CANADIAN CENTRE FOR BUILDING EXCELLENCE

Engineering Health and Efficiency

Fine particulate matter filtration and air cleaning in residential environments

Jeffrey Siegel, jeffrey.siegel@utoronto.ca

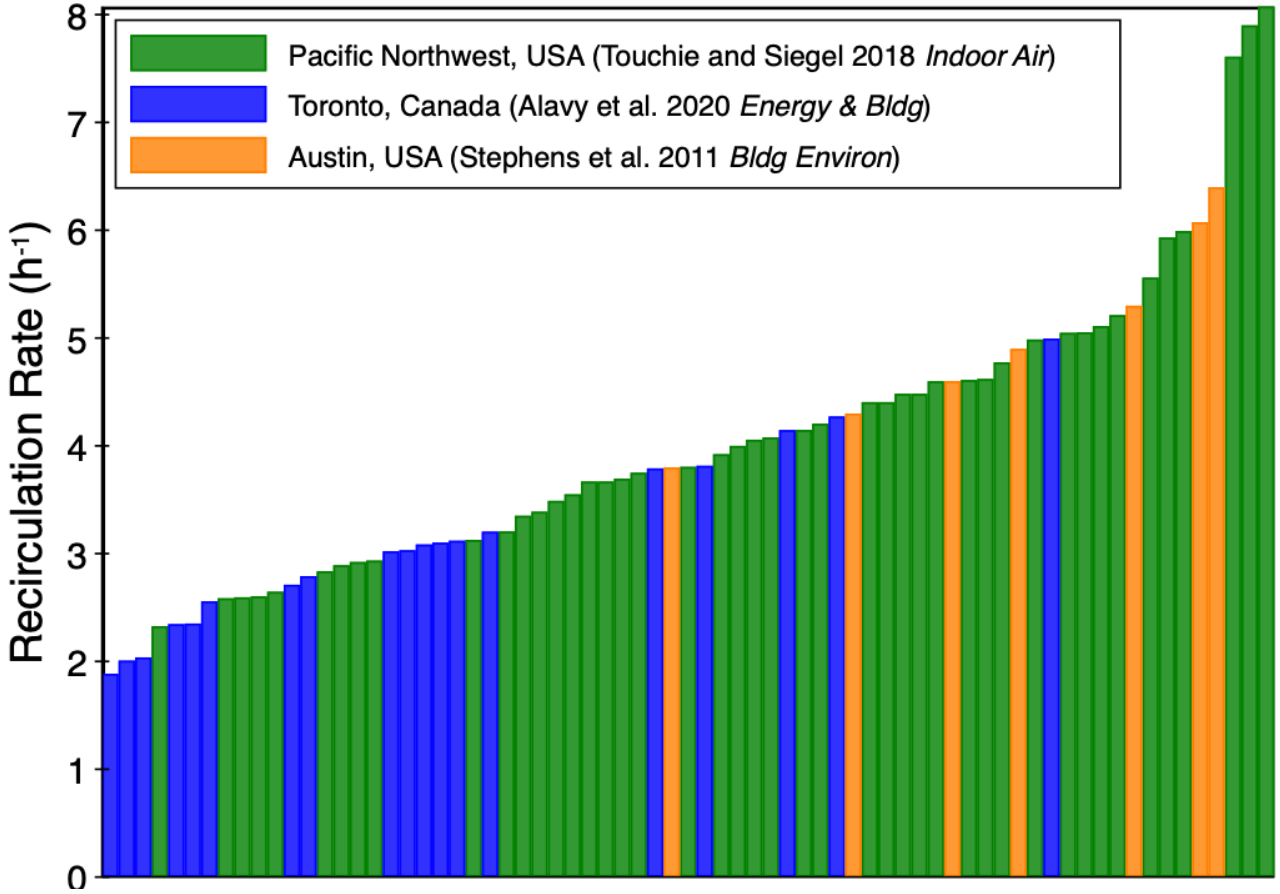
Civil & Mineral Engineering
UNIVERSITY OF TORONTO

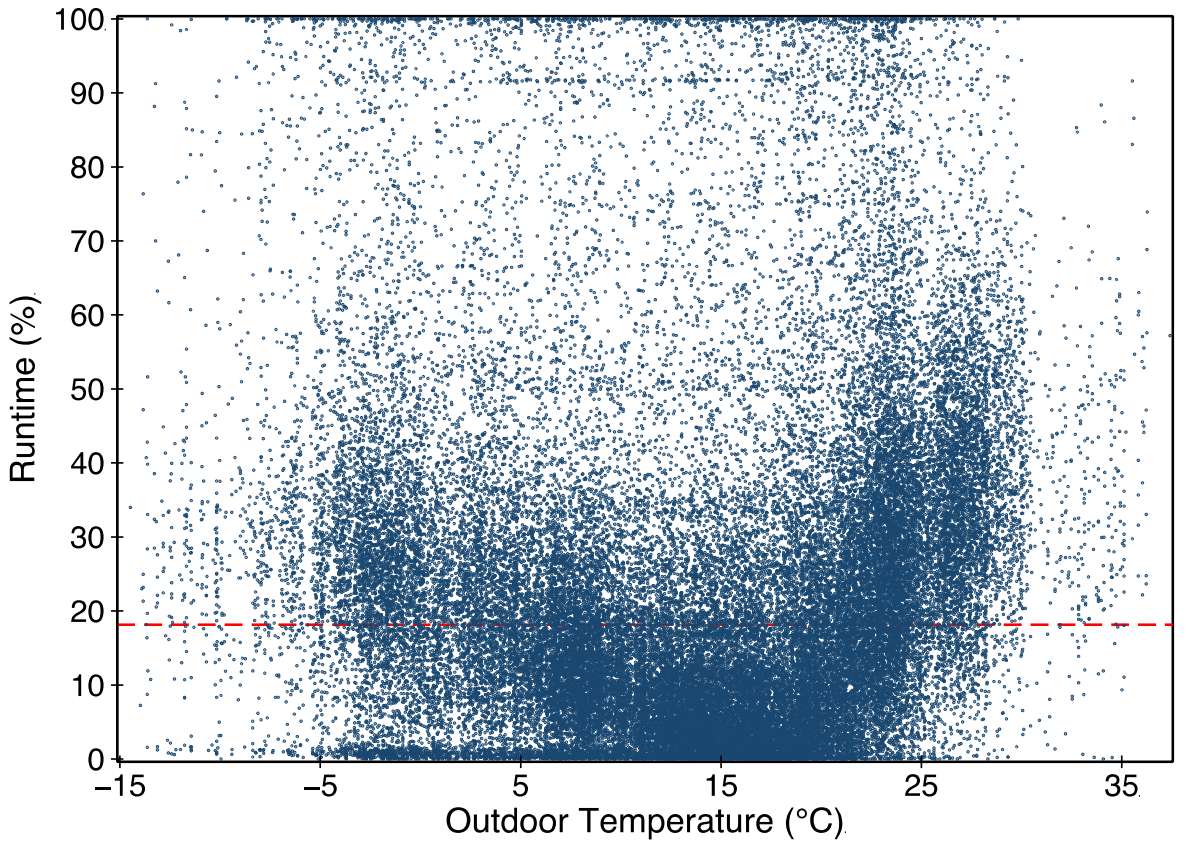
Filtration is a system.

