Particle Filtration Fundamentals

2019 HPC National Home Performance Conference

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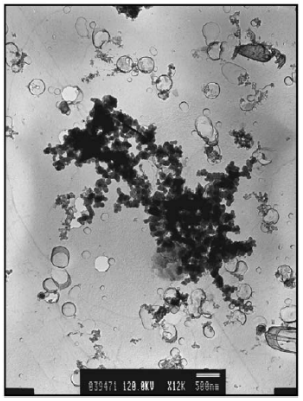
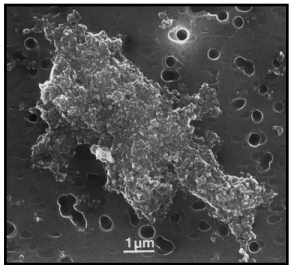
INDOOR PARTICLES AND HEALTH

Particulate matter (PM): Indoors and outdoors

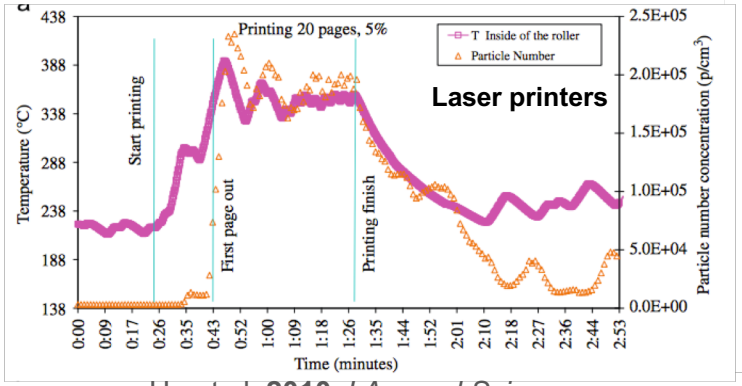
- Solid and liquid particles suspended in air
- Both indoor and outdoor sources
  - **Outdoors:** Traffic, industry, natural, atmospheric rxns



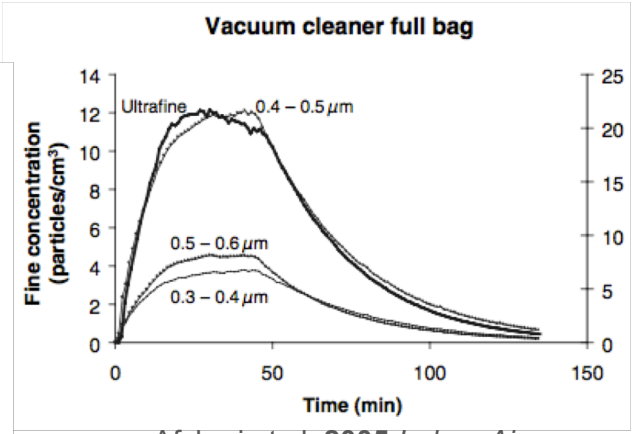


Casuccio et al. **2004** *Fuel Process Technol*
Ormstad **2000** *Toxicology*

  - **Indoors:** Appliances, cleaning, combustion, others

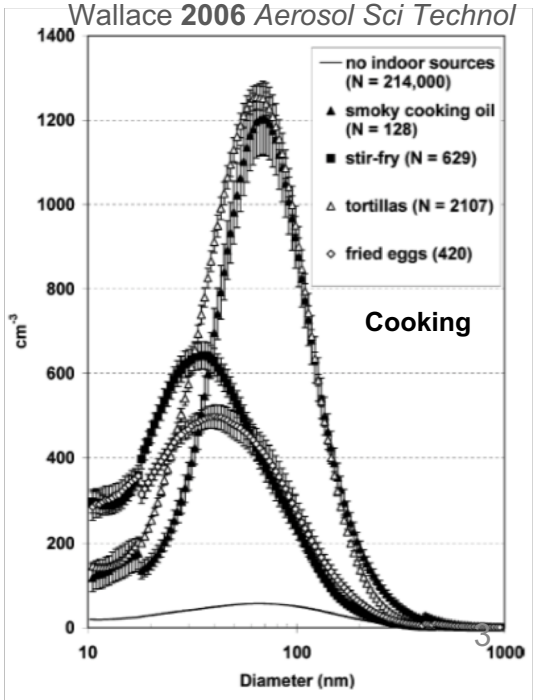


He et al. **2010** *J Aerosol Sci*



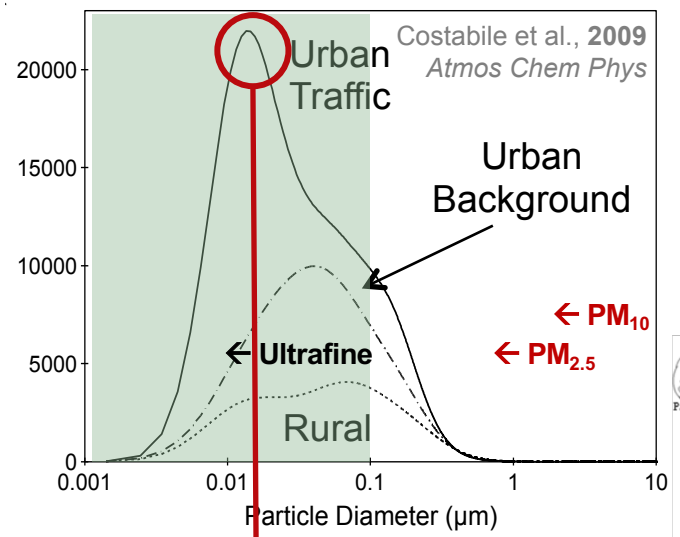
Afshari et al. **2005** *Indoor Air*

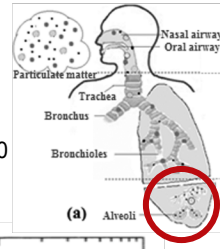
Wallace **2006** *Aerosol Sci Technol*

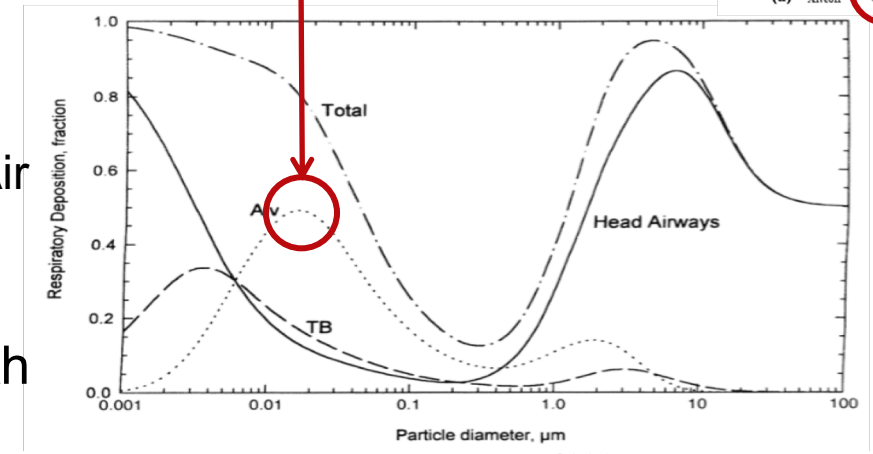


Particulate matter (PM): Indoors and outdoors

- Wide range of sizes and constituents
  - <5 **nanometers** to >50 **micrometers**
  - Size governs deposition in the respiratory tract
  - Most particles of outdoor origin are smaller than 100 nm
- Wide range of measurement methods and classifications
  - UFPs, $PM_{2.5}$, PM_{10}, etc.
  - $PM_{2.5}$ and PM_{10} are regulated in the U.S. as part of the National Ambient Air Quality Standards (NAAQS)
- We know ***much more*** about the health effects associated with outdoor PM sources than indoor PM sources



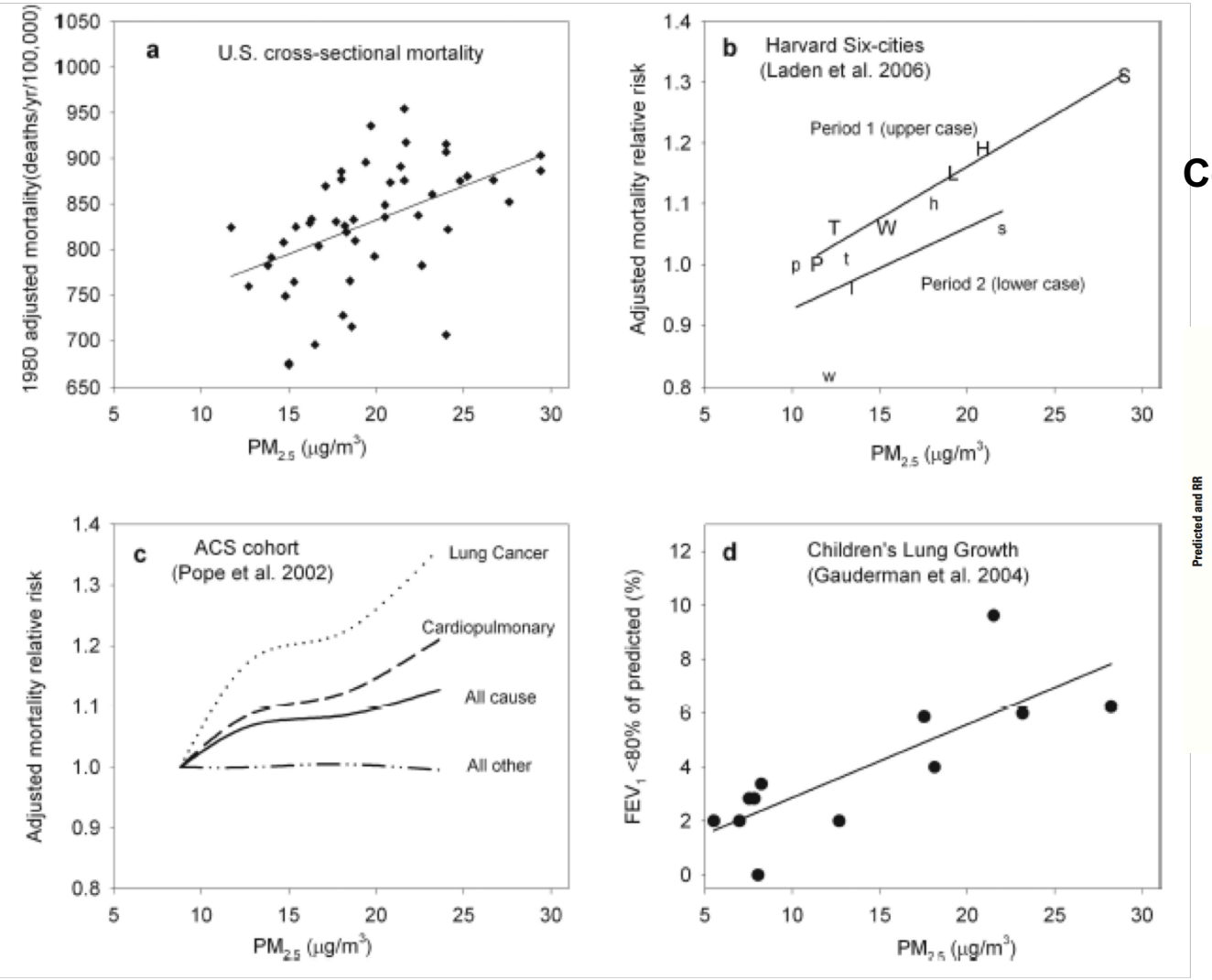




Hinds **1999** *Aerosol Technol*

Outdoor PM and health (epidemiology)

Associations with ambient fine particulate matter ($PM_{2.5}$)

