Effect of Elevated Air Movement on Radiant and Ceiling Fan Coupled Systems

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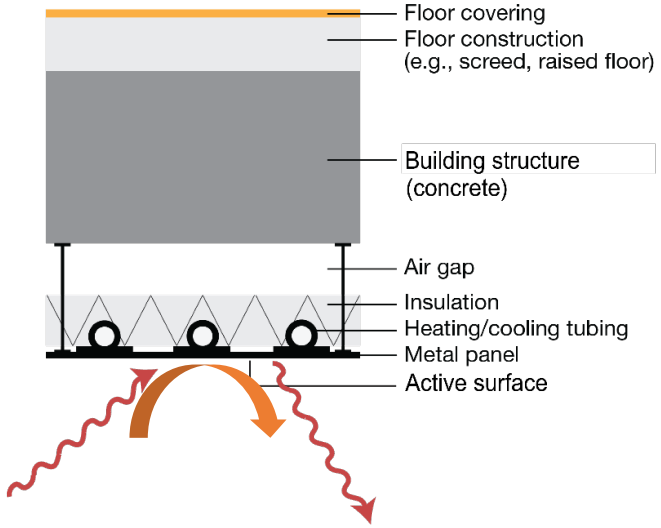
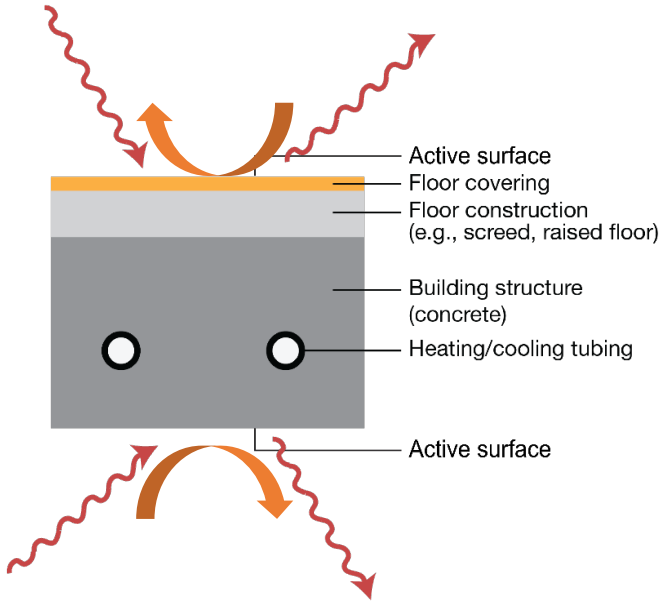
Air movement improves convective heat transfer in radiant systems

≥50% radiation heat transfer

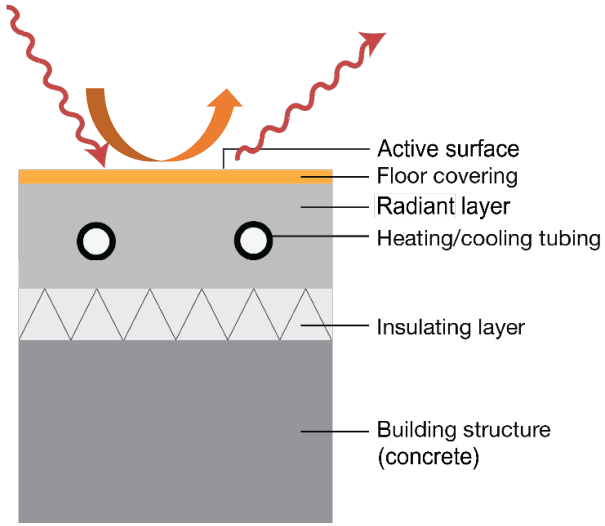
Remaining heat transfer is convection



Radiant ceiling panels (RPC)



Thermally activated building systems (TABS)

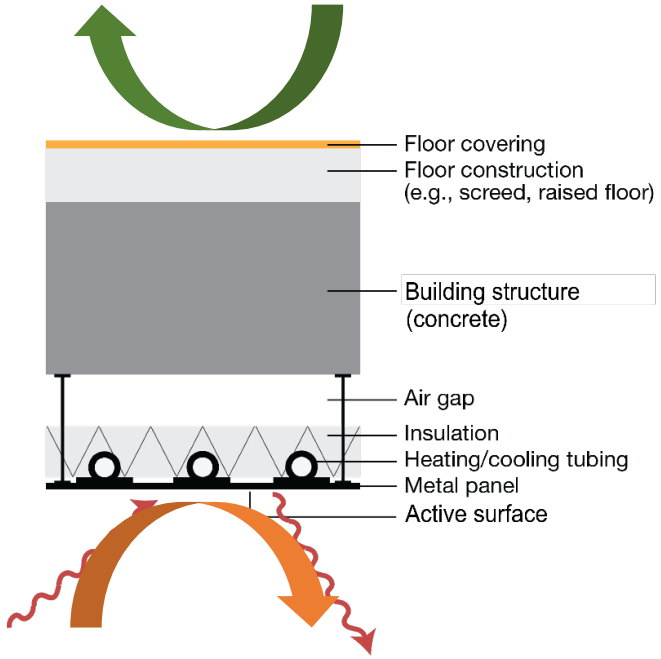


Embedded surface systems (ESS)

