



# REDUCING HOUSEHOLD PARTICLES W/ FILTRATION: MEASURED RESULTS, OPPORTUNITIES & CHALLENGES

## 5B. A Fresh Breath: Ventilation & Health & Buildings

December 5, 2018, 11 - 12:30 AM, New Orleans, LA

2018 Conference on Health, Environment & Energy

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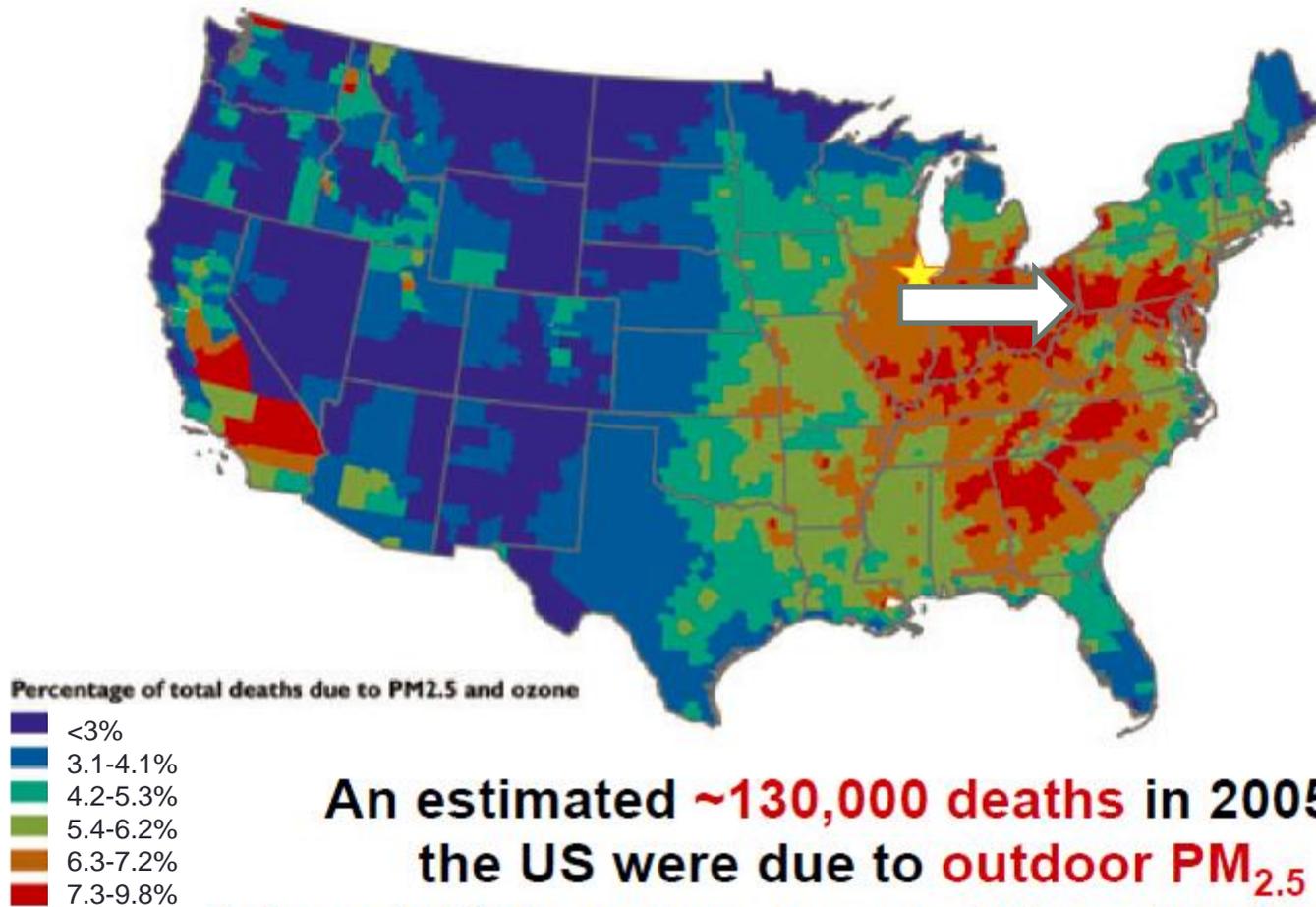


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# Outdoor Particles (PM) & Human Health



**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)**

# Filtering Air with Home Heating & Air Conditioning Systems

## Simultaneously...

- ***Significant missed opportunity*** to reduce particles
- ***Major liabilities*** (energy use, emissions, energy cost, equipment life, & performance)

*Our solutions reduce fine particles by 50-80% while minimizing risk*

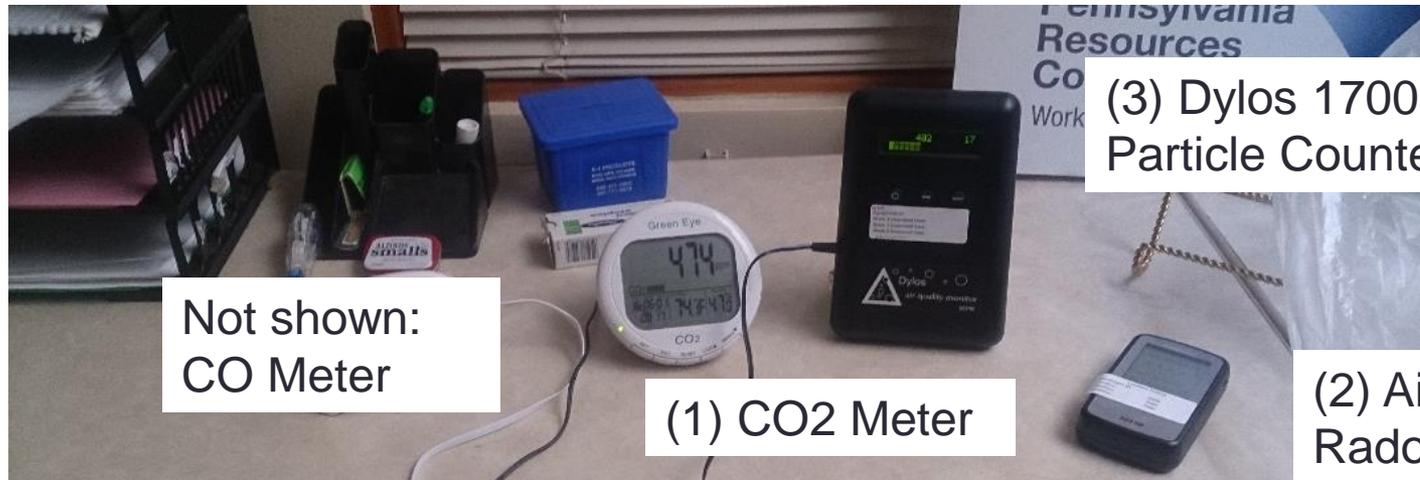
# ROCIS (*Rock-us*) or (*Raucous*) Reducing Outdoor Contaminants in Indoor Spaces

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



# ROCIS Monitoring Cohorts

- Initial 3-4 weeks – home or workplace
- Longer term monitoring with interventions
- 200 participants to date



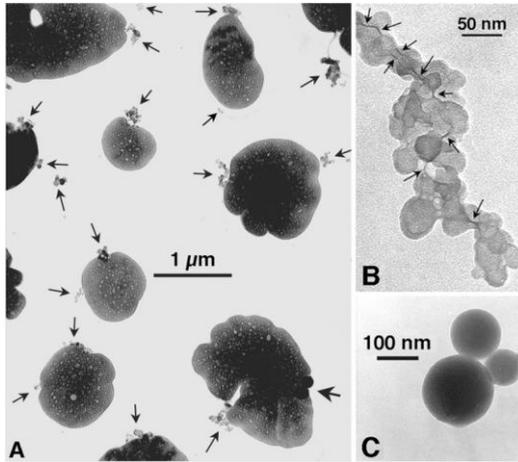
Not shown:  
CO Meter

(1) CO2 Meter

(3) Dylos 1700  
Particle Counter

(2) AirThings  
Radon Monitor

# Particles (PM)



**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

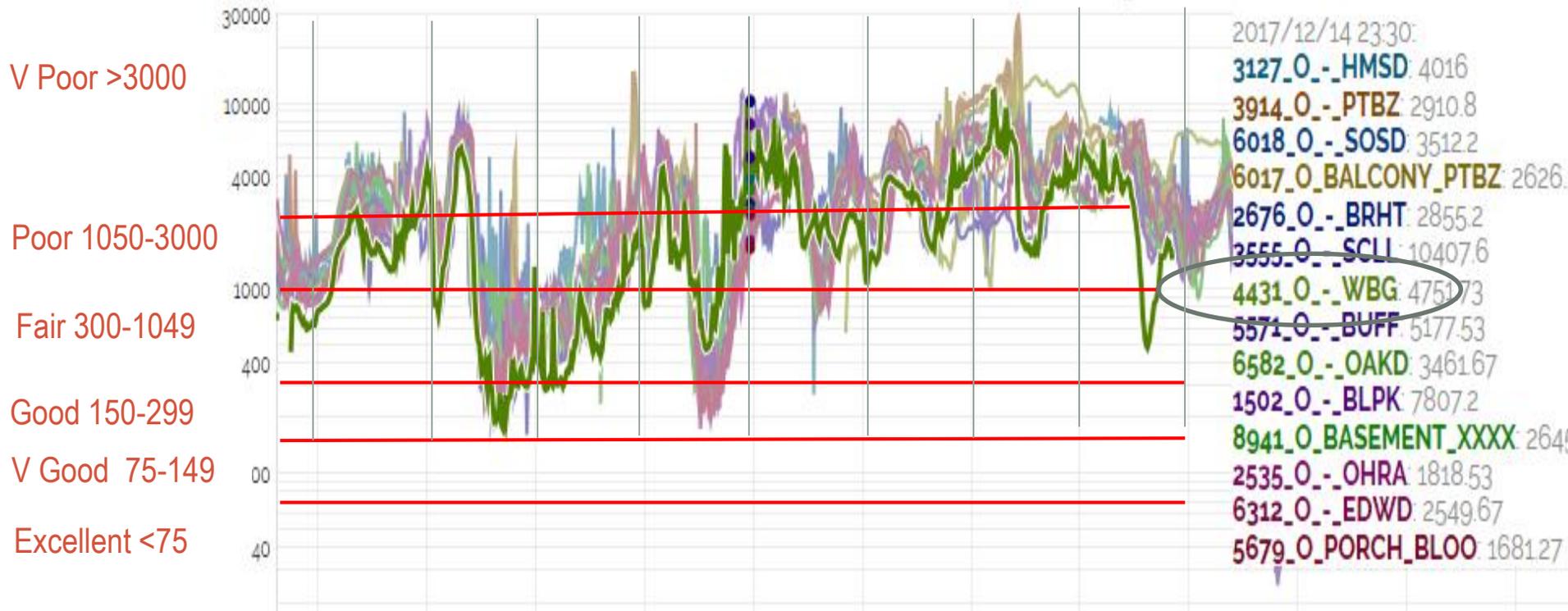
→ ROCIS LCMP Dylos: PM<sub>0.5+</sub>: Particles **greater than** 0.5 μm in diameter (1/100 of human hair!)

