प्रधान मंत्री आवास योजना-शहरी
Pradhan Mantri Awas Yojana-Urban

GLOBAL HOUSING TECHNOLOGY CHALLENGE INDIA

Ministry of Housing and Urban Affairs
Government of India

Azadi Ka Amrit Mahotsav

bmtpc | giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

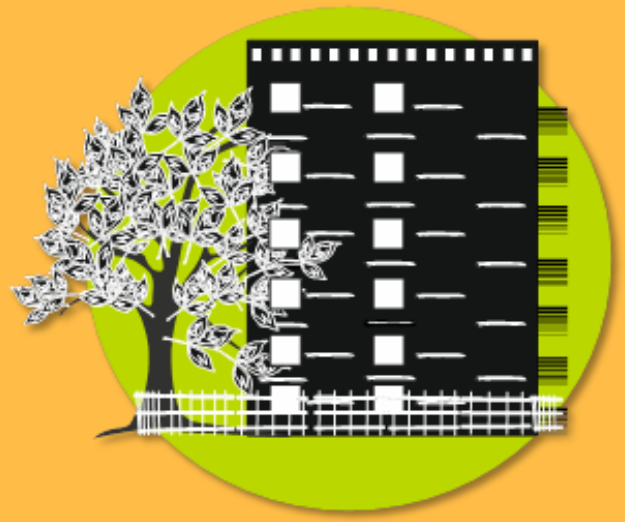
Session 1 - Fundamentals of Thermal Comfort

Date | Place

eds environmental design solutions

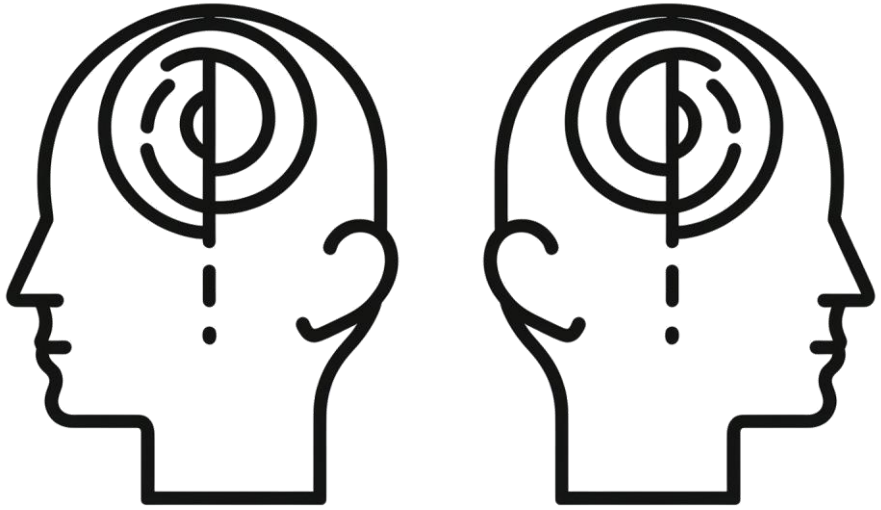
Wuppertal Institut

hunnarshālā FOUNDATION



What is Thermal Comfort

Thermal Comfort - Definition



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ISO 7730 defines thermal comfort as **'…that condition of mind which expresses satisfaction with the thermal environment.'**

ANSI/ASHRAE Standard 55 defines thermal comfort as…
'The condition of the mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation'

Thermal Comfort – Natural Phenomenon

Dogs sweat through their paws & heavy panting

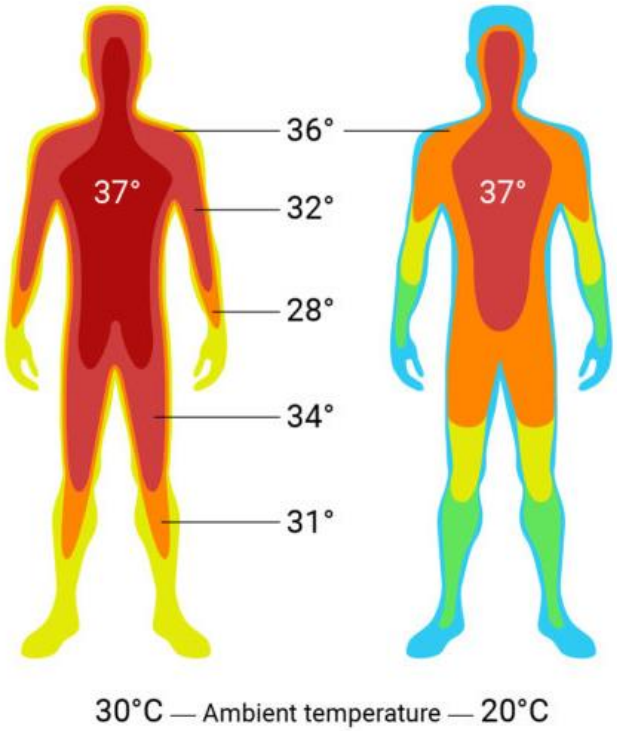
Dissipate excessive heat by panting

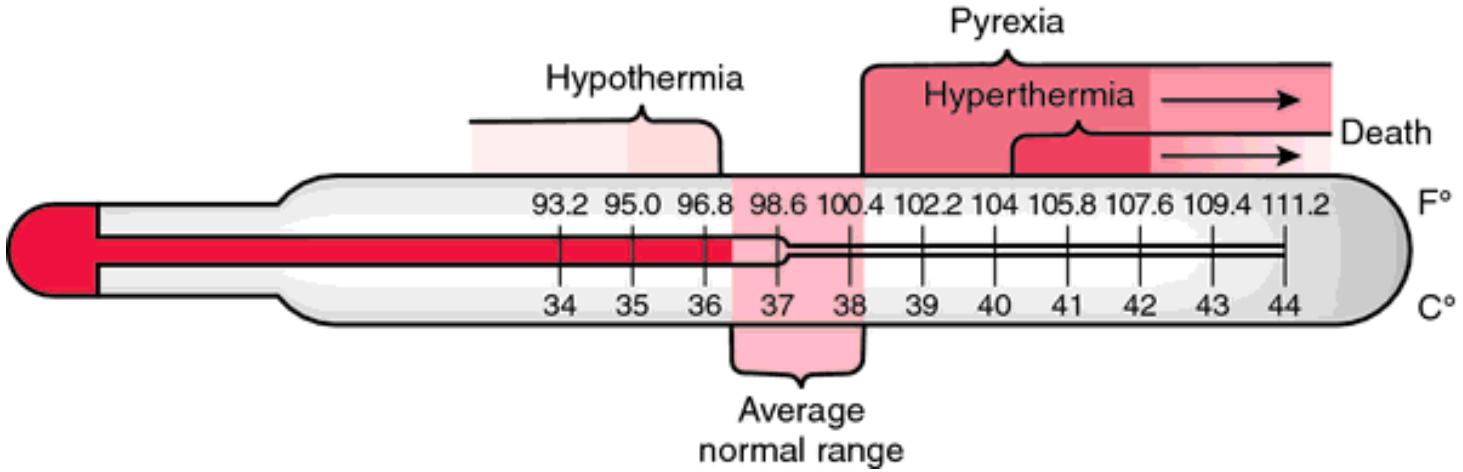
Crocodiles open their mouths and essentially sweat through their mouths.

Frog's use their moist skin to perspire

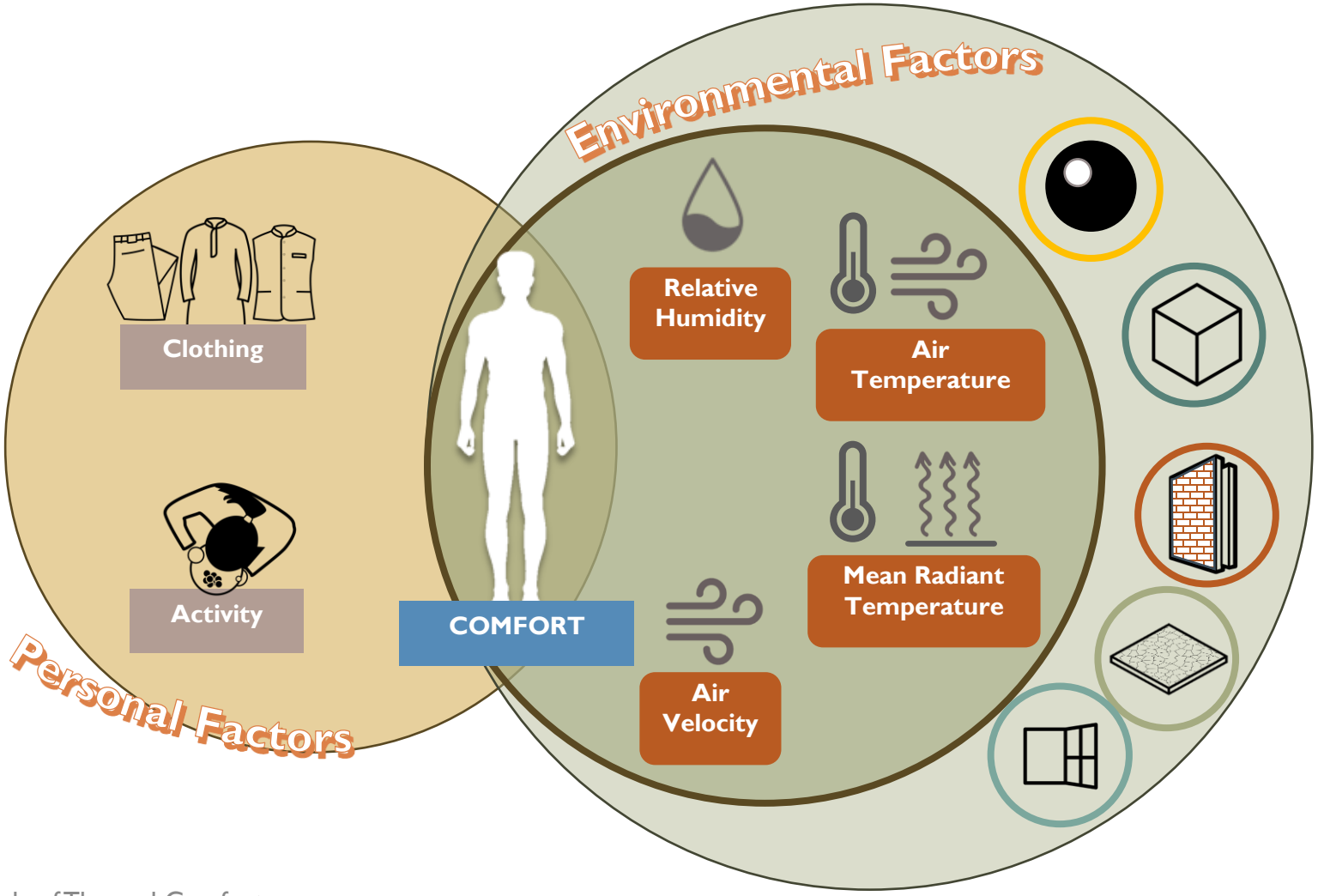
Tigers sweat through their paws & heavy panting

Thermal Comfort – Human Body Requirements





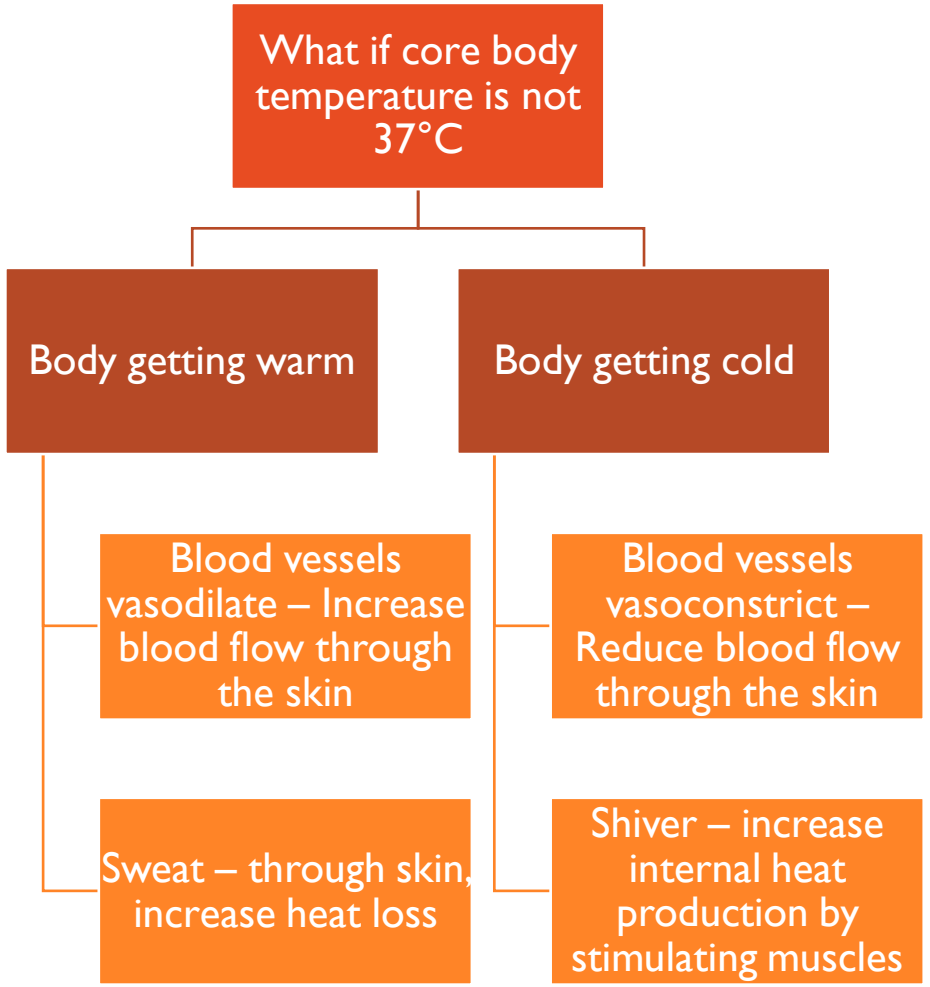
Thermal Comfort – Factors

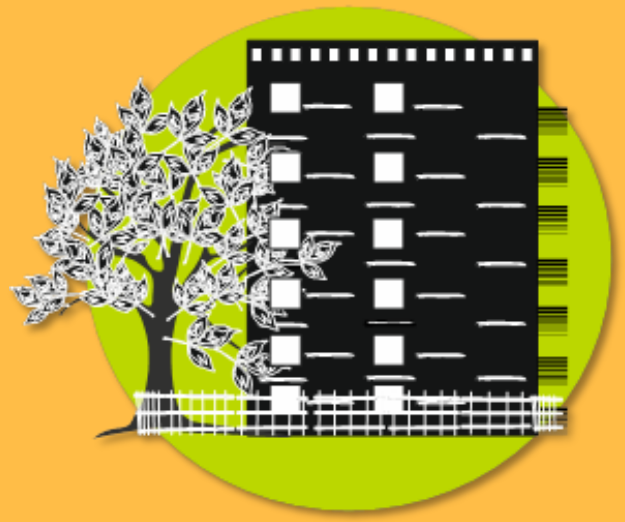


Thermal Comfort – How is body temperature regulated?

