What Did We Learn from Deploying Low-Cost Particle Monitors in 20 Homes?

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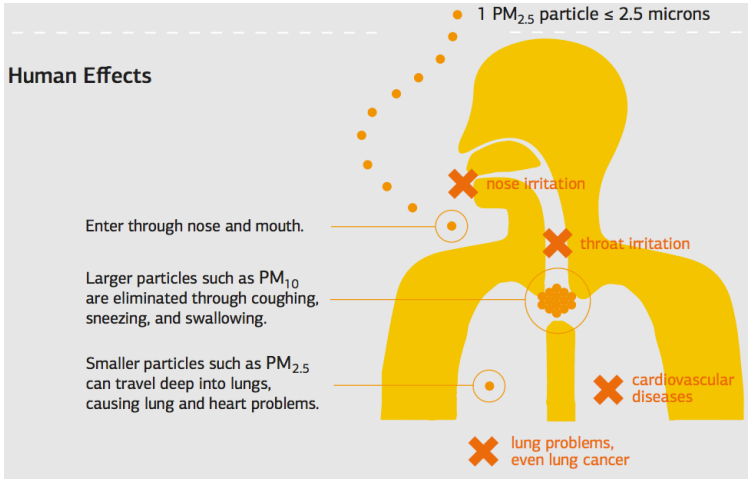
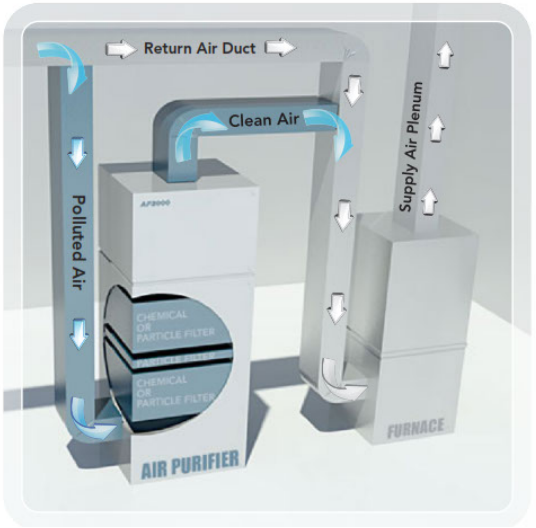
Background

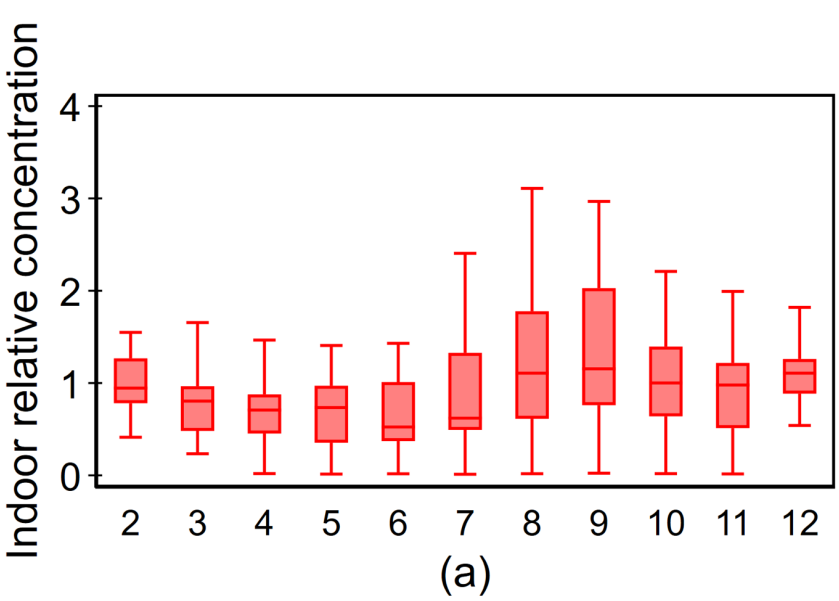
- Exposure to particulate matter (PM) has detrimental effects on our health
- Using HVAC filters is one approach to reduce exposure in residences