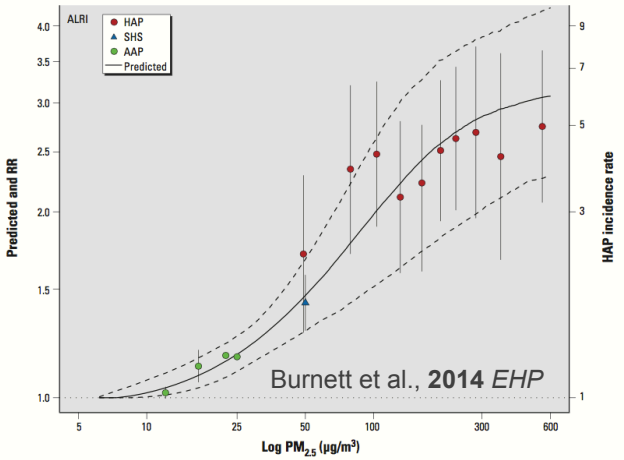


Pope and Dockery, **2006** *J Air Waste Manage Assoc*

PM in outdoor air

Concentration-Response (C-R) Function

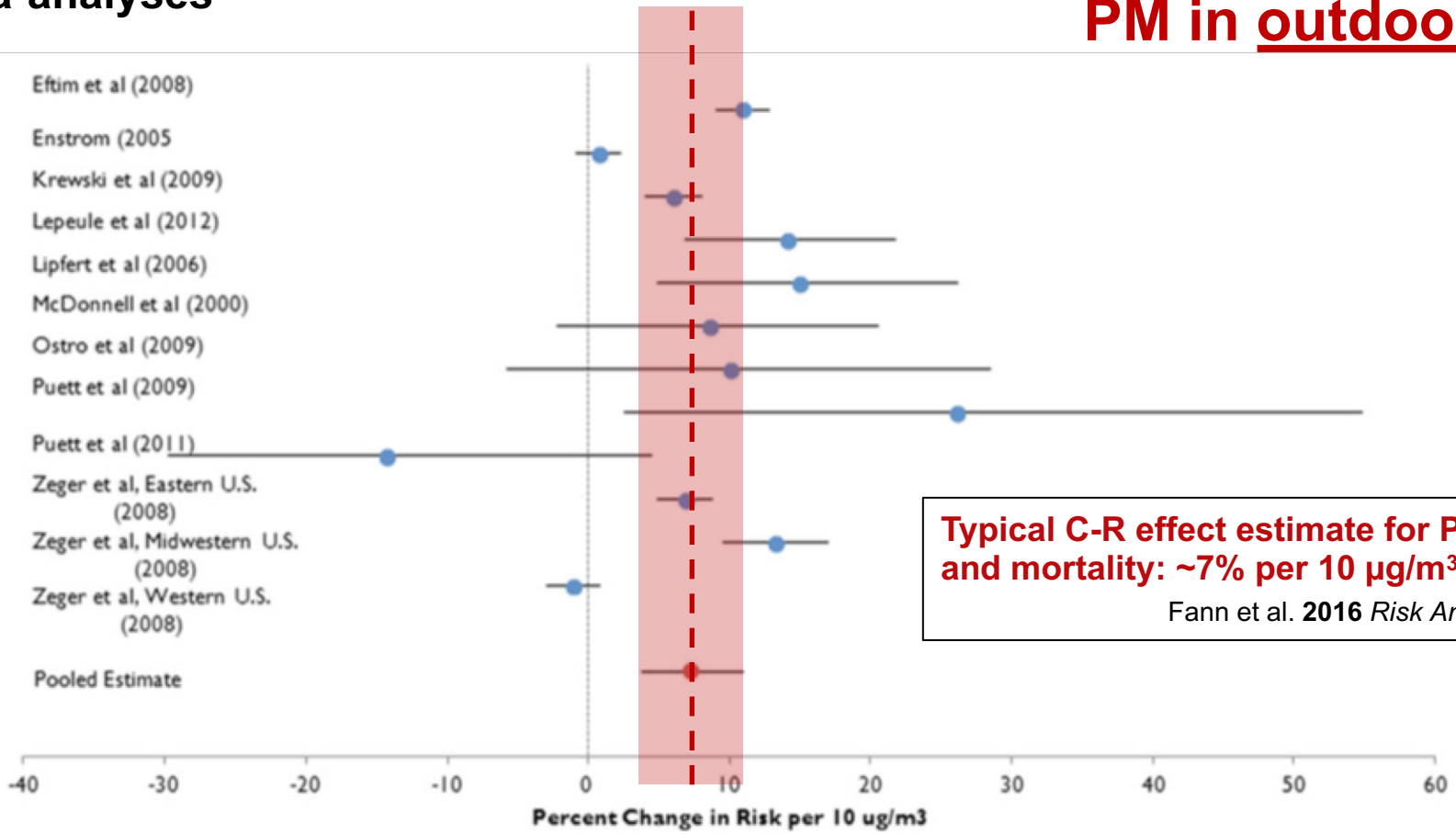
$$\Delta y_i = y_0[\exp(\beta_i \times \Delta E_i) - 1]$$



Outdoor PM and health (epidemiology)

Meta-analyses

PM in outdoor air

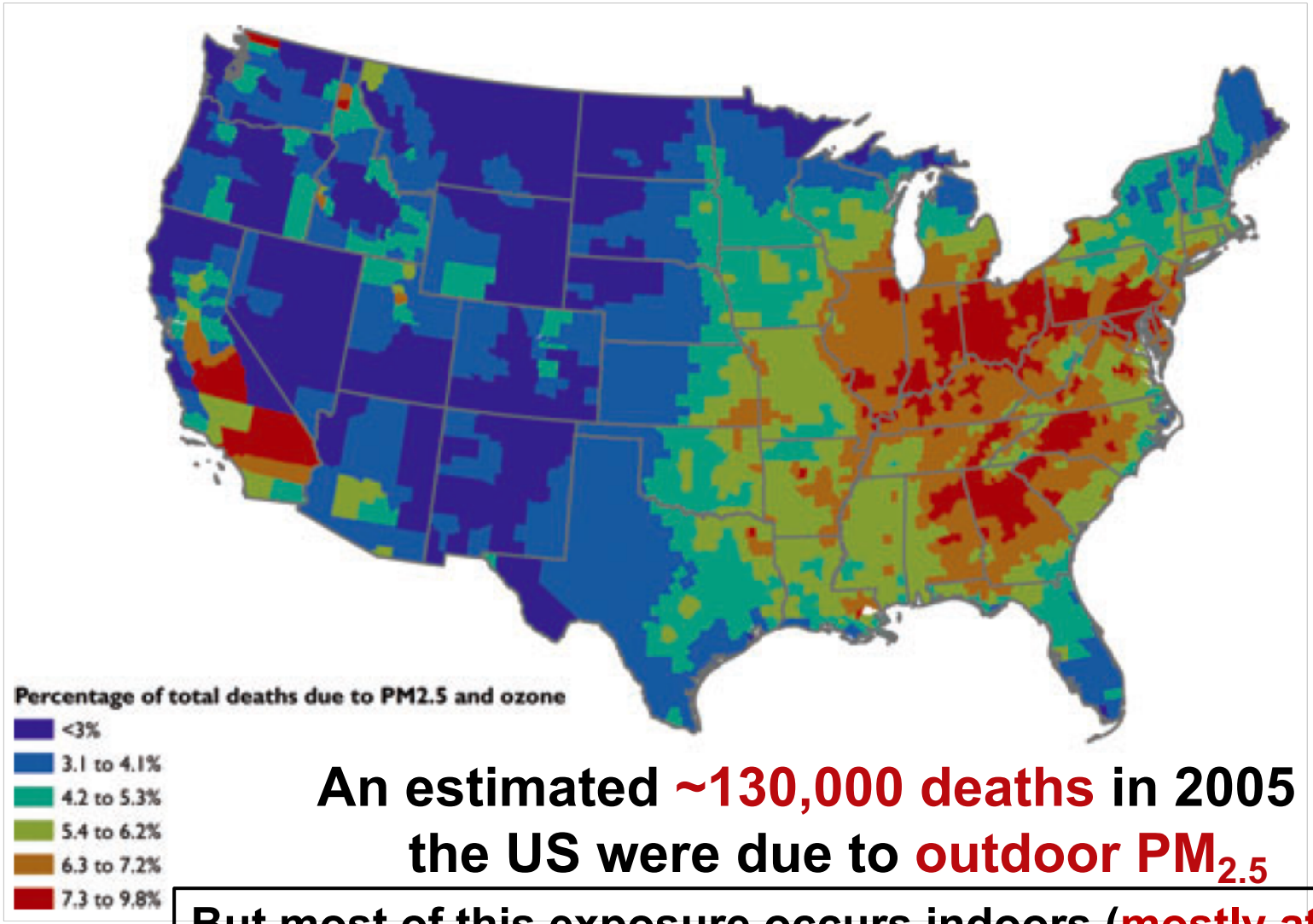


Typical C-R effect estimate for $PM_{2.5}$ and mortality: ~7% per 10 µg/m³

Fann et al. **2016** *Risk Analysis*

Fig. 2. Pooled estimate of long-term all-cause mortality using the studies available to the experts in USEPA's 2006 elicitation and the newer studies.

Outdoor PM and health (models)



An estimated ~130,000 deaths in 2005 in the US were due to outdoor $PM_{2.5}$

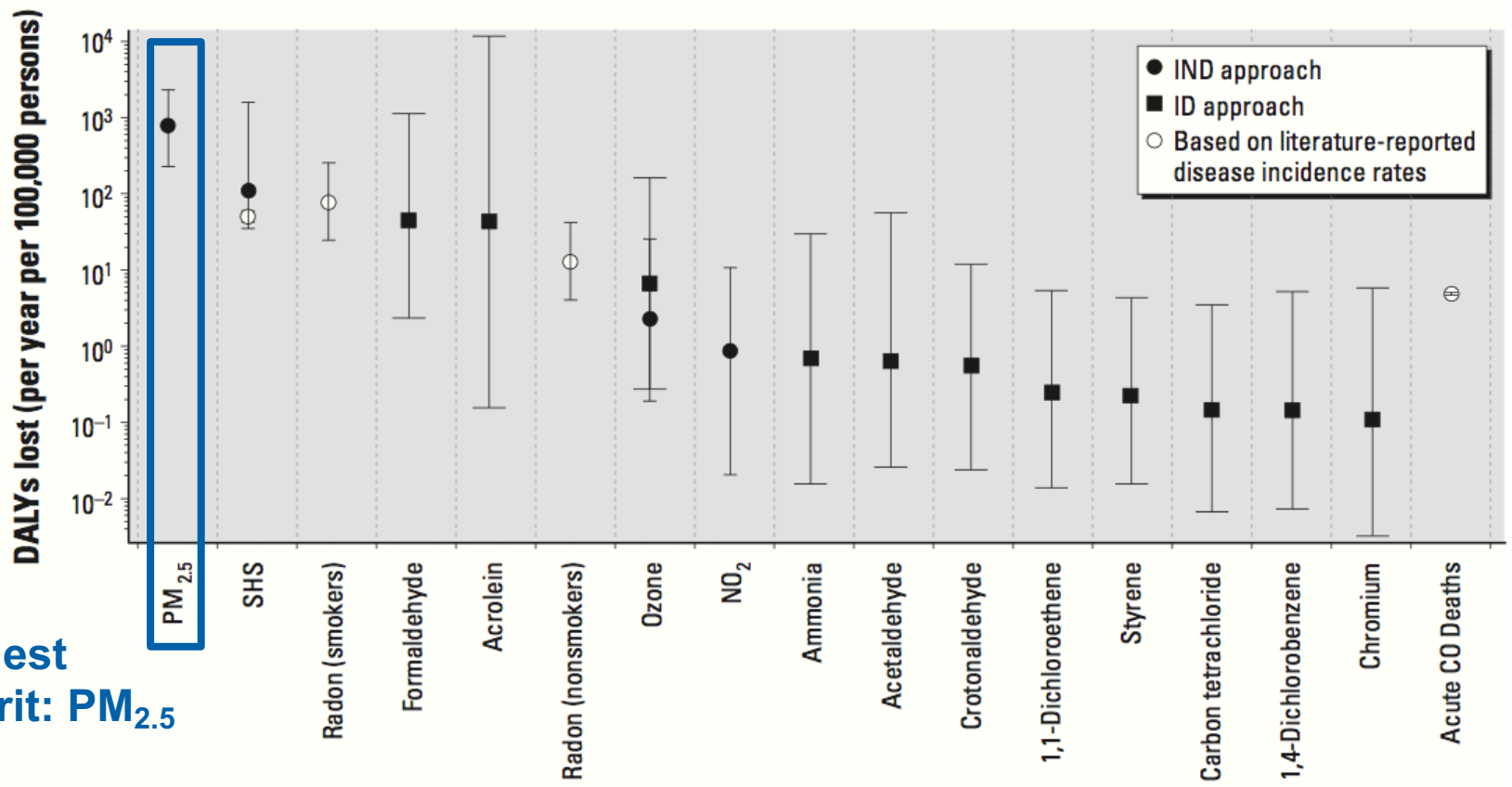
But most of this exposure occurs indoors (mostly at home)

Fann et al. **2012** *Risk Analysis*

Indoor PM and health (models)

Residential indoor air exposures account for **~5-14%** of the non-communicable/non-psychiatric **U.S. disease burden**

