Tradeoffs Between Indoor Air Quality and Sustainability for Indoor Virus Mitigation Strategies in Office Buildings

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Background and Motivation

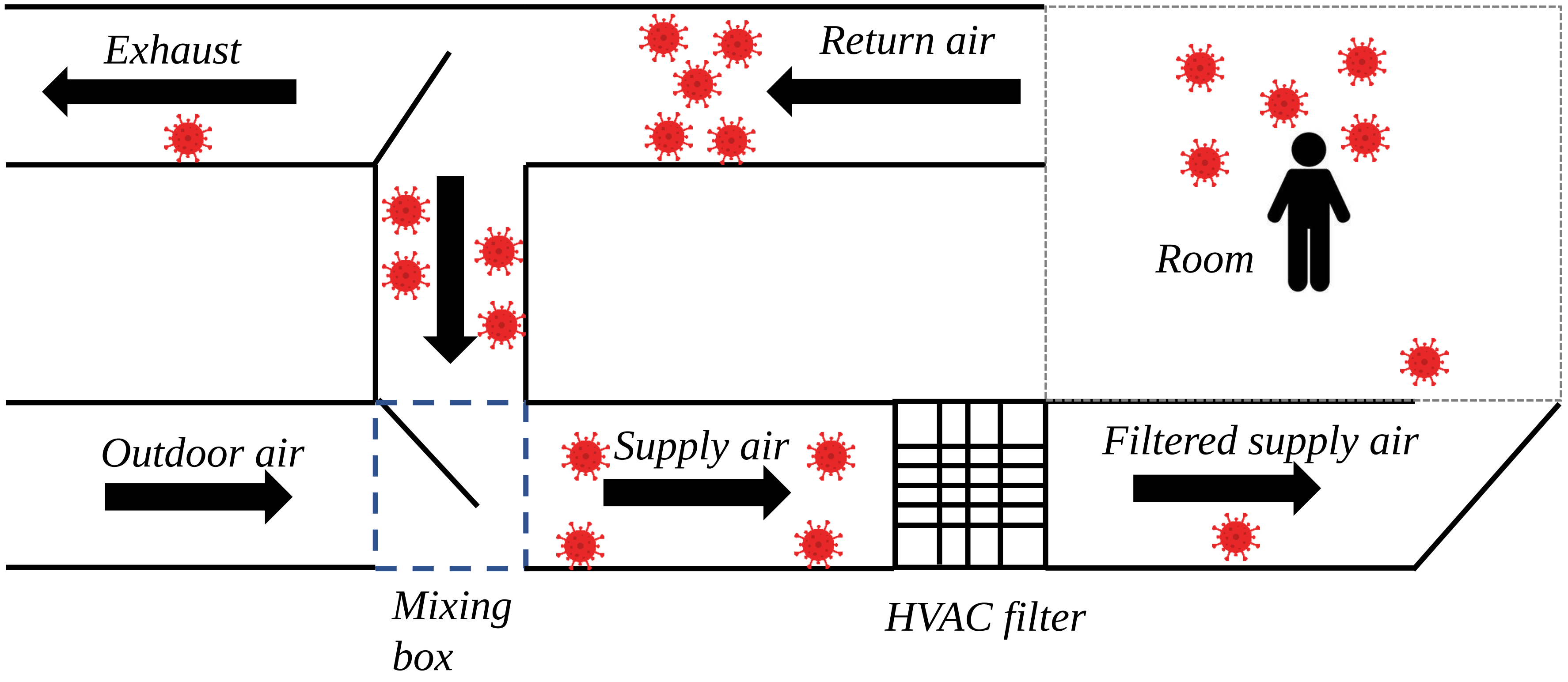
Buildings account for 40% of total energy consumption in the U.S and 36% of greenhouse gas emissions.

Americans spend 90% of time indoors.

Majority of COVID-19 outbreaks of occur indoors.

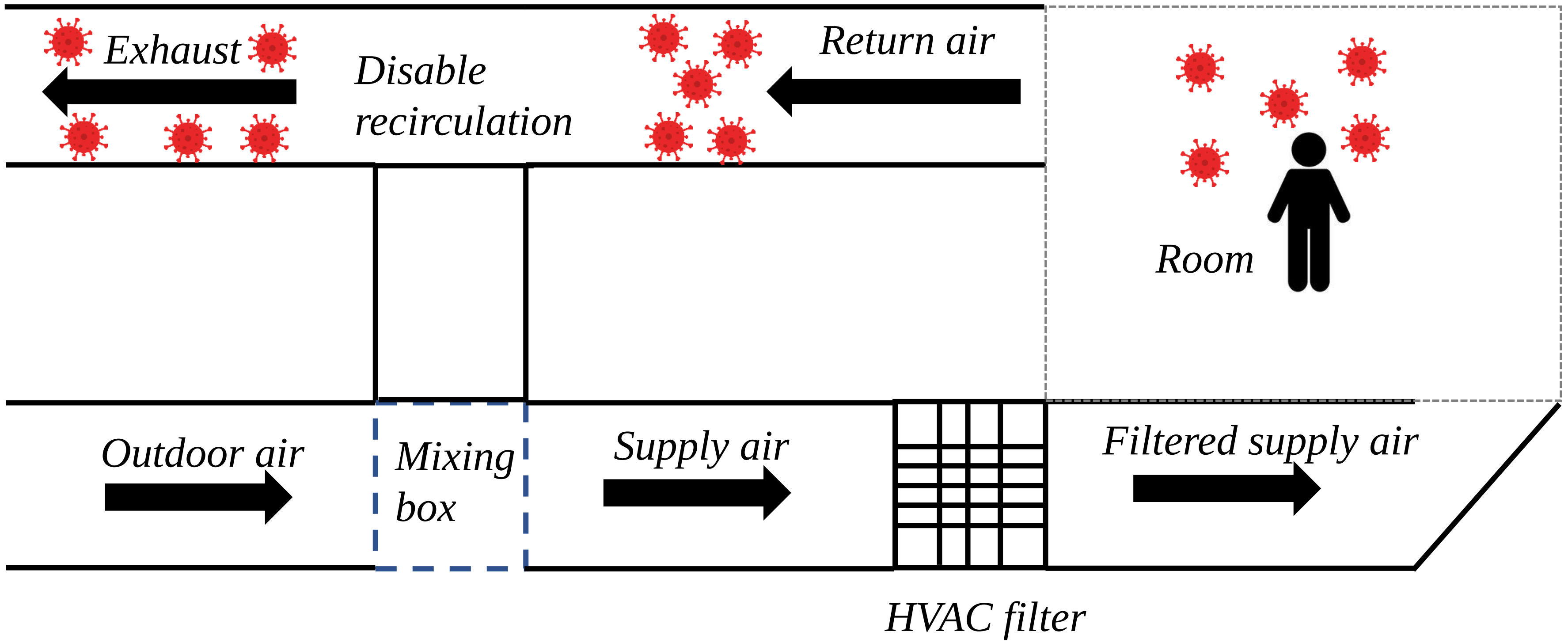
HVAC Filtration to Mitigate Indoor Virus

