CANADIAN CENTRE FOR BUILDING EXCELLENCE

Engineering Health and Efficiency

The Present and Future of Indoor Air Cleaning

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Conventional Model of Indoor Air Quality

1. Source control
2. Ventilation
3. Air cleaning

Why?

Health

Productivity, protection

"If there is a pile of manure in a space, do not try to remove the odor by ventilation. Remove the pile of manure."

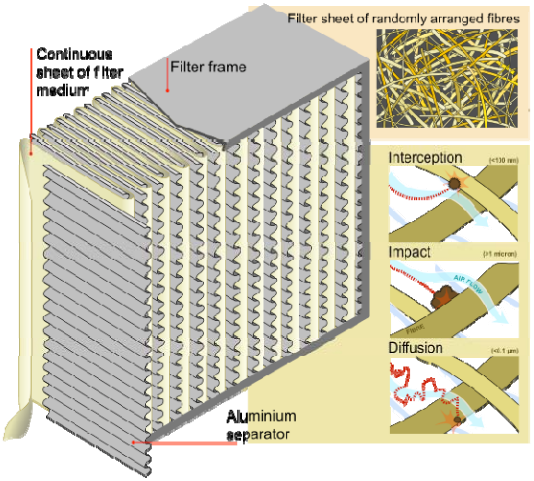
~ Max von Pettenkofer, 1858

Distance to Major Roadway

2M Canadians: 50 m
4M Canadians: 100 m
10M Canadians: 250 m

Obvious Benefits of Air Cleaning

+



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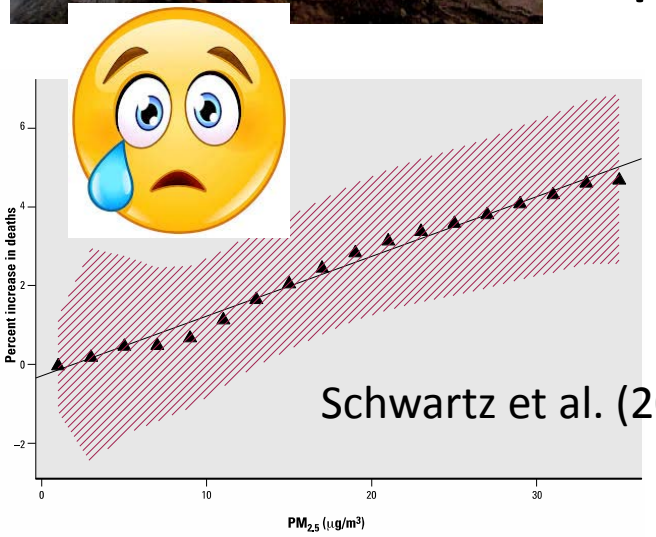
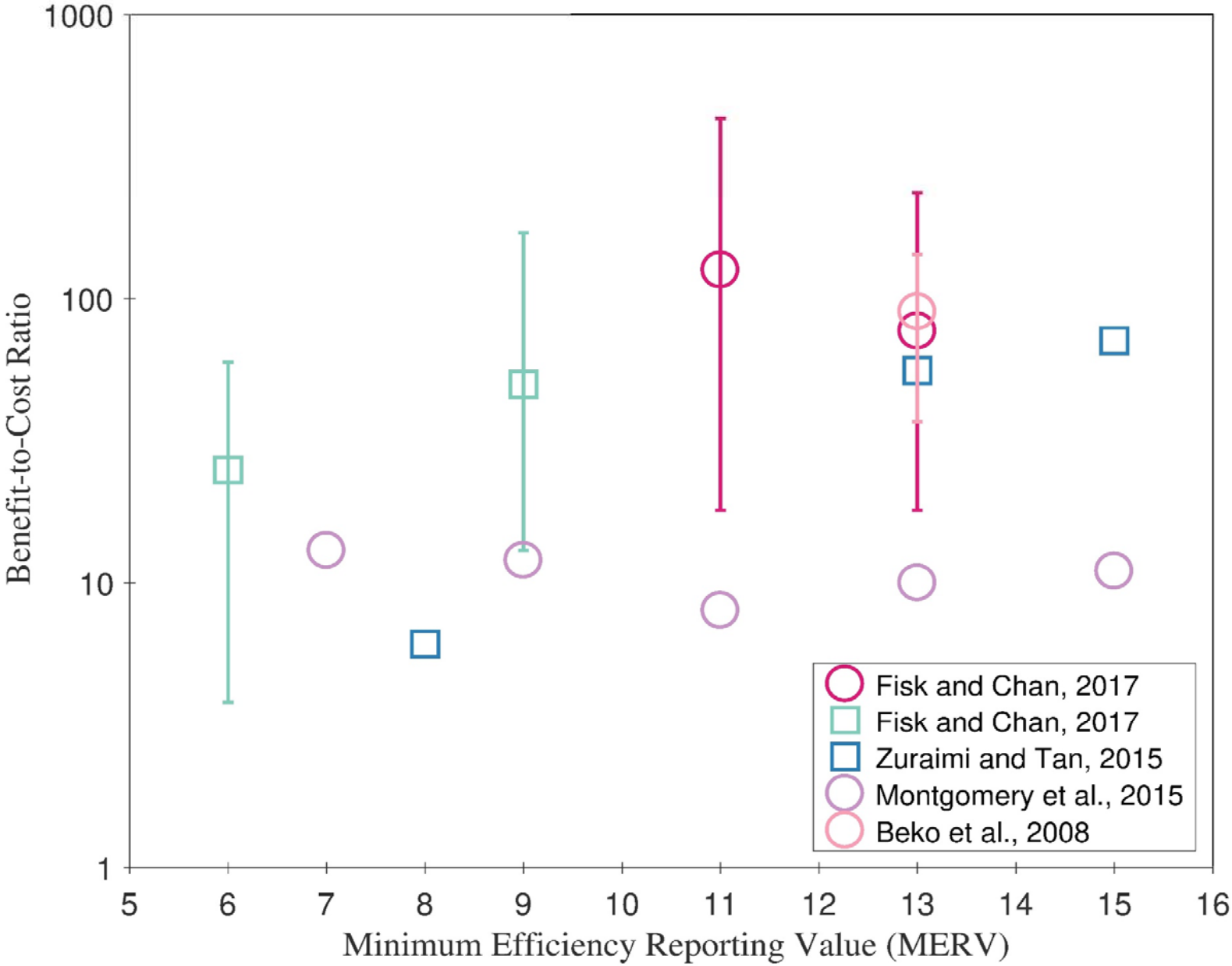