- Likely the **most harmful pollutants** inside residences:

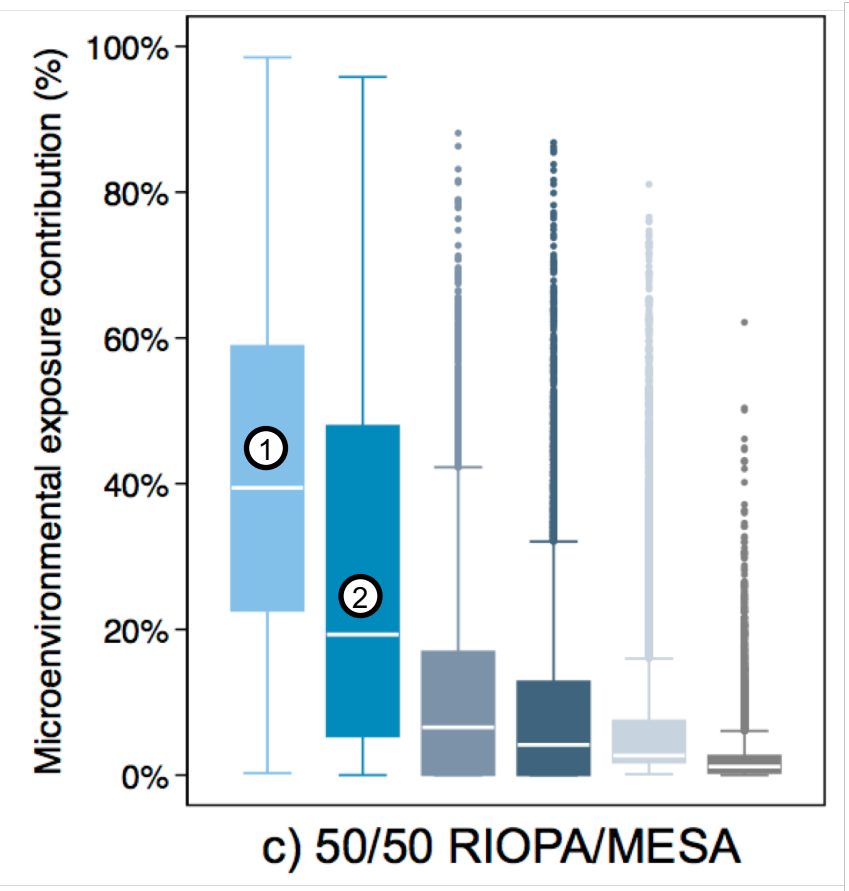


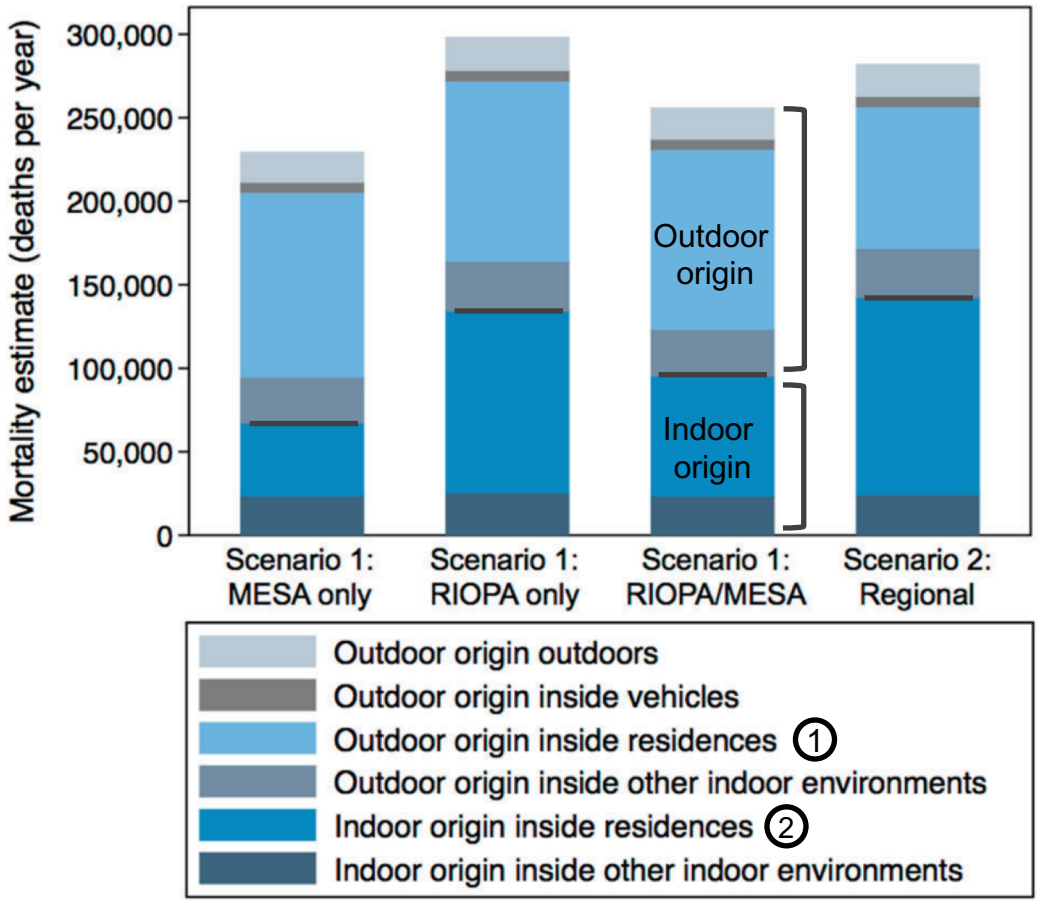
Biggest culprit: $PM_{2.5}$

Logue et al. **2012** *Environ Health Perspect*

Indoor PM and health (models)

A framework for estimating the US mortality burden of fine particulate matter exposure attributable to indoor and outdoor microenvironments





Azimi and Stephens **2019** *Journal of Exposure Science and Environmental Epidemiology*

Indoor PM and health (epidemiology)

Health benefits of particle filtration

Fisk **2013** *Indoor Air*

Photo from M.S. Waring and J.A. Siegel

PM in indoor air

Air cleaners typically reduce indoor PM concentrations by ~50%

- Usually $PM_{2.5}$
- Sometimes PM_{10} or total number counts (TNC) (e.g. <1 μm)

Documented health improvements with (mostly portable) air cleaners include:

- Modest improvements in lung function in asthmatics
- Fewer asthma-related doctor visits
- Modest improvements in markers of cardiovascular/pulmonary function
- *Very few studies on central filtration*

New EPA Guidance on air cleaners in the home:
https://www.epa.gov/indoor-air-quality-iaq/air-cleaners-and-air-filters-home

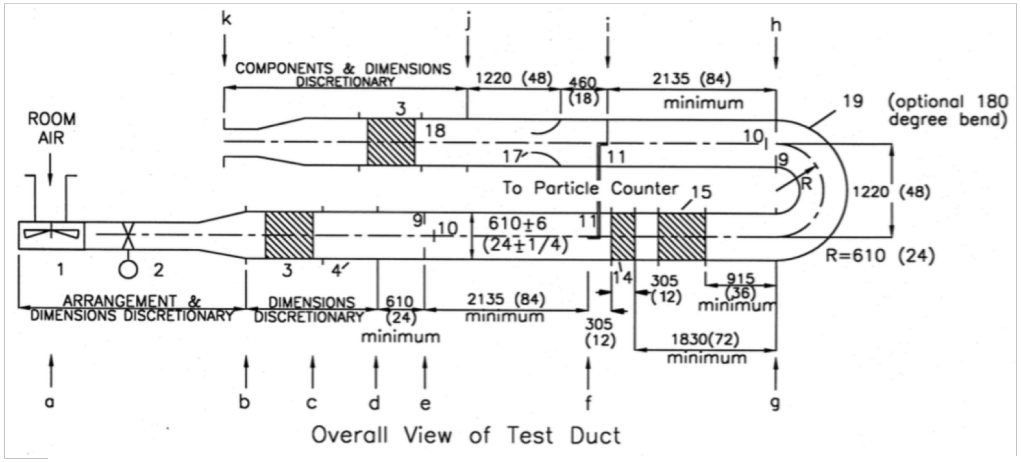
Residential particle filtration

Better filters can help improve IAQ, but there are a few things to consider:

1. **Fine or ultrafine PM removal**
2. **Pressure drop, airflow, and energy use**
3. **System runtimes**
4. **Dust loading**

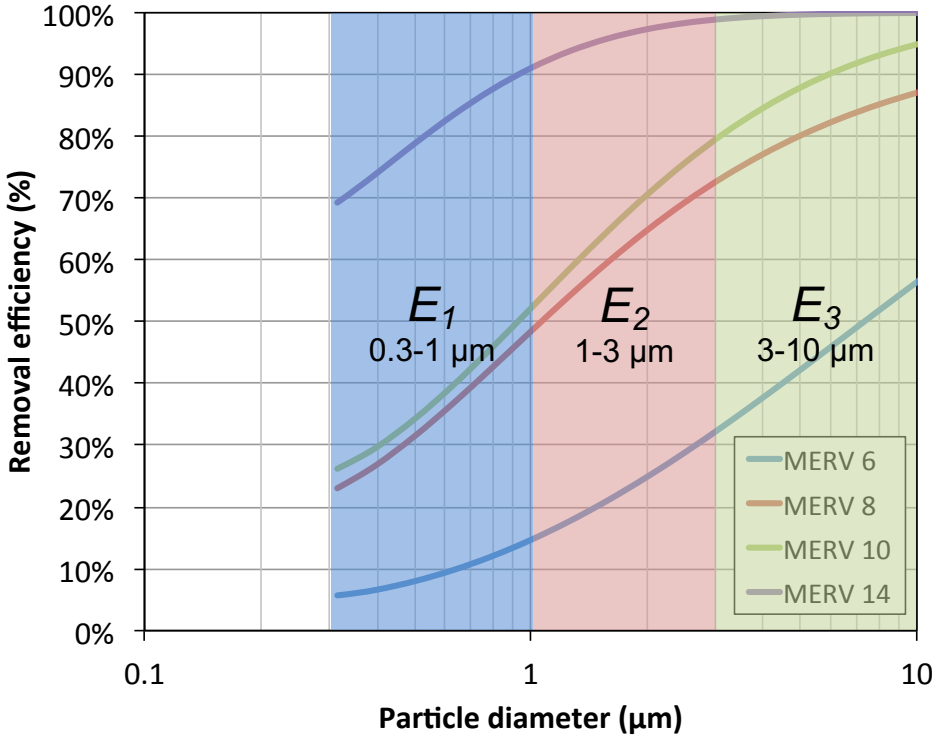
How is filtration <u>efficiency</u> typically measured/reported?

