Smart, Efficient, Comfortable

New Technologies for Occupant-Responsive Buildings

Center for the Built Environment (CBE)
University of California, Berkeley

SBIoT Workshop, November 2018

CBE background

- Industry/University Collaborative Research Center (I/UCRC) established in 1997 with support from the National Science Foundation
- Industry Advisory Board members sponsor and direct research agenda
- Semi-annual meetings in April and October emphasize collaboration, shared goals, and problem solving

CBE Industry Advisory Board 2018

Industry members offer diverse perspectives and feedback that guide CBE's research.

Sustaining Members

- Armstrong World Industries
- Big Ass Solutions
- California Energy Commission
- Daikin
- Ford Motor Company
- Genentech
- Google, Inc.
- Ingersoll Rand
- Pacific Gas & Electric Company
- REHAU
- Saint-Gobain
- Southern California Edison
- U.S. Department of Defense
- Wells Fargo
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Architecture, Engineering and Construction Members

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- Sanken
- Skidmore, Owings, & Merrill
- Stantec
- Syska Hennessy Group

AEC Teams

SERA Architects Team

- CPP
- EHDD Architecture
- P2S Engineering
- Perkins+Will
- SERA Architects

Taylor Engineering Team

- Atelier Ten
- Taylor Engineering
- TRC Energy Services
- Western Allied Mechanical, Inc.
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Small Business Members

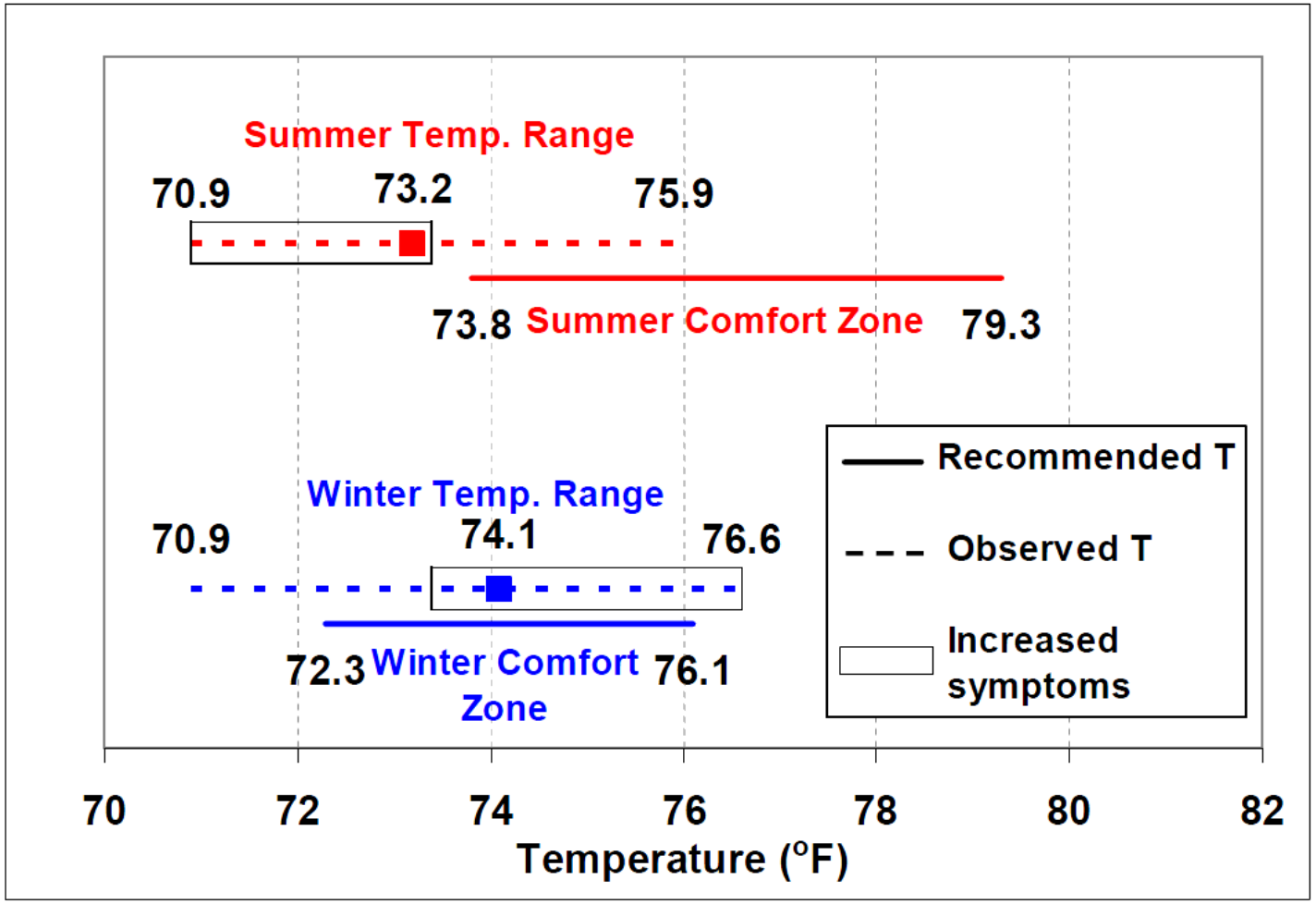
- Aclima
- Delos Living

Themes for today's talk

- Improving energy *and* comfort
- Personal comfort systems
- Air movement research and technology development

Energy vs. comfort is a false dichotomy

- We are overcooling buildings in summer, wasting energy and making people uncomfortable.
- Numerous CBE field intervention studies resulted in reduced energy use and equal or improved comfort



Source: Mendell, MJ, Mirer. AG (2009) Indoor Air 19(4): 291 - 302

Energy and comfort: Minimum airflow study

Objectives

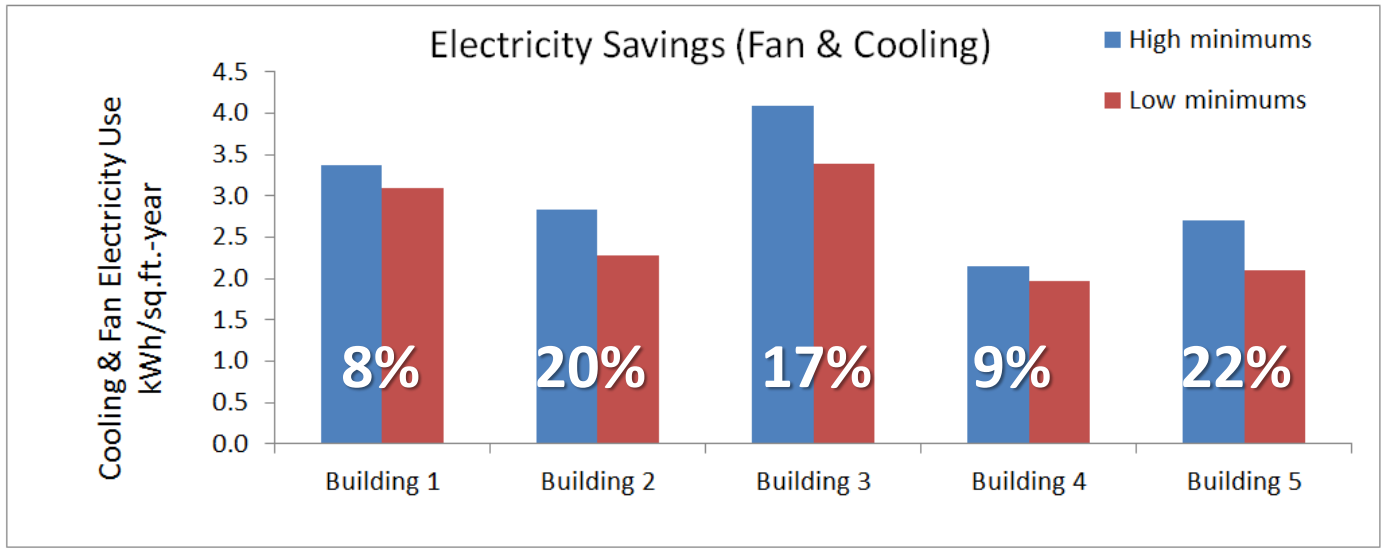
- Measure energy savings with minimum airflows reduced to 10% of max
- Determine comfort issues that may occur at low flow

