MŰEGYETEM 1782

Comfort in Buildings

Thermal Comfort 2

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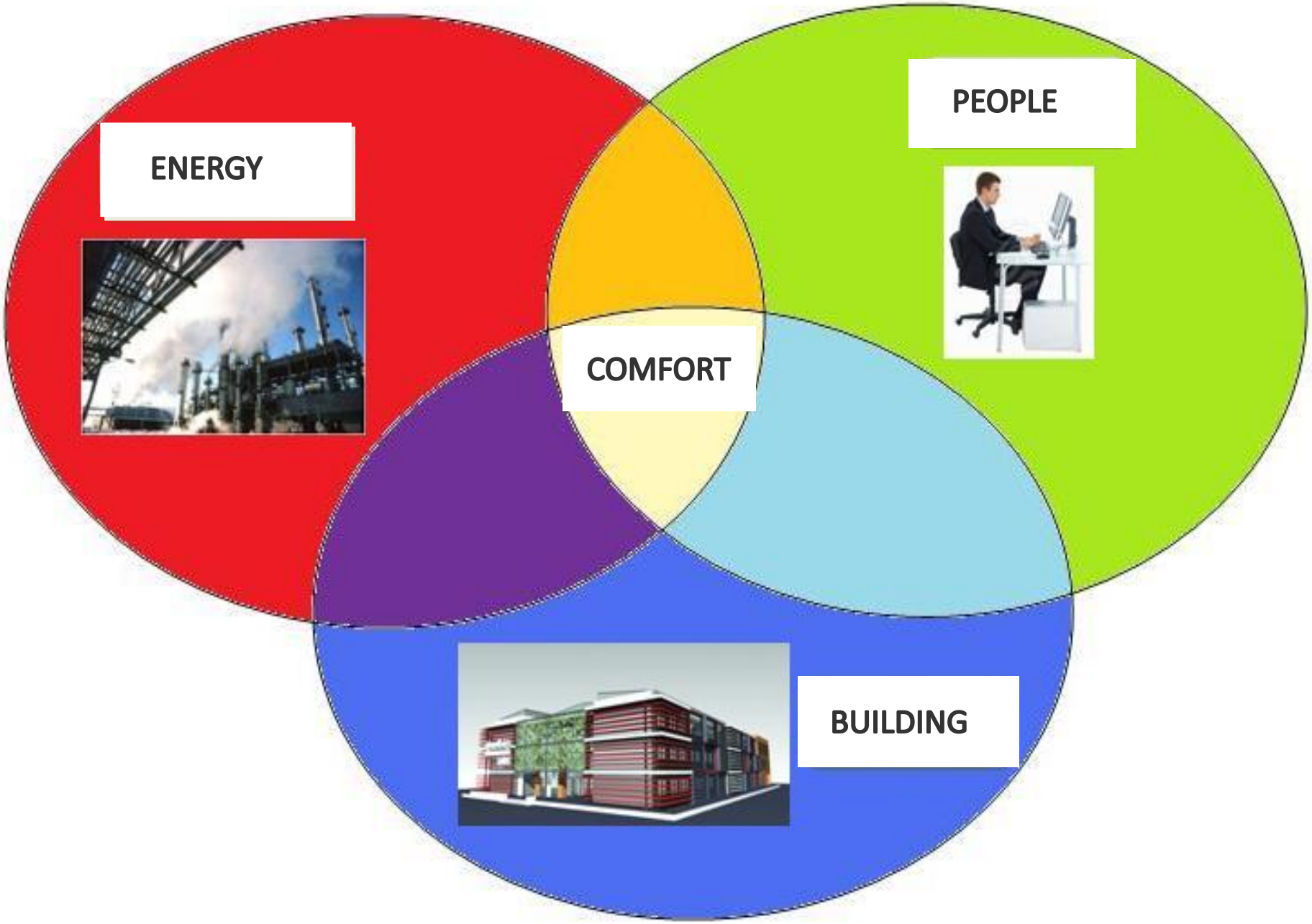
PROF / TRAC

