ENG-445
Energy and Comfort in Buildings

Thermal Comfort

19th September, 2024

HOBEL
HUMAN-ORIENTED BUILT ENVIRONMENT LAB

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Anything to share with your class?

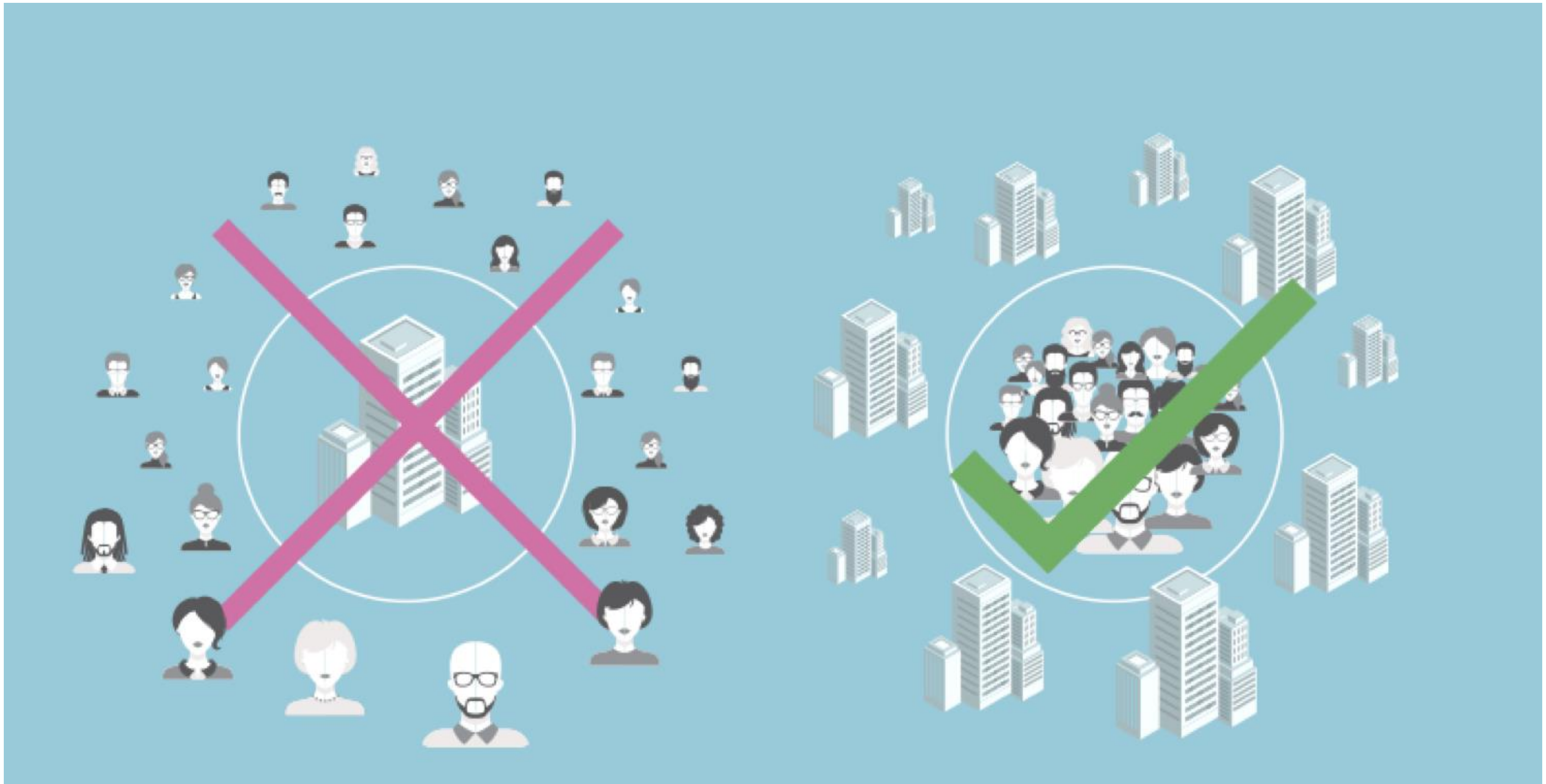
- *What do we do to reduce the consumption of energy to meet targets of Energy Strategy 2050?*
- *How to substitute the prevailing fossil fuels with renewable energies in buildings? Is reliance on renewables enough to overcome the challenge?*
- *Which are the economic and environmental implications?*

Review of key concepts from the first week

- Human activity is the cause of increased GHG concentrations, and therefore climate crisis.
- Energy use in buildings has the strongest (but not sole) influence on our climate.
- Reducing building carbon footprint requires setting priorities and hierarchy of actions.
- Buildings shape human health, comfort and well-being in substantial ways, many which have been neglected by people who commission, design, manage and use buildings.
- Investment in healthy buildings presents a better business model relative to investment in energy saving measures. However, both are extremely important!
- There is a strong nexus between building energy use and indoor environmental quality. We will explore this in the first half of the semester, starting from today!

Closing thoughts from the last time…

- Building are primarily for people! Is that taken into account when energy savings measures are implemented?



Have you thought of this task?

- *Do a detailed bullet point list of the tasks that you would do to assess the energy and indoor environmental quality of EPFL building*
- *Describe a strategy that may simultaneously increase energy efficiency and indoor environmental quality for that building*
- *Describe which steps would be needed to assess if the strategy is effective or not*

I. QUICK OVERVIEW OF THERMAL COMFORT
II. OVERHEATING OF BUILDINGS
III. COMFORT AND ENERGY EFFICIENCY
IV. EXERCISE

Human Thermal Comfort

Thermal comfort are consistently one of the main sources of complaints heard by building managers/owners

Thermal comfort decisions can have substantial energy and resource consumption implications

Thermal comfort is the basis for a substantial investment (in a HVAC control system)

Green building industry demands (sort of) thermal comfort

POWERFUL STATISTICS

Only 11% of the office buildings surveyed in the US provided thermal environments that met generally accepted goals of occupant satisfaction.

~40% of workers are dissatisfied with the thermal environment!

Thermal comfort affects mood, performance, and productivity

- 6% decline in staff performance when offices are too hot
- 4% fall in staff performance when offices are too cold

Productivity gains from making workplace thermal (and lighting) improvements can be quantified in the hundreds of billions of dollars!!!

1. Fisk, W.J., ASHRAE Journal

(Source: Fisk 2002, ASHRAE Journal)

What is Thermal Comfort?

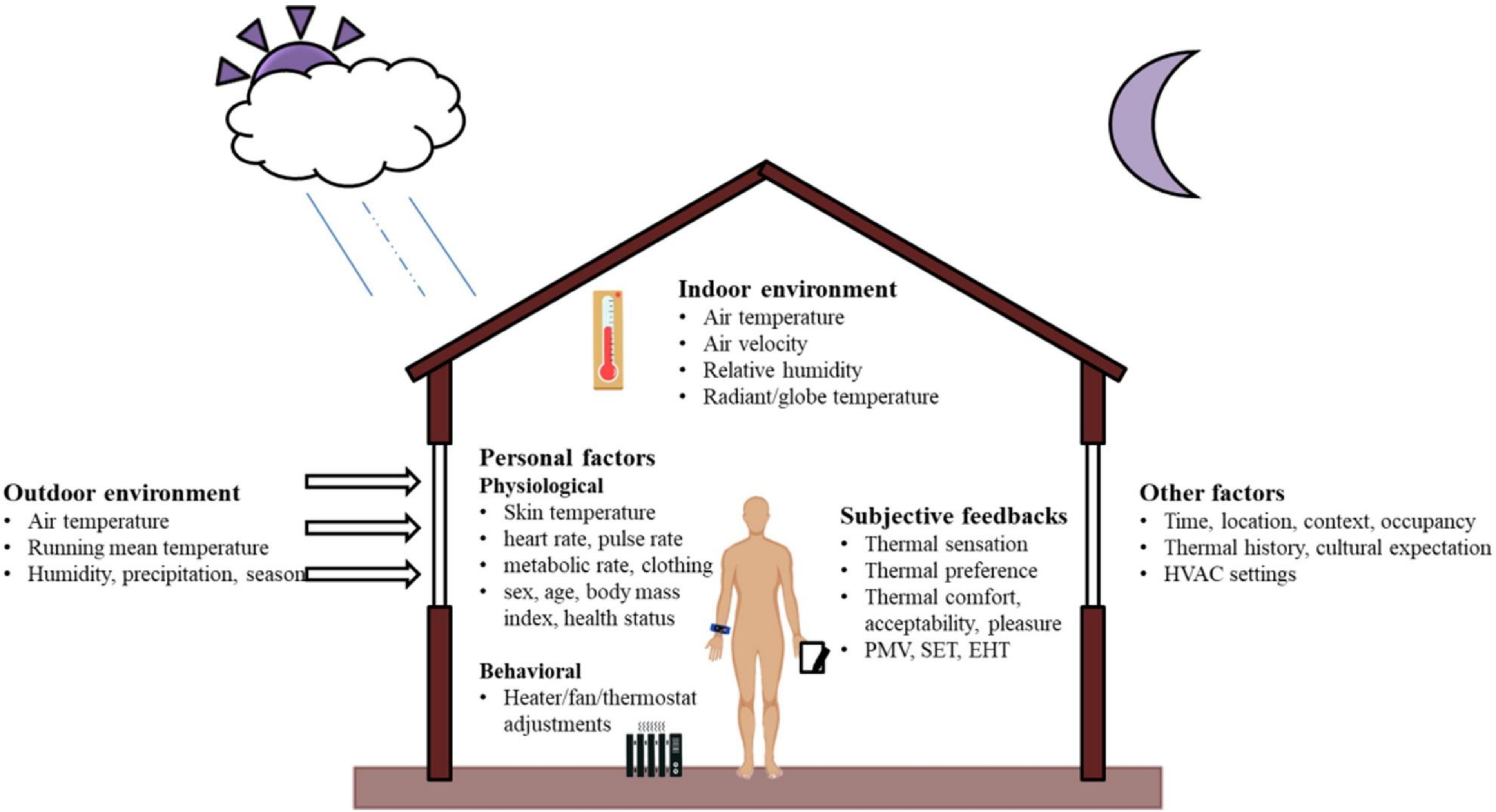
- **ASHRAE & ISO** definition: "…that condition of mind which expresses satisfaction with the thermal environment."

- Building design must ensure the means of achieving comfortable indoor climate

- Engineer's view on comfort:
  = absence of discomfort
  = "thermal neutrality"

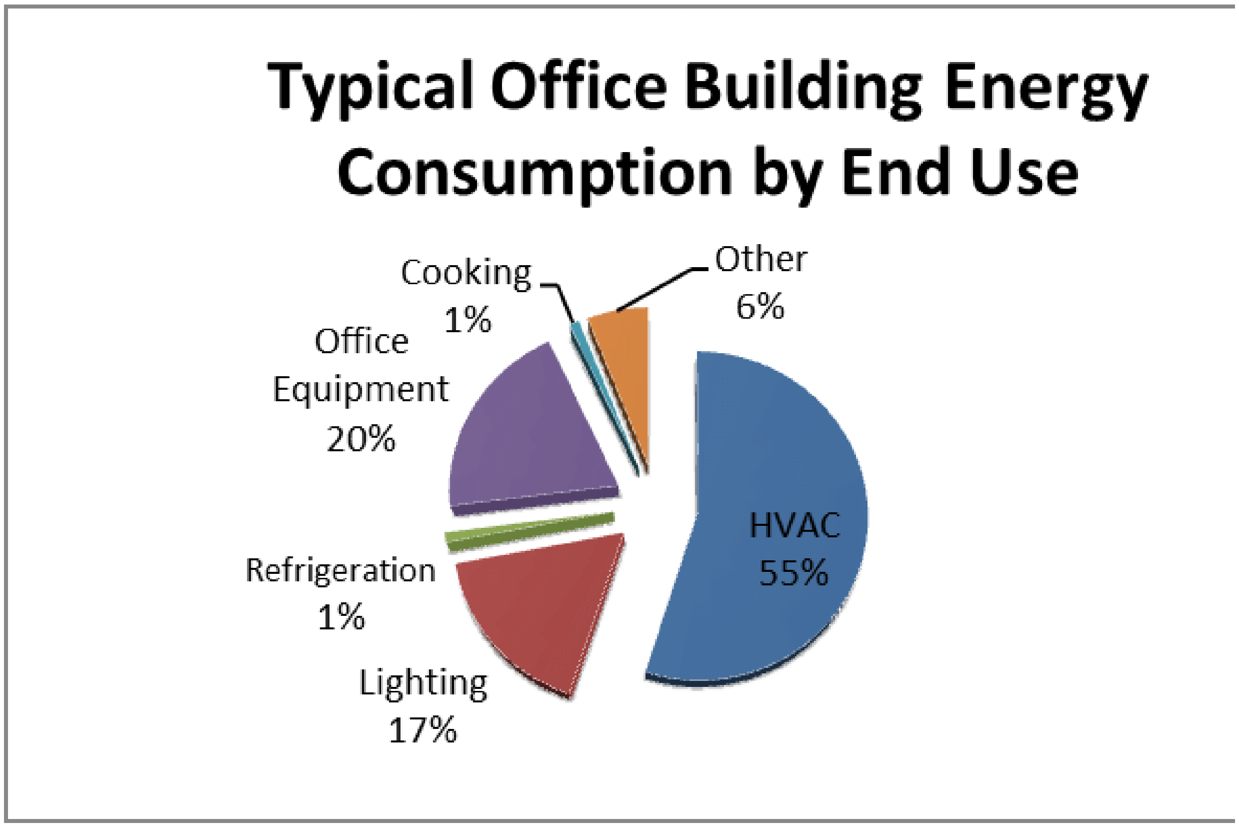
* *American Society of Heating, Refrigerating, and Air-Conditioning Engineers (abbreviated as ASHRAE)*

Factors affecting occupants' thermal comfort



(Source: Xie et al. 2020 Energy and Buildings)

Challenge 1: Massive energy consumption

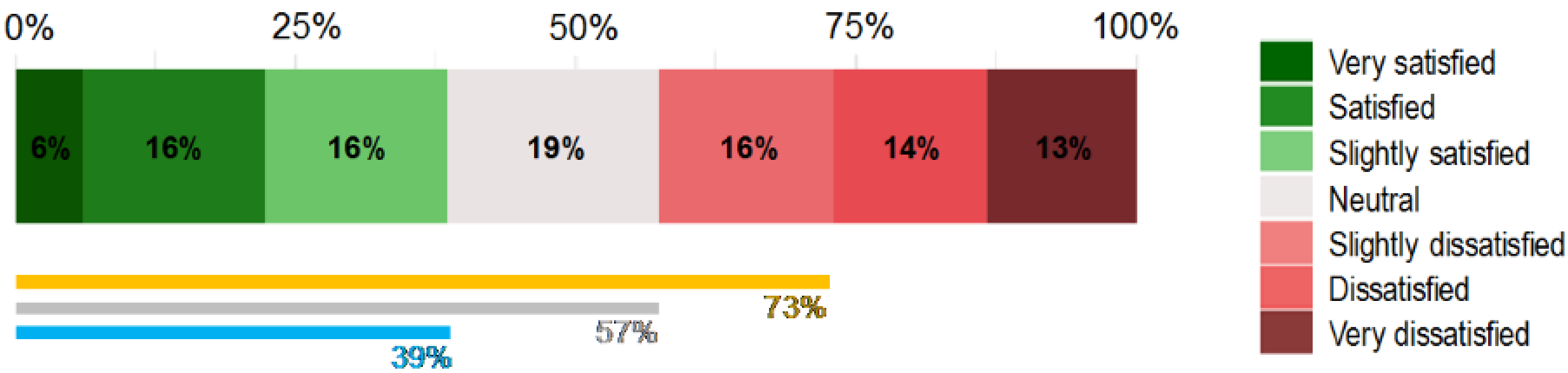


Heating, ventilation, and air conditioning (HVAC) systems typically account for a substantial portion of a commercial building's energy consumption, with a range of 40% to 60% or even higher in some cases. These percentages can vary significantly depending on building characteristics and location. Most of this energy is used to secure thermal comfort through heating and cooling.

(Source: National Action Plan for Energy Efficiency 2008)

Challenge 2: Insufficient occupant satisfaction

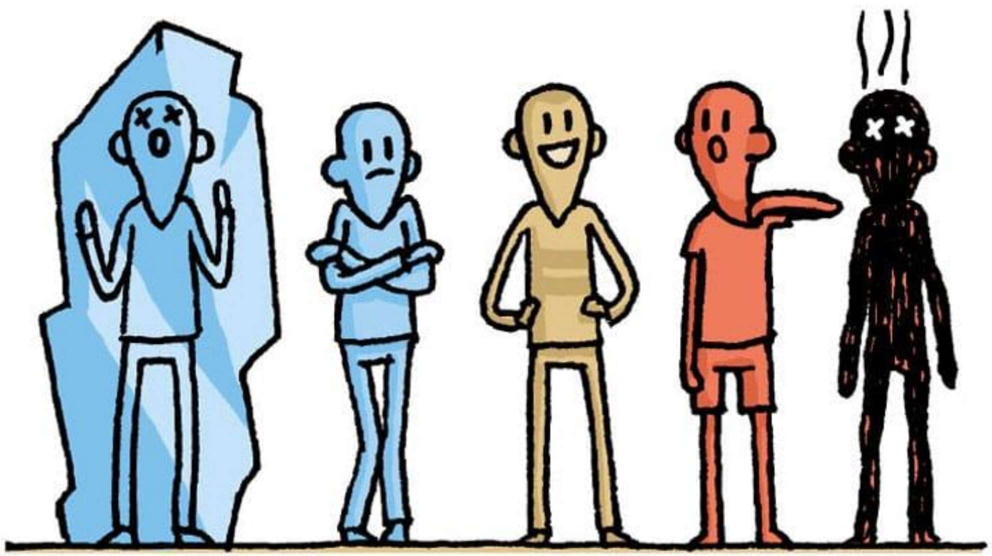
351 buildings
52,980 occupants



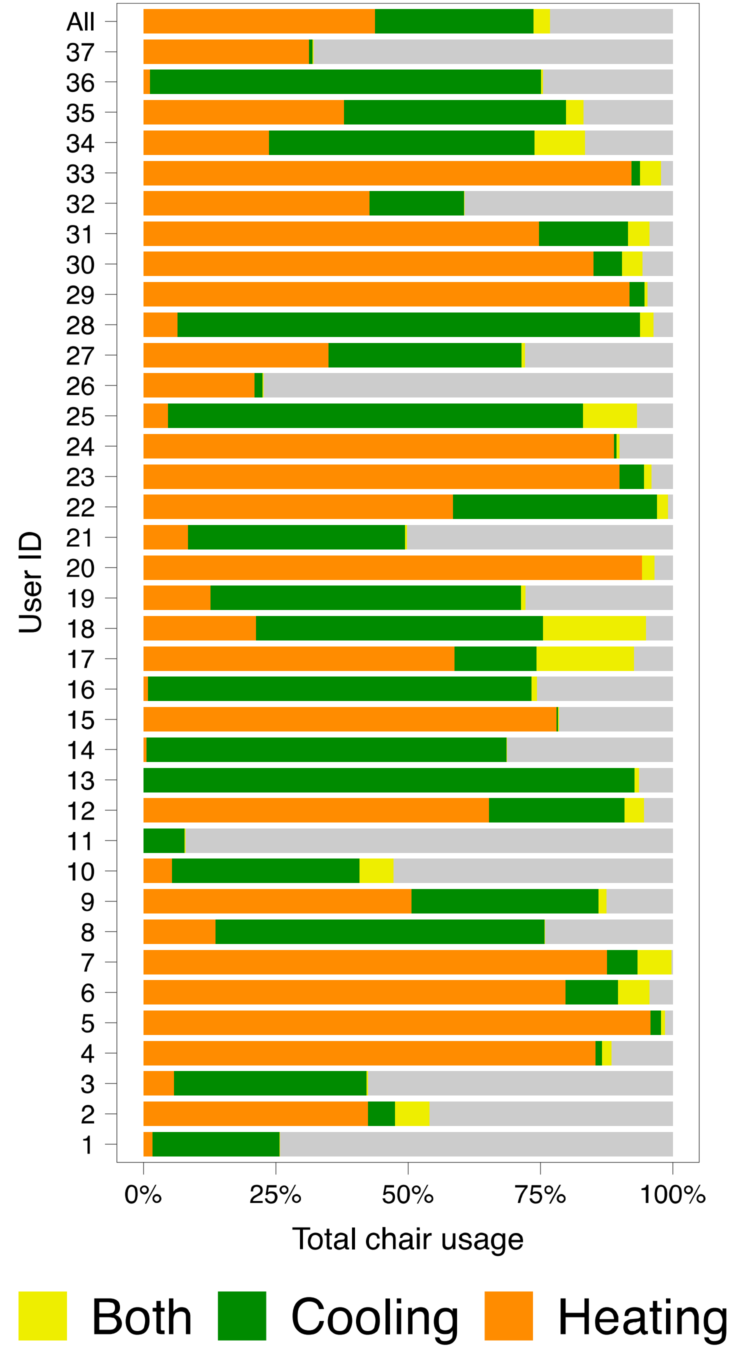
(Source: Karman et al 2018, Windsor Conference)

- ~40% of occupants are dissatisfied with air temperature
- Only ~40% of occupants are satisfied
- So we consume so much energy on buildings and still delivering such a poor performance -- what the heck can we do about it?

