

# BEYOND DILUTION – REDUCING EXPOSURE TO PARTICLE POLLUTION IN HIGH PERFORMANCE HOMES

Health and Wellness Track  
October 20, 2018, Pittsburgh, PA

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# Outline

- **Context: Particles**
  - **Monitoring Results**
  - **Reducing Exposure**
  - **Filtration Essentials**
- 
- **Implications for Passive House Projects throughout**

# SESSION DESCRIPTION

Even in high performance buildings, our greatest exposure to outdoor particle pollution occurs while we are indoors. Learn why particle pollution is a health concern. Find out what has been learned from low cost particle monitoring of over 200 sites in southwest PA through the [ROCIS](#) Low Cost Monitoring Project. Building operation, occupant behavior, and technical interventions can have a significant impact on indoor particle pollution. We will review strategies to reduce intrusion of these outdoor pollutants into homes: what determines an appropriate application?; how reliable are the strategies?; and what are the implications on energy use? How did the higher performance sites differ from typical housing stock? What insights can be applied for better IAQ in new and retrofitted high performance housing? Learn how the control of outdoor sources is different from and similar to improving air quality when the sources are generated indoors.

# SESSION OBJECTIVES

**By attending this session, participants will be able to:**

- **Identify two online resources to track outdoor air quality**
- **Recognize the range of impact of ambient pollution on indoor air quality**
- **List four strategies to reduce indoor exposure to particles**
- **Describe three ways that very tight buildings differ from standard buildings in their exposure and/or the mitigation of particle pollution**

# CONTEXT

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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](http://WWW.ROCIS.ORG)



# WHAT IS ROCIS ?

**MISSION**



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





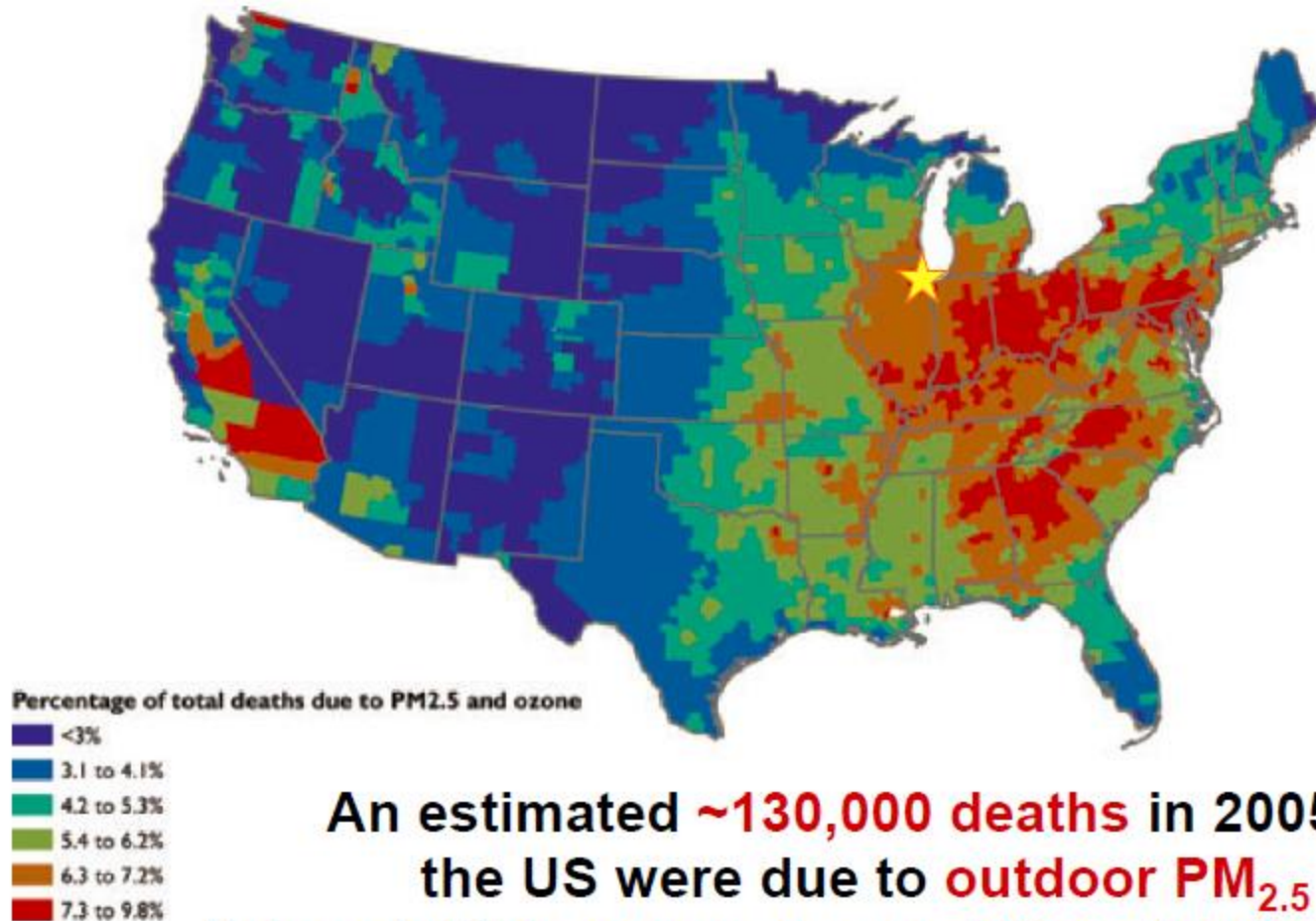
# Why??

Most of our exposure  
*to outdoor pollution*  
happens  
in buildings

# Focus on Particles

Also referred to as Particulate Matter (PM)

# Outdoor particulate matter and human health



An estimated **~130,000 deaths** in 2005 in the US were due to **outdoor PM<sub>2.5</sub>**  
But most of this exposure occurs indoors (**mostly at home**)

# Making the Invisible Visible

## Dylos 1700 Optical Particle Counter:

# Particles per 1/100 ft<sup>3</sup>, 1 min. resolution

### 2 size ranges:

> **0.5+  $\mu\text{m}$  (Dylos "Total")**

> **2.5+  $\mu\text{m}$  (Dylos "Large")**

**Cost:** \$300 - 400; 1 week data storage

### 3 Dylos / Site

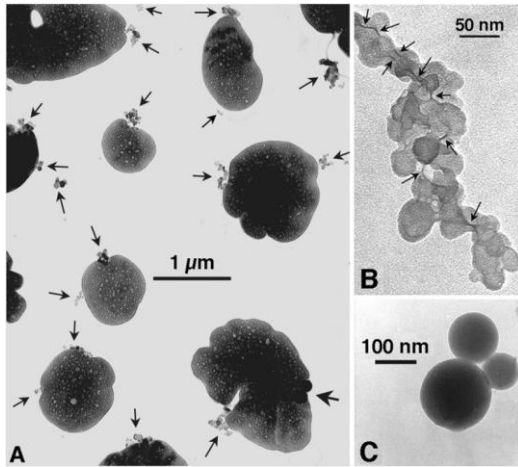
- Outside, Inside (living area) Roamer (usually bedroom)

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

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



Air Quality Chart .5 $\mu\text{m}$ – Small Count Reading	
3000 +	= VERY POOR
1050-3000	= POOR
300-1050	= FAIR
150-300	= GOOD
75-150	= VERY GOOD
0-75	= EXCELLENT



**OUTDOOR BLACK CARBON**  
**50 nm to 1 μm**

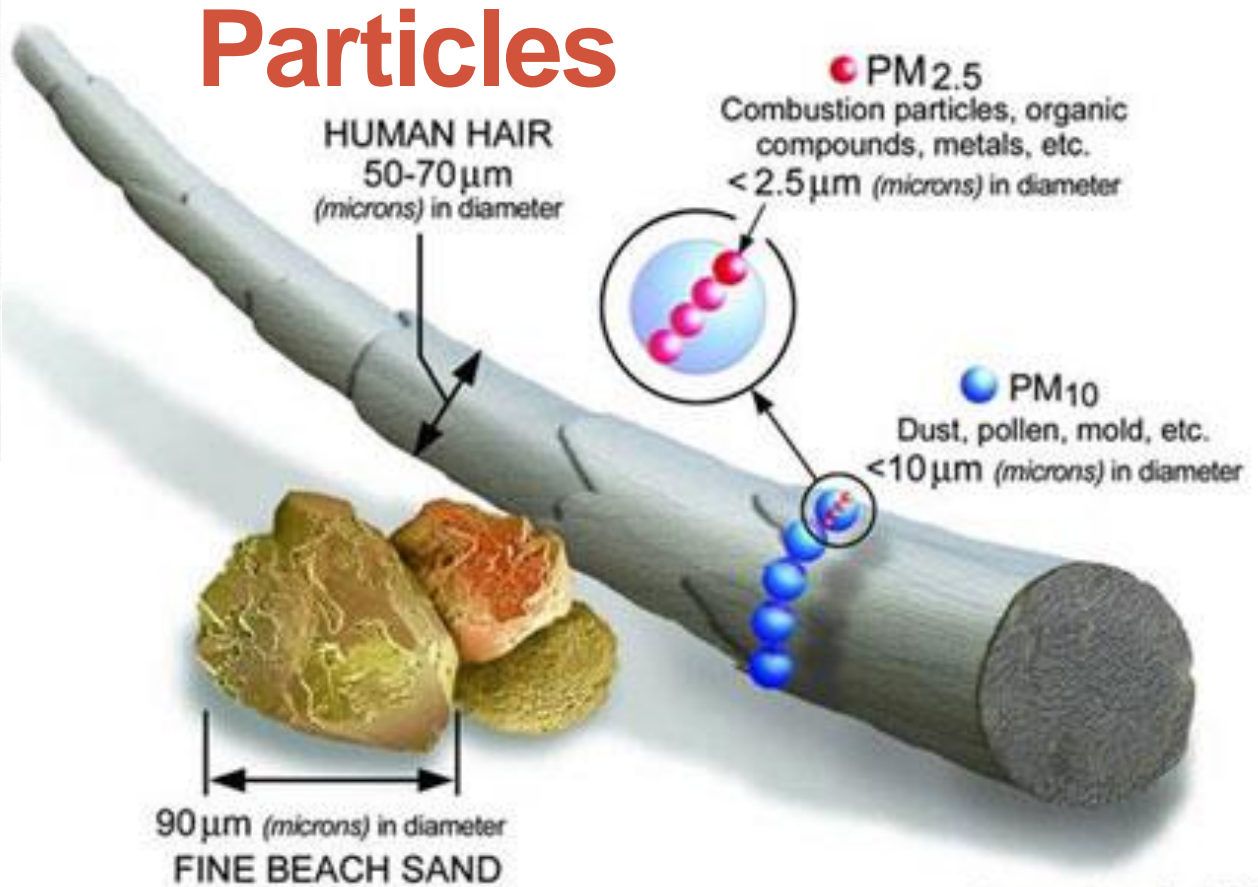


Image courtesy of the U.S. EPA

PM<sub>10</sub>: Particulate matter less than 10 μm in diameter

PM<sub>2.5</sub>: Particulate matter less than 2.5 μm in diameter

→ ROCIS LCMP Dylos: PM<sub>0.5+</sub>: Particulate matter is **greater than** 0.5 μm in diameter (1/100 of human hair!)

# Health Concerns (<PM10)

- 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

# 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<sup>1</sup> & worst city east of the Rockies)
- Allegheny County (Pittsburgh) is 13<sup>th</sup> worst

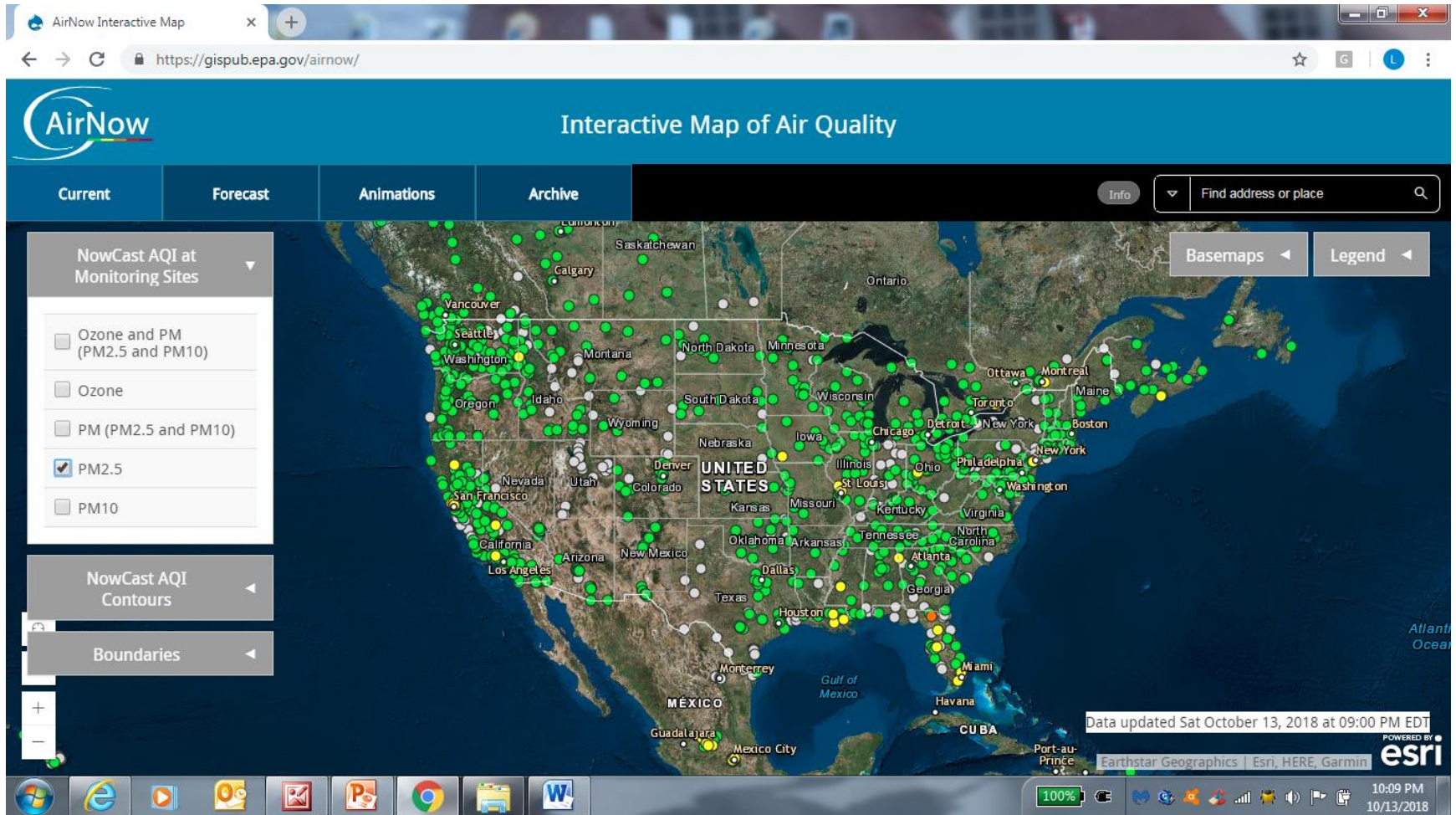
1. Pittsburgh-New Castle-Weirton (PA-WV-OH)

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>

# Air Now

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



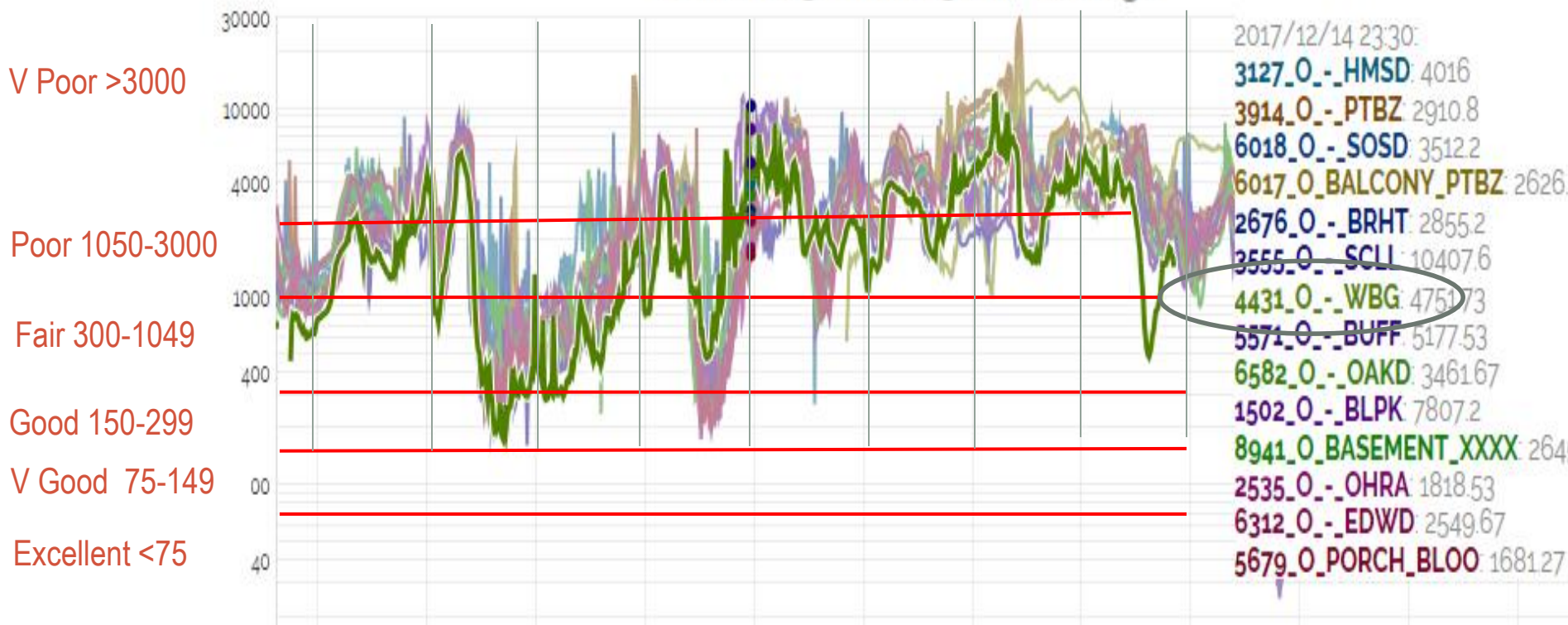
# Outdoor Data by Cohort - (70 mile spread) - Readings track

