Research on Smart Integration of Ceiling Fans with HVAC Systems

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CBE

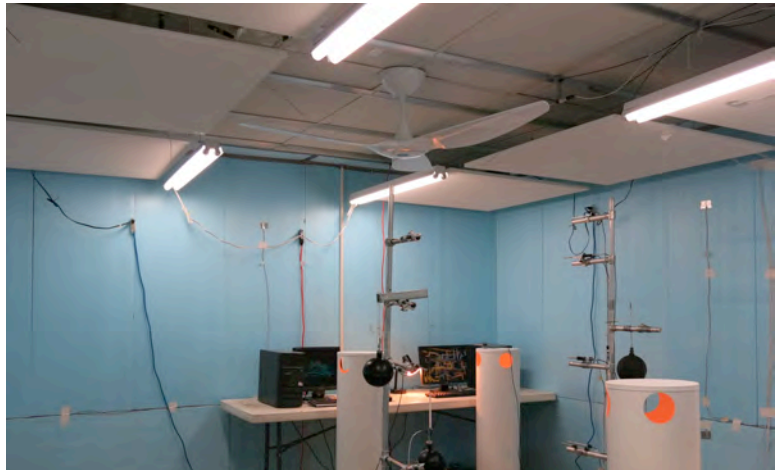
Presentation overview

1. Ceiling Fan Integrated Air Conditioning (CFIAC)

- Background to CFIAC
- Study 1: Chamber tests on airflow concepts
- Study 2: Human subject test
- Study 3: Cost analysis

2. Fan Integrated Radiant Systems

- Background
- Experimental set up
- Results



Part 1: Ceiling Fan Integrated Air Conditioning (CFIAC)

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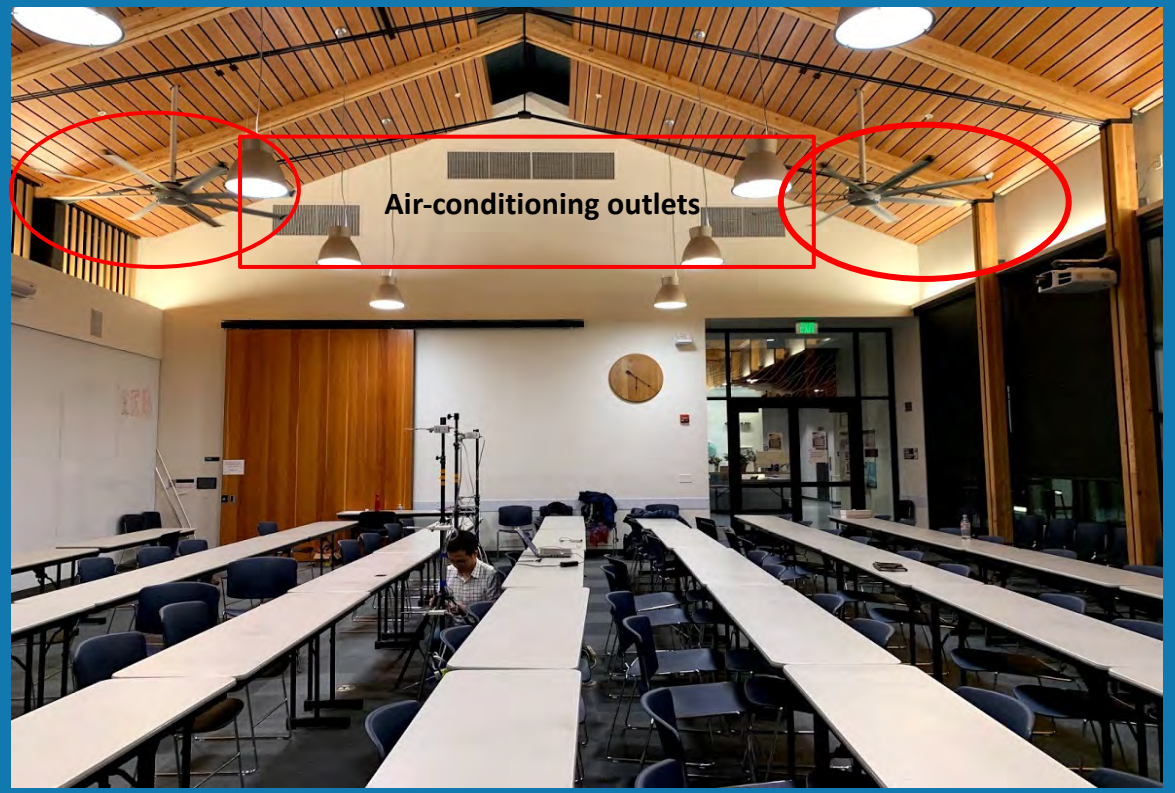
Conventional VAV design

A potential candidate for CFIAC

CFIAC design



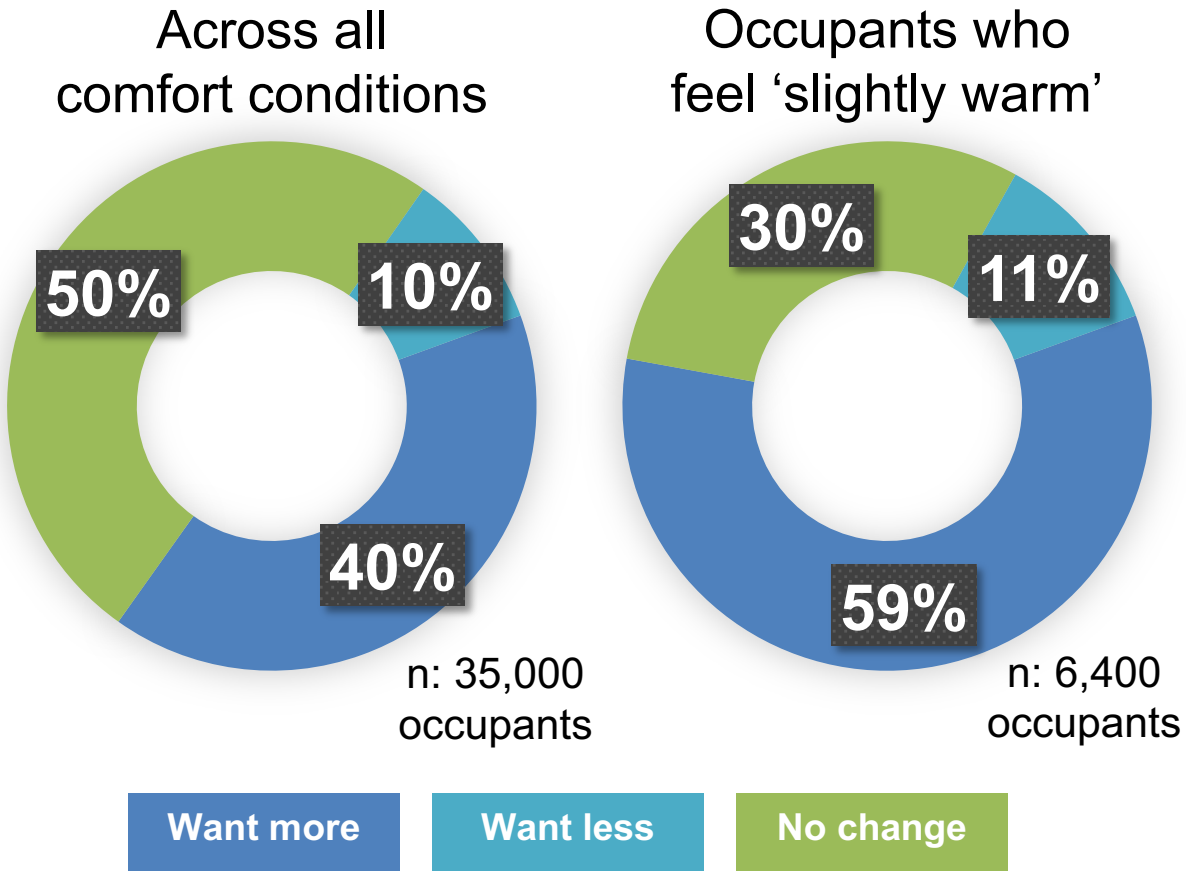
Santa Cruz biology seminar room, HVAC designed by Taylor Engineering

Background: Air movement

Why design with air movement?

- Occupants want it
- Improves perceived and measured air quality
- Instant comfort control
- Spaces can comfortably operate at higher temperatures, saving energy and operating costs
- Low cost: installed ceiling fans are approx. $2/ft^2$
- Reduce HVAC equipment and ductwork size and costs