Challenge 3: Multiple people – thermal preferences vary widely



Thermal preferences vary widely even when people are exposed to the same ambient conditions.



(Source: UC Berkeley)

Thermal Comfort Assessment

Actual (subjective) thermal comfort analysis is usually done through surveys of users in real spaces and questionnaires that rates comfort on a seven point scale

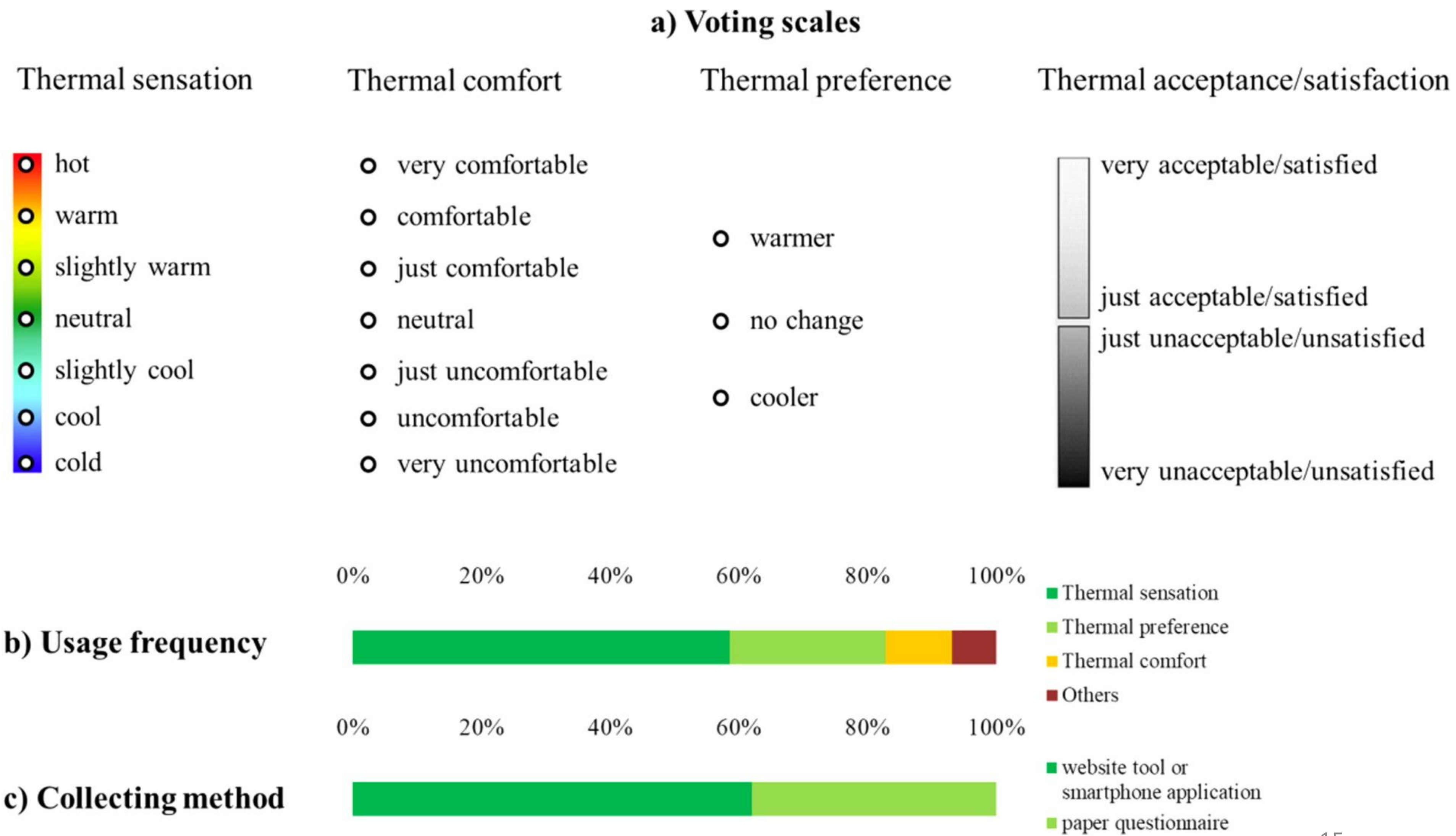
- The result of the survey is the Actual Mean Vote (AMV)

-3	-2	-1	0	+1	+2	+3
cold	cool	slightly cool	neutral	slightly warm	warm	hot

Predicted thermal comfort analysis aims to predict the results of a questionnaire through equations

- It results in a Predicted Mean Vote (PMV)
- PMV is an estimate of the mean value that would be obtained if a large number of people were asked to assess thermal comfort using a seven point scale

Actual (subjective) thermal comfort



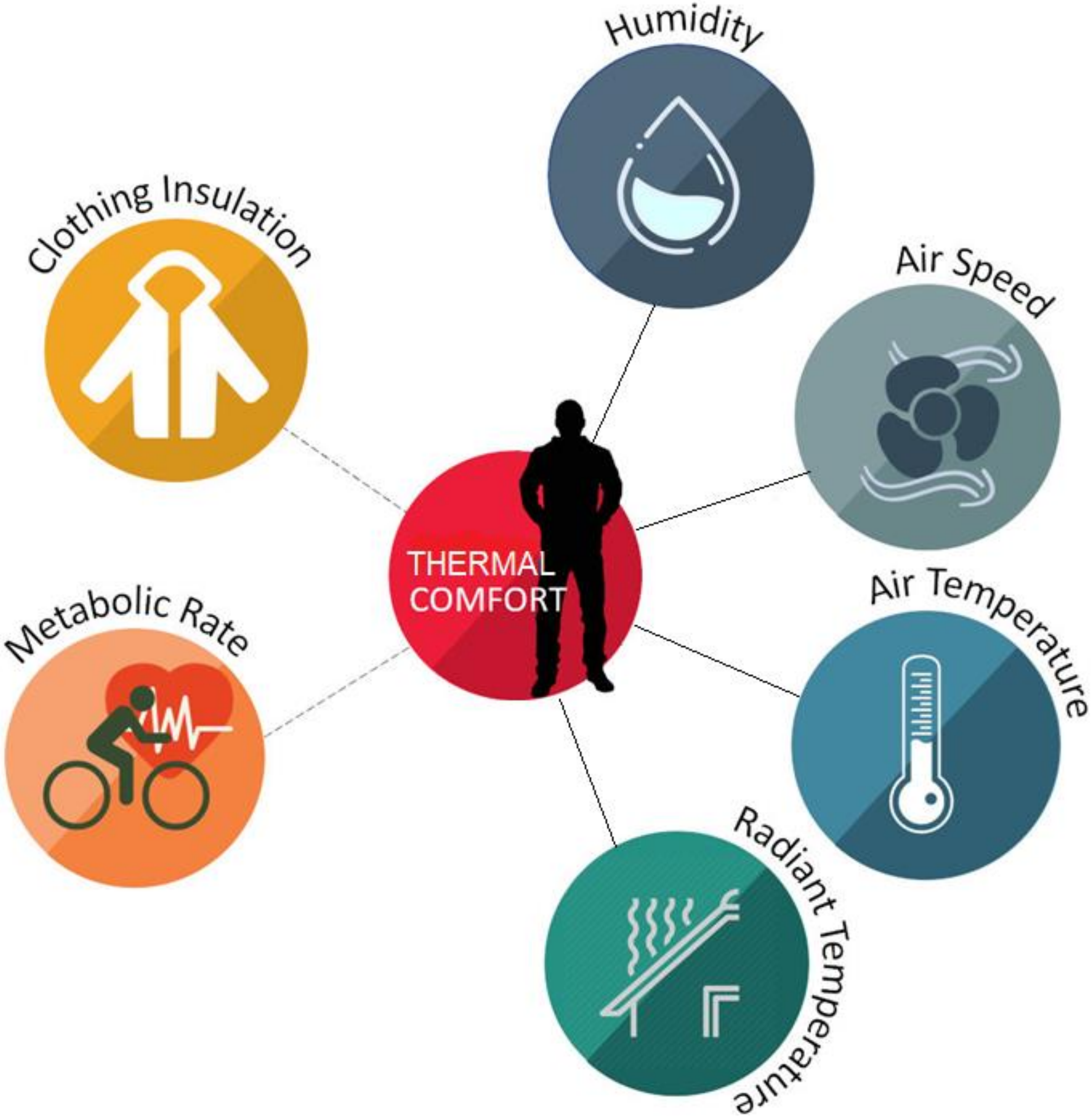
(Source: Xie et al. 2020 Energy and Buildings)

Predicted thermal comfort: Two models

- Predicted Mean Vote (PMV) / Percentage of People Dissatisfied (PPD) model:
  - Considers thermal comfort as a result of steady-state heat balance equation. It's a function of the 4 environmental parameters (air temperature, mean radiant temperature, air velocity and air humidity), and 2 personal factors: activity (metabolic rate) and clothing insulation. Applicable for moderate thermal environments.
- Adaptive model:
  - Considers thermal comfort as a result of occupant adaptation:
    - Behavioral (operating windows, blinds, fans, doors, etc.)
    - Physiological (acclimatization)
    - Psychological (adjusting thermal comfort expectations towards climatic conditions prevailing outdoor
  - Strong indoor/outdoor temperature relationship in naturally ventilated buildings

Major variables in PMV/PPD model

Personal factors



Environmenal factors

PMV: Predicted Mean Vote
PPD: Predicted Percentage of Dissatisfied

PMV = f (T_a, MRT, RH, V_a, Met, Clo)

When we know PMV (average results obtained), we need to estimate how many people are satisfied with the thermal conditions for that PMV

- We quantify that as the **percent of people dissatisfied (PPD)**
- Researchers found a non-linear dependence between **PPD** and **PMV** based on numerous experiments in controlled environments

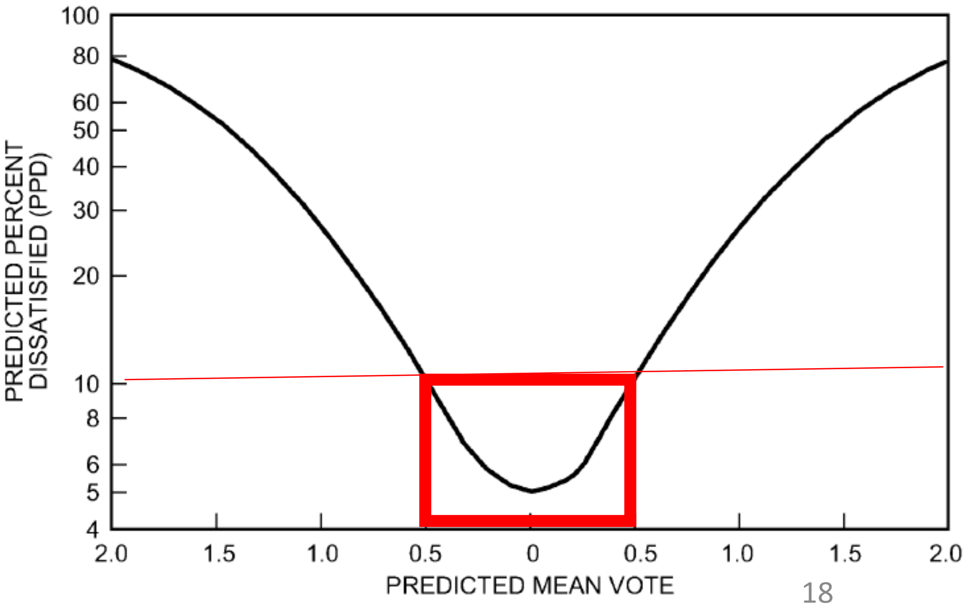
Typical design target:

-0.5 < PMV < +0.5

↓

PPD < 10 %

Notice that the absolute minimum PPD is 5% showing that you cannot satisfy everyone at the same time!



Theory: Equation of Fanger


Prof. Ole Fanger

How can we predict PMV and PPD?

- Physically: a relationship between the imbalance between heat flow from the body and the heat flow required for optimum thermal comfort
- Empirically: Correlations derived between sensations of thermal comfort (PMV/PPD) and environmental variables:

$$PPD = 1 - 0.95 \cdot \exp(-0.03353\, PMV^4 - 0.2179\, PMV^2)$$

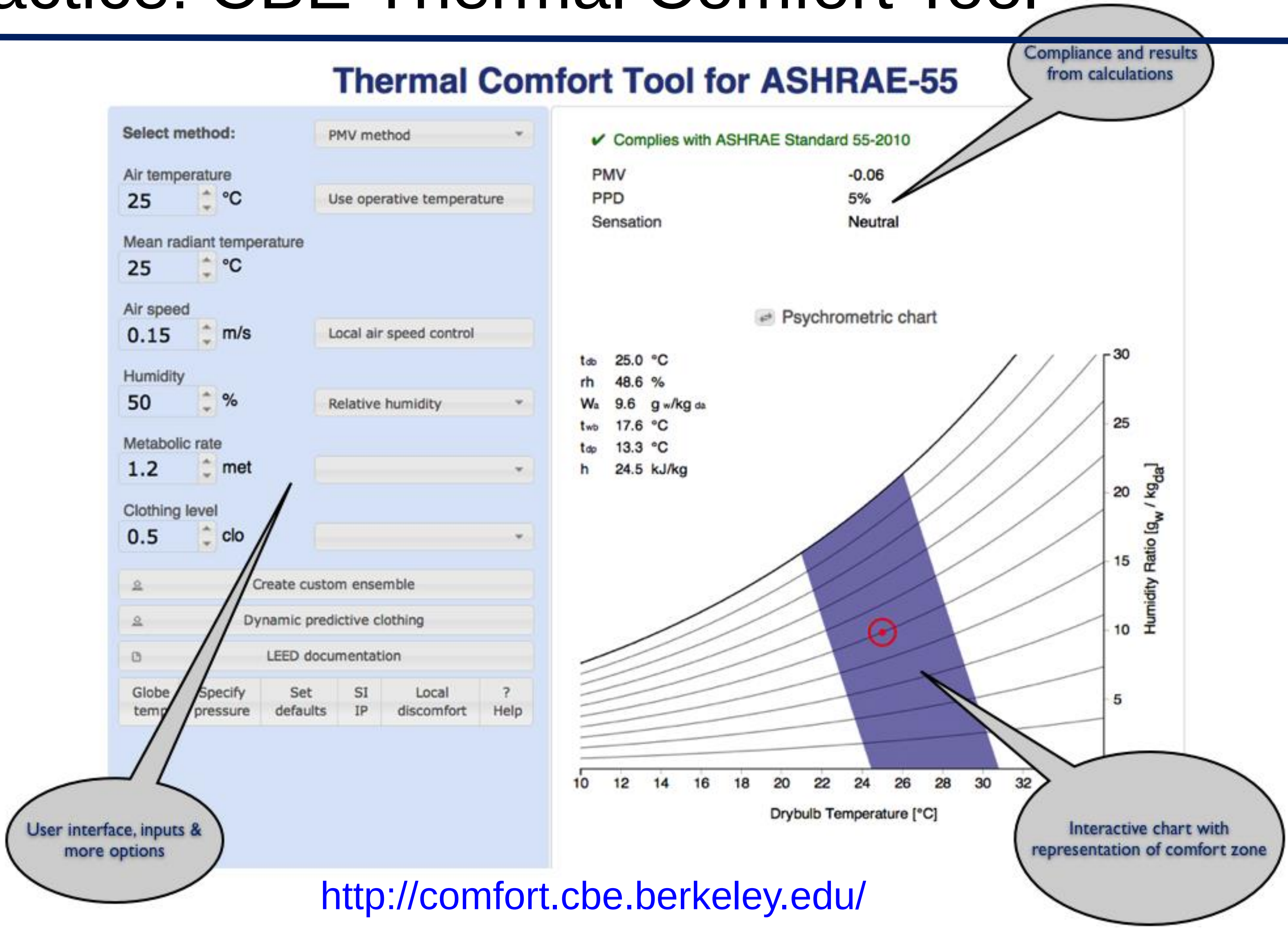
$$PMV = (0.303 \cdot \exp(-0.036M) + 0.028) \cdot L$$

M = metabolic activity (Met)

L = thermal load (difference between actual skin temperature and the skin temperature required for comfort) at a given activity

(Source: ASHRAE Handbook of Fundamentals 2019; ASHRAE Standard 55)

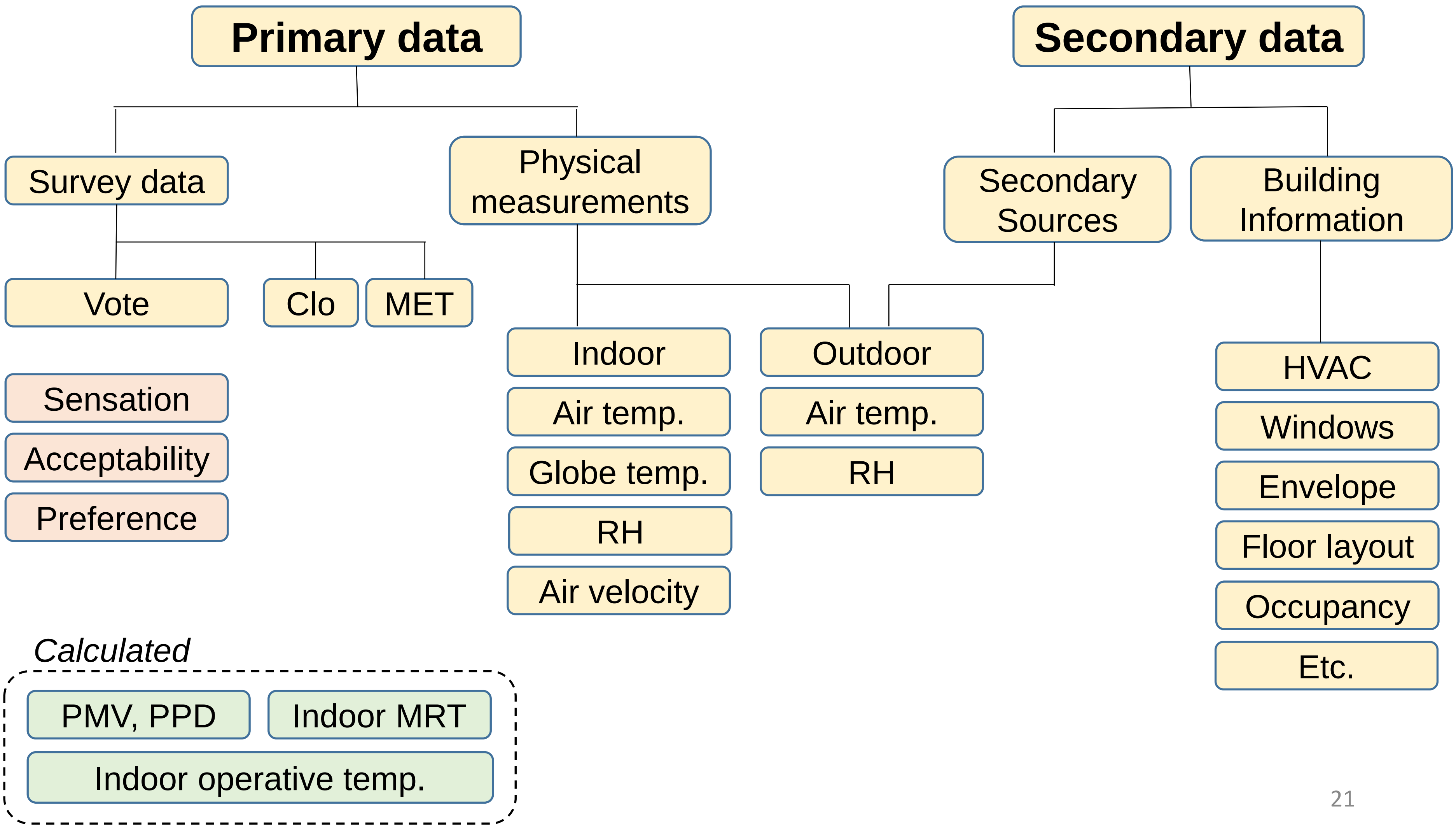
Practice: CBE Thermal Comfort Tool



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

Tutorial on how to use posted on Moodle (2 pager). Also see the following video tutorial: https://www.youtube.com/watch?v=yXhqkBSe9gQ