Schwartz et al. (2002) *Environ. Health. Persp.*

Figure 1. Overall estimated dose–response relation between total $PM_{2.5}$ and daily deaths in six U.S. cities. The estimate is obtained by combining the estimated smoothed curves in each of the cities, after controlling for weather, season, and day of the week. The shaded area indicates the pointwise 95% confidence intervals at each point. The line shown is a least-squares regression line through the estimated points.

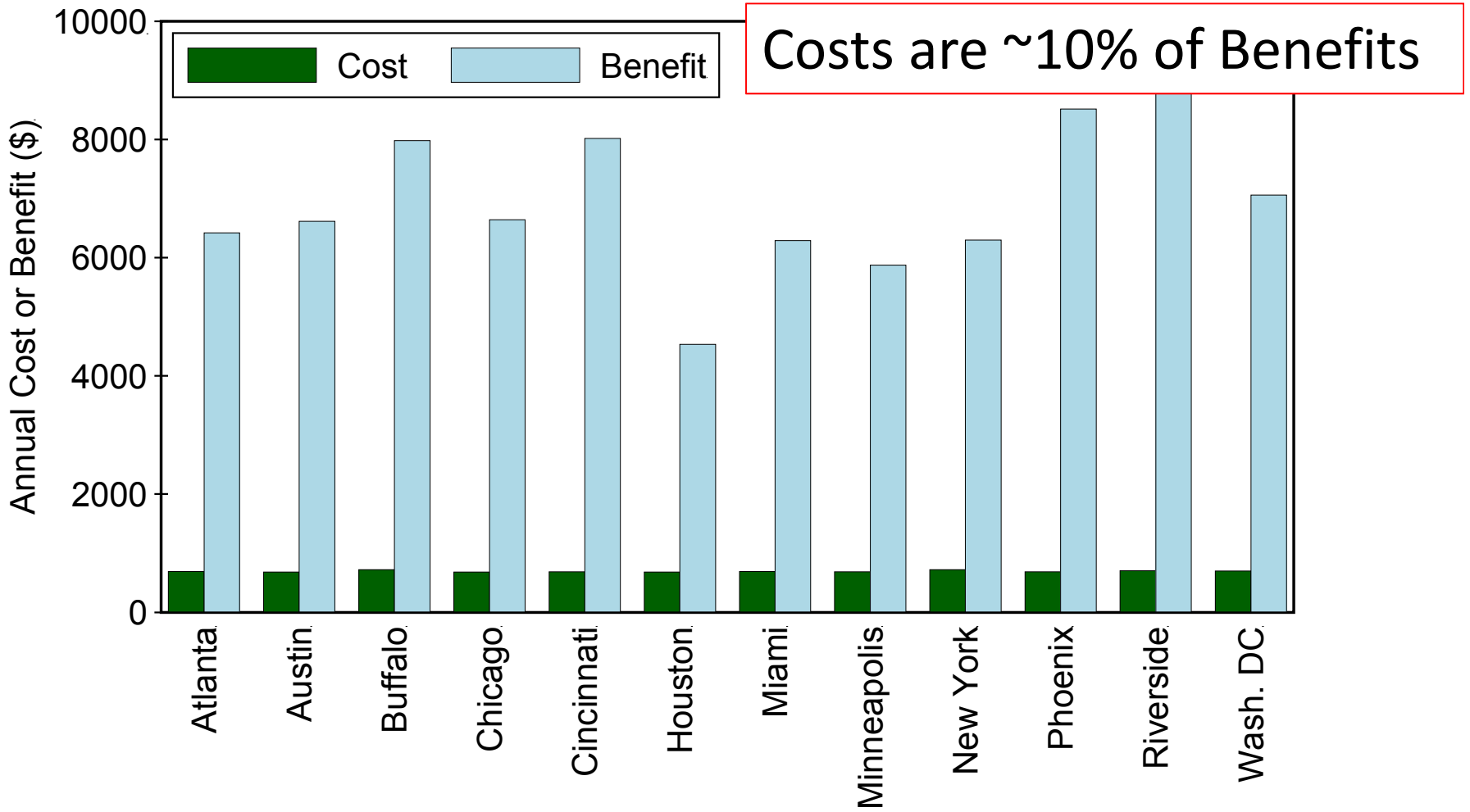
images: http://www.wikihow.com/Brighten-Up-a-Room, https://commons.wikimedia.org/w/index.php?curid=4552953