Open Training and Qualification Platform on NZEB construction and renovation


ENERGY
PEOPLE
COMFORT
BUILDING

Indoor environmental factors

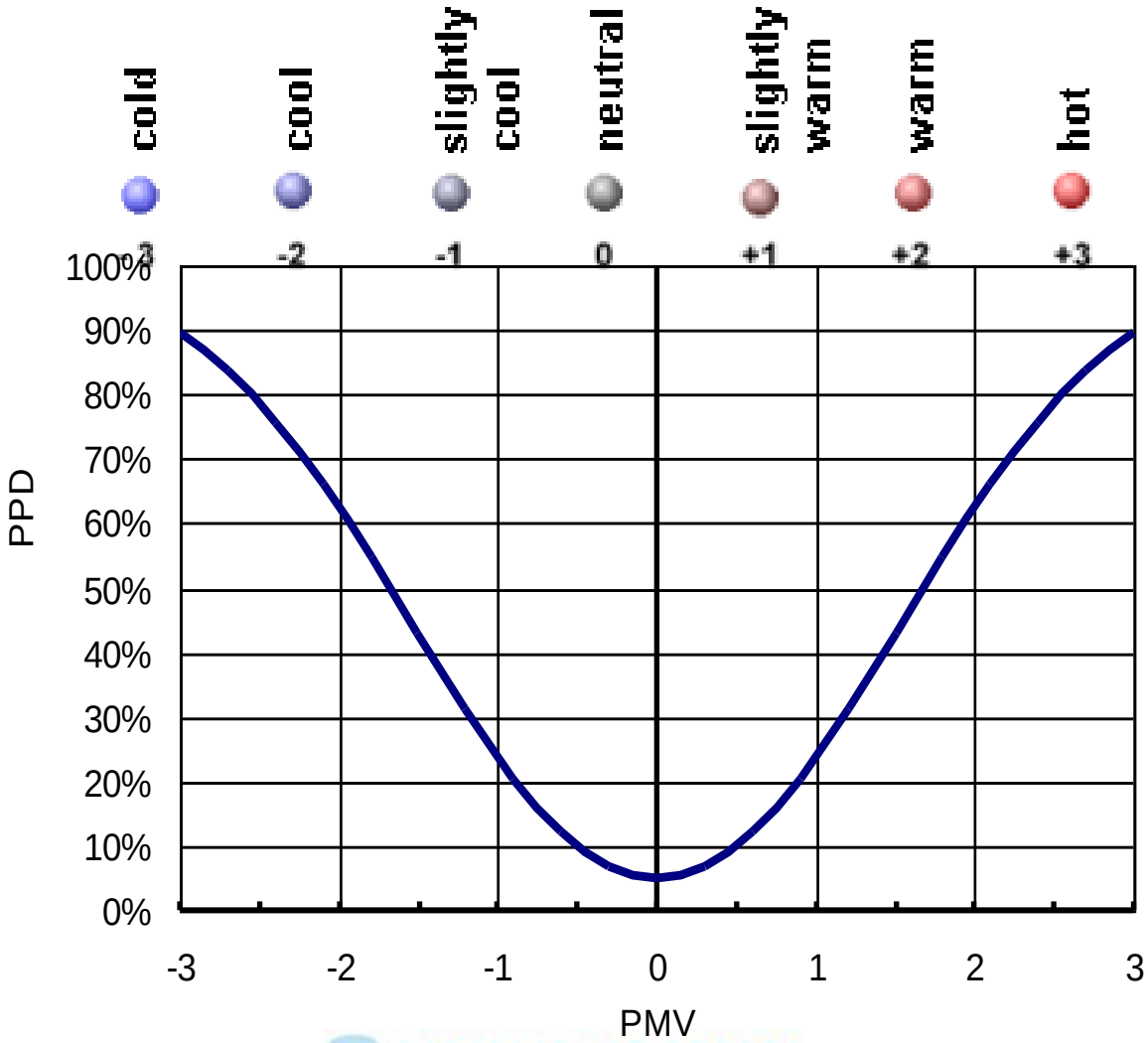
- **Thermal comfort or indoor climate**
  - Temperature, humidity, air velocity
- **Visual or lighting quality**
  - View, illuminance, luminance ratios, reflection,…
- **Indoor air quality**
  - odours, indoor air pollution, fresh air supply,…
- **Acoustical quality**
  - Outside and indoor noise and vibrations

Factors Influencing Thermal Comfort

- Human
  - **Metabolic Rate**
  - **Clothing Insulation**

- Space
  - **Air Temperature (Dry-Bulb)**
  - **Relative Humidity**
  - **Air Velocity**
  - **Radiation (Mean Radiant Temperature)**

PMV and PPD index



Thermal comfort

M - Metabolic Rate (m^2.K/W)

1Met = 58,15 W/m^2

Thermal comfort

I - Clothing Insulation (m^2.K/W)

