Buildings Are Dynamic: Implications for indoor chemistry

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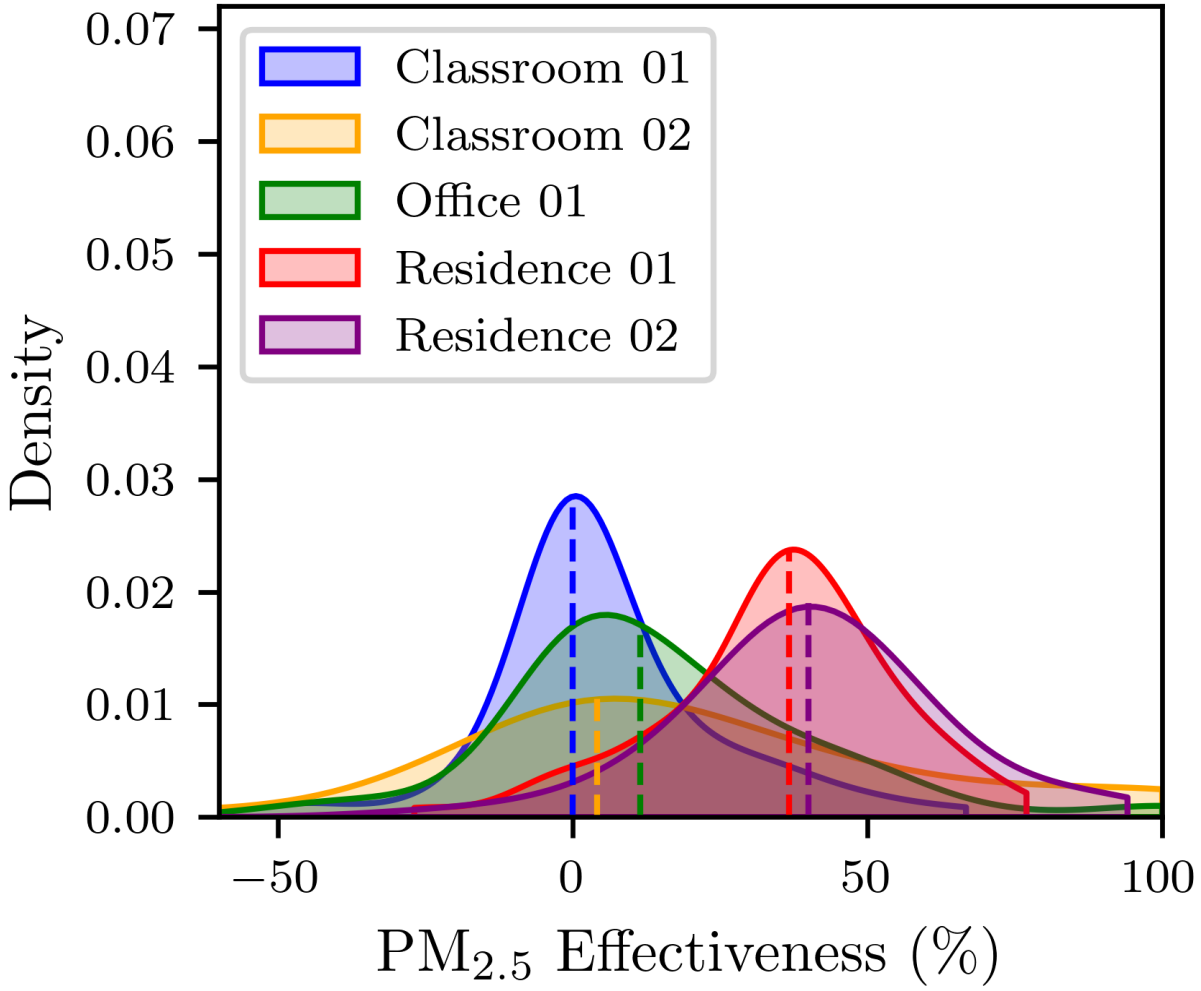
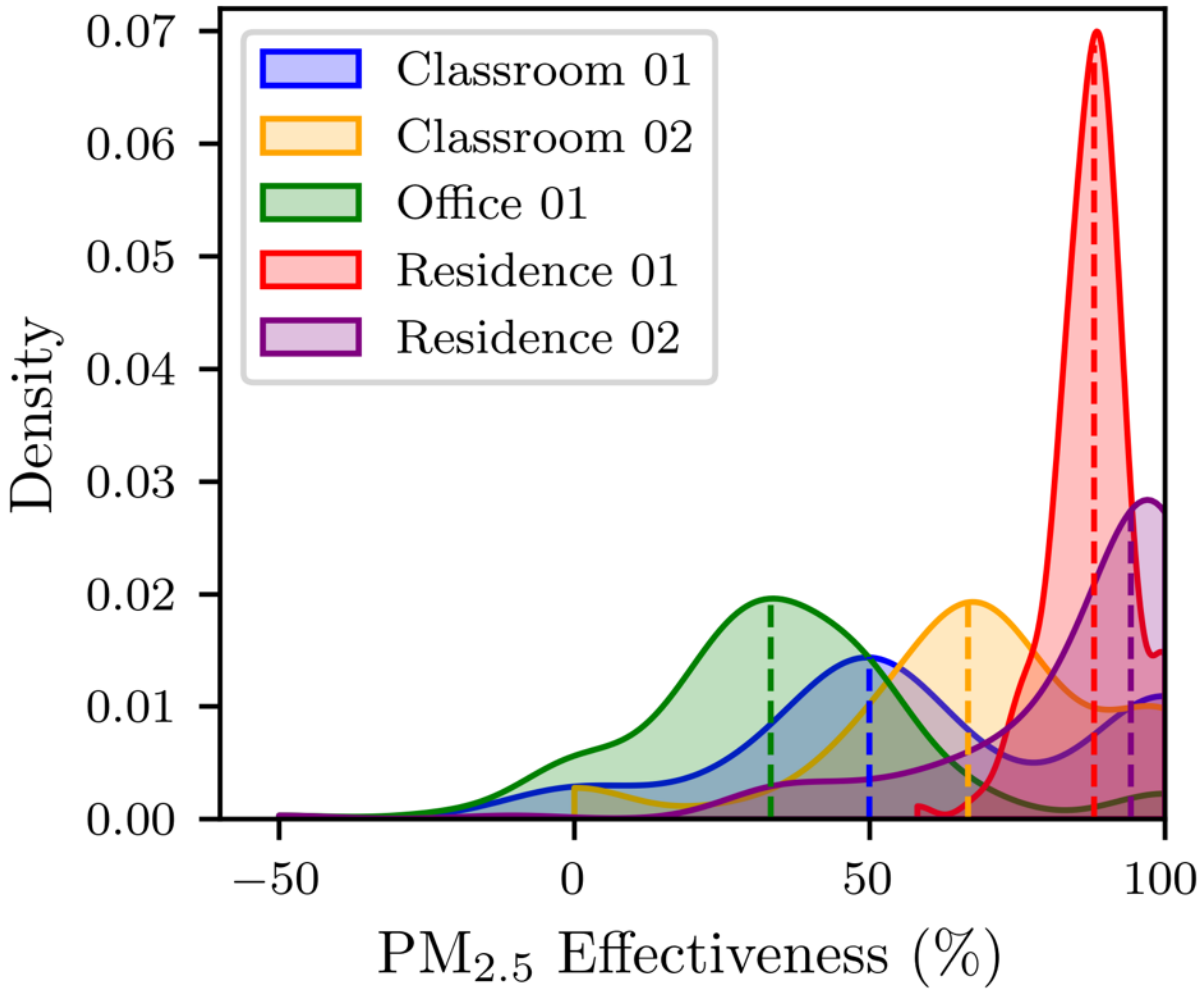