Example of thermal comfort analysis design



Adaptive Thermal Comfort Model

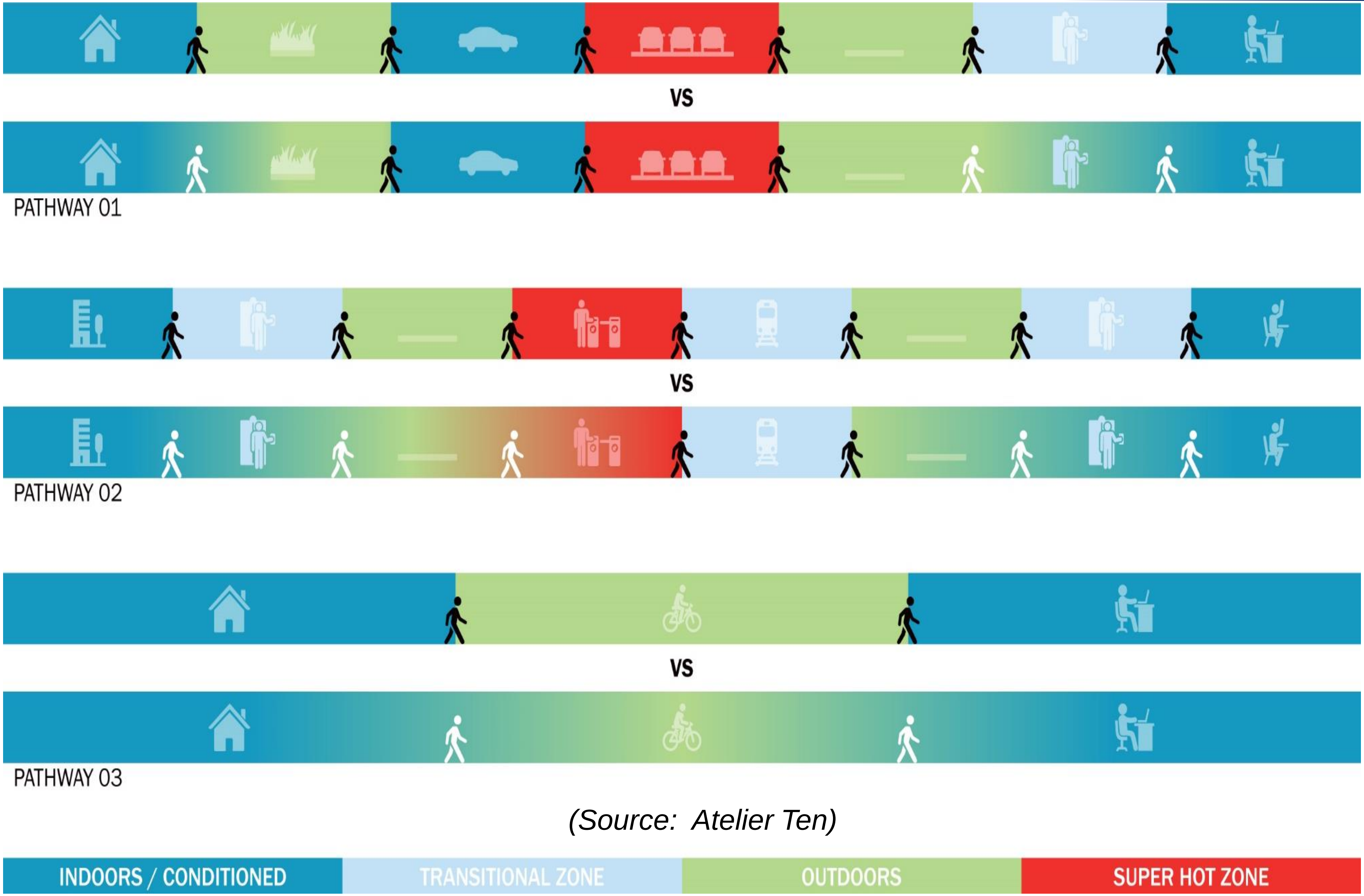
- Based on measurements and surveys done in real buildings
- Takes into account human behavior - Assumes that people change their behavior if they experience discomfort
- Applies to naturally ventilated buildings where occupants have access to windows and can adapt their Clo

Darwin:
"It is not the most intellectual or the strongest of species that survives; but the species that survives is the one that is able to ***adapt*** *to and adjust best to the changing environment in which it finds itself."*

Prof. Gail Brager

Prof. Richard de Dear

Human thermal adaptation throughout the day



(Source: Atelier Ten)

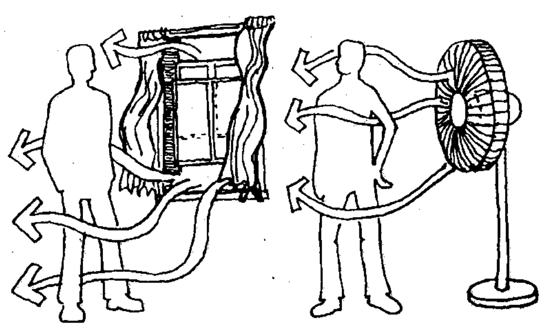
Voluntary and involuntary adaptations

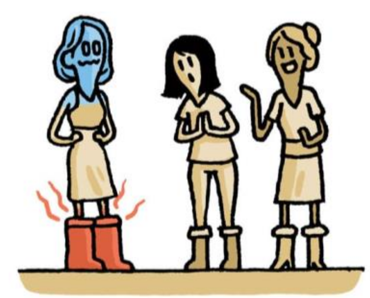
Voluntary

- Environmental opportunities (e.g., open/close window, turn on/off fan/heater, etc)
- Personal opportunities (e.g., Changing Clo and MET, eating/drinking, etc.)

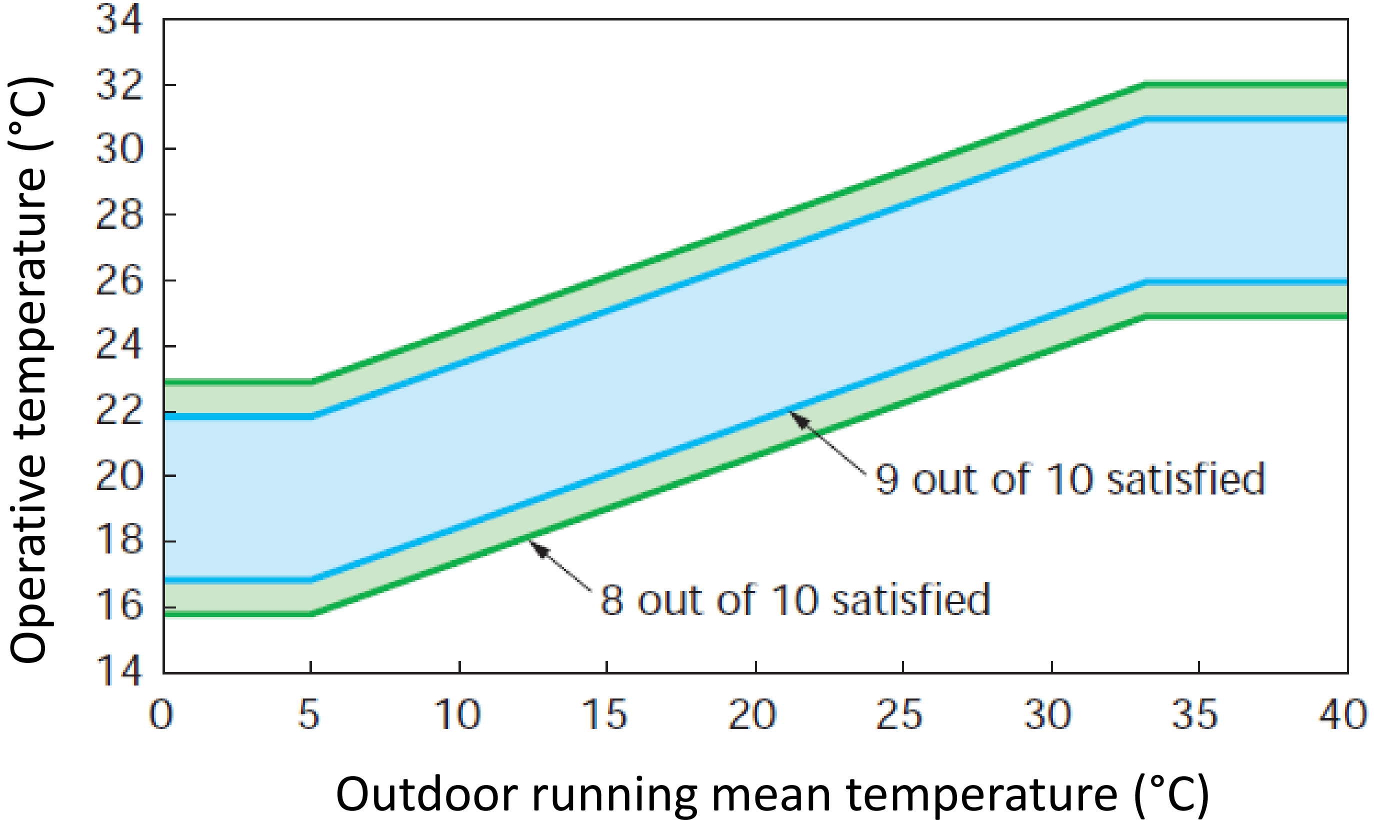
Involuntary

- Four adaptations by thermoregulatory system: blood flow (vasoconstriction or vasodilation), sweating, shivering, and goosebumps





Adaptive Thermal Comfort Model



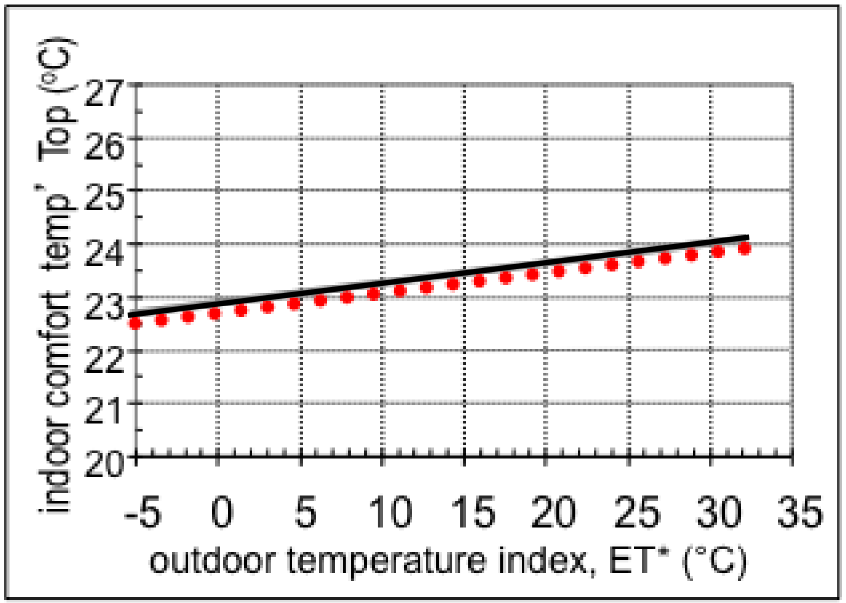
The outdoor running mean temperature is arithmetic average of the mean daily outdoor temperatures over no fewer than 7 and no more than 30 sequential days prior to the day in question

Think about the following…

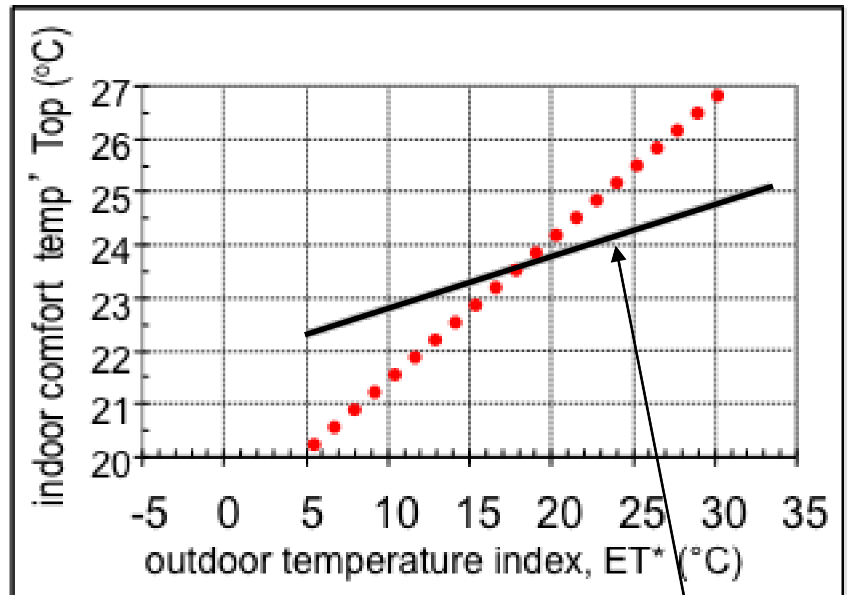
- *Between PMV/PPD and Adaptive models, which one do I select? What are the use considerations?*
- *Which of the two is considered more sustainable?*
- *What are the limitations of these models?*
- *Can you think of a model which could overcome these limitations?*

Is PMV model suitable for naturally vent. building?

Centrally-controlled HVAC bldgs



Naturally ventilated buildings



— Predicted: Lab-based heat-balance model

• • • • Observed: Field-based adaptive model

Lines are weighted linear regressions through the data points (*not shown*)

Despite drawbacks, the PMV/PPD model has been the dominant paradigm in thermal comfort engineering.

(Source: de Dear and Brager; 1998)

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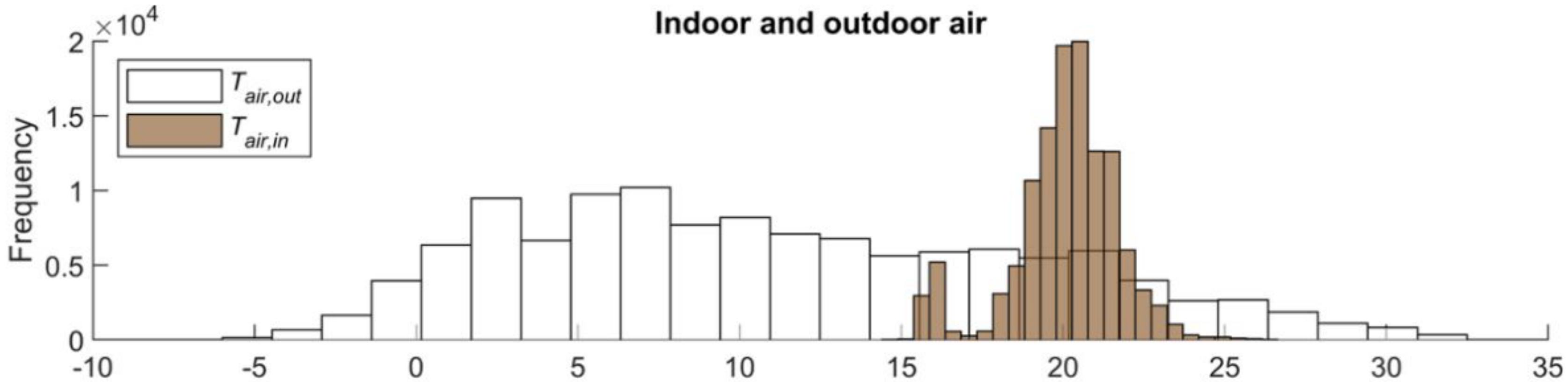
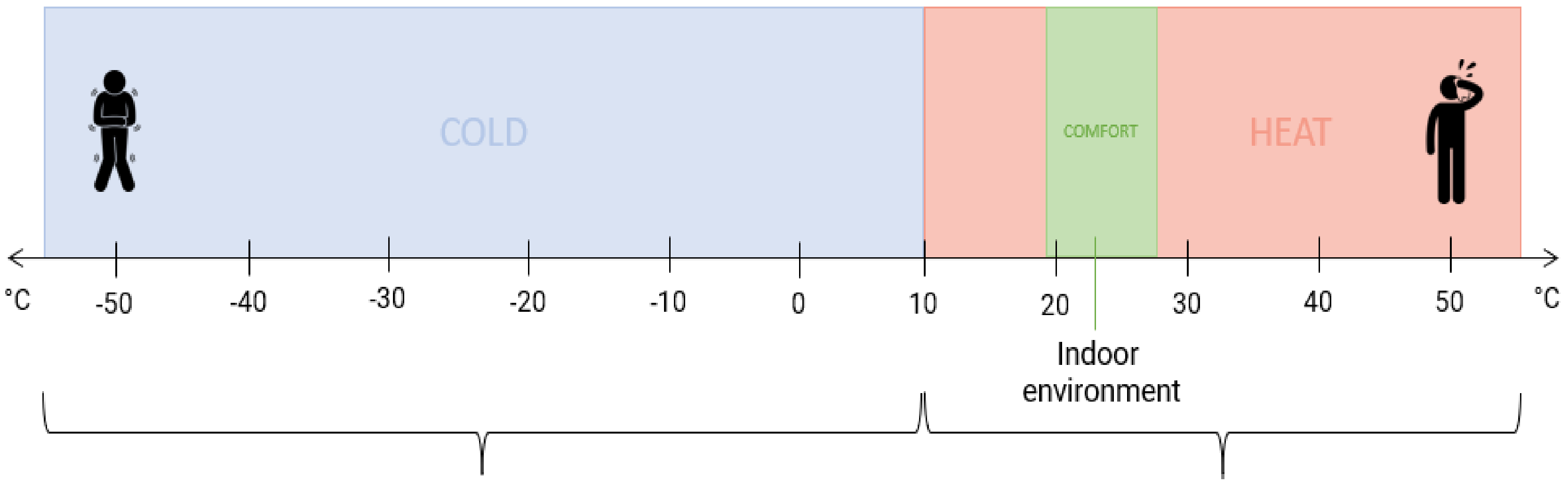
A bit of context: Thermal domains

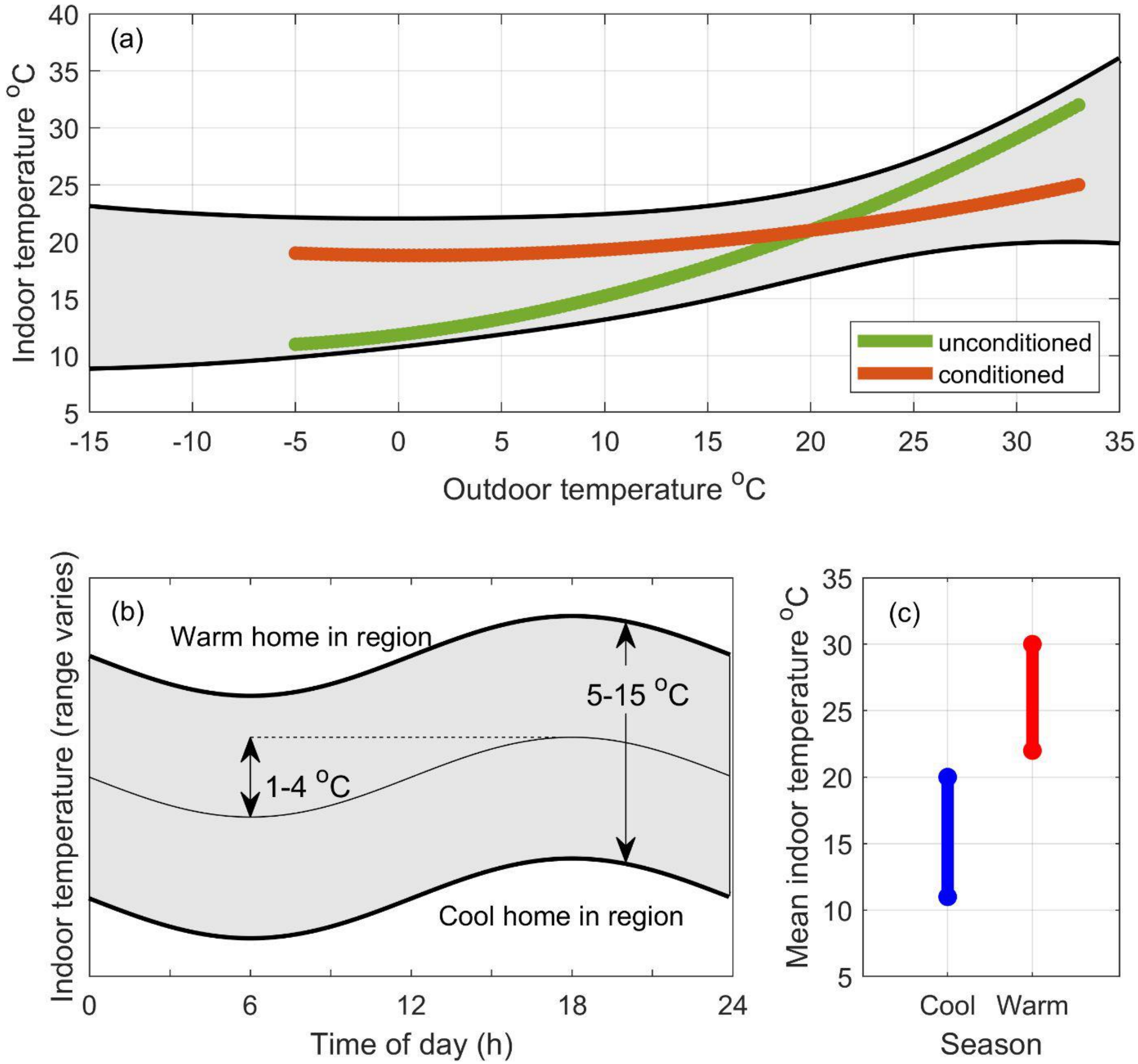


Thermal mode transition



(Source: Salthaimer and Morrison, Indoor Air 2021)