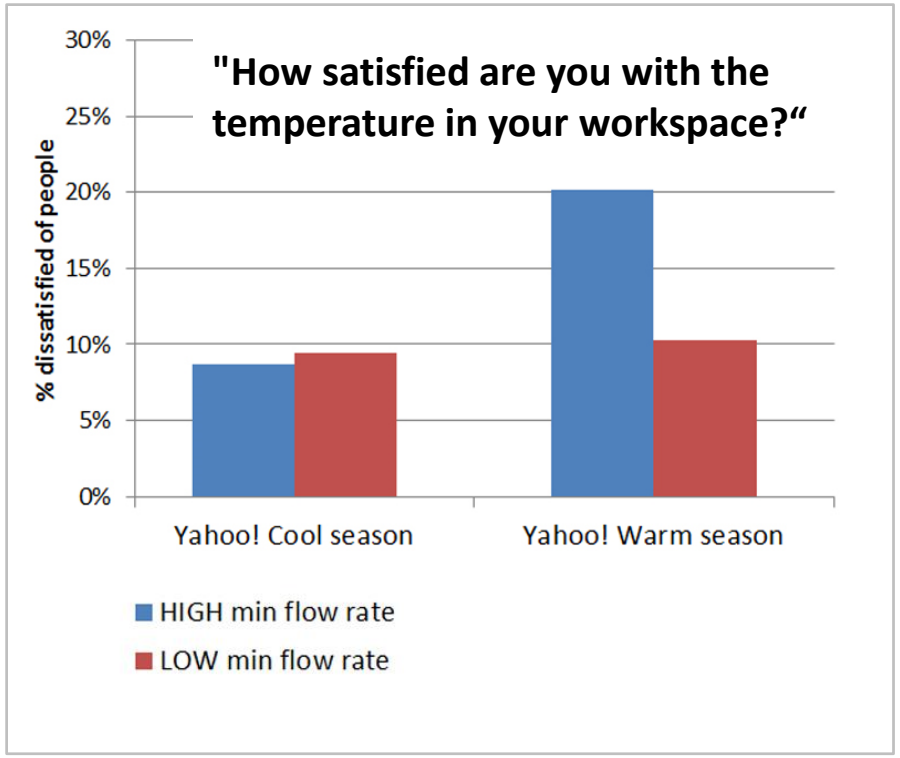
Approach

- Intervention study in seven buildings at Yahoo! campus
- Background occupant survey
- “Right now” survey matched to zone trends
- Energy monitoring

Minimum airflow results: Improved energy and comfort

- Cooling energy reduced 8 to 22%
- Warm season dissatisfaction was reduced by almost half





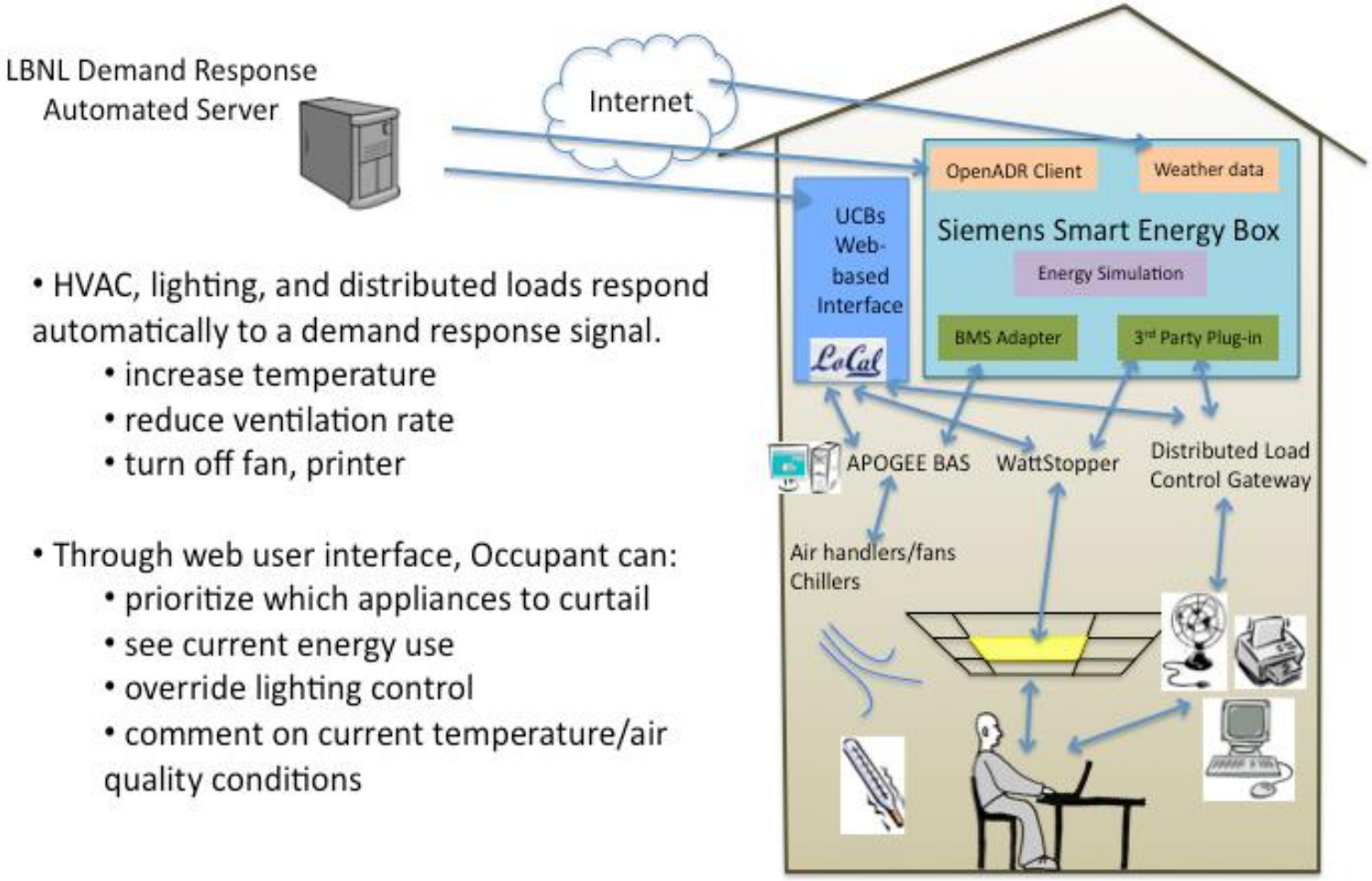
Arens, et al., 2015. Effects of Diffuser Airflow Minima on Occupant Comfort, Air Mixing, and Building Energy Use (RP-1515). www.escholarship.org/uc/item/6kj9t7cj

Distributed Intelligent Automated Demand Response (DIADR)

- Reduced peak electricity with annual cost savings up to $44K
- Device level control
- Led to numerous innovations
  - sMAP protocol, valuable for future research
  - Occupant-based control prototype and successful startup

http://i4energy.org/downloads/projects/sutardja-dai/DIADRFinalReport.pdf

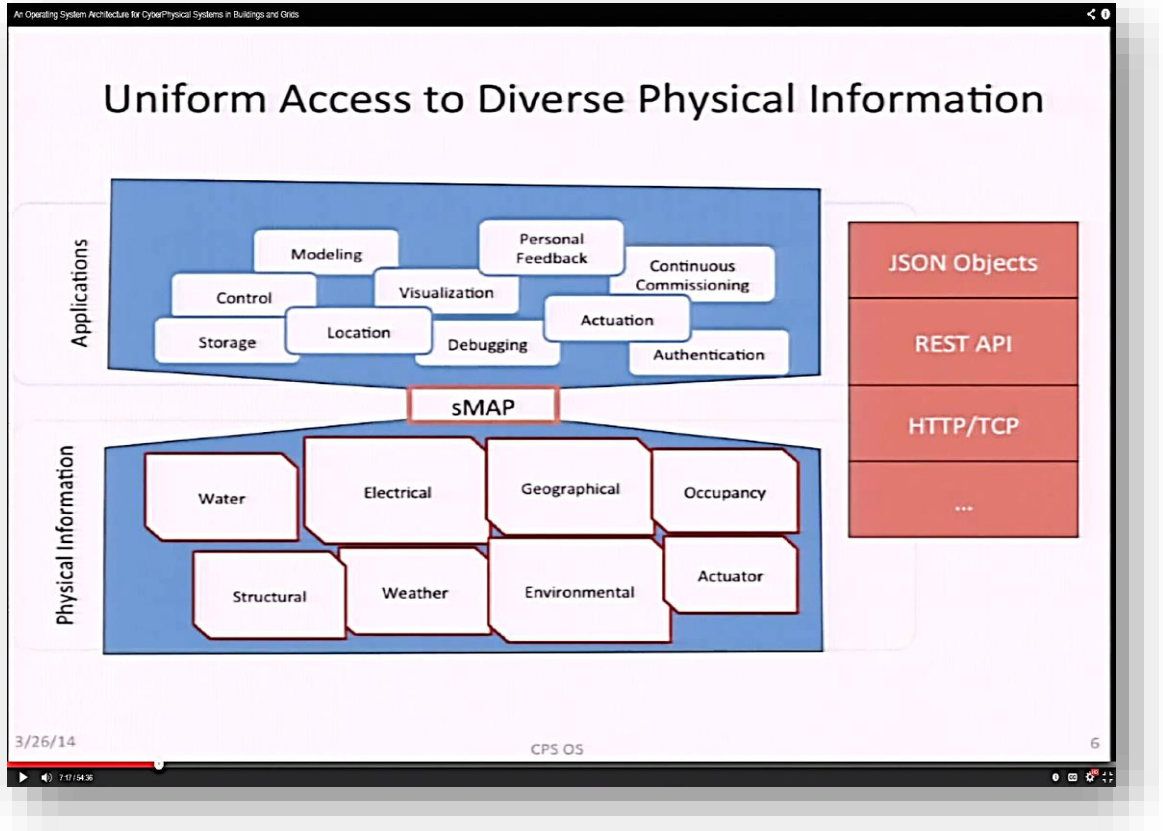
Credits: UCB depts. Of EECS and ME, with CIEE, CBE, Lawrence Berkeley National Lab and Siemens