**Log scale**

ROCIS Low Cost Monitoring Project

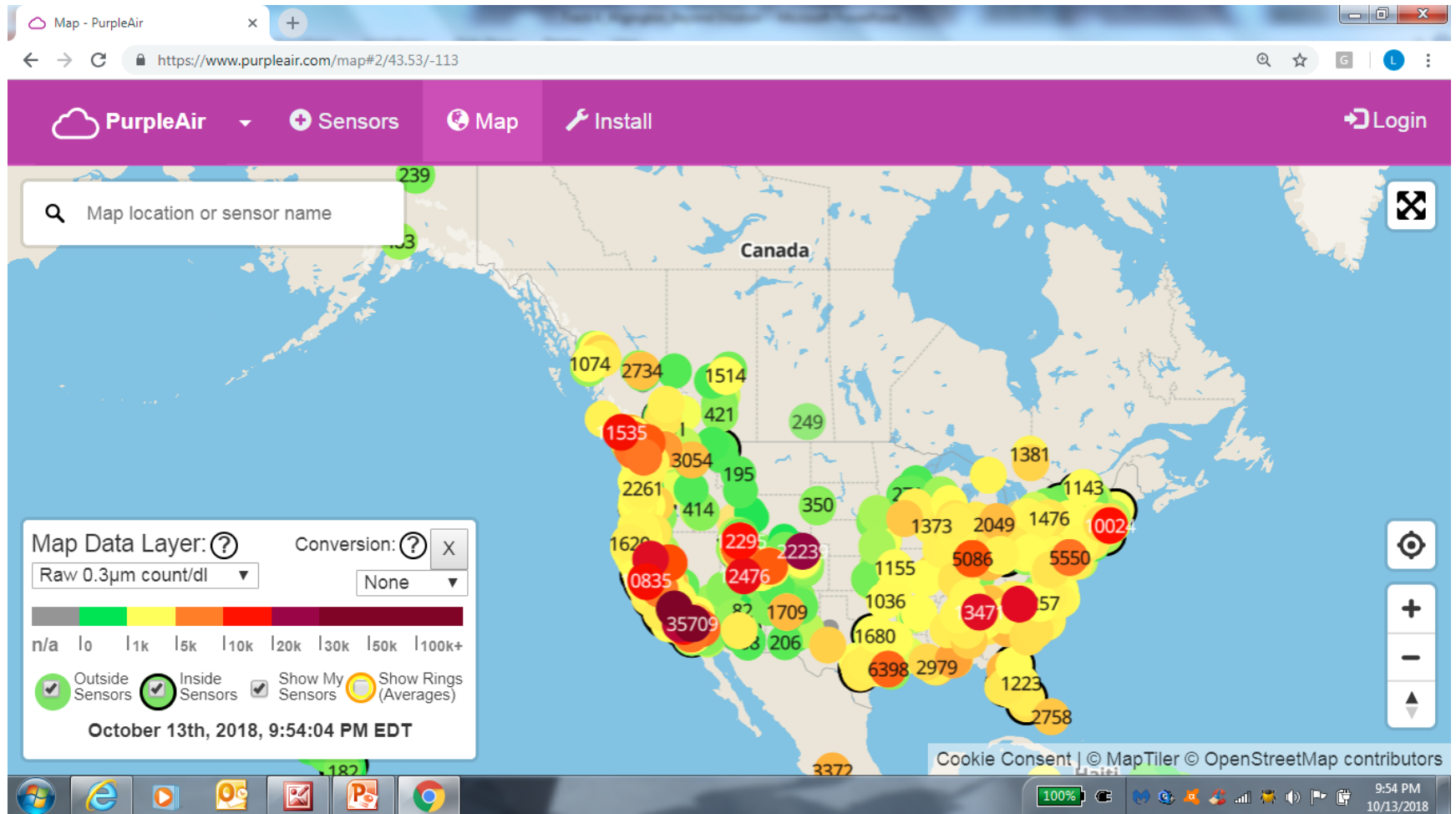


Cohort 25 Small 15 Min Average

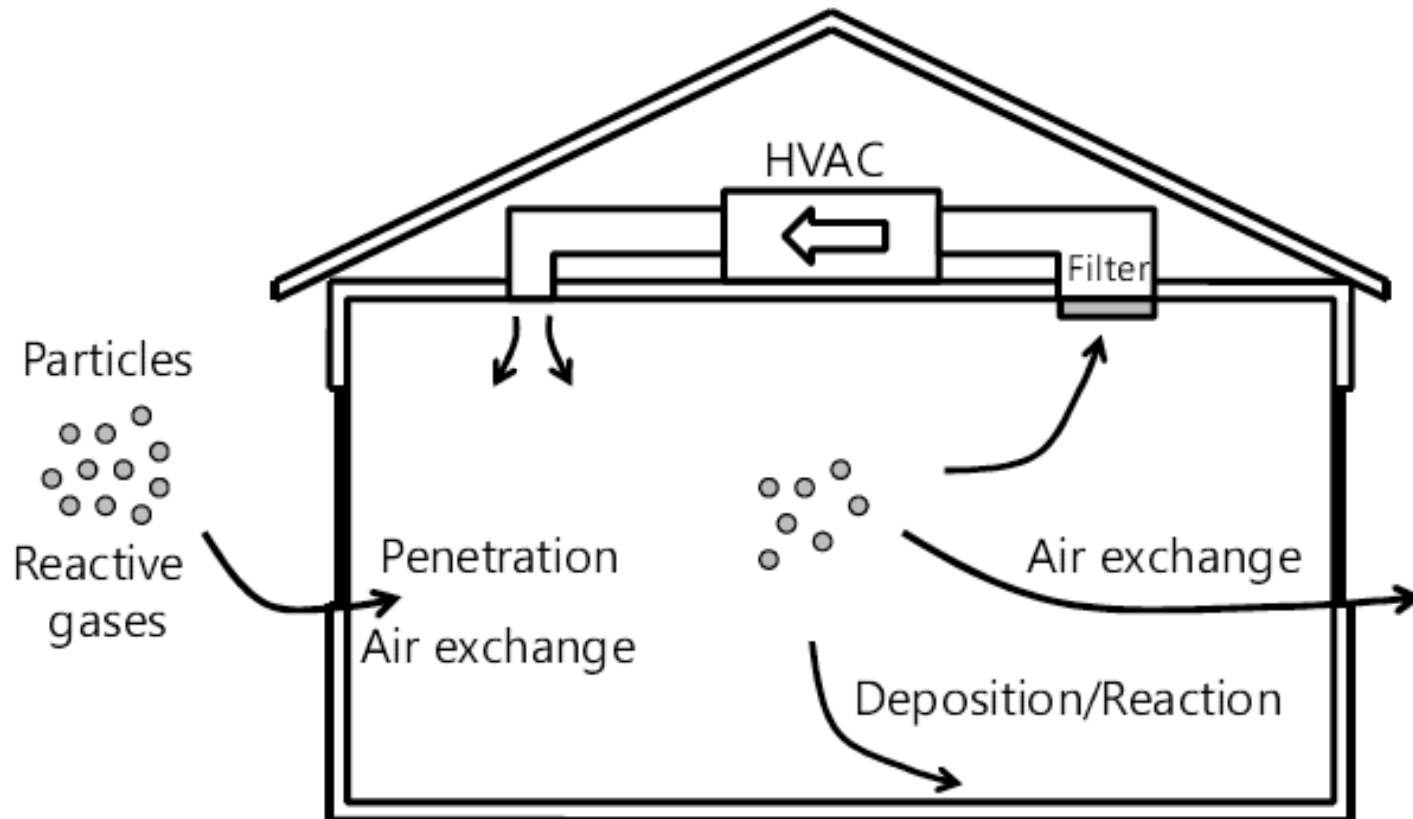


Most sites are Pittsburgh; Green line (Wbg) is 50 miles south  
Dylos particles (0.5+  $\mu\text{m}$ )

# PurpleAir Monitor Map World Wide or Local



# Infiltration of Outdoor Pollutants

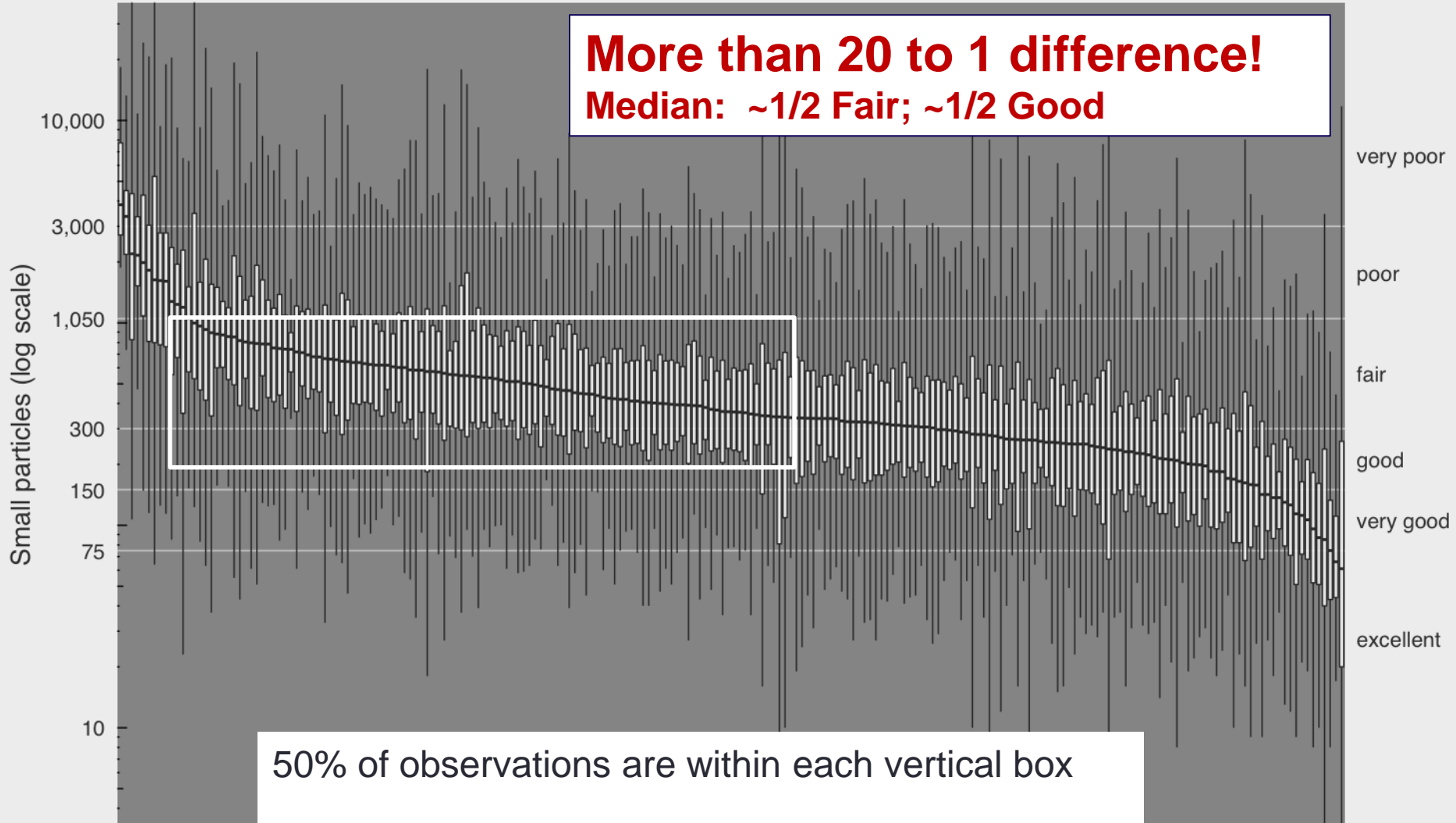


# LCMP PARTICLE DISTRIBUTION DATA

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# Indoor Particle Distribution – All Sites

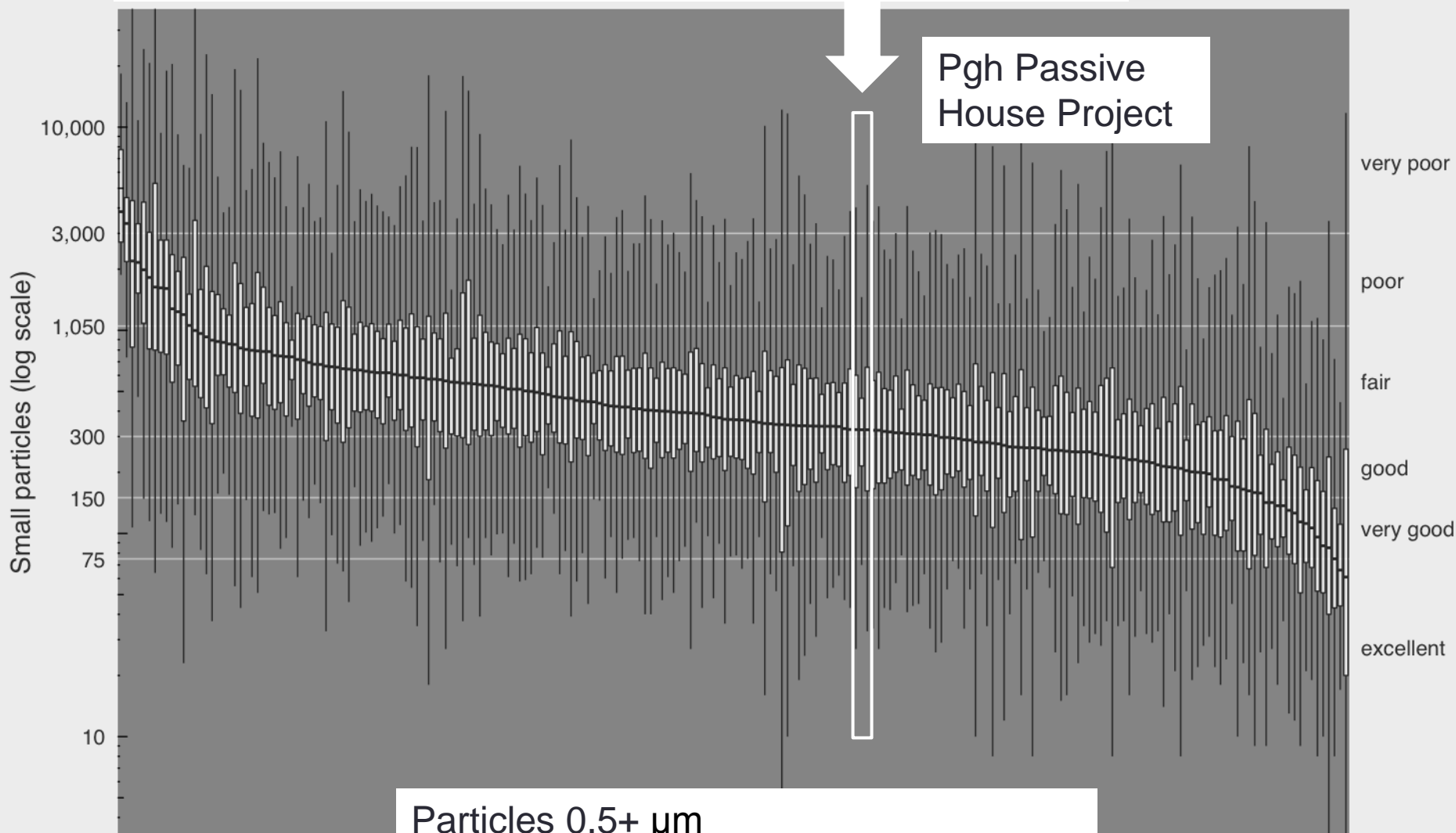
**More than 20 to 1 difference!**  
**Median: ~1/2 Fair; ~1/2 Good**