1 clo=0,155m^2.K/W

clo <0,5

0,6-1,2

>3,5

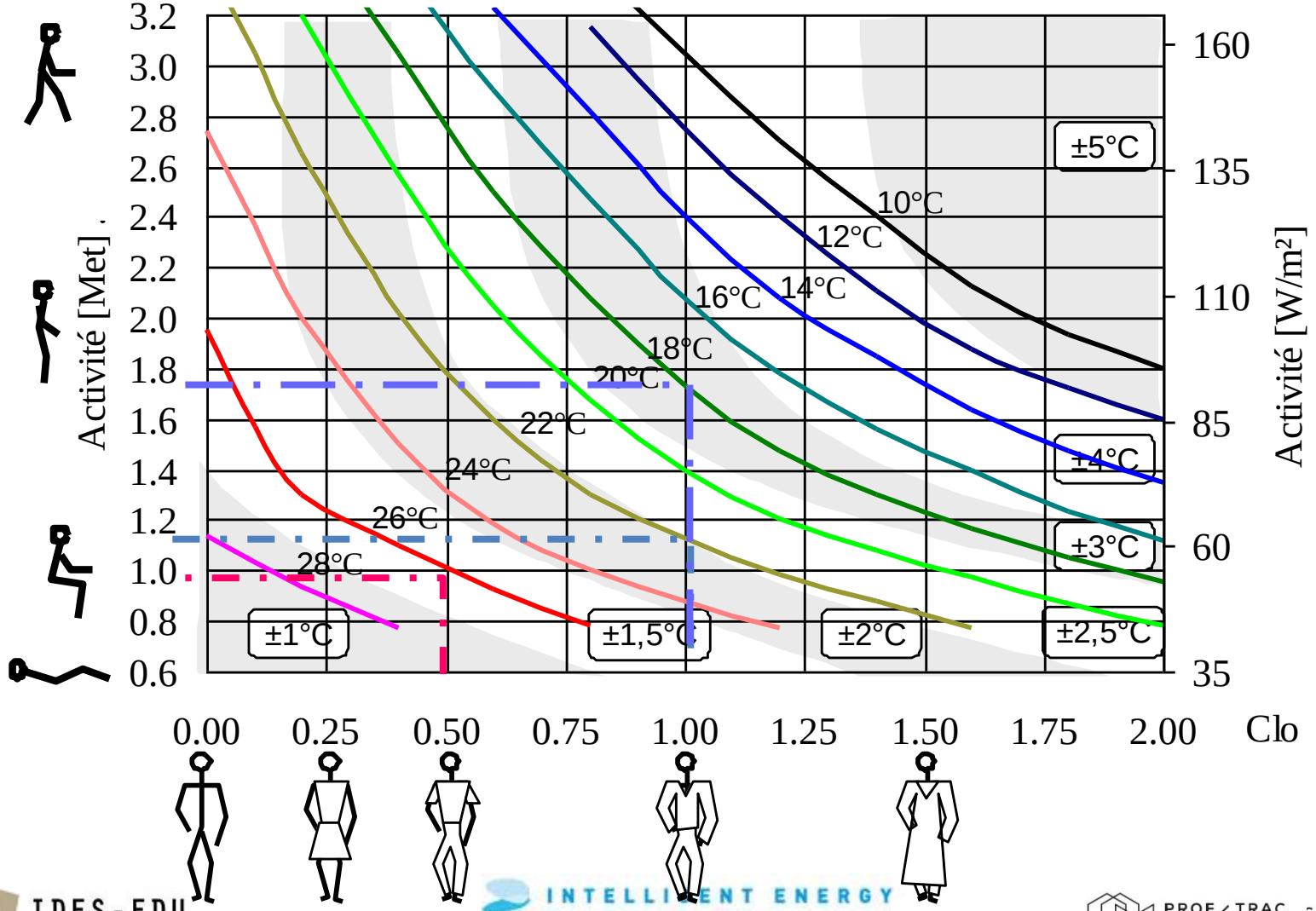
Environmental indices

- **Operative Temperature**

$$t_{op} = \frac{h_c t_a + h_r t_r}{h_c + h_r}$$

where t_{op} **= operative temperature**
t_a **= air temperature**
t_r **= mean radiant temperature (MRT)**
h_c **= convective heat transfer coefficient**
h_r **= mean radiative heat transfer coefficient**

Operative temperature



Comfort (Fanger) equation

$$H - E_d - E_{sw} - E_{re} - L = K = S + C$$

where H = the internal heat production in the human body
E_d = the heat loss by water vapour diffusion through the skin
E_{sw} = the heat loss by evaporation of sweat from the surface of the skin
E_{re} = the latent respiration heat loss
L = the dry respiration heat loss
K = the heat transfer from the skin to the outer surface of the clothed body (conduction through the clothing)
R = the heat loss by radiation from the outer surface of the clothed body
C = the heat loss by convection from the outer surface of the clothed body

Comfort (Fanger) equation

$$H - E_d - E_{sw} - E_{re} - L = K = S + C$$

Internal heat production: $$H = \frac{M}{F_{Du}} \cdot (1 - \eta)$$

Heat loss through the skin (vapour diffusion, sweating)

$$E_d = 0{,}41 \cdot F_{Du} \cdot (1{,}92 \cdot t_b - 25{,}3 - p_{vg}) \qquad E_{re} = 0{,}027 \cdot M \cdot (44 - p_e)$$

Heat loss of respiration:

$$E_{sw} = 0{,}49 F_{Du} \left[\frac{H}{F_{Du}} - 50 \right] \qquad L = 0{,}0014 \cdot M \cdot (34 - t_l)$$