Vasodialtion and Sweating

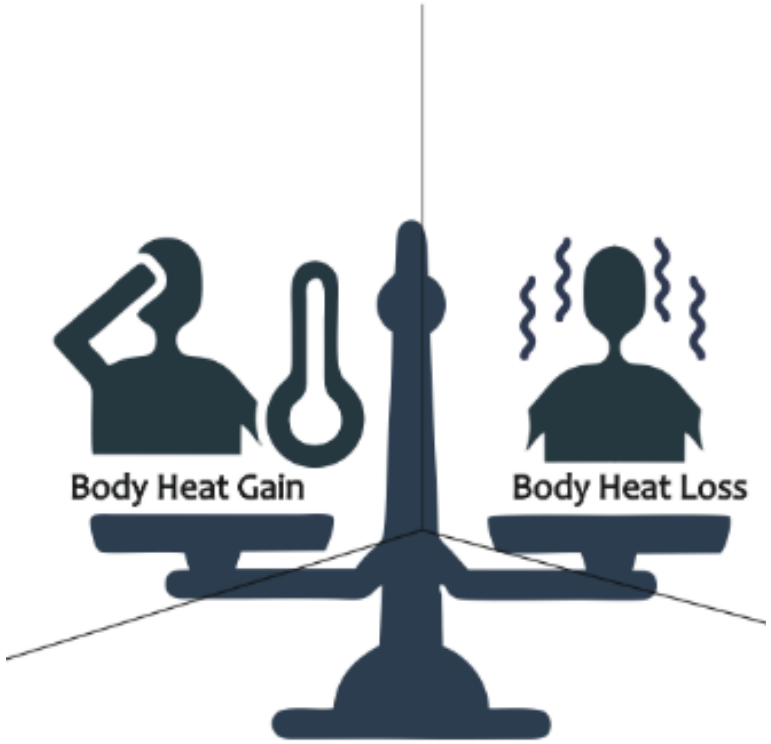
Vasoconstriction and Shivering

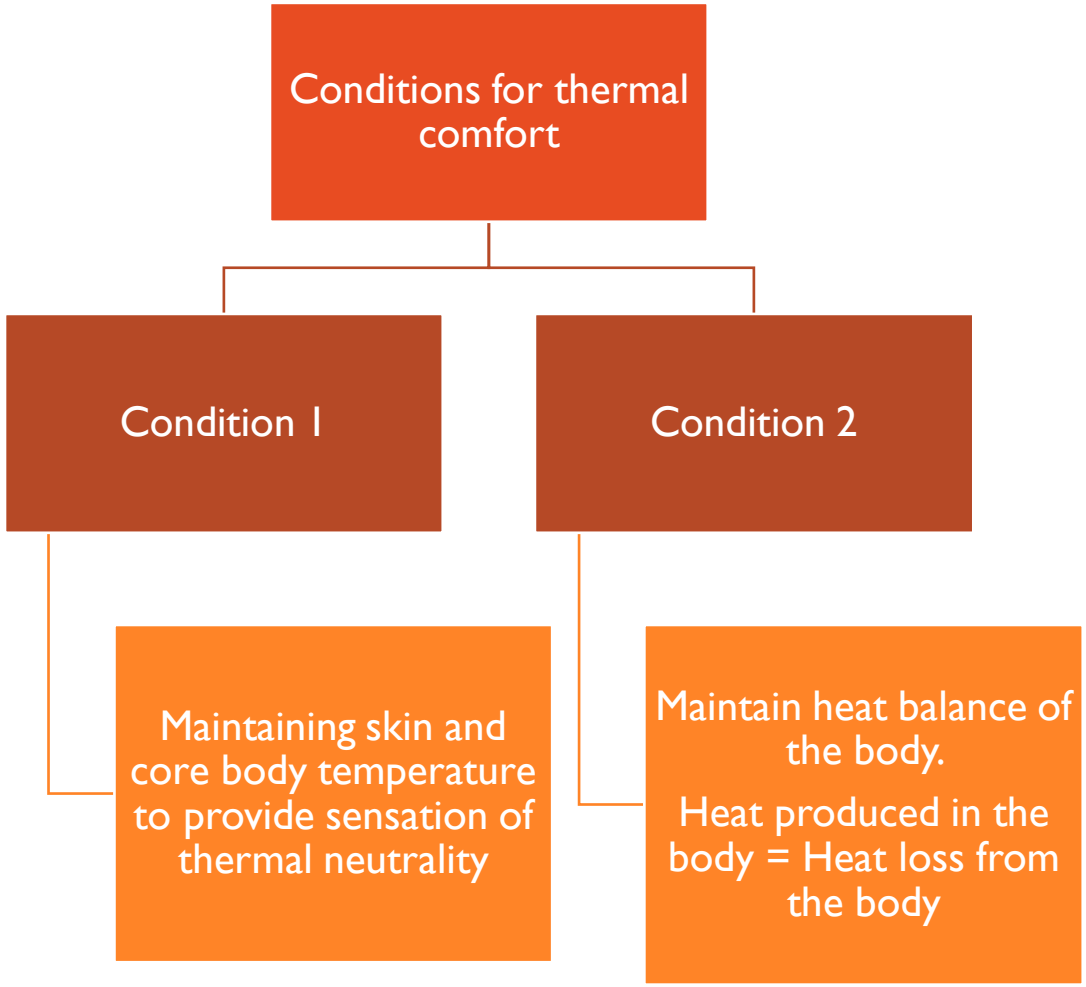




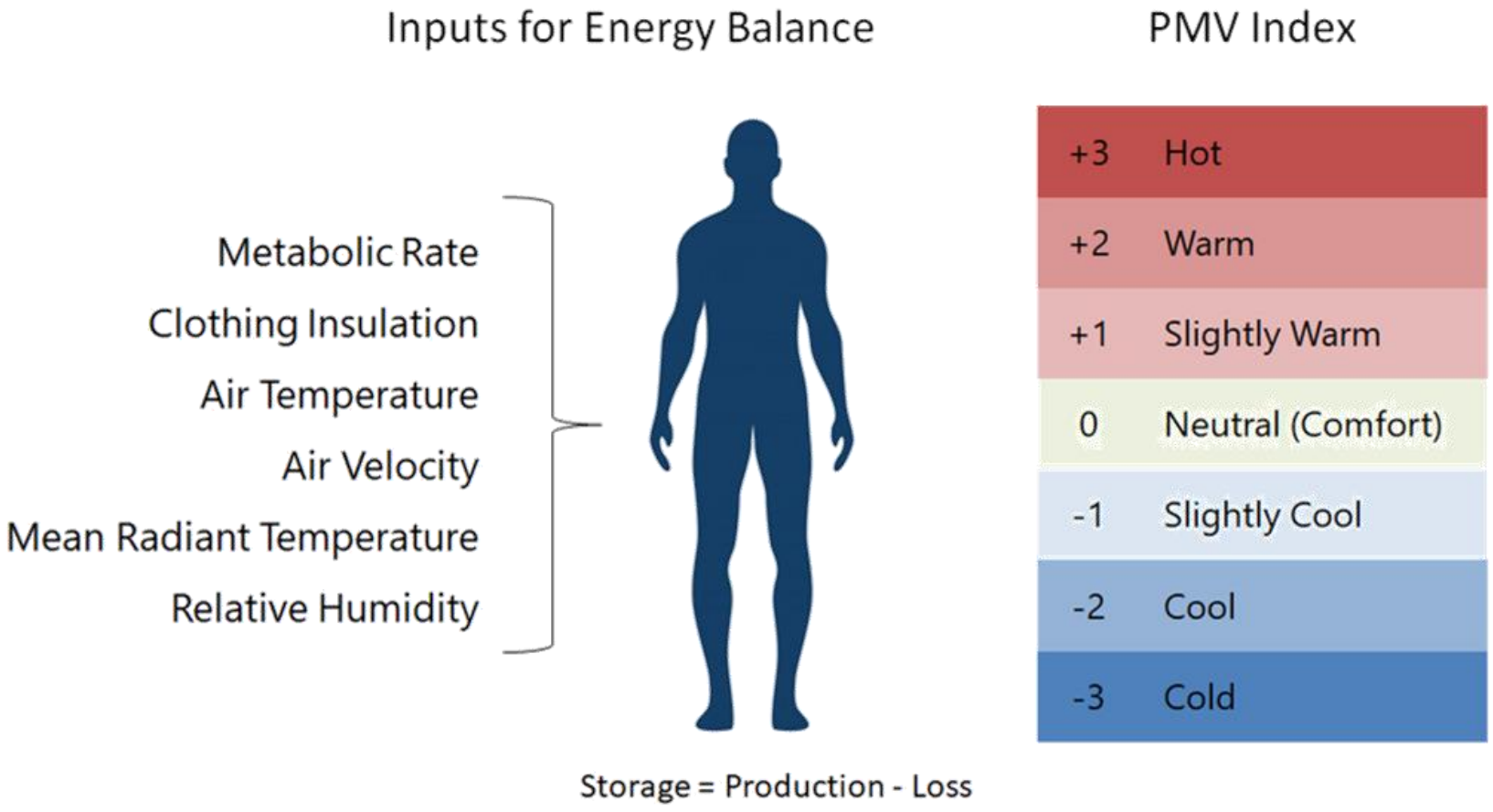
Metrics of Thermal Comfort

Thermal Comfort – First Conditions



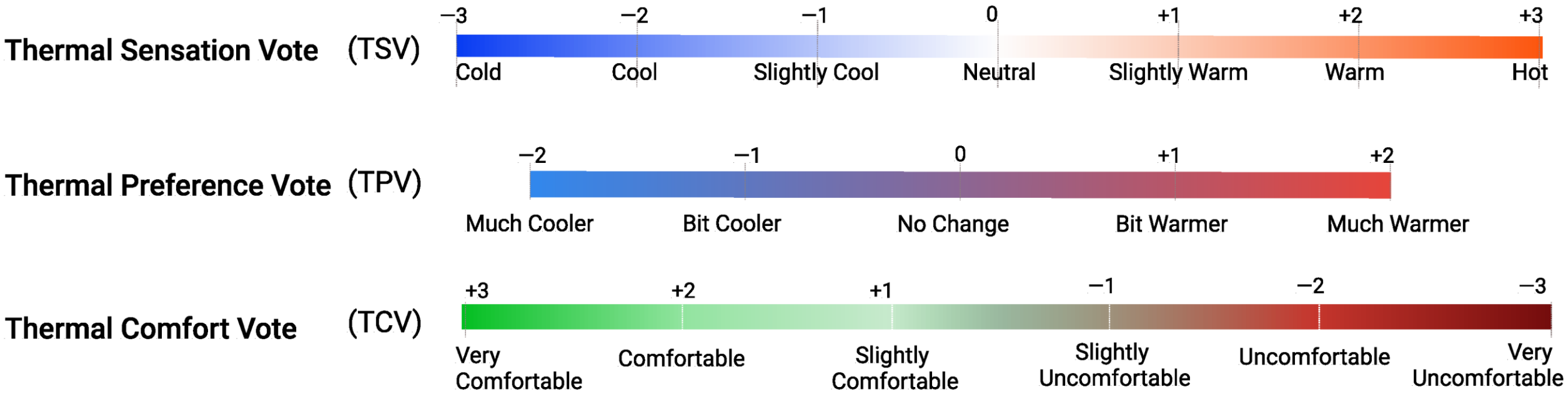


Thermal Comfort – Metrics



Source: https://www.simulationhub.com/blog/role-of-cfd-in-evaluating-occupant-thermal-comfort