50% of observations are within each vertical box

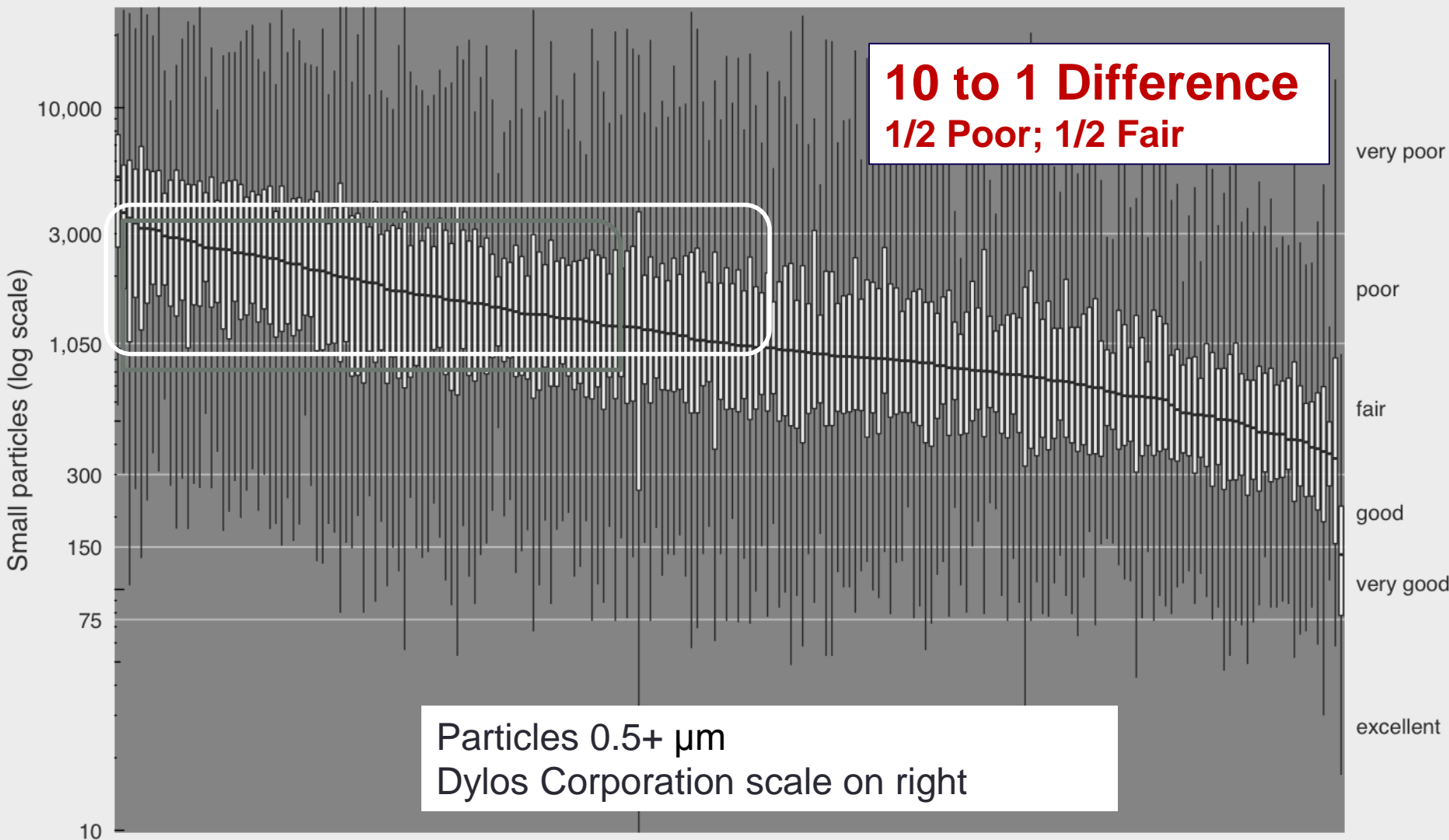
Particles 0.5+  $\mu\text{m}$   
 Dylos Corporation scale (on right)

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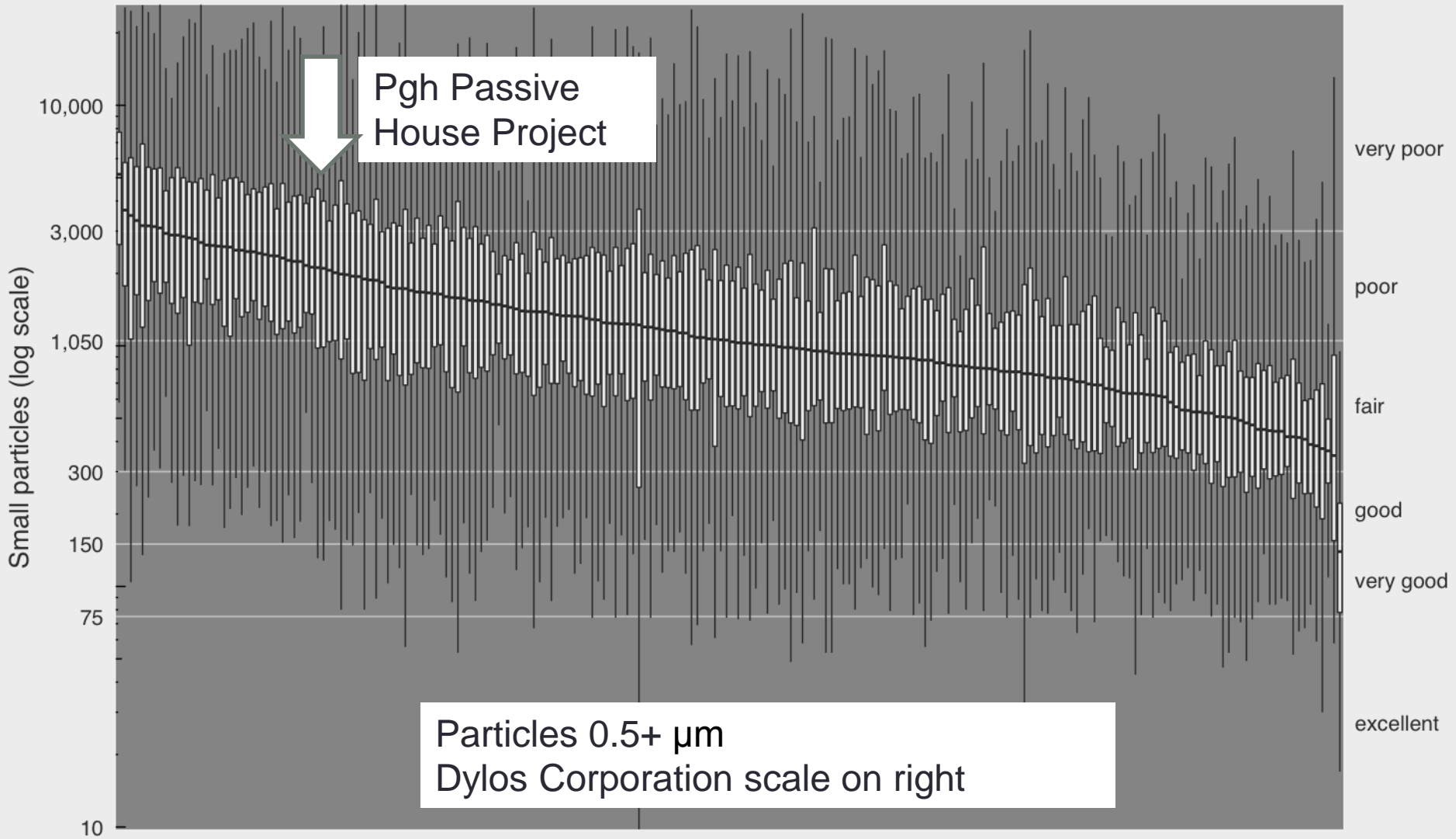


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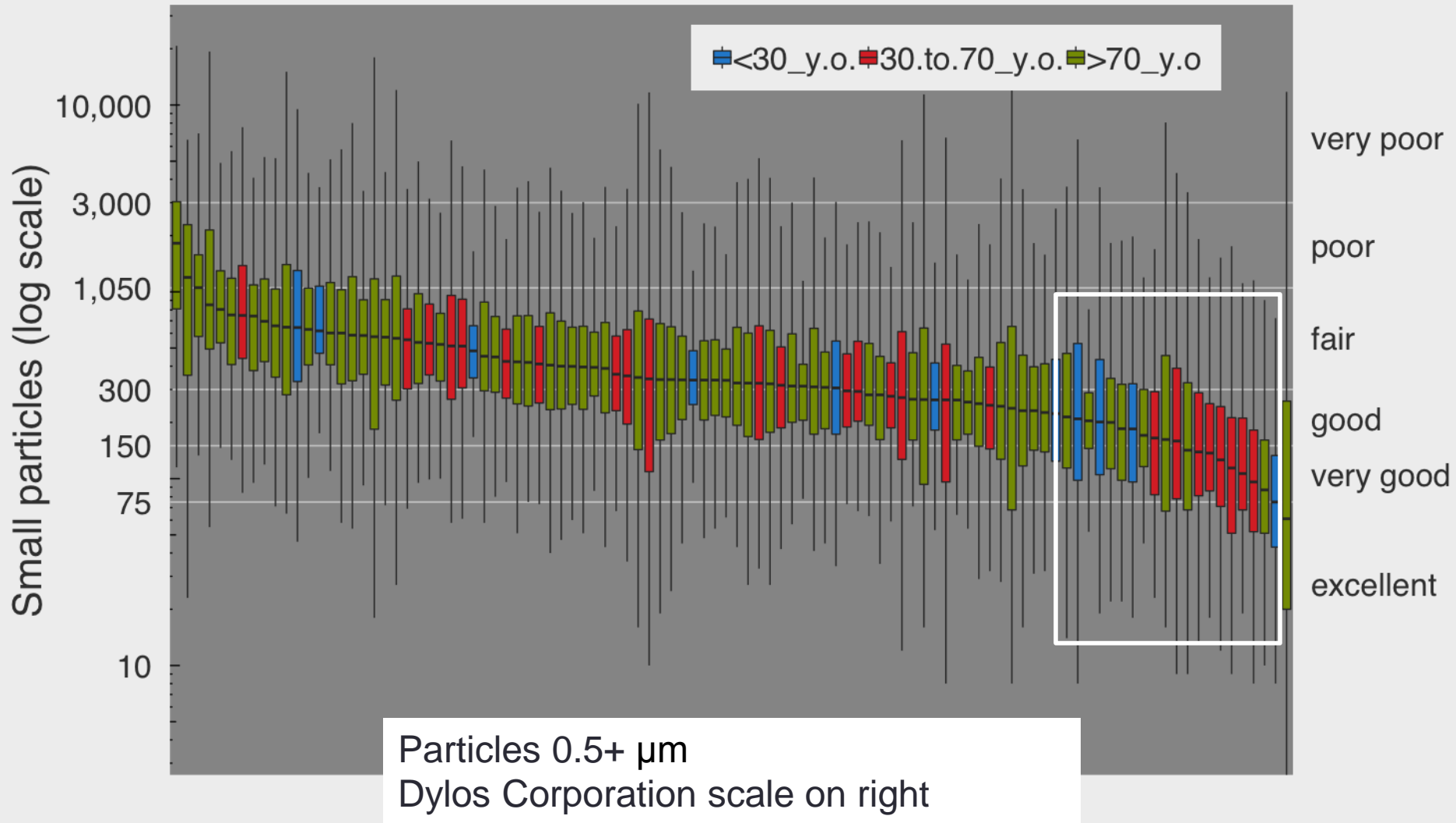


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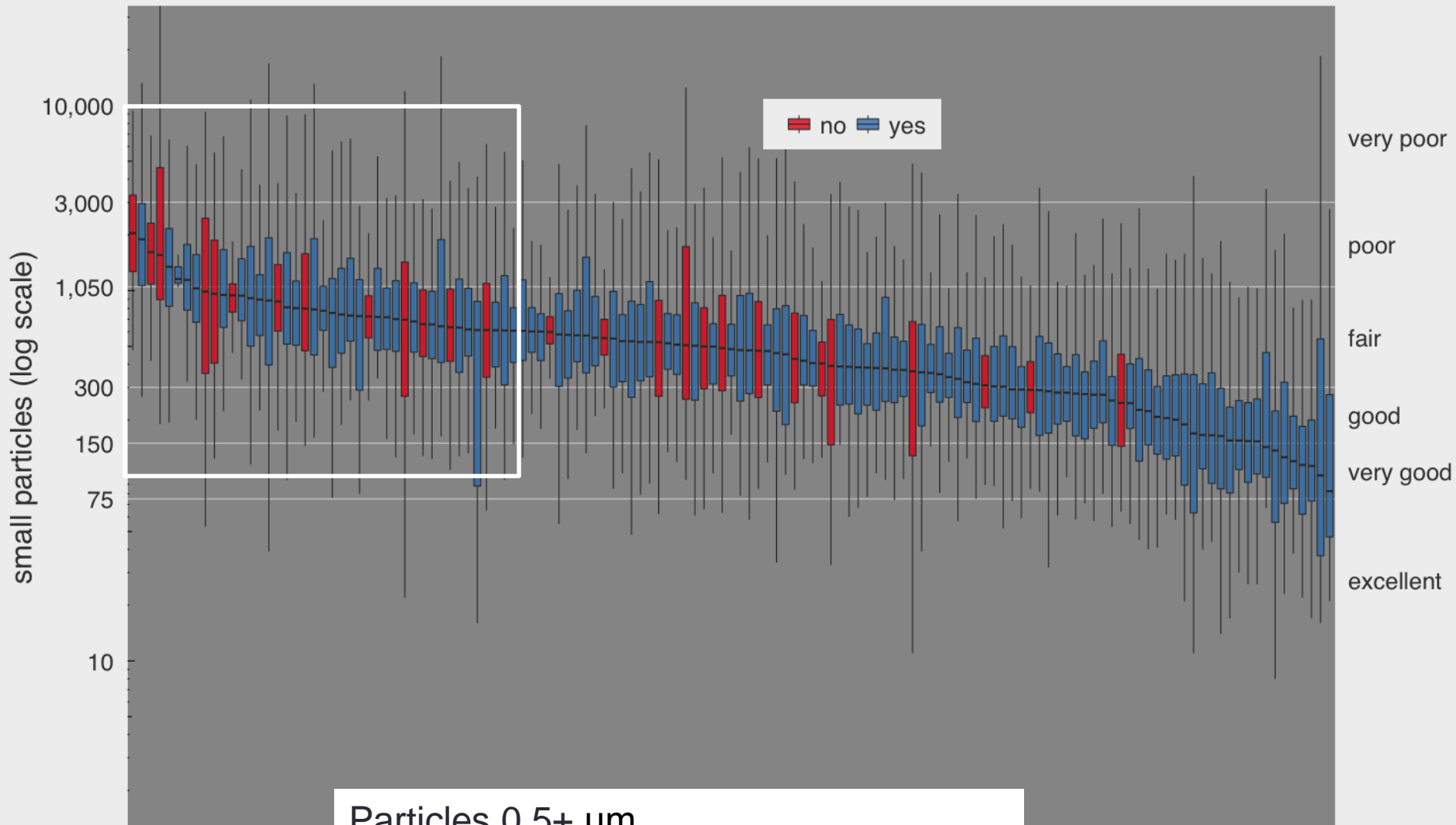
# Particle Comparison by Age of Homes