Air movement improves convective heat transfer in radiant systems

Increase in overall heat transfer

Affects all types of surfaces including non-radiant surfaces e.g. night cooling ventilation strategies



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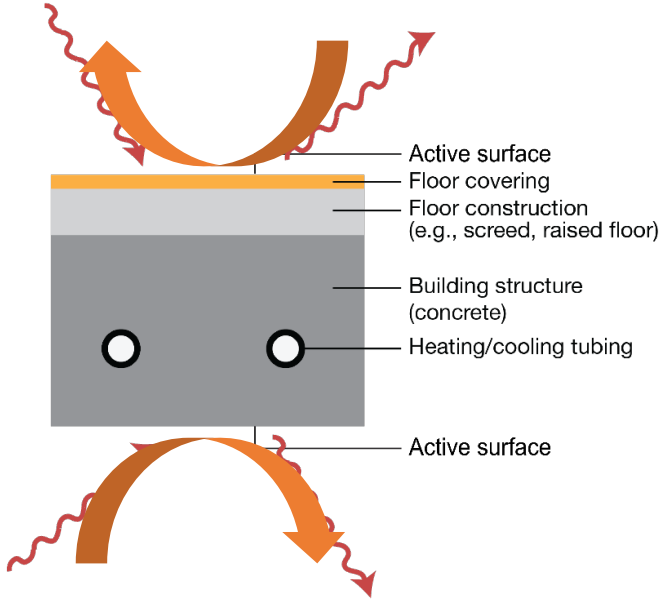

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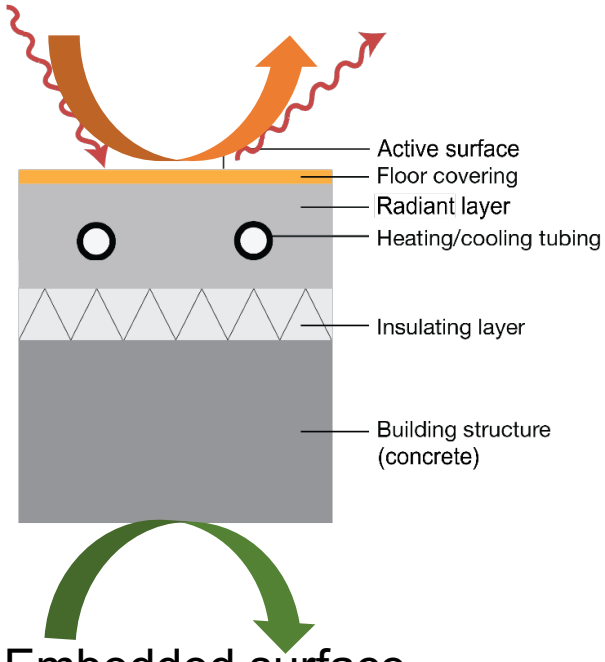


Embedded surface systems (ESS)

How do we quantify the impact of elevated air movement on radiant systems?

Overview

Objective

- Quantify the effect of elevated air movement on radiant systems

Approach

- Computation fluid dynamics (CFD)
  - Convective heat transfer coefficients
- Energy simulation with EnergyPlus
  - Evaluate impact of design factors
    - Cooling capacity, zone temperatures