Thermal Comfort – Metrics



Source: https://www.mdpi.com/2075-5309/12/6/750

Thermal Comfort – Metrics

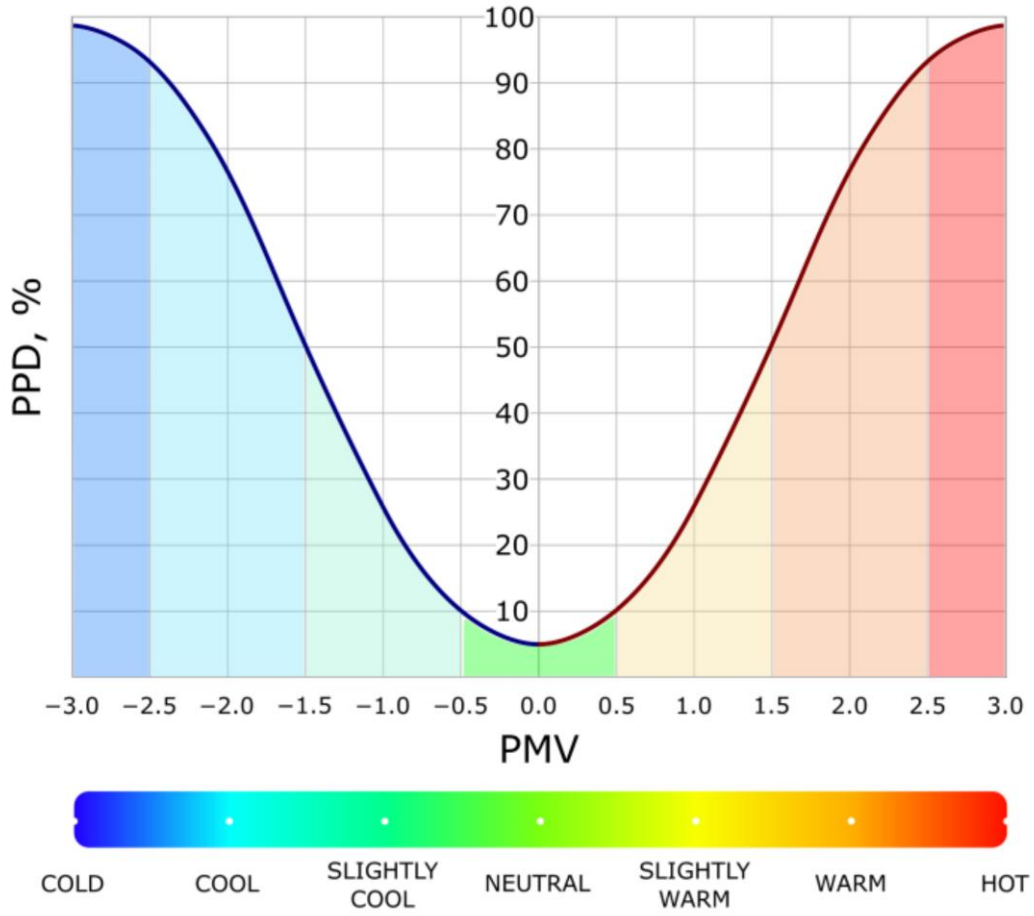
Analytical metrics for thermal comfort

PMV (Predicted Mean Vote)

PPD (Predicted Percentage of Dissatisfied)

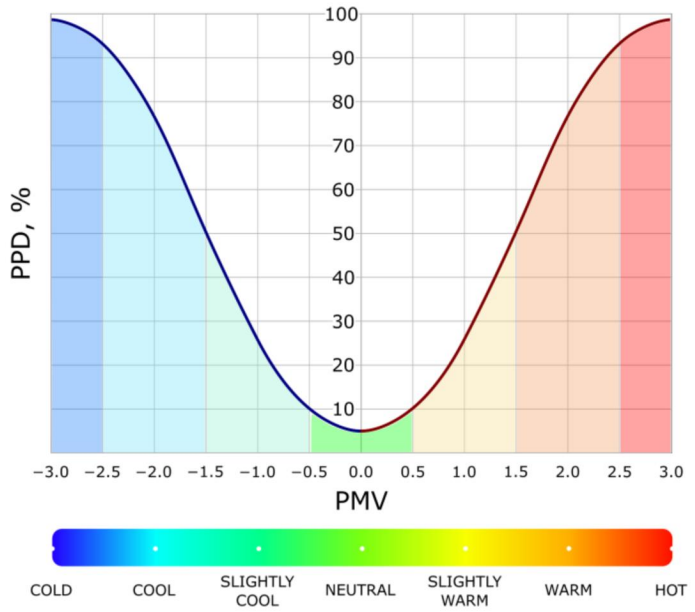
PMV provides an average assessment of thermal comfort

PPD gives an estimate of how many people within a group might be dissatisfied with those conditions

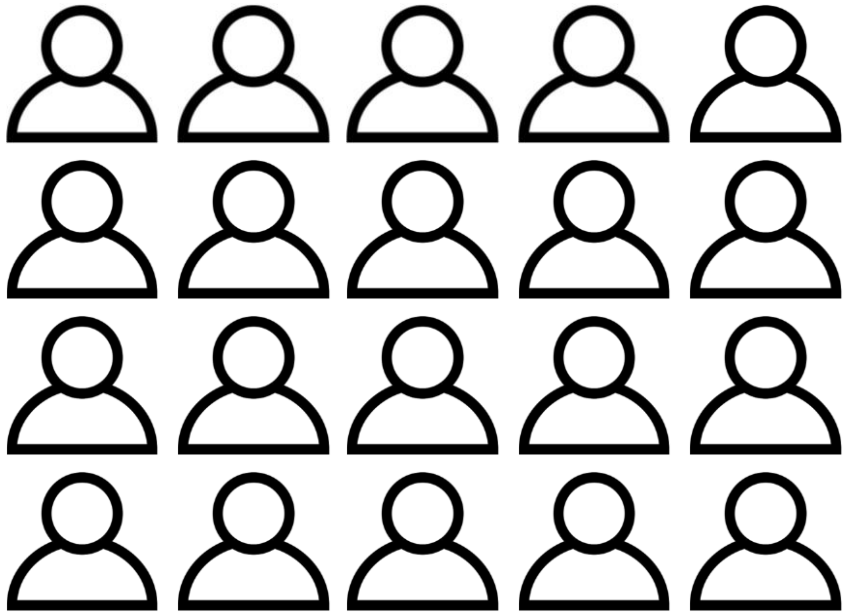


Thermal Comfort – Metrics

A deviation from a neutral Predicted Mean Vote (PMV) can lead to a higher Predicted Percentage of Dissatisfied (PPD)



Let us say we have a room with 20 people



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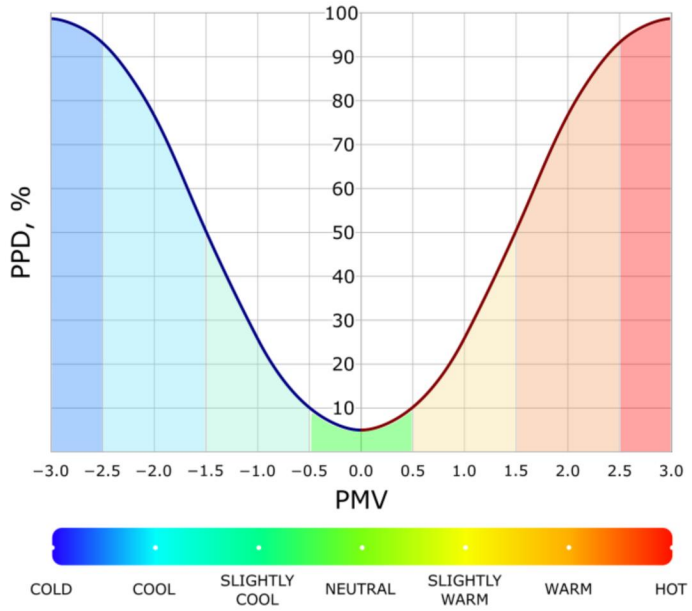
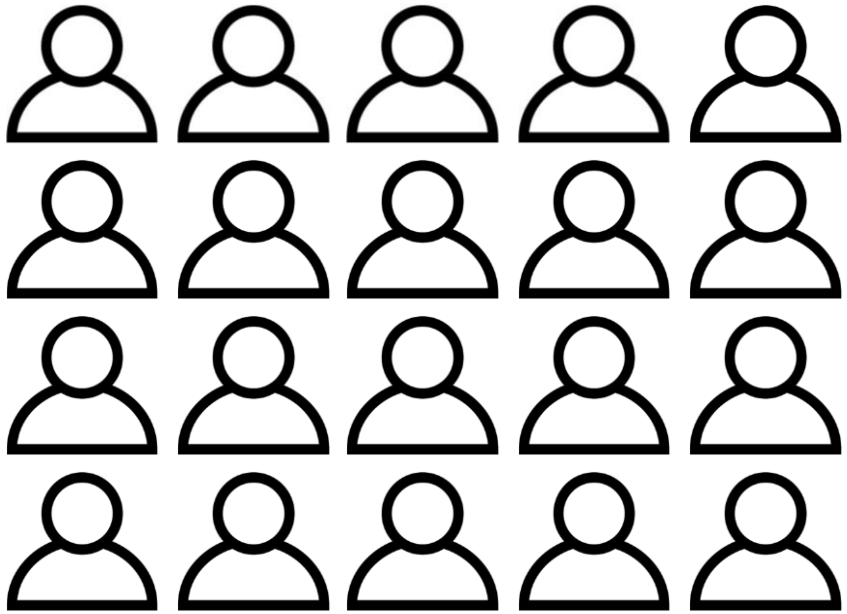


If PMV is -0.5 (slightly cool)
Then PPD will be around _____?



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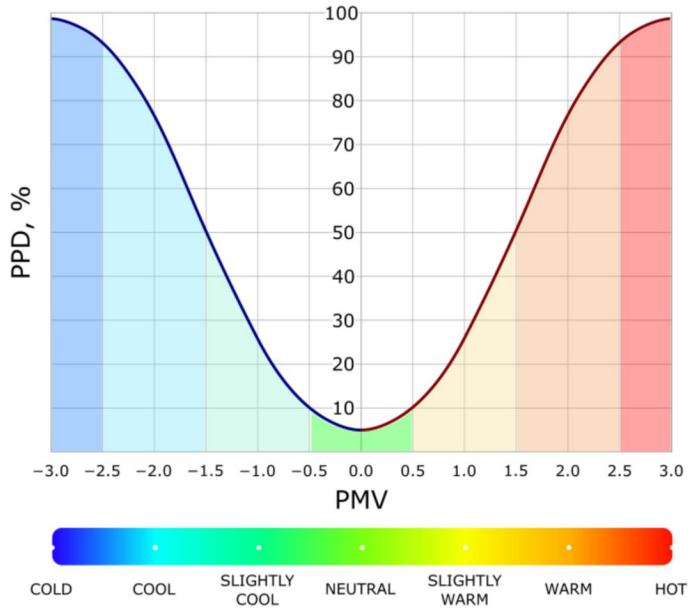
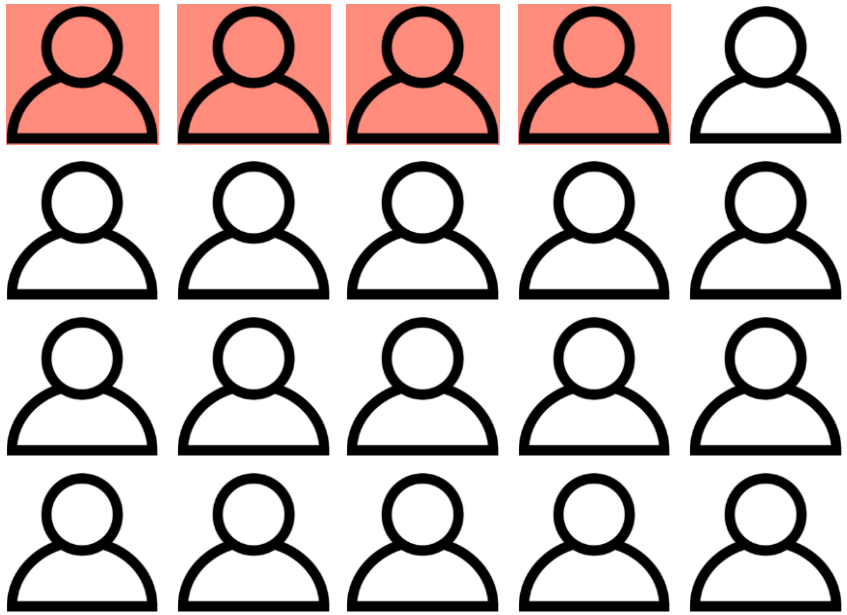


If PMV is -0.5 (slightly cool)
Then PPD will be around 20%



Thermal Comfort – Metrics

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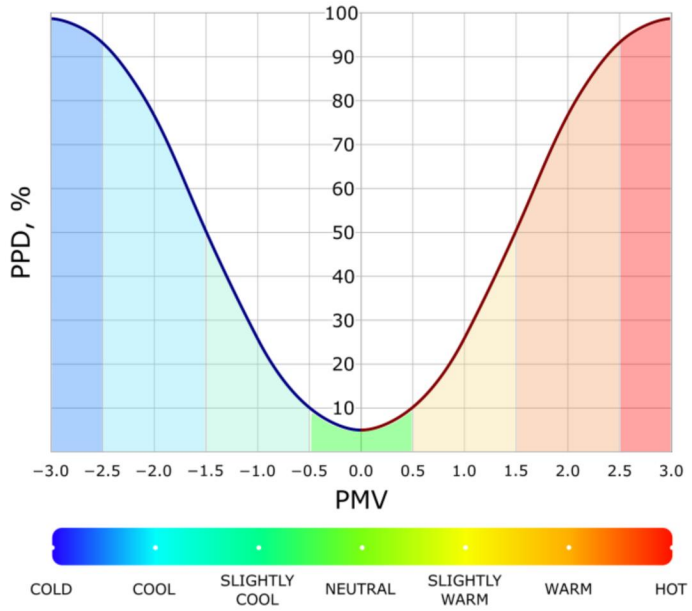
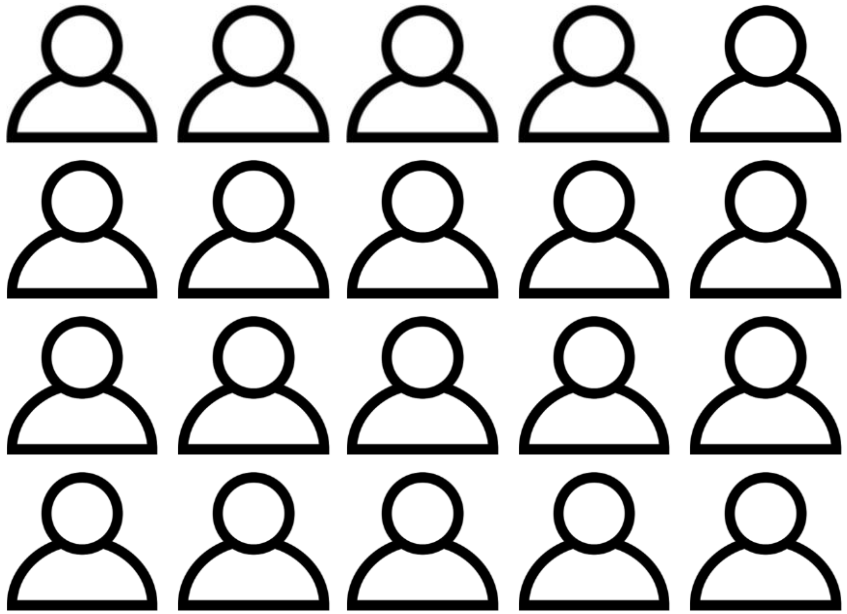


If PMV is -2.5 (cool)
Then PPD will be around ____?