All season



# Is your home DETACHED? (first weeks)

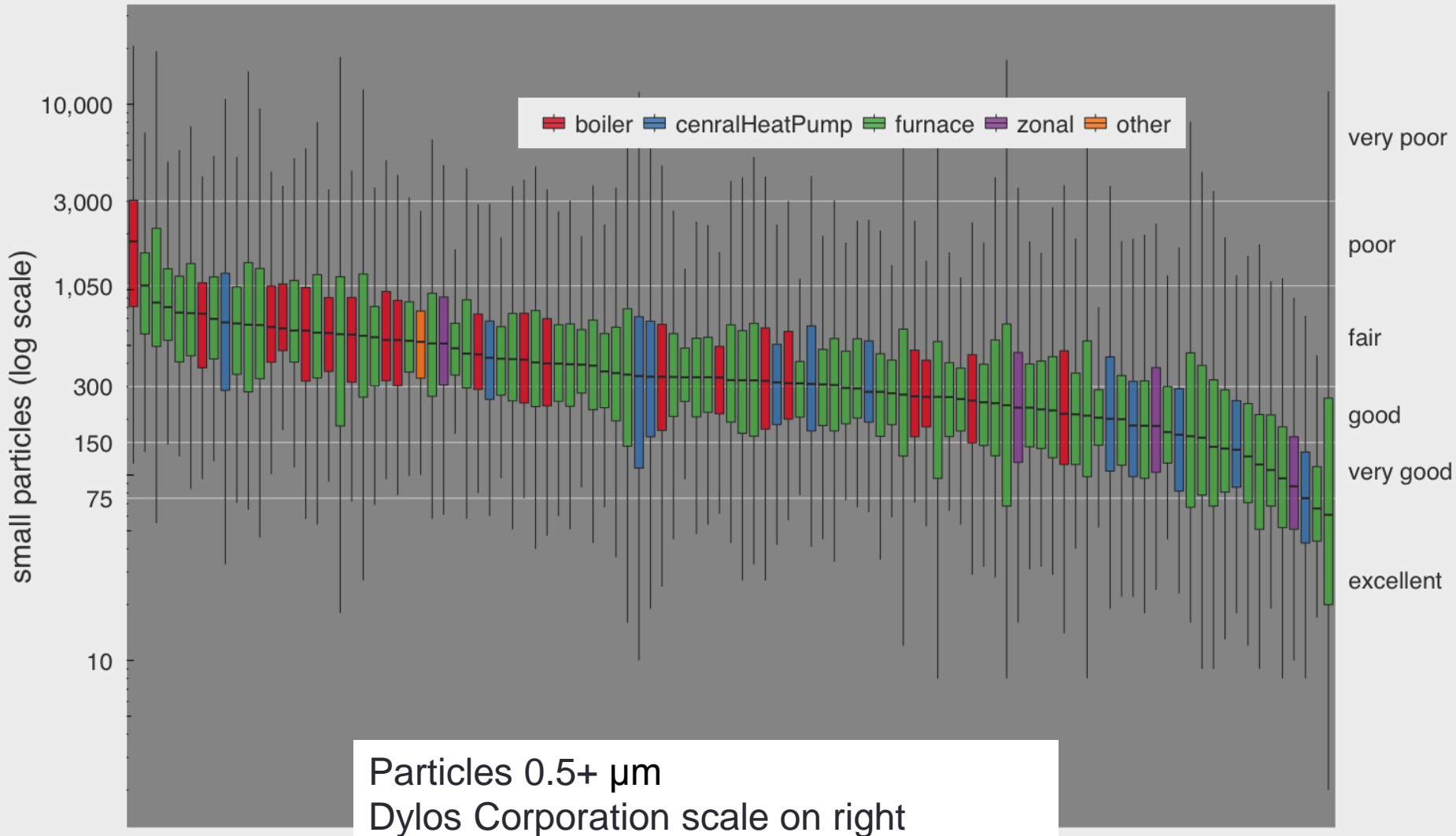
Particle Levels: Indoor location



Particles 0.5+  $\mu\text{m}$   
Dylos Corporation scale on right

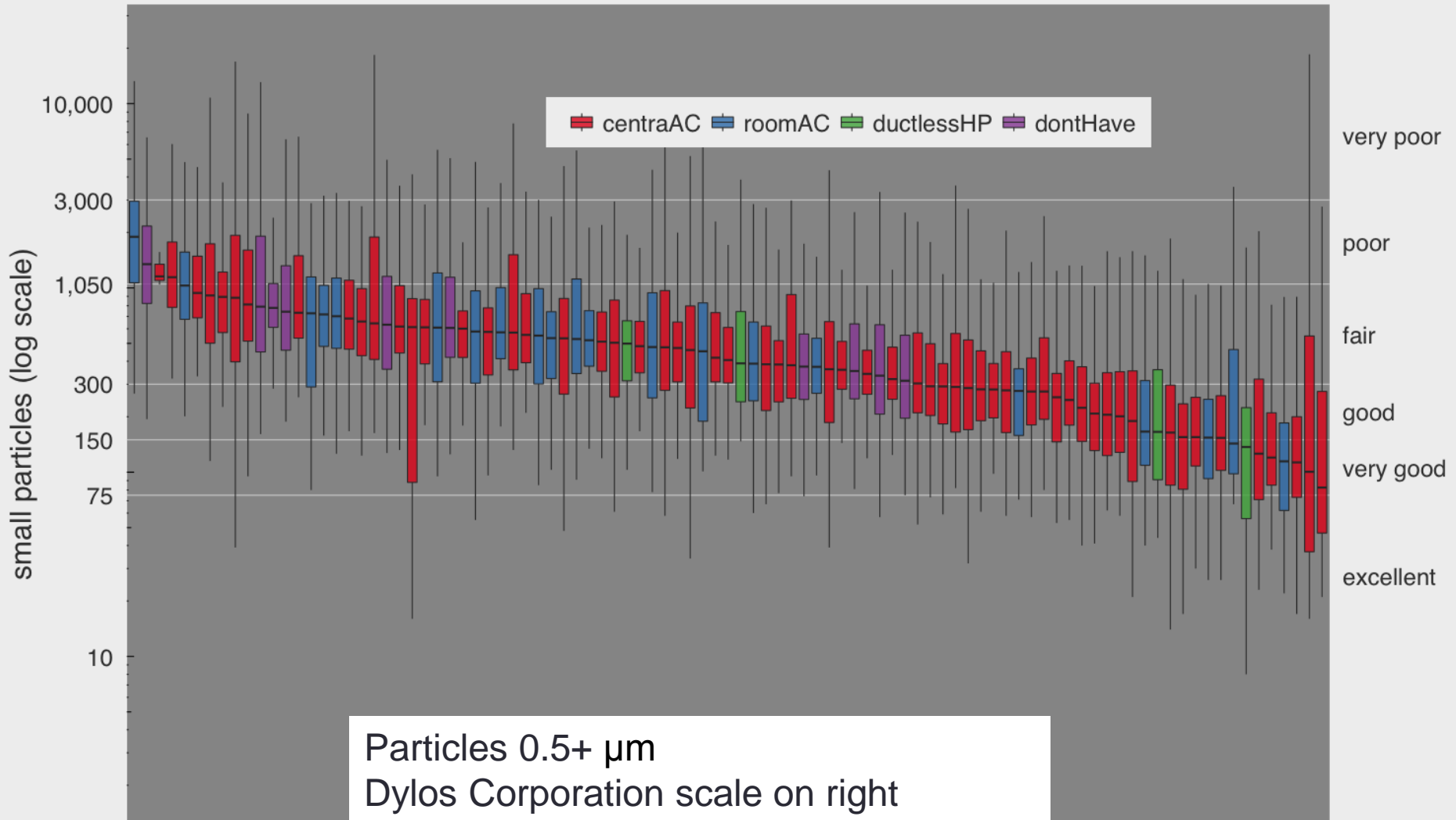
# What type of HEATING SYSTEM do you have?

Particle Levels: Indoor location



# What type of AIR CONDITIONER do you have?

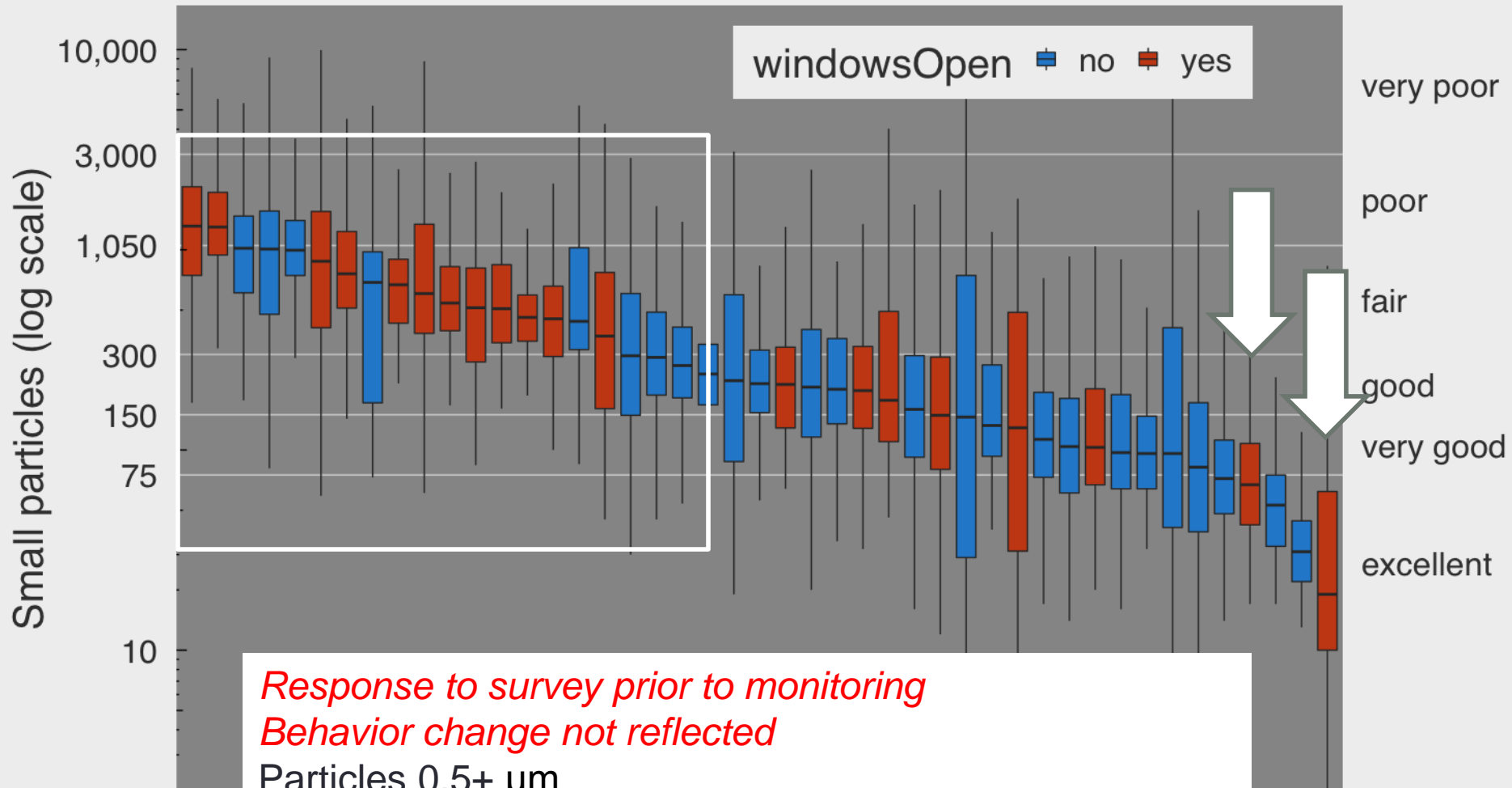
Particle Levels: Indoor location



Particles 0.5+ μm  
Dylos Corporation scale on right

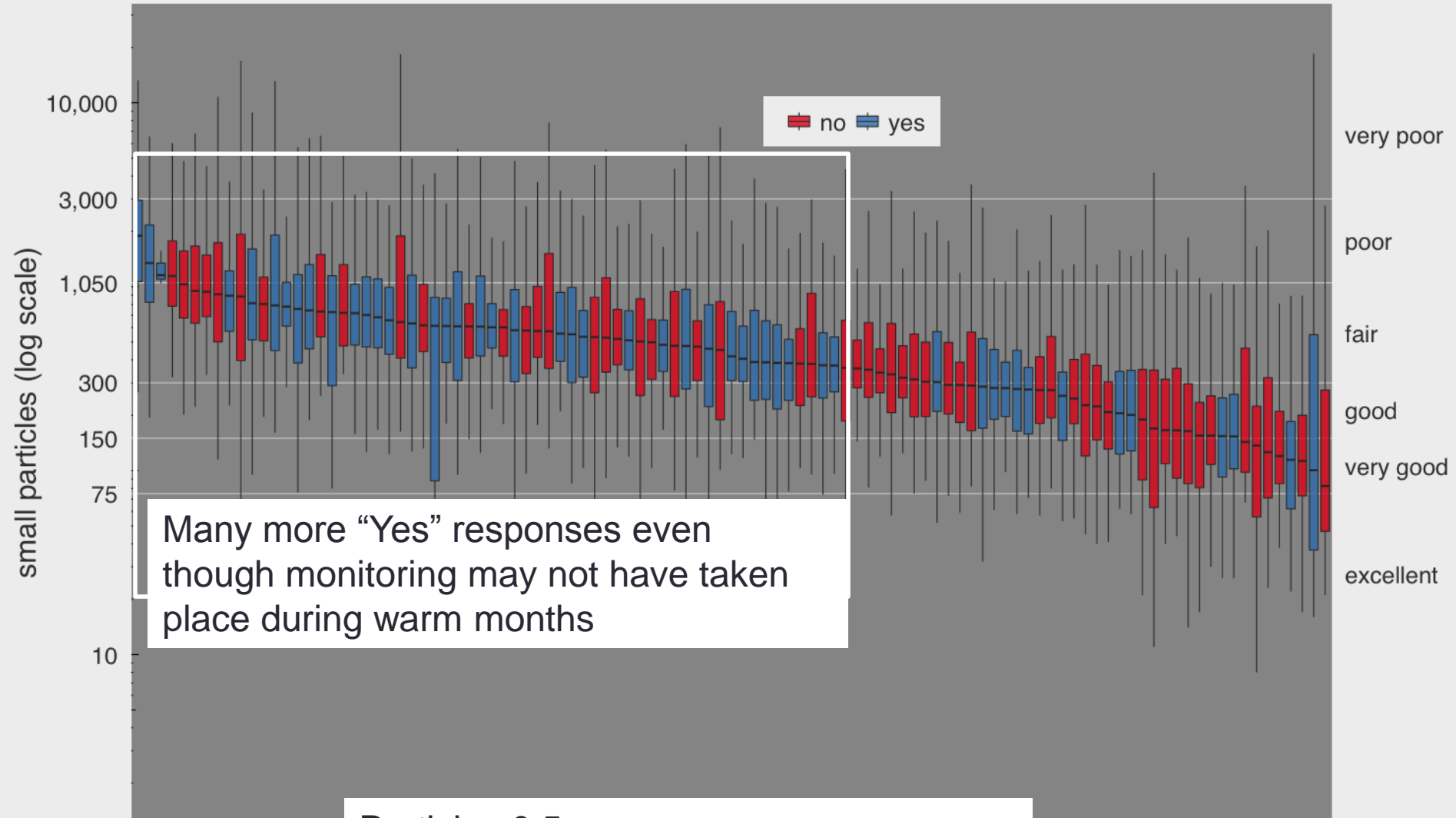
# Comparing Open vs Closed Windows

Summer Nights Only



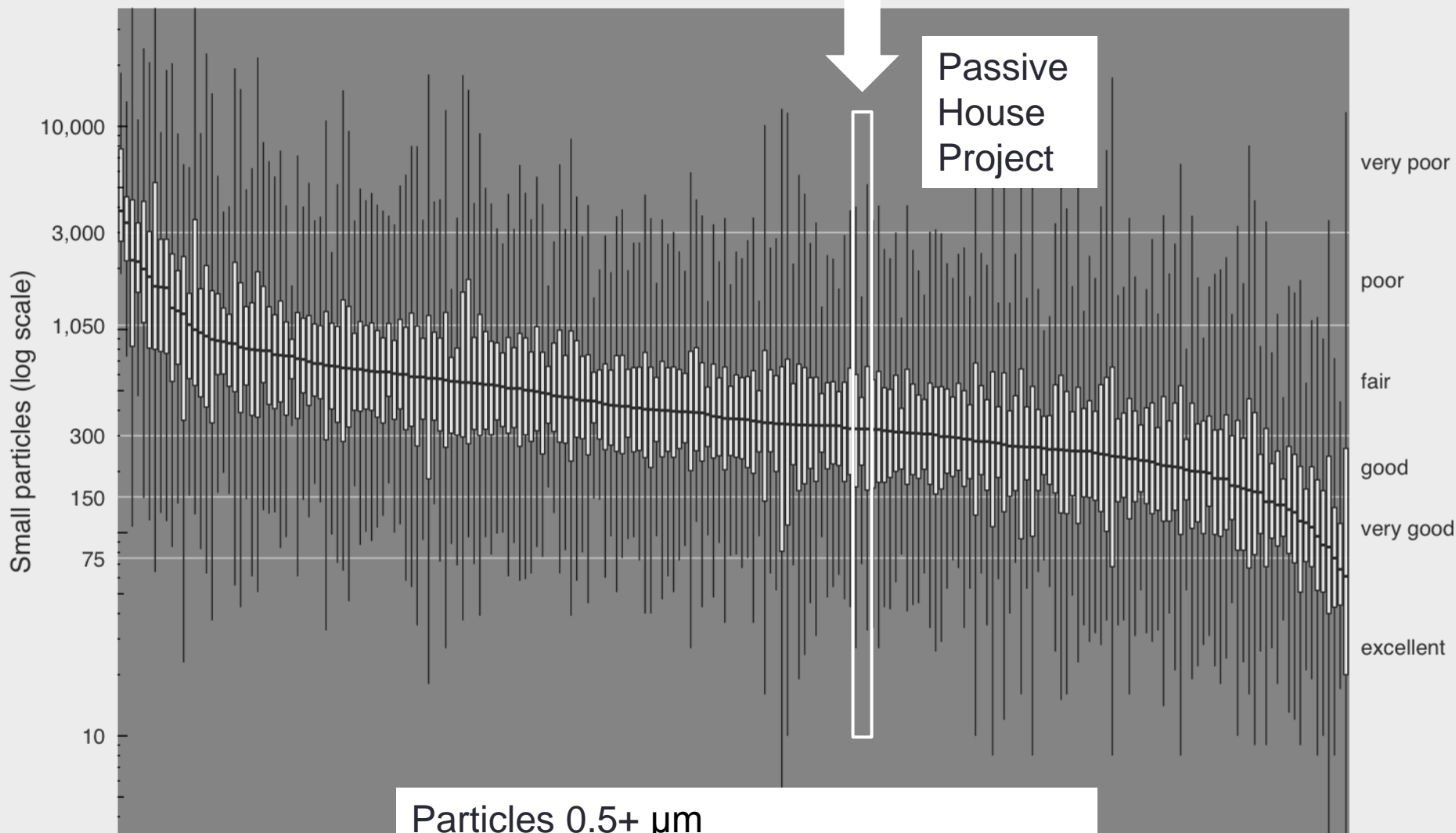
# Do you OPEN WINDOWS TO VENTILATE?

