



Carnegie Mellon University

Thermal comfort

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Learning objectives

1. Fundamentals of thermal comfort
2. Indices of thermal sensation

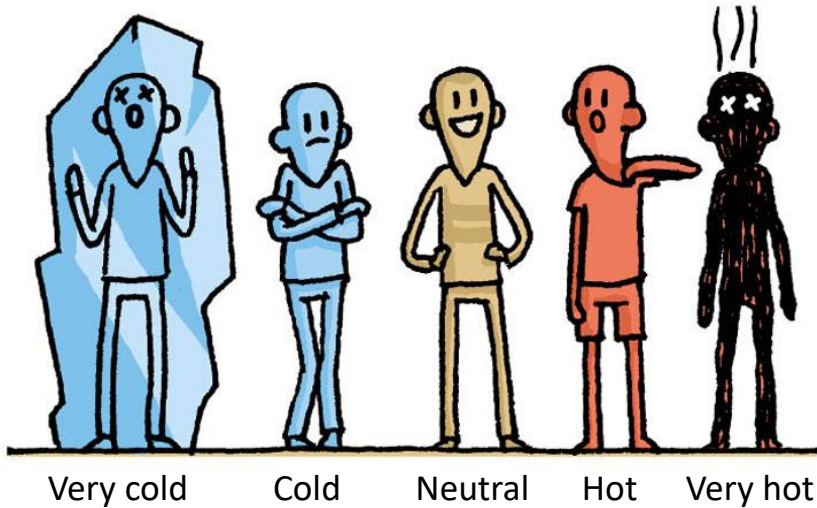
References

Parsons, K. C. “**Human Thermal Comfort**”. Boca Raton, FL: CRC Press/Taylor & Francis Group, (2020).

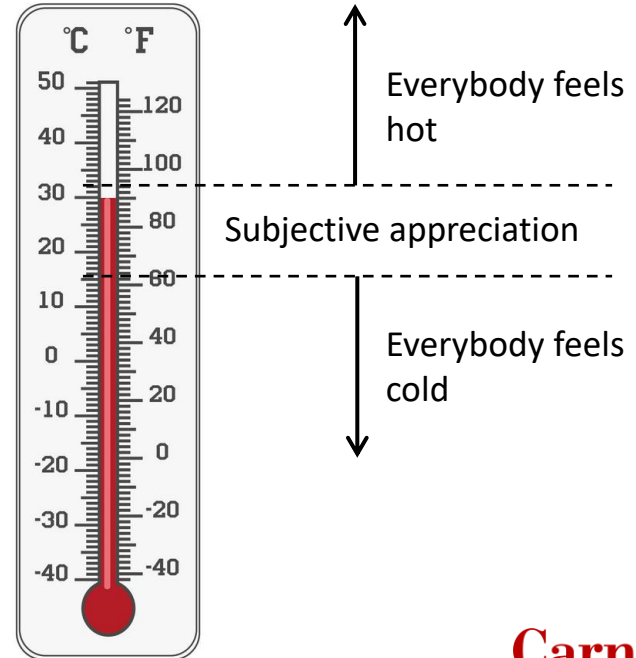
What are the fundamental notions of thermal comfort?

Thermal comfort

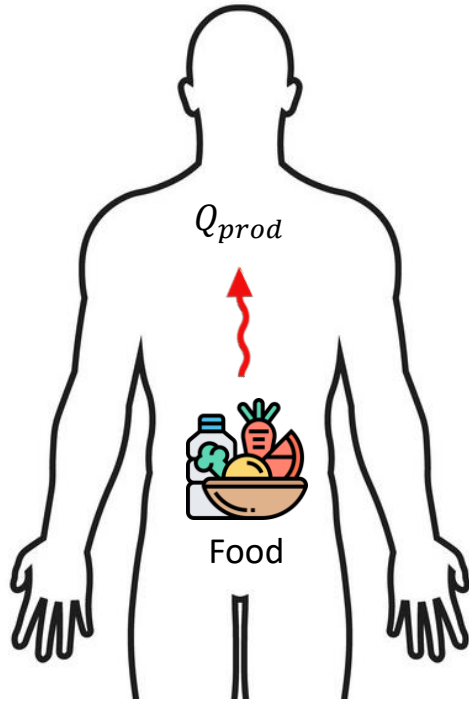
How hot or cold we feel in an indoor or outdoor space