# ROCIS Outdoor Data (70 mile spread) - Readings track

Log scale

ROCIS Low Cost Monitoring Project

Cohort 25 Small 15 Min Average



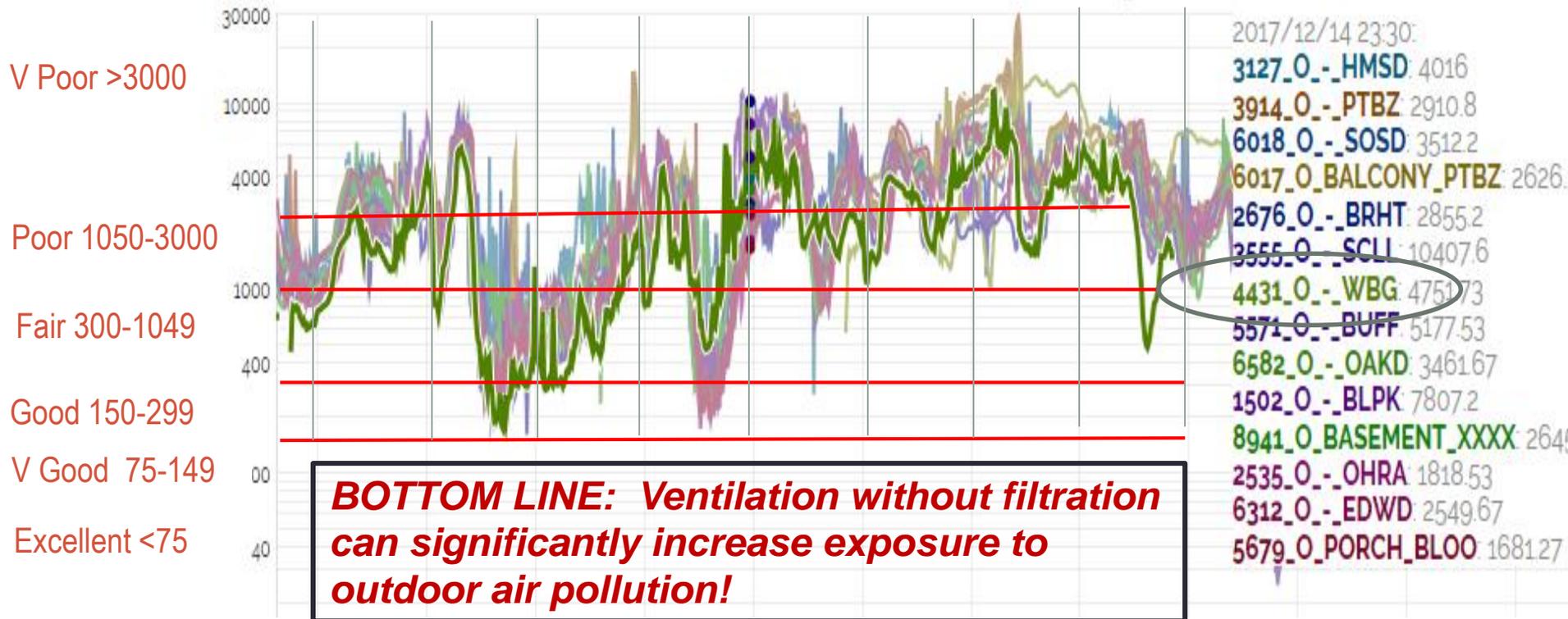
Most sites are Pittsburgh; Green line (Wbg) is 50 miles south  
Dylos particles ( $0.5+ \mu\text{m}$ )

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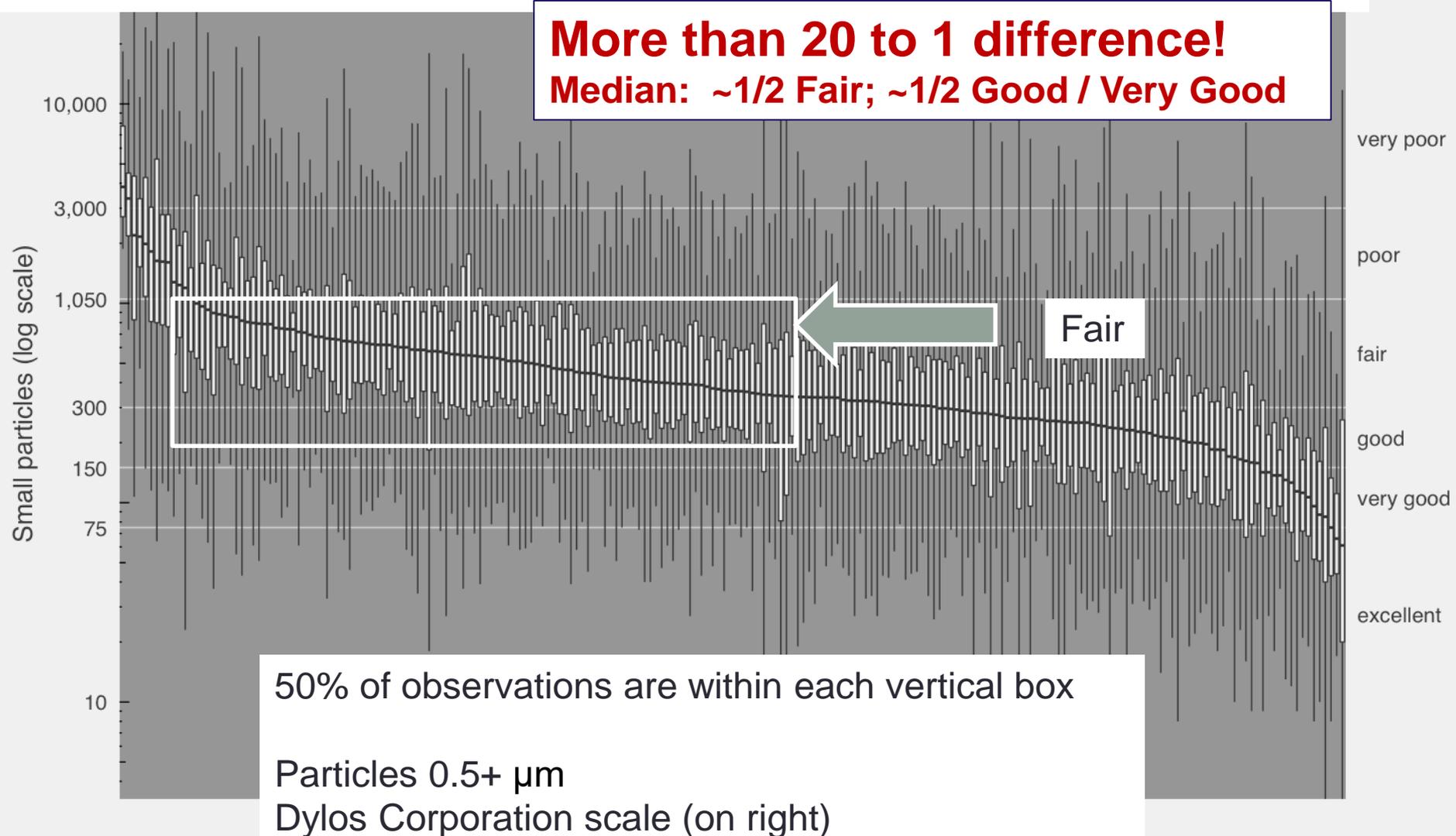
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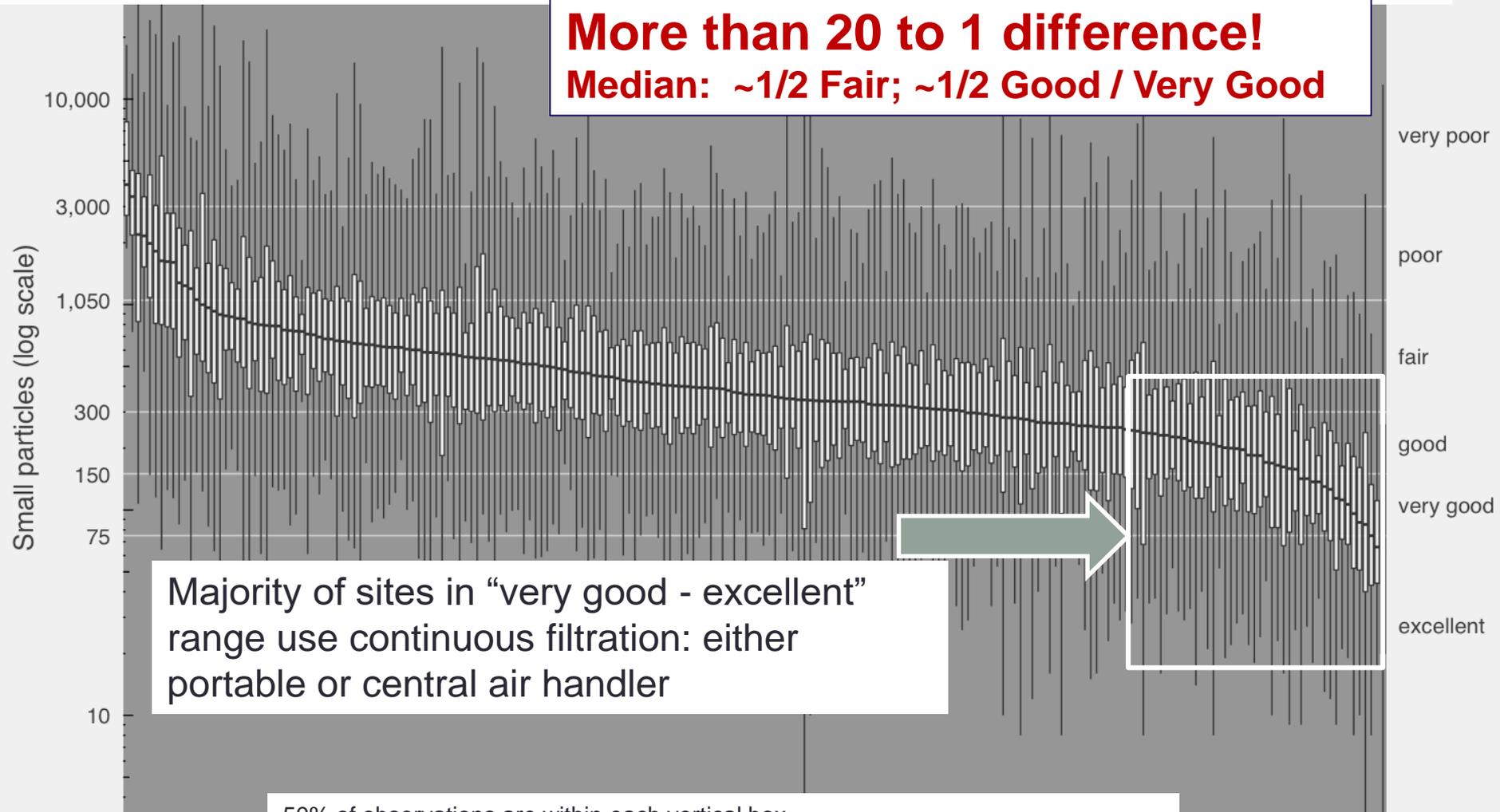
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# Indoor Particle Distribution – All Sites



# Indoor Particle Distribution – All Sites

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



50% of observations are within each vertical box  
 Particles 0.5+  $\mu\text{m}$   
 Dylos Corporation scale (on right)

# 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)



# 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

# Health Benefits of Air Filtration

**Air cleaners typically reduce indoor PM concentrations by ~50%**

**Documented health improvements with filtration:**

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

**William Fisk, 2013 Indoor Air**

# Health Benefits of Filtration

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

William Fisk, LBNL

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

# ROCIS AIR HANDLER / HIGH MERV FILTER INQUIRY

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# 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!!*

*Not applicable in sites w duct leakage to outside*

# An Air Handler, or Air Handling Unit

(often abbreviated to **AHU**), is a device used to regulate and circulate air as part of a heating, ventilating, & air-conditioning (HVAC) system<sup>1</sup>

Includes: ductwork, blower/motor, filter, coil, & controls

➤<sup>1</sup> Wikipedia

Return  
Drop



# Blower / Motor



Blower



multi-speed

## ECM (electronically commutated motor)

This model also allows us to set up a very low continuous movement of air for filtration, ~400 - 700 CFM, @120 - 180 Watts of power.