Filtration: Context is Everything

- The virus/particle/droplet/contaminant has to get to the filter
- The filter has to remove the virus/particle/droplet/contaminant
- The removal to the device has to contribute substantially to overall removal

Airflow, In-situ efficiency, Effectiveness

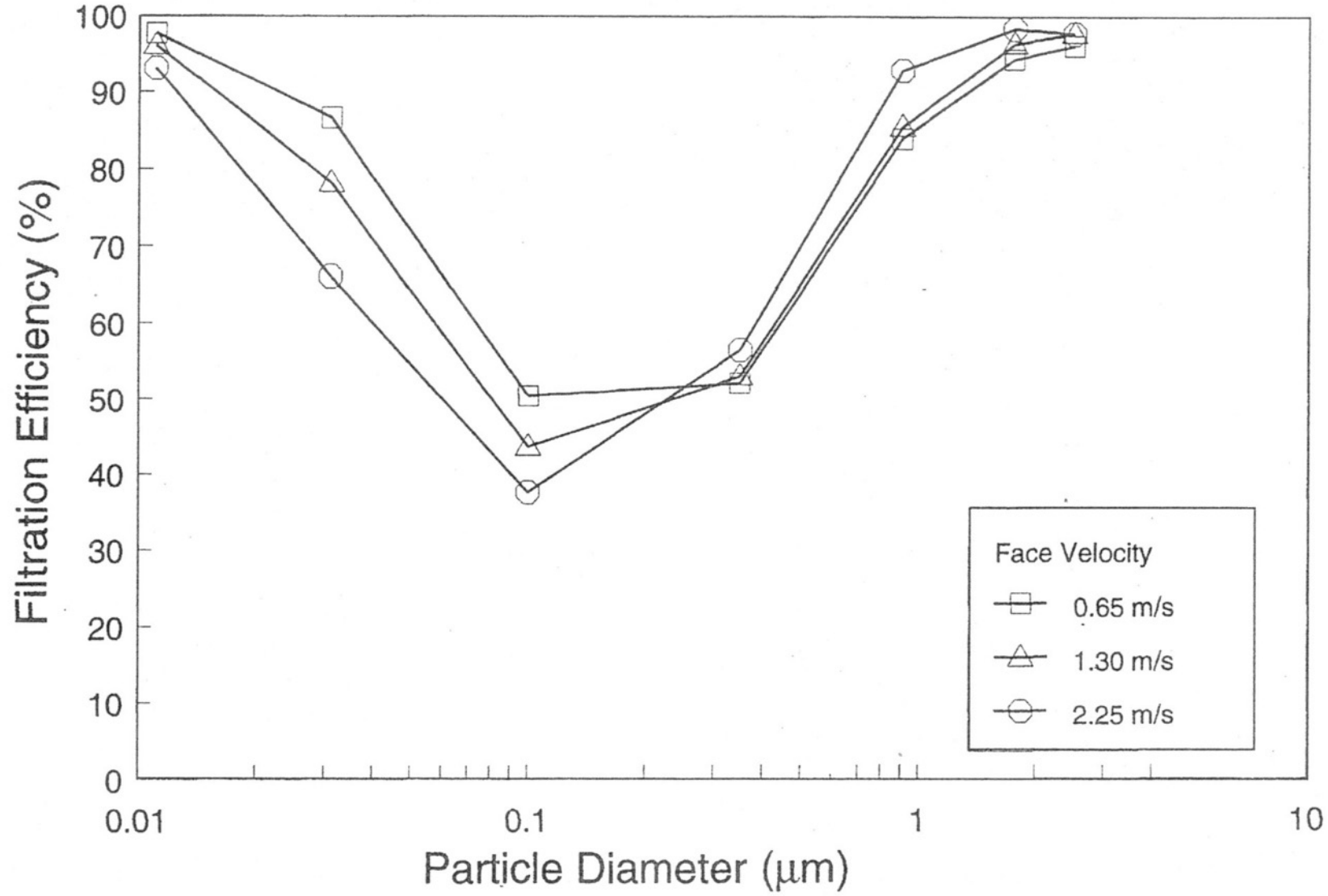




Touchie and Siegel (2018) *Indoor Air*

Recirculation: Home volumes that pass through filter when system operates

Runtime: Fraction of time that system operates



Ref: Hanley et al. (1994) *Indoor Air*

Efficiency: Single pass removal of particles

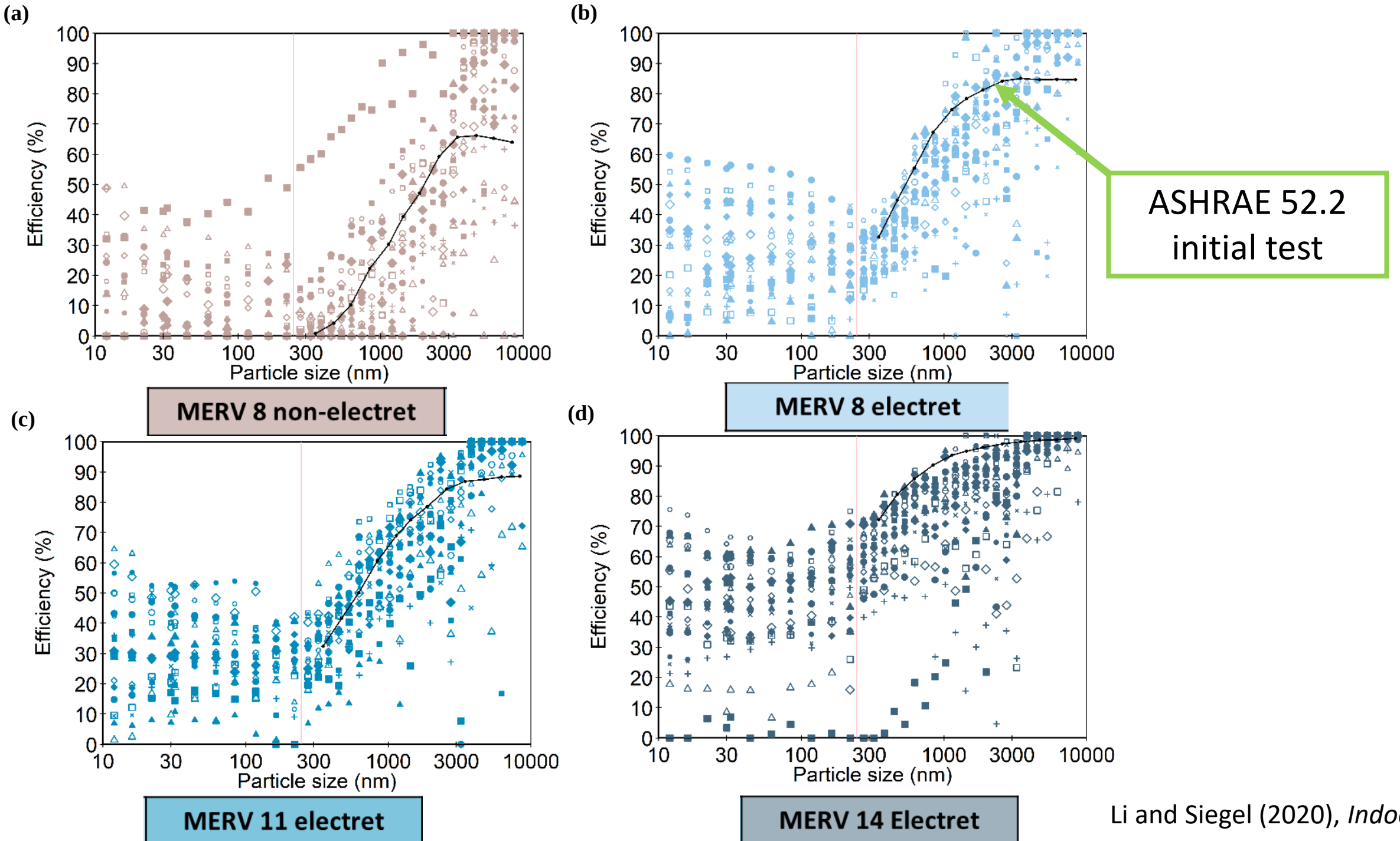
Efficiency: Standard 52.2

Table 12-1 Minimum Efficiency Reporting Value (MERV) Parameters