Comfort (Fanger) equation

$$H - E_d - E_{sw} - E_{re} - L = K = S + C$$

Heat transfer from the skin to the other surface of the clothed body

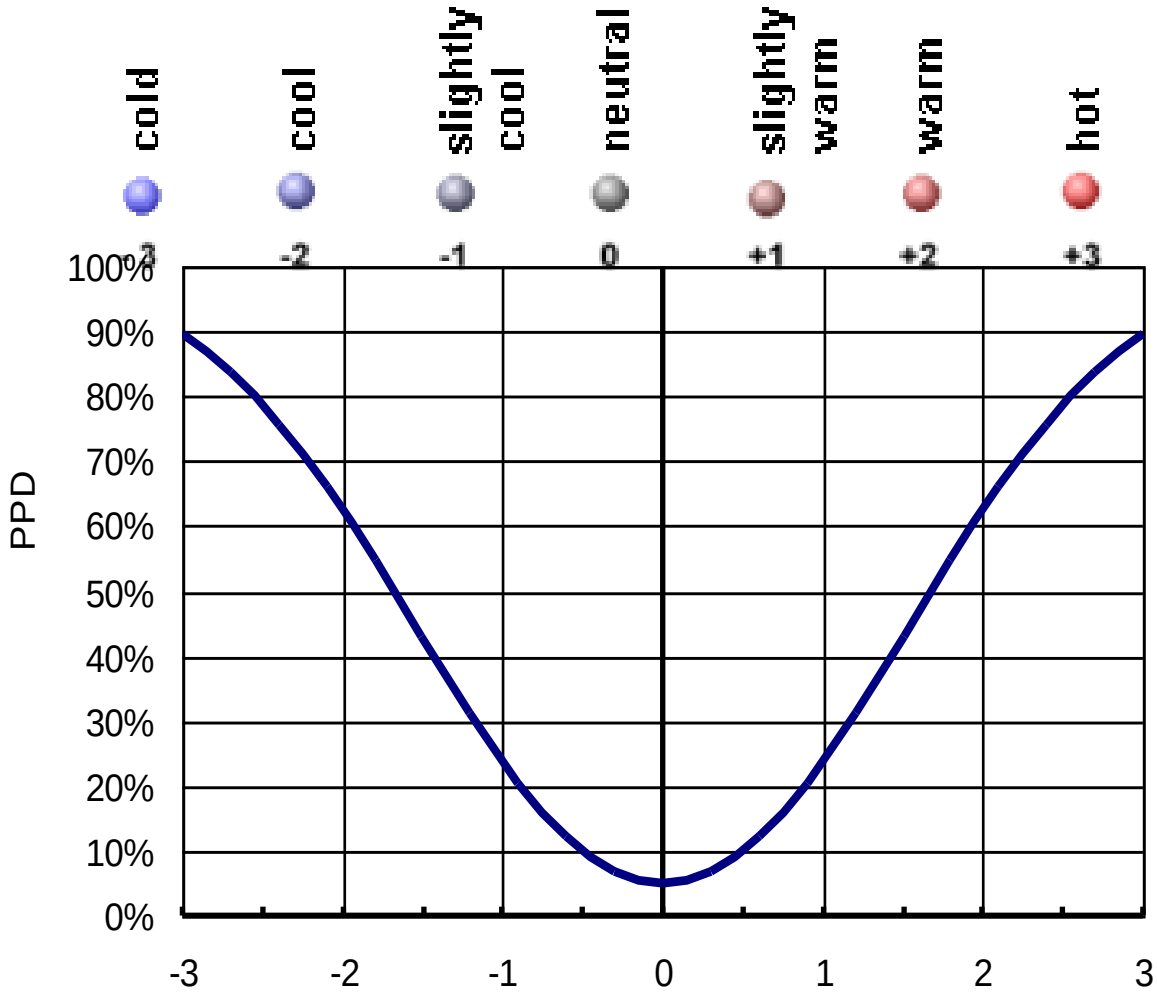
$$K = 0{,}163 \cdot F_{Du} \cdot \frac{t_b - t_{cl}}{0{,}18 \cdot I_{cl}} [W]$$

Heat loss by radiation and convection from outer surface ot the clothed body

$$S = 3{,}94 \cdot 10^{-8} \cdot F_{Du} \cdot f_{cl} \cdot (t_{cl} + 273)^4 - (t_{ks} + 273)^4 [W]$$

$$C = F_{Du} \cdot f_{cl} \cdot \alpha_c \cdot (t_{cl} - t_l)$$

PMV and PPD index



Comfort (Fanger) equation

$$PMV = \left[0.303\exp\left(-0.036m\right)+0.028\right]$$

$$\cdot\left[\begin{array}{l} m-w-0.00305\left(5733-6.99\left(m-w\right)-p\right) \\ -0.42\left(m-w-58.15\right)-0.000017m\left(5867-p\right) \\ -0.0014m\left(307-T_a\right)-F \end{array}\right]$$