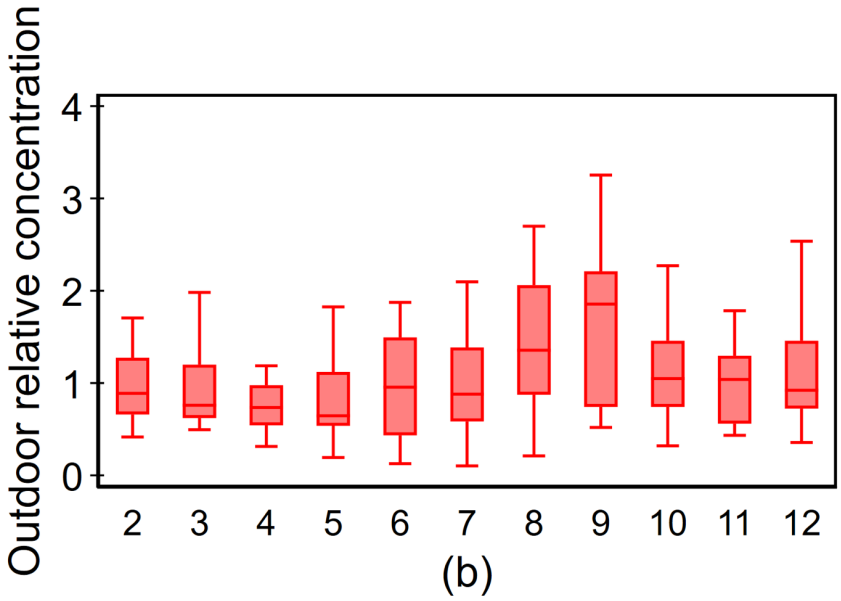


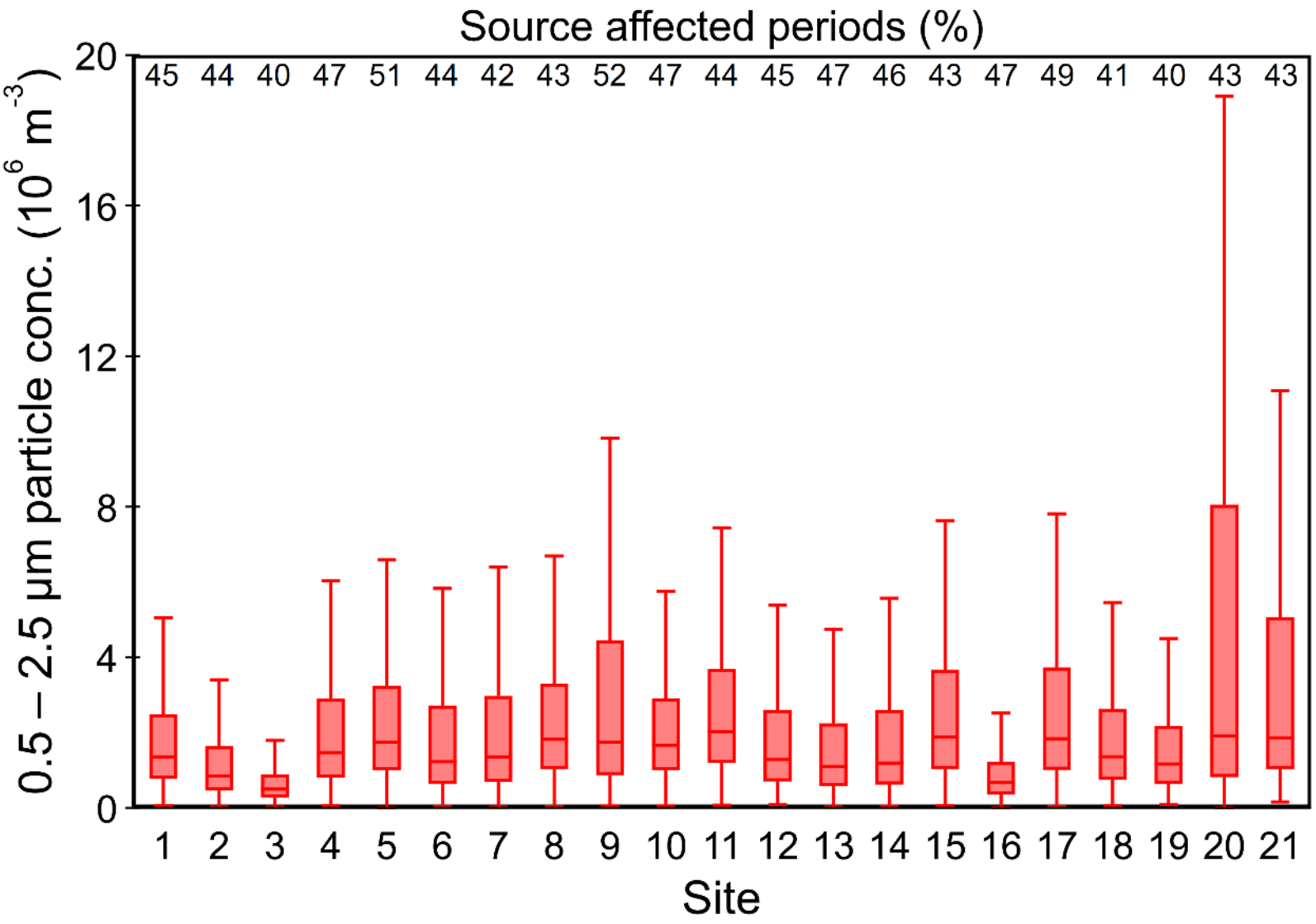


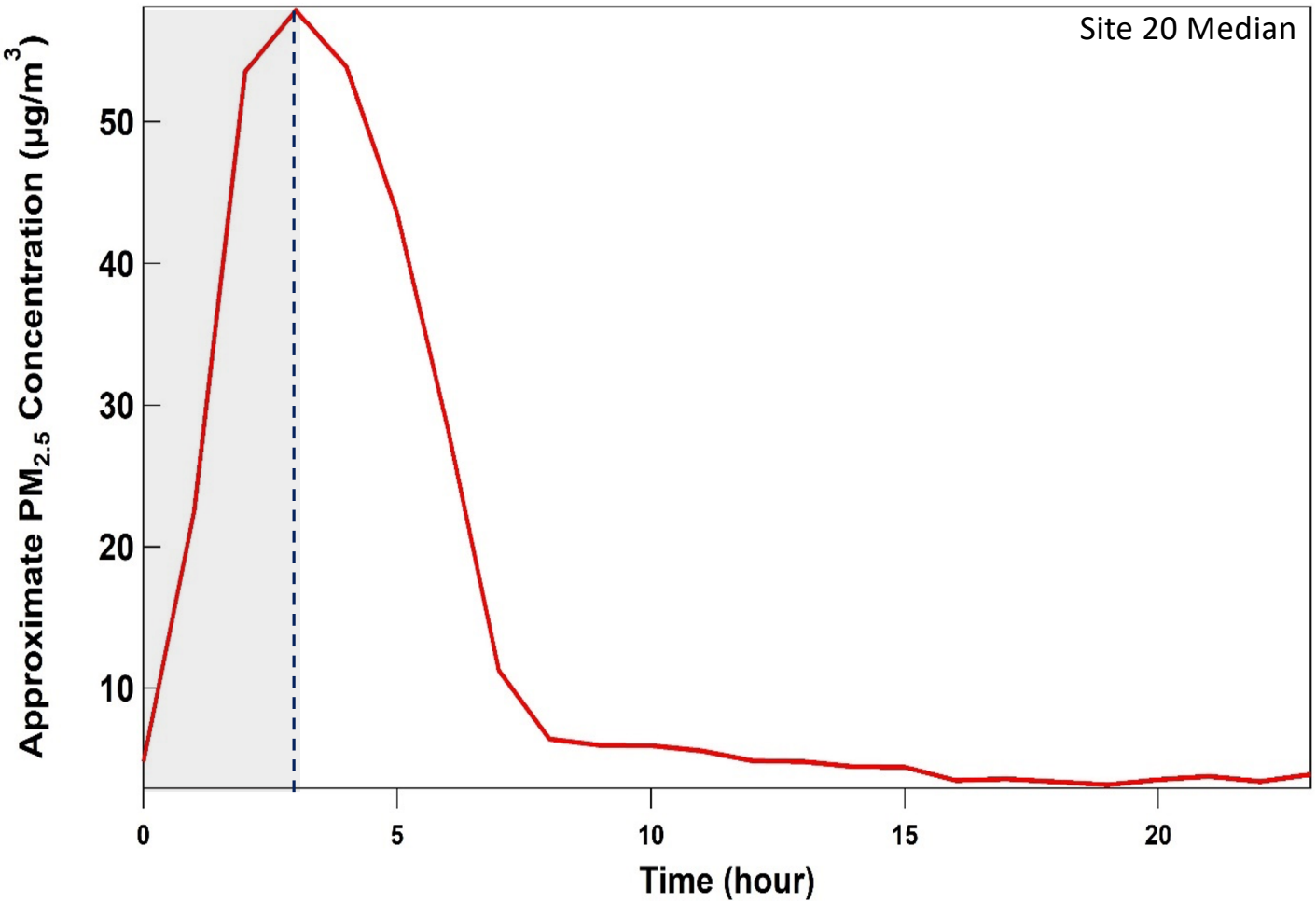
Concentration measurements

- Year-long monitoring in 21 Toronto homes
- Four levels of high-efficiency filters installed, each for 3 months (MERV 8, MERV 8E, MERV 11E, and MERV 14E)
  - MERV = Minimum Efficiency Reporting Value from ASHRAE Standard 52.2
- Collection of HVAC parameters including system operation status
- Low-cost monitor measured PM>0.5 µm & PM>2.5 µm **every hour**


Indoor relative concentration
0
1
2
3
4
2
3
4
5
6
7
8
9
10
11
12
(a)


Outdoor relative concentration
0
1
2
3
4
2
3
4
5
6
7
8
9
10
11
12
(b)


Source affected periods (%)
45 44 40 47 51 44 42 43 52 47 44 45 47 46 43 47 49 41 40 43 43
0.5 – 2.5 µm particle conc. (10^6 m^-3)
20
16
12
8
4
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Site

