WHAT CAN YOU DO WITH A CONSUMER IAQ MONITOR?

National Home Performance Conference

IAQ 2  April 24, 2018  1:30 – 3 PM

Linda Wigington
Team Leader, ROCIS Initiative
lwigington1@outlook.com
724-852-3085
www.ROCIS.org
Four Conclusions

1) Low-Cost monitors can contribute to awareness, behavior change, use of technical interventions, & building capacity of people, communities, & organizations.

2) Outdoor particle counts have a significant impact on indoor levels.

3) Visualization tools influence how one interprets the data.

4) Behavioral & technical interventions can substantially reduce indoor particle levels.
ROCIS *(Rock-us) or (Raucous)*
Reducing Outdoor Contaminants in Indoor Spaces

WWW.ROCIS.ORG
WHAT IS ROCIS?

A Southwestern Pennsylvania initiative to reduce the impact of exterior pollution in indoor spaces.
Why is IEQ Important? (Indoor Environmental Quality)

- About 90% of our time is spent indoors
- Vulnerable groups spend more time indoors (95%+)

**Avg. Daily Time (%)**

- **Indoor-Home**
- **Indoor-Other**
- **Outdoors**
- **In Vehicle**
- **Indoor Total 88.9%**

*Canadian Human Activity Pattern Survey 2, 2010-11*

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
Low Cost Monitoring Kit

(3) Dylos Particle Counter  DC1700  
http://www.dylosproducts.com/dc1700.html

(2) Corentium Radon  https://airthings.com/us/

(1-2) Carbon Monoxide (CO) Monitors  

(2) CO₂ TIM12 Datalogging Meter  www.co2meter.com

Our cost - ~ $1,600-$1,800/kit  
(Quantity discounts, some donated equipment)

No cost to participants for monitoring
Making the Invisible Visible

Dylos 1700 Optical Particle Counter:
# Particles per 1/100 ft³, 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

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 13$^{th}$ worst

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

**Particles**

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!)

**OUTDOOR BLACK CARBON**

50 nm to 1 µm
LCMP Design: Not a Regulatory Focus

- Measuring particle count, not mass; 1-min. resolution
- Focus on indoor / outdoor comparison
- Proof of concept – exploration of interventions

Health Concerns

- Fine (PM_{2.5}) & Ultra-Fine Particles (PM_{0.1}) can be vehicles to increase exposure of toxic contaminants such as SVOCs & metals
- Precautionary principle should apply – avoid or minimize exposure
Ambient Air Pollution Impacts

(WHO) 3.7 million excess deaths globally/year

130,000 deaths annually in U.S. alone
DATA VISUALIZATION
Opportunities & Challenge
Outdoor Impacts Indoors
Occupant Insights

Spikes dominate awareness

Biggest Impressions (Indoor Incidents)

- Cooking
- Cleaning
- Active occupants (e.g. children)
- Remodeling
Visualization Challenges
Making Sense out of Data!

80 million data points –
...downloaded manually, 20K at a time!

- Comparison to others
- Impact of outside counts on inside
- Comparison over time / Impact of interventions
  - Did actions make a difference? How much?
Visualize Impact of Outdoor on Indoor, and Impact of Interactions

ROCIS LCMP tools include:

(http://rocis.org/rocis-data)

- Outdoor Dylos Data Plot by Cohort (Weebly site)

- LCMP Averager (Excel macro)
  - Feedback after each download
  - http://rocis.org/rocis-averager

- LCMP Data Explorer (R Shiny web app)
  - http://rocis.org/rocis-data-explorer
Indoor Median & Distribution
(Dylos Total 0.5+ μm)

15-minute avg.

More than 10 to 1 difference!
Median: ~2/3 Fair; ~1/3 Good

Log Scale

V Poor >3000
Poor 1050-3000
Fair 300-1049
Good 150-300
V Good 75-149
Excellent <75
Outdoor Median & Distribution (Dylos Total - 0.5+ um)

15-minute avg.

~½ Poor; ½ Fair

Log Scale

50% of observations are within each vertical box
Outdoor Data by Cohort - (70 mile spread) - Readings track

Log scale

Most sites are Pittsburgh; Green line (Wbg) is 50 miles south of Pittsburgh. Dylos particles (0.5+ μm)
Online Data Explorer
Indoor Counts Track Outdoors

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

V Poor >3000
Poor 1050-3000
Fair 300-1049
Good 150-299
V Good 75-149
Excellent <75

Blue: treated zone
Orange: untreated zone
Deep red: outdoors
Tight, single family home
Though order of magnitude lower; Indoor (Blue/orange) tracks Outdoor
What if Outdoor AQ was “Good” All the Time?