Particle Levels: Indoor location



Particles 0.5+  $\mu\text{m}$   
Dylos Corporation scale on right

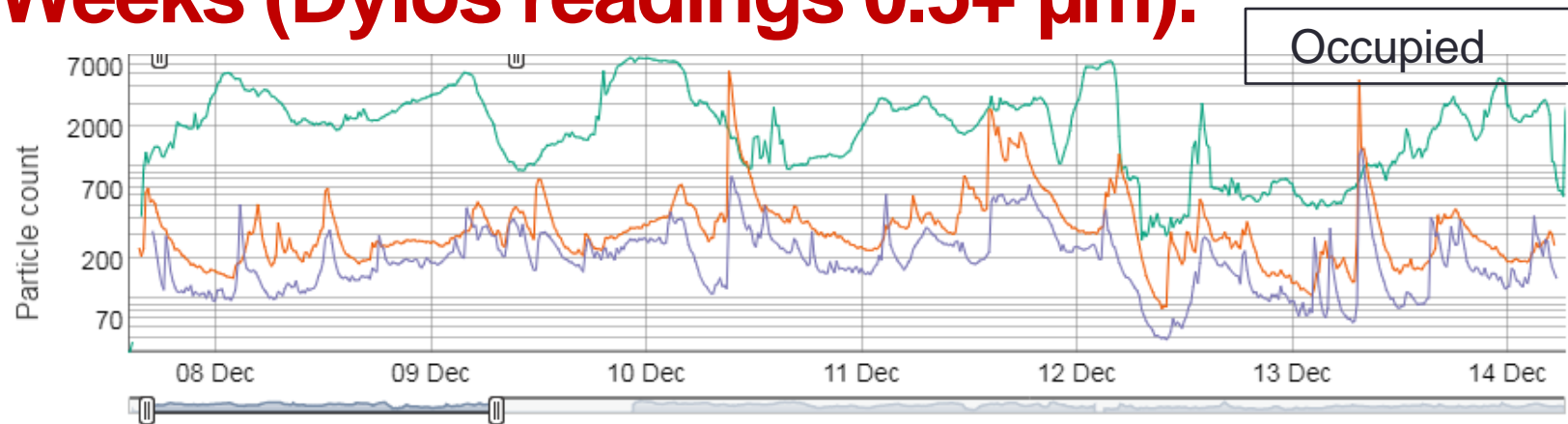
# Indoor Particle Distribution – All Sites



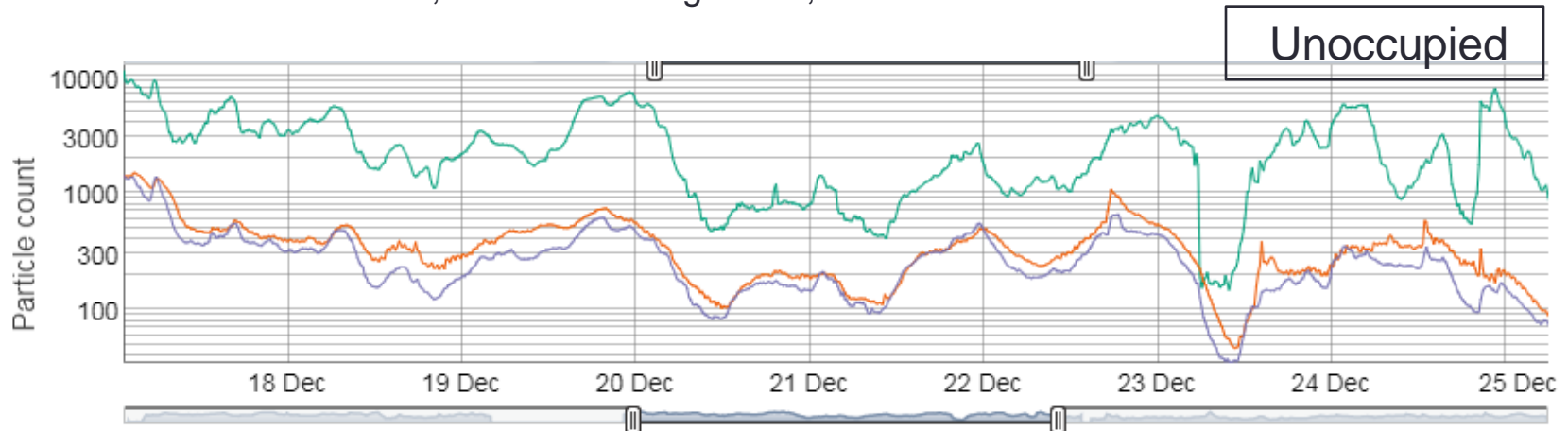
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Dylos Corporation scale on right

# Pgh. Passive House

## Comparing Occupied Vs. Unoccupied Weeks (Dylos readings 0.5+ $\mu\text{m}$ ).

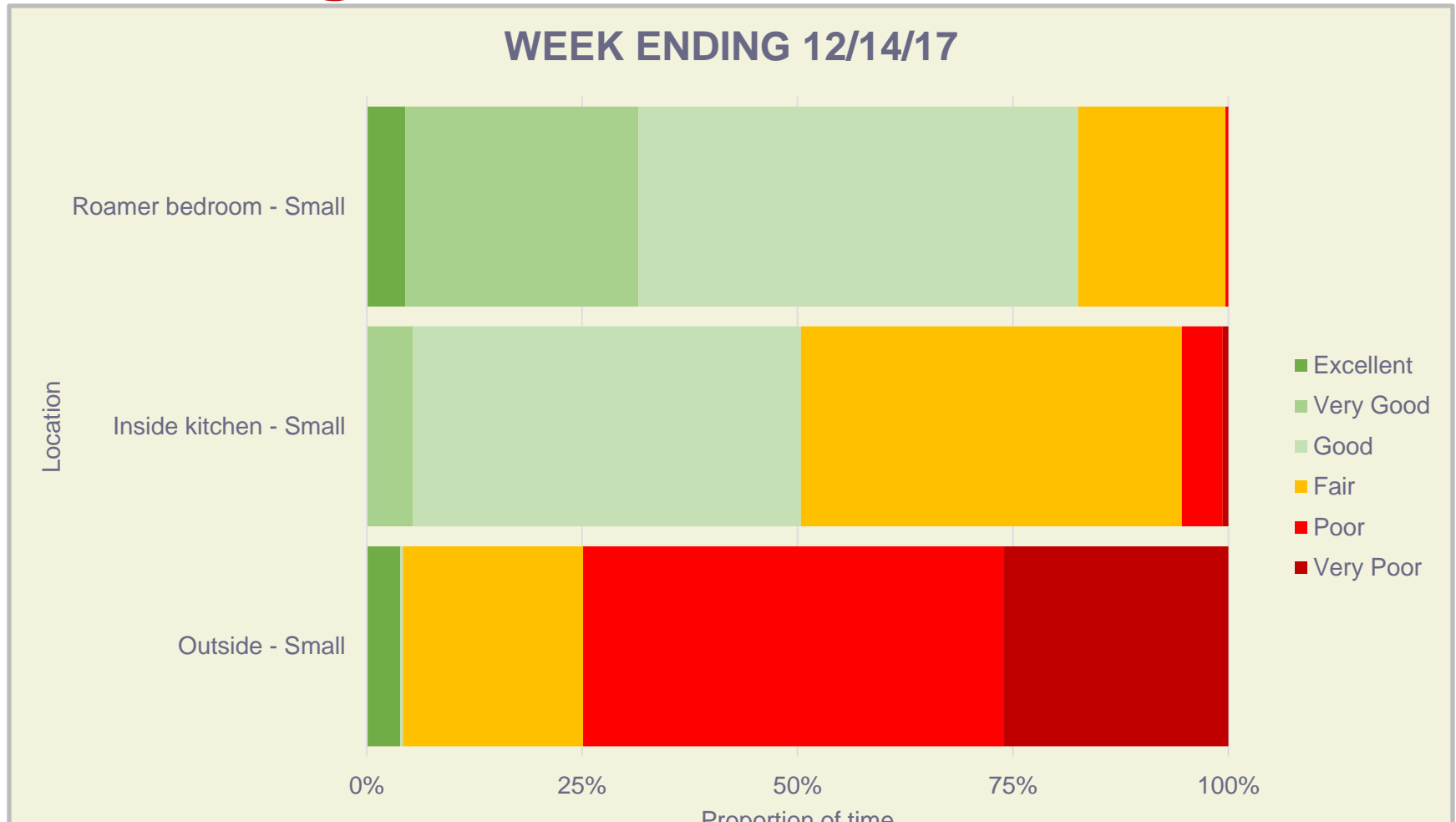


Green line - Outdoor; Red line - Living Room; Blue line - Master Bedroom



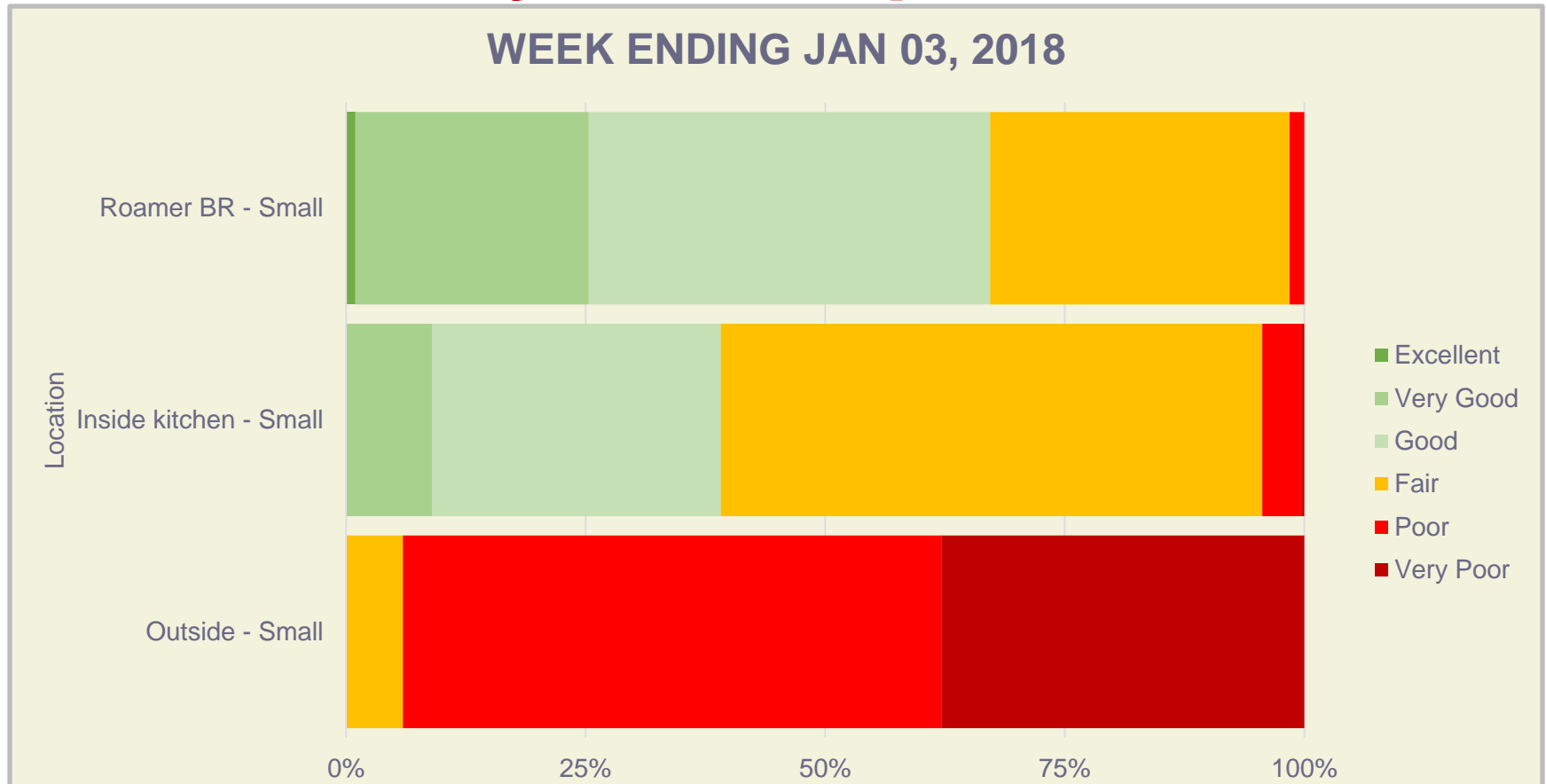
# Visualizing Data

## Pittsburgh Passive House



House occupied Outdoor air quality better than week ending 01/03/18

# Same House – Ventilation System off part of the Time



House occupied Outdoor air quality worse than week ending 12/14/17; Also made some changes to filter in ventilation system and range make-up air

# REDUCING EXPOSURE

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# 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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  - Use induction cook top & other good practices w/ cooking
- **Reduce resuspension**
  - HEPA vacuum
  - Walk-off mats; clean hard-surface floors thoroughly
  - Get rid of carpets, old upholstered furniture
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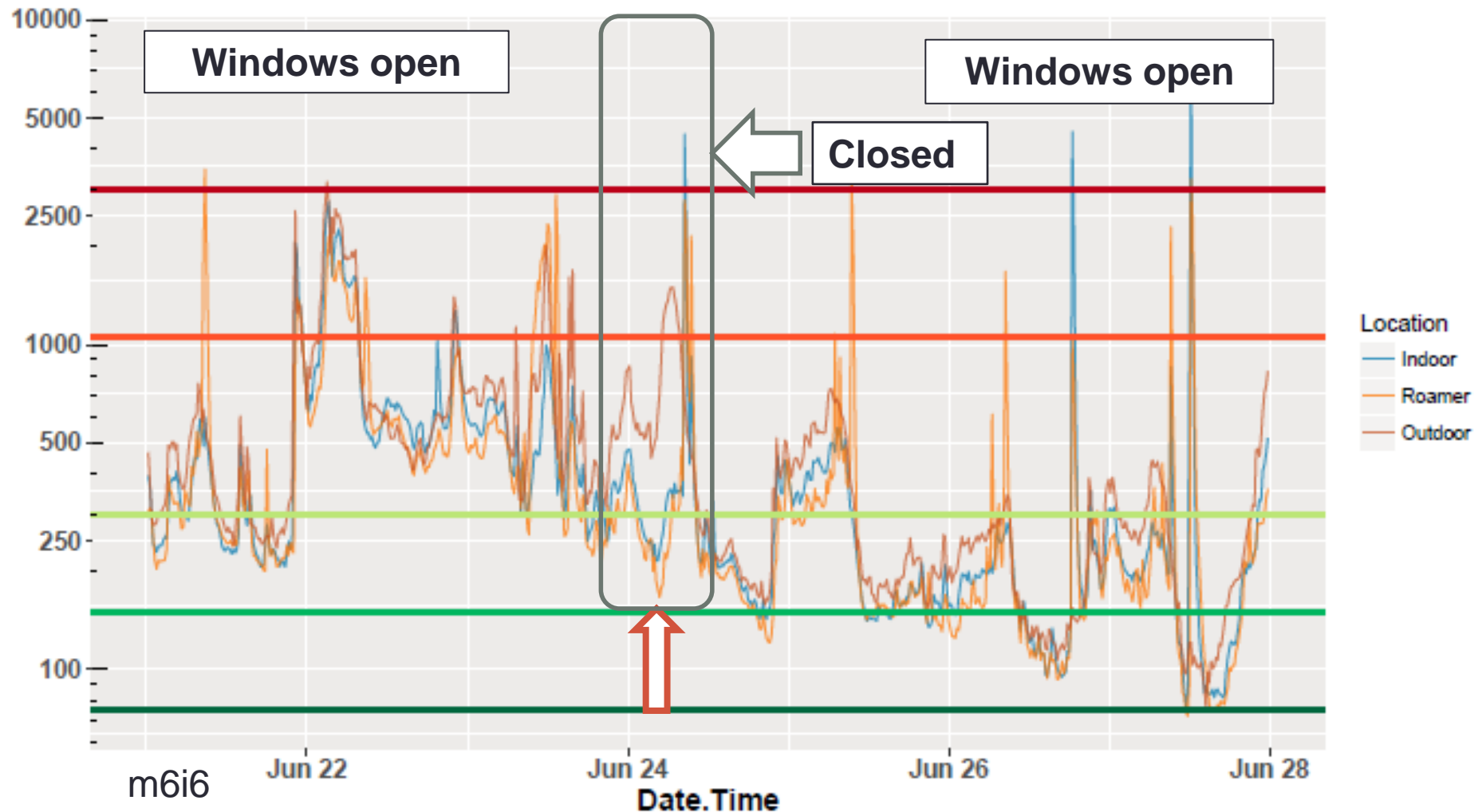
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# Window Operation

