Applying Thermal Comfort Concepts for Low-Energy Building Solutions

Speakers: Stefano Schiavon, PhD

August 18, 2022

AIA Provider H663 AIA Course Number NWB20220707

PG&E

CBE
CENTER FOR THE BUILT ENVIRONMENT

Course Description

Research shows that approximately 40 percent of commercial building users are dissatisfied with their thermal environments, achieving just half of the industry goal of 80 percent, and thereby representing one of the most bothersome aspects of indoor environments.

This class will cover key concepts of thermal comfort, how it can be improved, and how this knowledge can be used to create low-energy and comfortable buildings, including in buildings with radiant systems and ceiling fans that can provide equivalent or superior comfort. Finally, the course will discuss the relationship of the thermal environment to work performance.

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Agenda

9:30 am	Background and course overview
9:40 am	Overview of comfort fundamentals
10:20 am	Demonstration of the online CBE Thermal Comfort Tool
10:30 am	Temperature ranges and low-energy solutions using radiant systems and fans
10:45 am	Q&A
11:00 am	Conclude and course feedback

What is thermal comfort ?

- ASHRAE* definition:
  "…that condition of mind which expresses satisfaction with the thermal environment"
- But thermal discomfort is easier to define and measure, as a result ….
- Engineer's view:
  Comfort
  = absence of discomfort
  = "neutrality"

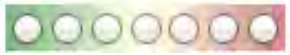
* American Society of Heating, Refrigerating, and Air-Conditioning Engineers

Thermal neutrality or thermal delight?

Onsen at Miyajima

CBE Indoor Environmental Quality survey

How satisfied are you with your ability to adjust your furniture to meet your needs?

Very Satisfied  Very Dissatisfied

Overall building

Overall workplace

Acoustic quality

Air quality

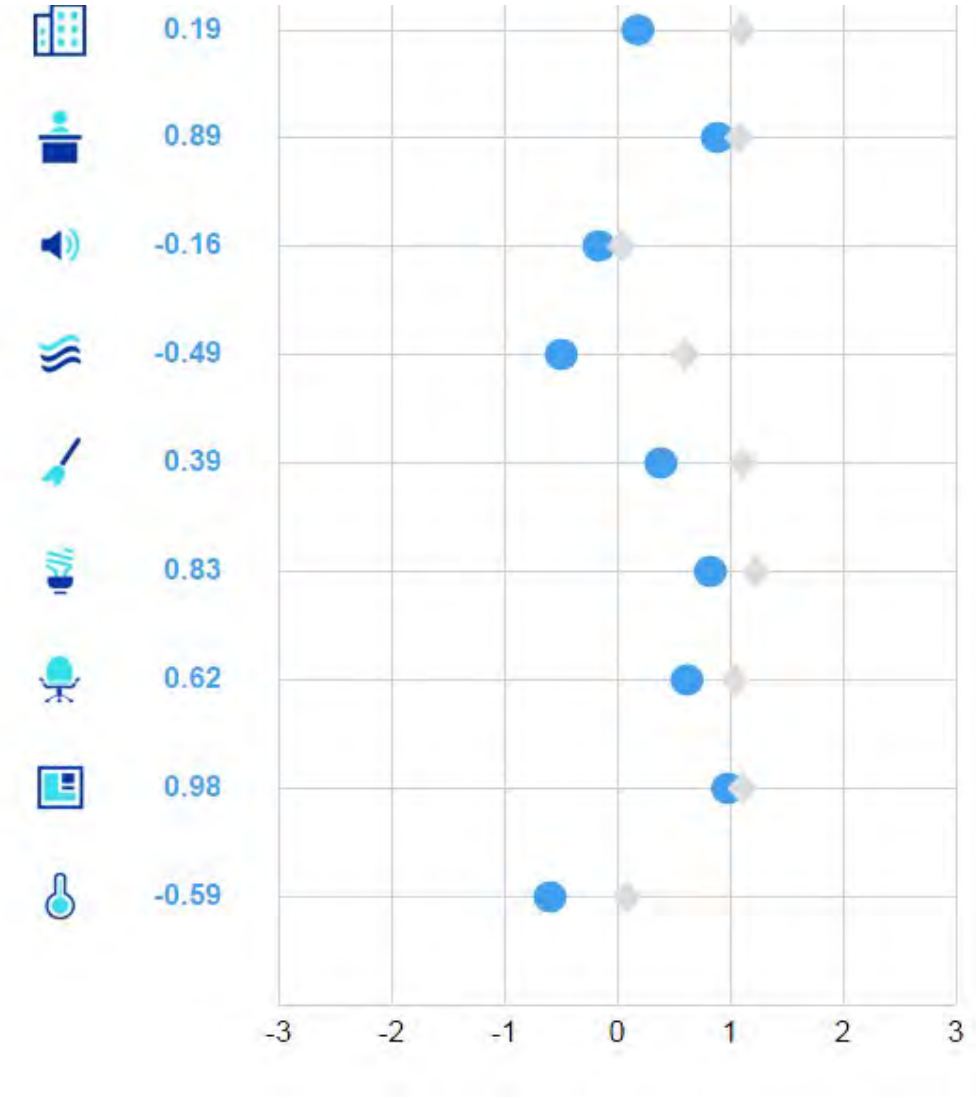
Cleanliness & maintenance

Lighting

Office furnishings

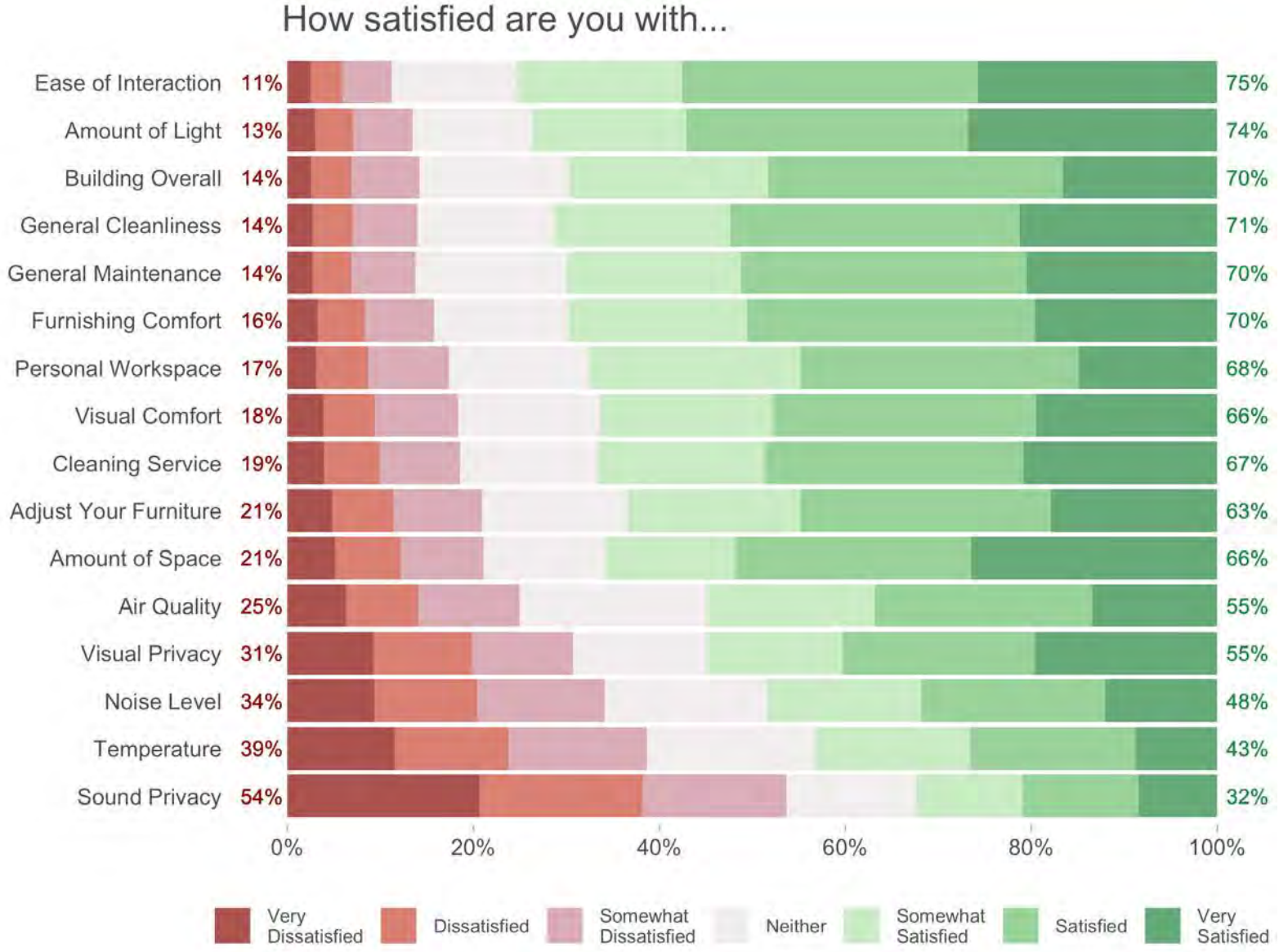
Office layout

Thermal Comfort



cbe.berkeley.edu/survey Leader: Lindsay Graham

Building occupant satisfaction



Graham, Parkinson, Schiavon 2021 *Buildings and Cities*

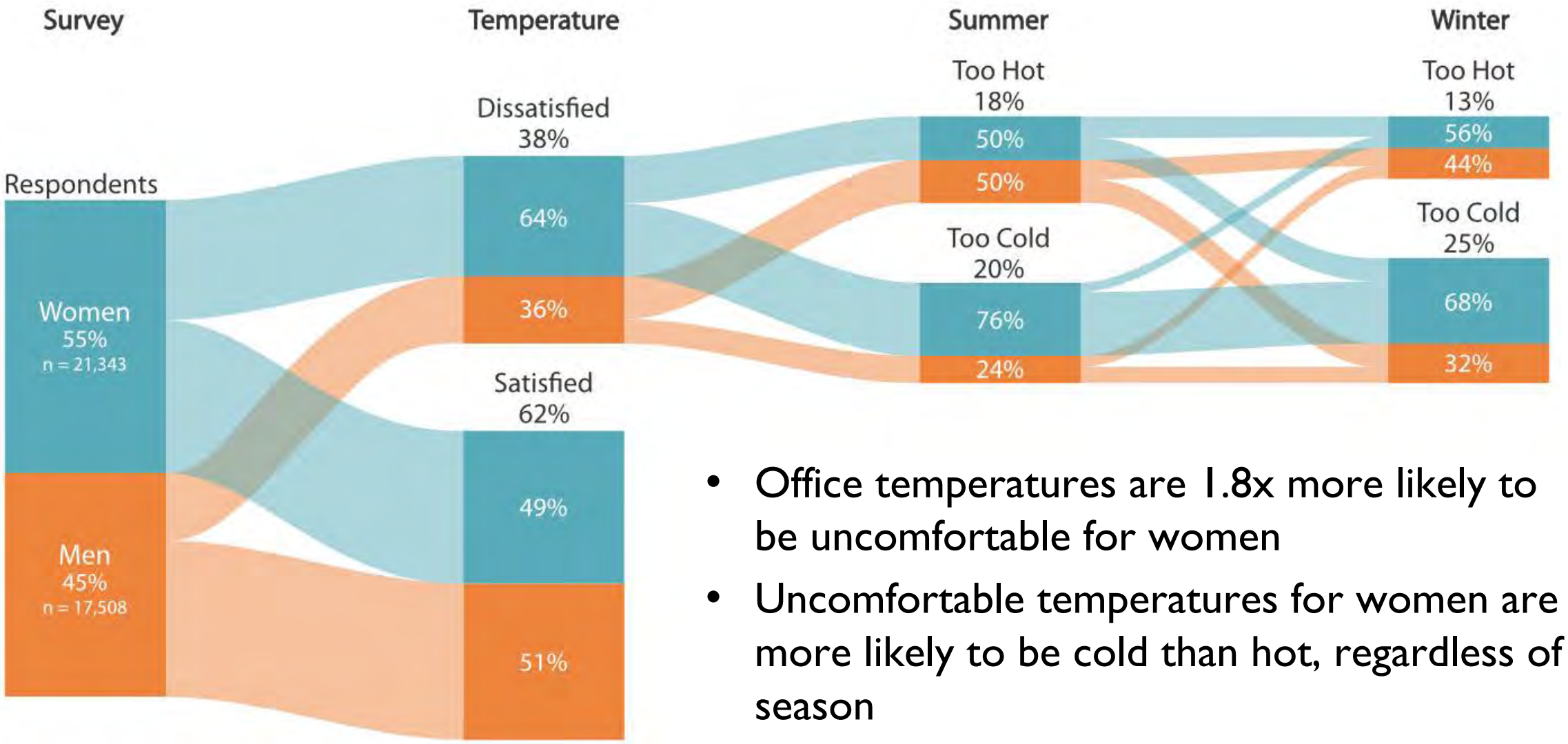
WELL Standard V2

c. The results of the survey responses comply with one of the target satisfaction thresholds as specified in the table below:

Tier	Thermal Comfort Satisfaction Thresholds	Points
1	80% of regular occupants	2
2	90% of regular occupants	3

https://v2.wellcertified.com/en/wellv2/thermal%20comfort/feature/2

Overcooling and gender



- Office temperatures are 1.8x more likely to be uncomfortable for women
- Uncomfortable temperatures for women are more likely to be cold than hot, regardless of season