Nahian & Siegel *in review*

Indoor Chemistry is Contextually Driven

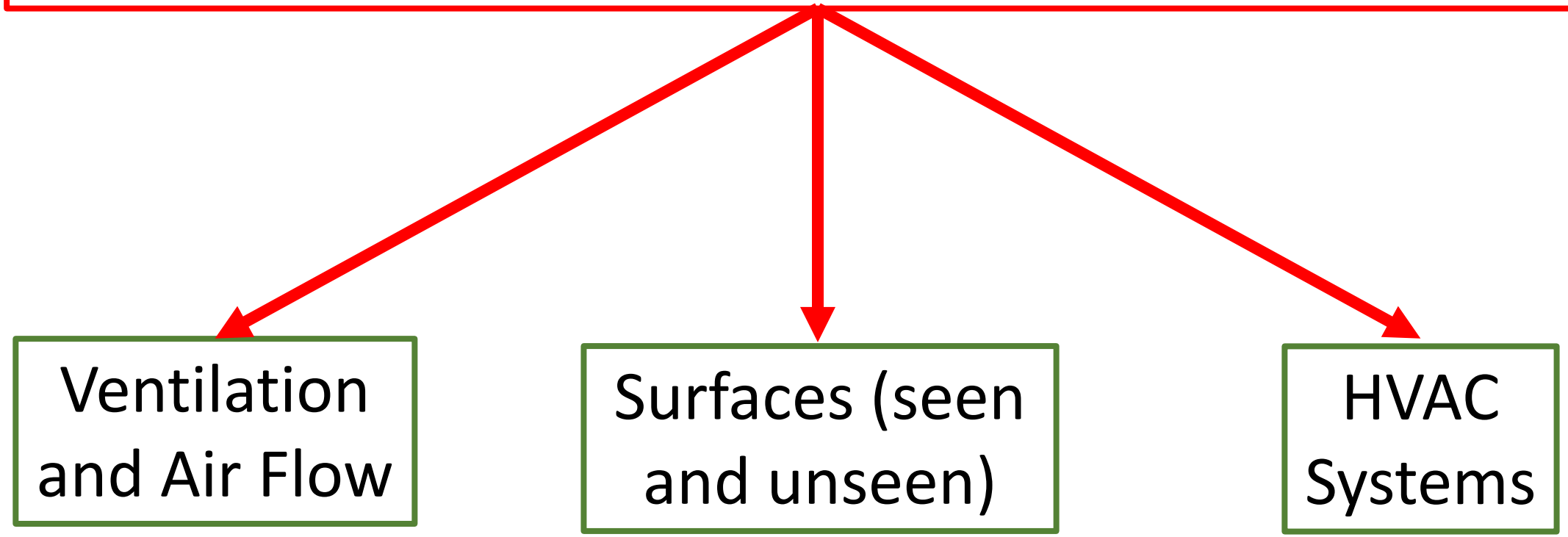
- In different buildings and in the same building over time…
  - Sources and reservoirs will lead to different concentrations, and partitioning behaviour
  - Chemical transformations will be different
  - Control and management of chemicals will have a different effect
  - Exposure to chemicals will be different

Indoor Chemistry

Indoor Chemistry

- What are some important building “systems” and how are they important to indoor chemistry?
- How can they be characterized/measured?
- How does building science tie to the recommendations in the report?

To understand/manage indoor chemistry, you need to understand the building



People/behaviour, microorganisms, energy and moisture flows, etc. etc.

Ventilation 101

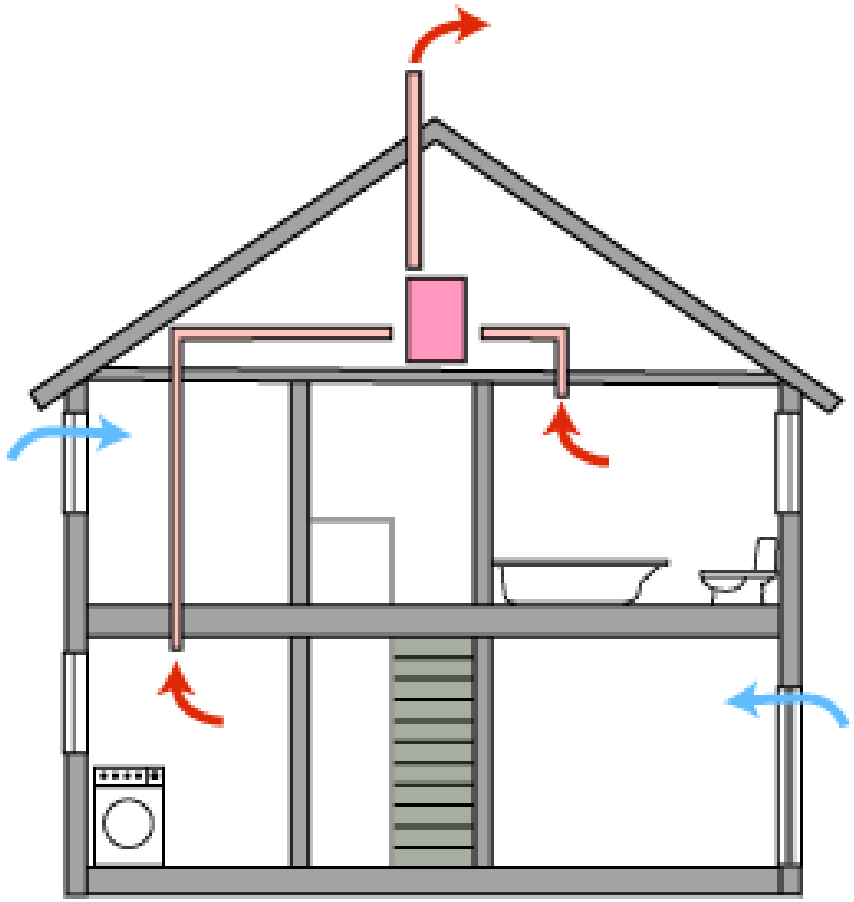


Image: https://www.bpcventilation.com/blog/what-is-a-mechanical-ventilation-system/

Mechanical Ventilation (fan-driven)

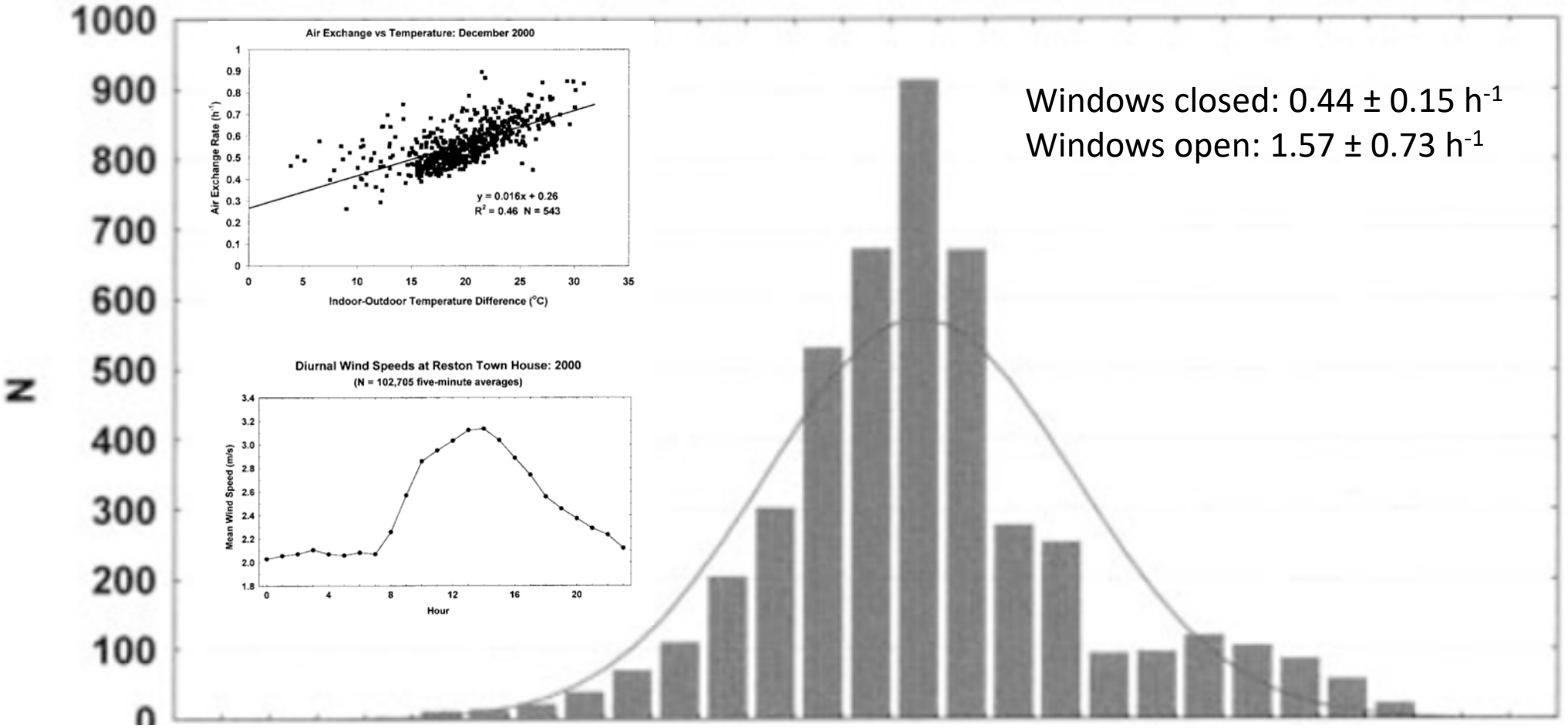
- Can be exhaust, supply, or balanced
- Can be integrated with H**V**AC
- Can be user controlled or scheduled

Leakage (not fan-driven)

- Can be intentional (natural ventilation)
- Depends on pressures caused by wind, stack effect, and HVAC

