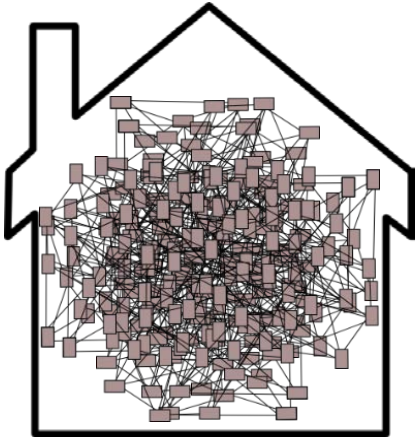
Summary

Indoor Exposure to Fine Particulate Matter & Practical Mitigation Approaches



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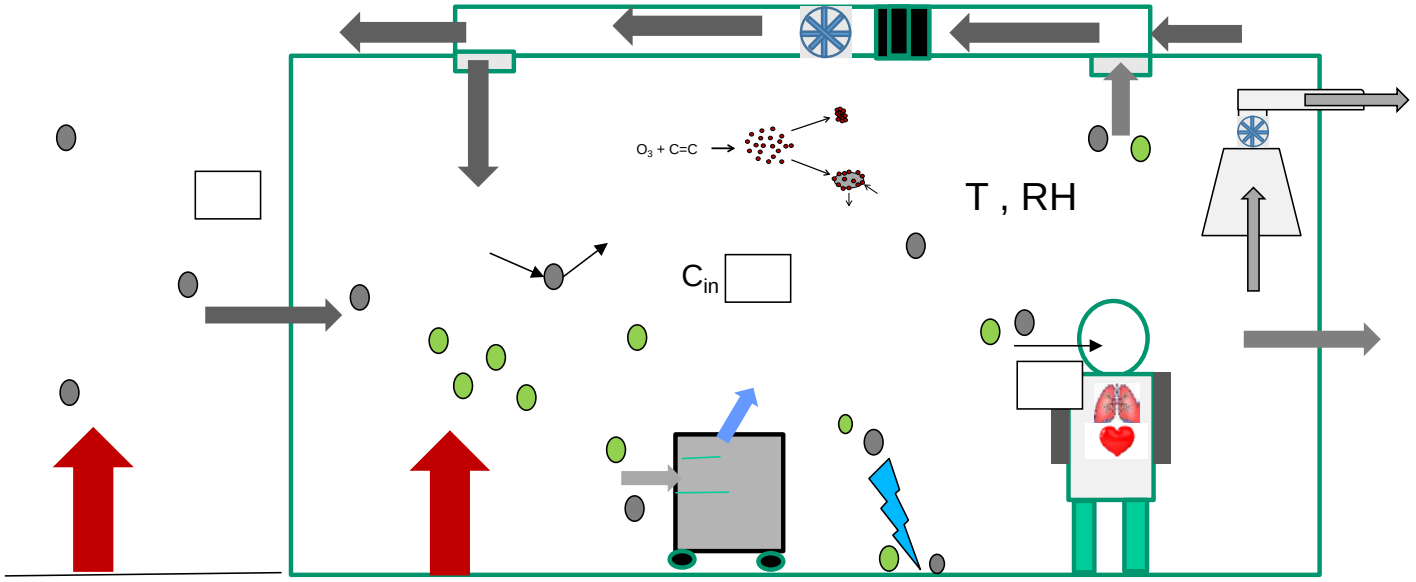
A Complex System