$$F = 3.96\cdot 10^{-8}\, f\left(T_{cl}^4 - T_{mrt}^4\right)+ f\, h\left(T_{cl}-T_a\right)$$

$$h = \max\left\{2.38\left(T_{cl}-T_a\right)^{1/4};12.06\sqrt{v}\right\}$$

$$T_{cl} = 308.9-0.028\left(m-w\right)-R\,F$$

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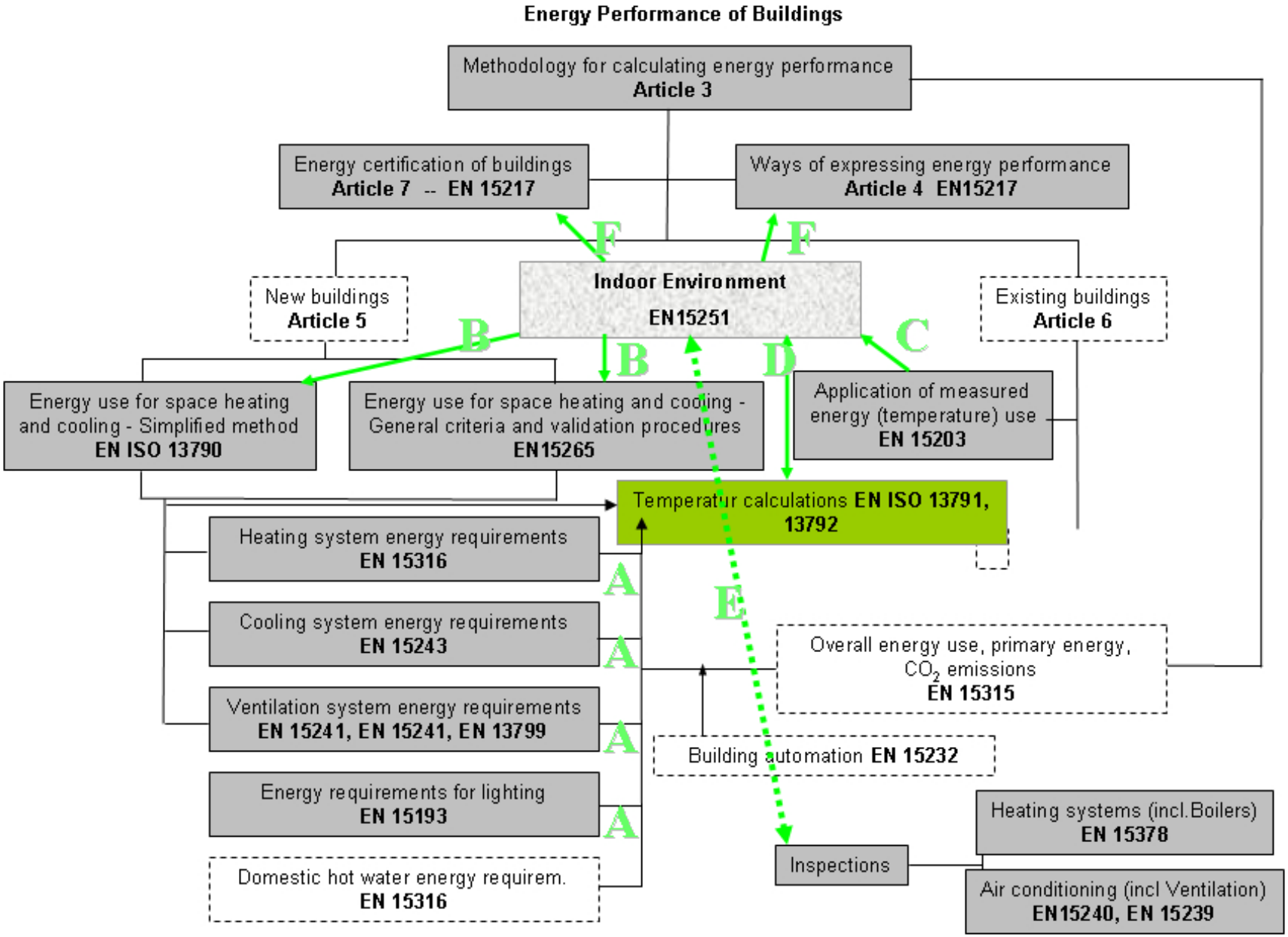
  - **Relative Humidity**
  - **Air Velocity**
  - **Radiation (Mean Radiant Temperature)**

IEQ – criteria for classification

- Standard EN 15251

Indoor environmental input parameters for design and assessment of energy performance of buildings – addressing indoor air quality, thermal environment, lighting and acoustics.


