BEYOND DILUTION – REDUCING EXPOSURE TO PARTICLE POLLUTION

Healthy Buildings Summit 2018
IEQ, Remediation, & Restoration: Research to Practice
October 25, 2018, Seven Springs, PA

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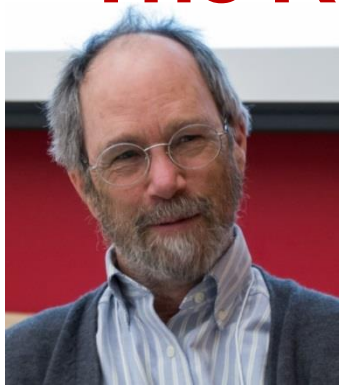
RESOURCES

- Health Risks of Indoor Exposure to Particulate Matter - http://www.nationalacademies.org/hmd/Activities/PublicHealth/Health-Risks-Indoor-Exposure-ParticulateMatter.aspx
- IL Institute of Technology (Built Environment Research Group) (papers & presentations) http://built-envi.com/
- IAQ Scientific Findings Resource Data bank -
- https://iaqscience.lbl.gov/indoor-air-quality-iaq-scientific-findings
- IAQ Radio - https://www.iaqradio.com/
- Purple Air Map - https://www.purpleair.com/gmap
- ROCIS website - http://ROCIS.org

ROCIS *(Rock-us) or (Raucous)* Reducing Outdoor Contaminants in Indoor Spaces

WWW.ROCIS.ORG

The ROCIS Team



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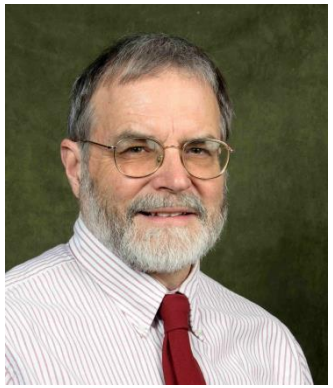

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Team Leader
Waynesburg. PA

WHAT IS ROCIS ?

MISSION

A Southwestern Pennsylvania initiative to reduce the impact of exterior pollution in indoor spaces.

Why??

Most of our exposure
to outdoor pollution
happens
in buildings

ROCIS LCMP
LOW COST MONITORING PROJECT

Low Cost Monitoring Project (LCMP)
Objectives

1) Learn how low-cost air monitors empower occupants

2) Examine the impacts of outdoor pollution on indoor air

3) Explore interventions to improve indoor air quality

Low Cost Monitoring Project (LCMP) Process

- Provide IAQ monitoring kit – short-term loan for baseline, longer term for testing interventions
- Tap participant's homes & workplaces
- Invest in participants' experience & knowledge
- Provide protocols for reporting & interventions
- Build baseline & develop/refine best practices
- ***Develop champions!!***

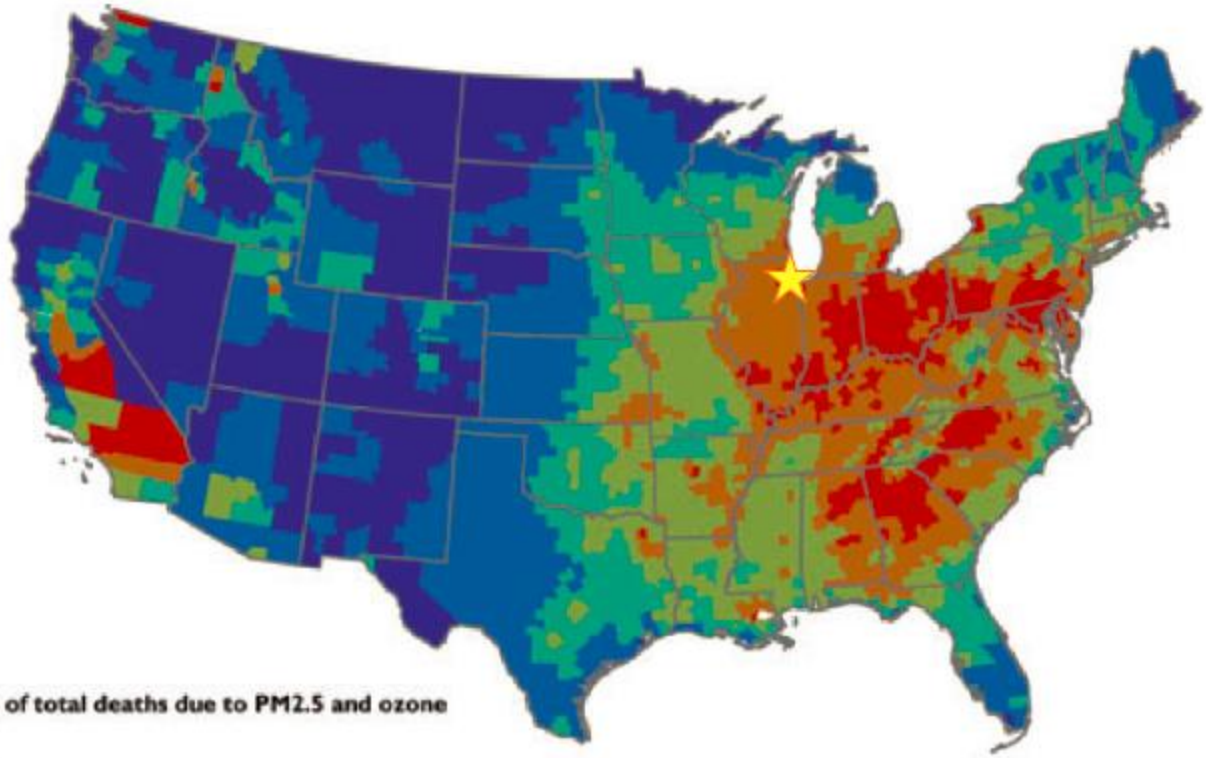
LCMP Cohorts

- Initial 3-4 weeks – home or workplace
- Longer term monitoring with interventions

FOCUS ON PARTICLES

Also referred to as Particulate Matter (PM)

Outdoor particulate matter and human health



Percentage of total deaths due to PM2.5 and ozone

- <3%
- 3.1 to 4.1%
- 4.2 to 5.3%
- 5.4 to 6.2%
- 6.3 to 7.2%
- 7.3 to 9.8%

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*

10

Slide credit – Stephens ASHRAE Chicago 2018

Making the Invisible Visible

Dylos 1700 Optical Particle Counter:
Particles per 1/100 ft^3, 1 min. resolution

2 size ranges:

> **0.5+ µm (Dylos "Total")**

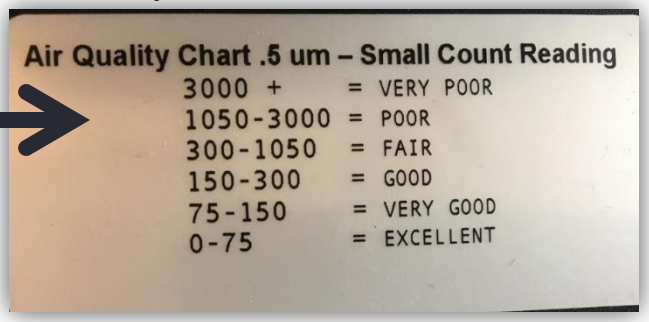
> 2.5+ µm (Dylos "Large")

Cost: $300 - 400; 1 week data storage

3 Dylos / Site

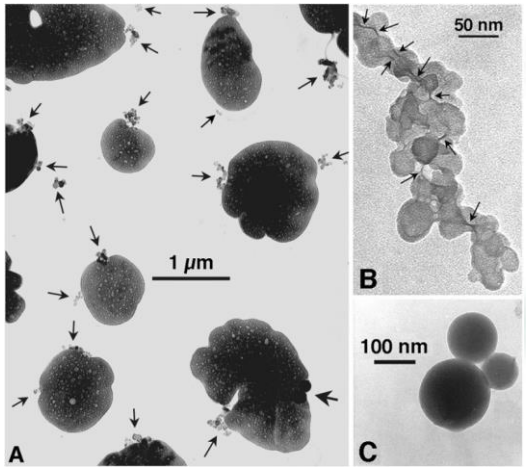
- Outside, Inside (living area) Roamer (usually bedroom)

NOTE: Scale at right is from manufacturer; not health based

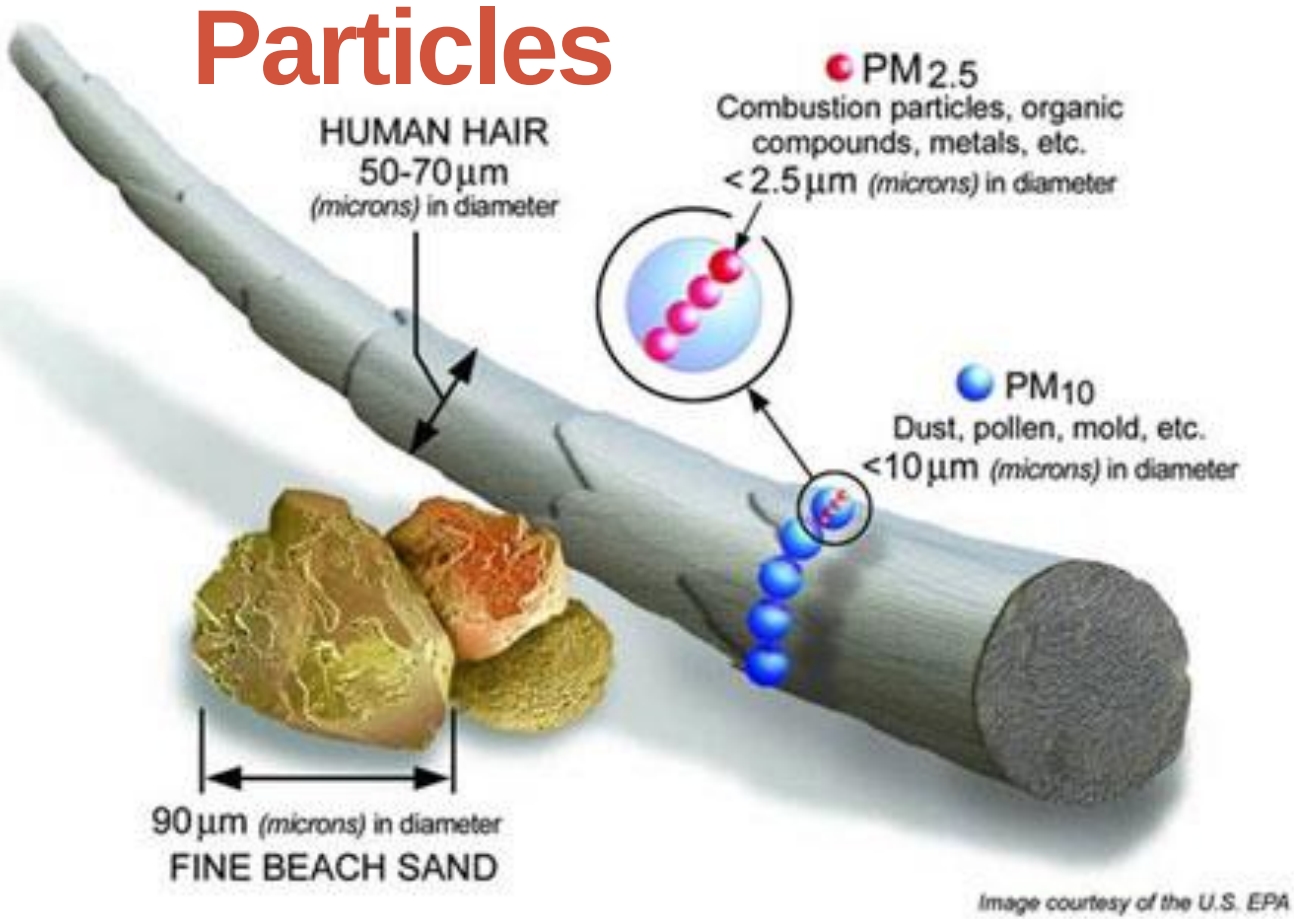


Dylos 1700 http://www.dylosproducts.com/dc1700.html

Particles



OUTDOOR BLACK CARBON
50 nm to 1 μm



PM_{10}: Particulate matter less than 10 μm in diameter
$PM_{2.5}$: Particulate matter less than 2.5 μm in diameter
ROCIS LCMP Dylos: $PM_{0.5}$+: Particulate matter is ***greater than*** 0.5 μm in diameter (1/100 of human hair!)

Health Concerns (<PM10)[1]

- Premature death in people with heart or lung disease
- Nonfatal heart attacks
- Irregular heartbeat
- Aggravated asthma
- Decreased lung function
- Increased respiratory symptoms, such as irritation of the airways, coughing or difficulty breathing

[1]Source EPA 7/1/2016

Pittsburgh's Air Quality is Poor

People Most at Risk in the U.S.

From Year-Round Particle Pollution (Annual $PM_{2.5}$)

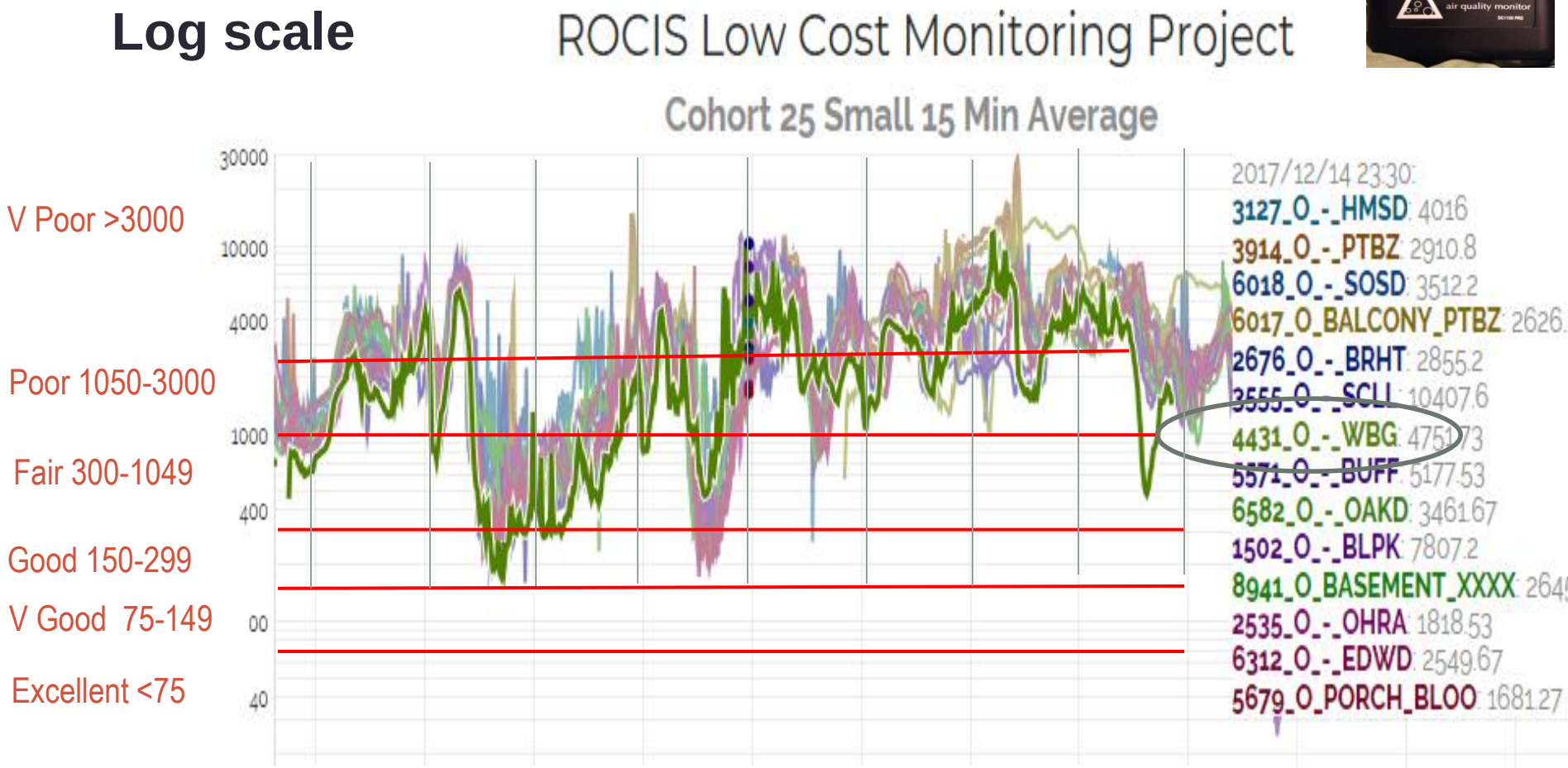
- 8th worst city[1] & worst city east of the Rockies)
- Allegheny County (Pittsburgh) is 13th worst

1. Pittsburgh-New Castle-Weirton (PA-WV-OH)

SOURCE: American Lung Association State of the Air Report 2017
http://www.lung.org/assets/documents/healthy-air/state-of-the-air/state-of-the-air-2017.pdf

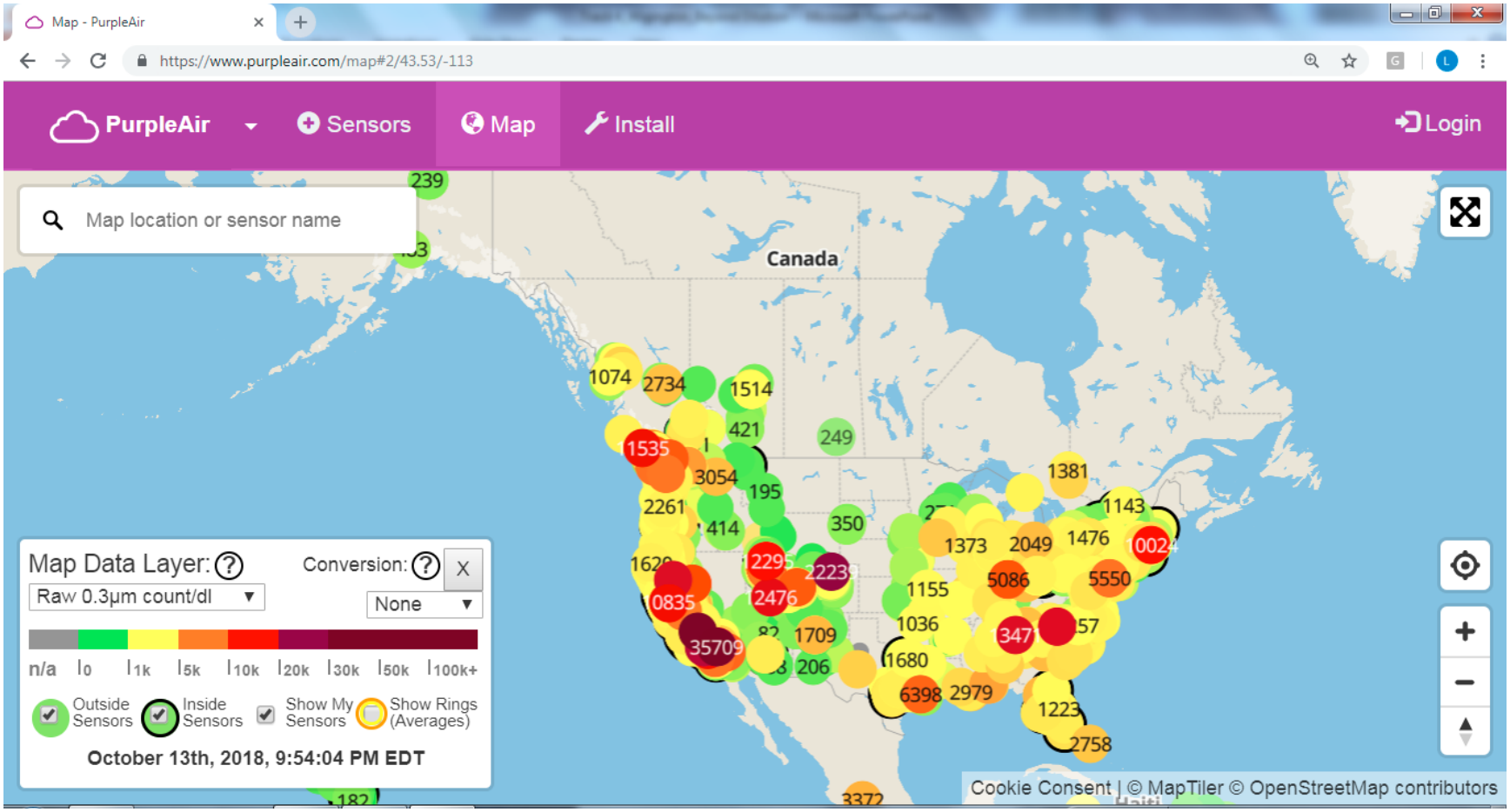
Outdoor Data by Cohort - (70 mile spread) - Readings track