Efficient **filtration** of supply air can reduce indoor virus concentration.



Outdoor Airflow to Mitigate Indoor Virus

Increasing **supply of clean outdoor air** and preventing recirculation can also mitigate indoor virus.

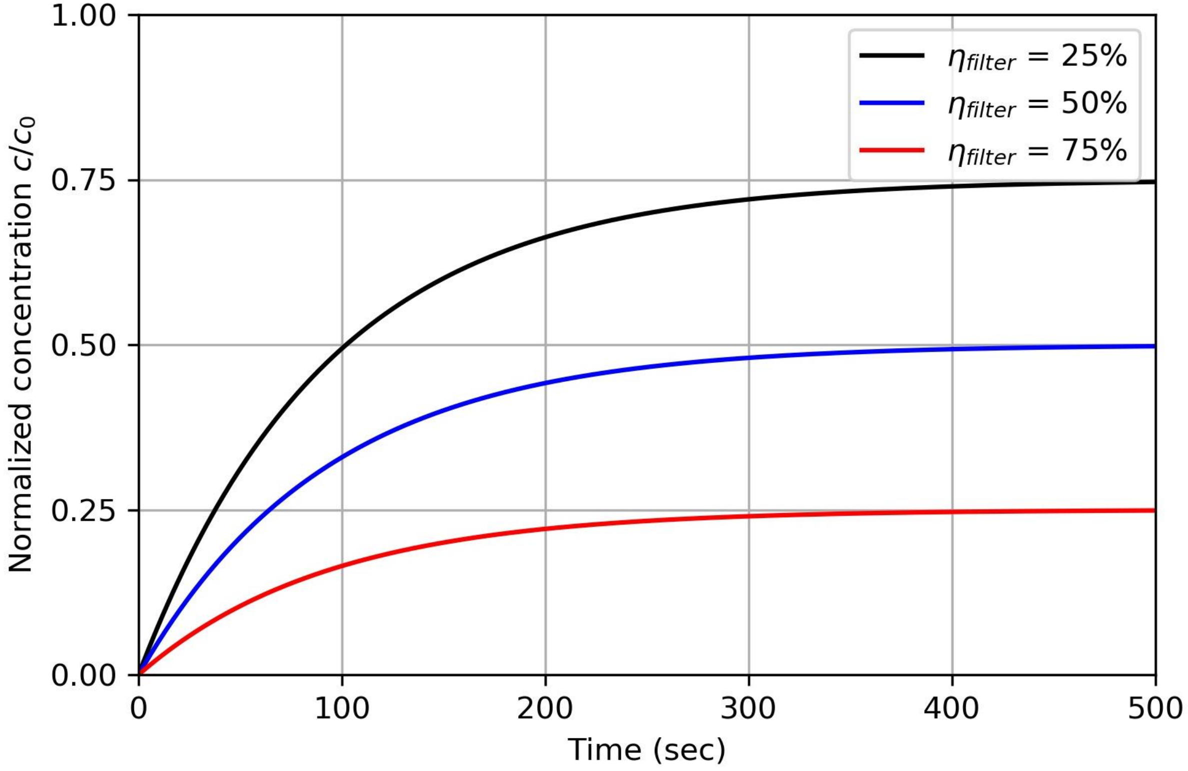


We compare efficient HVAC filtration with supplying 100% outdoor air in this work.

