ROCIS LOW COST MONITORING PROJECT: LESSONS LEARNED

Pittsburgh’s Air Quality, Indoor Environments, & You

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

**MISSION**

Reduce the impact of exterior environmental pollution in southwestern Pennsylvania to improve healthy & energy efficient indoor environments where we live, work, & learn.
Why??

Most of our exposure to outdoor pollution happens in buildings$^1$

Conclusions

• Outdoor particle counts have a significant impact on indoor levels

• Low cost monitors can contribute to awareness, behavior change, & use of technical interventions, & empower people, communities, & organizations

• Individual actions & community-level initiatives have the potential to substantially reduce the exposure to particles

• Integrated solutions are needed to enhance health, resilience, energy efficiency, & durability of homes, work places, & schools
FOCUS ON PARTICLES

Also referred to as Particulate Matter (PM)
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 greater than 0.5 µm in diameter (1/100 of human hair!)
ROCIS Low Cost Monitoring Project
Using Monitors to Empower Occupants
ROCIS LCMP
Low Cost Monitoring Project

Objectives:
1. Understand How to Use Monitors to Empower Occupants
2. Collect Baseline Data
3. Explore the Impact of Behavioral & Technical Interventions
LCMP – Cohort Model

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

Join us! We are still recruiting for Cohort 24

Kick-off Meeting: Friday, November 3, 2017
Wrap-up Meeting: Thursday, November 30, 2017
ROCIS – Low Cost Monitoring Project
Not a Regulatory Focus

- Based on count, not mass
- Household/bldg. level w/ low-cost monitors
- 1-min. resolution; 15-min avg.
- Focus on indoor/outdoor comparison
- Focus of interventions – proof of concept

Precautionary principle – lower the better

Fine & ultra fine particles could be the vehicle for more toxic contaminants to enter the blood stream
Low Cost Monitoring Kit

(3) Dylos **Particle** Counter DC1700
(1) Speck **Particle** Counter
(2) Corentium **Radon** [https://airthings.com/us/](https://airthings.com/us/)
(2) **CO₂** TIM12 Datalogging Meter [www.co2meter.com](http://www.co2meter.com)

Our cost - ~ $1,850 - $2,000/kit

Quantity discounts, some donated equipment
Making the Invisible Visible

3 particle counters per home: outside, inside, & roamer

Left: Particle Count 0.5+ um; (Dylos total)
Right: Particle Count 2.5+ um; (Dylos large)
Particles per 1/100 Ft³

NOTE: Scale at right is from manufacturer; not a 3rd party

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

Air Quality Chart .5 um – Small Count Reading

- 3000 + = VERY POOR
- 1050-3000 = POOR
- 300-1050 = FAIR
- 150-300 = GOOD
- 75-150 = VERY GOOD
- 0-75 = EXCELLENT
OUTDOOR IMPACTS INDOOR
Indoor Median & Distribution
137 Participants  (Dylos Total)

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

Log Scale

Homes – red bars
Workplaces – blue bars
Outdoor Median & Distribution
137 Participants (Dylos Total)

½ Poor; ½ Fair

V Poor >3000
Poor 1050-3000
Fair 300-1050
Good < 300
V Good 75-300
Excellent <75

Log Scale

Homes – red bars
Workplaces – blue bars
Visualize Impact of Outdoor on Indoor, & Impact of Interactions

ROCIS LCMP tools include:

- Averager v.6 (Excel macro)
- Outdoor Dylos data plot by cohort (Weebly site)
- LCMP Stacked Bar (R Shiny web app)
- LCMP Data Explorer v.2 (R Shiny web app)
Averager v6