- HVAC, lighting, and distributed loads respond automatically to a demand response signal.
  - increase temperature
  - reduce ventilation rate
  - turn off fan, printer
- Through web user interface, Occupant can:
  - prioritize which appliances to curtail
  - see current energy use
  - override lighting control
  - comment on current temperature/air quality conditions

Resulting innovation: Open source control protocol sMAP

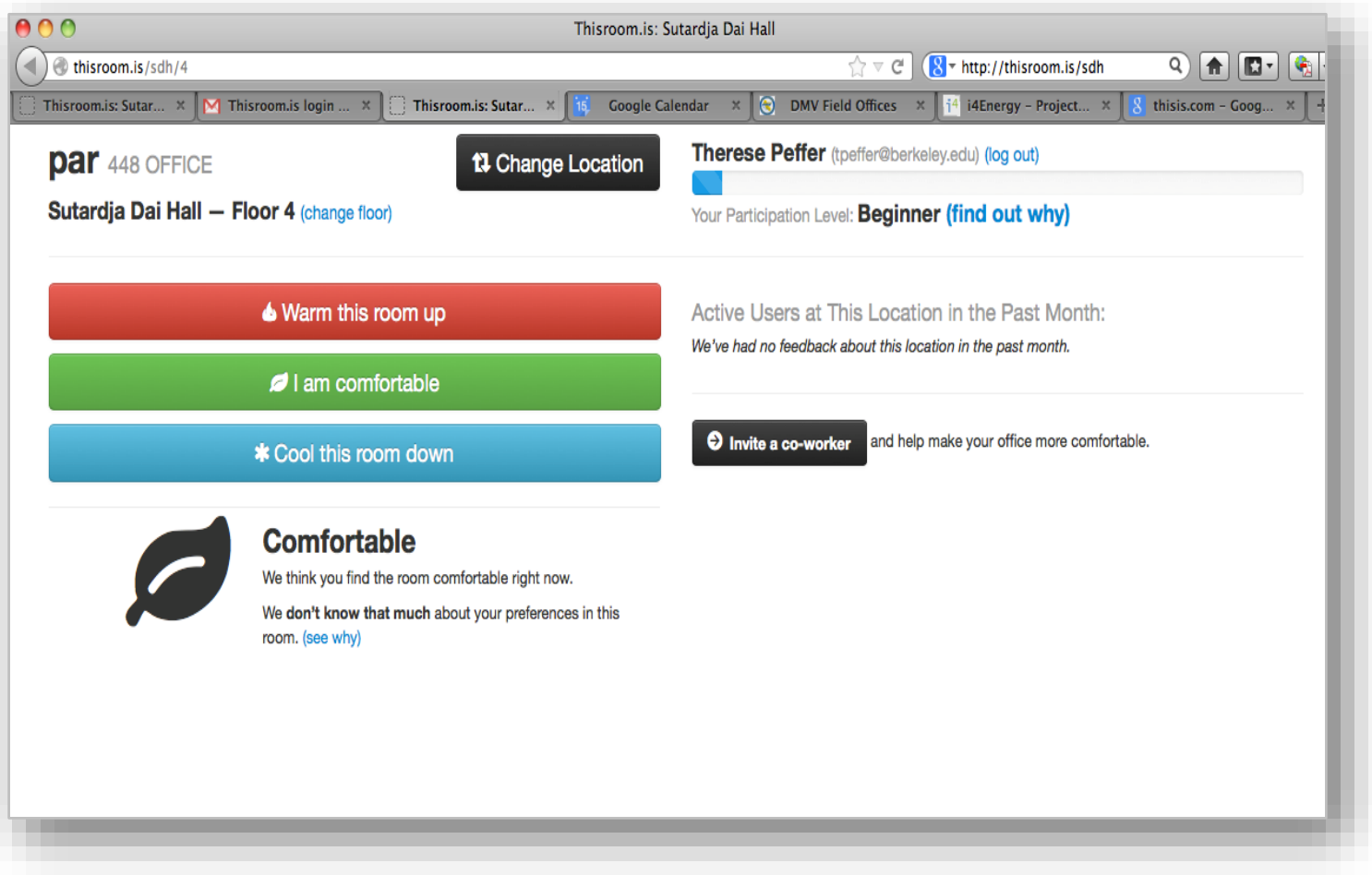
- Open-source protocol
  "Simple Measurement and Actuation Profile" (sMAP)
- Brings data into a common open-source format
  - BMS and sensor data
  - Weather data
  - Occupant data
- Enables development of new applications using standard web frameworks (Python)
- EECS team led by Prof. David Culler
- http://citris-uc.org/sMAP



Source: An Operating System Architecture for Cyber Physical Systems in Buildings and Grids, Prof. David Culler, UC Berkeley CITRIS Talk, April 2014