- Filters are evaluated in laboratory tests:
  - ASHRAE Standard 52.2 most widely used



- Test results:
  - Size-resolved efficiency
  - 0.3 to 10 µm particles

- Reporting metrics:
  - Minimum Efficiency Reporting Value (**MERV**)
  - Micro-particle Performance Rating (**MPR**)
  - Filter Performance Rating (**FPR**)



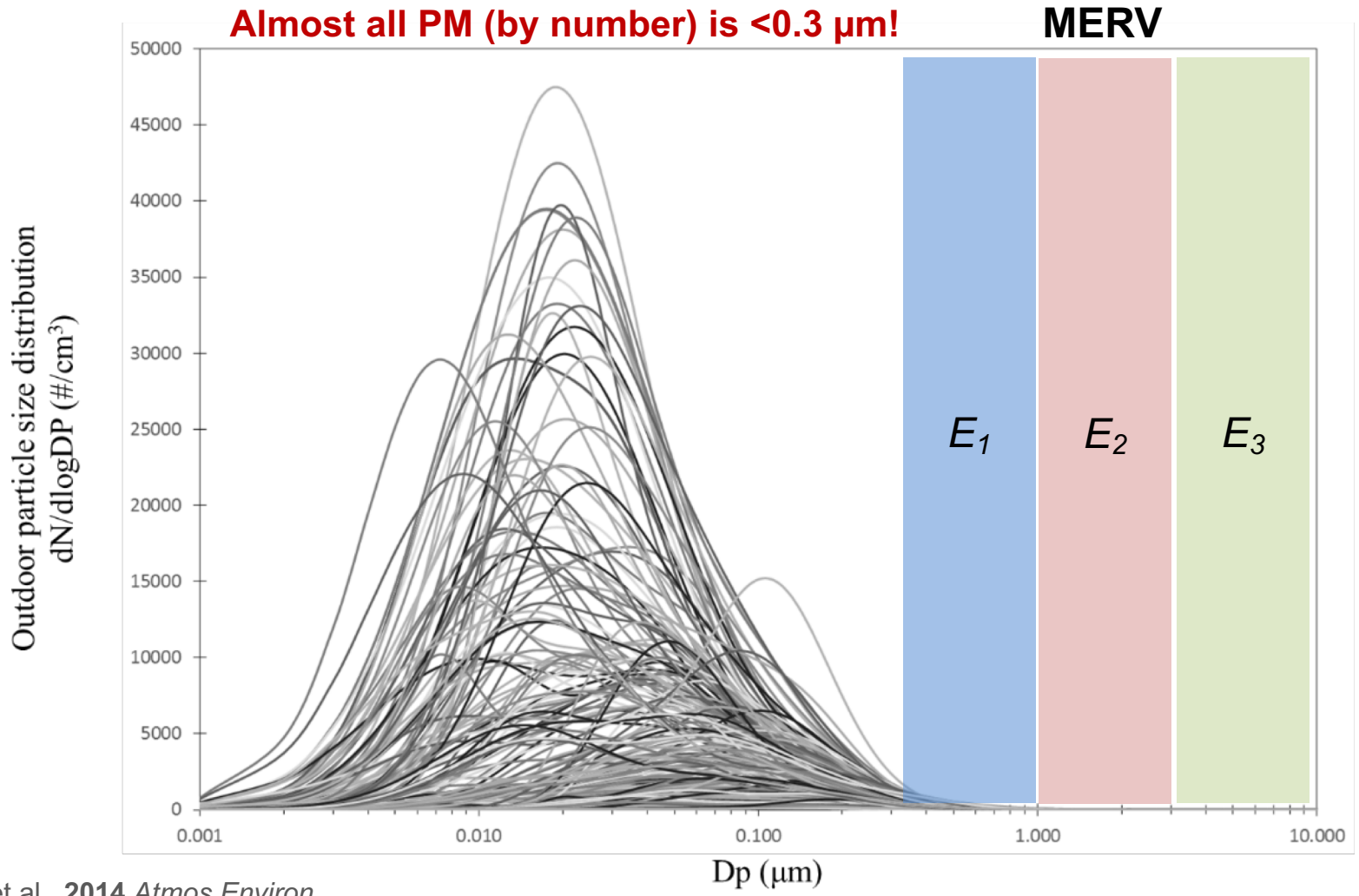
MERV efficiency table

Standard 52.2 Minimum Efficiency Reporting Value (MERV)	Composite Average Particle Size Efficiency, % in Size Range, µm			Average Arrestance, %
	Range 1 (0.3-1.0)	Range 2 (1.0-3.0)	Range 3 (3.0-10.0)	
1	n/a	n/a	$E_3 < 20$	$A_{avg} < 65$
2	n/a	n/a	$E_3 < 20$	$65 \le A_{avg} < 70$
3	n/a	n/a	$E_3 < 20$	$70 \le A_{avg} < 75$
4	n/a	n/a	$E_3 < 20$	$75 \le A_{avg}$
5	n/a	n/a	$20 \le E_3 < 35$	n/a
6	n/a	n/a	$35 \le E_3 < 50$	n/a
7	n/a	n/a	$50 \le E_3 < 70$	n/a
8	n/a	$20 \le E_2$	$70 \le E_3$	n/a
9	n/a	$35 \le E_2$	$75 \le E_3$	n/a
10	n/a	$50 \le E_2 < 65$	$80 \le E_3$	n/a
11	$20 \le E_1$	$65 \le E_2 < 80$	$85 \le E_3$	n/a
12	$35 \le E_1$	$80 \le E_2$	$90 \le E_3$	n/a
13	$50 \le E_1$	$85 \le E_2$	$90 \le E_3$	n/a
14	$75 \le E_1 < 85$	$90 \le E_2$	$95 \le E_3$	n/a
15	$85 \le E_1 < 95$	$90 \le E_2$	$95 \le E_3$	n/a
16	$95 \le E_1$	$95 \le E_2$	$95 \le E_3$	n/a

https://www.nafahq.org/wp-content/uploads/52-2-Brochure-November-2014-BW.pdf

What size are most <u>outdoor</u> particles?

We gathered 194 long-term average (1-year or more) outdoor particle size distributions from the literature from all over the world…

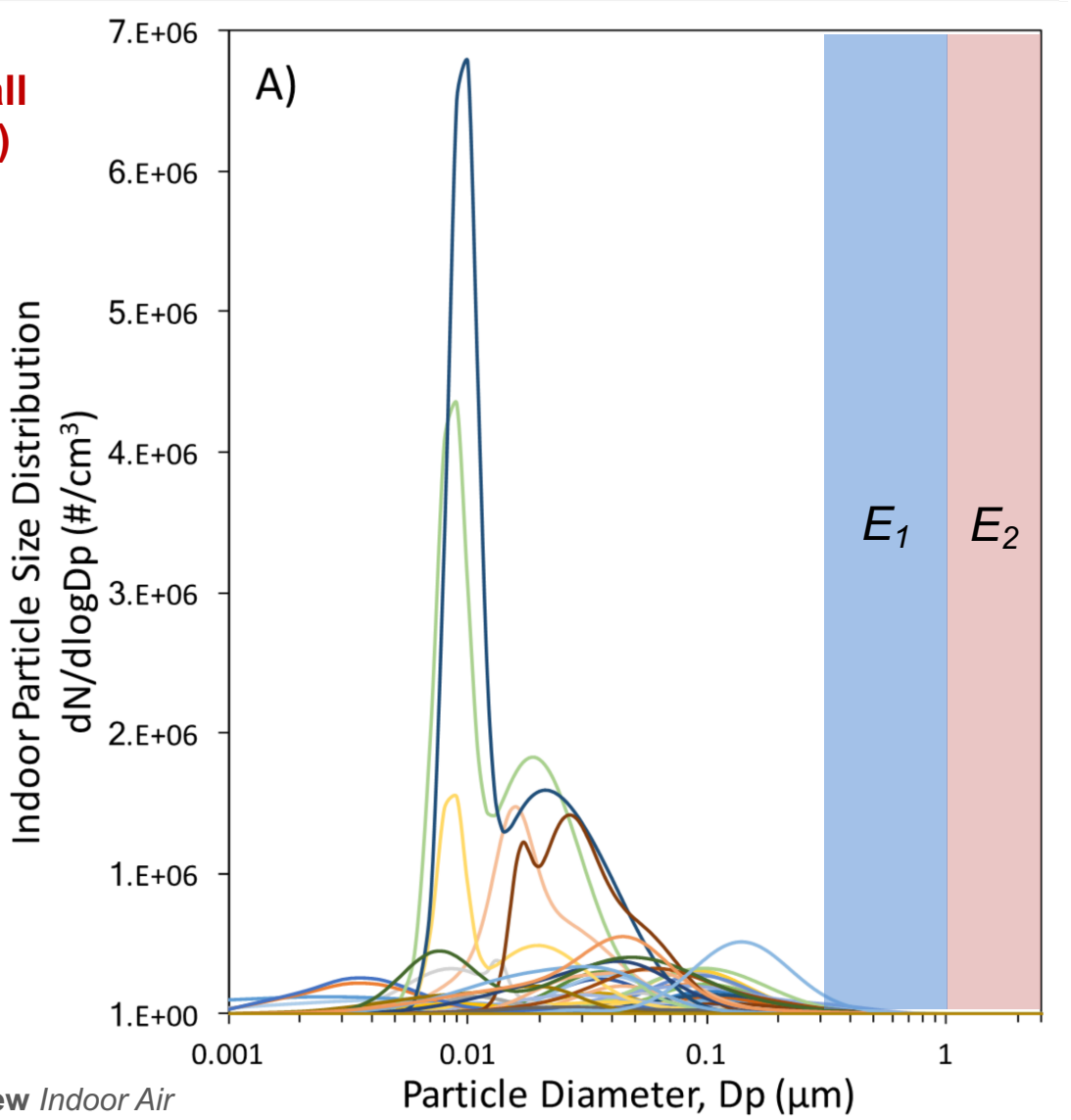


Azimi et al., **2014** *Atmos Environ*

What size are most indoor particles?

We gathered 201 residential indoor particle size distributions…

Again, almost all PM (by number) is <0.3 µm!



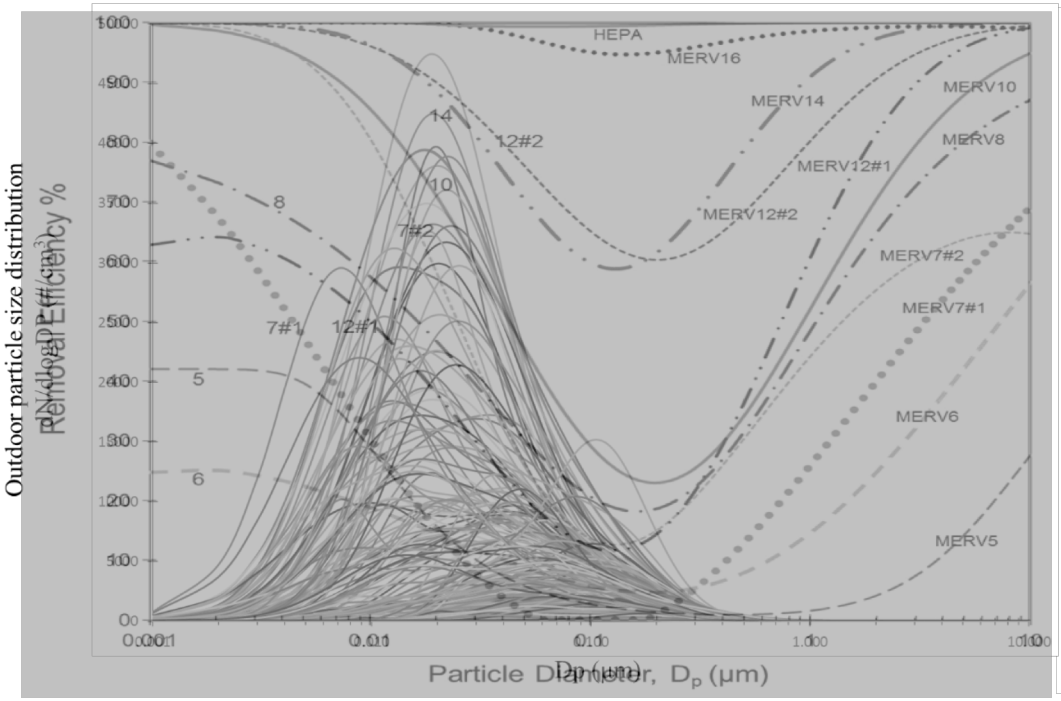
Fazli et al., **under review** *Indoor Air*

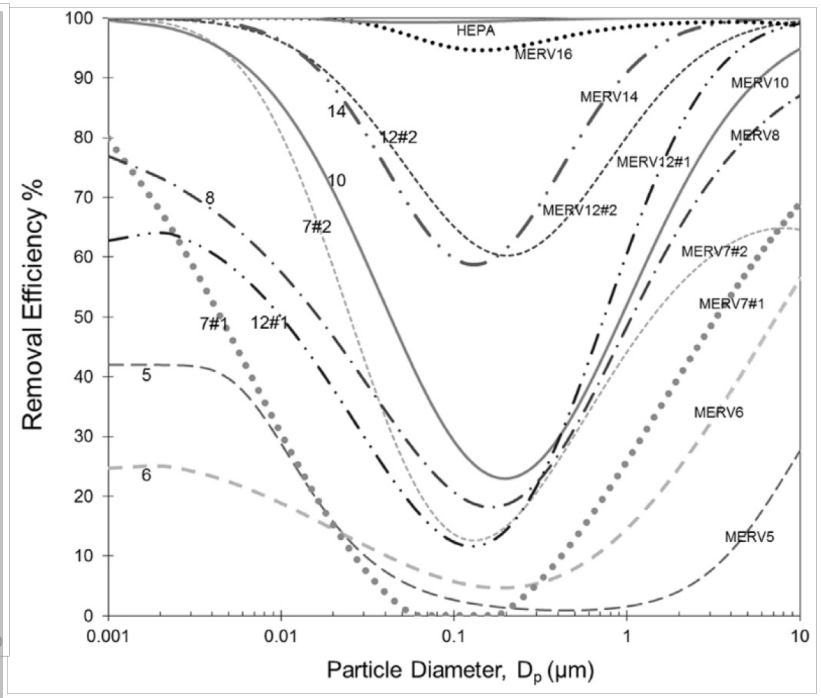
Estimating fine & ultrafine particle removal efficiency