Energy Performance of Buildings
Methodology for calculating energy performance
Article 3
Energy certification of buildings
Article 7 -- EN 15217
Ways of expressing energy performance
Article 4 EN15217
F
F
Indoor Environment
EN15251
New buildings
Article 5
Existing buildings
Article 6
B
B
D
C
Energy use for space heating and cooling - Simplified method
EN ISO 13790
Energy use for space heating and cooling - General criteria and validation procedures
EN15265
Application of measured energy (temperature) use
EN 15203
Temperatur calculations EN ISO 13791, 13792
Heating system energy requirements
EN 15316
A
E
Cooling system energy requirements
EN 15243
A
Overall energy use, primary energy, CO_2 emissions
EN 15315
Ventilation system energy requirements
EN 15241, EN 15241, EN 13799
A
Building automation EN 15232
Energy requirements for lighting
EN 15193
A
Heating systems (incl.Boilers)
EN 15378
Inspections
Air conditioning (incl Ventilation)
EN15240, EN 15239
Domestic hot water energy requirem.
EN 15316

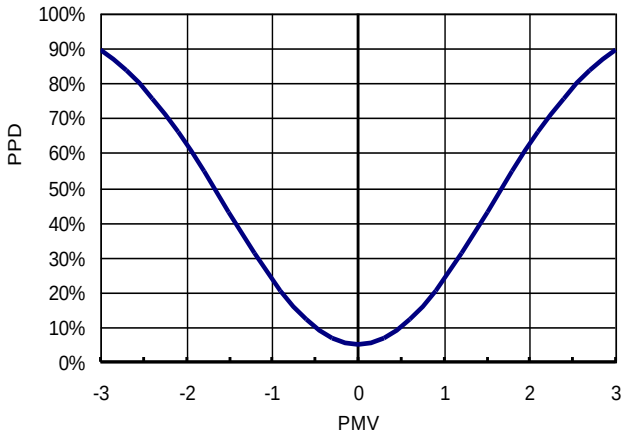
EN 15251 Comfort Categories

- **New categories**
- **Category II is assumed to be the 'norm'**

Category	Explanation
I	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons
II	Normal level of expectation and should be used for new buildings and renovations
III	An acceptable, moderate level of expectation and may be used for existing buildings
IV	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year

Thermal comfort

- EN ISO 7730 – parmeters especially for HVAC systems design
- 3 cathegories of thermal comfort according to PPD and PMV



Categories of thermal environment (EN ISO 7730)

Category of indoor thermal environment	Thermal state of the body as a whole	
	PPD	PMV
A	< 6%	– 0,2 < PMV < + 0,2
B	< 10%	– 0,5 < PMV < + 0,5
C	< 15%	– 0,7 < PMV < + 0,7

PMV - predicted mean vote, PPD - predicted percentage of dissatisfied

Indoor resultant (operative) temperature

Type of building, Space	Clothing, winter (clo)	Activity (met)	Category of indoor environment	Operative temperature, winter (°C)
Office	1,0	1,2	A	21,0 - 23,0
			B	20,0 - 24,0
			C	19,0 - 25,0
Open space office	1,0	1,2	A	21,0 - 23,0
			B	20,0 - 24,0
			C	19,0 - 25,0
Cafe, restaurant	1,0	1,2	A	21,0 - 23,0
			B	20,0 - 24,0
			C	19,0 - 25,0
Shopping center	1,0	1,6	A	17,5 - 20,5
			B	16,0 - 22,0
			C	15,0 - 23,0
Housing	1,0	1,2	A	21,0 - 23,0
			B	20,0 - 24,0
			C	19,0 - 25,0

Operative temperature, EN 15251 (40/2012 BM)

Type of building or space	Category	Temperature range for heating, °C Clothing ~ 1,0 clo	Temperature range for cooling, °C Clothing ~ 0,5 clo
Residential buildings, living spaces (bed room's living rooms etc.) Sedentary activity ~1,2 met	I	21,0 -25,0	23,5 - 25,5
	II	**20,0-25,0**	**23,0 - 26,0**
	III	18,0- 25,0	22,0 - 27,0
Residential buildings, other spaces (kitchens, storages etc.) Standing-walking activity ~1,5 met	I	18,0-25,0	
	II	**16,0-25,0**	
	III	14,0-25,0	
Offices and spaces with similar activity (single offices, open plan offices, conference rooms, auditorium, cafeteria, restaurants, class rooms, Sedentary activity ~1,2 met	I	21,0 – 23,0	23,5 - 25,5
	II	**20,0 – 24,0**	**23,0 - 26,0**
	III	19,0 – 25,0	22,0 - 27,0
Kindergarten Standing-walking activity ~1,4 met	I	19,0 – 21,0	22,5 - 24,5
	II	**17,5 – 22,5**	**21,5 – 25,5**
	III	16,5 – 23,5	21,0 - 26,0
Department store Standing-walking activity ~1,6 met	I	17,5 – 20,5	22,0 - 24,0
	II	**16,0 – 22,0**	**21,0– 25,0**
	III	15,0 – 23,0	20,0 - 26,0