Temperature variation can be substantial…



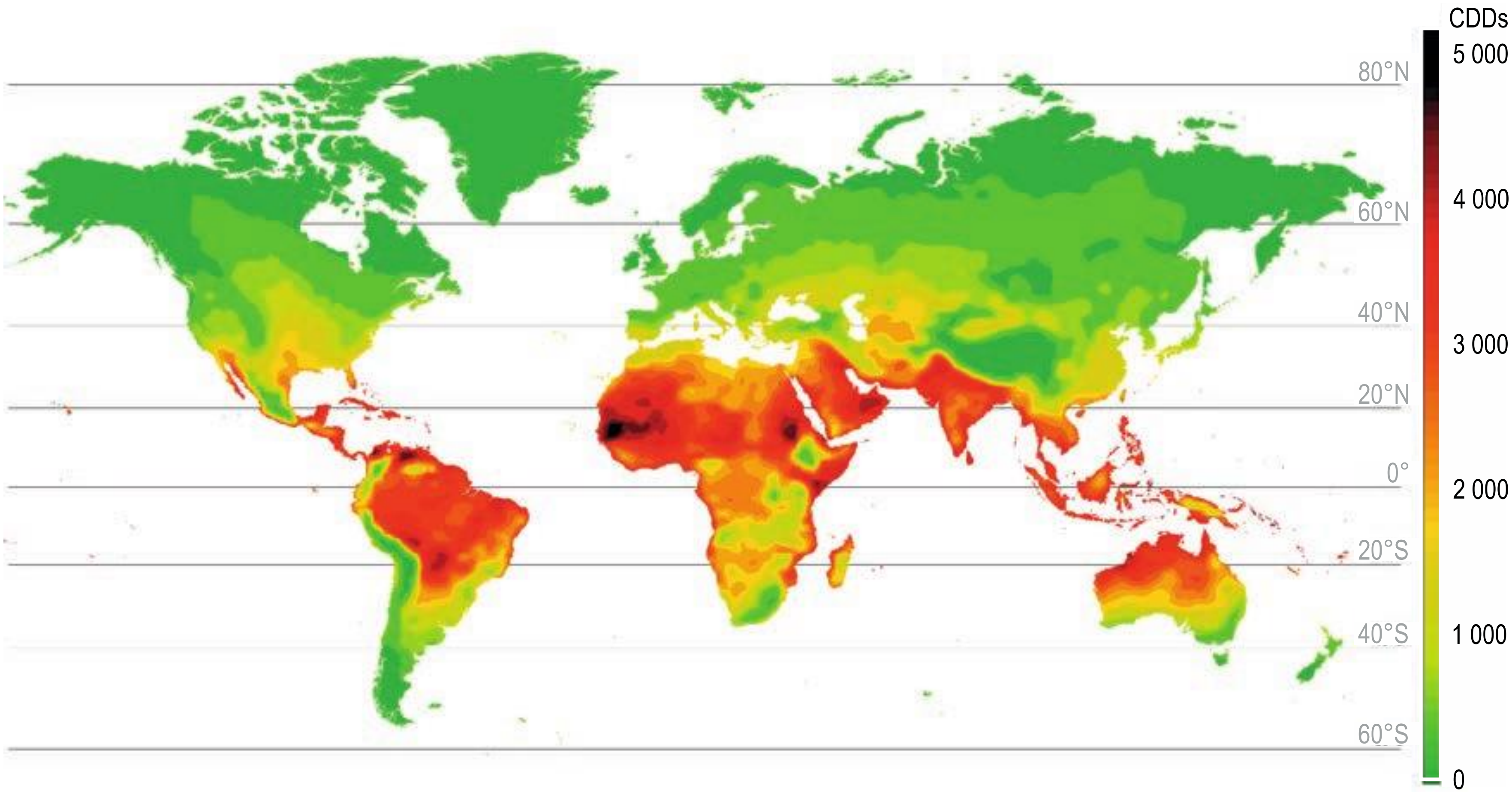
…by ventilation

…by time of day

…by season

(Source: Salthaimer and Morrison, Indoor Air 2021)

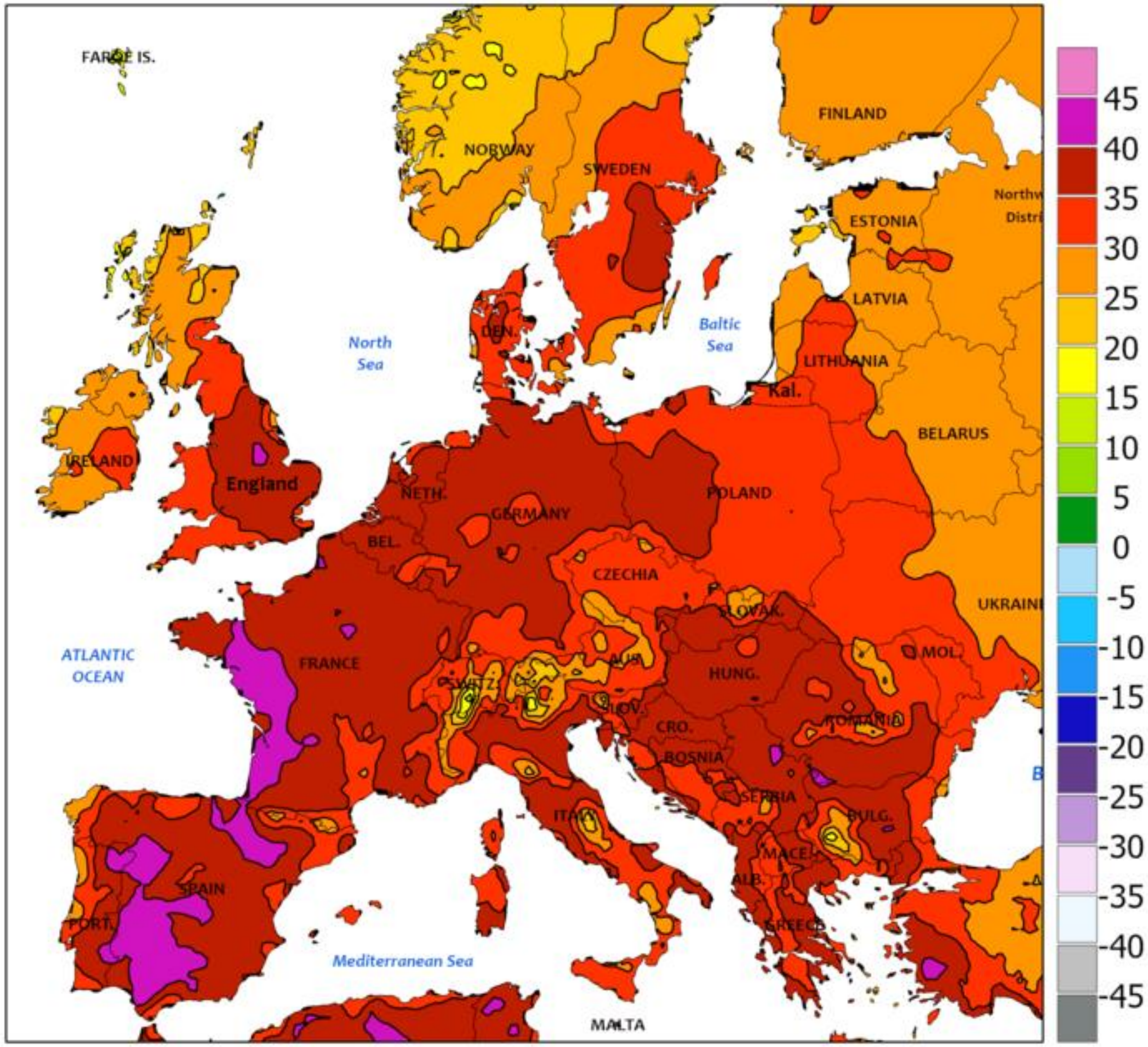
Global CDDs, annual average 2007-2017



Think about the following question…

How climate change will influence building energy use in relation to thermal comfort?

European Extreme Maximum Temperature



In summer 2022, persistent heatwaves affected Europe, causing evacuations and heat-related deaths. The highest temperature recorded was 47.0 °C in Pinhão, Portugal, on 14 July. In June of that year, temperatures of 40–43 °C were recorded in parts of Europe, with most severe temperature anomalies in France, where several records were broken. A second more severe heatwave occurred in mid-July, extending north to the United Kingdom where temperatures surpassing 40 °C were recorded for the first time. The heatwaves are presumed to be linked to climate change in Europe. A third heatwave began in August with parts of France and Spain reaching temperatures as high as 38 °C.

(Source: Climate Prediction Center, NOAA – Graph refers to July 17 – 23, 2022 period)

Overheating of buildings: Cause 1

Climate change

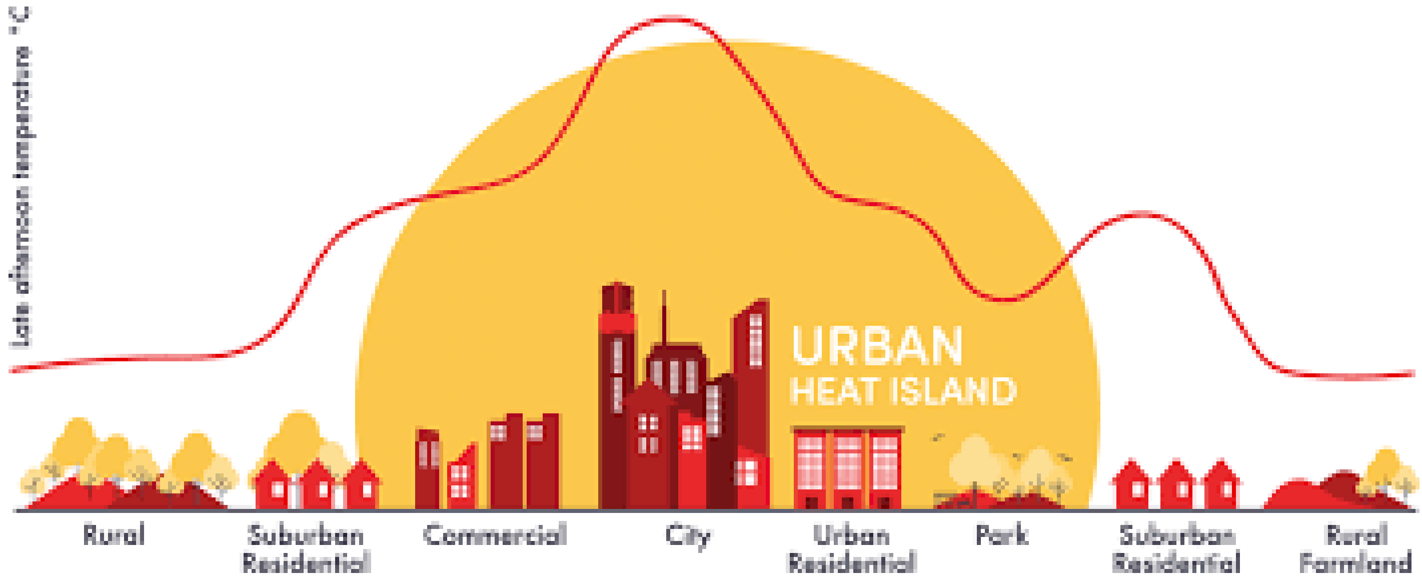
- The Intergovernmental Panel on Climate Change (IPCC) expects further global warming of 1.5–2 °C
- The strongest warming is projected to occur in central and eastern North America, central and southern Europe, the Mediterranean region (including southern Europe, northern Africa and the Near East), western and central Asia, and southern Africa (medium confidence)
- Switzerland's average temperature, which is rising two to three times faster than the global average, increased 2 ºC between 1864-2016
- The number of summer days in Switzerland (with maximum temperature above 25 °C) doubled between 1961 and 2016

(Source: www.iea.org)

Overheating of buildings: Cause 2

“Urban heat island” effect

- In summer, concrete and asphalt surfaces absorb solar radiation and heat up the surrounding air, with temperatures several degrees higher than in the rural areas around them
- 73% of Swiss population lives in cities. In Zurich, Bern, and Geneva, the gap between the city and areas outside of it can be up to 7°C on a summer’s night



(Sources: community.wmo.int; Swissinfo.ch)

Overheating of buildings: Cause 3

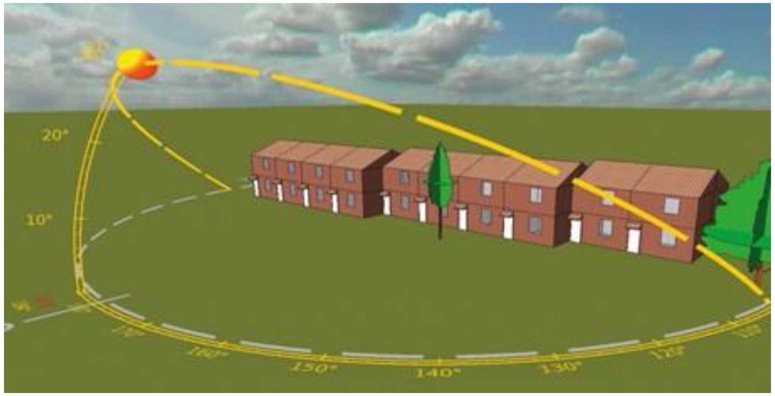
European regulation requirements

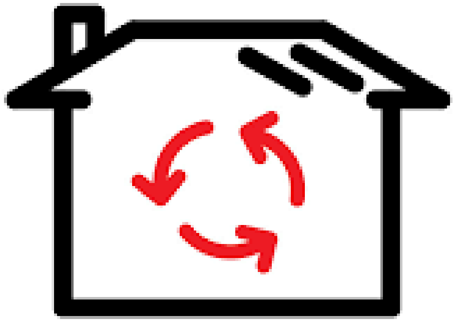
- Oriented to reduce the heating losses to a minimum
- More insulated and airtight buildings
  - Both directly present a danger for overheating in the summer months

Overheating of buildings: Cause 4

Various design and operation practices

- Suboptimal orientation
- Lightweight framed structures
- Internal sources of heat
- Inadequate ventilation

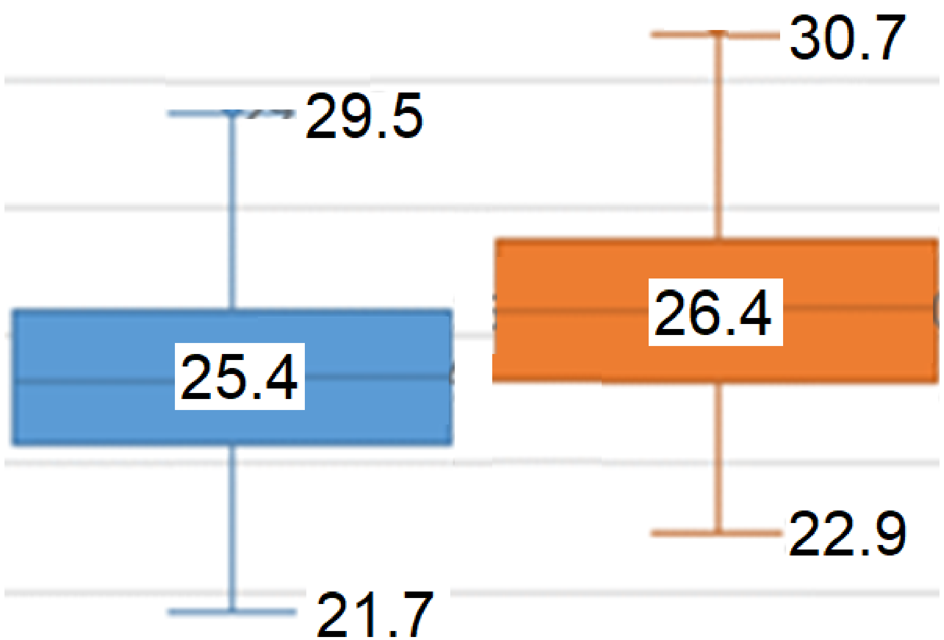




Overheating of buildings: Cause 5

Occupant (mis)behavior

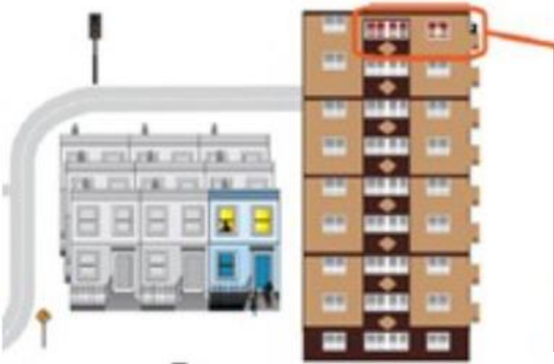
- Occupants are not used to heatwaves and do not know how to operate shadings and windows
- Apartments with identical properties could have different indoor climate due to occupant behavior (see below)



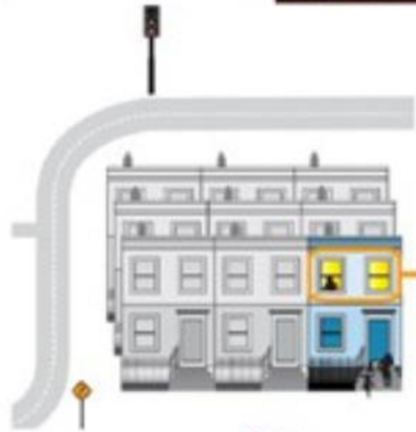
- Our case study in Vevey.
- Apartments *501* and *502* are identical (top floor, south oriented with big openings).
- During the summer of 2020, the users of one apartment (left), by shading and ventilating, managed to keep their apartment 1 °C cooler than their neighbors (right)

(Source: Evangelos Belias PhD thesis, EPFL)

Overheating of buildings: Levels of risk



High risk of overheating
Fully occupied apartment, top floor, small surface area, no roof insulation, located in a dense urban area, no solar shading



Medium risk of overheating

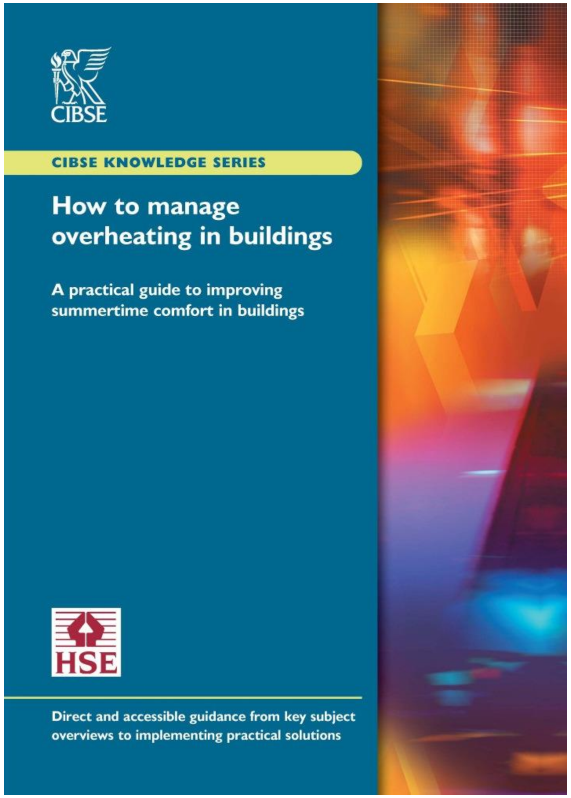
… something in between high and low…

Low risk of overheating
Mid-level floor apartment with well insulated walls in a quiet residential area in rural neighborhood. Balcony with shading devices

Overheating of buildings: Facts

Absence of an adequate definition of overheating
- CIBSE stated: “Overheating implies that building occupants feel uncomfortably hot and that this discomfort is caused by the indoor environment”

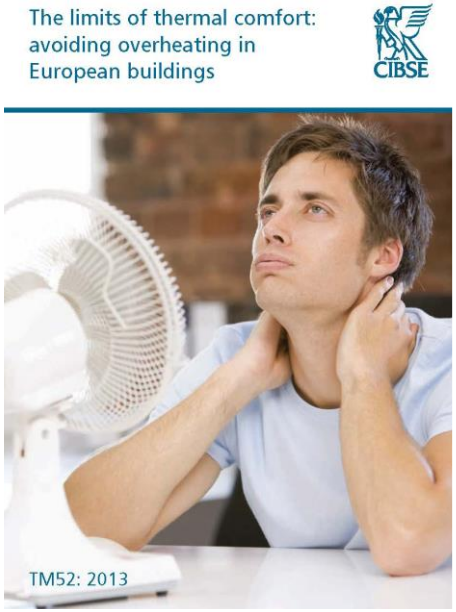
No regulations to prevent overheating
- Mainly based on thermal comfort approaches (PMV/PPD or Adaptive)
  - “Too hot” sensation (+3 on the 7-point scale)



(Source: CIBSE - Chartered Institution of Building Services Engineers)

Overheating: CIBSE 2006 approach

- In the past the CIBSE approach to overheating was based on not exceeding a single limiting temperature
  - 25°C for > 5% of occupied hours
  - 28°C for > 1%