New HVAC Filter Model

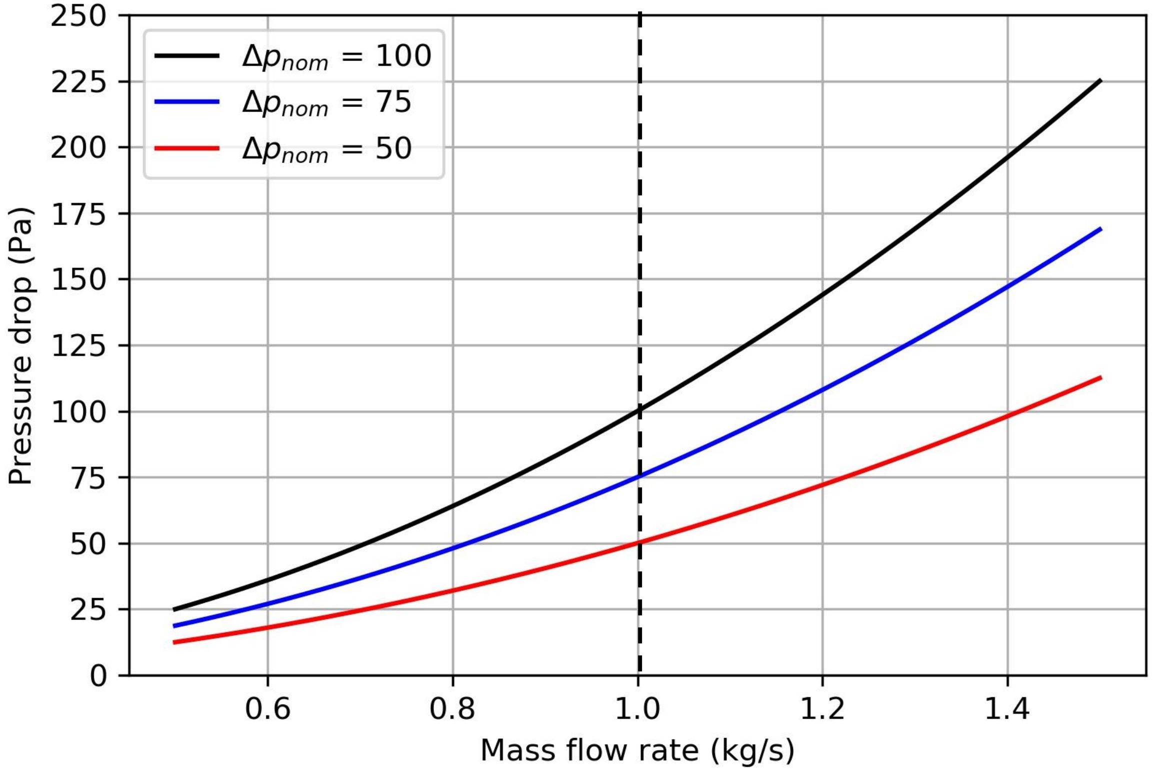
The filter model accounts for 1) **removal of virus** and 2) **pressure drop** from the resistance of the filter.

1) $c_{out} = \left(1 - \eta_{filter}\right) c_{in}$



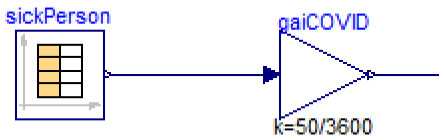
2) $\Delta P = k_{filter} \dot{m}^2{}_{flow}$

3) $k_{filter} = \dfrac{\Delta P_{nom}}{\dot{m}^2{}_{nom}}$

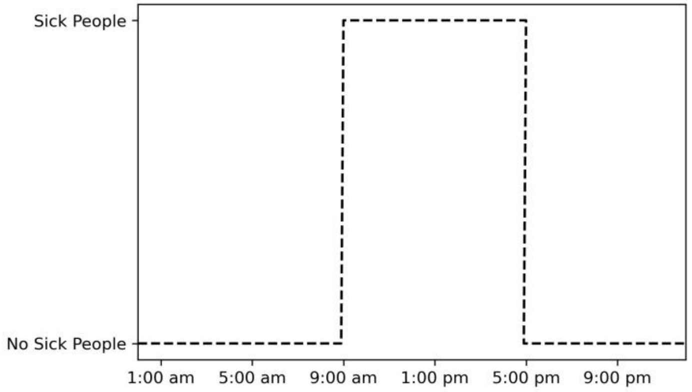


Indoor Virus Transmission Modeling

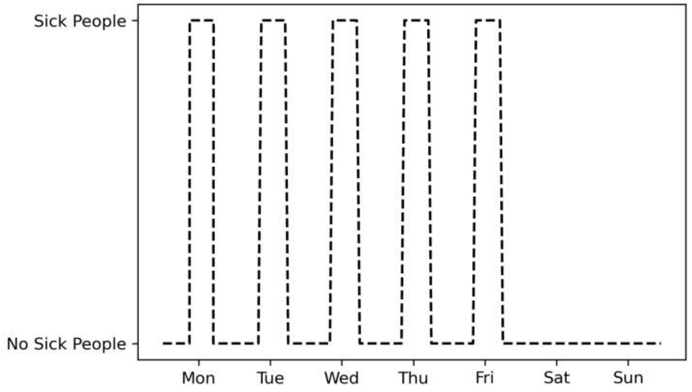
Virus generation and first order **decay of viral particles** are modeled.