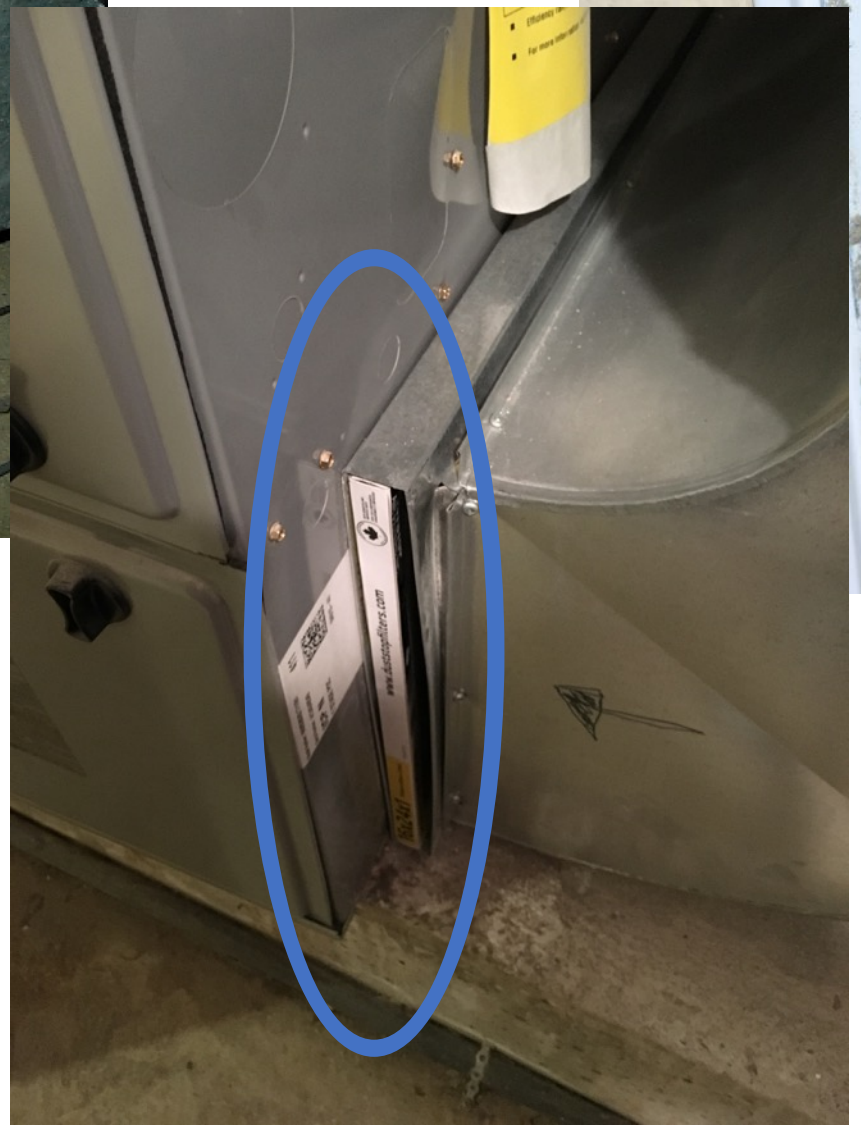
Standard 52.2 Minimum Efficiency Reporting Value (MERV)	Composite Average Particle Size Efficiency, % in Size Range, µm		
	Range 1 0.30 to 1.0	Range 2 1.0 to 3.0	Range 3 3.0 to 10.0
1	N/A	N/A	$E_3 < 20$
2	N/A	N/A	$E_3 < 20$
3	N/A	N/A	$E_3 < 20$
4	N/A	N/A	$E_3 < 20$
5	N/A	N/A	$20 \le E_3$
6	N/A	N/A	$35 \le E_3$
7	N/A	N/A	$50 \le E_3$
8	N/A	$20 \le E_2$	$70 \le E_3$
9	N/A	$35 \le E_2$	$75 \le E_3$
10	N/A	$50 \le E_2$	$80 \le E_3$
11	$20 \le E_1$	$65 \le E_2$	$85 \le E_3$
12	$35 \le E_1$	$80 \le E_2$	$90 \le E_3$
13	$50 \le E_1$	$85 \le E_2$	$90 \le E_3$
14	$75 \le E_1$	$90 \le E_2$	$95 \le E_3$
15	$85 \le E_1$	$90 \le E_2$	$95 \le E_3$
16	$95 \le E_1$	$95 \le E_2$	$95 \le E_3$