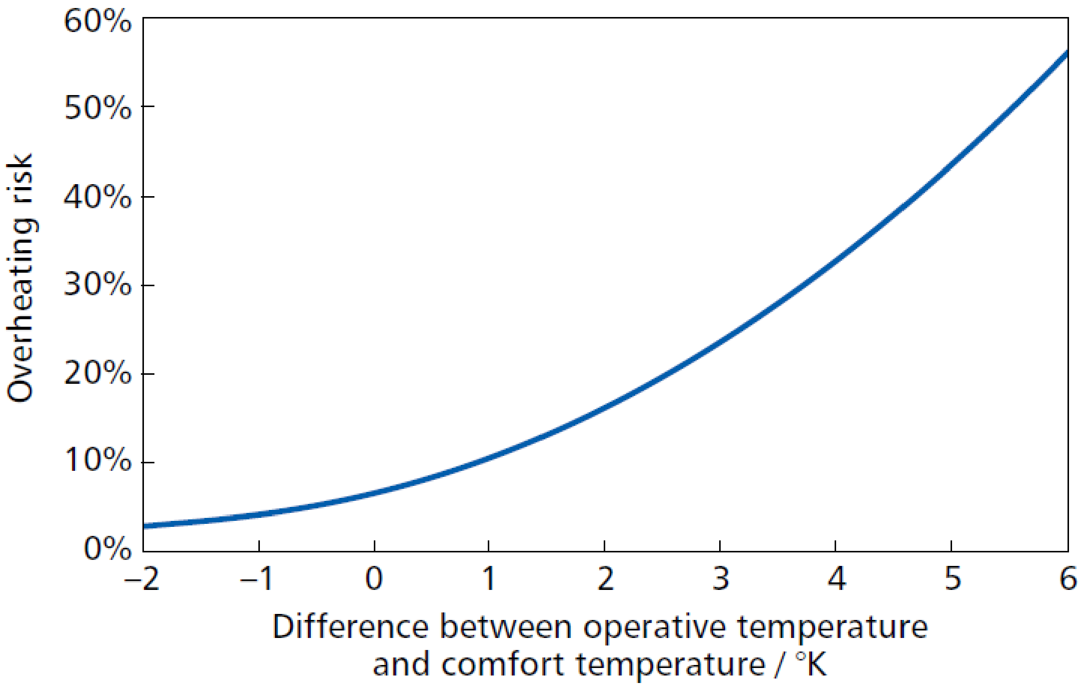
Problems:

- No acknowledgment that the extent of overheating was a concern as well as its duration
- The existing guidance was found to be inadequate, taking little account of the type of building and the climatic dependence of comfort on outdoor temperature
- The definitions on which it was based took little account of the actions of building occupant

Overheating: New CIBSE approach

In new and energy-renovated buildings, the maximum acceptable temperature (T_{max}) can be calculated from the running mean of the outdoor temperature (T_{rm}) using the formula:

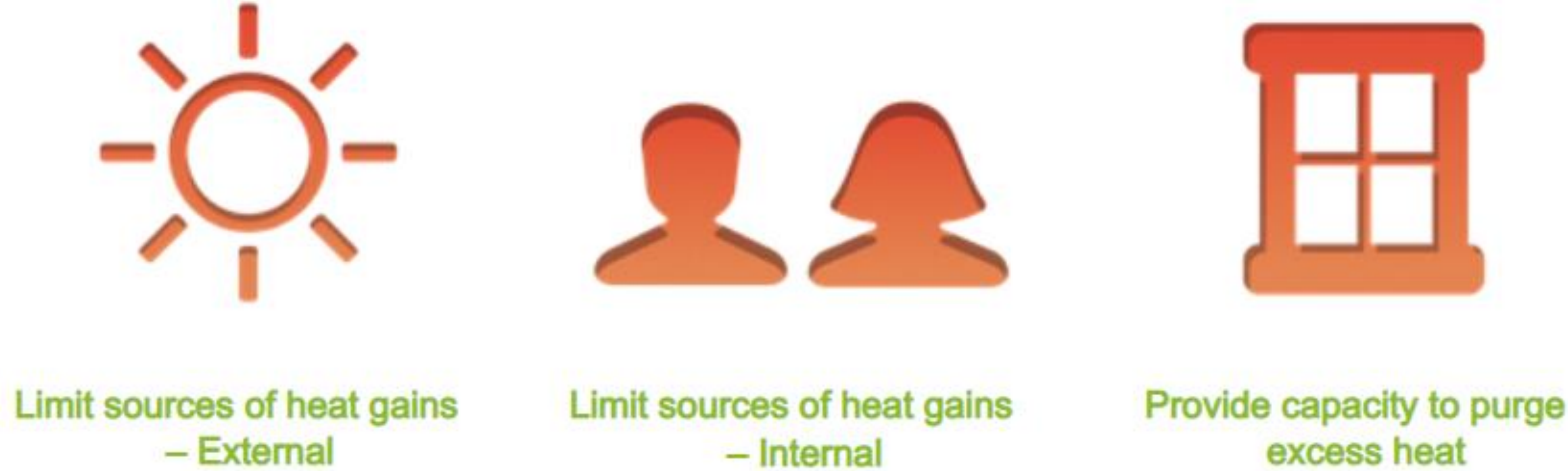
$$T_{max} = 0.33T_{rm} + 21.8\ (°C)$$



The criteria is all defined in terms of ΔT

$$\Delta T = T_{op} - T_{max}\ (°C)$$

Overheating: 3 ways to tackle the problem

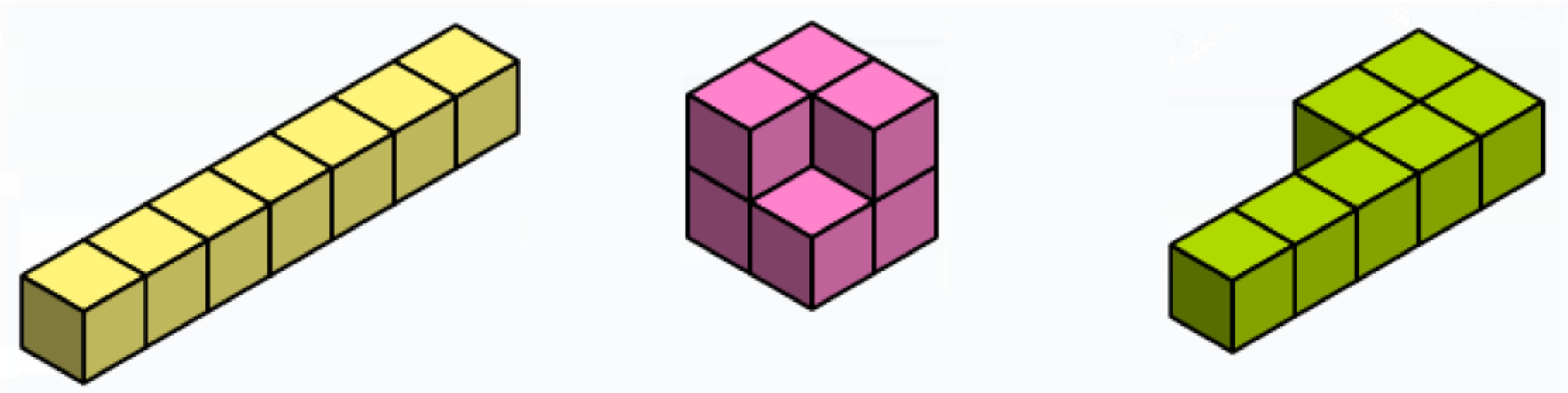


Ideally, passive strategies should always be first considered at the design stage in order to avoid or at least minimize the requirement of active strategies (technical installations and their final energy consumption) to ensure comfortable buildings!

Doing so ensures that the successful achievement of indoor comfort performance (including avoidance of overheating) will stay under the main responsibility of the architects instead of being partly (if not largely...) transferred to building service engineers

Example 1: Optimizing area to volume ratio (S/V)

- Overheating could be largely influenced by the thermal boundary area and it's shape.
- Heat transmission through the thermal boundary can be minimized with more "compact" (smaller S/V ratios) building shapes!



S/V=30/(7x)=4.3/x   S/V=24/(7x)=3.4/x   S/V=28/(7x)=4/x

with x= side length of a single cube

Other typical passive strategies

- Building orientation with respect to the Sun position
- Window-to-wall ratio and external shading
- Good insulation of walls
- Light colors (=high albedo) at the outer building façade
- Vegetation covering on the building envelope or nearby a building
- Etc.

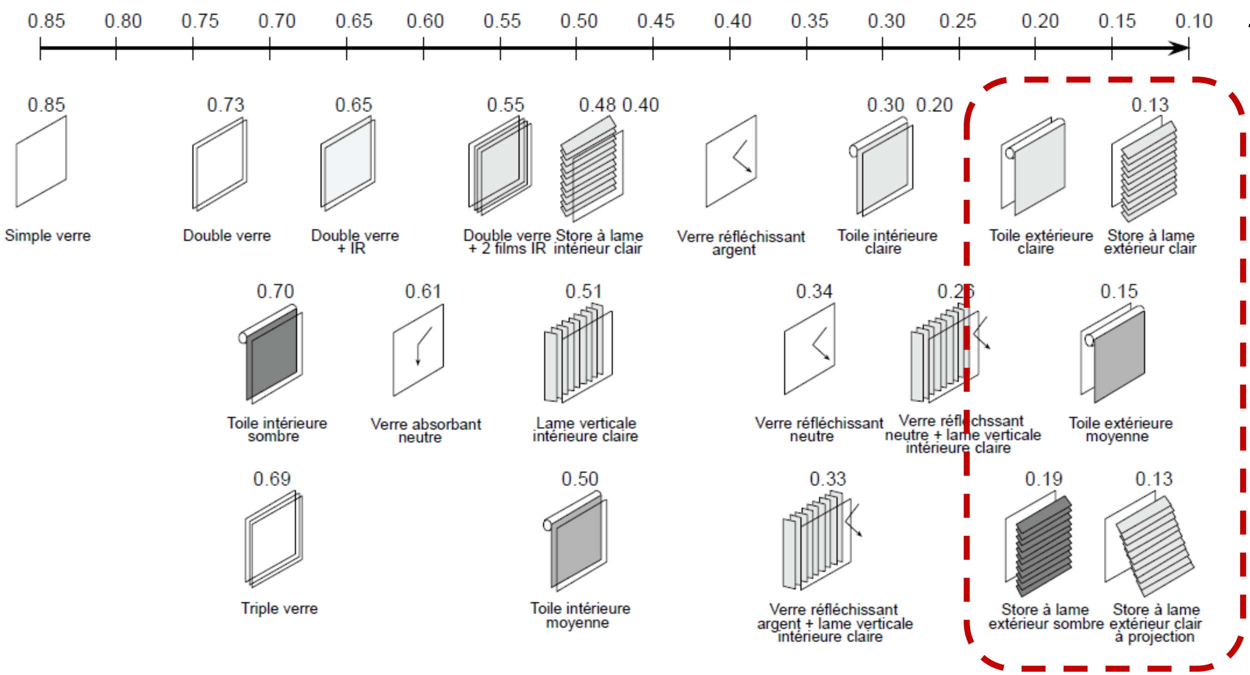
''Whitewashed'' houses in Greece

Nanyang Technical University in Singapore

Example 2: Solar gains through glazing

Solar gains ~ surface of the glazed area
~ g value of the glazing element
~ solar irradiation incident over the place of window

To effectively prevent overheating, all 3 factors must be decreased!



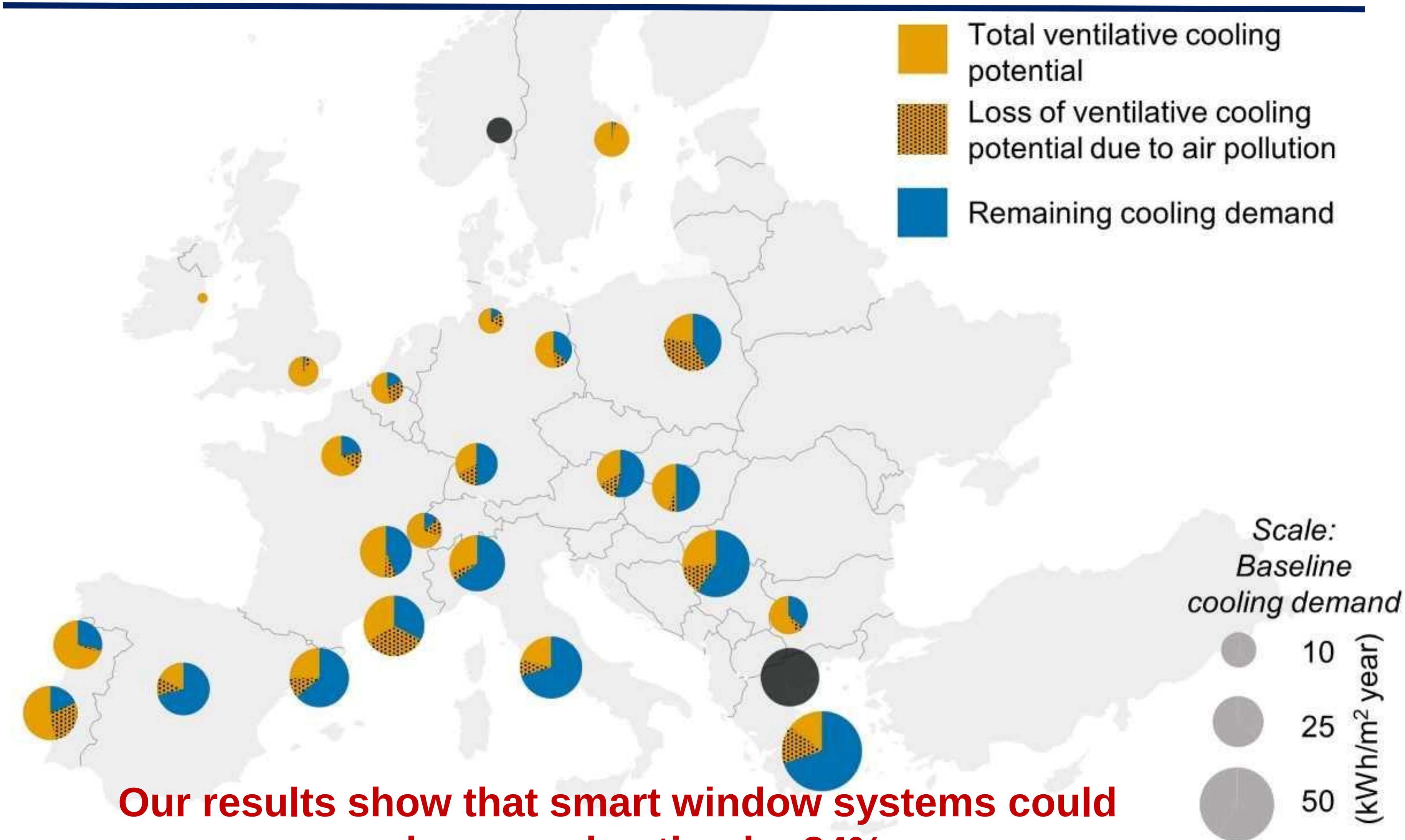
Typical ranges of g values

$$g = \frac{solar\ gains}{incident\ irradiation}$$

External solar protection (shading) can effectively reduce g value

(Source: Architecture climatique équilibrée, PACER, 1996)

Example 3: How much can we reduce cooling demand & overheating with optimal window use?



Our results show that smart window systems could reduce overheating by 84%

(Source: Belias and Licina, 2023, Energy and Buildings)

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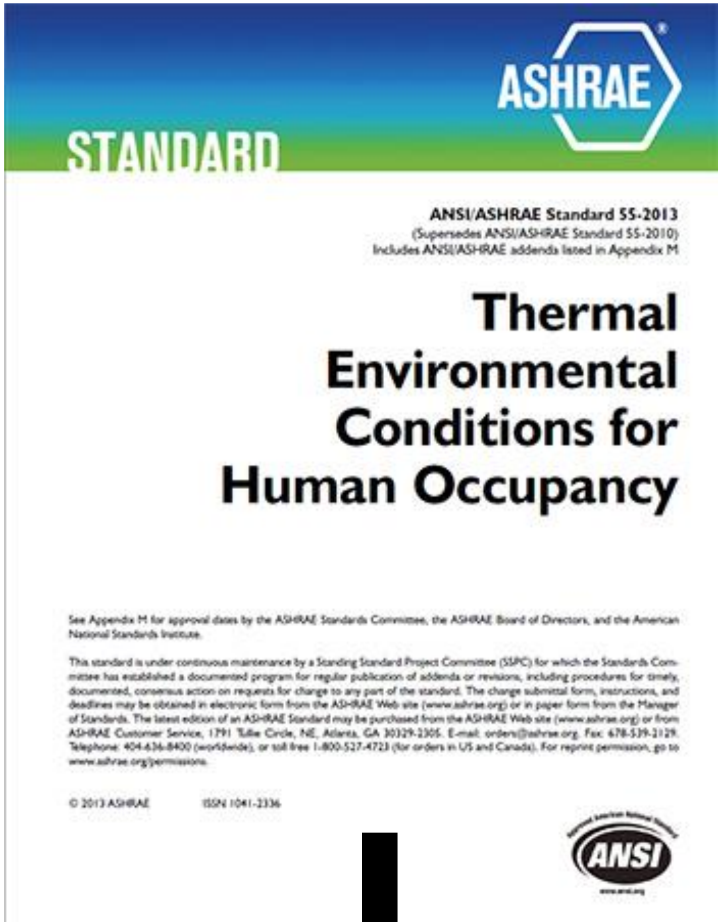
Thermal comfort standards in building design


STANDARD

ASHRAE

ANSI/ASHRAE Standard 55-2013
(Supersedes ANSI/ASHRAE Standard 55-2010)
Includes ANSI/ASHRAE addenda listed in Appendix M

Thermal Environmental Conditions for Human Occupancy

See Appendix M for approval dates by the ASHRAE Standards Committee, the ASHRAE Board of Directors, and the American National Standards Institute.

This standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE Web site (www.ashrae.org) or in paper form from the Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from the ASHRAE Web site (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 678-539-2129. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

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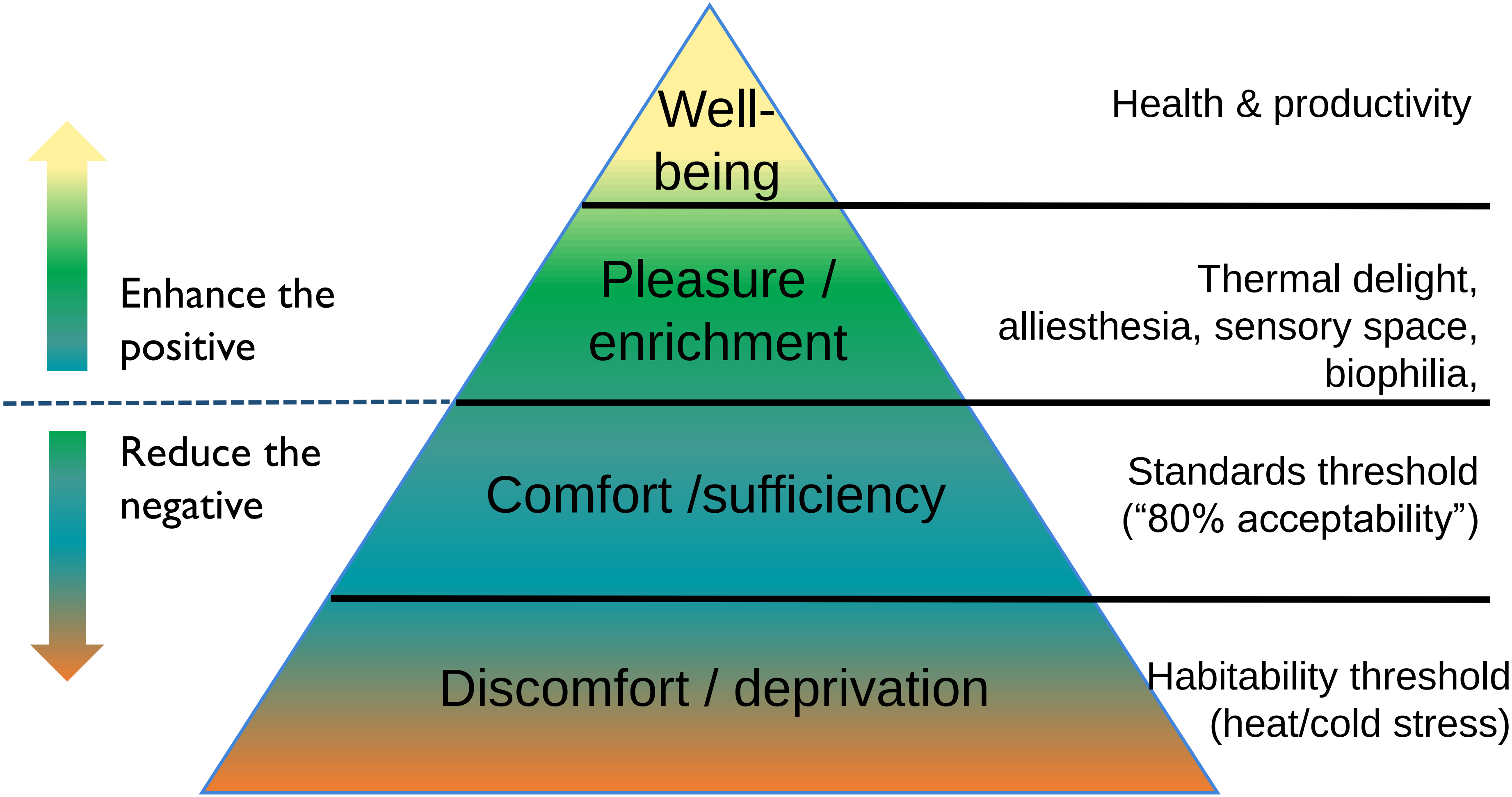
ANSI

- ASHRAE Standard 55
- ISO 17772
- CEN Standard EN-16798
- ISO 7730
- Together, these:
  - Often produce thermal conditions acceptable to **80%** or more of building occupants

1. PURPOSE

The purpose of this standard is to specify the combinations of indoor thermal environmental factors and personal factors that will produce thermal environmental conditions acceptable to a majority of the occupants within the space.