Thermal Comfort – Metrics

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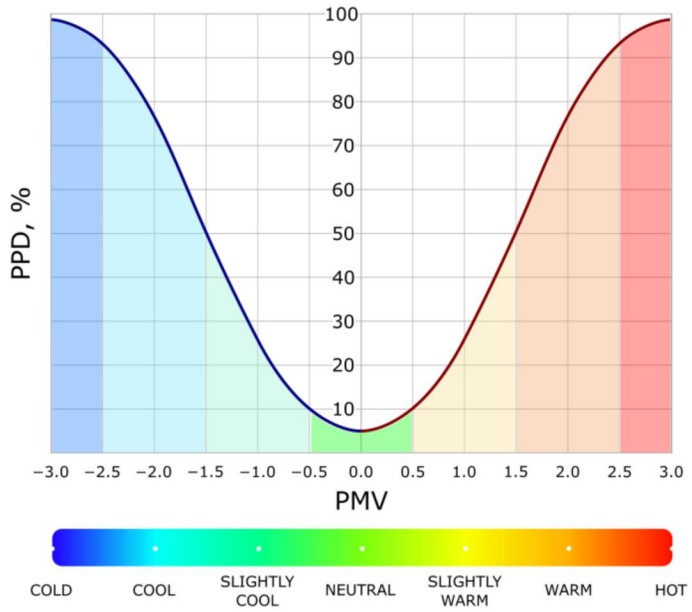
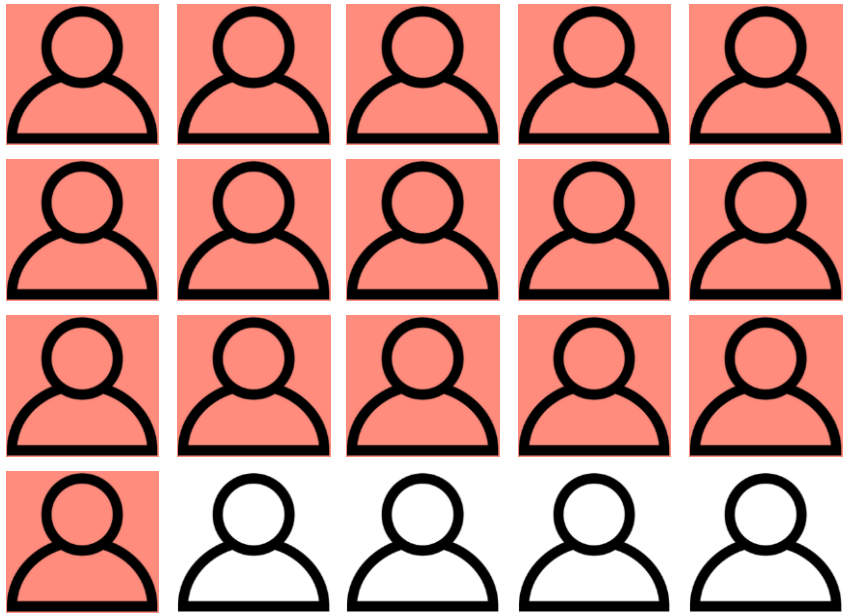
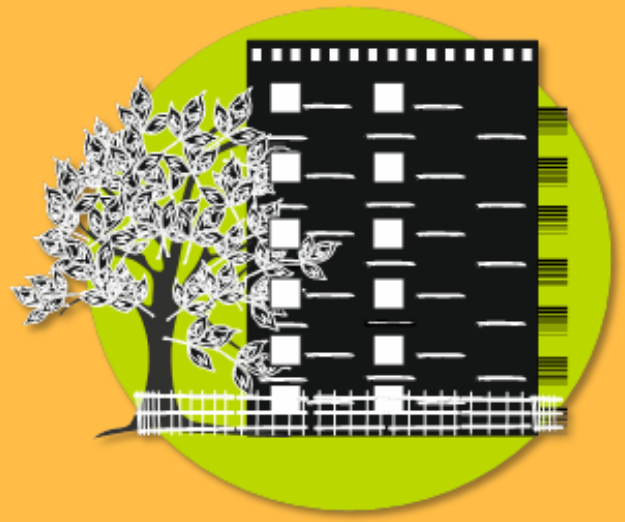


If PMV is -2.5 (cool)
Then PPD will be around 80%



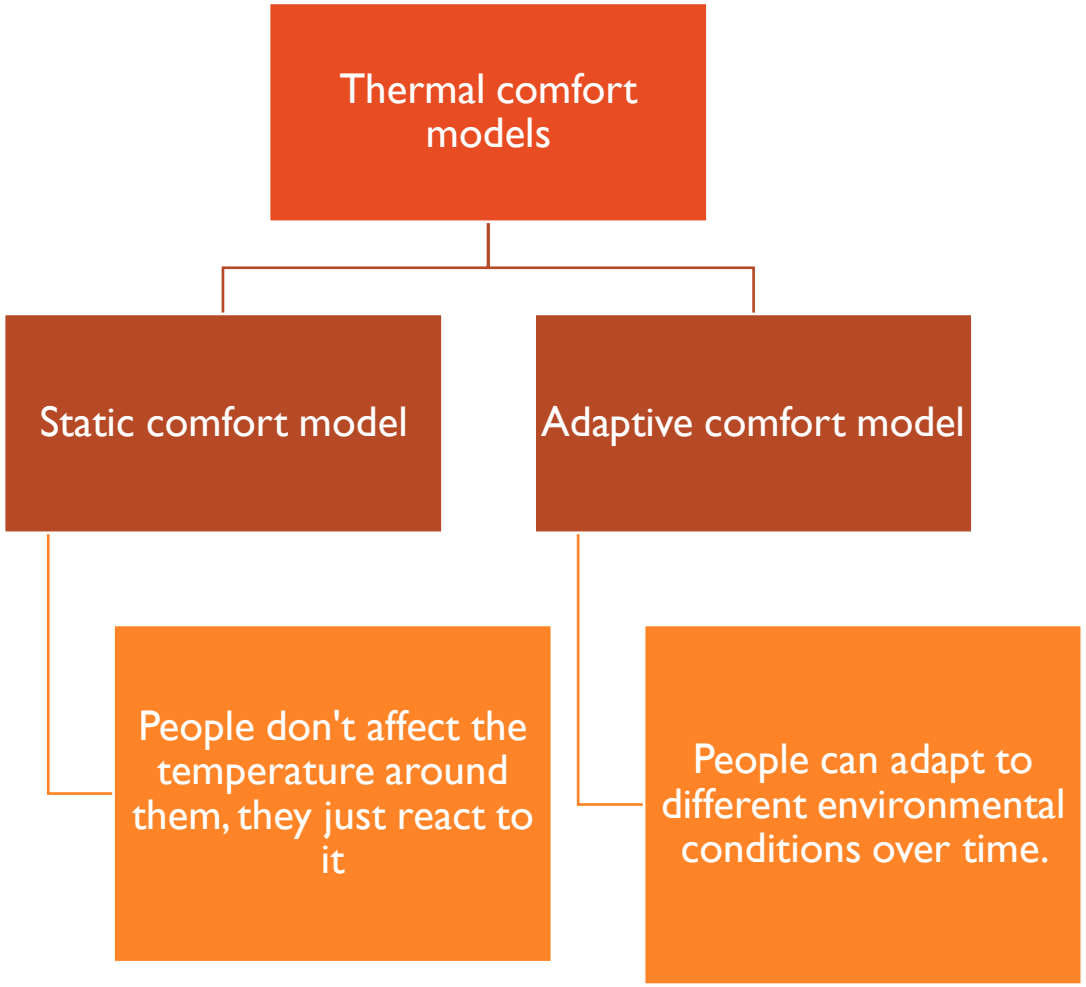
Thermal Comfort – Metrics

Designing for thermal comfort typically involves targeting a PMV close to 0 while keeping PPD at an acceptable and manageable level.



Thermal Comfort Models

Thermal Comfort – Comfort Models



Thermal Comfort – Static Model

Comfort Equation

$$M - W = q_{sk} + q_{res} + S$$
$$= (C + R + E_{sk}) + (C_{res} + E_{res}) + (S_{sk} + S_{cr})$$

Where,

M = rate of metabolic heat production, W/m^2
W = rate of mechanical work accomplished, W/m^2
q_{sk}= total rate of heat loss from skin, W/m^2
q_{res}= total rate of heat loss through respiration, W/m^2
$C + R$ = sensible heat loss from skin, W/m^2
E_{sk}= total rate of evaporative heat loss from skin, W/m^2
C_{res}= rate of convective heat loss from respiration, W/m^2
E_{res}= rate of evaporative heat loss from respiration, W/m^2
S_{sk}= rate of heat storage in skin compartment, W/m^2
S_{cr}= rate of heat storage in core compartment, W/m^2

What to estimate

MET·VALUE (Metabolism)
CLO·VALUE (Clothing level)

What to measure

Air Temperature + Mean Radiant Temperature + Air Velocity + Humidity

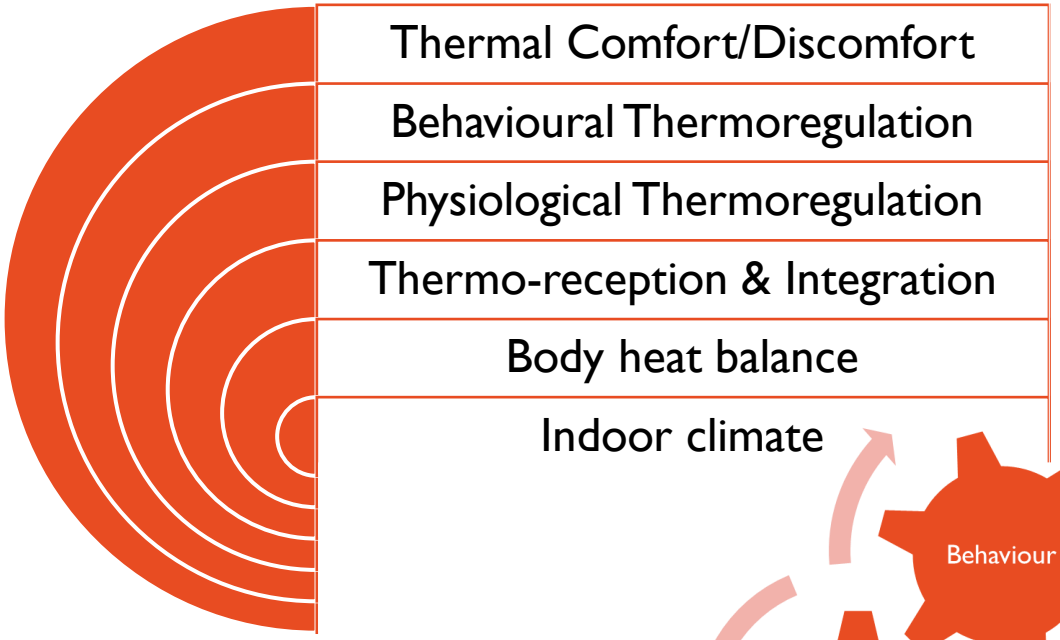
OR

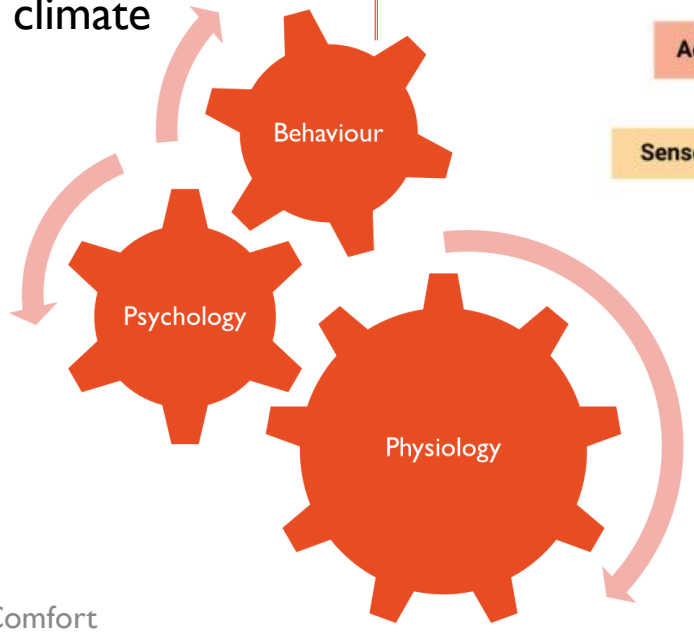
Operative Temperature + Air Velocity + Humidity