*Not as efficient (or expensive) as the variable speed ECMs in many new heating & air conditioning systems.*



# Air Handler Operation

Thermostat usually set to “Auto”, not “On”

Average annual run-time is ~15%

Inadequate for filtration

Call for heat & cool does not align with need for filtration

With smart thermostats more control of “on time”



# 45 DIAGNOSTIC VISITS LATER

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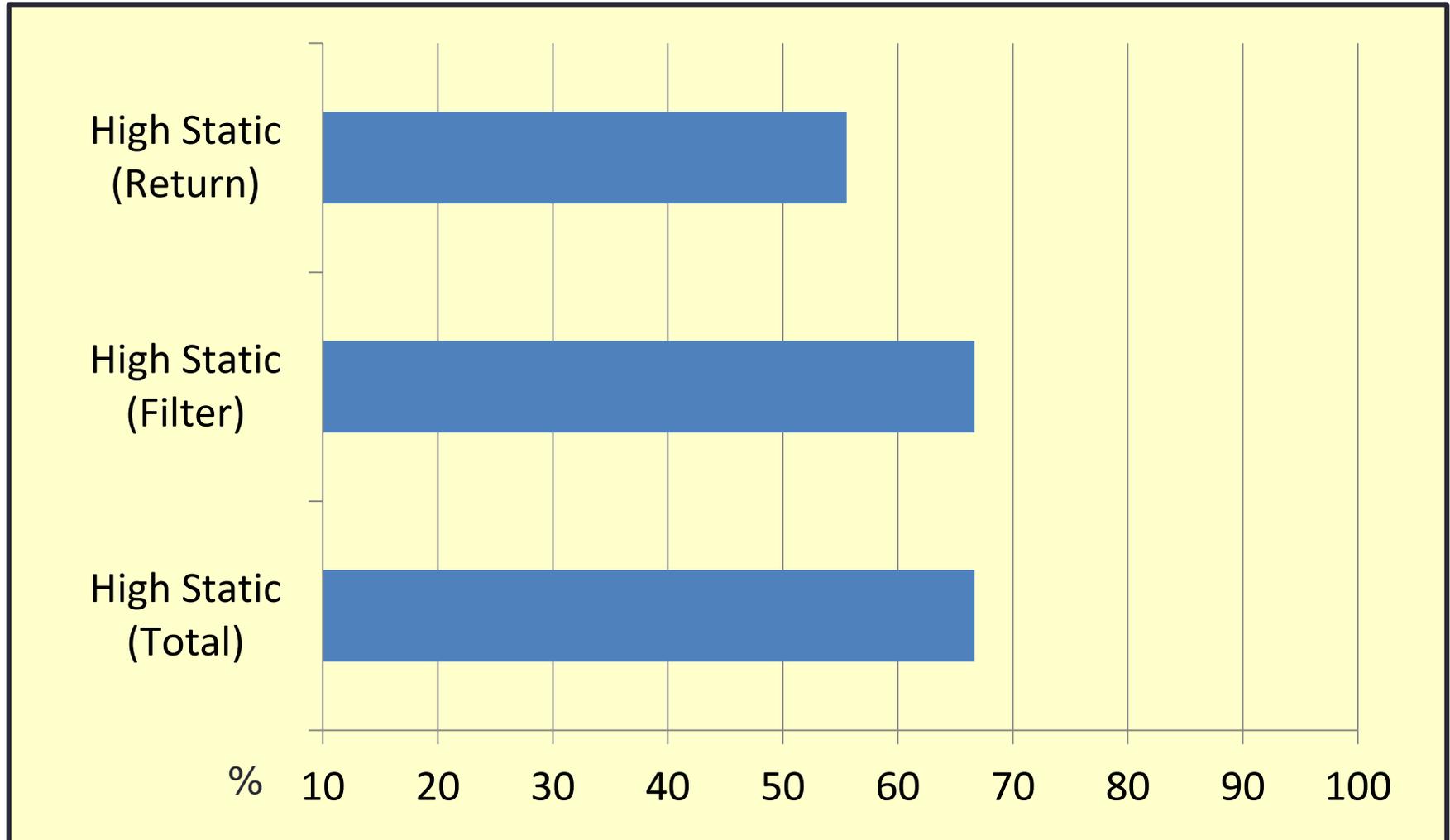
## 3 Big Issues with 24/7 High MERV Filter

- **Air handler (AHU) energy use /cost** 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 (system air flow)**
  - 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)

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

# Problems Identified (%)

45 systems (as found)



# OUR RETROFIT

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# ROCIS Air Handler Retrofit

## Post-retrofit (Case w2i9)

### STEP 1

Modified larger return drop



(Case w2i9)

# ROCIS Air Handler Retrofit

## STEP 1

### Modified larger return drop

Larger return drop

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

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



## RESULTS:

**Pressure drop across filter:**

Pre: 93 Pa, Post: 16 Pa

**Allowable (total system) TESP: 125 Pa**

(Case w2i9)

# ROCIS Air Handler Retrofit

STEP 2 (not always needed)

New ECM

Labor & materials \$500



## RESULTS:

**In continuous mode:**

- 4.27 CFM/watt
- 120 Watts

ECM  
replacement

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

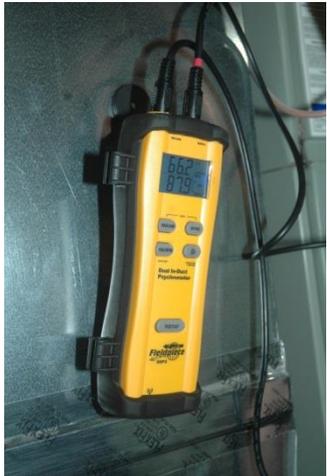
(Case w2i9)

# ROCIS Air Handler Retrofit

## STEP 3

Adjust fan speeds to optimize heating, cooling, & continuous performance

Verify system air flows, watt-draw, & static pressure



# ROCIS Air Handler Retrofit

## STEP 4

Monitor performance

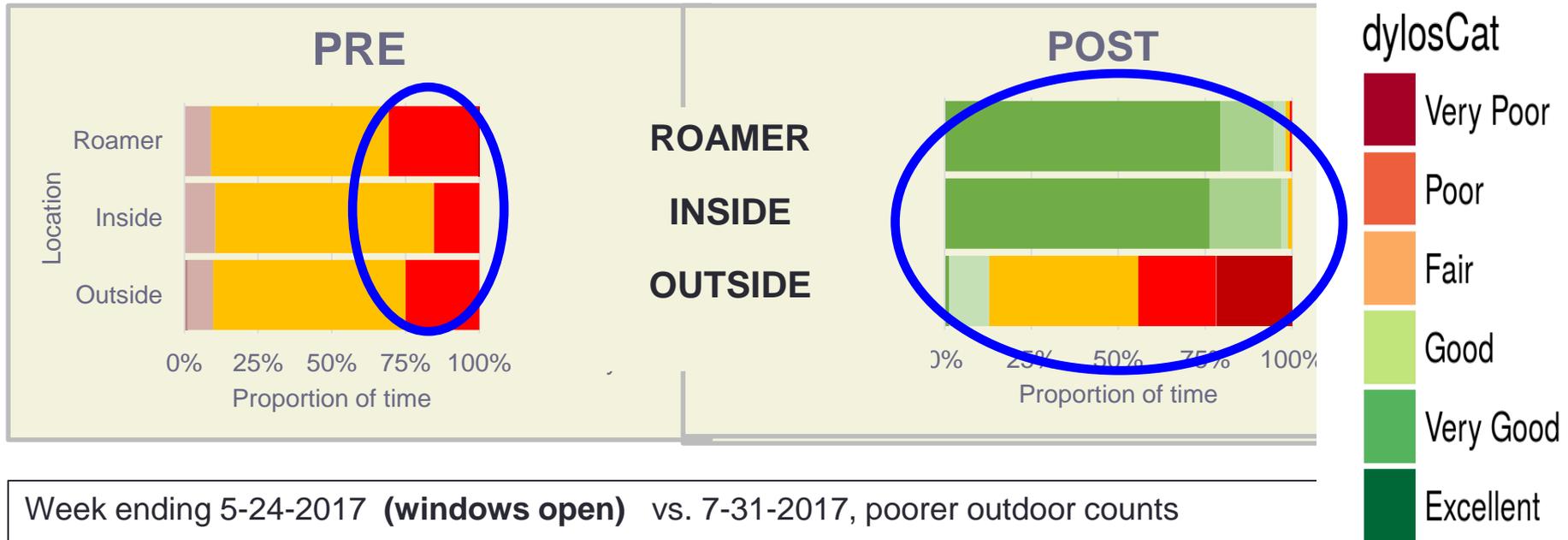
Monitor inside particles

(0.3, 0.5, 1.0 & 2.5 microns)



Monitor change in static across filter

# Case w2i9 Pre & Post – Air Handler Retrofit



## 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**

# Selected ROCIS Intervention Homes

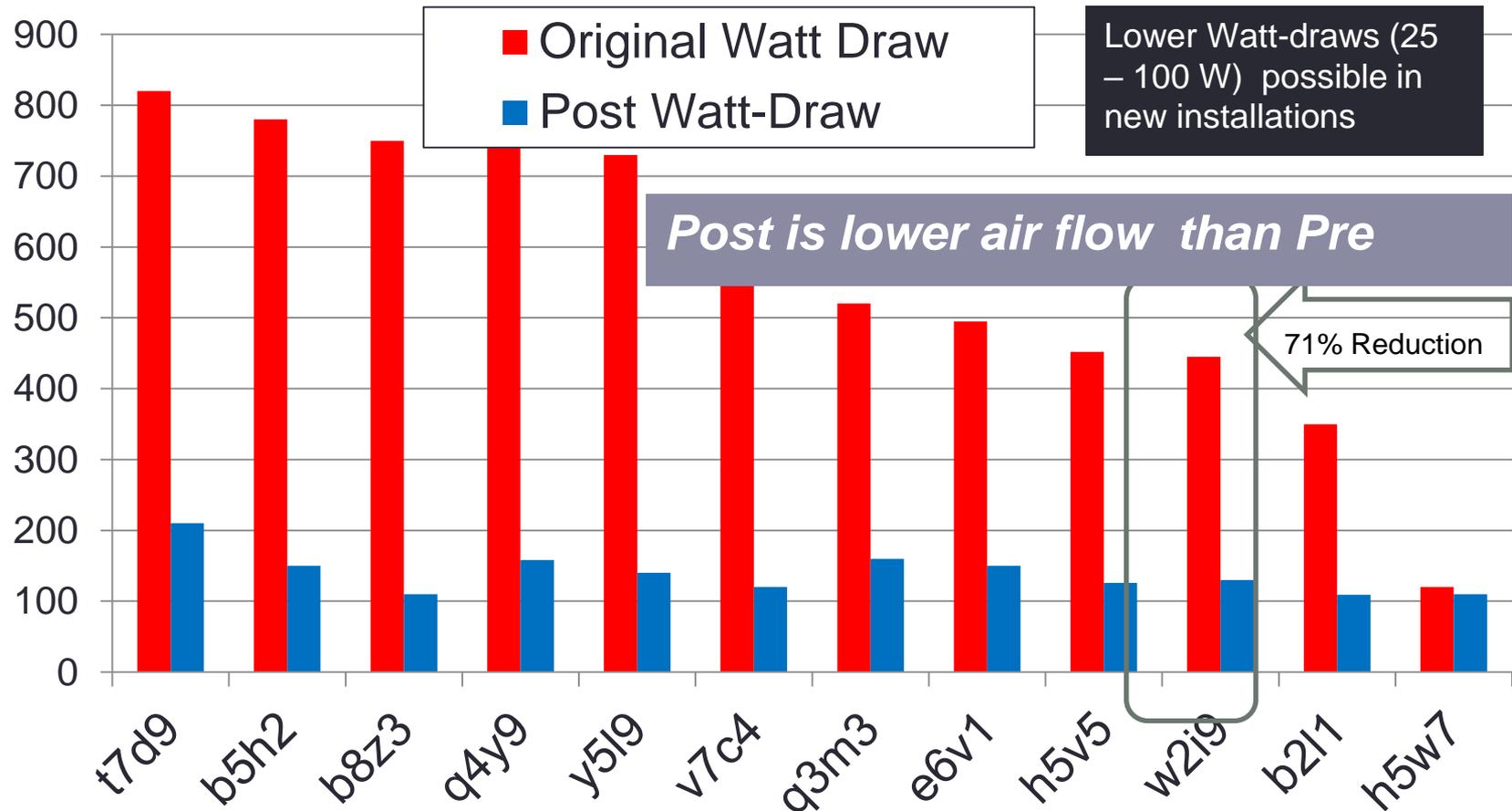
## Pre-Post Median Particle Count



(Case w2i9)

