



Healthy Indoor Air Quality Guidelines & Smart Ventilation

Presented by Victor Nino, PhD. PE
Director of Business Development
Build Equinox

Outline

Basic Understanding of Indoor Air Quality (IAQ):

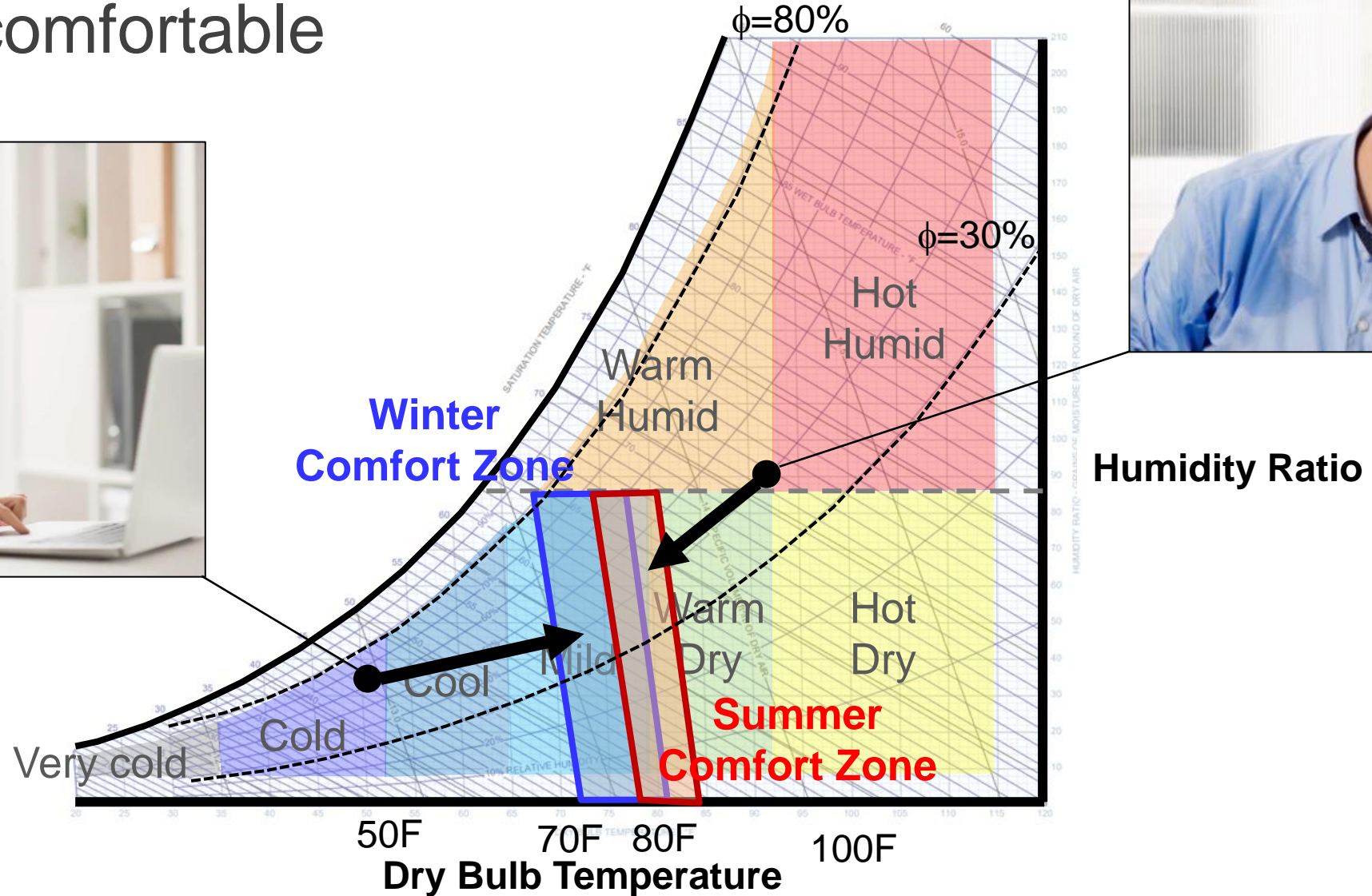
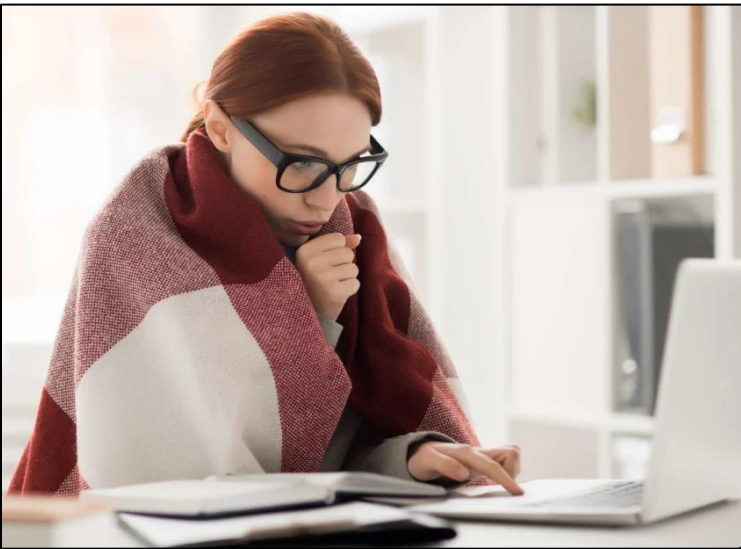
- Smart Systems
- Pollutants & Effect on Health
- Achieving Healthy Indoor Air Quality
 - *Monitoring Pollutants*
 - *Healthy IAQ Guidelines*
 - *Mechanisms to Reduce Pollutants*
- Sustainability & Cost of Health
 - *Minimum standards vs. Healthy standards*



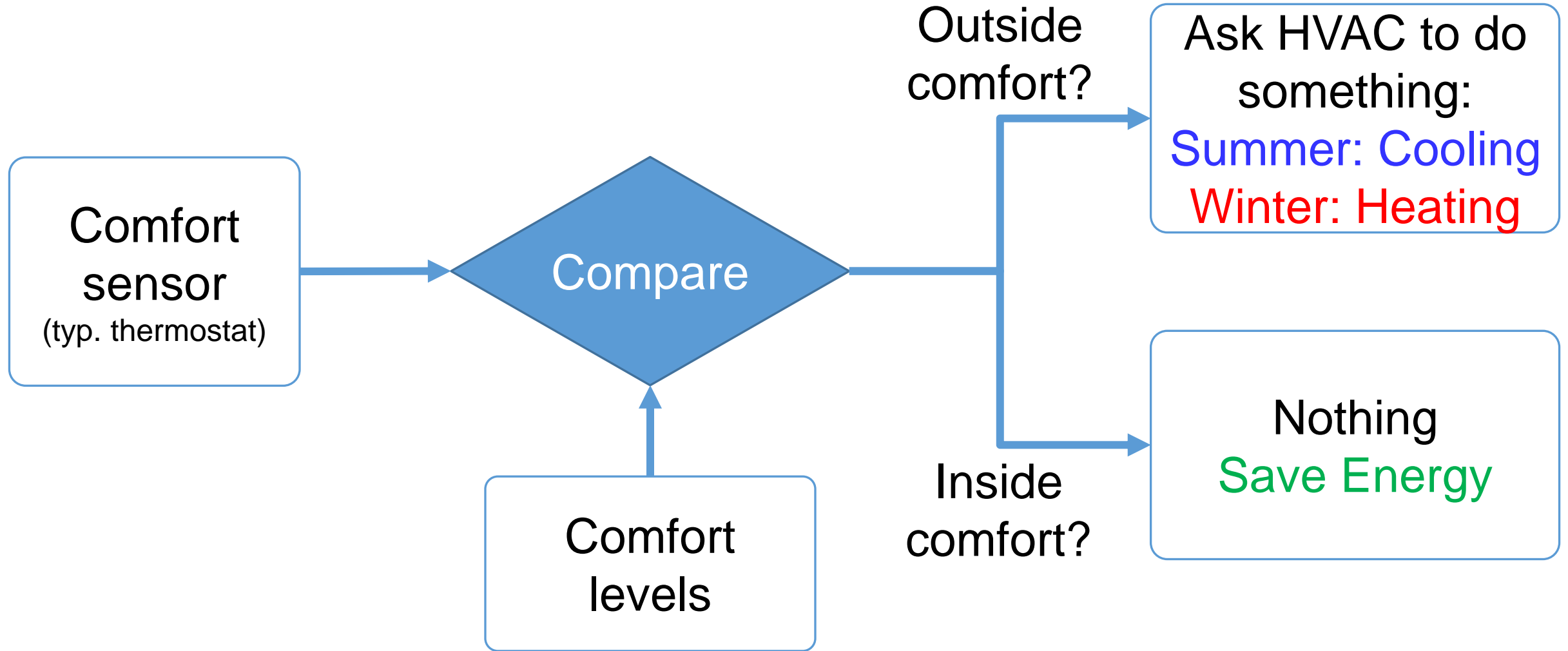
Smart Systems

We Know Comfort

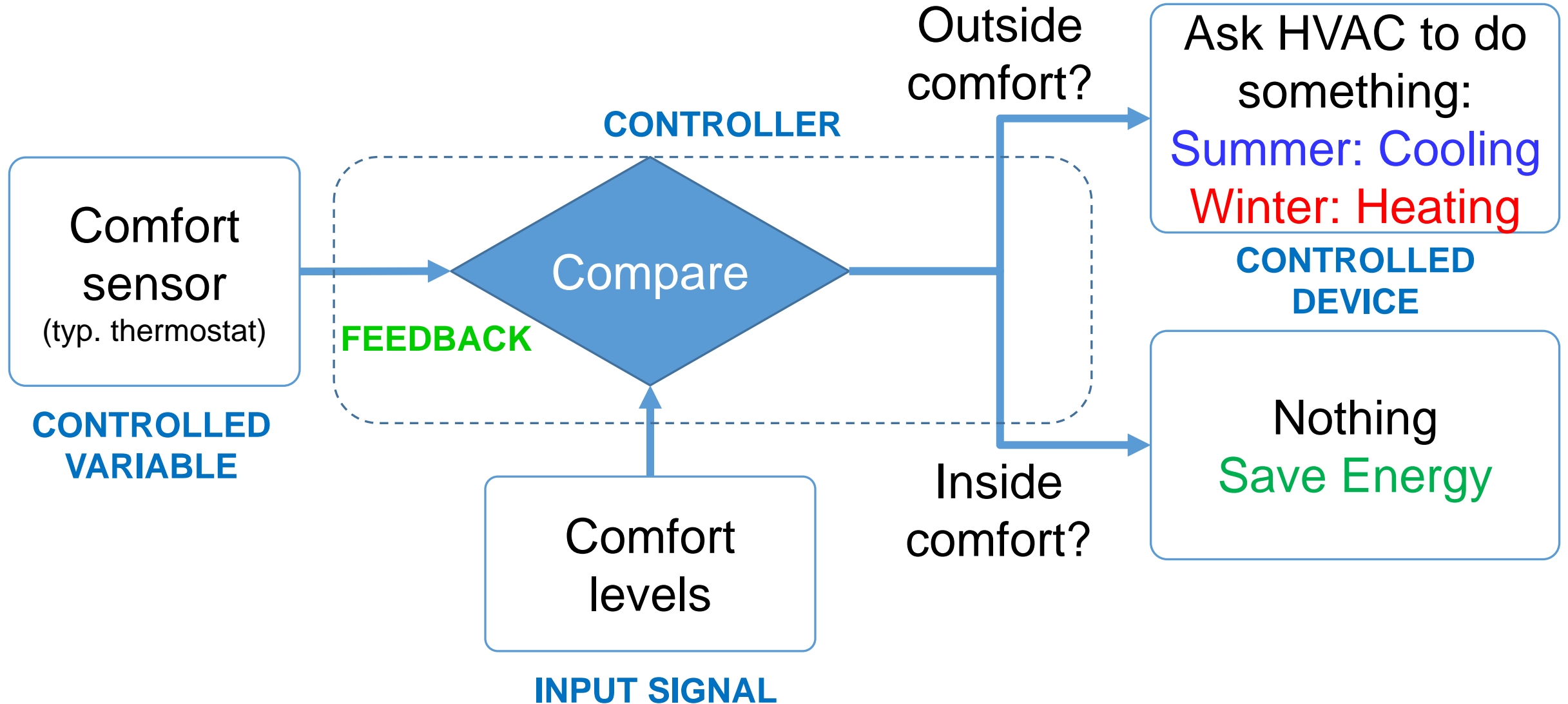
We know how we make ourselves comfortable



Smart System for Comfort



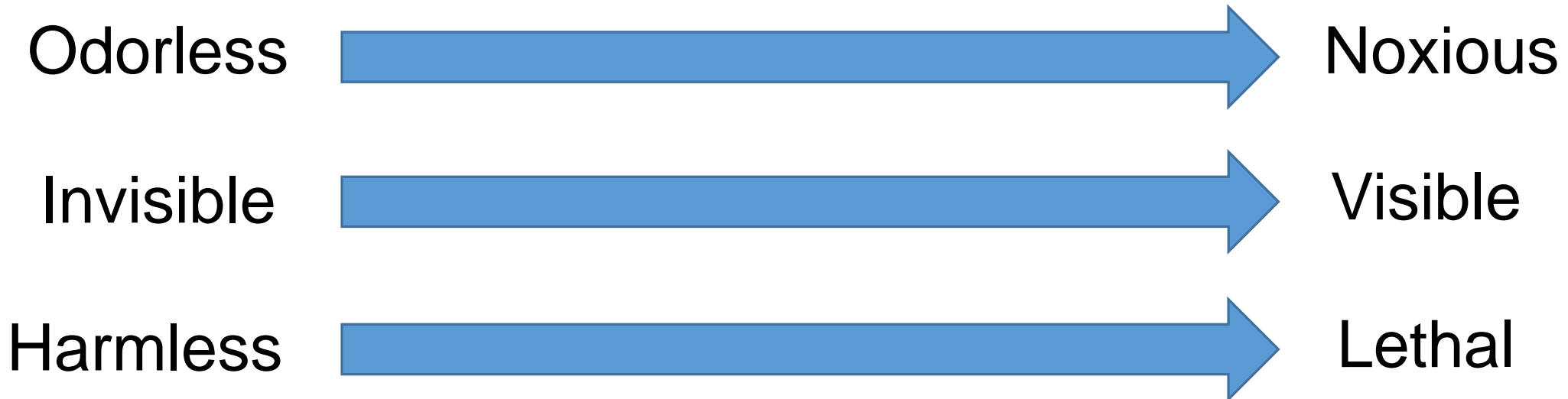
Smart System for Comfort



Can we notice unhealthy IAQ?

When we talk about indoor air quality (IAQ), we are talking about indoor concentrations of **gases, tiny particles and germs**

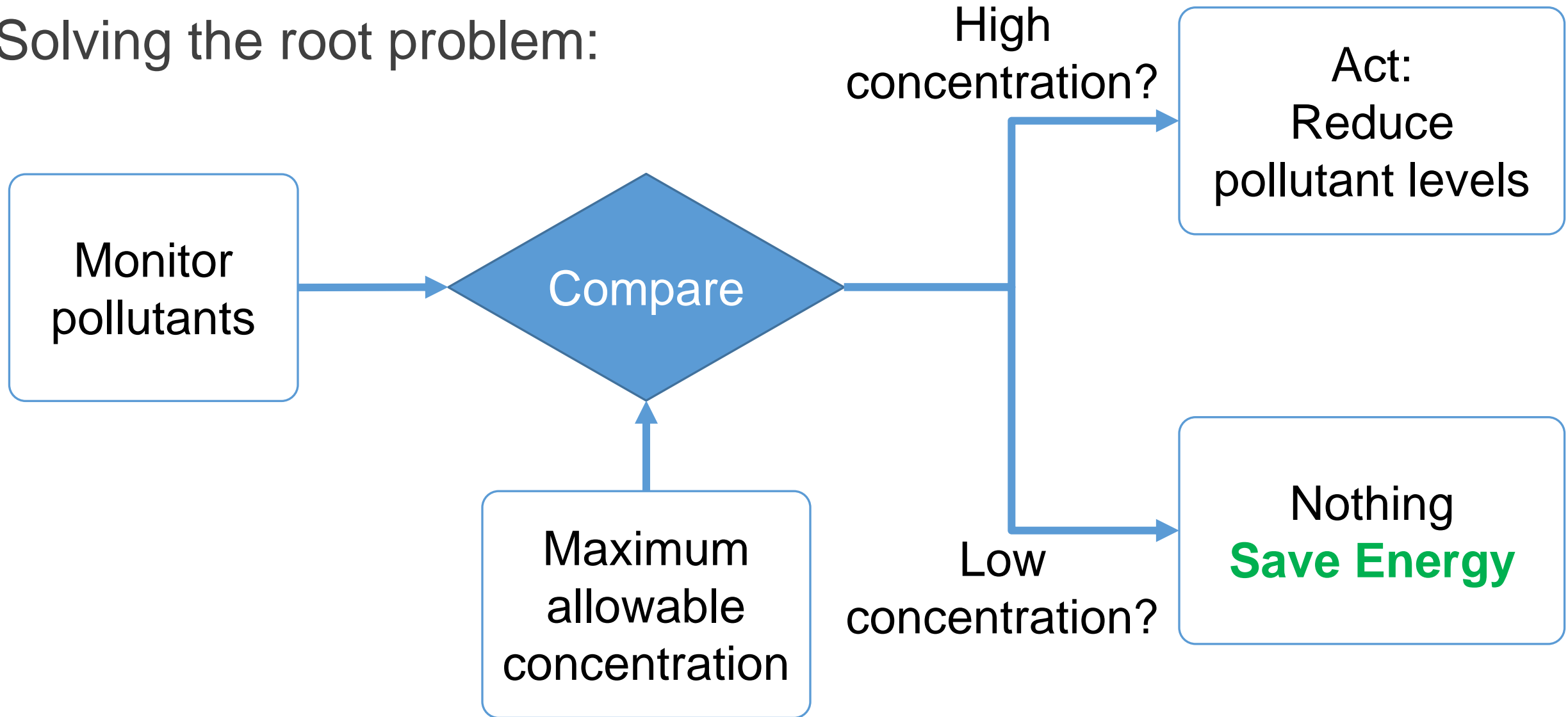
Wide range of characteristics:



