zhang et al., 2024

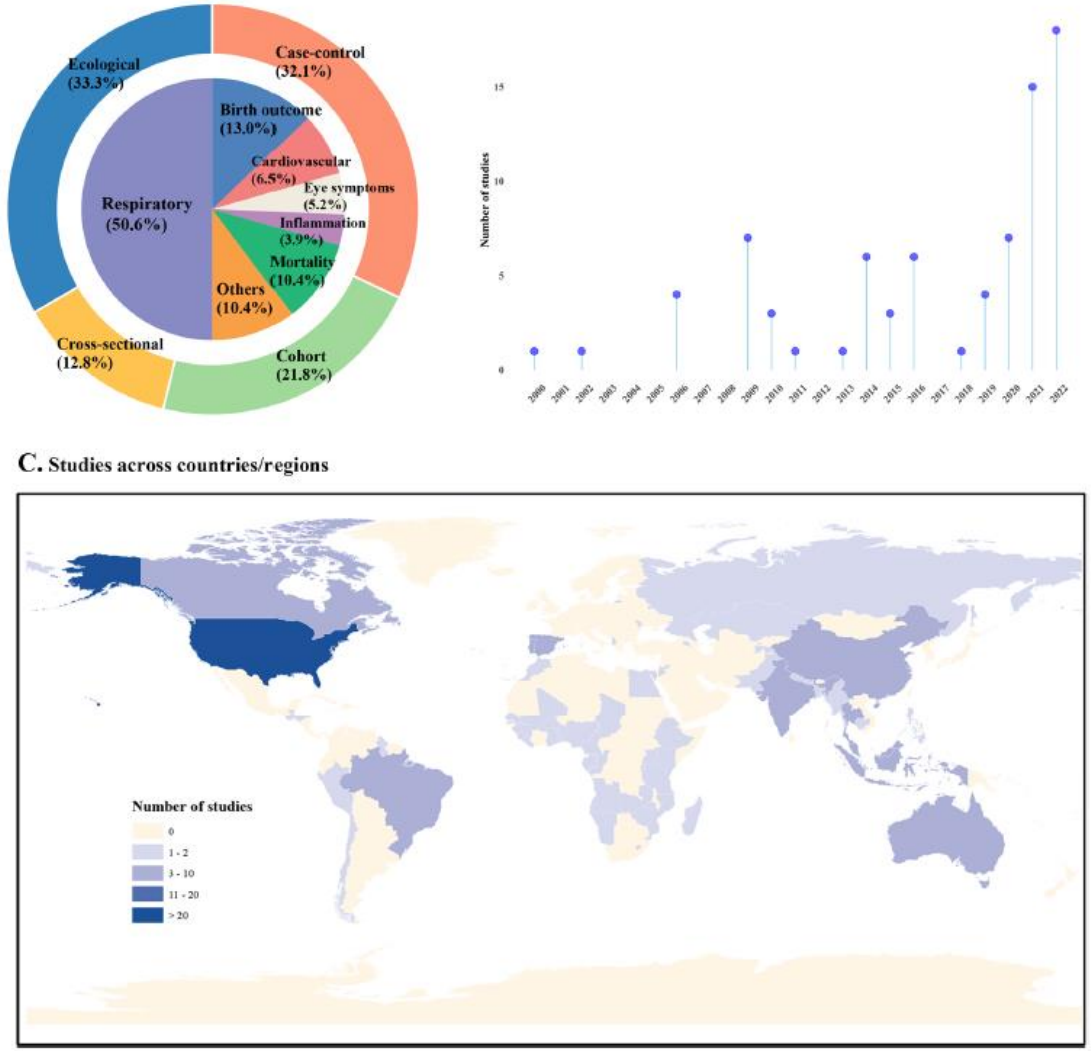
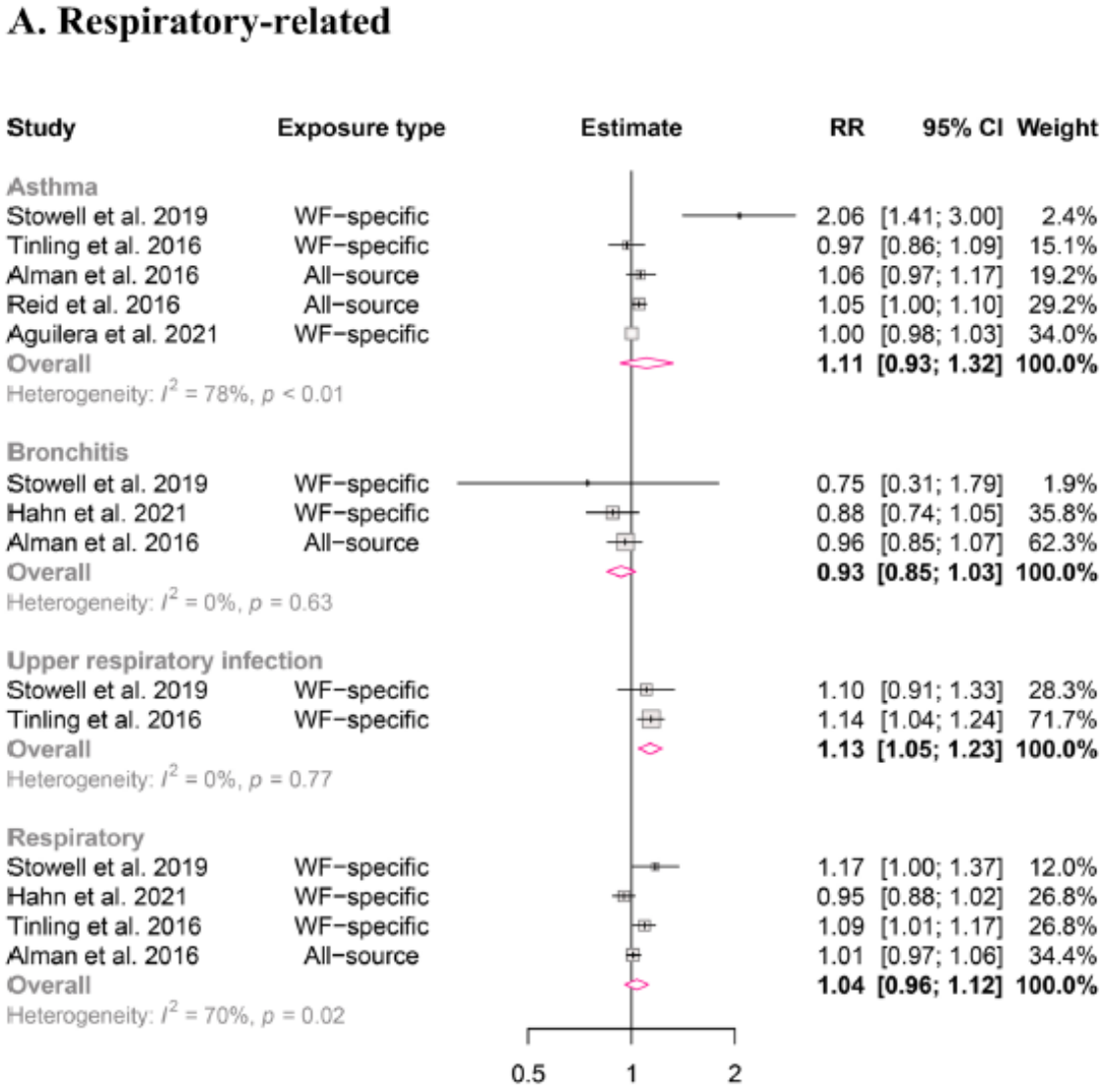


Fig. 2 Study characteristics. **A** The number of studies across study design and health outcomes; **B** the number of studies across years; **C** the number of studies across countries/regions around the world

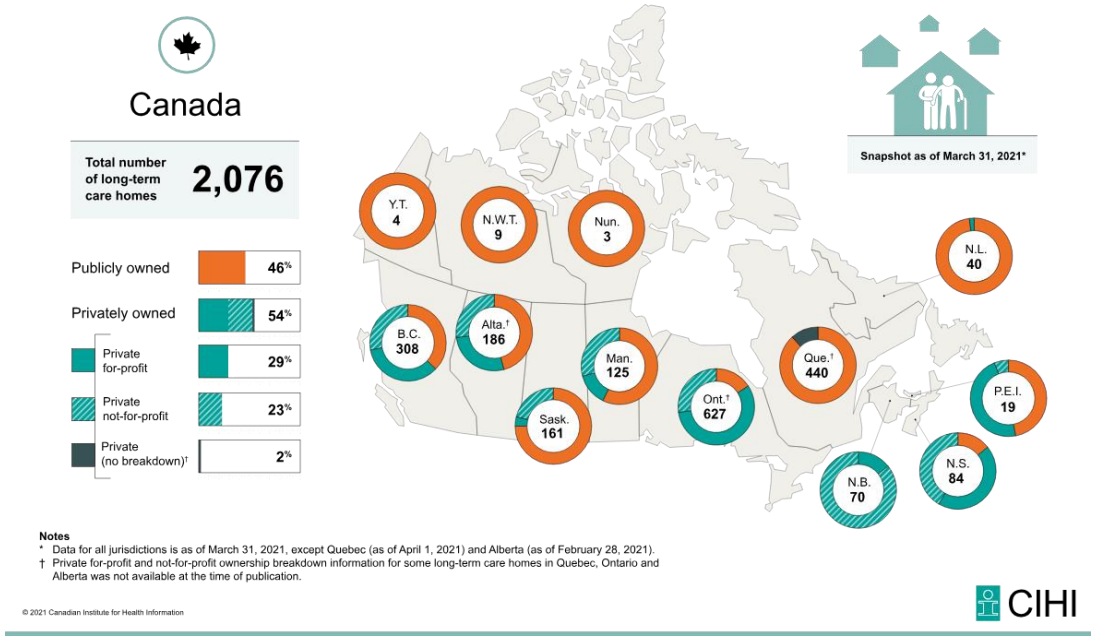
Health Impacts of Wildfire Smoke on Children and Adolescents: A Systematic Review and Meta-analysis

Zhang et al., 2024



Vulnerability of Residential Long-term Care Patients to Wildfire Smoke

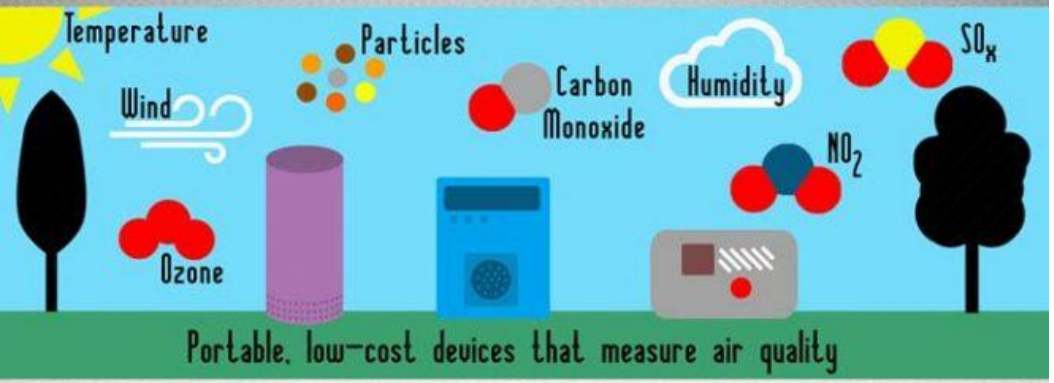
- Canada has an aging population with a large population of people with long-term care needs
- Much older than general population
- High prevalence of comorbidities, including respiratory and cardiovascular diseases



RESIDENT DEMOGRAPHICS IN LONG-TERM CARE, 2018/19-2022/23

INDICATOR	2018/19	2019/20	2020/21	2021/22	2022/23
AVERAGE AGE	84	84	84	83	83
% OF RESIDENTS 85+	56%	55%	54%	53%	53%
% OF RESIDENTS <65	6%	6%	6%	6%	6%
% RESIDENTS THAT ARE FEMALE	65%	64%	64%	63%	63%
% RESIDENTS IN A WHEELCHAIR	52%	52%	52%	53%	53%

WHAT ARE AIR SENSORS?



Portable, low-cost devices that measure air quality

WHAT ARE THE BENEFITS?

Localized air quality

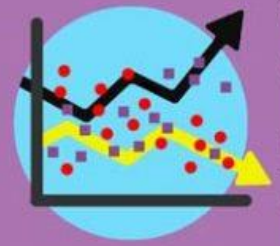
Real-time data

Some are mobile compatible

WHAT ARE SOME CHALLENGES?