MERV, FPR, MPR – none tell you about $PM_{2.5}$ or UFP removal efficiency

Using size-resolved removal efficiency to estimate removal of $PM_{2.5}$ and UFPs

- Mapping size-resolved filtration efficiency for typical MERV filters to <u>outdoor</u> particles





Azimi et al. **2014** *Atmos Environ*

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Using size-resolved removal efficiency to estimate removal of $PM_{2.5}$ and UFPs

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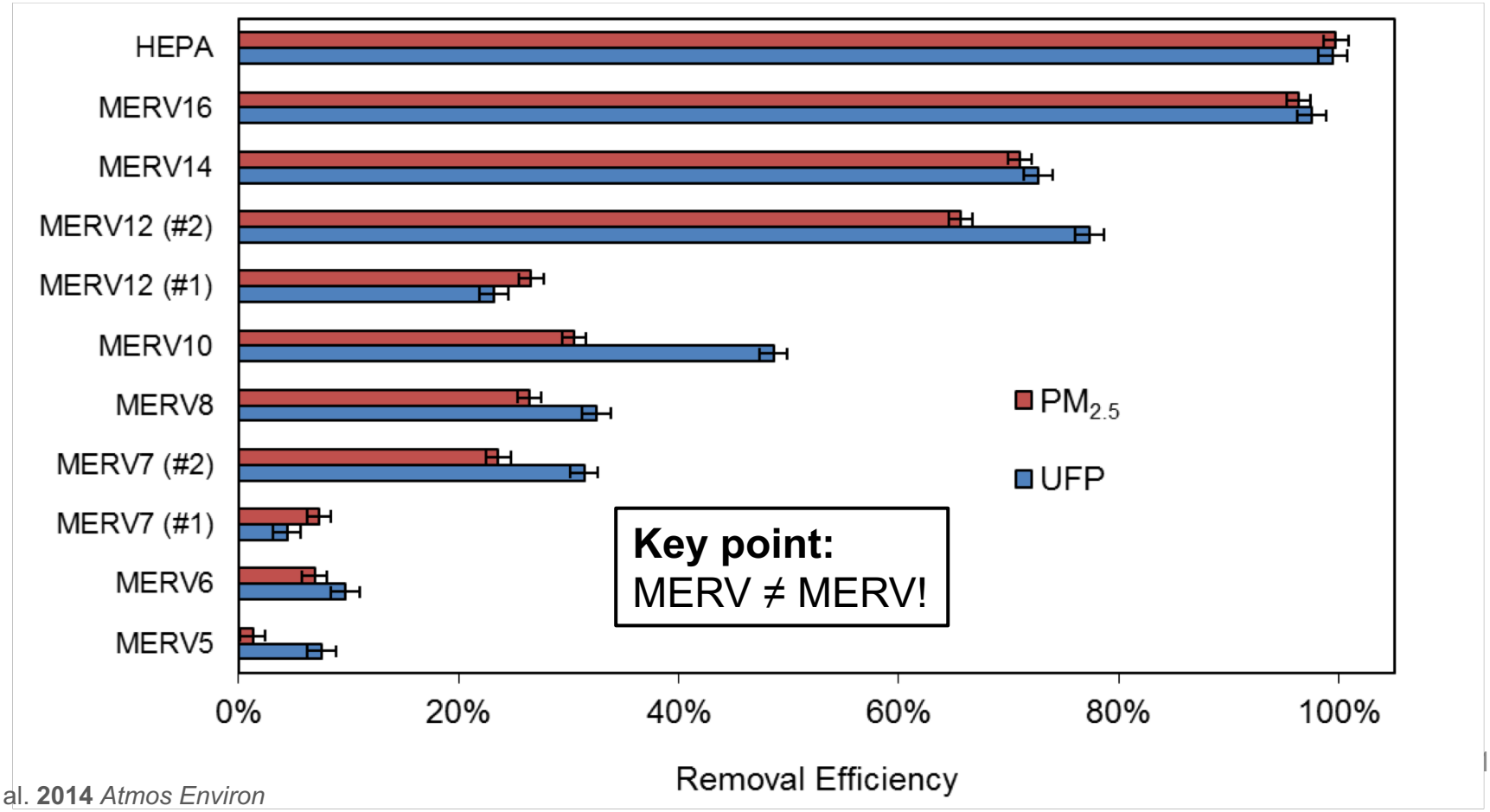
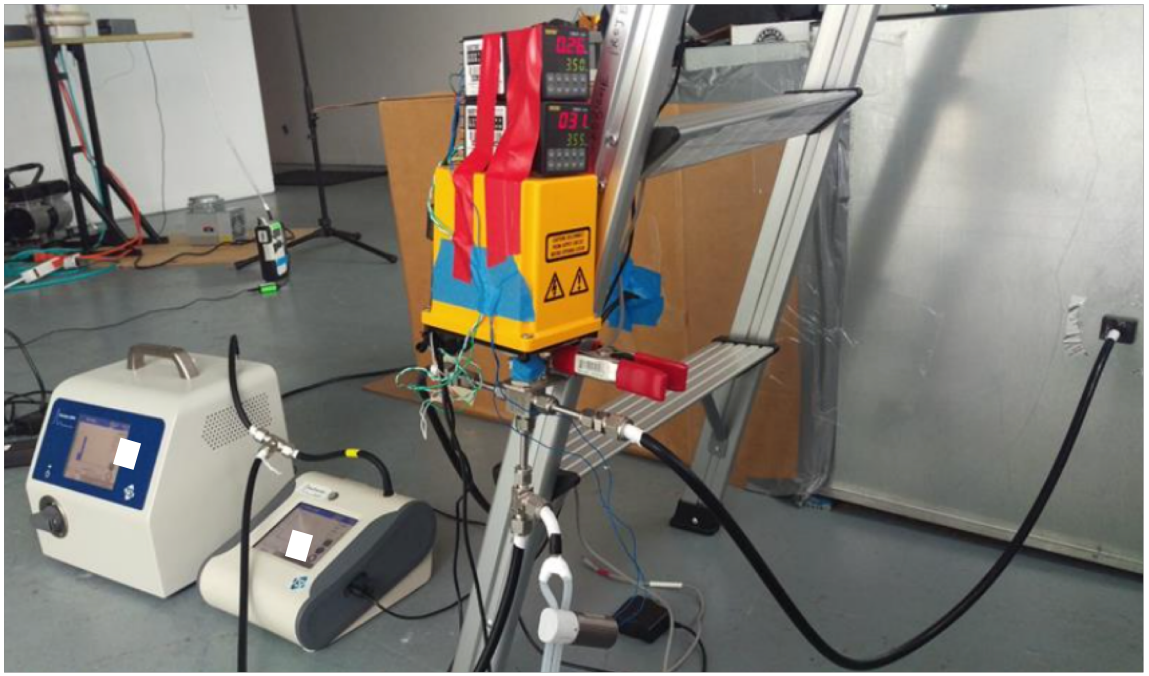


Azimi et al. **2014** *Atmos Environ*

Measuring fine & ultrafine particle removal efficiency

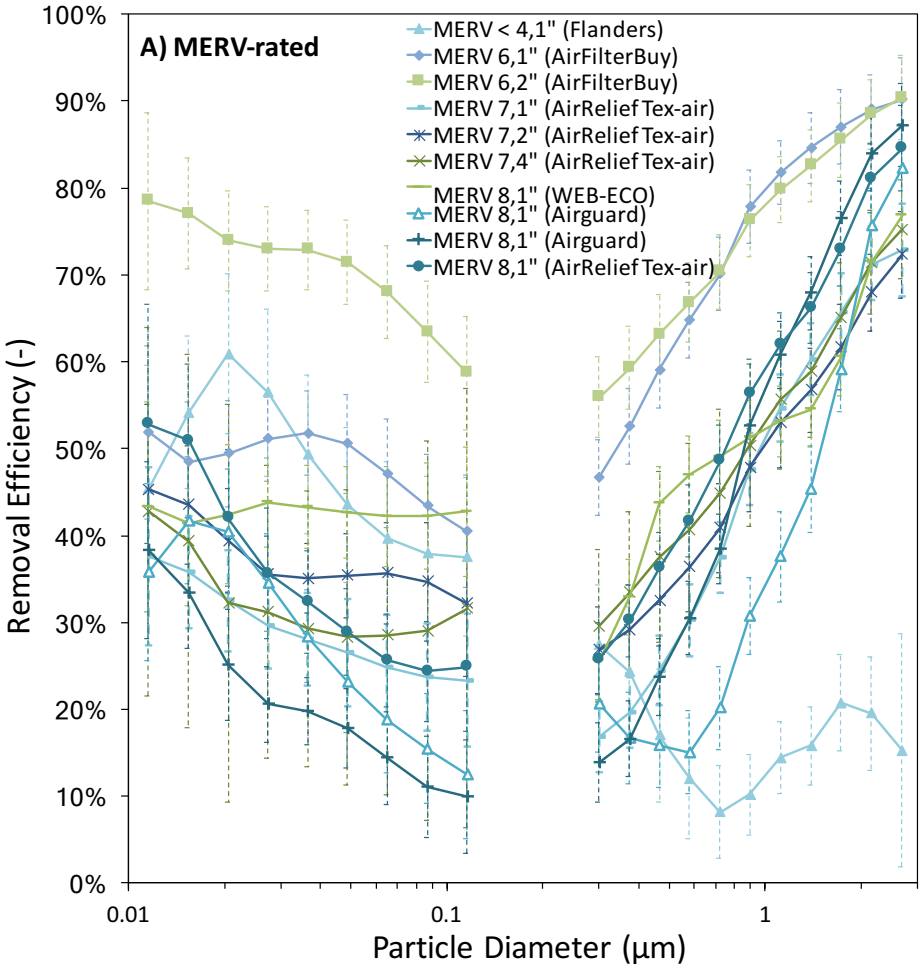
- We have been making measurements of particle removal efficiency of a large number of residential HVAC filters
- Particles from 10 nm to 10 μm
- Database now includes **50 filters**
- Size-resolved + mapped to total UFPs & $PM_{2.5}$
- http://built-envi.com/portfolio/filter-testing/