Carbon monoxide: Odorless, invisible, lethal

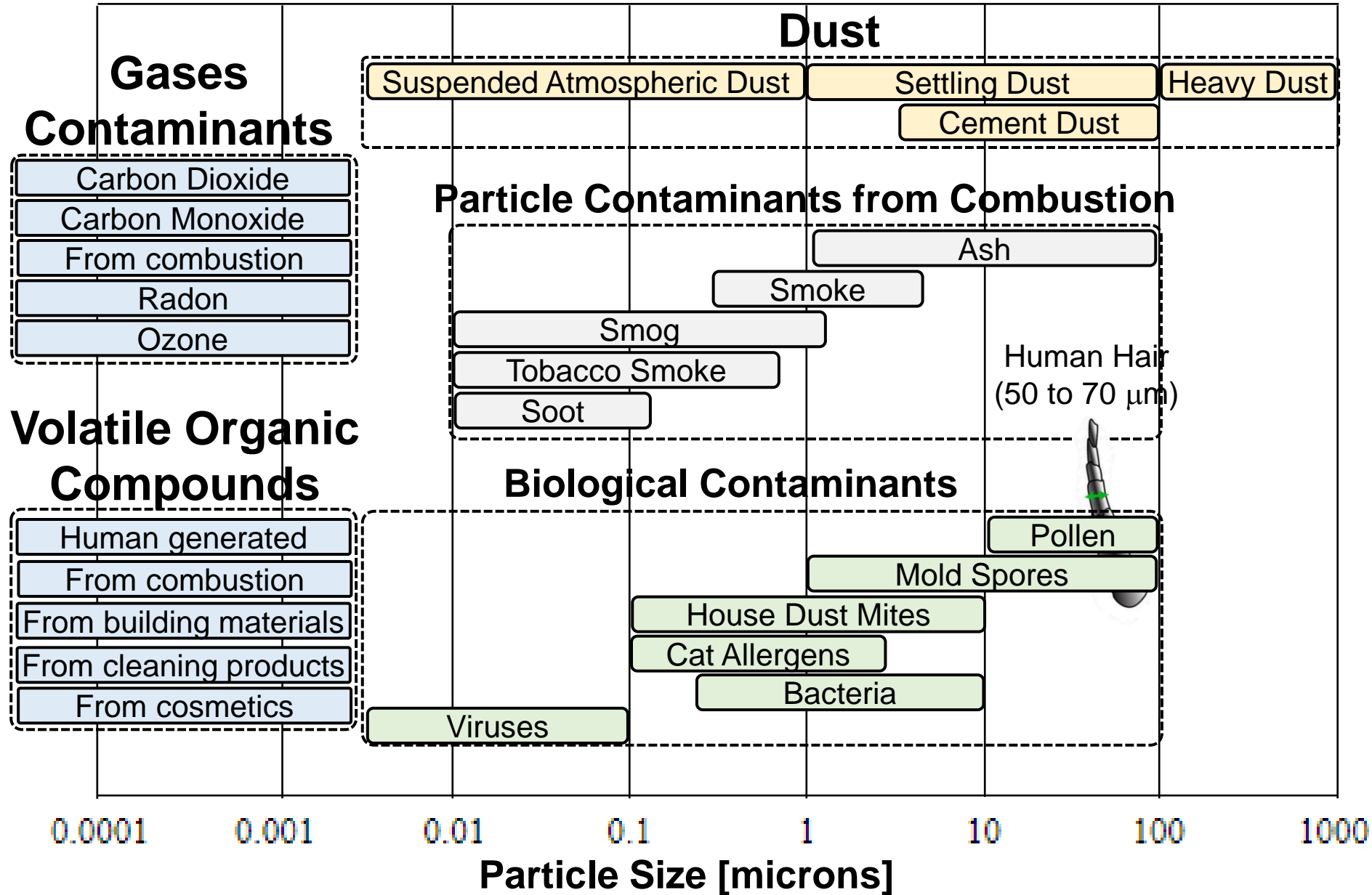
Reducing Pollutant Concentration Levels

Solving the root problem:



Pollutants & Health Effects

Type of Indoor Pollutants



What we know

We spend a considerable time indoors

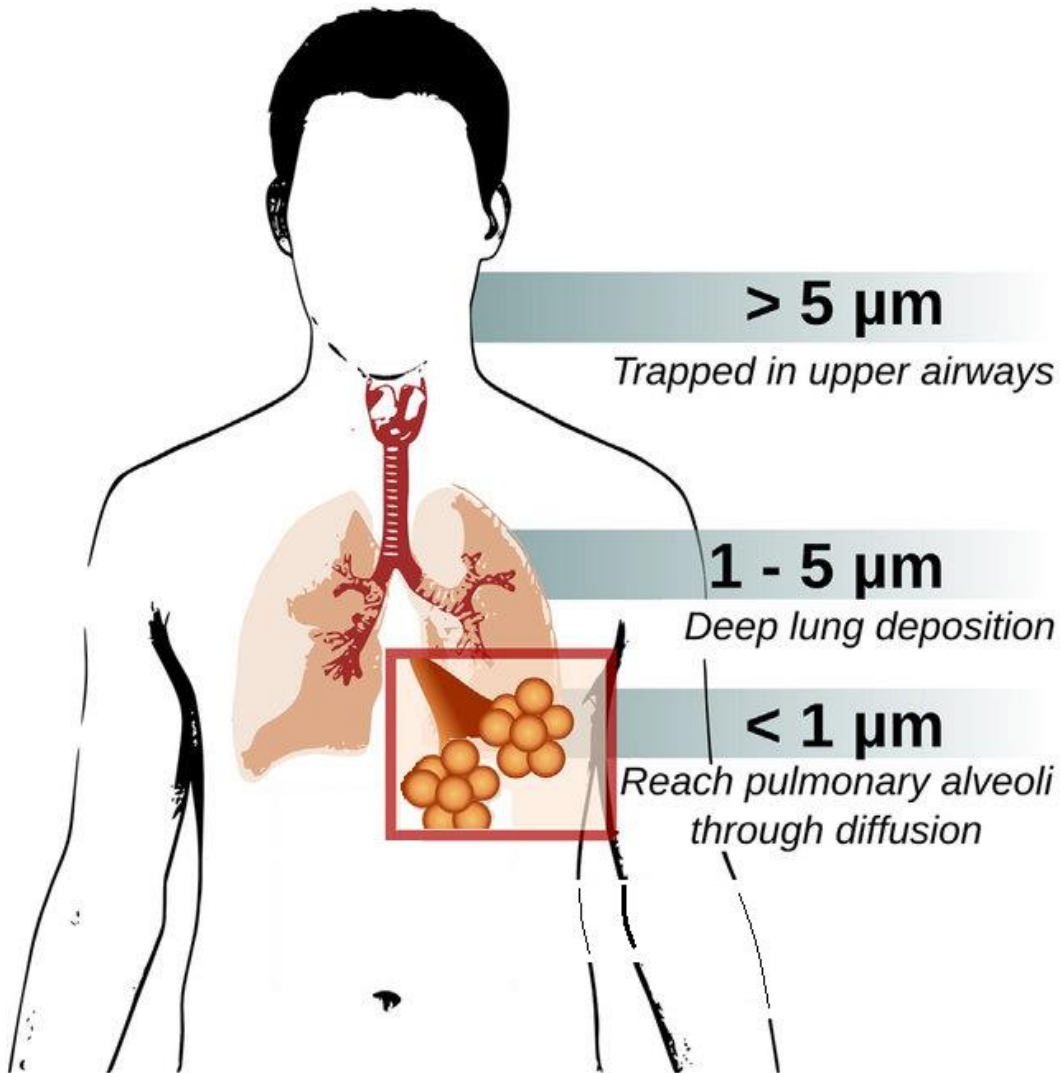
- Approx. 90% of our time

Pollutants levels indoors are often 2 to 5 times higher than typical outdoor concentrations (U.S. EPA)

Effects on human health:

- **Annoying:** Odors
- **Immediate / Health Threatening:** Irritation, headaches, allergies, asthma, fatal consequences.
- **Contagious airborne diseases**
- **Long term effects:** Cancer, respiratory diseases, debilitating well-being

Particle deposition in lungs



Exposure to fine particles:

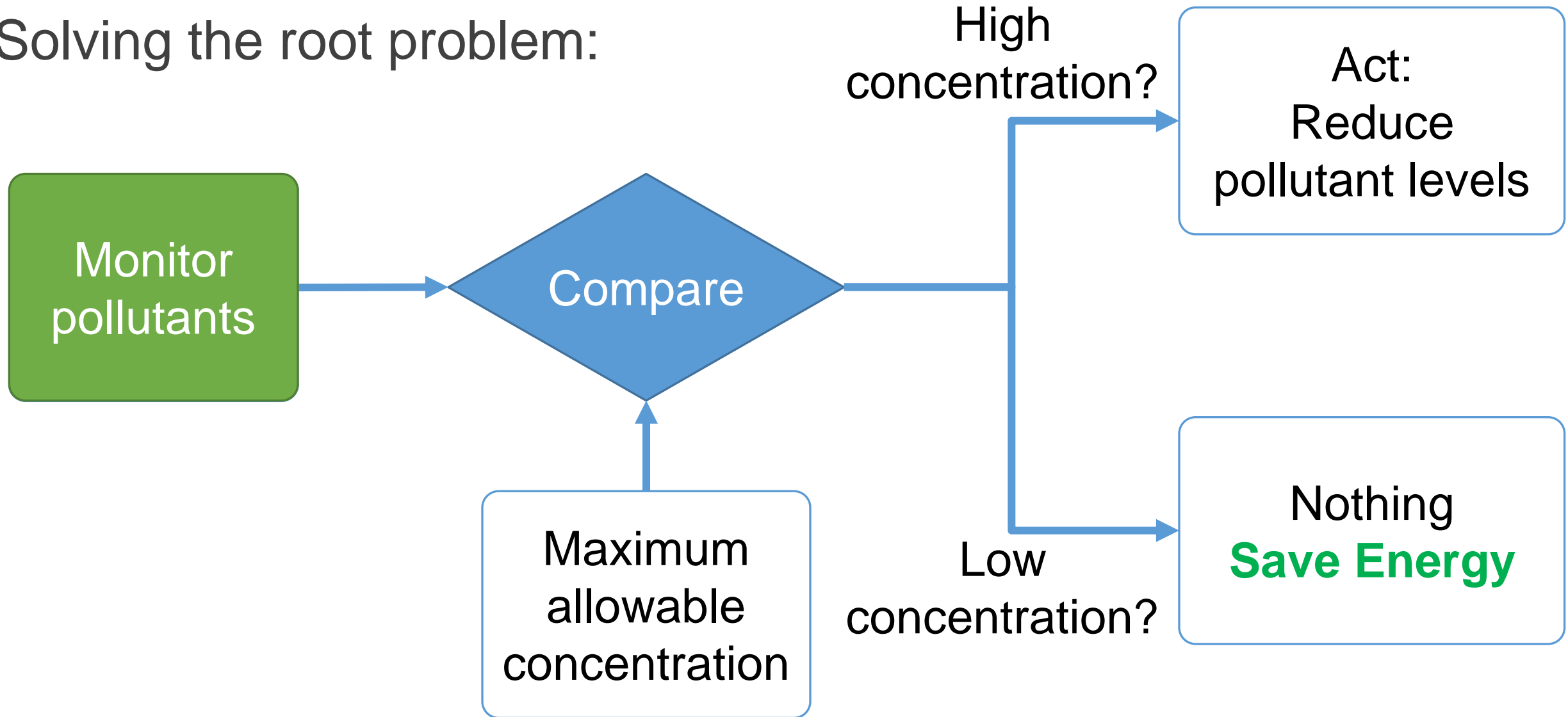
- Coughing & wheezing
- Shortness of breath
- Asthma attacks
- Cardiovascular effects including heart attacks, heart failure, and strokes.
- Reduced lung development in children.

It depends on concentration levels, exposure time, age and health conditions

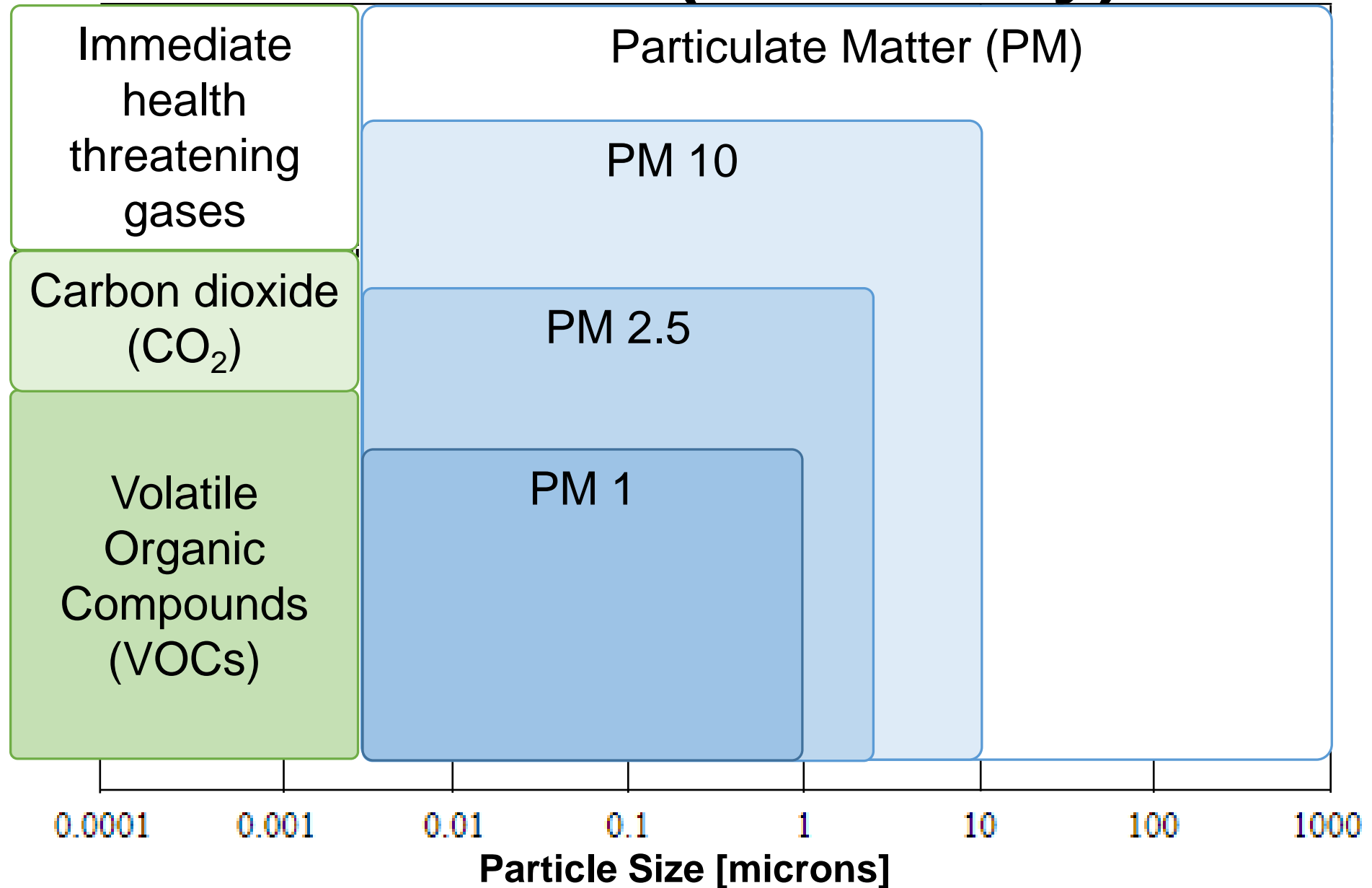
Achieving Healthy Indoor Air Quality: Monitoring Pollutants

Reducing Pollutant Concentration Levels

Solving the root problem:



What can we measure (affordably)?