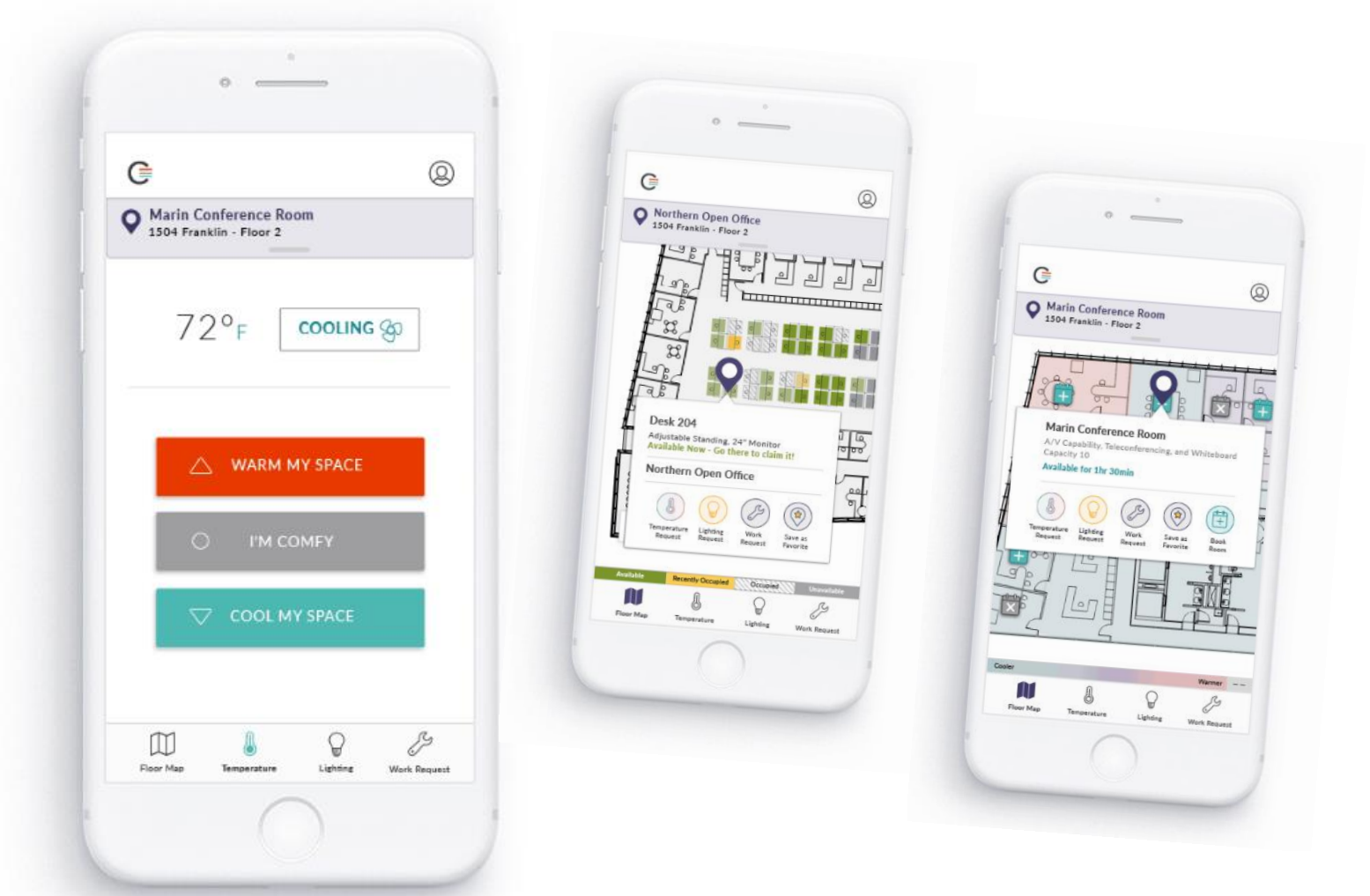
sMAP temperature control application

- Occupants in campus building interfaced directly with BMS through sMAP application
- Social aspect, requires more than one vote for warm or cool blast



Commercialization of the Comfy app

- Oakland CA startup founded by Berkeley grads, sMAP innovators Stephen Dawson-Haggerty and Andrew Krioukov
- Initial focus on thermal comfort, now includes maintenance, lighting, scheduling
- Installed in ~50M ft^2 of office space
- Obtained $19M in VC funding, recently acquired by Siemens (June 2018)



Cost-responsive supply air temperature (SAT) reset

Objective

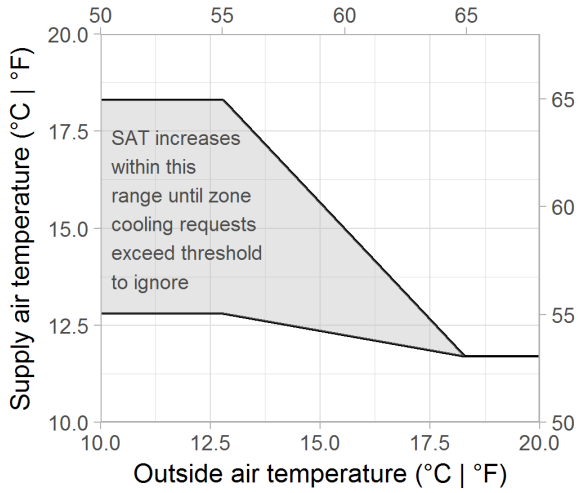
- Develop and test a control strategy that identifies the optimal supply air temperature for an air handling unit

Approach

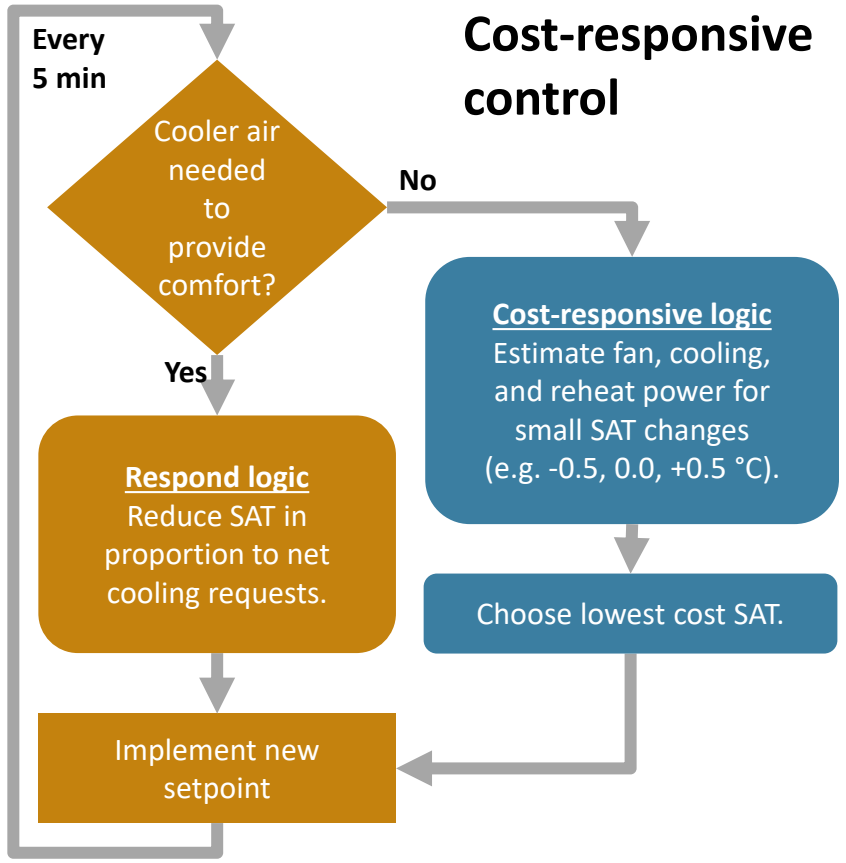
- No new hardware
- Minimize complexity so it can be implemented within commonly used building automation systems and hardware
- Tested in a randomized controlled trial of six months

Sutardja Dai Hall

Cost-responsive control concept and results



Current best practice



Cost-responsive control

- Dynamically calculates the optimal SAT setpoint, based on minimizing the combined costs of chilled water, fan, and reheat energy, while maintaining comfort
- 17% HVAC savings during randomized control trial
- 29% HVAC savings when normalized to typical office hours in a typical climate year

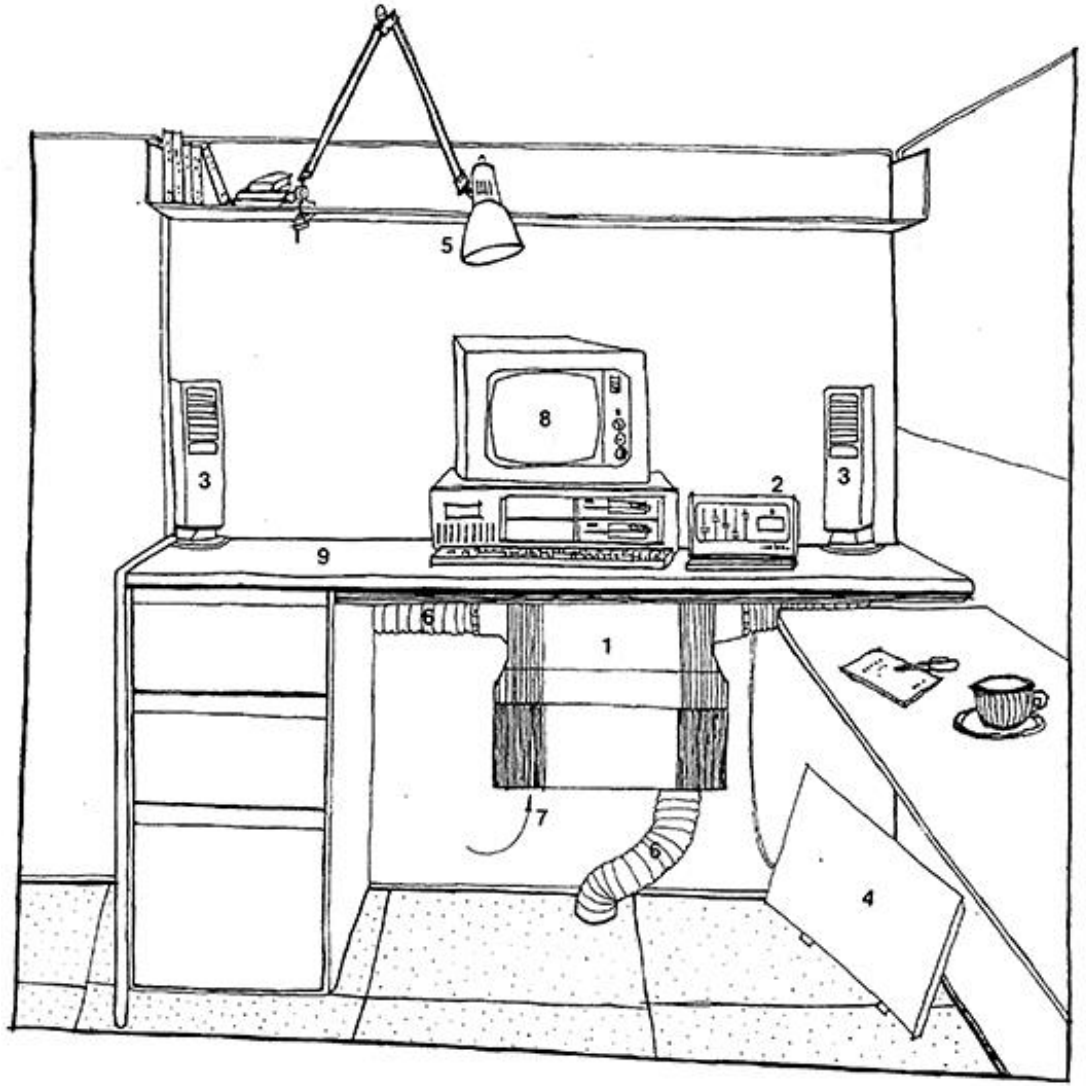
Raftery, et al., 2018. Evaluation of a cost-responsive supply air temperature reset strategy in an office building. *Energy and Buildings*. https://escholarship.org/uc/item/1fk2m3v6