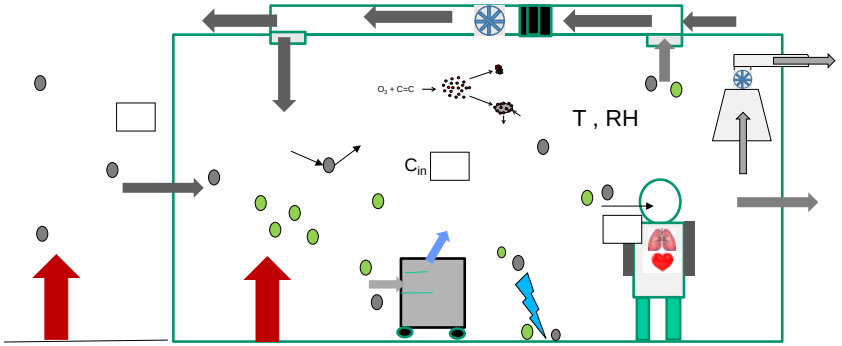


$PM_{2.5}$ of outdoor origin mixed w/ particles of indoor origin; transformations; ventilation; deposition; engineered controls; exposure; inhalation dose; health effects; signif' temporal variations; signif' spatial gradients; occupant behavior; policies; SES issues

Need interdisciplinary approach!

Outdoor Sources of $PM_{2.5}$

- Roadways
  (vehicles; paved road dust)
- Industry
- Controlled burns
- Wildfires
- Agricultural
- Cooking
- SOA
- etc.

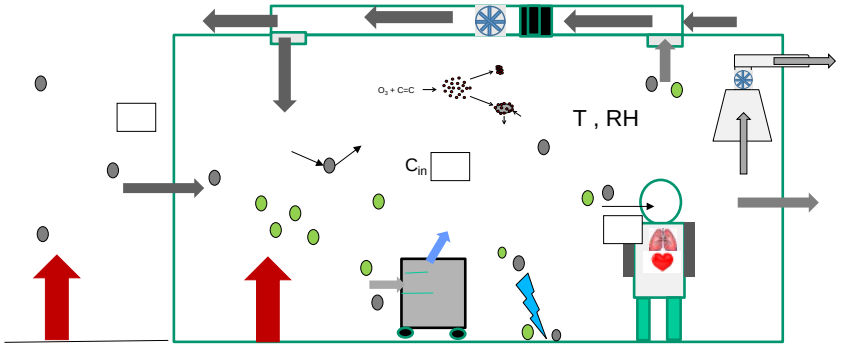


Temporal variations; Spatial gradients

Significant environmental justice issues (outdoor/indoor)

Outdoor-to-Indoor Transport of $PM_{2.5}$

- Infiltration Factor = F
- $F = C_{in}/C_{out}$ (no indoor sources)
- $F_{median} \approx 0.5$
- Varies a lot by home
- Varies by city & season
- Major Factors
  - Properties of $PM_{2.5}$
  - Ventilation mode
  - Air exchange rate
  - Filtration & HVAC run time

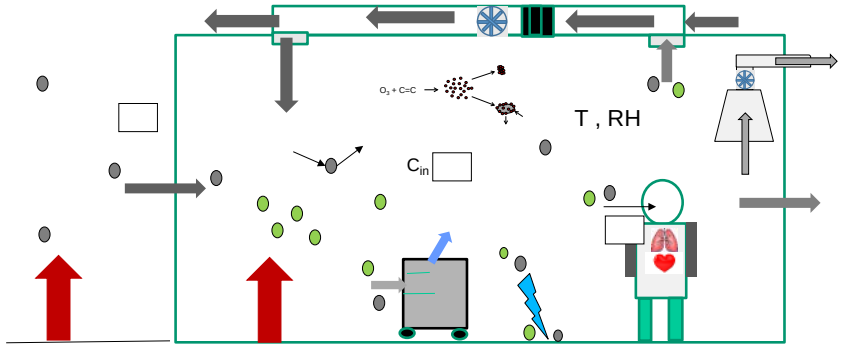


Microenvironmental $PM_{2.5}$ Exposures

- 71% inside home
- 20% inside other buildings
- ≈ ½ of outdoor origin & ½ of indoor origin

Indoor Sources of $PM_{2.5}$

- Combustion (cooking, candles, fuels, etc.)
- Phase change (e.g., heated oils)
- Mechanical
- Biological (e.g., resp aerosols …)
- Chemical reaction (O_3, C=C, AER)
  - Wide range of products(g) + SOA