Log scale



Most sites are Pittsburgh; Green line (Wbg) is 50 miles south
Dylos particles (0.5+ µm)

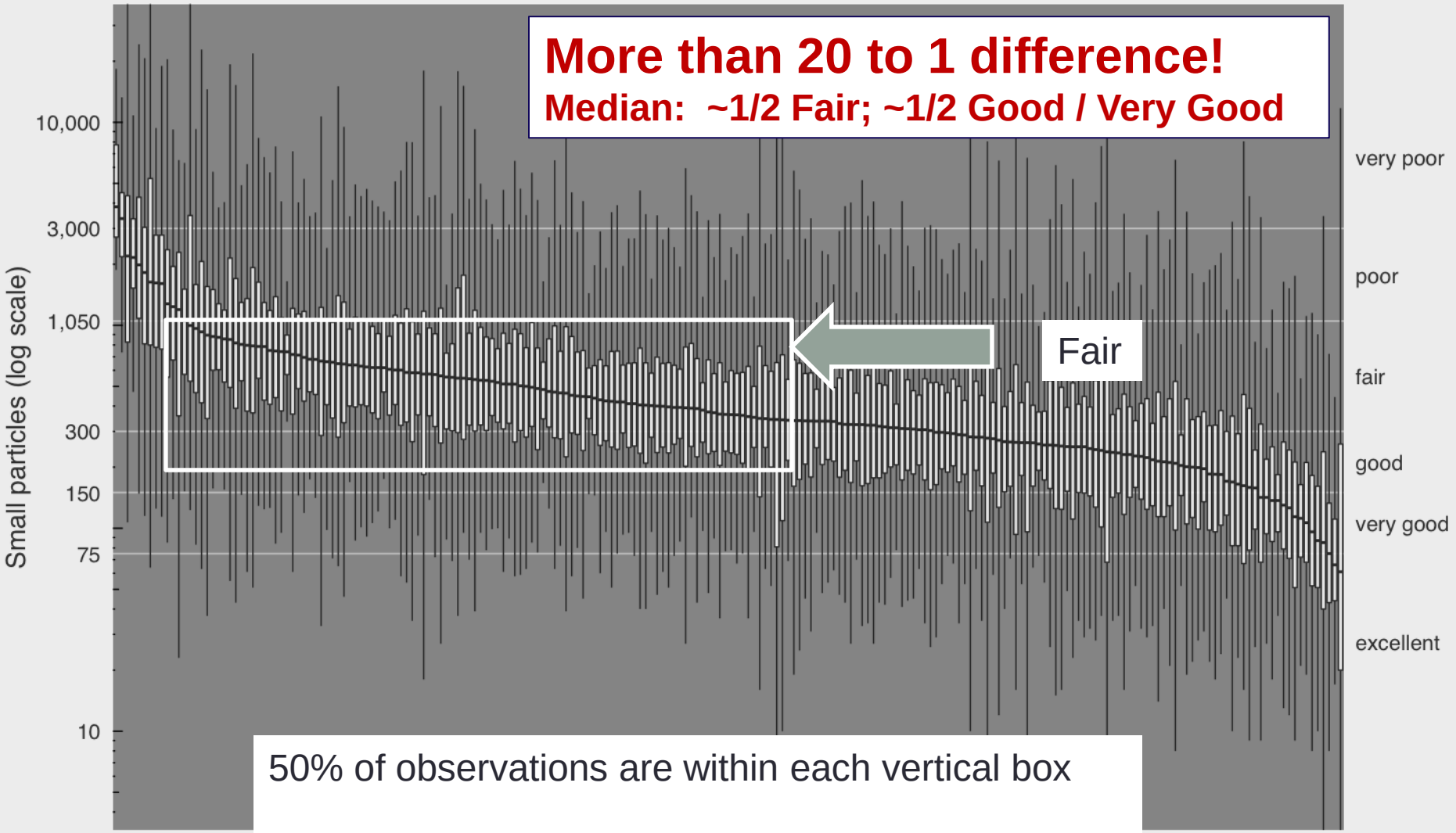
PurpleAir Monitor Map
World Wide or Local



https://www.purpleair.com/gmap

LCMP PARTICLE DISTRIBUTION DATA

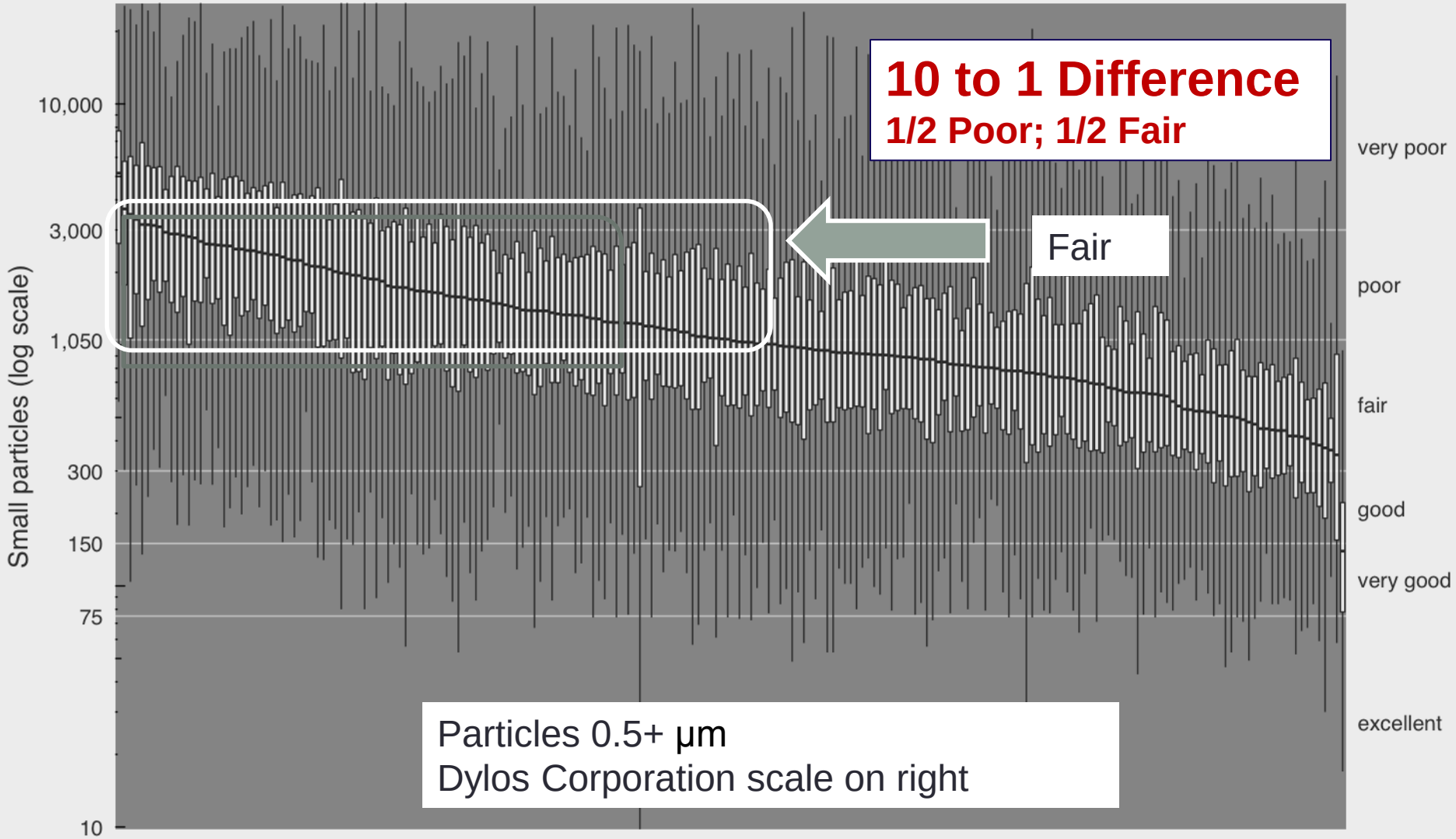
Indoor Particle Distribution – All Sites



50% of observations are within each vertical box

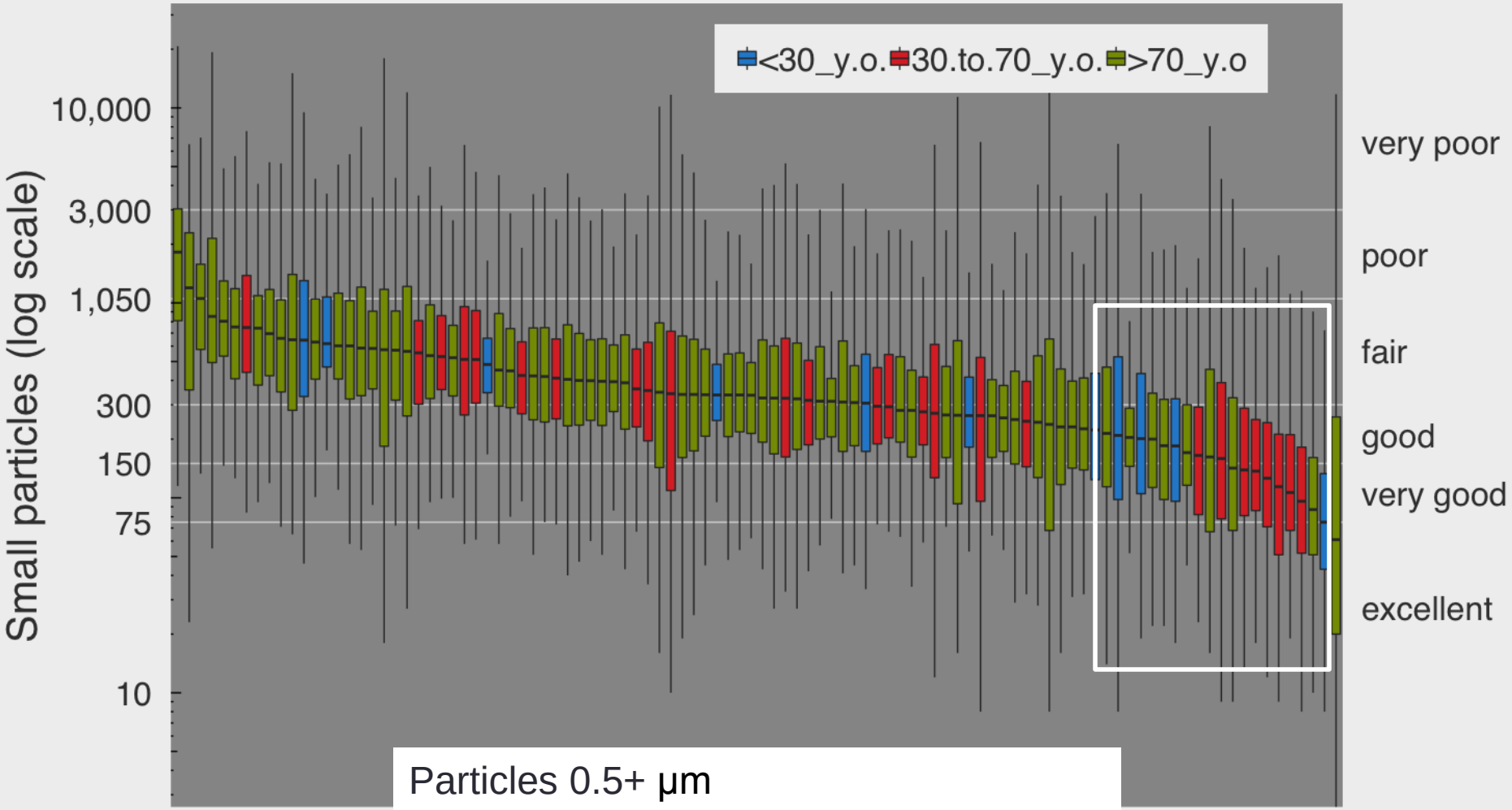
Particles 0.5+ µm
Dylos Corporation scale (on right)

Outdoor Particle Distribution – All Sites



Particle Comparison by Age of Homes

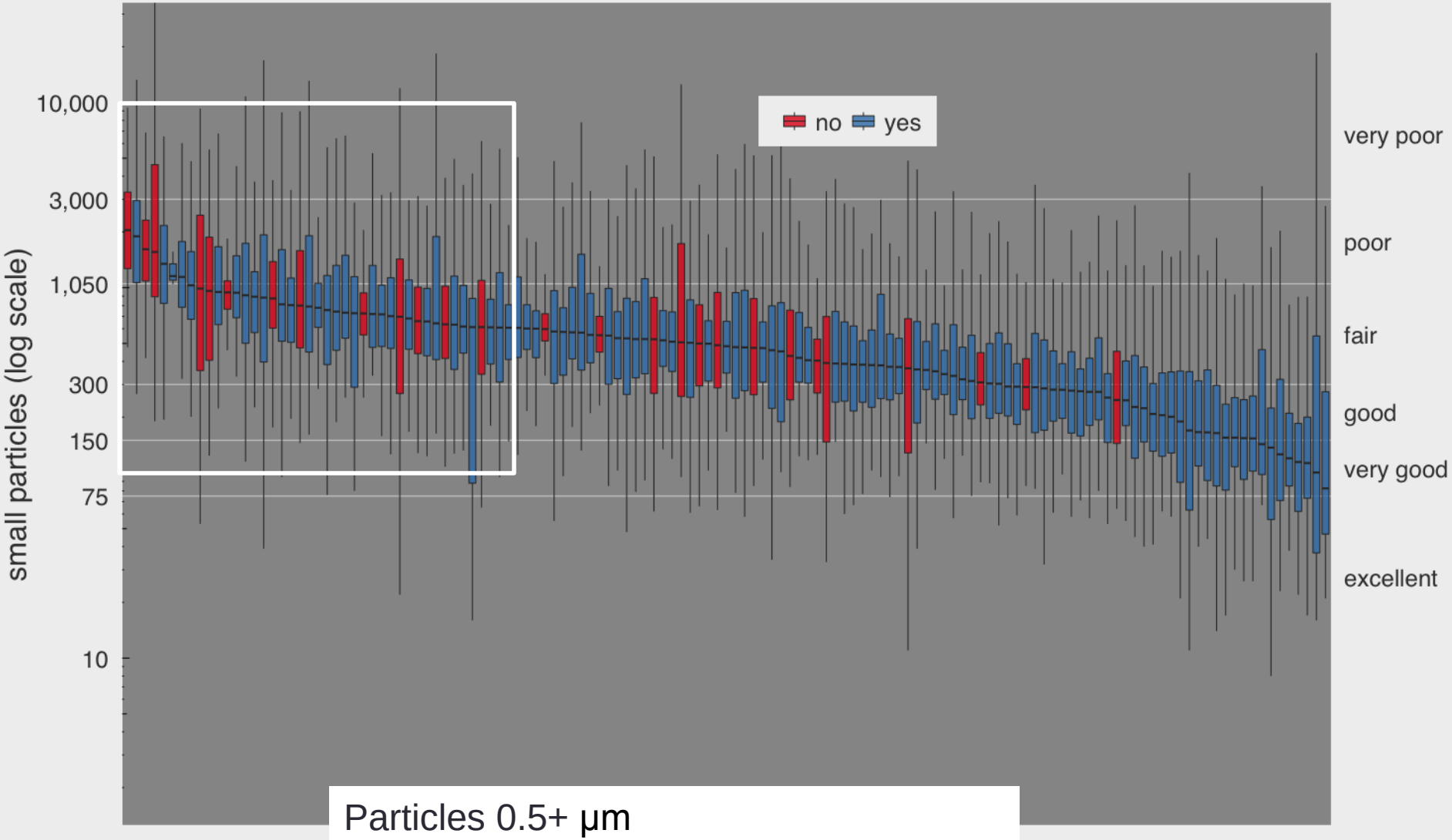
All season



Particles 0.5+ µm
Dylos Corporation scale on right

Is your home DETACHED? (first weeks)

Particle Levels: Indoor location



Particles 0.5+ µm
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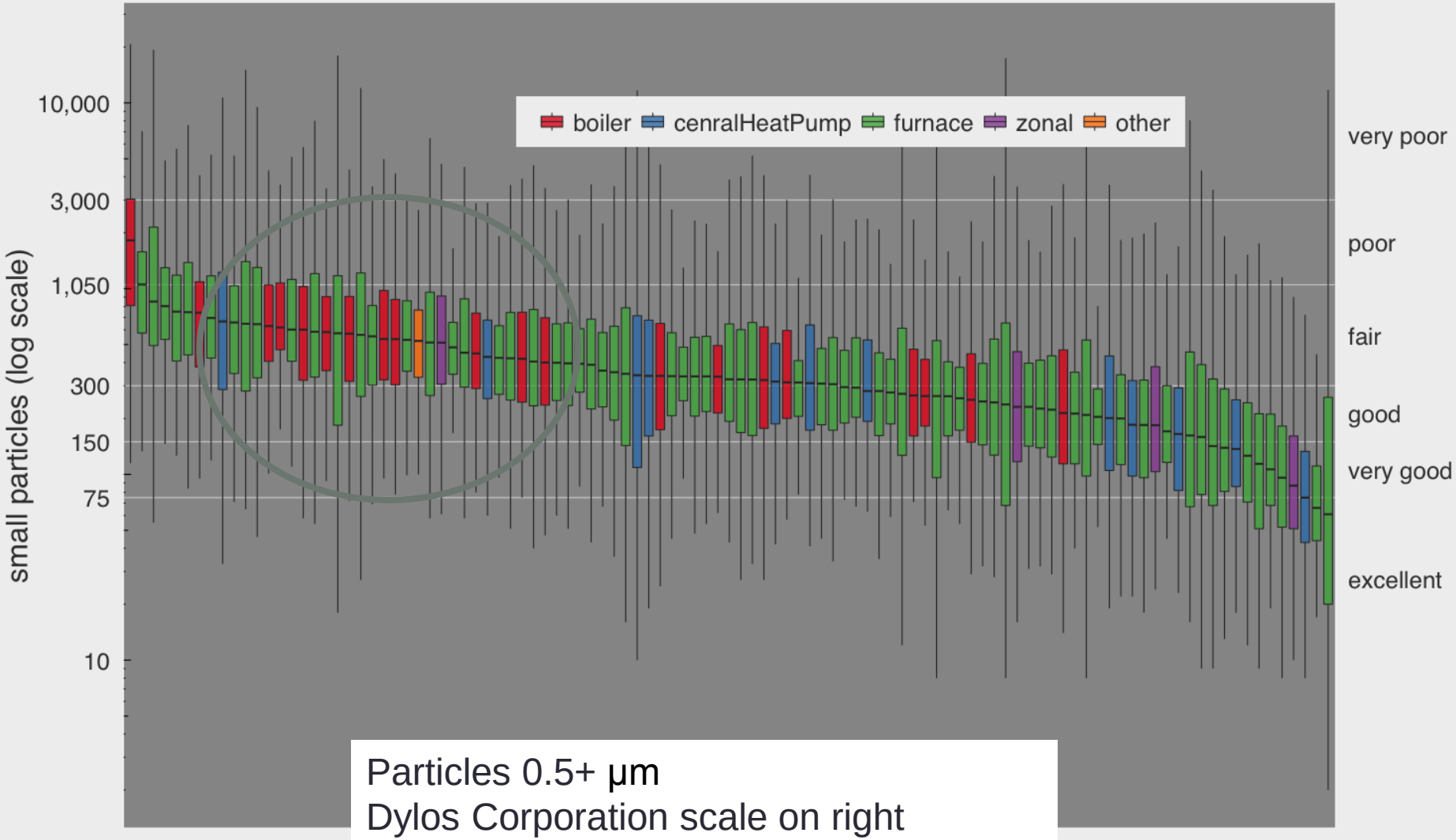
What type of HEATING SYSTEM do you have?