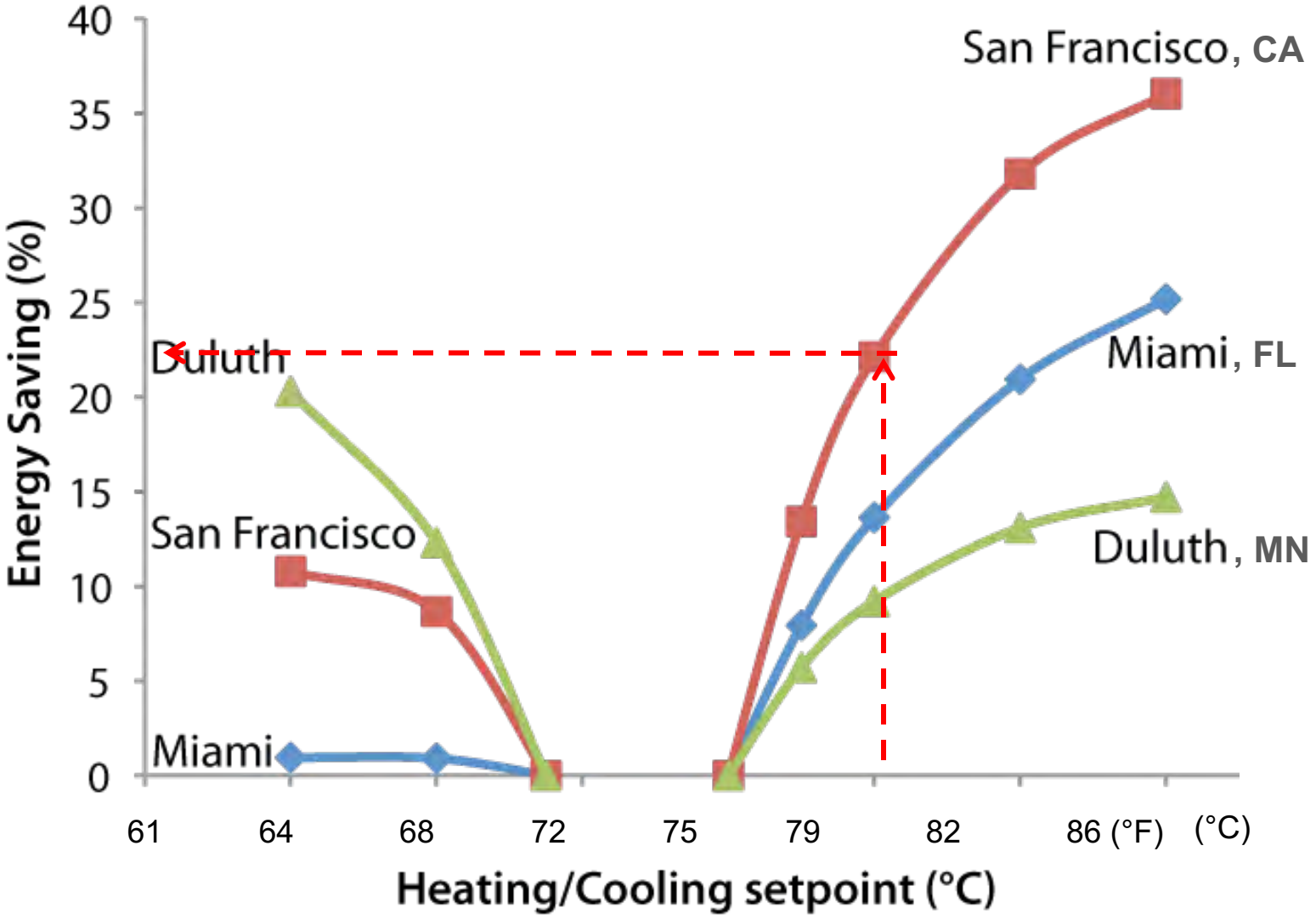
Air movement preference



From ASHRAE Global Thermal Comfort Database II

Expanded cooling setpoint reduces HVAC energy 4 – 8% per °F

- Tight control is very energy intensive.
- A modern 5-foot diameter DC-motored fan draws 6 W at medium speed; less than an LED bulb



Hoyt, T., E. Arens, and H. Zhang. 2015. Extending air temperature setpoints: Simulated energy savings and design considerations for new and retrofit buildings. *Building and Environment* 88, 89-96

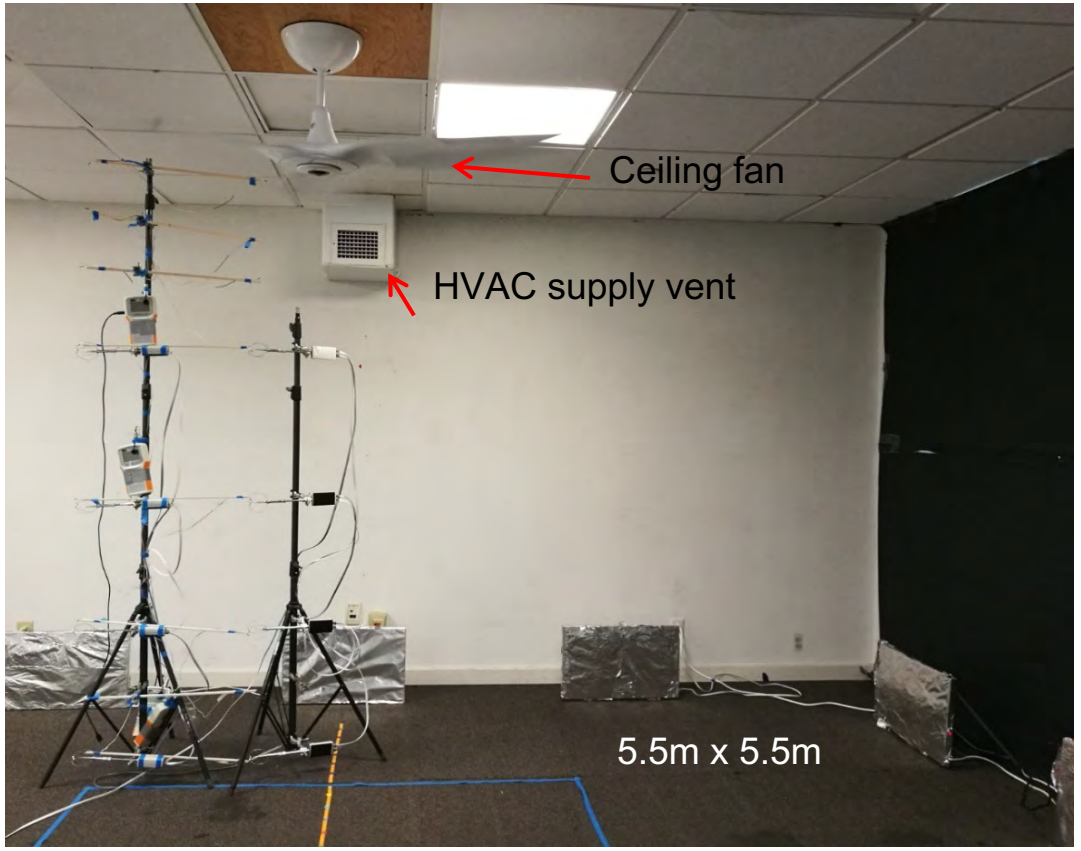
Study 1.1: Chamber test for air distribution and temperature

Objective

- Evaluate how fans distribute air jets from supply air inlets

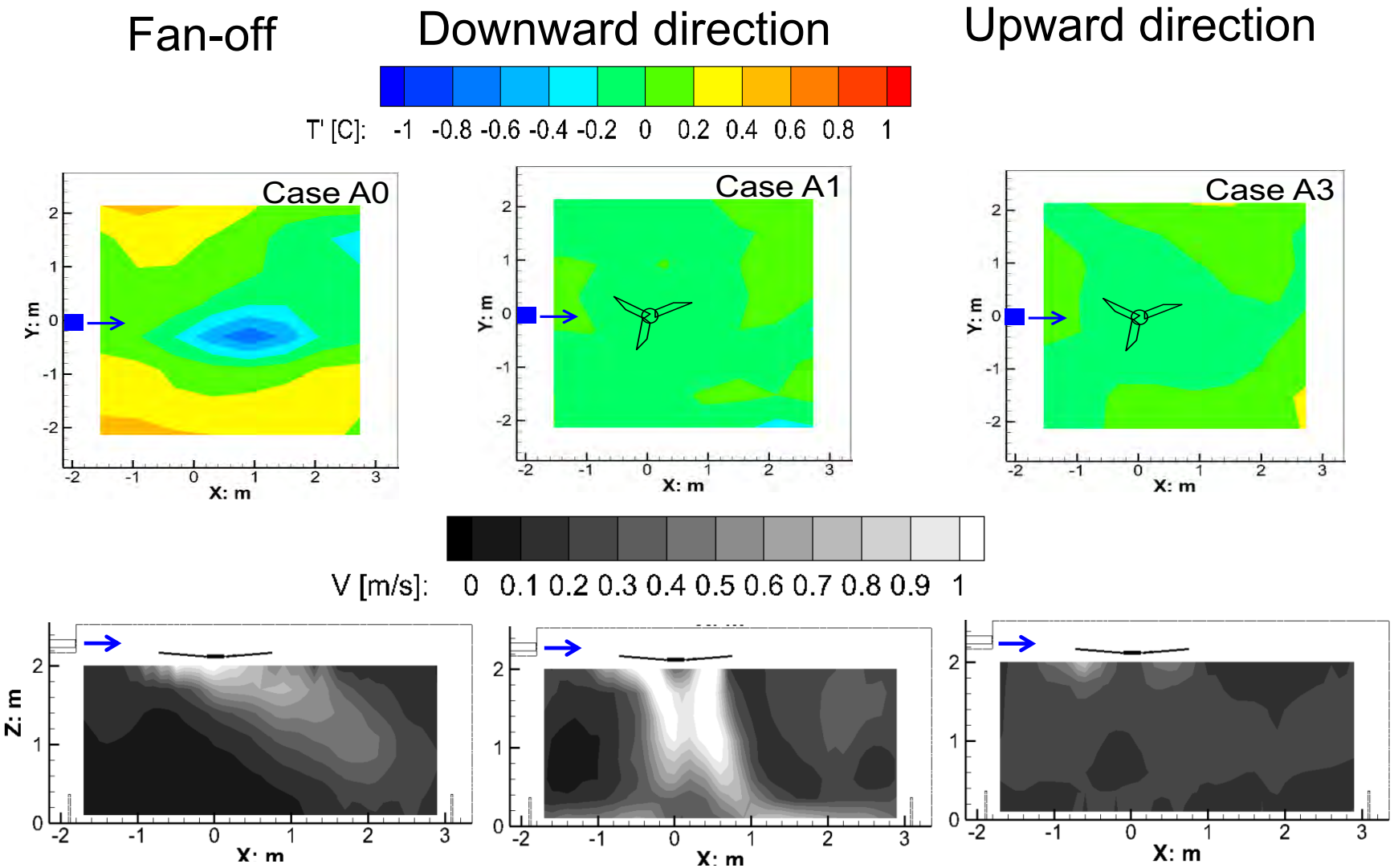
Approach

- Air speed, temperature, and fresh air distributions measured in the Environmental Chamber



Chamber setup for the CFIAC tests

Chamber tests: fan mixes temperature, velocity follows fan profiles



Chen, W., H. Zhang, E. Arens, M. Luo, Z. Wang, L. Jin, J. Liu, F.. Bauman, P. Raftery, 2020. Ceiling-Fan-Integrated Air Conditioning: airflow and temperature characteristics of a sidewall-supply jet interacting with a ceiling fan. Building and Environment 171, 106660