Parkinson, Schiavon, Brager, de Dear 2021 *Nature Scientific Reports*

Code compliance may not be sufficient

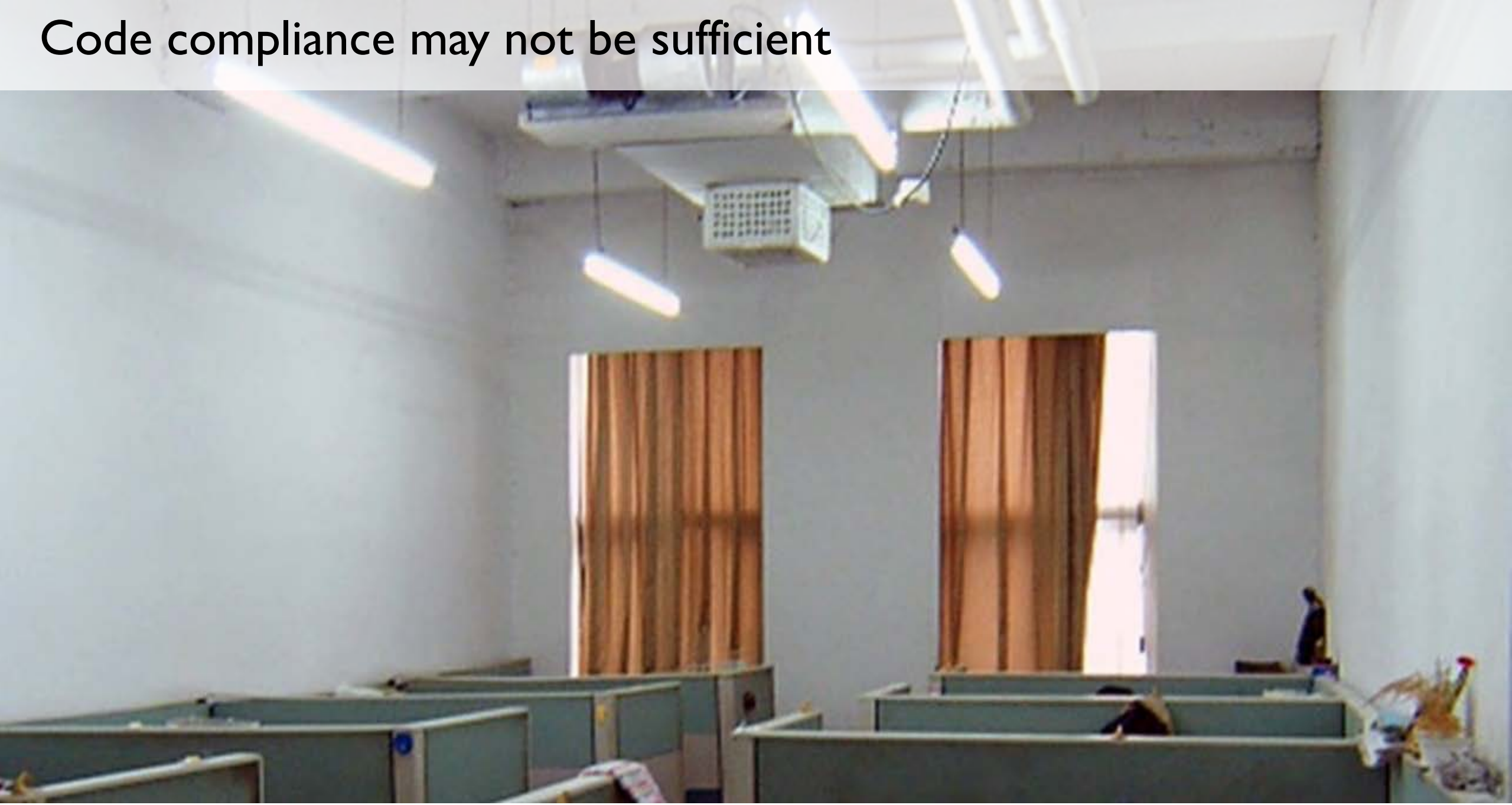


Photo by S. Schiavon

Good design may not be sufficient

Kresge Foundation HQ, US, by Valerio Dewalt Train Associates

Good design may not be sufficient

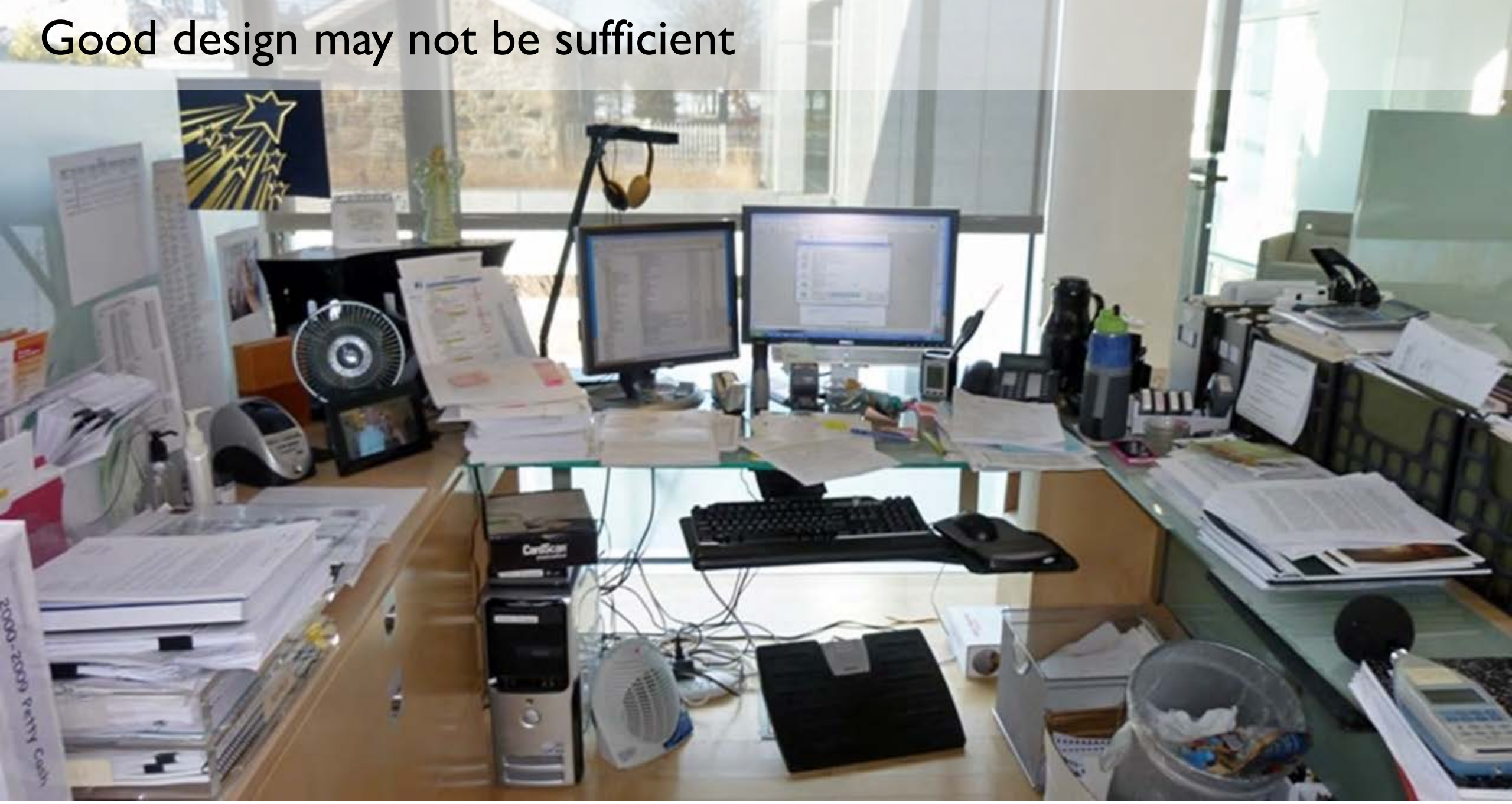
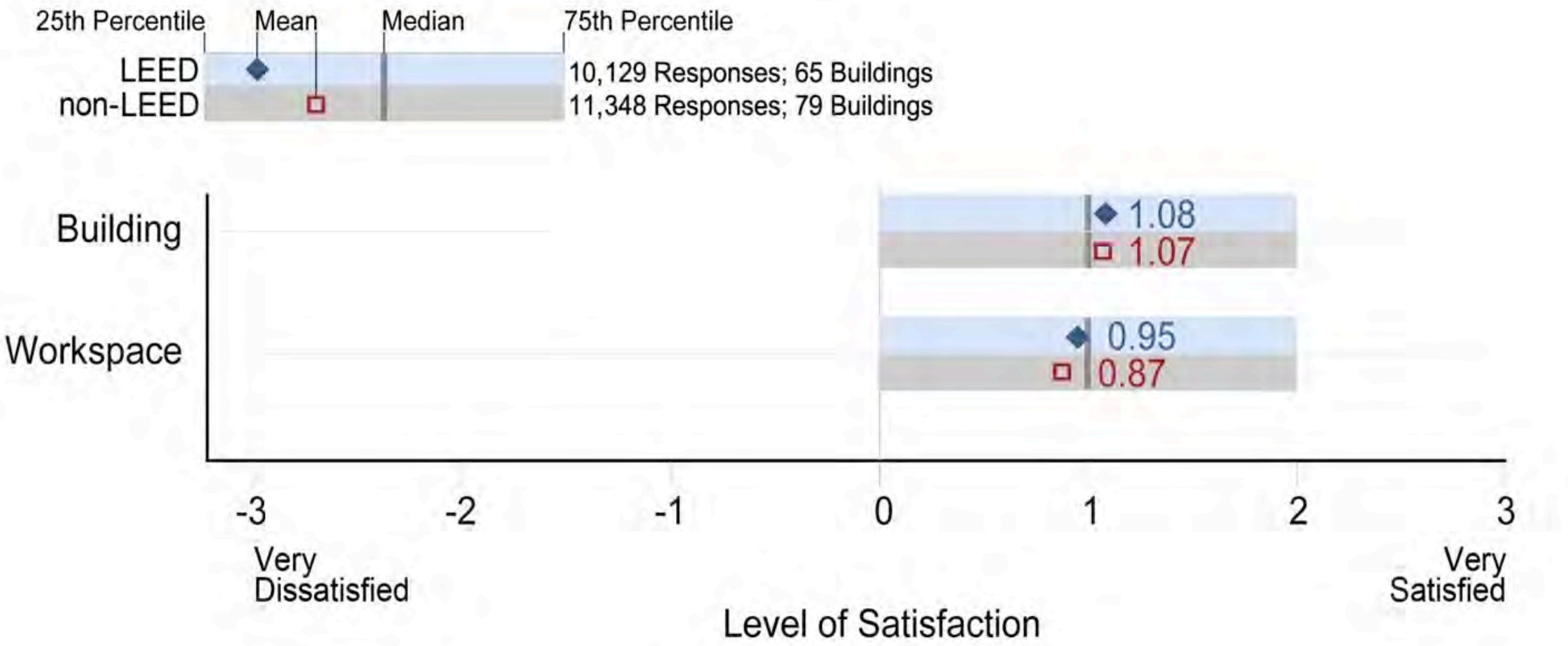


Photo by S. Schiavon

Green certification may not be sufficient



Altomonte & Schiavon 2013 *Building and Environment*

WHAT CAN WE DO?

Personal is the best option out there

Left: George Washington's Fan Chair, Mt Vernon, VA, circa 1790, Right: CBE Personal Comfort Chair

https://www.numaproducts.com/

WELL Standard V2

Part 1

Provide Personal Cooling Options (1 Point)

For All Spaces except Dwelling Units

All regular occupants can cool their individual environment through one or more of the following:

a. A user-adjustable thermostat connected to the building's mechanical cooling system or to an air conditioning unit. The room or thermal zone controlled by the thermostat may not be regularly occupied by more than one person.[1]

b. Desk fan or ceiling fan that does not increase air speed for other occupants.[1]

c. Chair with mechanical cooling system.[1]

d. Any other solution capable of affecting a PMV change of -0.5 within 15 minutes from activation, without changing the PMV for other occupants.[1]

Part 2

Provide Personal Heating Options (1 Point)

For All Spaces except Commercial Kitchen Spaces & Dwelling Units

All regular occupants can warm their individual environment through one or more of the following:

a. A user-adjustable thermostat connected to the building's mechanical heating system. The room or thermal zone controlled by the thermostat may not be regularly occupied by more than one person.[1]

b. Electric parabolic space heater.[1]

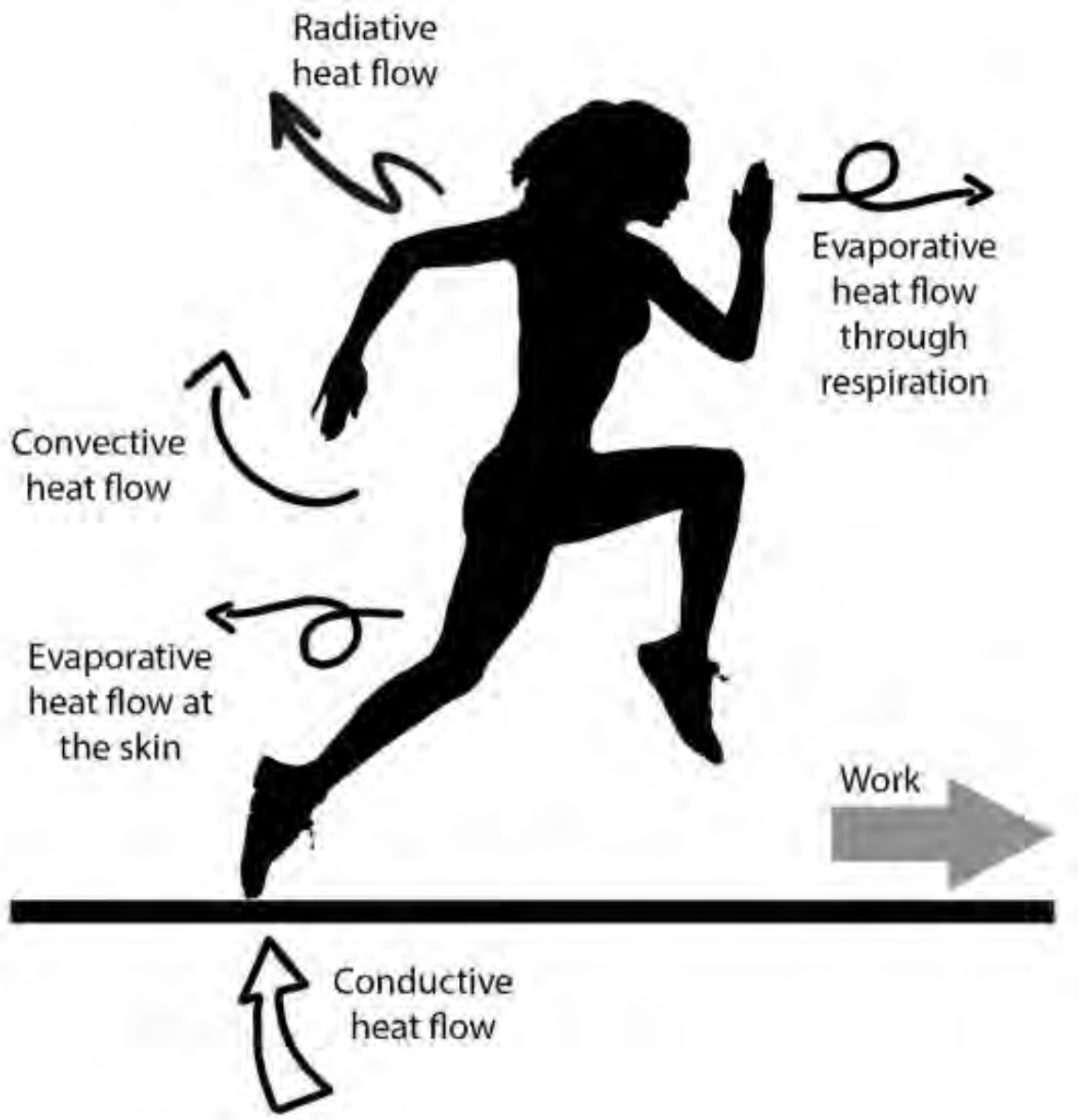
c. Electric heated chair or footwarmers.[1]

d. Blankets. Shared blankets that have been used are washed or disinfected at least weekly.[1]

e. Any other solution capable of affecting a PMV change of +0.5 within 15 minutes from activation, without changing PMV for other occupants.[1]

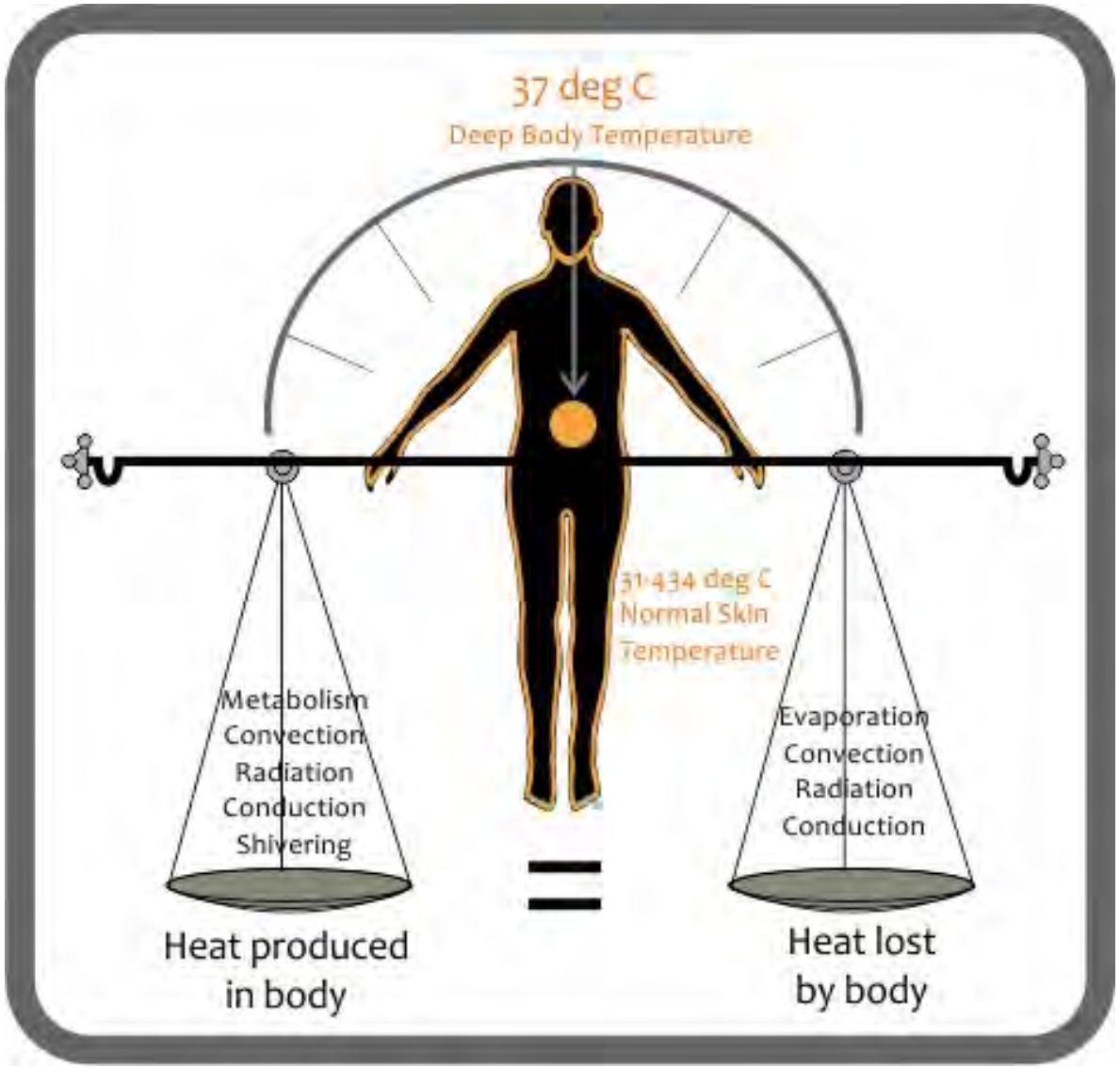
https://v2.wellcertified.com/en/wellv2/thermal%20comfort/feature/4

Body heat balance

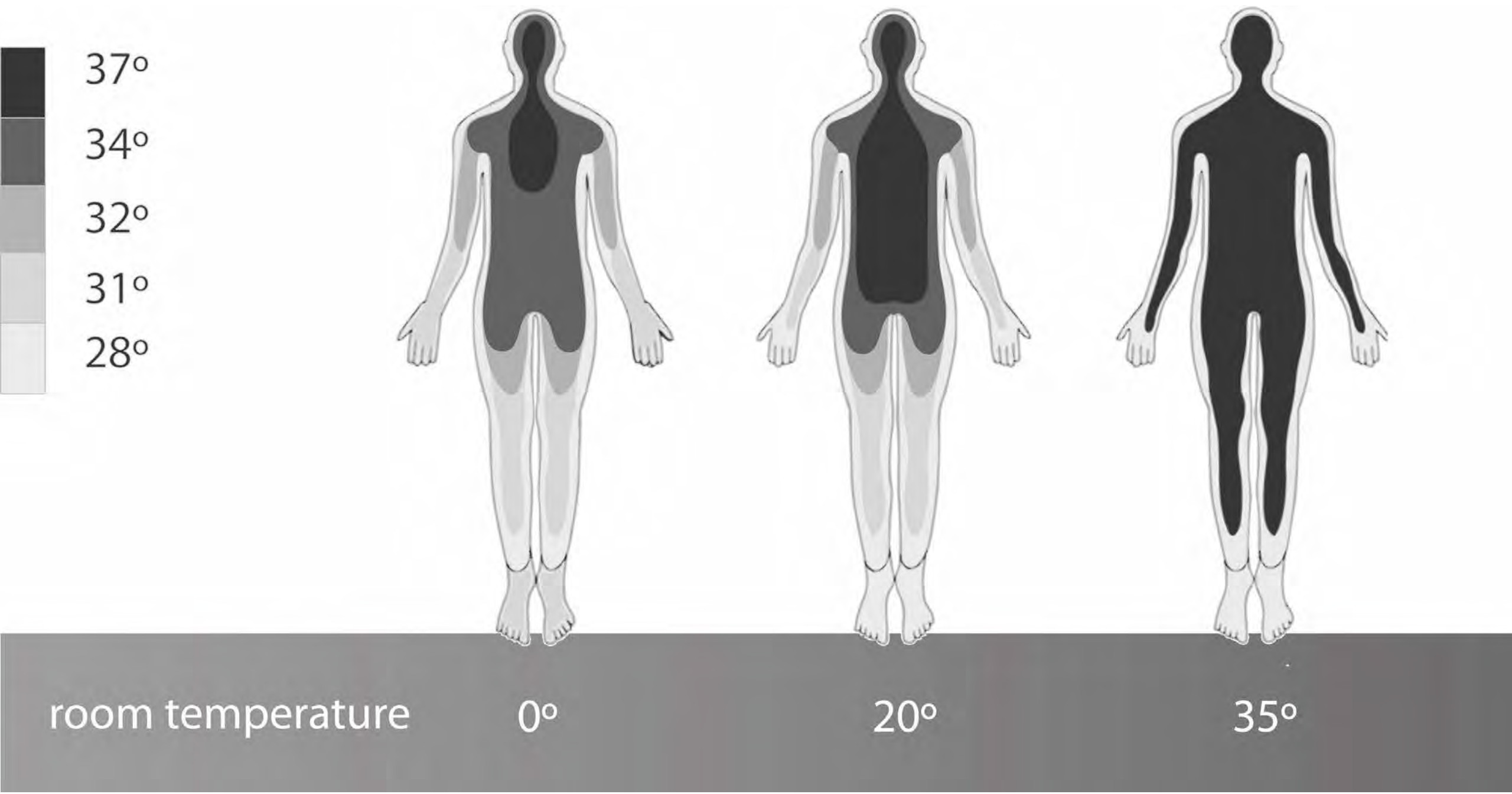


Source: https://www.mdpi.com/2073-4433/10/12/769/htm

Heat gains and losses



Source: https://nzebnew.pivotaldesign.biz/knowledge-centre/passive-design/thermal-comfort/