Alavy and Siegel (2019) *Sci Tech Built Environ*

Ozone Filtration – Benefits

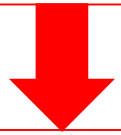
2 inch activated carbon filters in office buildings



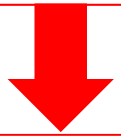
Aldred et al. (2016) *Indoor Air*

Why Minimal Investment in Air Cleaning?

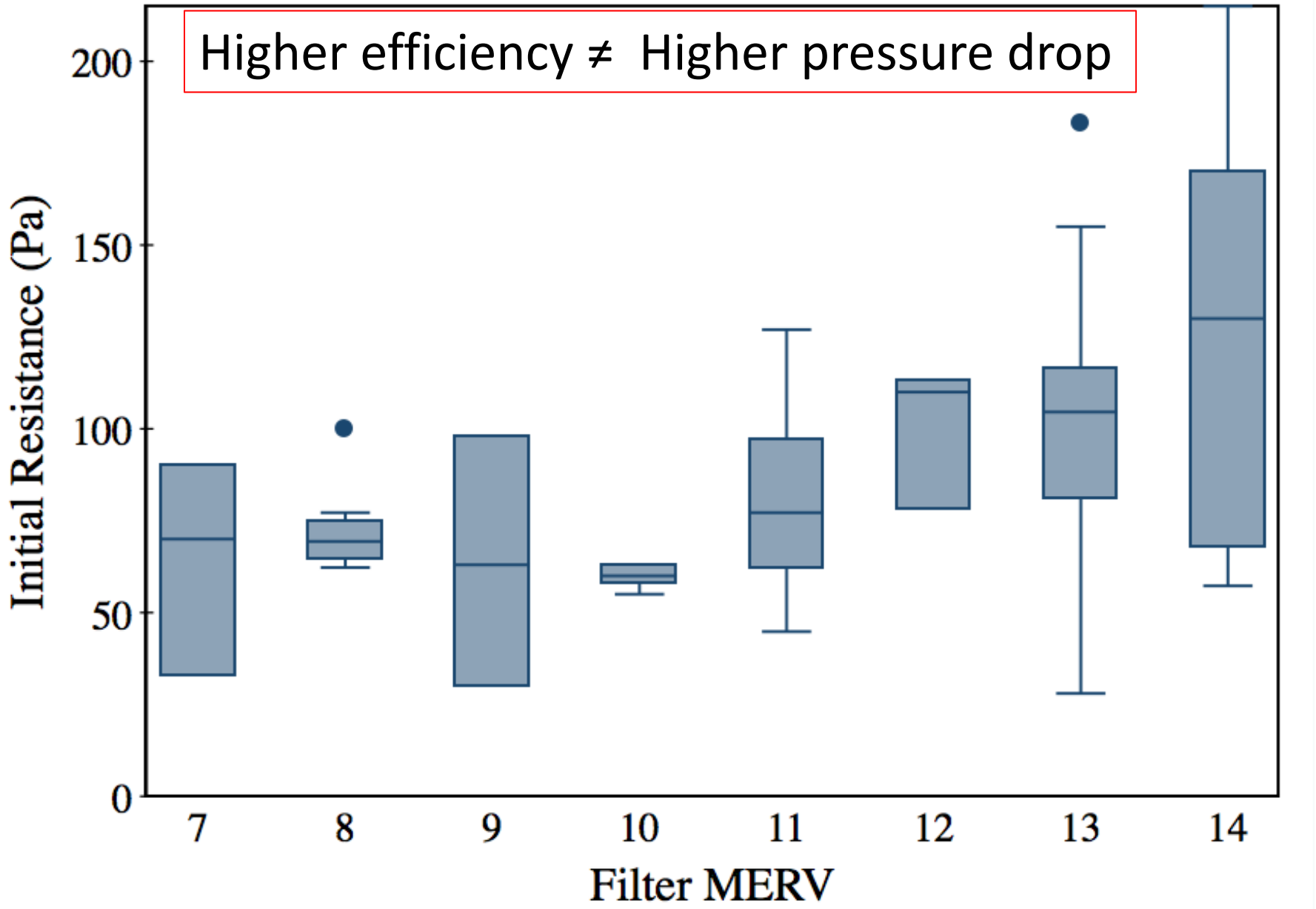
Higher efficiency = Higher pressure drop