Study 1.2: Chamber test with human subjects

Objective

- Evaluate human comfort under CFIAC

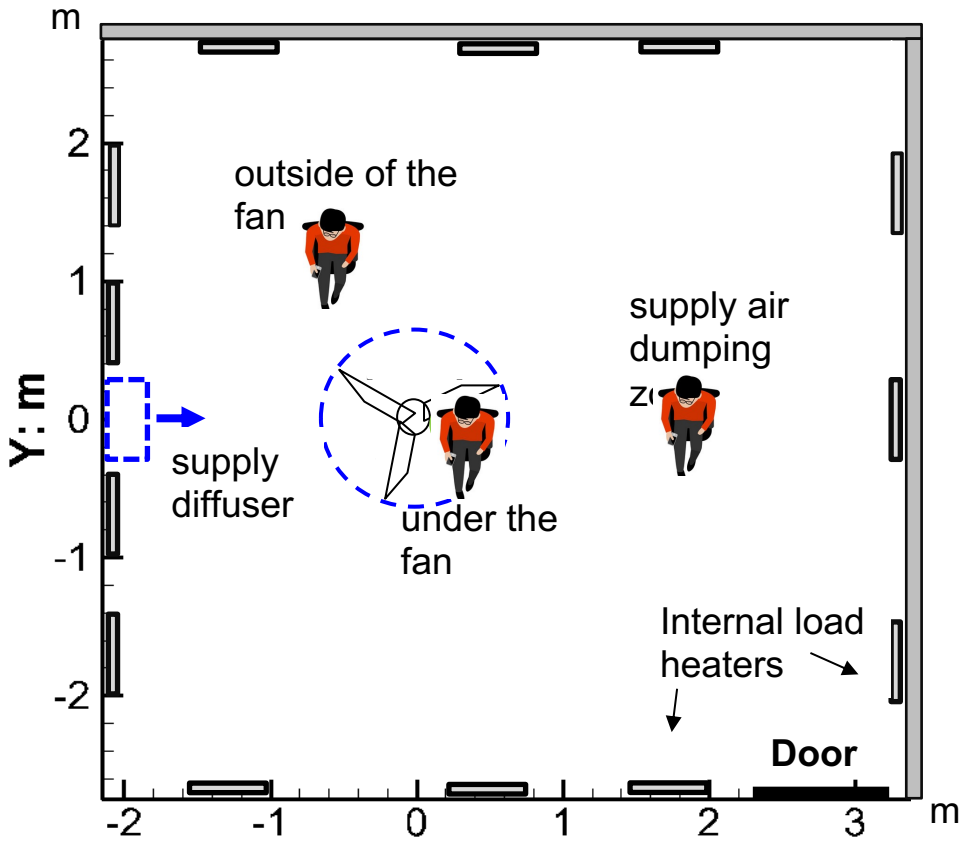
Approach

- Human subject tests
- Similar chamber set up as previous study

Human subject study parameters

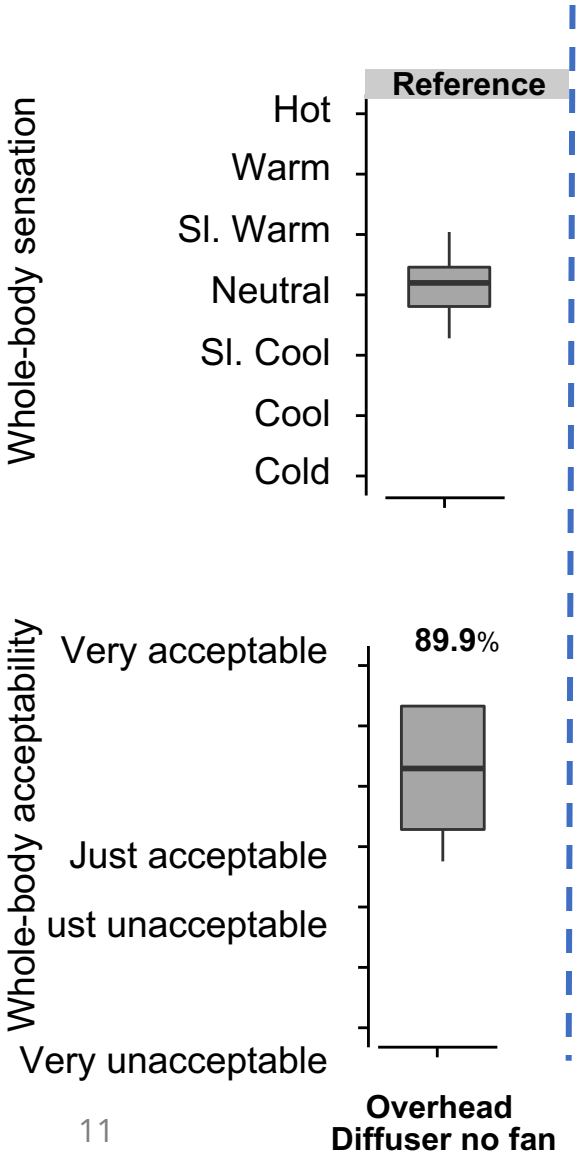
- 24 subjects (12 females, 12 males)
- 79, 82°F
- Supply air temperature: 50ºF

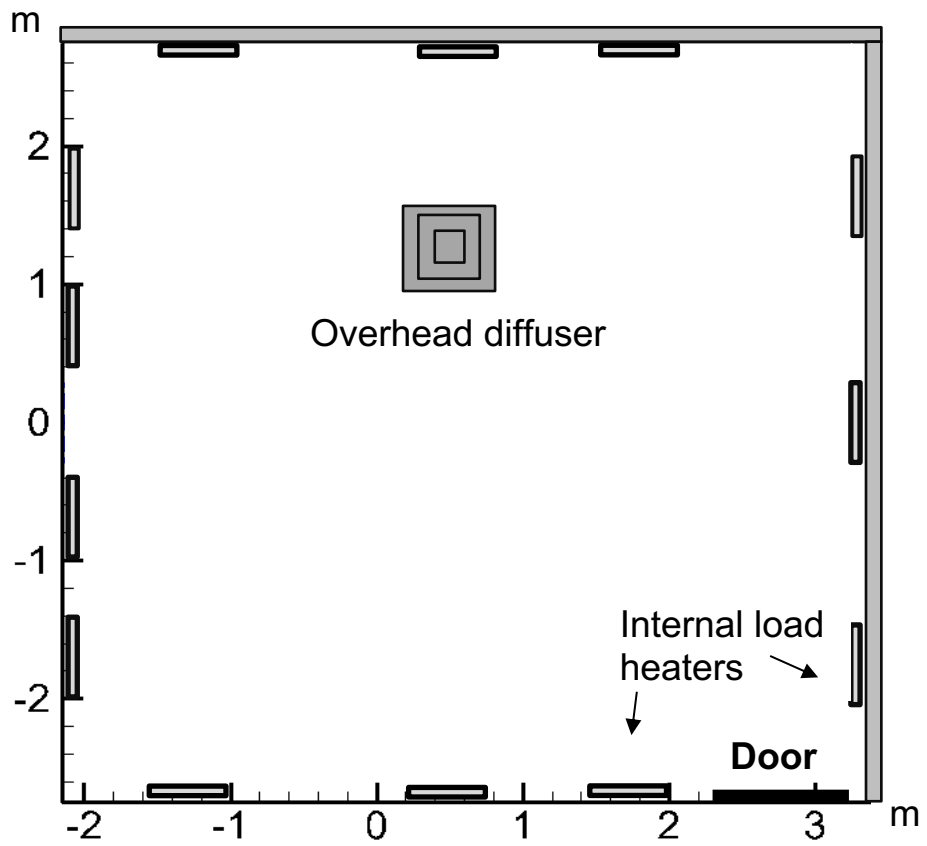
- Tested multiple fan configurations
  - Low-downward
  - Medium-downward
  - Medium-upward
  - Fan-off
- Subject test locations
  - Under and outside of the fan jet
  - Supply air dumping zone with fan-off



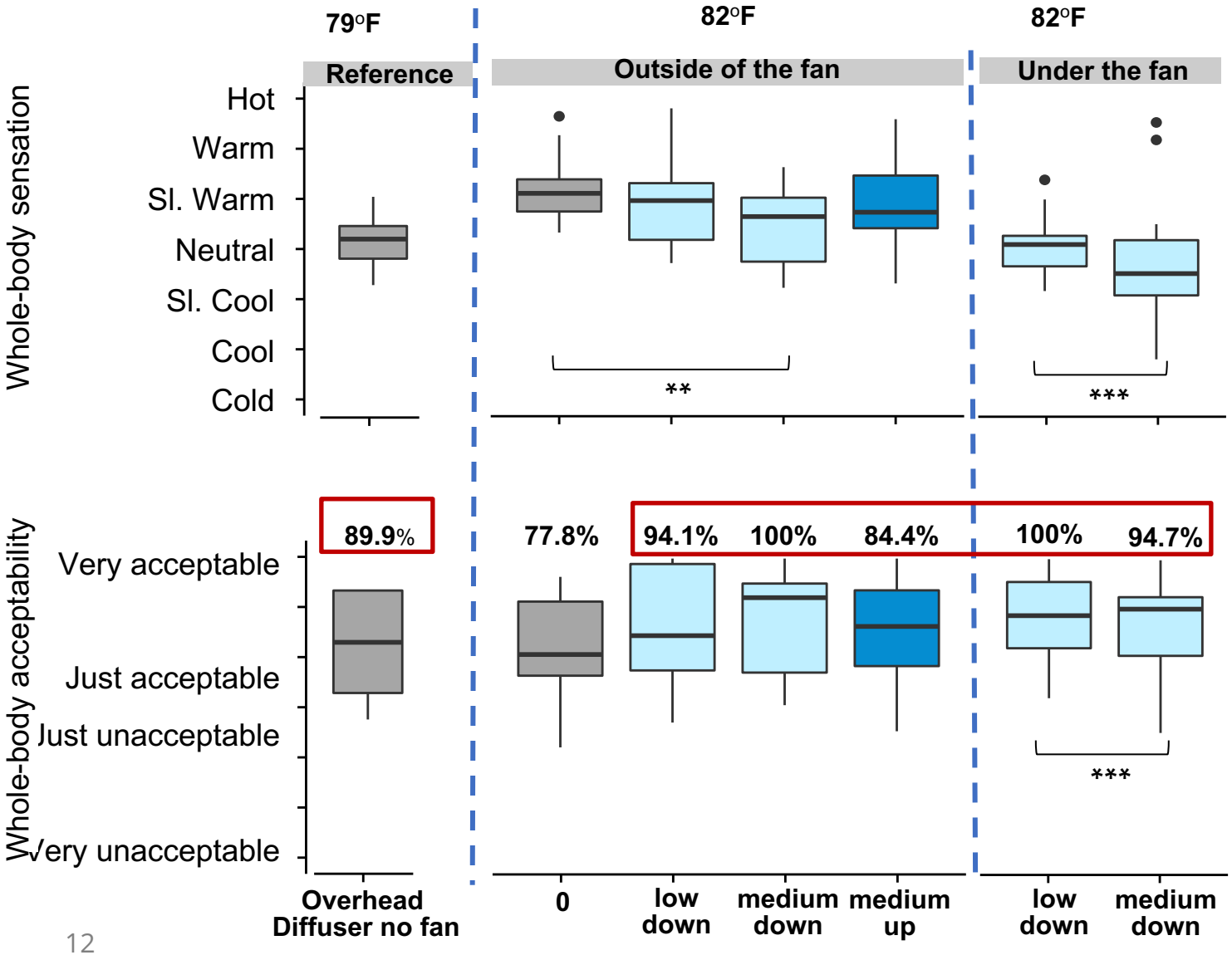
Luo, M., Zhang, H., Wang, Z., Arens, E., Chen, W., Bauman, F. S., & Raftery, P. (2021). Ceiling-fan-integrated air-conditioning: thermal comfort evaluations. Buildings and Cities, 2(1), 928–951.