# Air Handler Interventions

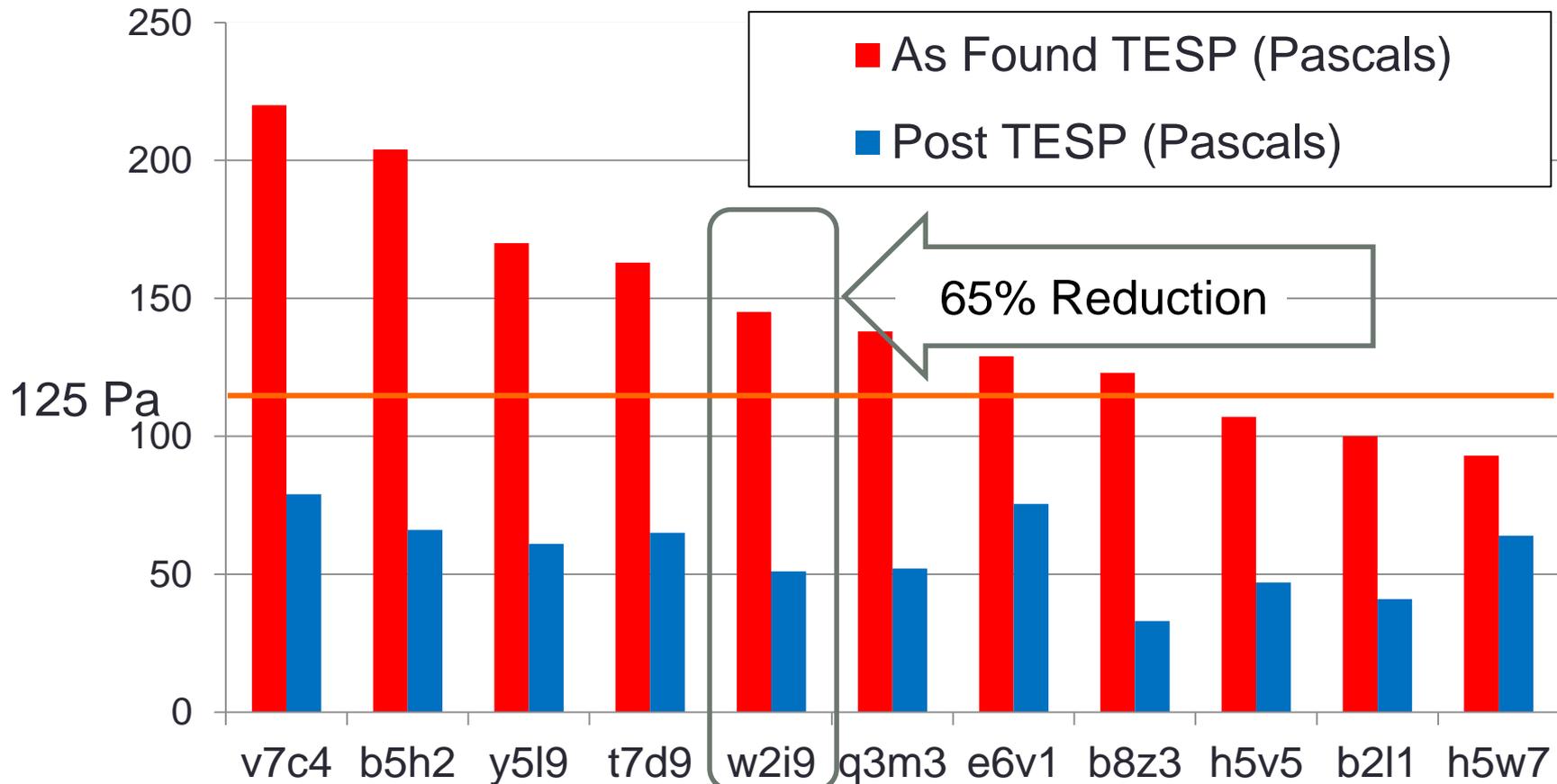
## Pre-Post Continuous Watt-Draw



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**

# Filter Essentials

- Use large filter (surface area)
- Use deep filter (we prefer 4")
- Use low resistance filter (check label on filter)
- Minimize filter bypasses
  
- Use MERV 12 or above to reduce 0.3 to 0.5  $\mu\text{m}$  particles (MERV is like R-Value; *performance depends on installation/operation*)
  
- Provide adequate run/on time (if system passes diagnostic screening)

# ROCIS Air Handler Retrofit

## Current Focus

- ✓ Get more retrofits done; continue monitoring, collecting data
- ✓ Examine potential for better summertime humidity control
- ✓ Lower the installation cost of retrofit (just return drop?)
- ✓ Gain experience with different control options (lower energy cost & emissions further)

# 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
  
- Making the value proposition...
  - How can potential filtration health & comfort benefits add impetus to getting HVAC systems designed & installed correctly?

# In Summary: Filtering Air with Home Heating & Air Conditioning Systems Simultaneously...

***Significant opportunity*** to reduce particles

***Represent a major liability*** (energy use, emissions, energy cost, equipment life & performance)

- ECM failure/replacement due to high static in HVAC systems can cost occupants \$1000
- Variable speed ECMs (best & worst performance)
- Restrictive filters (particularly 1" pleated) lead to high static

***Our solutions reduce fine particles by 50-80% while minimizing risk***

# Join Us! Next Steps

- Engage key players for input & buy-in

<> HVAC manufacturers <> utility companies <> energy efficiency program implementers <> vocational trainers <> trade groups <> affordable housing providers <> sustainability/environmental advocates <> local gov't

- Clarify opportunity to transform practices

***particularly in replacement & new installations***

*Thanks to Phil Johnson &  
The Heinz Endowments for supporting the  
ROCIS initiative  
(Reducing Outdoor Contaminants in Indoor Spaces)  
**and**  
Our 200+ LCMP Participants!*

# 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>



## *Questions? Comments?*

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**Project Lead, ROCIS Initiative**

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**724-986-0793 (Cell – best at this time)**

**[lwigington1@outlook.com](mailto:lwigington1@outlook.com)**

**<http://ROCIS.org>**

**Range Hood Guidance Document**

**<http://rocis.org/kitchen-range-hoods>**

**More info on Air Handler Inquiry**

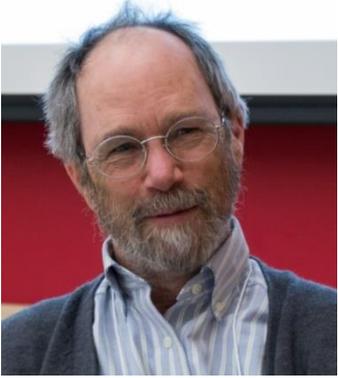
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# **MORE ON ROCIS AIR HANDLER INQUIRY**

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# The ROCIS Team



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

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

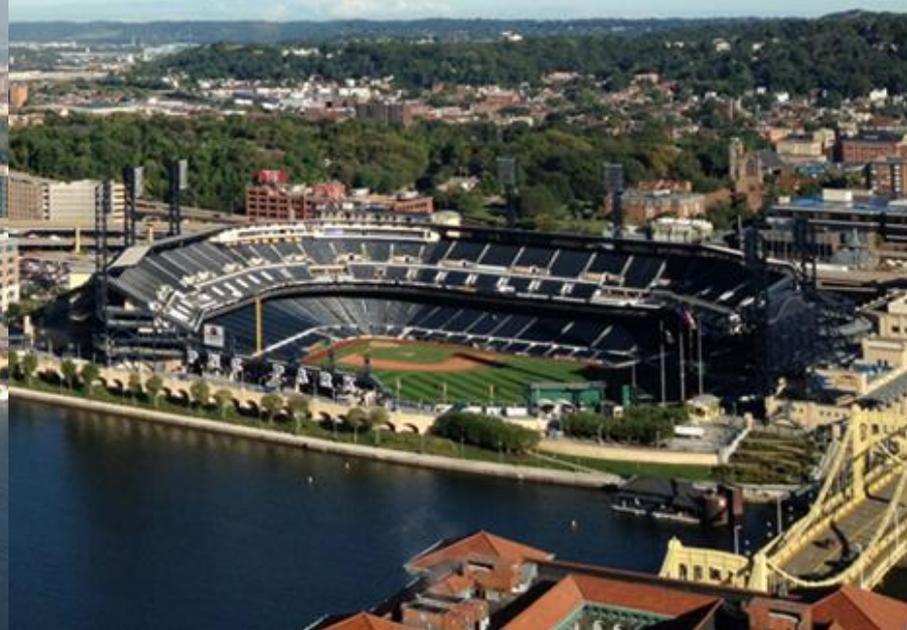


# WHAT IS ROCIS ?

**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

# ROCIS LCMP LOW COST MONITORING PROJECT

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# 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!!***

# 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

# 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>

# Health Concerns (<PM10)<sup>1</sup>

- 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

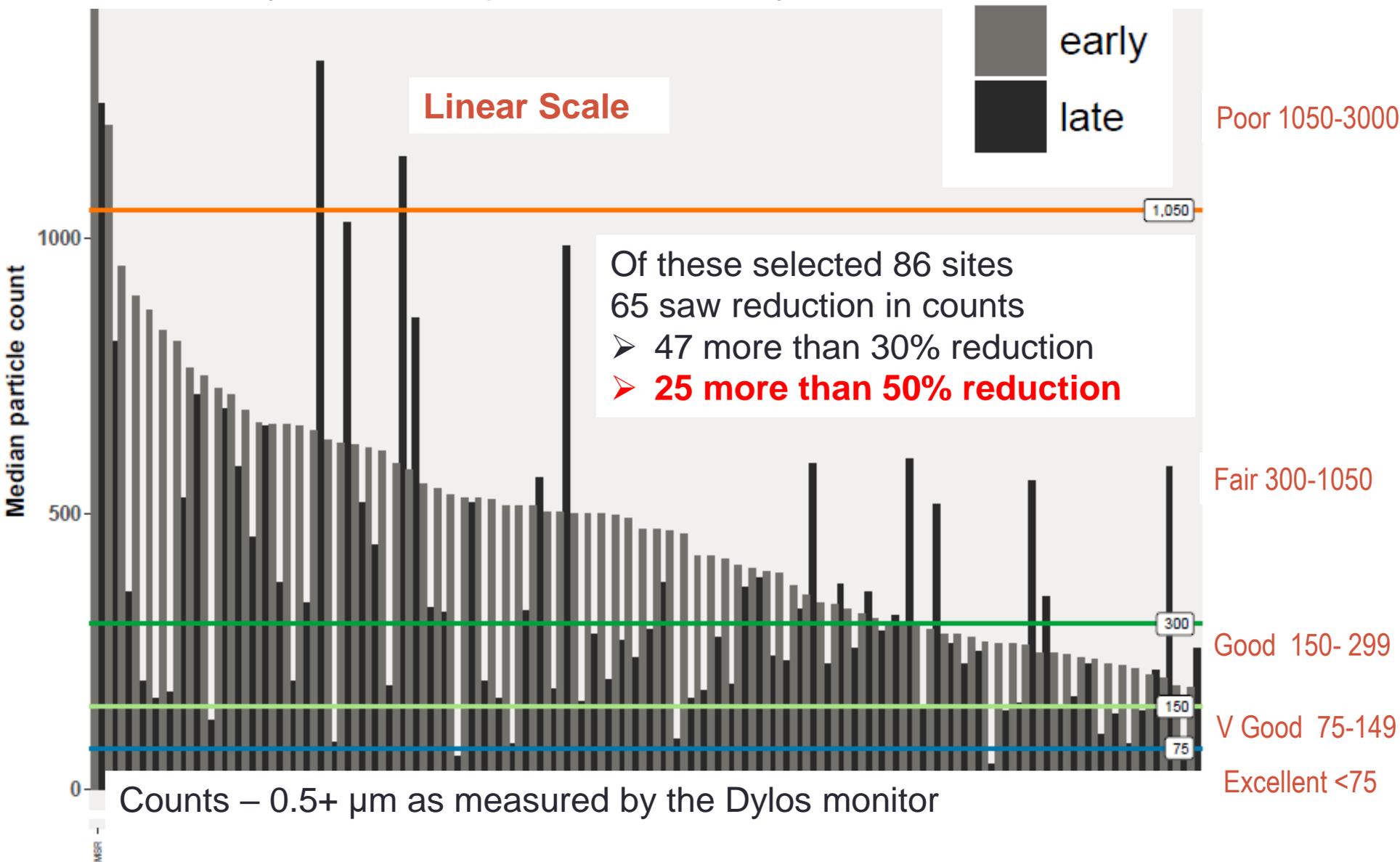
<sup>1</sup>[Source EPA 7/1/2016](#)