Generation of virus based on sick people schedule

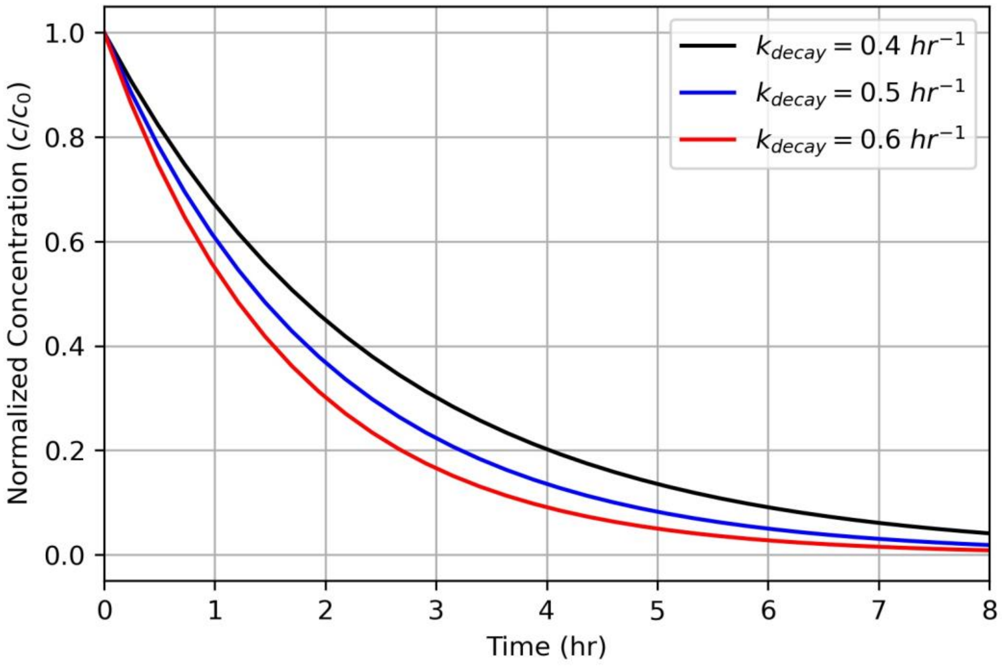


Daily (weekday) schedule



Weekly schedule

$$\dot{c}_{decay} = k_{decay} c_{zone}$$



Example of viral decay model

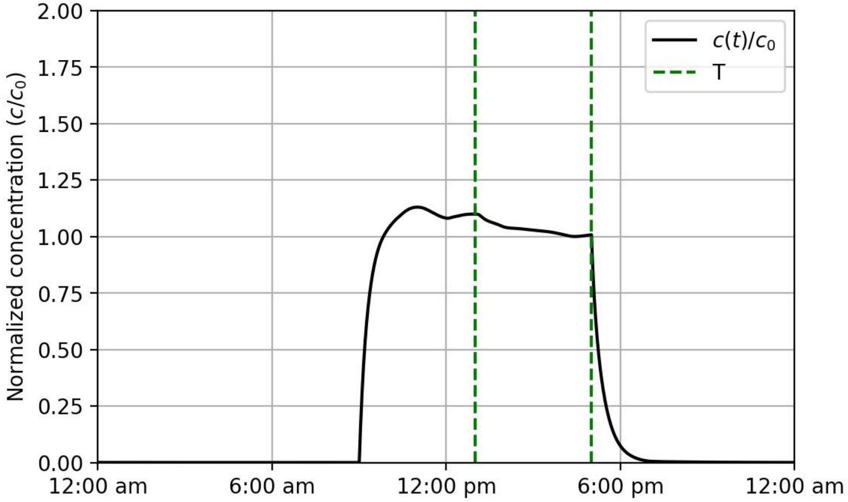
Risk Based on Predicted Number of Infections

Risk is calculated based on the amount of **viral particles inhaled by an occupant**.

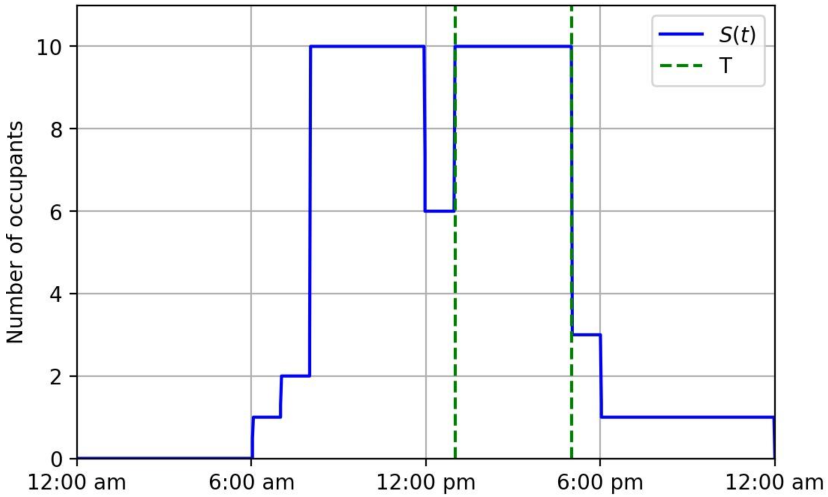
Predicted number of infections is calculated based on the varying **risk and occupancy** over time.