Cooking (heat source, oils, food)

- w/o exhaust up to 100s µg/m^3
- Particle # dominated by fuel source
- Emissions/composition highly variable *(ingredients, oils, heat source, T, ..)*

Highly variable (episodic)

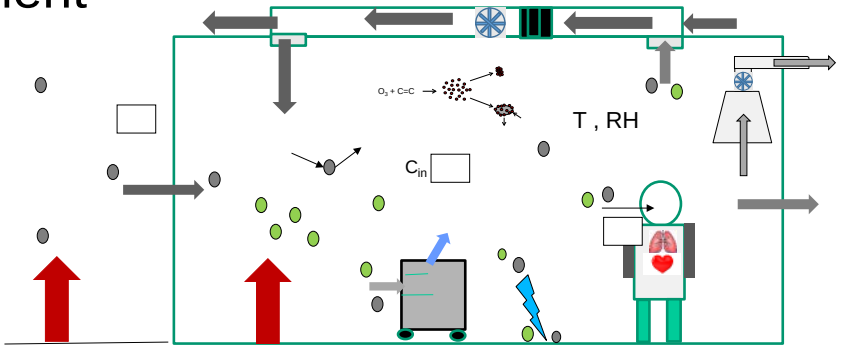
Spatial gradients

Ventilation / local exhaust important

Impacts on health?

Transformations in Indoor Atmospheres

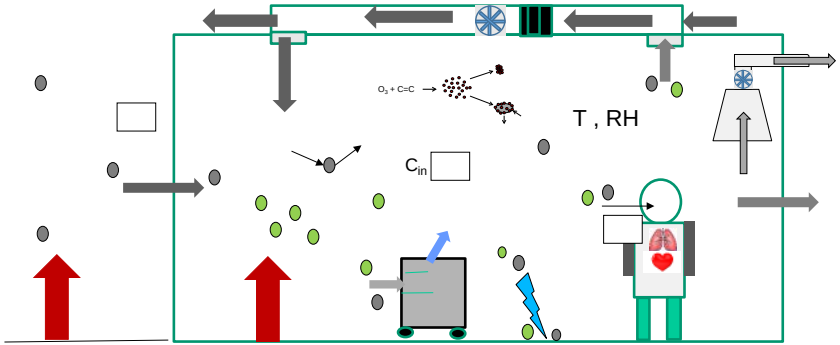
- Outdoor $PM_{2.5}$ into different environment
  - Large A/V
  - Low oxidants
  - A lot of VOCs/SVOCs
- Evaporation
- Thermal partitioning
- Uptake of SVOCs
- $PM_{2.5}$ transformation can be signif'
  - Size, pH, composition
- Similar for $PM_{2.5}$ of indoor origin



Does transformation of particles change health effects?

Effects of RH on $PM_{2.5}$

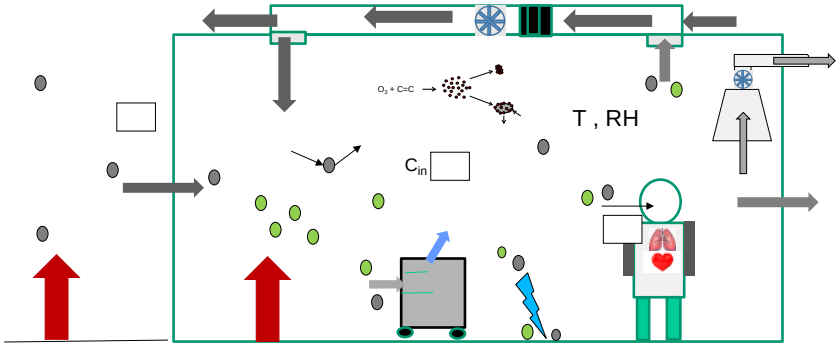
- RH effects water content of $PM_{2.5}$
  - Size (e.g., respiratory particles)
  - Chemistry
  - Biology
- Bacteria survival (low at low RH)
- Virus survival (low at mid-RH)



What are optimum environmental conditions to reduce impacts of $PM_{2.5}$?