Particle Levels: Indoor location



Particles 0.5+ µm
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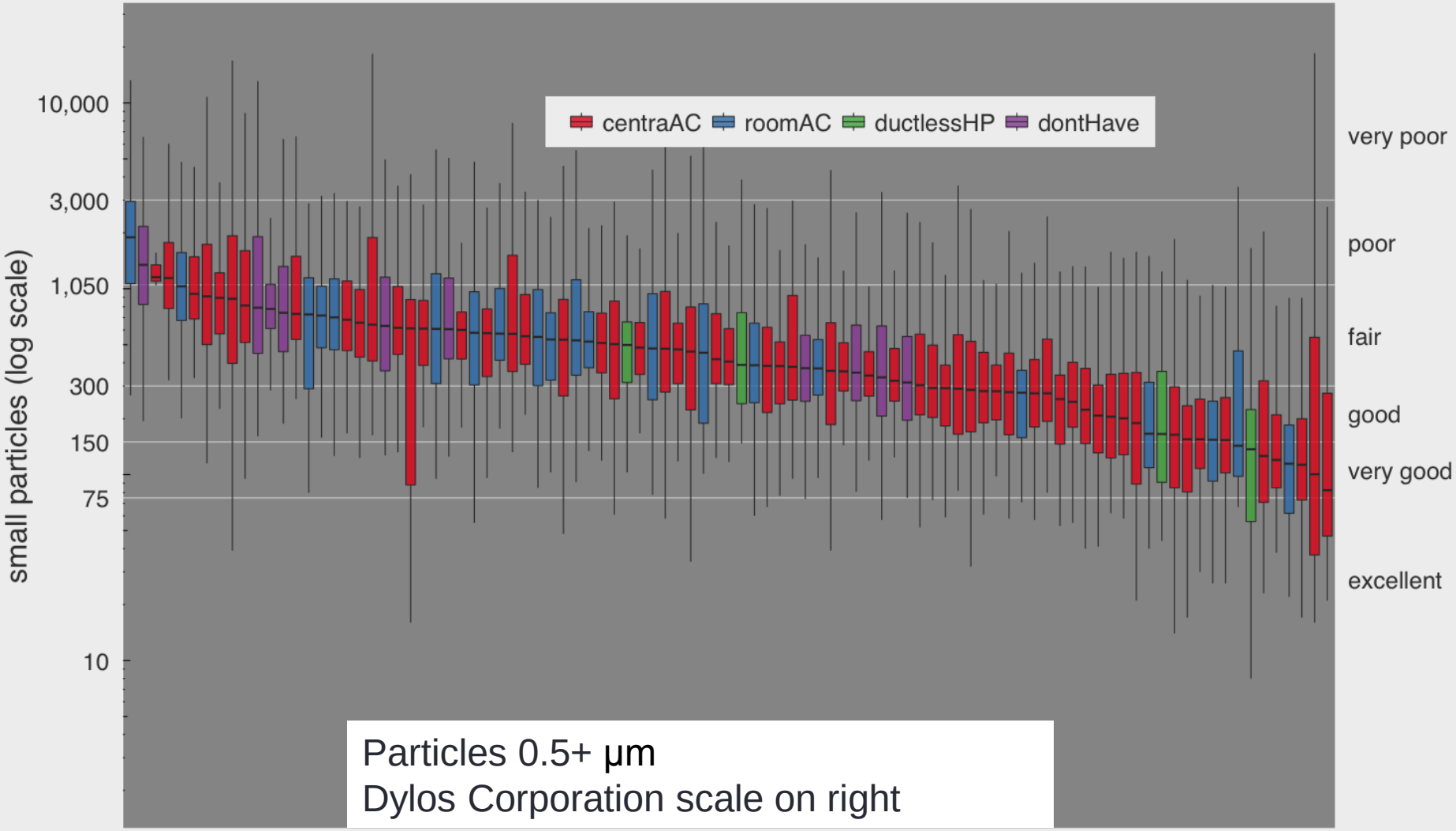
What type of AIR CONDITIONER do you have?

Particle Levels: Indoor location



Particles 0.5+ µm
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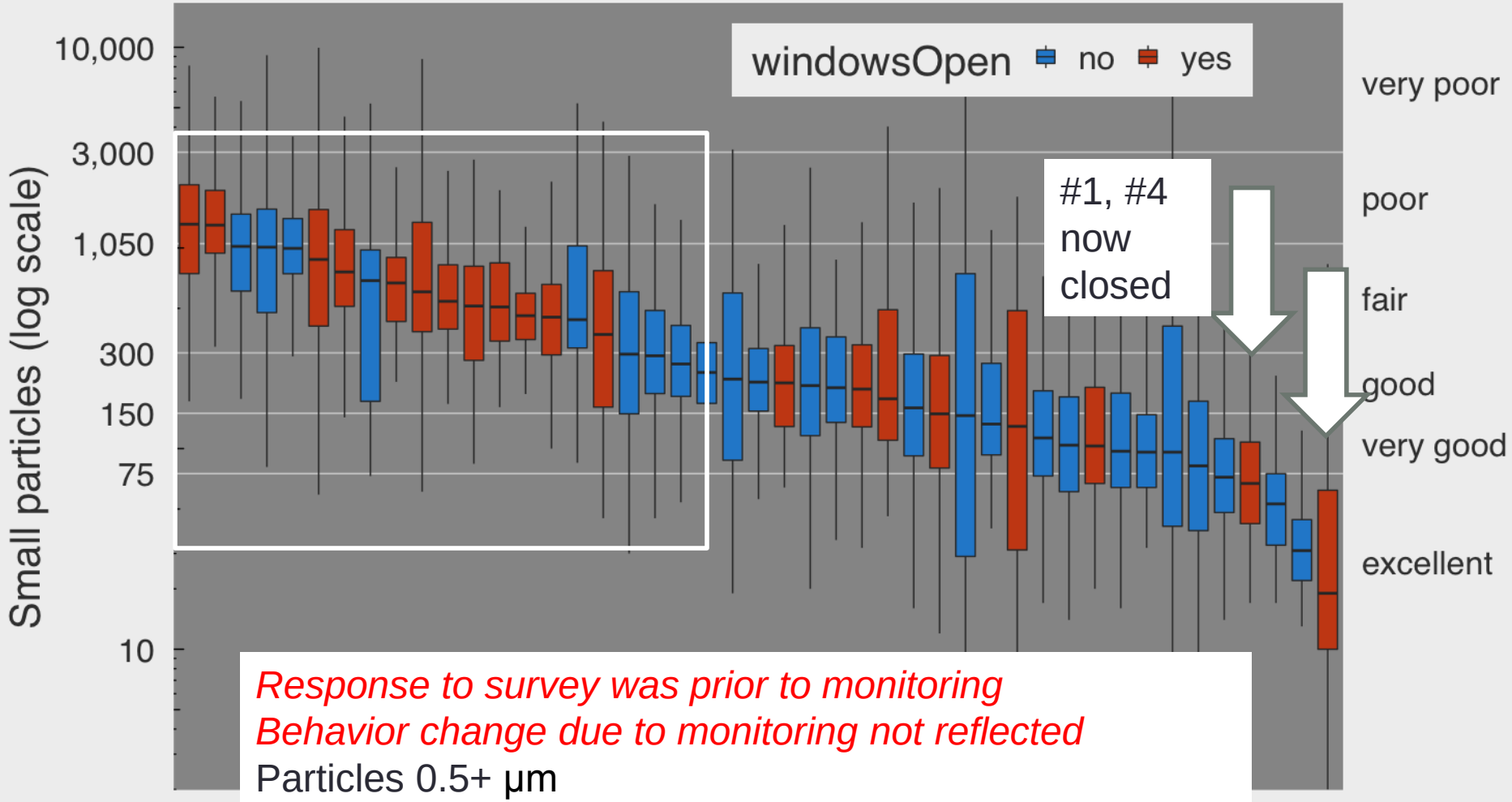
Comparing Open vs Closed Windows

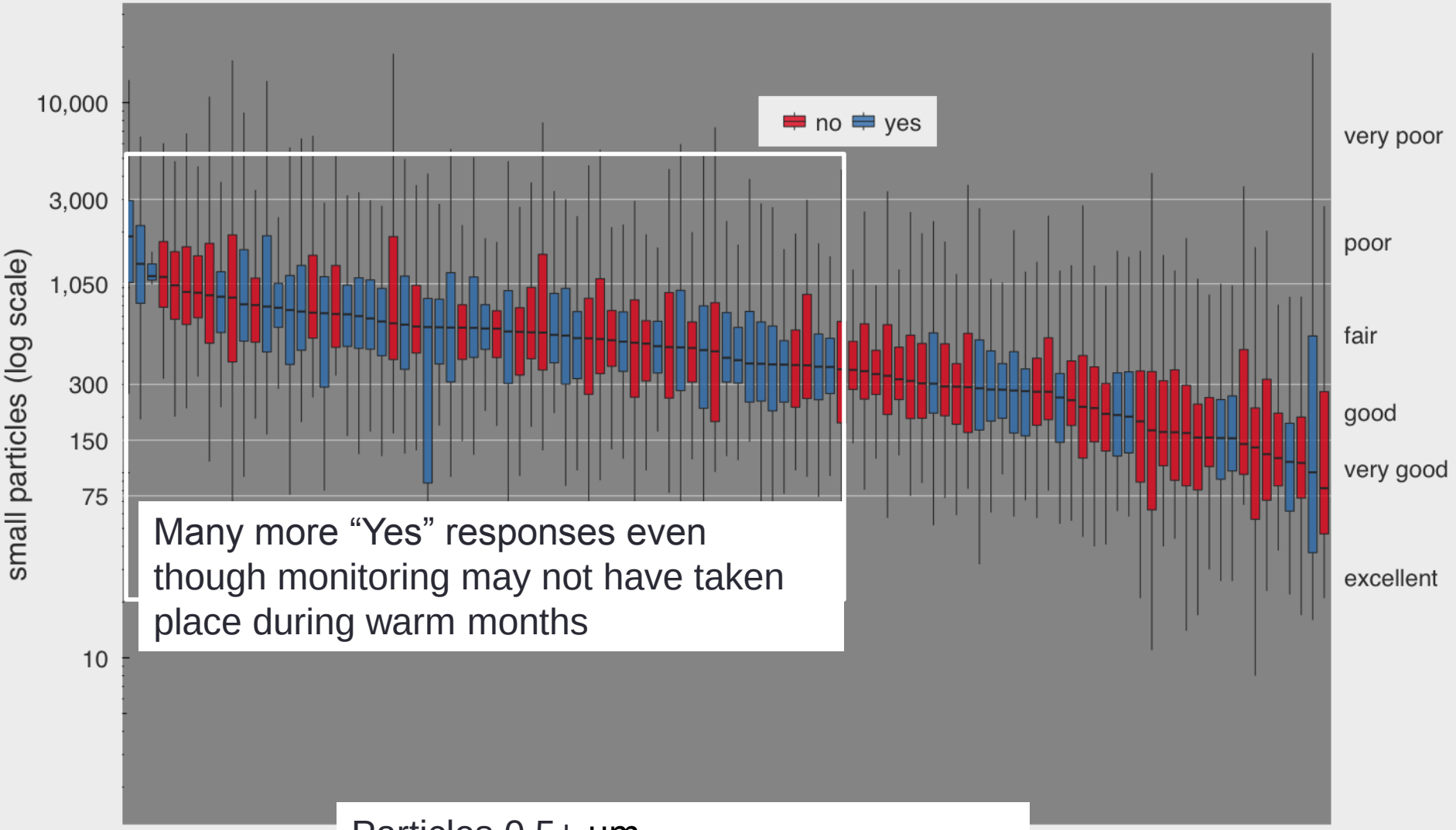
Summer Nights Only



Response to survey was prior to monitoring
Behavior change due to monitoring not reflected
Particles 0.5+ µm
Dylos Corporation scale on right

Do you OPEN WINDOWS TO VENTILATE?

Particle Levels: Indoor location



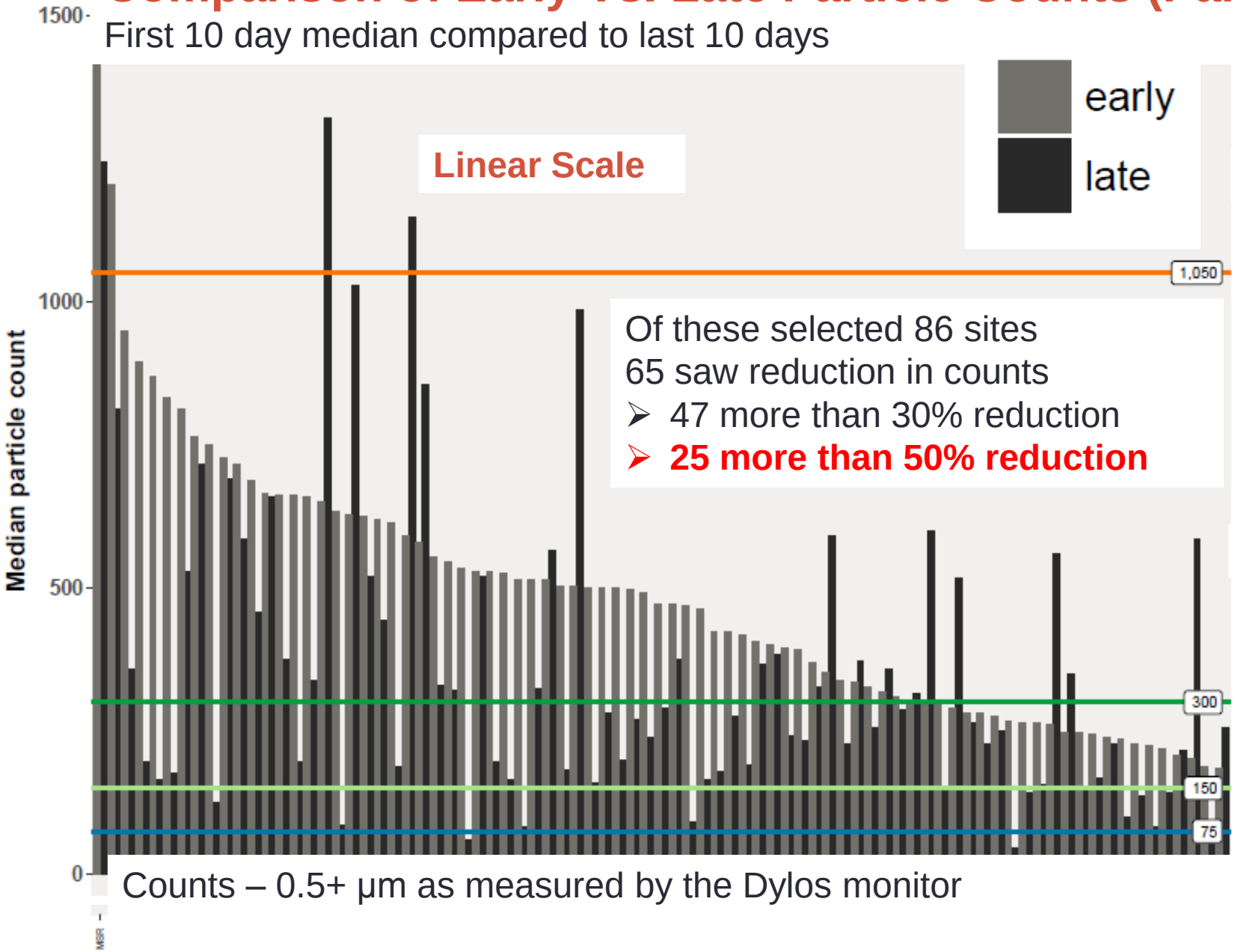
Many more “Yes” responses even though monitoring may not have taken place during warm months

Particles 0.5+ µm
Dylos Corporation scale on right

INTERVENTION INSIGHTS

Comparison of Early Vs. Late Particle Counts (Paired)

First 10 day median compared to last 10 days

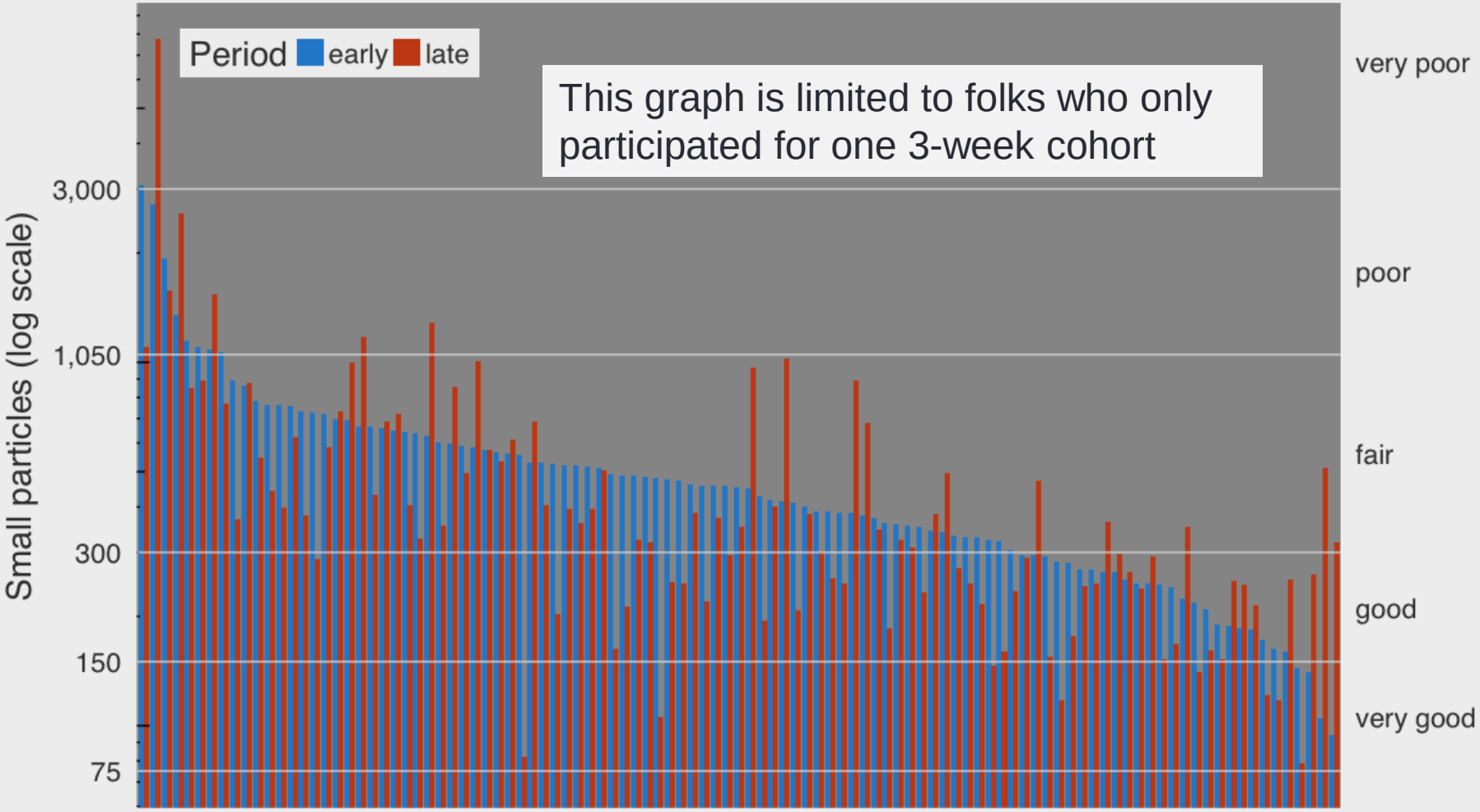


Of these selected 86 sites
65 saw reduction in counts
- 47 more than 30% reduction
- **25 more than 50% reduction**