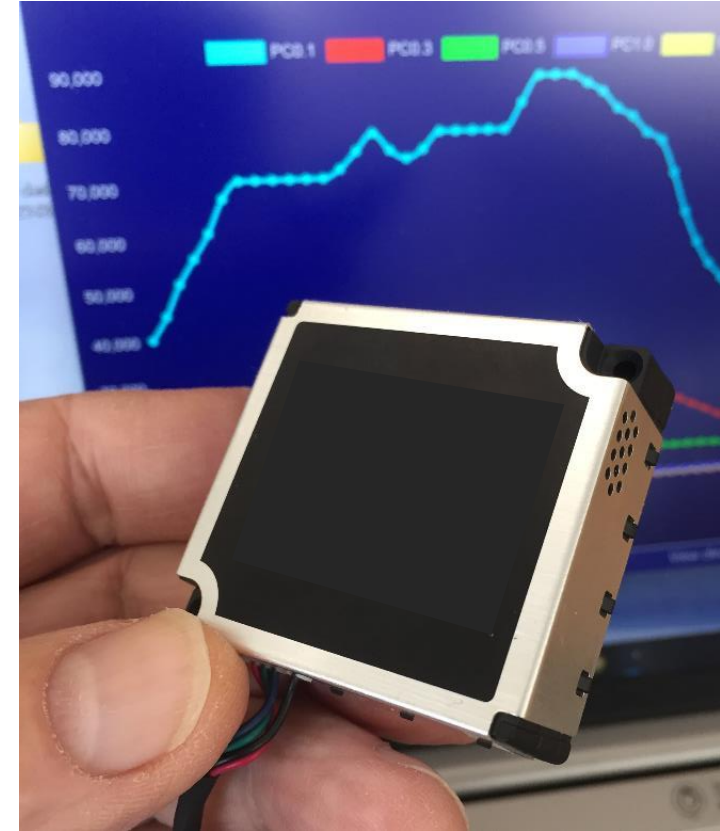


Indoor Air Quality Sensors

Innovation is making sensors more affordable & accurate

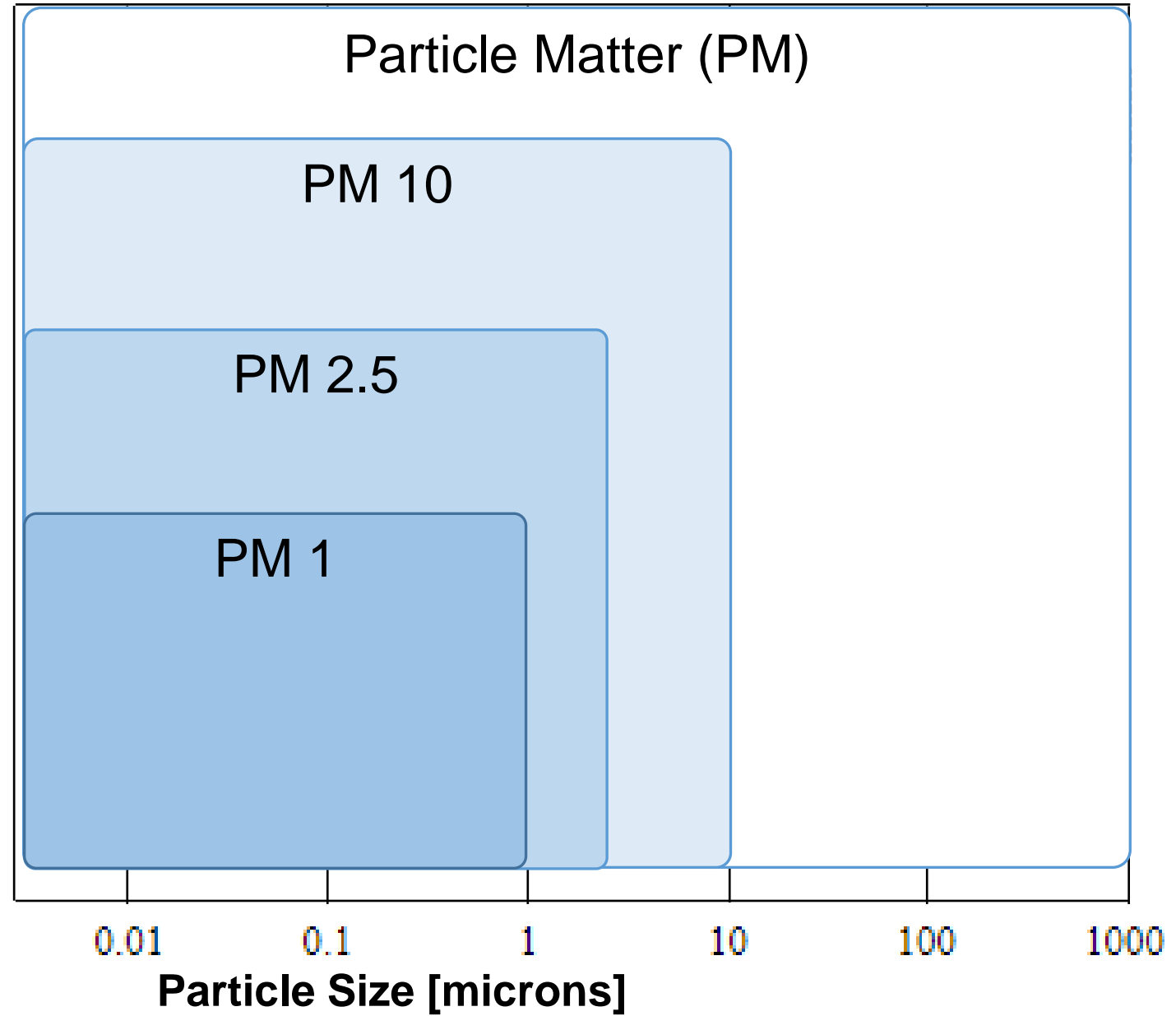
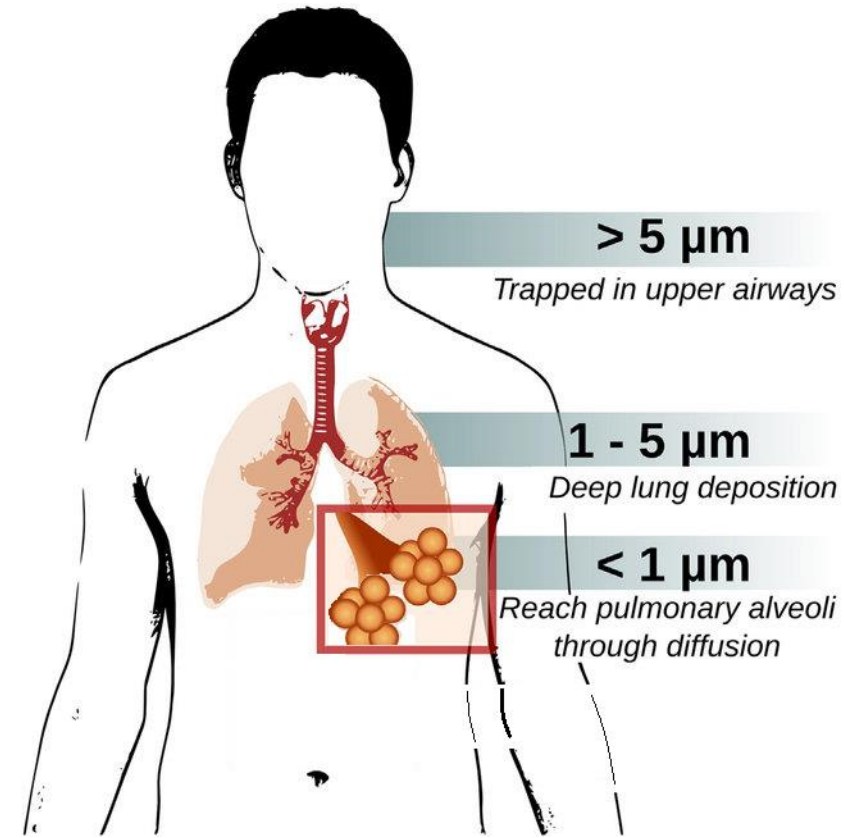


Every space should measure
CO₂ and VOCs

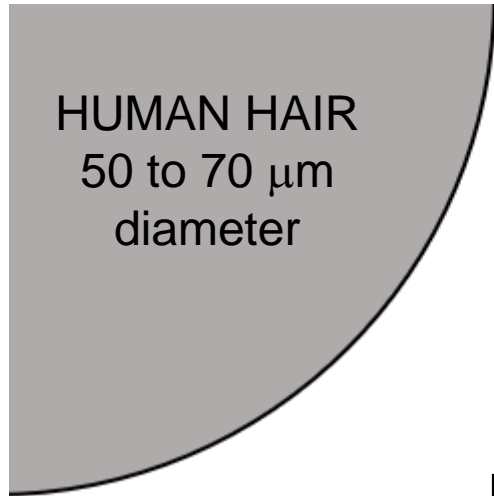


Accurate particle sensors
measuring as low as PM0.1

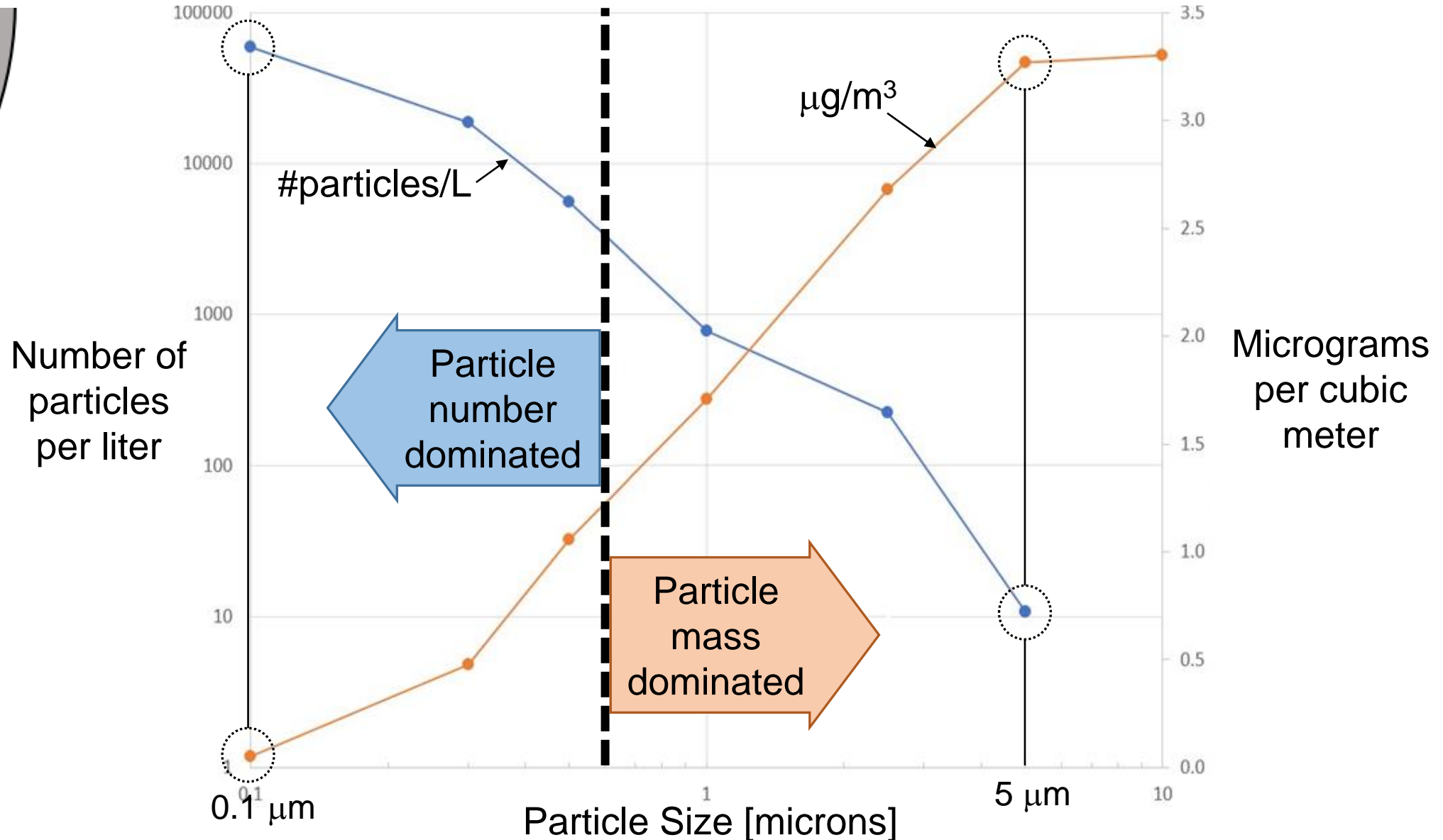
Particle size matters



Recommended Approach for Particulates



- 10 μm
- 2.5 μm
- 1 μm



Build Equinox Recommendations

Monitoring pollutants constantly:

Carbon Dioxide (CO₂)
Sensor

Weight based
Particle Matter
Sensor
(PM10 or PM2.5)

Volatile Organic
Compounds (VOCs)
Sensor

Particle Count based
Particle Matter
Sensor

Additional considerations:

- Fuel based appliances
(stove, furnace, fireplace, etc.):

Carbon Monoxide (CO)
Sensor

- Check periodically:

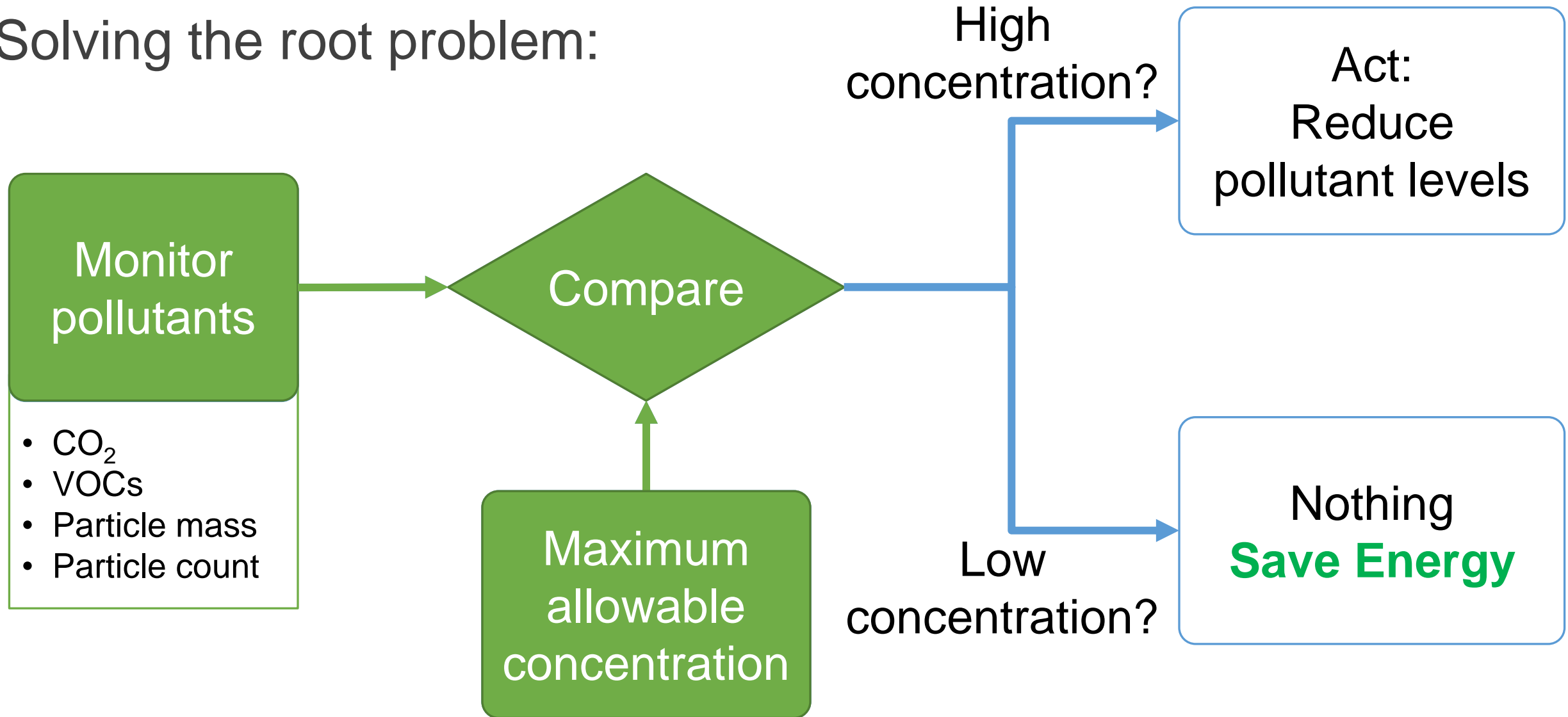
Radon Sensor

Achieving Healthy Indoor Air Quality:

Healthy IAQ Guidelines

Reducing Pollutant Concentration Levels

Solving the root problem:



Benefits of Fresh Air



There is a reason we like to breath fresh air:

- Cleanse our lungs and provides oxygen to our brain.
- In general, it makes us happier.
- CO₂ ~ 400ppm, very little gas contaminants & particle matter (seasonal)

Benefits of Fresh Air

Health



Feel better

Cognition



Think better

Sleep Quality



Sleep better

Productivity



Accomplish more

Healthy IAQ Standards

Carbon Dioxide (CO₂)
< 800ppm

Total mass of all
particulates 10µm
and smaller
PM₁₀ < 10µg/m³

Volatile Organic
Compounds (VOCs)
< 125 ppb
(equiv. to human
@ 800ppm CO₂)

Total count of all
particulates 0.3µm
and greater
**PC₁₀ < 40,000
particles/liter**

Additional considerations:

Carbon Monoxide (CO) < 9 ppm

Radon < 4 pCi/liter

Based on literature &
experimental research:

- Known to improve health
- Practical and achievable
- Reduce sickness
- Improve productivity
- Can be achieved in an energy efficient manner

Exposure time becomes
important when higher
than those values

Carbon Dioxide < 800ppm

Extensive research about the impact of pollutants on health, cognition, sleep quality and productivity:

Risk of Sick Leave Associated with Outdoor Air Supply Rate, Humidification, and Occupant Complaints

D. Milton, M. Glencross, M. Walter

40% sick day reduction (~1 day per year) when CO₂ reduced from today's building standard ventilation to 800 ppm

Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments

J. Allen, P. MacNaughton, U. Satish, S. Santanam, J. Vallarino, and J. Spengler

Cognition impacted as CO₂ increases more than 800ppm. About 10% decrease of cognition (9 areas including creativity, information organization, decision making, concentration) at today's ventilation standard.