$$1)\ R(t) = 1 - \exp\left(-IR\int_{t_0}^{t} c(t)dt\right)$$

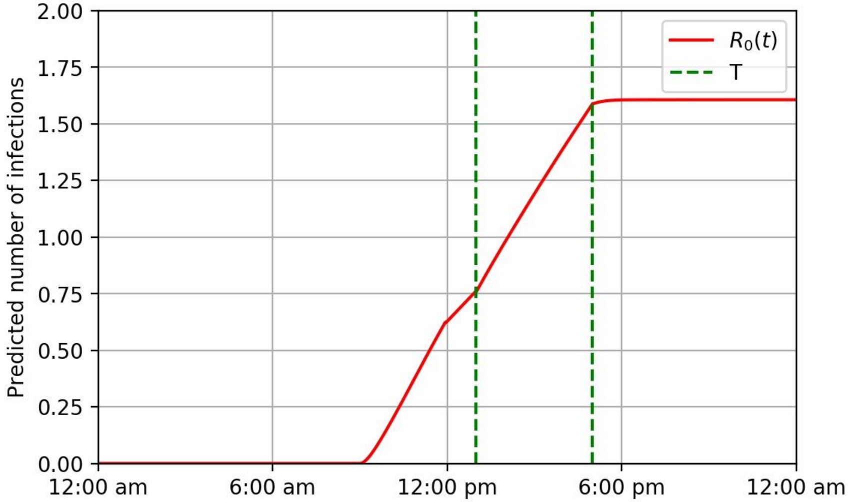
$$2)\ R_0(t) = S(t)R(t)$$



Virus concentration



Occupancy schedule

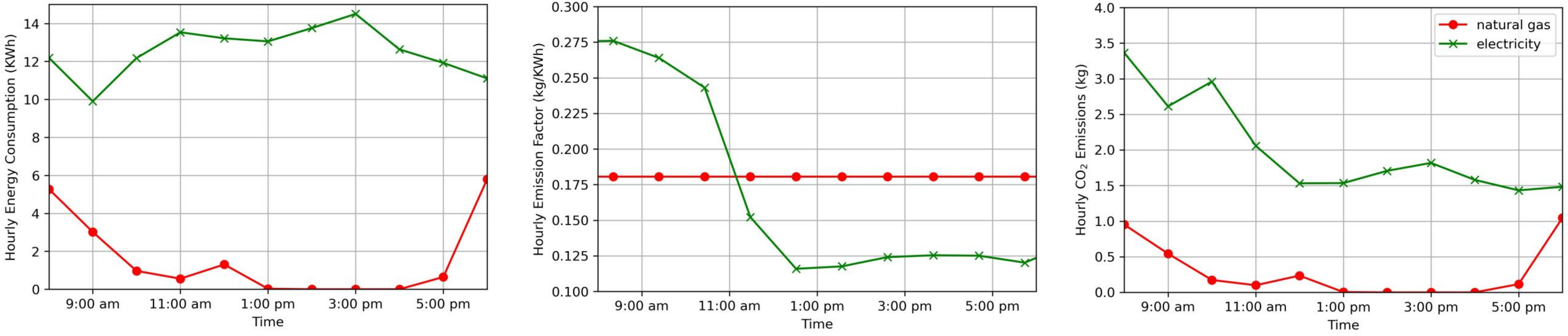


Predicted number of infections

Methods to Calculate Costs and Emissions

Costs to run the HVAC system based on filter costs, electricity costs (power the fan and provide cooling), and natural gas costs (provide heating). CO2 costs based on emissions from natural gas and electricity.

$$J_{total} = \underbrace{J_{filter} + J_{elec} + J_{gas}}_{\text{HVAC costs currently in practice}} + \underbrace{J_{CO_2}}_{\text{Hypothetical Carbon Tax}}$$



$$Energy \times Emission\ factor = Emissions$$

Methods for Combined Metrics

What is the improvement in IAQ (virus concentration) per increase in costs relative to MERV 10?

The percent increase in costs for MERV 13 relative to MERV 10

$$\Delta J_{MERV13} = \frac{J_{MERV13} - J_{MERV10}}{J_{MERV10}}$$

Sign convention: increase in costs relative to MERV 10 is positive.

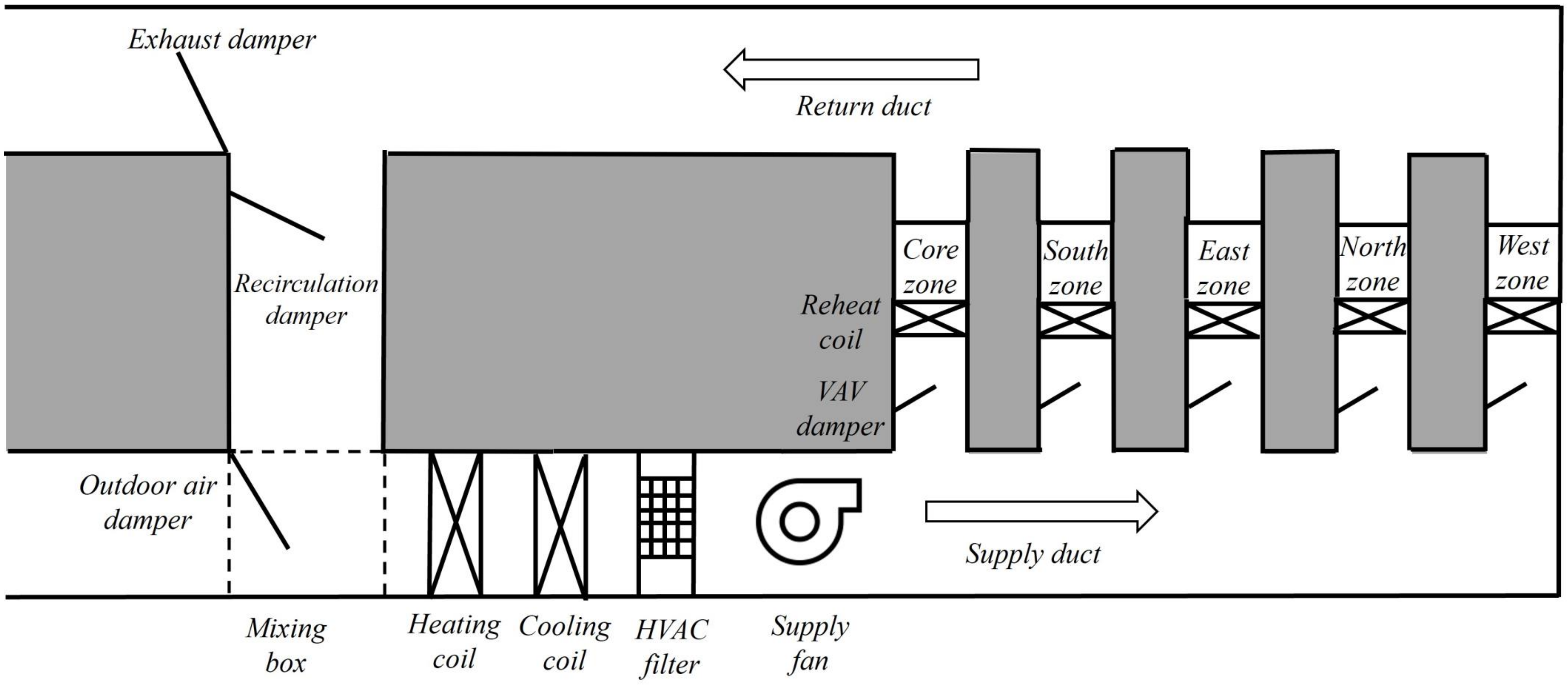
The percent improvement in IAQ per increase in costs for MERV 13 relative to MERV 10

$$\Delta IAQ/\Delta J_{MERV13} = \left(\frac{IAQ_{MERV10} - IAQ_{MERV13}}{IAQ_{MERV10}}\right)/\Delta J_{MERV13}$$

Sign convention: reduction (improvement) in IAQ relative to MERV 10 is positive.