# INTERVENTION INSIGHTS

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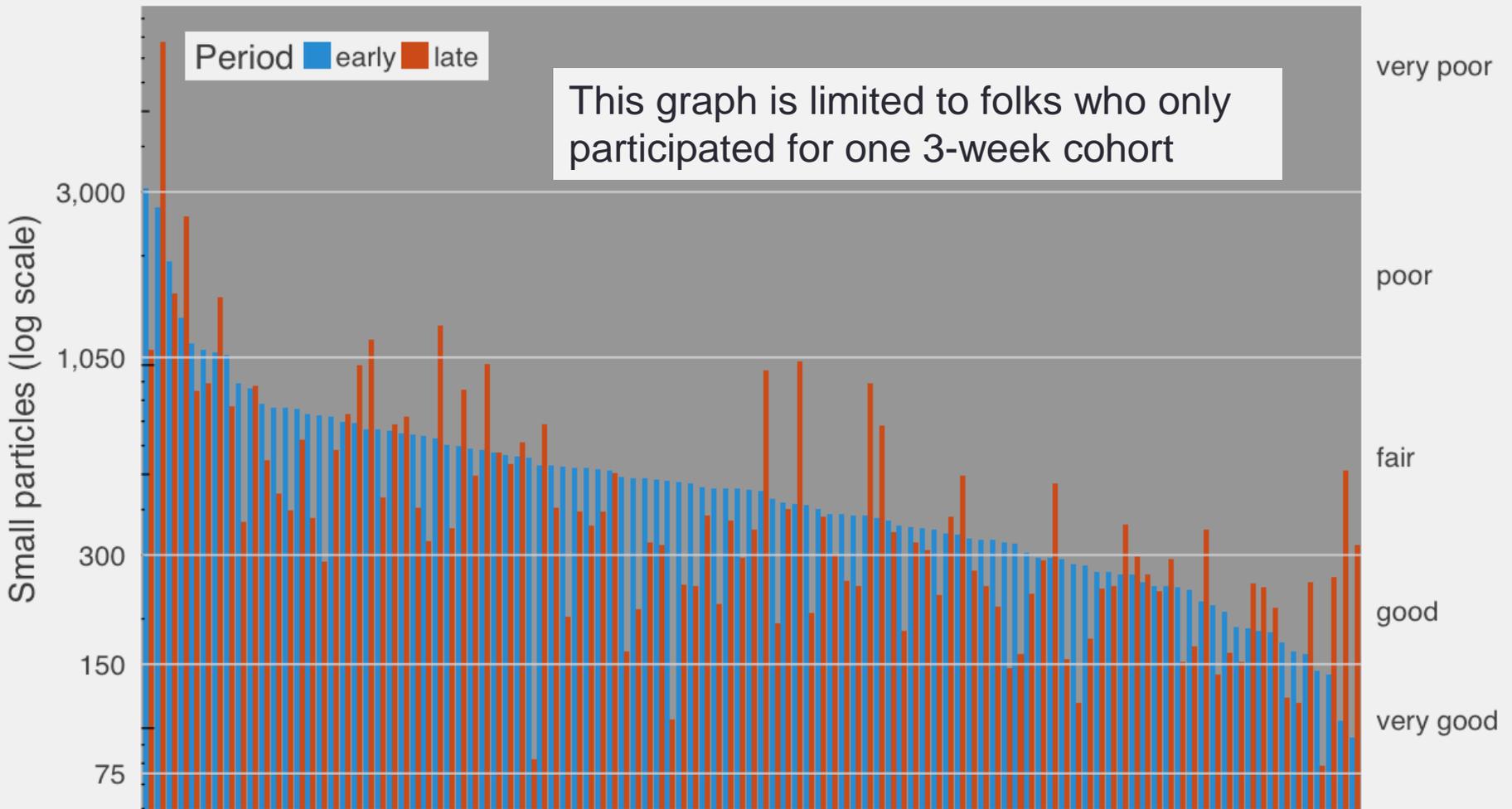
# Comparison of Early Vs. Late Particle Counts (Paired)

First 10 day median compared to last 10 days



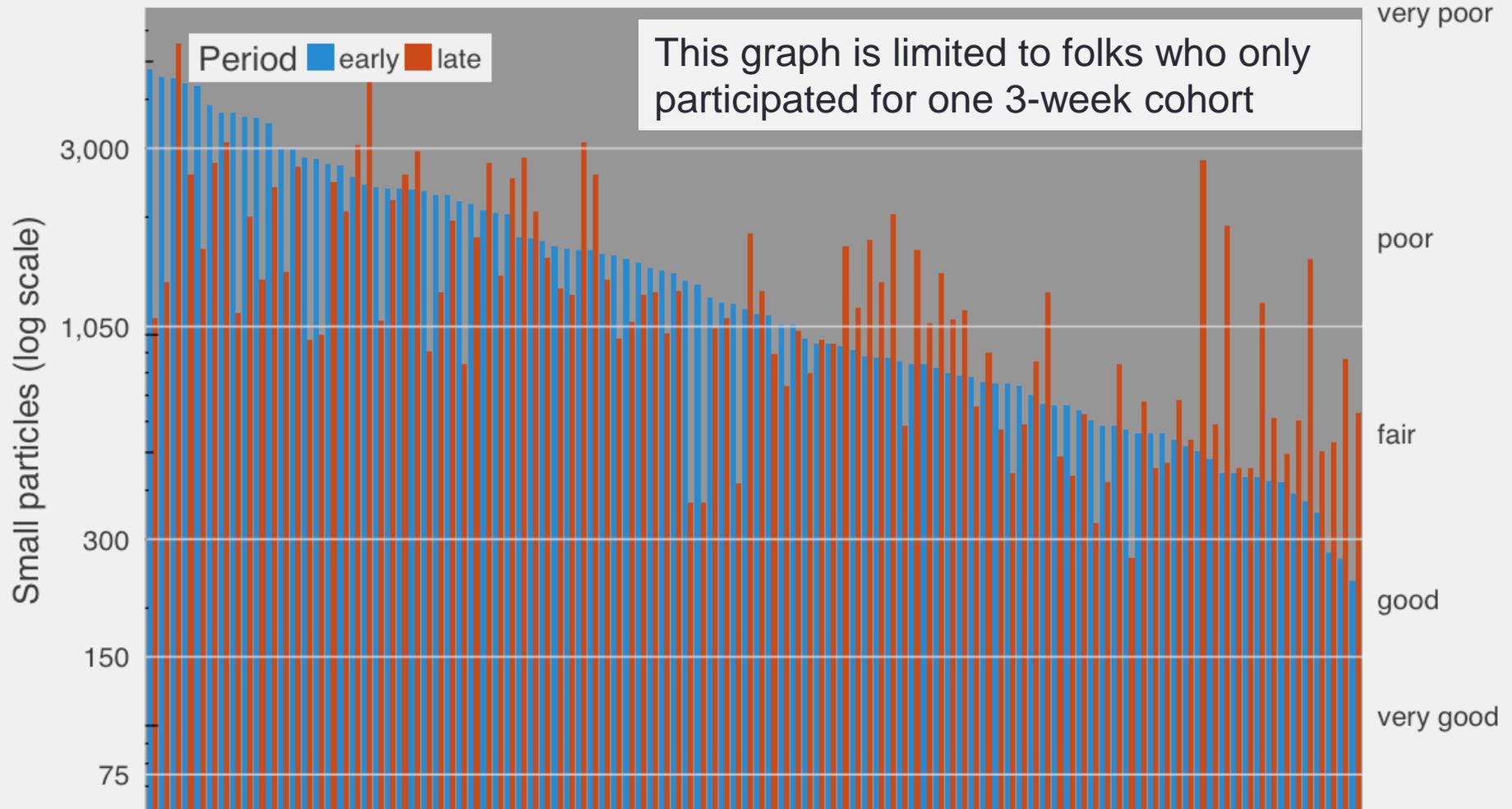
# Indoor Particle Levels

Comparing early vs. late in monitoring period



# Outdoor Particle Levels

Comparing early vs. late in monitoring period



# 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

# 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!!



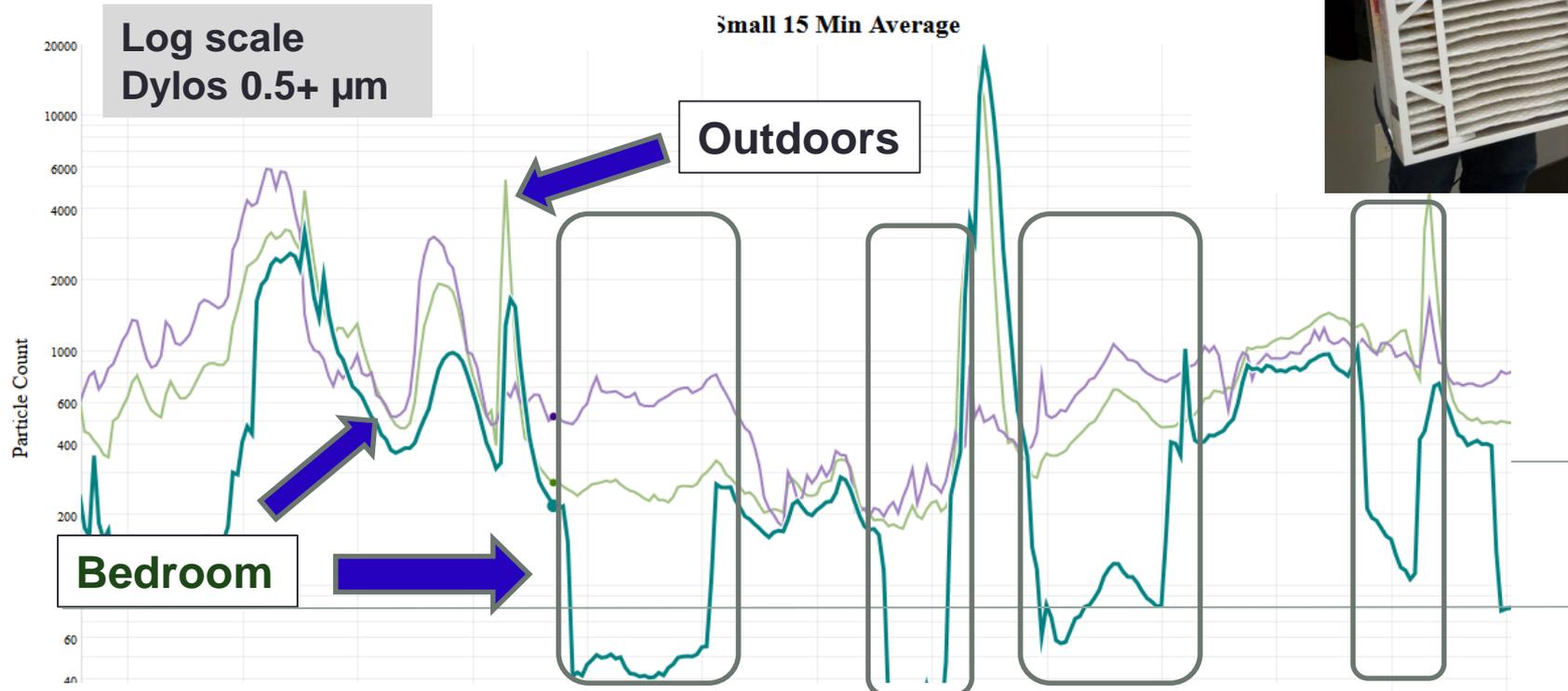
# Fan/Filter Intervention: Low Cost, MERV 13