The effects of bedroom air quality on sleep and next-day performance

P. Strøm-Tejsen, D. Zukowska, P. Wargocki, D. P. Wyon

Sleep degradation and decreased work productivity at elevated CO₂ concentration

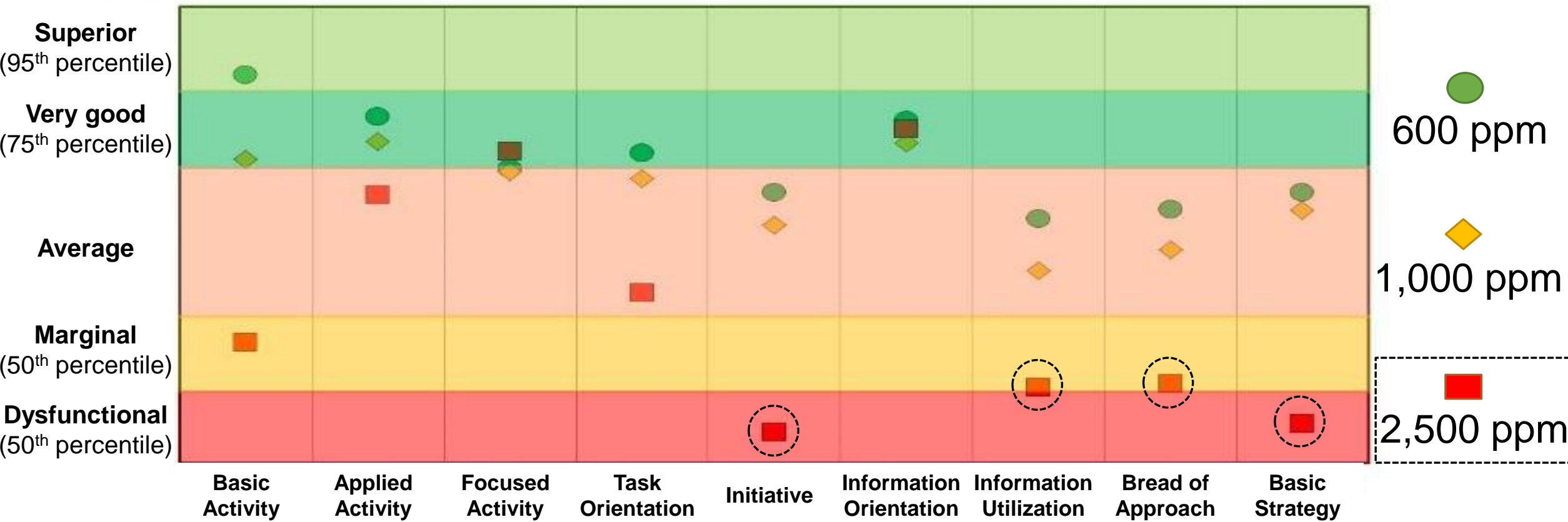
Economic, Environmental and Health Implications of Enhanced Ventilation in Office Buildings

P. MacNaughton, J. Pegues, U. Satish, S. Santanam, J. Spengler, and J. Allen

"The health benefits associated with enhanced ventilation rates far exceed the per-person energy costs relative to salary costs"

CO₂ Impairs Cognitive Performance

Impact of carbon dioxide on human decision-making performance [3]:

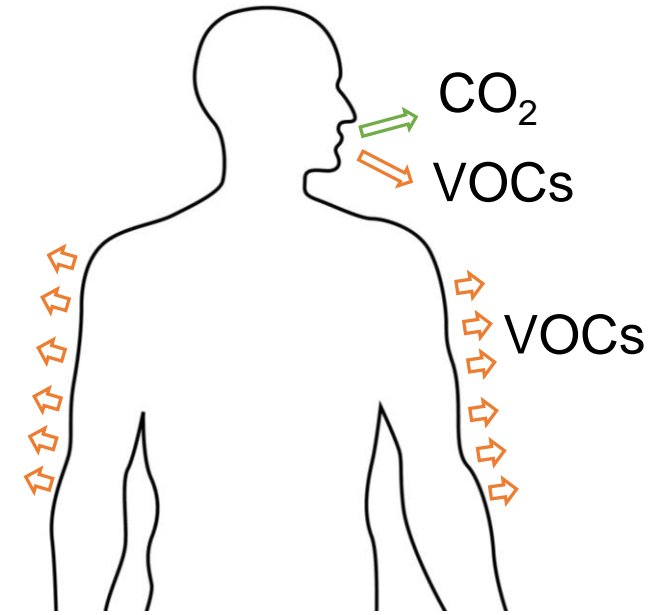


Strongly impairs: Initiative, Information Utilization, Approach, and Strategy

Notes about Volatile Organic Compounds

Today's ventilation standards do not specify VOC levels.

- Humans produce about 2,400 mg/hour of VOCs
 - (primarily isoprene, acetone, ethanol, methanol, and isopropanol).
- Both CO₂ and VOCs are proportional to metabolism levels.
- VOCs impair productivity and degrade sleep (same as CO₂)
- Maximum level of VOCs recommended (~125 ppb) is associated with human generated CO₂ max. level (800 ppm).



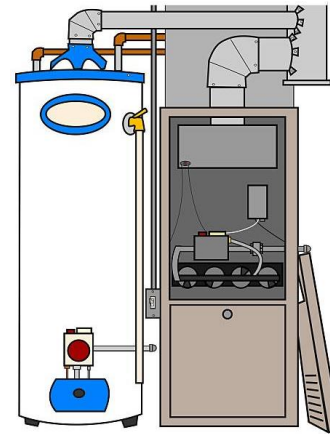
Other sources of VOCs:



Cooking & gas combustion



Wood combustion

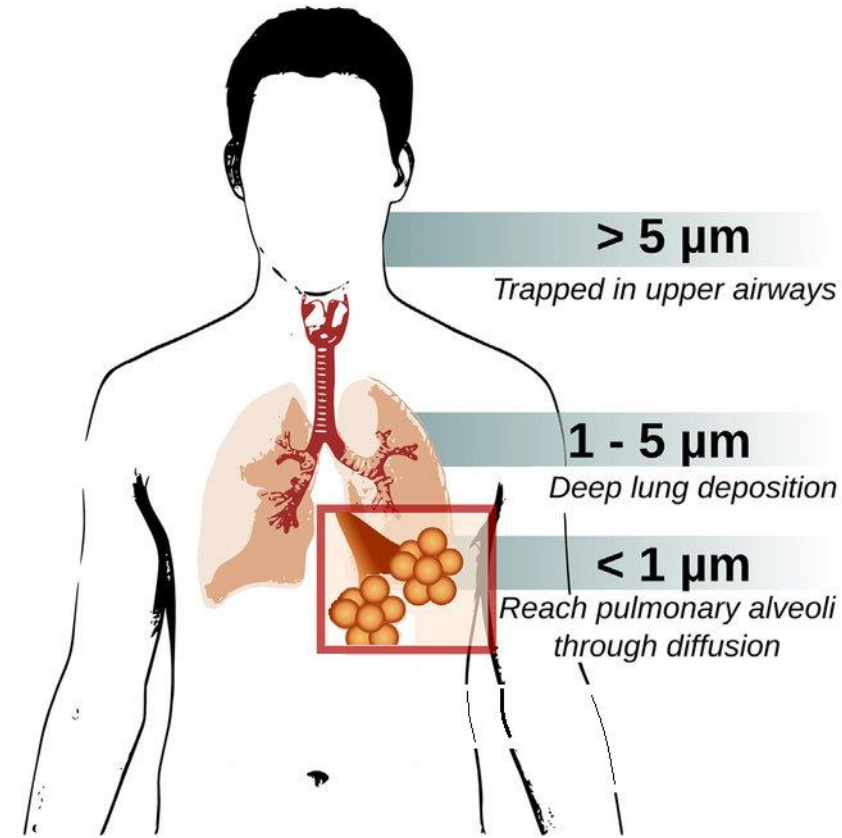


Fuel combustion in furnace and water heater

Others:



Notes about Particles



Studies show cancer, stroke, heart attack, dementia, respiratory afflictions are all reduced as particulates are reduced.

- No low safe limit defined for number of particles.

U.S. EPA particulate guidelines recommend $\text{PM}_{2.5} < 12\text{-}15\mu\text{g}/\text{m}^3$

- $\text{PM}_{2.5}$ represents the mass of all particulates $2.5\mu\text{m}$ and smaller

Recommended to measure both total mass and total particle count:

- $\text{PM}_{10} < 10\mu\text{g}/\text{m}^3$ (more stringent)
- Particle count $< 40,000$ particles/liter (practical)

Healthy IAQ Standards

Carbon Dioxide (CO₂)
< 800ppm

Total mass of all
particulates 10µm
and smaller
PM₁₀ < 10µg/m³

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Compounds (VOCs)
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Based on literature &
experimental research:

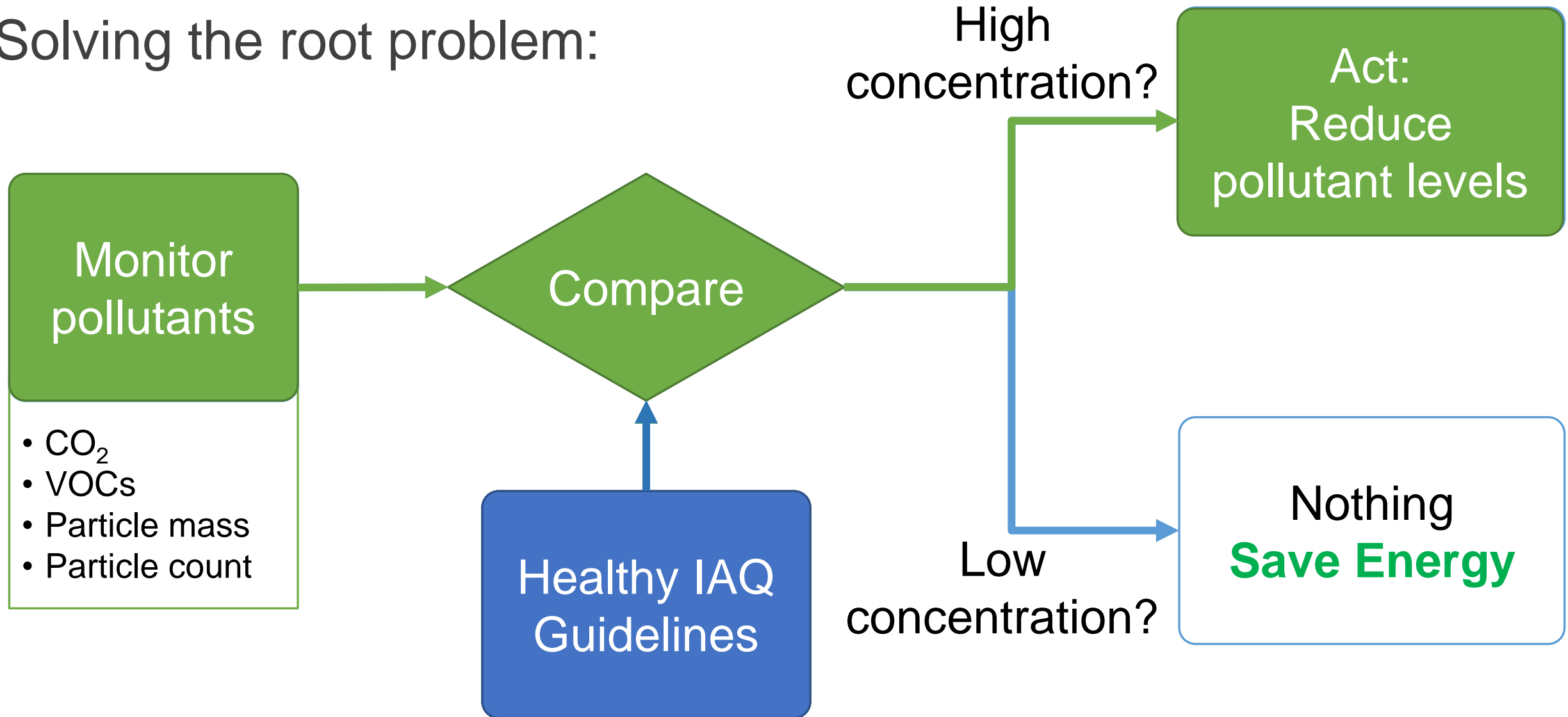
- Known to improve health
- Practical and achievable
- Reduce sickness
- Improve productivity
- Can be achieved in an energy efficient manner

Exposure time becomes
important when higher
than those values

Achieving Healthy Indoor Air Quality: Mechanisms to Reduce Pollutants

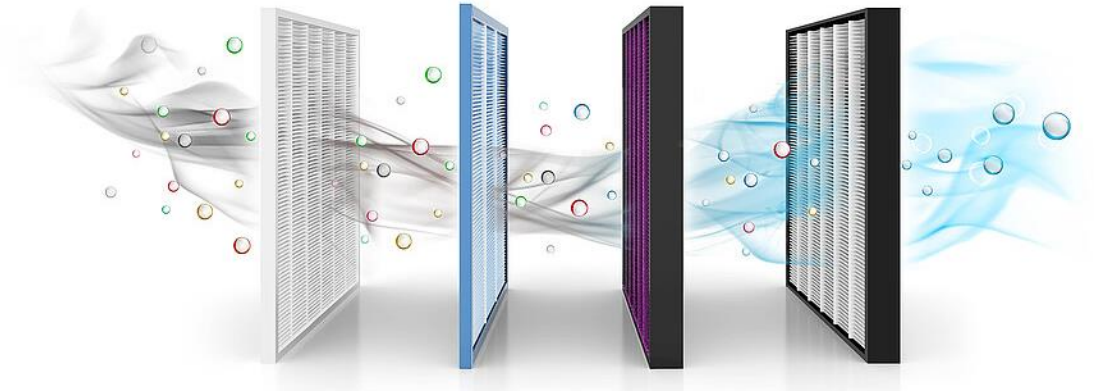
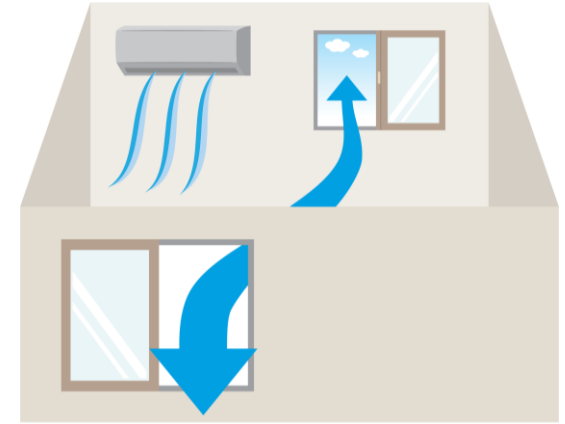
Reducing Pollutant Concentration Levels

Solving the root problem:



Mechanisms to Reduce Pollutants

- ☐ Source control
- ☐ Ventilation (Dilution)
- ☐ Filtration
- ☐ Microbe deactivation



The most effective system
is the one that use them all



Source Control

Restricting pollutant or contaminant access:

- By design
- Maintenance
- Prohibiting use



Building Electrification



- Gas water heater
- Furnace (space heating)
- Gas stove

- Heat pump water heater
- Heat pump for space heating & cooling
- Electric stove

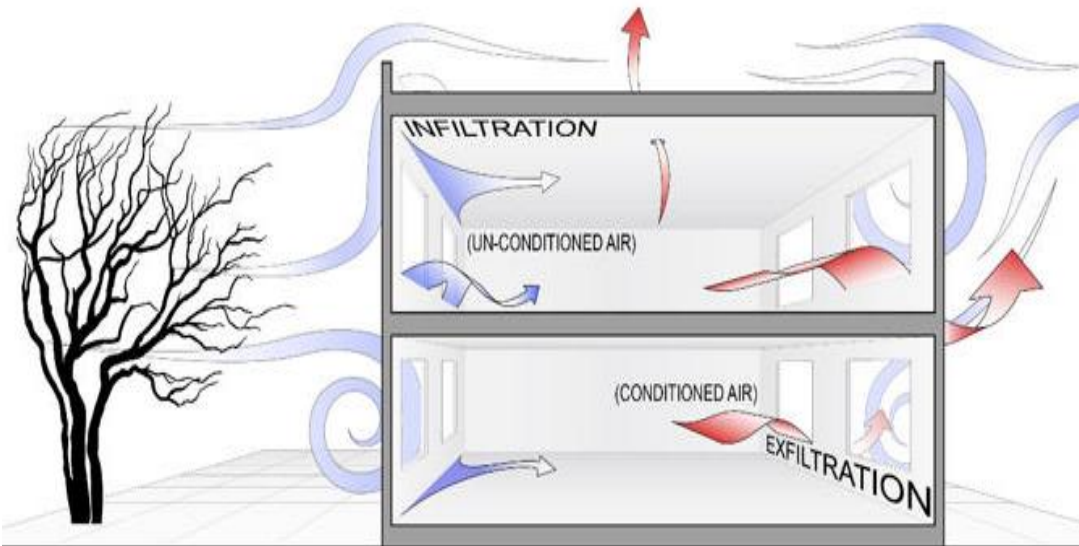
- Remove combustion indoors (no CO₂/VOCs).
- Improve safety (zero probability of CO leaks)
- Access to clean electric energy.

Ventilation

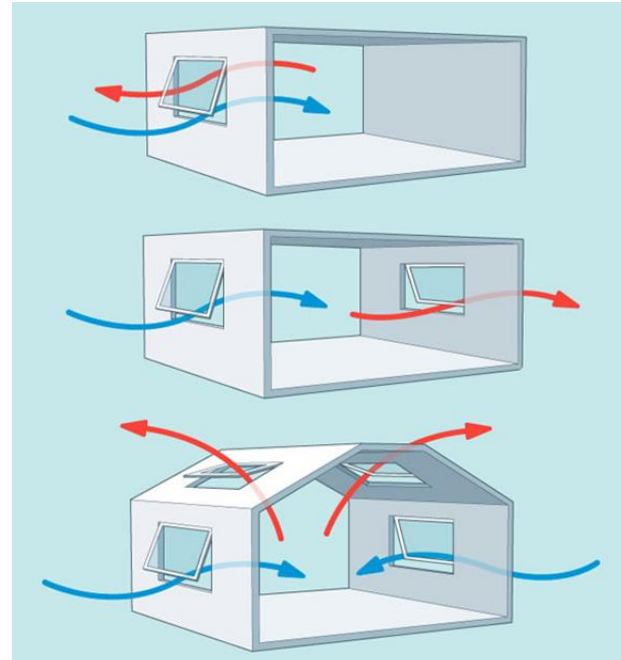
The purpose of ventilation is to bring outdoor air to dilute indoor contaminants (reduce concentration).