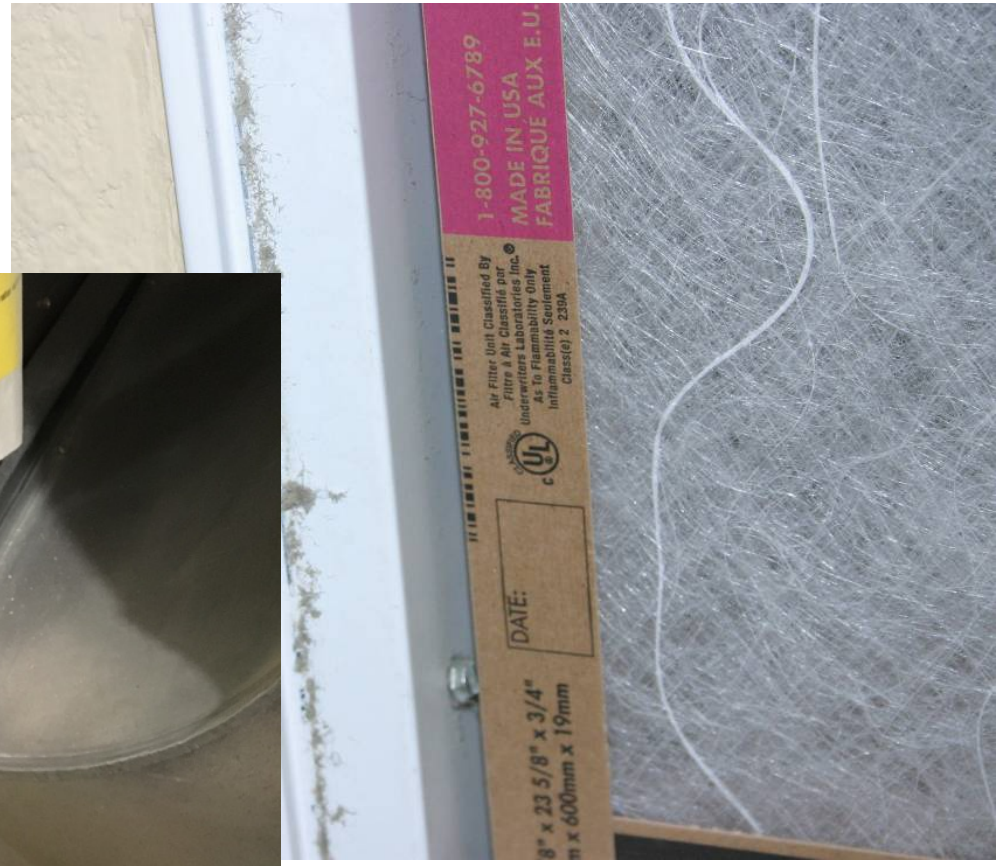
ASHRAE Standard 52.2-2017

- Test approach
  - In a lab
  - Perfectly installed
  - At a fixed flow rate
  - Potassium chloride aerosol
  - With successive dust loadings
  - Optional conditioning step
- Notes
  - Not a residential standard
  - Not an in-situ standard
  - Only addresses 0.3-10 µm particles



Li and Siegel (2020), *Indoor Air*





Ward & Siegel (2005) *ASHRAE Trans.*
Siegel et al. (2008) *Indoor Air Conf.*
Chojnowski et al. (2009) *ASHRAE Trans.*
VerShaw et al. (2009) *ASHRAE Trans.*

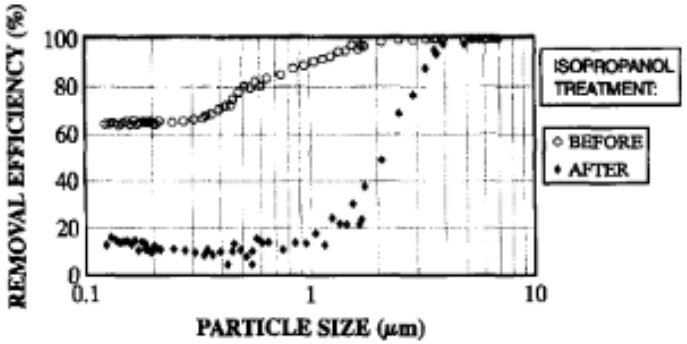


Fig. 2. Effect of isopropanol treatment on the removal efficiency of an "EU7" electret filter, flow velocity 0.33 m/s.

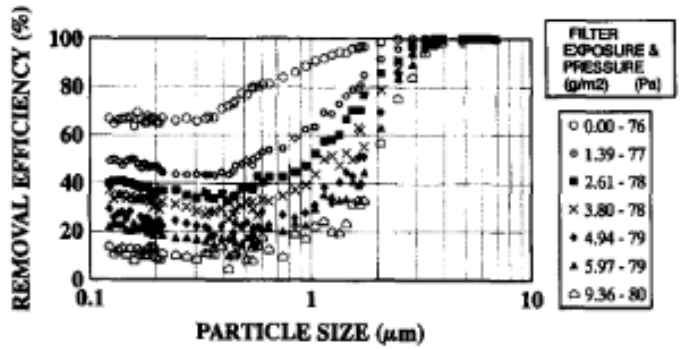


Fig. 3. Effect of diesel fume aerosol on the removal efficiency of an "EU7" electret filter, flow velocity 0.33 m/s.