Room temperature



Metabolic heat rate

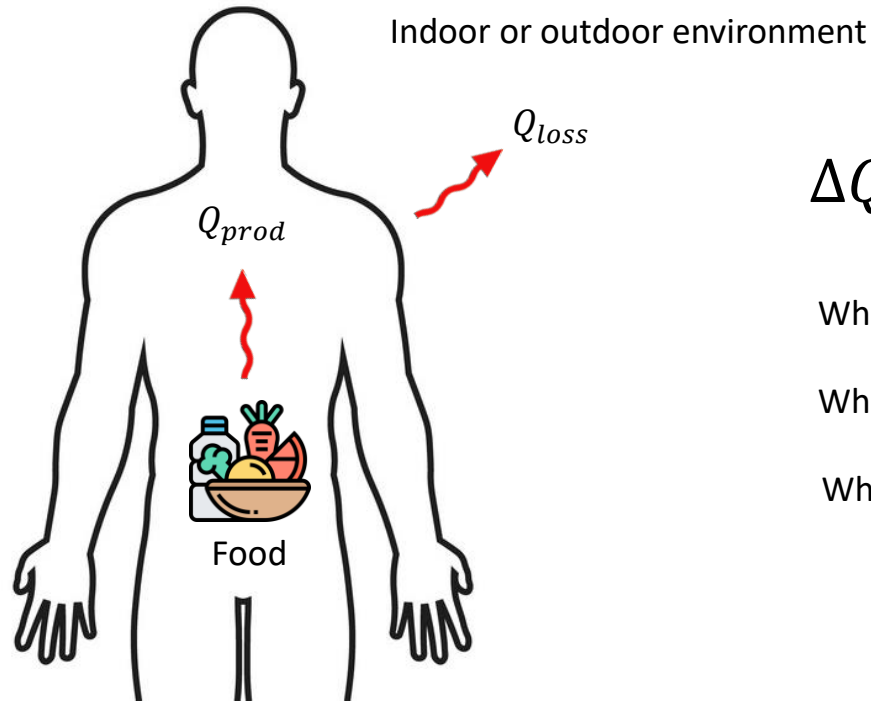


Work during activity (W_{act})