- Gases contaminants: CO₂, VOCs, CO, Radon, etc.
- Particles: Particle contaminants & biological particles

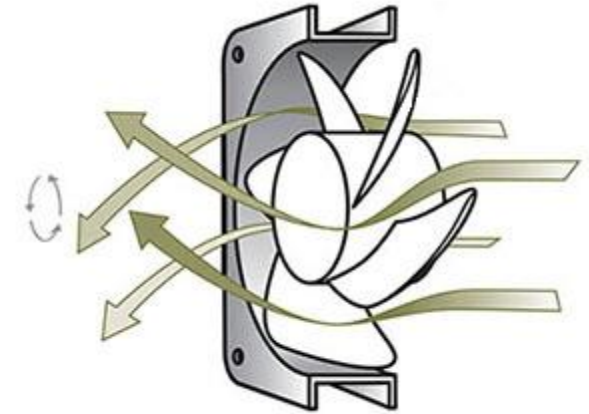
Air Infiltration / Exfiltration



Natural (Passive) Ventilation



Mechanical Ventilation



Filtration

Filtration is the removal of contaminants from the air:

- Particles: Particle contaminants & biological particles



Removal Efficiency:
$$\eta = \frac{C_1 - C_2}{C_1}$$

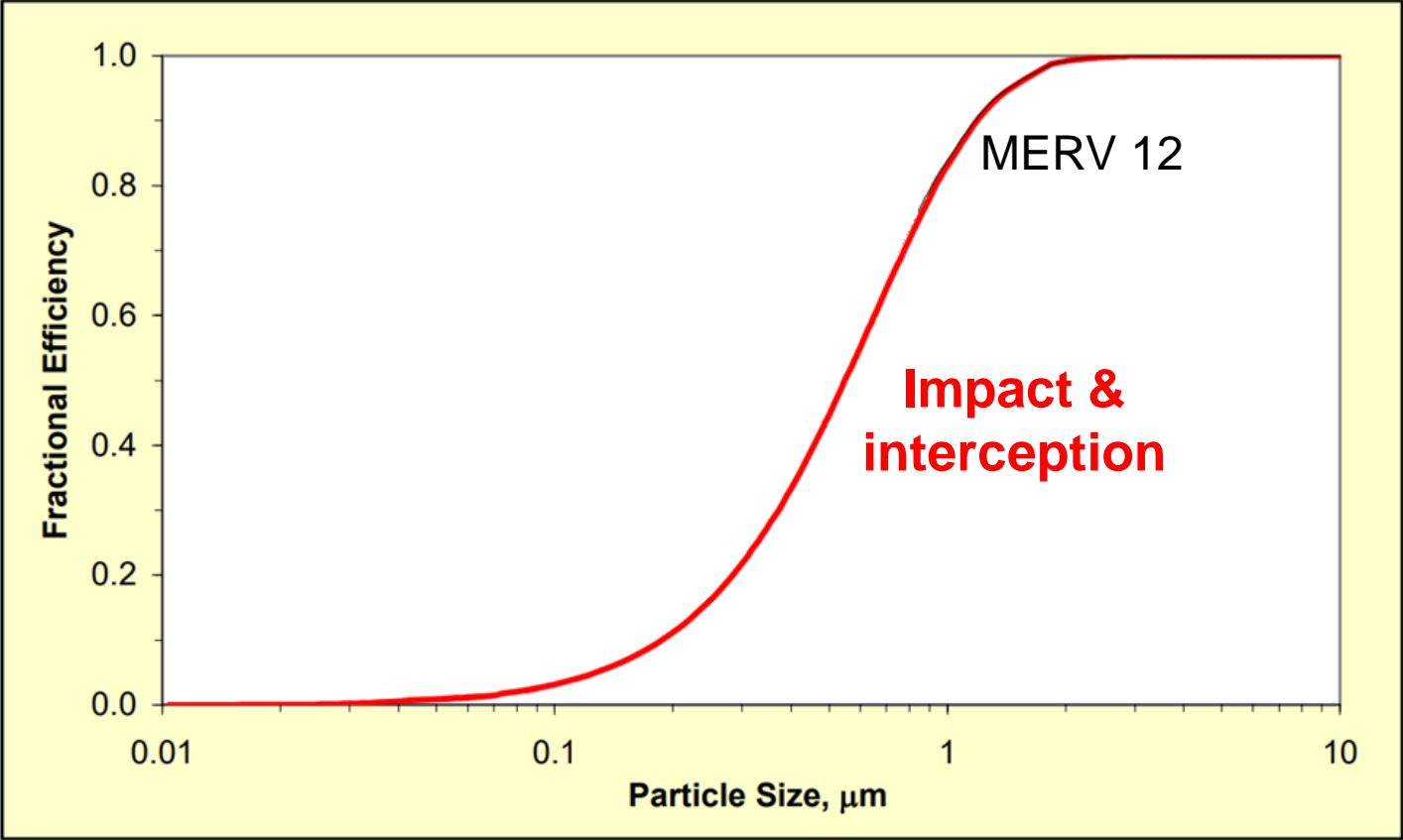
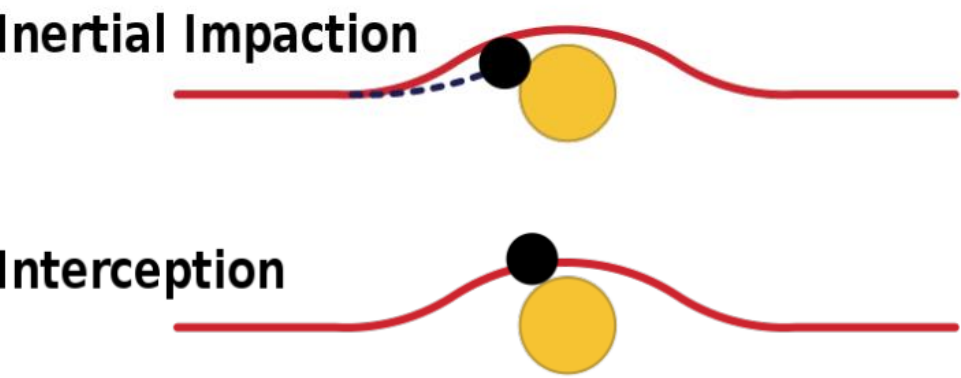
*C_1 is the concentration upstream the filter and
 C_2 is the concentration downstream the filter*

Most common removal efficiency: Minimum Efficiency Reporting Values (MERV)

- Classification of filters into one of 16 levels
- Test according to ASHRAE Standard 52.2

Filter Removal Efficiency

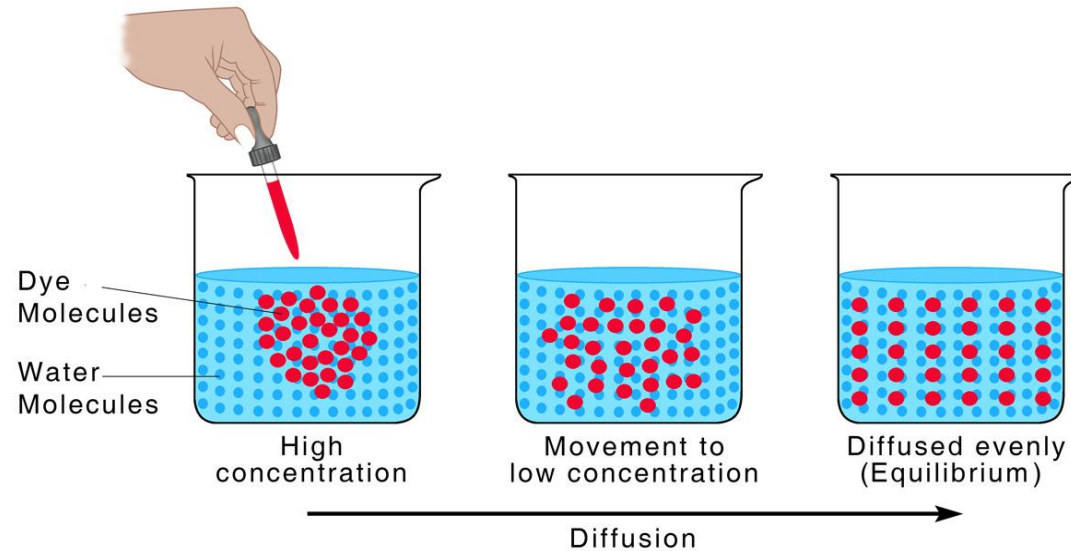
Mechanisms to trap particulates in filters [4], [5]:



Filter Removal Efficiency

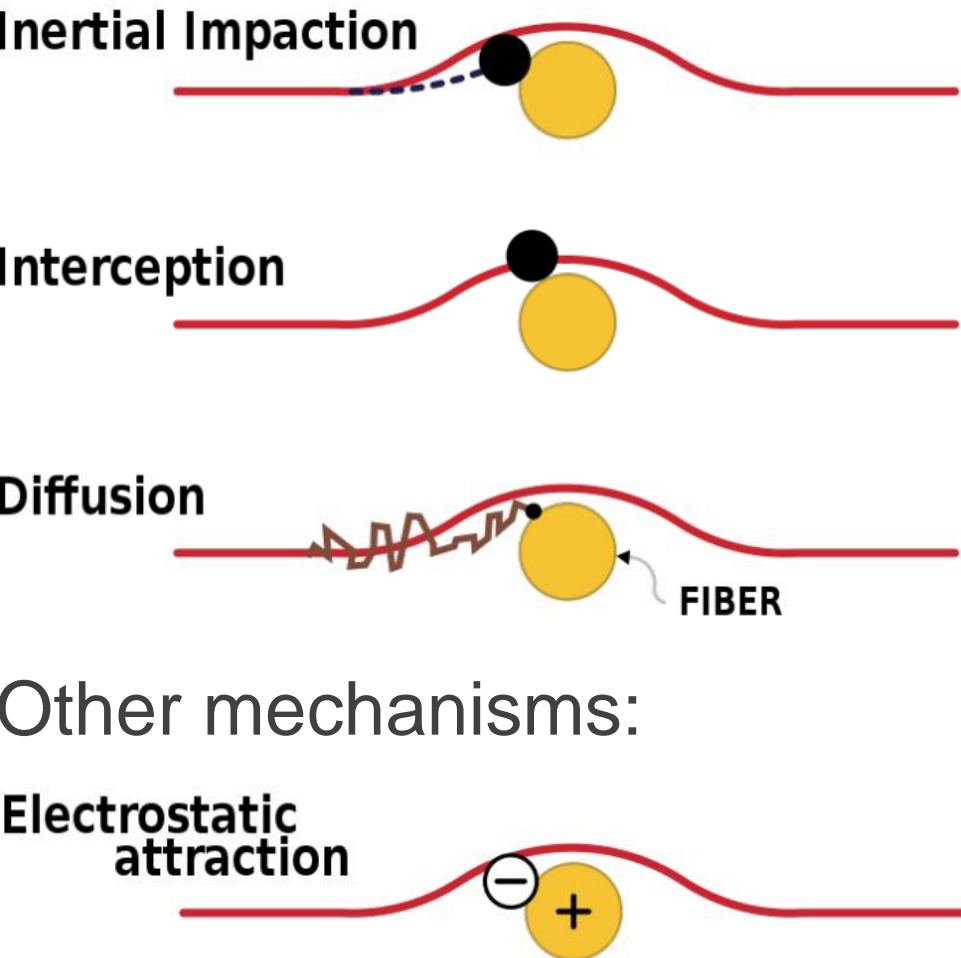
Diffusion:

- Movement of particles from high to low concentration

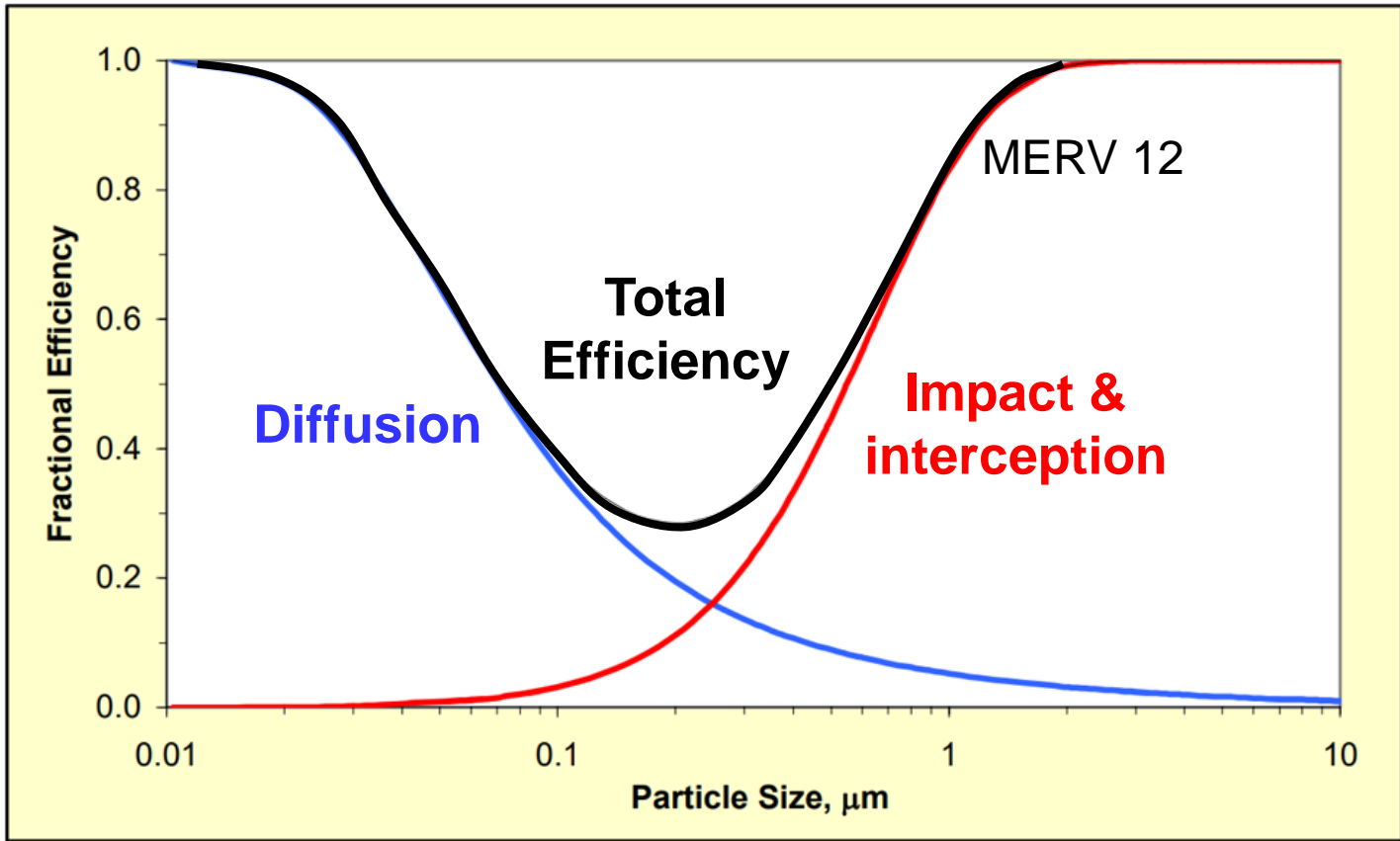


Filter Removal Efficiency

Mechanisms to trap particulates in filters [4], [5]:

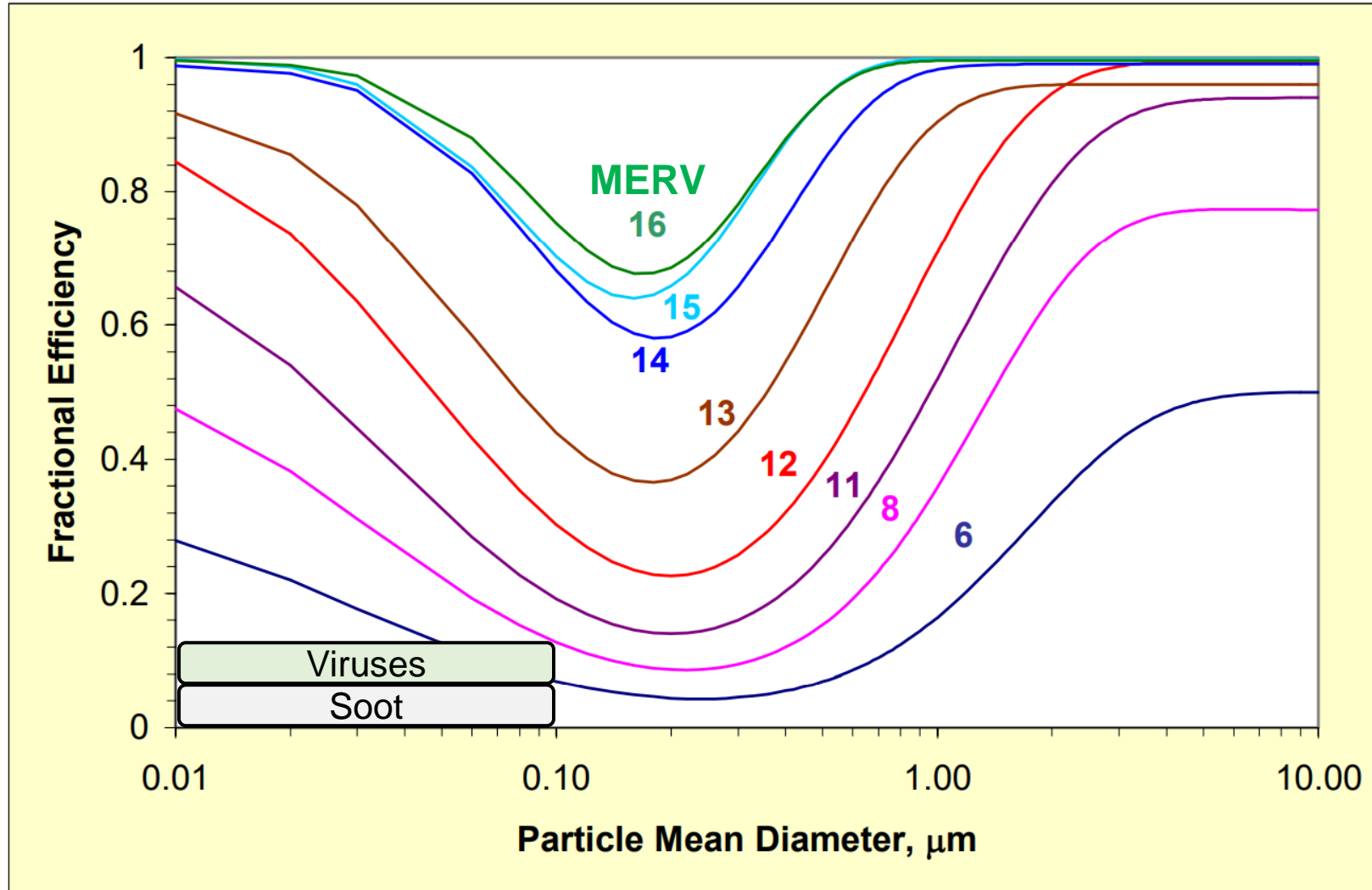


Other mechanisms:



Filter Removal Efficiency

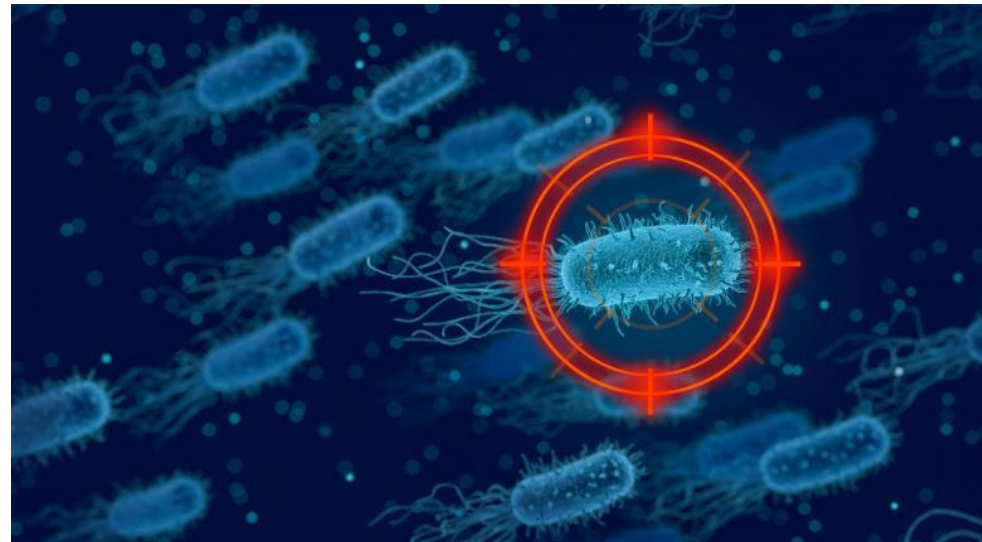
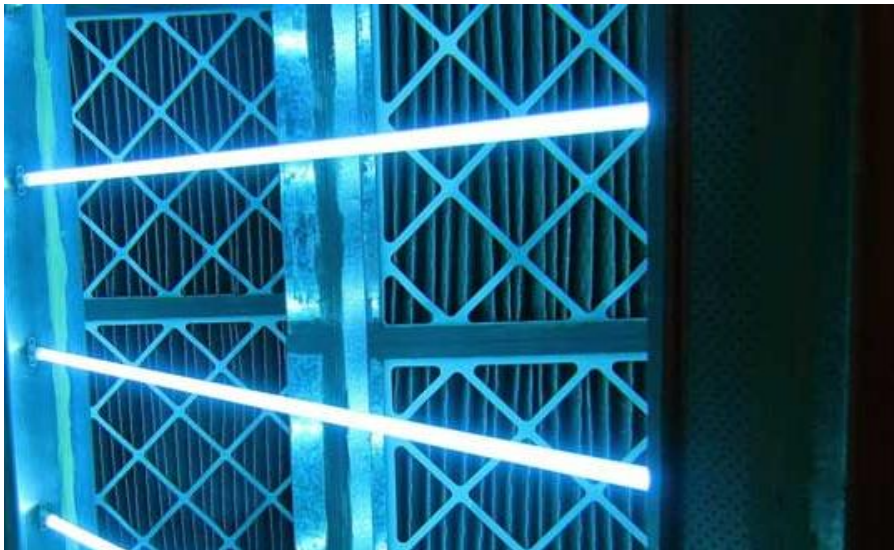
ASHRAE Epidemic Task Force recommends MERV 13 or higher.



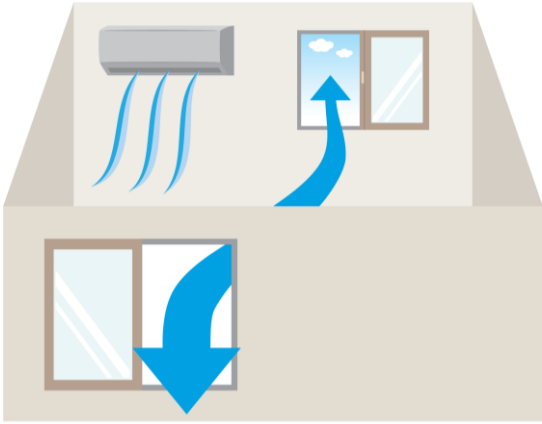
Microbe Deactivation

Ultra-Violet Germicidal Irradiation (UVGI) filters:

- Used in hospitals and laboratories for disinfection. Now affordable.
- Short-wave ultraviolet light to inactivate biological contaminants by bombarding the microorganisms with radiation and damaging their DNA.
- Add-on (do not remove particle contaminants).
- LED lamps: No risk of ozone production.



Recommendations: Healthy Buildings & Homes



Ventilation

40 cfm / person
Equivalent to reaching
healthy level
of 800 ppm CO₂

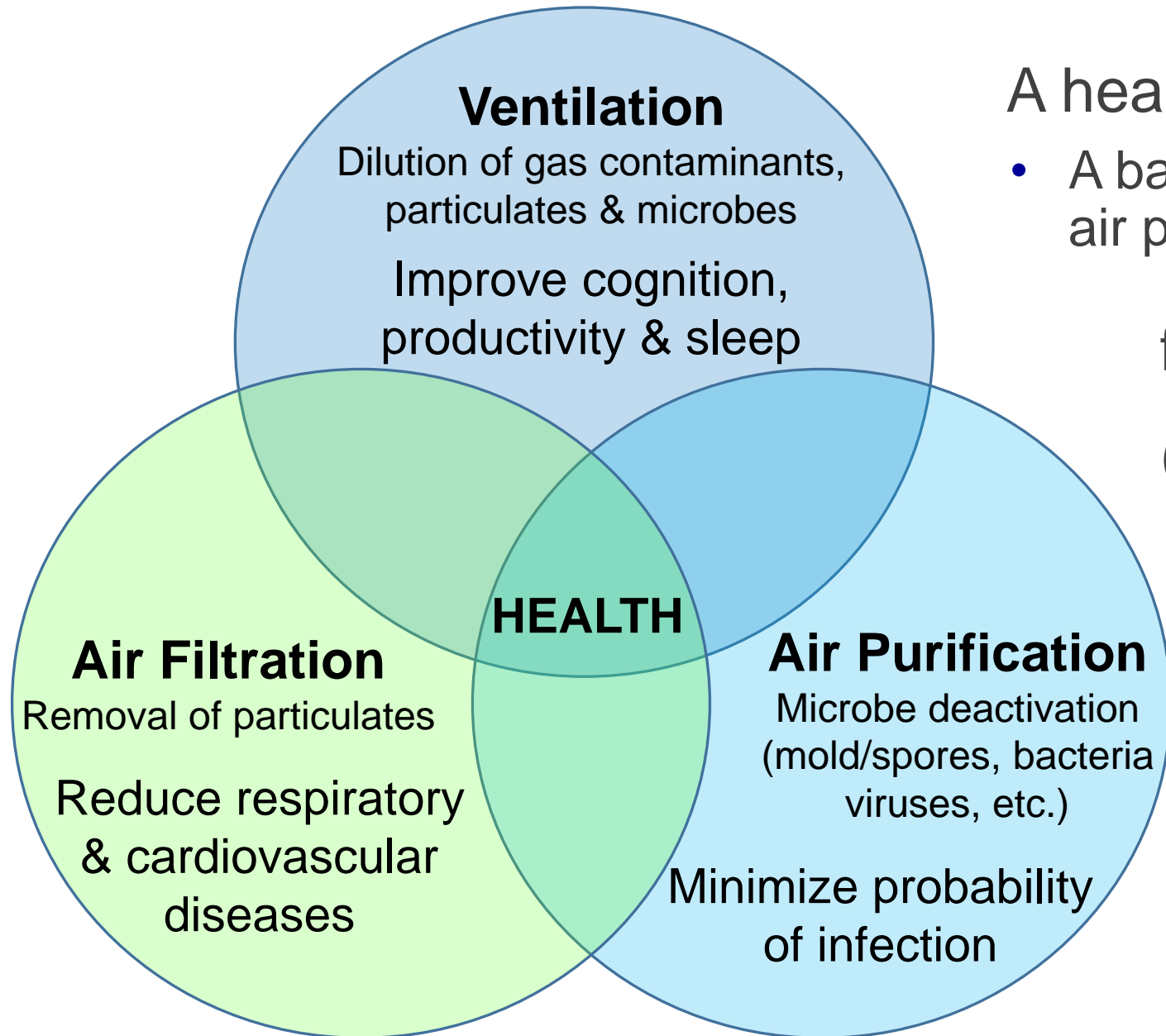
Air Filtration

MERV 13
For air recirculation
For fresh air coming in

Air Purification

Microbe deactivation with
Ultraviolet germicidal
irradiation (UVGI) using
UV-C without ozone
production

Healthy Buildings & Homes



A healthy and safe space:

- A balance of ventilation, air filtration, and air purification has synergistic benefits

f_{microbes} = fraction removed

$$(1 - (1 - f_{\text{ventilation}}) \times (1 - f_{\text{filter}}) \times (1 - f_{\text{UVGI}}))$$

$$f_{\text{ventilation}} = 50\%$$

$$f_{\text{filter}} = 90\%$$

$$f_{\text{UV}} = 85\%$$

$$f_{\text{microbes}} = 99.3\% \text{ microbes removed}$$

Notes About Outside (Fresh) Air

Outside air not always “fresh”:



Recommendations:

- Filter outside air coming to the building (MERV 13).
- Smart system: Ability to monitor & close vents when high levels of pollution outside and use recirculation mode to filter / purify indoor air.

Health Statistics

2022 Statistics from the American Lung Association [6]:

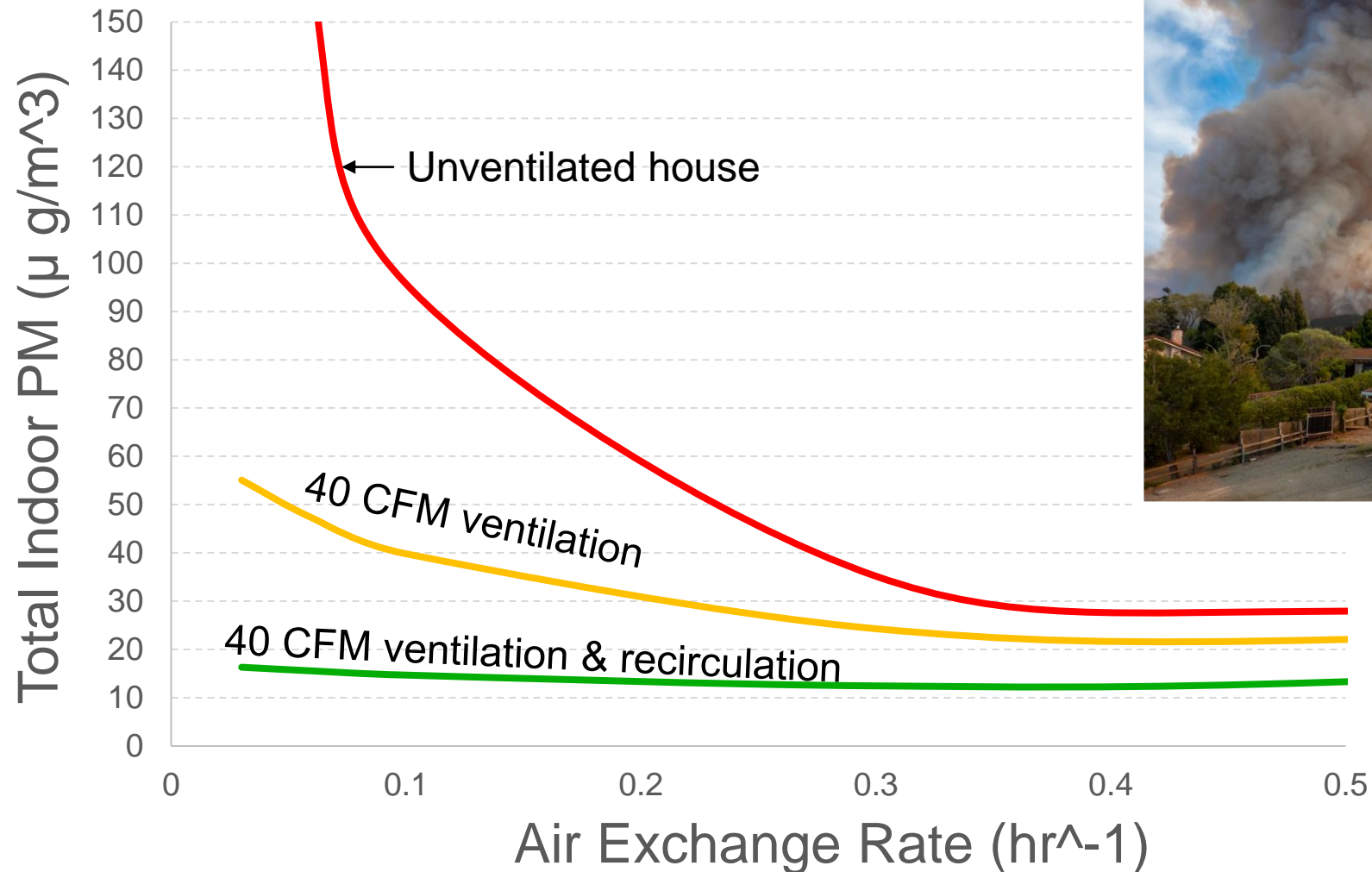


More than 4 in 10 Americans live in places with unhealthy levels of air pollution.

“[In the 3 years covered by report], Americans experienced more days of “very unhealthy” and “hazardous” air quality than ever before in the two-decade history [of Report]”

Particulates from wildfire

Home with PMs outside $\sim 50 \mu\text{g}/\text{m}^3$ and indoor air generating $1.2 \mu\text{g}/\text{m}^3$



Sustainability & Cost of Health

Sustainable Building Design

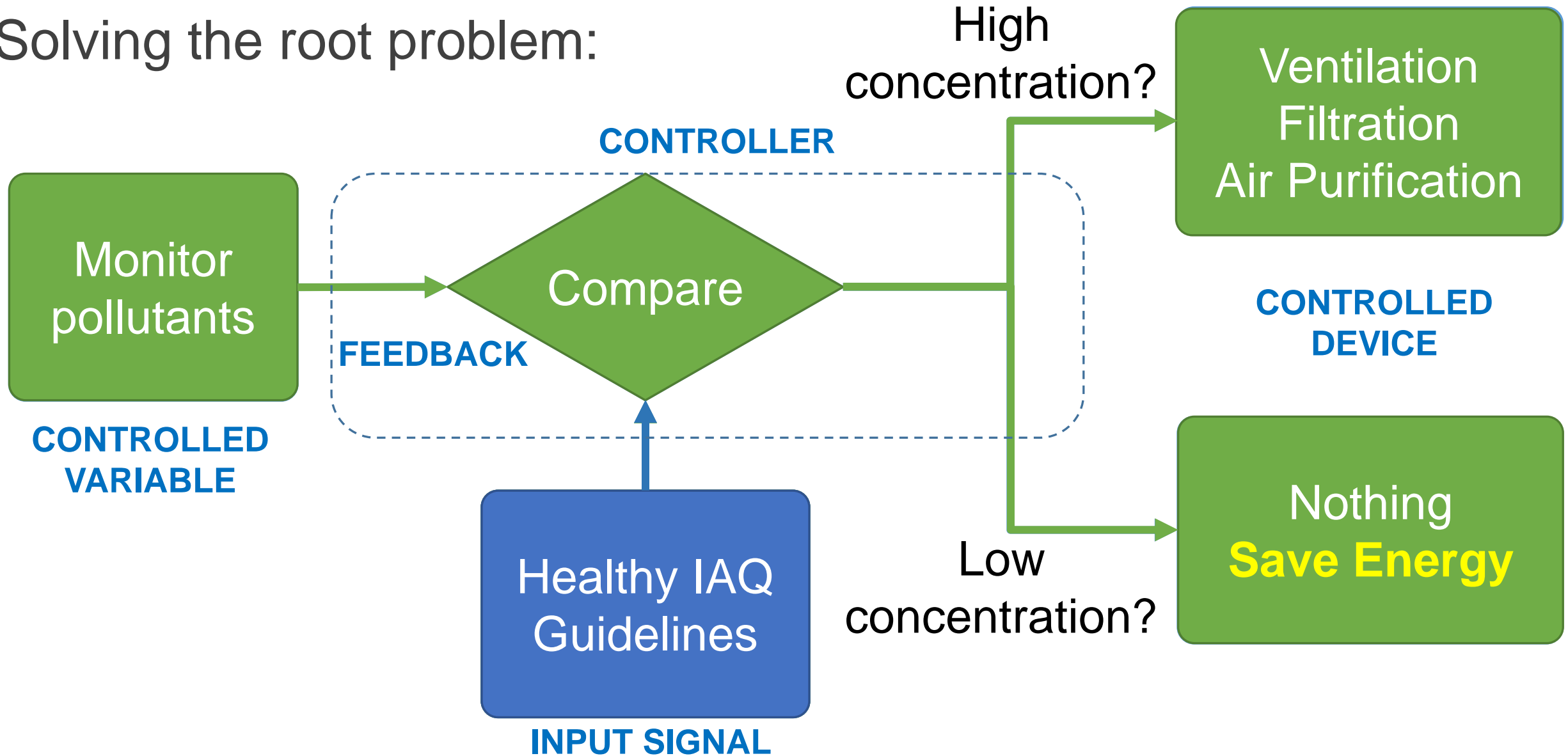


When designing or renovating buildings:

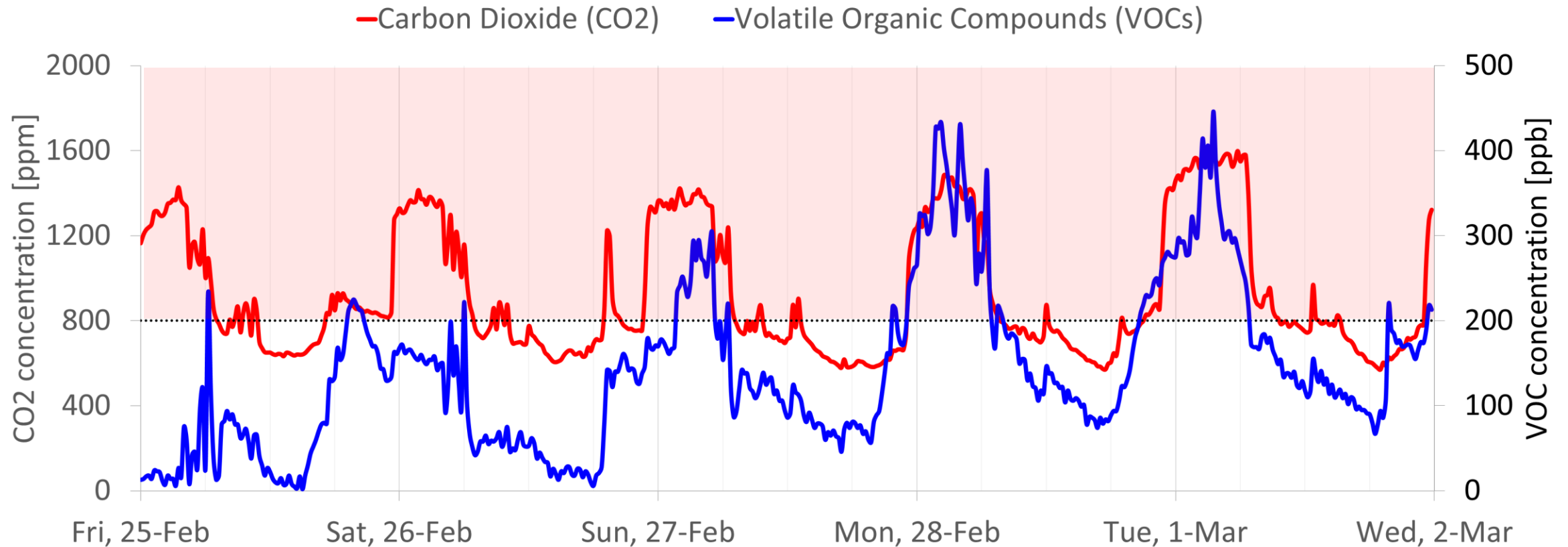
- **Top priority:** Healthy indoor air (humancentric design)
- **Limits:** Energy and carbon emissions (sustainability)

Smart Controls

Solving the root problem:

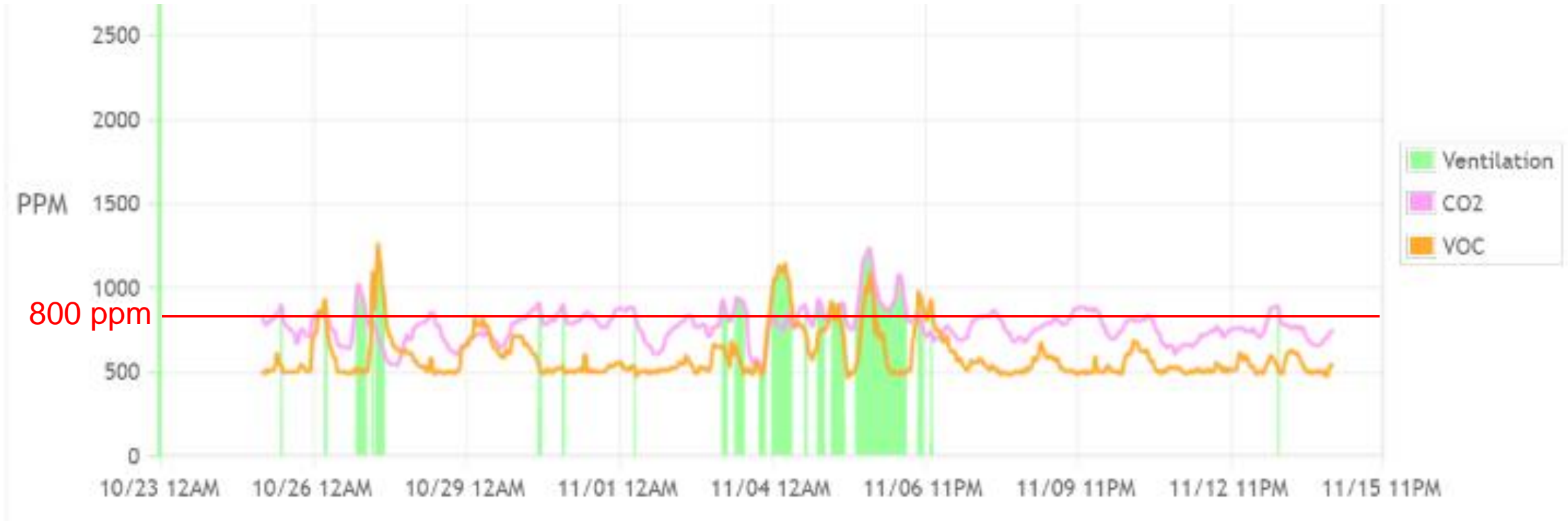


Life at Home is Dynamic



**IAQ measurements on a 2,700 ft² home and 7 ACH@50 infiltration with no ventilation system*

Smart IAQ Ventilation



- Ventilates when needed (smart controls)
- Uses energy only when needed.

Sustainable Building Design

Moving beyond building codes:

- Minimum requirements

Paths to sustainable buildings:

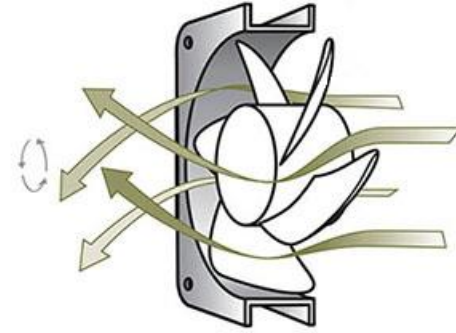
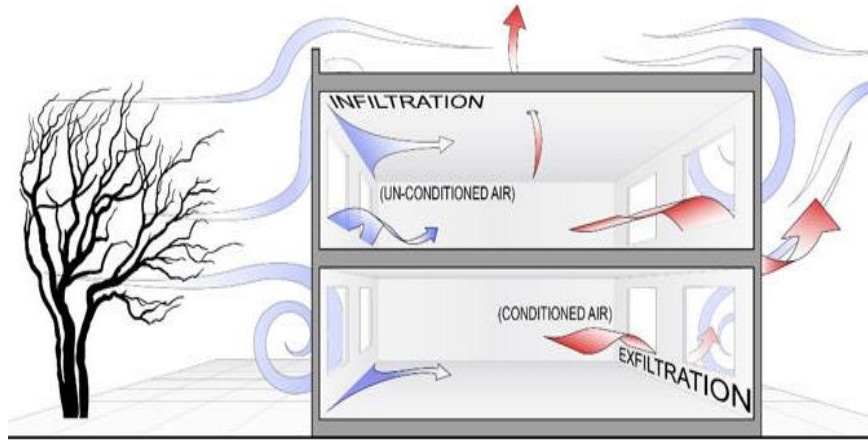
- PHIUS (Passive House)
- ZERH (U.S. DOE Zero Energy Ready Home)
- ASHRAE 189.1
- Etc.

Achieving ultra-tight enclosure:

- Reducing energy losses due to infiltration / exfiltration



Notes about Ventilation Rates



Achieving ultra-tight enclosure:

- Focusing on reducing energy loss may worsen health issues
- Balanced mechanical ventilation needs to be added.

Ventilation less than 20 CFM per person:

- Research shows it may cause sick building syndrome (SBS), cognitive function decline, and productivity losses.

Healthy & Sustainable Building Design

Minimum standards (not healthy):

- ASHRAE 62.2-2019 (current version)
- EPA Indoor airPLUS
 - ASHRAE 62.2-2010 (**Unhealthy**) or later
- LEED v4 Homes
 - ASHRAE 62.2-2010 (**Unhealthy**)

Strongly recommended to move beyond minimum standards to achieve healthy environment:

$\text{CO}_2 < 800\text{ppm}$

$\text{PM}_{10} < 10\mu\text{g}/\text{m}^3$

$\text{VOCs} < 125 \text{ ppb}$

$\text{PC}_{10} < 40,000 \text{ \#}/\text{L}$



ASHRAE Standard 62.2 – 2019

- Distinction between 62.2 (Residential) & 62.1 (All other buildings)
- Ventilation & **Acceptable** Indoor Air Quality Standards
 - *Dissatisfaction with respect to odor and sensory irritation.*
- It does not address specific pollutant concentration levels.
- Based on constant flow (odor based):

$$Q_{tot} = 0.03 * A_{floor} + 7.5 * (N_{br} + 1)$$

Q_{tot} is total required ventilation rate (CFM),

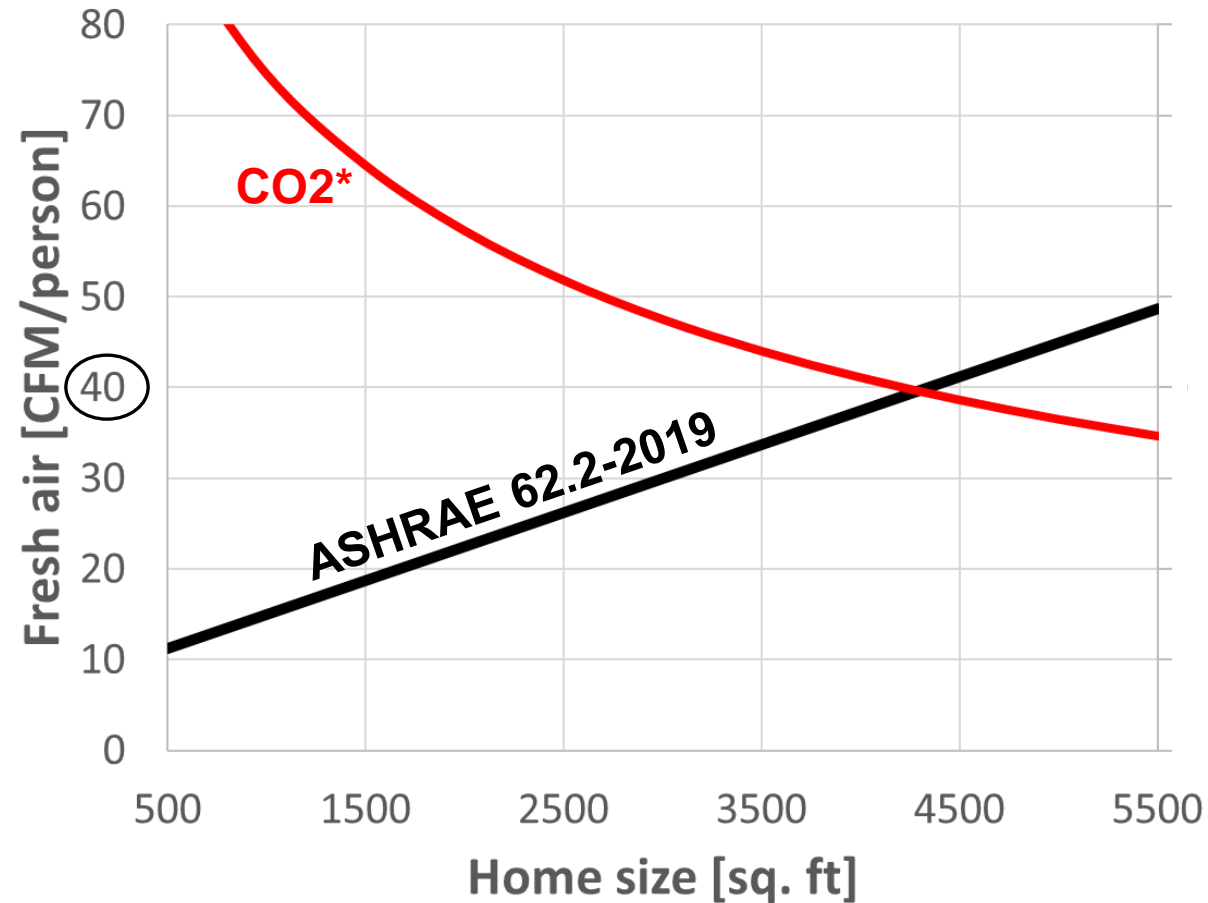
A_{floor} is dwelling-unit floor area (ft²), N_{br} is number of bedrooms

2010 version: $Q_{tot} = \mathbf{0.01} * A_{floor} + 7.5 * (N_{br} + 1)$

It may cause a very unhealthy environment

Carbon Dioxide Levels vs. Ventilation Rate

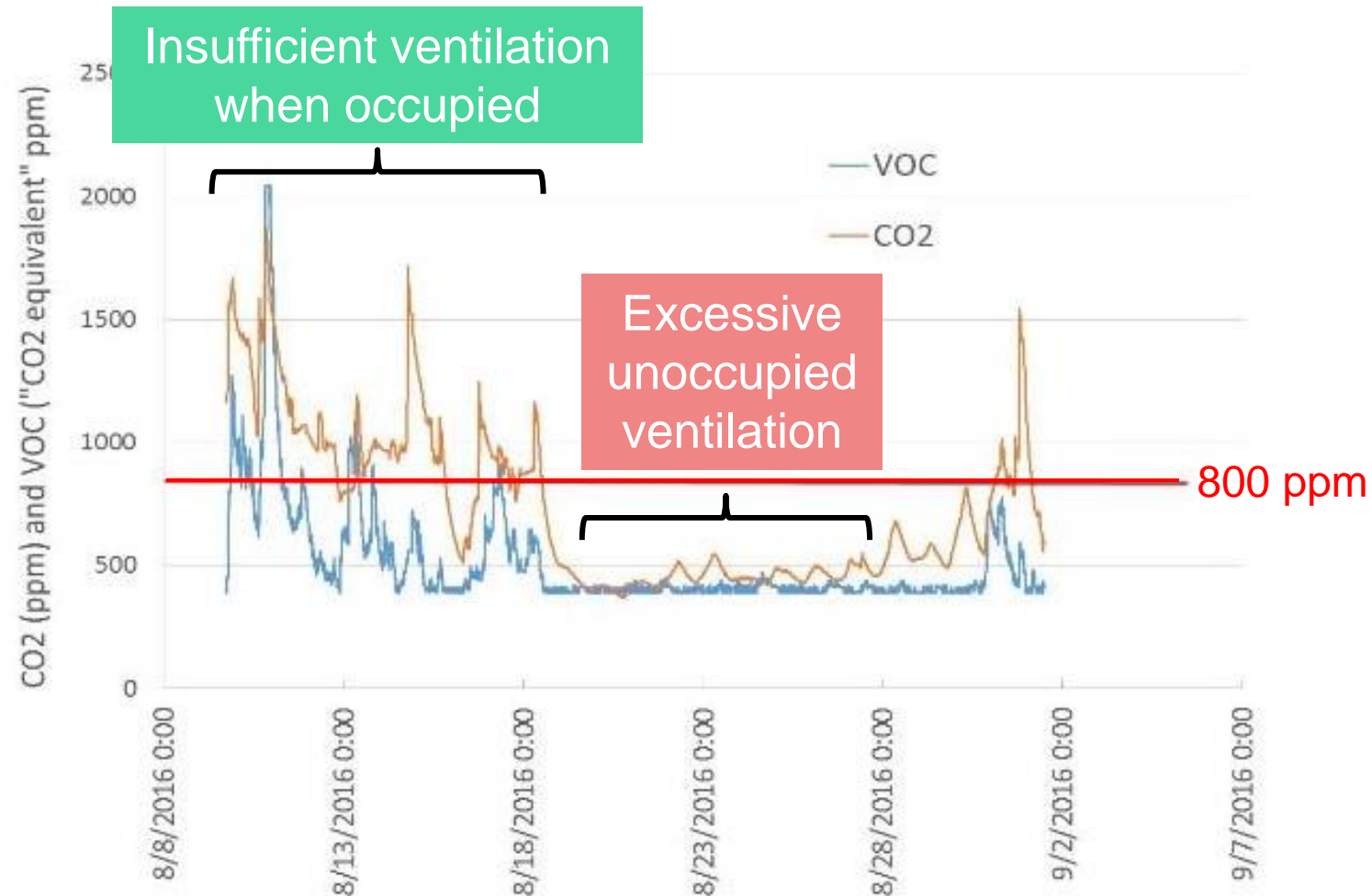
3 bedrooms
(4 people)



**Occupants at 1.2 – 1.5 Met*

ASHRAE Standard 62.2 – 2019

Certified Passive House, with HRV, no recirculation, “acceptable” constant ventilation