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>

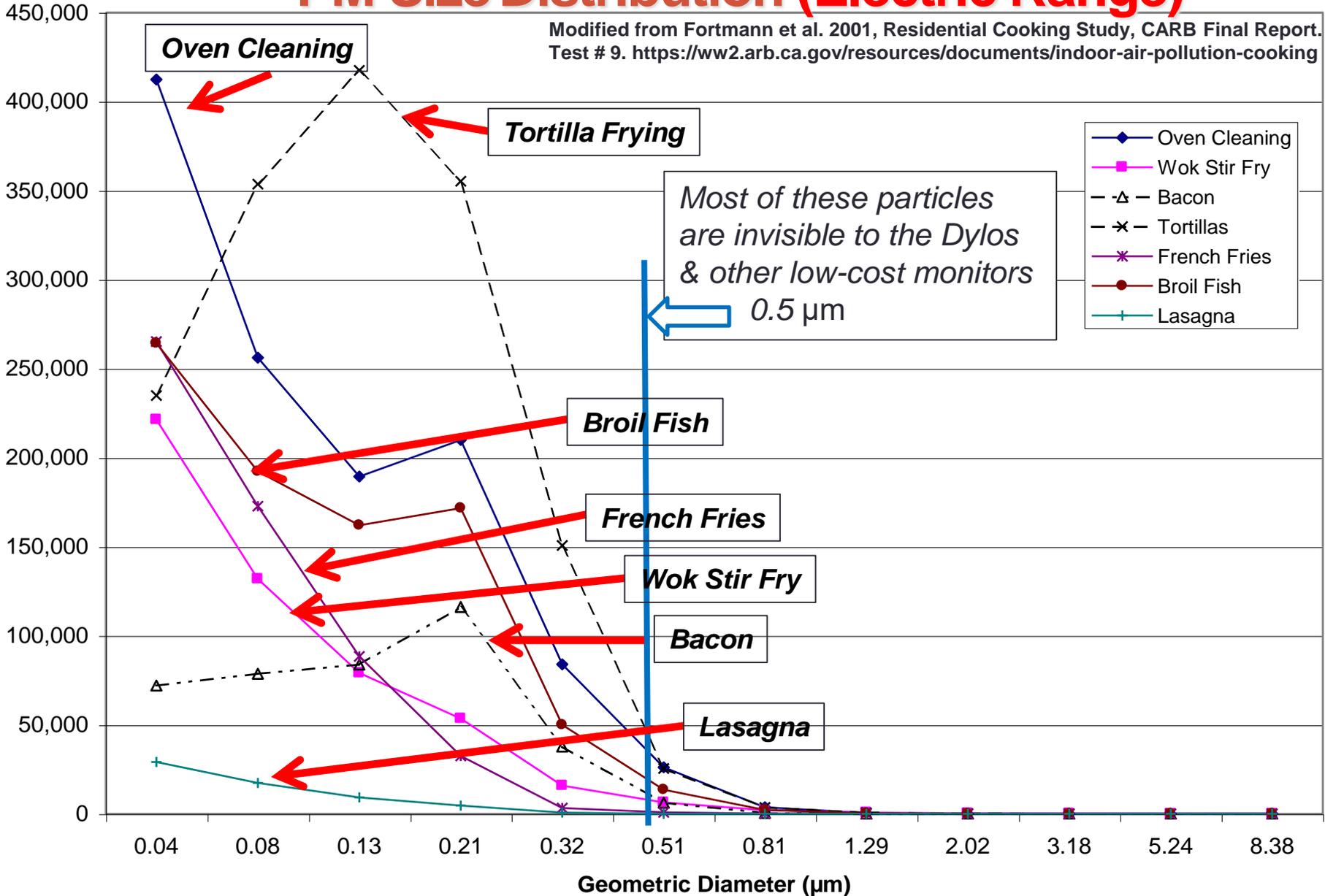
Online Kitchen Ventilation group on Home Energy Pros

[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>



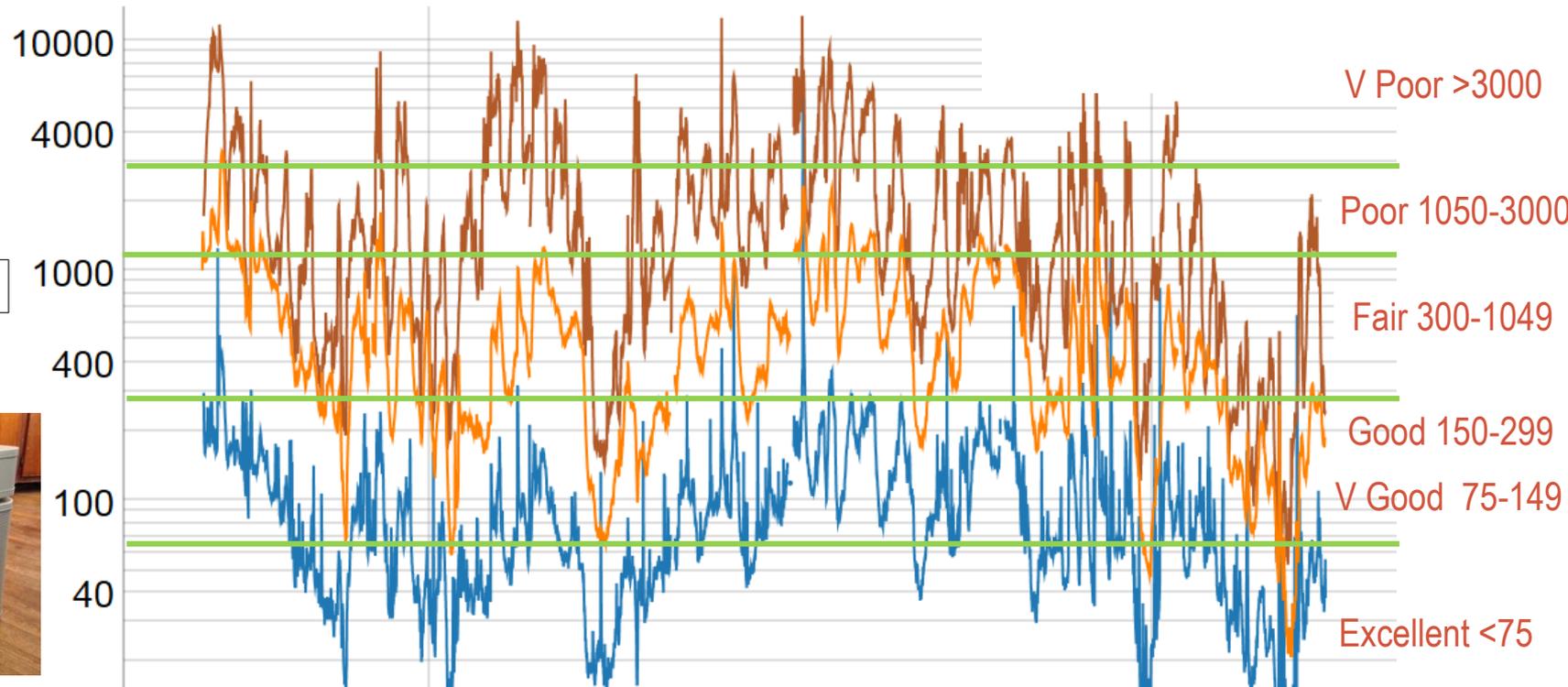
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- Filter air
  - Portable air cleaners
  - Central air handler (furnace, AC, or ventilation)

# 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



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).

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

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

<sup>1</sup> 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)

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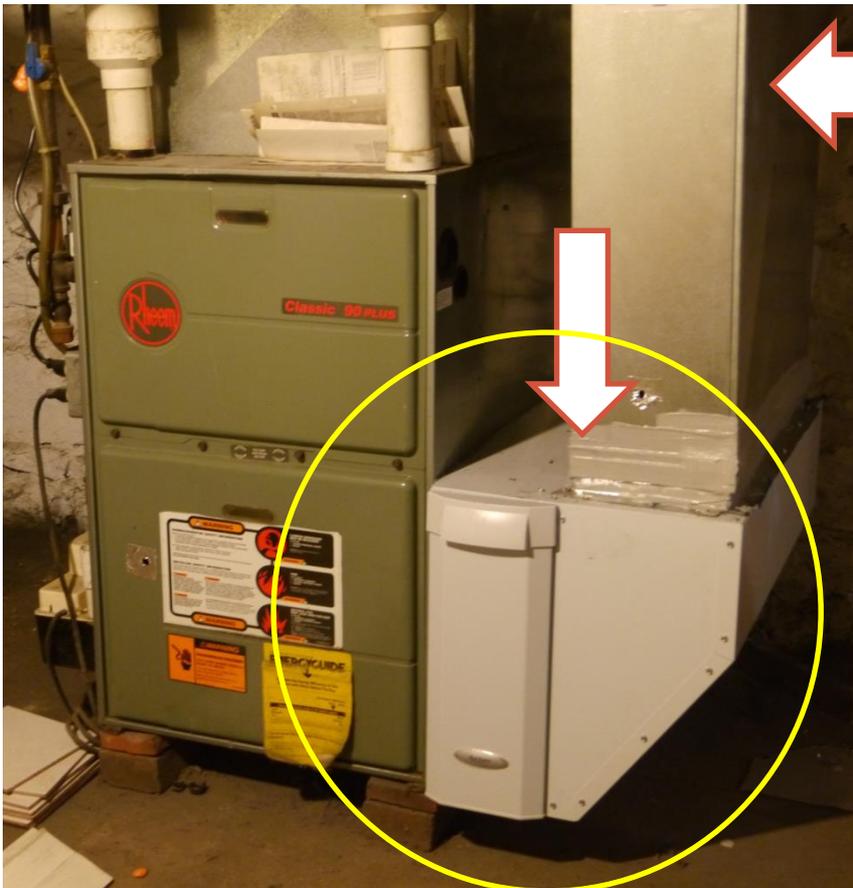