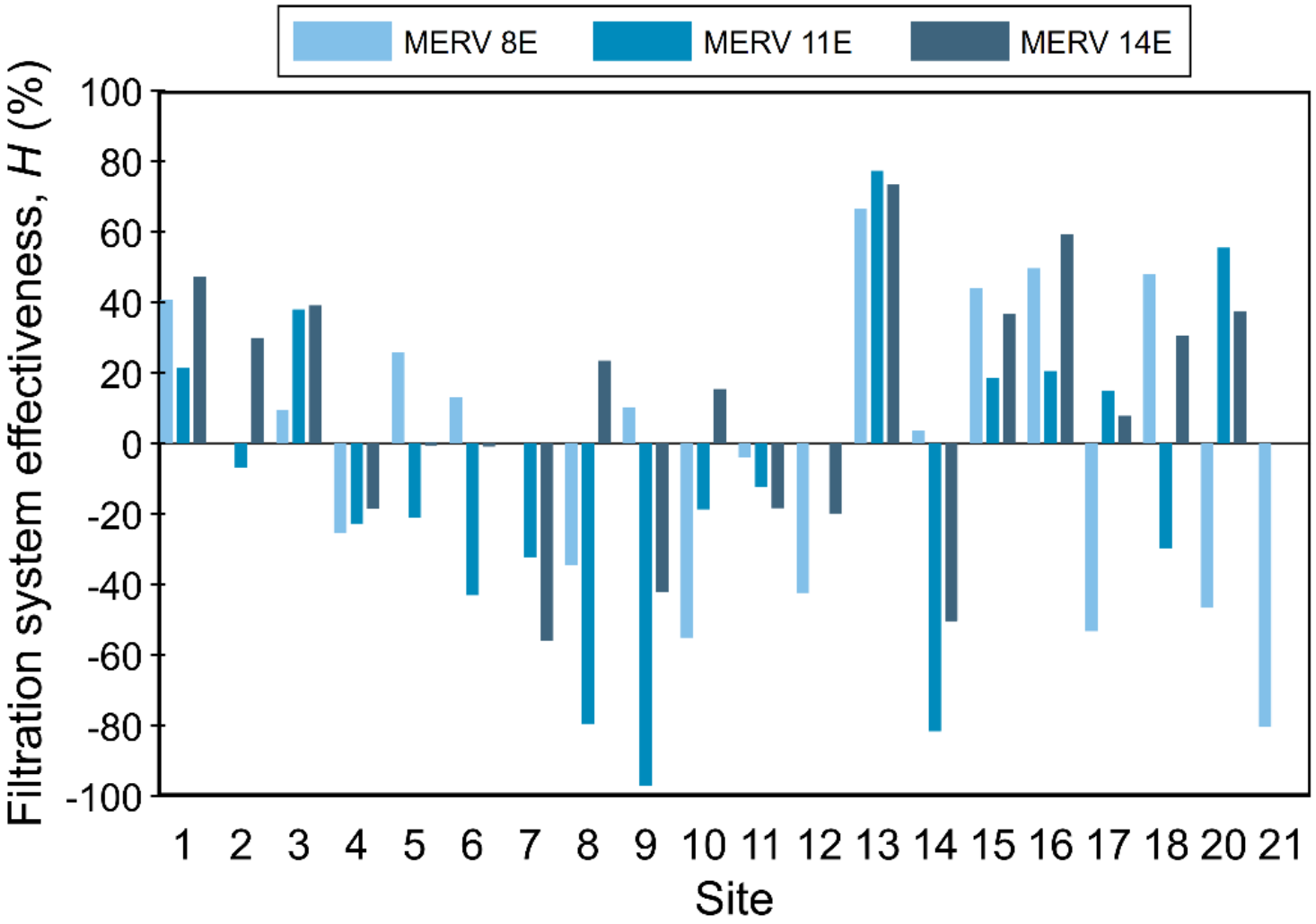

Site 20 Median
Approximate $PM_{2.5}$ Concentration ($\mu g/m^3$)
50
40
30
20
10
0
5
10
15
20
Time (hour)

Long-term filter effectiveness

$$H = 1 - \frac{C_{MERV\ \#}}{C_{MERV\ 8}}$$

where: $C_{MERV\ \#}$ = median concentration of particles when one of MERV 8E, 11E, and 14E filters was installed in the system

$C_{MERV\ 8}$ = median concentration of particles when MERV 8 filter was installed in the system


MERV 8E
MERV 11E
MERV 14E
Filtration system effectiveness, H (%)