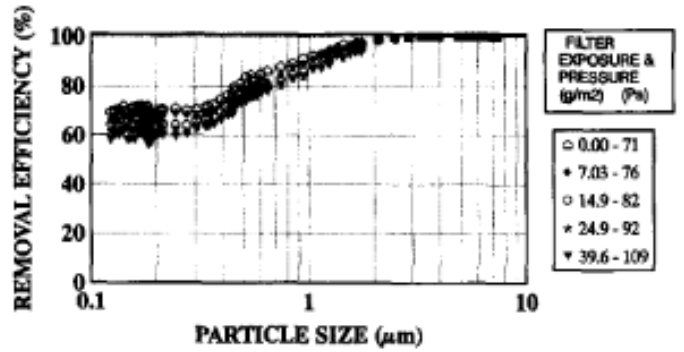
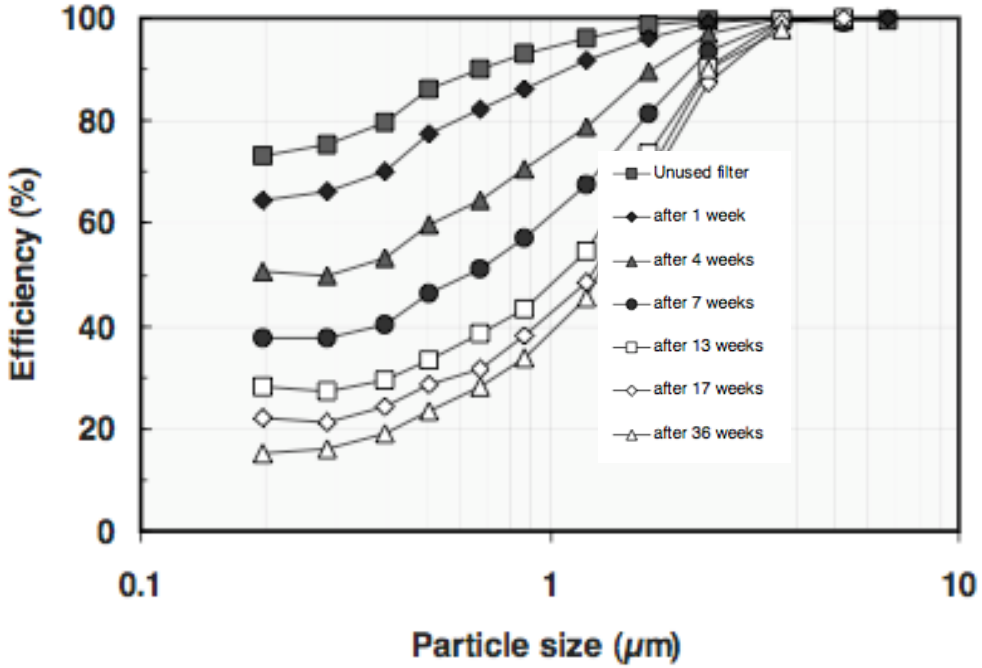
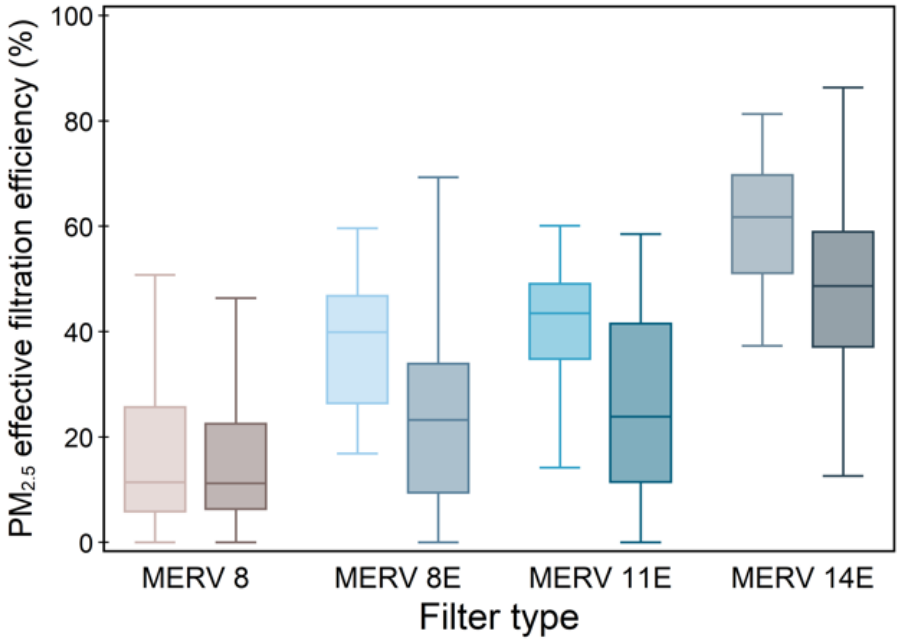


Fig. 4. Effect of Arizona road dust loading on the removal efficiency of an "EU7" electret filter, flow velocity 0.33 m/s.

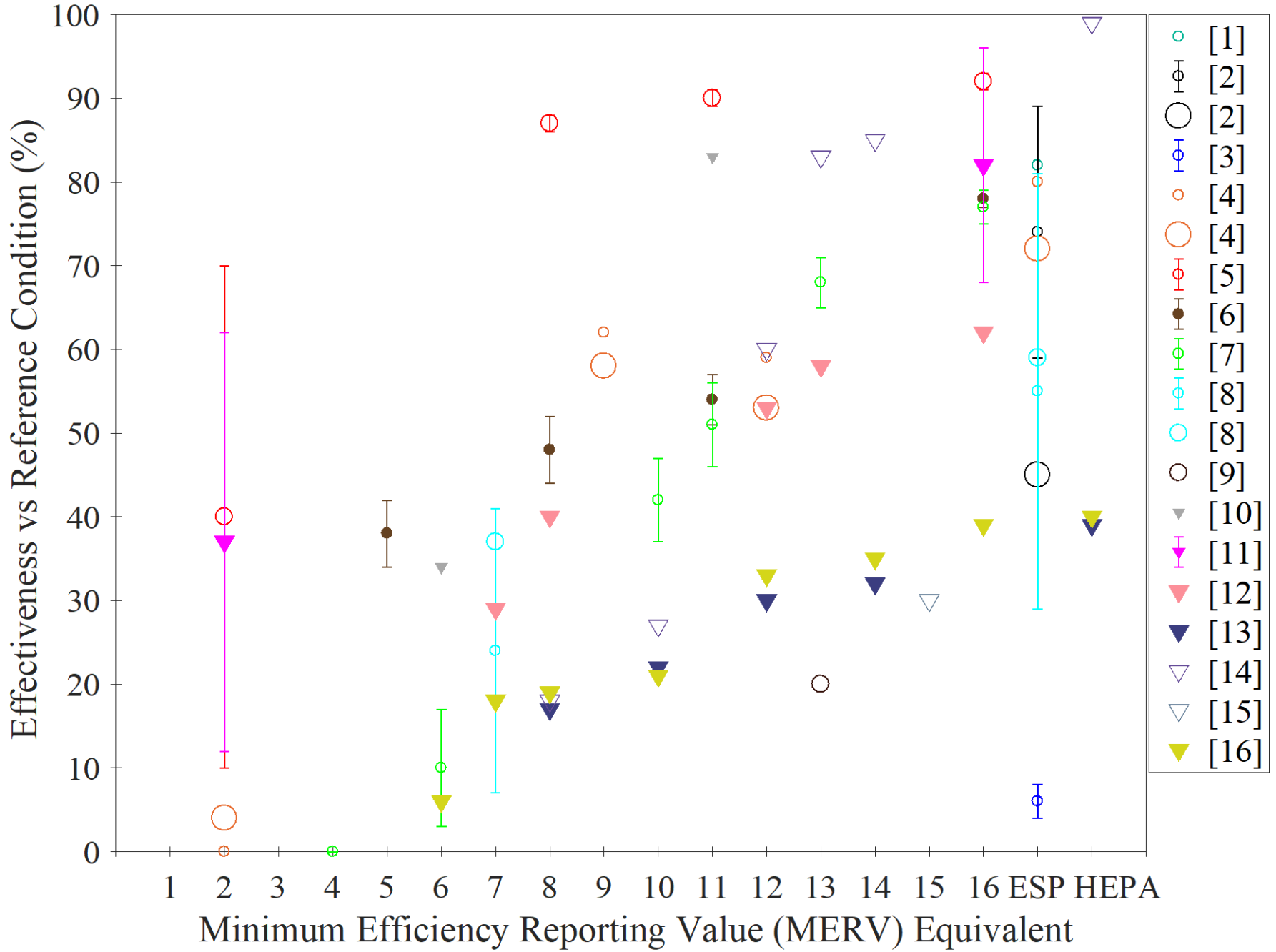
Lehtimäki & Heinonen (1994) *Bldg Environ*