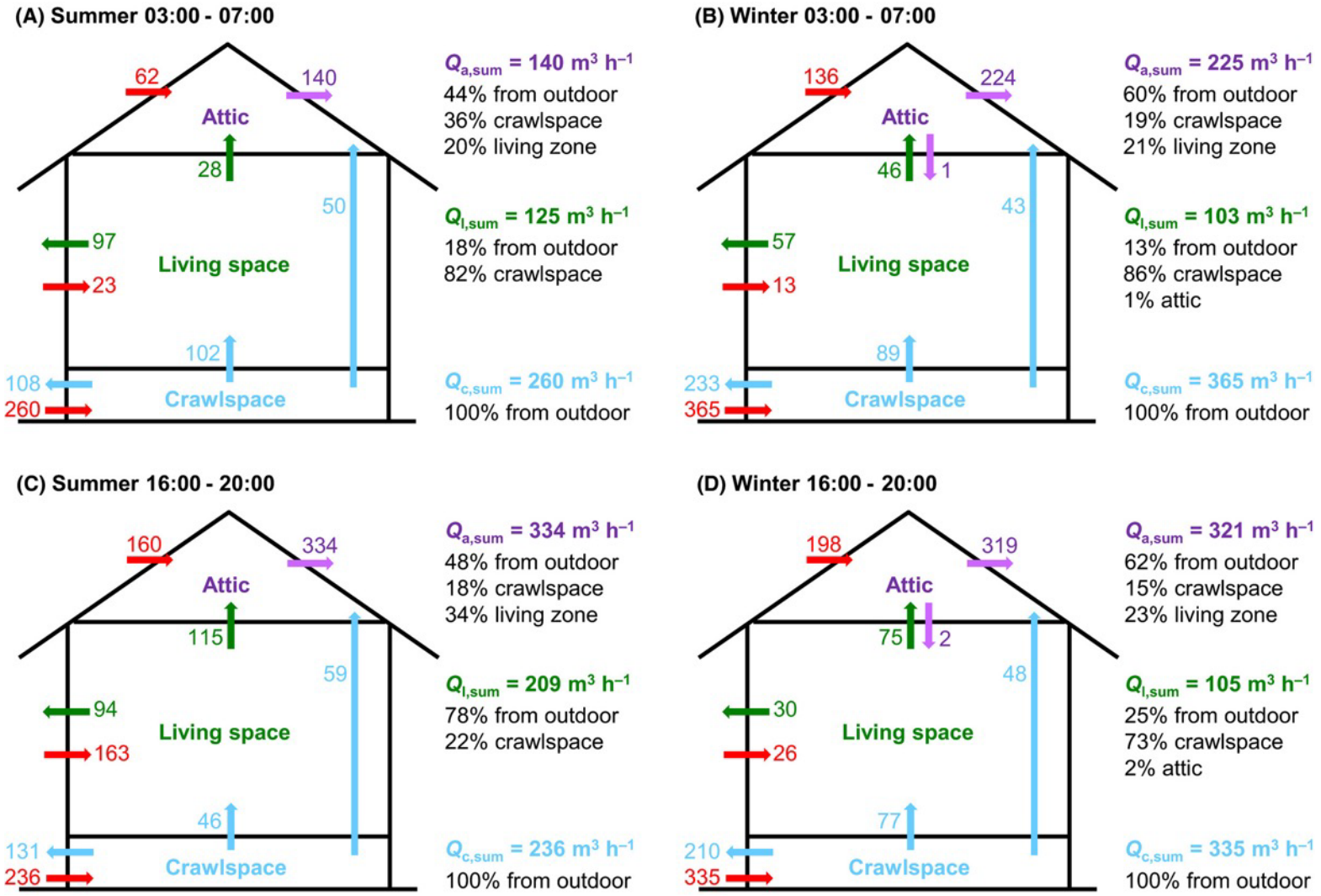
In general, ventilation increases the indoor concentration of outdoor compounds and decreases the concentration of indoor compounds
Time scale for ventilation is crucial to indoor chemistry

Distribution of Air Exchange Rates (logarithms) at Reston Town House: 2000 (N = 4653)



Wallace et al. (2002) *JESEE*

Ventilation Measurement



Liu et al. 2018 *Indoor Air*

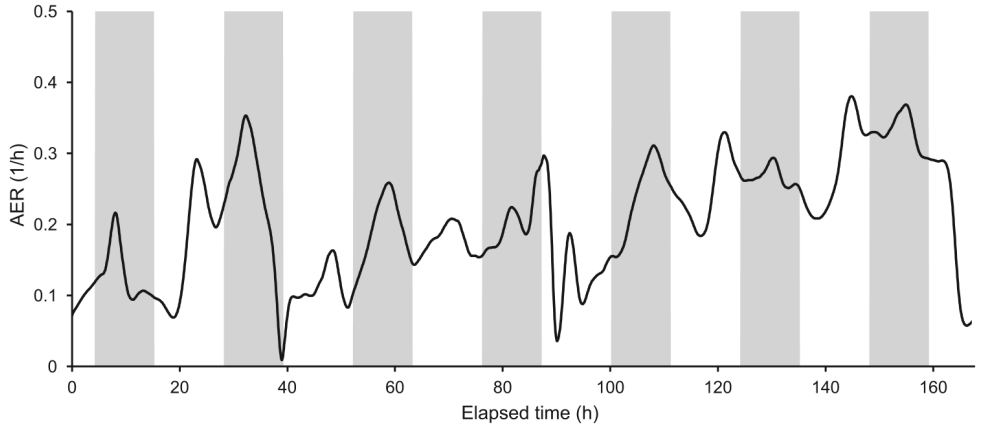
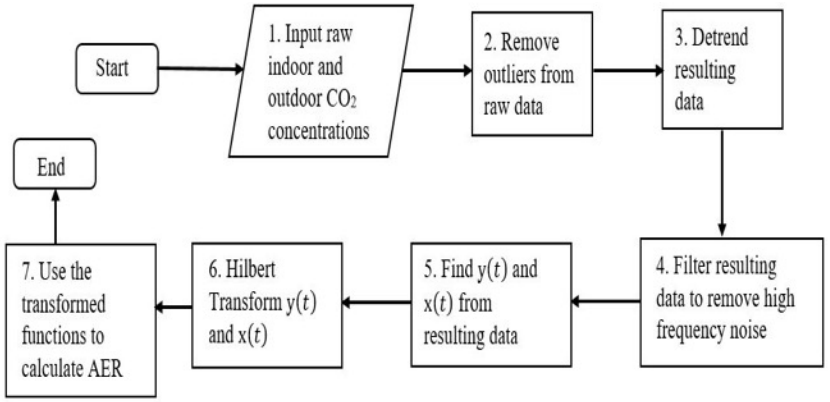
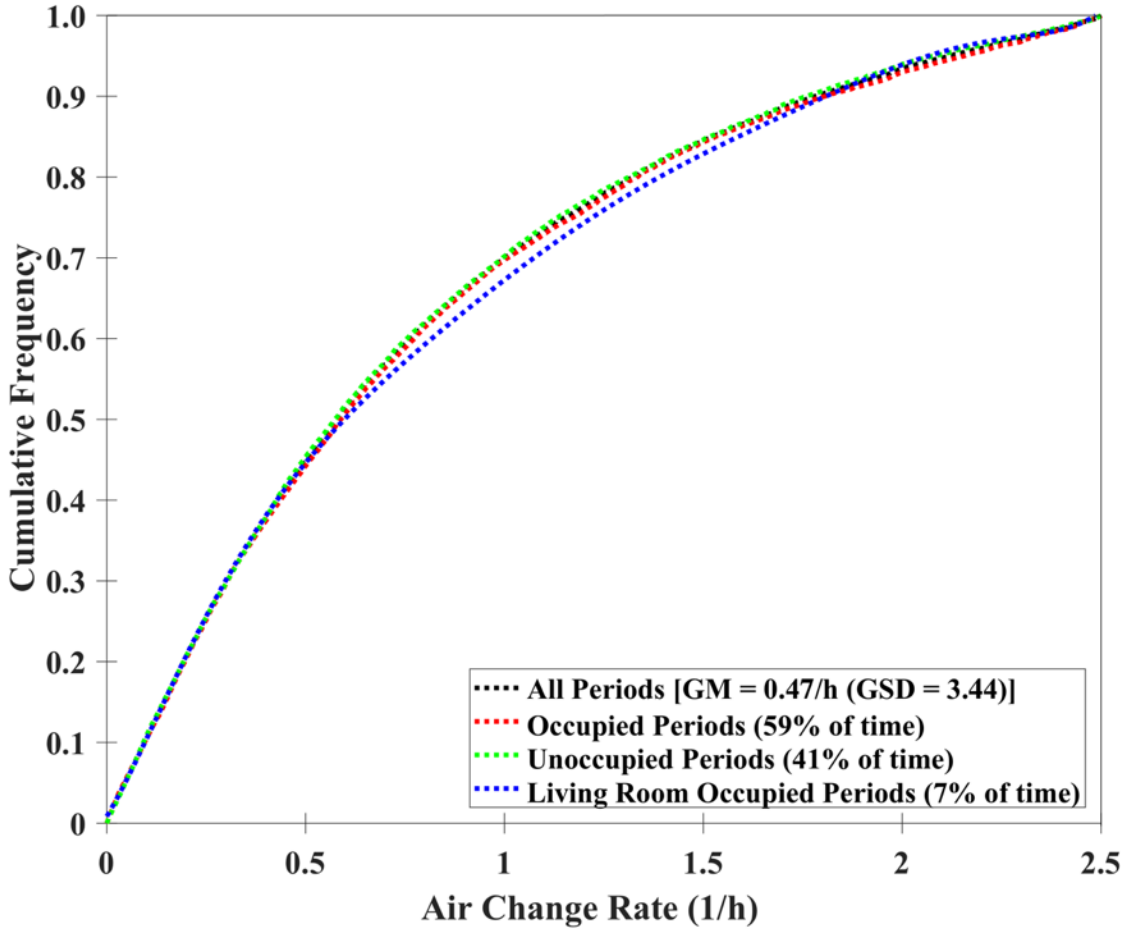