Using online ROCIS Data Explorer
http://rocis.org/rocis-data-explorer
What if Outdoor AQ was “Bad” All the Time?

When Outdoor: Highest 25%ile (Worst)

Using online ROCIS Data Explorer
http://rocis.org/rocis-data-explorer
PARTICLE DISTRIBUTION
BY SITE VS

Household Characterization Survey Data
Indoor Particle Levels

What kind of AIR CONDITIONER do you have?

- very poor
- poor
- fair
- good
- very good
- excellent

Small particles (log scale)
Indoor Particle Levels

Is your home DETACHED?
Indoor Particle Levels

Do you have PETS?

havePets: no, yes
Indoor Particle Levels
Do you REMOVE YOUR SHOES in the house?
Indoor Particle Levels

How frequently do you use your STOVE TO COOK?

![Graph showing indoor particle levels with categories very poor, poor, fair, good, very good, excellent, and frequencies ranging from 10 to 10,000 small particles on a log scale. The graph includes data for stove usage frequency, categorized as daily and rarely.]
INTERVENTION INSIGHTS

And the Role of Low Cost Monitors
Comparison of Early Vs. Late Particle Counts
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

This graph is limited to folks who only participated for one cohort & did not do an intervention, other than changes within the 3-week 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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  - 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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LCMP Focus - Proof of Concept

• Explore interventions: **effectiveness & feasibility**

• What is **possible?** What are the constraints?

• Gain **experience and insight** to help bring interventions to pilot & / or scale
Options to Reduce Indoor Particles

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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+ μm + (Particle #/100ft³)

Windows open

Closed
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!
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• **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)
Behavior *Plus* Technical Intervention

**Motivated Occupant**

**INTERVENTIONS**

1) Change use of humidifier
2) Add induction stovetop & use fan/filter (living room)
3) Add fan/filter (bedroom)

[2-burner Induction Stovetop](http://rocis.org/rocis-data-explorer) (h9j2) (example 2)
Options to Reduce Indoor Particles

- Reduce air exchange from outside
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- Filter air
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  - Central air handler (furnace, AC, or ventilation)
Impact of Portable Air Cleaner

http://rocis.org/rocis-data-explorer (jt8) 0.5+ μm Particles by Time (15-min. avg.)

Your Indoor Particles vs. Time

Blue: treated zone
Orange: untreated zone
Red: outdoors

Tight, single family home
Though order of magnitude lower; Indoor (Blue/orange) tracks Outdoor

Log scale
Indoor Fan Filter 24/7 Impact

http://rocis.org/rocis-data-explorer (k4x3)
Portable Air Cleaners
Fan/filters

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

Issues
• Inadequate run time
  • Role of feedback (low cost monitor)
• Noise and wintertime discomfort
• Filter replacement
• Cost of air cleaner(s) ($, kWh, GHG emissions)
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
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- **Filter air**
  - Portable air cleaners
  - Central air handler (furnace, AC, or ventilation)
# MERV Filter Rating – Particle Size

...your mileage will vary at any given MERV rating

<table>
<thead>
<tr>
<th>MERV</th>
<th>Particle Size Range</th>
<th>Typical controlled contaminant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–4</td>
<td>&gt; 10 μm</td>
<td>Pollen, dust mites, cockroach debris, sanding dust, spray paint dust, textile fibers, carpet fibers</td>
</tr>
<tr>
<td>5–8</td>
<td>3 – 10 μm</td>
<td>Mold, spores, dust mite debris, cat and dog dander, hair spray, fabric protector, dusting aids, pudding mix</td>
</tr>
<tr>
<td>9–12</td>
<td>1 – 3 μm</td>
<td>Legionella, humidifier dust, lead dust, milled flour, vehicle emission particles, nebulizer droplets</td>
</tr>
<tr>
<td>13–16</td>
<td>0.3 – 1 μm</td>
<td>Bacteria, droplet nuclei (sneeze), cooking oil, most smoke and insecticide dust, most face powder, most paint pigments</td>
</tr>
</tbody>
</table>

*Due to air resistance, filters over MERV 13 not recommended in home HVAC systems*

Source: Adapted from EPA, 2009 in Wikipedia, 2018
ROCIS AIR HANDLER INQUIRY
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 too high
  - Duct leaks (energy waste & pressure-related problems)

\(^1\) $0.12/kWh
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
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”
**RESULTS:**
5 yr. old home
Significant comfort improvement!