Source: Emanuele Nabboni

Physiological control mechanisms: Involuntary

1. Blood flow
   - vasoconstriction
   - vasodilation
2. Sweating
3. Shivering
4. Goosebumps

Behavioral control mechanisms: Voluntary

Environmental

- Turning on/off
  - Fan
  - Heating/Cooling
- Opening/closing
  - windows
  - blinds & shades

Behavioral control mechanisms: Voluntary

Personal

- Changing clothing
- Changing activity
- Changing posture
- Eating/drinking something cold or hot

Source: http://gawker.com/

Major variables influencing thermal comfort

Personal

1. Metabolic activity
2. Clothing

Environmental

1. Air temperature
2. Mean radiant temperature
3. Air Velocity
4. Humidity

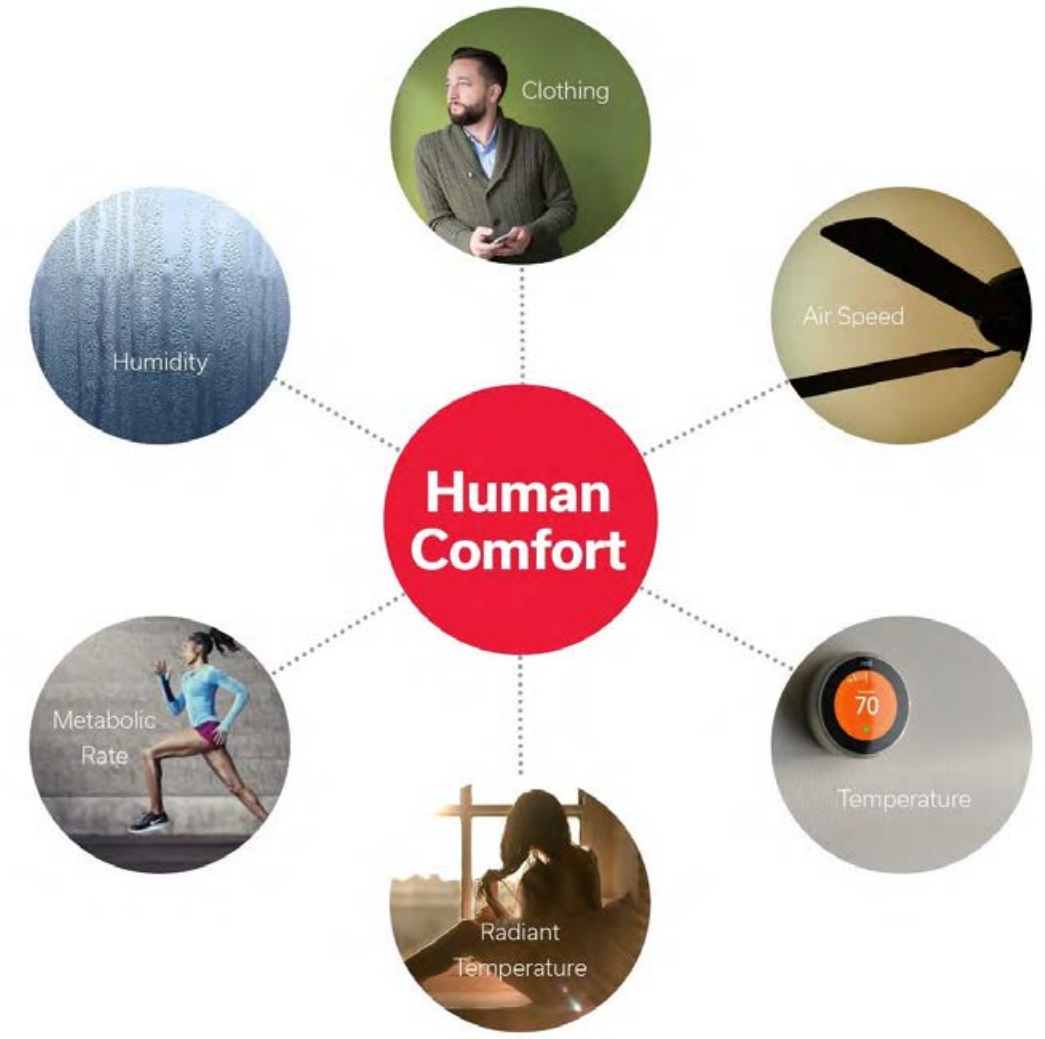
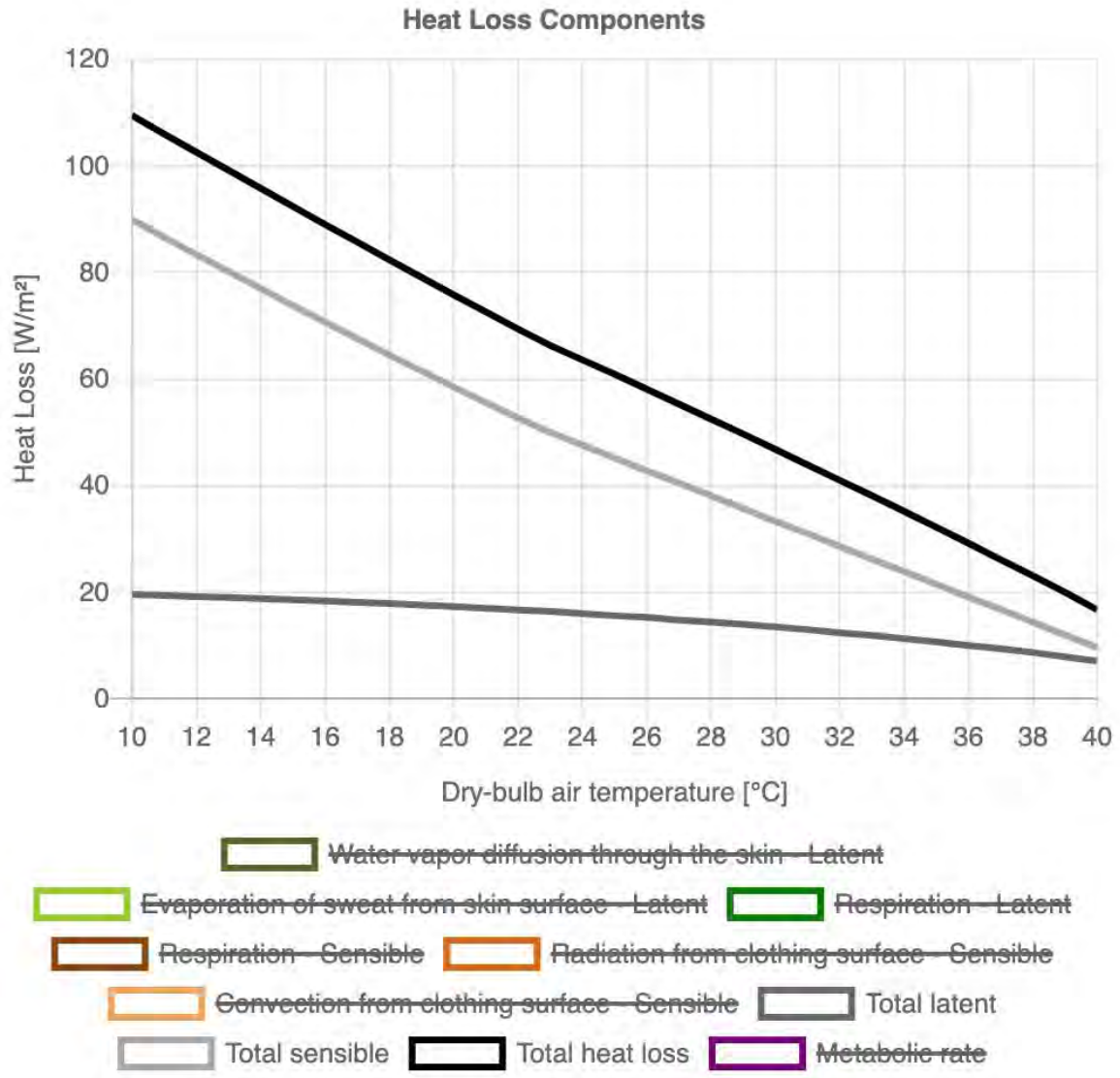


Image courtesy of: Paul Schwer, PAE engineers

Dry-bulb (air) temperature (DBT)

DBT is the temperature of air measured by a thermometer freely exposed to the air but shielded from radiation and moisture