Higher pressure drop = Fans work harder



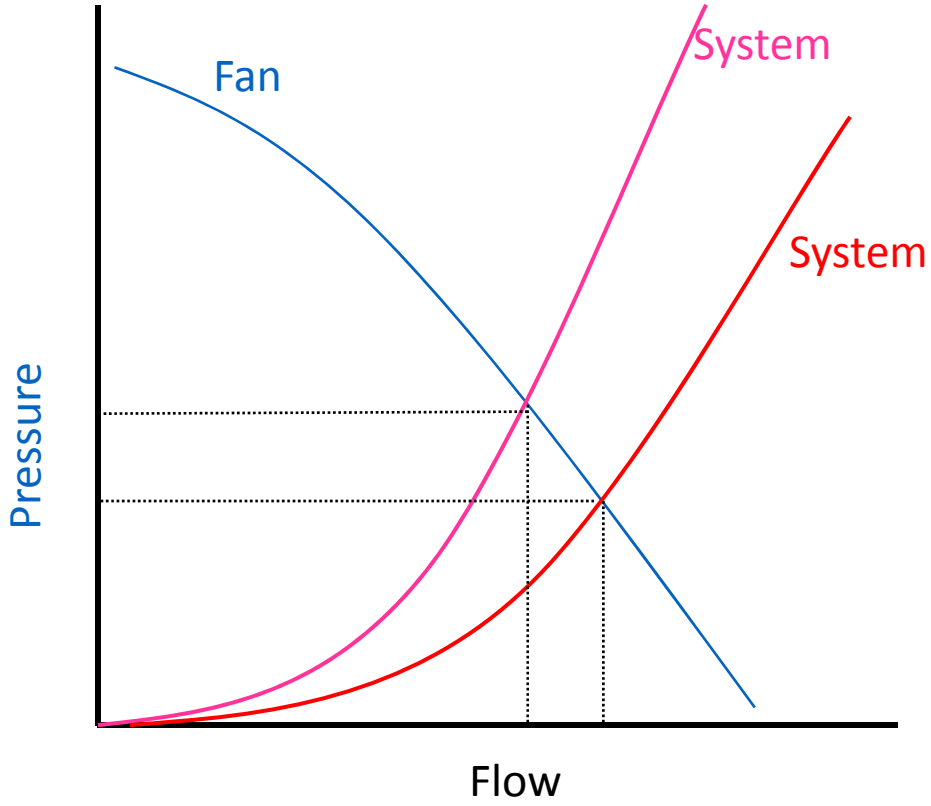
Fans work harder = More system energy use



Siegel (2016) *Indoor Air* (data compiled by Marwa Zaatari)

HVAC Fans and Speed Control

- Some fans have speed control, many do not



- If you add a pressure drop
  - ΔP_{fan} ↑
  - Flow ↓
- Amounts depend on fan and system curve

Higher pressure drop ≠ Fans work harder

Pressure Drop != Flow Resistance

- Flow resistance is a function of velocity

Filter flow resistance increases

↓

Velocity decreases

↓

Filter pressure drop increases much less

Details depend on fan, system, and filter

Filter flow resistance increases

↓

Bypass flow changes

↓

Filter system pressure drop decreases

Details depend on fan, system, filter, bypass gap size and geometry

Energy Implications Are Very Complicated

- Flow decreases, fan energy goes down
- Fan can become more or less efficient, depending on how it shifts on operating curve
- Cooling system energy is poorly understood
  - Generally, diminished flow = diminished cooling output
  - However:
    - Fan uses less energy, less heat from fan motor has to be removed
    - Lower flow shifts from sensible to latent cooling
    - Dynamics of refrigerant flow during short cycling are important and system-specific