Counts – 0.5+ µm as measured by the Dylos monitor

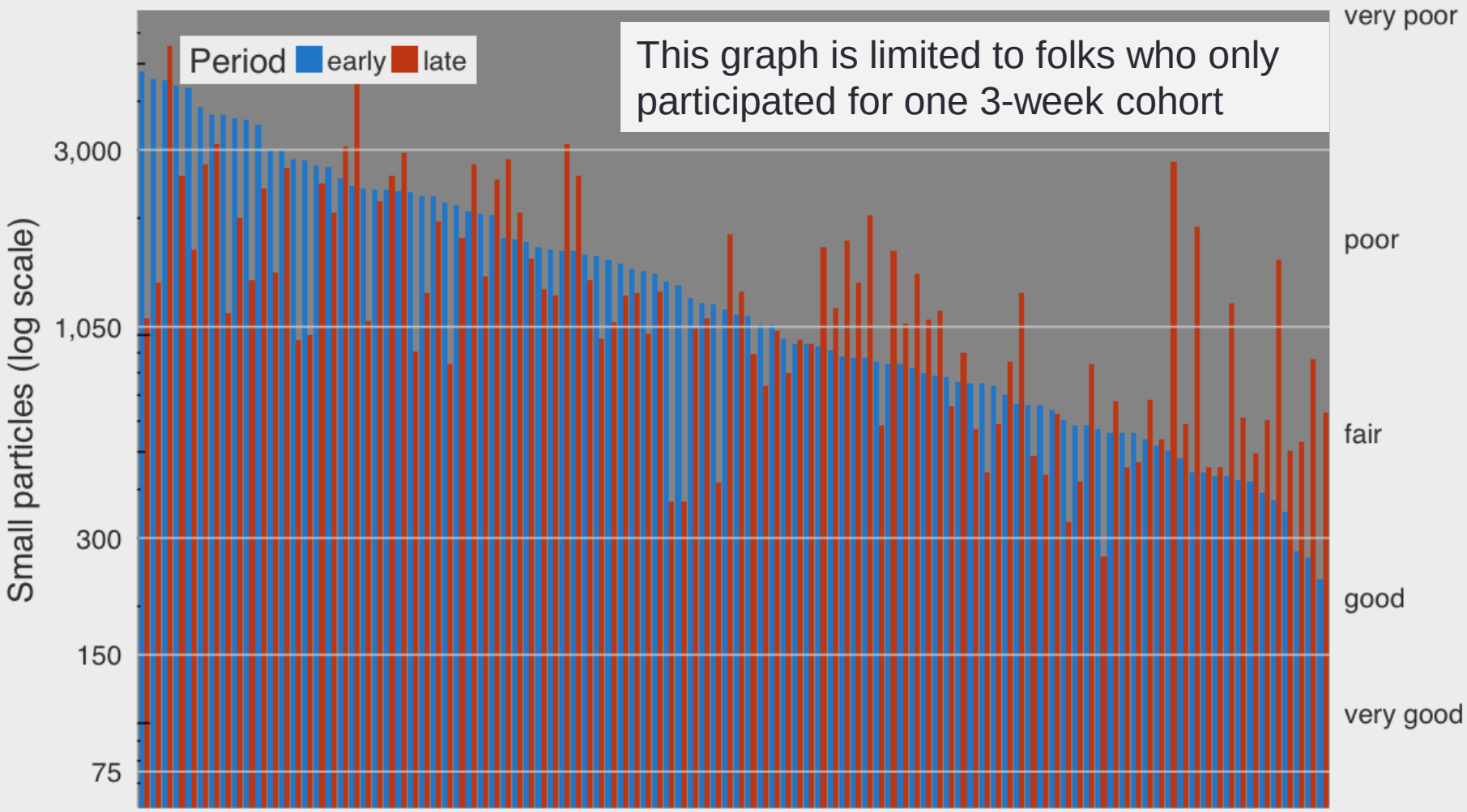
Indoor Particle Levels

Comparing early vs. late in monitoring period



Outdoor Particle Levels

Comparing early vs. late in monitoring period



Options to Reduce Indoor Particles

- **Reduce air exchange from outside**
  - Close windows
  - Tighten home or building
- **Reduce indoor sources**
  - Use an effective ducted kitchen hood!
  - Use induction cook top & other good practices w/ cooking
- **Reduce resuspension**
  - HEPA vacuum
  - Walk-off mats
  - Get rid of carpets, old upholstered furniture
- **Filter air**
  - Portable air cleaners
  - Central air handler (furnace, AC, or ventilation)

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  - Walk-off mats; clean hard-surface floors thoroughly
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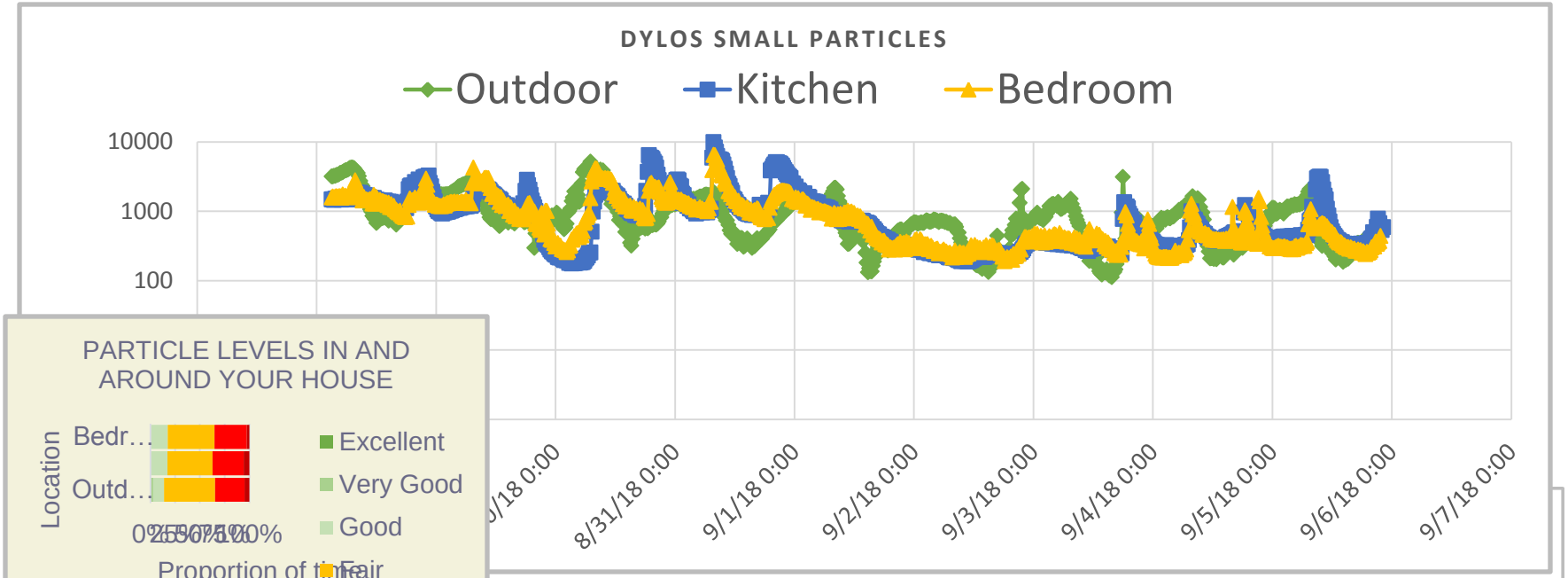
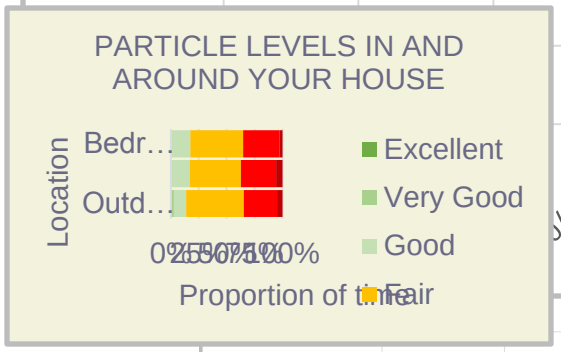
Window Operation

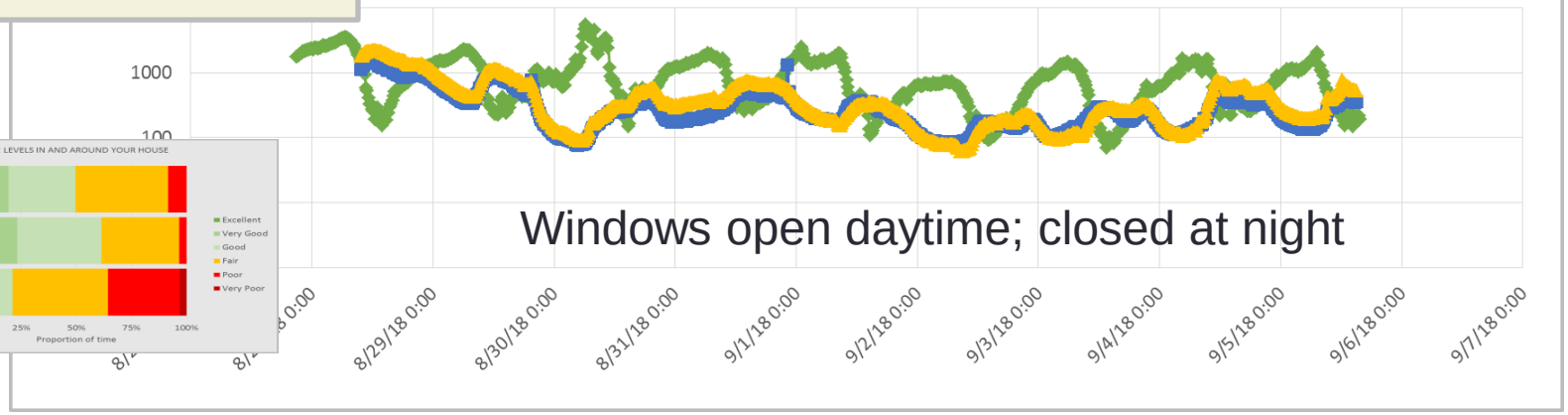
- Single **biggest factor** affecting IAQ when outdoor counts are high
- In Pittsburgh, particle counts tend to be **higher at night** & early morning when windows are often open
- **Poor air quality usually not perceptible (terrible AQ is)**
- Most **contentious**!
- Balancing passive cooling, preferences, dilution of indoor pollutants, & ventilation
- Implications – social justice, heat stress (no AC)

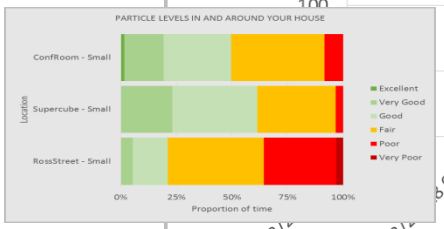
Windows Open vs. Closed (night)

(two different sites – same week; log scale)

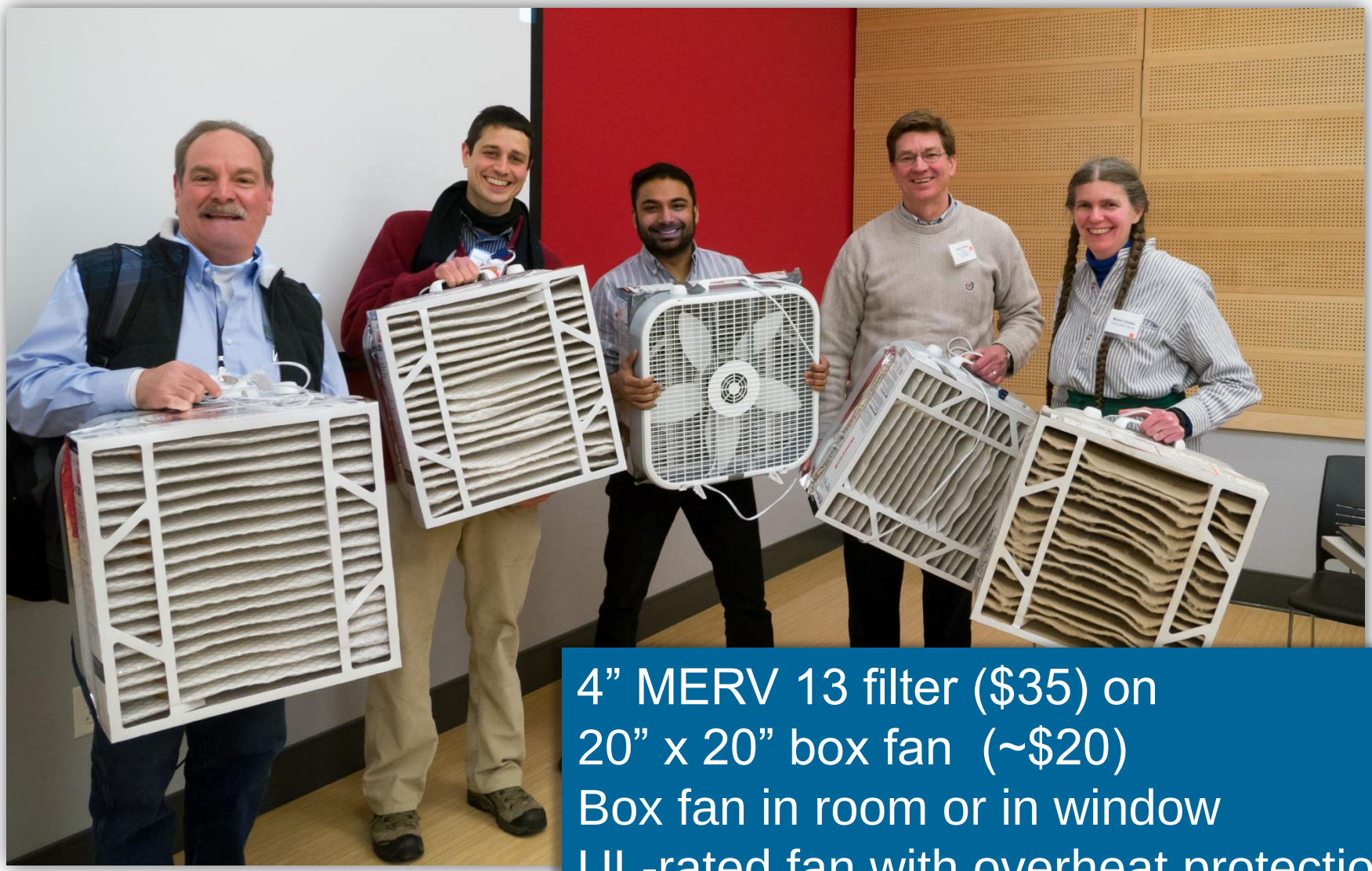








Fan/Filter Intervention: Low Cost, MERV 13

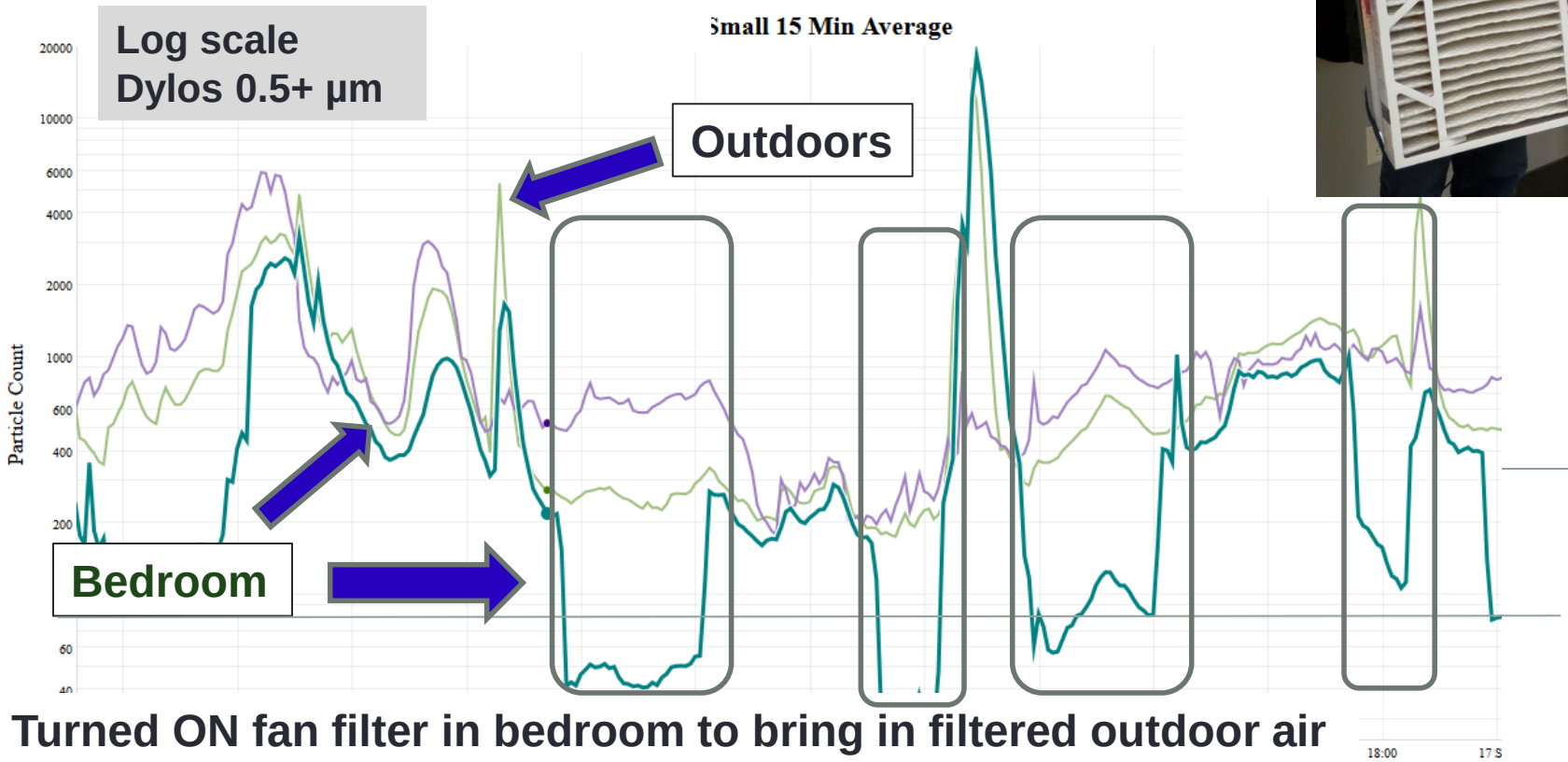


4” MERV 13 filter ($35) on
20” x 20” box fan (~$20)
Box fan in room or in window
UL-rated fan with overheat protection