Effect of air temperature & heat loss



https://comfort.cbe.berkeley.edu/

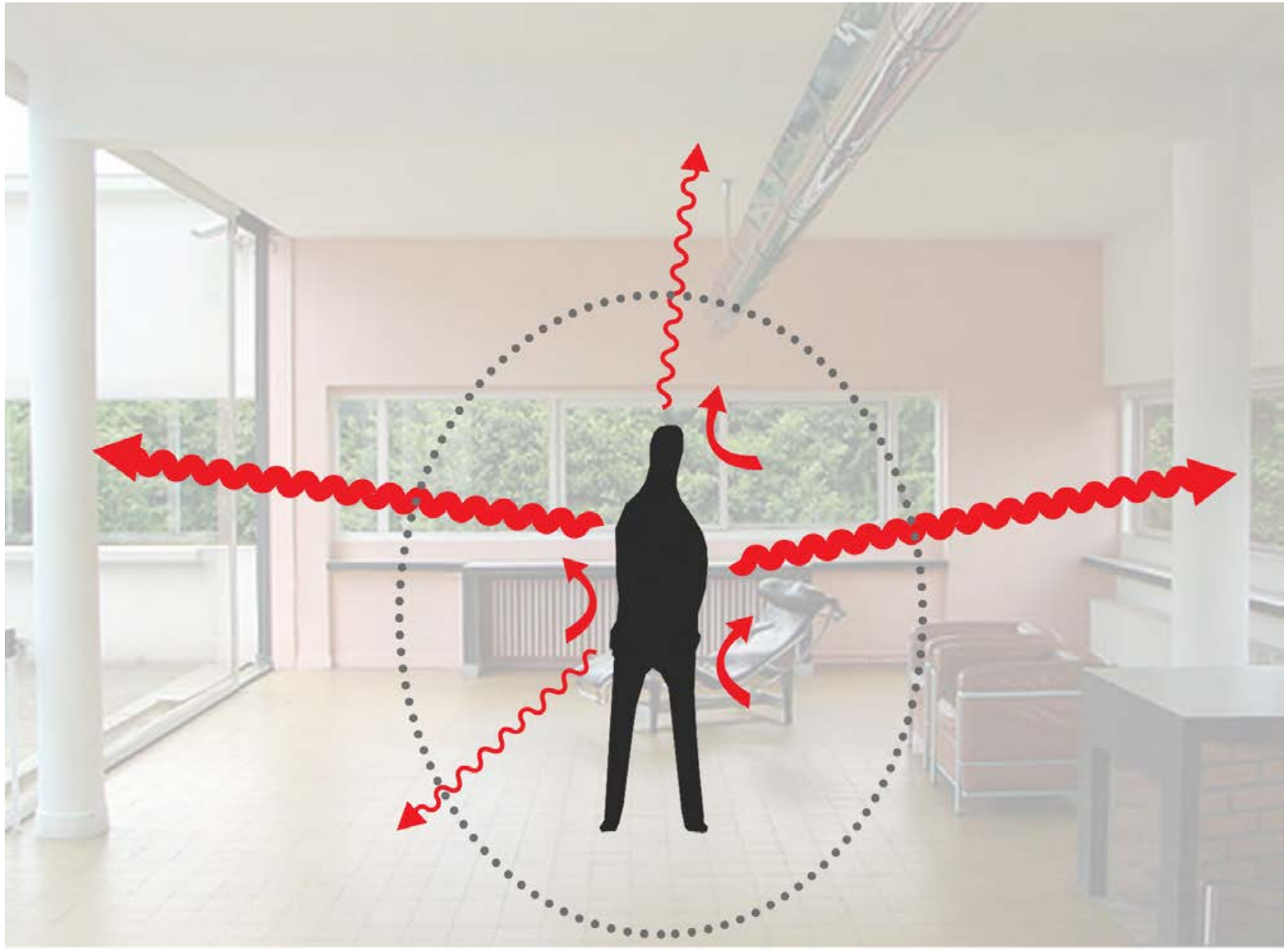
Temperatures in a complex environment

Villa Savoye by Le Corbusier and Pierre Jeanneret

Temperatures in a complex environment

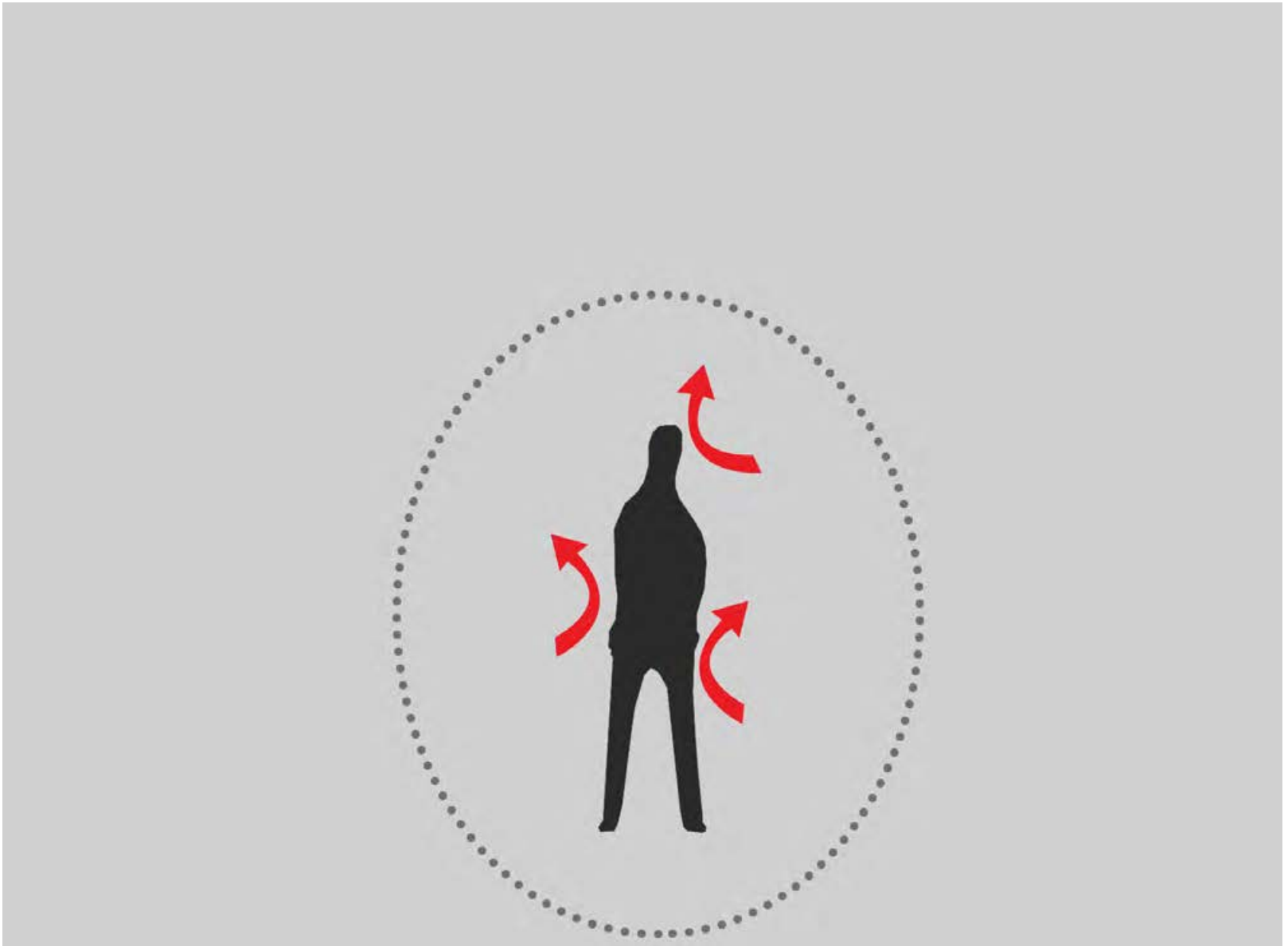
Source: Caroline Karmann

Temperatures in a complex environment



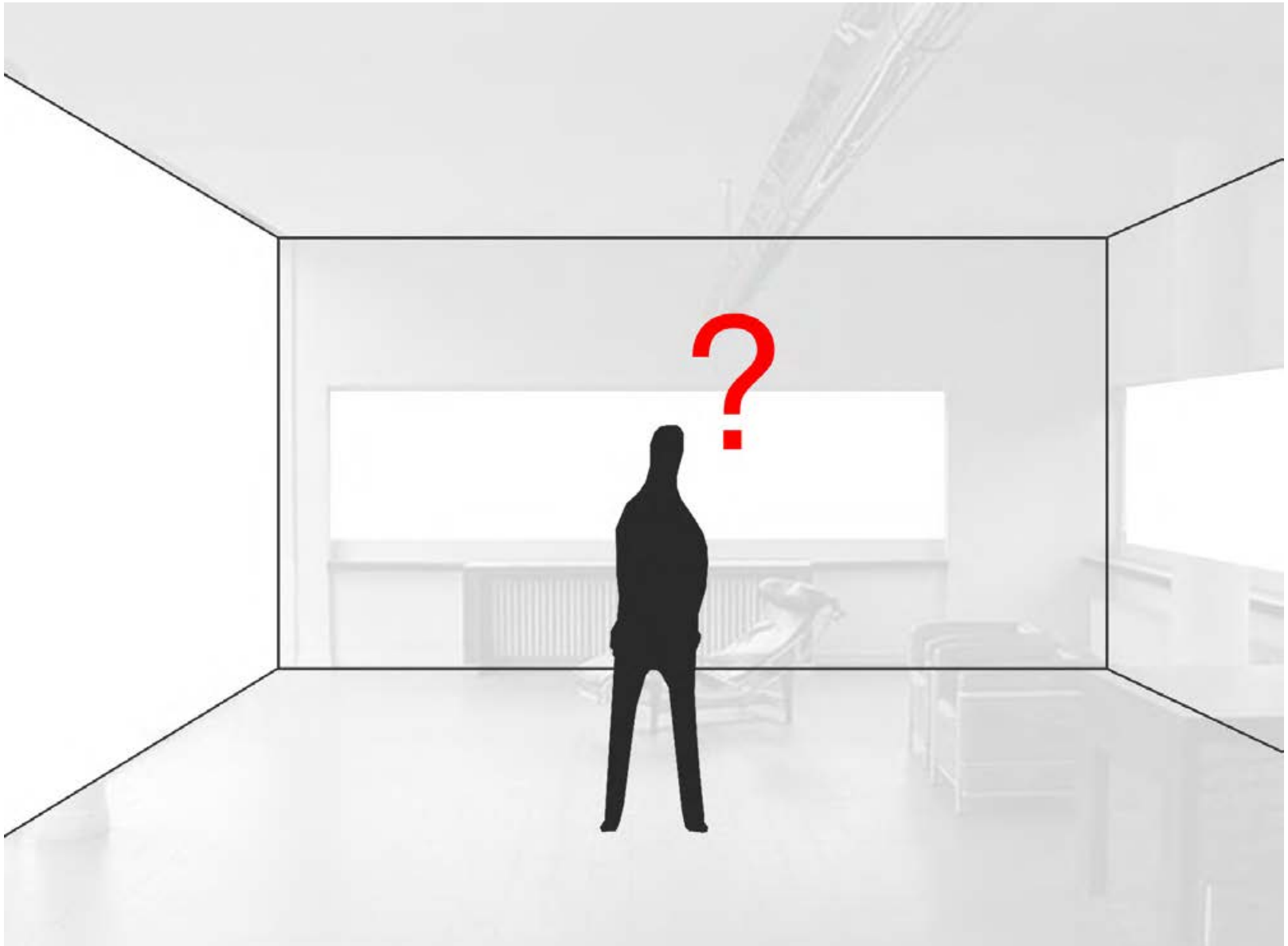
Source: Caroline Karmann

Air temperature



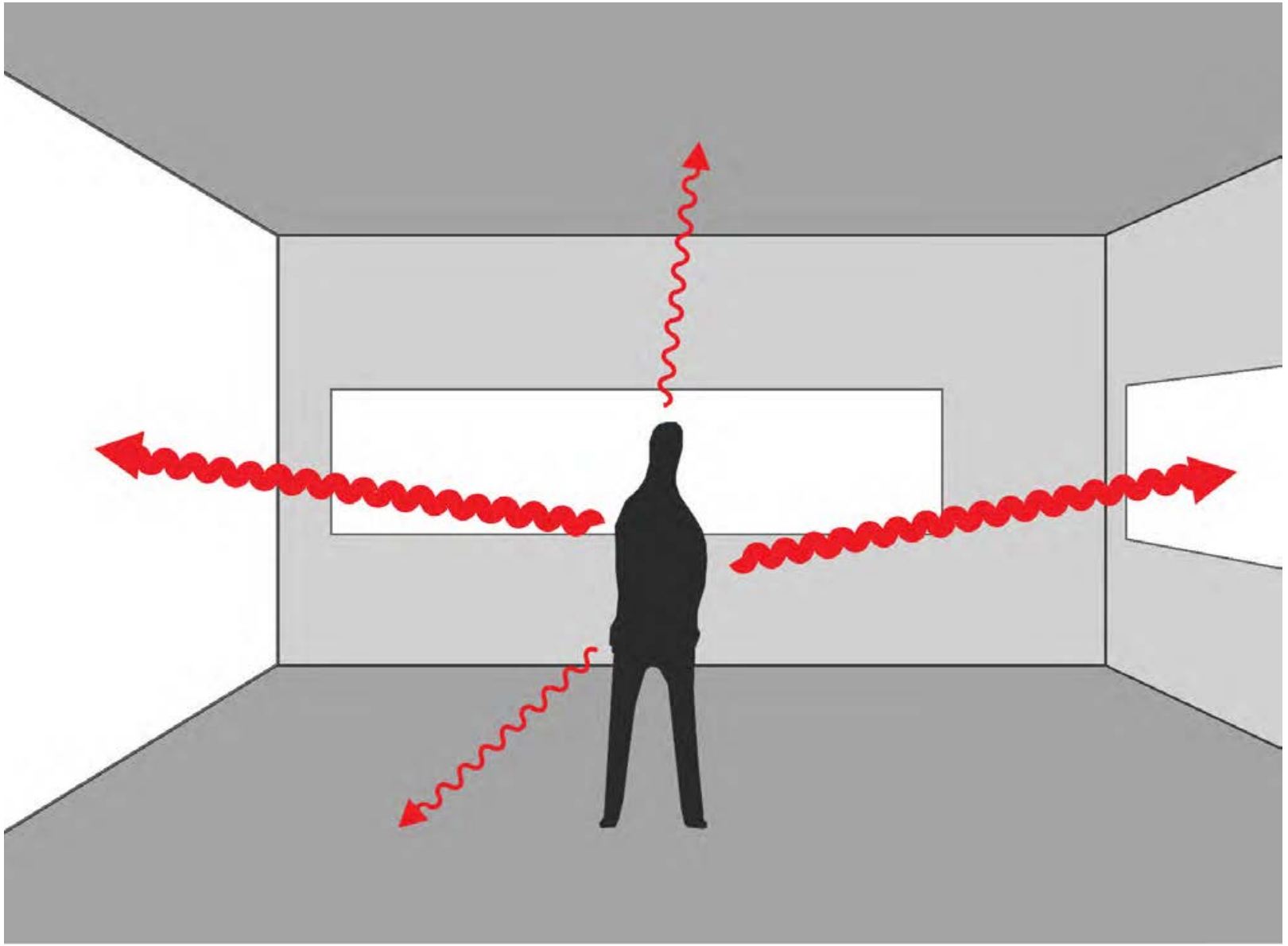
Source: Caroline Karmann

Surface temperatures



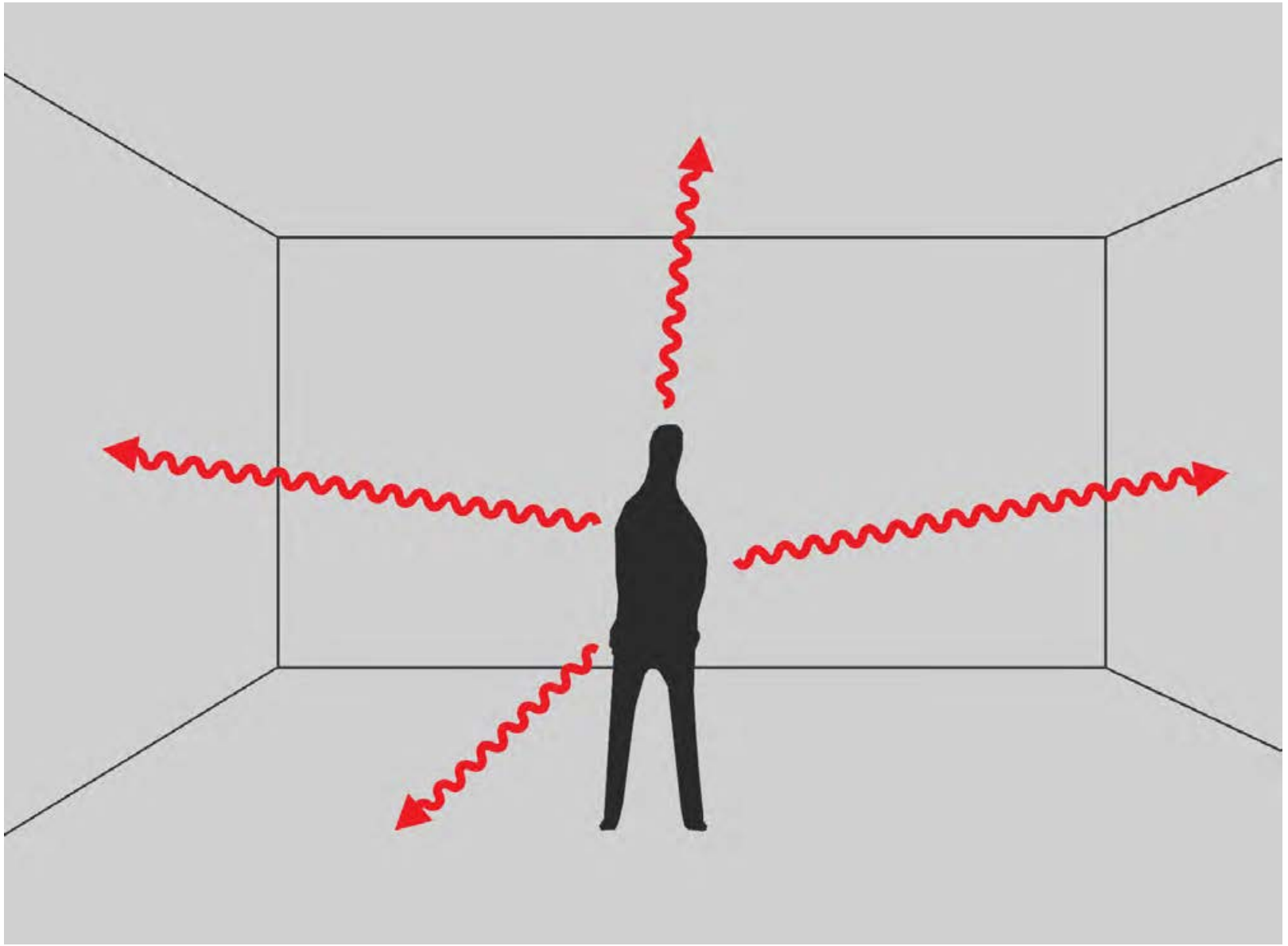
Source: Caroline Karmann

Surface temperatures



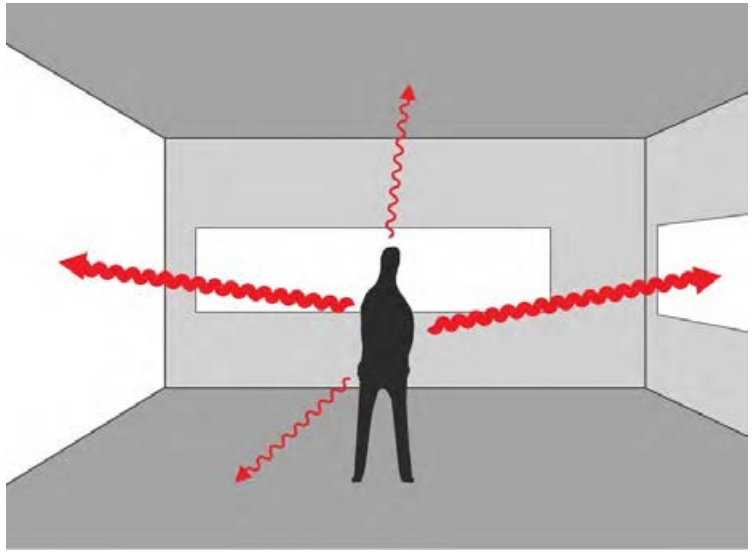
Source: Caroline Karmann

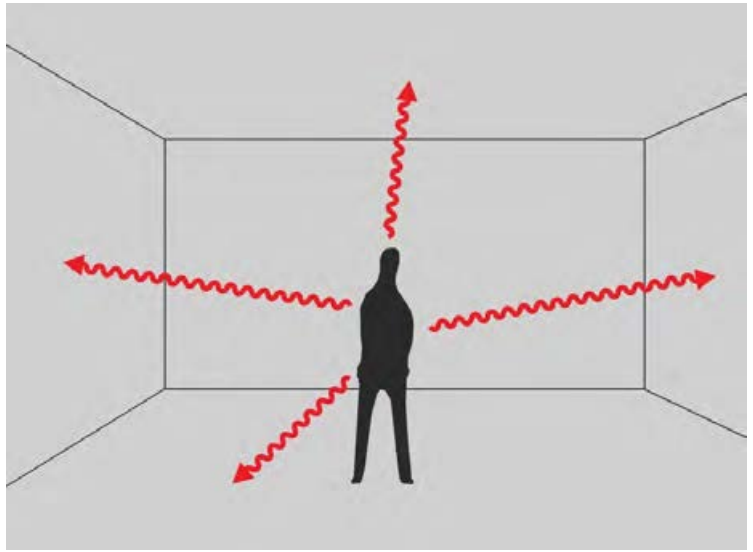
Mean radiant temperature



Source: Caroline Karmann

Mean radiant temperature

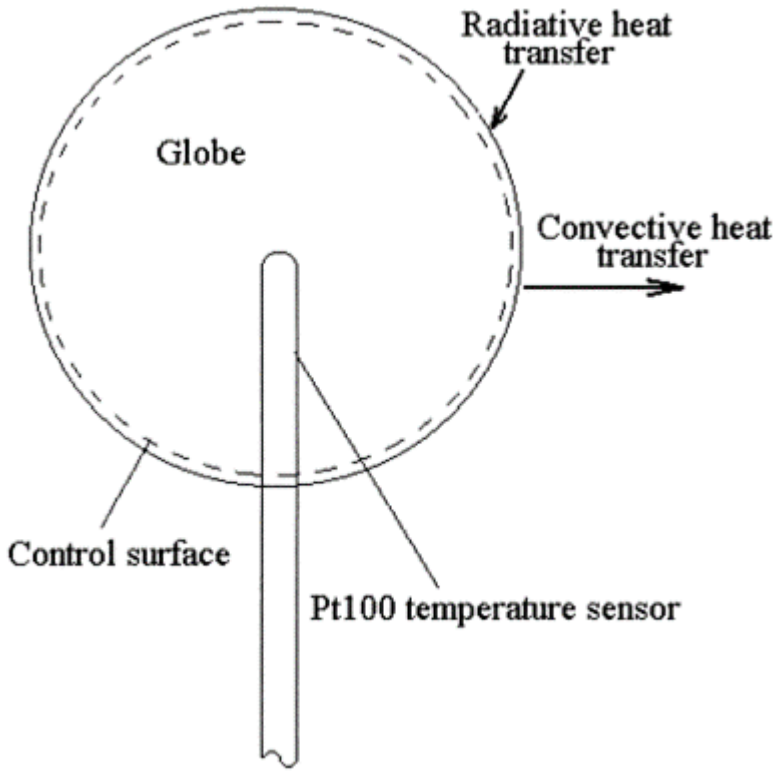




- MRT: the uniform surface temperature of an imaginary black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual nonuniform space
- In a non uniform thermal environment the MRT change in each point of the room