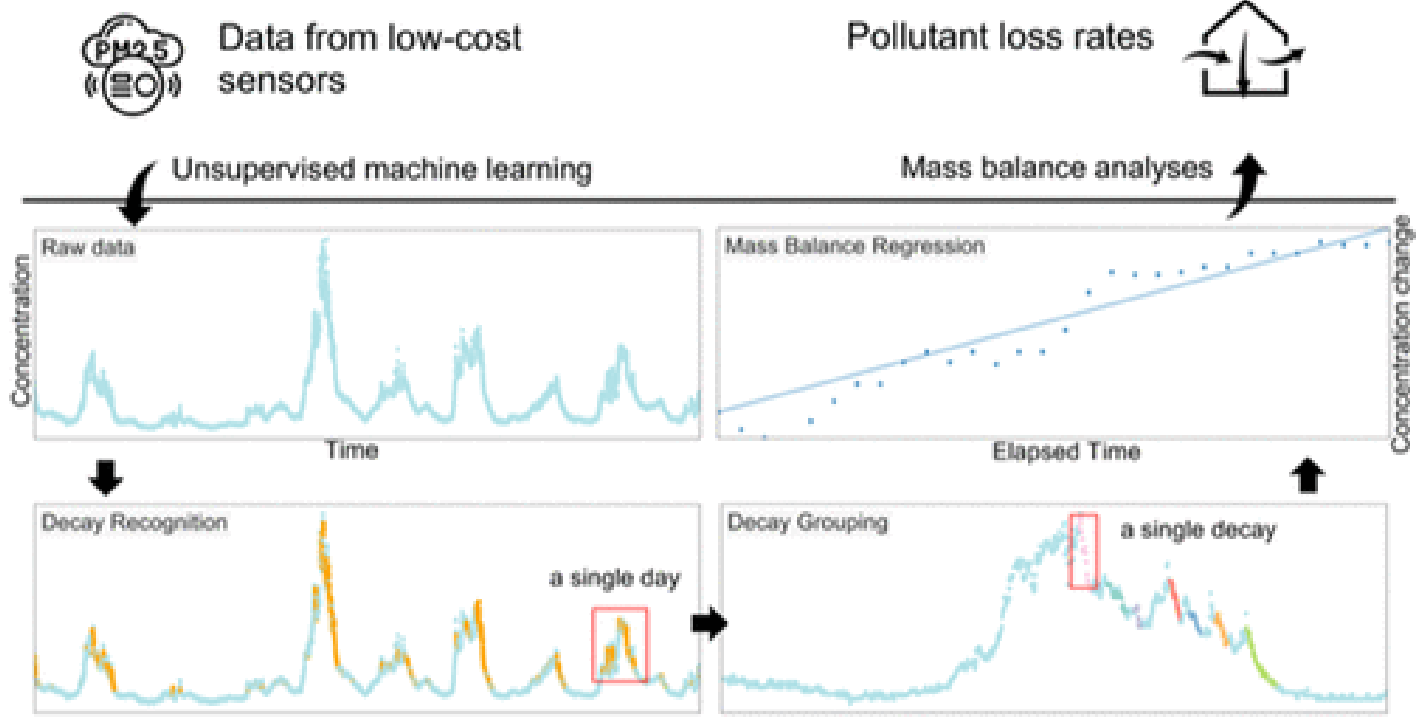
Fig. 4.
The infiltration AER obtained with the proposed method from the data acquired during the first measurement phase. Shaded areas identify night periods (20:00 to 07:00).

Carrilho et al. (2015) *Energy Bldg.*

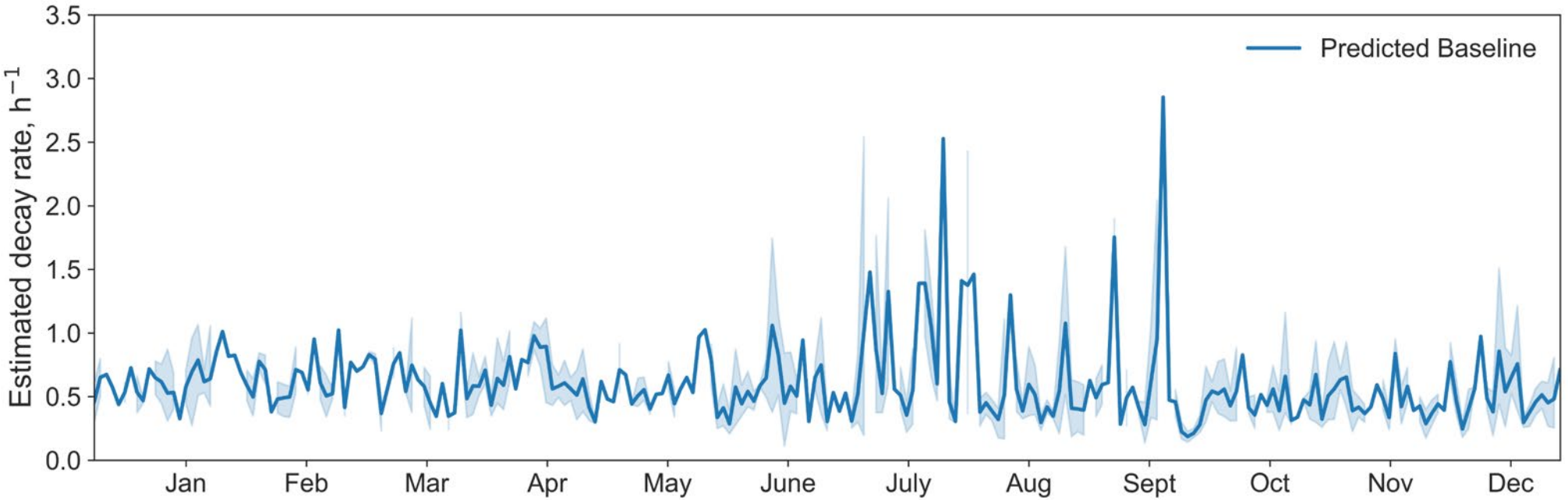




Alavy et al. (2018) *Bldg Environ*

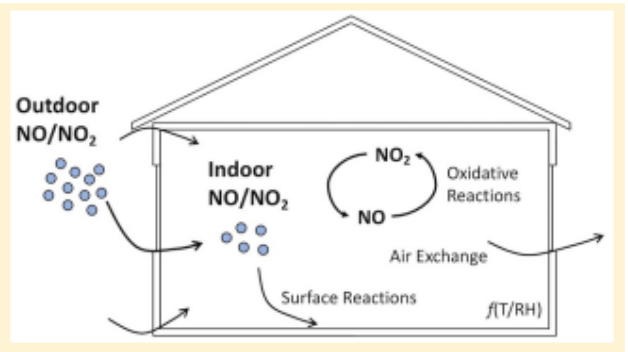


Du & Siegel (2023) *ES&T*



Ventilation Summary

- Ventilation is usually important for indoor chemistry, particularly when
  - Ventilation time scales are long
  - You are assessing indoor sources/reactions by assessing concentrations
  - Indoor chemistry is dependent on outdoor concentrations
  - You are controlling products of indoor chemistry or sources
  - You are considering control approaches
- Ventilation is dynamic and has multiple pathways
  - Assessments need to be continuous
  - Impact on indoor compounds can be complicated by processes that happen while ventilation occurs