Fan/Filter Intervention– Bedroom Window at Night

Open window with/without box fan and filter on:

Indoor tracks outdoor closely



Turned ON fan filter in bedroom to bring in filtered outdoor air
Turned OFF fan filter each morning (f5q4)

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Cooking –

Check out ROCIS guidance document and webpage

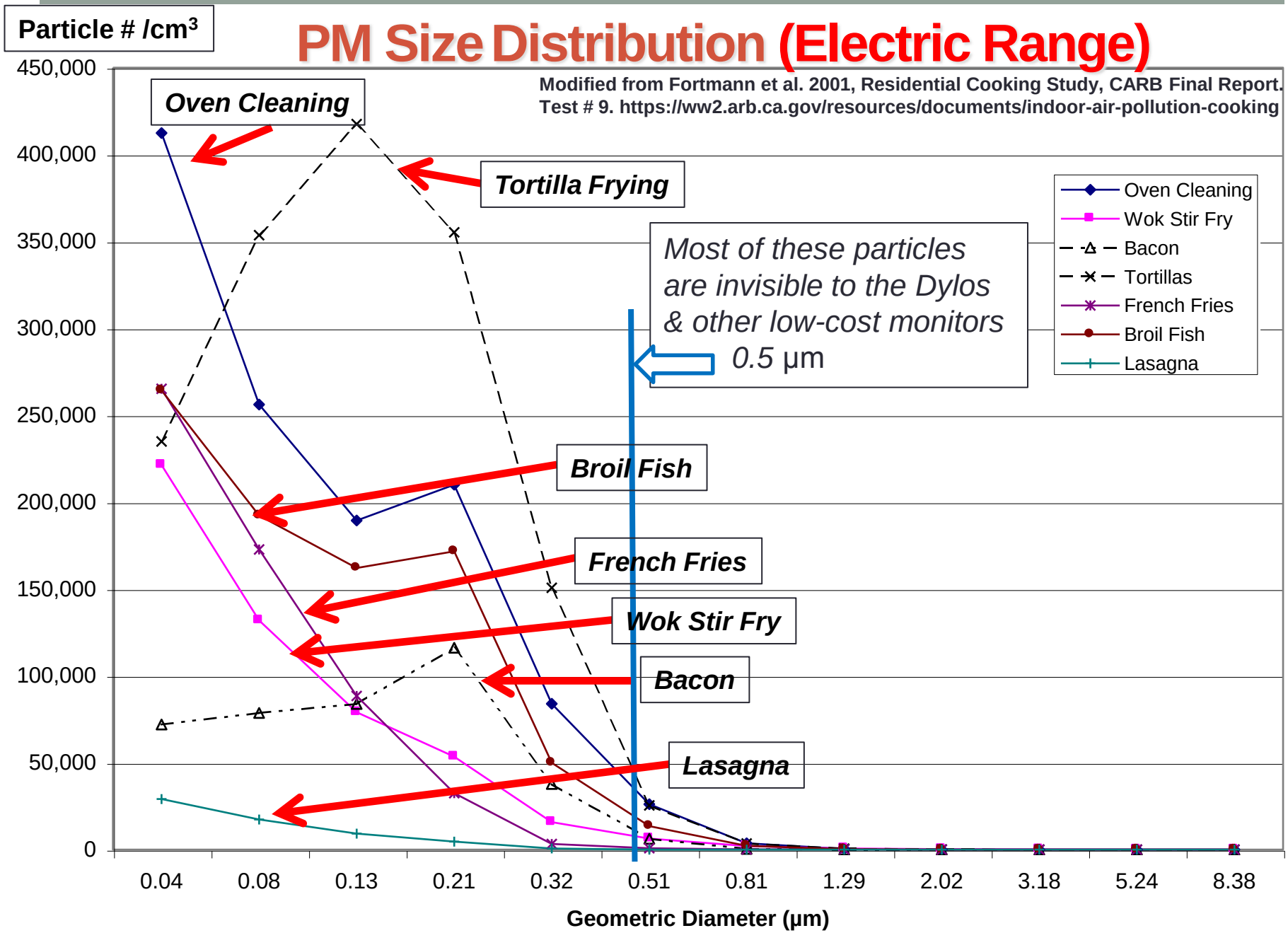
ROCIS ISSUE BRIEF, Ducted Range Hoods: Recommendations for New and Existing Homes

http://rocis.org/kitchen-range-hoods

Online Kitchen Ventilation group on Home Energy Pros

http://homeenergypros.org/group/kitchen-ventilation?xg_source=msg_wel_group

PM Size Distribution (Electric Range)



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Health Benefits of Air Filtration

Air cleaners typically reduce indoor PM concentrations by ~50%

Documented health improvements with air cleaners include:

- Improvements in lung function in asthmatics
- Fewer asthma-related doctor visits
- Improvements in cardiovascular & pulmonary function

Fisk 2013 Indoor Air

Health Benefits of Filtration

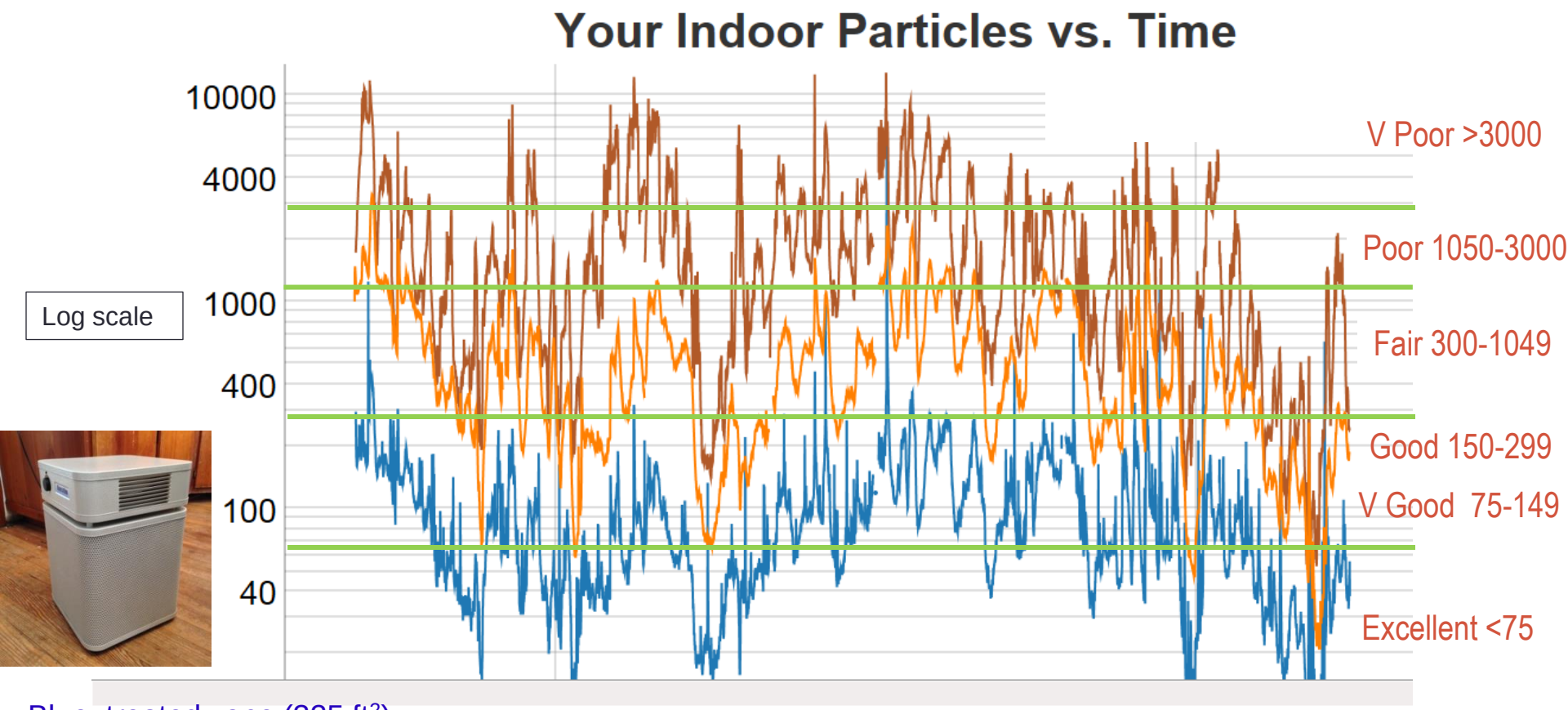
"Fisk said, The filtration of incoming outdoor air & recirculated indoor air should be the first approach taken to mitigate individual exposure to PM."

… the greatest potential (health benefits of filtration) comes from using better filtration to **reduce indoor concentrations of outdoor PM,** thus reducing the morbidity and mortality associated with outdoor air PM. "The health benefits are predicted to far exceed the costs for those interventions,…"

(2016, NAS, Health Risks of Indoor Exposure to Particulate Matter: Workshop Summary)

Impact of Portable Air Cleaner

http://rocis.org/rocis-data-explorer (j1t8) 0.5+ µm Particles by Time (15-min. avg.)



Blue: treated zone (325 ft^2)
Orange: untreated zone
Brown: outdoors
Tight, single family home
Though order of magnitude lower; Indoor (Blue/orange) tracks Outdoor

Portable Air Cleaners

ROCIS experience on capacity & impact

Results in tighter homes were very impressive – reduced particles on an entire floor of a home.

Received donation[1] of more air cleaners, and found impact more limited to single room (leakier, older homes with more activity).

More (3-5) air cleaners needed for medium-large home

NOTE: Full impact/benefit (e.g. chemicals) not measured due to our equipment limitations

[1] *Thanks to donation of air cleaners from Austin Air*

Portable Air Cleaners Fan/filters

Match the load of contaminants –
Volume (air exchange & pollutant strength)

Issues

- Inadequate **run time**
- **Noise** & wintertime discomfort
- **Filter** replacement
- **Cost** of air cleaner(s) & operation ($, kWh)

- *Low cost monitor can demonstrate effectiveness*
- *Examine use of timers to reduce discomfort*
- *Dirty filter on DIY fan-filter makes a big impression*

DIY Fan-Filter (Box fan with MERV 13 filter)

High MERV Filter - Air Handler (Filter/AHU) Inquiry

Initial Question…

Is there an **easy way** to determine if I can use a high MERV filter with a **longer air handler run-time** without causing problems ($, equipment durability, performance, or GHG emissions)?

High MERV Filter - Air Handler (Filter/AHU) Inquiry

Initial Question…

Is there an **easy way** to determine if I can use a high MERV filter with a **longer air handler run-time** without causing problems ($, equipment durability, performance, or GHG emissions)?

NO !!

Diagnostic Screen is Required

ROCIS Air Handler Inquiry: *Context*

SW Pennsylvania typical housing stock

- Basements
- Mostly gas heat; central AC (oversized)
- Sheet metal ducts in basement
- Supplies & returns to each room

Implications are different w/ attic or crawlspace ducts & homes with central returns

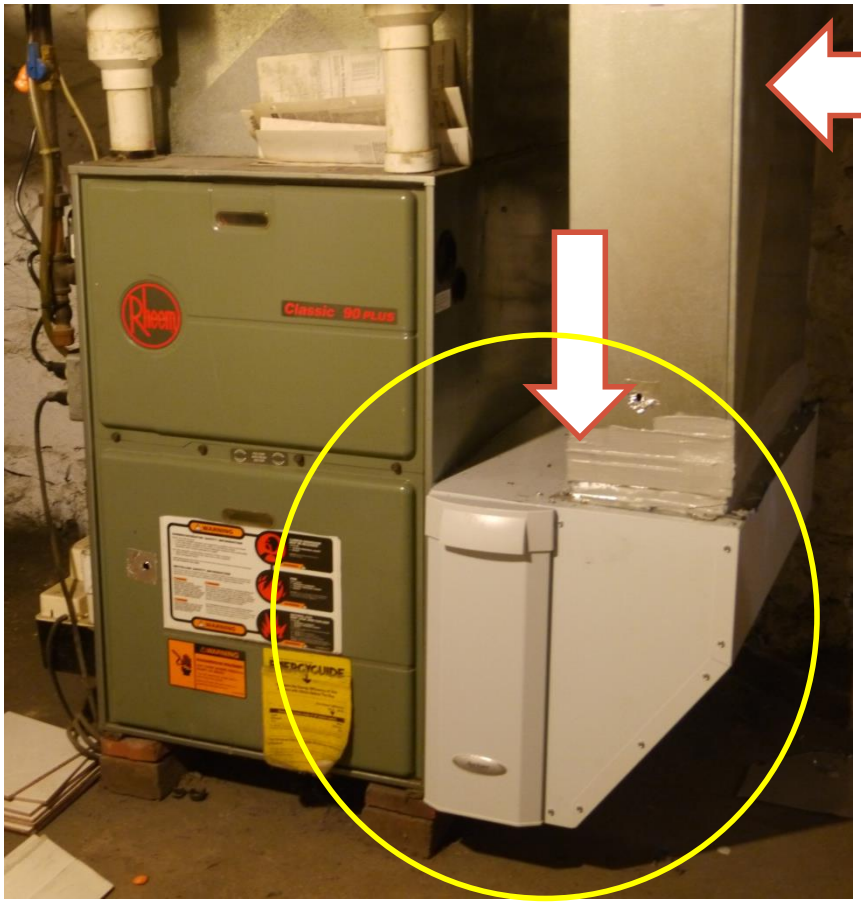
Big Issues with 24/7 High MERV Filter

- **Air handler (AHU) energy use** can be high due to 500 to 1,500 watt-draw
  - High cost of running air handler continuously (360 kWh to 1080 kWh/month = ~$500 to $1500/year[1])
- **Wrong blower speed**
  - Seldom set in field
  - Often defaults to high speed, not low, in continuous mode
  - Higher energy cost, less effective filtration
- **Ductwork issues** introduce additional problems
  - Static pressure (TESP) too high
  - Duct leaks (energy waste & pressure-related problems)

[1] **$0.12/kWh**

Case 1 Lessons Learned: An Early Change-out

In search of an easy fix…. Don't do this!!!



Not Effective!

1) Return drop restricted due to size (8" x 25")
2) Poor design at throat w hard 90 degree angle
3) Filter still only 16" x 25"
4) Static too high to install ECM
5) One option: significantly downsizing w new AC

6) Better option …

Case 2

Typical basement system

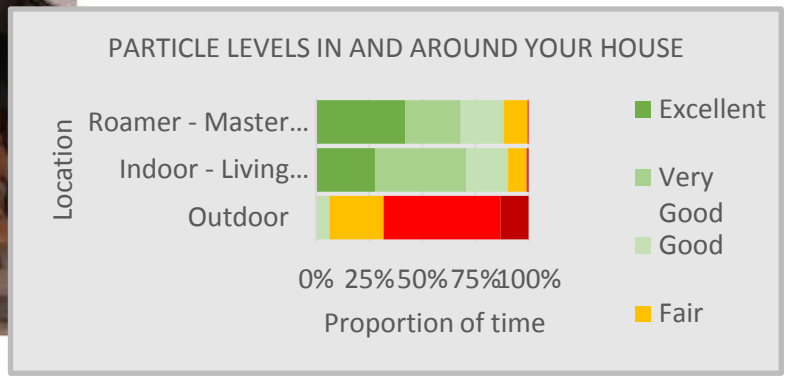
16x25x1 MERV 12

BEFORE

CASE STUDY: Indoor Air Quality Interventions
Chris Guignon, evolveEA

Case 2

20x25x4 MERV 13



AFTER

CASE STUDY: Indoor Air Quality Interventions
Chris Guignon, evolveEA

Air Handlers – PSC vs. ECM (below)

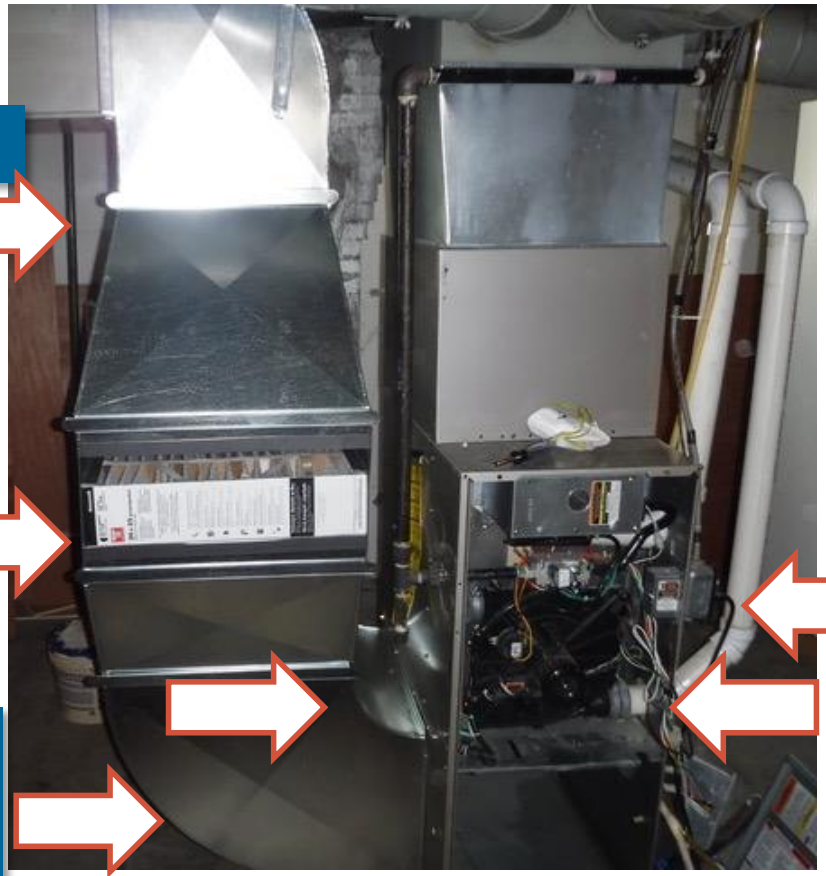
ECM change out replaces permanent split capacity motor for a drop in watts/kWh, & the ability to move less air in continuous or circulation mode (ECM 400 CFM @ 120 W or better)

Case 3: Air Handler Retrofit 2.0

Larger return drop

2-part filter rack (20” x 25”) Horizontal (4” MERV 13 + 2” pre or post filter)

90 degree transition designed for better air flow (heel & throat); lower static



ECM replacement

Fan speed adjusted to optimize heating, cooling, & continuous performance.

