Enable
A CLEANER, HEALTHIER, MORE ENERGY EFFICIENT WORLD

Performance Materials

Energy Efficiency and Air Filtration
A roadmap for the future

Geoff Crosby  4-Apr-2018
US Energy Consumption (1776-2040), Quadrillion BTU

2017 projections

petroleum and other liquids

natural gas

coal

nuclear

hydro

World Record: 0 to 400 to 0 km/h in 33.3 seconds
Koenigsegg Agera RS
November 2017 in Nevada

For those SI unit challenged, this is 0 – 250 mph and back down to zero before you can get a cup of coffee from your Keurig®

1160 BHP at a cost of 10? MPG
Goal
To Help Designers, Manufacturers, Installers, and Operators understand selection of filtration devices that can help with their energy use.

Purpose
To establish a consistent methodology to determine the energy consumption created by the introduction of air cleaning and filtration devices into an air stream.

- Applies to devices for removing particulate or gas phase contaminants.
- Not UV-C or electrically-powered devices.
Why isn’t it this easy?

- Energy Consumed is Power x Time
- Air Flow x Resistance (with a conversion factor) = Power, then pick our run-hours to get to Energy consumed.
- Since we know our testing flow rate, we can also easily get to cubic feet of clean air delivered per Watt-Hr
- This math is straightforward!

Except there are at least six categories of problems to address
Theme: **Build upon Knowledge, Use Cases, and Continuous Improvement**

**Disruptive Technology**
Problem 1

Filters don’t actually consume energy
Flow Rate, Resistance and Time to Energy Consumed

Air Flow (cfm) x Resistance (in w.g.)
K (conversion factor) = Power (Watts)

\[
\frac{1968 \text{ ft}^3/\text{min} \times 1.13 \text{ in H}_{2}\text{O}}{8.524 \text{ ft}^3/\text{min} \times \text{in H}_{2}\text{O/Watt}} = 261 \text{ Watts}
\]

To convert to WHr (watt-hour, energy!), we need to specify time. Run for 1 hour, then multiply by 1, and get 261 WHr.

In that time, we supplied 118,080 ft\(^3\) of clean air.

This would be 453 ft\(^3\) clean air/Whr energy consumed.

Except for the damn fan/drive/motor/control systems...
Easy Street: Combined Efficiency Curve with VFD

In this hypothetical VFD-based model:

A: 40% Full-Flow = 46% efficiency.

B: 70% Full-Flow = 61% efficiency.

Except for:
- Constant Flow or VAV?
- VFD or Non-VFD Motor?
- Damper Settings?
- Inlet Vanes?
- Altitude?
- Humidity?

Concept/Source: A. Krukowski & C. Wray, Standardizing Data for VFD Efficiency, ASHRAE Journal, June 2013
Fan Curves*, Pressure Increases. Constant Flow? To VFD or not to VFD?

A: Initial Design Flow
A: 10,000 CFM at 4.6 in H₂O – and expect 0.5 in pressure increase

B: Constant RPM Without a VFD
Pressure increase of 0.5 in H₂O decreases flow to 9,000 cfm

C: Variable RPM With a VFD
To maintain flow, increases motor RPM to 2600

What else?
• How to integrate all these variables?
• What about different control systems?

* A huge thank you to Dustin Meredith, P.E. of Trane for his patience and clear explanations!
Help is on the way! (I knew you were concerned)

- Dept. of Energy (DOE) Fan Energy Index
  - Energy-Plus Building Simulation Tool now contains a component-based fan system model, and a pressure versus flow system curve model

- Air Movement and Control Association (AMCA)
  - AMCA Standard 207: Fan System Efficiency and Fan System Input Power Calculation

- ASHRAE Research:
  - RTAR-1626 – Commercial Buildings
  - RP-1649 – Residential Buildings
What is Typical? Commercial Buildings HVAC Operations

RTAR-1626: Energy Implications of Air Filtration in Commercial Buildings

Moving air for ventilation and space conditioning may account for 20% to 80% of HVAC site energy consumption.¹

14 out of 15 had no speed controls.²

What is Typical? Residential Buildings Air Filtration

RP-1649: IAQ and Energy Implications of High Efficiency Filters in Residential Buildings

- 21 Residential homes in urban Toronto, visited 9 times over the course of a year.
- Filters: MERV 8 mechanical, MERV 8 electret, MERV 11 electret, MERV 14 electret.
- Fundamental parameters measured:
  - System run time
  - Filter dP and flow
  - Filter efficiency
  - Filter effectiveness
- Now 12+ months in.
Problem 2

What is a “typical” installation?
By 2050, 70% of the World’s Population Will Live in Urban Environments.

82% of the US Population Already Does.

One hundred years ago, 2 out of every 10 people lived in an urban area. By 1990, less than 40% of the global population lived in a city, but as of 2010, more than half of all people live in an urban area. By 2030, 6 out of every 10 people will live in a city, and by 2050, this proportion will increase to 7 out of 10 people.