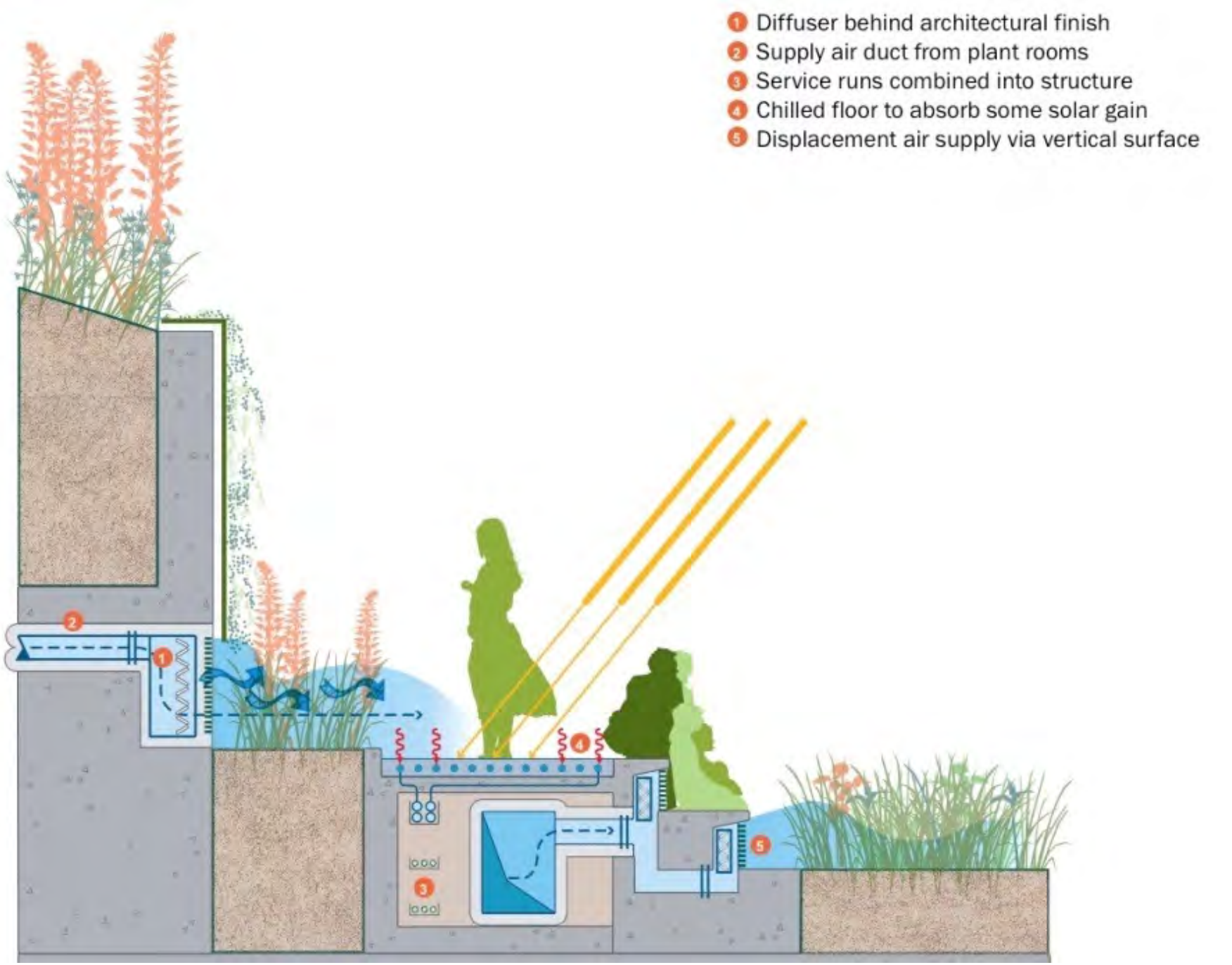
Source: Caroline Karmann

Globe thermometer



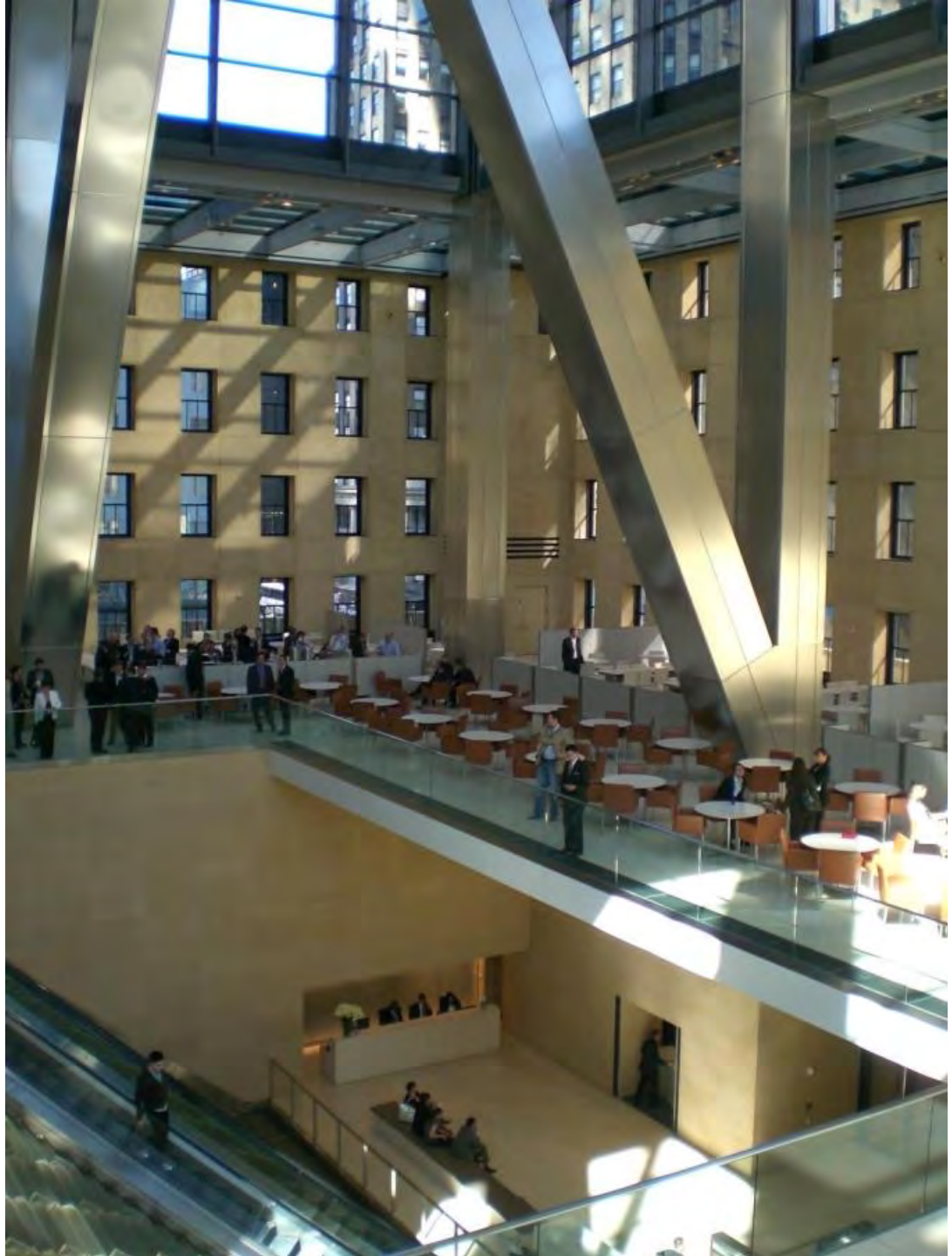
http://dx.doi.org/10.1016/S0263-2241(00)00033-6

Sendai Mediatheque by Toyo Ito

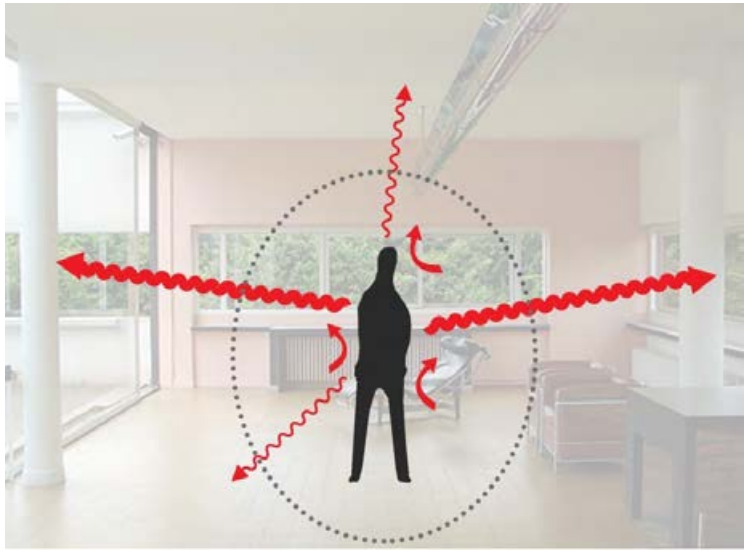


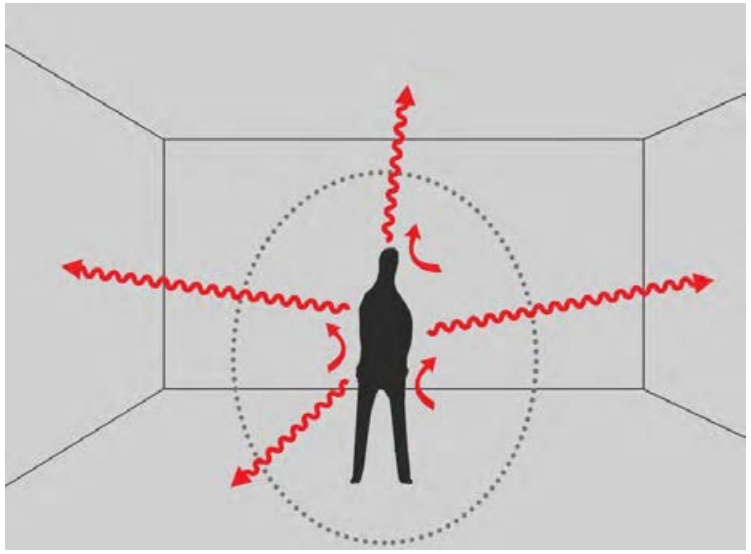
Garden by the Bay, Singapore. Source: Atelier Ten

Hearst Tower By Norman Foster, NY, US



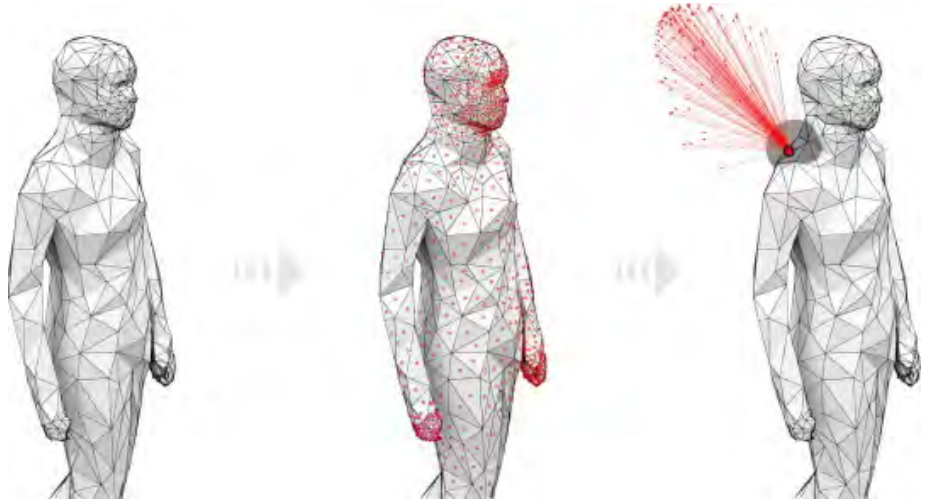
Operative temperature

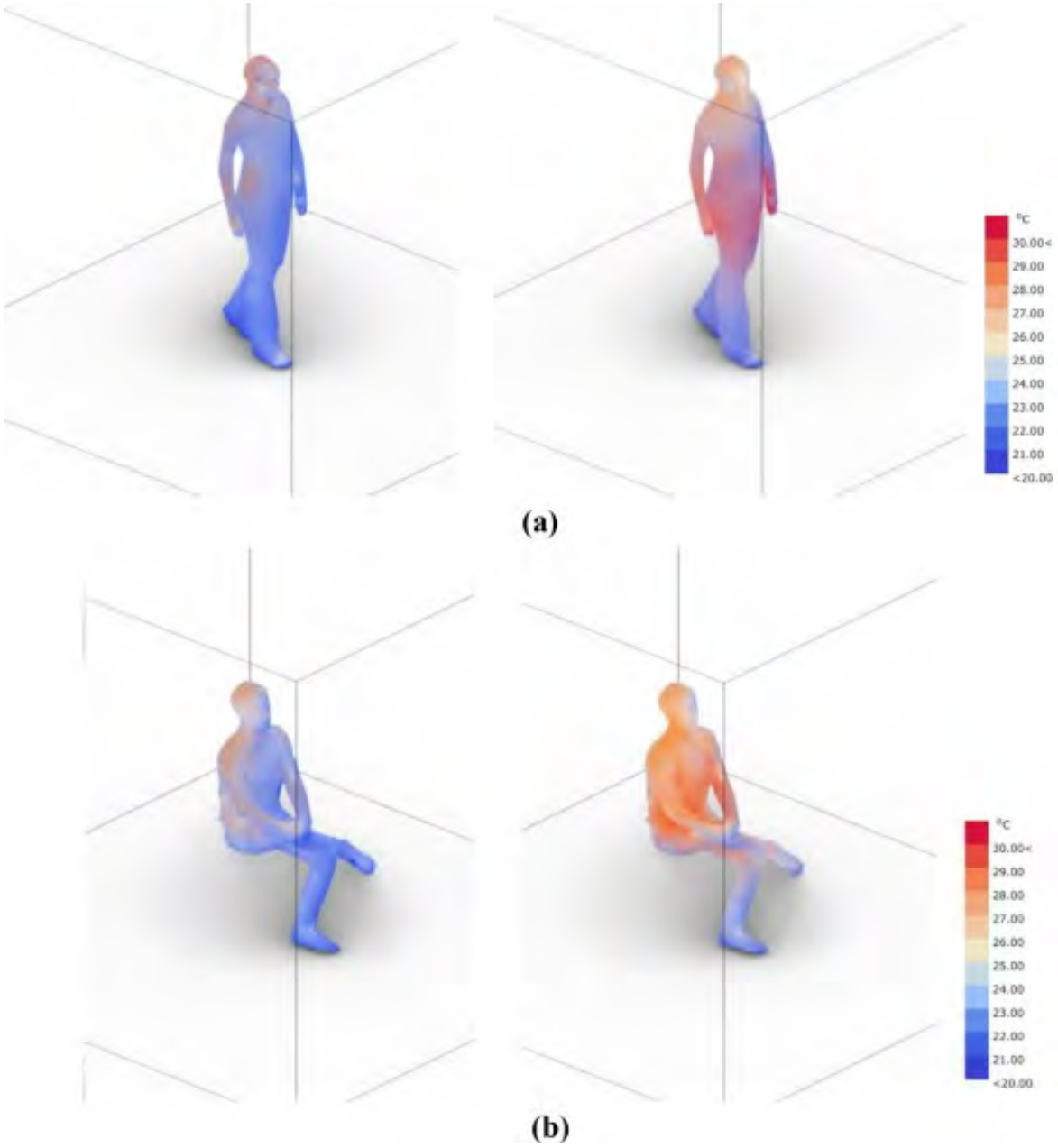




Operative temperature: the uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment.

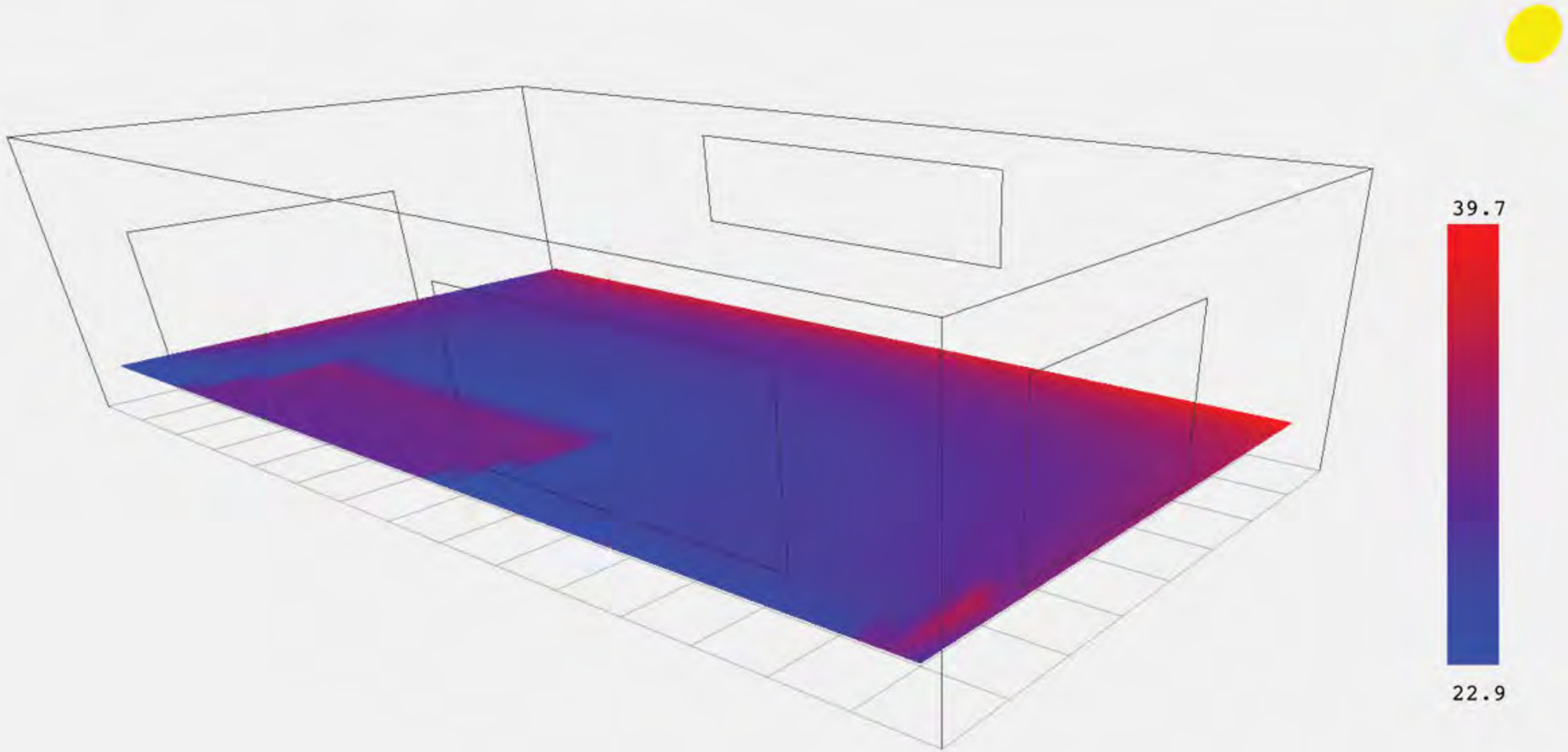
Mean Radiant Temperature





MRT is a spatial property, it may change in every point of the room and depend on people position. Source: Avit et al 2022.