RESULTS:

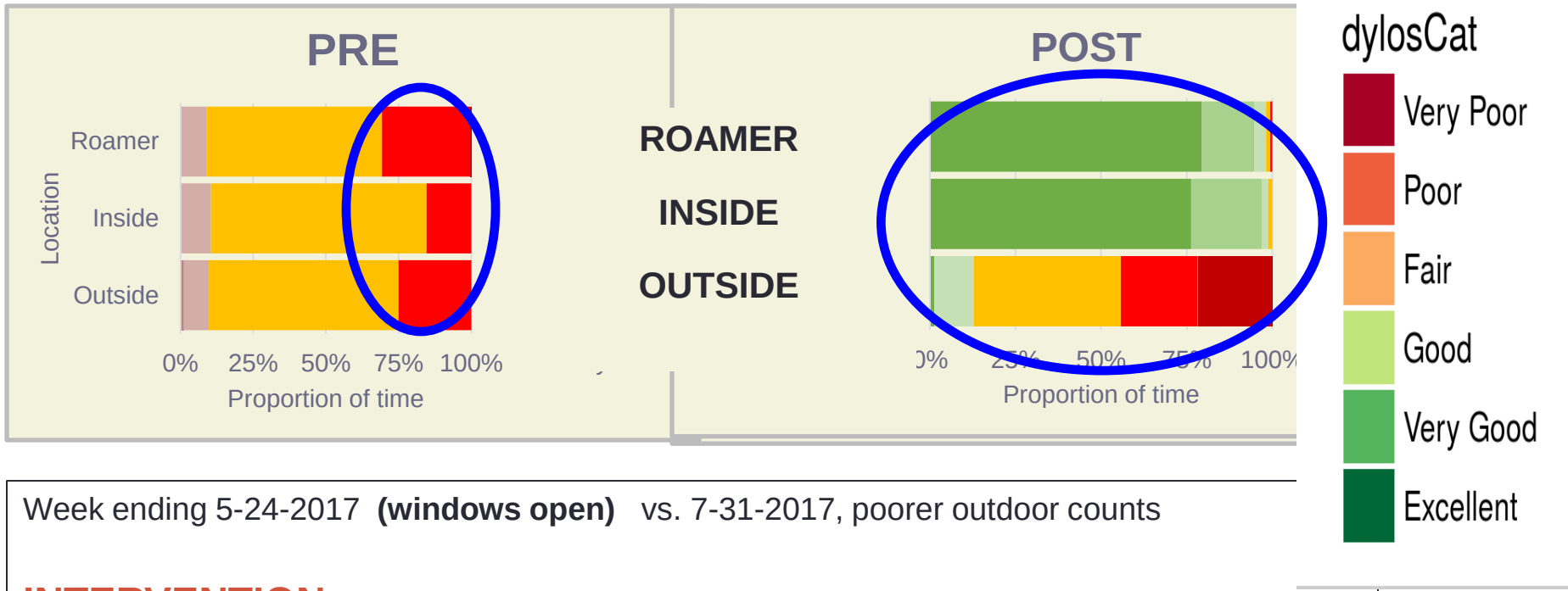
In continuous mode:

- 4.27 CFM/watt
- 120 Watts

- Pressure drop across filter Pre: 93 Pa, Post: 16 Pa
- **Allowable TESP: 125 Pa**
- **(total system)**

Case 3: Post-retrofit

Case 3 Pre & Post – Air Handler Retrofit



Week ending 5-24-2017 **(windows open)** vs. 7-31-2017, poorer outdoor counts

INTERVENTION:

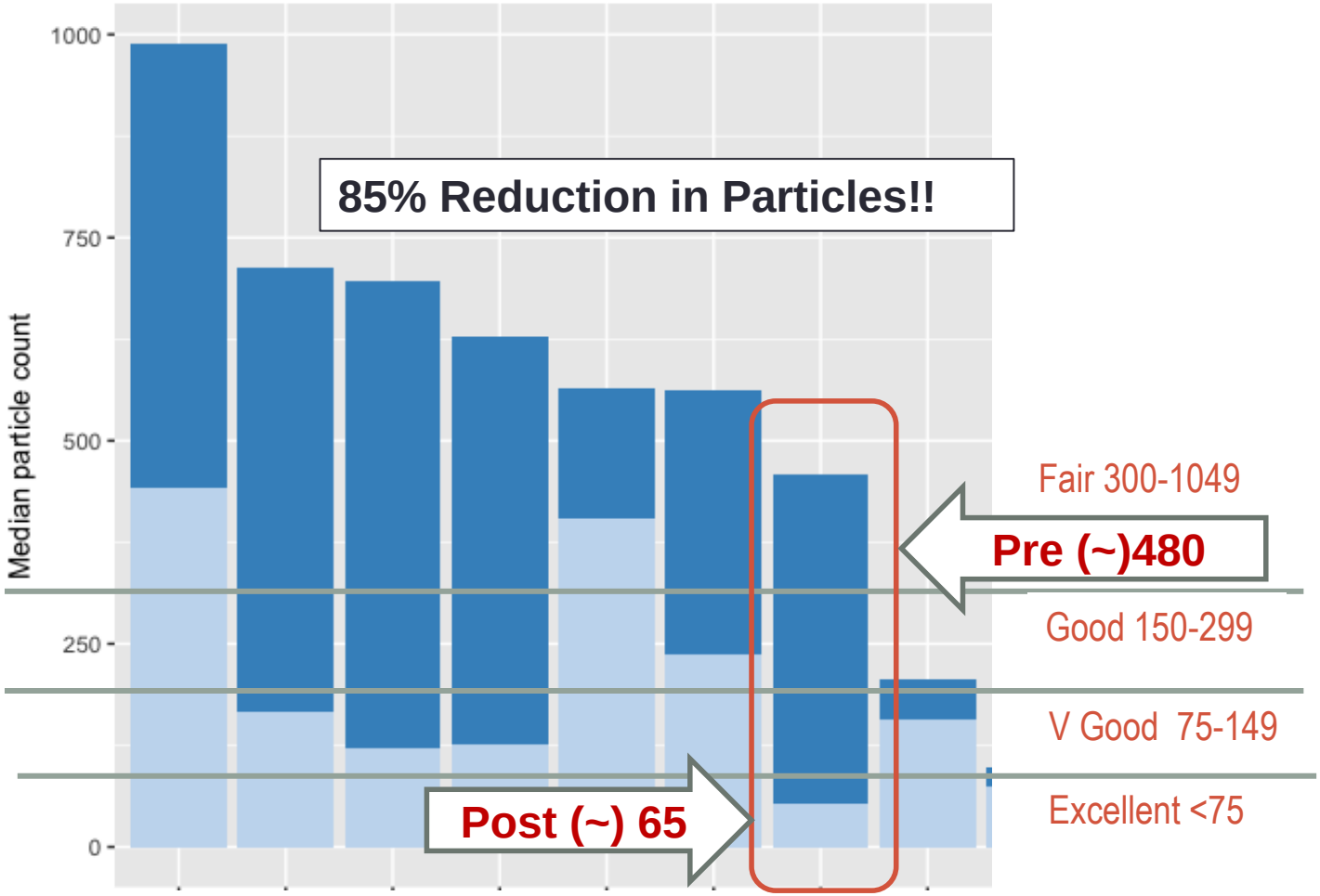
ECM blower (lower air flow & energy cost on continuous setting)

New return (larger 20" x 25" MERV 13 filter & pre-filter)

Cost – labor & materials: $1,000

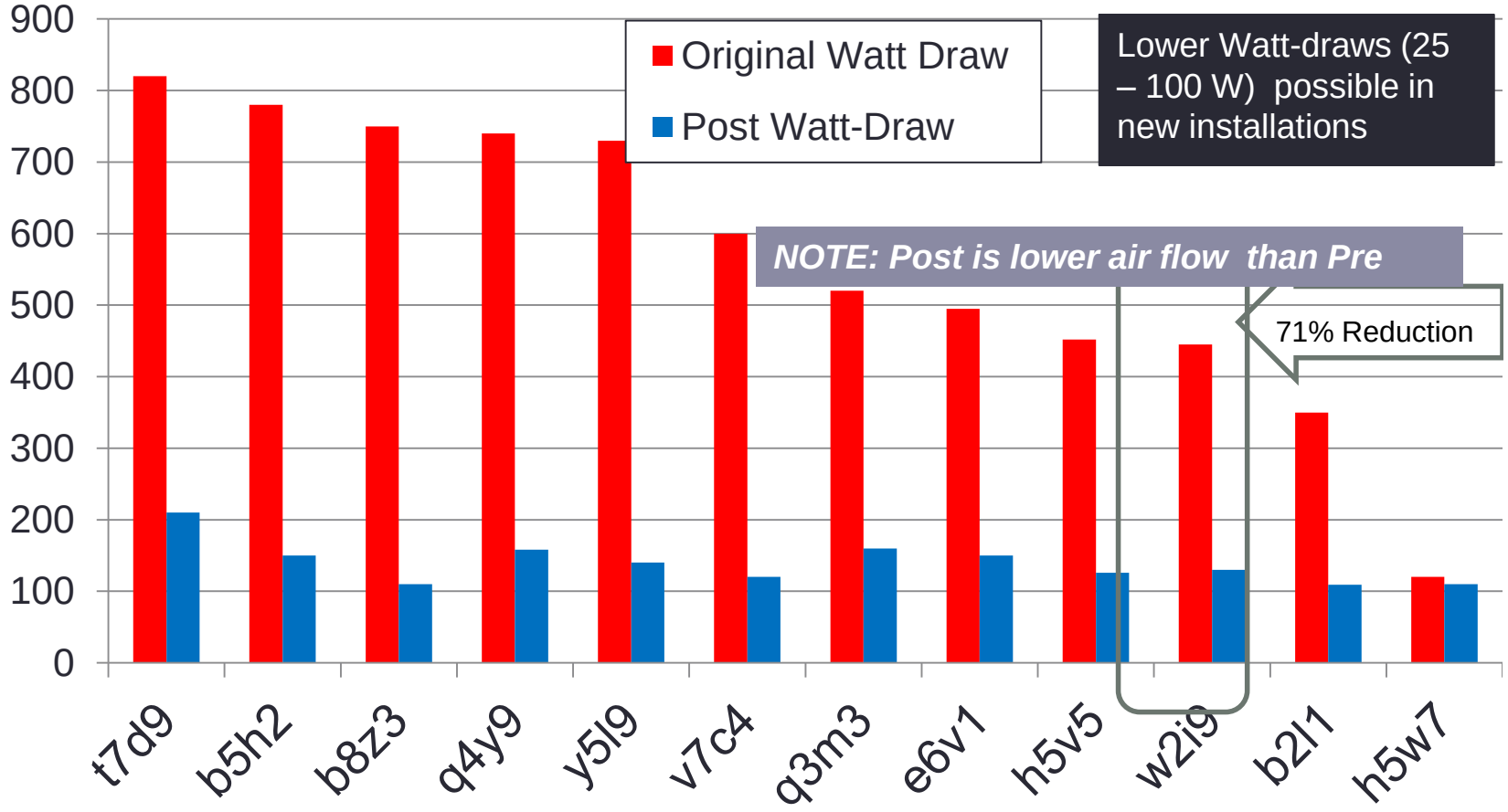
RESULTS: Lower CO_2 in bedroom **24/7 annual operating cost: $131.40**

Selected ROCIS Intervention Homes Pre-Post Median Particle Count



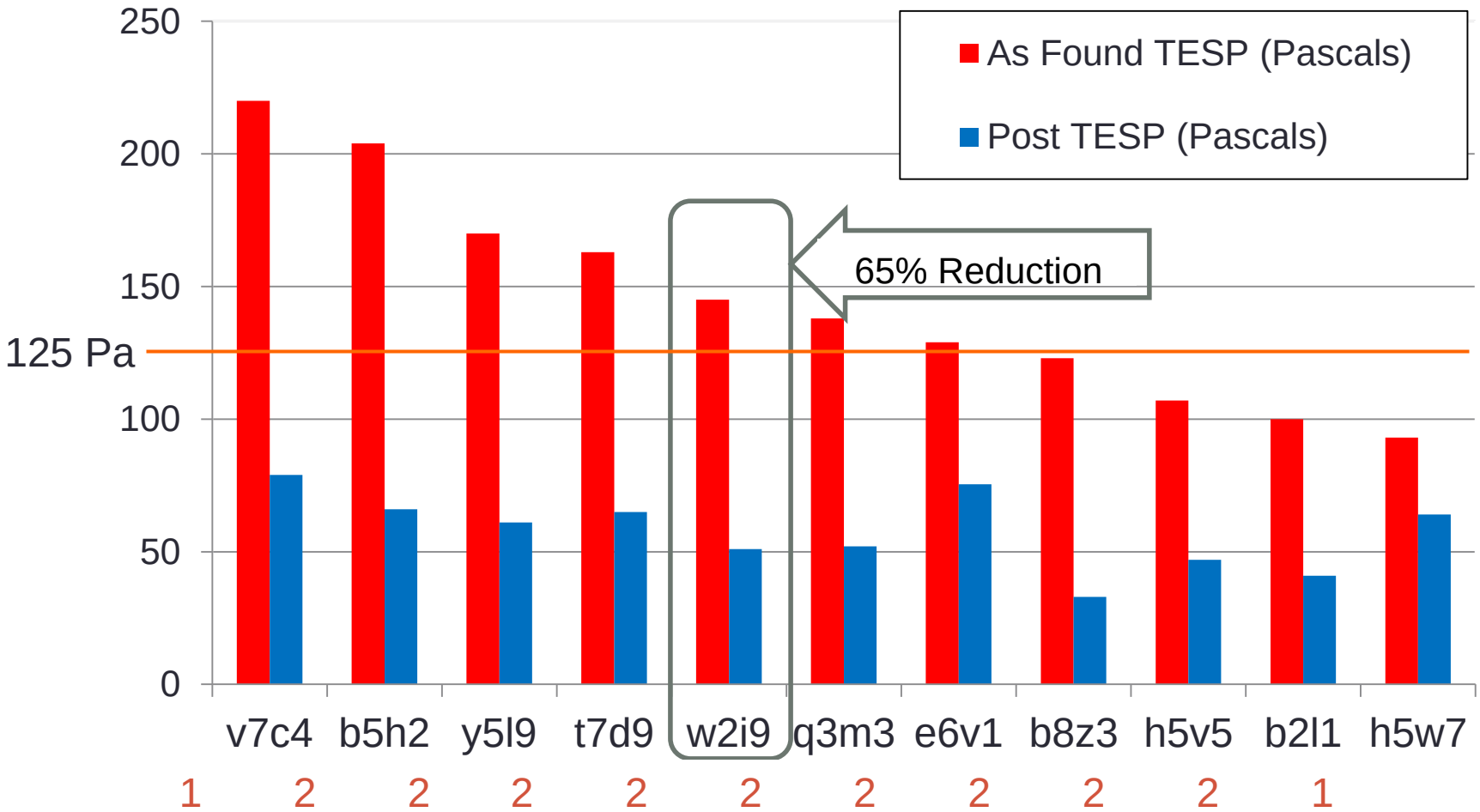
Use above code **(w2i9)** to view data on ROCIS LMCP Data Explorer
http://rocis.org/rocis-data-explorer

Air Handler Interventions Pre-Post Continuous Watt-Draw



Use these codes **(w2i9)** to view particle data on ROCIS LMCP Data Explorer
http://rocis.org/rocis-data-explorer

Air Handler Interventions Pre-Post TESP (Continuous Mode)



Reduction due to 1) adjusting speed of existing ECM (2 cases); 2) ECM change-out (9 cases). **PSC motors & ECMs are ½ HP w/ nameplate TESP limit of 125 Pascals.**

High Performance Filtration Essentials

- MERV (just like R-Value)
  performance depends on installation/operation
- Verify & address static pressure (TESP)!!!
- Provide adequate run/on time
- Minimize filter bypasses
- Verify/monitor filtration particle performance
  ideally @ 0.3 - 0.5 µm
- Use MERV 12 or above to reduce 0.3 to 0.5 µm particles
- Avoid 1” pleated high performance filters
  due to resistance & clogging

Filtration: Energy Use & Energy Cost

Air Handler or Portable Air Cleaner 24/7 operation

- Widely variable
- Air Handlers: <30 watts to 1,500 watts

Key metric for air handlers: at least 4 CFM/watt

Portable air cleaners –

Typical: 50 - 125 watts (lower possible)

Filtration Energy & Cost

50 Watt 24/7 = 438 kWh/year ($53/year[1])

100 Watt 24/7 = 876 kWh/year ($105/year[1])

500 Watt x 24 hours x 365 days x .001kW/W = 4,380 kWh/yr. @ $.12/kWh = $526 per year

Some of our ROCIS intervention projects are using air handler 24/7, plus several air cleaners –

... Easily 3,000+ kWh+/year

[1] 12 cents/kWh

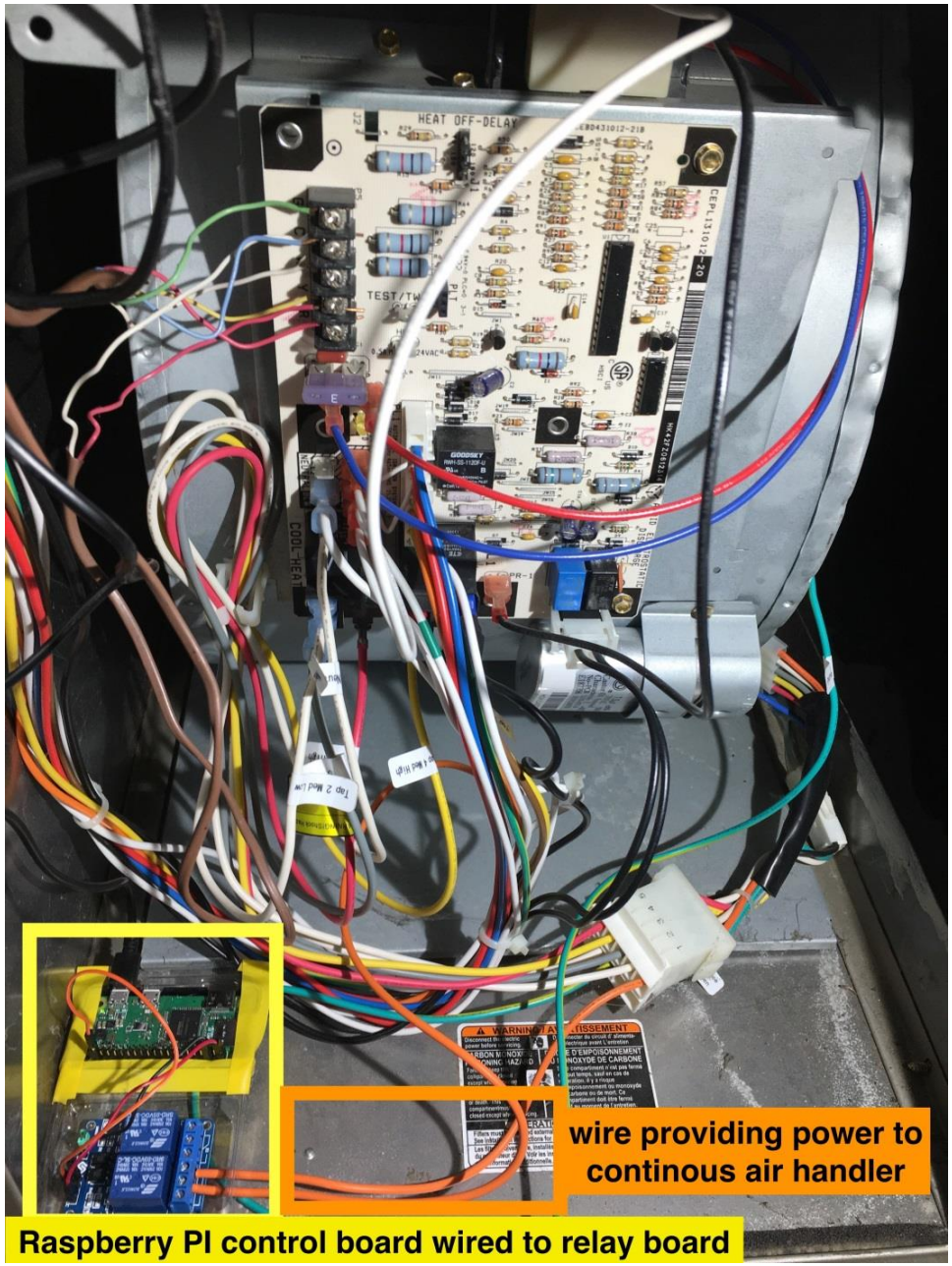
ROCIS Air Handler Retrofit 3.0

- Document inspection & retrofit results to date
- Increase % of sites where retrofit is a good option
- Lower the installation cost of retrofit
- Gain experience with different control options
- Engage key players in region (HVAC manufacturers, vocational trainers, trade groups, affordable housing providers, sustainability/environmental advocates, local gov't)
- Clarify opportunity to transform practices

particularly in new installations

Control Strategies

- Needed!! (alternative to 24/7 operation)
- Lots of activity/options
- What drives “on” time?
  - Clock or Occupancy
  - Sensor – what sensitivity? What is it sensing?
- Verify performance (particle count & size distribution, CO_2, humidity) & monitor over time



Low-cost Air Handler Control

Tied to PurpleAir monitor (inside location)

Can be adjusted to any “on-time” (particle level) desired

Previously set to 100% runtime (134 watts)

We will monitor impact of different set points & control strategies on particle levels by size (0.3, 0.5, 1.0, 2.5 µm)

New Installations - Lost Opportunity!!