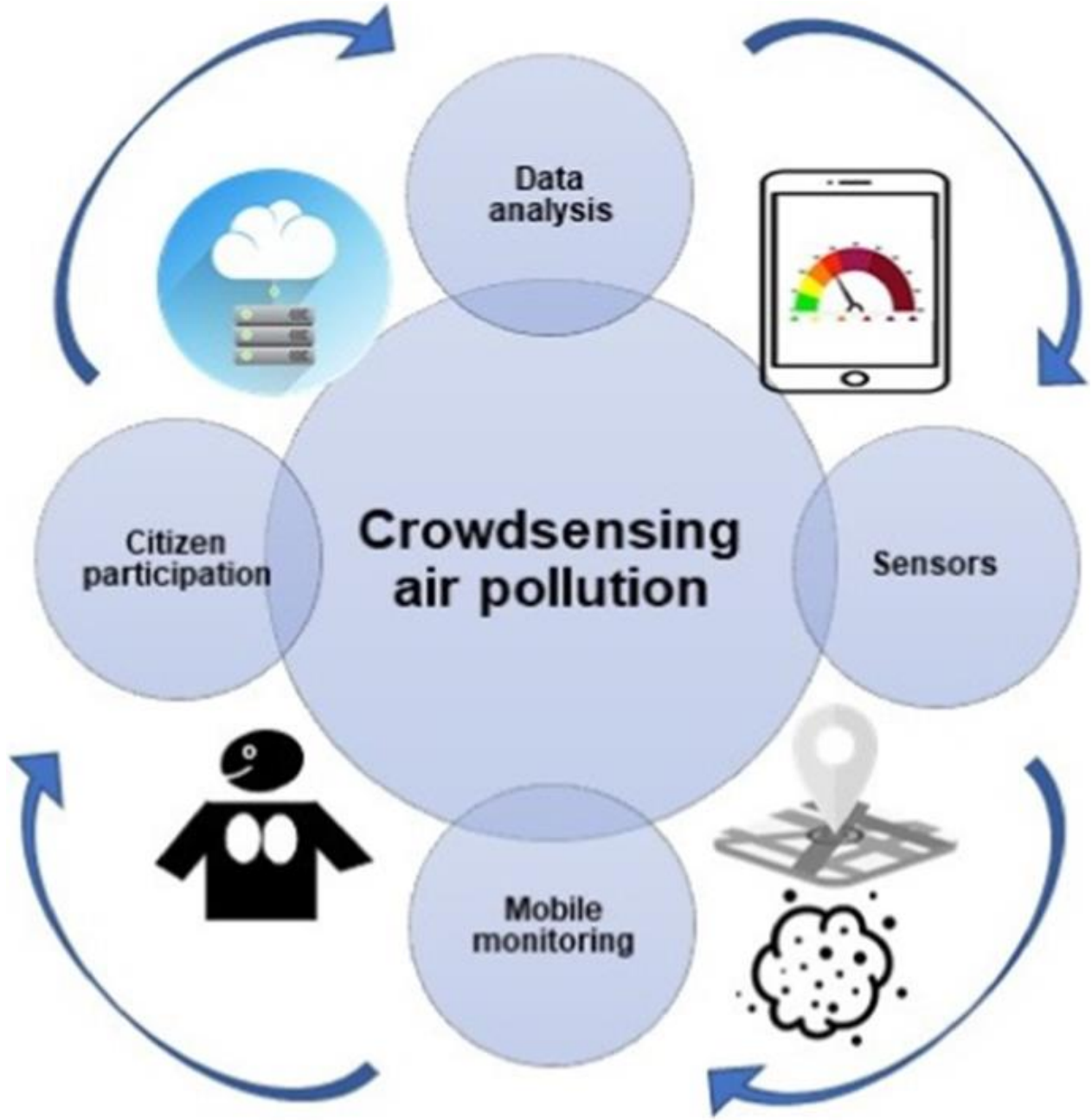
No health standards for short periods of time

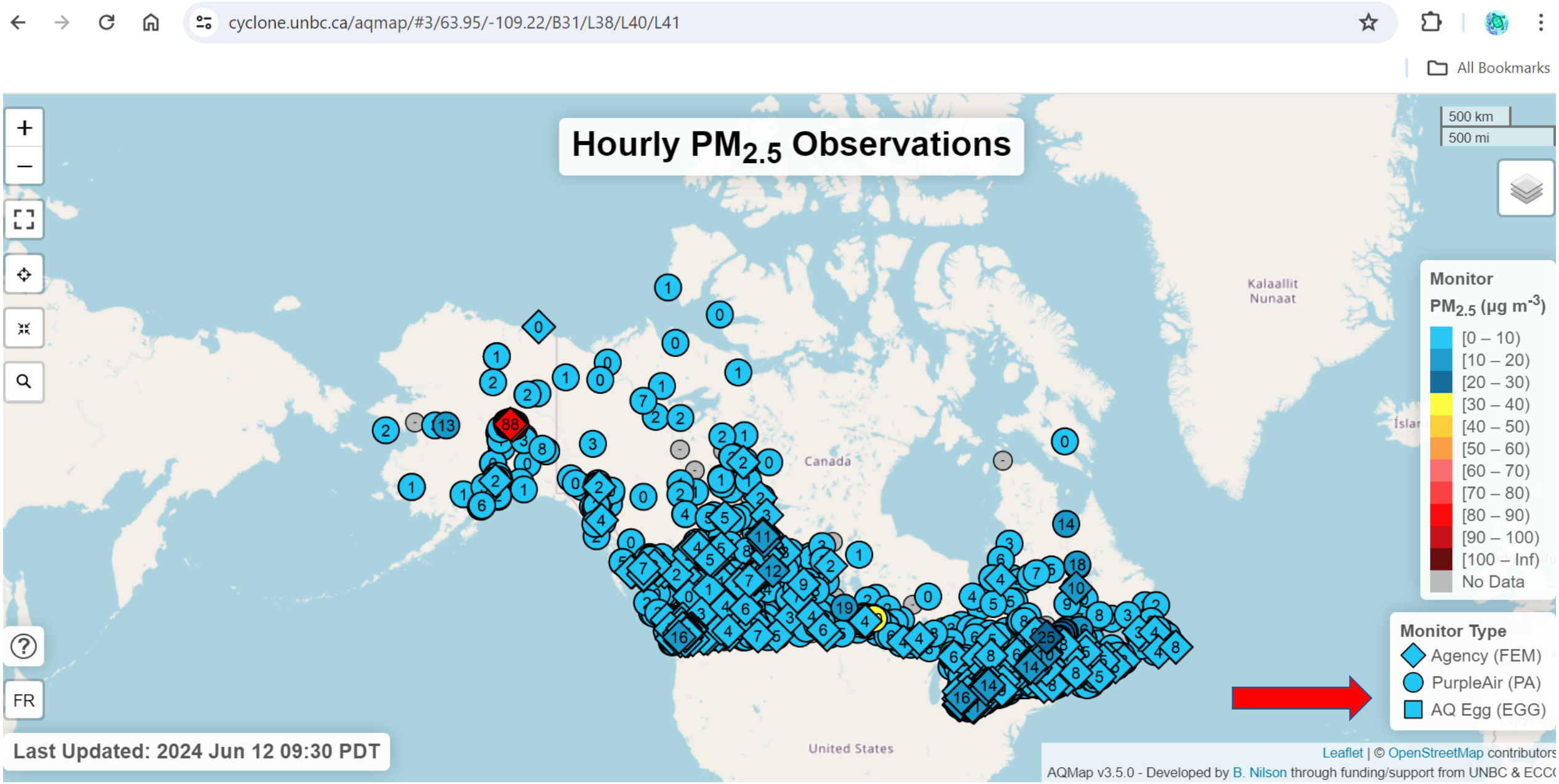
Devices need to be tested for long period of time for accuracy & precision



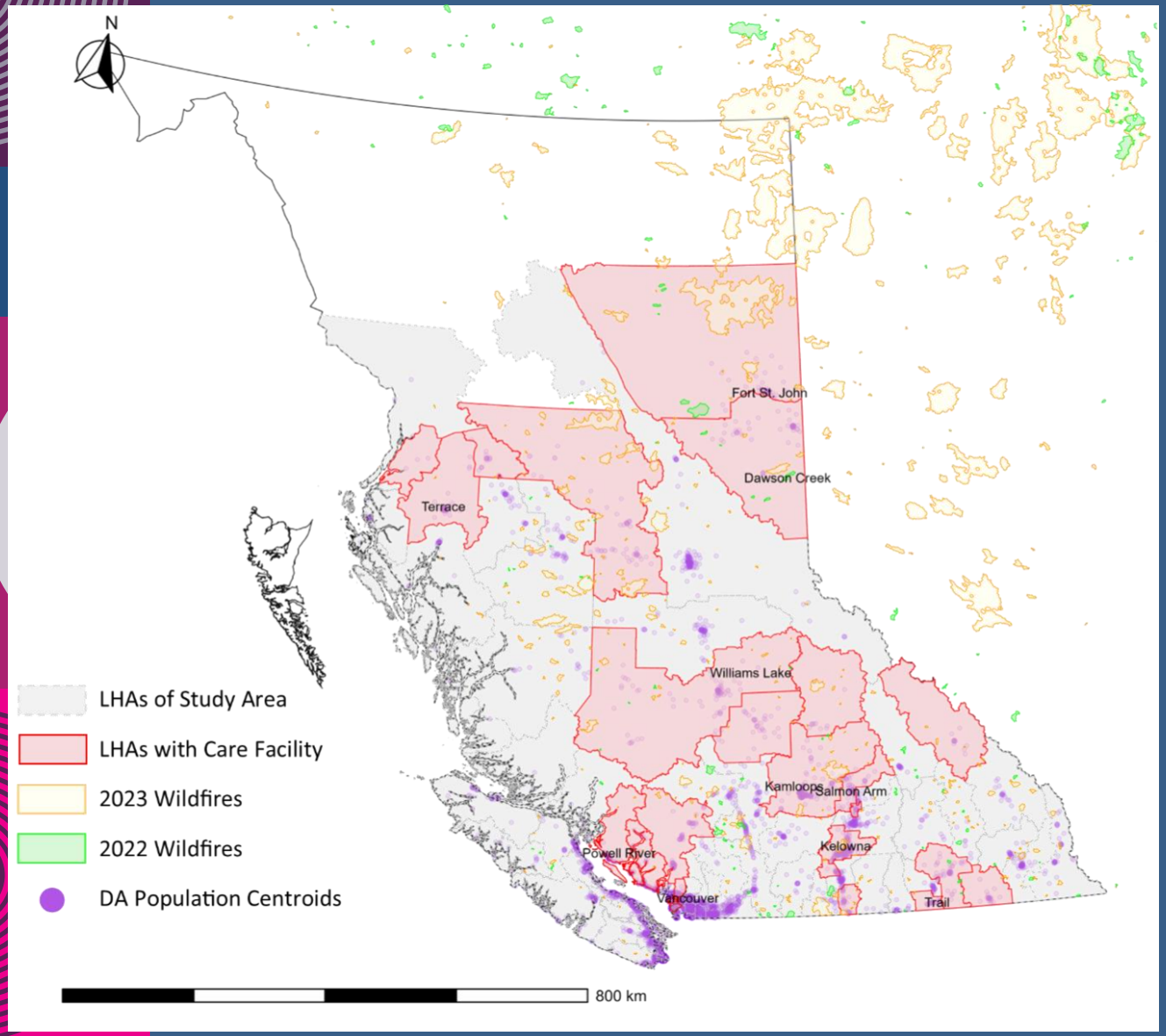
Data overload – hard to interpret

Infographic originally created by Chris Hewes for Santa Barbara County Air Pollution Control District




cyclone.unbc.ca/aqmap/#3/63.95/-109.22/B31/L38/L40/L41
All Bookmarks
Hourly PM2.5 Observations
500 km
500 mi
Kalaallit Nunaat
Canada
United States
Monitor
PM2.5 (µg m-3)
[0 – 10)
[10 – 20)
[20 – 30)
[30 – 40)
[40 – 50)
[50 – 60)
[60 – 70)
[70 – 80)
[80 – 90)
[90 – 100)
[100 – Inf)
No Data
Monitor Type
Agency (FEM)
PurpleAir (PA)
AQ Egg (EGG)
FR
Last Updated: 2024 Jun 12 09:30 PDT
Leaflet | © OpenStreetMap contributors
AQMap v3.5.0 - Developed by B. Nilson through funding/support from UNBC & ECC

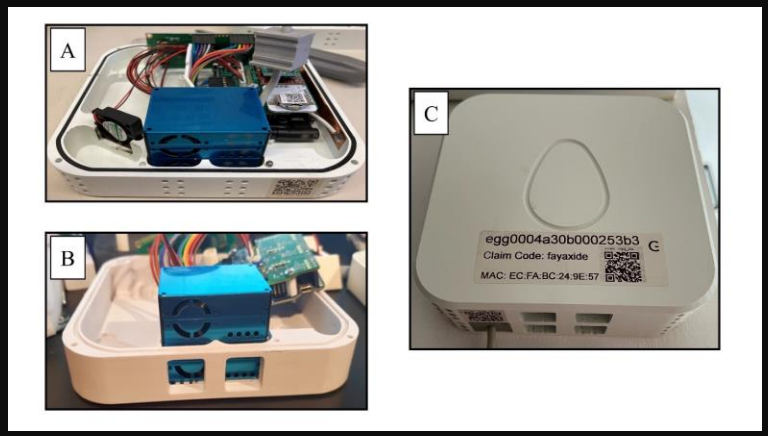
BCCDC'S LOW-COST AIR QUALITY SENSOR NETWORK

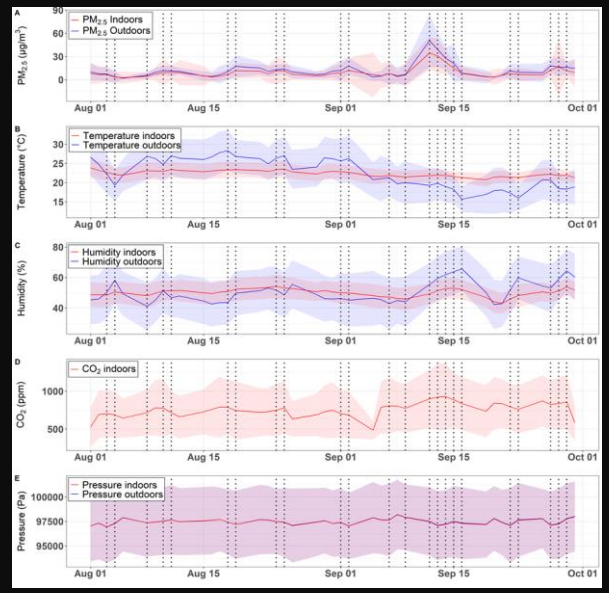


- **~50 care facilities**
  - Sensors installed indoors and outdoors
  - 44 Childcare facilities
  - 4 Long-term care facilities
  - Interior Health, Northern Health, Vancouver Coastal, Island Health
- **Ongoing expansion**
  - Cleaner air spaces in Fraser Health
  - Hospitals in Yukon Territory