Perspective: Spectrum of occupant experience



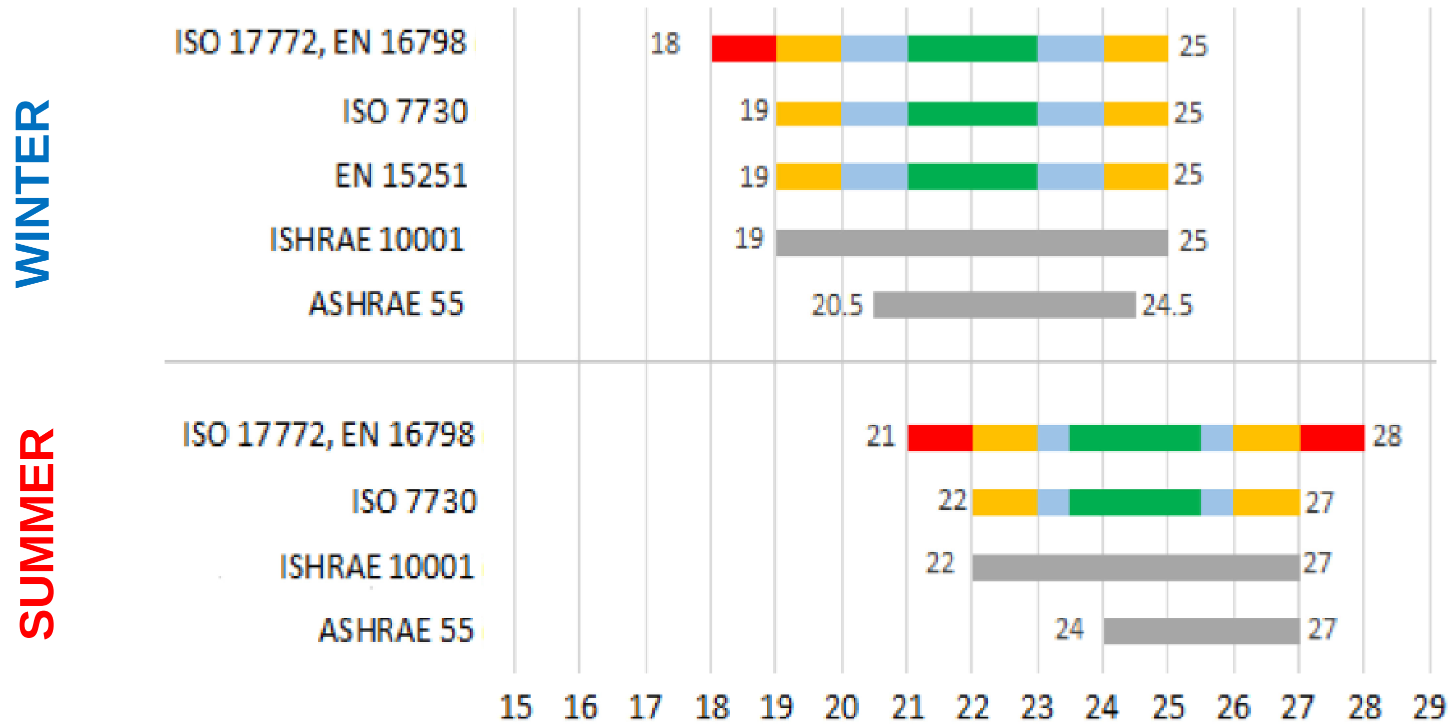
(Courtesy of Gael Brager, UC Berkeley)

Standards and categories for thermal comfort

- **ISO 7730:2005** – Ergonomics of theThermal Environment
- **ASRHAE 55-2020** – Thermal Environmental Conditions for Human Occupancy
- **ISO 17772:2017** – Energy performance of buildings Indoor environmental quality
- **EN 16798:2019** – Energy performance of buildings–Ventilation for buildings

Standards	Category I	Category II	Category III	Category IV
ISO 17772	**High** For occupants with special needs (children, elderly, handicapped)	**Medium** (typically used) For regular building design and operation	**Moderate** Can provide an acceptable environment with some risk of reduced occupants' performance	**Low** Can be used for a short time of the year or in spaces with a very short time of occupancy
ASHRAE 55	No categorization (defines only "acceptable"/"unacceptable" level)			

Thermal comfort standards: Categories

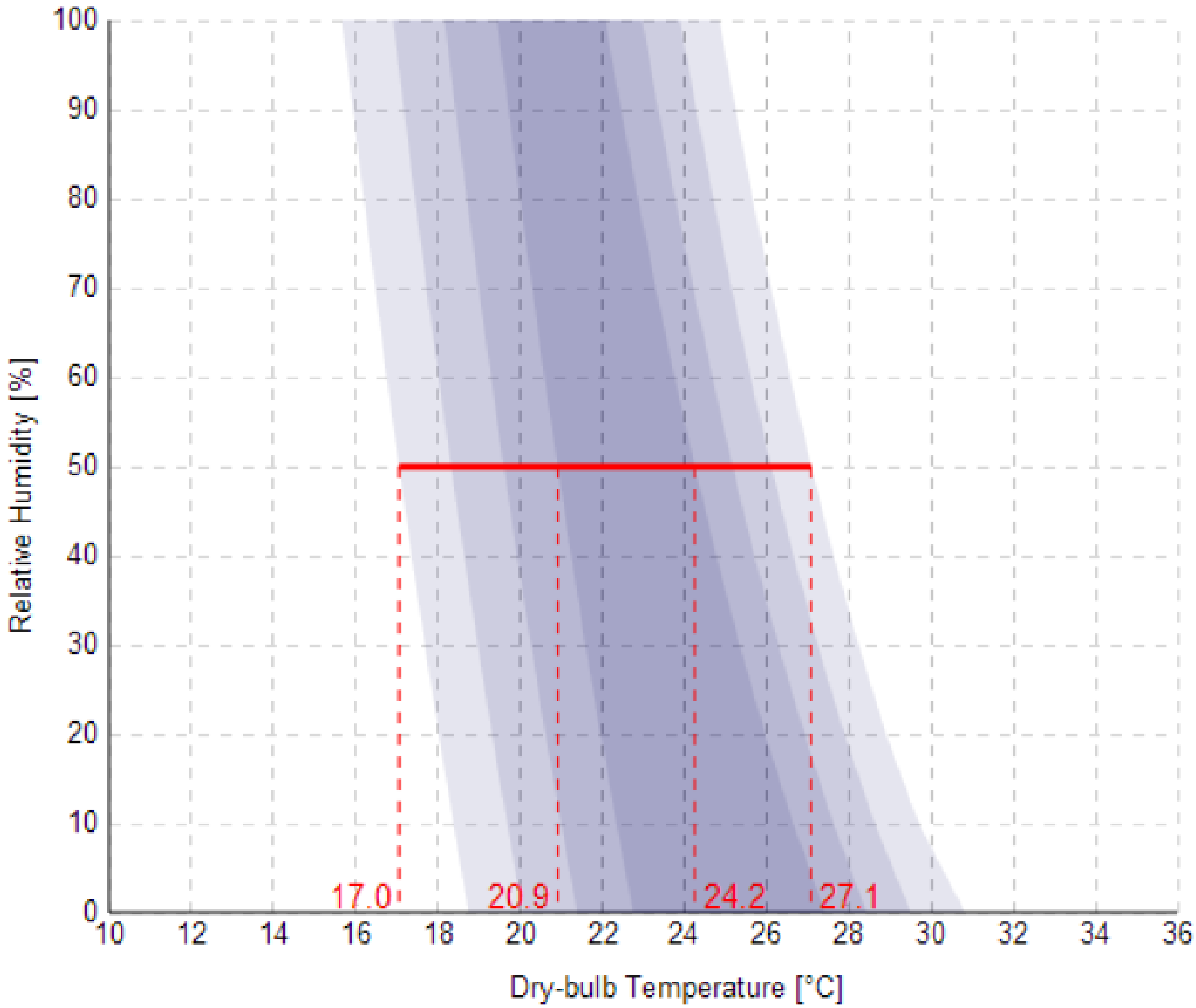


(Adapted from Khovalyg et al. 2020, Energy and Buildings)

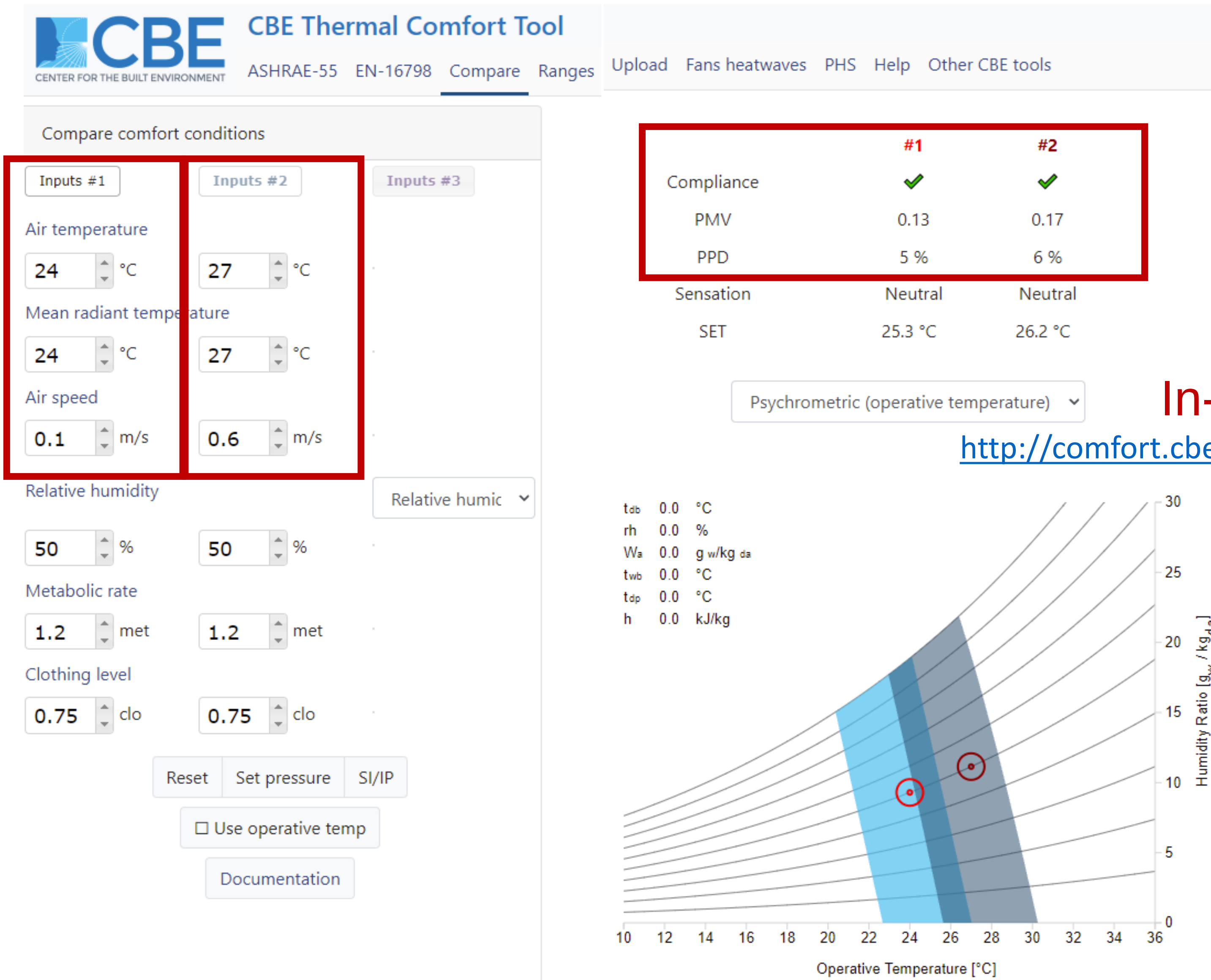
Depending on the standard category selected, energy use in buildings can be largely affected:

- Typically, higher category requires more energy
- What approached can we think of that yield enhanced thermal comfort with reduced energy use?

Do we really need a narrow indoor T range?



Can we get rid of air-conditioning in summer?



In-class exercise:
http://comfort.cbe.berkeley.edu/compare

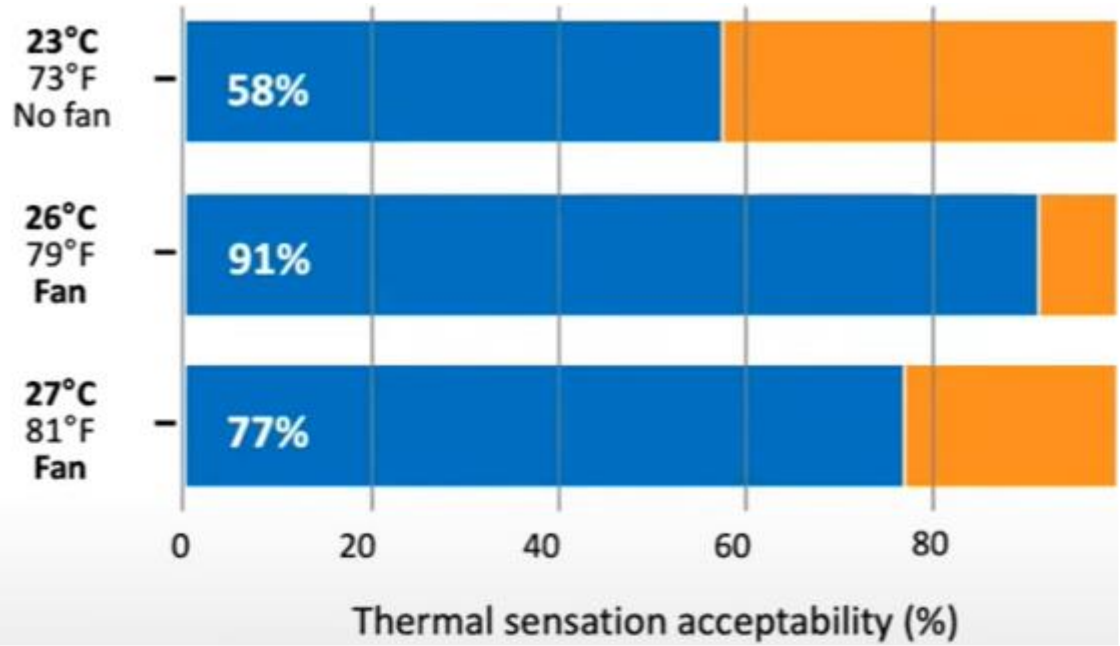
Can we get rid of air-conditioning in summer?

or

500 –1500 W

5 -100 W

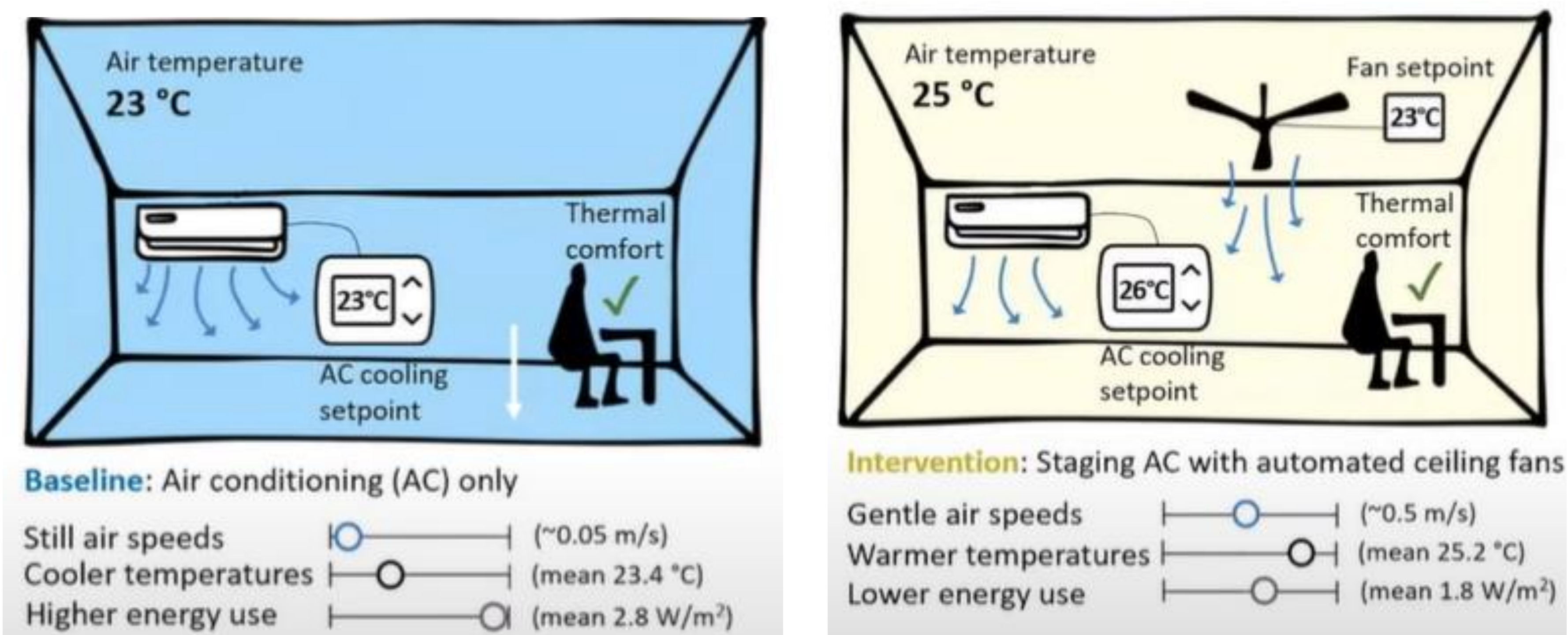
Ex 1: Higher thermal comfort with ceiling fans



- The most comfortable conditions at 26 °C with fans
- Ceiling fans provide neutral thermal sensation with temperatures up to 27 °C
- Self-reported productivity increases with an increase in occupants' thermal satisfaction

(Source: Lipczynska et al. 2018, Building and Environment)

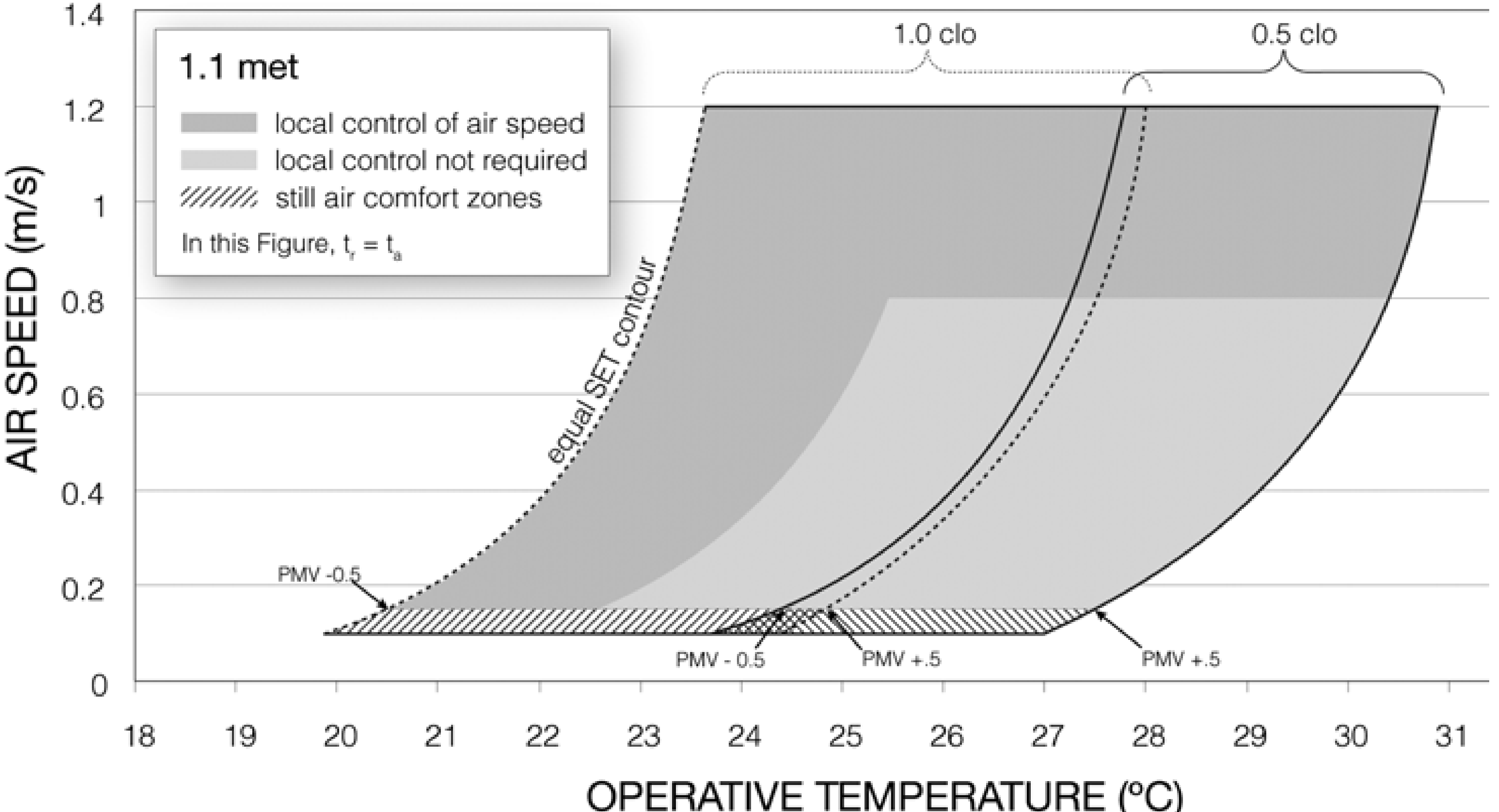
Ex 2: Higher thermal comfort with ceiling fans