Funding

- Clark Pacific
- In-kind support: Big Ass Fans

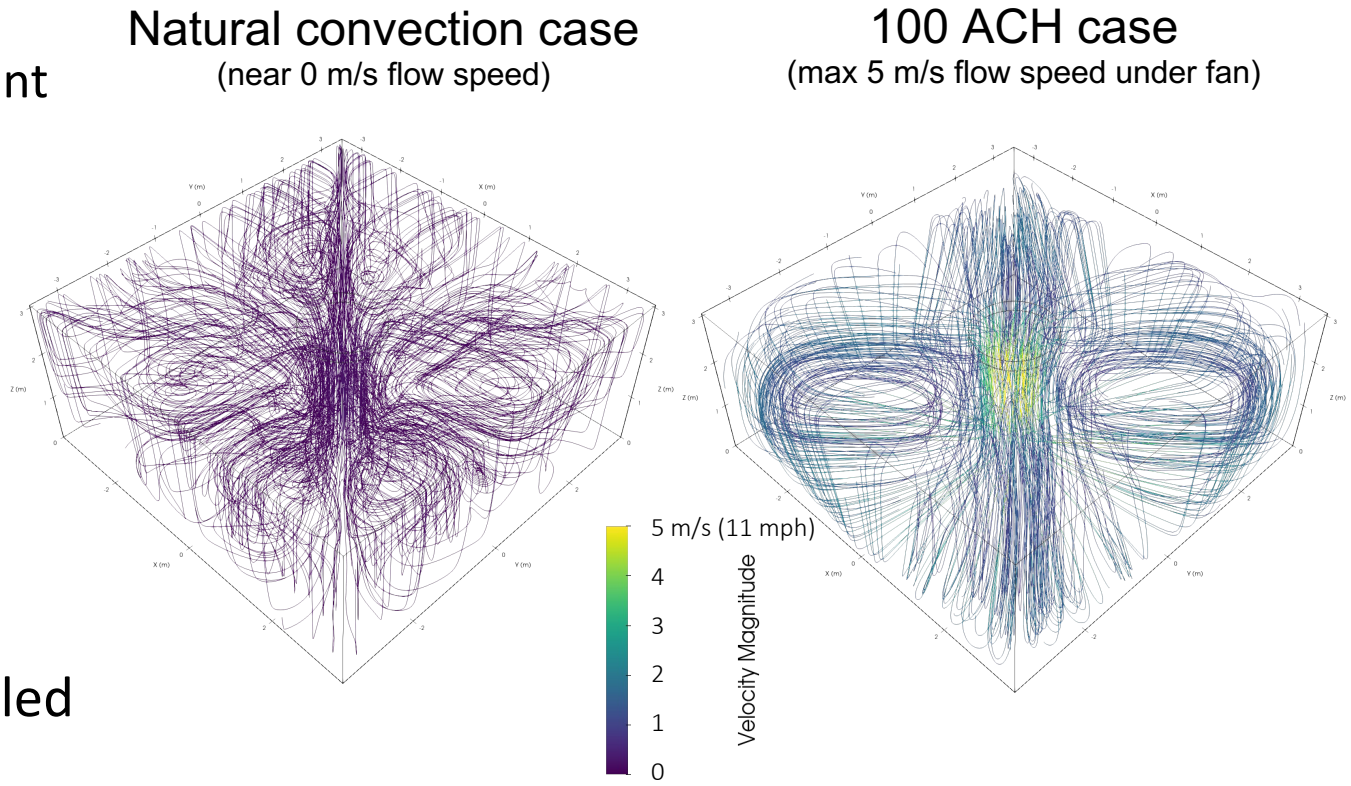
SMUD East Campus Operations Center has radiant and ceiling fan system

CFD simulation is used to calculate convective heat transfer coefficients

- Steady-state conditions
  - Room air and surfaces held at constant temperatures
- Ceiling and floor are cooled surfaces
- Ceiling fan generalized to a flow
  - No simulation of rotating fans
- No radiation heat transfer modeled