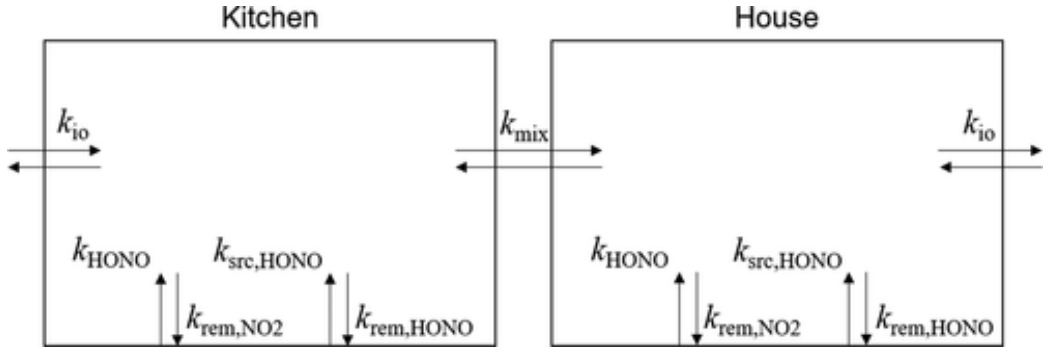
P_{NO} = ~1

P_{NO2} = 0.72 ± 0.06

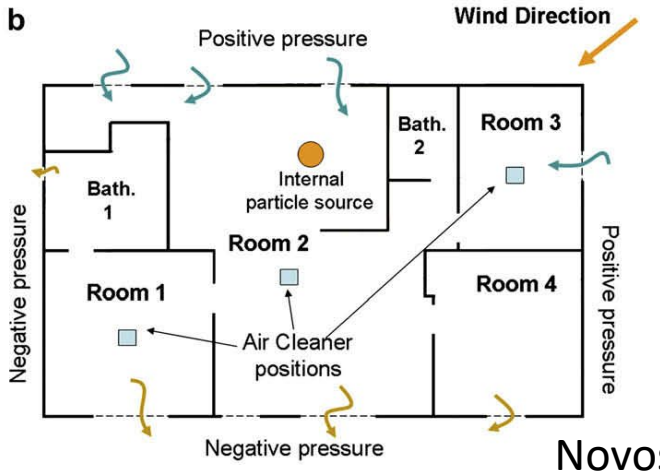
Zhao et al. (2019) *ES&T*

Ventilation 201

- Air movement within and between building zones/rooms is often important too



Collins et al. (2018) *ES&T*



Novoselac and Siegel (2009) *BAE*

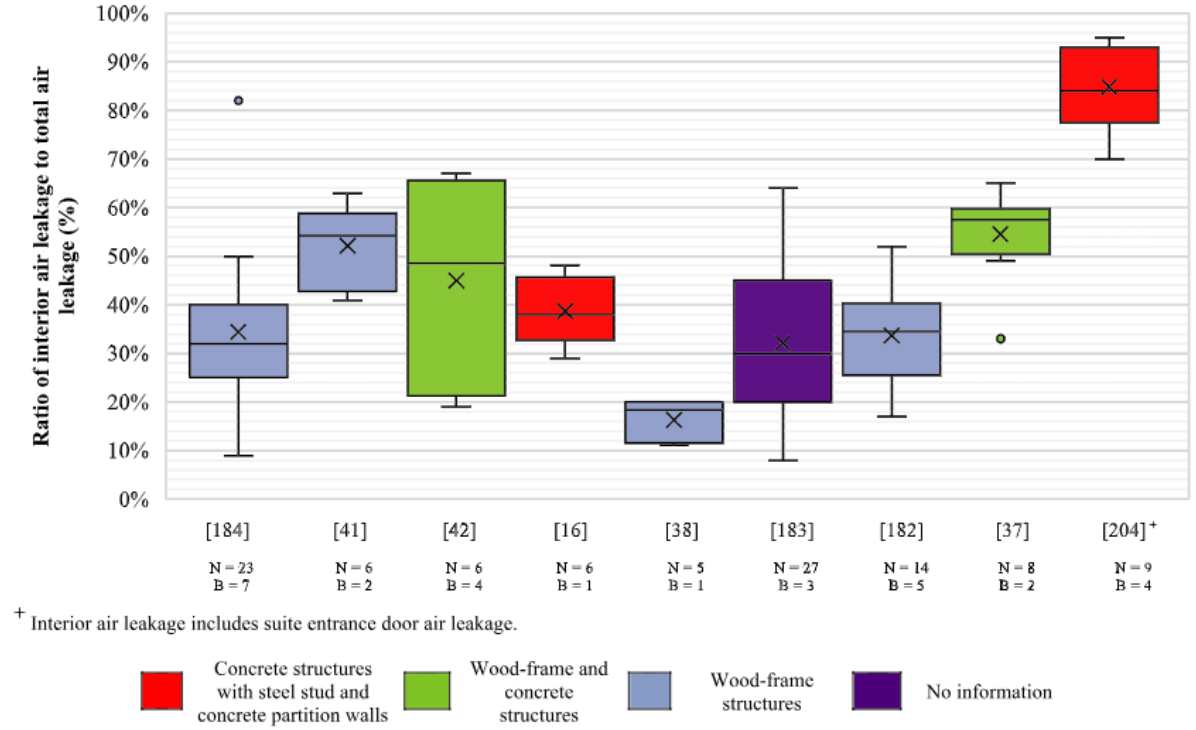


FIGURE 3 Contribution of interior air leakage paths to total suite air leakage from previous studies

Lozinsky and Touchie (2020) *Indoor Air*

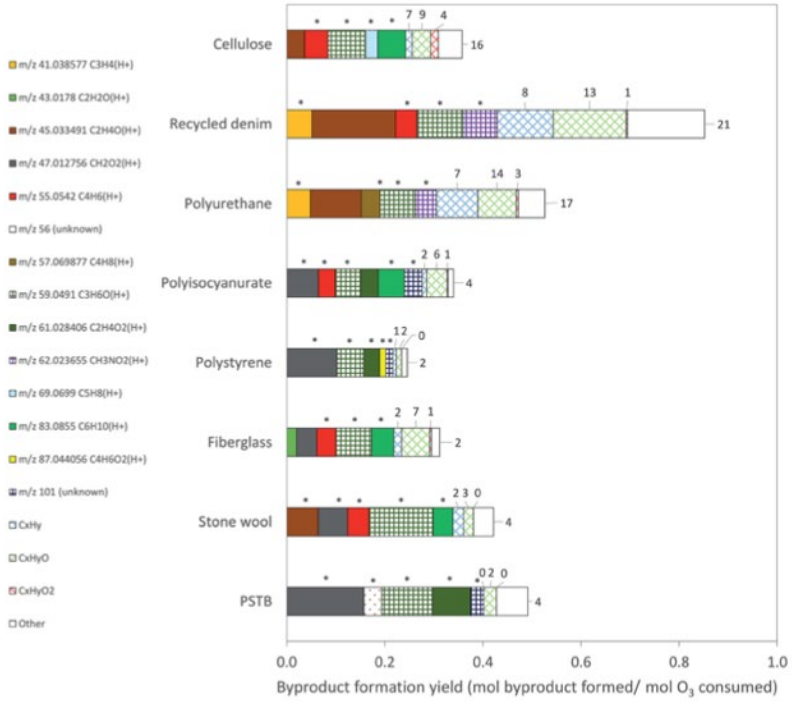
Surfaces 101

- Surfaces are enormously important to many aspects of indoor chemistry
- Surface area/volume ratios of 1-4/m in indoor environments
- Surfaces have two components
  - Substrate: Changes slowly compared to many indoor chemical processes
  - Patina/coating/layer: Changes over variable time scales & prior history is relevant

Image: https://www.vecteezy.com/free-vector/cloth

Unseen Surfaces

Image:https://en.m.wikipedia.org/wiki/File:Berber_Carpet_%28macro%29.jpg

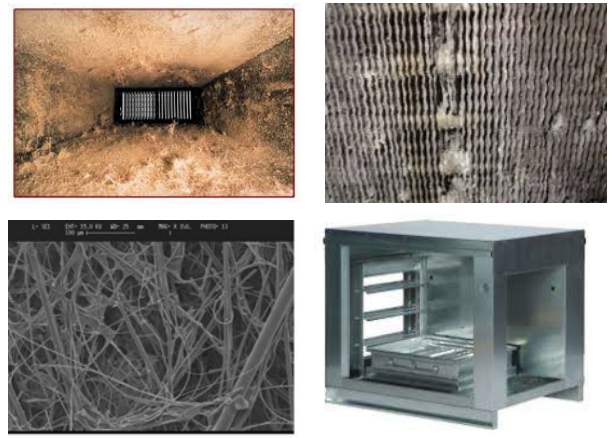


Chin et al. (2019) *Env Sci Proc. Impacts*

Image: beautyharmonylife.com/

Image: jadelearning.com/

- Clean surface area to volume ratios
  - Ducts (~1-10/m)
  - Heat exchangers (100-1000/m)
  - HVAC filter (~100/m)



Images: https://www.pickhvac.com, https://www.dh-ts.com, https://www.captiveaire.com

Measurement of Surfaces

- In processes where surfaces are important
  - Consider physical and/or biological as well as chemical characterization
- Role of water (and particularly adsorbed water)
- Consider history of surfaces

https://www.reddit.com/r/Mold/comments/skry8k/is_this_mold_on_the_popcorn_ceiling/