MRT: 28.8
Occupant (x, y): (4.8, 5.4)



Humidity

Souirce: https://en.wikipedia.org/wiki/Humidity

Measures of humidity

RH	**Relative Humidity**	(%)
DP	**Dew Point temperature**	(°F)
WB	**Wet-Bulb temperature**	(°F)
W	**Humidity ratio**	(lb,water / lb,air)

http://en.wikipedia.org/wiki/Humidity

Major variables influencing thermal comfort

Environmental

1. Air temperature
2. Mean radiant temperature
3. Air Velocity
4. Humidity

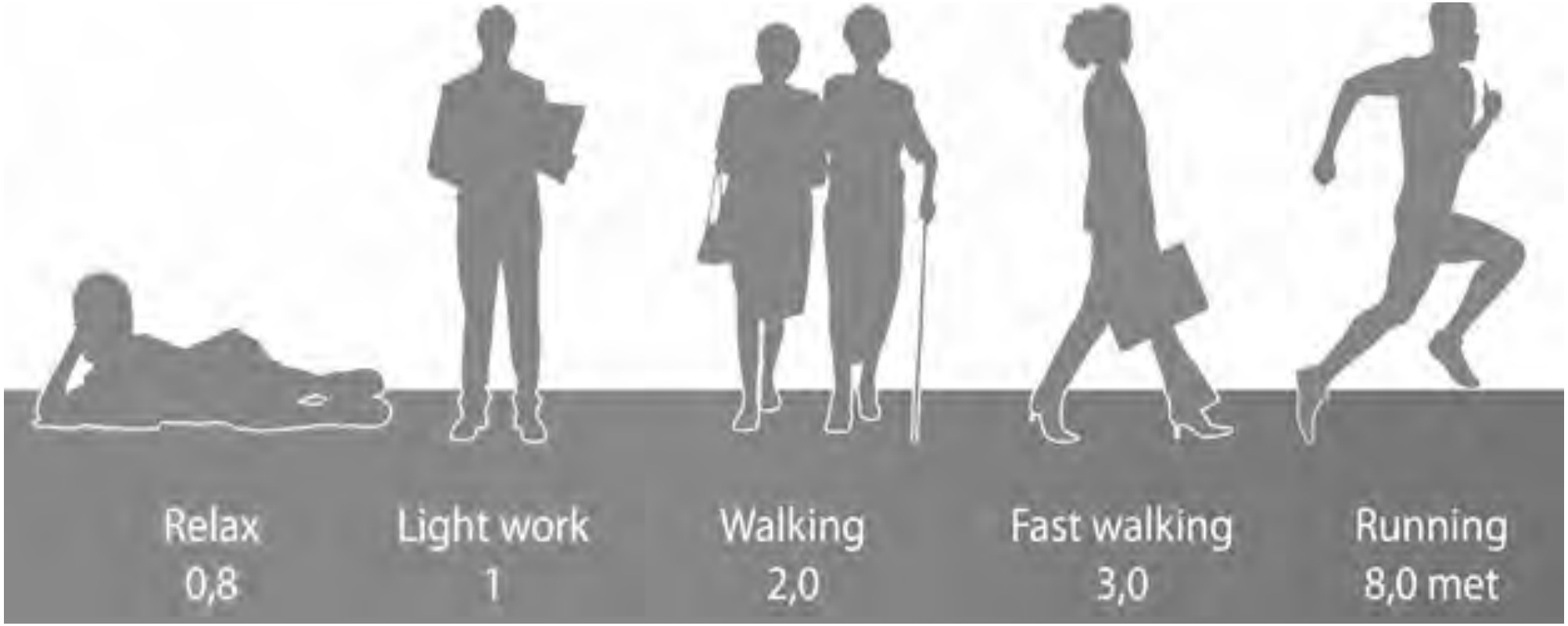
Personal

1. Metabolic activity
2. Clothing

Measurable factors that influence the body's heat balance

Metabolic activity: Heat produce

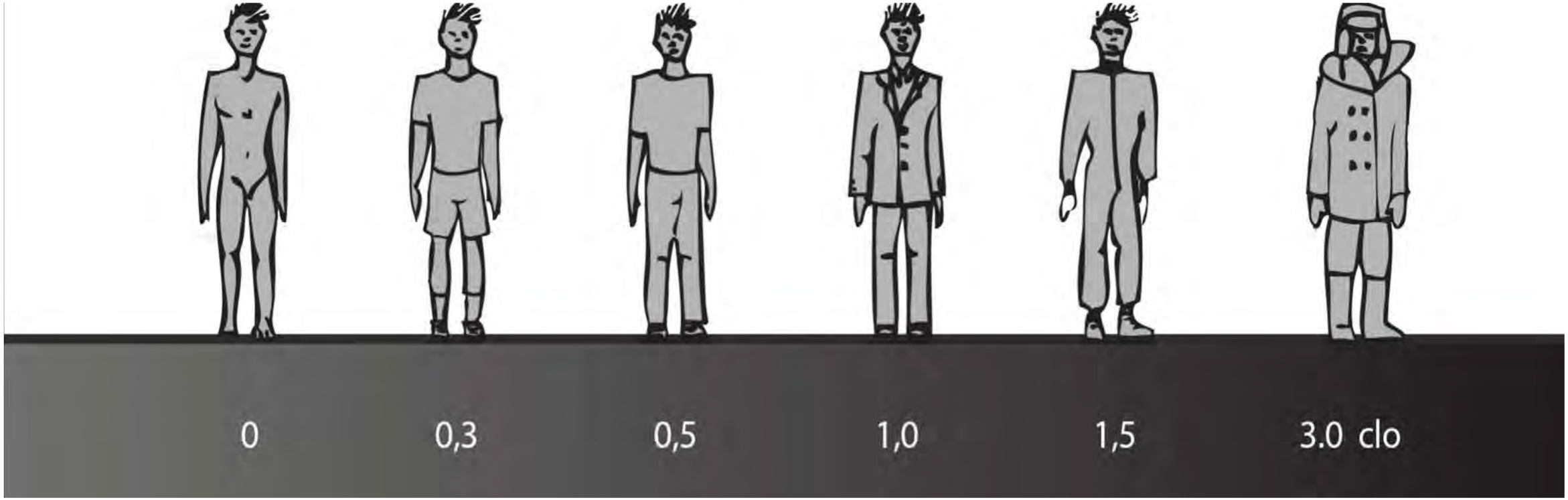
- 1 MET = 18.4 Btu/ft^2-hr (58 W/m^2) = Sedentary activity
- Approx. equivalent to a 100 W light bulb



Source: Emanuele Nabboni. Table of activity & met values - See http://cbe.berkeley.edu/comforttool/

Clothing insulation

1 CLO = 0.88 (hr ft^2 °F/Btu), 0.155 m^2 C/W
1 CLO = typical 3-piece suit

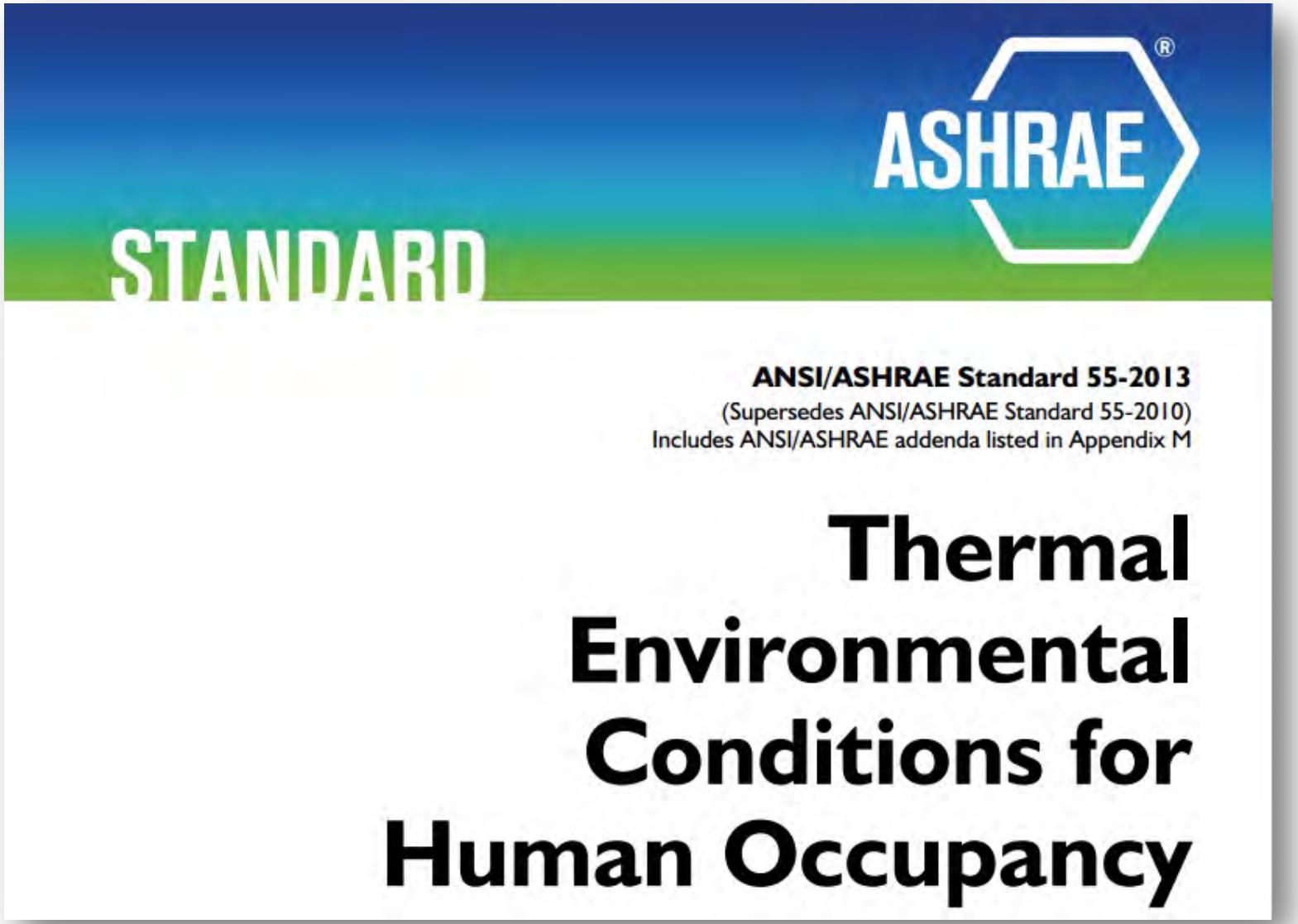


Source: Emanuele Nabboni

Clothing adaptation

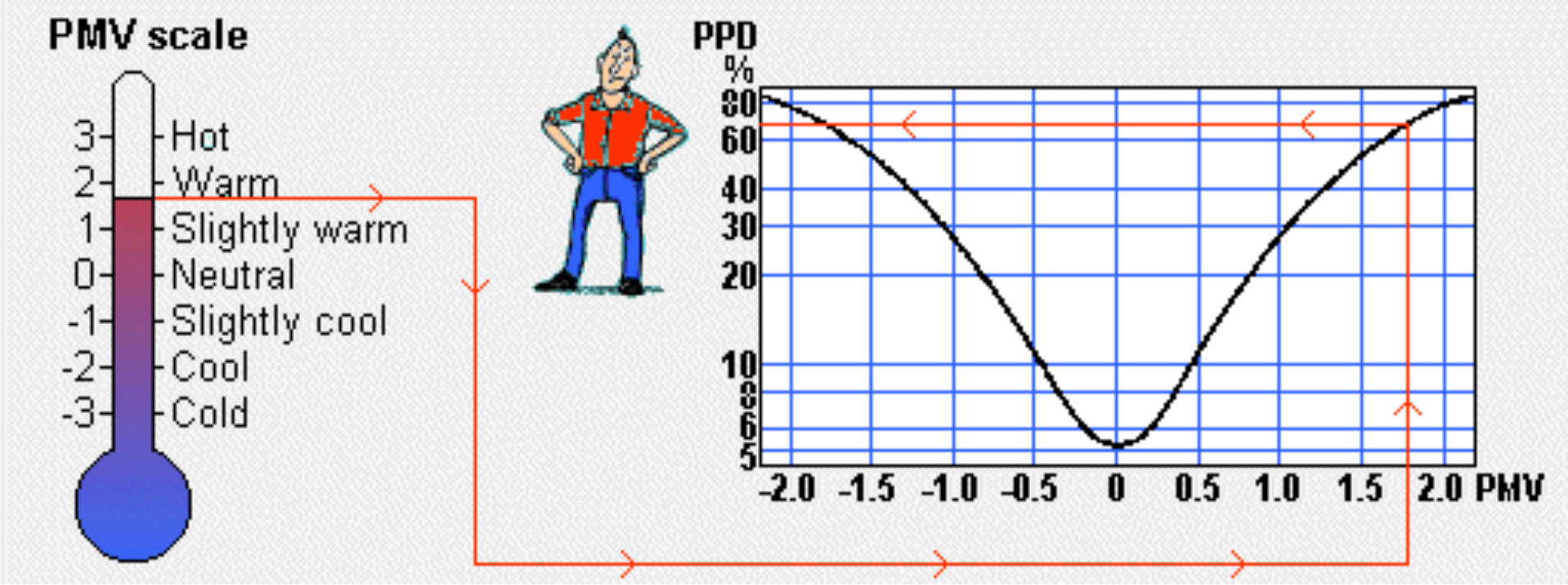
Source: https://de.wikipedia.org/wiki/Datei:Nivkh_men.jpg

ASHRAE Thermal Comfort Standard



American Society of Heating, Refrigerating, and Air-Conditioning Engineers

ASHRAE Std 55-2020: PMV / PPD



PMV: Predicted Mean Vote

PPD: Predicted Percentage of Dissatisfied.

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CBE Thermal Comfort Tool

Help Other CBE tools

ASHRAE-55 EN-16798 Compare Ranges Upload Fans & Heat PHS

Inputs

Select method: PMV method

Air temperature

25 °C ☐ Use operative temp

Mean radiant temperature

25 °C

Air speed

0.1 m/s No local control

Relative humidity

50 % Relative humidit

Metabolic rate

1 met Seated, quiet: 1.(

Clothing level

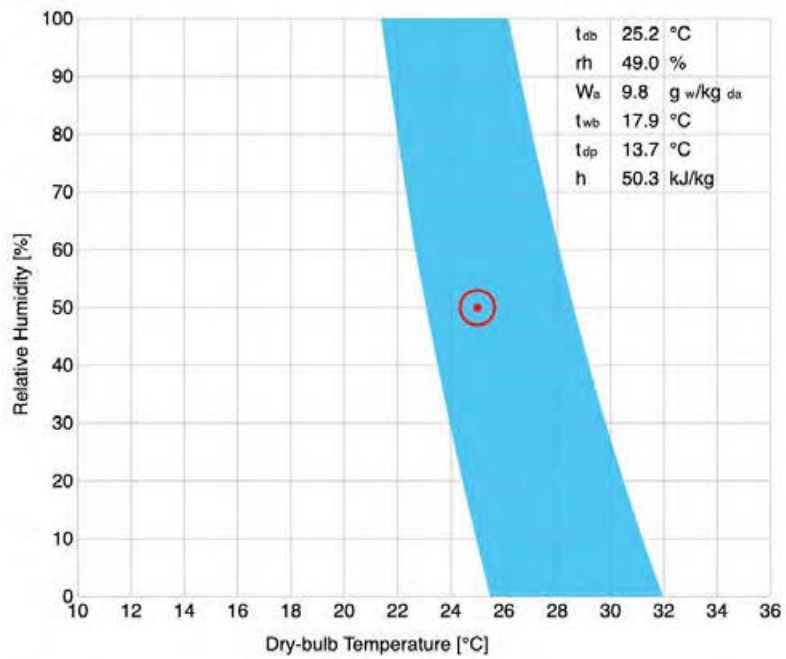
0.61 clo Trousers, long-s

✓ Complies with ASHRAE Standard 55-2020

PMV = -0.16 PPD = 6 %

Sensation = Neutral SET = 24.8 °C

Relative humidity vs. air temperature



NOTE: This chart represents only two variables, dry-bulb temperature and relative humidity. The PMV calculations are still based on all the psychrometric variables, but the visualization becomes easier to understand.

http://comfort.cbe.berkeley.edu/

DEMO

pythermalcomfort

Python package to calculate thermal comfort indices.

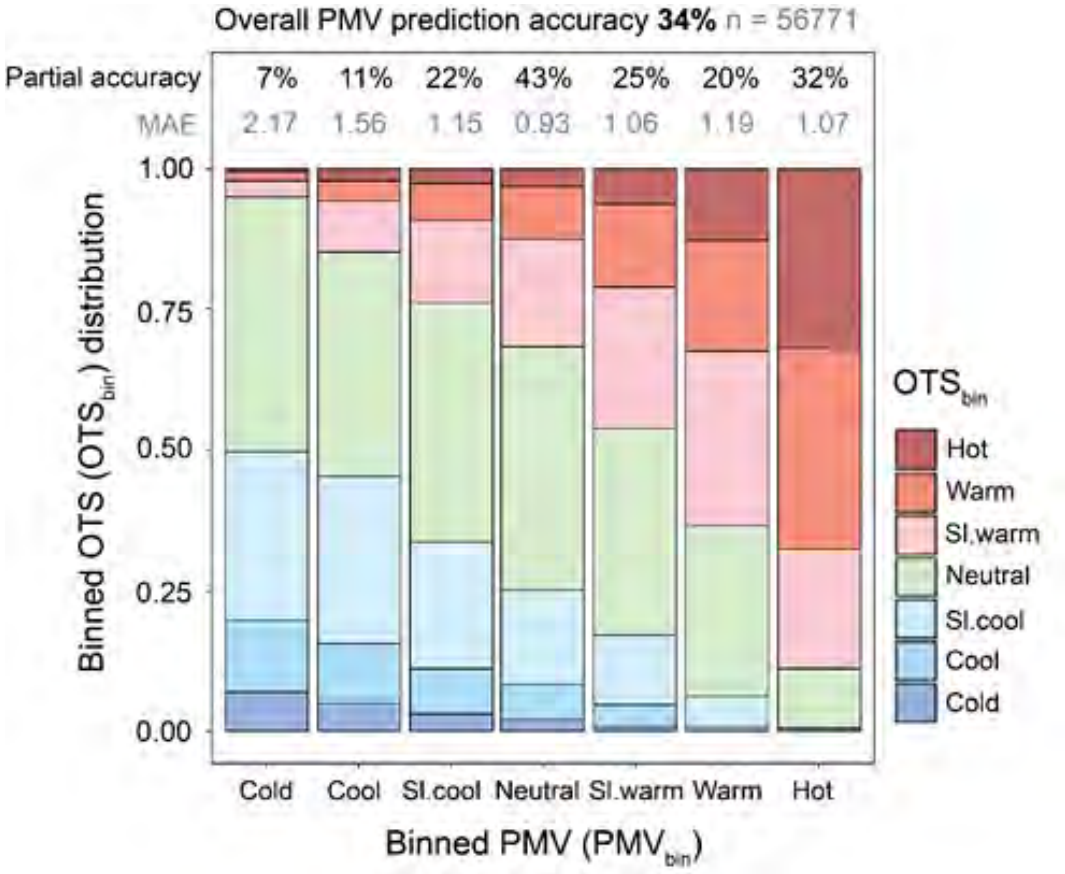
Comfort models available:

- Predicted Mean Vote (PMV);
- Standard Effective Temperature (SET);
- Adaptive model (ASHRAE and EN);
- Solar gains estimation on people.