Source: World Health Organization 2012
What is Typical Urban Air?  Particle Size Distributions

Outdoor Air, 30 Global Locations

ASHRAE Test Dust

# of Particles per cm³

Source: Azimi et al, Estimates of HVAC filtration efficiency for fine and ultrafine particles of outdoor origin, Atmospheric Environment September 2014

ASHRAE Test Dust starts at 2 µm particles, and has a peak at 20 µm particles. It contains no submicron particles, and the bulk of it is well within the settling dust range.
Purdue University Herricks Labs: Center for High Performance Buildings

The building IS the laboratory!

Image courtesy of Purdue University
Reproducing the Typical Urban Aerosol

What is urban?
Geographical differences

Particle size distribution
Particle mass
Particle surface area
Particle density
Particle morphology
Physicochemical makeup
Surface energy
Particle charge
Generation methods

Seinfeld & Pandis
Problem 3

Can we test in a cost-effective, timely manner?
Why isn’t it this easy? Use ASHRAE 52.2?

- 52.2 already gives us this data

Integrate the dust loading versus the pressure drop curve to get average pressure drop for a given filter
Goal: Get across a body of water

Michael Phelps
Top Speed: 6 miles/hour

Viking Boat
Top Speed: 11.5 miles/hour

F-35 Joint Strike Fighter
Top Speed: 1200 miles/hour
Goal: Challenge a filter

- ASHRAE dust was developed to challenge a filter quickly and cost effectively. 52.1 – 1992. We have learned a lot since then.

- The energy consumption math is based on increased resistance to filter loading – this part is critical!

Filter 1: Avg dP = 1.3”
Filter 2: Avg dP = 0.9”
Filter 2: Avg dP = 0.6”
Problem 4

Should we tie filtration performance to energy efficiency?
### Should We Tie Performance & Quality to Energy?

<table>
<thead>
<tr>
<th><strong>Option 1</strong></th>
<th><strong>Option 2</strong></th>
<th><strong>Option 3</strong></th>
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</thead>
<tbody>
<tr>
<td><strong>Toyota Prius</strong></td>
<td><strong>Mercedes AMG E63</strong></td>
<td><strong>Ford Raptor</strong></td>
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<tr>
<td>• 48 MPG City</td>
<td>• 16 MPG City</td>
<td>• 15 MPG City</td>
</tr>
<tr>
<td>• 43 MPG Highway</td>
<td>• 21 MPG Highway</td>
<td>• 18 MPG Highway</td>
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</table>

But 577 HP, 0-60 in 3.4 seconds, top speed of 186 mph and my dogs go in the back!

But 450 HP and look at those tires!
Plywood and all my tools fit in the bed.
## EnergyGuide - Refrigerators

<table>
<thead>
<tr>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
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<tbody>
<tr>
<td><strong>College Fridge</strong></td>
<td><strong>“Standard” Fridge</strong></td>
<td><strong>“High-End” Fridge</strong></td>
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</table>

Use or disclosure of information contained on this sheet is subject to the restrictions on the title slide.
Problem 5

Can we give end-users (building systems designers, maintenance, purchasing) useful data to make decisions?
Data, Sensors, and IoT are coming

Global ambient air pollution (WHO)

- 24/7 Global PM2.5 data
- Filter Manufacturer Sensors
- Advanced power management systems
- Fan Energy Index!
Problem 6

What is the value of clean air to users?
Pop Quiz: ASHRAE 52.2-2017

- What is MERV 11? E2 removal of:
  - A ≥ 35%
  - B ≥ 50%
  - C ≥ 65%

- What is MERV 14? E2 removal of:
  - A ≥ 80%
  - B ≥ 90%
  - C ≥ 95%

- What is E2? Particle sizes of:
  - A 1.0 to 2.0 micron
  - B 0.3 to 2.5 micron
  - C 1.0 to 3.0 micron

<table>
<thead>
<tr>
<th>MERV</th>
<th>E1 (0.3 to 1.0 micron)</th>
<th>E2 (1.0 to 3.0 micron)</th>
<th>E3 (3.0 to 10.0 micron)</th>
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</table>
How much does America spend on bottled water per year?

12.8 Billion Gallons in 2016. 9% growth YOY.
$16 Billion in wholesale dollars.

America’s growing thirst
Bottled water consumption over the last three decades, per person

What are they buying?
What about air?

Source: Beverage Marketing Corporation and Beverage Digest
Expand the Market

A rising tide lifts all boats

• How do we sell more clean air?
• ISO 16890 can make air filtration accessible to more people
• I can explain that an ePM$_{2.5}$ 50% filter removes ~50% of PM$_{2.5}$
• Sensors are becoming available to measure IAQ
• Communicate value of energy, filter life, and filter performance
• I would argue that educated users make better customers
Roadmap: Build upon Research, New Data, and End-User Value

- ISO 16890 Standard
- Will the US adopt?
- Residential Research
- Urban Aerosol Research
- Sensors & Research
- Commercial Research
- Fan/Motor/System Research
- DOE Fan Energy Index / ACMA
- End-User Validations
- F.E.E.R. System

Will the US adopt?
Is this what end-users want?

We will be validating our concepts with end-users during the next phase.
We have learned *a lot* over the past 30 years!

1. We need to make it easy to understand air filtration, *in order to expand the market.*

2. We need to build better models and tests based on research, *in order to demonstrate value to decision makers.*

3. We need to think systems and systems integration, *in order to maximize our value.*

Are you selling a better filter, or are you solving for the highest quality, lowest cost clean air?