Health Effects of Indoor $PM_{2.5}$

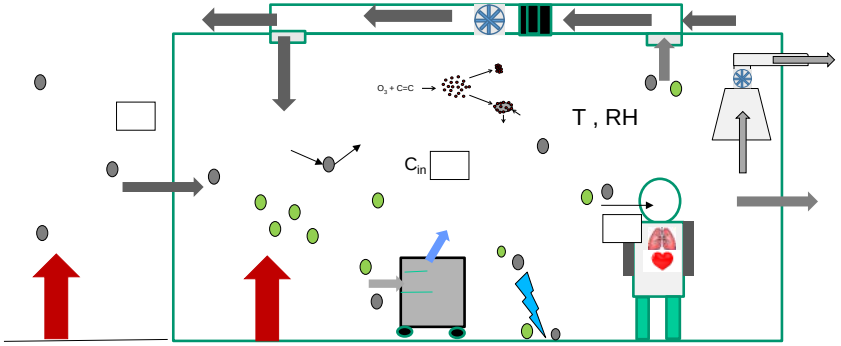
- A lot of epi studies on outdoor $PM_{2.5}$
  - US $PM_{2.5}$ mortality ≈ 230K – 300K/yr
  - Cardiovascular effects dominate
- Indoor dose of $PM_{2.5}$ of outdoor origin ≈ 70% of total dose (outdoor epi = indoor epi)



- Increases in indoor $PM_{2.5}$ assoc w/ increases in asthma & COPD morbidity
  - Reduced $PM_{2.5}$ w/ portable HEPA filters reduces symptoms
- Toxicity: Indoor $PM_{2.5}$ > outdoor $PM_{2.5}$
  - Mice/rats: Inflammatory & cytotoxic effects (limited studies)

Complexity of Assessment & Metrics

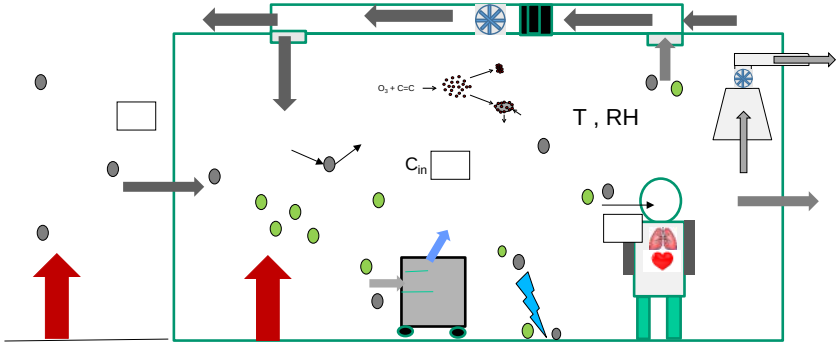
- Indoor measure better than outdoor
- Personal measurements better
- Indoor $PM_{2.5}$ 4D Complexity
  - Broad size range
  - Chemically complex
  - Temporally variable
  - Spatially variable
- No instrument measures everything



What measurements are most important, where, & when?