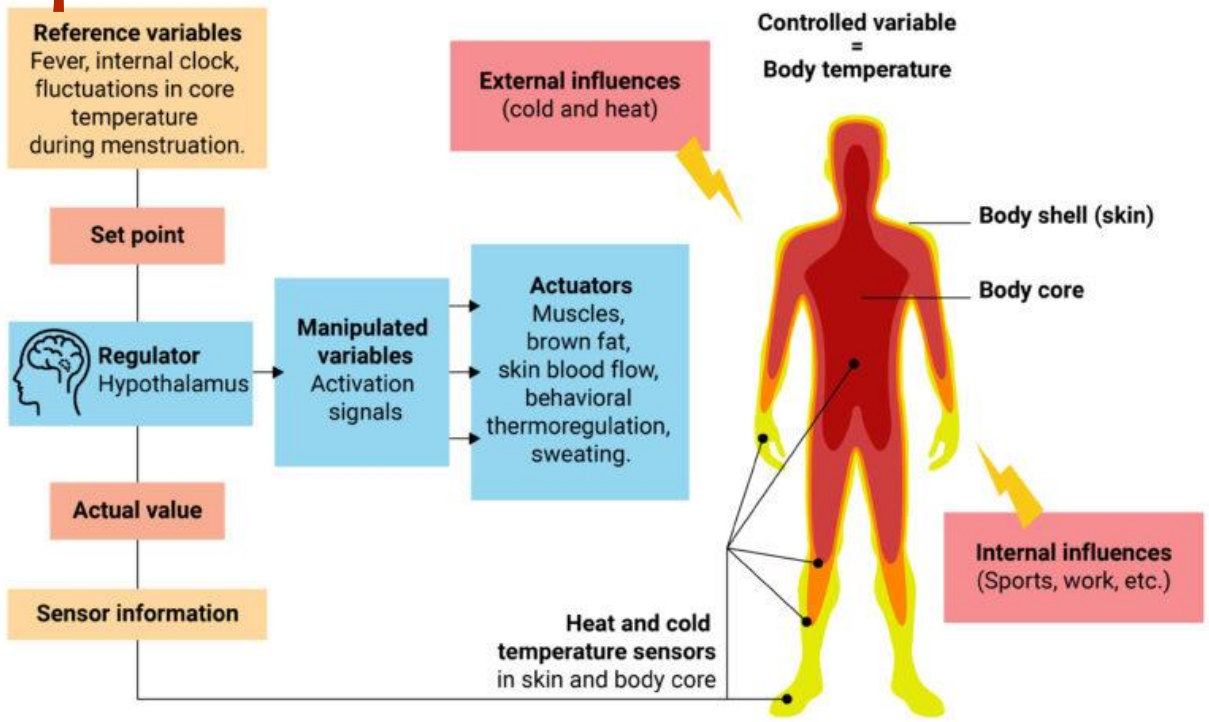
OR

Equivalent Temperature + Humidity

Thermal Comfort – Adaptive Model





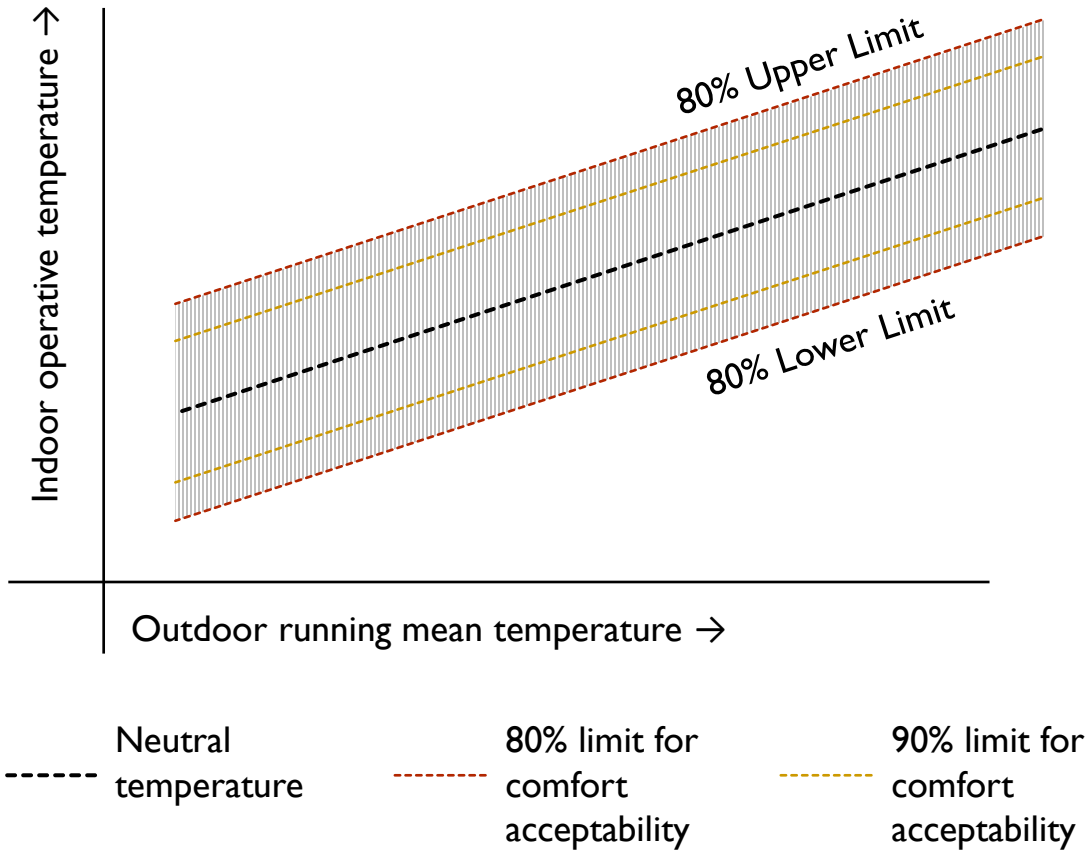


- The body's temperature is influenced by various factors.

- The hypothalamus detects these changes and initiates adjustments to return the temperature to the setpoint.

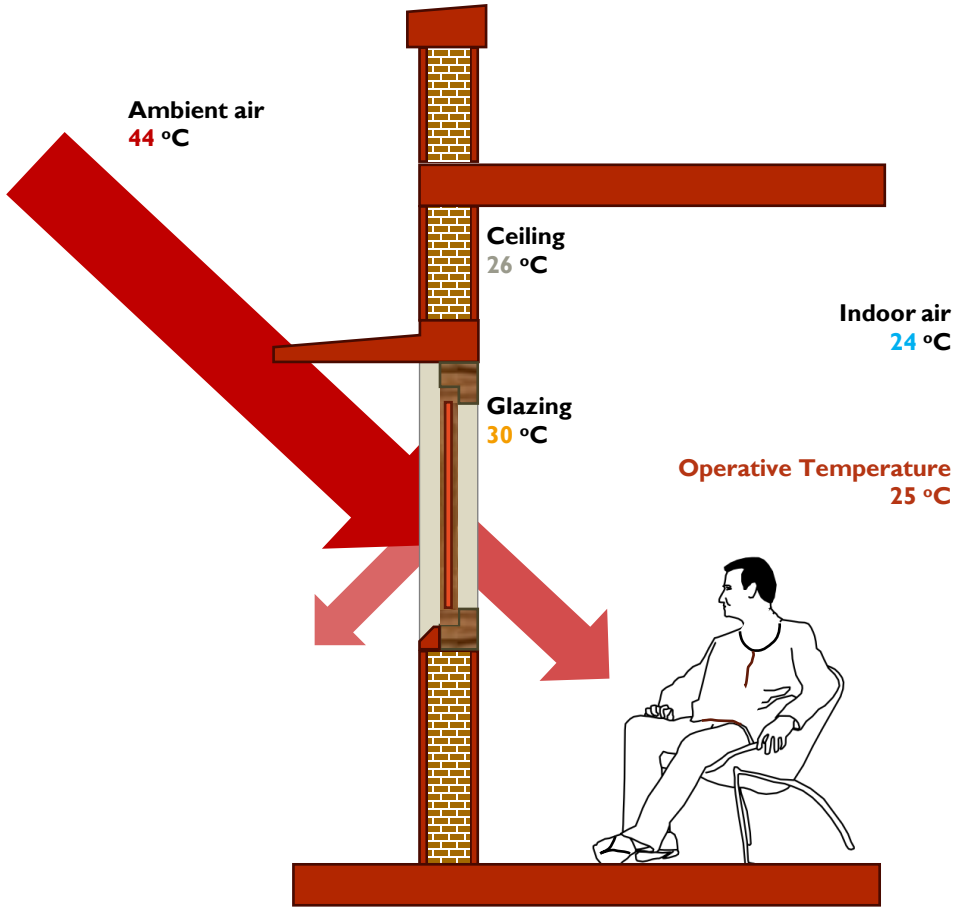
Source: https://www.cosinuss.com/en/measured-data/vital-signs/body-temperature/

Thermal Comfort – Adaptive Model



The 80% and 90% comfort limits define the range of temperatures in which a specific percentage of people are expected to feel thermally comfortable based on statistical predictions.

Thermal Comfort – Measuring Thermal Comfort

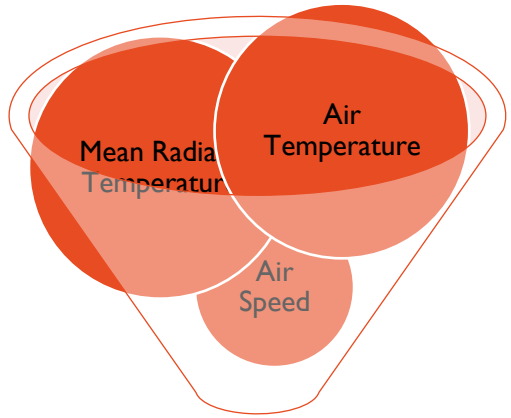


- There are more than **40 indices** to measure thermal comfort (indoor and outdoor).
- The Indoor Operative Temperature is one of the simpler metrics that is also utilised by the adaptive comfort model for determining acceptable temperature ranges.

Operative temperature

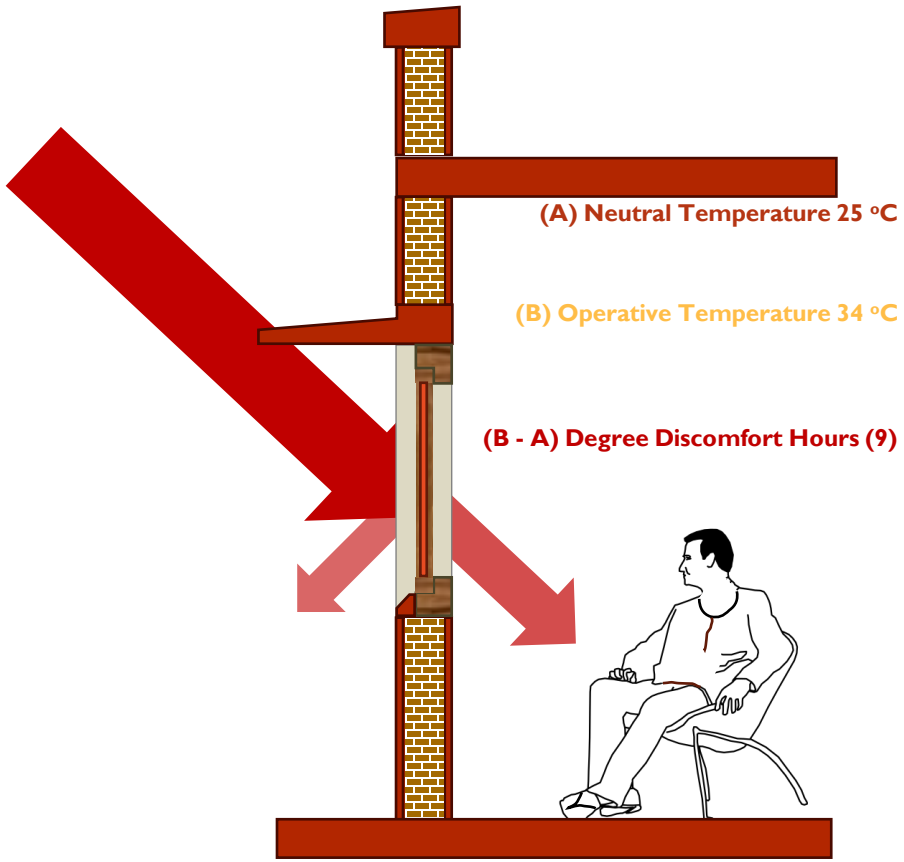
≠

Air temperature



Operative temperature

Thermal Comfort – Measuring Thermal Comfort



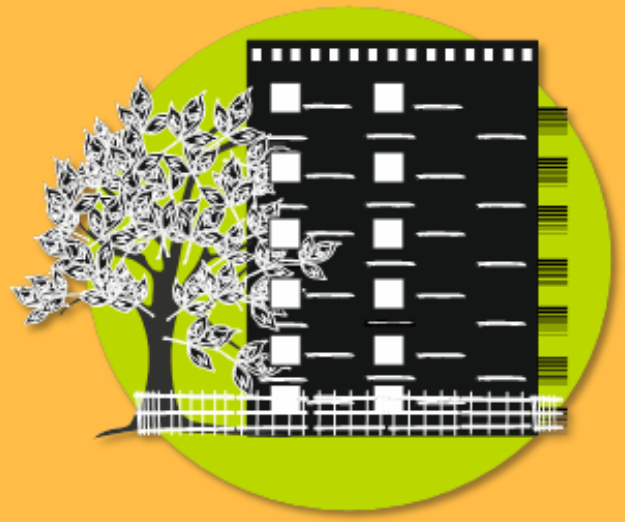
Degree Discomfort Hours (DDH) helps quantify how far the actual temperatures deviate from the desired comfort range over a specific period, giving an indication of discomfort due to thermal conditions.