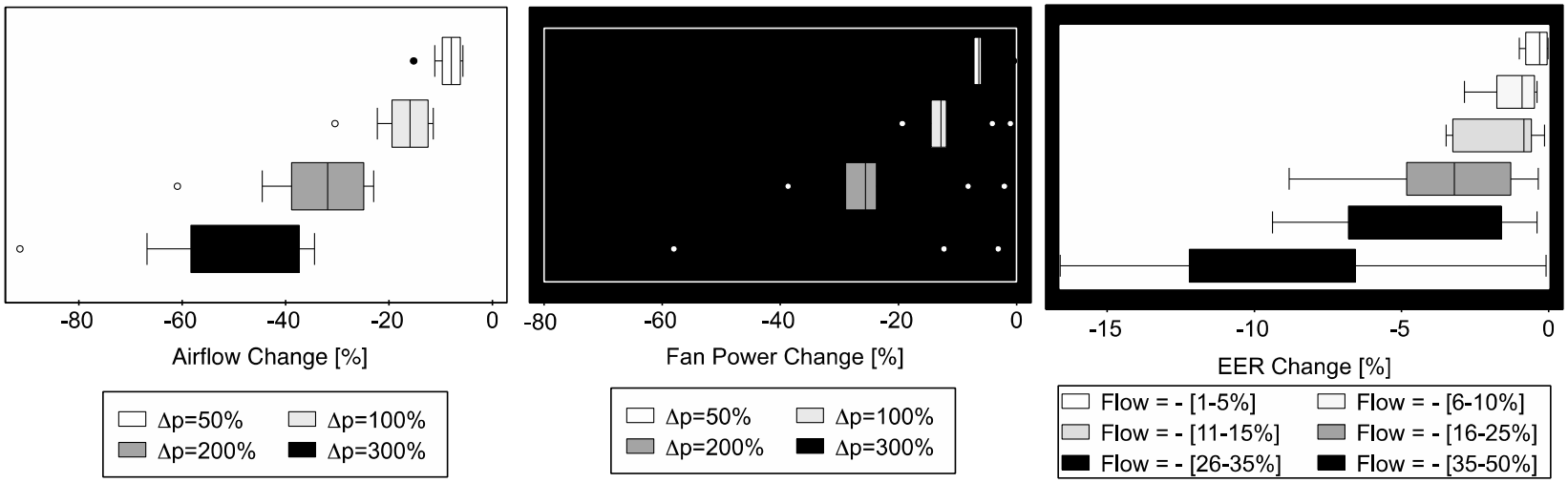
Fans work harder ≠ More system energy use

North American Residential

Study	Method	Impact as MERV Increases					
		Airflow		Fan Energy		Sys. Energy	
		No Spd.	Spd. Ctrl.	No Spd.	Spd. Ctrl.	No Spd.	Spd. Ctrl.
Stephens et. al., (2010a)	Meas	↓	N/A	↓	N/A	~	N/A
Stephens et. al., (2010b)	Meas	↓	N/A	↑	N/A	↑	N/A
Nassif, (2012)	Mod	↓	~	↑	↑	↑	~
Wilson et al., (2013)	Mod	↓	N/A	↓	N/A	~	N/A
Walker et al., (2013)	Meas Mod	↓	↑	↓ ↓	↑ ↑	N/A ~	N/A ~
Fazli et al., (2015)	Mod	↓	~	↓	↑	↑	↑