Personal comfort systems

- Paradigm shift from space-based to person-based conditioning
- …and from indoor environmental parameters to variable and occupant-selected modes

Personal comfort systems (PCS)

- Compliance with ASHRAE Standard 55 (thermal comfort) is 80% of occupants satisfied
- However this is only met in 11% of buildings (2006 study with 215 buildings in CBE occupant survey)
- 1997 field study showed 100% occupant satisfaction for thermal quality with PEM devices

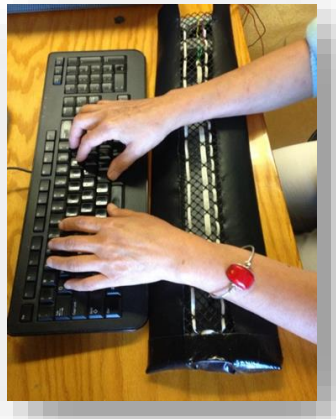


Personal Environmental Module by Johnson Controls, 1990s

Personal comfort systems developed and tested by CBE

Footwarmer+fan prototype

Heated/cooled chair prototype



Spot comfort prototypes

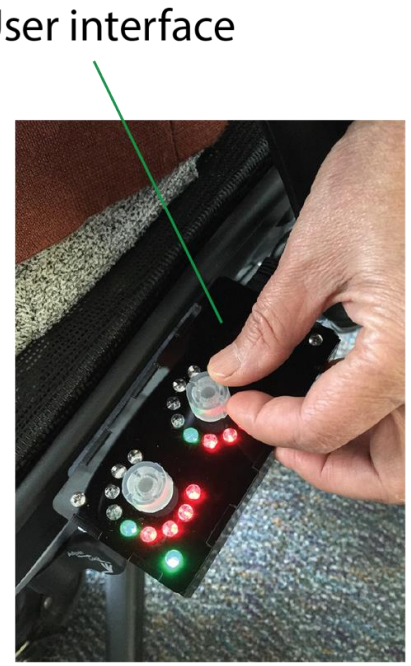
Connecting PCSs to the Internet of Things

Heated and cooled chair prototype

- User controls for cooling and heating
- Low power use (14 W max)
- Rechargeable battery
- Wireless connectivity
- Sensors (environmental, occupancy)

Continuous data streams

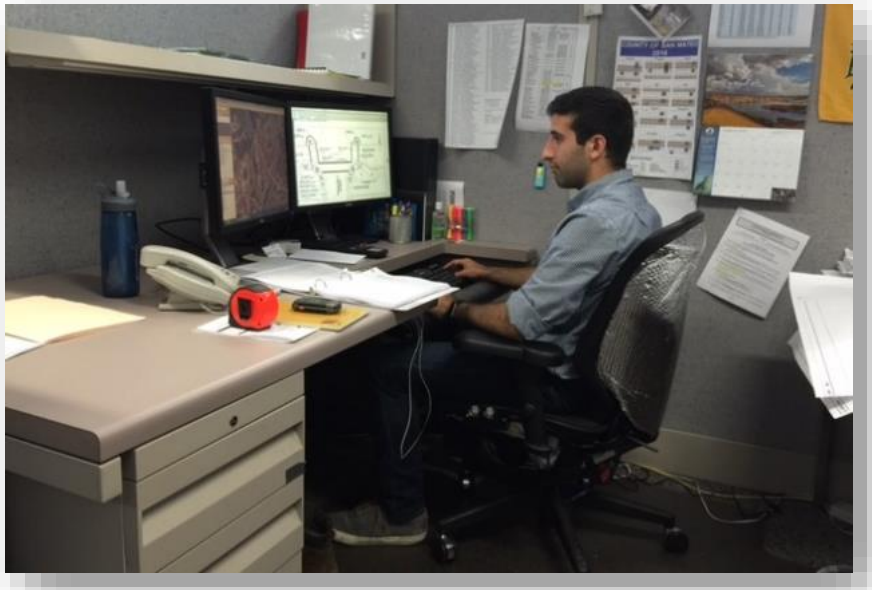
- Heating/cooling intensity and location (seat or back)
- Chair occupancy status
- Air temperature, relative humidity
- Battery status, latency in telemetry, etc.

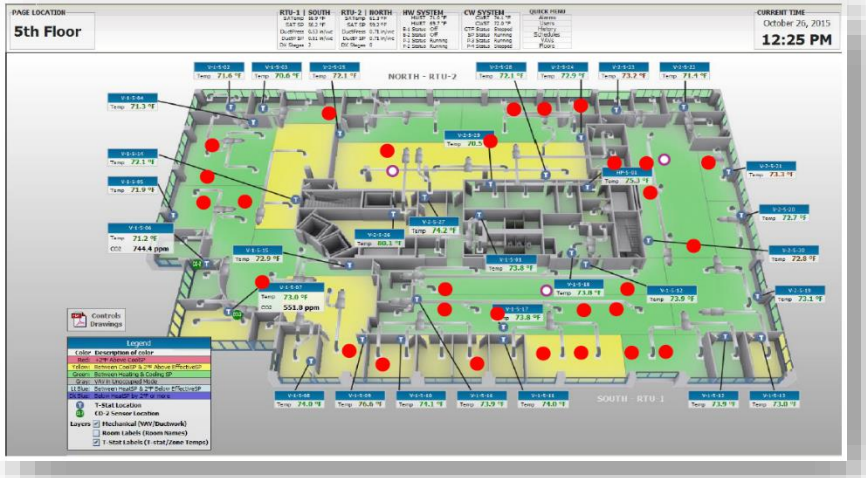


Field study with PCS

Approach

- San Mateo County office building (Apr-Oct 2016)
- 40 employees used chairs equipped with monitoring sensors (temp, usage, settings)
- Entire building used Comfy app