https://pypi.org/project/pythermalcomfort/

On the accuracy of the PMV-PPD model

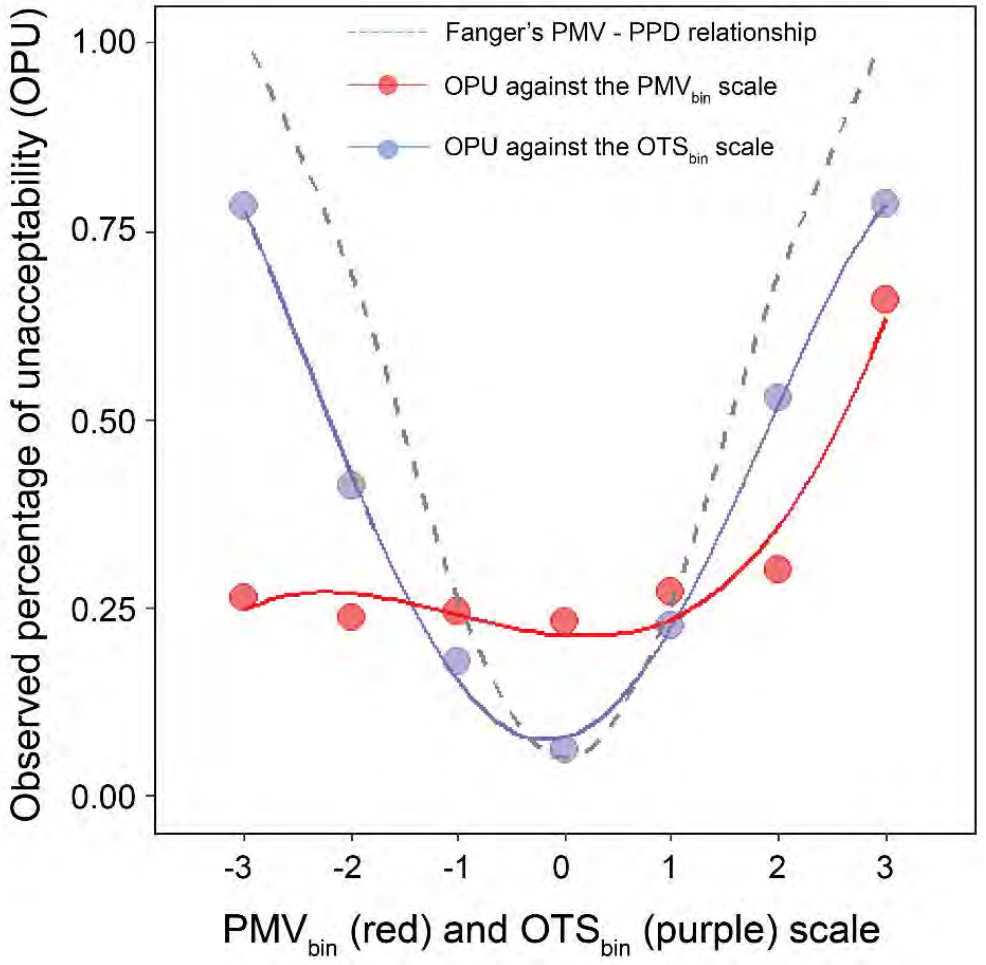
PMV predicted thermal sensation
correctly only
one out of three times



Cheung, Schiavon, Parkinson, Li, Brager 2019 *Building and Environment*

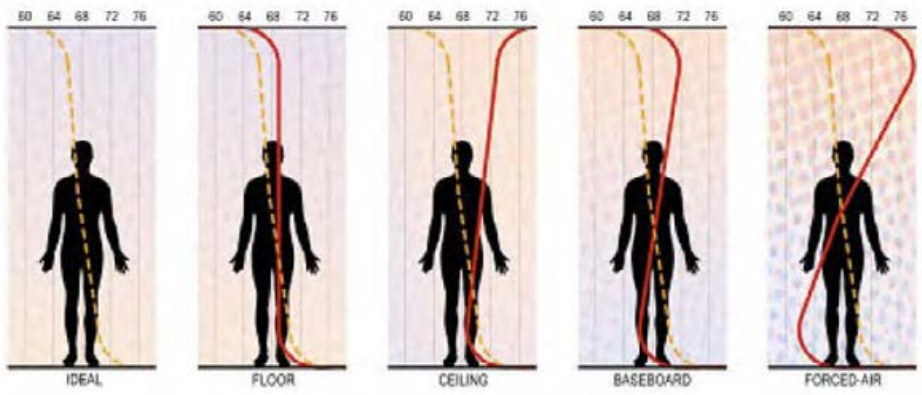
On the accuracy of the PMV-PPD model

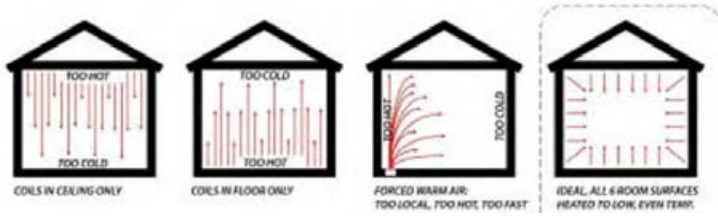
PPD model should not be used in practice nor in thermal comfort standards

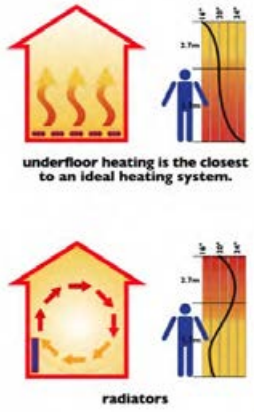


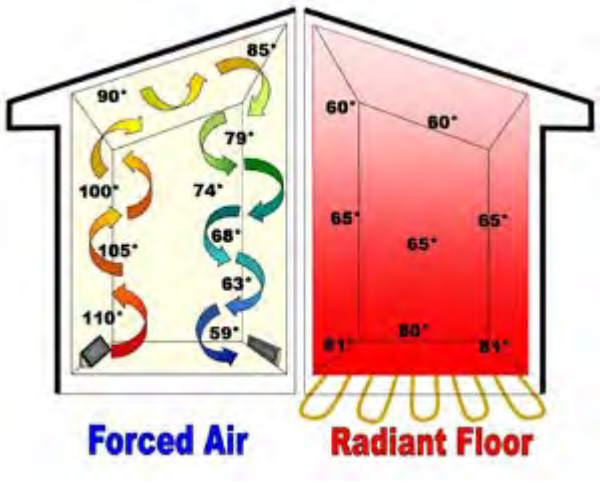
Cheung, Schiavon, Parkinson, Li, Brager 2019 *Building and Environment*

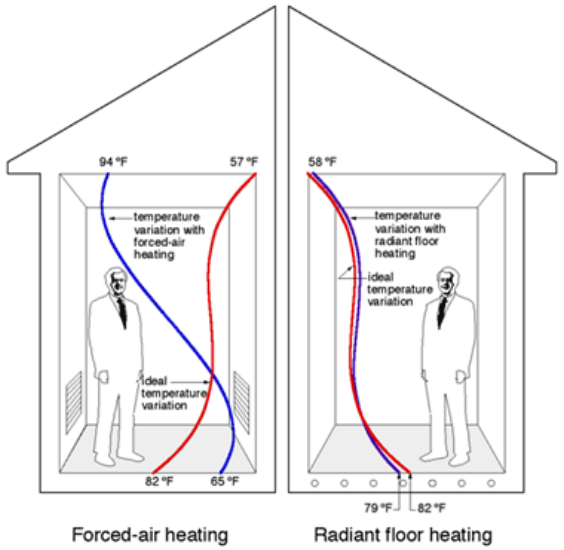
Is a uniform environment more comfortable?











Adaptive model

Inputs

Select method: Adaptive method

Mean radiant temperature

25 °C

Prevailing mean outdoor temperature

25 °C

Air speed

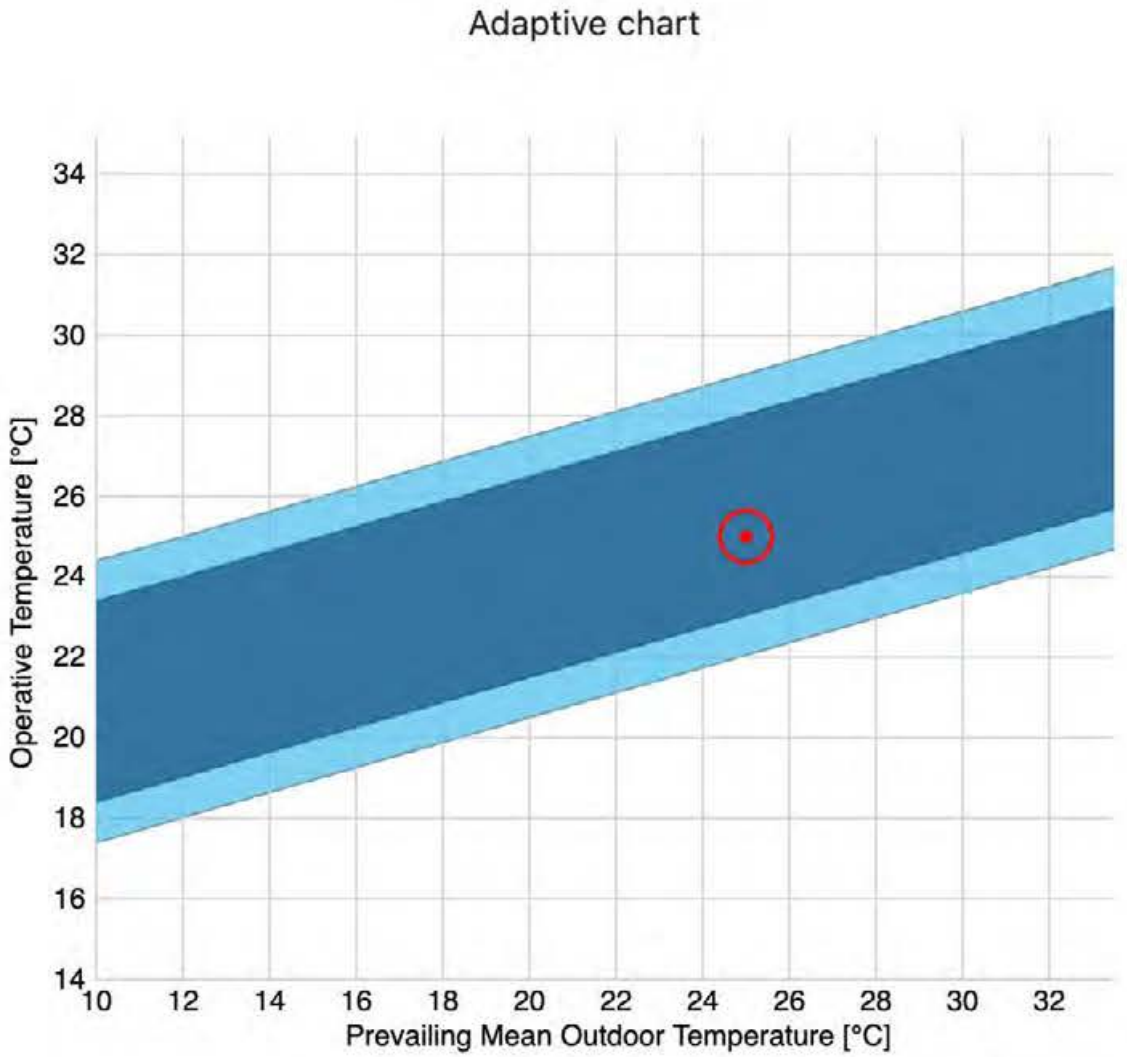
0.3 m/s (59 fpm)

Set pressure | SI/IP

Local discomfort | Globe temp

Reset | Save | Reload | Share

Documentation



BCA ZEB Plus, Singapore

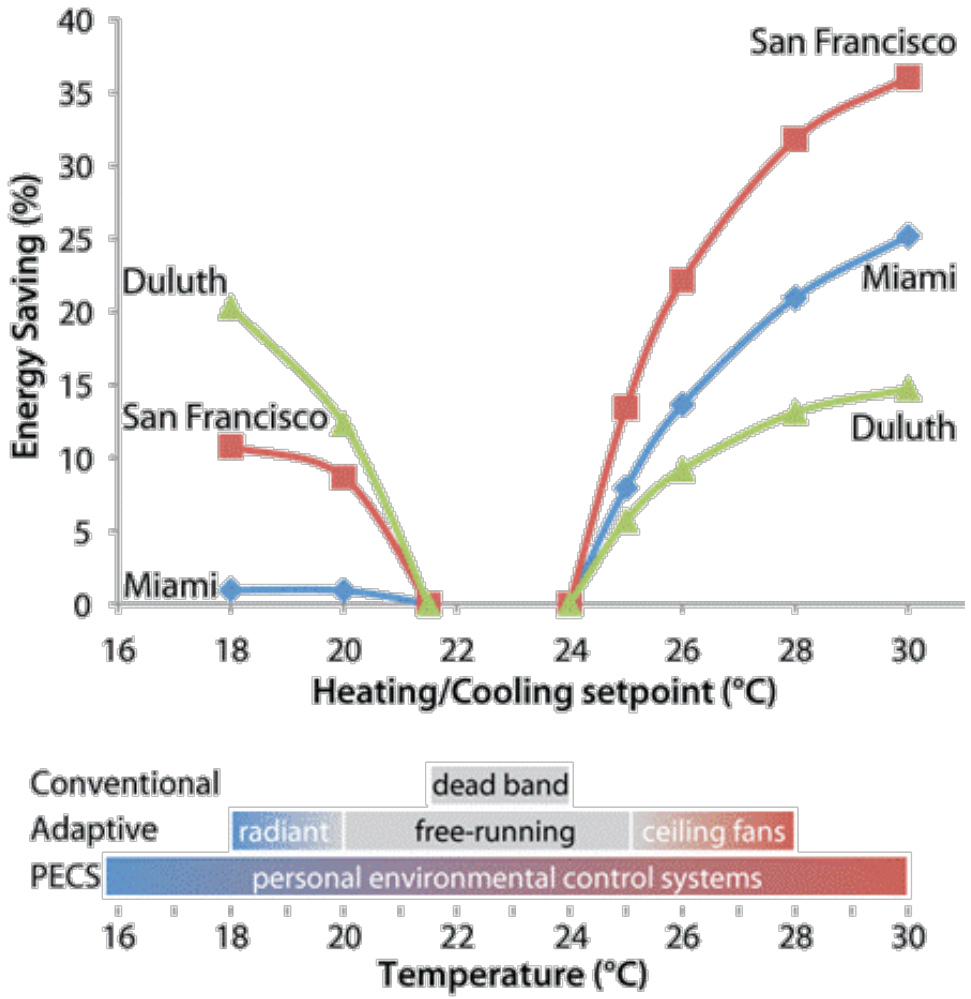
Energy savings and comparative costs

500 – 1500 W
Thousands $

2-100 W
Hundreds $

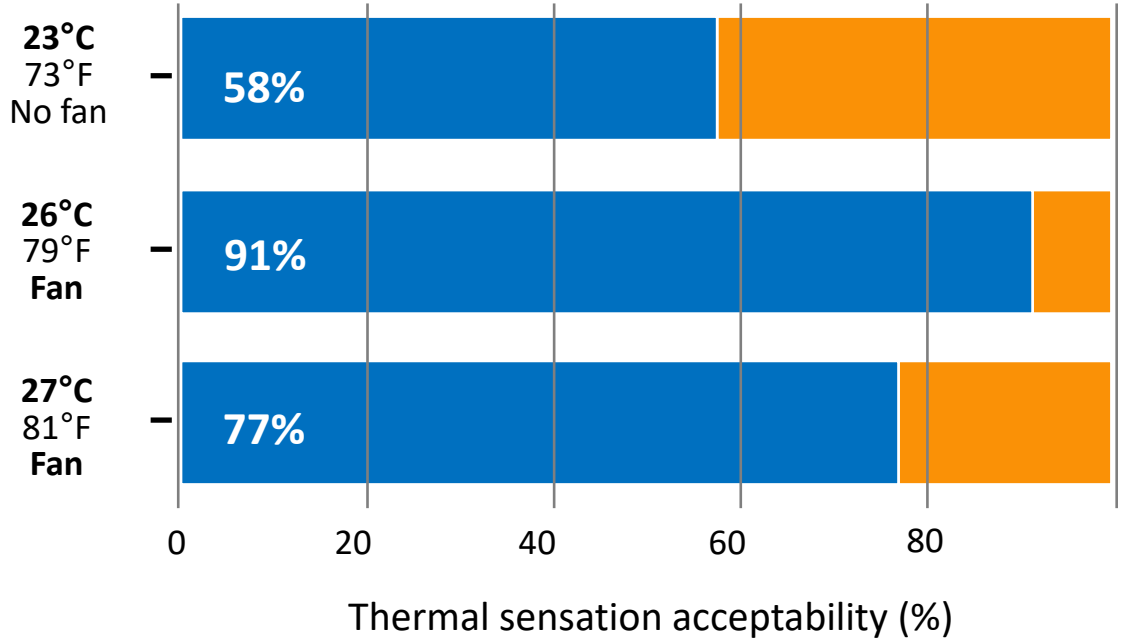
Saving energy with a wider dead band

- Wider dead band reduces HVAC energy 7-15% per degree C



Schiavon & Melikov 2008 *Energy and Buildings* - Hoyt et al. 2015 *Building and Environment*

Ceiling fans with warm temperatures



33% increase in thermal comfort with ceiling fan and higher temperature setpoints in commercial office in Singapore

Lipczynska, Schiavon and Graham 2018 *Building and Environment*

Commonwealth Club, San Francisco, CA

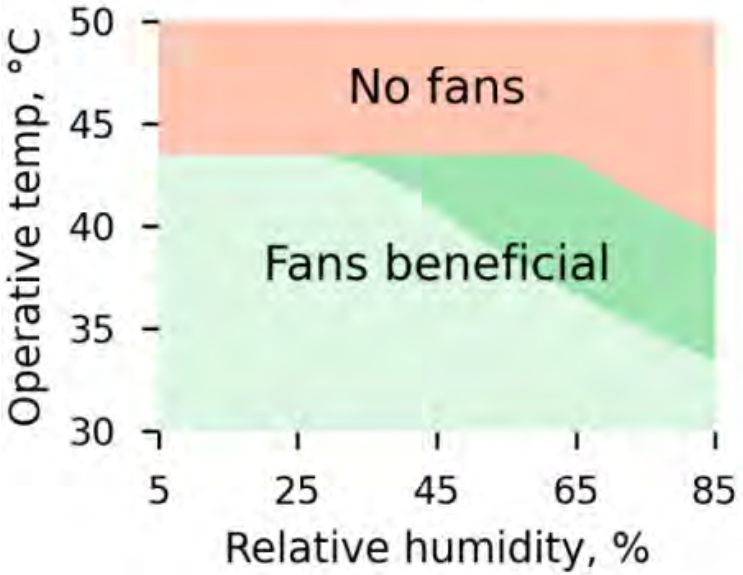
Can electric fans be safely used during heatwaves? Yes