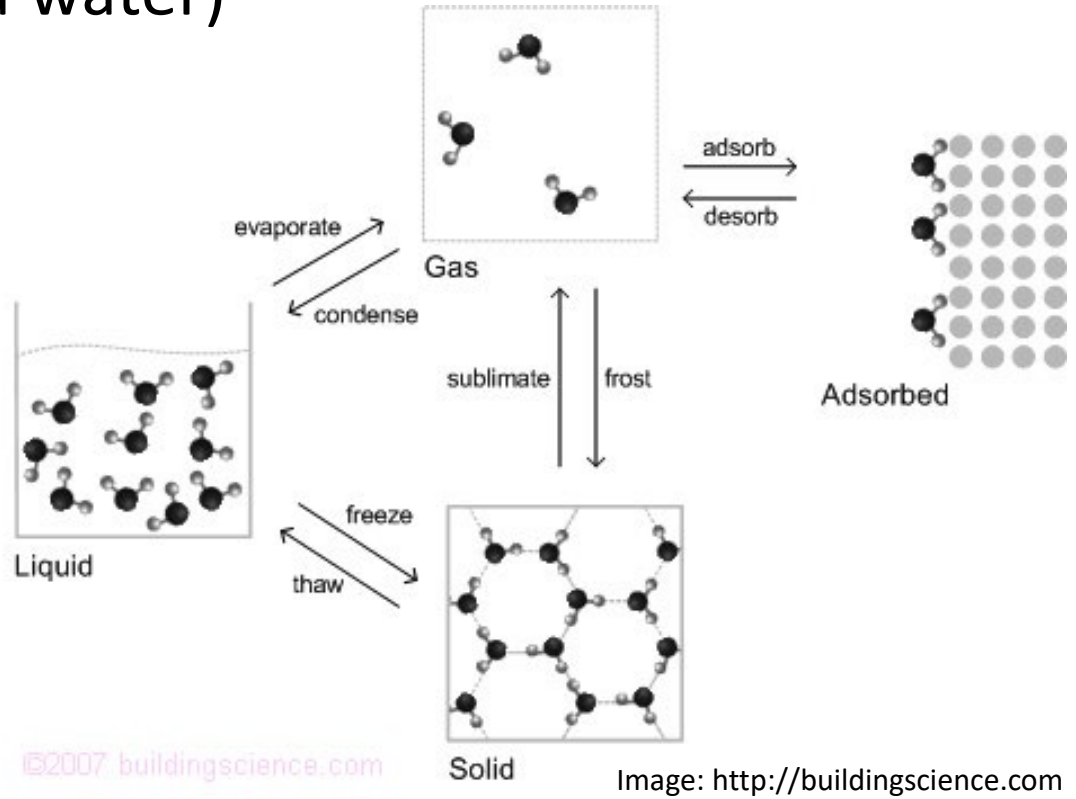
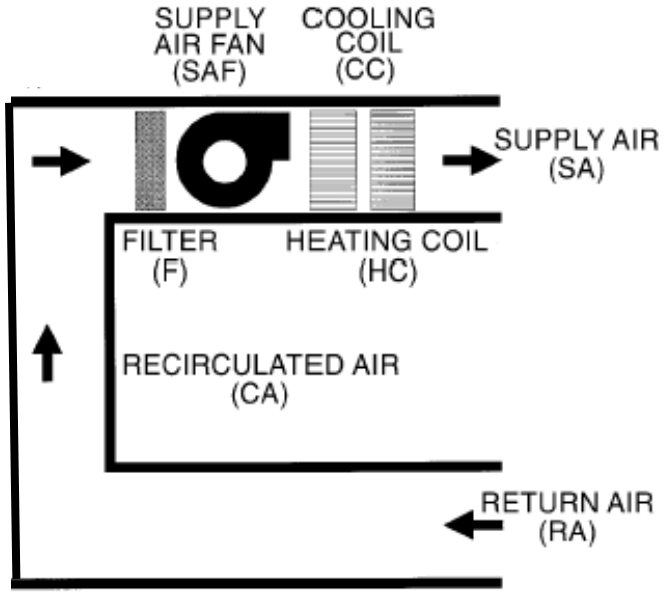


Image: http://buildingscience.com

HVAC 101

Core functions

- Heating & cooling
- Ventilation
- Humidity control
- Air flow control



- HVAC systems are **carefully designed** to provide **comfort** and maintain **indoor air quality**, **installed and maintained** by trained **professionals**, and **operated** in an **energy efficient** manner.

- HVAC systems are **designed** using **rules of thumb** that were **marginally appropriate** to a building at the **time of construction**, **installed** by the **least-cost bidder**, have been **minimally maintained**, and likely have **significant control and/or operational failures**.

Table 1. Emission sources and problems identified in HVAC systems

SOURCES AND PROBLEMS	TYPICAL EXAMPLES
Intrinsic emission sources	
1. *Seals, caulks, adhesives*	outgassing of VOCs, deterioration
2. *Fibers*	asbestos, fiber shedding
3. *Metal degradation products*	deterioration and entrainment of coatings, platings, metal surfaces
4. *Lubricating oils, etc.*	fans, motors in the air stream
5. *Ozone*	release by electrostatic air cleaners
Emission sources resulting from contamination	
1. *Dust*	construction material, skin cells, etc., with accumulation possibly leading to microbial contamination, VOC sorption-desorption, and low flows
2. *Other organic debris*	leaves, bird droppings
3. *Growth of microorganisms*	growth and aerosolization of bioaerosols and VOCs from micro-organisms at sites including: cooling coils, drain pans, drains, traps and sumps, filters, insulation, duct surfaces, plenums, humidifiers and evaporative coolers, cooling towers
4. *VOC sinks*	filters, sound absorbers, insulation materials, deposited dust
5. *Cleaning compounds and biocides*	biocides, disinfectants, deodorizers
6. *Boiler steam*	anticorrosives, biocides, slimicides, oxygen-scavenging or filming chemicals, anti-corrosives, pH control neutralizers
Design/operational effects on IAQ	
1. *Entrainment and re-entrainment*	leaks, polluted outside air, building exhaust
2. *Rotary heat exchangers*	sorption-desorption of VOCs
3. *Building pressurization*	intake of polluted outside air
4. *Transport*	odor, VOC and particle migration
5. *Climate control*	high humidity
6. *Ventilation and air exchange*	inadequate dilution of internal sources, inadequate outside air

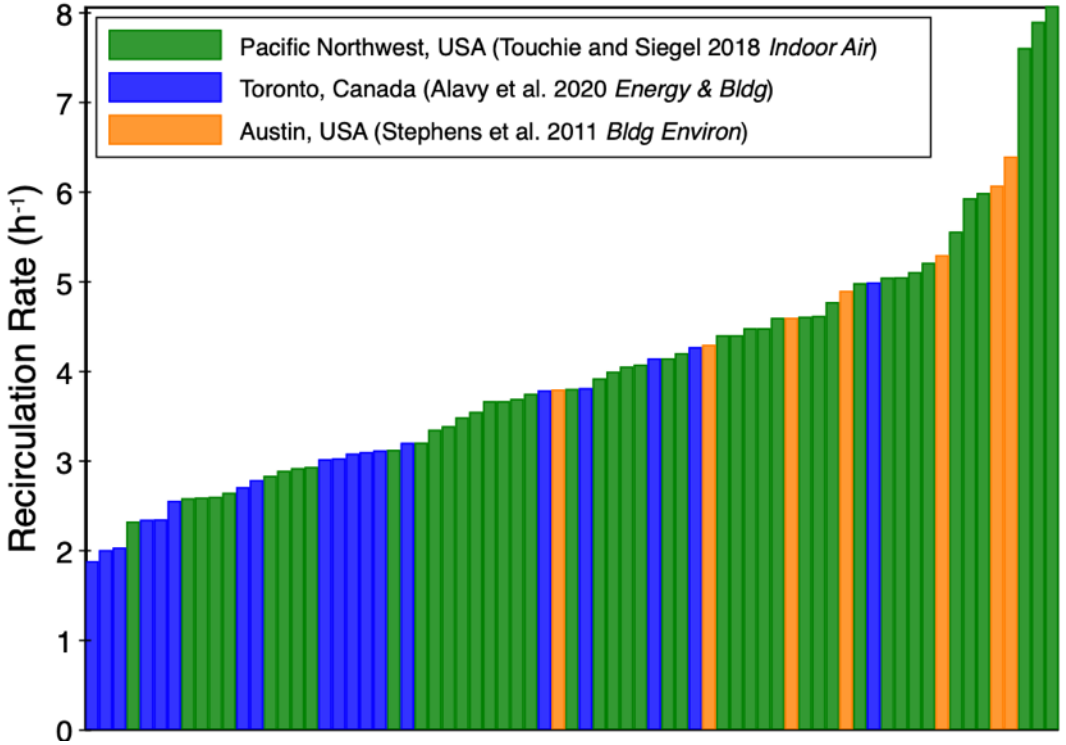
Batterman and Burge (1995) *HVAC&R Res.*

Table 3. Emission rates of total volatile organic compounds (TVOC) and aldehydes from duct components after exposure to ozone for 24 hr.

Material	Emission Rate ($\mu g\ m^{-2}\ hr^{-1}$) [a]					Ozone (ppb)	
	TVOC	HCHO	CH_3CHO	Acetone	C_5-C_{10} Aldehydes	Inlet	Chamber/Outlet
NDL2	550	b	20	166	380	110	72 ± 12
NDL3	b	60	b	b	b	140	31 ± 8
neoprene gasket	6400	b	b	120	330	140	65 ± 9
duct sealant	4000	24	290	b	660	100	27 ± 15