100
80
60
40
20
0
-20
-40
-60
-80
-100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 20 21
Site

What is going on?

- Runtimes were short (~10% average)
  - Mild weather year, heating-dominated climate
- Buildings were leaky
  - Largely older homes (mostly semi-attached)
  - Filtration couldn’t compete with ventilation
- Source pattern becomes important
  - Sources may have been different for different filters

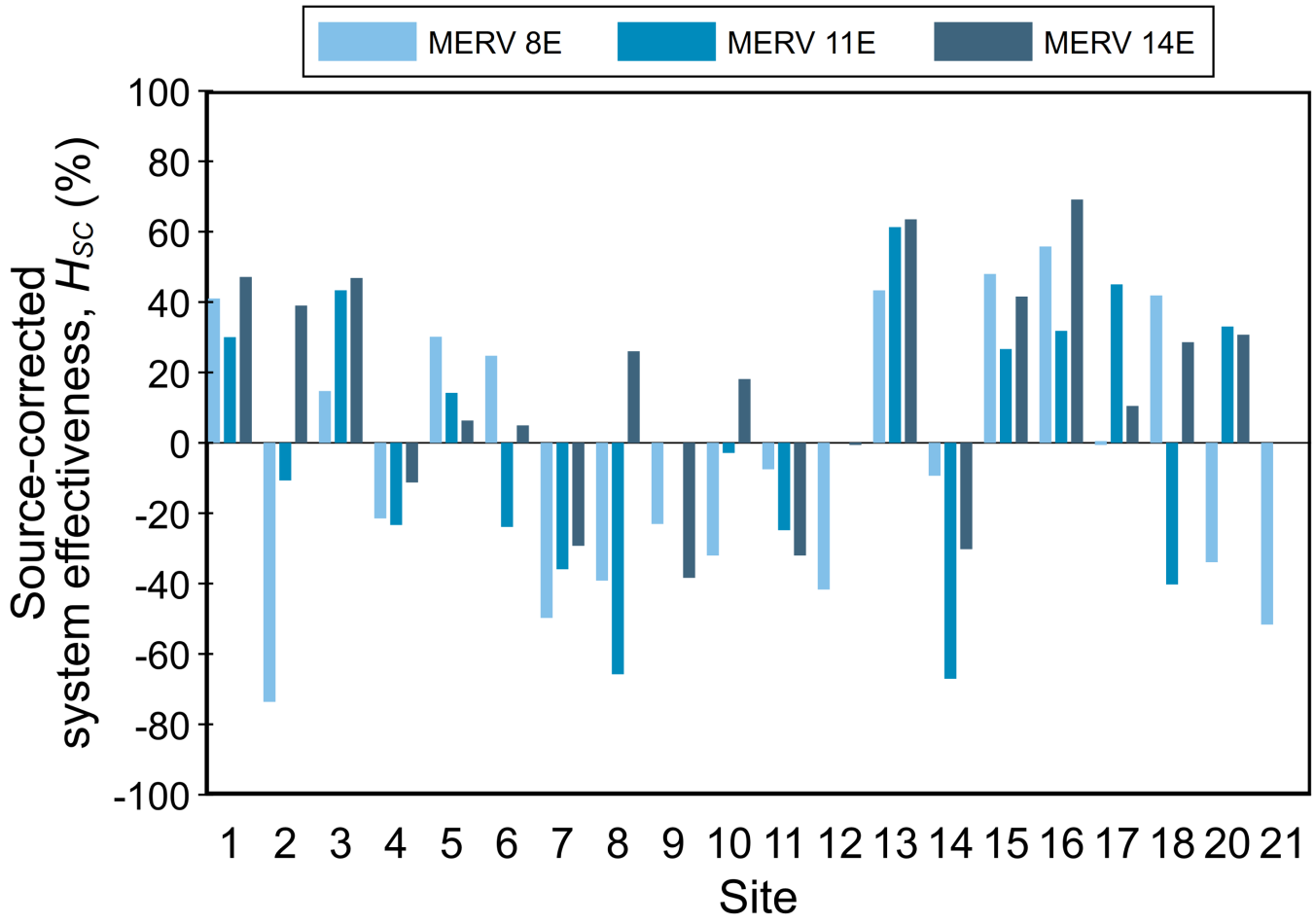
Source-Corrected Long-term filter effectiveness