Air Quality EGGS to Measure Indoor and Outdoor Environmental Conditions

- $PM_{2.5}$
- Temperature
- Humidity
- CO_2 (Indoor Only)
- Pressure





1.0 Materials

1.1 What's included in your project package

- ❑ This instructional booklet
- ❑ One Air Quality Egg intended for indoor use (the ID sticker is below the egg design)
- ❑ One Air Quality Egg intended for outdoor use (the ID sticker is above the egg design, and the word 'Outdoor' is engraved in the bottom)
- ❑ Two USB wall chargers
- ❑ Two Egg stands
- ❑ Health Canada & BCCDC fact sheets related to wildfire smoke and health

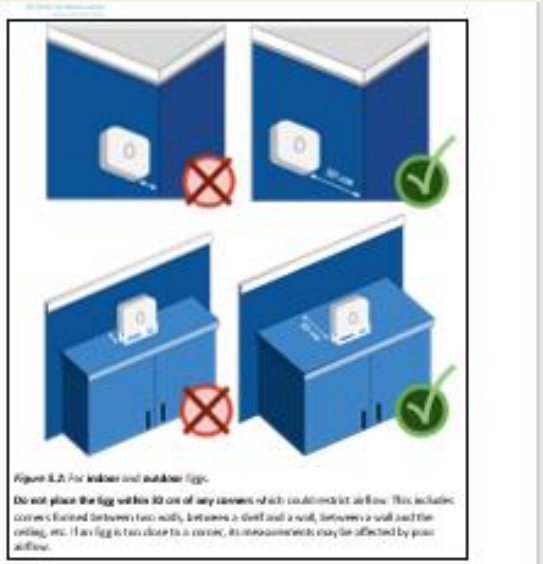
Figure 1.1: Indoor Egg

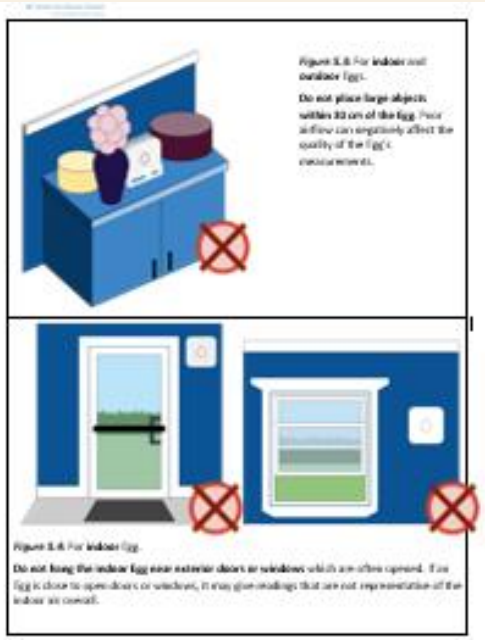
1.2 What else do you need to get started?

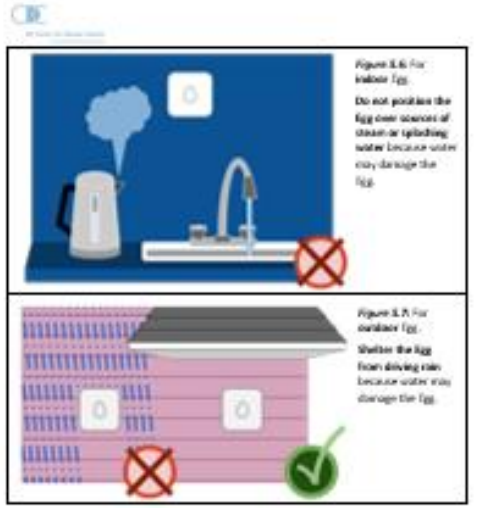
- ❑ Paper and pencil or pen
- ❑ Compatible WiFi network (see section "2.0 Choosing a WiFi network for the Eggs")
- ❑ Compatible computer (see section "3.0 Connecting your Eggs to WiFi")
- ❑ Optional: Screws for hanging one or both Eggs
- ❑ Optional: Outdoor outlet cover (see Figure 5.11)
- ❑ Optional: USB-A/USB-C adapter

Figure 1.2: Outdoor Egg. (Note the word 'Outdoor' engraved in the bottom right)

1-HOUR $PM_{2.5}$ ($\mu g/m^3$)	PROVINCIAL AQHI	AQHI RISK CATEGORY	HEALTH MESSAGE FOR PEOPLE AT HIGHER RISK	HEALTH MESSAGE FOR GENERAL POPULATION	ACTIONS TO REDUCE WILDFIRE SMOKE EXPOSURE
0 – 10	1	LOW	**Enjoy** your usual outdoor activities.	**Ideal air quality** for outdoor activities.	**Normal air quality** in British Columbia
11 – 20	2				
21 – 30	3				
31 – 40	4	MODERATE	**Consider reducing** or rescheduling strenuous activities outdoors if you experience symptoms.	**No need to modify** your usual outdoor activities unless you experience symptoms.	• Use a portable air cleaner to reduce smoke in your home • Stay inside with doors and windows closed, but keep cool – being too hot is more risky than breathing smoke for most people • Visit places with cleaner and cooler air, such as libraries, community centres, and shopping malls • If you cannot access cleaner air, consider using a well-fitted N95 respirator or relocating to an area with less smoke
41 – 50	5				
51 – 60	6				
61 – 70	7	HIGH	**Reduce or reschedule** strenuous activity outdoors.	**Consider reducing** or rescheduling strenuous activities outdoors if you experience symptoms.	
71 – 80	8				
81 – 90	9				
91 – 100	10				
101+	10+	VERY HIGH	**Avoid** strenuous activity outdoors.	**Reduce or reschedule** strenuous activity outdoors, especially if you experience symptoms.	







AIR QUALITY APP FOR CARE FACILITIES

Select your facility:

Start date

2023-09-26

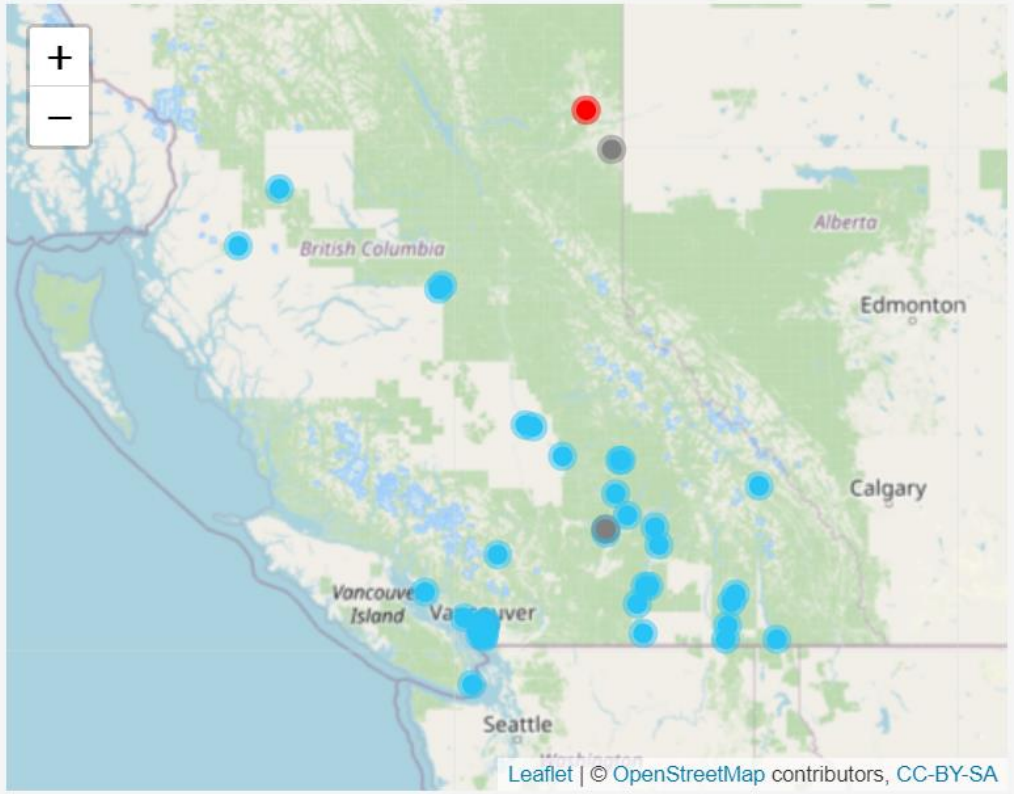
End date

2023-09-26

access selected data

Please allow a few moments for the graphs to load. Tip: The more data you select, the longer it will take to load!

Map | $PM_{2.5}$ | Temperature | Humidity | CO_2 | $PM_{2.5}$ Infiltration



Map

This is a map of all participating facilities that were online last week. Click on your facility to load the last 48 hours of data!

AQHI RISK CATEGORY	HEALTH MESSAGE FOR PEOPLE AT HIGHER RISK	HEALTH MESSAGE FOR GENERAL POPULATION
LOW	**Enjoy** your usual outdoor activities.	**Ideal air quality** for outdoor activities.
MODERATE	**Consider reducing** or rescheduling strenuous activities outdoors if you experience symptoms.	**No need to modify** your usual outdoor activities unless you experience symptoms.
HIGH	**Reduce or reschedule** strenuous activity outdoors.	**Consider reducing** or rescheduling strenuous activities outdoors if you

Select your facility:

Start date

2023-09-09

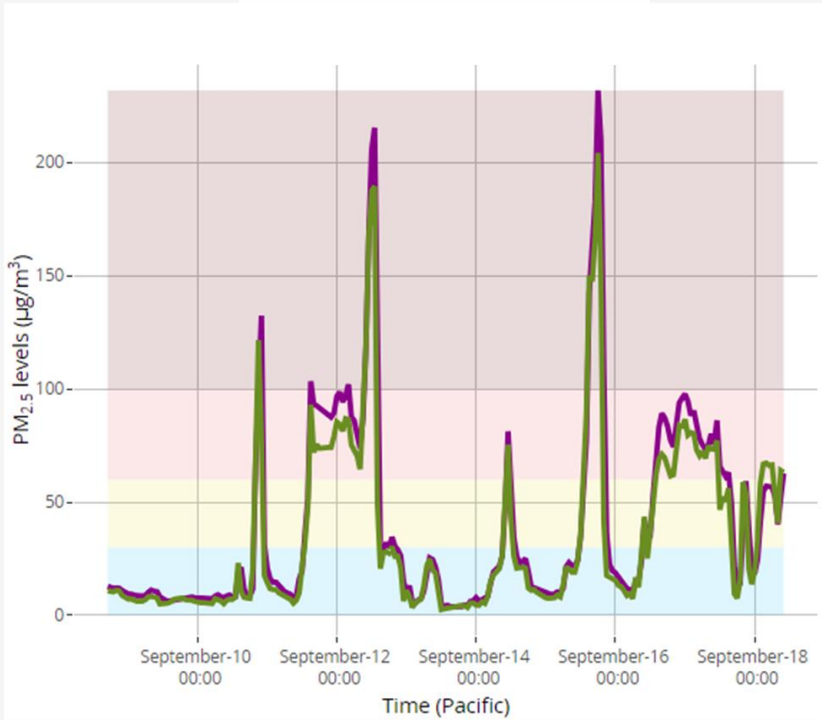
End date

2023-09-18

access selected data

Please allow a few moments for the graphs to load. Tip: The more data you select, the longer it will take to load!

Map | $PM_{2.5}$ | Temperature | Humidity | CO_2 | $PM_{2.5}$ Infiltration



$PM_{2.5}$ Levels

◉ Indoor

◉ Outdoor

$PM_{2.5}$ (particulate matter smaller than 2.5 microns) is a measurement of the tiny particles in wildfire smoke or smoke from residential wood heating. $PM_{2.5}$ is also created by activities such as cooking food or running a vehicle engine. According to the British Columbia Air Quality Health Index (AQHI), people who are susceptible to the effects of $PM_{2.5}$ should limit their activitivities outdoors when concentrations are higher than 60 µ/m^3.

For more information, click here.

AQHI RISK CATEGORY	HEALTH MESSAGE FOR PEOPLE AT HIGHER RISK	HEALTH MESSAGE FOR GENERAL POPULATION
LOW	**Enjoy** your usual outdoor activities.	**Ideal air quality** for outdoor activities.
MODERATE	**Consider reducing** or rescheduling strenuous activities outdoors if you experience symptoms.	**No need to modify** your usual outdoor activities unless you experience symptoms.
HIGH	**Reduce or reschedule** strenuous activity outdoors.	**Consider reducing** or rescheduling strenuous activities outdoors if you experience symptoms.
VERY HIGH	**Avoid** strenuous activity outdoors.	**Reduce or reschedule** strenuous activity outdoors, especially if you experience symptoms.