Complexity of Measuring Actual Exposure to $PM_{2.5}$

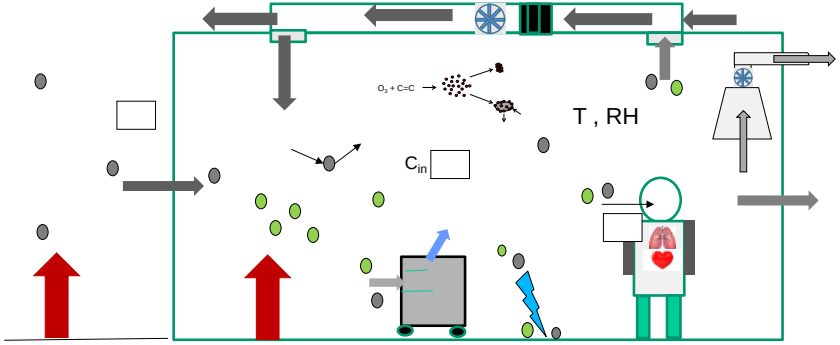
- Time scales (hrs, days, wks, mos)
  - Acute vs. chronic health effects
- Time between exposure & onset
- Substantial differences in exposures
  - By person
  - By day
  - Dominated by inside home
- Inhalation dose & location important



How do we improve our ability to more easily measure or estimate exposure?

Low-Cost Consumer Instruments for $PM_{2.5}$

- Growing use / protocols lacking
- Metrics: compare w/ ref instrument; LOD; reproducibility; size, composition, environmental challenges
- Lab generally ± factor of 2 (not field)
- Problems at < 10 µg/m^3
- Trends applicable (up/down)
- How best to use / improve
  - wildfire season
  - controls (lower AER, PAC, ..)

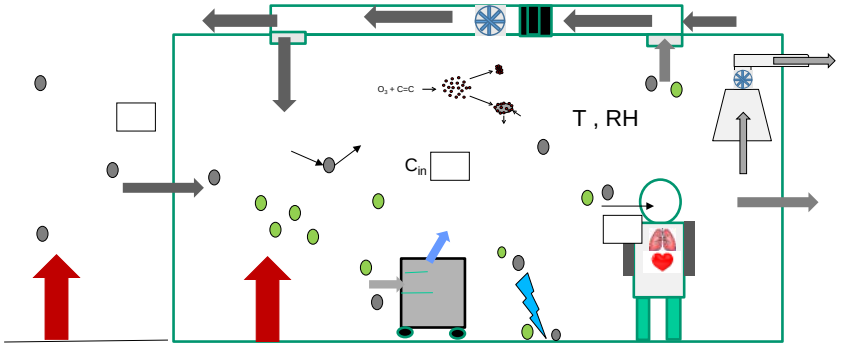


Moving Forward

- *Individual perception* of IAQ impt
- Can sensors help w/ perception
- Healthy action visuals preferred
- Clear, graphical, & actionable
- Provide steps to overcome poor IAQ
- Do we need an IAQ Alexa?

Mitigation of Indoor $PM_{2.5}$ (Health Benefits)

- Improved filtration assoc w/
  - Sub-clinical cardiovascular benefits
  - Increased birthweight
  - Reduced asthma morbidity
  - Higher test scores

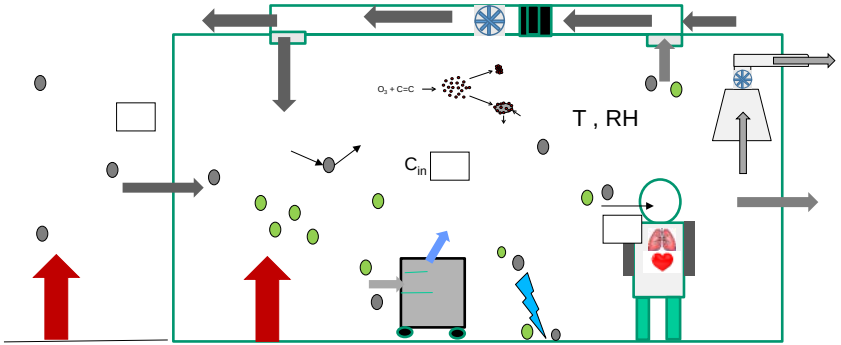


- Portable HEPA air cleaners
  - In homes of children w/ asthma
  - $PM_{2.5}$ reduced 50%
  - symptom-free days: 14-18% increase
  - General response supported by modeling

- But studies limited in number
- Improved communication
- Conversion to standards? (need for more studies?)