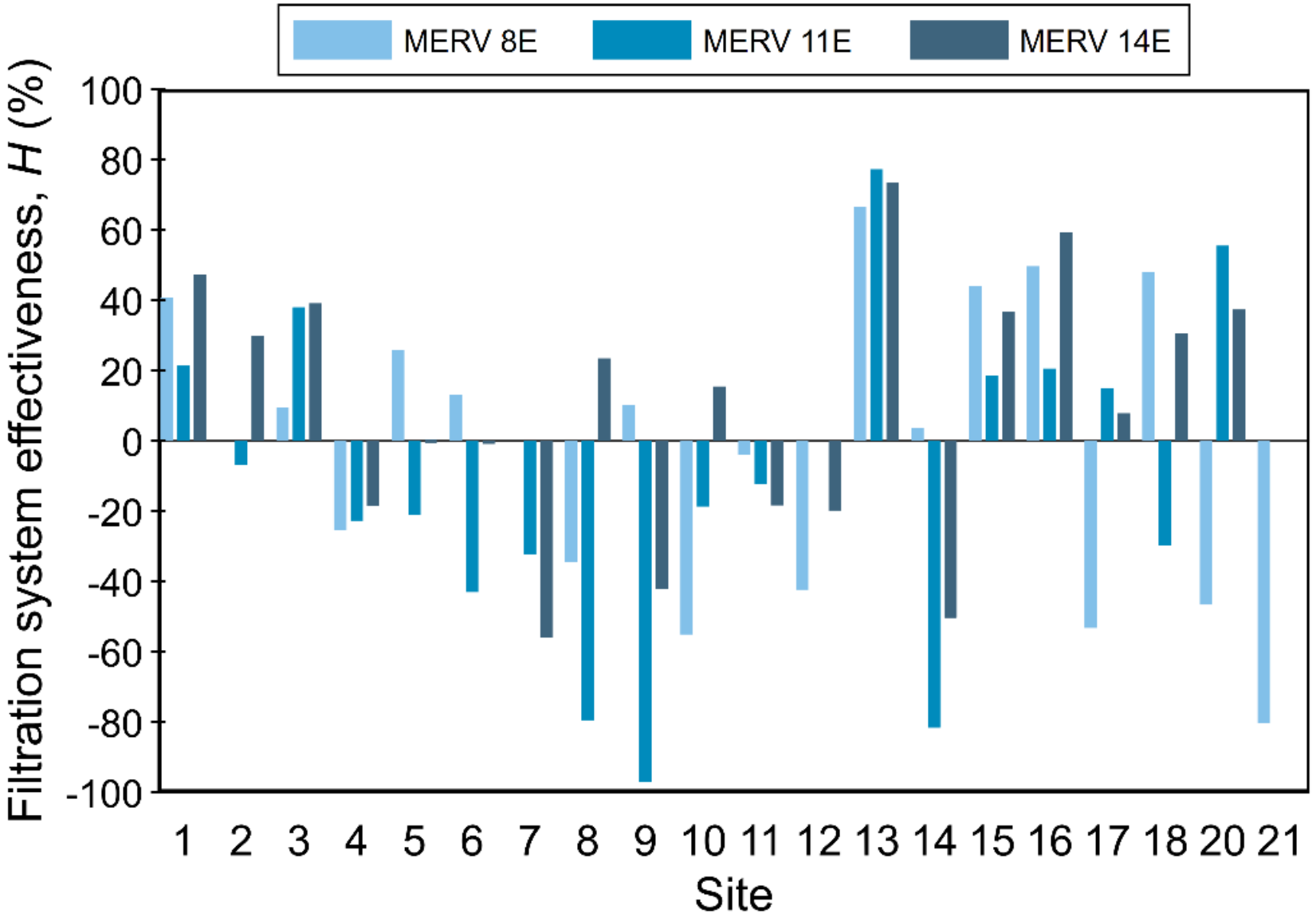
Lehtimäki et al. (2002) *ASHRAE RP-1189 Report*



Li & Siegel (2020) *Indoor Air*



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



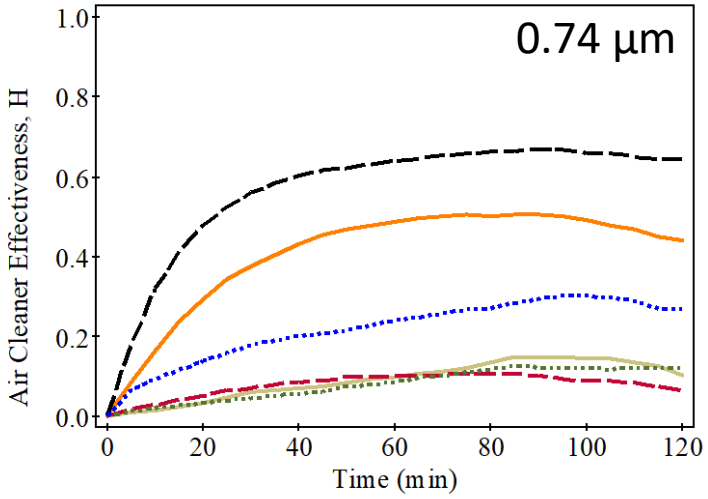
- Low runtimes (~10%)
- Leaky older homes
- Lots of bypass

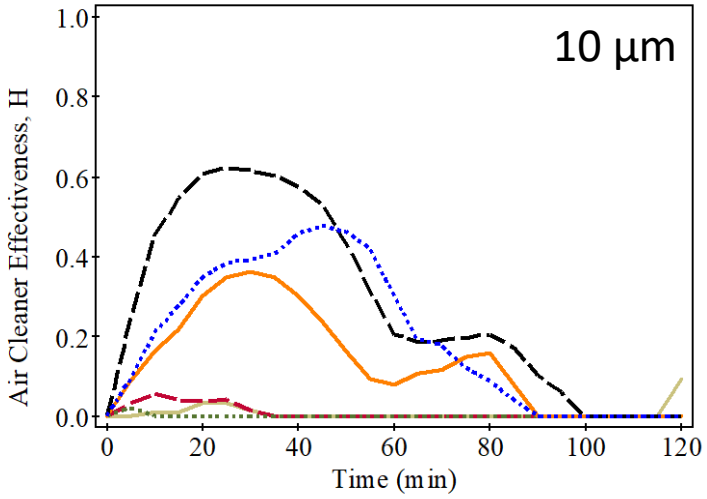
Zhang et al. (2020) *Sci Tech Built Environ*