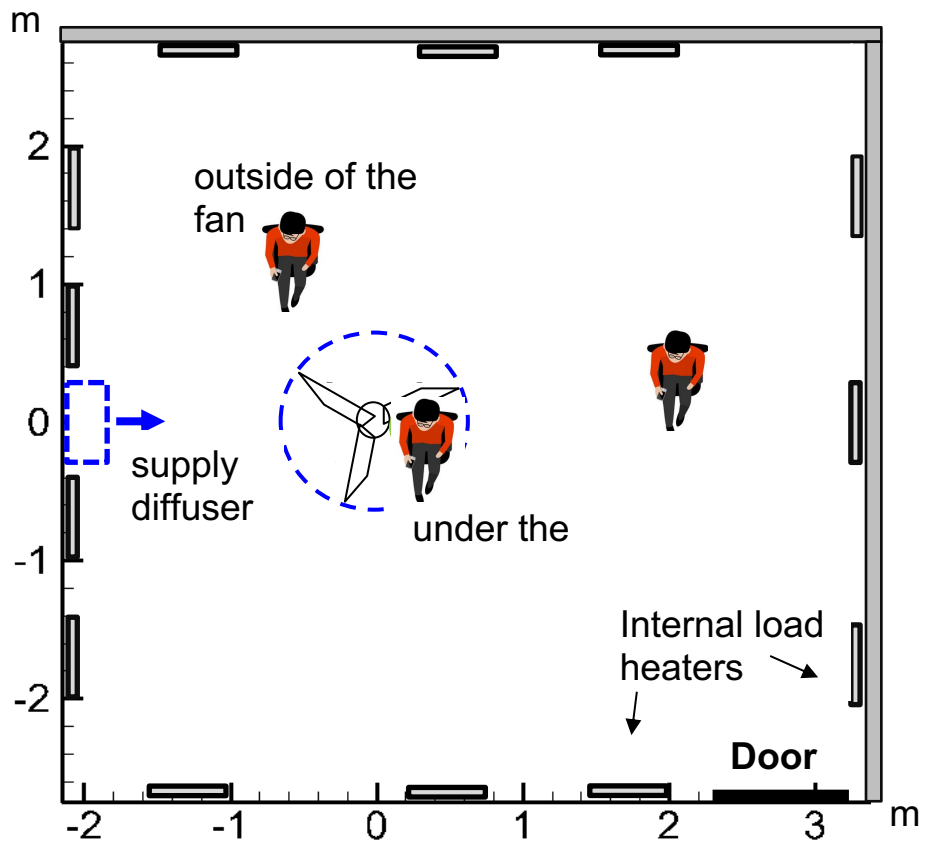
Comfort results: Still-air neutral reference condition (79°F)





Comfort results: *Under* and outside of the fan jet at 82°F





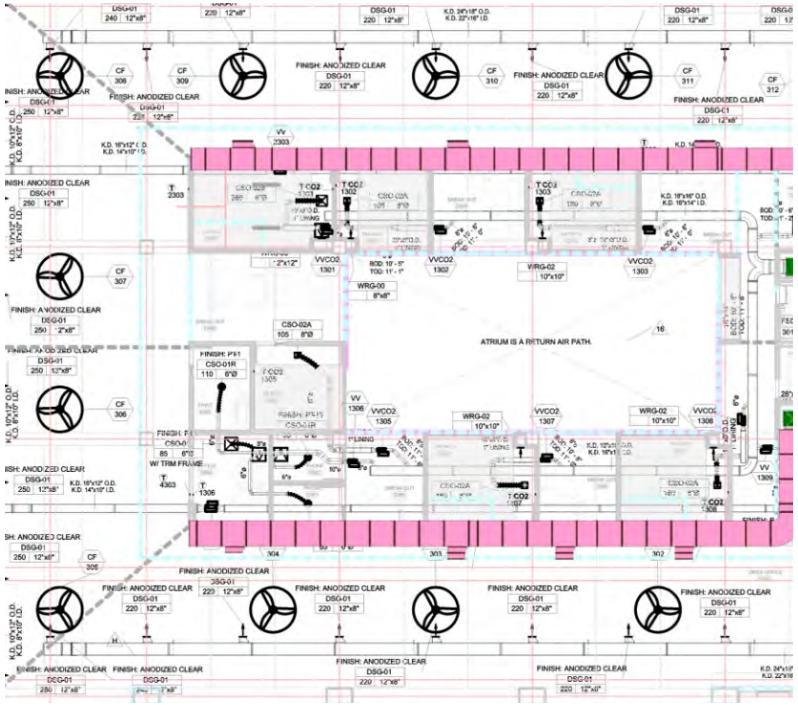
Study 1.3: CFIAC Cost analysis study

Objective

- Compare the cost differences between CFIAC and conventional VAV designs

Approach

- Use documents from a building under design
- Cost comparisons among different CFIAC versions and conventional VAV design

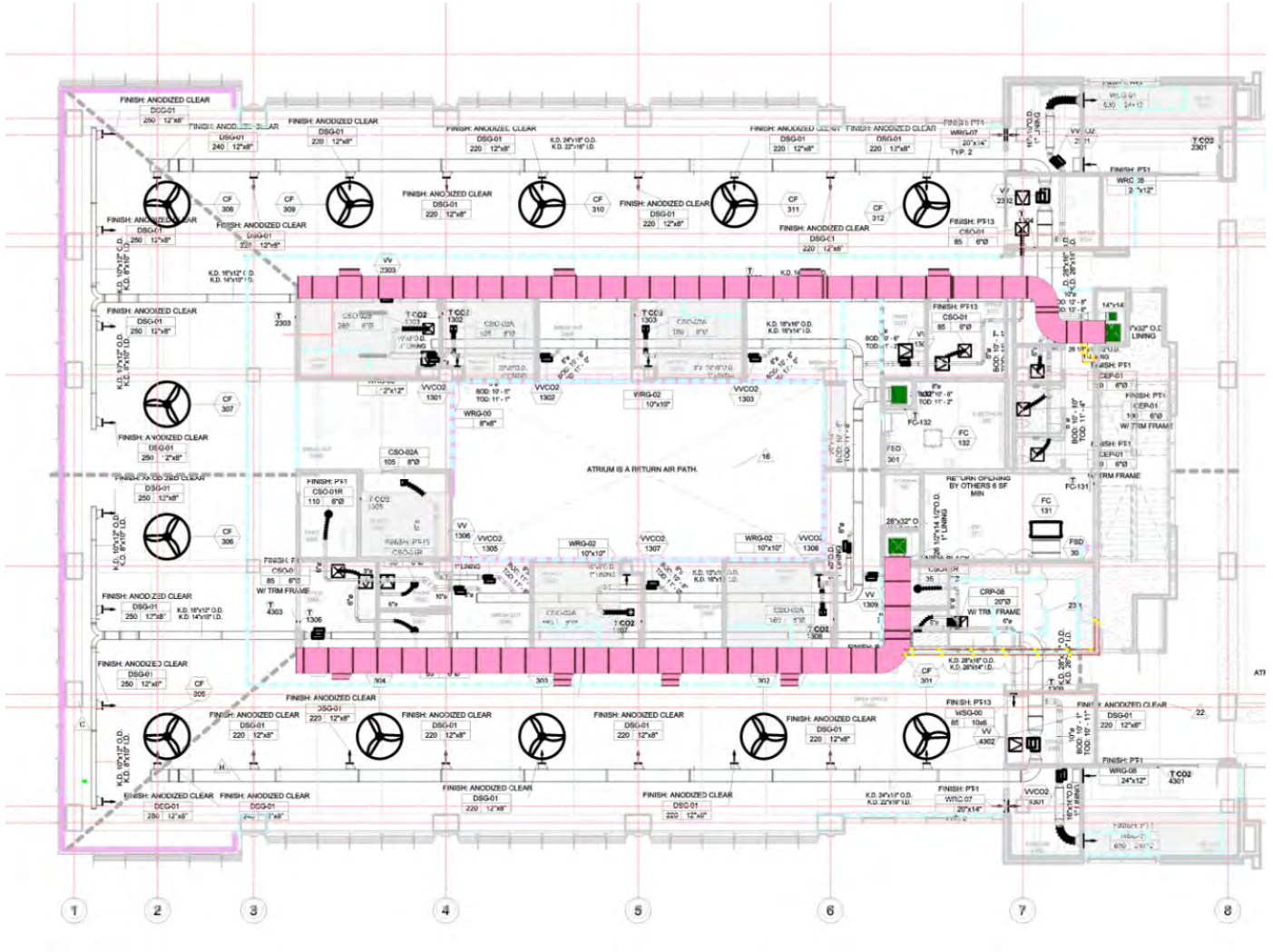


CFIAC cost analysis by replacing HVAC terminal ducts and diffusers with ceiling fans