- Two recent HVAC installations by ROCIS participants
- Motivated homeowners, asking the “right” questions

1) New system oversized
2) Significant leakage to outside (attic ducts)
3) Un- and underinsulated ducts (attic ducts)
4) Incorrect installation (major depressurization of basement – inefficiency, high radon)
5) Air flow not set correctly in field
6) Static pressure above name plate rating
7) 24/7 “filtration” operation not advisable (as found)

Big Opportunity at HVAC Replacement

- Downsize HVAC to reduce static pressure
- Incorporate return drop modification & option for larger, deeper filter
- Set blower speeds for optimal performance
- Address duct system shortcomings

- To ponder…
  - Could potential filtration health & comfort benefits add impetus to getting HVAC systems designed & installed correctly?

Intervention Summary

- These interventions can be effective; but household & HVAC **screening is essential**
- The **tighter** the house/building, the **greater** the **impact** of filtration…
- But, the tighter the building, the more critical it is to **control indoor sources**
- One option - shift focus from building exposure to **human exposure,** e.g., air quality in bedrooms **while people are sleeping**

Conclusions – Reducing Exposure

1) Air filtration can significantly reduce particle counts if the application is appropriate

2) Low cost monitors reinforce use of filtration as well as identification of particle sources

3) Whole building solutions are needed that integrate blg. tightness, ventilation, source control, behavior, O&M)

Ideally, improve outdoor air quality!

Thanks to Phil Johnson &

The Heinz Endowments for supporting the

ROCIS initiative

(Reducing Outdoor Contaminants in Indoor Spaces)

and

Our 200+ LCMP Participants!

Questions? Comments?

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MORE ON ROCIS AIR HANDLER INQUIRY

ROCIS Air Handler Inquiry

Purpose:

- Explore feasibility of using air handler w/ high MERV filer to reduce particle counts
- 1-minute resolution particle counts for 3+ weeks (0.5+ microns, 2.5+ microns)
- Gain experience w interventions & impact

http://rocis.org/air-handler-inquiry

ROCIS Air Handler Inquiry

- Purpose: explore feasibility of using air handler w/ high MERV filer to reduce particle counts
- Tested 40+ air handlers in SW PA
- Determine watt-draw, external static pressure, & air flow at different HVAC system settings
- 1-minute resolution particle counts for 3+ weeks (0.5+ microns, 2.5+ microns)

http://rocis.org/air-handler-inquiry
NOTE:HVAC systems were mostly in basements

Fans – HVAC Air Handlers

"Fan Auto" – most common

For better filtration increase in use of "Fan On"

Air handler fans on 24/7 (@300-700 W *or significantly more*)

500 W x 24/7 = $526 per year!!

Air Handler Inquiry: Key Findings

- Air handlers nearly always on factory settings (highest speed)
- Diagnostic visit adjustment usually reduced energy use with both PSC & ECM blowers
- In “as found” condition running air handler 24/7 not advisable
- With duct modifications & ECM change-out some systems can be optimized w/ larger/deeper 4” MERV13 filter & 24/7 runtime
- Noticeable reduction in particle counts & watt-draw

MERV 7 Filter New & Used (Better Performance – Used than New

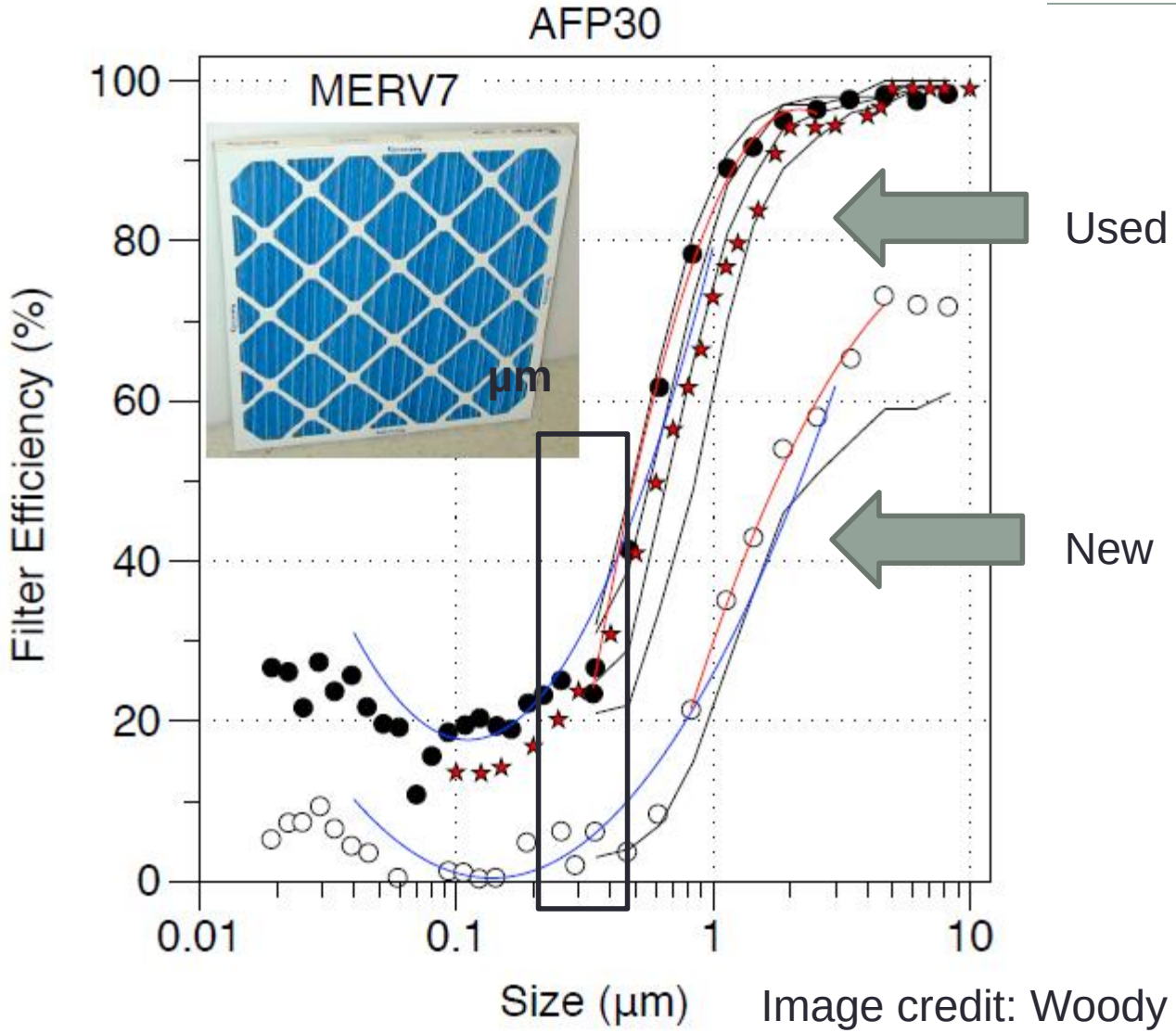


Image credit: Woody Delp

MERV 12 …in this case
Better Performance Used than New

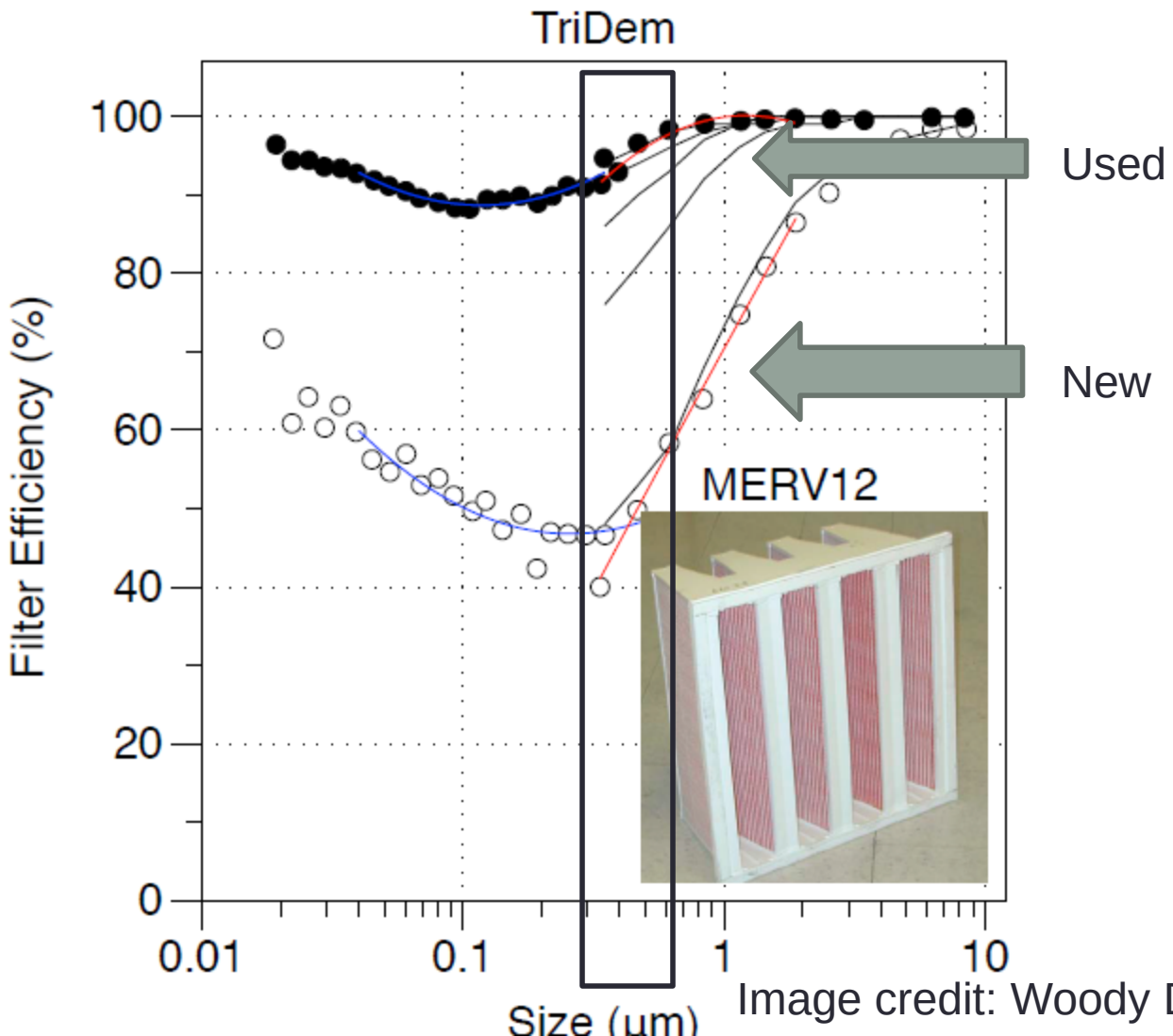
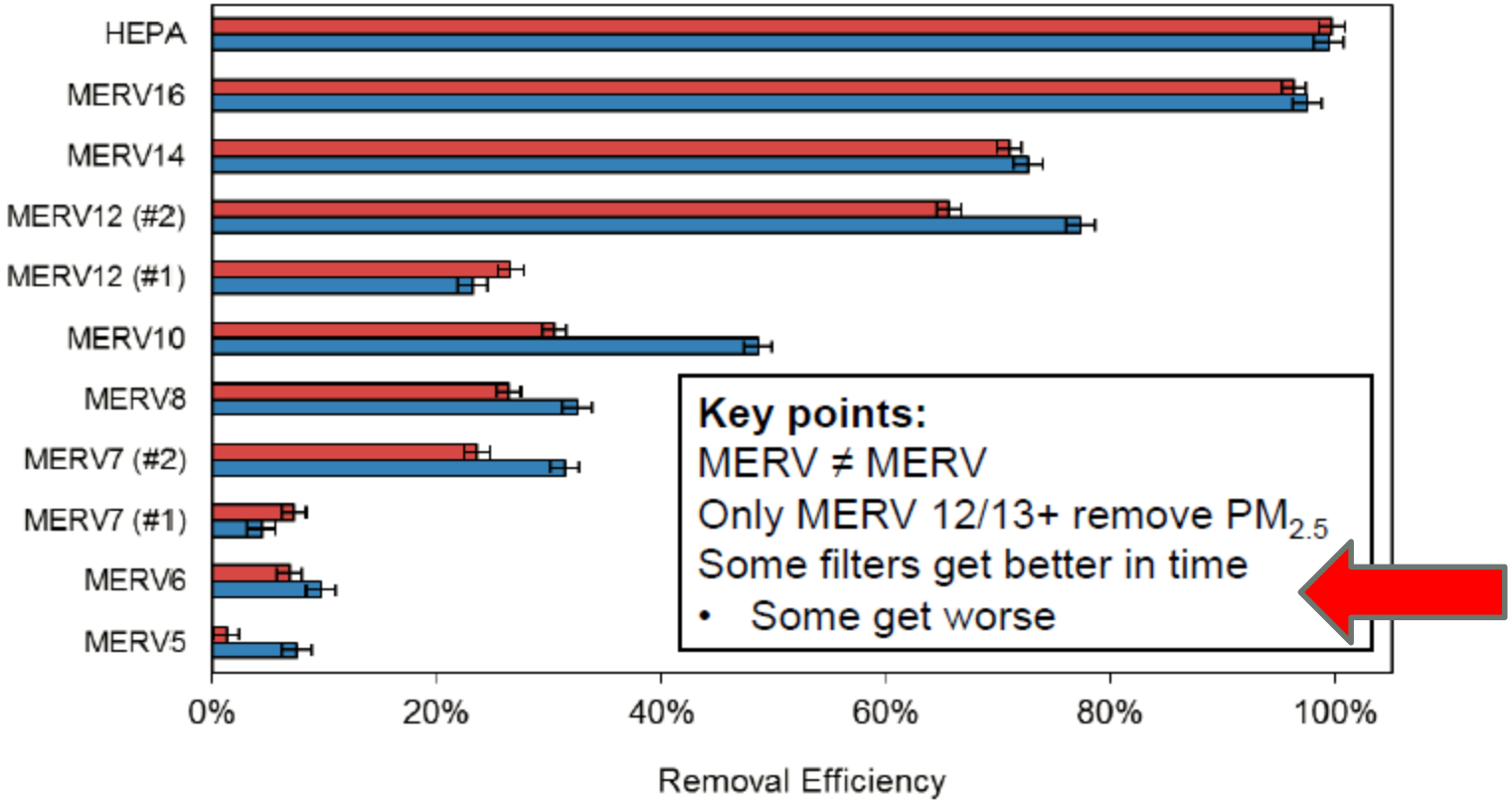


Image credit: Woody Delp

Fine and ultrafine particle removal efficiency

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



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

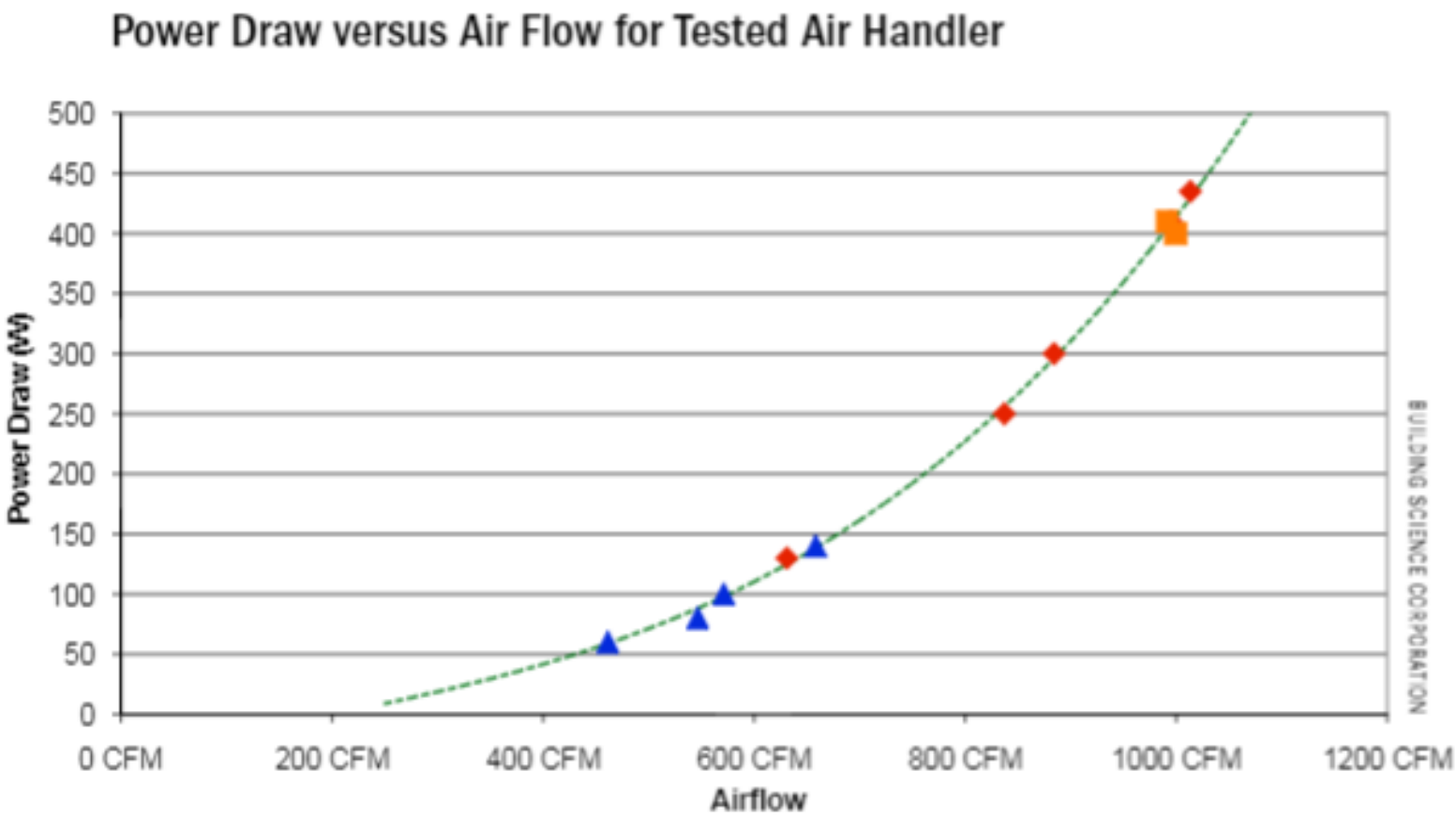
Slide credit Stephens – ASHRAE Chicago 2018