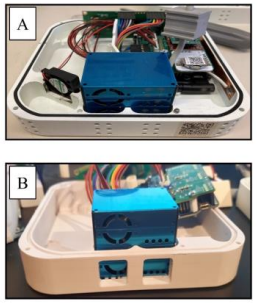
Indoor/Outdoor Sensor Project

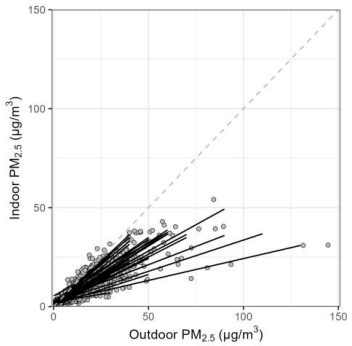
Phase 1 Objectives

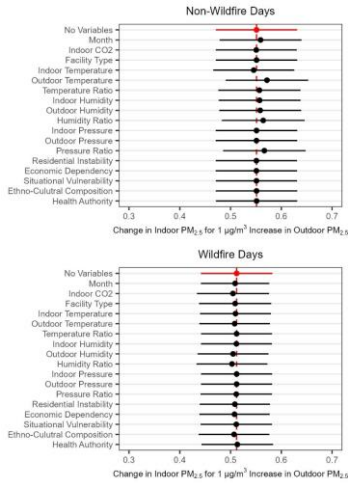
Analyzed $PM_{2.5}$ data from co-locate low-cost air quality sensors (AQ Eggs) indoors and outdoors at childcare facilities in BC

Estimated the relationship between daily outdoor and indoor $PM_{2.5}$ as a proxy of $PM_{2.5}$ infiltration

Compare infiltration on days impacted by wildfire smoke versus days without smoke impacts





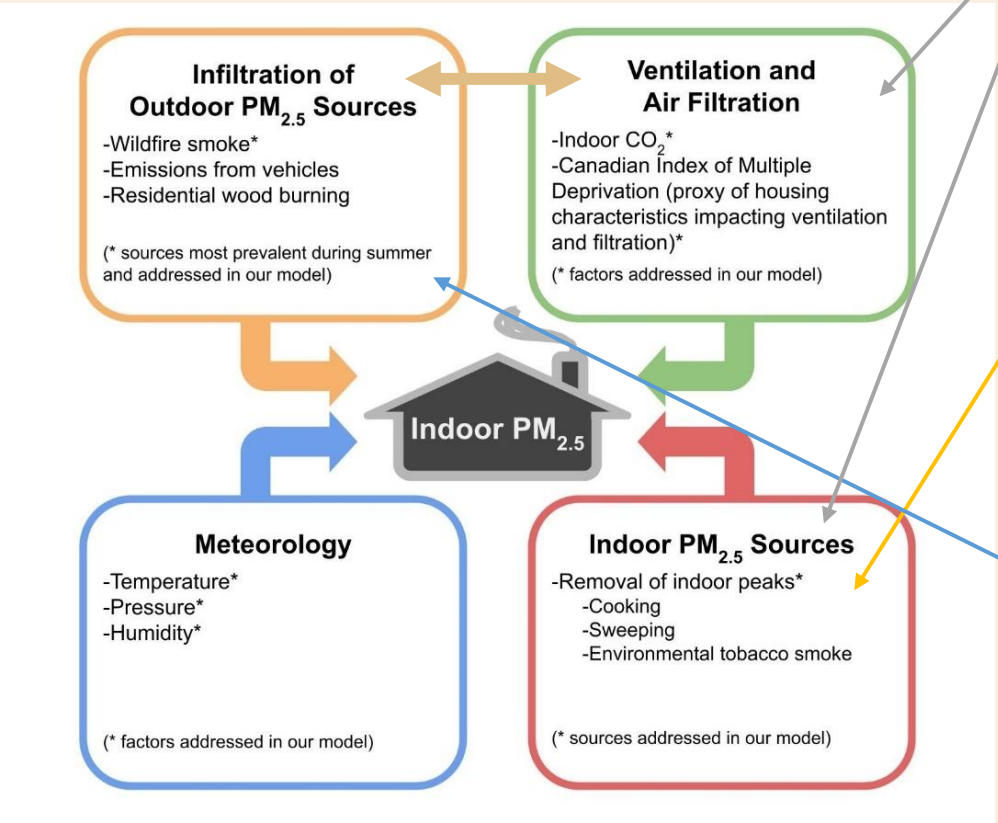


Phase 2 Objectives

- Develop an indoor PM2.5 exposure model for BC using machine learning by combining data from our deployed sensors and publicly available sources

- Estimate ventilation at daycares using time-resolved indoor CO_2 data
- Design and implement a survey to ascertain reported occupancy, protective behaviors during smoke episodes, and building characteristics

$PM_{2.5}$ DATA PROCESSING STEPS



1

QA/QC measures

Calibrations

Data completeness

2

Data restrictions

Aug 1, 2022 to Oct 31, 2022

Monday to Friday

8:00 AM to 6:00 PM

3

Indoor peak removal

Nguyen et al., 2021

4

Defining days impacted by wildfire smoke

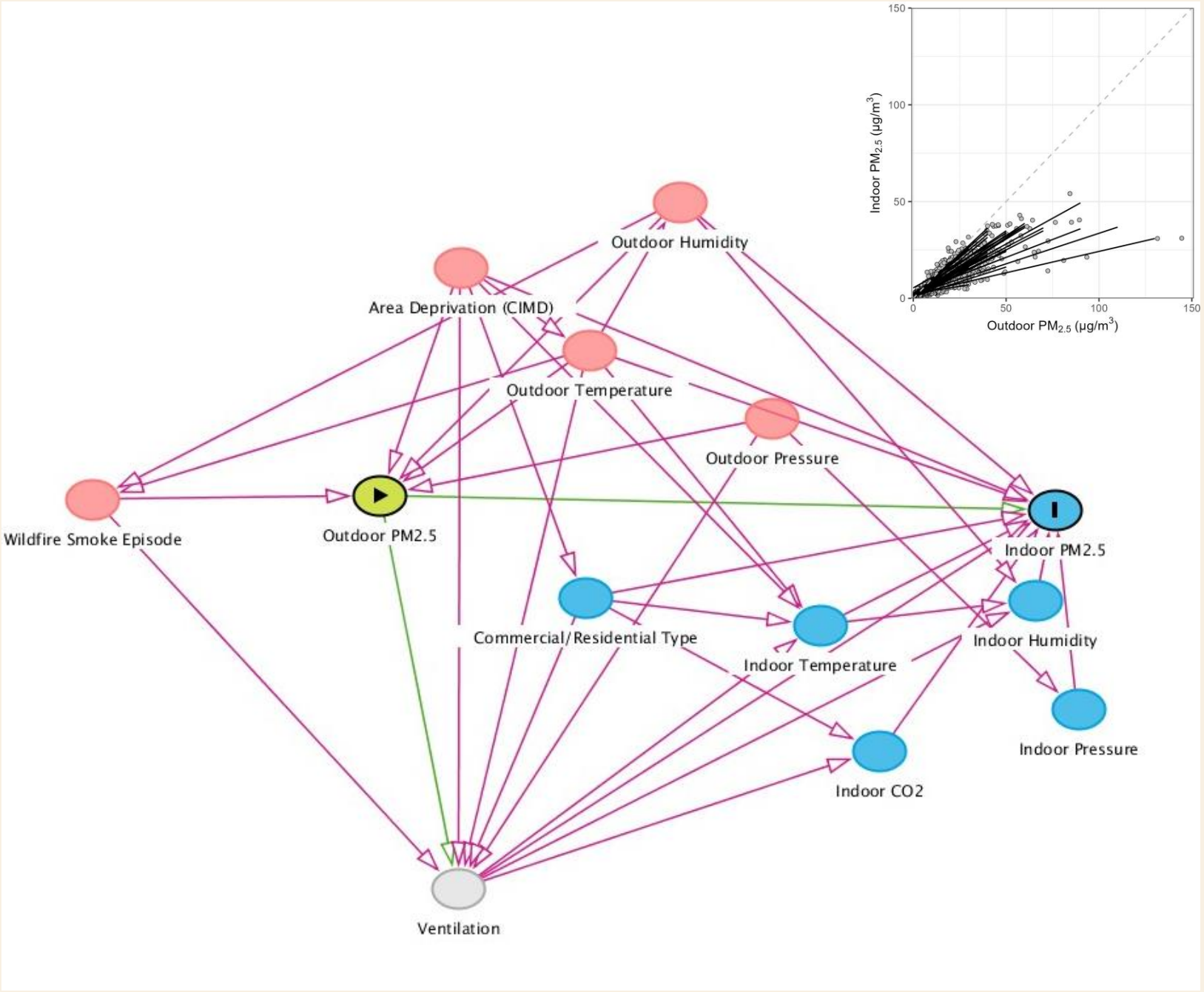
O'Dell et al., 2023

ADDITIONAL QA/QC MEASURES

- Testing pairs of AQ EGGs in EHS lab
  - <20% difference
- Installation instructions
- Automated data quality checks using the real-time data
- Correction of $PM_{2.5}$ sensor measurements

Correction and Accuracy of PurpleAir $PM_{2.5}$ Measurements for Extreme Wildfire Smoke

Karoline K. Barkjohn [1,*], Amara L. Holder [1], Samuel G. Frederick [2,3] and Andrea L. Clements [1]