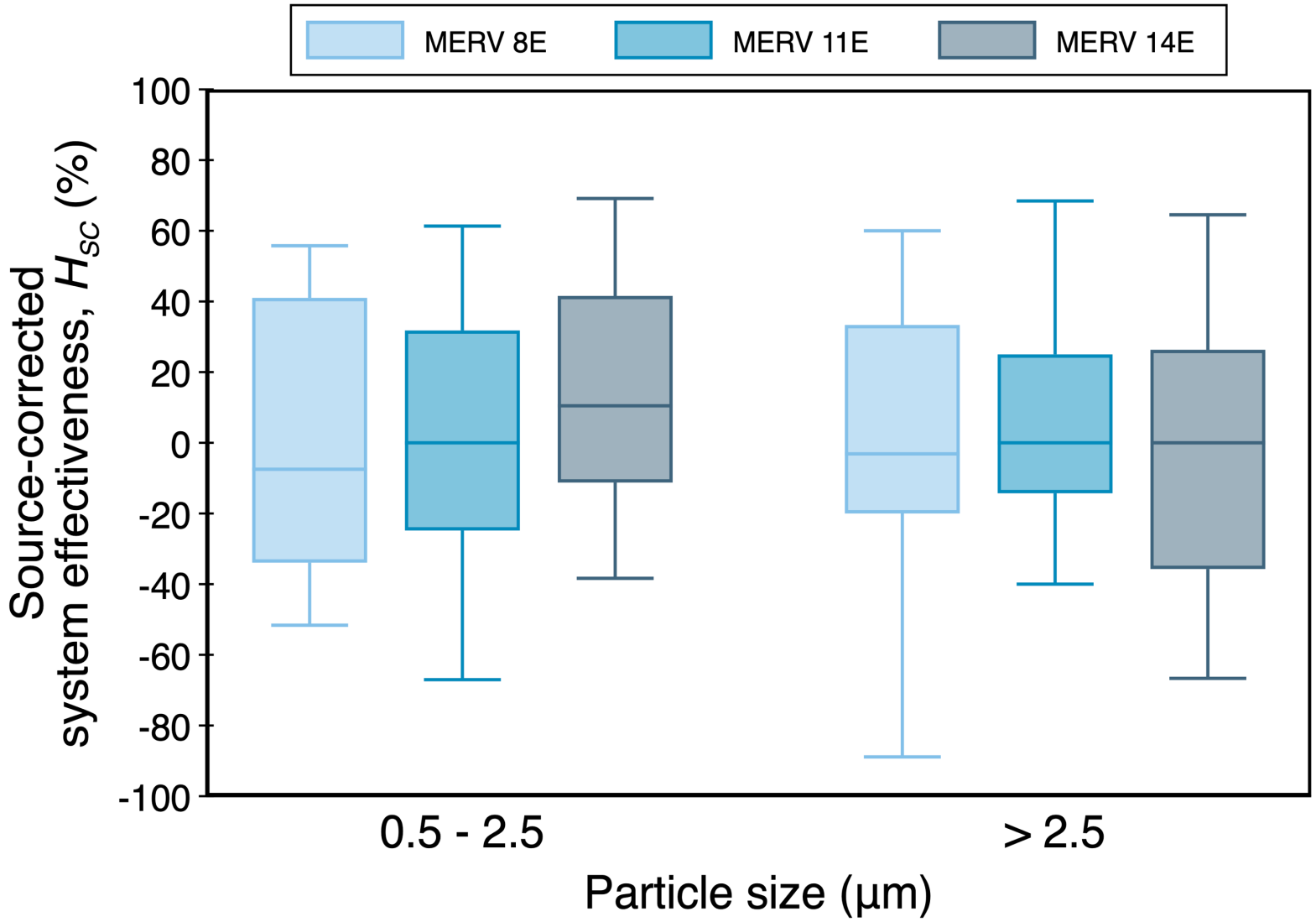
$$H = 1 - \frac{C_{MERV\ \#}}{C_{MERV\ 8}}$$