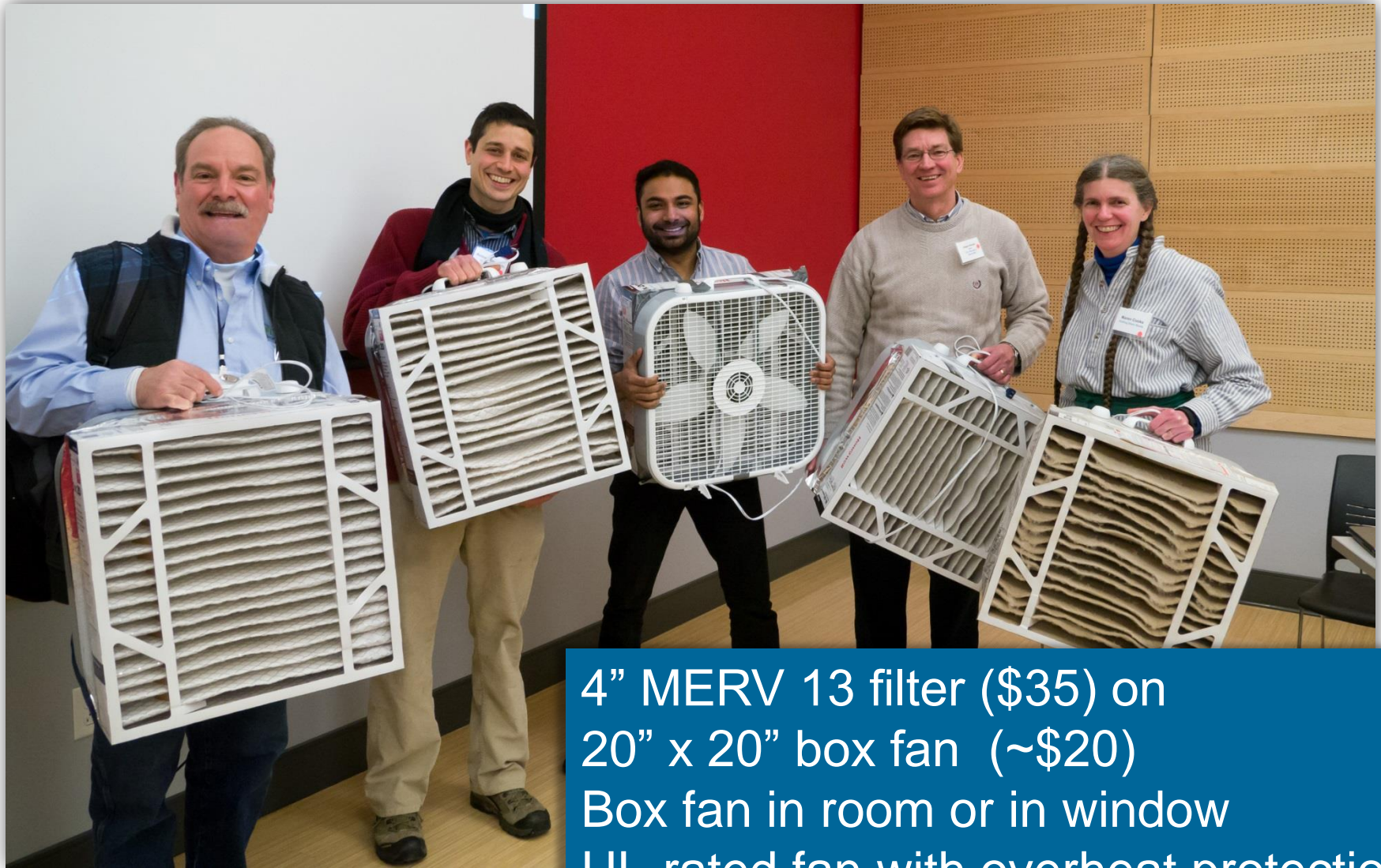
- Single **biggest factor** affecting IAQ when outdoor counts are high
- In Pittsburgh, particle counts tend to be **higher at night** & early morning when windows are often open
- **Poor air quality usually not perceptible (terrible AQ is)**
- Most **contentious!**
- Balancing passive cooling, preferences,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

# Occupant Behavior: Windows Open vs. Closed

Dylos 0.5+  $\mu\text{m}$  + (Particle  $\#/100\text{ft}^3$ )



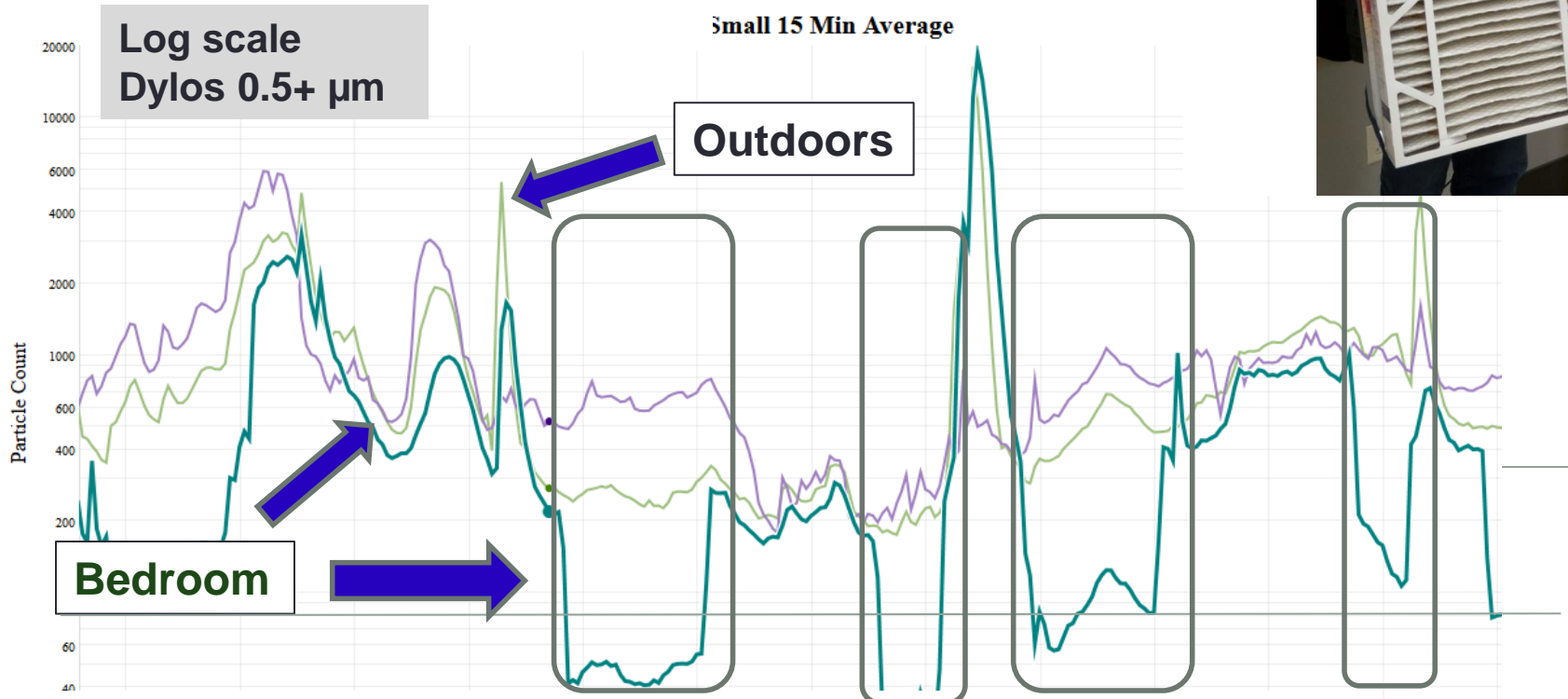
# Fan/Filter Intervention: Low Cost, MERV 13



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)

# 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)

# 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>

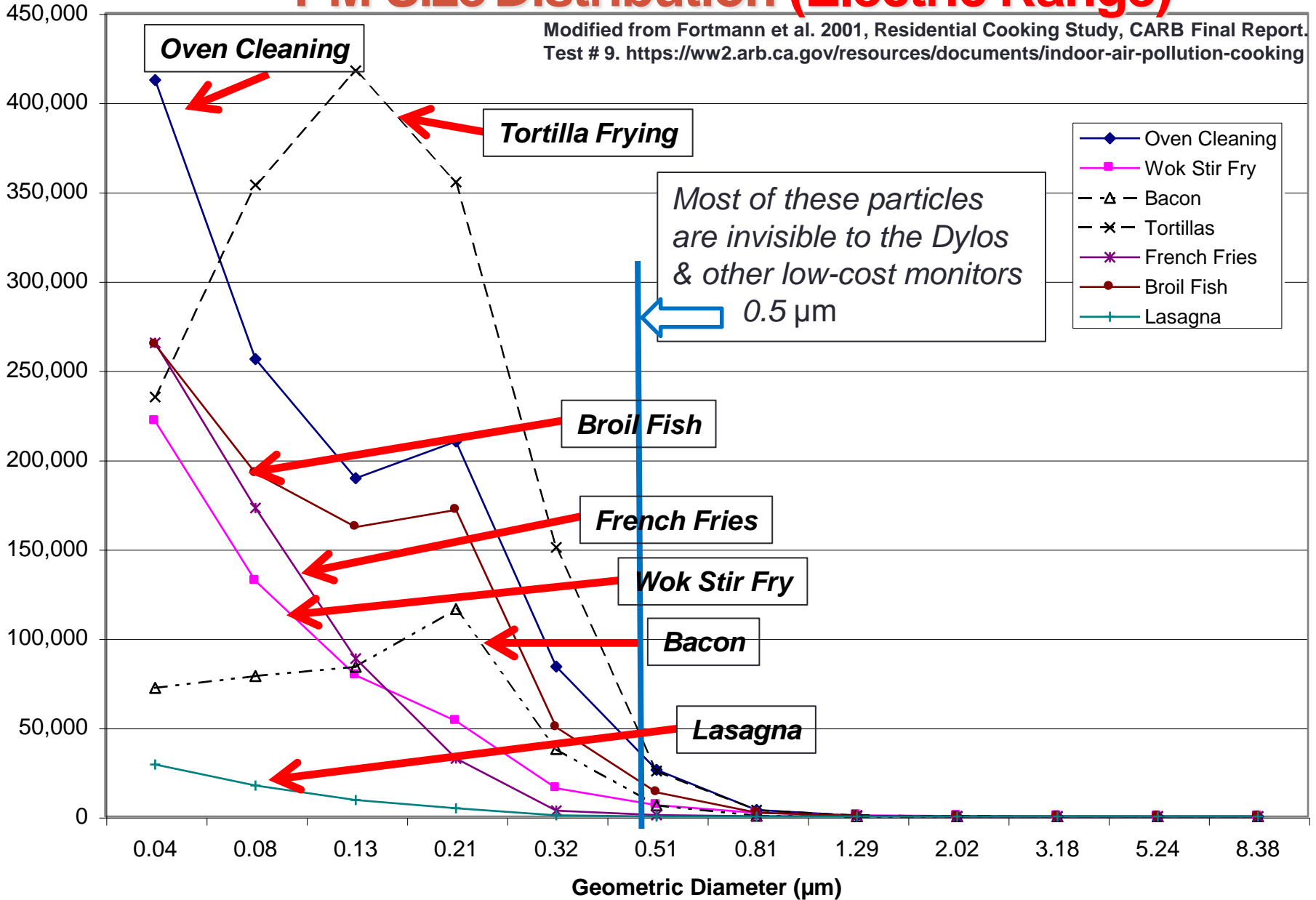
- Online Kitchen Ventilation group on Home Energy Pros

[http://homeenergypros.org/group/kitchen-ventilation?xg\\_source=msg\\_wel\\_group](http://homeenergypros.org/group/kitchen-ventilation?xg_source=msg_wel_group)

# PM Size Distribution (Electric Range)

Particle # /cm<sup>3</sup>

Modified from Fortmann et al. 2001, Residential Cooking Study, CARB Final Report, Test # 9. <https://ww2.arb.ca.gov/resources/documents/indoor-air-pollution-cooking>



# Options to Reduce Indoor Particles

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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**

# 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*
- *Dirty filter on DIY fan-filter makes a big impression*

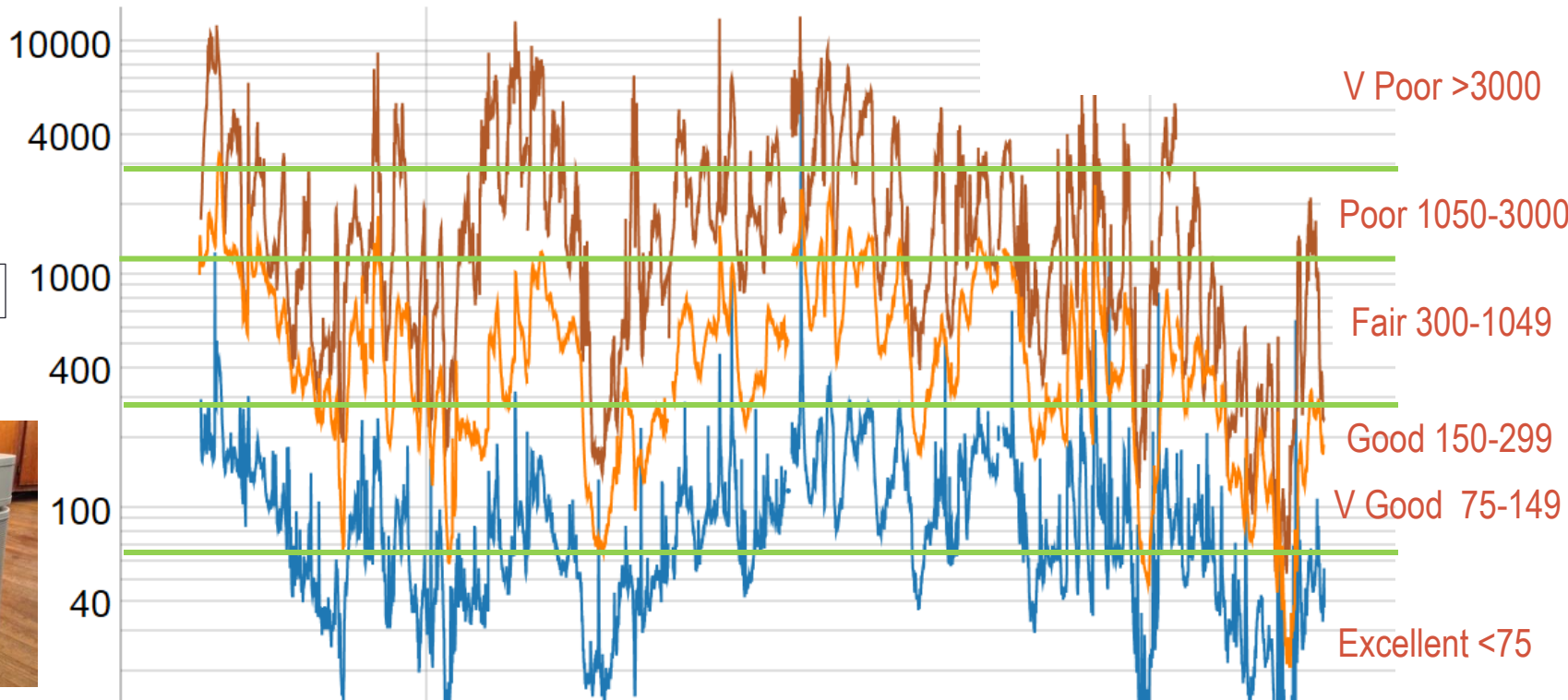


DIY Fan-Filter  
(Box fan with  
MERV 13 filter)

# Impact of Portable Air Cleaner

<http://rocis.org/rocis-data-explorer> (j1t8) 0.5+  $\mu\text{m}$  Particles by Time (15-min. avg.)

## Your Indoor Particles vs. Time



Log scale



Blue: treated zone (325 ft<sup>2</sup>)

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<sup>1</sup> of more air cleaners, and found impact more limited to single room (leakier, older homes with more activity).**

**<sup>1</sup> Thanks to donation of air cleaners from Austin Air**

# 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**

# 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<sup>1</sup>)
- **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 too high
  - Duct leaks (energy waste & pressure-related problems)