Suggested relative humidity values

Type of building/space	Category	Design relative humidity for dehumidification, %	Design relative humidity for humidification, %
Spaces where humidity criteria are set by human occupancy. Special spaces (museums, churches etc) may require other limits	I	50	30
	II	60	25
	III	70	20
	IV	> 70	< 20

Local discomforts

VERT. TEMP. GRADIENT

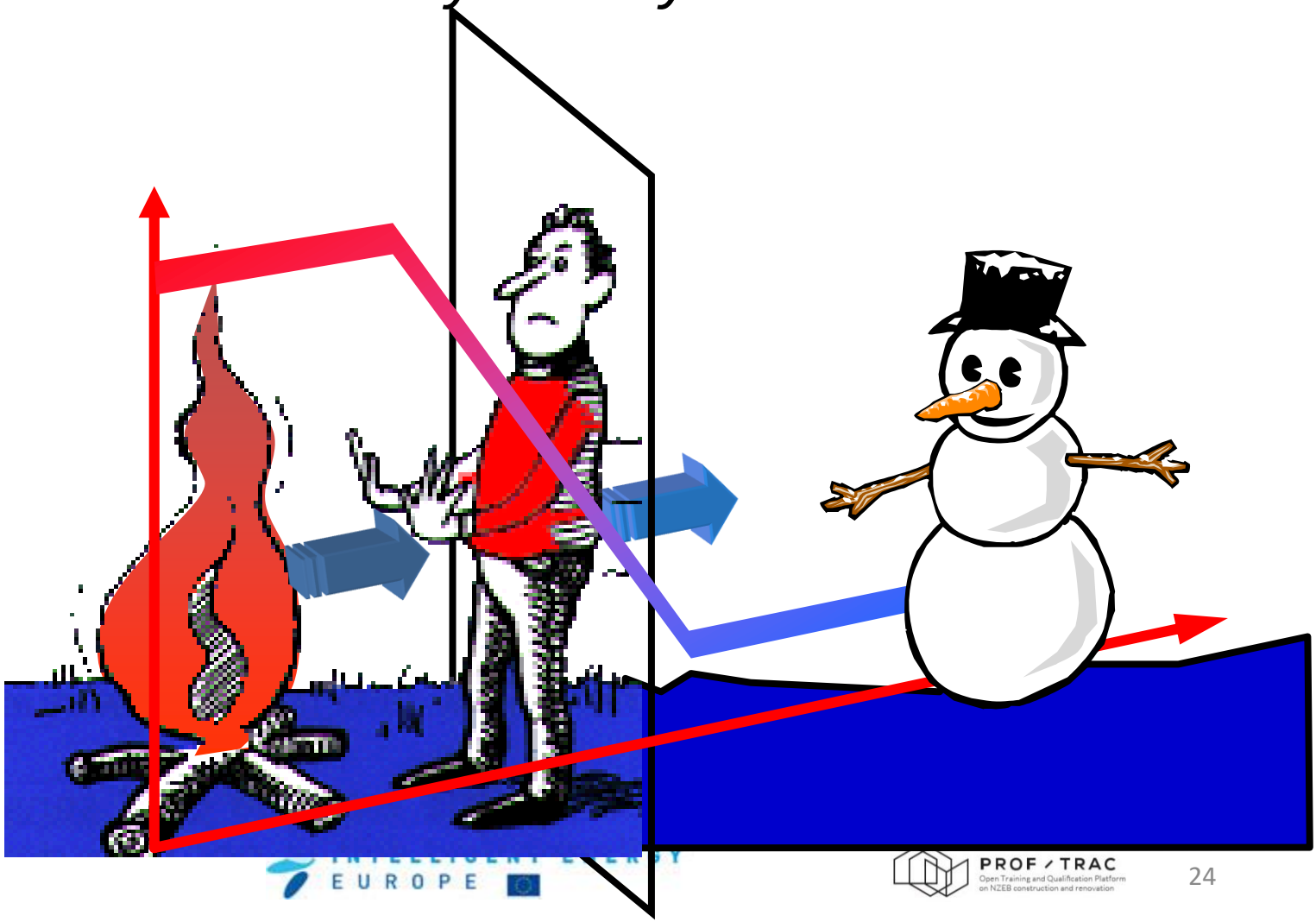
FLOOR TEMPERATURE