- The building is 172,000 ft2
- The full floor is about 110’ x 400’
- Four floors
- Traditional zoning case for comparison (baseline)
  - VAV reheat design
  - 14 zones in open office
  - 9 perimeter and 5 interior

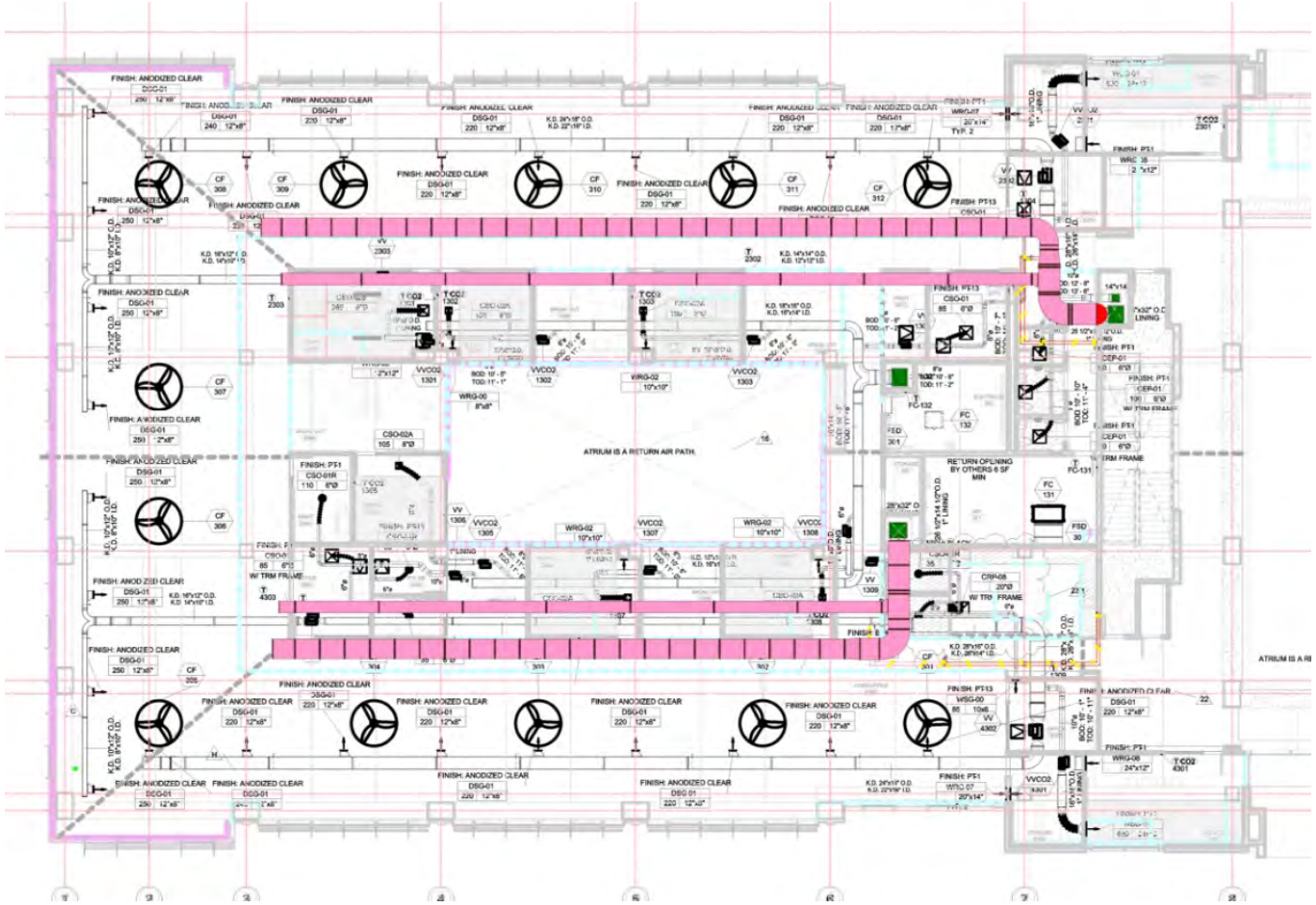
CFIAC design option: 2 zones in open office, most extreme reduction

- 12 fans per half floor
- 7-foot diameter Haiku fans
- Terminal duct and diffuser installation cost reduction: 50%



CFIAC design option: 4 zones in open office, conservative reduction

- 12 fans per half floor
- 7-foot diameter Haiku fans
- Terminal duct and diffuser installation cost reduction: 35%



Summary from three CFIAC studies

- Fan mixing the air temperature well in the space
- Using fans for efficient cooling
- The age-of-air is improved 15 – 30% (not presented here)
- Significant cost reduction compared to traditional VAV terminal ducts and diffusers

Architecture benefits from CFIAC because of the removal of terminal HVAC terminal ducts and diffusers

Part 2: Fan-Integrated Radiant Systems

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Bill Frantz, Kenneth Roy
Armstrong World Industries

Mike Koupriyanov, Harmanpreet Virk, Jared Young,
Tom Epp, Jerry Sipes
Price Industries

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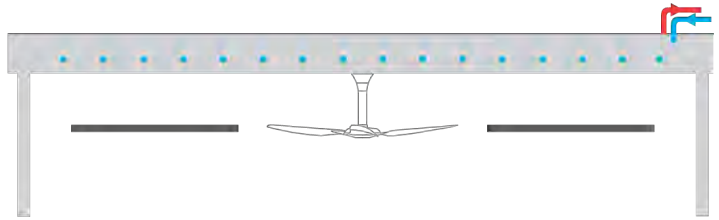
Background: Exposed concrete

- Radiant spaces shows lower occupant satisfaction with acoustics
- Exposed concrete is highly sound reflective

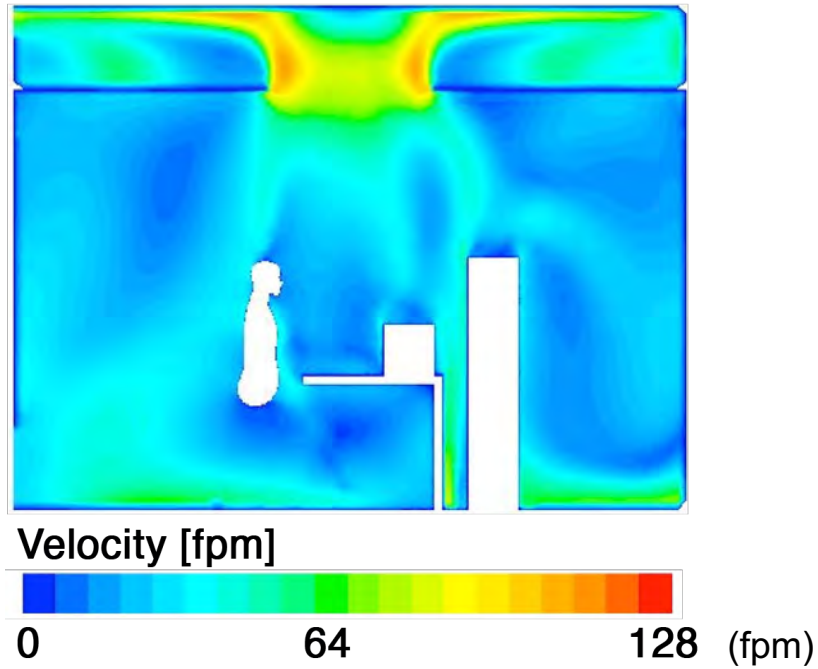
- Effect of ***acoustical canopies*** on:
  - Cooling capacity of radiant ceiling might be reduced

Background: Adding air movement

- CBE study 2013: Use of a **fan** to increase convective heat exchange between the acoustical canopies and the radiant ceiling
- Method: CFD study
- Results: up to **50% increase** of cooling capacity of the radiant ceiling with coverage and fan



Section of the system studied



Results: air velocity mapping
(fan blowing upward, Wilmer Pasut 2013)

Guo, X., S. Wan, W. Chen, H.Zhang, E.Arens, Y. Cheng, W. Pasut, 2023, Numerical simulation of cooling performance of radiant ceiling system interacting with a ceiling fan, Energy and Buildings, Volume 297, 113492

Project overview

Objective: Energy performance of a radiant chilled ceiling with acoustical canopies and fans

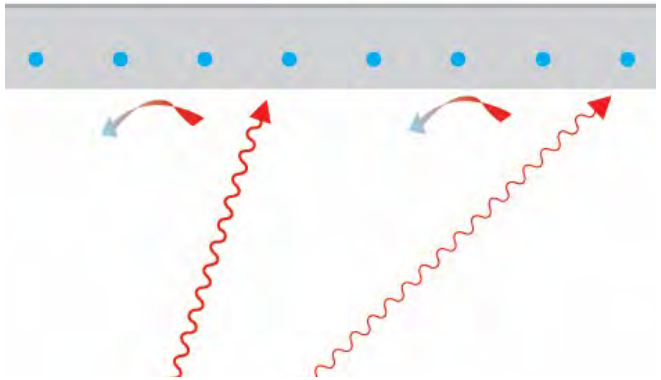
Methods: Joint lab study

- Acoustical tests (at Armstrong)
- Cooling capacity tests (at Price)

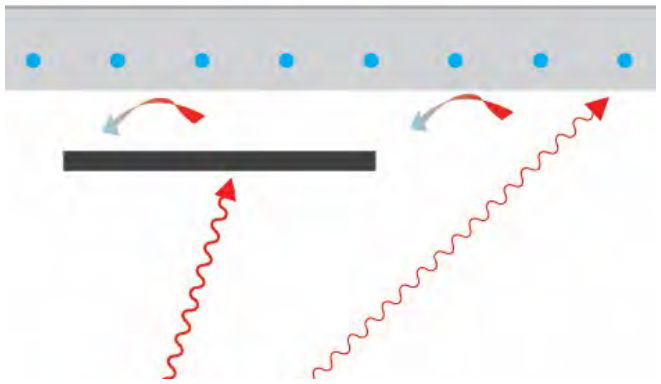
Funding

- EPIC grant
- In-kind and material support from:
  - Price Industries
  - Armstrong World Industries
  - Big Ass Fans

Karmann, C., F. Bauman, P. Raftery, S. Schiavon, and M. Koupriyanov. 2018. Effect of acoustical clouds coverage and air movement on radiant chilled ceiling cooling capacity. Energy and Buildings 158.