Studied Building HVAC System

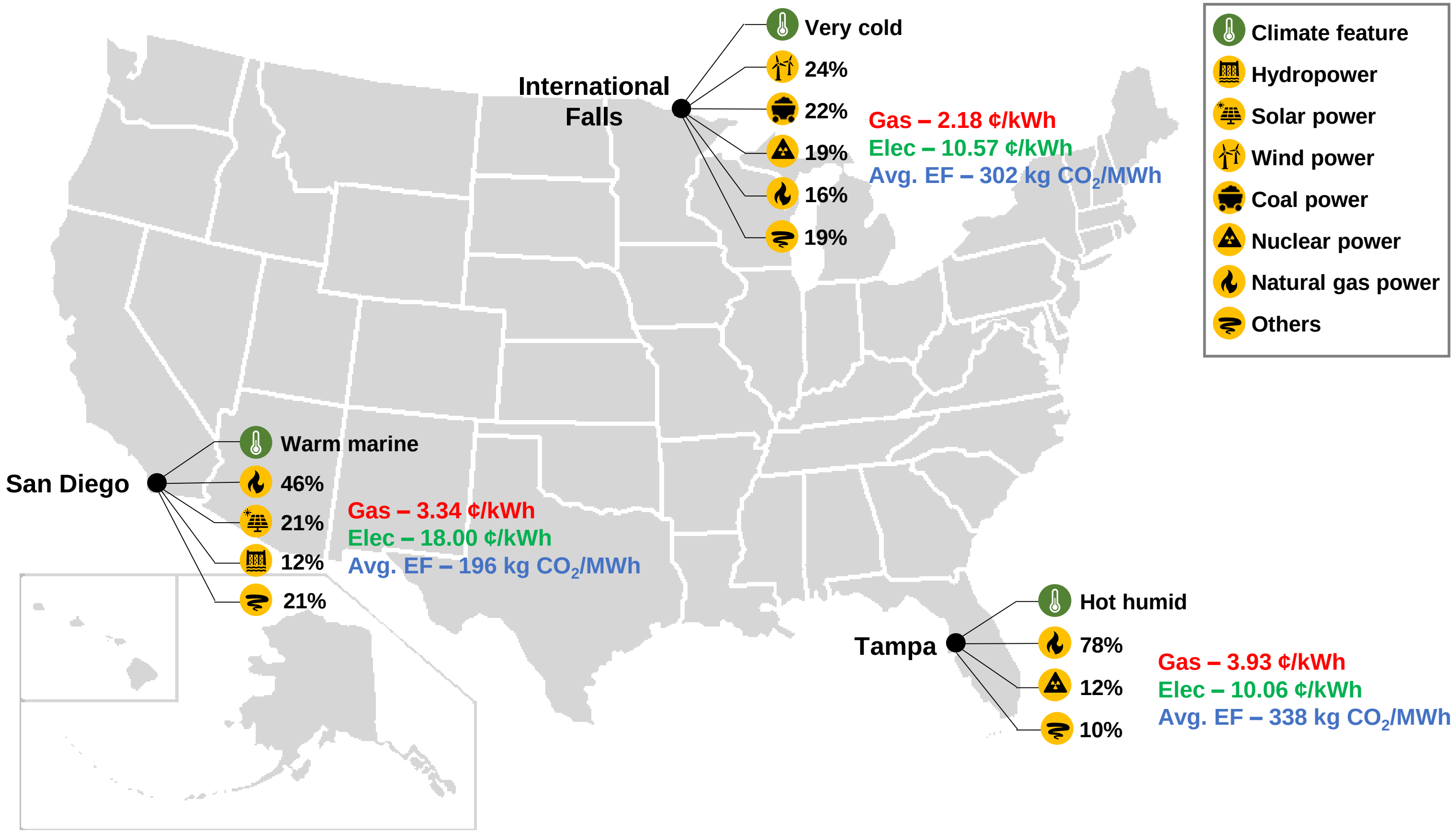
System for **floor of a five-zone medium office building** with area of 1,664 m^2.



Scope of Analysis

Three mitigation strategies are studied in three locations.