<sup>1</sup> \$0.12/kWh



16x25x1 MERV 12

**BEFORE**

CASE STUDY: Indoor Air Quality Interventions  
*Chris Guignon, evolveEA*

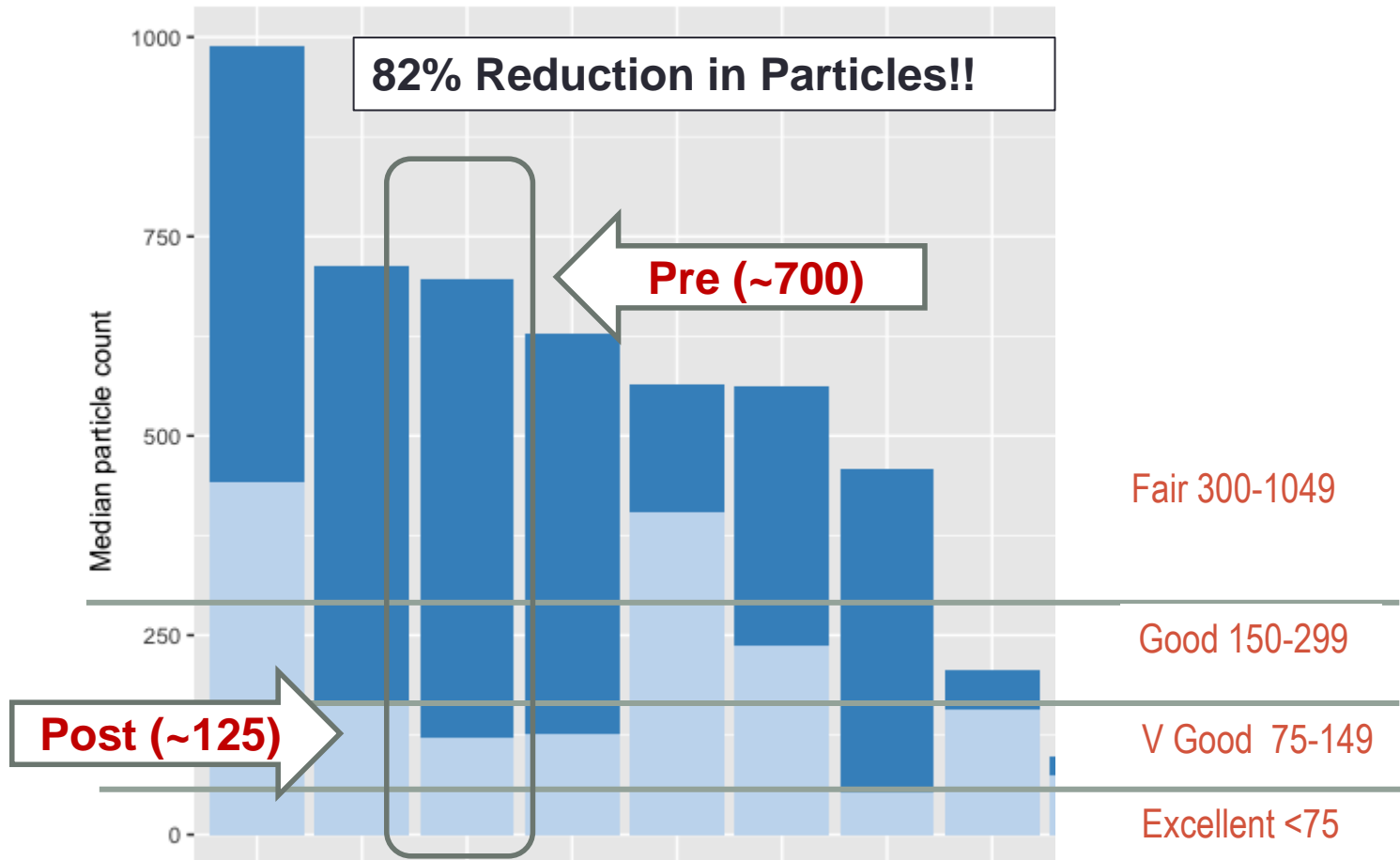


20x25x4 MERV 13

**AFTER**

CASE STUDY: Indoor Air Quality Interventions  
*Chris Guignon, evolveEA*

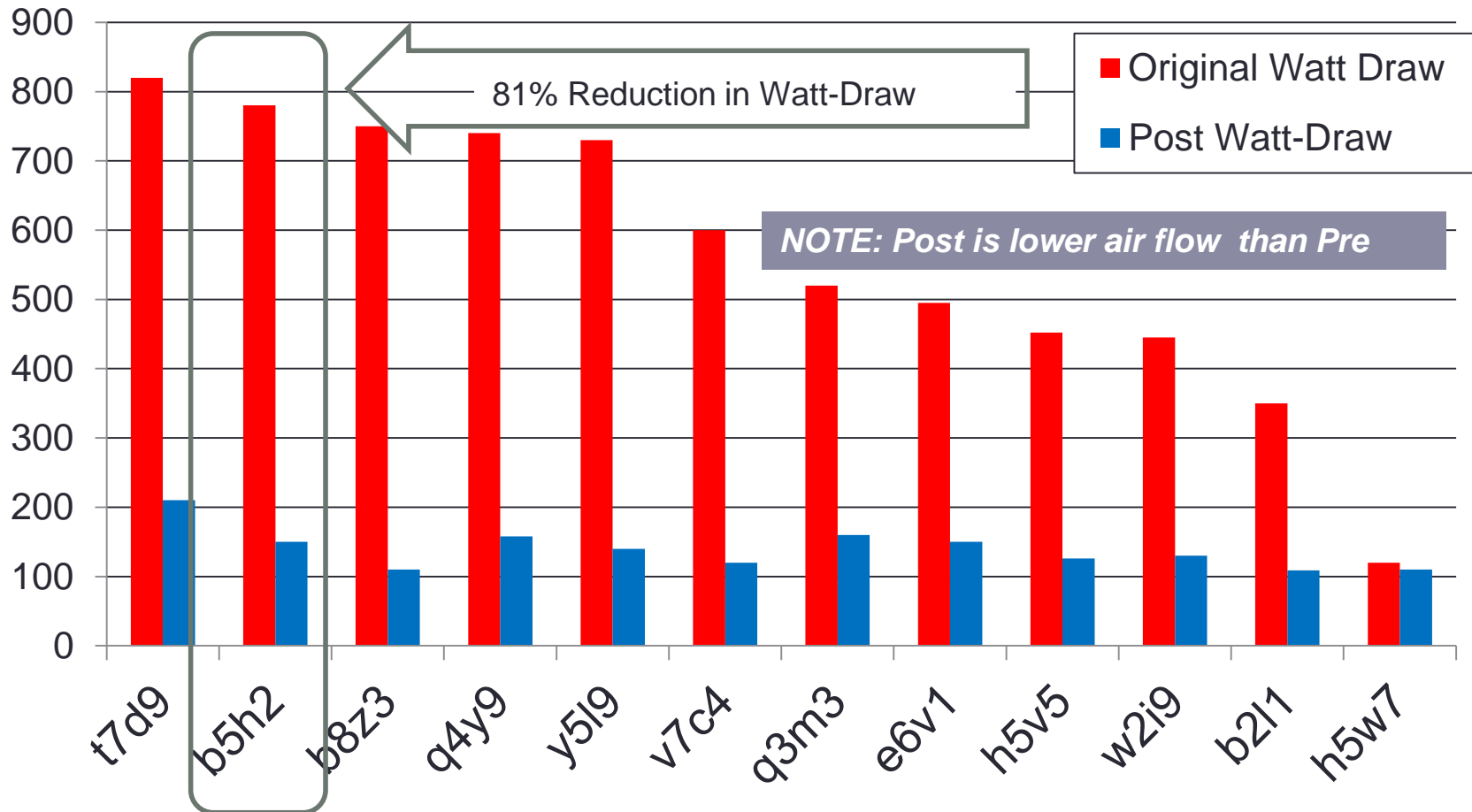
# Selected ROCIS Intervention Homes Pre-Post Median Particle Count



Use above code (**b5h2**) 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 (**t7d9**) to view particle data on ROCIS LMCP Data Explorer  
<http://rocis.org/rocis-data-explorer>

## Case 2: Front View of Retrofitted Furnace Showing Filter in Place

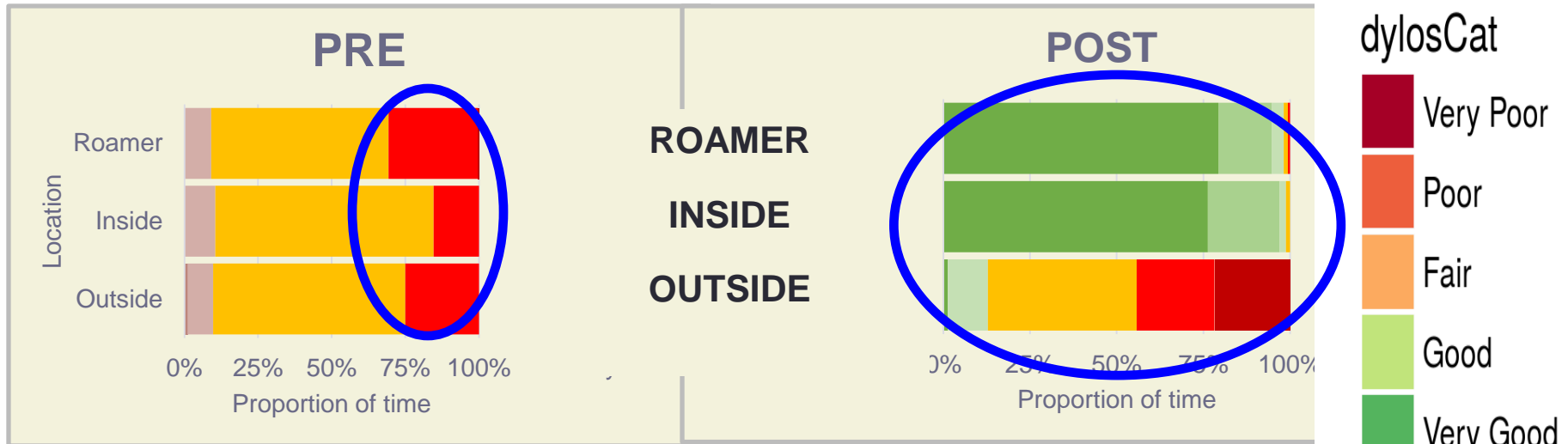


- New return drop
- Space for larger & deeper filter
- Space for optional pre or post filter
- Less restrictive transition from filter rack to furnace
- New ECM

# Case 2: Post-retrofit



# Case 2 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<sub>2</sub> in bedroom **24/7 annual operating cost: \$131.40**

# High Performance Filtration Essentials

**MERV is like R-Value**

**performance depends on installation/operation**

**Verify & address static pressure**

**Provide adequate run/on time**

**Minimize filter bypasses**

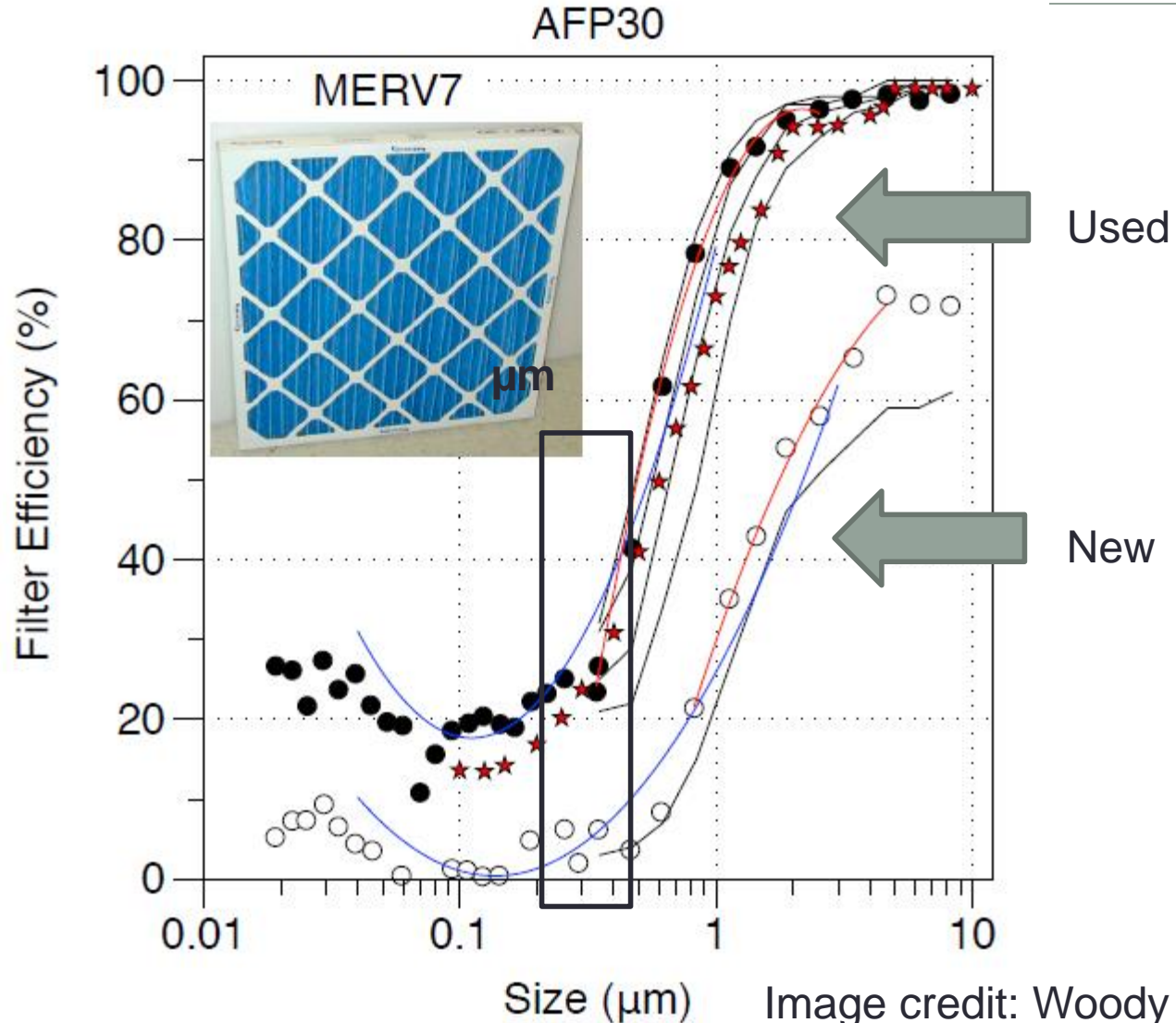
**Verify/monitor filtration particle performance**

**ideally @ 0.3 - 0.5  $\mu\text{m}$**

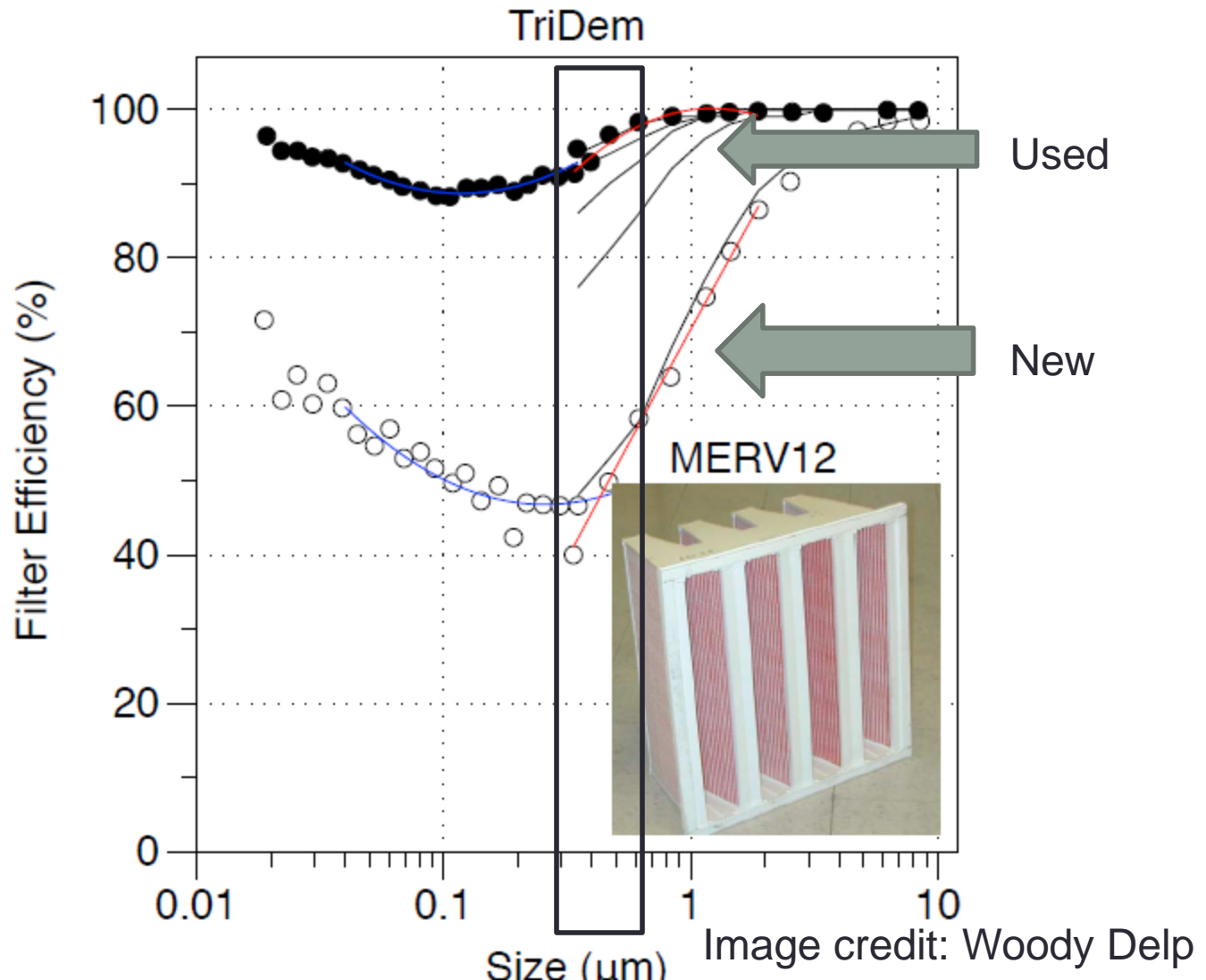
**Use MERV 12 or above to reduce 0.3 to 0.5  $\mu\text{m}$  particles**