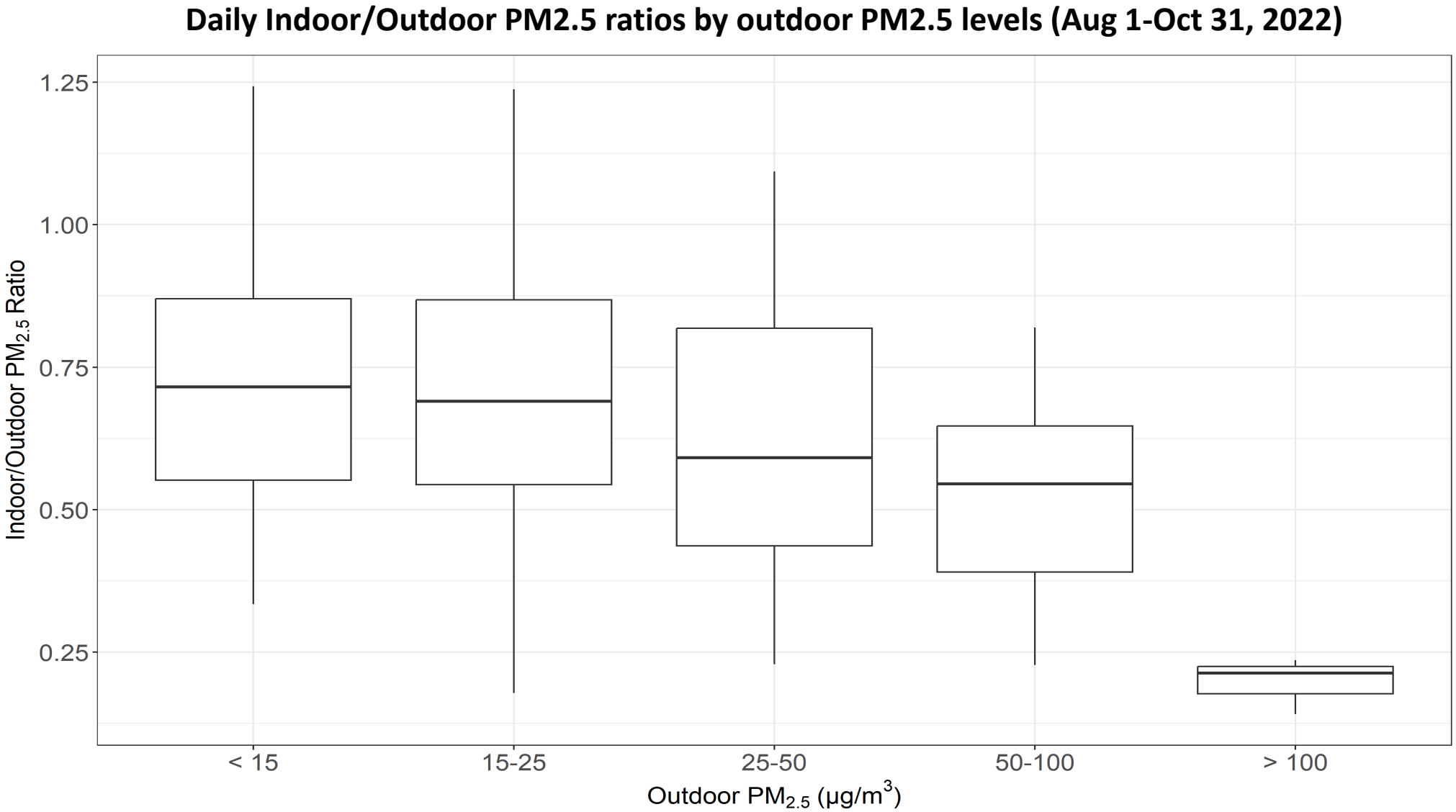
LINEAR MIXED EFFECTS REGRESSION MODEL

$PM_{2.5\_Indoors}$ ~ $PM_{2.5\_Outdoors}$

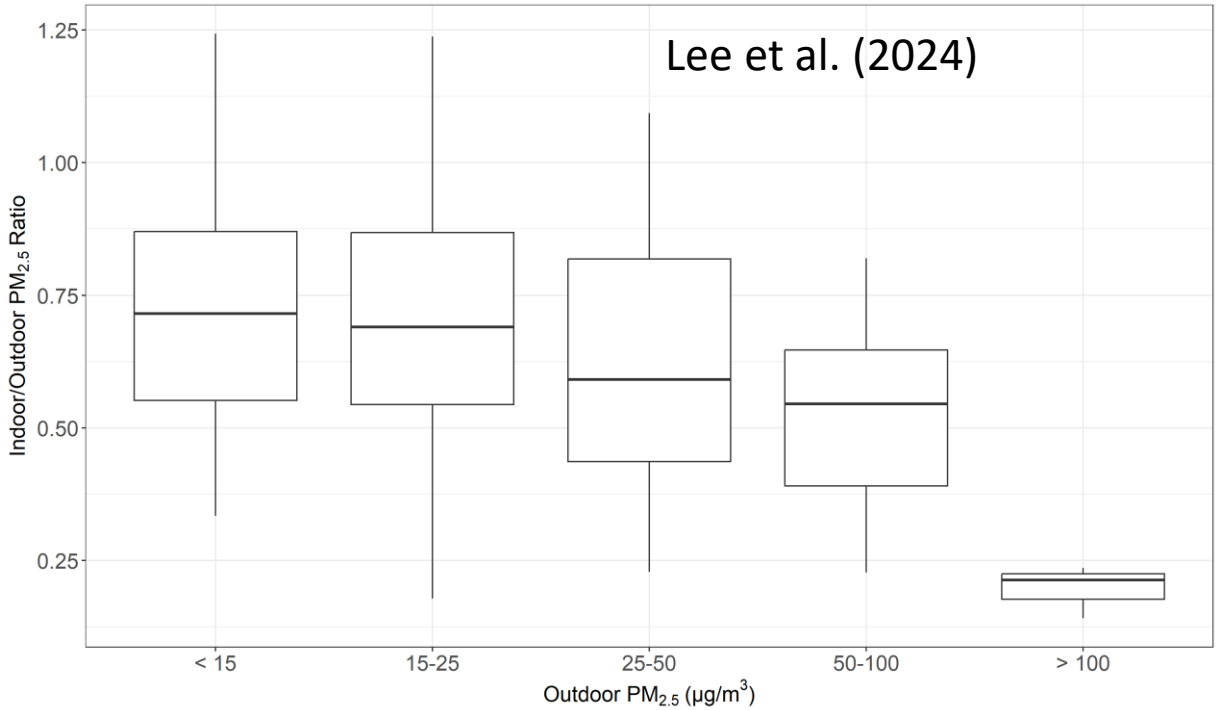
- Random intercept and random slope for facility
- Covariate adjustment
- Stratified analyses by days impacted by wildfire smoke and days not impacted wildfire smoke

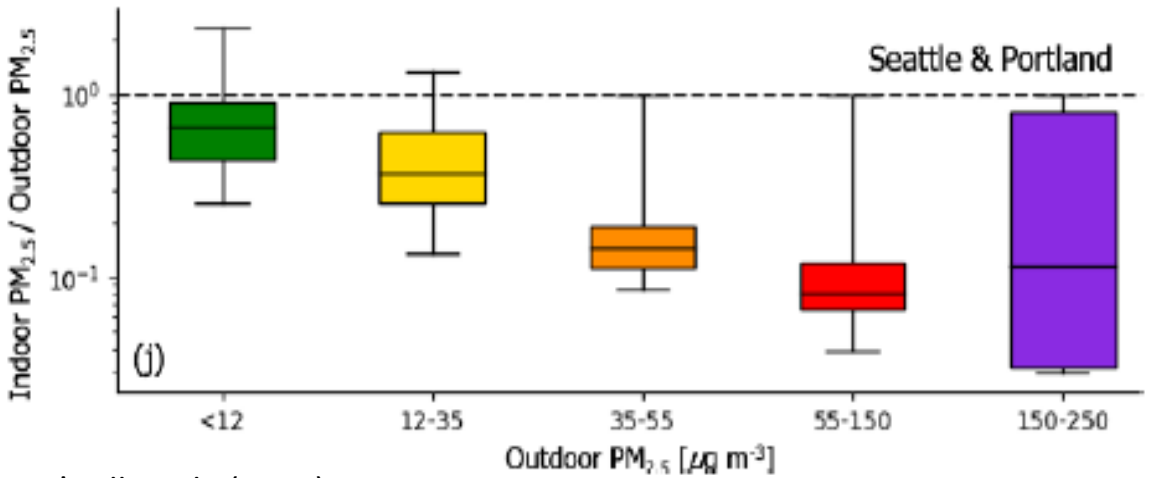
Results

Using low-cost air quality sensors to estimate wildfire smoke infiltration into childcare facilities in British Columbia, Canada (2024)

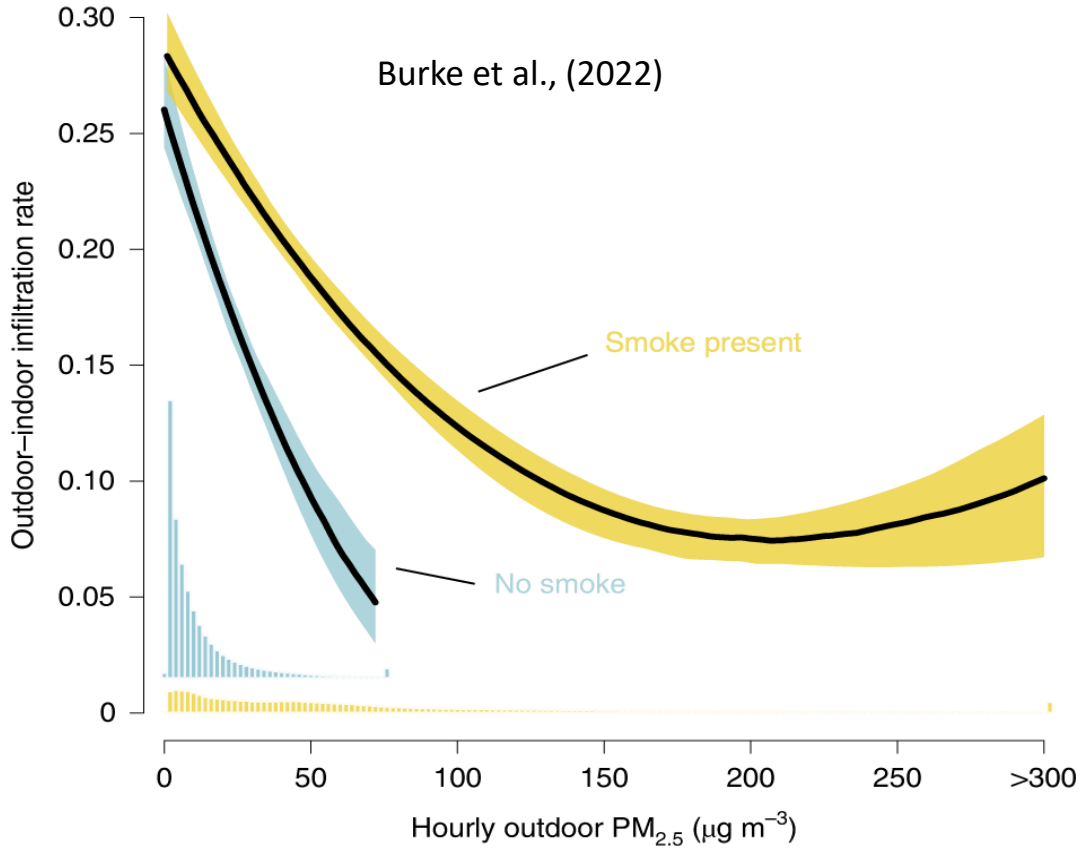


Daily Indoor/Outdoor PM2.5 ratios by PM2.5 levels at childcare centres in BC (Aug 1-Oct 31, 2022)

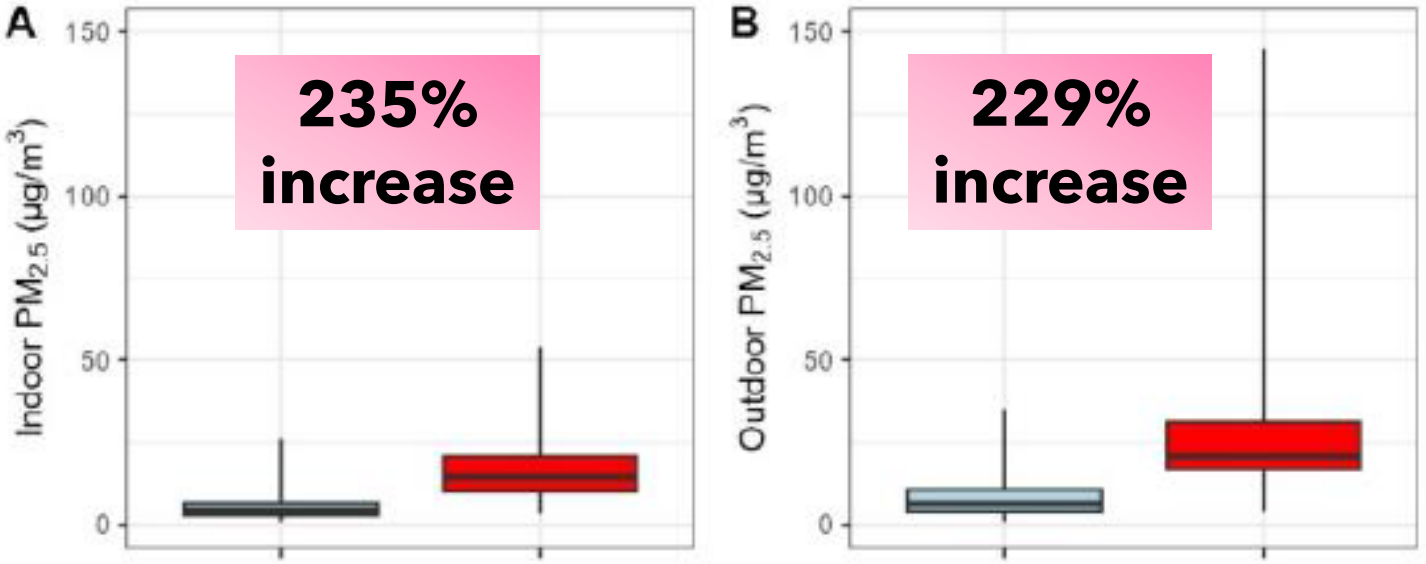


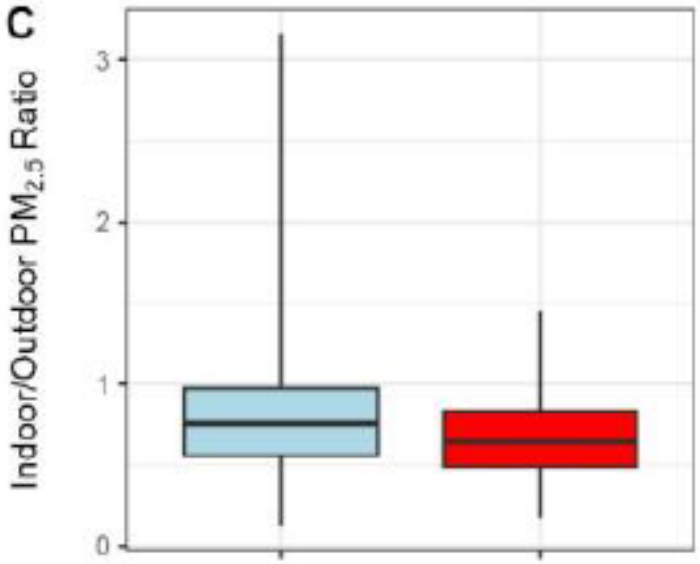


O'Dell et al., (2022)

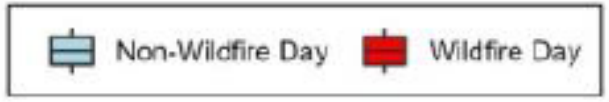


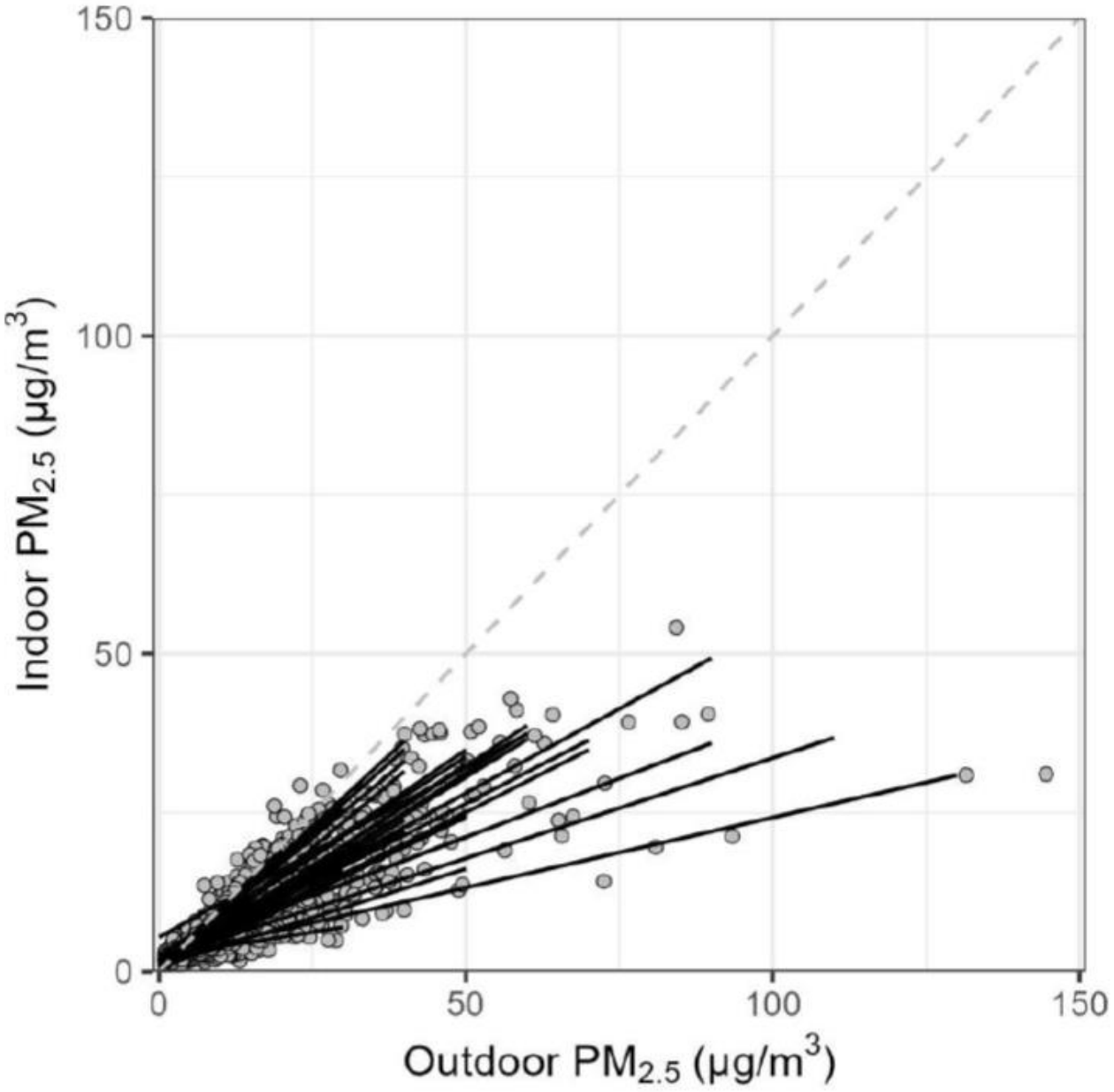
Lunderberg et al. 2023; Liang et al., (2022)