Alavy and Siegel (2019) *Sci Tech Built Environ*

North American Commercial

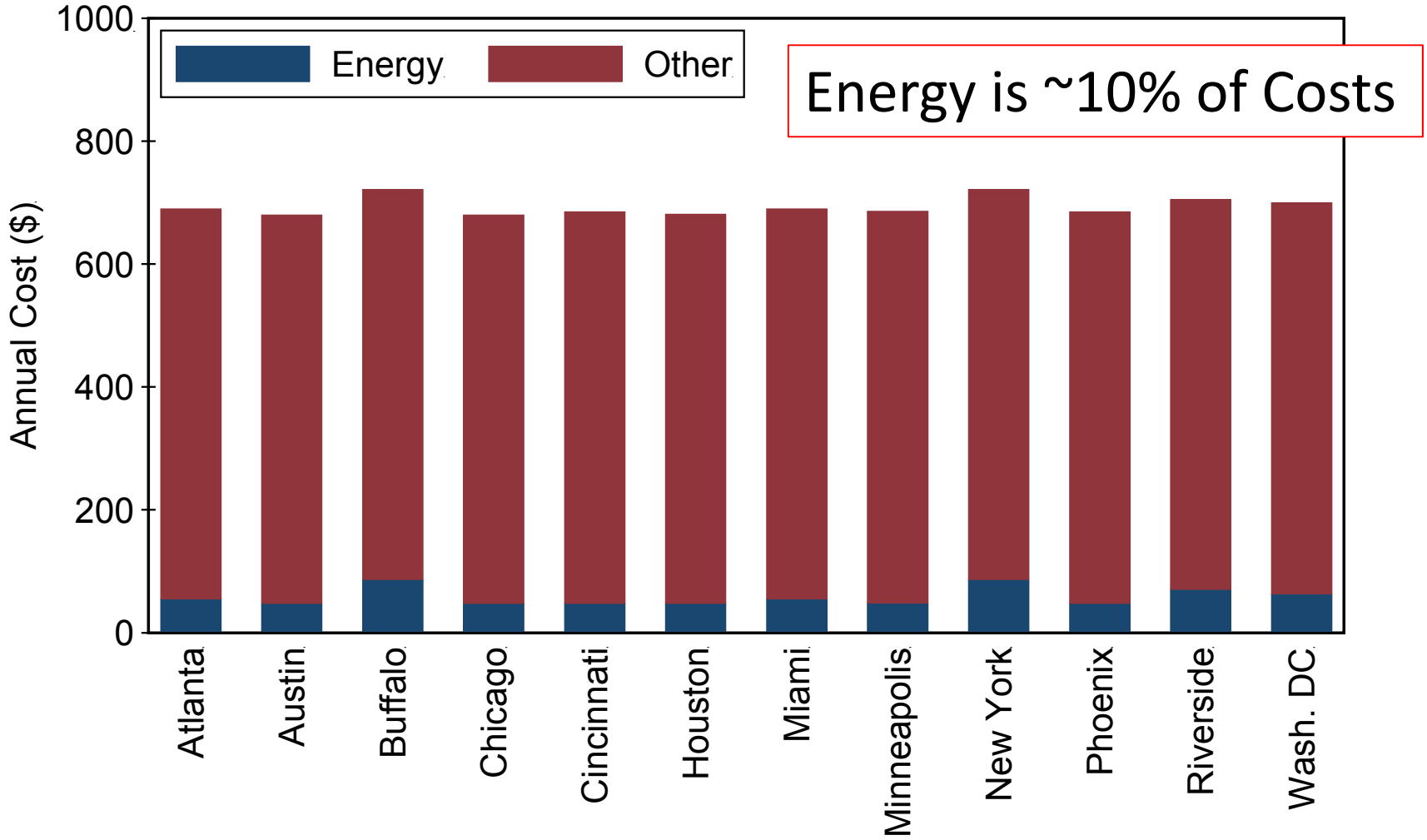


- Even units that were equipped with variable frequency drives for speed control did not use them

Zaatari et al. (2014) *Bldg Environ*

Ozone Filtration – Costs

2 inch activated carbon filters in office buildings



Aldred et al. (2016) *Indoor Air*

Why No Investment In Filtration?

- Benefits are mostly health benefits and are much larger than costs
- Energy is a small amount of cost (but perceptions may be different)

Air cleaning should be an obvious target for investment

COMMENTS OF DONALD R. BAHNFLETH, PRESIDENT
AMERICAN SOCIETY OF HEATING, REFRIGERATING
AND AIR-CONDITIONING ENGINEERS

IAQ 86 OPENING SESSION
APRIL 20, 1986

Good afternoon, and thank you for joining us for this very important conference on Managing Indoor Air for Health and Energy Conservation. During the next four days, we will hear from experts in indoor air quality. A diverse group of talented men and women from around the world will present us with the latest findings in virtually every aspect of the issue.

More than 100 authors will present papers, either orally during the 12 sessions or in poster sessions on Monday and Tuesday. They represent government, corporations, universities and colleges, private laboratories. All of them have worked for months to gather the data for their presentations and they have done it for one purpose: because they believe it important to provide solutions to indoor air quality problems.

ASHRAE has organized and is co-sponsoring with the Department of Energy and the Environmental Protection Agency this conference for the same reason. Because indoor air quality is an important issue. In fact, ASHRAE believes that indoor air quality is and will remain the single most important health issue facing us in the 1980's. Unacceptable indoor air quality can impair our health, affect our sense of well-being, and affect our productivity in terms of both lost time and loss of productive effort.