$$\underbrace{A_{skin} \cdot q_{met}} = Q_{prod} + W_{act}$$

Total energy produced
by human body

Heat balance for human body



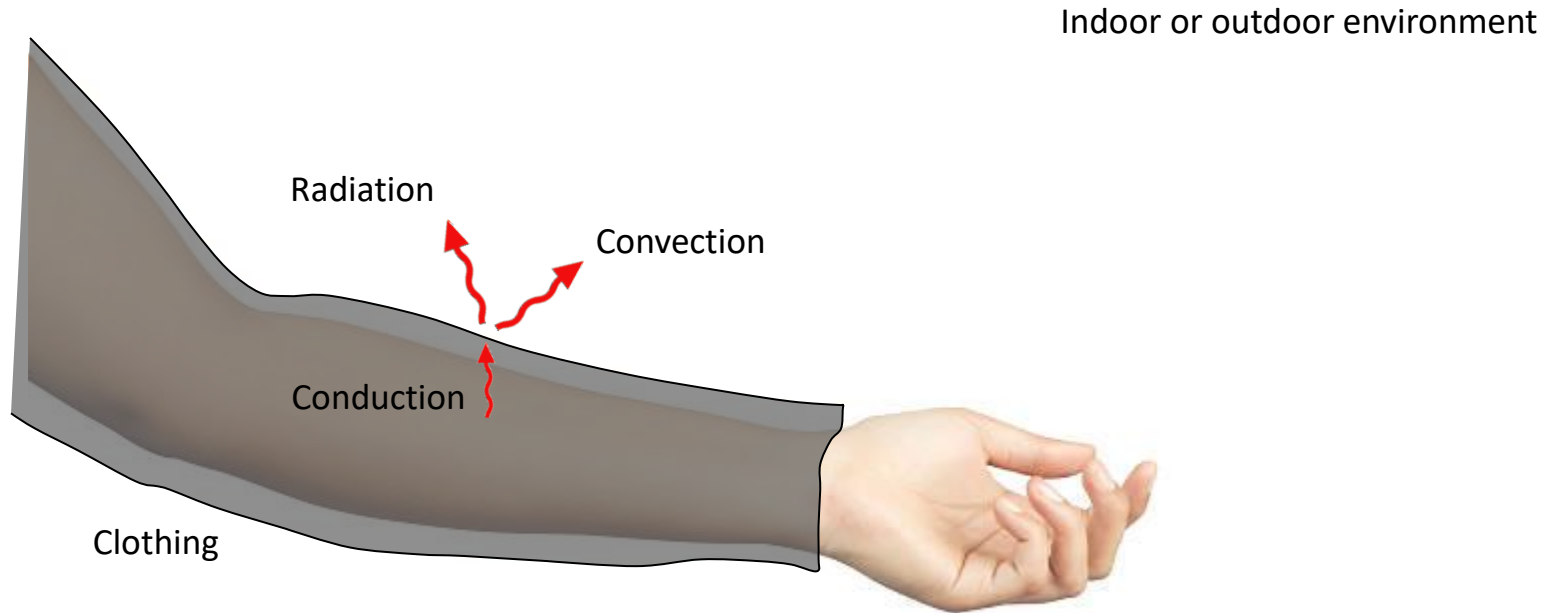
$$\Delta Q_{stored} = Q_{prod} - Q_{loss}$$

What if $\Delta Q_{stored} > 0$?

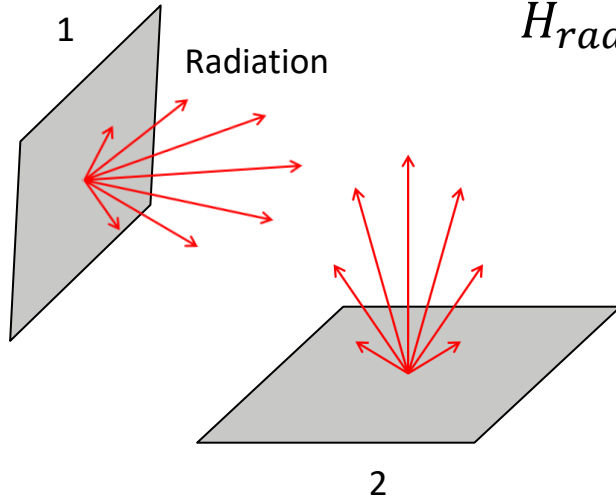
What if $\Delta Q_{stored} < 0$?

What if $\Delta Q_{stored} = 0$?

Sensible heat loss through skin



Net heat transfer by radiation



$$H_{rad} = \sigma \varepsilon_1 A_1 \boxed{F_{1 \rightarrow 2}} (T_1^4 - T_2^4) = \sigma \varepsilon_2 A_2 \boxed{F_{2 \rightarrow 1}} (T_2^4 - T_1^4)$$

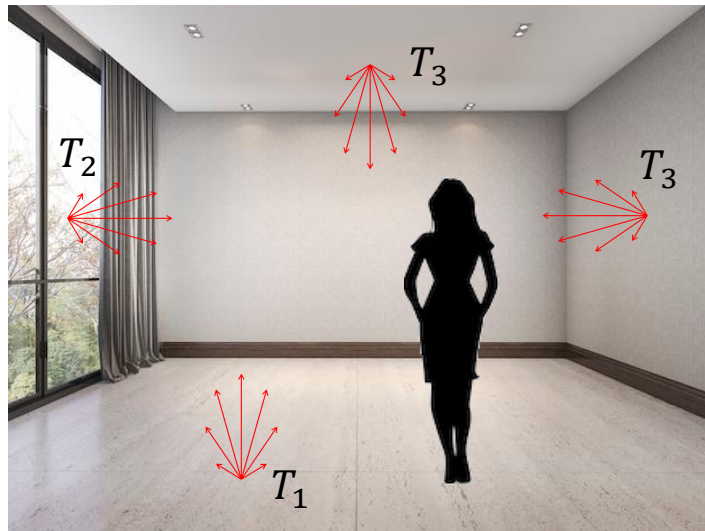
View factor

Properties:

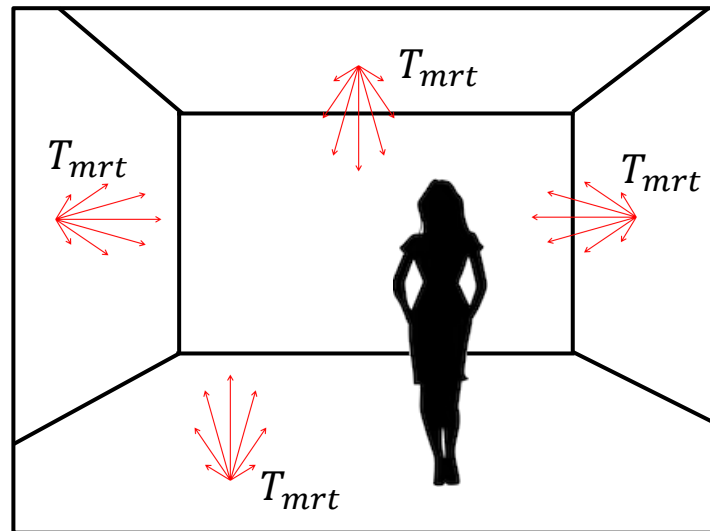
- $\sum_n F_{i \rightarrow n} = 1$ (summation)
- $F_{i \rightarrow (j,r)} = F_{i \rightarrow j} + F_{i \rightarrow r}$ (superposition)
- $A_i F_{i \rightarrow j} = A_j F_{j \rightarrow i}$ (reciprocity)