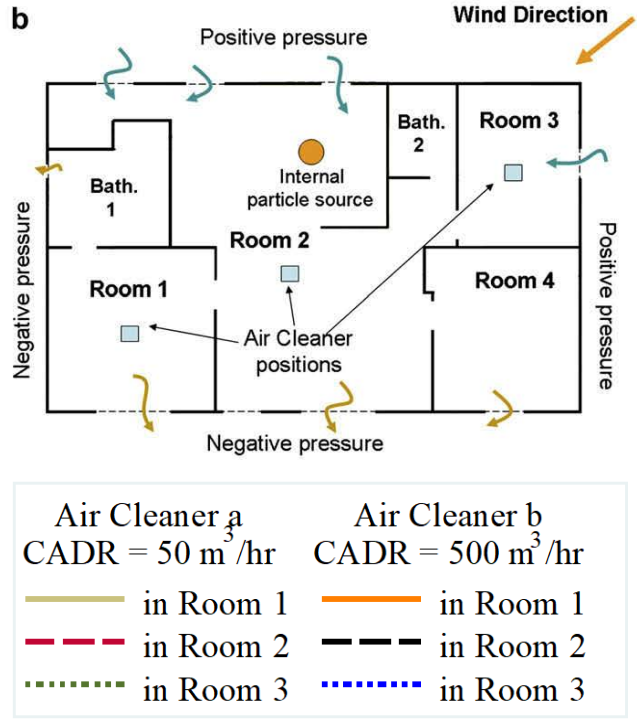
Effective Filtration

- Good filter
- Properly installed
- With large enough flow rate
- With high enough run time
- Changed frequently

Effectively compete with deposition and ventilation losses







Novoselac & Siegel (2009) *Bldg Environ*

Other Air Cleaning Technologies

Image ref: Allergy Cosmos

- Photocatalytic oxidation, plasma, ionization, sprays
  - These are **not** terms with firm definitions
- There is not independent evidence of efficacy – many (most?) don't work/have low performance
- There is evidence of **harm** (ozone emission, ion concentration, byproduct formation)

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

Pettenkofer (1883)

Research Needs #1

- In-situ effective filtration performance test with low-cost monitors
- Continuous performance monitoring
- Personal monitoring to assess exposure reduction

ISO 29462:2013

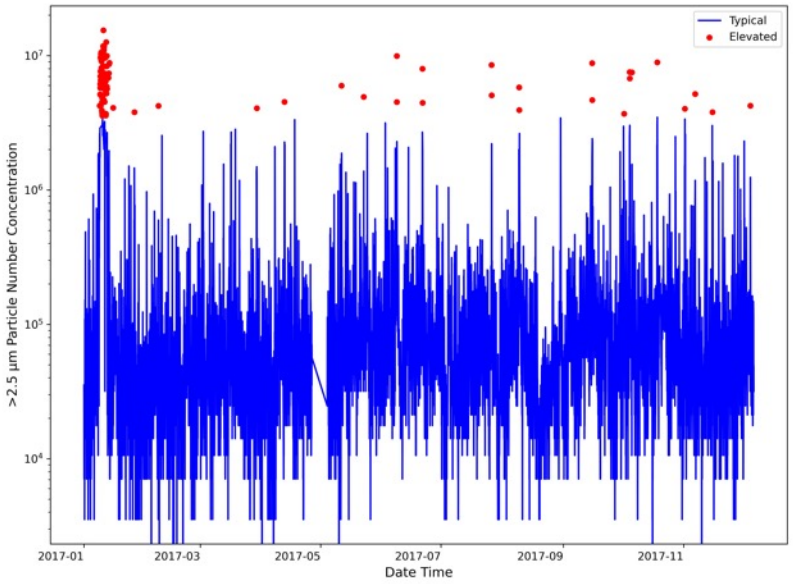
Field testing of general ventilation filtration devices and systems for in situ removal efficiency by particle size and resistance to airflow

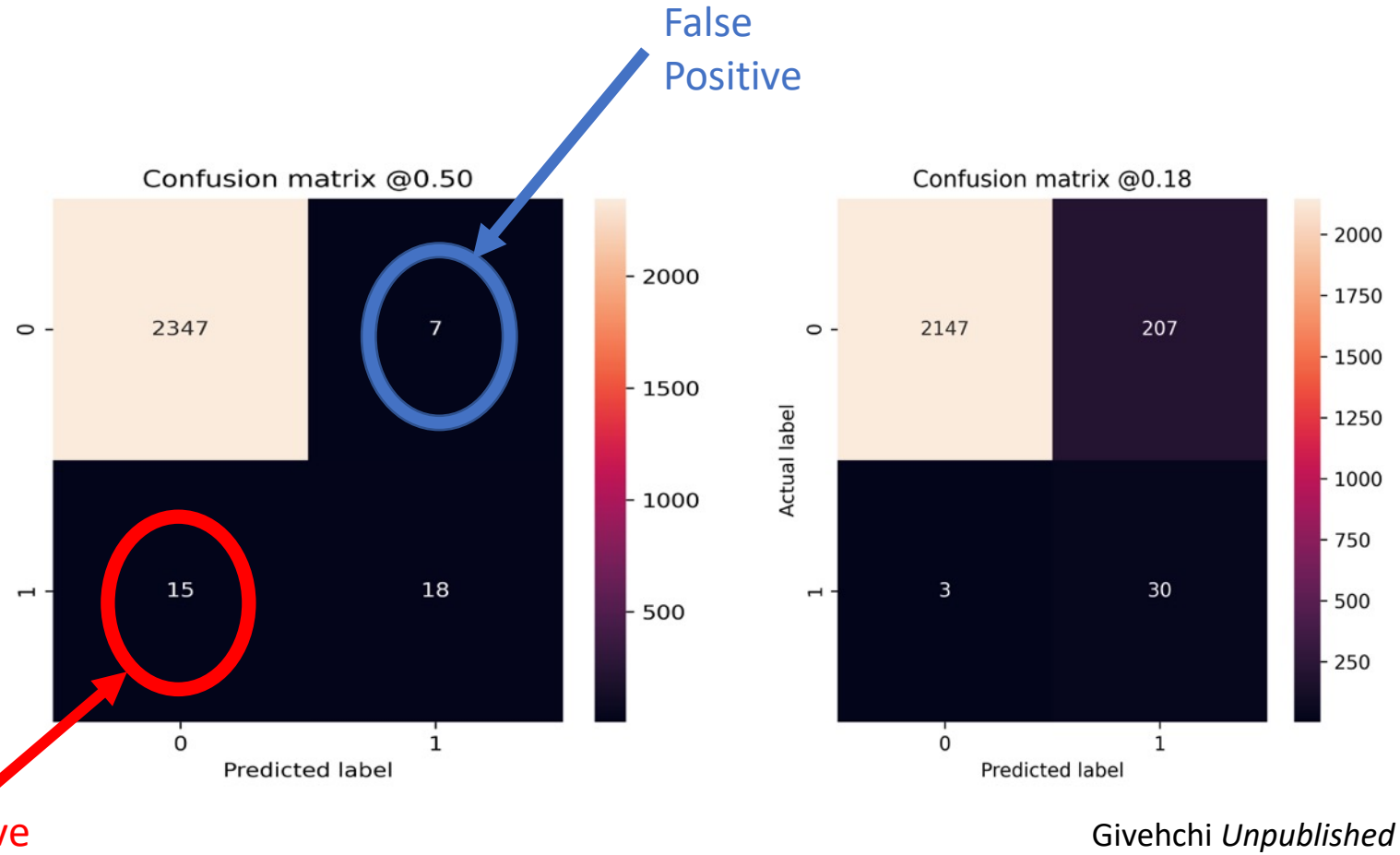
Comparison of Test Methods for Determining the Particle Removal Efficiency of Filters in Residential and Light-Commercial Central HVAC Systems