Healthy & Sustainable Building Design

ASHRAE 62.2-2019

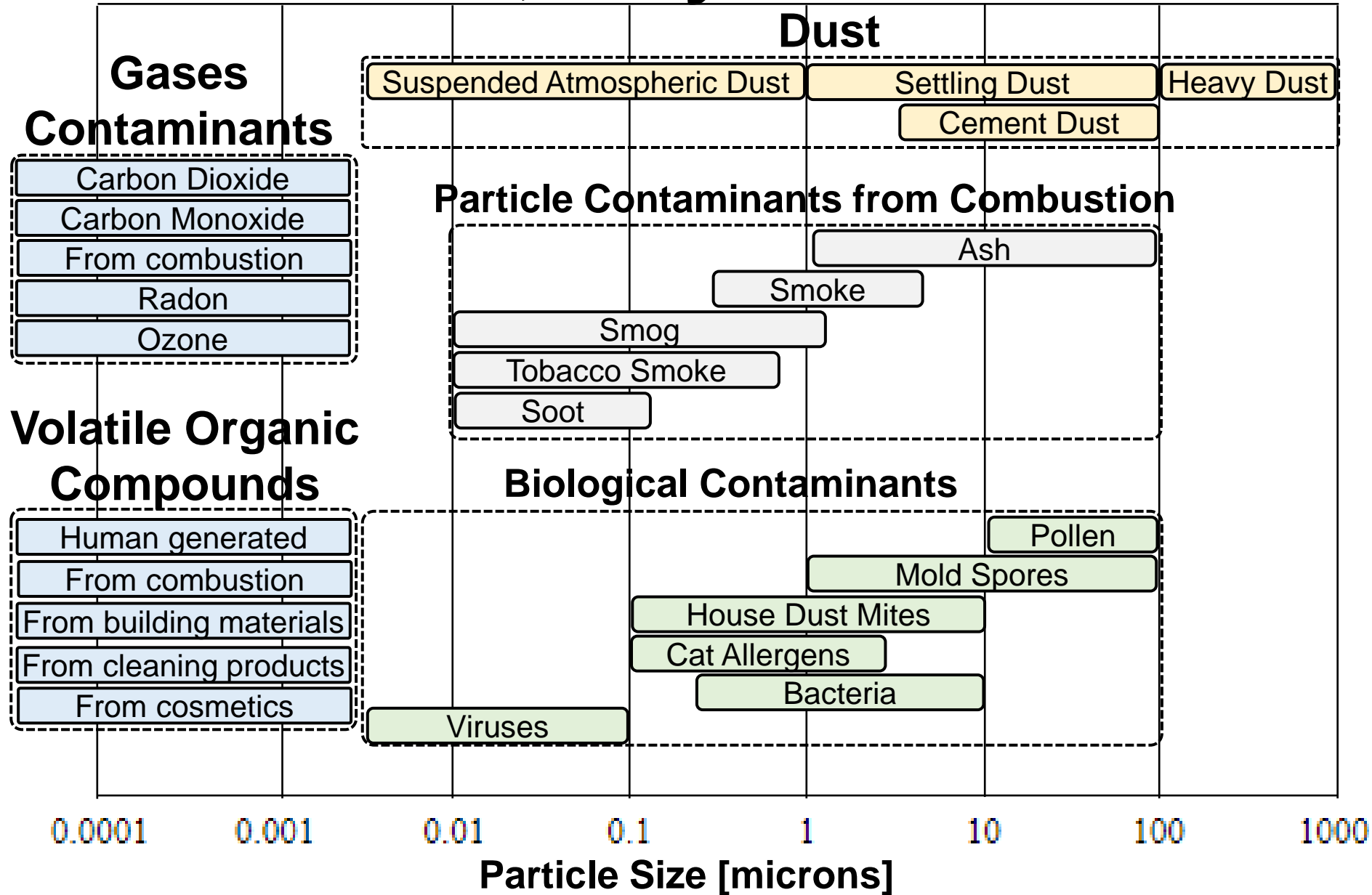
Healthy IAQ Guidelines

Maximum concentrations	Not defined	CO ₂ <800ppm, VOC <125ppb PM10 <10µg/m ³ , PC10 <40,000#/L
Ventilation	Minimum 20 CFM/person (CO2 ~ 1,200ppm)	40 CFM/person (CO2 ~ 800ppm)
Filtration	MERV 11 (Recirc.) MERV 6 (Fresh intake)	MERV 13 (Recirc.) MERV 13 (Fresh intake)
Microbe Deactivation	Not defined	Ultraviolet Germicidal Irradiation (No ozone generation)
Smart controls	Constant flow (no feedback)	Monitor pollutants (feedback) Reduce pollutants / save energy

- **Additional sustainable feature:** Energy Recovery to pre-condition fresh air coming in with exhaust air coming out

Summary

Gas Contaminants, Tiny Particles & Germs



Effects on Human Health



It depends on concentration levels, exposure time, age and health conditions

Annoying

- Odors

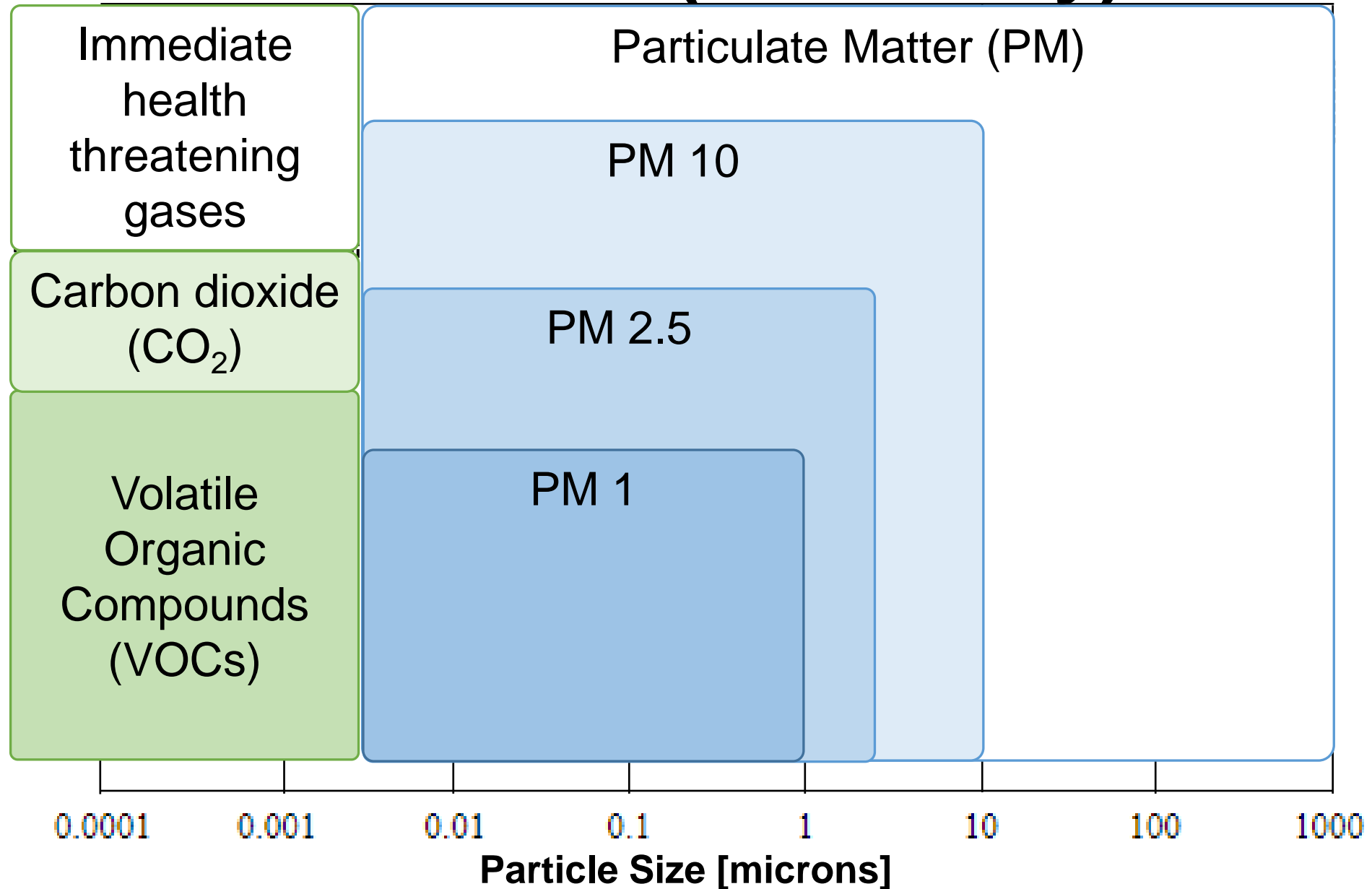
Immediate / Health Threatening

- Irritation of eyes, nose and throat
- Headache
- Allergic reaction & asthma
- Contagious disease
- Fatal consequences

Long Term Effects

- Cancer
- Respiratory diseases
- Debilitating well-being

What can we measure (affordably)?



Healthy IAQ Guidelines

Carbon Dioxide (CO₂)
< 800ppm

Total mass of all
particulates 10µm
and smaller
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Volatile Organic
Compounds (VOCs)
< 125 ppb
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Total count of all
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Additional considerations:

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Radon < 2pCi/liter

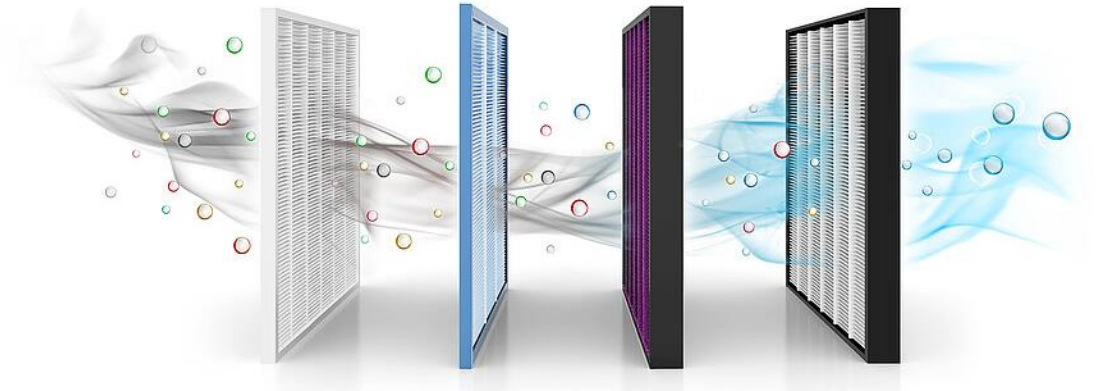
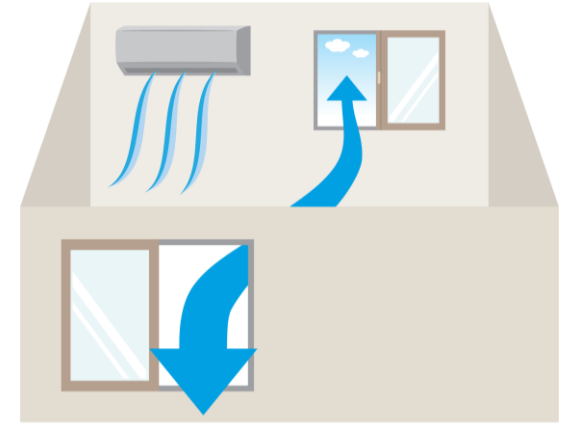
Based on literature &
experimental research:

- Known to improve health
- Practical and achievable
- Reduce sickness
- Improve productivity
- Can be achieved in an energy efficient manner

Exposure time becomes
important when higher
than those values

Mechanisms to Reduce Pollutants

- ☐ Source control
- ☐ Ventilation (Dilution)
- ☐ Filtration
- ☐ Microbe deactivation

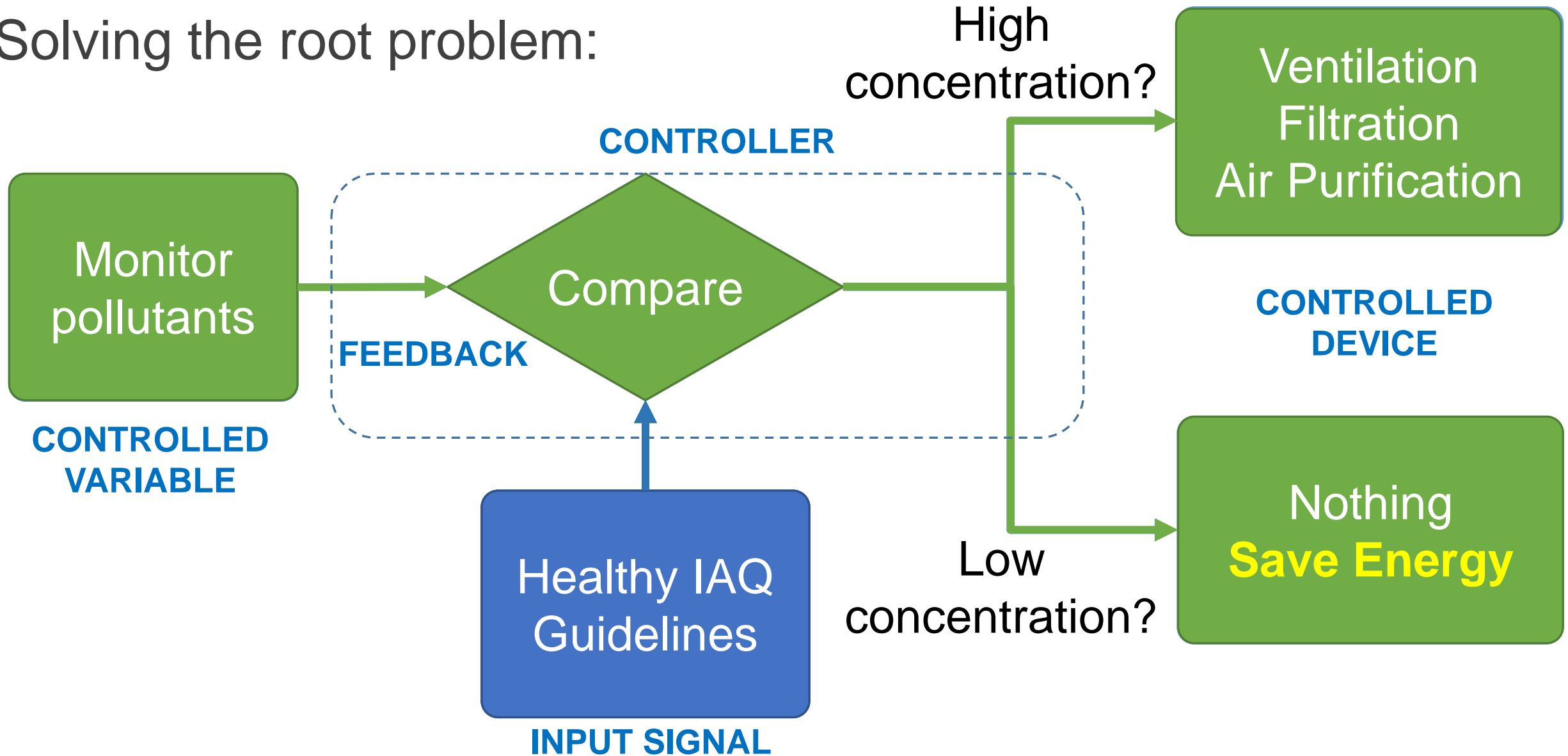


The most effective system
is the one that use them all



Smart Controls

Solving the root problem:



Sustainable Building Design

Paths to sustainable buildings:

- PHIUS (Passive House)
- ZERH (U.S. DOE Zero Energy Ready Home)
- ASHRAE 189.1
- Etc.

Achieve Healthy IAQ Guidelines:

$\text{CO}_2 < 800\text{ppm}$

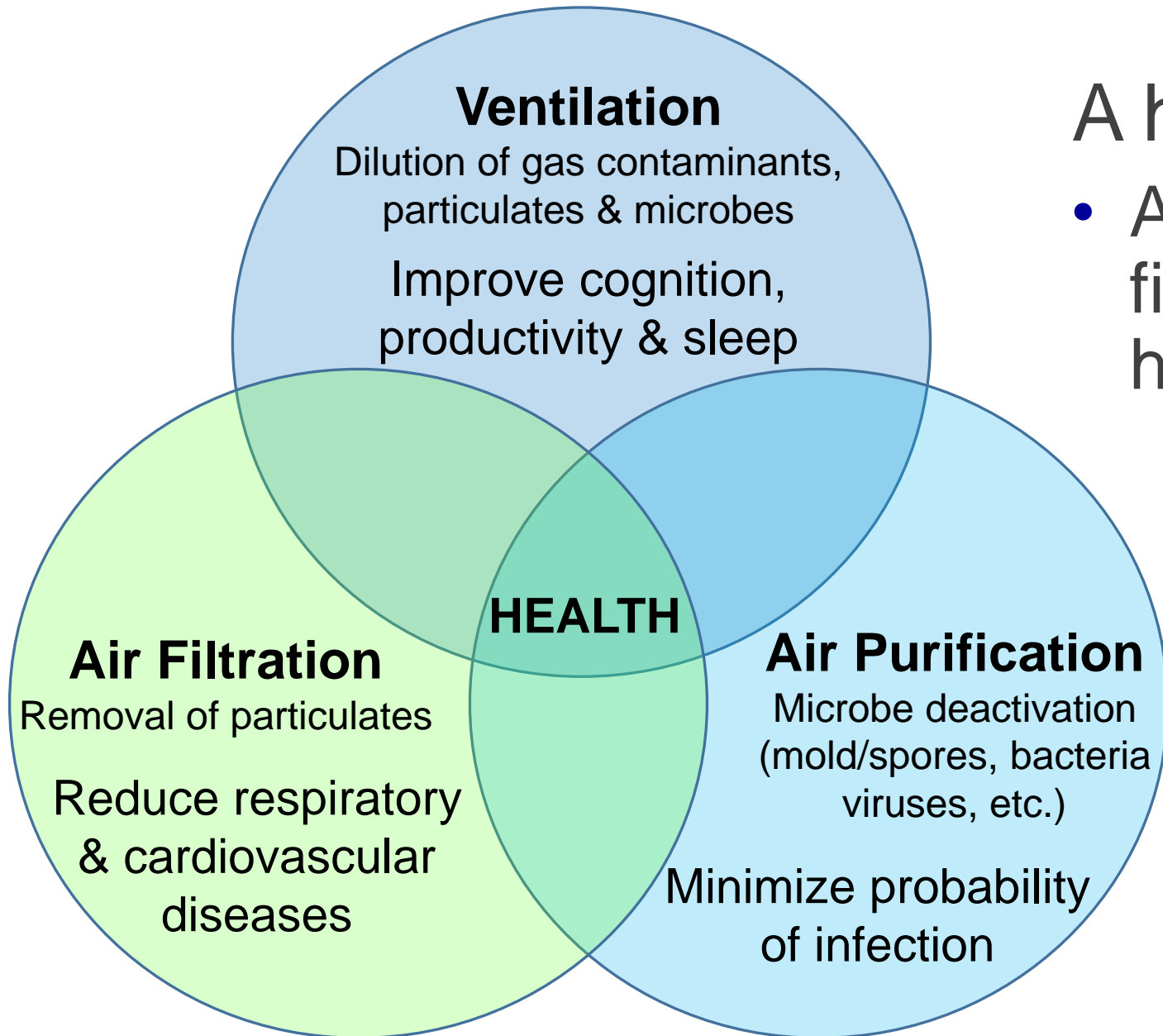
$\text{PM}_{10} < 10\mu\text{g}/\text{m}^3$

$\text{VOCs} < 125\text{ ppb}$

$\text{PC}_{10} < 40,000\text{ \#}/\text{L}$



Healthy Buildings & Homes



A healthy and safe space:

- A balance of ventilation, air filtration, and air purification has synergistic benefits

Thank you!

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