Indoor mean radiant temperature

Actual room

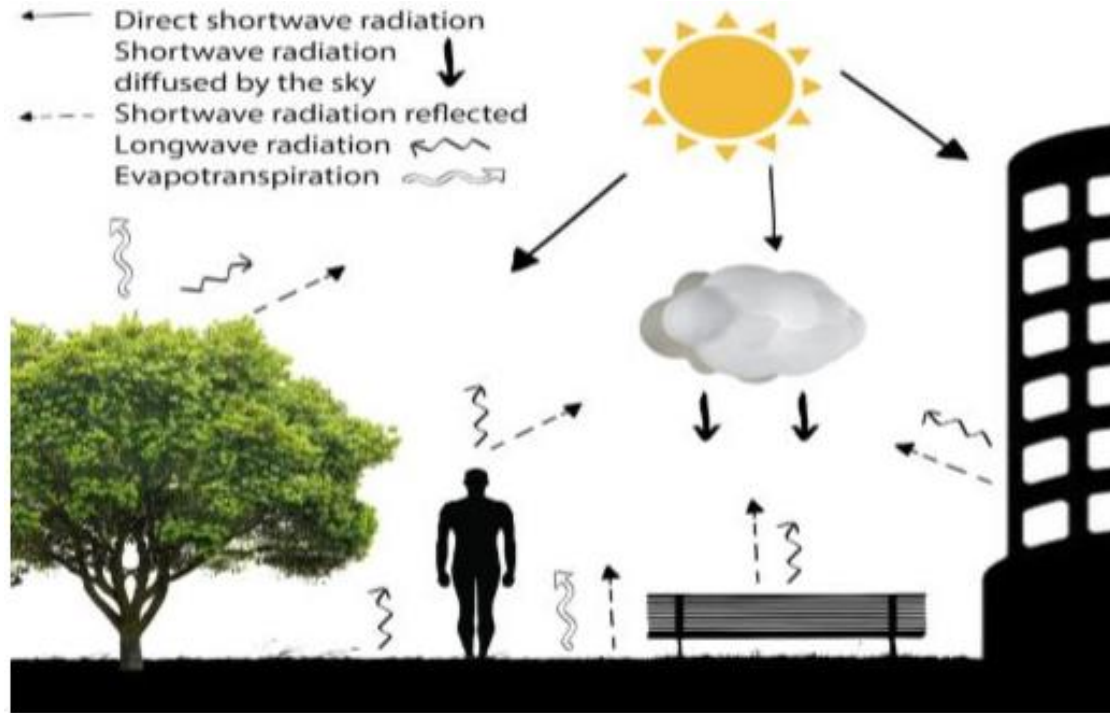


Imaginary room

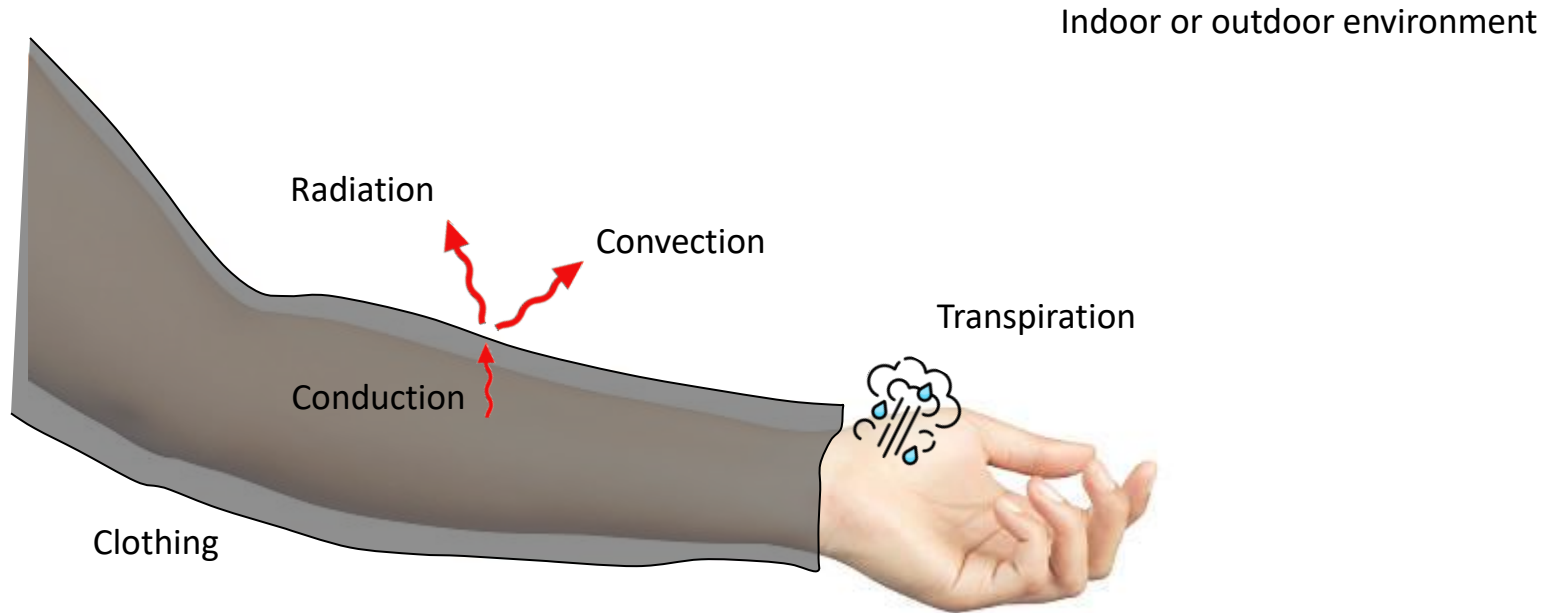


$$T_{mrt} = \sum_n F_{body \rightarrow n} T_n \Rightarrow H_{rad} = \sigma \epsilon_{skin} (T_{skin}^4 - T_{mrt}^4)$$