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

**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)

**ECM replacement**

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

**Much Better Performance!**
Pre & Post – Air Handler Retrofit

**PRE**

- Roamer
- Inside
- Outside

**POST**

- Roamer
- Inside
- Outside

**Location**

- Proportion of time

---

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 CO₂ 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

85% Reduction in Particles!!

Pre (~) 480
Post (~) 65

Fair 300-1049
Good 150-299
V Good 75-149
Excellent <75
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 limit of 125 Pascal's.
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

Even lower post Watt-draws should be possible with a different ECM

71% Reduction
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
Big Opportunity at HVAC replacement

- Downsize HVAC to reduce TESP
- 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**
Low Cost Monitors

- Huge Potential
  - Making the *invisible* visible
  - Changing *perception*
  - Reinforcing behavior & interventions
    - Adoption & continued use

- Ideally within a framework of technical support and peers

- Not known: How much of LCMP impact is due to *engagement*, not just presence of low cost monitors
Low Cost Monitors - Cons

- False assurance –
  - No problem – Monitor says AQ is pretty good!
- Monitor limitations not understood
Four Conclusions

1) Low-Cost monitors can contribute to awareness, behavior change, use of technical interventions, & building capacity of people, communities, & organizations.

2) Outdoor particle counts have a significant impact on indoor levels.

3) Visualization tools influence how one interprets the data.

4) Behavioral & technical interventions can substantially reduce indoor particle levels
Bottom Line!

Integrated solutions are needed to enhance health, resilience, energy efficiency, comfort, & durability (engagement, building tightness, source control, 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!
The ROCIS Team

Don Fugler
LCMP Research
Ottawa, Canada

Kacy McGill
LCMP Coordinator
North Huntingdon, PA

Bill Turner, P.E.
Consultant
Harrison, ME

Norm Anderson
Advisor
Winthrop, ME

Yujie Xu
Data Management
Pittsburgh, PA

Rhett Major
Air Handler Inquiry
North Huntingdon, PA

Greg Fanslow
LCMP Data Analysis
Burlington, VT

Rob Busher
Air Quality Fellow
Pittsburgh, PA

Tom Phillips
Range Hood Brief
Davis, CA

Linda Wigington
Team Leader
Waynesburg, PA
Questions?

http://ROCIS.org/

- White papers & presentations
- Access to resources & research results
  - LCMP http://rocis.org/rocis-low-cost-monitoring-project
  - ROCIS Brief - Ducted Range Hood (Tom Phillips)
    - http://rocis.org/kitchen-range-hoods
  - Air Handler Inquiry http://rocis.org/air-handler-inquiry
  - ROCIS Data http://rocis.org/rocis-data

- Stay Tuned
  - ROCIS Brief - Portable Air Cleaners
  - Video Shorts - Telling the Story
For 2 years, ROCIS (http://rocis.org/) has engaged over 180 professionals & homeowners in monitoring their homes (& a few workplaces) in southwestern PA. Emphasis has been on monitoring particles (0.5+ microns) inside & outside to better understand the impact of outdoor air pollution on IAQ. While typical participation is for a 3-week period, 40+ sites have tested interventions & monitored for longer periods. Explore what we have learned in an effort to understand the 10 to 1 difference in median particle counts from one site to another.
Infiltration of Outdoor Pollutants

Examining the interface…


Illinois Institute of Technology (For PDF: Scroll down to "other publications“): http://built-envi.com/pubs/
Resources: Filtration & Air Cleaners

Available from:
U.S. EPA's web site
http://www.epa.gov/iaq/pubs/residair.html

Residential Air Cleaners
Resources: Low Cost Monitoring

EPA’s Air Sensor Toolbox for Citizen Scientists

https://www.epa.gov/air-sensor-toolbox

- Data interpretation guidelines
- Education & outreach
- Low cost sensor performance information
TOPICS

- Building Ventilation
- Indoor Dampness
- Indoor Volatile Organic Compounds
- Human Performance and Productivity
- Benefits of Improving Indoor Environmental Quality
- Air Cleaning Effects on Health and Perceived Air Quality
- Climate Change, Indoor Environmental Quality, & Health

https://iaqscience.lbl.gov/
Current Trends: Outdoor & Indoor AQ

- Worse **outdoor air quality**
- More frequent and larger **wildfires**
- More and a longer pollen season
- Hotter, longer, and more frequent **heat waves**
- More **exposure time indoors**
- Increasing population **density and proximity** to traffic and industrial emissions