INSTRUCTIONS:
1. This is a macro-enabled Excel workbook that will average your Dylos data from multiple monitors at an interval that you set. It also allows multiple raw data files from the same monitor to be strung together. In order for it to run, you may need to enable macros in your Excel options. In Excel 2007 go to the File tab, select Options, then Trust Center, click Trust Center Settings, then check the box next to Enable all macros.
2. Enter your site name (e.g. your initials), the averaging interval you want in minutes, and the number of monitors you have in the indicated box below.
3. Make sure you know where your raw data Dylos text files are, then hit the GO button below. The macro will then ask you to name the first monitor by location (e.g. indoor). Then it will open a file explorer box so you can browse to the location of your files and select the first file for this monitor. The macro will then prompt you for any more files for this monitor. It will cycle through each monitor this way and then display the averaged results in the table and graph on
Outdoor Data by Cohort - (70 mile spread) - Readings track

ROCIS Low Cost Monitoring Project

Cohort 15 Small 15 Min Average

Log scale

Equipment Error??
Outdoor Data by Cohort - (70 mile spread)
Linear scale shows differences between sites

NOTE: Some of high counts in this period are due to high humidity
Stacked Bar - Outdoor Impacts Indoor

Online ROCIS LCMP Stacked Bar
Data Explorer v.2 – Indoor Counts Track Outdoors

Your Indoor Particles vs. Time

Log Scale
Though order of magnitude lower; indoor tracks outdoor
Blue = roamer, sanctuary “clean” zone
What Could You Expect if…
Outdoor Air was Bad All the Time?
Good All the Time?

Dylos (small) ~0.5+

INDOOR

25% worst outdoor

25% best outdoor

Using online ROCIS Data Explorer
INTERVENTION INSIGHTS
And the Role of Low Cost Monitors
Options to Reduce Particles

• Reduce air exchange from outside
  • Close windows
  • Tighten home or building

• Filter air
  • Portable
  • Central Air handler (furnace, AC, or ventilation)

• Reduce resuspension

• Reduce indoor sources
  • Vent kitchen stove!
  • Use induction cook top
Window Operation

• Single biggest factor affecting IAQ when outdoor counts are high

• 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? Closed?

Windows closed here
Fan Filter – Bedroom Window at Night

Impact of open window with/without box fan & filter

Windows open? – inside (green) tracks outdoors (purple line)

Log scale
Dylos total

Outdoors

Bedroom (green)

Red arrow – turned on fan filter in bedroom to bring in filtered outdoor air
Blue arrow – turned off fan filter each morning
Low-Cost Fan/Filter (MERV 13)

4” MERV 13 filter ($35) on 20” x 20” box fan (~$20)
Place within room or in window
Outstanding issues – filter emissions, warranty
UL-rated fans do have overheat protection
Attention to Cooking
Portable Induction Stove Top

Portable, double-burner induction stove top unit ~$275.
(Single burner, lower quality units <$100)

Care when cooking
Cover the pan!
Portable Air Cleaners

Match the load of contaminants –
  Volume & pollutant
HEPA filtration, not “HEPA-like”

ISSUES

• Role of feedback (low cost monitor)
• Noise & wintertime comfort
• Filter maintenance
• Location
• Cost of air cleaner
• Inadequate run time
Portable Air Cleaners – Fan/Filters

![Portable Air Cleaners Diagram]

- **dylosCat**
  - Very Poor
  - Poor
  - Fair
  - Good
  - Very Good
  - Excellent

![Portable Air Cleaner Image]
Impact of Portable Air Cleaner

Your Indoor Particles vs. Time

Sanctuary Zone – Blue (550 sq ft.) Up to 2 air cleaners on – blower setting varies in response to Dylos readings

Log Scale
Purchased Air Cleaner or DIY Fan/Filter

DIY Fan/filter (with $30 4” filter) often drops particles faster – *but only addresses particles*

**Initial cost**
- Portable Air Cleaners – $200 - $800
- Fan/Filter – $50

**Operational cost (for both)**
- Electricity
- Cost of replacement filters
When can a high MERV filter in a forced air system be a good option for filtering air to reduce particle counts?