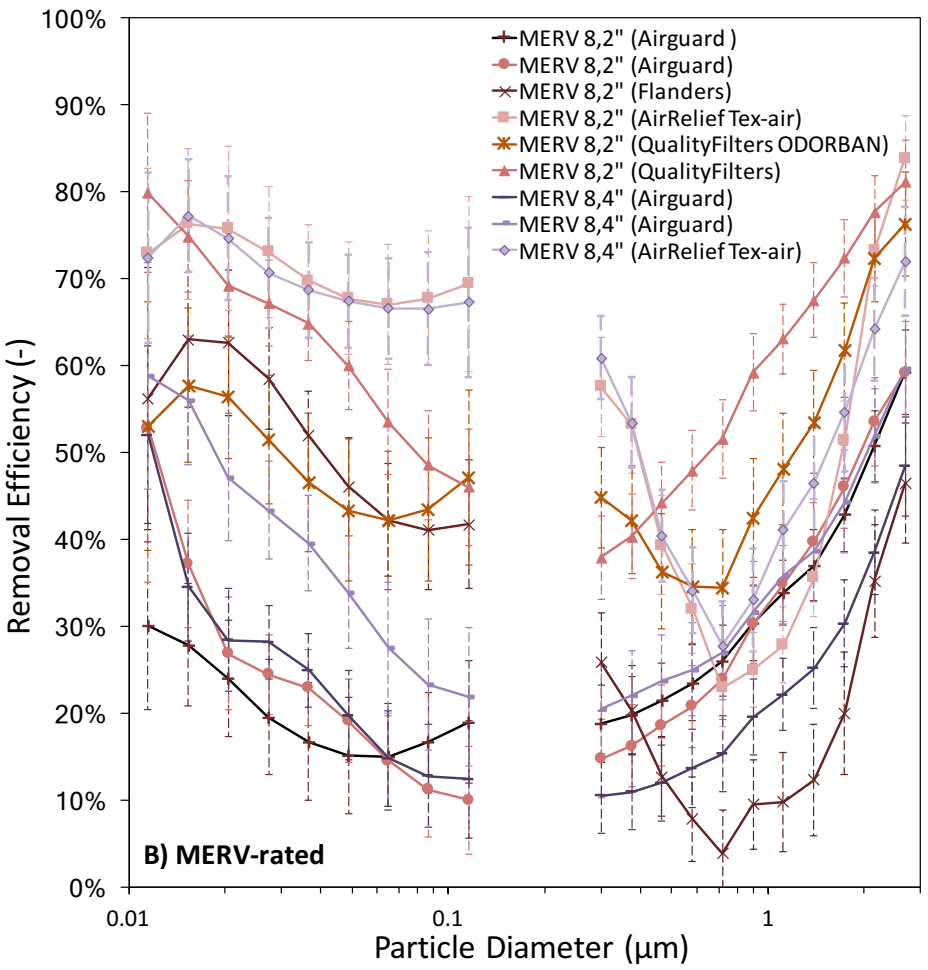


Fazli et al., **under review** *Indoor Air*

Measuring fine & ultrafine particle removal efficiency

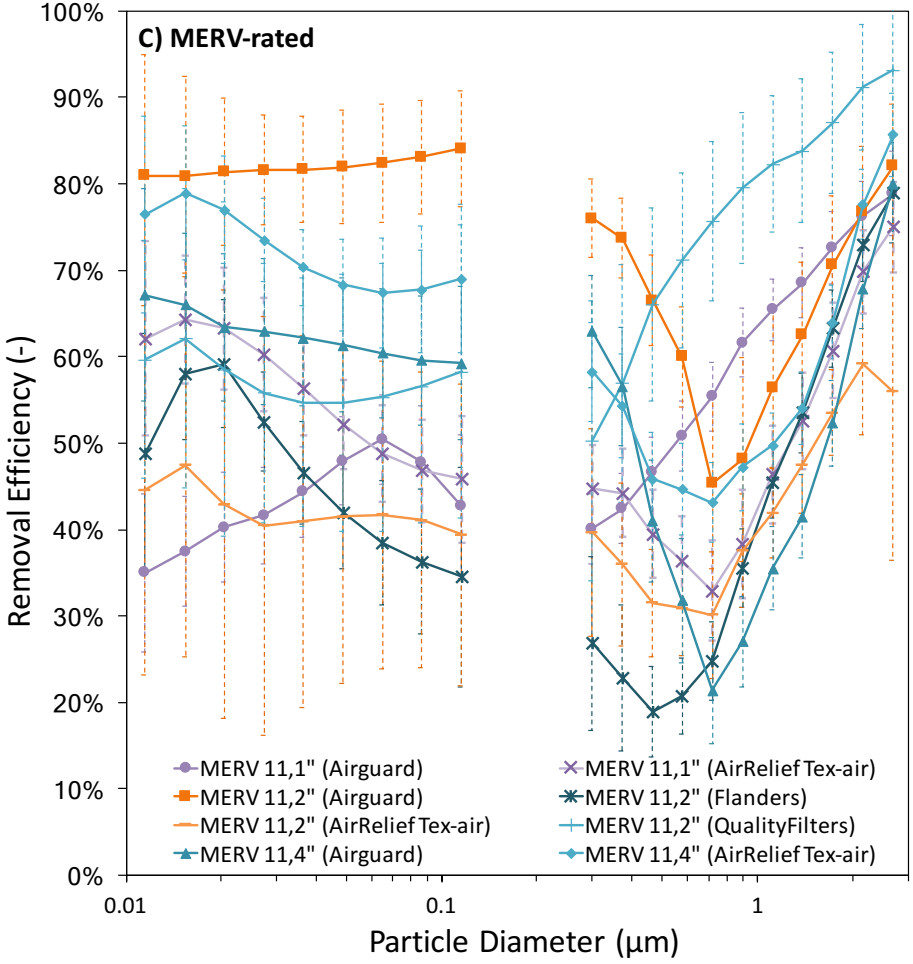
MERV filters

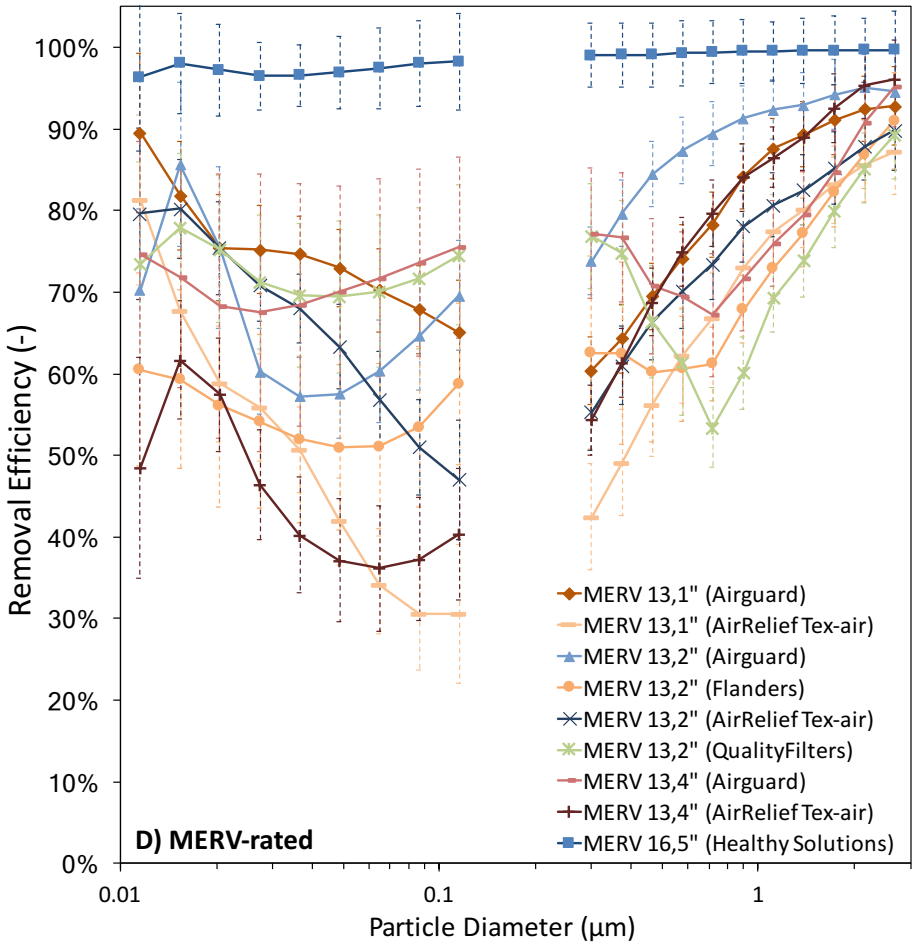




Measuring fine & ultrafine particle removal efficiency

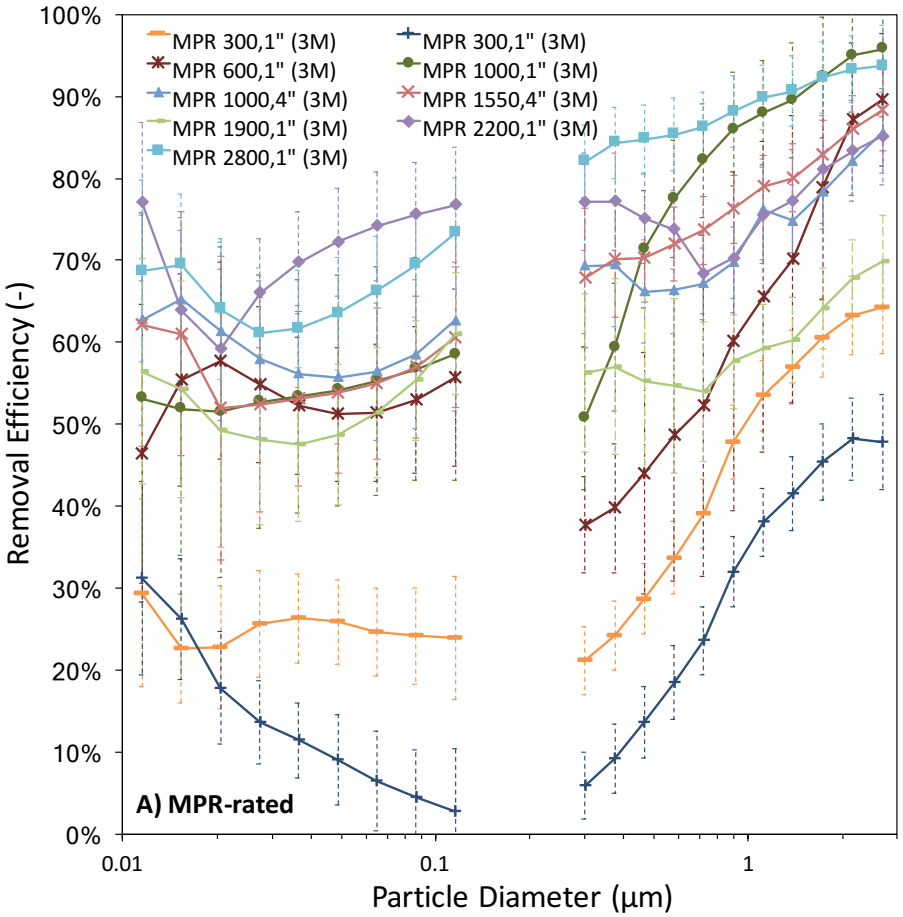
MERV filters

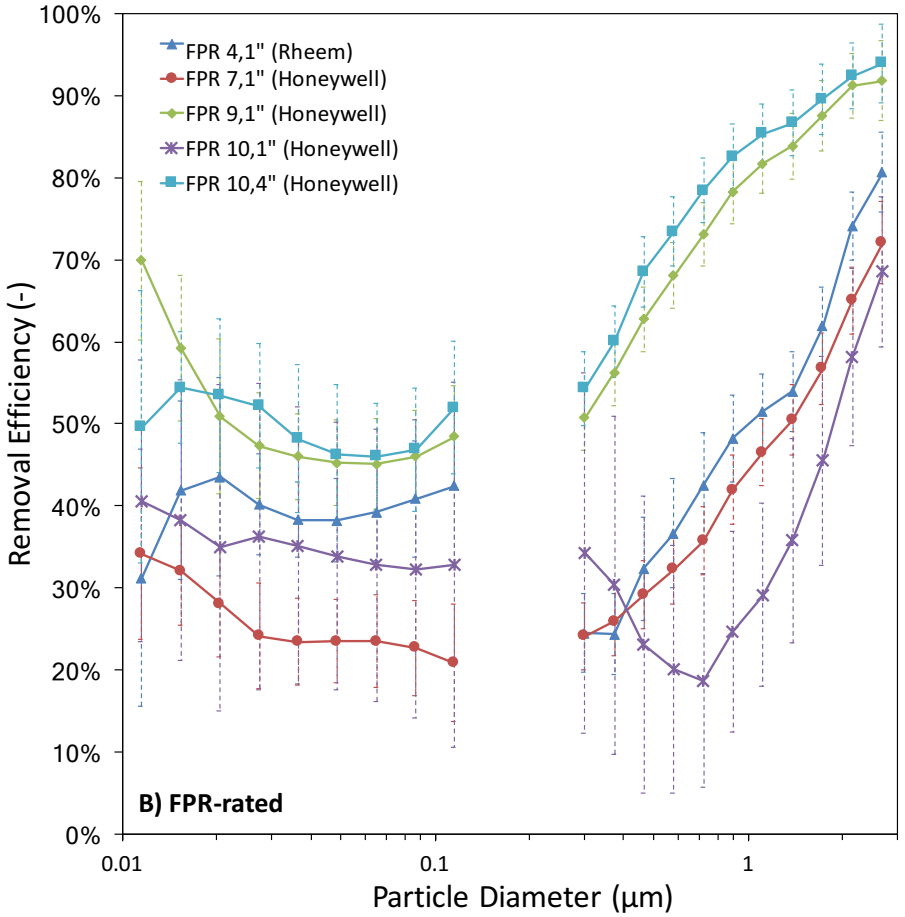




Measuring fine & ultrafine particle removal efficiency

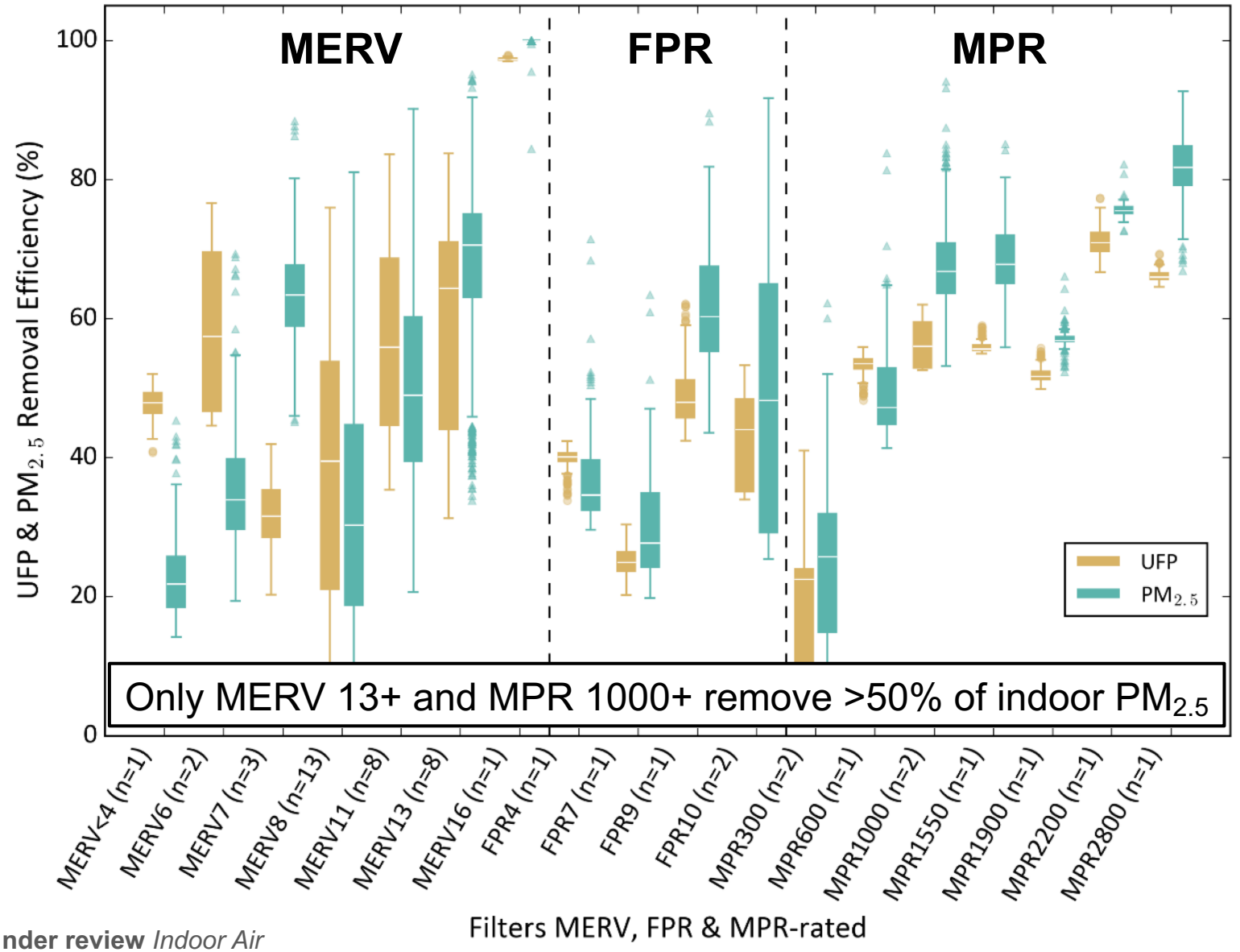
MPR and FPR filters





Fazli et al., **under review** *Indoor Air*

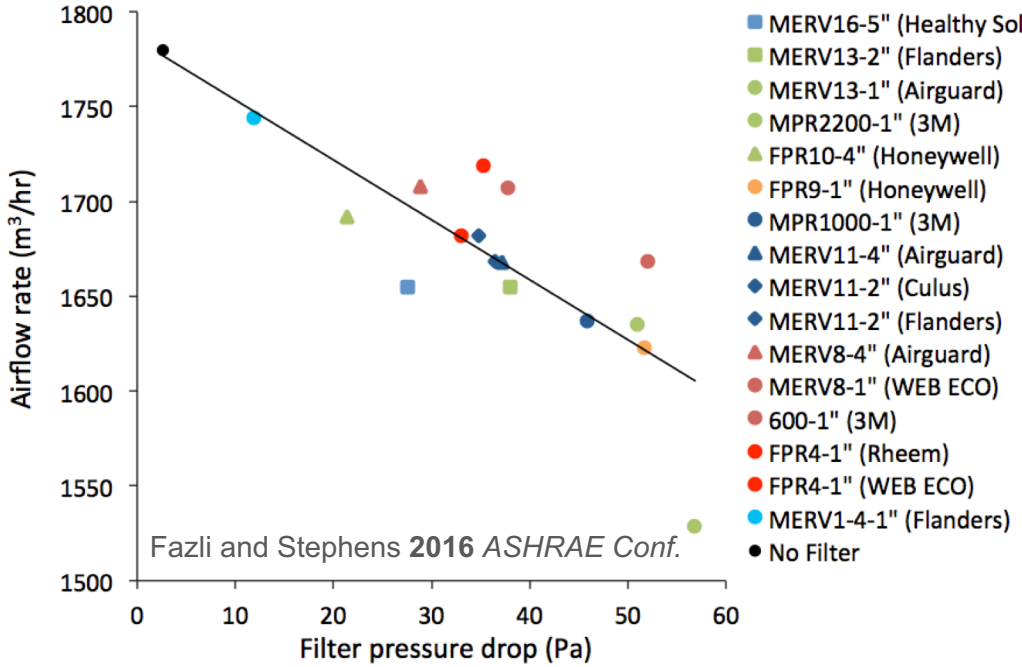
Estimating fine & ultrafine particle removal efficiency