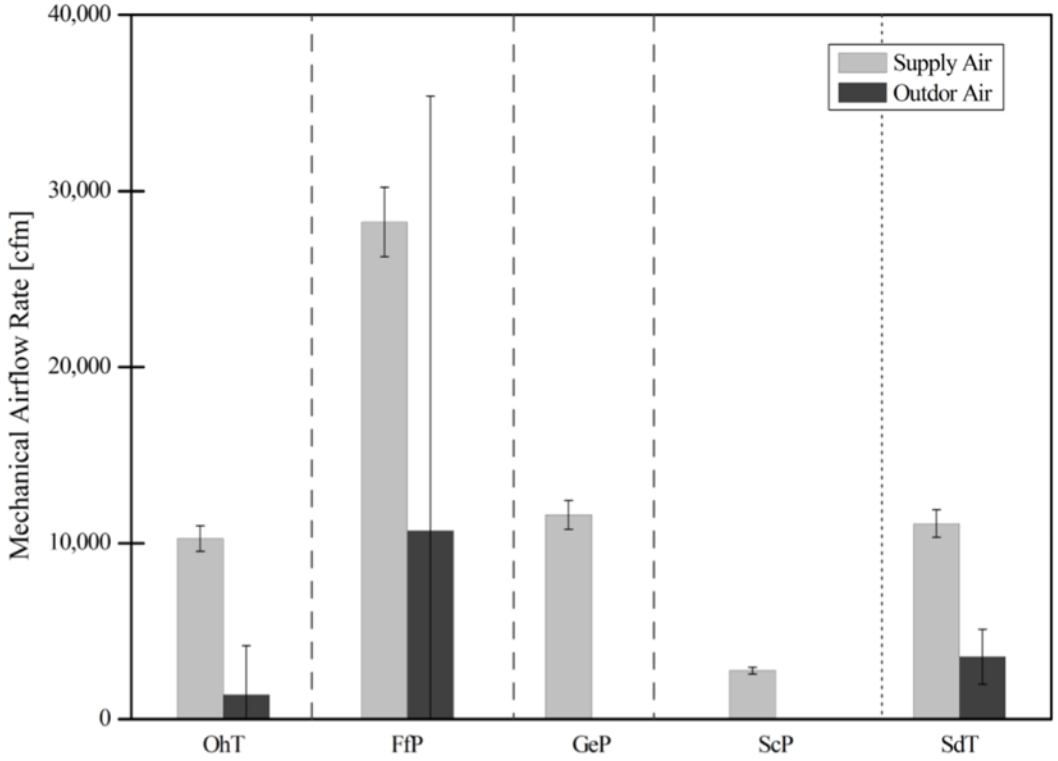
Morrison et al. (1998) *JAWMA*

Recirculation: Building volumes that pass through system

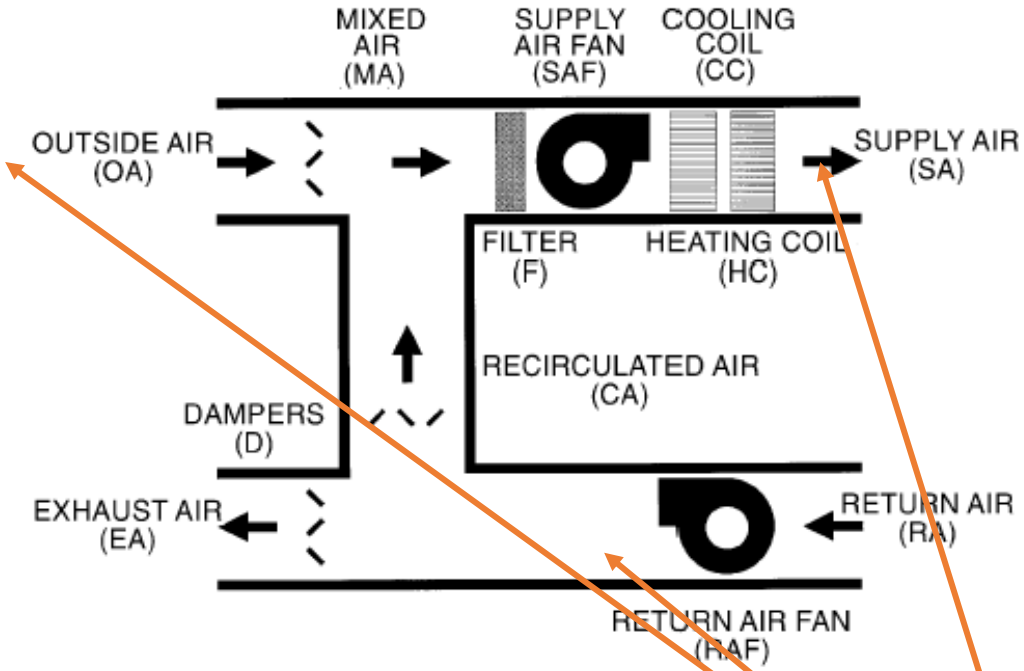


- Another time scale for comparison to time scales of HVAC chemistry
- Degree of connection between HVAC surfaces and indoor air
- Removal by filter/air cleaner
- Distribution and air mixing
- Dilution of indoor sources
- Chemistry at extreme conditions
  - Heat, liquid water, UV lamps

Outdoor Air: Fraction/amount of outside air entering through mechanical ventilation

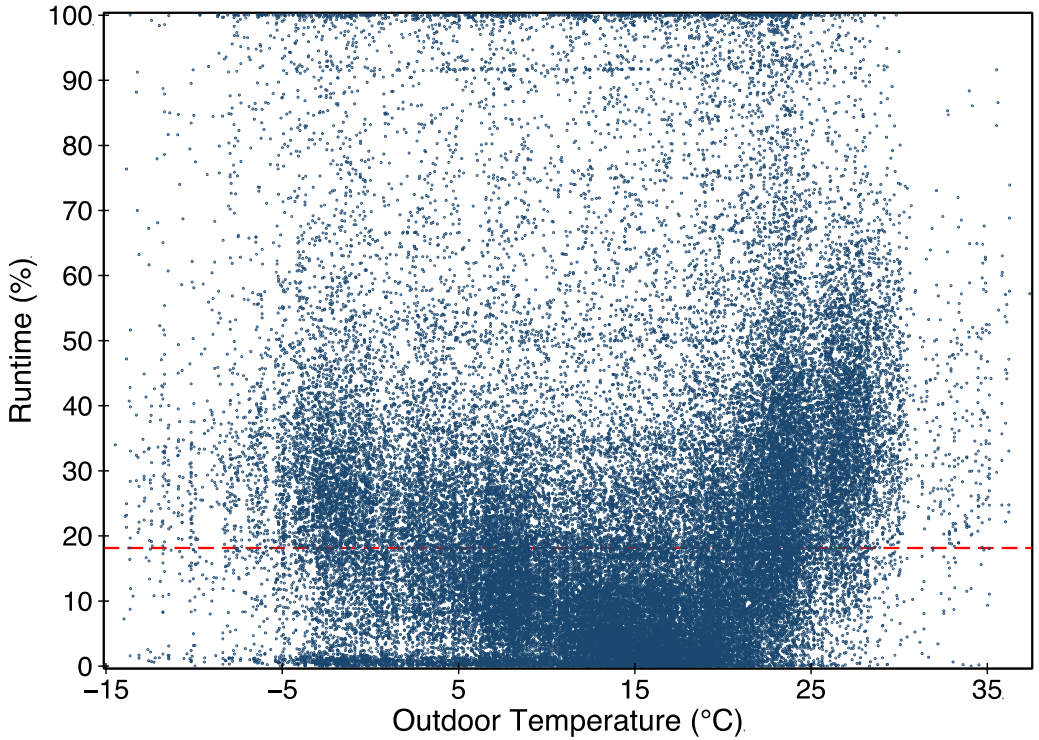


Siegel et al. (2013) *ASHRAE RP-1596 Report*



- Inflow of outdoor contaminants
- Often highly dynamic

Runtime: Fraction of time that system operates



Data from: Touchie and Siegel (2018) *Indoor Air*

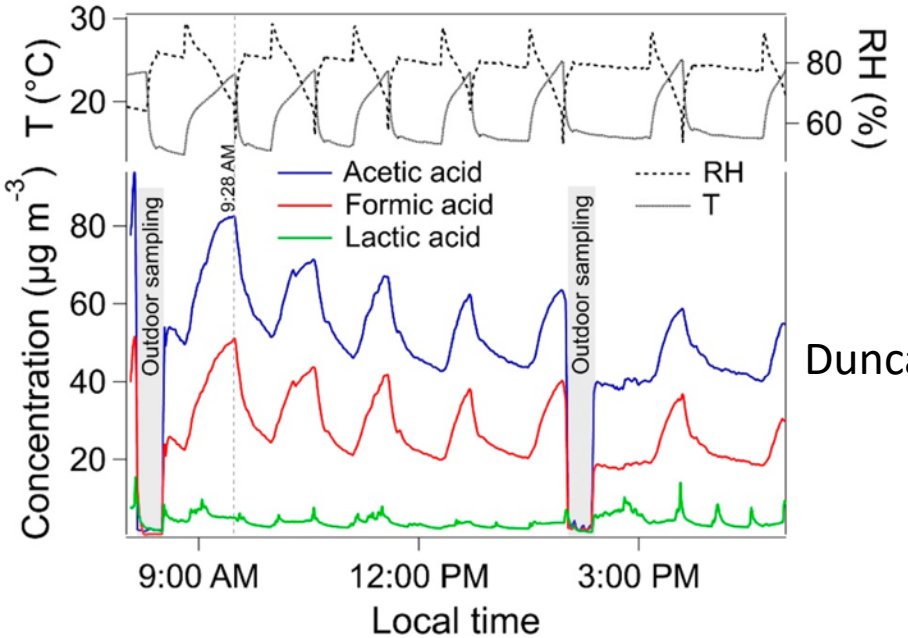
Table 1
Summary of direct approaches to measure system runtime.