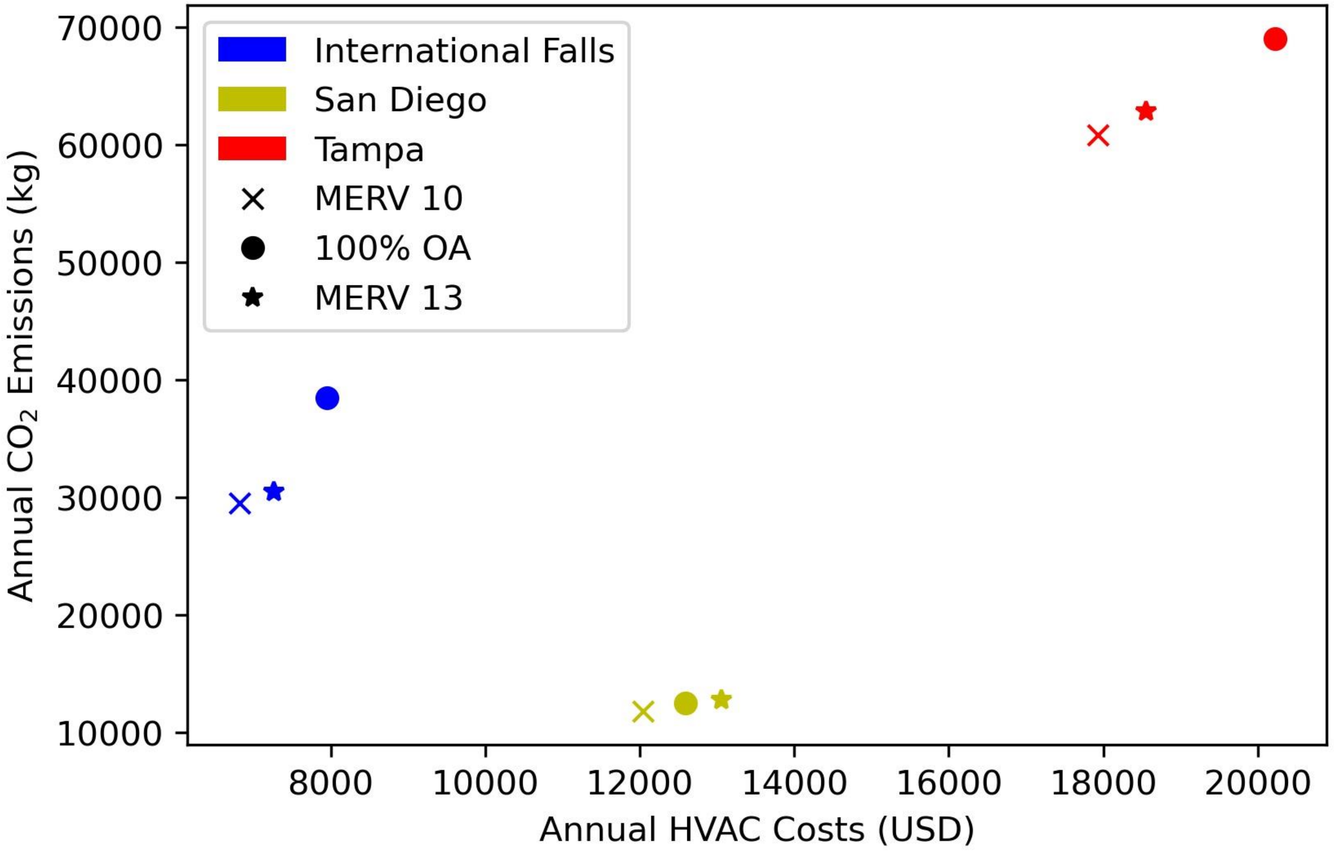
Strategy	Removal efficiency	Nominal pressure drop (Pa)
MERV 10	50%	143
MERV 10 + 100% Outdoor Air	100%	143
MERV 13	85%	162



HVAC Costs vs CO_2 Emissions

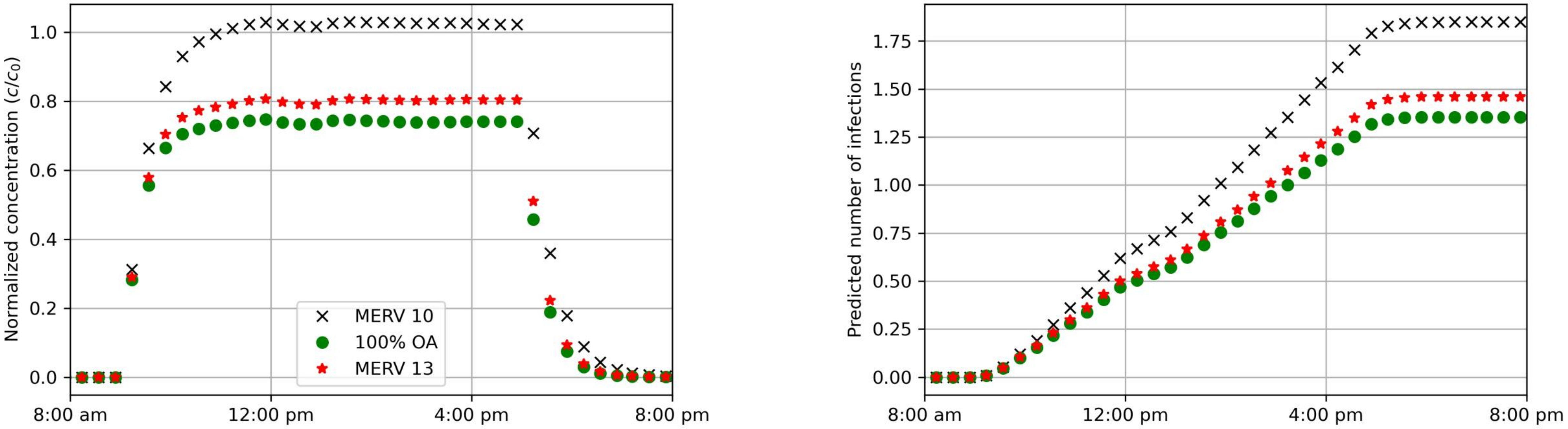
Warmer climates lead to higher costs than colder climates.

San Diego generates electricity with less CO_2 Emissions compared to Tampa and International Falls.