$$DDH = \sum_{i=1}^{8760} \left| T_{neut}^{i} - T_{op}^{i} \right|$$

Summer Discomfort — Reported as positive quantity

Winter Discomfort — Reported as positive quantity

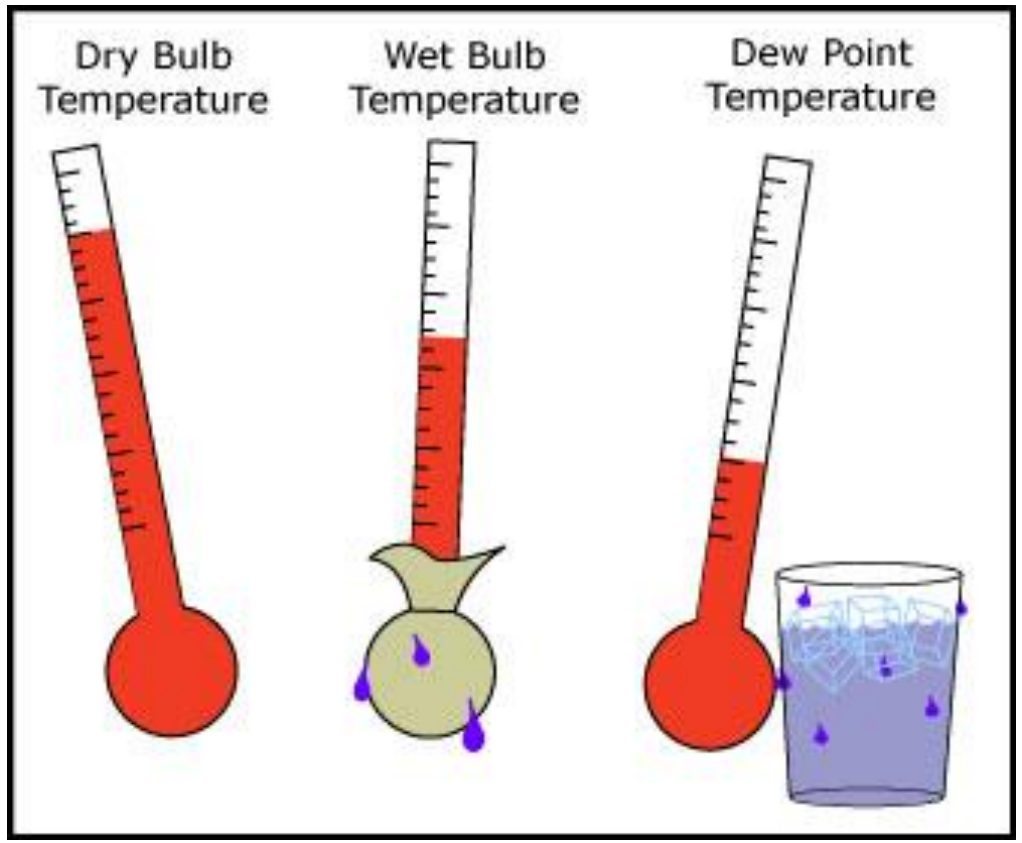
Annual Discomfort — Use only absolute values



How to Measure Thermal Comfort?

Thermal Comfort – Measuring Thermal Comfort

Air Temperature



Source: Wet-Bulb temperature | EvapoPedia

Temperature of the air surrounding the body Dry Bulb Temperature (DBT)

Measured by a thermometer freely exposed to the air, but shielded from radiation and moisture.

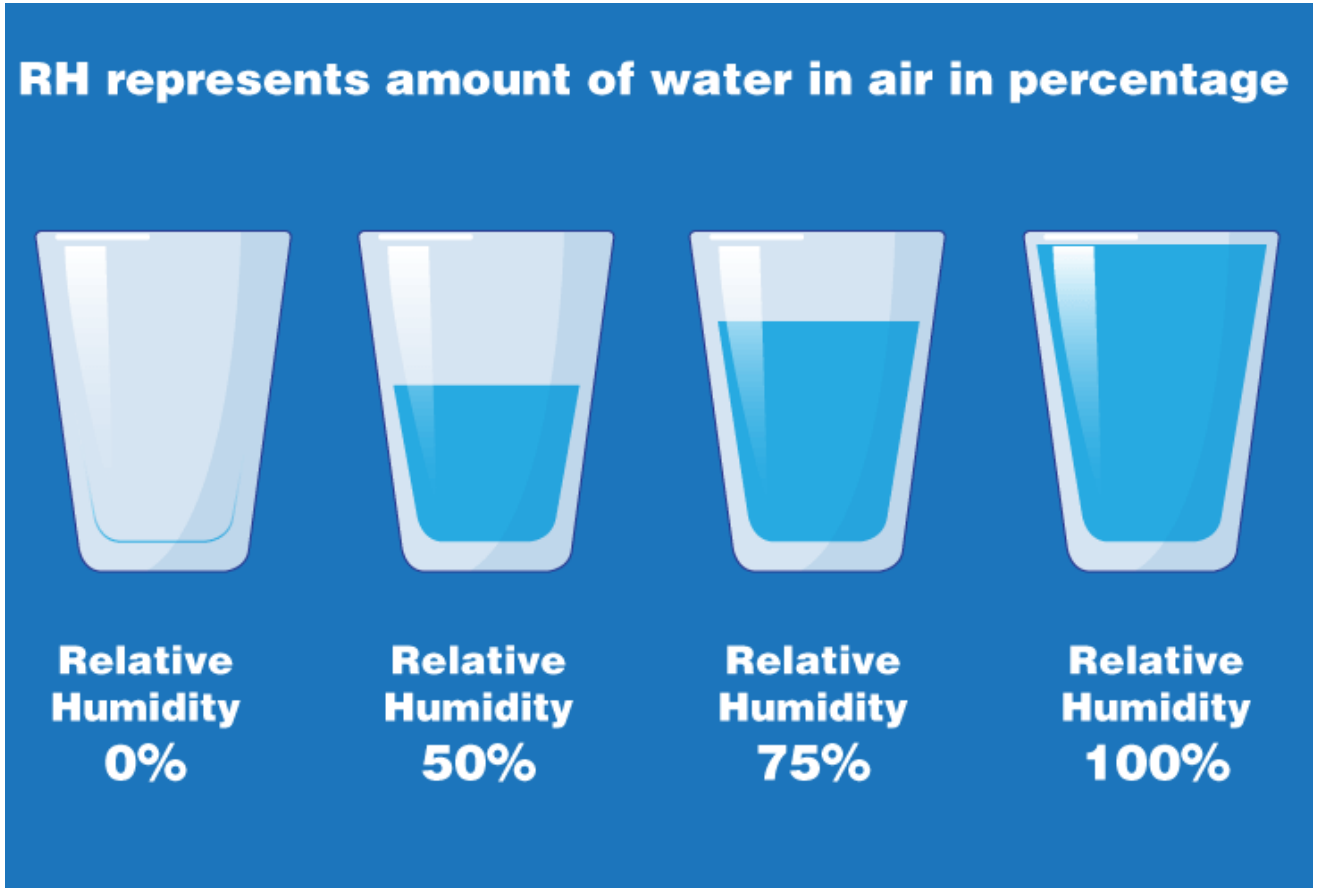
Expressed in

- Degrees Celsius (C)

- DBT directly affects how warm or cool the air feels.
- If DBT is too high, it can make a space feel uncomfortably hot, and when it's too low, it can make a space feel uncomfortably cold.

Thermal Comfort – Measuring Thermal Comfort

Relative Humidity



Source: https://scijinks.gov/what-is-humidity/

Moisture Content of the air

The amount of moisture in the air depends upon

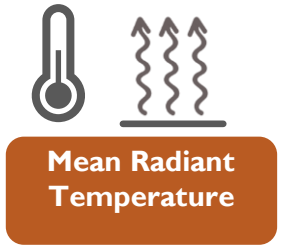
- Air Pressure
- Air Temperature

Expressed in

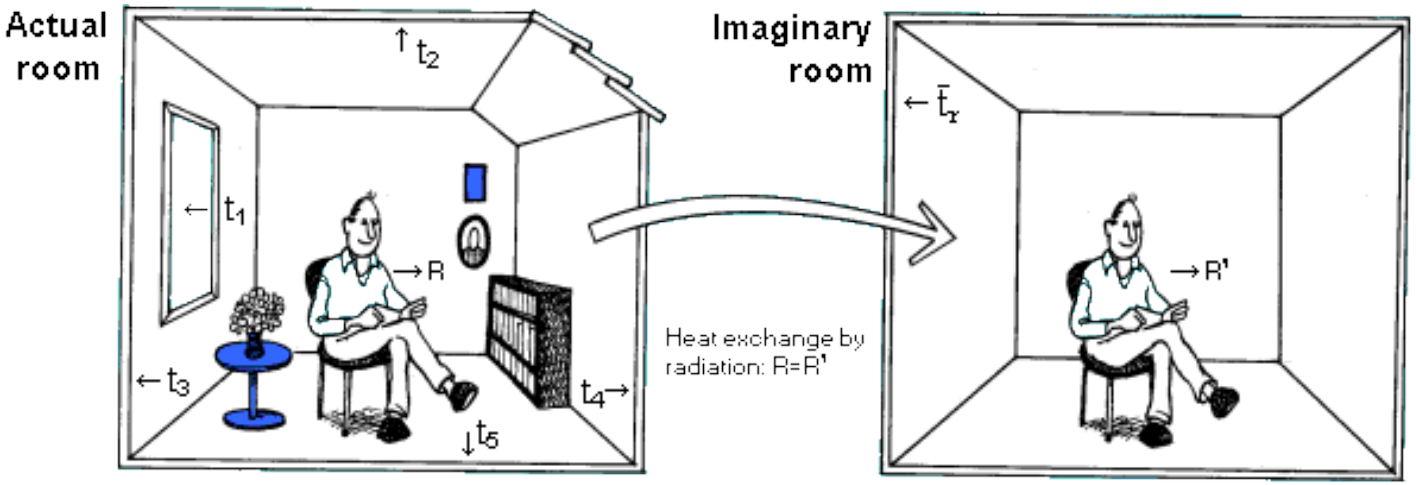
- Percentage (%)

- RH affects how effectively our bodies can cool themselves through sweat evaporation.
- Ideal RH for thermal comfort is typically between 40% and 60%

Thermal Comfort – Measuring Thermal Comfort



Globe temperature



- Uniform temperature of an imaginary enclosure
- Measure of the effect of Radiant interchanges at a point in space
- Calculated using Globe temperature (Tg), Air temperature(Ta), and air velocity

- Perceived Temperature: People don't just feel the air temperature; they also exchange heat with their surroundings. For example, sitting next to a cold window will make you feel cooler, even if the air temperature is warm.

http://www.blowtex-educair.it/downloads/thermal%20comfort.htm

Thermal Comfort – Measuring Thermal Comfort

Air Velocity

Air Speed is the rate of air movement at a point, without regard to direction

Average air speed, height and directions

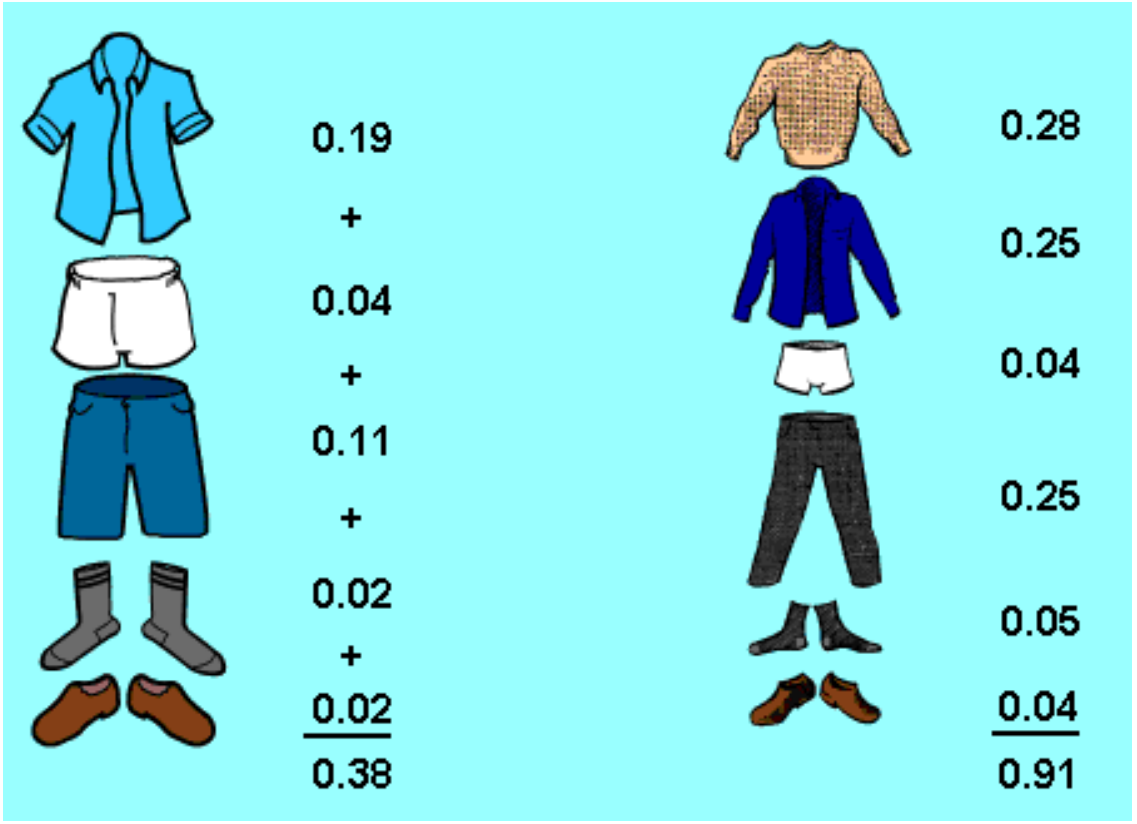
Specified in

- Meter per second (m/s)

- It affects how we feel temperature and humidity. Managing air movement is essential in creating comfortable environments.
- It influences heat loss, moisture evaporation, and personal comfort preferences.