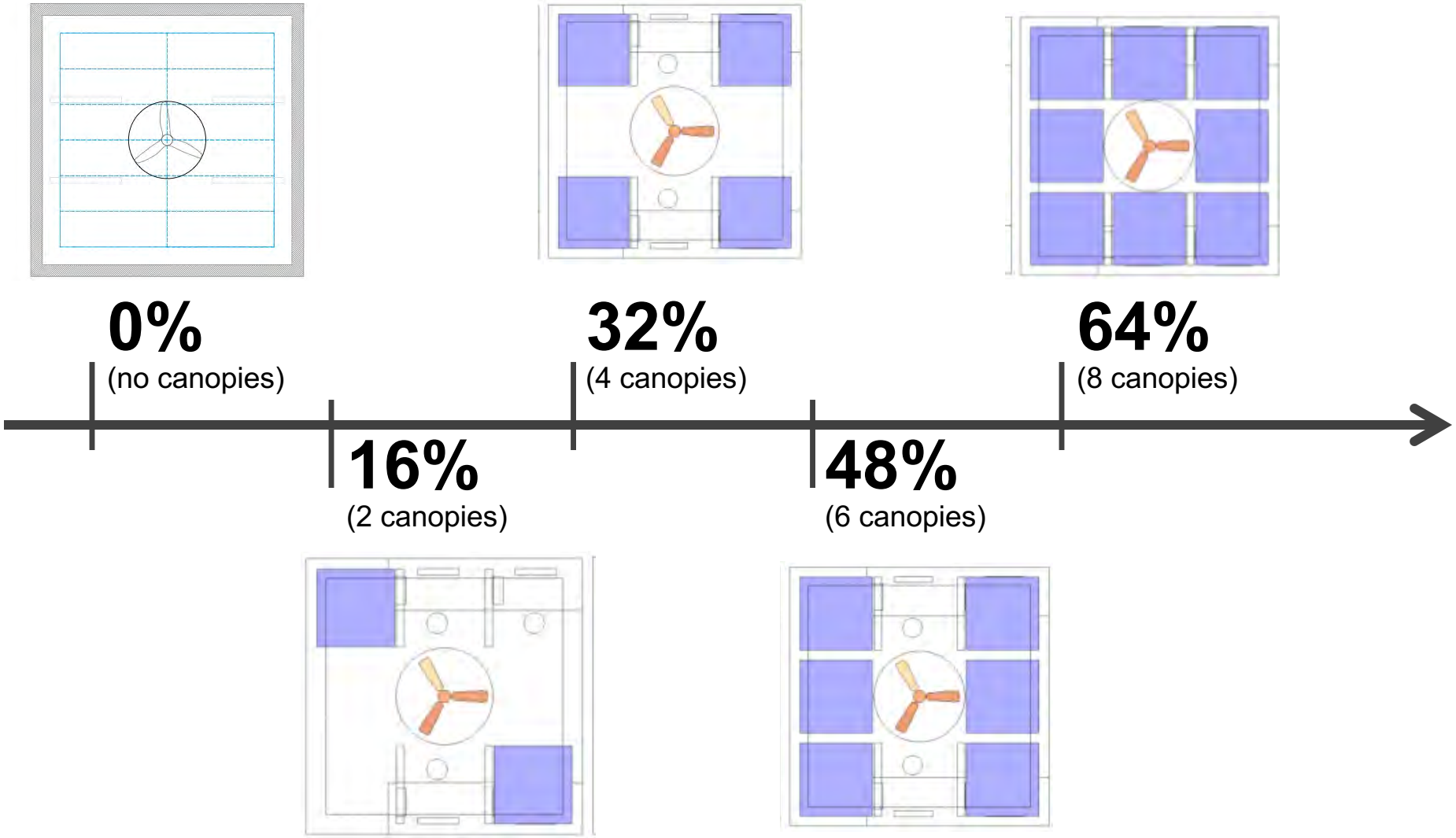


Schematic section of a radiant slab



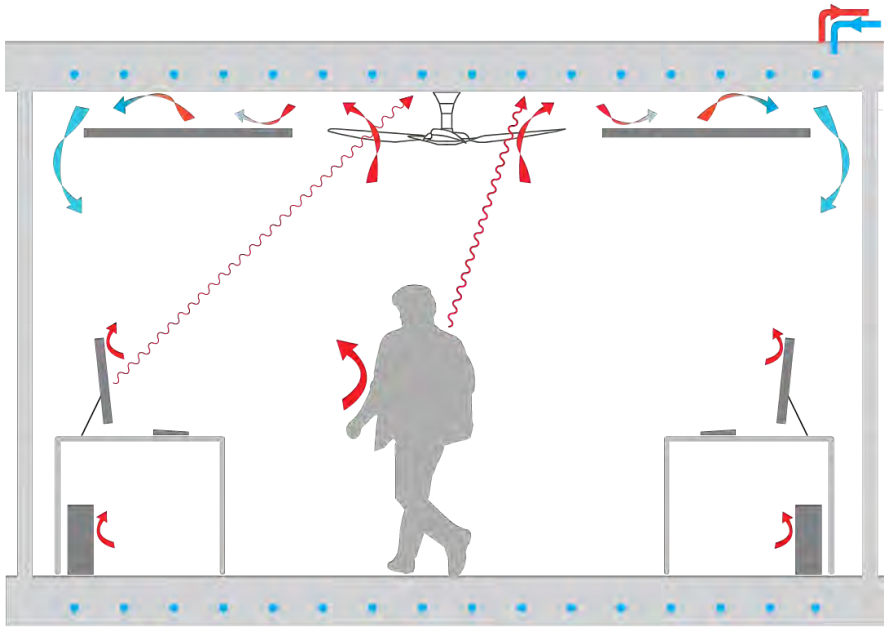
Schematic section of a radiant slab with acoustical canopy

Test configurations: Acoustical coverage

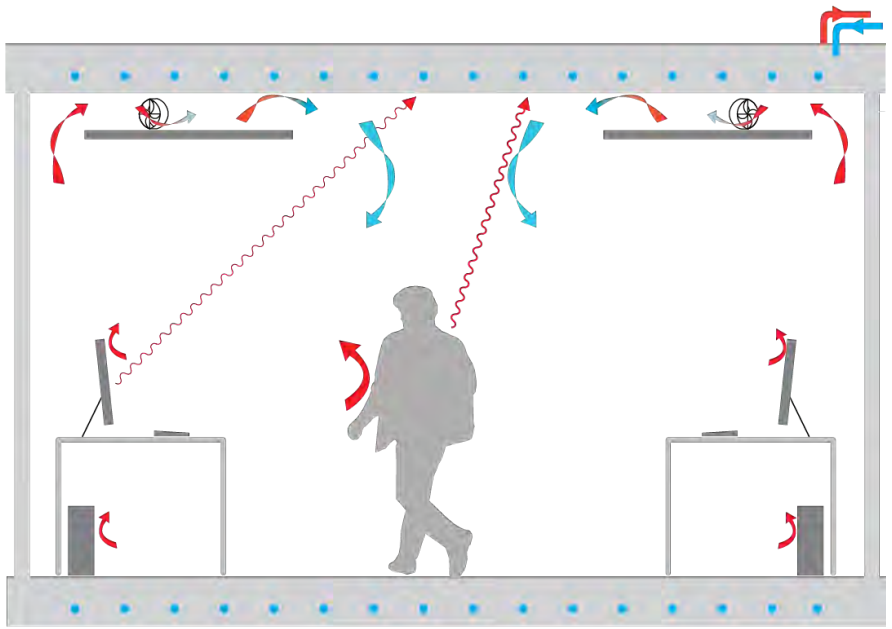


Test configurations: Fans

- **No fan** (reference case)
- **Ceiling fan** (**Haiku**) blowing **up** and **down *between*** the canopies
- **Small fan *hidden above*** the canopies