- Field study: 13 air-conditioned zones retrofitted with 99 automated ceiling fans
- Over 2.5 years, intervention provided comparable comfort to baseline with substantially less energy use

(Source: Miller et al. 2021 Energy and Buildings)

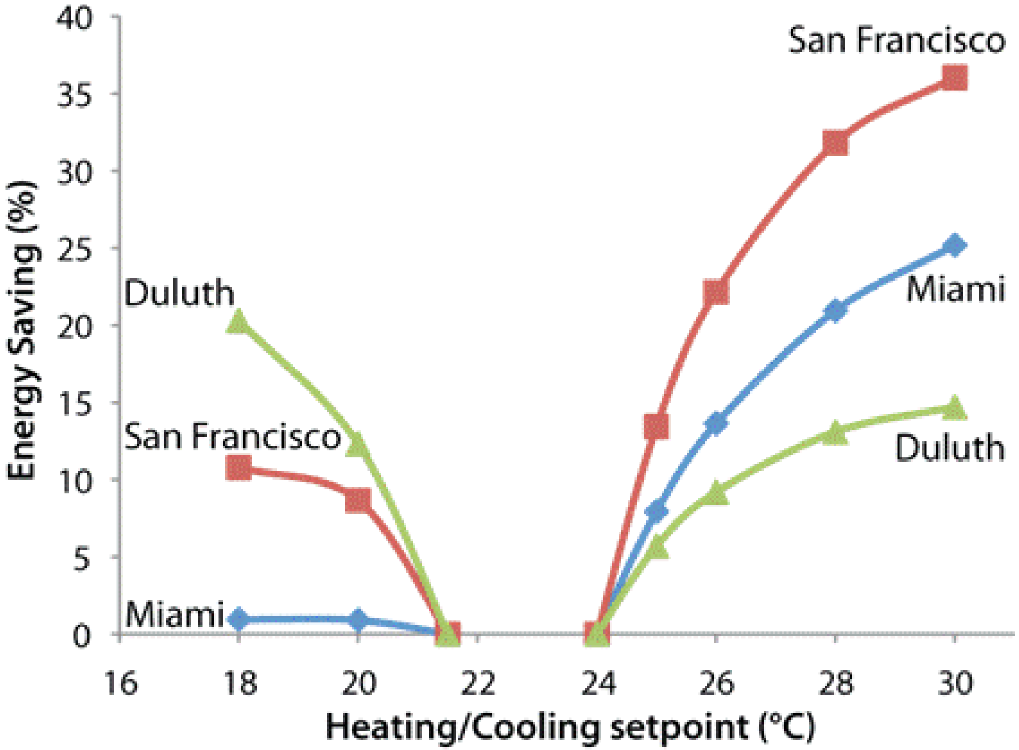
Comfortable T increases with air speed



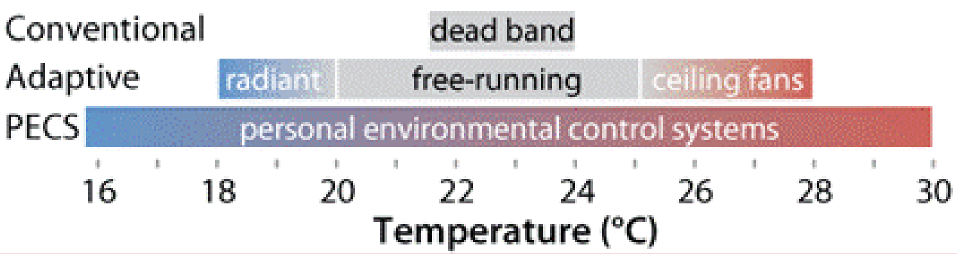
(Source: ASHRAE Standard 55)

Energy savings with wider T setpoint range

- Wider T band reduces HVAC energy 7-15% per degree C
- Comparable results in the tropics
- What about personal comfort systems?



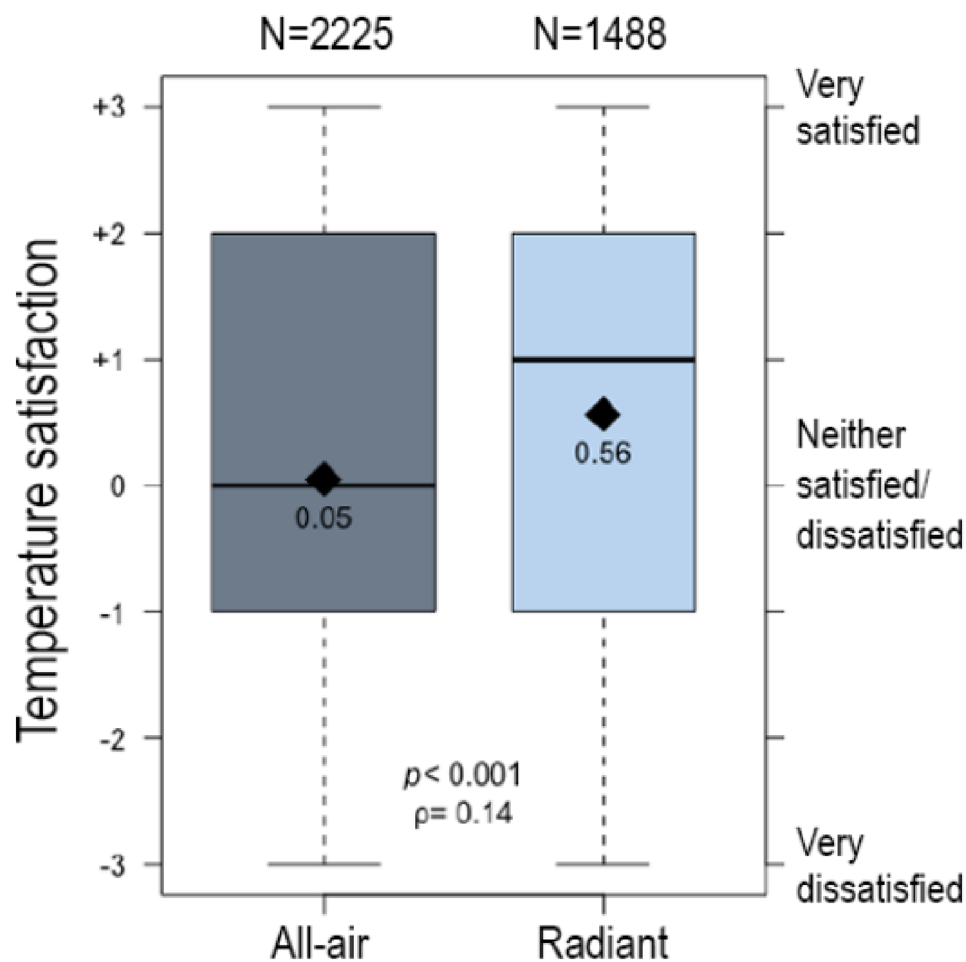
Extended thermostat dead band zones providing equal comfort



(Sources: Hoyt et al. 2015, Building and Environment; Schiavon and Melikov 2008, Energy and Buildings)

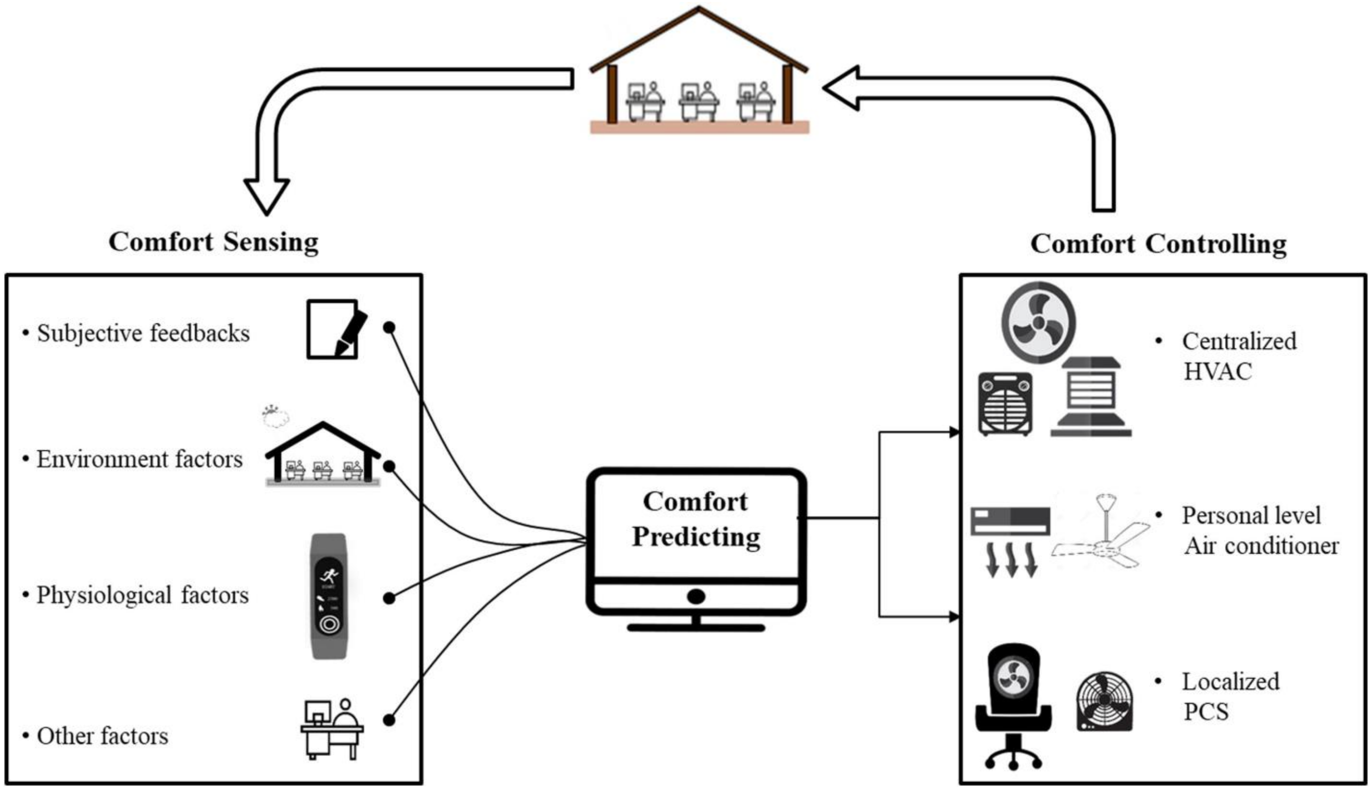
What about radiant systems?

Radiant and all-air spaces have equal indoor environmental quality with a tendency towards improved temperature satisfaction in radiant buildings. These systems can often be more energy-efficient.



(Source: Karmann et al. 2017, Building and Environment)

Occupant-centric thermal comfort control



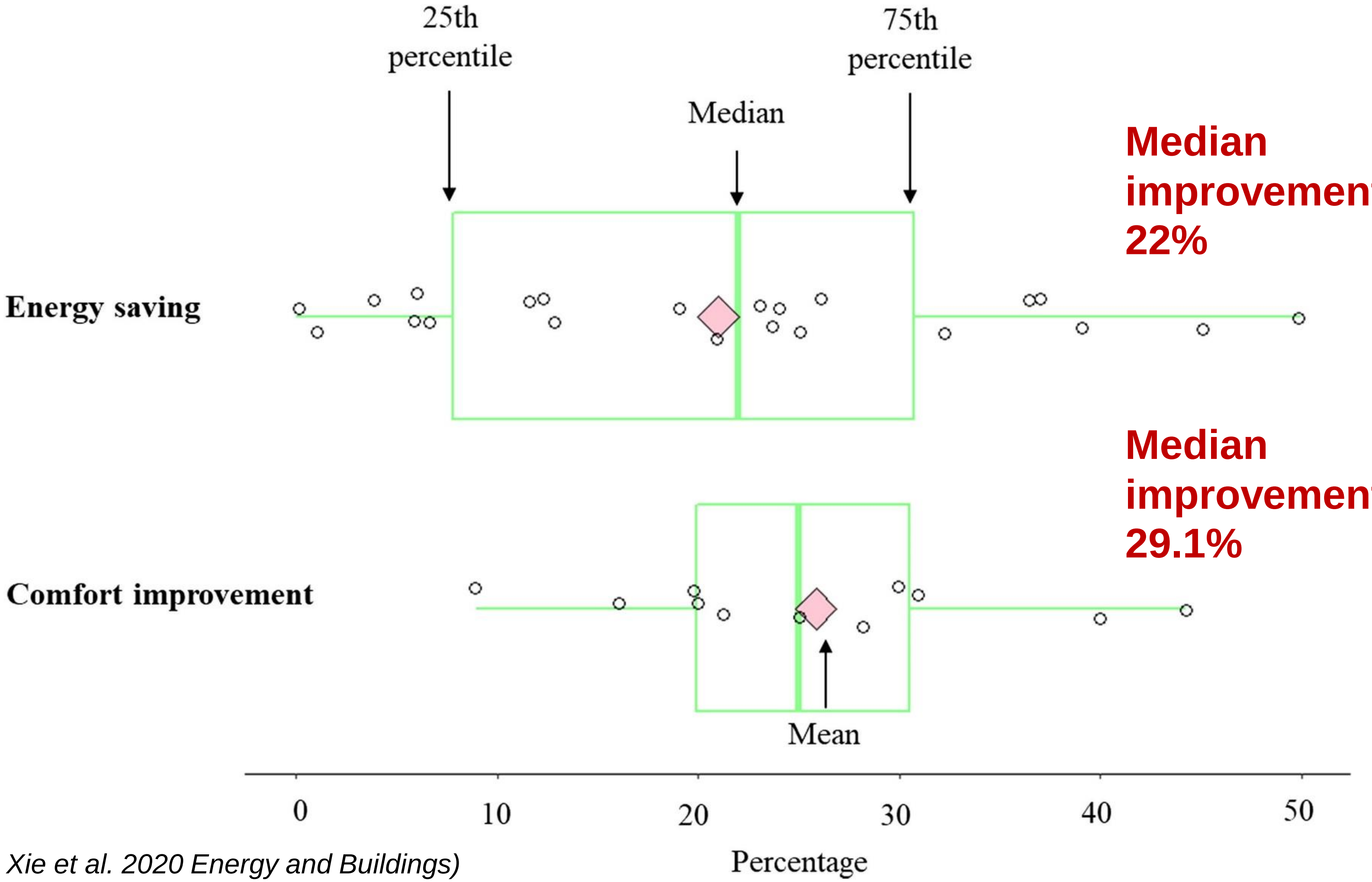
(Source: Xie et al. 2020 Energy and Buildings)

Occupant-centric building control: refers to control systems utilizing data from occupants, indoor environment, and outdoor climate to regulate indoor environments (including illuminance, temperature, humidity, CO_2, noise) via components like the thermostat, light switch, window, blind, fans, etc.

The goal is to improve both occupant comfort and energy efficiency.

Energy saving and comfort improvement potential of occupant-centric control

Summary of existing occupant-centric thermal comfort control studies:



Median improvement 22%

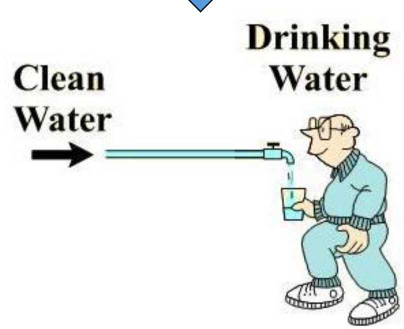
Median improvement 29.1%

(Source: Xie et al. 2020 Energy and Buildings)

What about personalized systems?

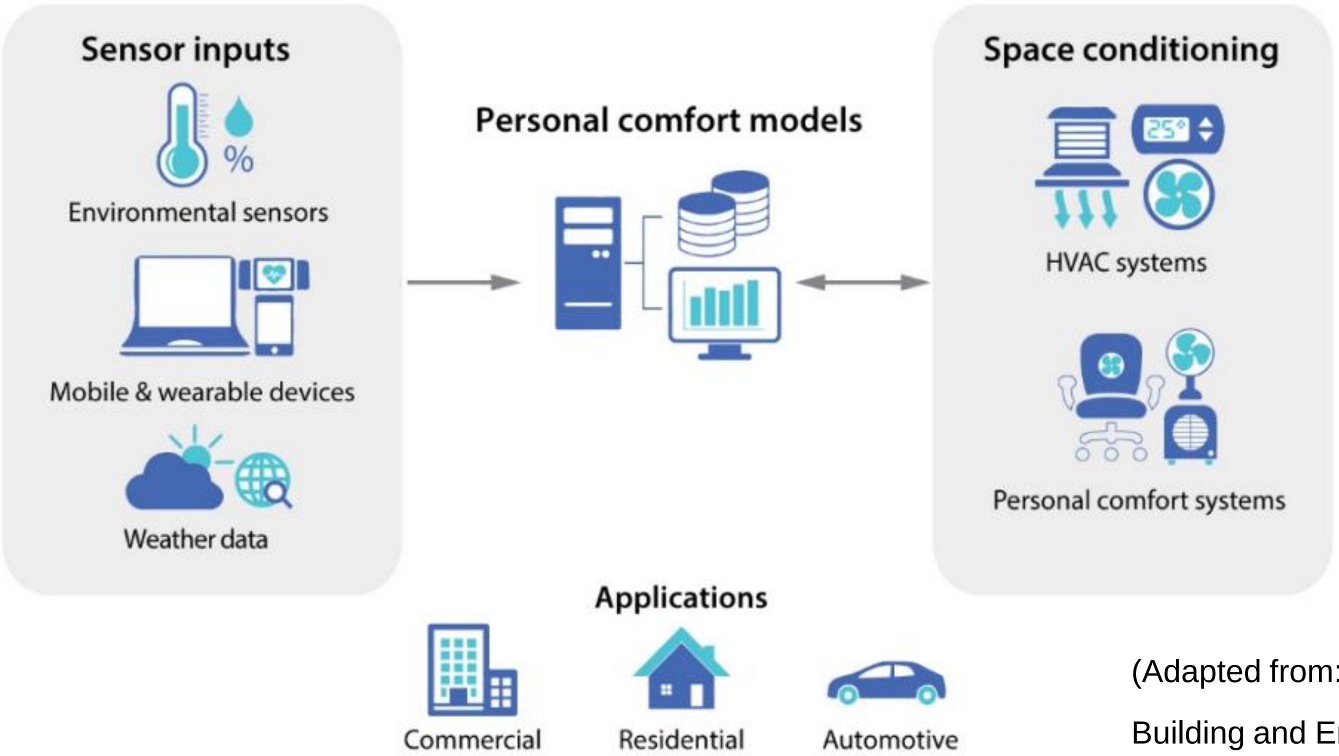
Traditional comfort model

(Courtesy of Arsen Melikov, DTU)



Personalized comfort model

Personal comfort systems and models



(Adapted from: Kim et al. 2018

Building and Environment)

- Personal comfort models produce individual-specific and context-relevant predictions.
- They improve predictive power compared to PMV, Adaptive models.
- The proposed framework provide a unified approach to develop and evaluate personal comfort models.
- Personal comfort models can be integrated into real-world systems (buildings, vehicles, aircraft, etc.) to enable intelligent comfort management.

New Model for Personal Comfort

Personal comfort model is a new approach to thermal comfort modeling that predicts individuals' thermal comfort responses, instead of the average response of a large population

It could be based on:

- Environmental factors (e.g., outdoor air temperature)
- Behavioral parameters (e.g., occupant feedback through for example Comfy, Cozie Apps)
- Physiological parameters (e.g., skin temperature)
- Others (e.g., dress code, time)

(Source: Kim et al. 2018 Building and Environment; Image sources: comfyapp.com; cozie.app)

Personal Environmental Control (PES) devices

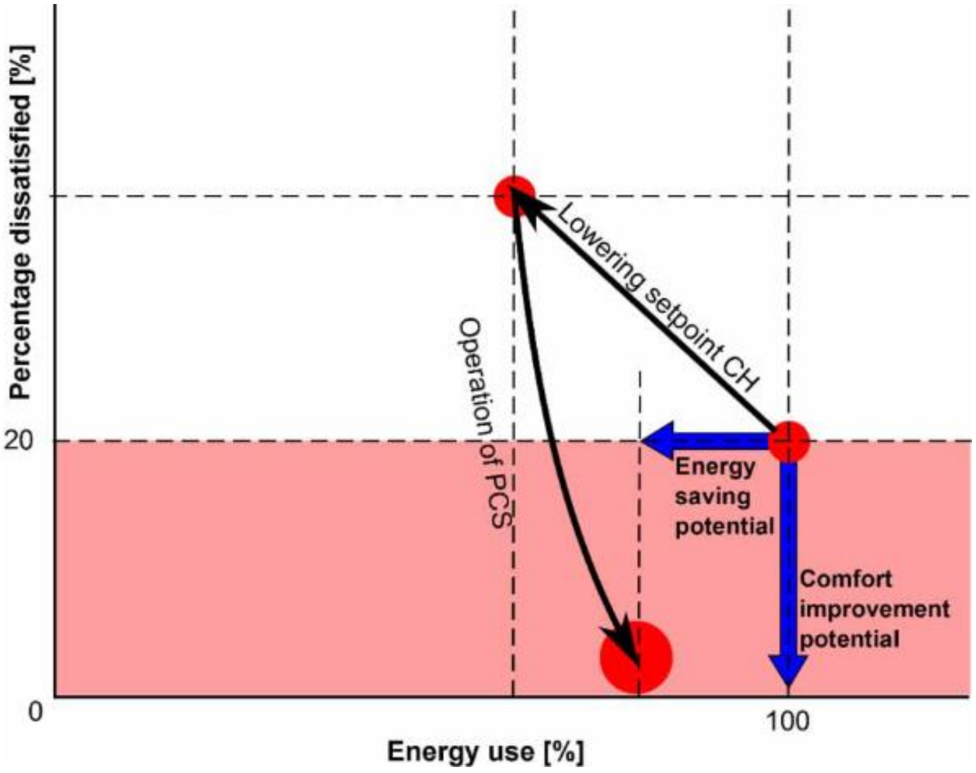
PEC Devices (Fans and a Radiant Foot Warmer) in an Office. Photograph by Ed Arens; courtesy of Center for the Built Environment

Can T setpoint be reduced in the winter?