#	Measurement Parameter	Approximate Cost (USD $)	Reference
1	Motor magnetic field	100–180	[7]
2	Pressure	300–500	–
3	Current or power	100–300	[8,10]
4	Modified current or power[a]	200–600	[9,13]
5	Smart thermostat records	200–300	[11]

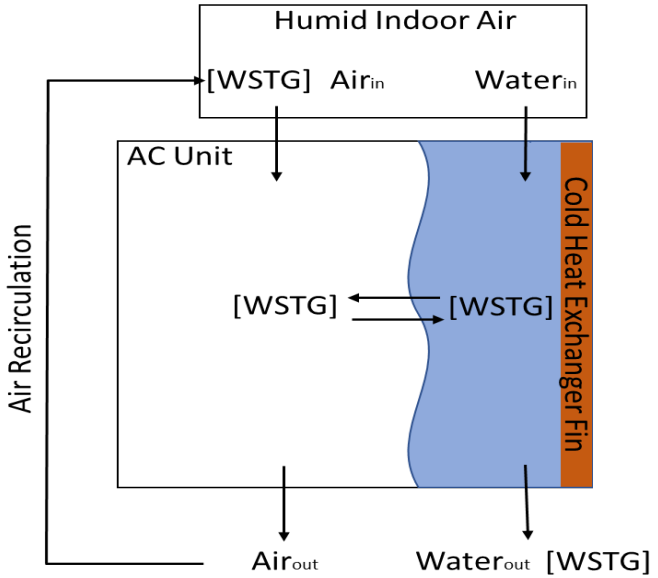
[a] The modified method uses current or power transducers on both the fan and on the compressor.

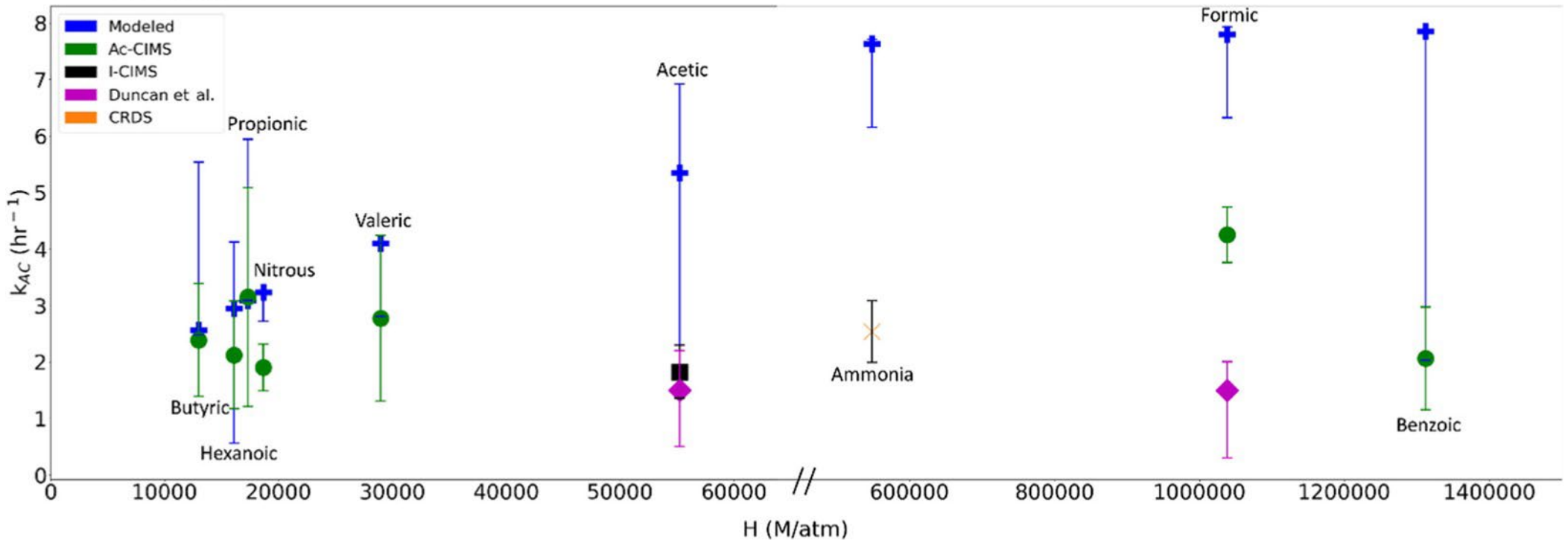
Li et al. (2019) *Bldg Environ*

- Every HVAC impact on indoor chemistry is tied to runtime



Duncan et al. (2019) *ES&T*





Schwartz-Narbonne et al. (2021) *ES&T*

Indoor Chemistry Matters

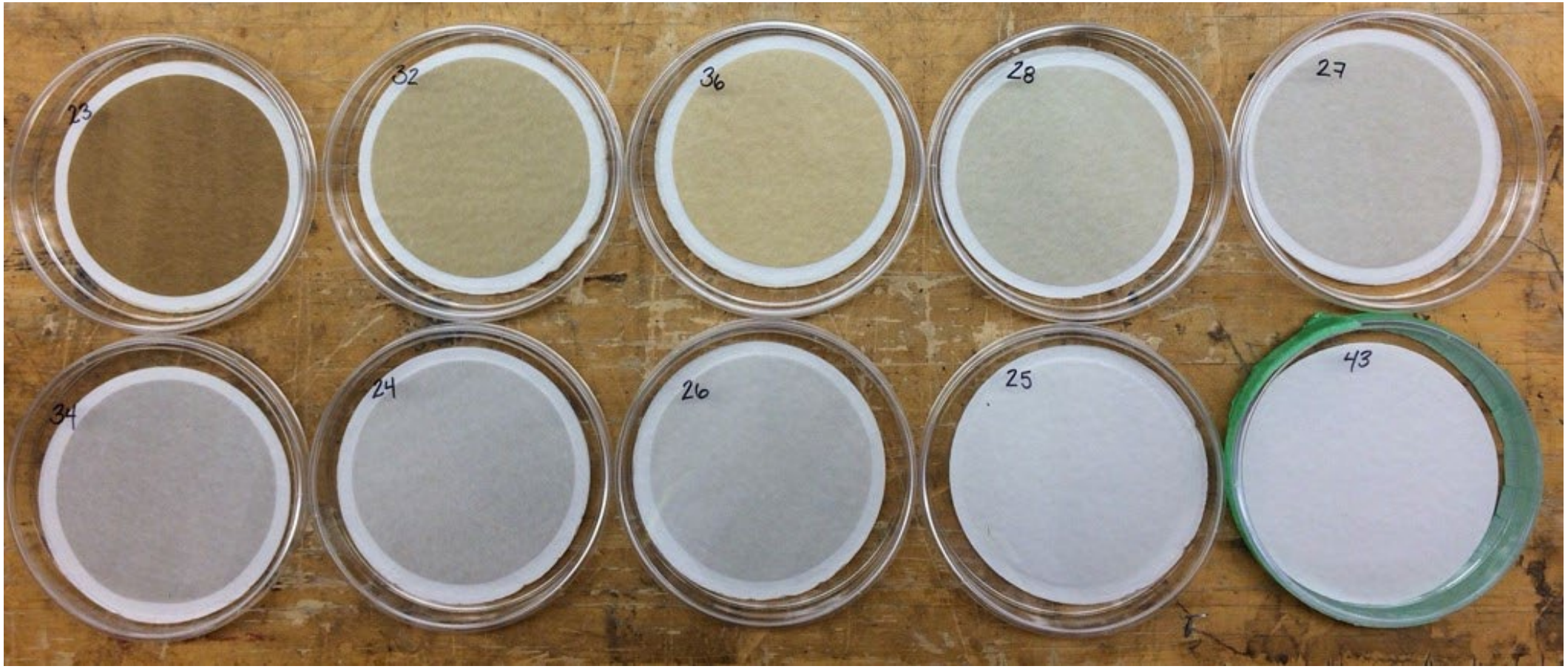
- 11 Recommendations include researchers
  - Characterizing the building is often needed to fully contextualize chemistry
  - Characterizing the building allows for generalization of results to other indoor environments
  - Extreme environments are common in buildings
    - James Scott: "…few places on earth get as hot as a rooftop or as dry as the corner of a heated living room." *Wired* 2011
    - Does this lead to extreme chemistry?

Building Aware Indoor Chemistry Research

Indoor Chemistry Matters

- Three recommendations include funders/funding agencies
  - Consider characterization of the building in program design/granting
  - Many measurements/measurement approaches can be collected with low-cost sensors or involve analysis of existing data
- Two recommendations involve building design/standardization and two highlight the importance of interdisciplinary collaborations
  - Indoor chemistry's impact on other fields will come from adopting language and valuing contribution of other fields

Indoor Chemistry Matters



Acknowledgements

- Postdocs and Students: Masih Alavy, Bowen Du, Raheleh Givehchi, Daniel Haaland, Zoe Hoskins, Alireza Mahdavi, Alex Mendell, Tianyuan (Amy) Li, Yuchao Wan, Federico Noris, Brent Stephens, Marwa Zaatari, Yizhi (Annabel) Zhang
- Collaborators: Arthur Chan, Richard Corsi, Miriam Diamond, Sarah Haines, Kerry Kinney, Seungjae Lee, JP Maestre, Bill Nazaroff, Atila Novoselac, Jim Rosenthal, Marianne Touchie, Ying Xu, ASHRAE TC 2.4 & RP1649 PMS, NASEM Fine PM/Mitigation Committee
- Funding

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