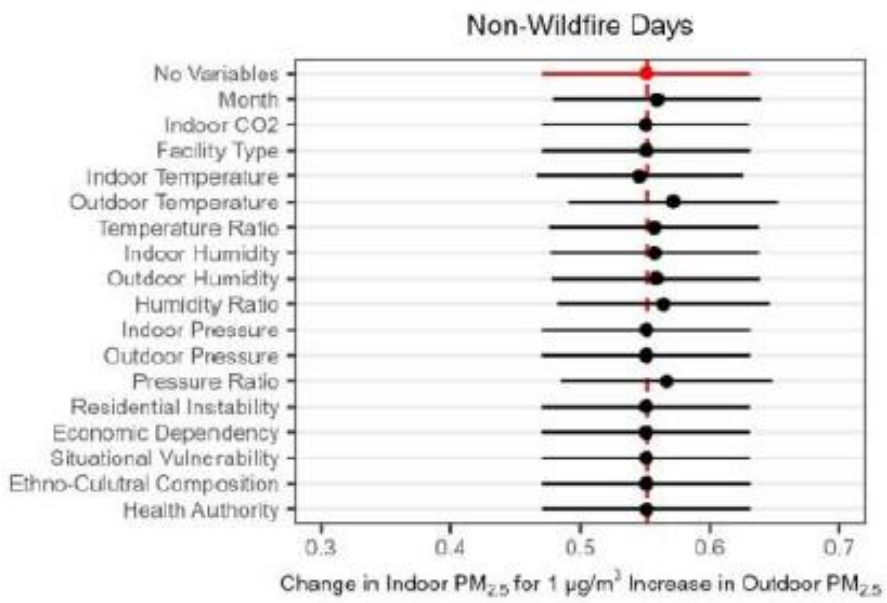


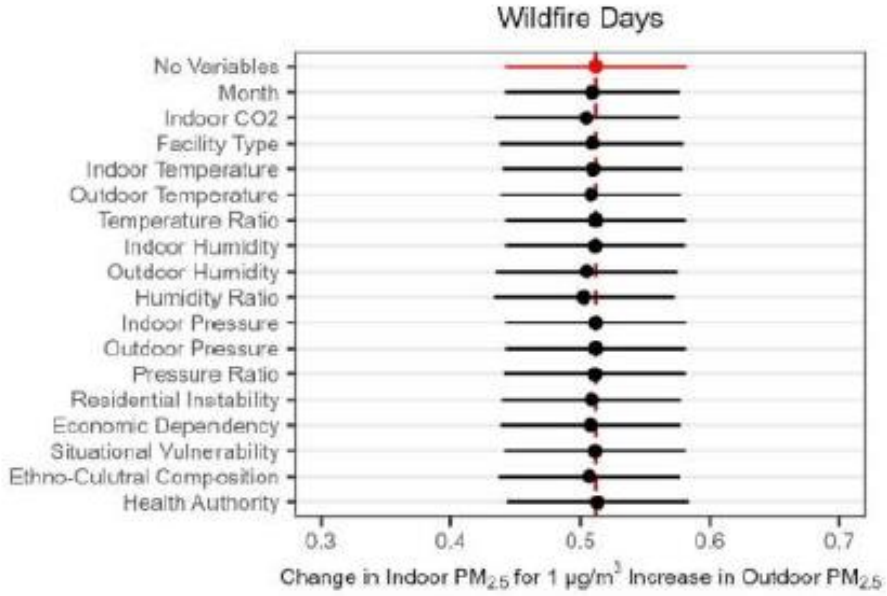


Wildfire Days
Median (Range)
13 (3 – 17)

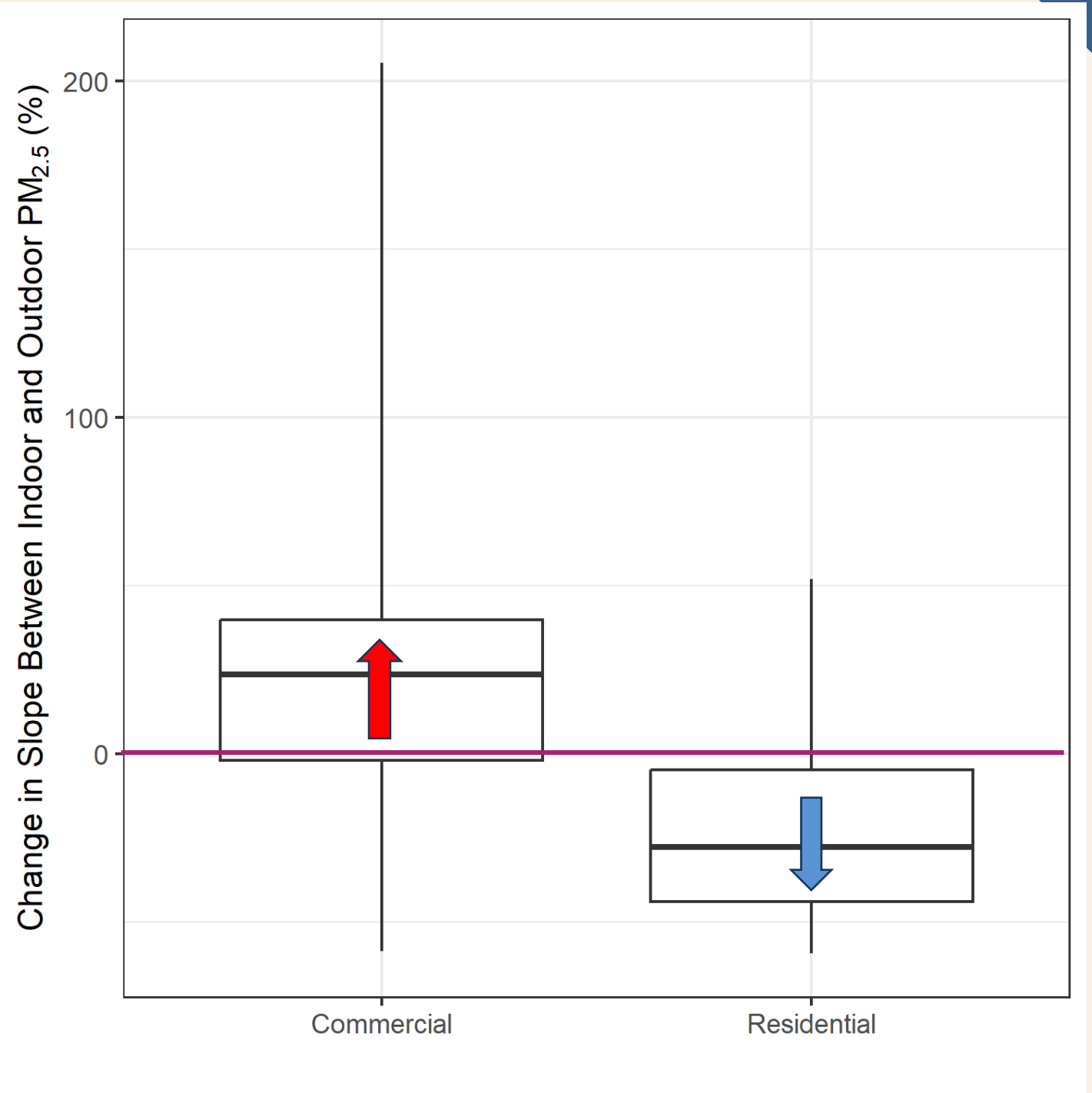



150
100
50
0
0
50
100
150
Indoor $PM_{2.5}$ (µg/m^3)
Outdoor $PM_{2.5}$ (µg/m^3)


Non-Wildfire Days
No Variables
Month
Indoor CO2
Facility Type
Indoor Temperature
Outdoor Temperature
Temperature Ratio
Indoor Humidity
Outdoor Humidity
Humidity Ratio
Indoor Pressure
Outdoor Pressure
Pressure Ratio
Residential Instability
Economic Dependency
Situational Vulnerability
Ethno-Culutral Composition
Health Authority
0.3
0.4
0.5
0.6
0.7
Change in Indoor $PM_{2.5}$ for 1 µg/m^3 Increase in Outdoor $PM_{2.5}$


Wildfire Days
No Variables
Month
Indoor CO2
Facility Type
Indoor Temperature
Outdoor Temperature
Temperature Ratio
Indoor Humidity
Outdoor Humidity
Humidity Ratio
Indoor Pressure
Outdoor Pressure
Pressure Ratio
Residential Instability
Economic Dependency
Situational Vulnerability
Ethno-Culutral Composition
Health Authority
0.3
0.4
0.5
0.6
0.7
Change in Indoor $PM_{2.5}$ for 1 µg/m^3 Increase in Outdoor $PM_{2.5}$

INFILTRATION WAS HIGHER ON WILDFIRE SMOKE DAYS AT COMMERCIAL BUT LOWER AT RESIDENTIAL FACILITIES



Aerosol and Air Quality Research

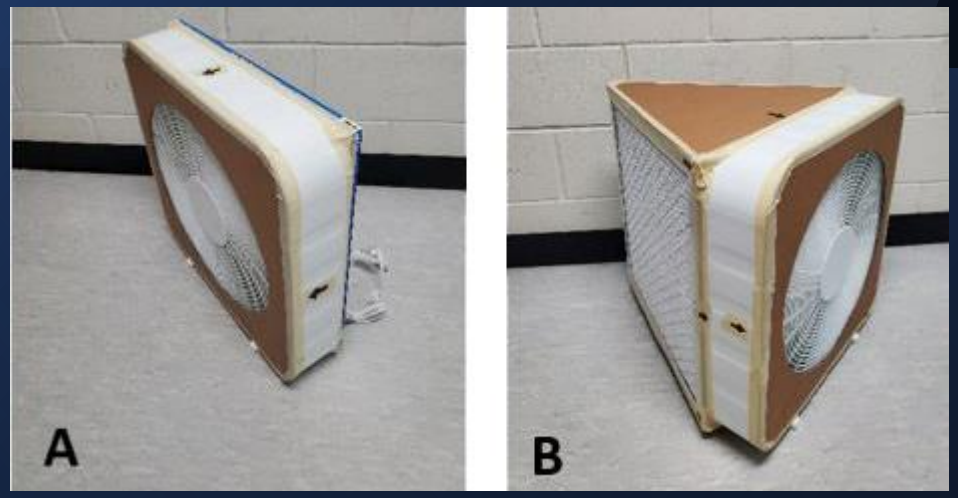
TECHNICAL NOTE
https://doi.org/10.4209/aaqr.210046