# Air Handler Inquiry: Key Findings

- 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

# 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

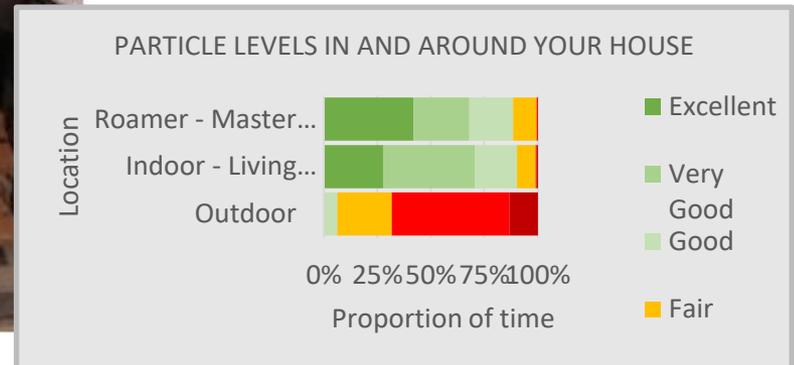
# BEFORE

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



# Case 2

20x25x4 MERV 13

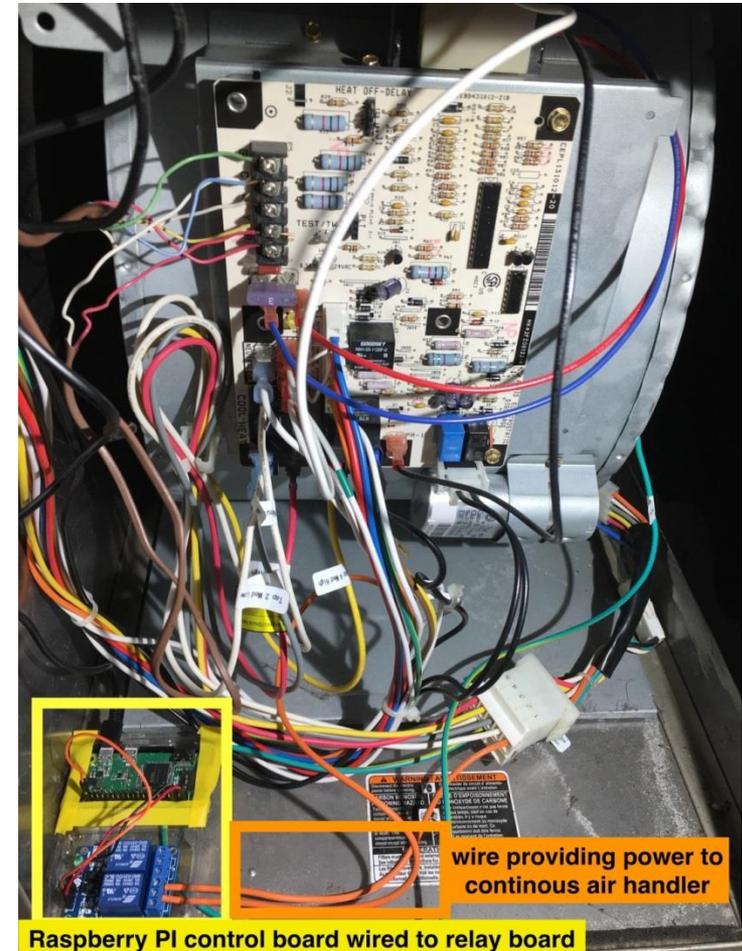


# AFTER

CASE STUDY: Indoor Air Quality Interventions  
Chris Guignon, evolveEA

# 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<sub>2</sub>, humidity) & monitor over time



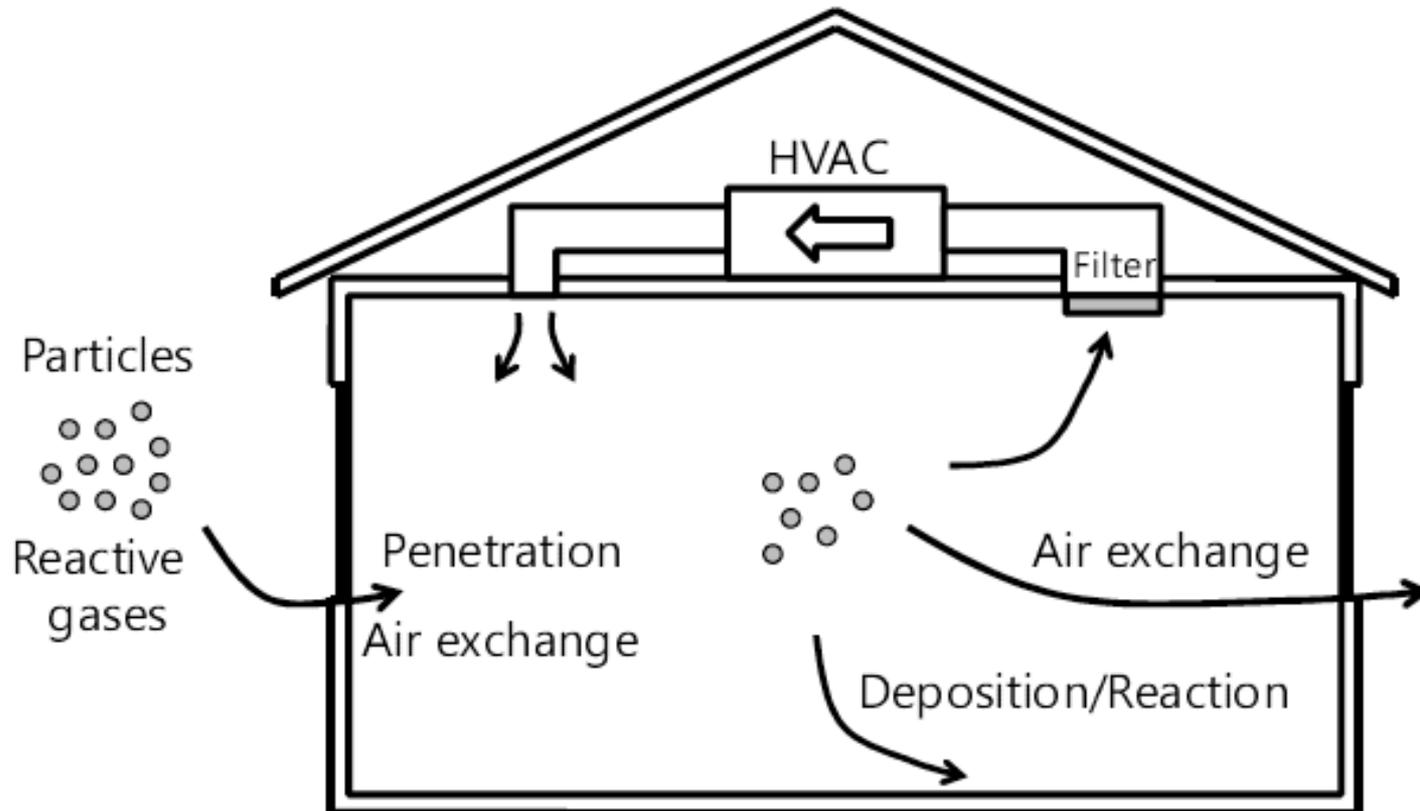
# New Installations - Lost Opportunity!!

- 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)

# EXTRAS

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# Infiltration of Outdoor Pollutants