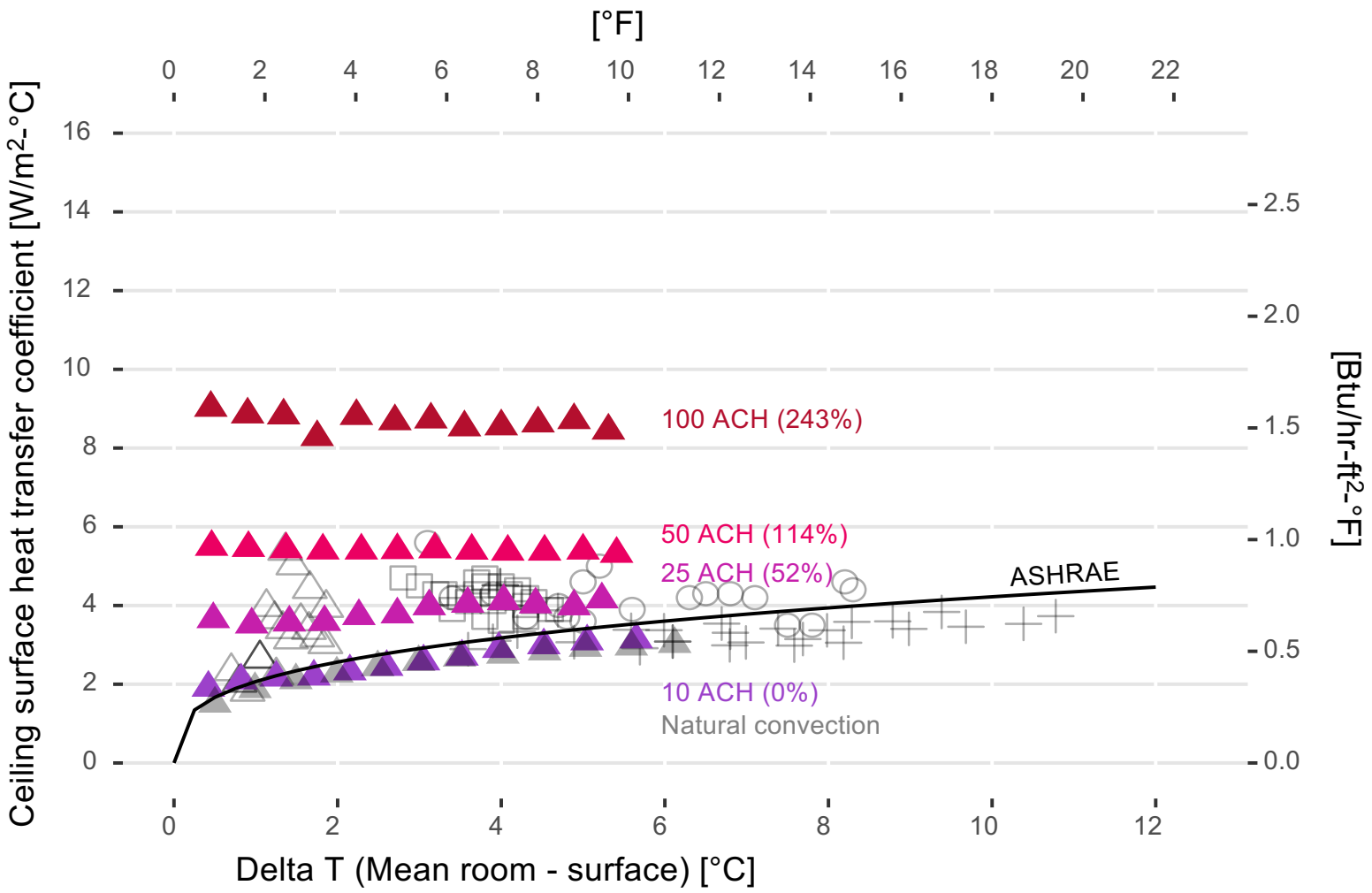
Design factors evaluated

- Temperature difference between cooled surfaces and rest of the room
- Ceiling fan (up/down) flow rate normalized as air circulations per hour (ACH)
- Small vs. large room



Air flow visualizations for natural convection and 100 ACH downward flow

Ceiling: Convective heat transfer with air movement

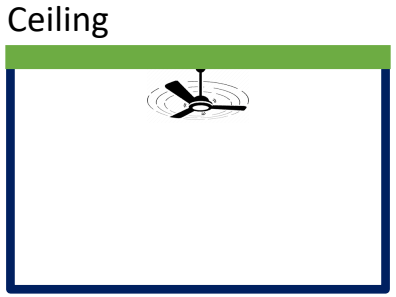


Study

- CFD
- Andres-Chicote et al. (2012)
- Causone et al. (2009)
- Cholewa et al. (2017)
- Yuan et al. (2017)