- The case study demonstrates a substantial energy-saving potential of personalized heating of up to 35% of HVAC energy consumption during the winter period
- The rate of occupant satisfaction has improved

Set point (°C)	HVAC energy consumption for the winter season (MWh)	Energy savings (%)[a]
21.5	566	Reference
20	421	22
18	370	35

Note: [a]Compared with a set point of 21.5°C

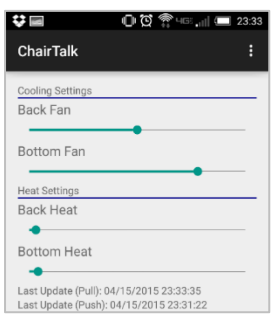


Strategy for reducing energy consumption and increasing comfort level in an office building: first lower the set point of the thermostat, reducing the comfort level, then introduce personalized environmental control (PEC)

(Source: Verhaart et al. 2015, Building Research & Information)

Example of a heated/cooling chair

- Low power use, max:
  - 14 W for heating
  - 3.6W for cooling
- User controls for cooling and heating
- Saves energy by allowing wider HVAC temperature setpoints
- Rechargeable battery
- WiFi and Bluetooth communication with BMS
- Collects temp, humidity, occupancy & usage data
- 50 built for research



Touchscreen

Phone app

Demonstrated comfort and energy savings

- Field testing prototypes in multiple sites
  - Summer/winter
  - NV, VAV, radiant
  - With and without PEC (chairs, fans, food warmers, legwarmers)

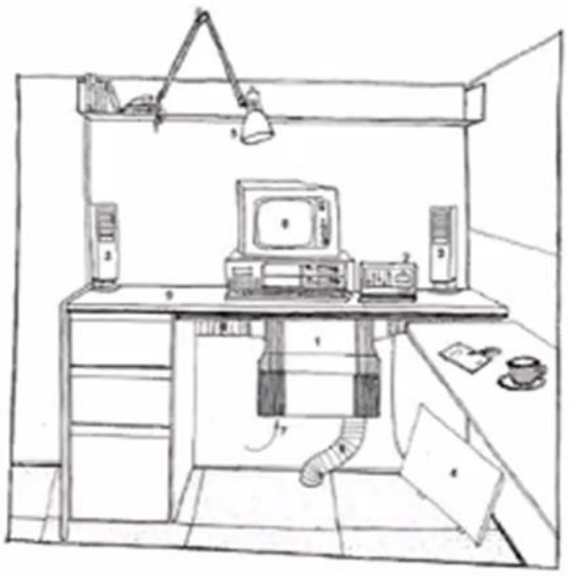
- <u>Comfort</u>:
  - Lab tests: At 18-29 ºC more than 90% of subjects were comfortable with the chair and a desk fan.
  - Field studies: 96% thermal acceptability; chairs used 77% of the time when seated

(Source: Pasut et al., 2015. Energy efficient comfort with a heated and cooled chair)

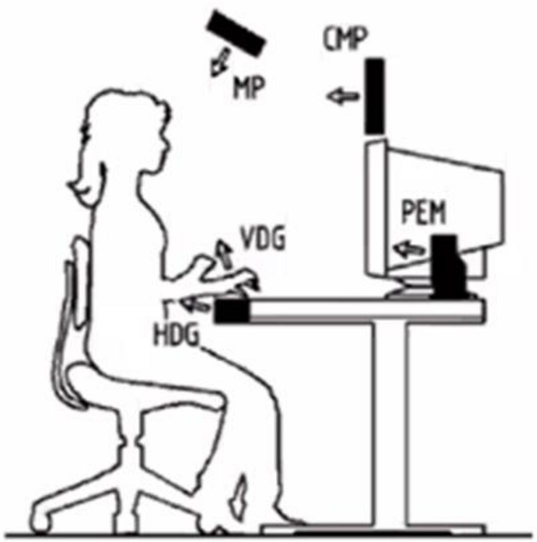
What do the scientists say?

- There is a need to replace the present strategy of indoor environment design based on assumption that “one size fits all” with individually controlled environment.

- Personalized environmental control (PEC) systems will become “mega trend” of the 21st century.



Bauman et al. 1997



Melikov 2002

Examples of workstation-integrated PEC

I. QUICK OVERVIEW OF THERMAL COMFORT
II. OVERHEATING OF BUILDINGS
III. COMFORT AND ENERGY EFFICIENCY
IV. EXERCISE

In-class exercise #1

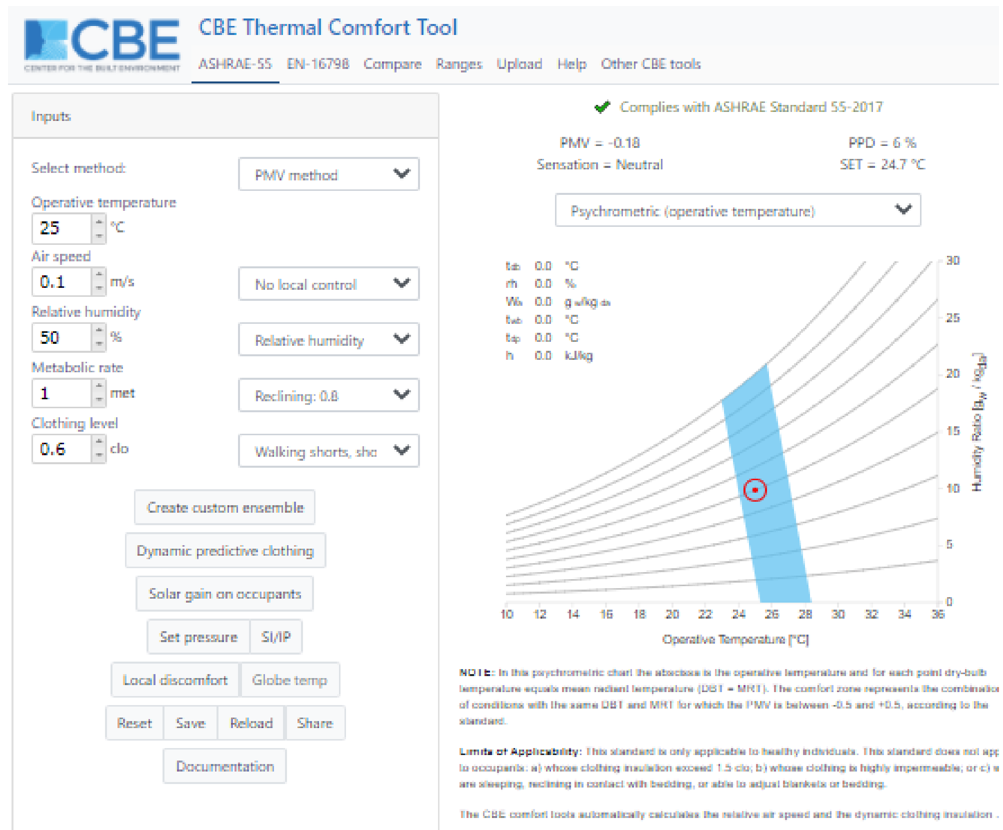
By means of the CBE thermal comfort tool, determine PMV, PPD and EN-16798 Standard compliance and category for the following conditions:

- Dry-bulb T = 22 °C
- MRT = 20.5 °C
- Air speed = 0.05 m/s
- RH = 30%
- MET = 1.1
- Clo = 0.85

Would the same conditions comply with ASHRAE?

Solutions:

PMV=-0.61
PPD=13%
Category III (EN-16798)
No compliance with ASHRAE



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

In-class exercise #2

Use the CBE Thermal Comfort Tool for EN-16798 to answer the following questions. A person is exposed to the following winter indoor conditions:

- Clothing insulation = trousers, long-sleeve shirt
- Metabolic activity = typing
- Wet-bulb temperature = 15 °C
- Mean radiant temperature = 23 °C
- Absolute humidity (humidity ratio) = 7 g/kg
- Air velocity = 0.11 m/s

(a) The PMV is (**-0.57**), the PPD is (**12%**), and the category of compliance is (**III**). (**Dry-bulb T = 24 deg C; RH = 38%)**

(b) If the same person was lifting and packing items, would these conditions comply with the standard? (possible answers are Yes or No)? (**Yes**)

(c) Air movement can compensate for higher temperature. In case of lifting and packing activities, the minimum air speed needed to comply with the standard category III is (**0.046 m/s**). Briefly discuss the possible pros and cons of using fan as an alternative to air conditioning.

In-class exercise #3

The prevailing outdoor winter conditions are 60% relative humidity, 9 °C web-bulb temperature, and low air speed. Average indoor conditions include air speed 0.17 m/s, dry-bulb temperature 24 °C and mean radiant temperature 22 °C.

(a) By means of the CBE Thermal Comfort Tool, determine the range of operative temperatures in order to remain within 80% acceptability limits.

Outdoor dry bulb T = 13 °C.
Indoor operative temperature 23 °C
80% acceptability limits = Operative temperature: 18.3 to 25.3 °C

(b) Under the same indoor conditions, what would be the minimum operative temperature in order to remain within comfortable range based on 90% acceptability limits if the prevailing mean outdoor temperature was 17 °C?

Min operative temperature: 20.6 °C
(you need to fine tune the operative temperature on the chart

In-class exercise #4

In the future large office building of United Nations in Geneva, multiple activities are envisioned. The building owners would like to provide increased satisfaction with thermal comfort for future occupants of the building. However, the budget is relatively small and does not permit implementation of personalized comfort systems. As a designer, think of a strategy that will increase satisfaction with thermal comfort for as many as possible occupants.

- *Please read the question carefully*
- *Divide yourself into groups*
- *Select a spokesperson to represent views of your group*

In-class exercise #5

You have been appointed as a lead consultant to a luxurious hotel property in a hot and humid climate and have been provided with the following key specifications:

- 10 storey building that has a window-to-wall ratio exceeding 70%
- Total roof area of about 2,500 m^2 exposed to direct solar radiation
- Variable occupancy pattern that can range between 30 and 90% during the day and between 70 and 100% during the night
- Air-conditioning provision in the hotel is for 24 hours and 7-days a week

You have been asked to identify an thermal conditioning concept/strategy that can be seen as the key contributing factor towards the hotel securing a Leadership in Energy and Environmental Design (LEED) Platinum rating. Discuss your choice of the thermal conditioning concept/strategy with suitable justifications that should at least include the following criteria:

a) Thermal comfort
b) Individual environmental control
c) High energy efficiency

- *Please read the question carefully*
- *Divide yourself into groups*
- *Select a spokesperson to represent views of your group*

Summary of key concepts from today

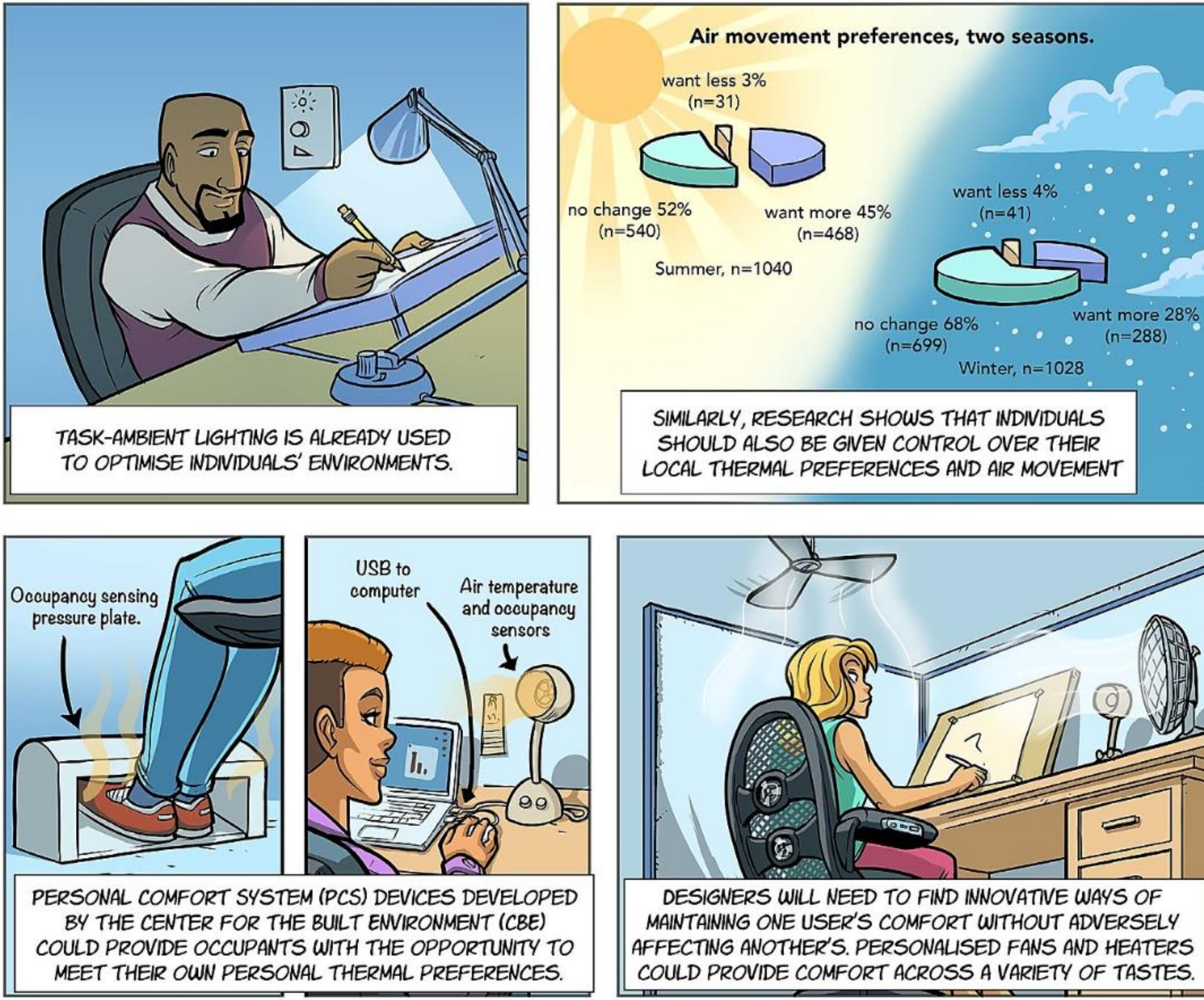
- Thermal comfort greatly affects building design, energy consumption, human well-being and productivity
- Thermal comfort models work well, but not always. One major point is that different people have different needs
- Current standards do not aim high because thermal comfort is subjective - not everyone will be equally comfortable under the same conditions
- Europe has many buildings that overhead during the summer. Problem is solvable
- There is a need for a holistic approach to thermal comfort that can satisfy individual preferences and energy use
- Lots of opportunities to save energy with expanding the deadband setpoint of T, by relying on PEC devices, …

Next time…

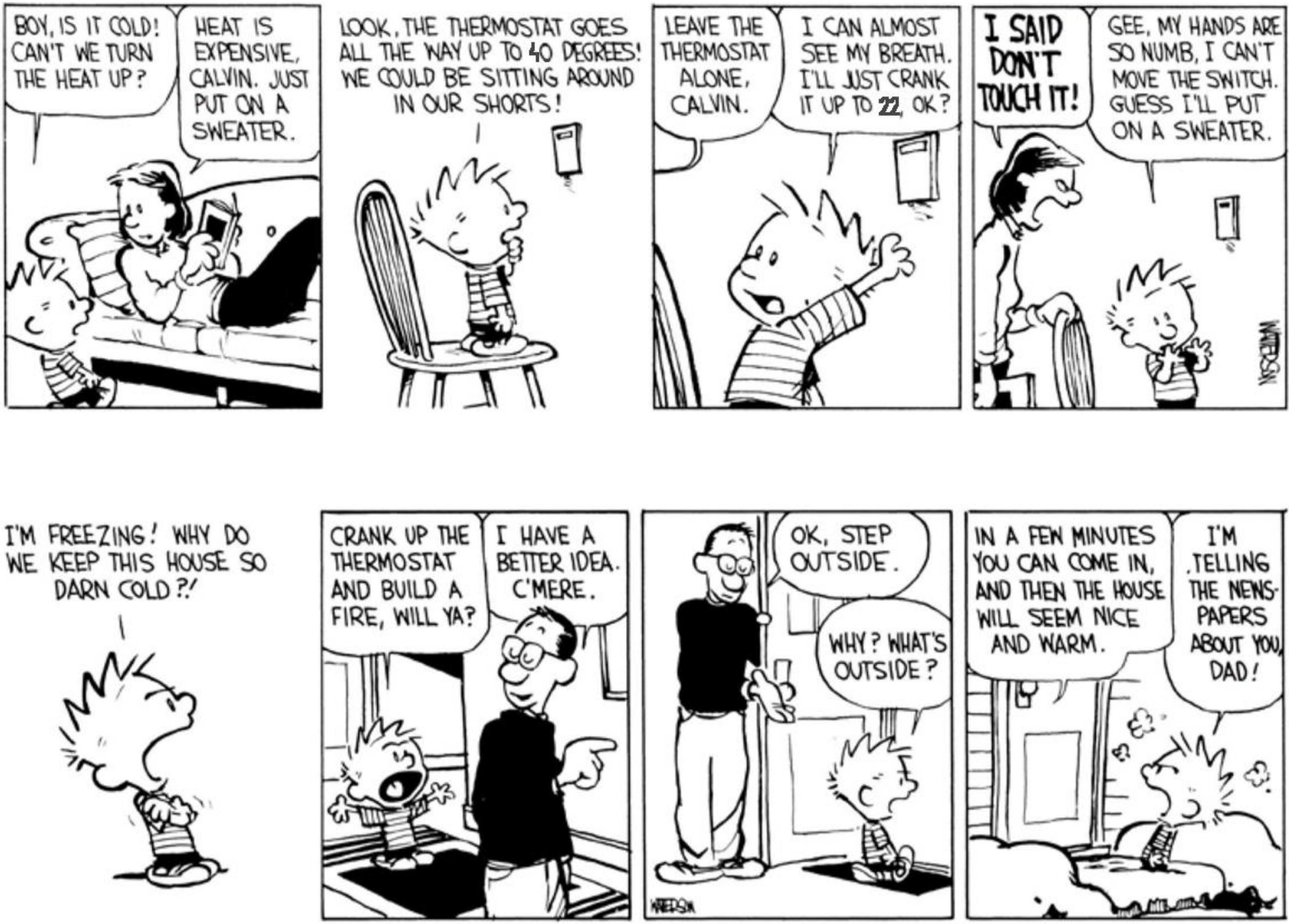
IAQ and Ventilation #1

- IAQ: why we must care?
- Perceived and physical air quality
- Assessment methods
- Exercises
- Ventilation introduction

Important Note:
For those who have previously encountered the topics of thermal comfort fundamentals and thermal comfort assessment, please check out extra slides available on Moodle (within Week 02).



(Source: Center for the Built Environment, UC Berkeley)


BOY, IS IT COLD! CAN'T WE TURN THE HEAT UP?
HEAT IS EXPENSIVE, CALVIN. JUST PUT ON A SWEATER.
LOOK, THE THERMOSTAT GOES ALL THE WAY UP TO 40 DEGREES! WE COULD BE SITTING AROUND IN OUR SHORTS!
LEAVE THE THERMOSTAT ALONE, CALVIN.
I CAN ALMOST SEE MY BREATH. I'LL JUST CRANK IT UP TO 22, OK?
I SAID DON'T TOUCH IT!
GEE, MY HANDS ARE SO NUMB, I CAN'T MOVE THE SWITCH. GUESS I'LL PUT ON A SWEATER.
I'M FREEZING! WHY DO WE KEEP THIS HOUSE SO DARN COLD?!
CRANK UP THE THERMOSTAT AND BUILD A FIRE, WILL YA?
I HAVE A BETTER IDEA. C'MERE.
OK, STEP OUTSIDE.
WHY? WHAT'S OUTSIDE?
IN A FEW MINUTES YOU CAN COME IN, AND THEN THE HOUSE WILL SEEM NICE AND WARM.
I'M TELLING THE NEWSPAPERS ABOUT YOU, DAD!