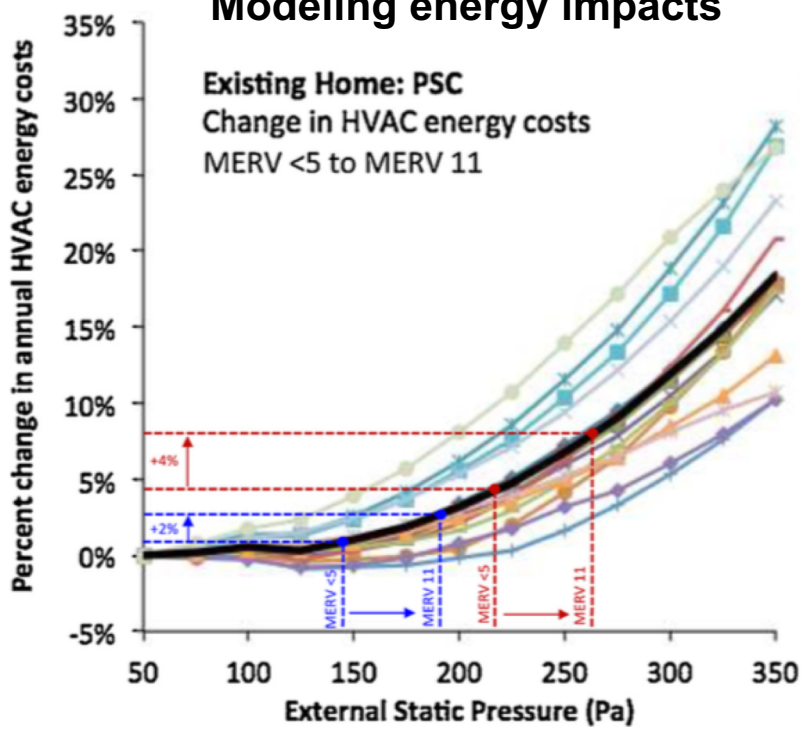
Fazli et al., **under review** *Indoor Air*

Pressure drop, airflow, and energy use of in-duct filters

Measurements of pressure drop and flow



Modeling energy impacts



Fazli et al. **2015** *Energy and Buildings*

Key points:

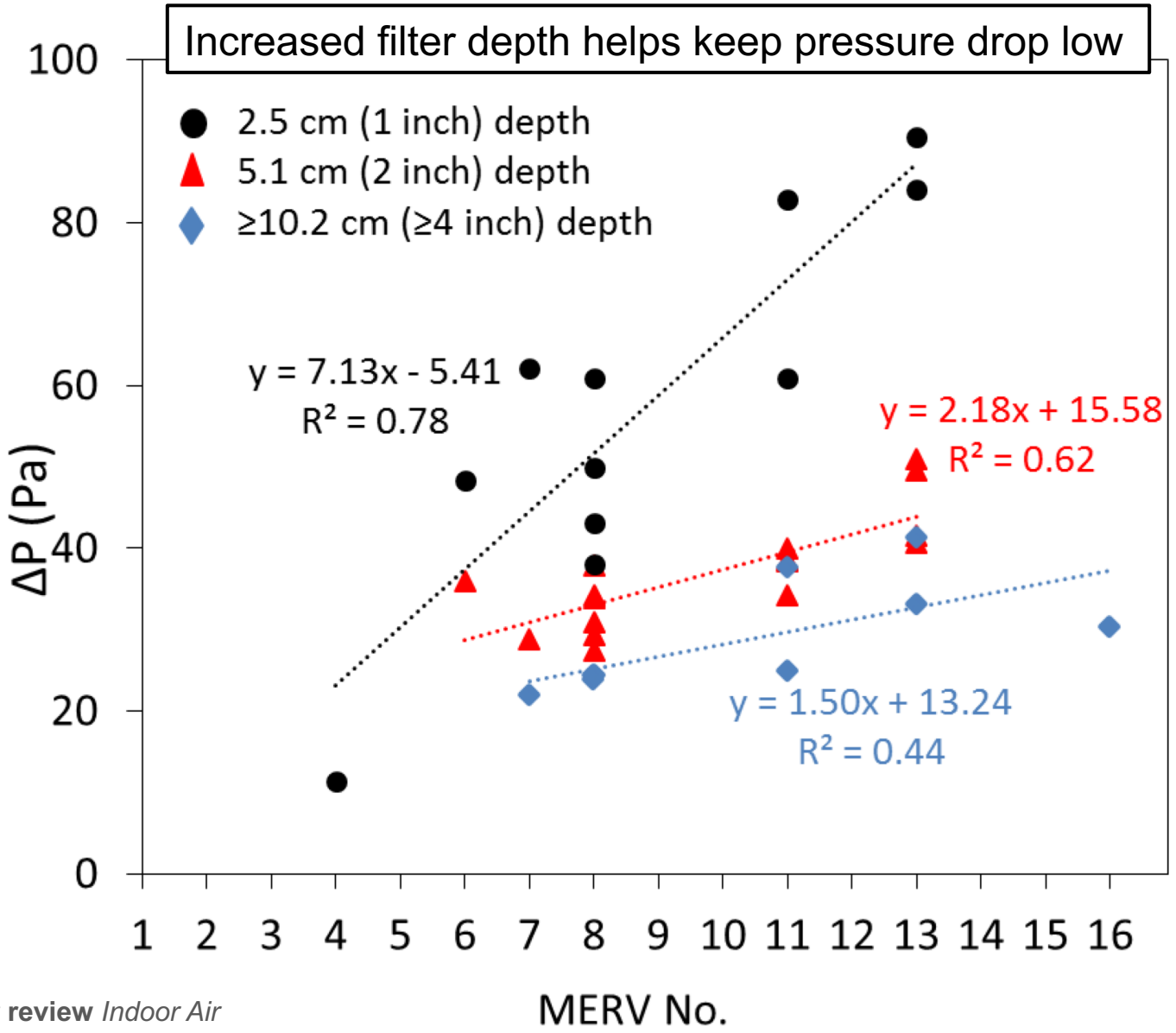
Higher efficiency residential filters often have a higher pressure drop, which:

- reduces airflow rates (PSC blowers)
- increases power draw (BPM blowers)

But the energy impacts are *usually* small

Others: Stephens et al. **2010** *ASHRAE Trans*; Stephens et al. **2010** *HVAC&R Res*; Walker et al. **2012** *LBNL-6143E*