Outdoor mean radiant temperature

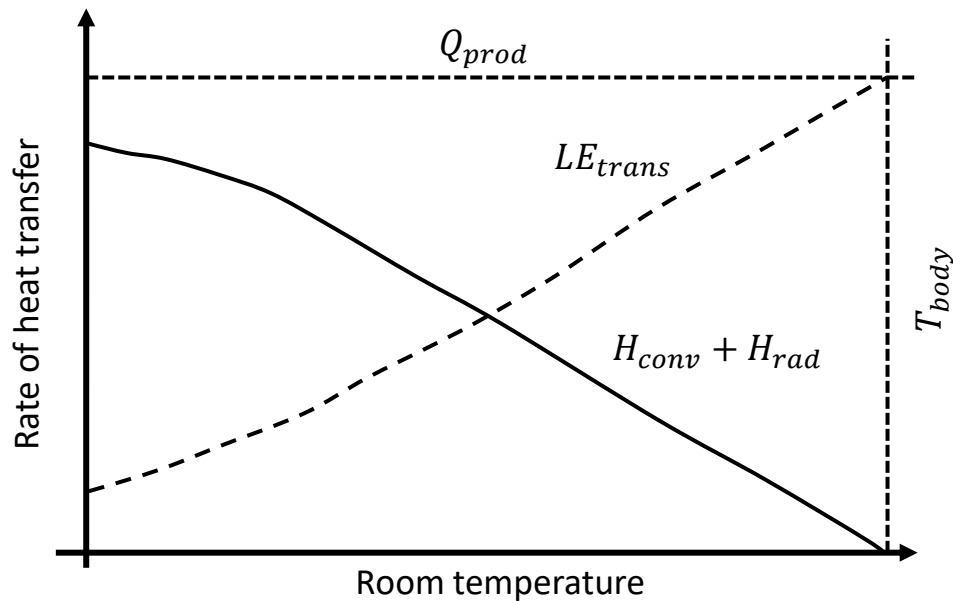


Latent heat loss through skin



Heat balance for human body

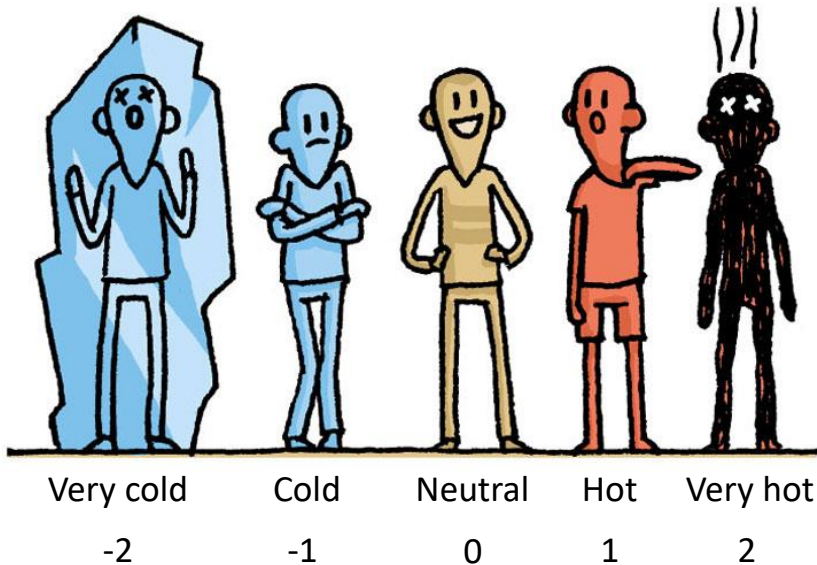
$$Q_{prod} = H_{conv} + H_{rad} + LE_{trans} + H_{res} + LE_{res}$$



What are the indices of thermal comfort?