ONLY when sources were not active (50-60% of all data)

where: $C_{MERV\ \#}$ = median concentration of particles when one of MERV 8E, 11E, and 14E filters was installed in the system

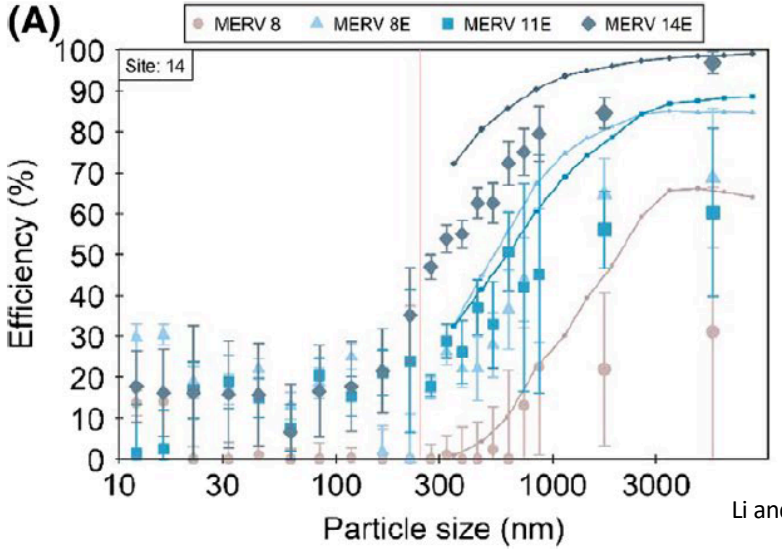
$C_{MERV\ 8}$ = median concentration of particles when MERV 8 filter was installed in the system


MERV 8E
MERV 11E
MERV 14E
Source-corrected system effectiveness, H_{SC} (%)
100
80
60
40
20
0
-20
-40
-60
-80
-100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 20 21
Site

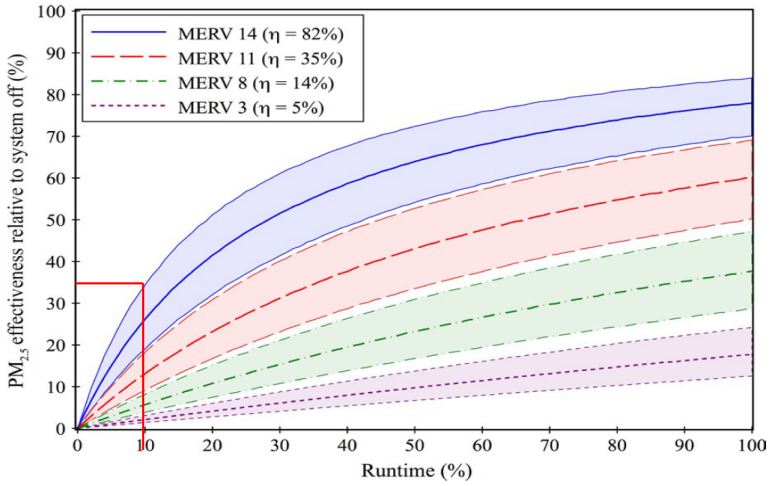

MERV 8E
MERV 11E
MERV 14E
Source-corrected system effectiveness, H_{SC} (%)
100
80
60
40
20
0
-20
-40
-60
-80
-100
0.5 - 2.5
> 2.5
Particle size (µm)