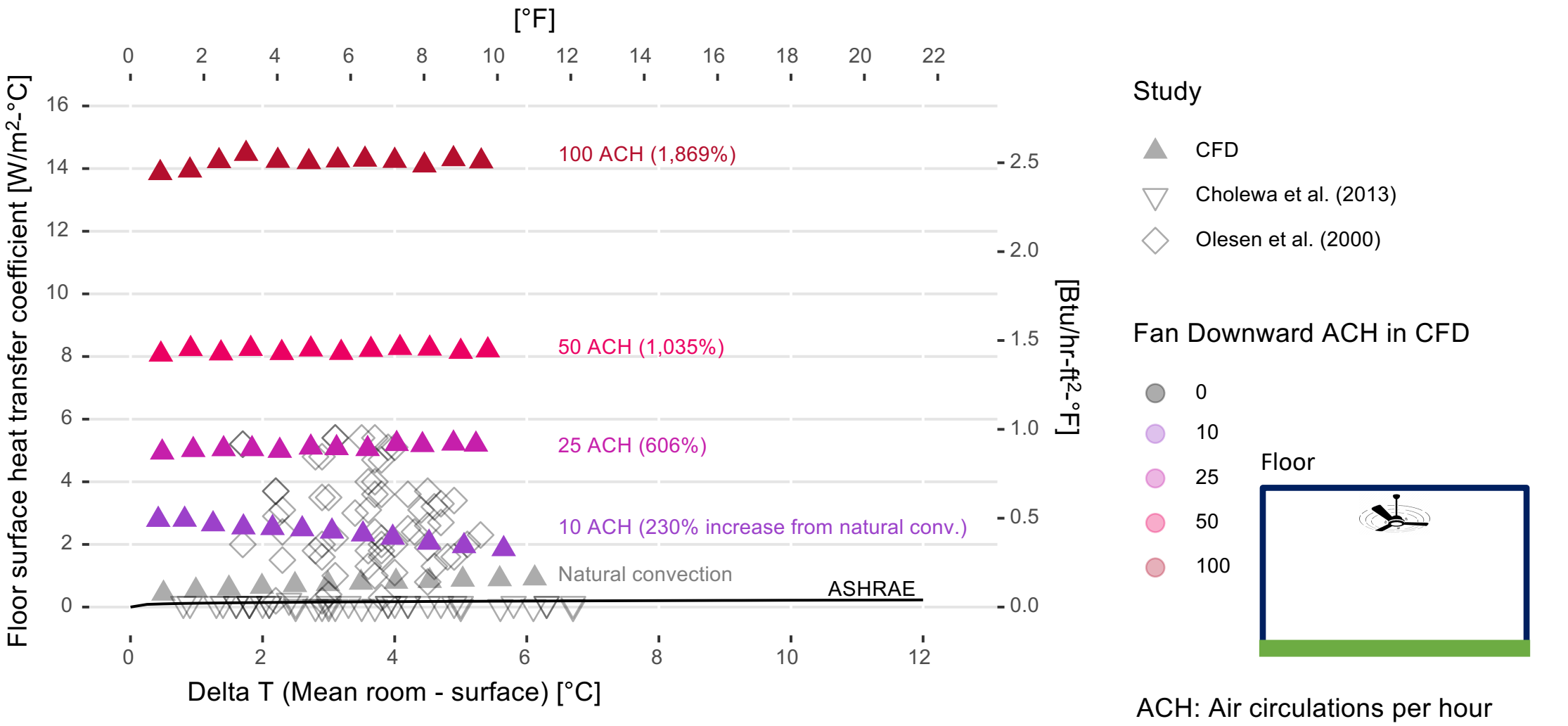
Fan Downward ACH in CFD

- 0
- 10
- 25
- 50
- 100



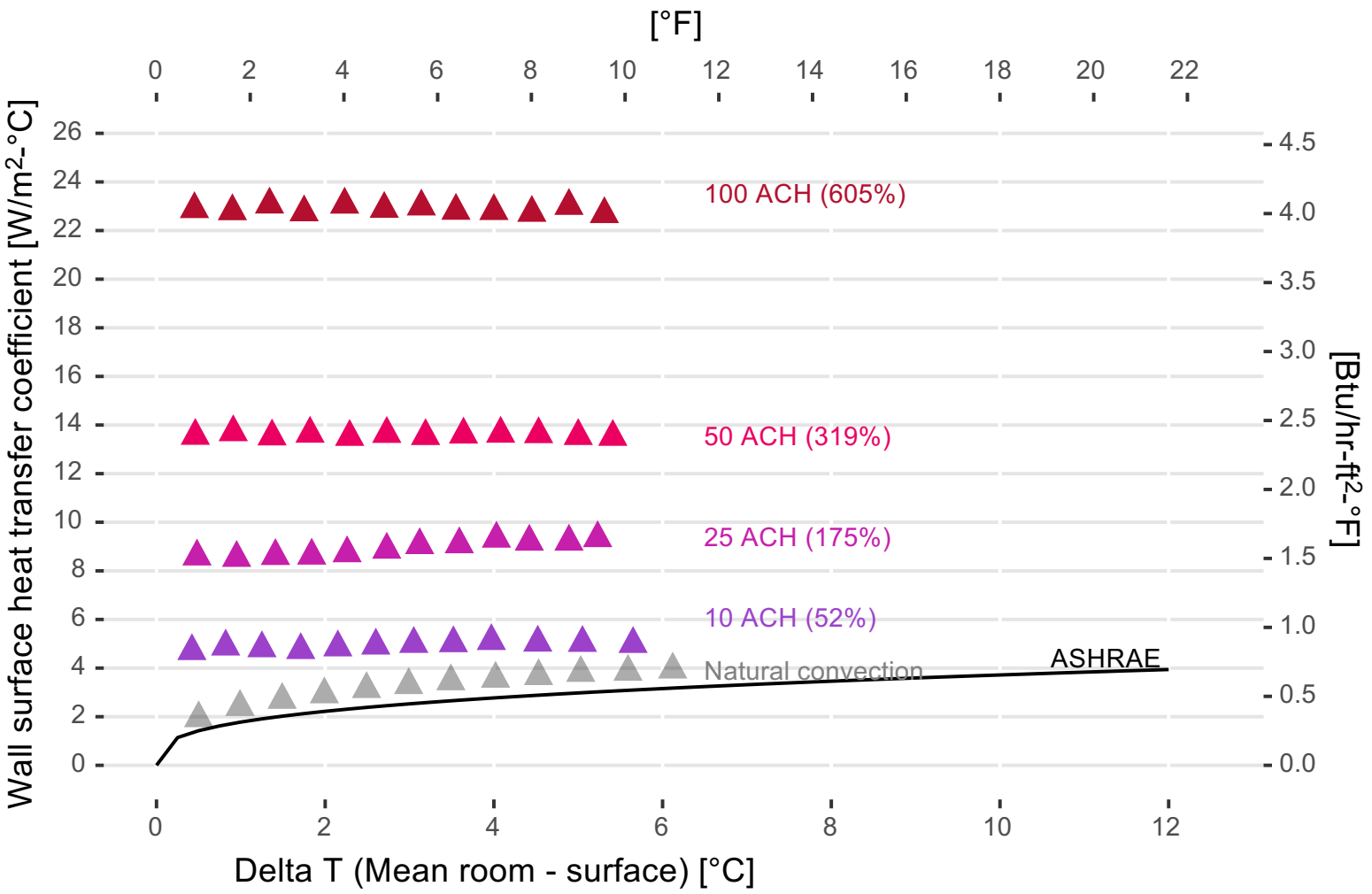