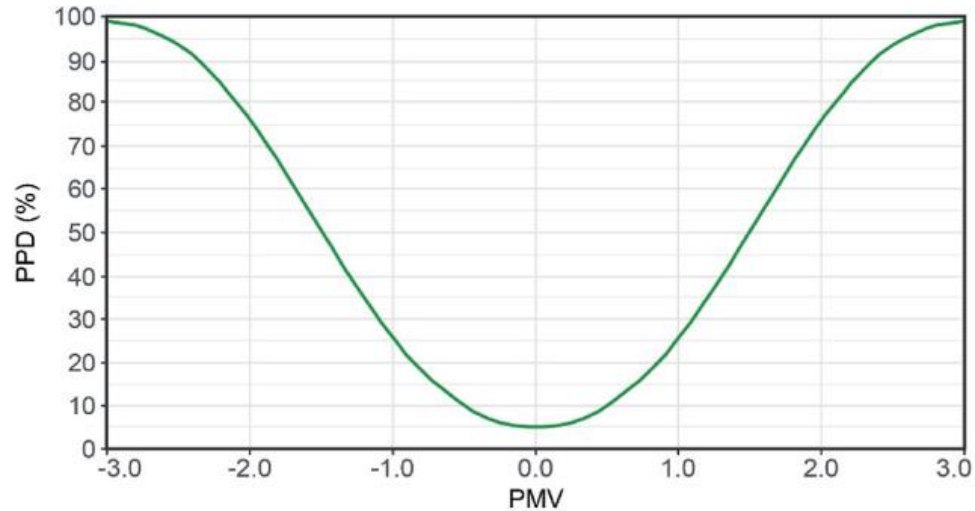
Thermal sensation index

How hot or cold we feel in an indoor or outdoor space



$$TSI = f(T_{air}, T_{mrt}, \phi_{air}, \dot{V}_{air})$$

Predicted mean vote (PMV)



Operative temperature

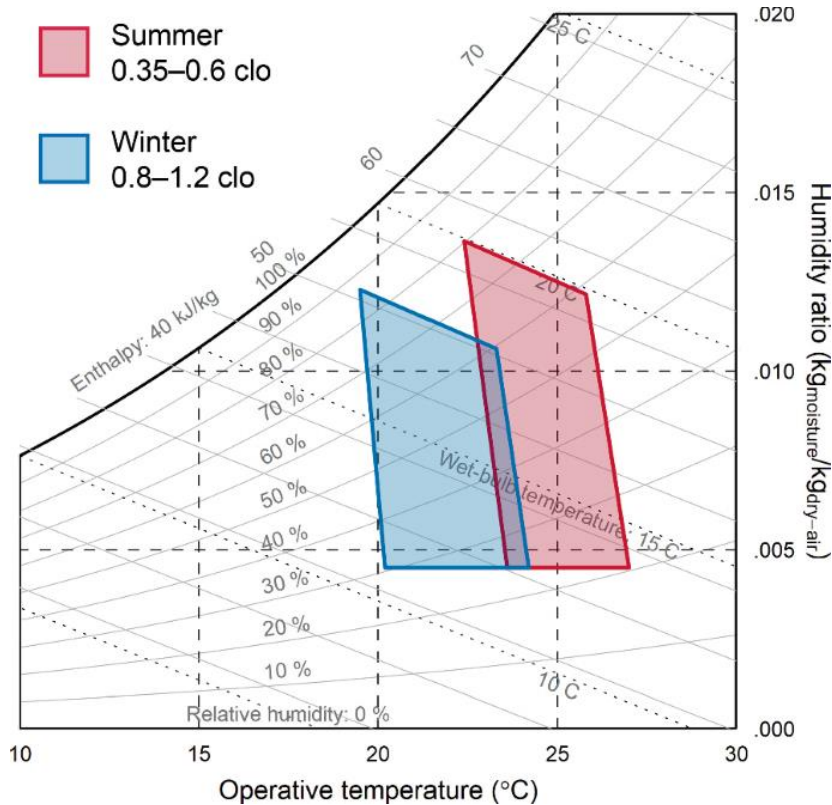
$$T_{op} = f(T_{air}, T_{mrt}, v_{air})$$

$$T_{op} = \frac{T_{air} + T_{mrt}}{2}$$

$$T_{op} = \frac{h_{conv}T_{air} + h_{rad}T_{mrt}}{h_{conv} + h_{rad}}$$

$$T_{op} = \frac{T_{mrt} + T_{air} \cdot 10\sqrt{v_{air}}}{1 + 10\sqrt{v_{air}}}$$

ASHRAE comfort chart



clo: unit to describe the level of insulation due to clothing