- Develop protocol to screen & verify AHU performance
- 35+ air handler systems tested to date
- Very good reductions in particles when operated 24/7!
- Minimal impact if air handler operated in “Auto” mode
NOTE: Air Handler Inquiry

Context for this work
SW Pennsylvania typical housing stock
   Basements
   Mostly gas heat; central AC (oversized)
   Sheet metal ducts in basement
   Supplies & returns to each room

Implications very different w/ attic or crawlspace ducts & homes with central returns
## MERV Filter Rating – Particle Size

<table>
<thead>
<tr>
<th>MERV</th>
<th>Min. particle size</th>
<th>Typical controlled contaminant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–4</td>
<td>&gt; 10.0 μm</td>
<td>Pollen, dust mites, cockroach debris, sanding dust, spray paint dust, textile fibers, carpet fibers</td>
</tr>
<tr>
<td>5–8[^3]</td>
<td>10.0–3.0 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>3.0–1.0 μm</td>
<td>Legionella, Humidifier dust, Lead dust, Milled flour, Auto emission particulates, Nebulizer droplets</td>
</tr>
<tr>
<td>13–16</td>
<td>1.0–0.3 μm</td>
<td>Bacteria, droplet nuclei (sneeze), cooking oil, most smoke and insecticide dust, most face powder, most paint pigments</td>
</tr>
</tbody>
</table>

Air Handler Inquiry

But…Big Issues –

- Air handler (AHU) energy use can be high (500 to 1,500 watts)
- High cost of running air handler continuously (\textit{@500 to 1,500 watts: $54 - $130/month})

- Ductwork issues introduce additional problems
  - Leaks
  - Air flow
  - Static pressure too high

Blower speed seldom set in field; defaults to high, not low in continuous mode
Air Handler Inquiry - Intervention

**Modified return drop** to reduce static pressure & accommodate bigger filter

**4” MERV 13** filter (plus 1 or more specialty filters) all in horizontal location

Adjust blower speed for continuous/longer operation

Consider ECM replacement
Elements for 24/7 Operation of AHU

ECM (electronically commutated motor) Blower

- Increase control to optimize air flow
- Drops electricity use, **but only if static pressure** is low

4” Pleated MERV 13 filter – ideally also larger area

- Lower air flow thru filter increases reduction of smaller particles
- 4” deep filter longer life without clogging

Good Duct System

- Minimal leaks to outside
- Air flow & TESP within name plate specifications

**NOT RECOMMENDED:**

1” pleated MERV 11 or 13 filter (equivalent) without performance testing for TESP, air flow, & watt-draw
24/7 Air Handler w High MERV Filter

Our 1st air ECM handler retrofit!

ECM change-out

In June 2016 using existing 1” pleated filter

The return drop modification with larger, fatter MERV 13 filter was early Sept. 2016

CTG
Pre & Post – Air Handler Retrofit

Week ending 5-24-2017 vs. 7-31-2017

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
Another One – 24/7 High MERV Filtration

PARTICLE LEVELS IN AND AROUND YOUR HOUSE

Location

- Roamer2 - Small
- Roamer1 - Small
- Indoor - Small
- Outdoor - Small

Proportion of time

0% 25% 50% 75% 100%
Night-time Air Handler Use

Lower exposure during periods of greatest occupancy
Key Questions - Issues
Window /Filtration Operation

• Ambient air quality varies greatly over short periods
• How bad is bad?  Whose criteria is basis for action?
• How to alert folks re ambient air quality?
• How to provide feedback – automatic building control?

• Opportunities for reductions other than particles

• Opportunity for new construction and/or renovation (lower cost than upgrading existing installation)
Insight to Date re Interventions?

Proof of concept

Tighter the house, the greater the effectiveness of filtration

Tighter the building, the more critical it is to control indoor sources

Significant potential in homes – address air quality in bedrooms while people are sleeping
Conclusions

• Outdoor particle counts have a significant impact on indoor levels

• Low cost monitors can contribute to awareness, behavior change, & use of technical interventions, & empower people, communities, & organizations

• Individual actions & community-level initiatives have the potential to substantially reduce the exposure to particles

• Integrated solutions are needed to enhance health, resilience, energy efficiency, & durability of homes, work places, & schools
ROCIS LCMP Online Tool Demo