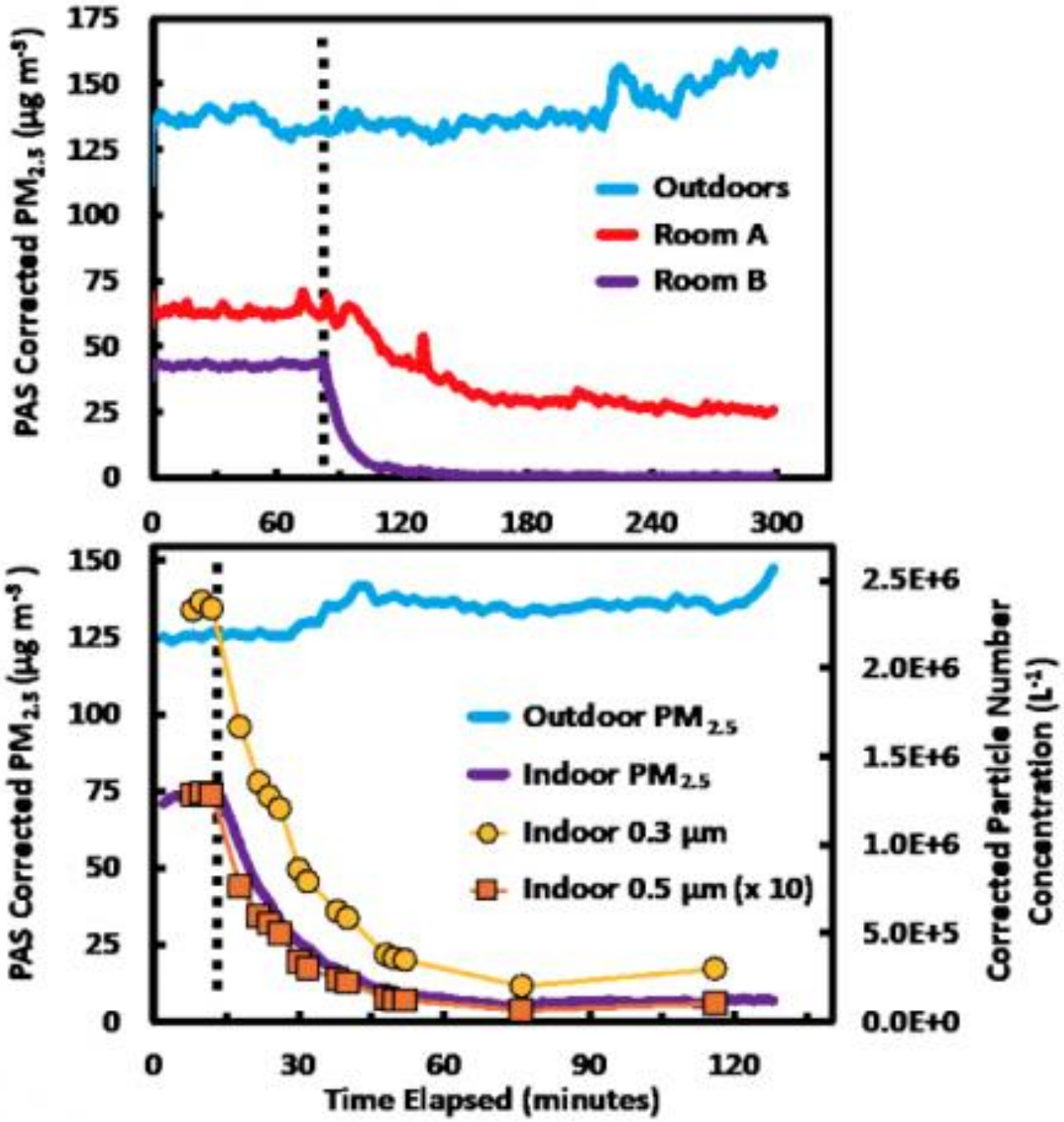
Impact of Wildfire Smoke Events on Indoor Air Quality and Evaluation of a Low-cost Filtration Method

Nathaniel W. May[1*], Clara Dixon[1], Daniel A. Jaffe[1,2]

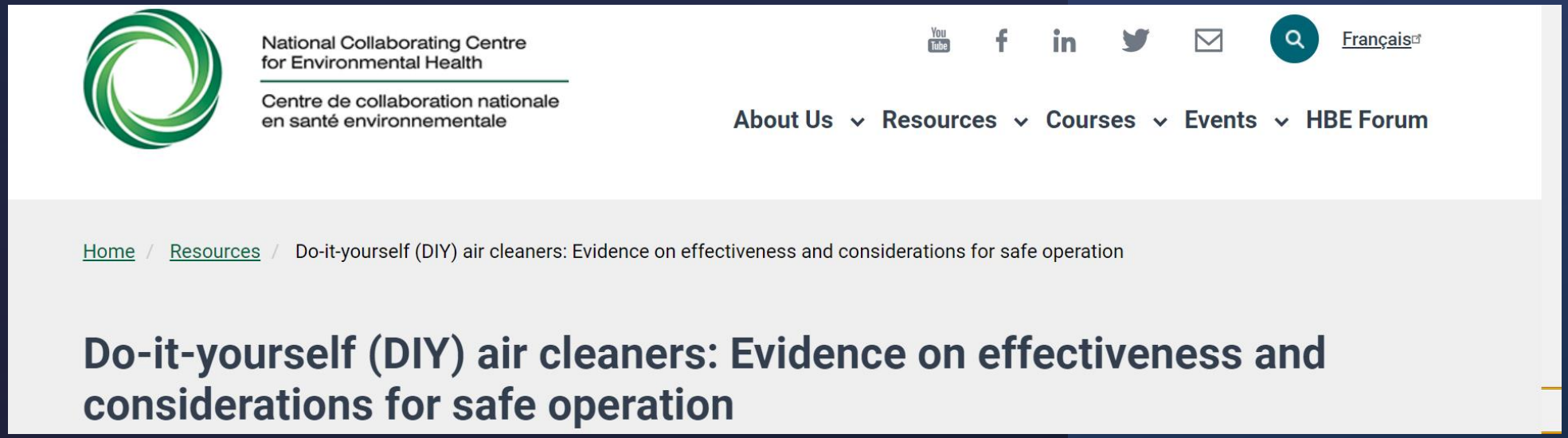
[1] University of Washington Bothell, Bothell, WA 98011, USA
[2] University of Washington, Seattle, WA 98195, USA

Effect of FFUs Indoor Air Quality





http://www.bccdc.ca/resource-gallery/Documents/Guidelines%20and%20Forms/Guidelines%20and%20Manuals/Health-Environment/BCCDC_WildFire_FactSheet_BoxFanAirFilters.pdf



https://ncceh.ca/resources/evidence-reviews/do-it-yourself-diy-air-cleaners-evidence-effectiveness-and

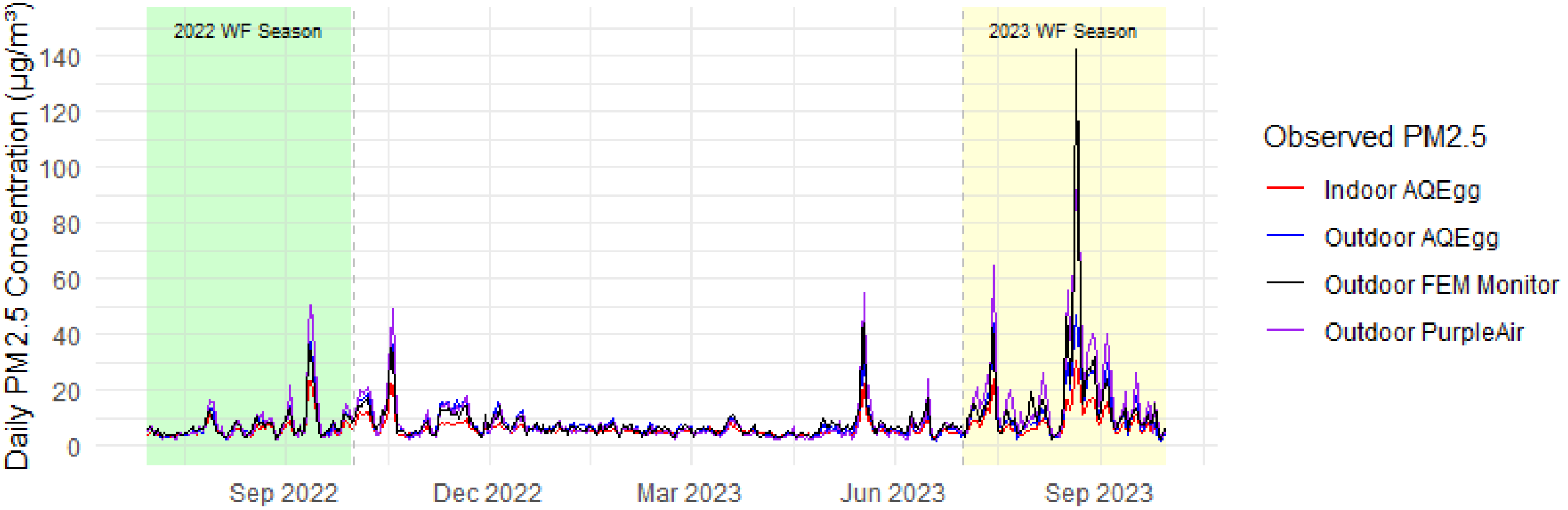
DISCUSSION OF KEY FINDINGS

All childcare facilities experienced wildfire smoke episodes	• Most facilities experienced ≥13 days of wildfire smoke during the study period
Indoor environment provides some relative protection during smoke events	• ~50% lower indoor $PM_{2.5}$ on wildfire smoke days • However, indoor $PM_{2.5}$ increased by >230% on wildfire smoke days
Infiltration attenuated on wildfire smoke days	• Possibly due to behavioral responses to wildfire smoke events • Although infiltration was more often higher at commercial facilities during wildfire smoke days
Wide variability in the level of $PM_{2.5}$ infiltration between childcare facilities	• Likely explained by differences in multiple factors related to human behaviors and building characteristics