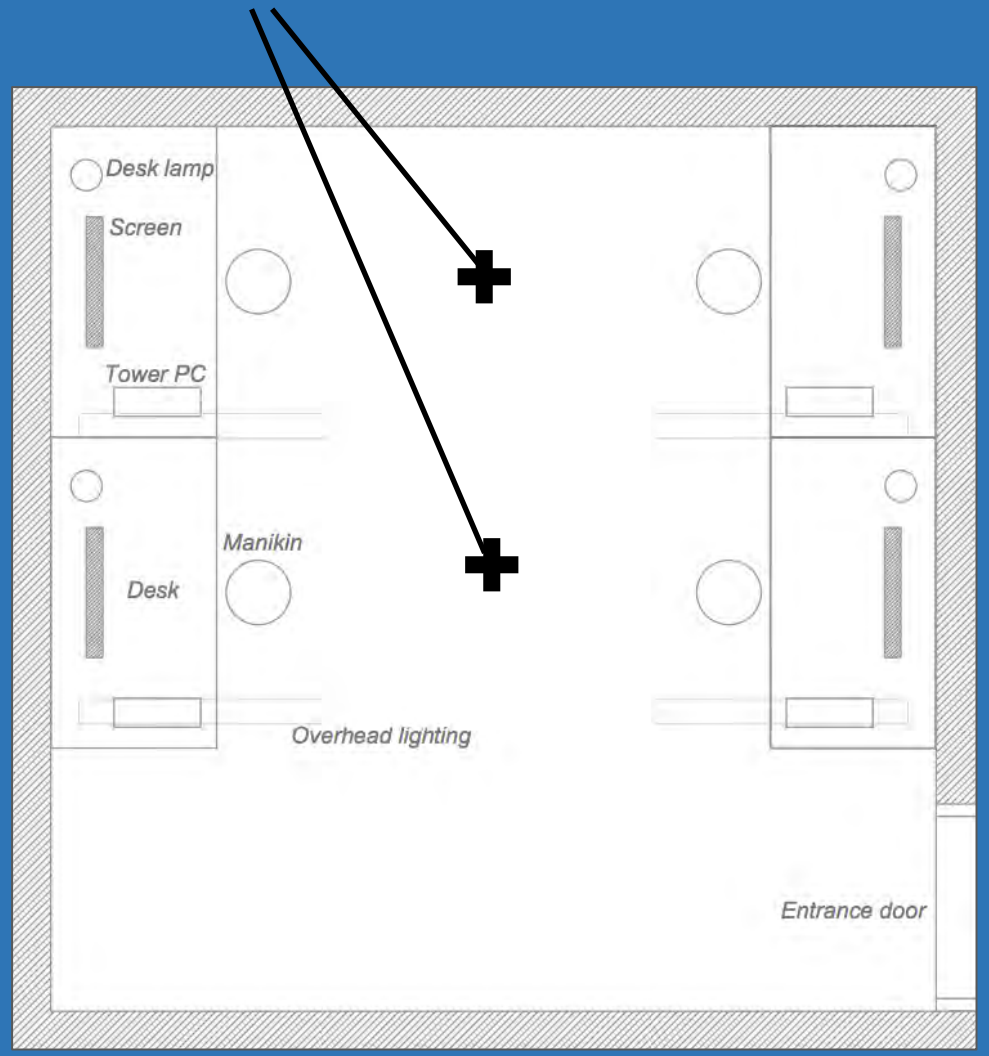


Central ceiling fan



Small fans hidden above the canopies

Location of the 2 measurement trees



Plan of the chamber

Internal loads simulated through workstations

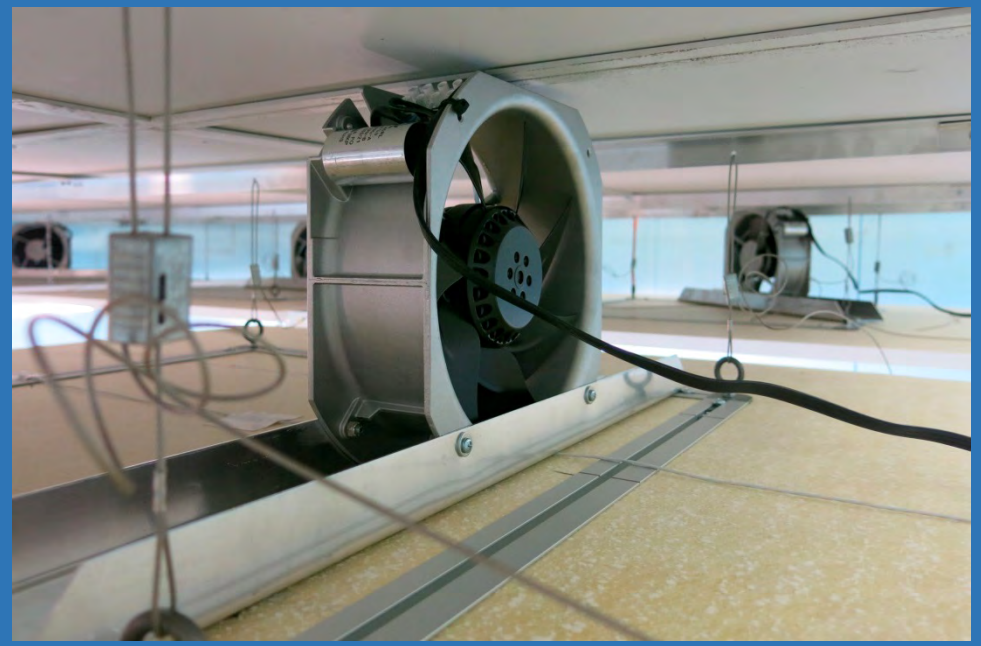
Ceiling fan variants

Blowing ***up***
Blowing ***down***

Central ceiling fan (Haiku)