Thermal Comfort – Measuring Thermal Comfort

Clothing



The resistance to sensible heat transfer provided by clothing ensemble

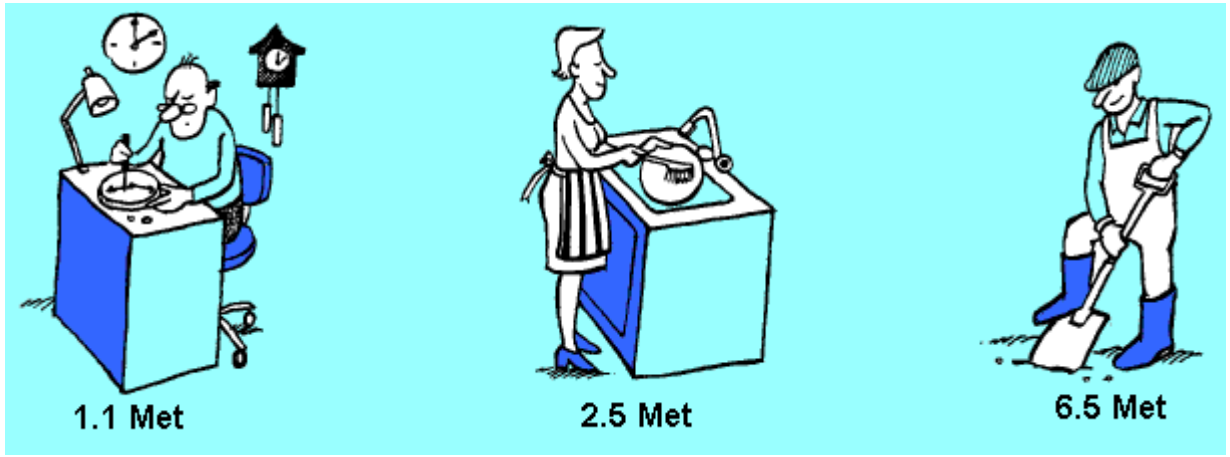
Clothing Insulation Value (clo-Icl)

Impact of furniture such as chair and beddings

- Clo value determines the insulating properties of your clothing.
- It affects how well your clothing keeps you warm or cool, which is crucial for maintaining comfort in different environmental conditions.

Source: http://www.blowtex-educair.it/downloads/thermal%20comfort.htm

Thermal Comfort – Measuring Thermal Comfort



The rate at which metabolism occurs in a living organism.

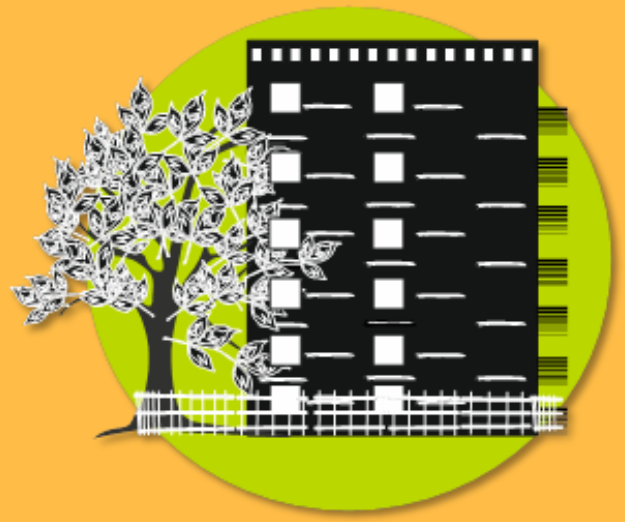
Rate of energy expenditure per unit time

Average adult 1.8 square meter.
Expressed in:

- watts per square meter (W/m^2)

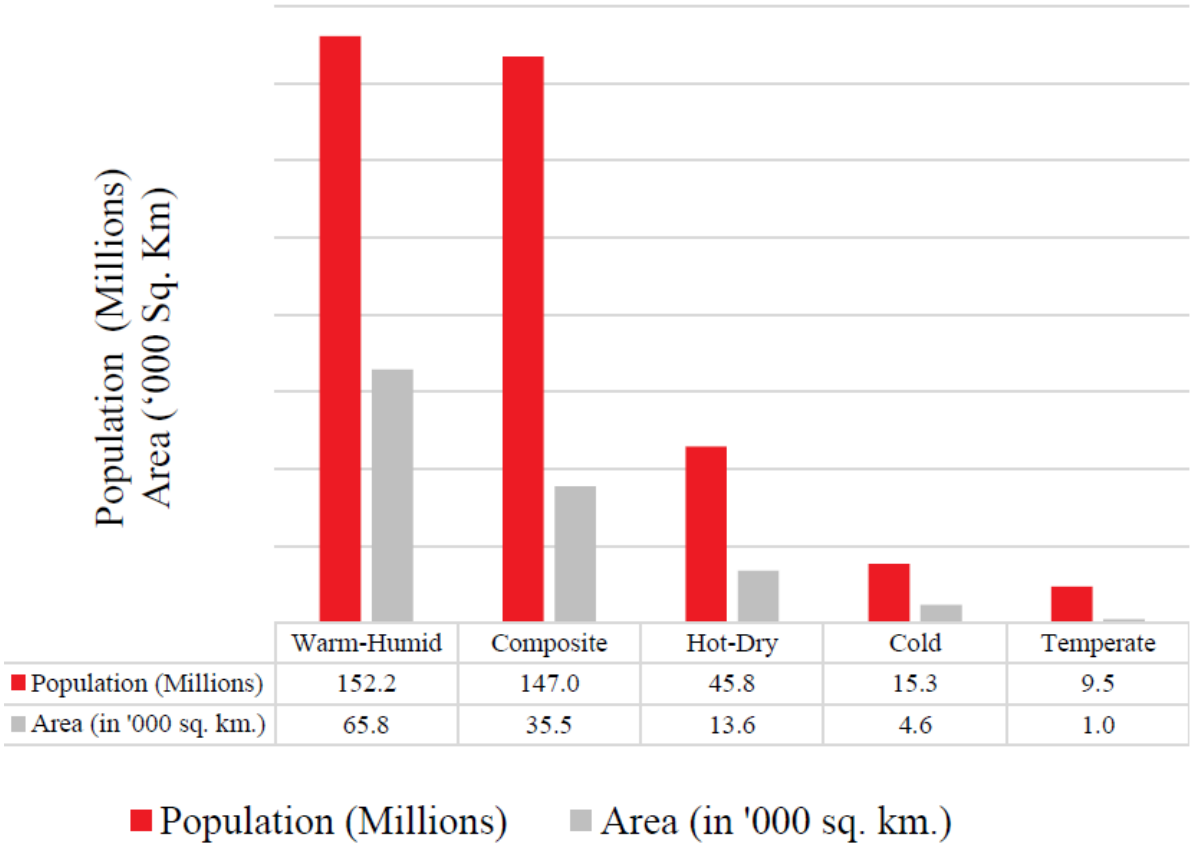
- Met value quantifies a person's level of physical activity and heat production.
- It helps assess how much heat a person generates, which is a key factor in maintaining comfort in various thermal environments.

Source: http://www.blowtex-educair.it/downloads/thermal%20comfort.htm



Thermal Comfort – Indian Context

Indian Context



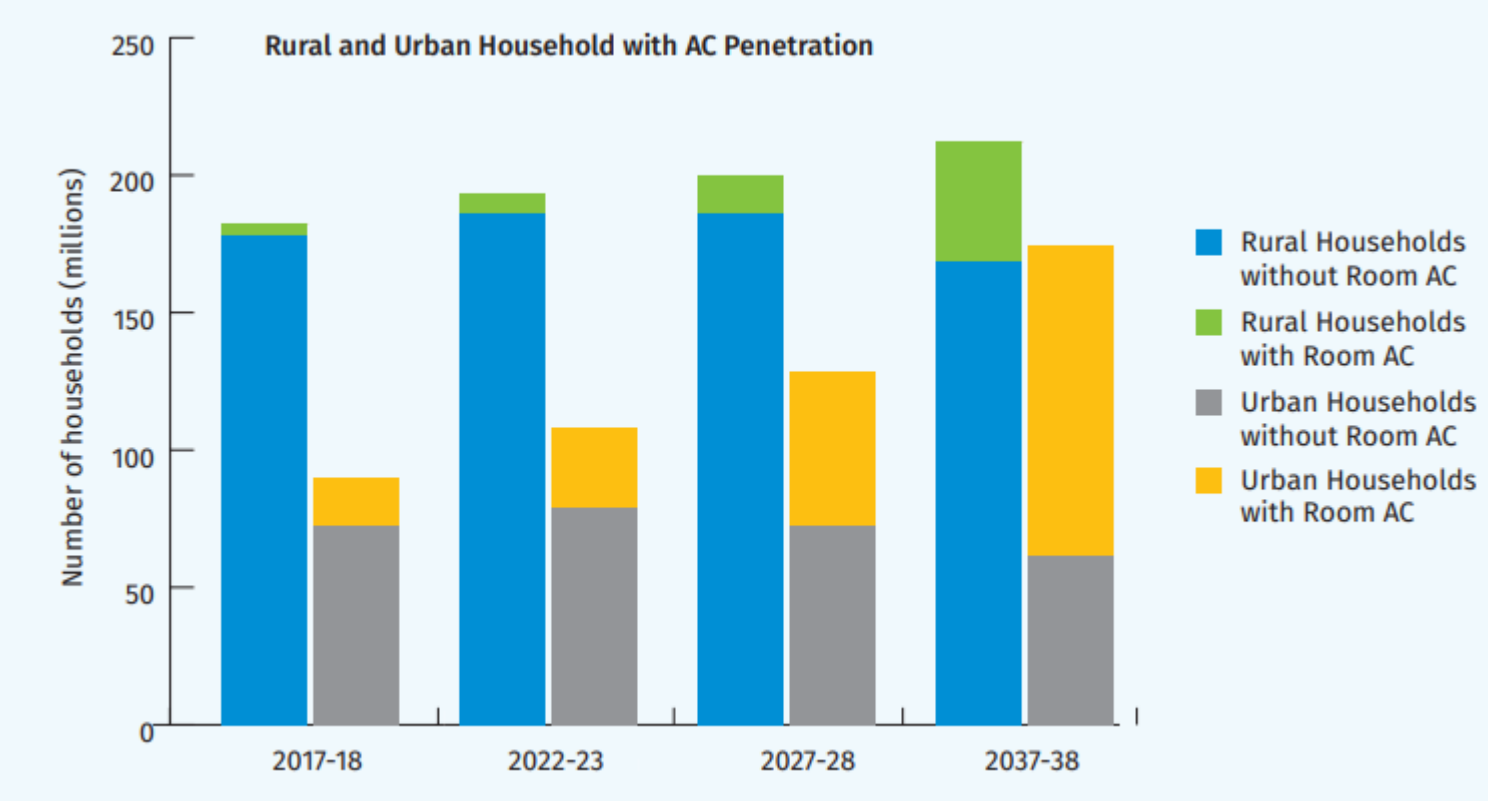
More than 50% of India lives in a warm and humid climate

Cooling Degree Days

- Kolkata 3360 (19.7 million)
- New Delhi 3015 (29.9 million)
- Mumbai 3469 (24.5 million)
- Chennai 4108 (10.6 million)

Source: *Ministry of Home Affairs, Government of India. Population projection. Census of India. (2011). Retrieved from https://www.censusindia.gov.in/2011census/dchb/DCHB.html*

Indian Context

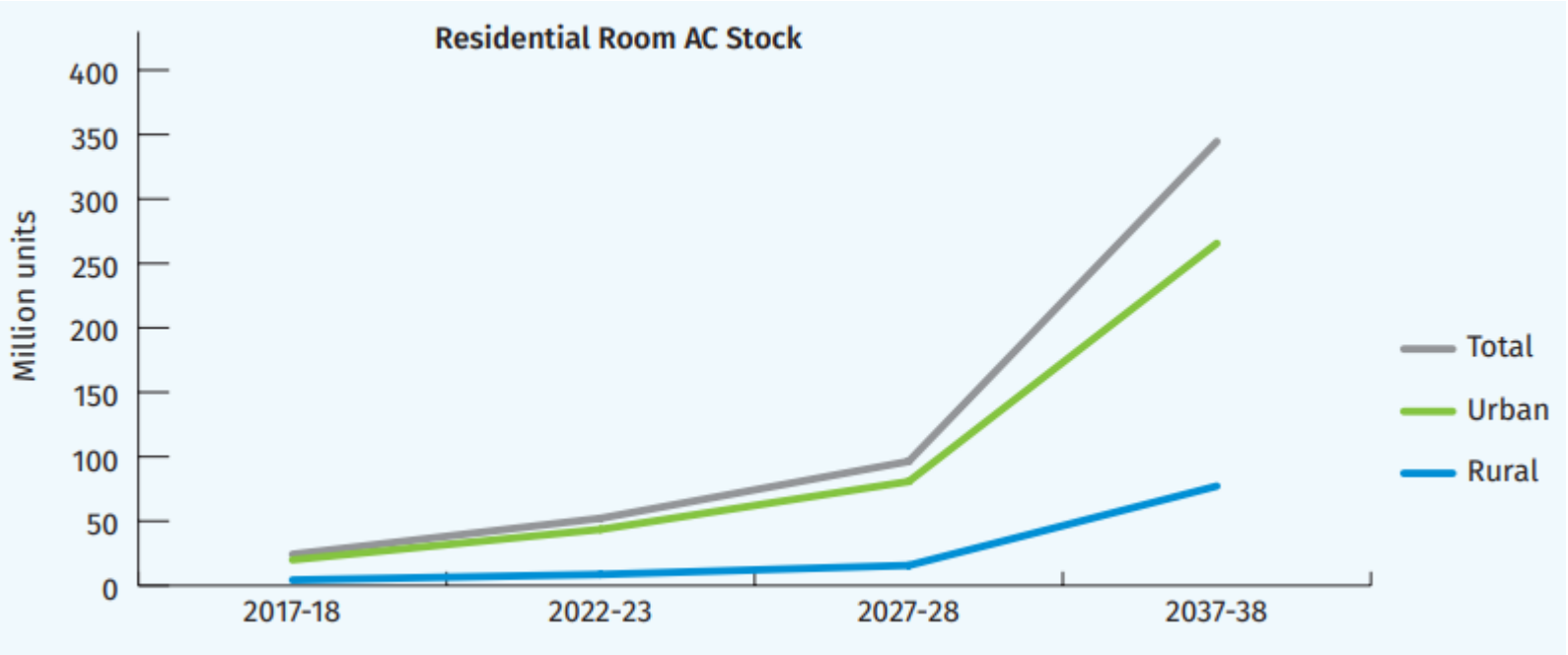


India's cooling demand

- 8 times by 2037-38
- 11 times for Building Sector compared to the baseline 2017-18
- India's Total Primary Energy Supply (TPES) for Cooling 4.5 times in 2037-38
- 30% reduction possible due to intervention –from better design and technology