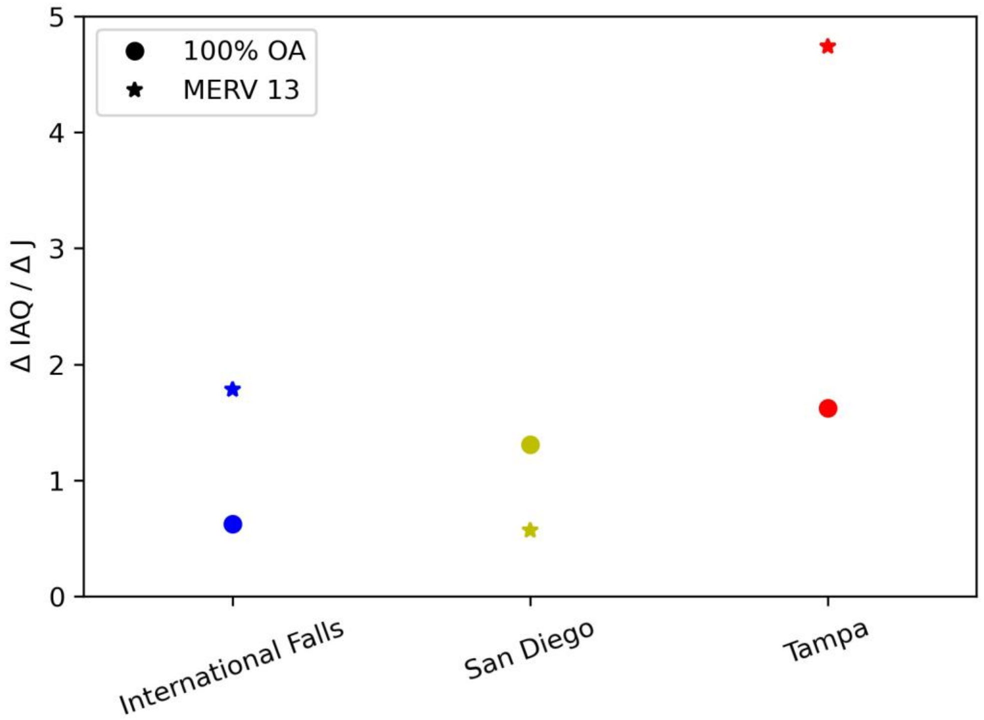
Indoor Virus Concentration Trends for a Sample Day

Summer day (June 24) in Tampa when filter cases use minimum outdoor airflow.

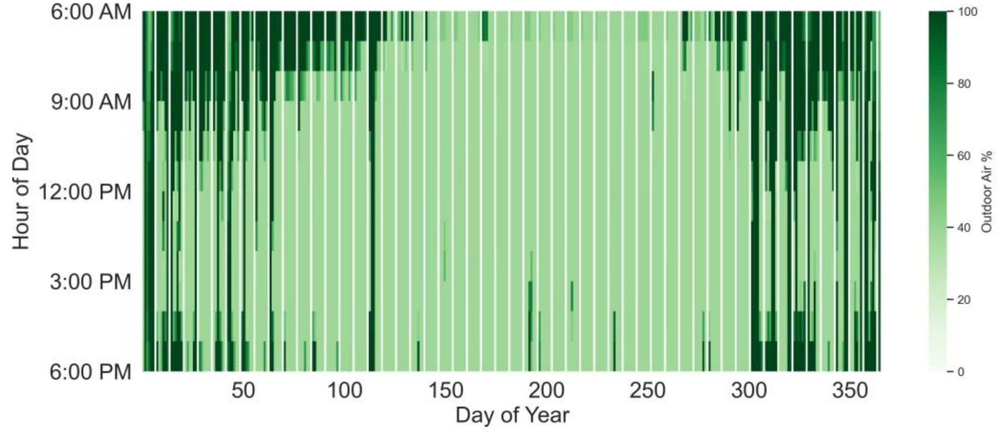


Improvement in IAQ per Costs/Emissions

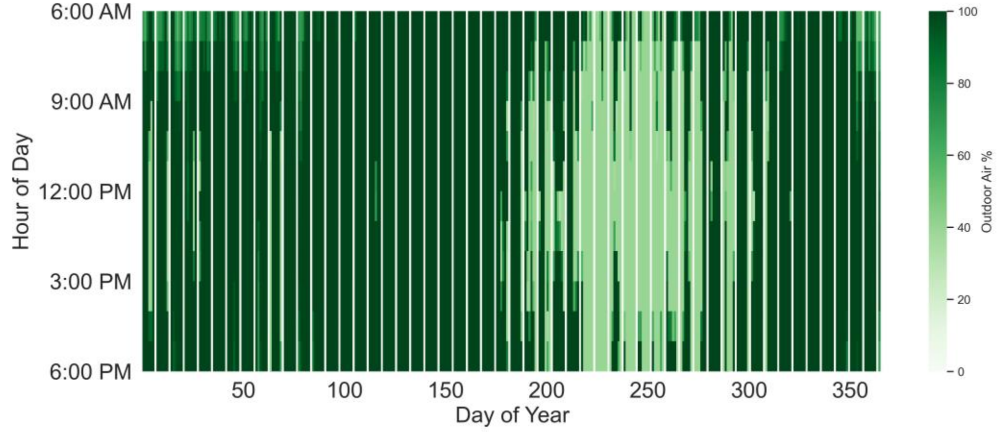
MERV 13 offers the best improvement in IAQ per cost/emissions in 2 of 3 locations. The exception is San Diego due to its milder climate.



Outdoor air usage for MERV 10 Cases



Tampa



San Diego

Conclusions

- MERV 10 filtration is usually the cheapest and lowest emission option, but typically has the worst IAQ.

- Use of 100% outdoor air often provides the best IAQ, but can significantly increase costs and emissions. The exception is for the milder climate in San Diego.

- MERV 13 filtration demonstrates the best improvement in IAQ per costs in 2 of the 3 climates. It outperforms 100% outdoor air in the more extreme weather climates.

C. A. Faulkner, J. E. Castellini, W. Zuo, D. M. Lorenzetti, M. D. Sohn 2022. "Investigation of HVAC Operation Strategies for Office Buildings During COVID-19 Pandemic." Building and Environment, 207 (B), pp. 108519.

C. A. Faulkner, J. E. Castellini, Y. Lou, W. Zuo, D. M. Lorenzetti, M. D. Sohn. 2022. "Tradeoffs among Indoor Air Quality, Financial Costs, and CO2 Emissions for HVAC Operation Strategies to Mitigate Indoor Virus in U.S. Office Buildings," Building and Environment, 221, pp. 109282.

Q&A

- Any questions?

Thank You!

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