ACH: Air circulations per hour

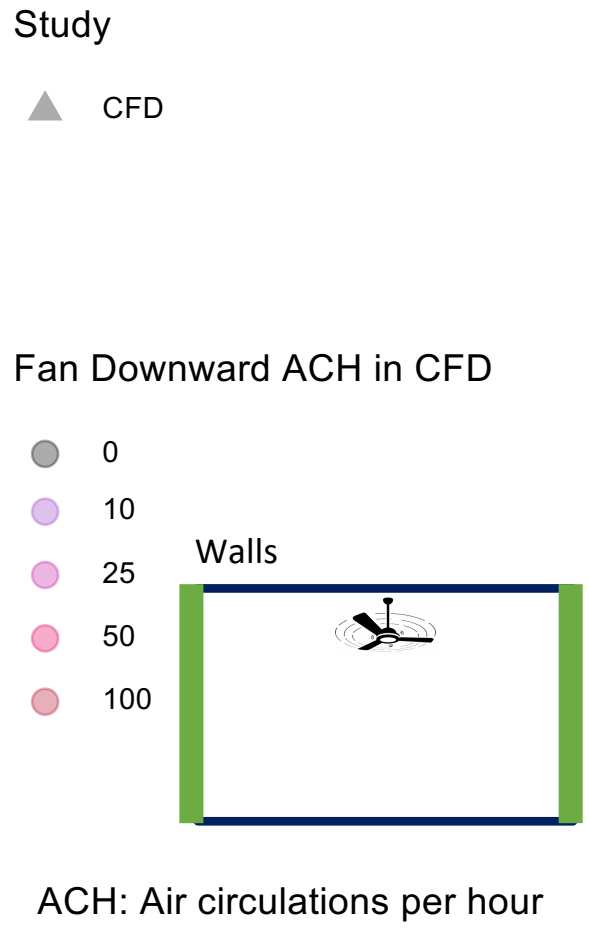
Floor: Convective heat transfer with air movement