Years ago, whenever there was a problem regarding the indoor air, we usually tried what I call "granny's solution." We just threw open the door or the window and brought in outside air. Today, we might not always want to bring in unfiltered uncontrolled outside air. In some cities, what's outside could be worse than what's inside. Large amounts of outside air also require expending large amounts of energy for heating and cooling. Concern for the IAQ issue is still growing.

The way we live today, spending more than 90 percent of our time indoors, creates the need for a better knowledge of what contaminants are present in the indoor environment and their effect on people. The issue of indoor air quality is a sleeping giant whose time has come. The total number of serious health effects related to IAQ in non-industrial buildings have been miniscule compared to the total building stock. But there have been enough to indicate that a problem exists. Fortunately, addressing the situation this early gives us time to move rationally. The issue does not need to be sensationalized. We do not need knee-jerk reactions.

Why Not?

- “Where the profit motive is nonexistent, industry support does not materialize at an adequate level.”
- The health benefits are real and large, but
  - Very hard to motivate people about chronic health endpoints that occur decades in the future
  - Very hard to monetize health impacts when people inhabit different buildings
  - Industry (and individuals) pay the cost but don’t necessarily accrue the benefits

We need an alternative model

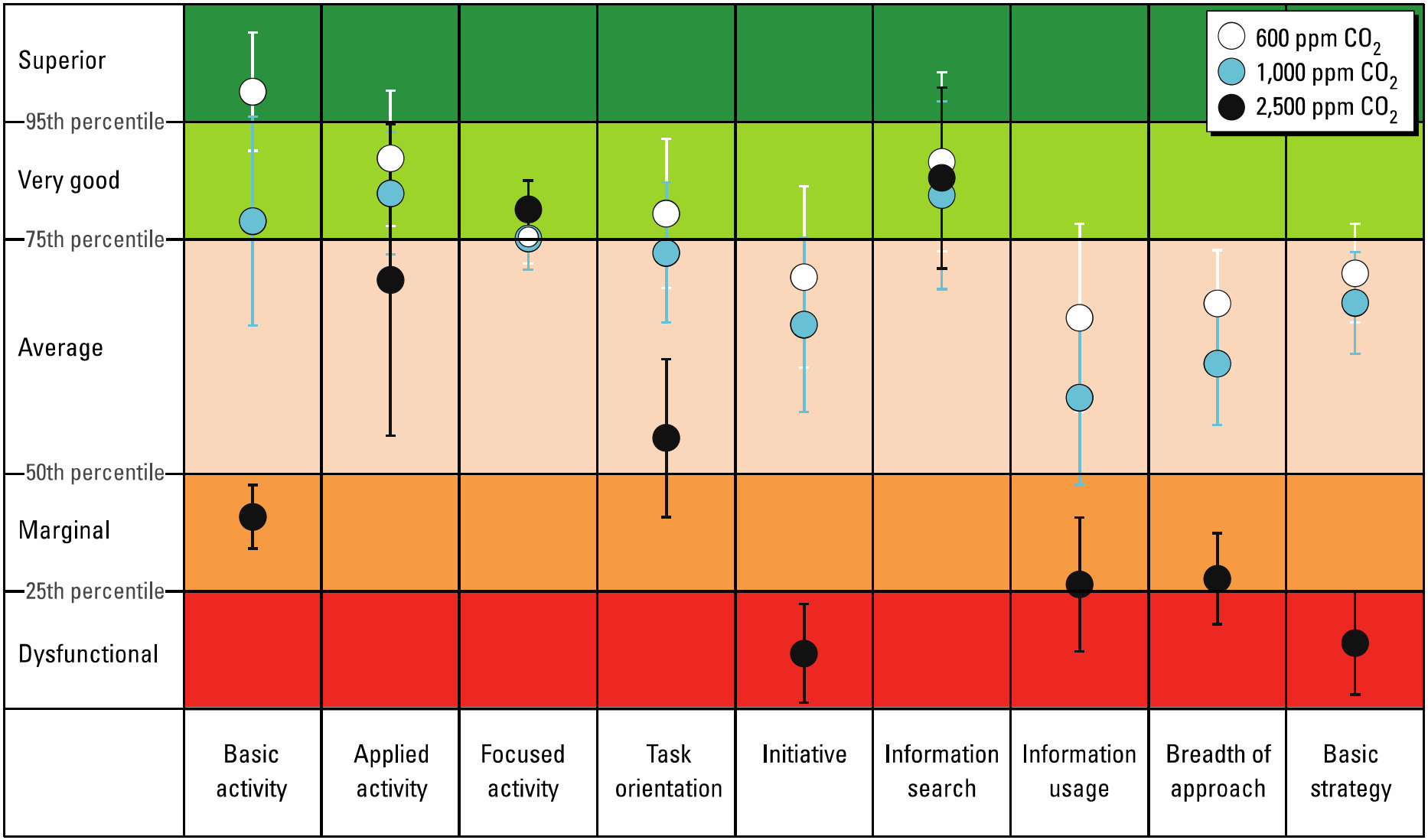


Figure 2. Impact of CO_2 on human decision-making performance. Error bars indicate 1 SD.