Stephens & Siegel (2012) *Aerosol Sci Tech*

Research Needs #2

- Alternative control approaches (energy, electricity availability, filter longevity)
- Predictive air cleaning





Givehchi *Unpublished*

Research Needs #3

Moore[1]. Ash was determined by weighing a separate sample because the use of porcelain filter crucibles renders impossible any further analytical treatment of the ash from the carbon determination. R_2O_3 and SiO_2 were determined by standard analytical methods[2,3]. These results are summarized in Table 1.

[2]*Standard Methods of Chemical Analysis*, by W. W. Scott (D. Van Nostrand Co., Inc., New York, 1939; Fifth Edition, pp. 800-801).
[3]*Talbot's Quantitative Chemical Analysis*, by L. F. Hamilton and S. G. Simpson (Macmillan Co., New York, 1947, Ninth Edition, pp. 318-319).

major groups, the workers ... ial hygiene and the work- air cleaning and ventilating Industrial hygienists are in the materials which ect the health of the people identifying characteristics, ystalline form, which would the source of the dust. rest is further focused on

the greatest soiling material in atmospheric dust, namely, free carbon[1].

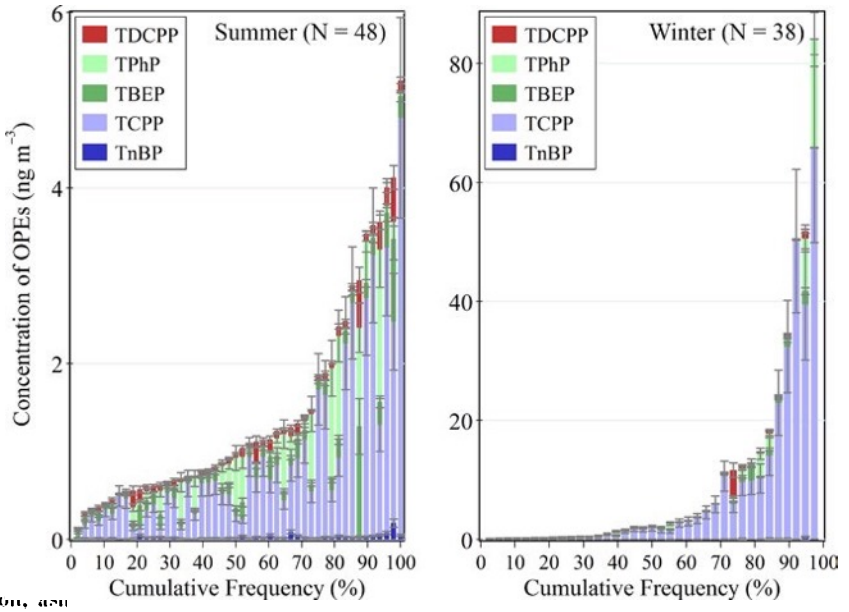
Free carbon is defined as uncombined carbon in any of its various forms, and the term *ash*, as used in this paper, refers to the product left after a sample has been burned in

analyzed for free carbon, ash and mixed oxides.

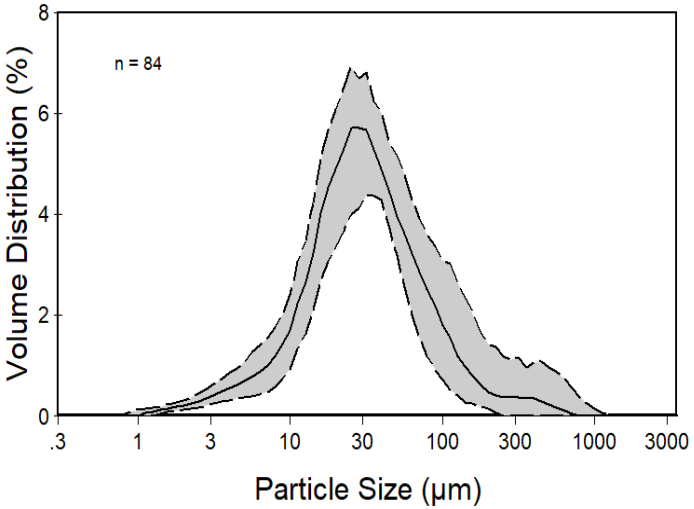
Sampling

A careful consideration sampling problems indicate large installations of dry typ provided a readily available of samples. The same type was used in all tests. In th

Moore et al (1954) *HPAC*



Givehchi et al. (2019) *Indoor Air*



Mahdavi and Siegel (2021) *Indoor Air*

Review & Quantitative Approach

Haaland & Siegel (2017) Indoor Air

	Pre-Filters		Final Filters	
	Total Number (n)	Number Positive (%)	Total Number (n)	Number Positive (%)
	20	7 (35)	12	2 (16.67)
Cumulative Gene Copies ($\bar{x}$)	354.8 (34.2)		103.2 (86.2)	

Horve et al. *arXiv preprint*

Overall Summary

- Variety of challenges and opportunities with filtration
- Challenges: effective use of filtration, inclusion of filtration in intervention studies, addressing behaviour and communication/education issues, minimally effective/harmful technologies
- Opportunities: Better utilization and control, exposure assessment