ACH: Air circulations per hour

Wall: Convective heat transfer with air movement





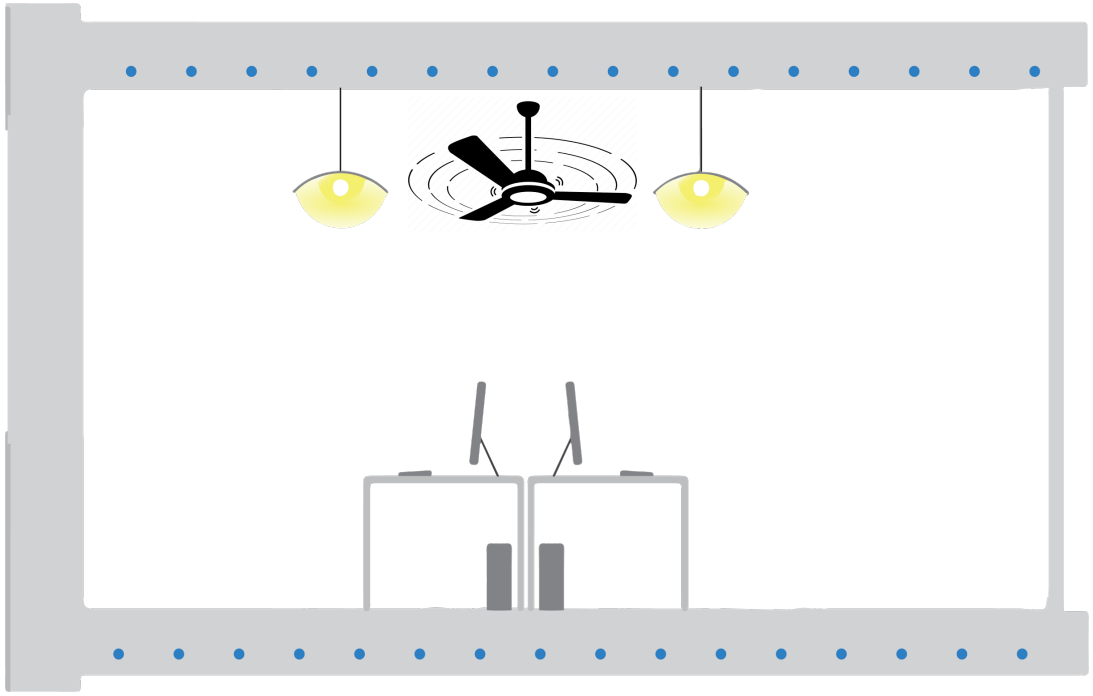
ACH: Air circulations per hour

EnergyPlus simulations

- Steady-state conditions
- TABS system with no ventilation
- No external heat transfer (no windows)
- Middle floor of a building
- Lighting and plug loads only

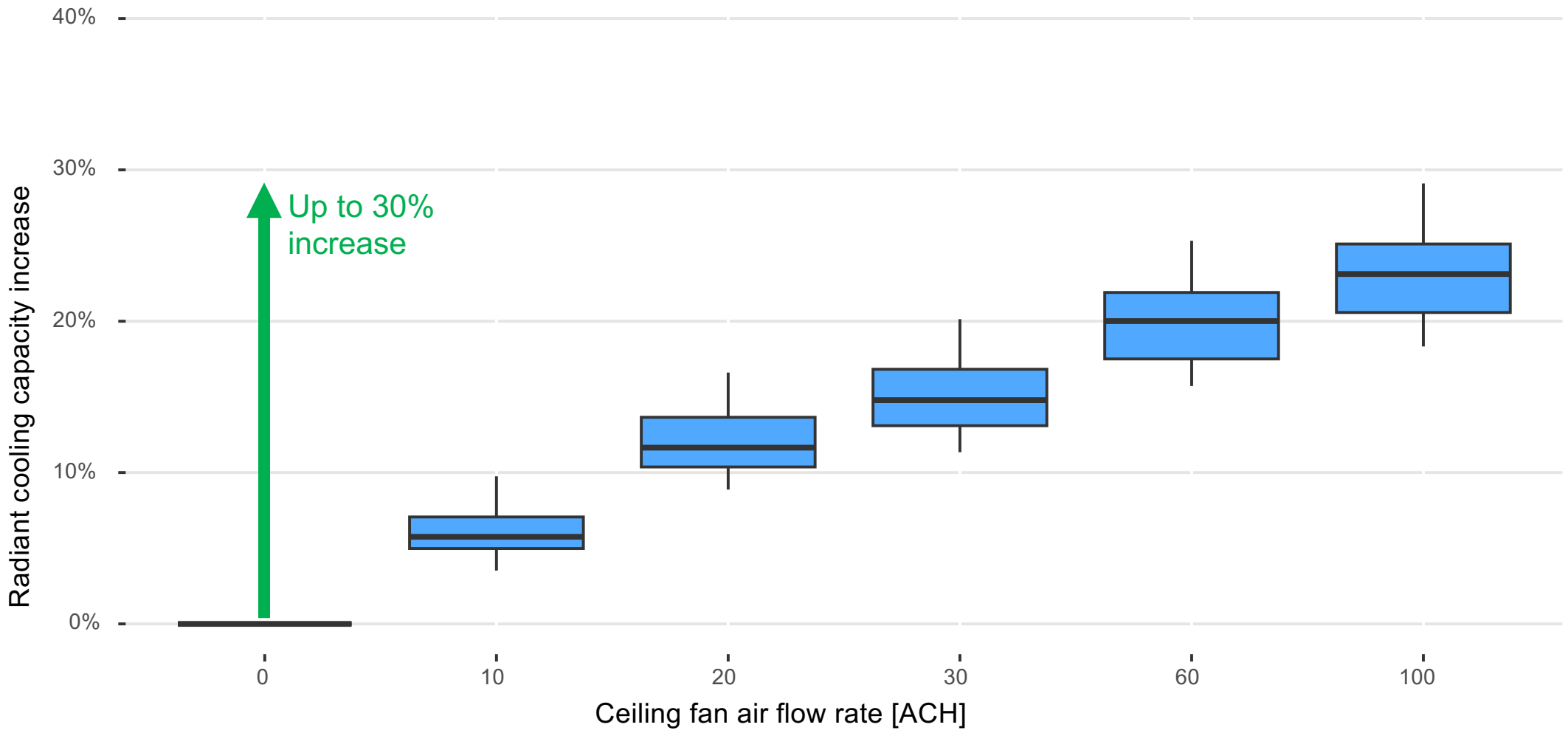
Design factors evaluated

- Radiant system supply water temperature, tube spacing, floor covering
- Ceiling fan flow in air circulations per hour (ACH)
- Room area
- Target room temperature vs fixed heat gains