Satish et al. (2012) *Environ Health Persp*

Does CO_2 impact cognitive performance?

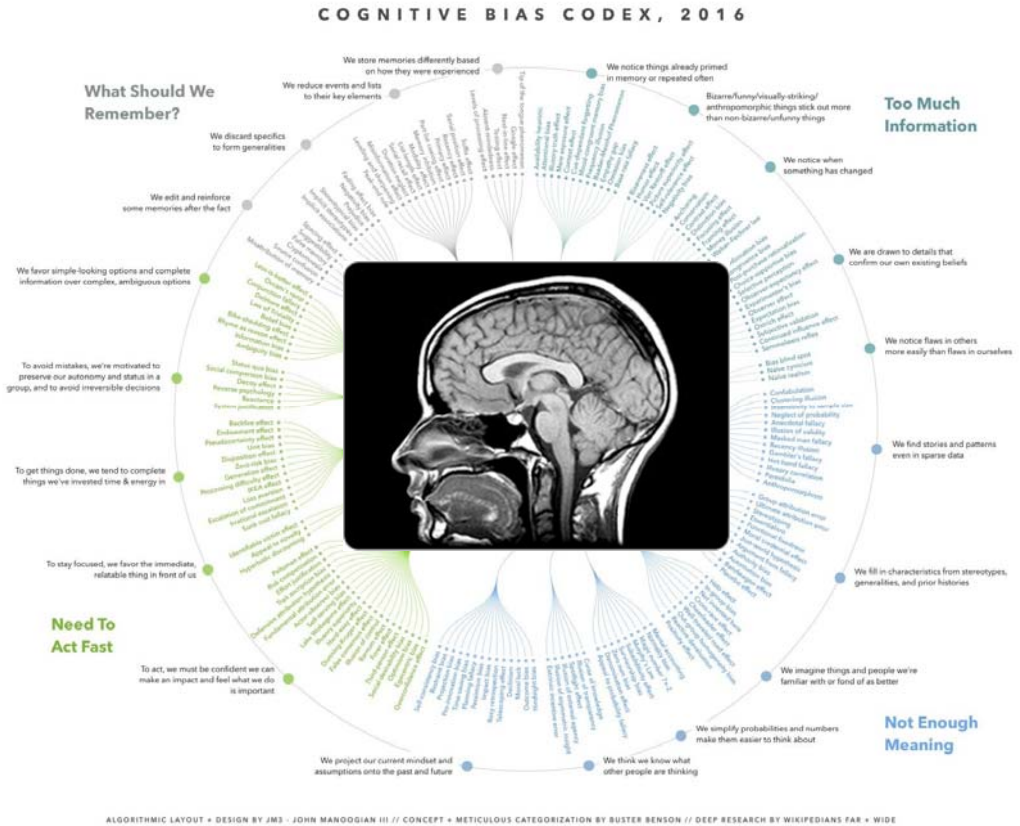
- Maybe, but these results are pointing to something else more important
- Variations in environmental variables, including exposures, impact cognitive function
- This is an enormous potential opportunity for IAQ community
  - It is an acute impact
  - It is easily monetizable in some environments

Invest in air cleaning to improve cognitive function. Use benefits to pay for air cleaning improvements. Chronic health outcome improvement are a “side” benefit.

Model Evaluation

- Need to understand fundamentals of neural and cognitive processes

Dr. Michael Mack



Bowen Du

Preliminary Experiment

No essential oil diffuser No HEPA filter	Essential oil diffuser No HEPA filter 
No essential oil diffuser HEPA filter 	Essential oil diffuser HEPA filter  

Heather Schwartz-Narbonne

Preliminary Results

- Subjects exposed to essential oil diffuser emissions made more impulsive decisions
- There was also a filter effect (that we don’t completely understand)
- We are currently conducting follow-up experiments and preparing for MRI testing

One Final Point

- We need to do much better at communicating our results
- We have great science, we also need great communicators
- We need to understand what people think and care about (very big difference from indoor scientists) *and how they make decisions*

Conclusions

- Air cleaning has small costs and large (modelled) benefits
- Energy costs drive the conversation but are often small
- Health benefits, although large, may not provide adequate motivation
- We need to develop alternative models to motivate improvements in the indoor environment.

Acknowledgments

- Current and former graduate students, colleagues, and community
- Funding