PCS chairs improves comfort

96% thermal acceptability

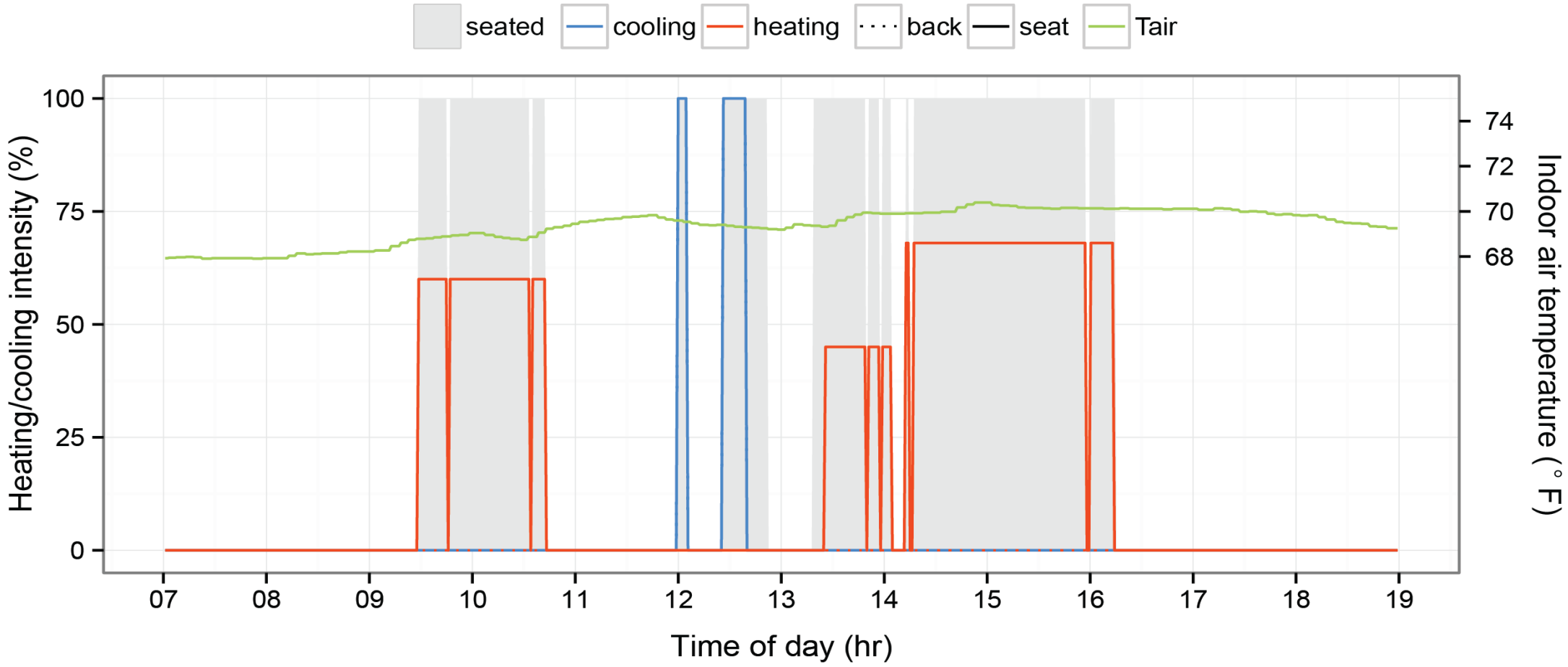
People use PCS chairs frequently

On average 77% of the time used when seated

People really like PCS chairs

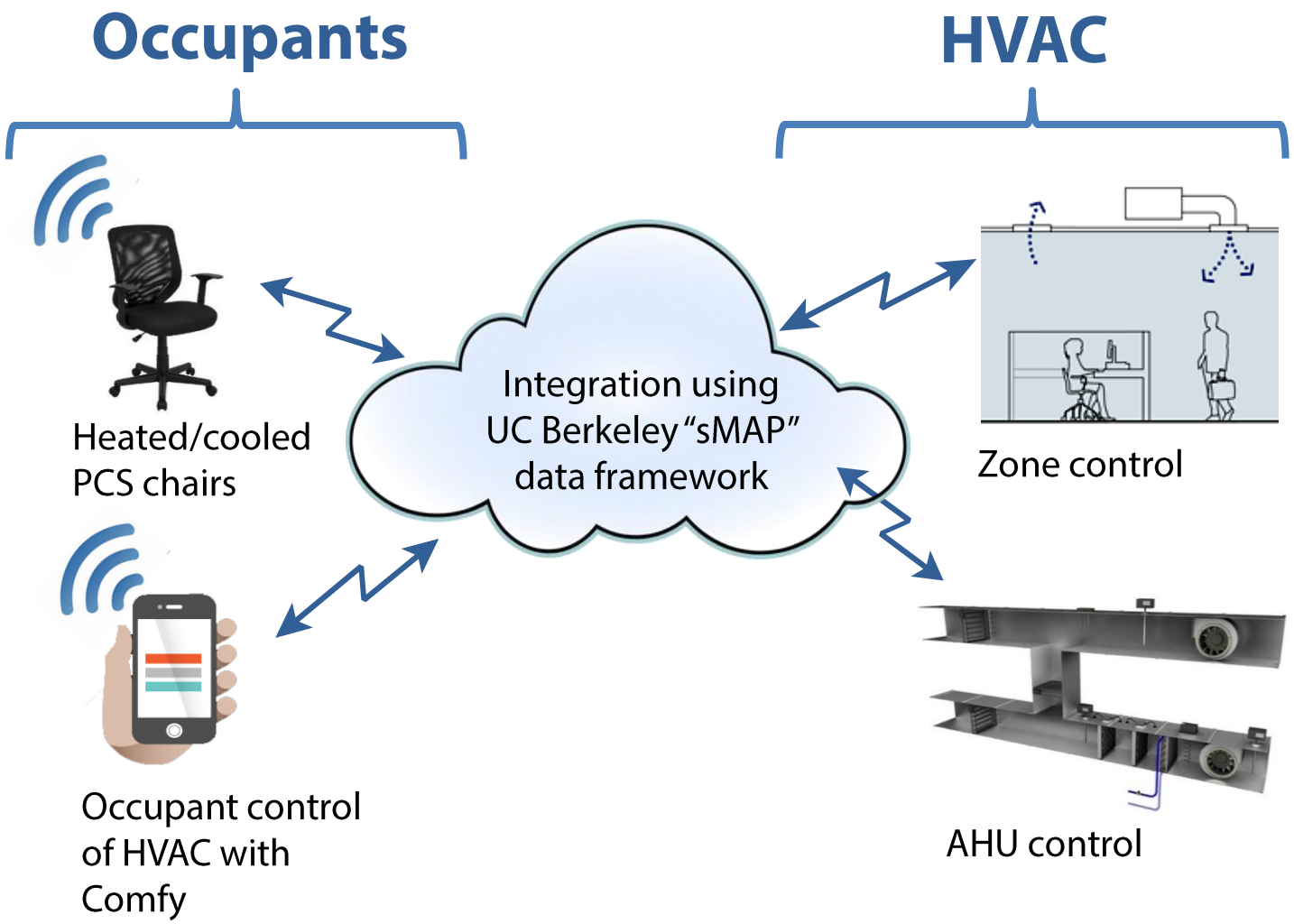
99% satisfaction with the chair

Studying how people use the chairs, lots of data!