**Avoid 1" pleated high performance filters (resistance)**

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

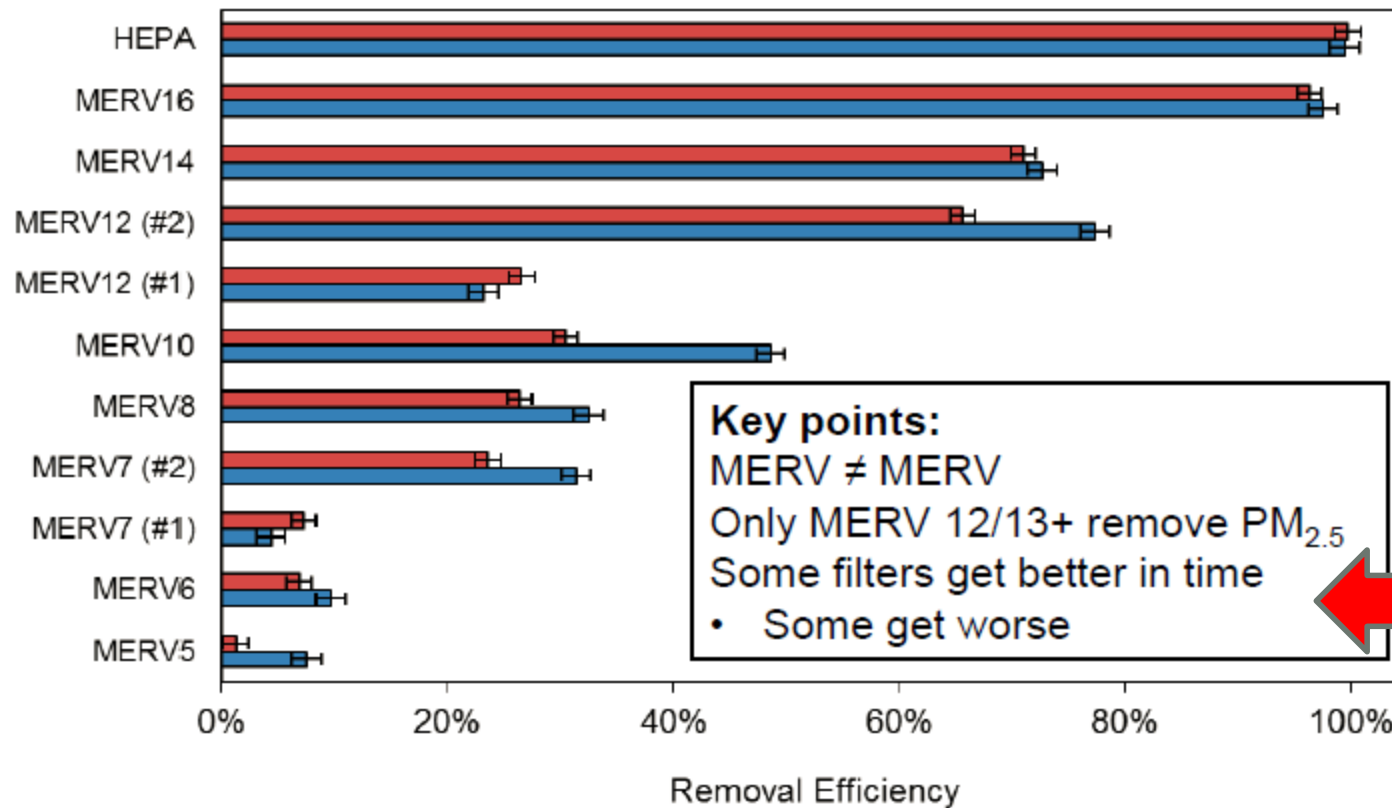


# MERV 12 ...in this case Better Performance Used than New



# Fine and ultrafine particle removal efficiency

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



Slide credit Stephens – ASHRAE Chicago 2018 <sup>34</sup>

## Filter bypass is relatively common in homes

Filter bypass reduces filtration effectiveness

VerShaw et al. 2009 *ASHRAE Transactions*



Photo credit: Brent Stephens

# Filtration: Energy Use & Energy Cost

**Air Handler or Portable Air Cleaner 24/7 operation**

- **Easily break a Passive House budget !**
- **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 - 100 watts (much lower possible)**

# Filtration Energy & Cost

**50 Watt 24/7 = 438 kWh/year**

**100 Watt 24/7 = 876 kWh/year**

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

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

**... Easily 2,000 kWh+/year**

# Health Benefits of Filtration

“Fisk said, The filtration of incoming outdoor air and 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)

# Control Strategies

- **Needed!! (alternative to 24/7 operation)**
- **Lots of activity/options**
- **What drives “on” time?**
  - **Clock**
  - **Sensor – what sensitivity? What is it sensing?**
- **Verify performance over time**

# 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**



# To Ponder

**What is the energy cost of  
cleaning dirty air?**

# 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 180+ Project Participants!*

# *Questions? Comments?*

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# EXTRAS

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# Fans – HVAC Air Handlers

“Fan Auto” – most common

For better filtration increase in use of “Fan On” or

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

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



# ROCIS Air Handler Inquiry

- **Purpose:** explore feasibility of using air handler w/ high MERV filter 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

# Air Handler Inquiry: Key Findings

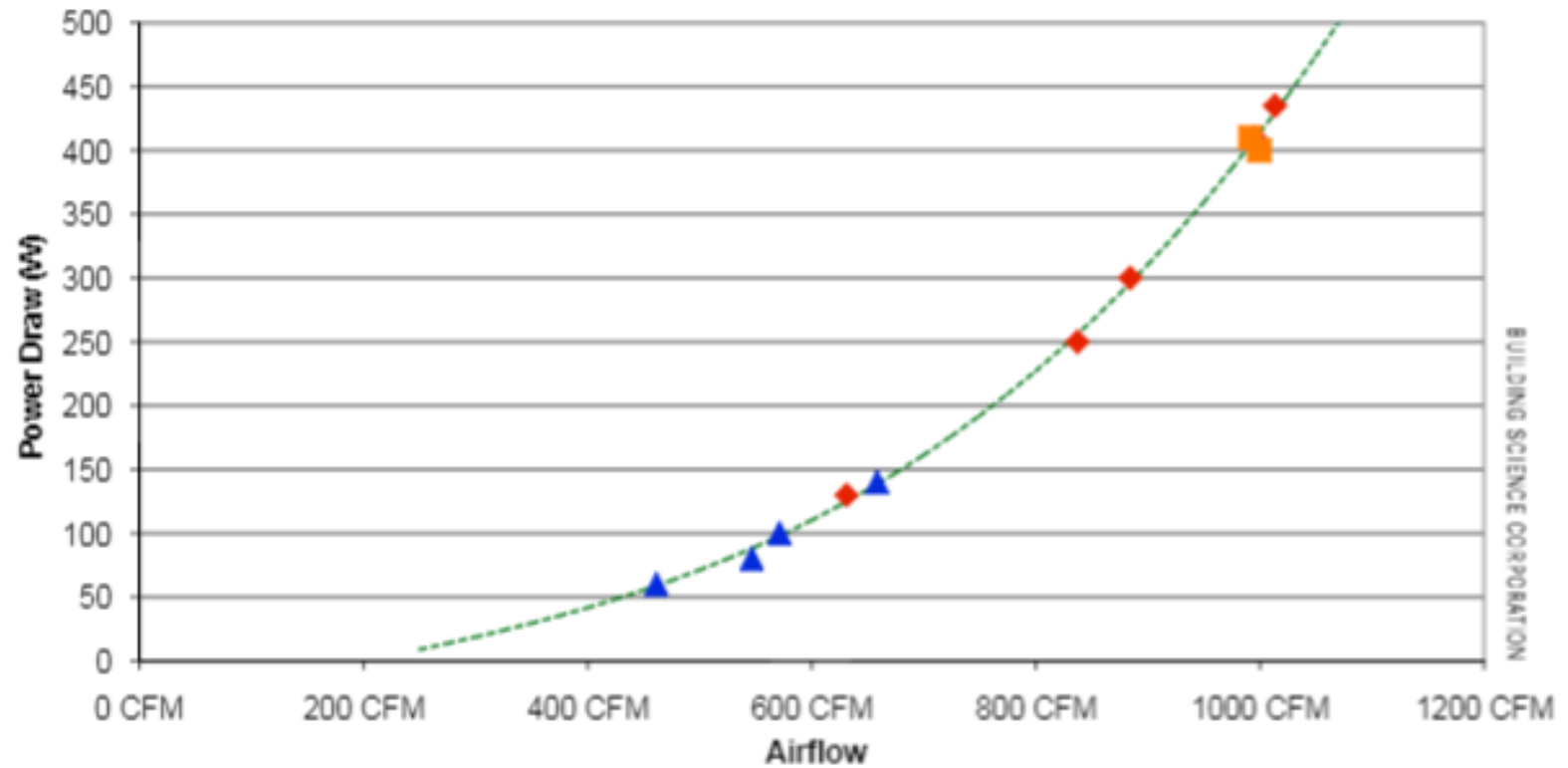
- Air handlers nearly always on factory settings (highest speed)
- Diagnostic visit adjustment usually reduced energy use with both PSC & ECM blowers
- In “as found” condition running air handler 24/7 not advisable
- With duct modifications & ECM change-out some systems can be optimized w/ larger/deeper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

# Air Handlers – PSC vs. ECM (below)



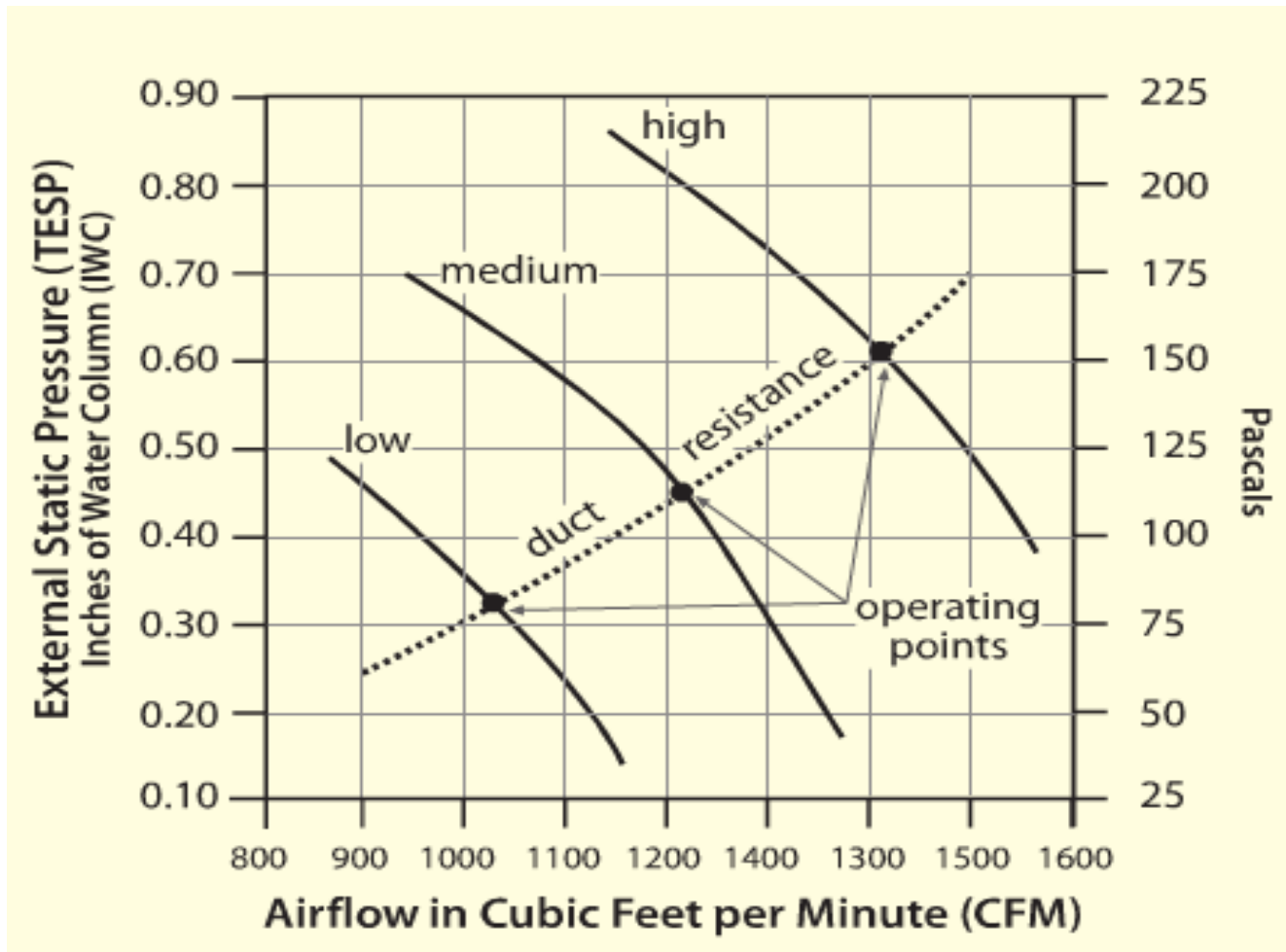
ECM change out replaces permanent split capacity motor for a drop in watts/kWh, & the ability to move less air in continuous or circulation mode (400 CFM @ 120 W)

## Power Draw versus Air Flow for Tested Air Handler



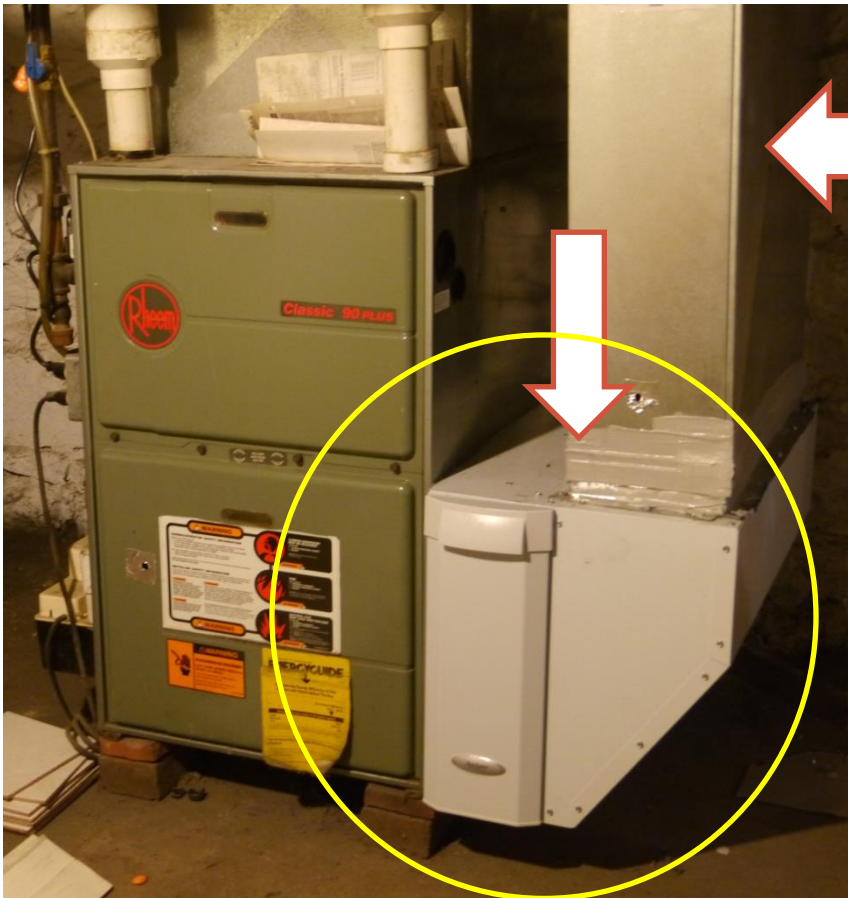
Slide credit: Building Science Corporation

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



# 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

2) Filter still only 16" x 25"

# Much Better Performance!

## RESULTS:

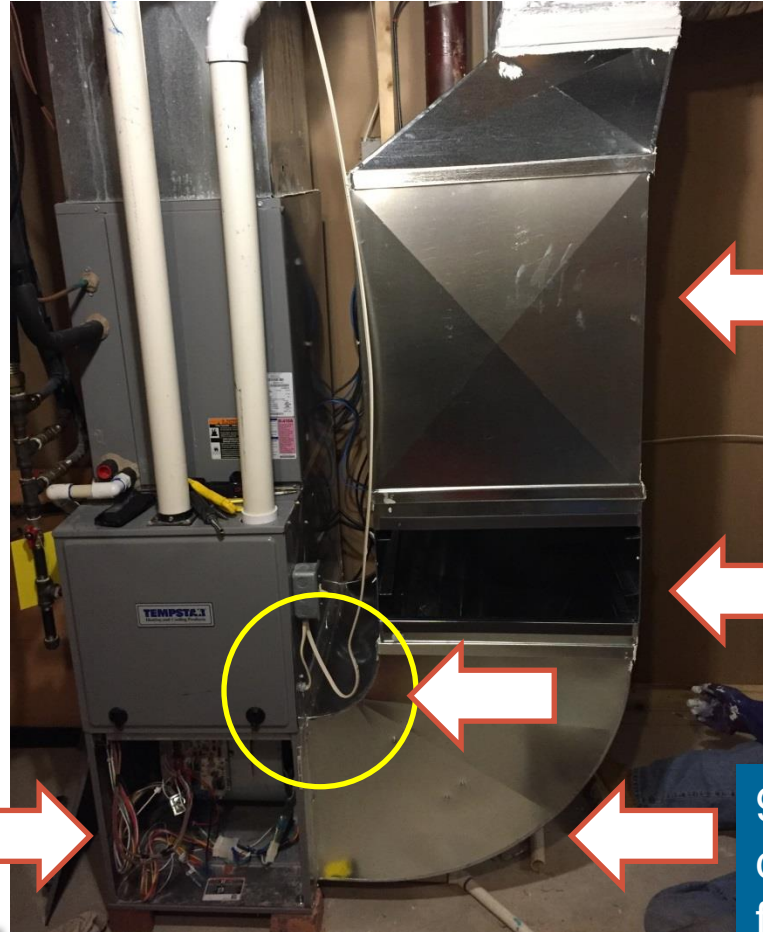
5 yr. old home  
Significant comfort  
improvement!

## In continuous mode:

- 3.38 CFM/watt
- TESP Pre: 138, Post: 52
- 360 Watts (reduction)

ECM  
replacement

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



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; lower static (with  
turning vanes)