Source: INDIA-COOLING-ACTION-PLAN-e-circulation-version080319.pdf (ozonecell.nic.in)

Indian Context

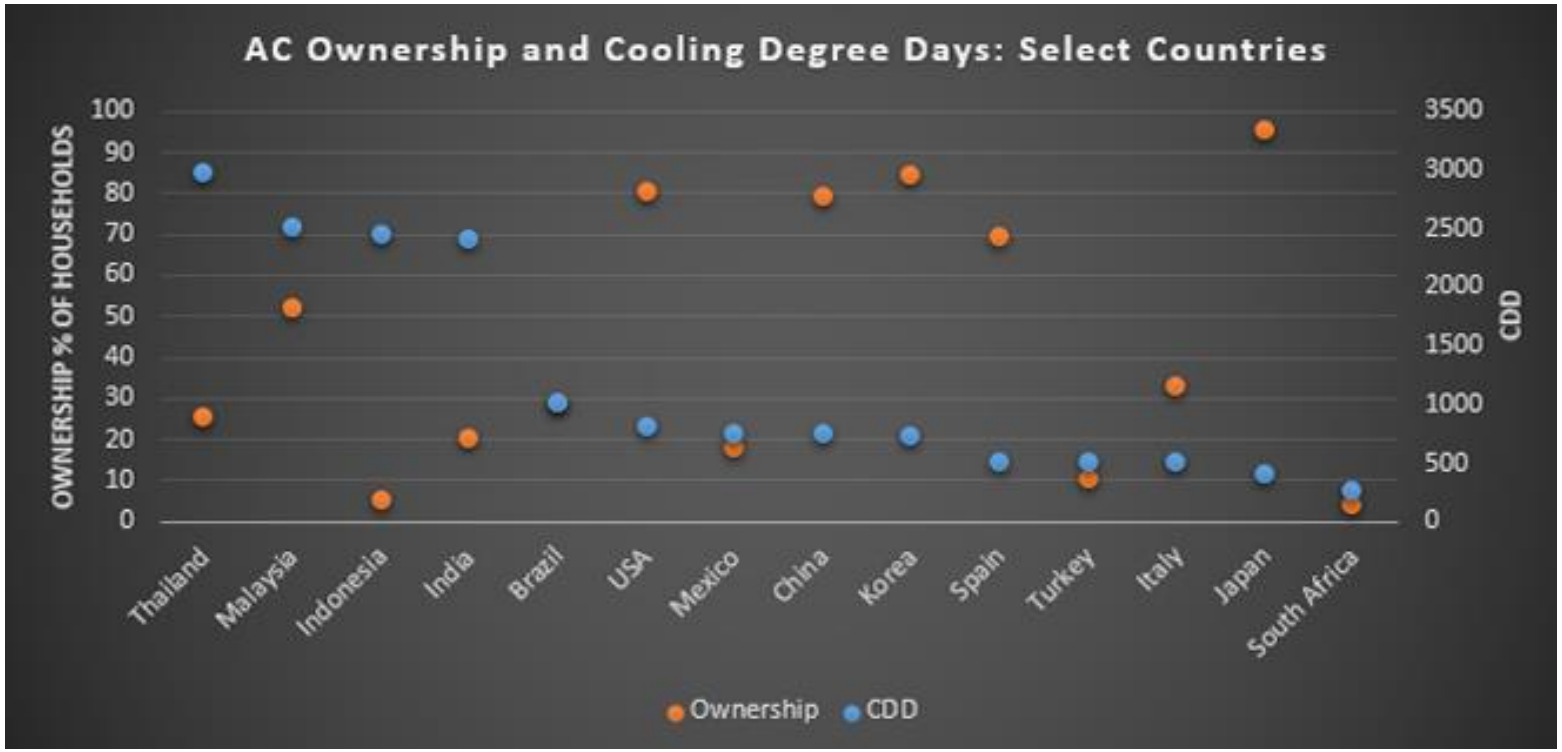


AC Stock for Residence

- Urban AC stock expected to rise 2.5 times in 2037-38 as compared 2017-18.
- Rural AC stock expected to rise by 5 times in 2037-38 as compared 2017-18.

Source: INDIA-COOLING-ACTION-PLAN-e-circulation-version080319.pdf (ozonecell.nic.in)

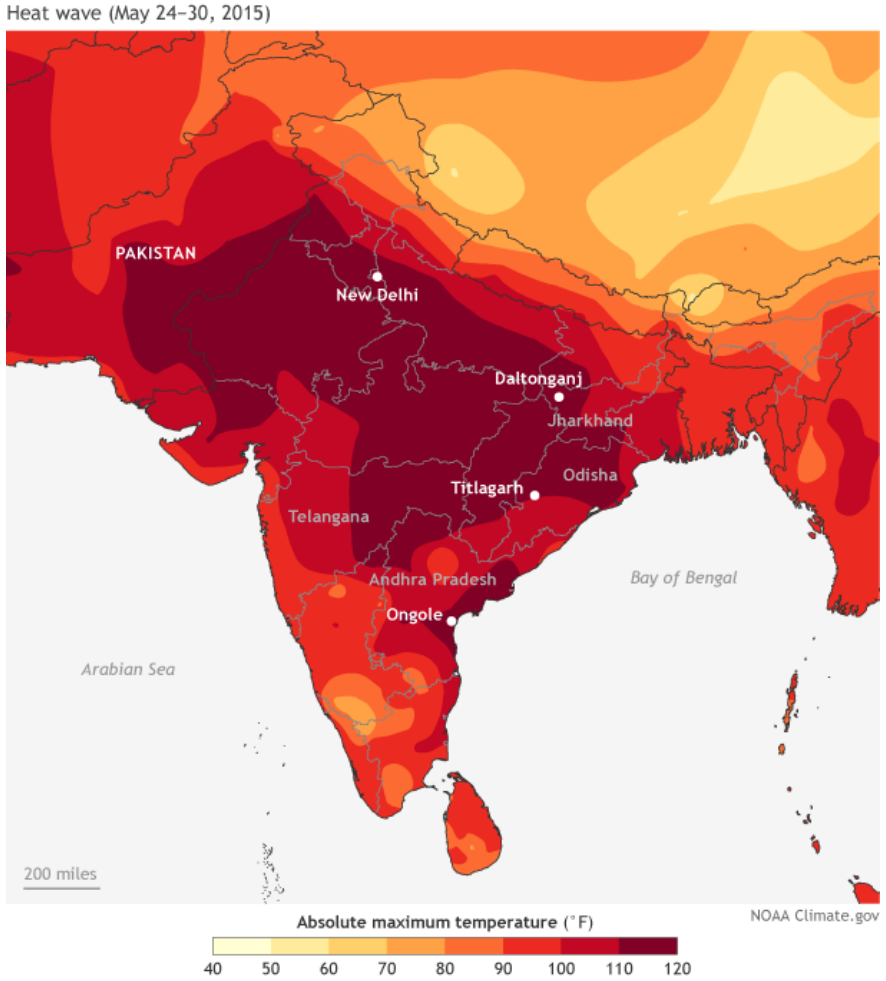
Indian Context



- India, which has more than 3000 CDDs consumes just 70 kilowatts hours (kWh) for space cooling compared to 800 kWh in South Korea which has only 750 CDDs.
- This disparity is mainly on account of the low affordability of AC use in India.
- Currently, less than 10 percent of Indian households own ACs but the demand is growing rapidly.
- Studies show that the correlation between wealth and AC use is stronger than the correlation between climate and AC use.

Source: Air-conditioner use in India: The cause of or the solution to a warmer world? | ORF (orfonline.org)

Indian Context



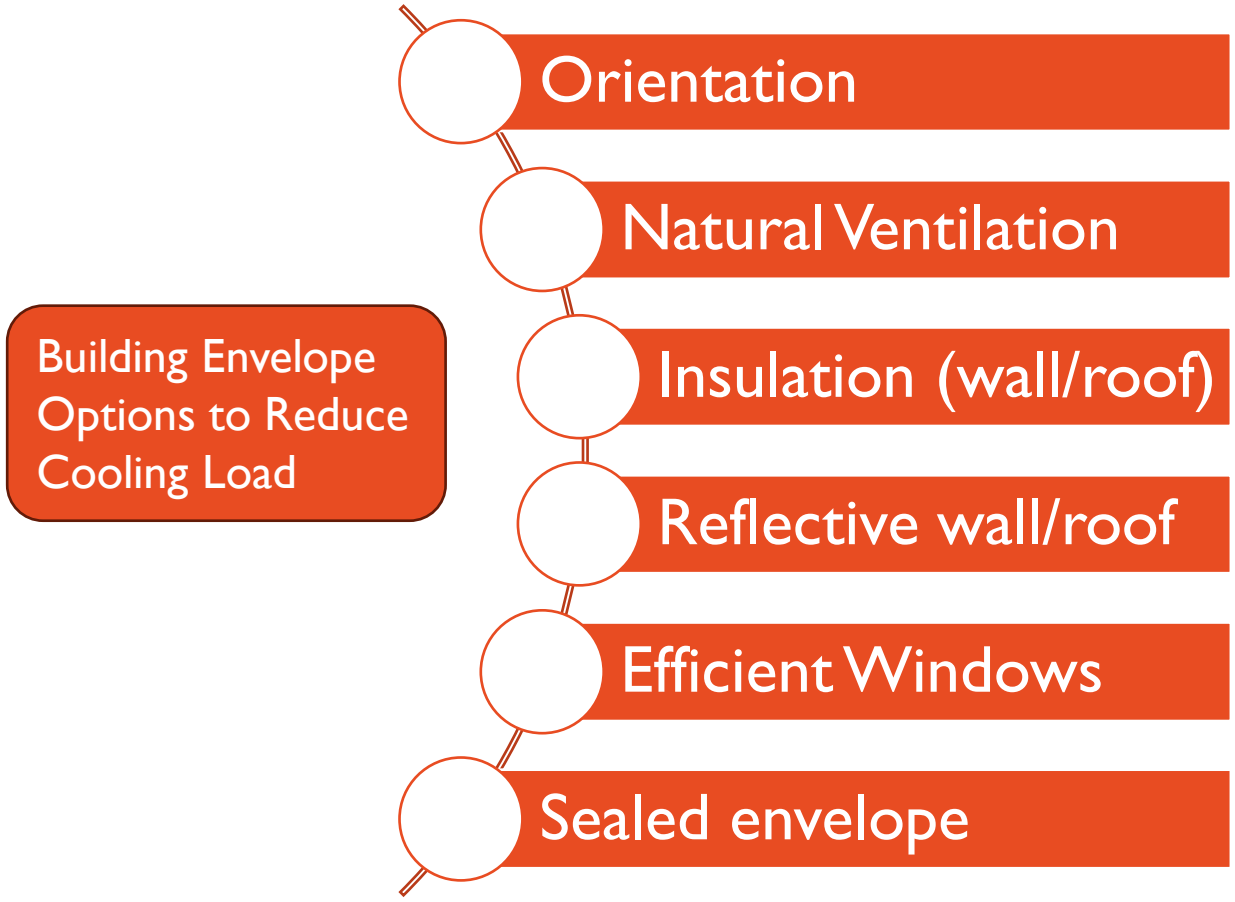
Source: Air-conditioner use in India: The cause of or the solution to a warmer world? | ORF (orfonline.org)

- Severe heat wave in plains of India.
- Temperatures exceed 43°C in the Indo-Gangetic plain & Deccan Plateau region.
- Peak temperatures exceed 47.6°C.
- Over 2,300 deaths.
- Vulnerable groups most affected.
- People suspended work during peak heat hours (Construction labourers, Transport operators, etc.).

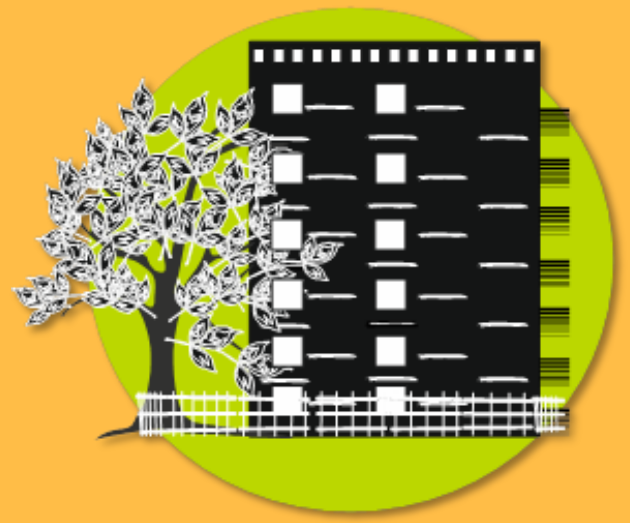
Indian Context

So,
What to do?

Indian Context



- India's future buildings offer a chance to enhance energy efficiency and reduce cooling needs.
- Passive design strategies can minimize heat gain and lower the demand for air conditioning.
- Building codes play a crucial role in promoting efficient building practices.
- Accelerating ECBC/ENS compliance can ensure better insulation and reduced cooling requirements.
- This contributes to sustainable and energy-efficient construction.



Thanks!