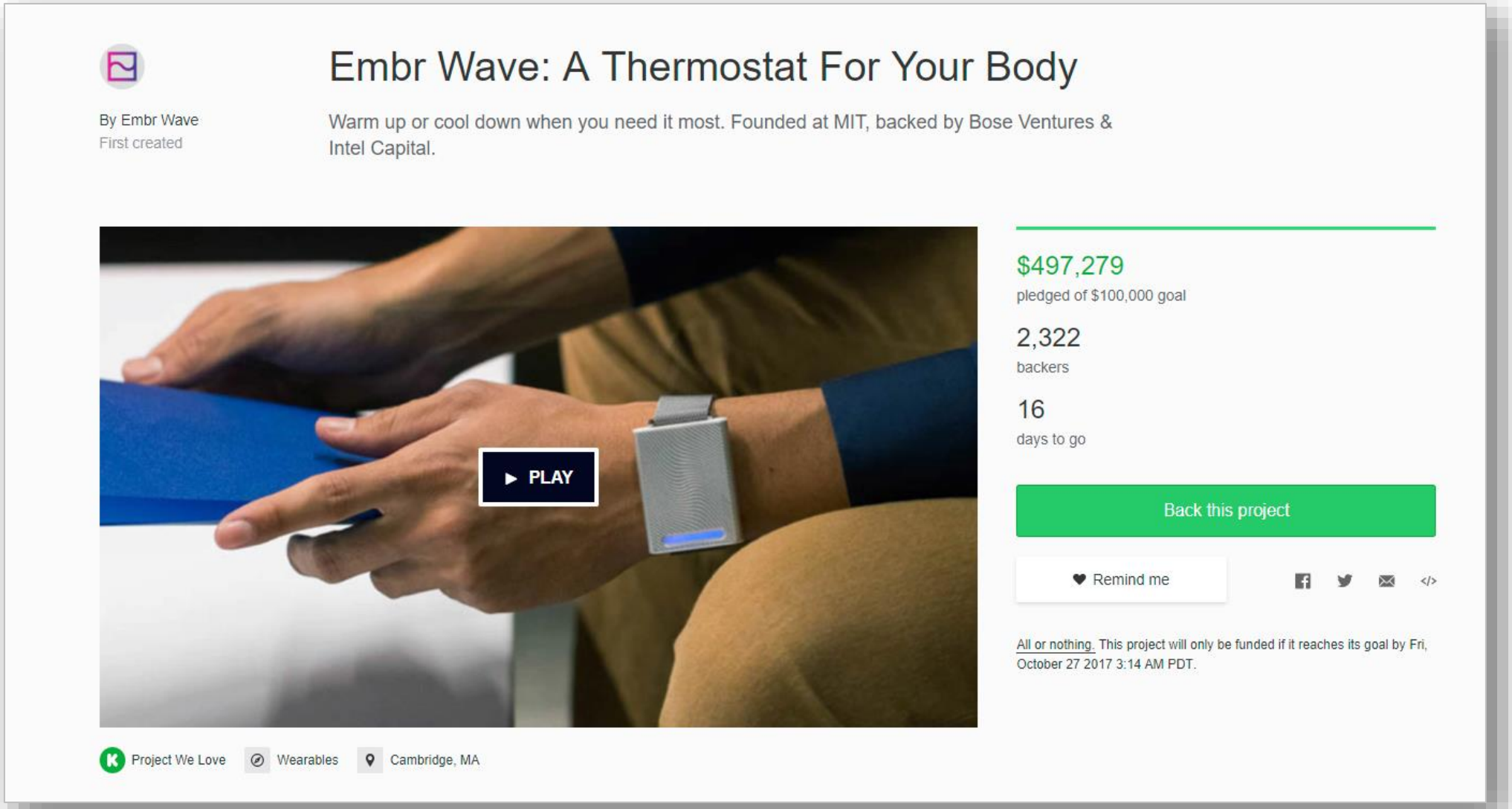


Bauman et al.: 2016

Future directions: Occupant-in-the-loop control

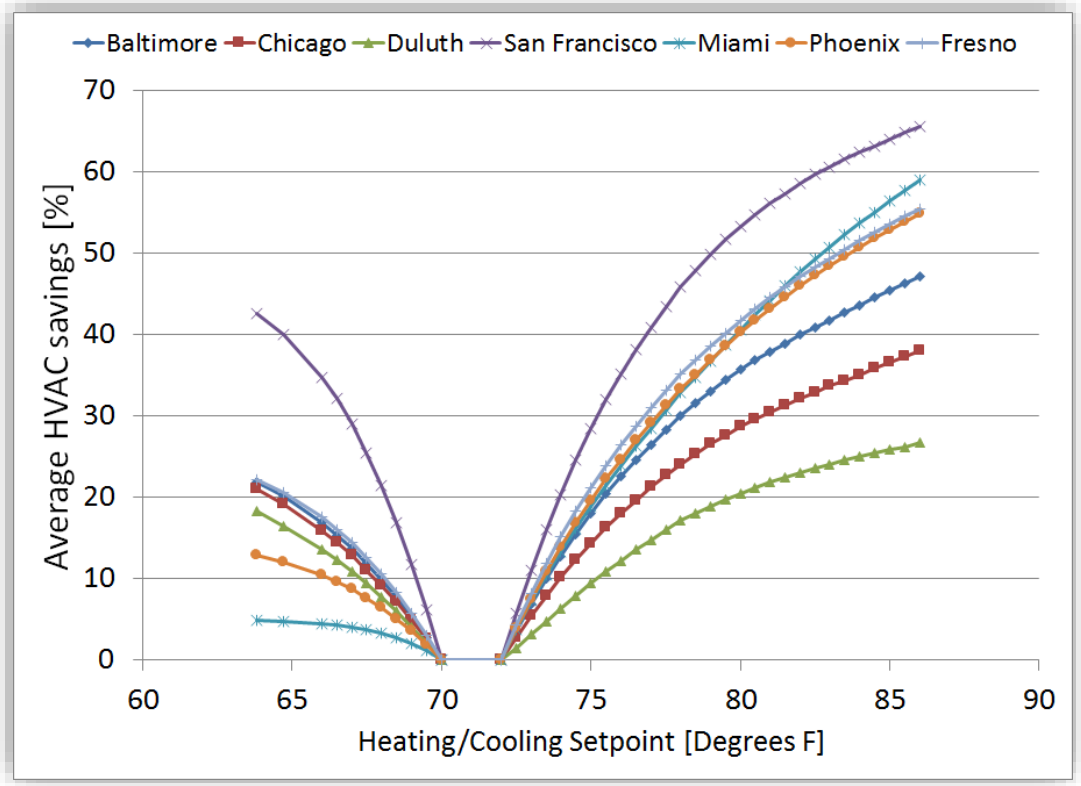


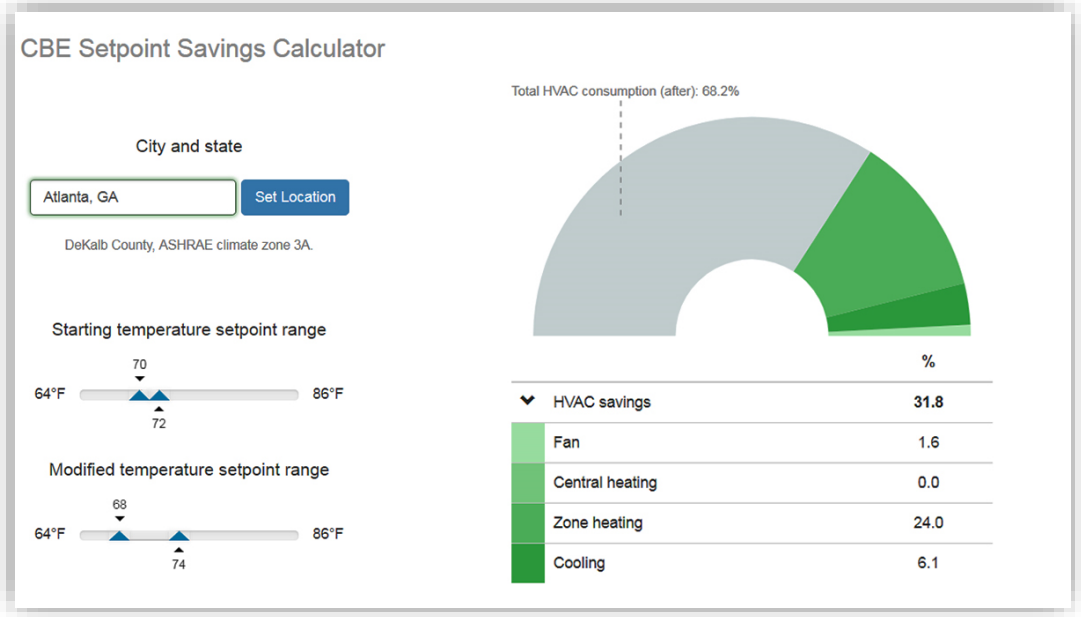
Future directions: Spot heating and cooling



Energy savings with PCSs by expanding the 'dead band'

Expanding temperature ranges save 5-7% HVAC energy per degree F





Setpoint Energy Savings Calculator
http://comfort.cbe.berkeley.edu/energycalc/

Hoyt, T., E. Arens, and H. Zhang. 2014. 'Extending air temperature setpoints: Simulated energy savings and design considerations for new and retrofit buildings.' *Building and Environment*

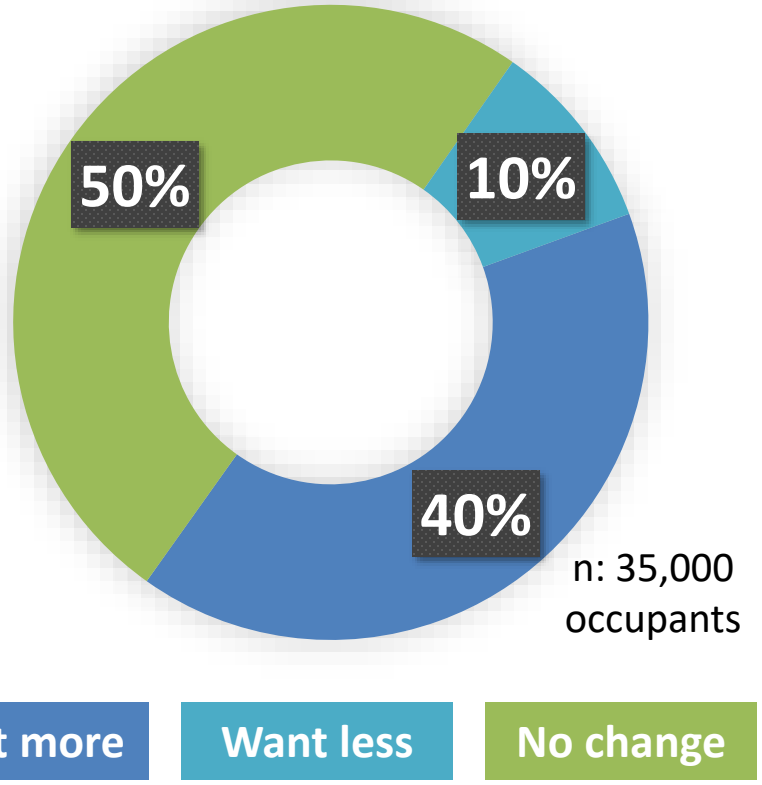
Air movement research and technology development

- PCS and ceiling fans
- Airspeed sensing technology

Why design with air movement?