Filter bypass is relatively common in homes

Filter bypass reduces filtration effectiveness

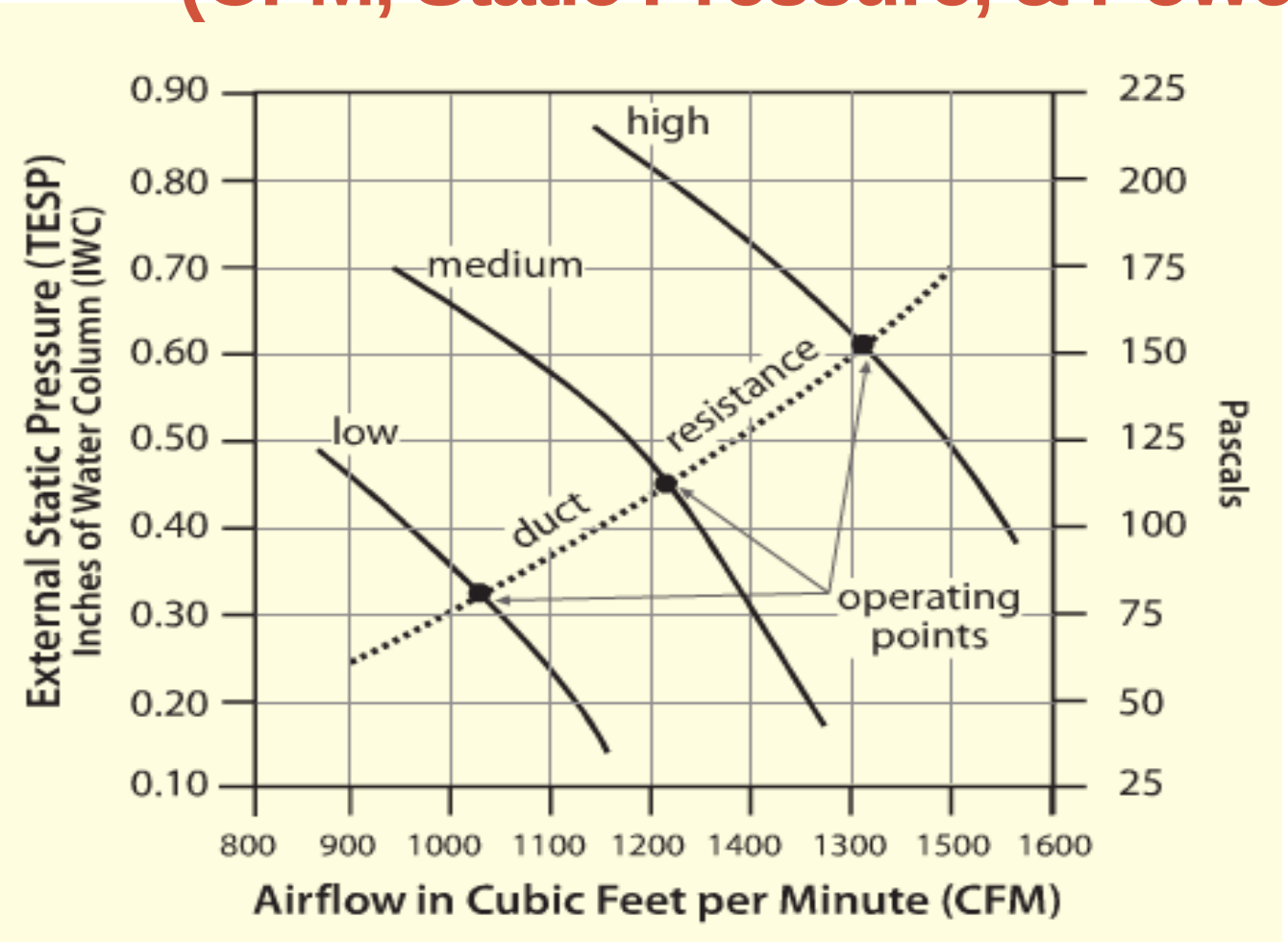
VerShaw et al. **2009** *ASHRAE Transactions*

Photo credit: Brent Stephens



Slide credit: Building Science Corporation

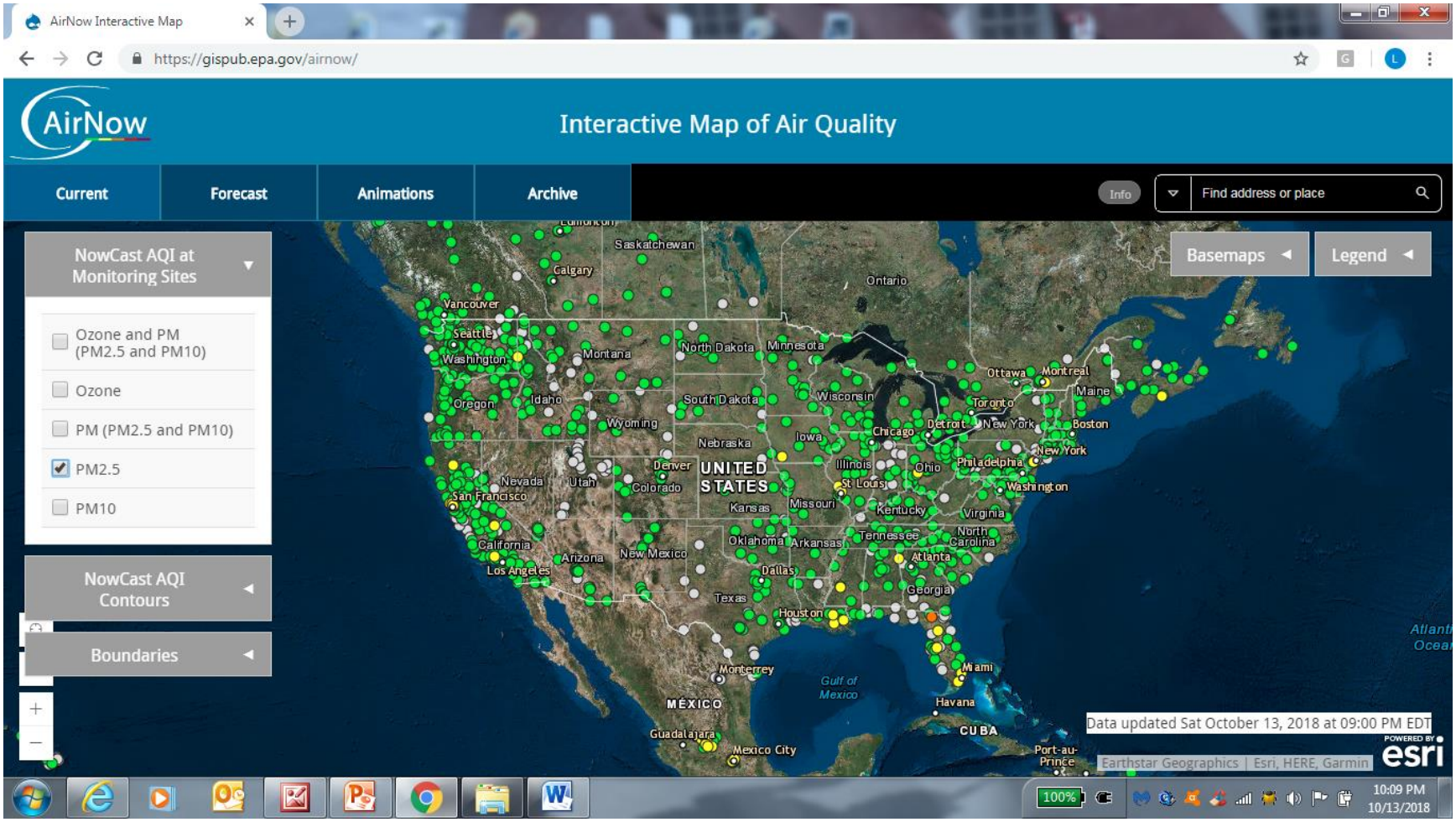
Fan Curves Address Performance (CFM, Static Pressure, & Power)



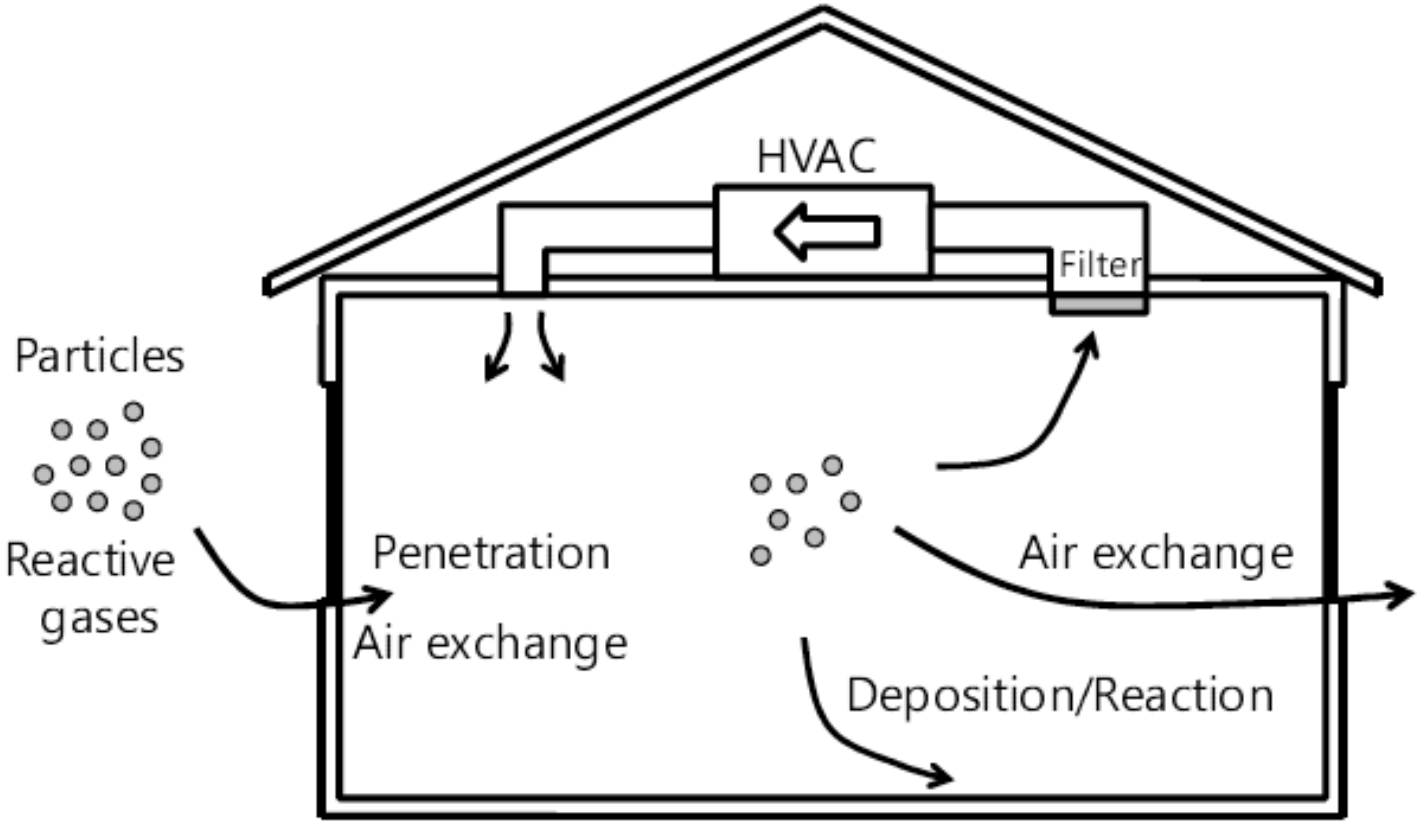
EXTRAS

Air Now

https://gispub.epa.gov/airnow/

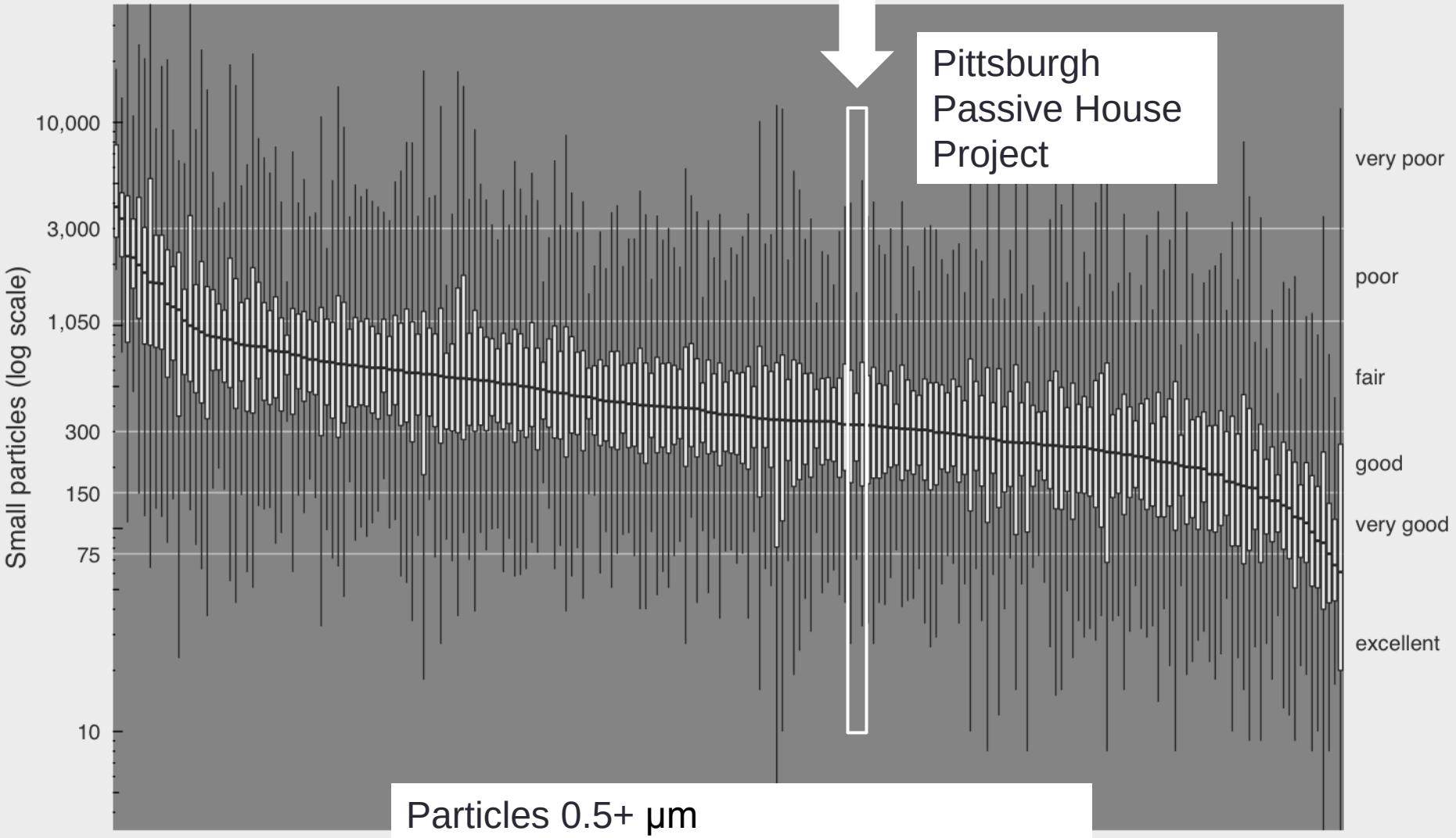


Infiltration of Outdoor Pollutants



"Infiltration of Outdoor Pollutants" – Home Energy Magazine, May/June 2015, Brent Stephens, Illinois Institute of Technology (*For PDF: Scroll down to "other publications"):* http://built-envi.com/pubs/

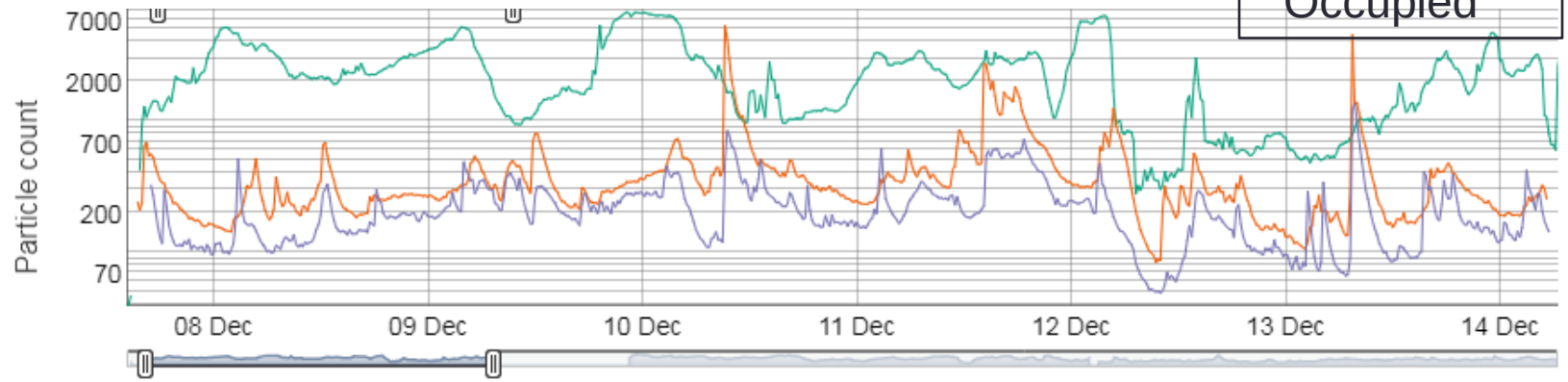
Indoor Particle Distribution – All Sites



Particles 0.5+ µm
Dylos Corporation scale on right

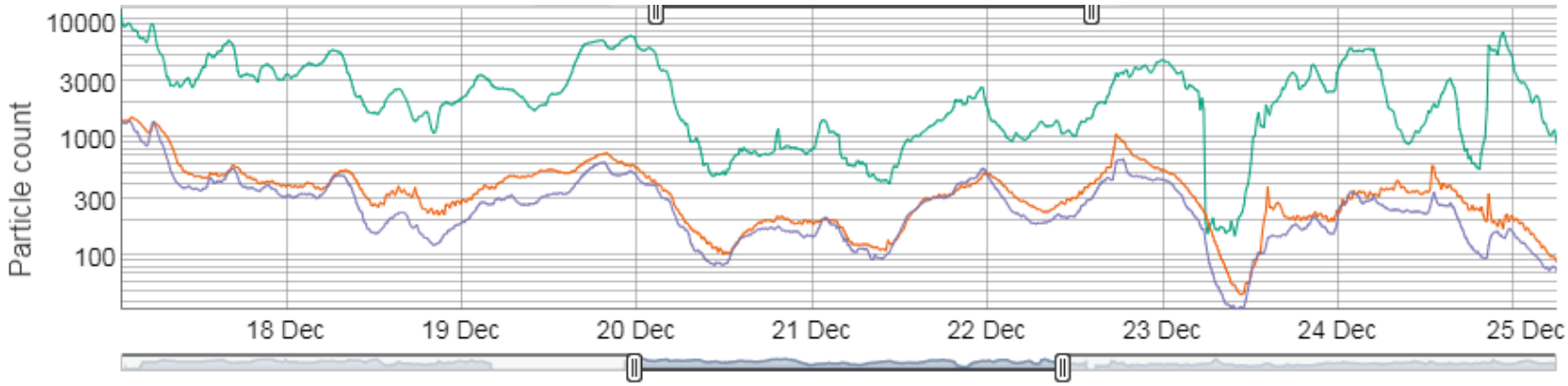
Pgh. Passive House Comparing Occupied Vs. Unoccupied Weeks (Dylos readings 0.5+ µm).

Occupied



Green line - Outdoor; Red line - Living Room; Blue line - Master Bedroom

Unoccupied



Top graph shows impact (spikes) of indoor occupant behavior.
Bottom graph shows that even in very tight home, indoor tracks outdoor. Explore better filtration for whole-house ventilation system..