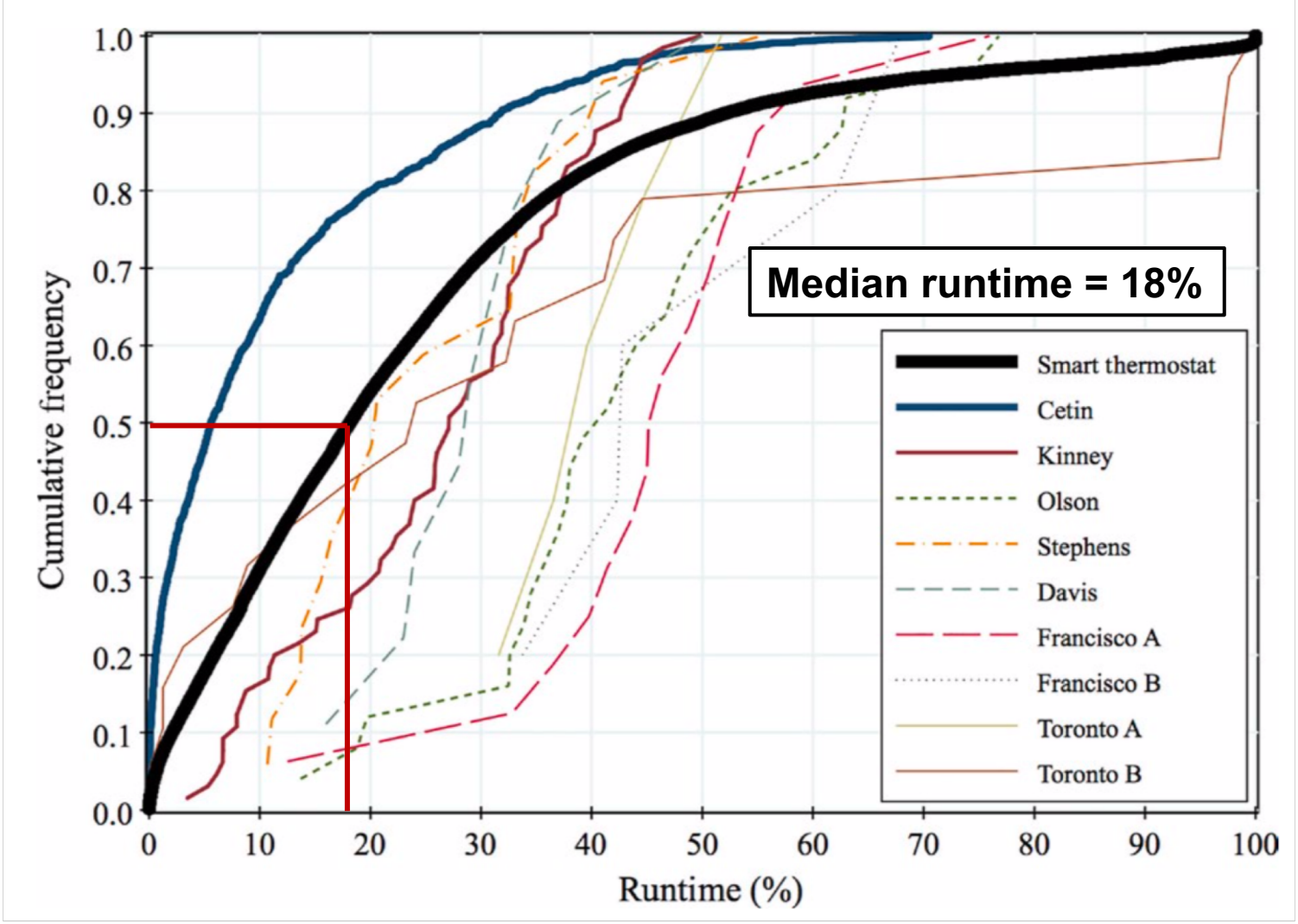
Filter pressure drop vs. MERV (and depth)



Fazli et al., **under review** *Indoor Air*

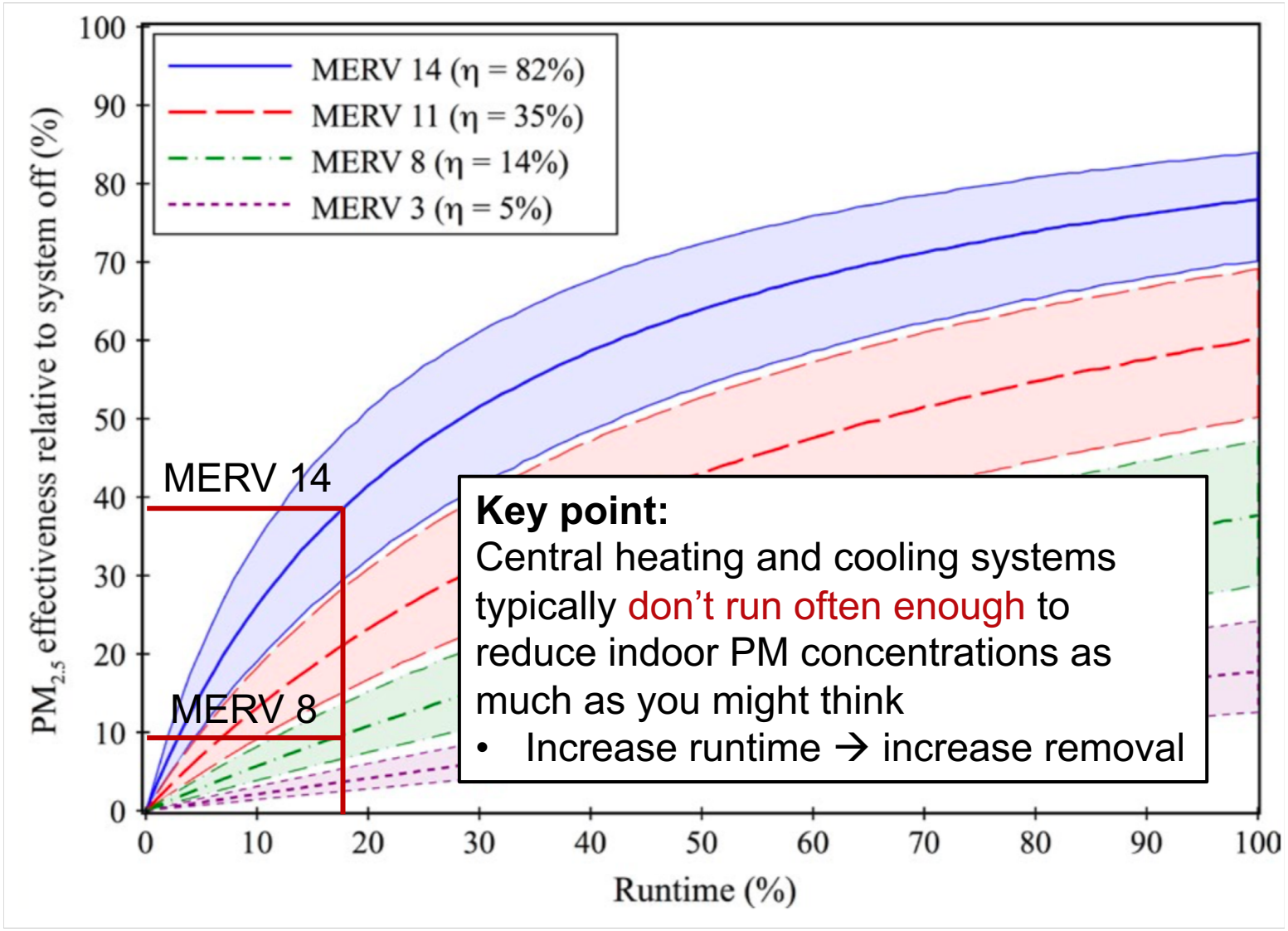
HVAC runtimes limit the effectiveness of in-duct filters

Air handler runtimes from over 7000 homes in North America



Touchie and Siegel **2018** *Indoor Air*

HVAC runtimes limit the effectiveness of in-duct filters

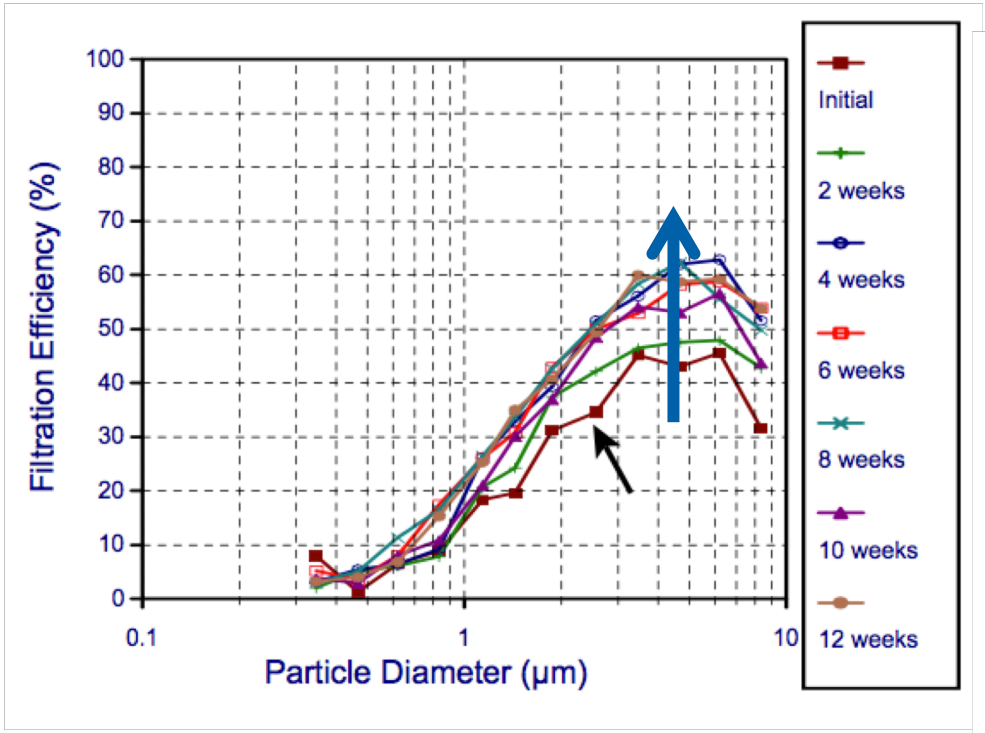


Touchie and Siegel **2018** *Indoor Air*

Dust loading affects removal efficiency of filters

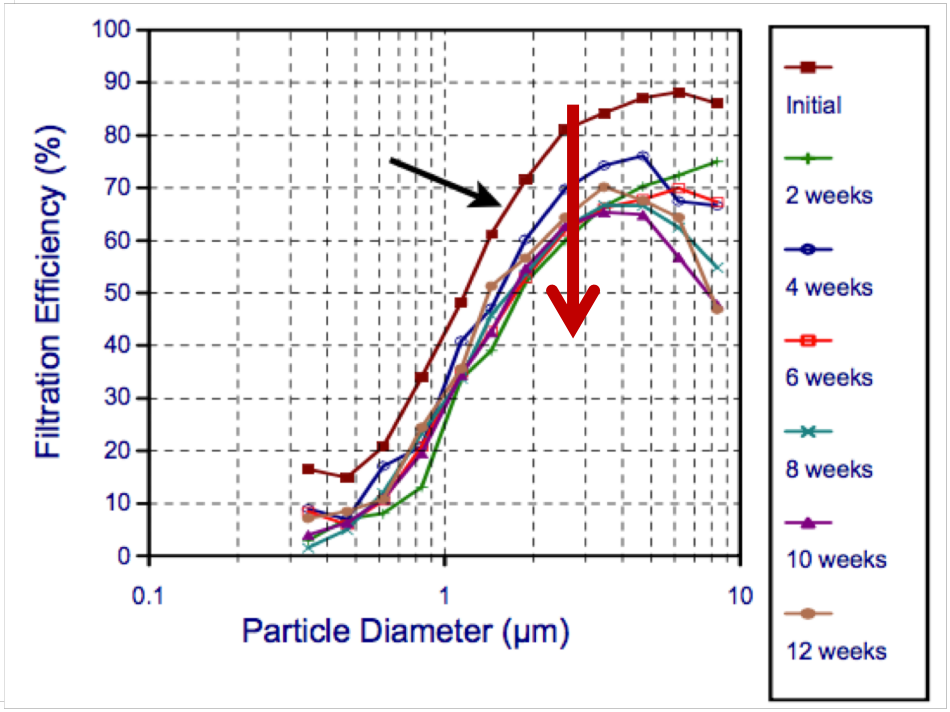
Some get better…

Non-electret media filters (MERV 5 when clean)



… some get worse!

Electret media filters (MERV 11 when clean)



Hanley and Owen **2003** ASHRAE Research Project Final Report 1190-RP
Owen et al. **2013** ASHRAE Research Project Final Report 1360-RP

Residential particle filtration: key points

1. **Fine or ultrafine PM removal**

   Filters aren't tested or rated for fine or ultrafine PM removal

2. **Pressure drop, airflow, and energy use**

   Relationships between pressure drop, airflow, and energy use are complicated, and not always straightforward

3. **System runtimes**

   Low system runtimes often limit filtration effectiveness

4. **Dust loading**

   Filtration efficiency changes over time with dust loading

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