- Occupants prefer it
- Improves perceived and measured air quality
- Instant comfort control
- Save energy and operating costs
- Reduce HVAC equipment and ductwork sizing and first costs
- Ceiling fans: ~$2/ft^2 installed cost

Air movement preference
(across all comfort conditions)



From ASHRAE Global Thermal Comfort Database II

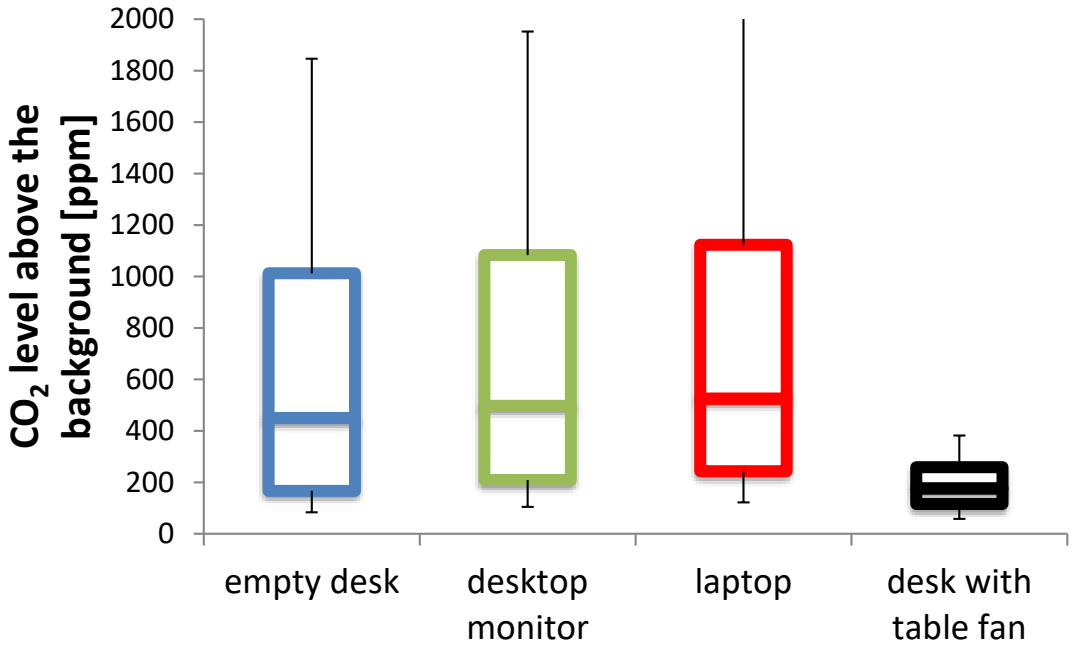
Bursting the CO_2 bubble

Study conditions

- Simulated office activities in the environmental chamber
- CO_2 measurement in the inhalation zone, and the background level

Results

- CO2 'bubble' in the inhalation zone
- Concentrations ~400 ppm above background levels
- Impacts on alertness and productivity
- However small desk fans are highly effective in reducing this effect



Integrating smart ceiling fans and communicating thermostats

Project Overview

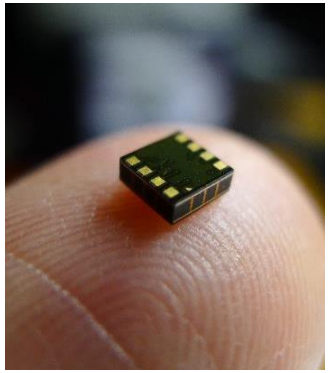
- Lab studies, field studies, case studies, codes and standards, and ceiling fan design tool
- Builds on past collaboration on smart fan development

Preliminary findings

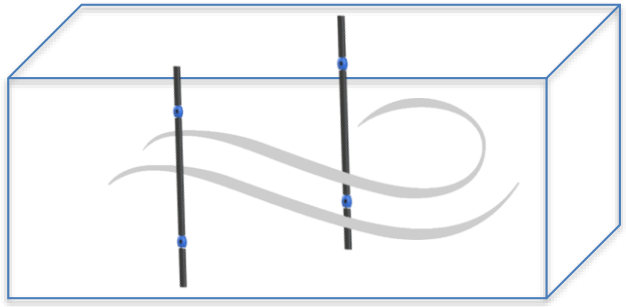
- Integration with AC shows 50% savings ($800/month) in compressor energy use during cooling setpoint increases (74 - 78 ^{0}F)
- Anecdote: study site had AC failure, however 89% of occupants comfortable with indoor temperature ~ 80 ^{0}F
- Running fans upwards provides lower but very uniform airspeeds throughout a space

Low-cost anemometers for in rooms and in HVAC ducts

- Developing low-cost, low-power, accurate, calibration-free airflow sensors ('anemometers') for measuring:
  - Volumetric air flow in HVAC systems
  - Air speeds in rooms
- Accuracy to 0.05 m/s
- Also measures temperature and direction

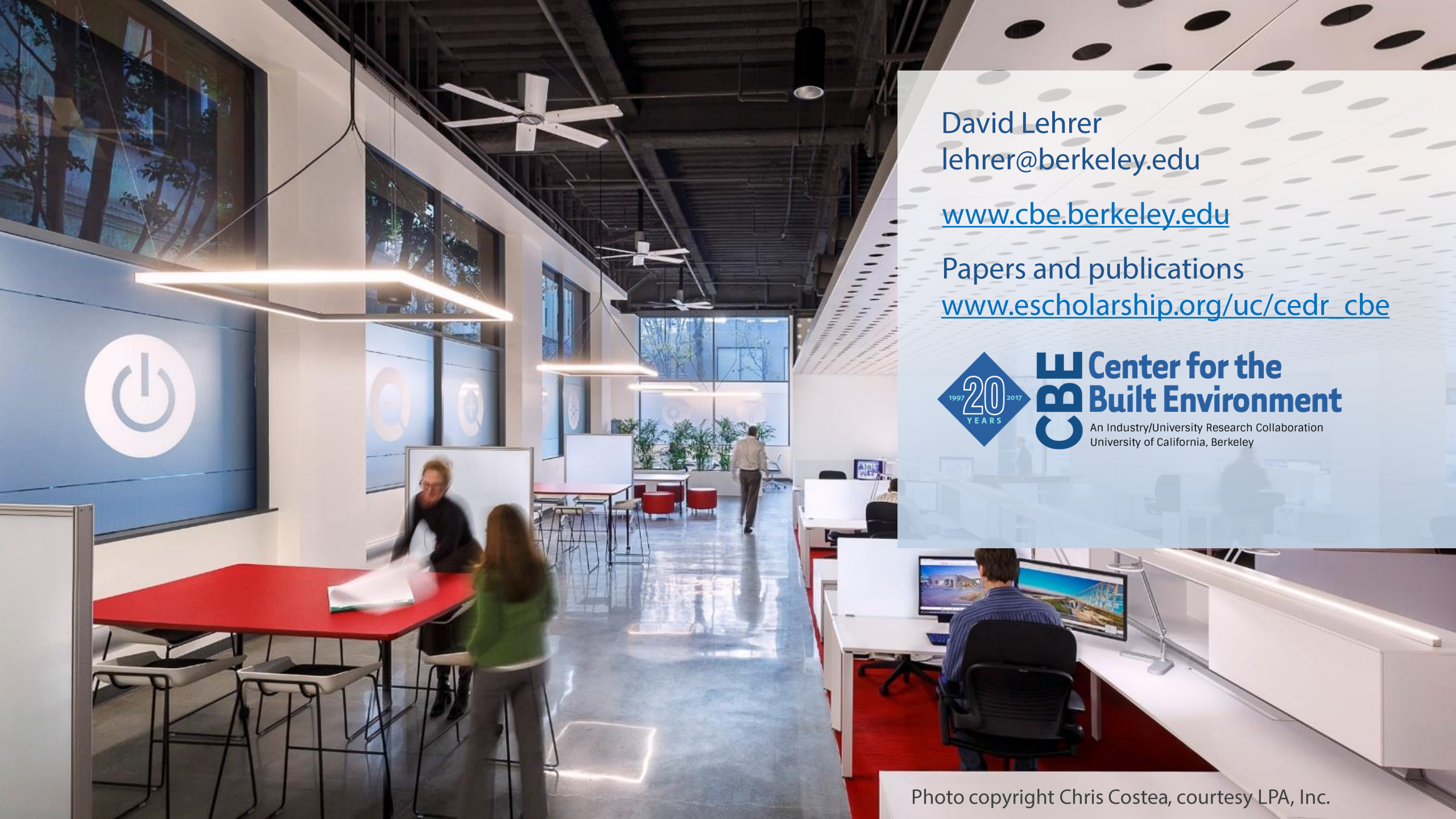


Integrated ultrasound sensor from Berkeley startup Chirp Micro



Duct anemometer concept

Room anemometer prototypes



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