- [https://bluetree.shinyapps.io/lcmpDemo/](https://bluetree.shinyapps.io/lcmpDemo/)

- [https://bluetree.shinyapps.io/stackbarexplorer/](https://bluetree.shinyapps.io/stackbarexplorer/)

- b8z3
- q4y9
Reducing Outdoor Contaminants in Indoor Spaces (ROCIS) Website

http://ROCIS.org/

- White papers
- Access to resources & research results

- Stay Tuned

  ROCIS Brief - Range Hood Venting (Tom Phillips)
  ROCIS Brief - Portable Air Cleaners
  Video Shorts - Telling the Story
Thanks to Phil Johnson &
The Heinz Endowments for support
of the ROCIS initiative
(Reducing Outdoor Contaminants
in Indoor Spaces)

And our 150+ Low Cost Monitoring Project Participants
Next Pgh. class & certification test – Nov. 13-15, 2017  8:30 - 5:00
CCI Center,  64 S 14th St.; Pittsburgh, PA 15203
For more information:  TheEnergyDoctor@comcast.net
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http://ROCIS.org
People Most at Risk in the U.S. 
Year-Round Particle Pollution (Annual PM$_{2.5}$)

8$^{th}$ worst city – Pittsburgh$^1$
County-wide
13 worst – Allegheny County (Pittsburgh)
22 worst – Washington County
(12 worst counties are in California or Idaho)

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

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/
Data Visualization Challenges

- Framing: What is typical? What is best of class? How bad is bad?
- Clarify exposure over time (vs. spikes)
- Balance indoor & outdoor impacts
- Too much data! (1-minute resolution – 10 channels per house)
- Too many variables
- Did action(s) make a difference?
Two Examples

When Outside Better - Inside Better

- DylosCat
  - Very Poor
  - Poor
  - Fair
  - Good
  - Very Good
  - Excellent

Date (by periods of 1 days)
Mitigation Strategies: Deposition - Removal Treatment…

Better cleaning & reducing track-in dust
   Carpets
   Hard surfaces – *mopping vs. cleaning!*
Consider reservoirs
   *building upgrades*
   *may disturb*

Lots of anecdotal information; LCMP have not attempted to quantify
High MERV Filter - Air Handler 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, or performance)

No!
Air Handler Inquiry

- Developed protocol to screen & verify
- Over 30 air handler systems tested to date
- Adjustment made at time of initial visit – blower speed
- Evaluate opportunity for MERV 13, 24/7 operation

- **Very good reductions in particles when operated 24/7**!
  - Minimal impact if air handler operated in “Auto” mode
  - Targeted operation (operating at night during highest house occupancy) shows promise

Best performance – w/ air cleaner in bedroom w 24/7 whole house filtration.
Air Handler Inquiry

But...Big Issues –

- Static pressure (TESP) too high in 70% of systems tested
- Air handler energy use can be high (500 to 1,500 watts)
- High cost of running air handler continuously \((@500 \text{ to } 1,500 \text{ watts: } $54 - $130/\text{month}^1)\)
- Filter maintenance / replacement / cost ($100+ per year)
- ECM replacement an option (lower airflow option & cost)
- High TESP? - ECM bad option (cost & motor energy)

\(^1\) $.12/kWh
24/7 Air Handler MERV 13 Filter

Already had electronic air cleaner in place.

At diagnostic visit adjusted settings.

Now running 24/7 (lower speed; lower cost)
Implications – Low Cost Monitoring

Aha – particle monitors make the invisible visible –

“Wow! Look what happens when we fry bacon!, or burn the toast”

“Air quality in the region is worse than I thought”

Often difficult to interpret raw indoor readings

Monitors can reinforce behavior change

Monitors can inform occupants to take an action
Stay Tuned

• Easier/reliable systems to track behavior & house conditions (apps)
• More analysis (macro & case study)
• Open source data
• Draft guidance documents - interventions
• Tell the story
• Hopefully - exploration of integrated solutions – e.g. ventilation options to address filtration & dehumidification

• www.ROCIS.org