Mitigation of Indoor $PM_{2.5}$ (Local Exhaust – Cooking)

- Cooking: UFP, PM2.5, CO, NOx, HCHO, etc.
- Local exhaust of cooking emissions
  - Range hood
  - Downdraft exhaust
  - Ceiling or wall exhaust
  - Open window
- Hood capture efficiency
  - Increases with air flow increase
  - Best for back burners (huge impact)
  - Outdoor exhaust (not recirculation)
    - *Expensive to retrofit*
  - Irrelevant if not used

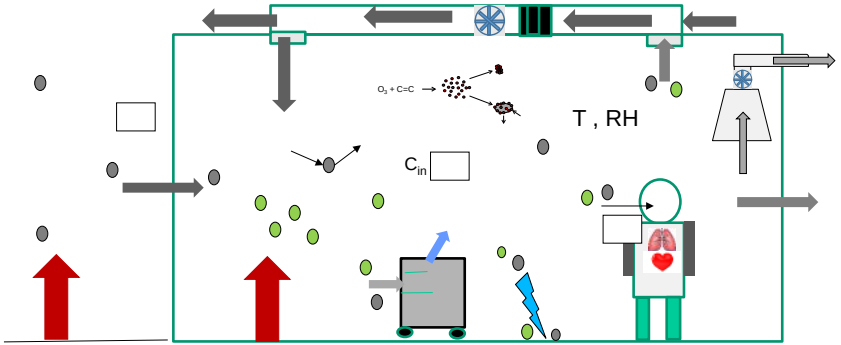


Occupant behavior

- Most used hood < 50% of time
- Communication / sensors?
- Visual/verbal reminder?
- Automatic?
- Quiet(er)?

Mitigation of Indoor $PM_{2.5}$ (Filtration)

- Filtration in AHU
  - Flow, efficiency, run time, no by-pass
  - Same MERV: huge efficiency variation
  - Recirculation rates 2 to 8/hr
  - Fraction of time on = often very low
- Effective Filtration
  - Good filter / properly installed
  - Large enough flow / run time
  - Replace filter frequently (important)

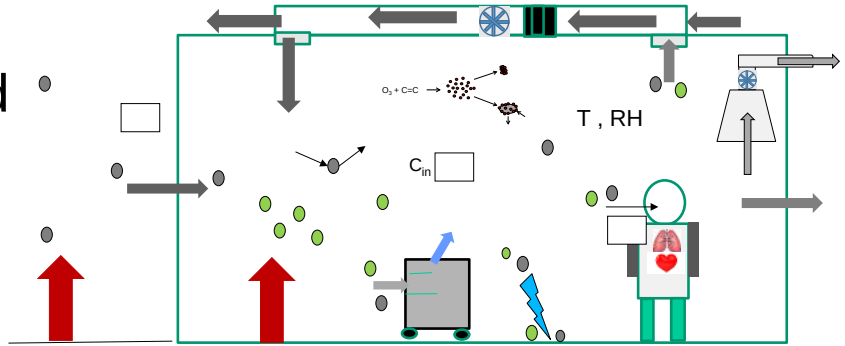


Other cleaning technologies
- Not well defined
- Lacking independent evaluation
- Potentially harmful

Anions from ion generators assoc with
- Markers of inflammation in adults
- Decrease in HRV of children

Mitigation of Indoor $PM_{2.5}$ (Filtration & Carbon)

- 15% of *schools* w/in 250 m major road
  - *Environmental justice issue*
- TRAP impacts asthma, cognition
- BC, UFP, $PM_{2.5}$ > urban background
- Signif' reduction w/ MERV 8 + 16
- Signif' quench of SOA w/ AcC