Confounding factors

- Lower in-situ efficiency than nominal efficiency
- Low HVAC system runtime



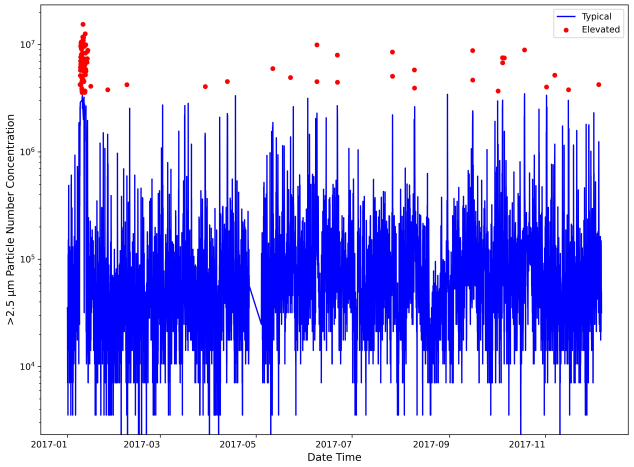
Li and Siegel (2020), *Indoor Air*.

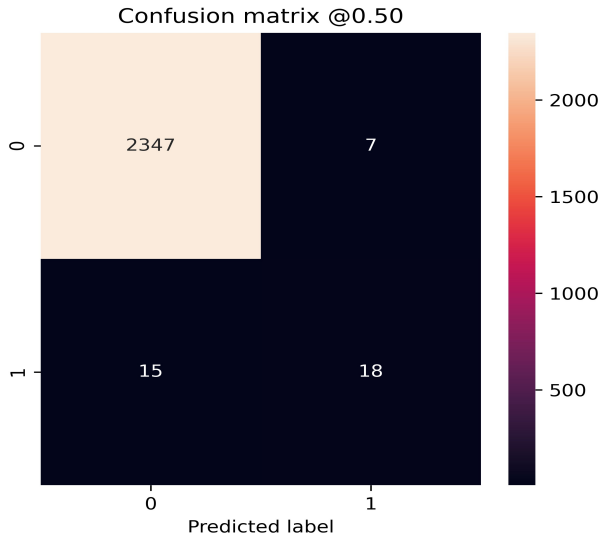


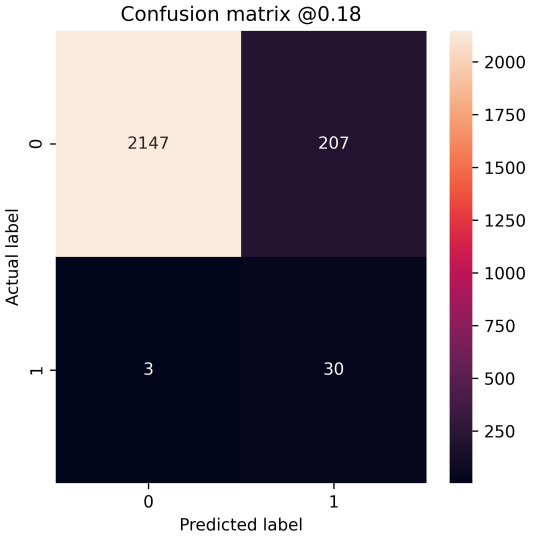
Touchie and Siegel (2018), *Indoor Air*.

Where can we go next?

- Machine learning – are there factors that would allow us to predict indoor concentrations?
  - Short answer – no, not in this data
  - Longer answer – unsupervised model can find elevated concentrations, but can't always predict them (accuracy 47-95%)







Conclusion

- High-efficiency filters have highly variable relative effectiveness
- No conclusive evidence that filters can substantially reduce indoor PM concentration in this sample of homes
- Machine learning (ML) from datasets like these might offer opportunities for control of air cleaning approaches
  - Substantial effort on interpretation and models
  - High time resolution data may be better for ML models

Acknowledgments and Further Information

- Funding: ASHRAE RP1649 and NSERC RGPIN-2014-06998

- Further reading:
  - Zhang Y, Li T, Siegel JA. 2020. Investigating the Impact of Filters on Long-term Particle Concentration Measurements in Residences (RP-1649). *Science and Technology for the Built Environment*, **8**, 1037-1047. https://doi.org/10.1080/23744731.2020.1778402.