Fans are an effective, affordable, and sustainable cooling technology

Current health guidelines discourage the use of fans at temperatures above 35°C

- WHO
- CDC
- EPA
- Ready.gov

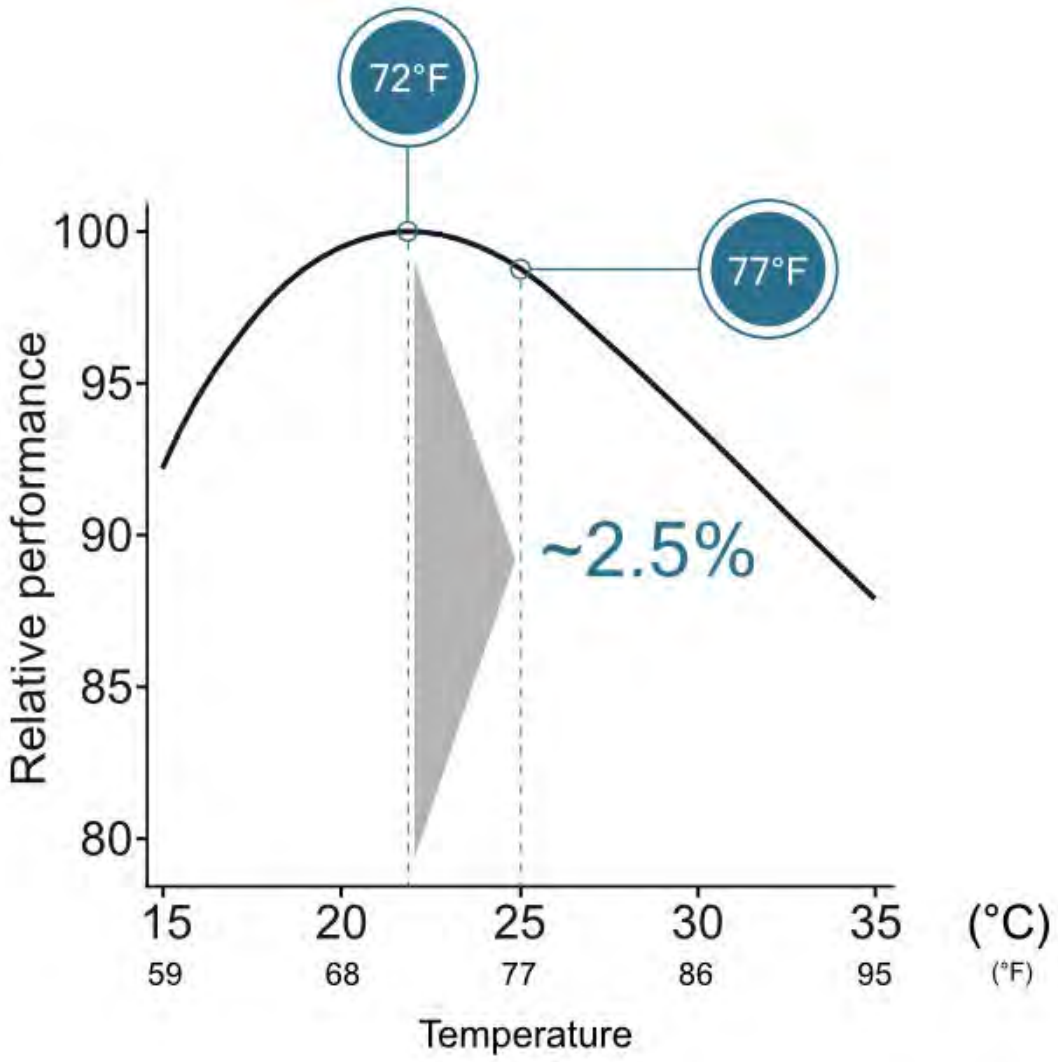
Fans can safely be used by healthy individuals in the following conditions



Tartarini, Schiavon, Jay, Arens, and Huizenga (2021) *Building and Environment*

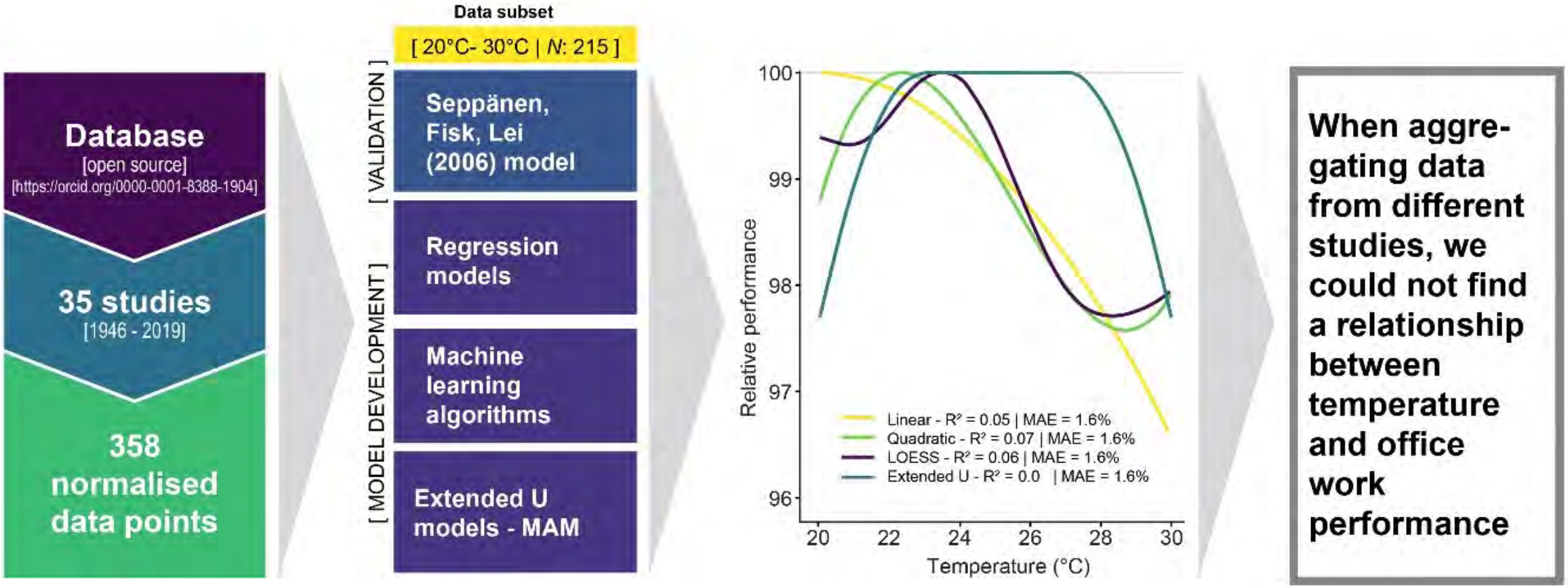
Can we increase the temperature in a space?

Increasing the indoor temperature from 72 ° F to 77 ° F will reduce the work performance of employees by 2.5%, which means yearly losses for an organization of about ~$5,000 per employee



Porras-Salazar, Schiavon, Wargocki, Cheung, Tham 2021 *Building and Environment*

Does the thermal environment affect productivity in typical indoor conditions? Probably not



Porras-Salazar, Schiavon, Wargocki, Cheung, Tham 2021 *Building and Environment*

Thermal comfort for radiant vs. all-air systems

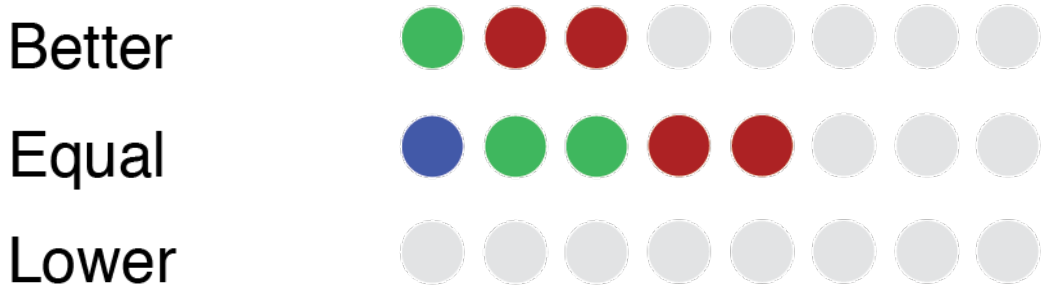
Do radiant systems provide a better thermal comfort than all-air systems?

73 papers found

53 papers excluded

20 papers kept

8 judged conclusive

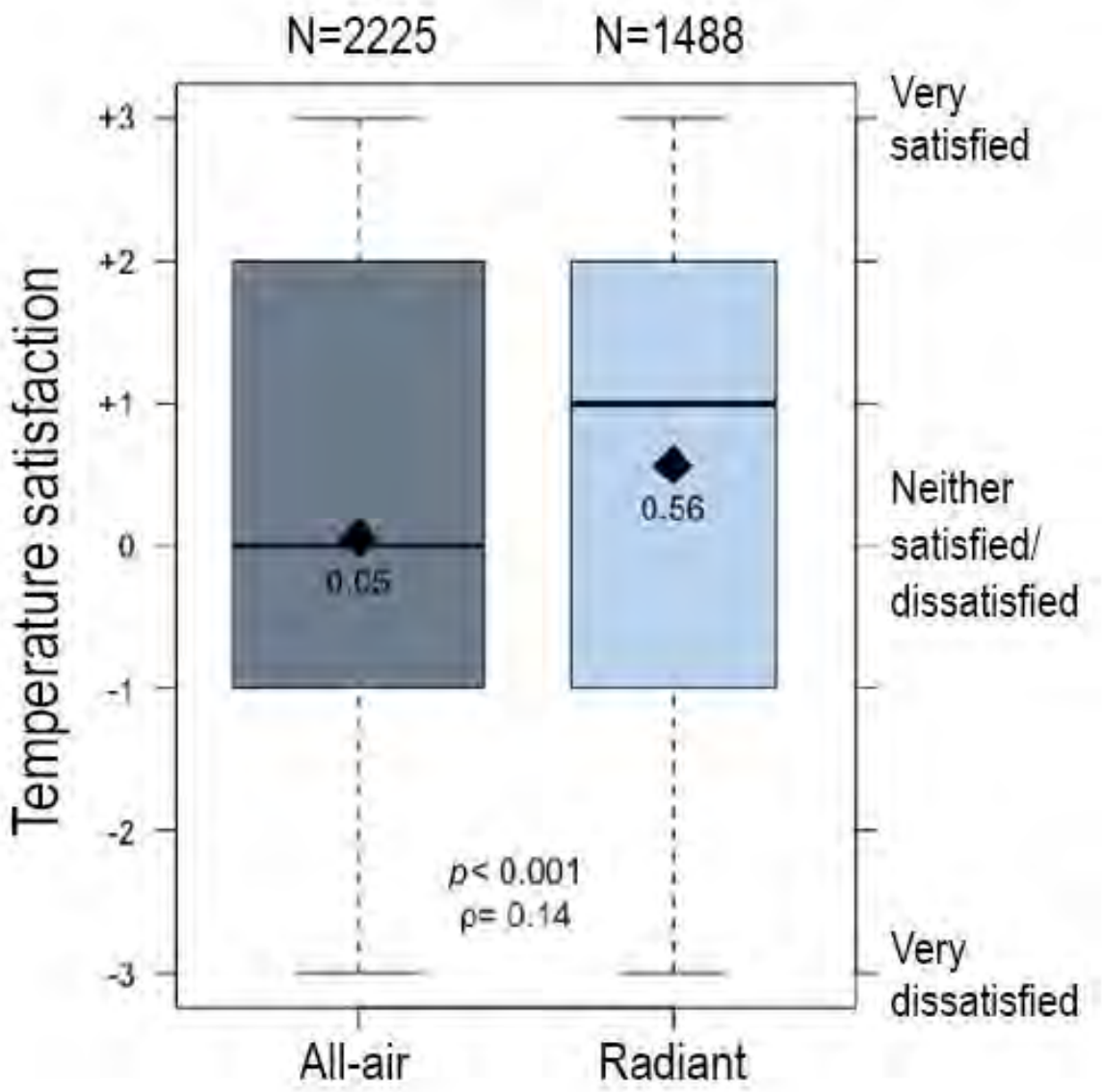


Building performance simulation
Physical measurements
Human subject / occupant based

Karmann C, Schiavon S, Bauman F 2017 *Building and Environment*

Temperature satisfaction for radiant vs. all-air systems

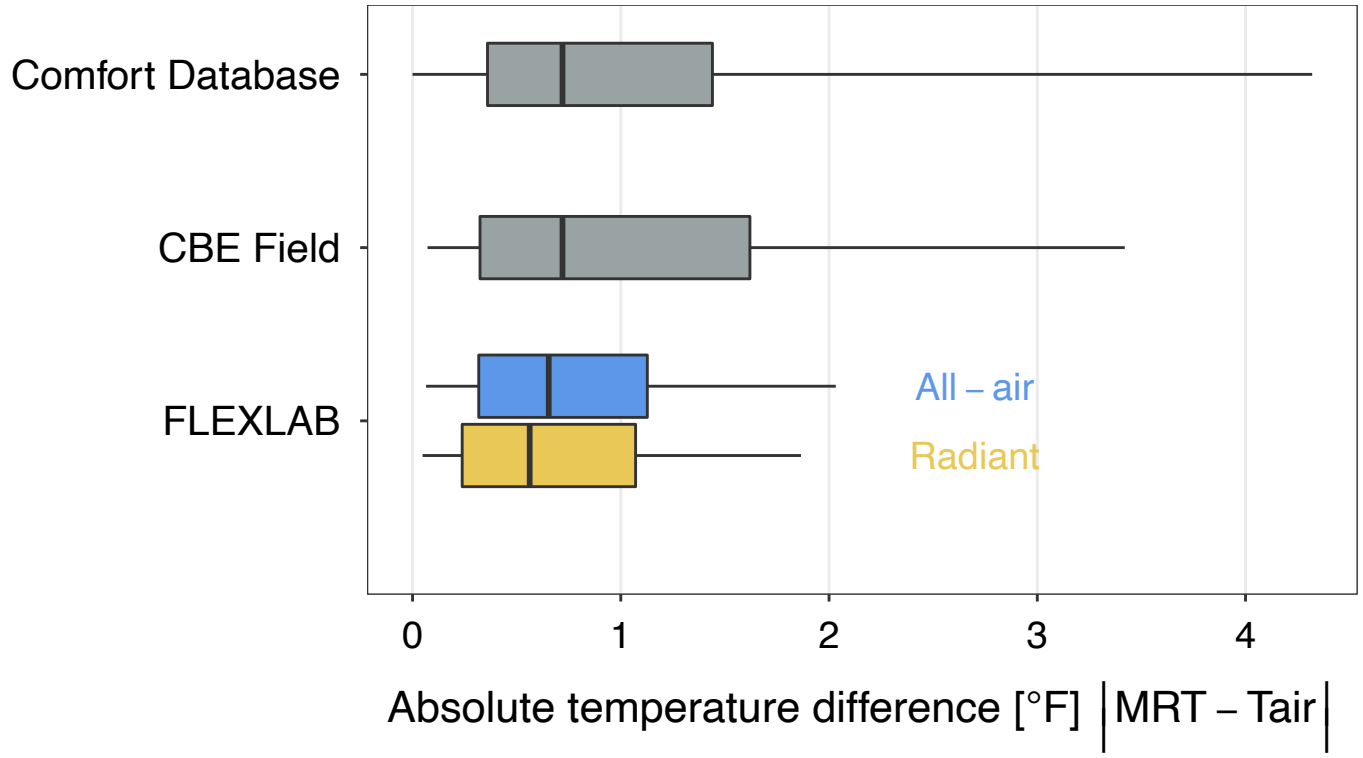
Radiant and all-air spaces have equal indoor environmental quality with a tendency towards improved temperature satisfaction in radiant buildings



Karmann et al 2017 *Building and Environment*

MRT vs Air temperature

- Thermostat readings of air temperature are appropriate estimates of MRT
- In general, MRT = Air temperature + 0.5 ° F



Megan Dawe et al. 2018

Stefano Schiavon

Professor at UC Berkeley

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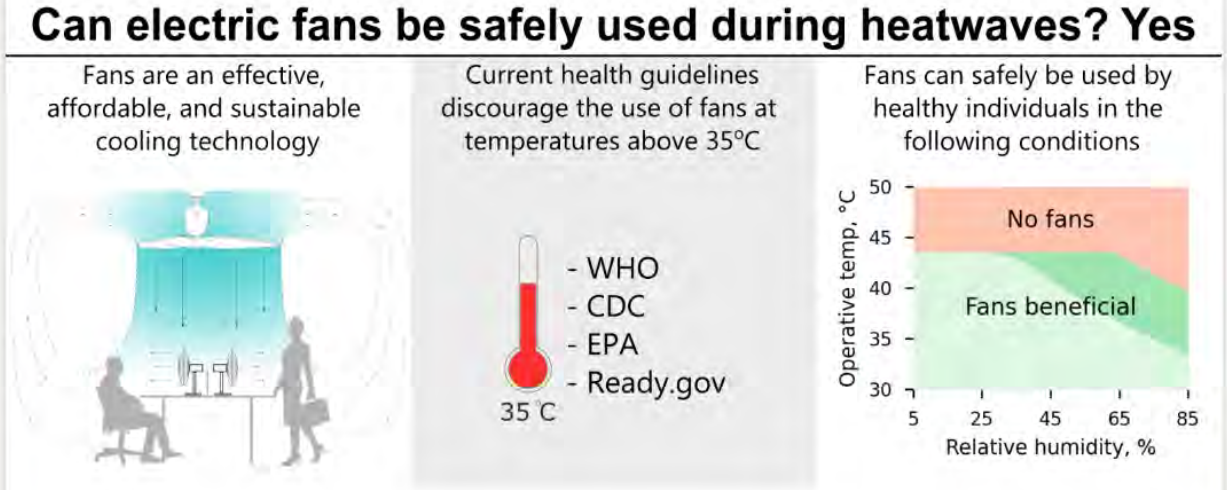

Can electric fans be safely used to cool people during heatwaves?

Stefano Schiavon on LinkedIn

November 2, 2021

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THANK YOU

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