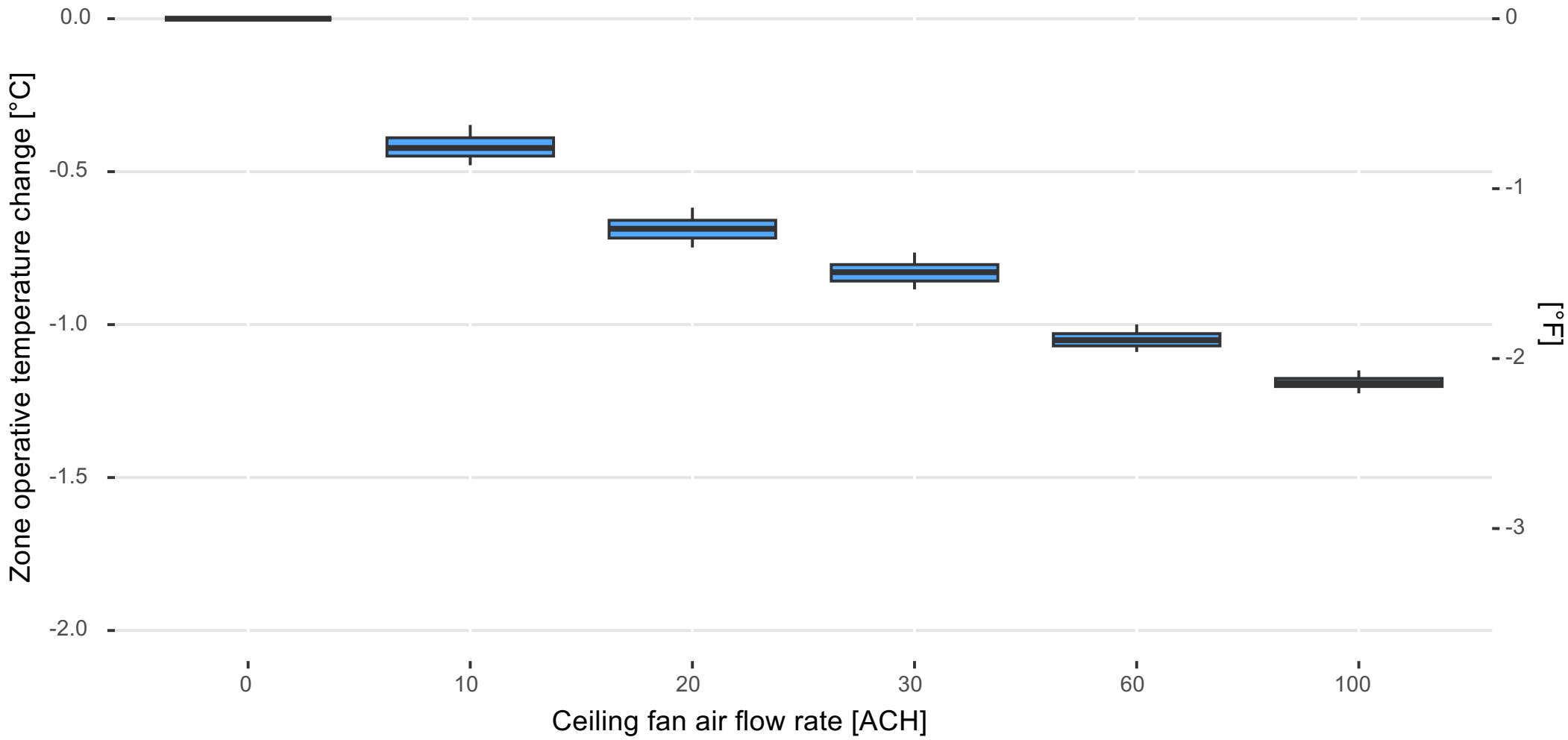


Schematic of room for EnergyPlus simulations

Target operative temperature and supply/return temperature difference



Fixed design radiant cooling capacity at 34 W/m^2 (11 Btu/hr-ft^2)



Conclusion for radiant and ceiling fan coupled systems

- CFD convective heat transfer coefficients show good agreement with previous studies
- Ceiling fans provide an almost 30% radiant cooling capacity increase over no fan case
- Ceiling fans provide up to 6 °F flexibility for maintaining occupant thermal comfort
- Coefficients also apply to other scenarios
  - Passive nighttime cooling ventilation with fans
  - Heating applications

Next steps

- Finalize and submit journal paper
- Expand study to include transient effects

Q&A

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Clark Pacific’s integration of ceiling fans into their radiant systems.