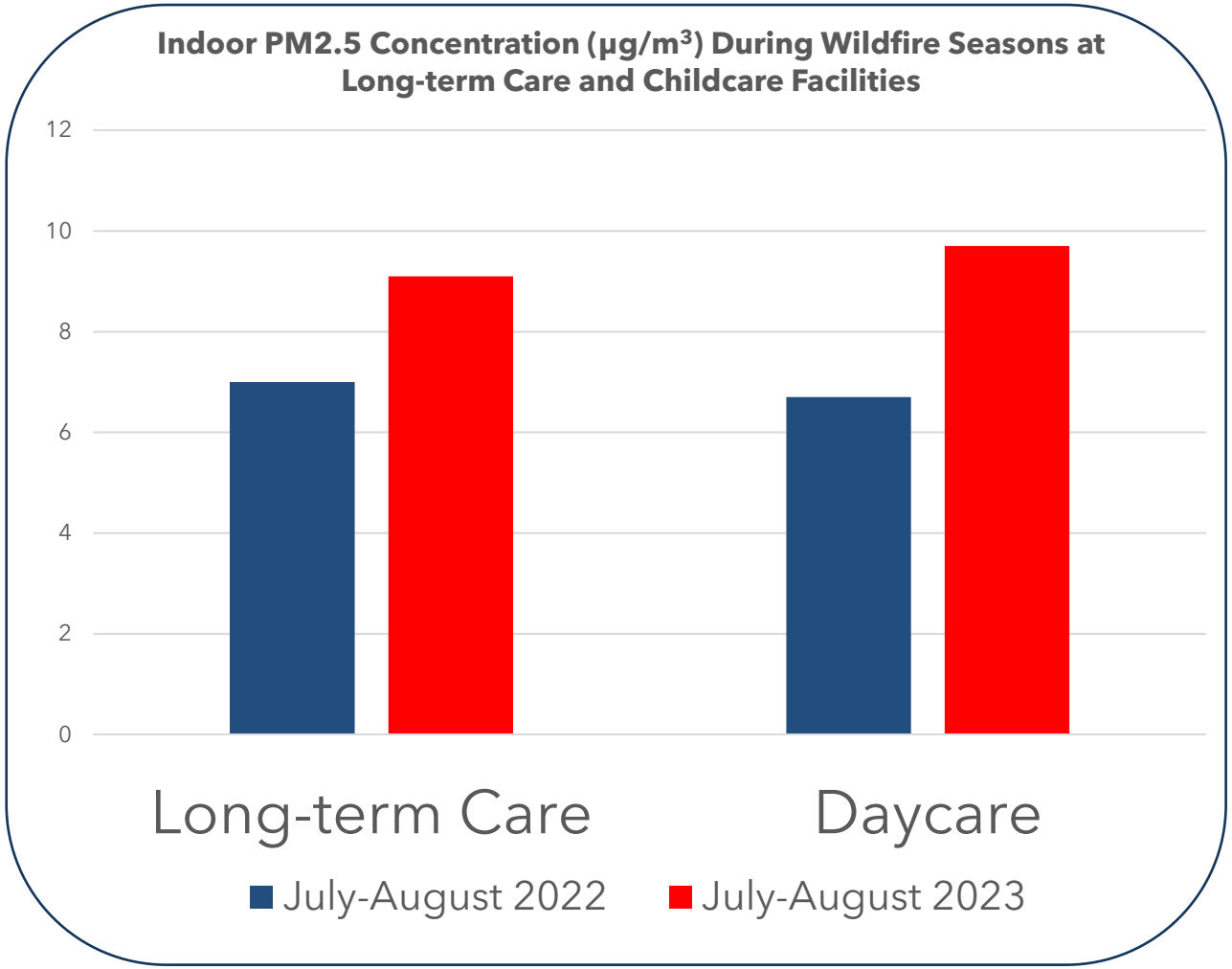
Next Steps

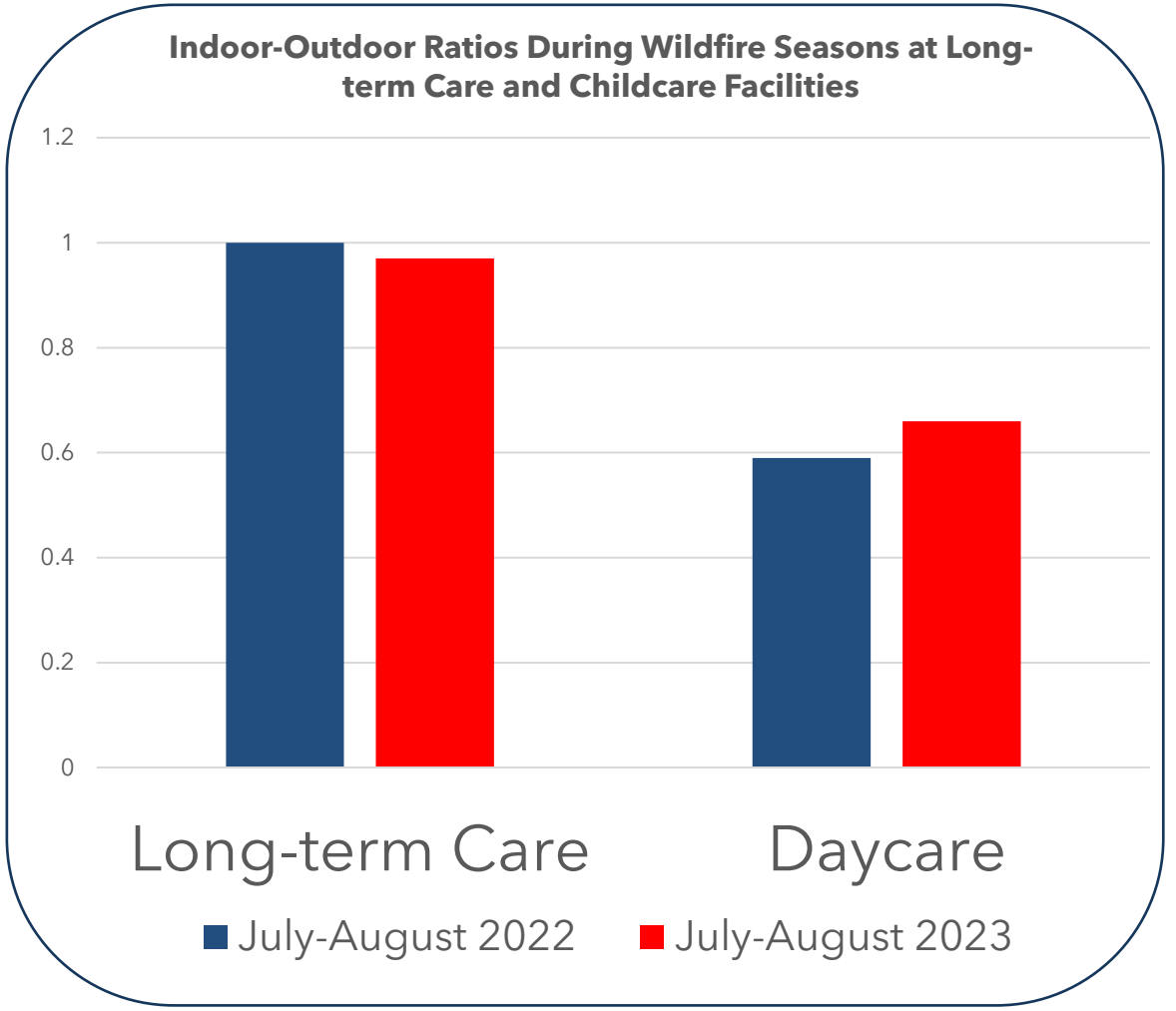
- Analysis of care facility survey
  - Assess usability of the air quality app
  - Learn about protective measures during wildfire smoke events and facility characteristics to mitigate indoor exposures
- Estimate ventilation rates at childcare facilities using indoor CO_2 measurements
- Evaluate indoor air quality at cleaner air spaces (CASs) during wildfire smoke events
- Make improvements to existing air quality app and build new app for CASs

Our care facility survey focuses primarily on the 2023 wildfire season

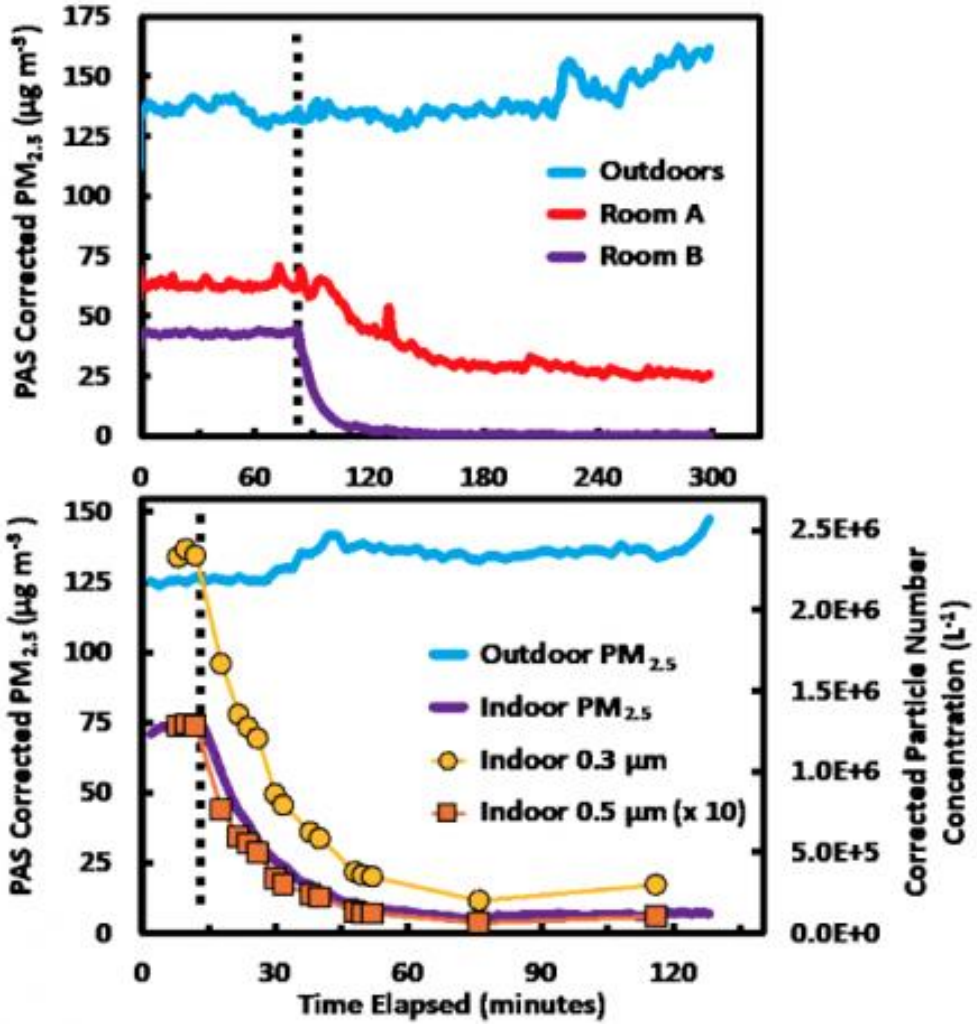


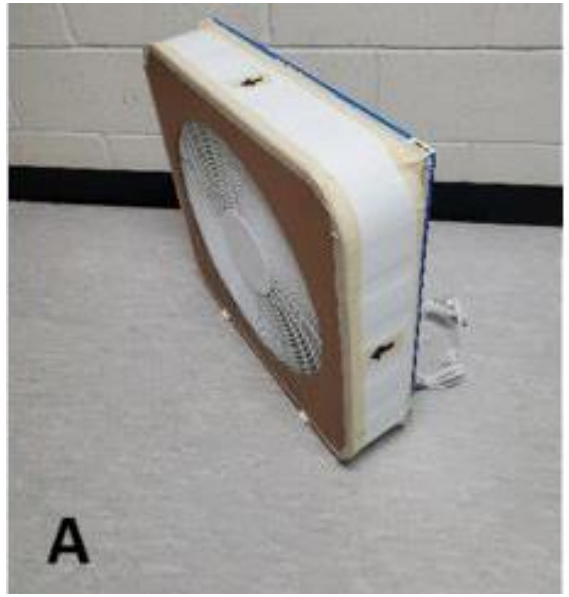
Indoor $PM_{2.5}$ from wildfire smoke was much higher in 2023 and infiltration was higher at long-term care facilities

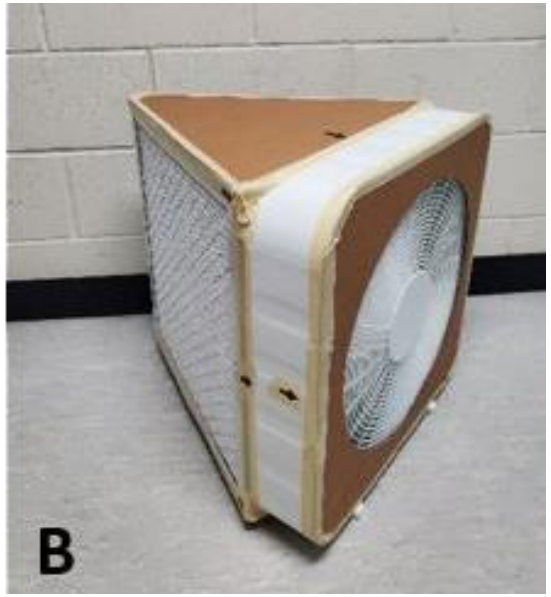




Protective effect of fan filter units on Indoor Air Quality







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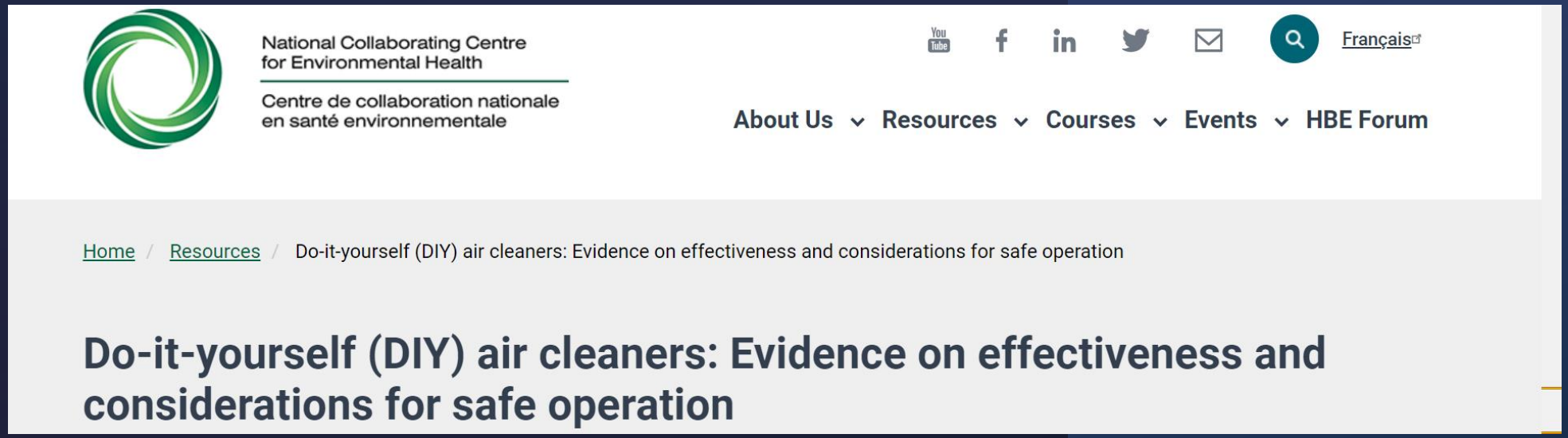

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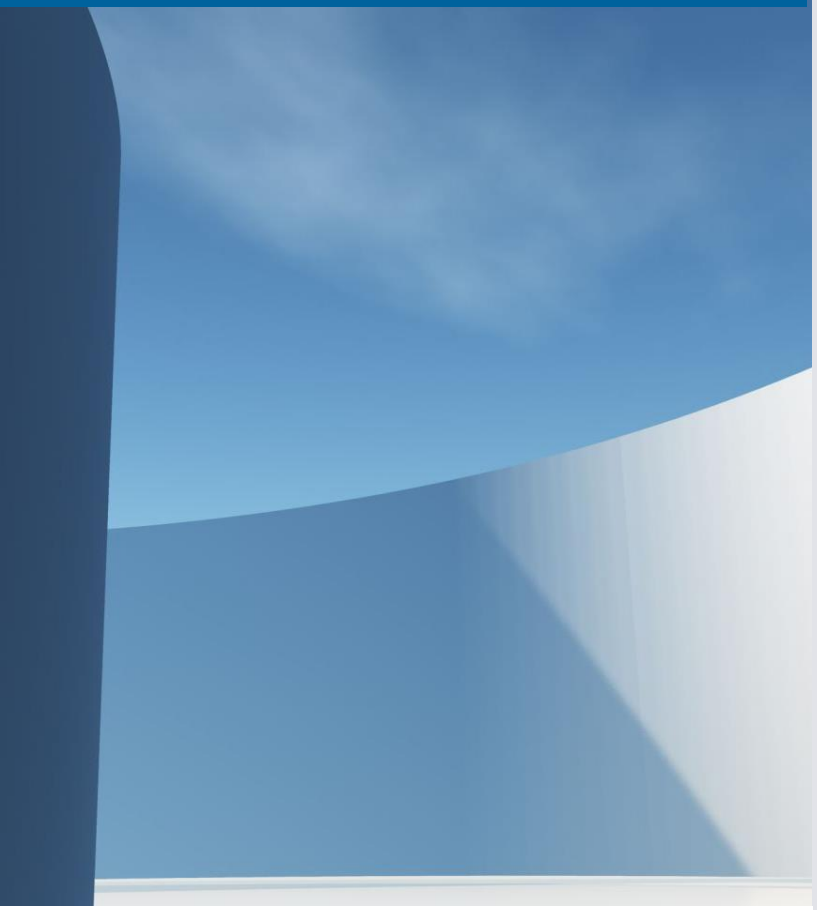
BC Centre for Disease Control



Health Canada Santé Canada

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