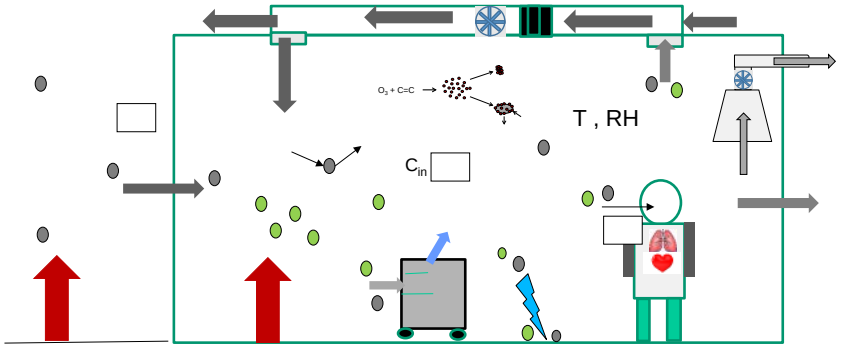


Opportunities to Reduce $PM_{2.5}$

- Increase distance from roadway
- Alter time of activities / ventilation
- Employ effective filtration
- Reduce indoor sources
- Quench chemistry

Mitigation of Indoor $PM_{2.5}$ (Portable HEPA)

- Portable HEPA filtration
- 50-80% PM reduction in bedrooms
- Field study
  - Drop off in use dramatic (low use)
  - Signif' diff in use by households
  - Perceptions of e^- cost?
  - Measurable health benefits? *(area for more research)*
  - Modeling: reduction in asthma burden

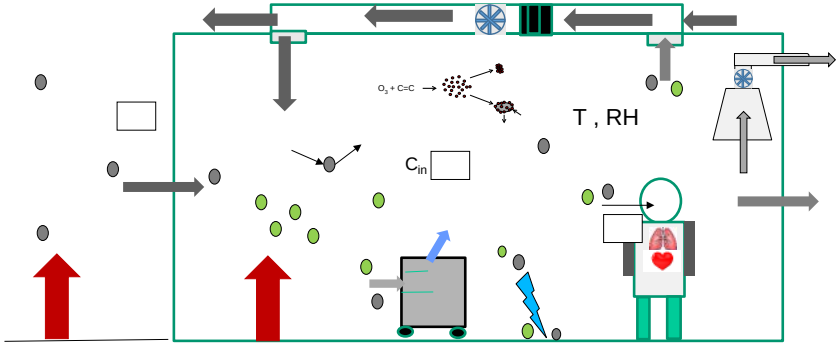


Opportunities to Improve

- HEPA = proven technology
- Particularly valuable: lower AER
- Smaller, less noise, draft
- User feedback
- Improved controls (auto)

Variations of Indoor $PM_{2.5}$ (Wildfires)

- Foot traffic (door openings)
- Ventilation (door/window open)
- Filtration (MERV8; high variability in IAQ)
- HVAC maintenance critical
- Reduce exposure
  - Messaging is CRITICAL (emphasized)
  - Preparation critical
  - Control ventilation / increase filtration
  - Need more @ policy level (standards)



Opportunities

- Portable HEPA w/ low AER (loaners, triage, $)
- Go to cleaner air (evacuation)
- Cleaner air shelters?
- Awareness via sensors?
- Factor – funding!

Economic Disparities are V*E*R*Y Important

- Substantial exposure/health disparities related to SES & $PM_{2.5}$
- Underserved communities = high priority
- Proximity to outdoor sources (higher O & I $PM_{2.5}$)
- Physical structure of residences
  - Size of home / occupant density
  - Single vs. multi-family
  - Nature of ventilation & local exhaust
- Time spent at home
- Cooking practices (including wood/coal = increased asthma symptoms)
- Smoking & smoking-related disease > at lower SES
- Increased $PM_{2.5}$ assoc w/ asthma morbidity (worse w/ obesity & poor diet)
- Economic barriers to control systems, e.g., portable HEPA filtration, exhaust vents

https://www.texastribune.org/2020/05/19/texas-evictions-coronavirus/

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