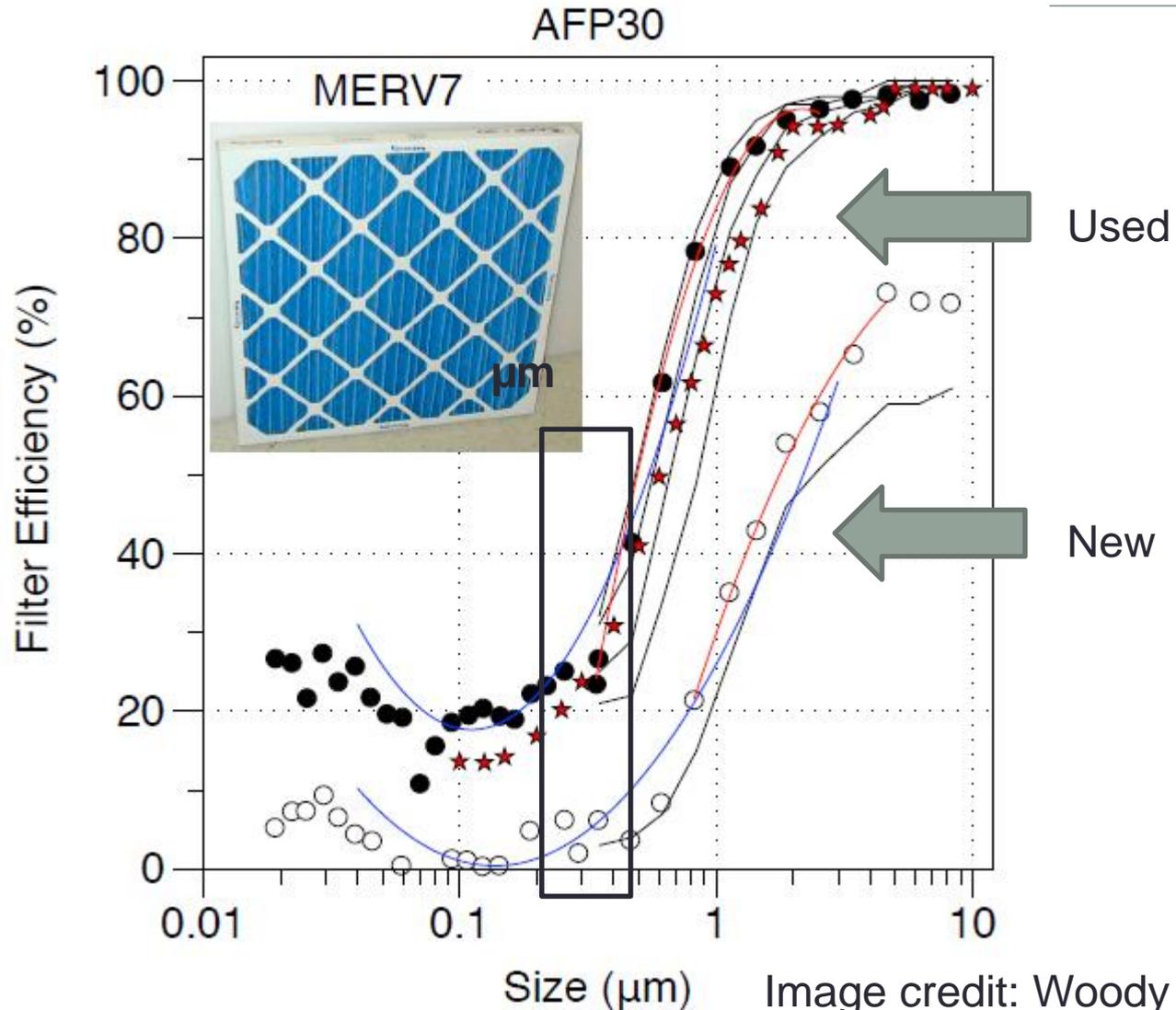


# Air Now

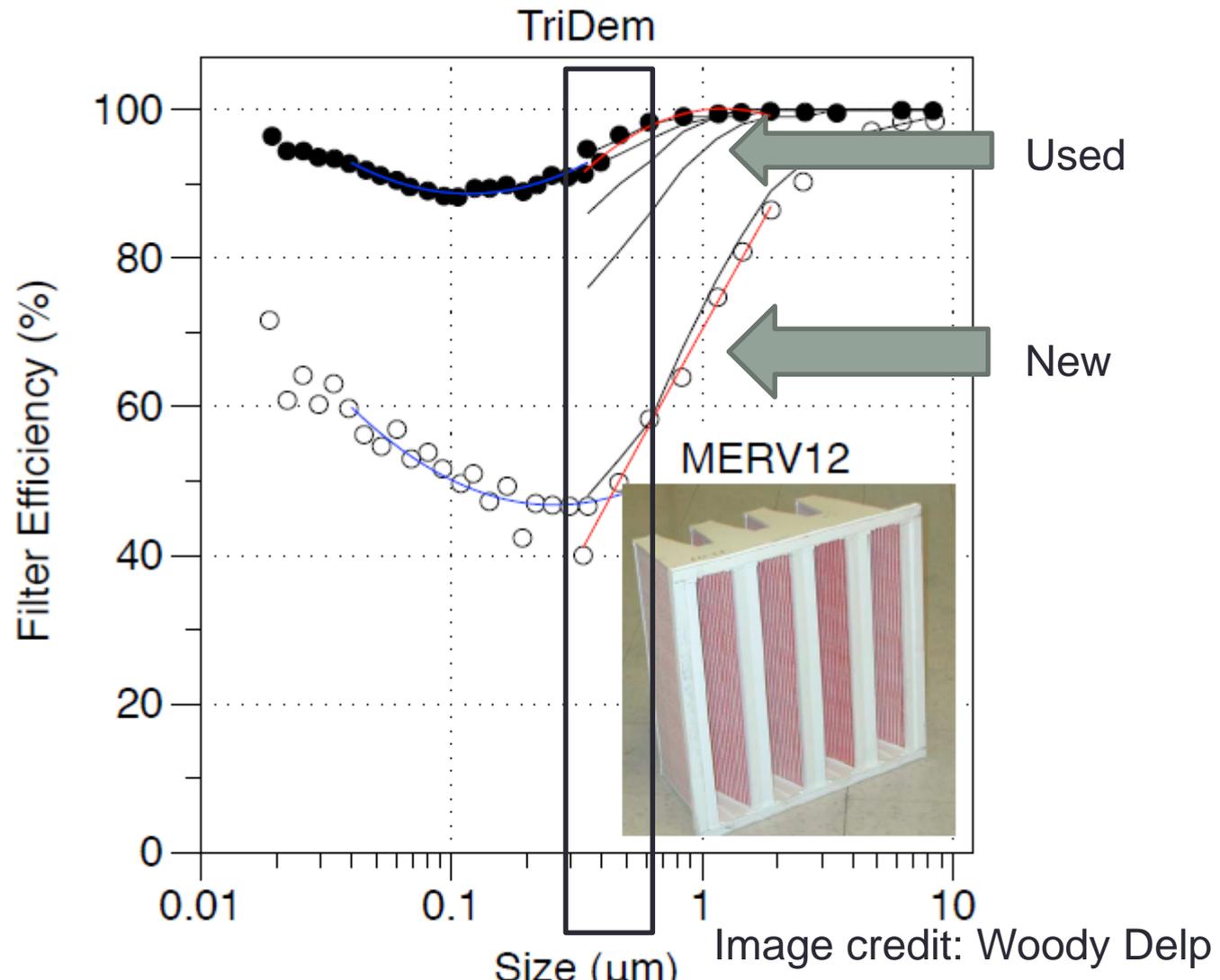
<https://gispub.epa.gov/airnow/>

The screenshot displays the 'AirNow Interactive Map of Air Quality' web application. The browser address bar shows the URL <https://gispub.epa.gov/airnow/>. The application header includes the 'AirNow' logo and the title 'Interactive Map of Air Quality'. Below the header is a navigation menu with tabs for 'Current', 'Forecast', 'Animations', and 'Archive'. A search bar on the right contains the text 'Find address or place'. On the left side, there are several interactive panels: 'NowCast AQI at Monitoring Sites' with a dropdown menu, a list of pollutant categories (Ozone and PM, Ozone, PM, PM2.5, PM10) with checkboxes, 'NowCast AQI Contours', and 'Boundaries'. The main map area shows the United States with numerous green and yellow circular markers representing monitoring sites. The map includes state and city labels, and a 'Data updated Sat October 13, 2018 at 09:00 PM EDT' notice. The bottom of the screen shows a Windows taskbar with various application icons and a system tray with the time '10:09 PM 10/13/2018' and a battery level indicator at '100%'. The Esri logo is visible in the bottom right corner of the map area.

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

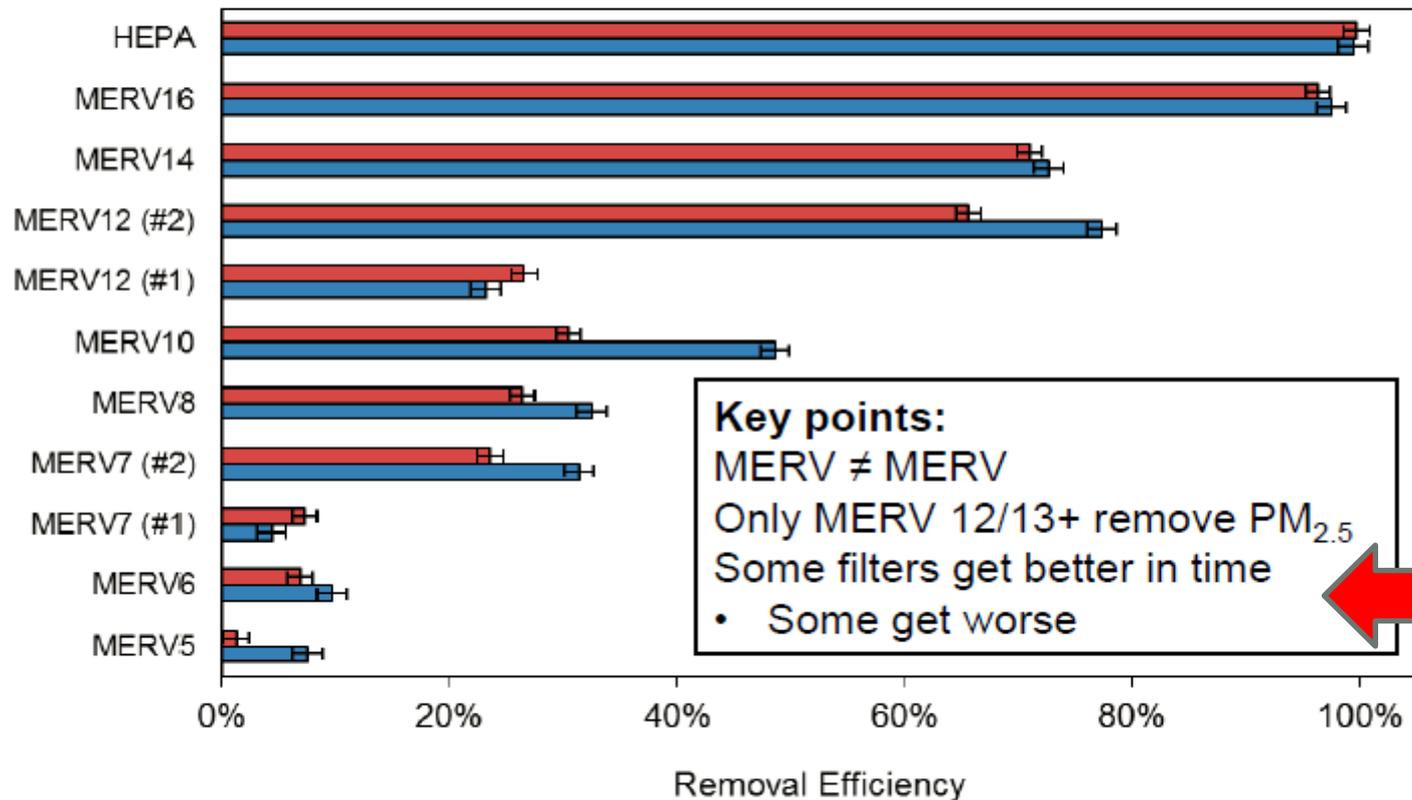


# MERV 12 ...in this case Better Performance Used than New



# 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 34

## Filter bypass is relatively common in homes

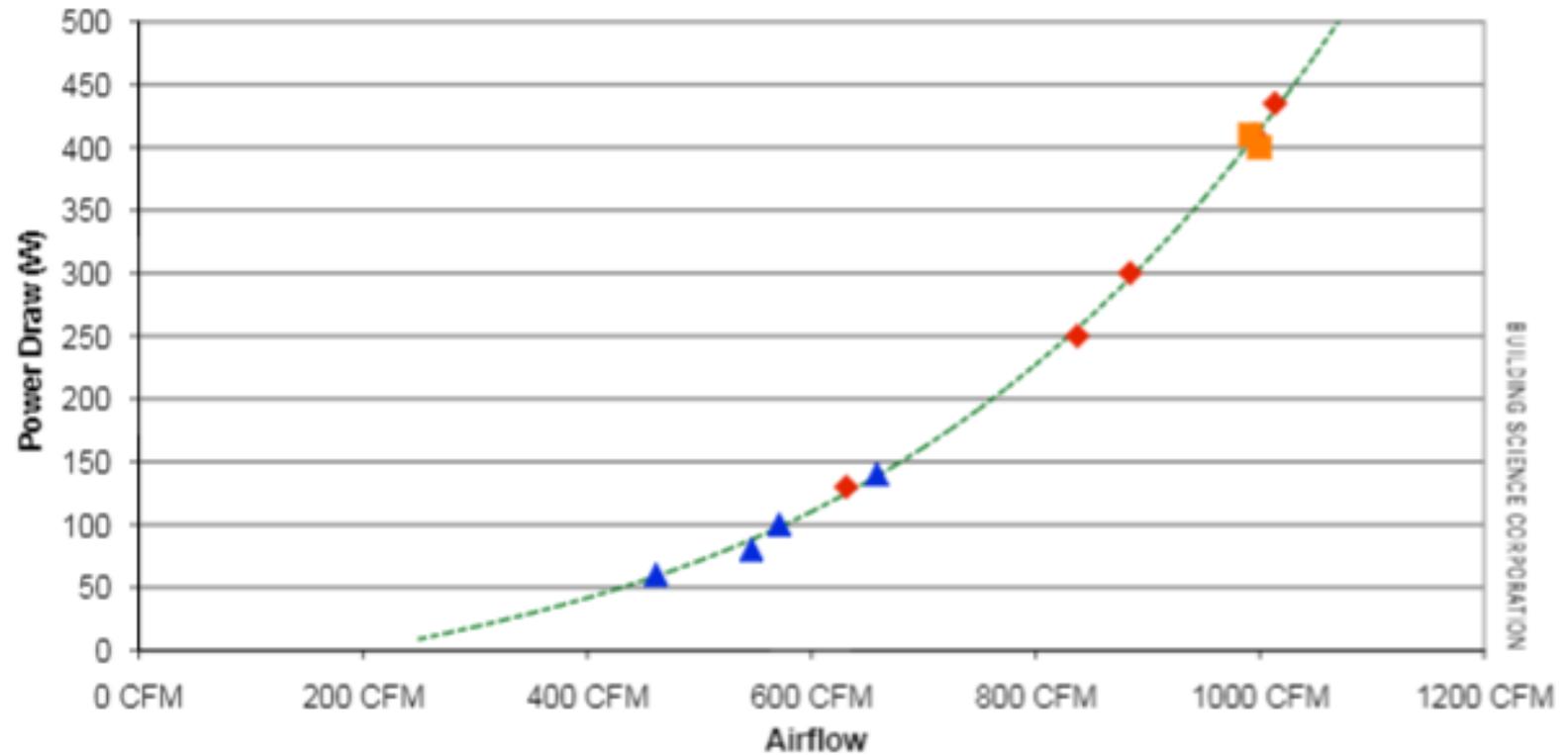
Filter bypass reduces filtration effectiveness

VerShaw et al. 2009 *ASHRAE Transactions*



Photo credit: Brent Stephens

### Power Draw versus Air Flow for Tested Air Handler



Slide credit: Building Science Corporation

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