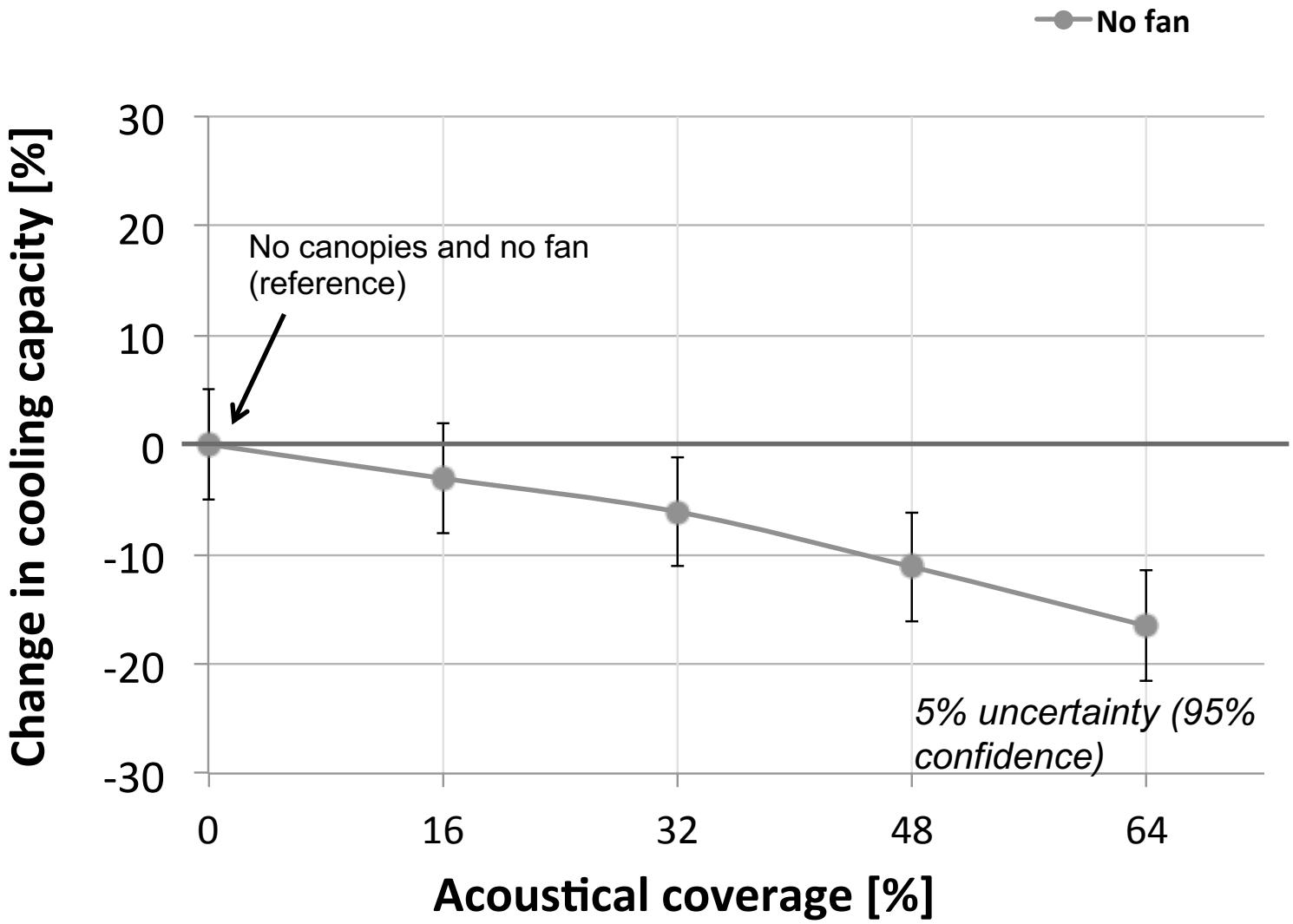
Small fan variants

Low speed
Medium speed

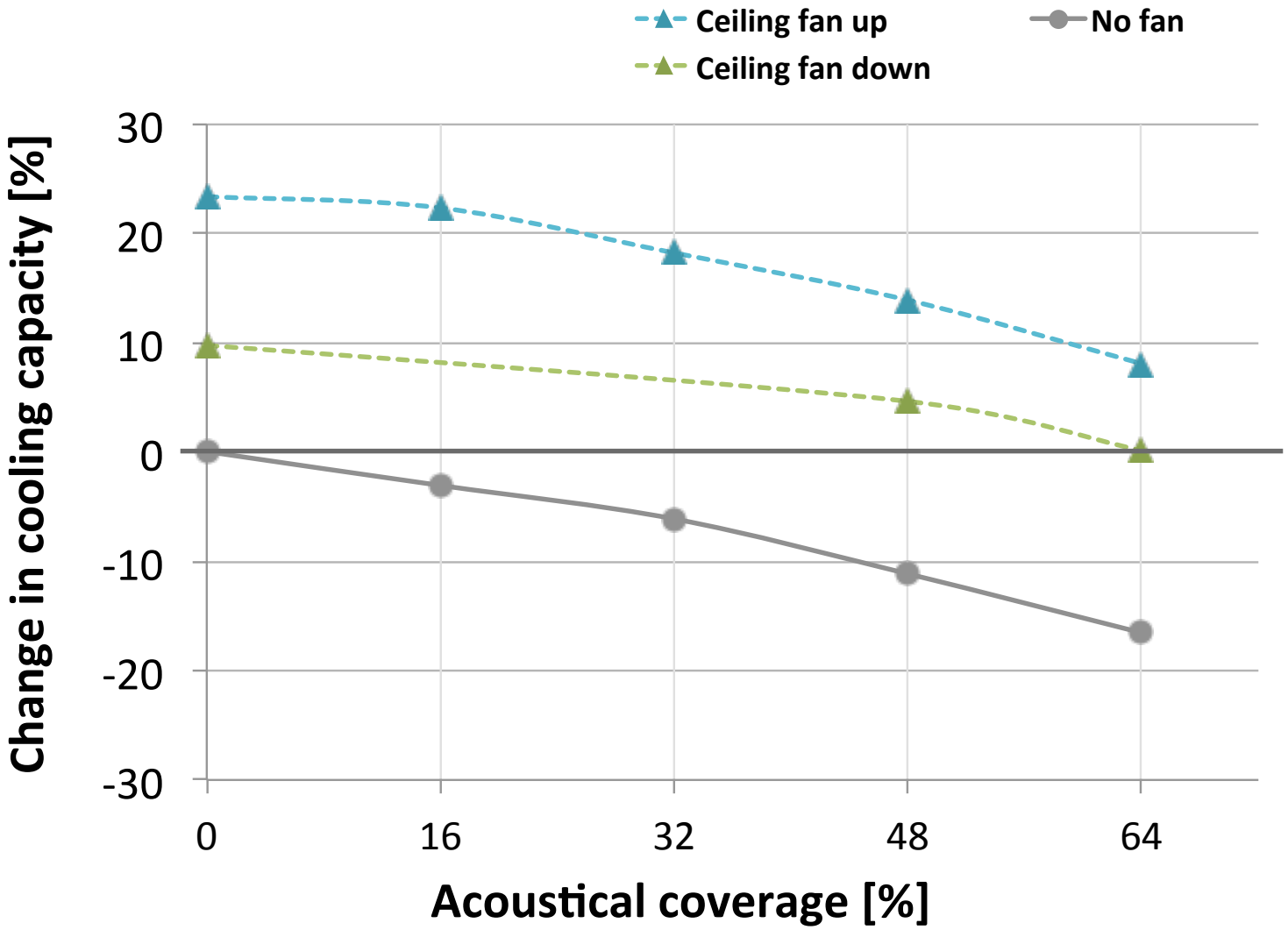


Small hidden fan (located above the canopy)

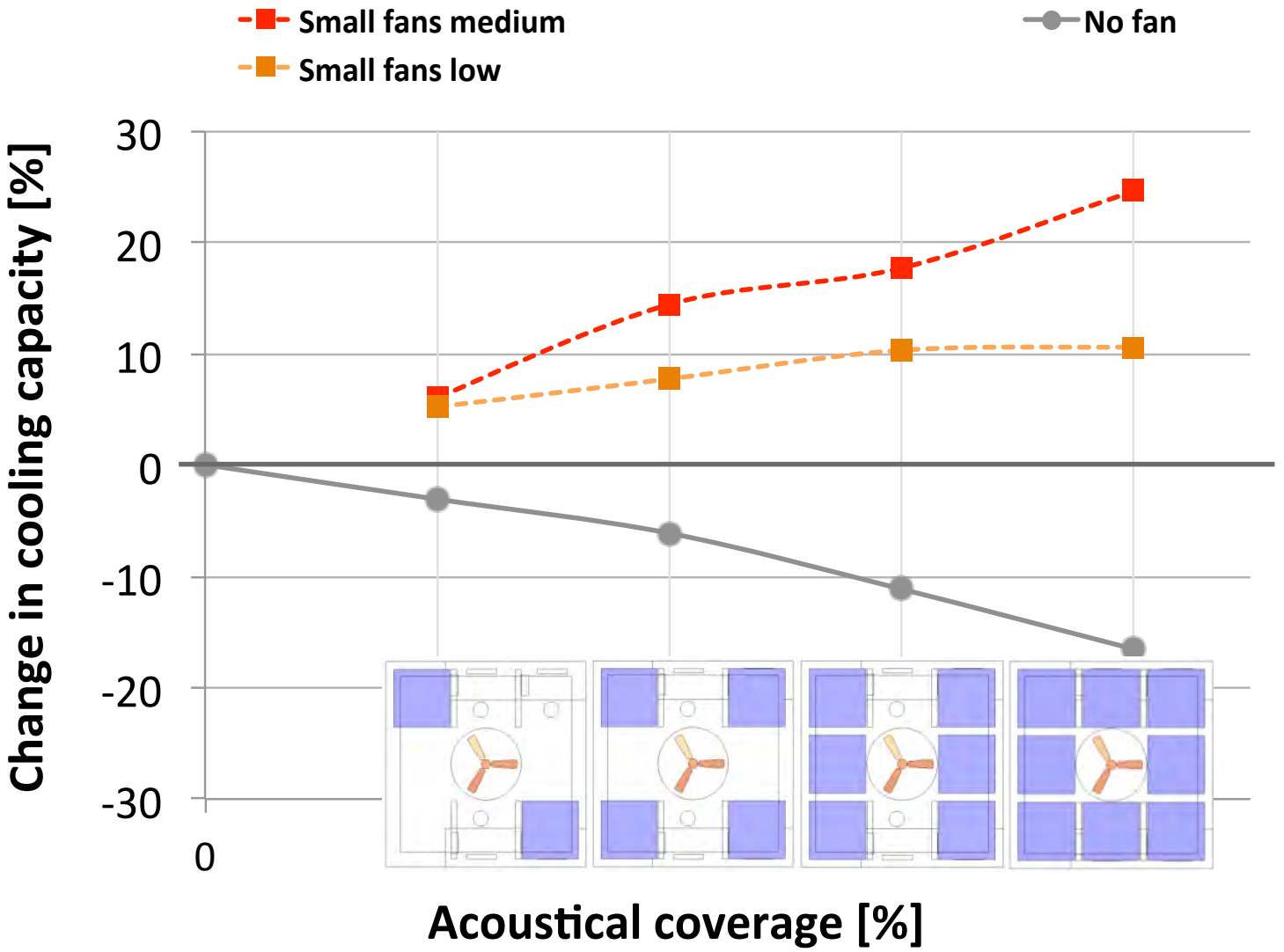
Early results: Canopies without fans



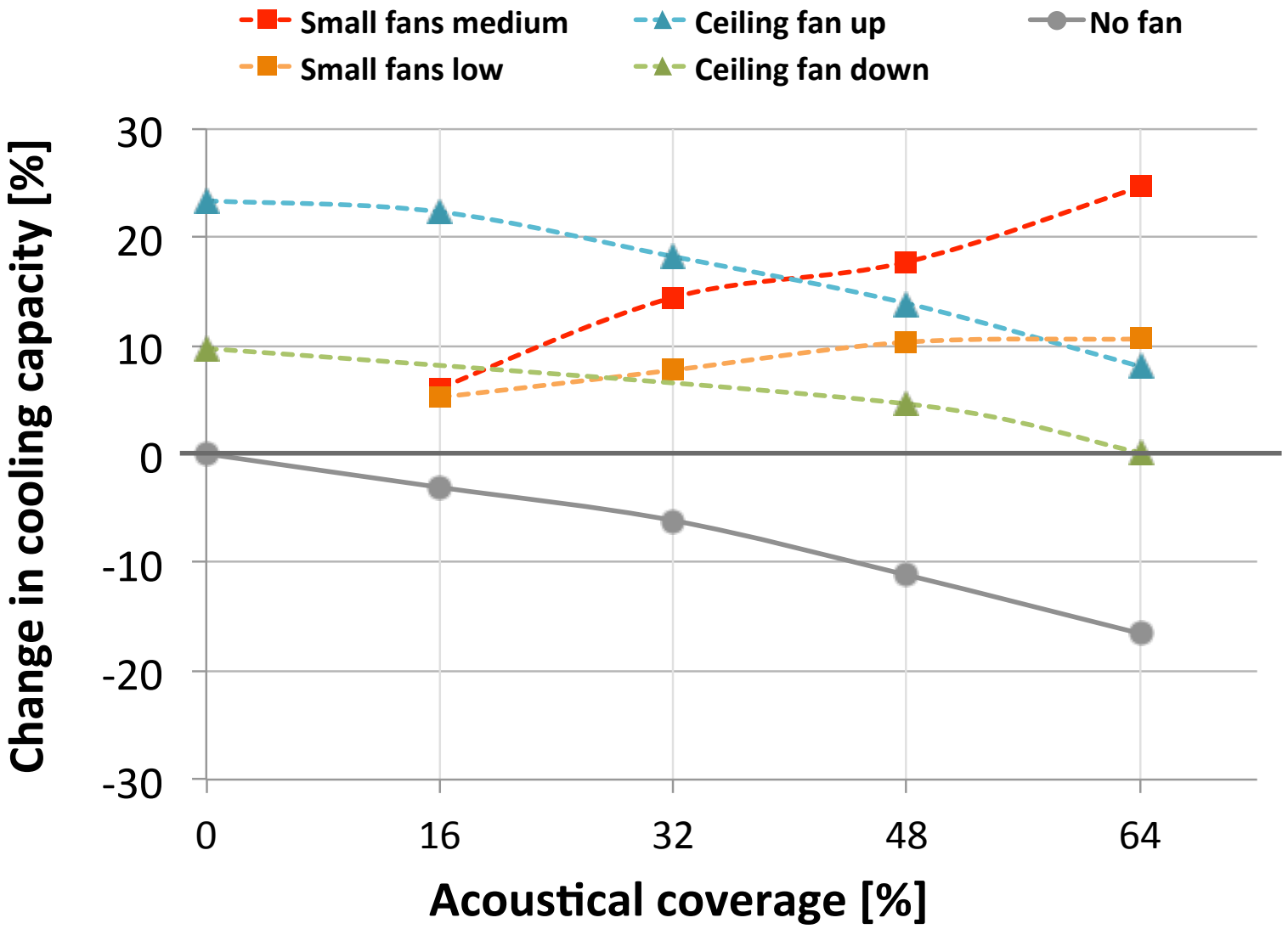
Early results: Canopies with ceiling fan



Early results: Canopies with small fans



Early results: All variants



Summary of fan integrated radiant systems

- Only ***small reduction*** of the cooling capacity of the radiant chilled ceiling with canopies
- ***Fans*** can ***increase*** the cooling capacity
- Results are for ***cooling***
  (heating case may be different)
- Use of fans may improve ***control*** of thermally massive radiant slabs
- Ceiling fan ***downward*** also addresses thermal comfort through increased air motion

Concrete ceiling (Brower Center)
Image: Tom Griffith

Acoustical *canopies*
Image: Armstrong


Thank you!
MAUI