RADIANT ASYMMETRY

DRAUGHT

Local thermal discomfort

Radiant asymmetry



Local thermal discomfort

Radiant asymmetry

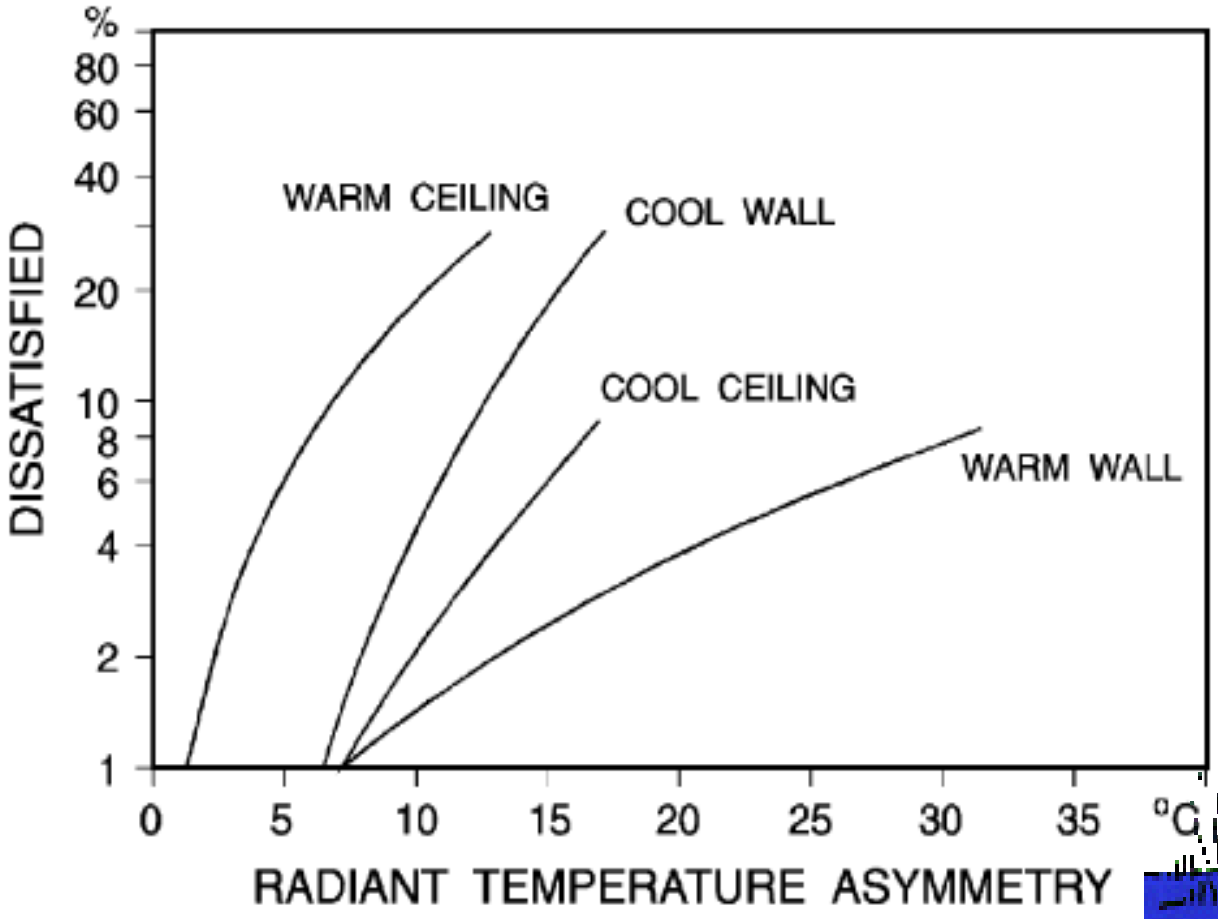
Cold surfaces

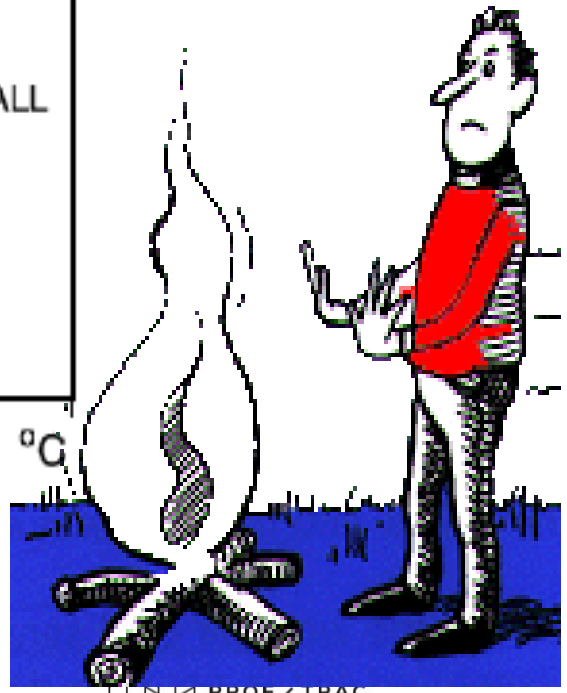
- Glazing
- Poorly insulated exterior wall
- Ceiling and / or underfloor cooling

Warm surfaces

- Glazing (sun)
- Ceiling and / or underfloor heating
- Radiant heat emitter (lighting, heating, etc ...)

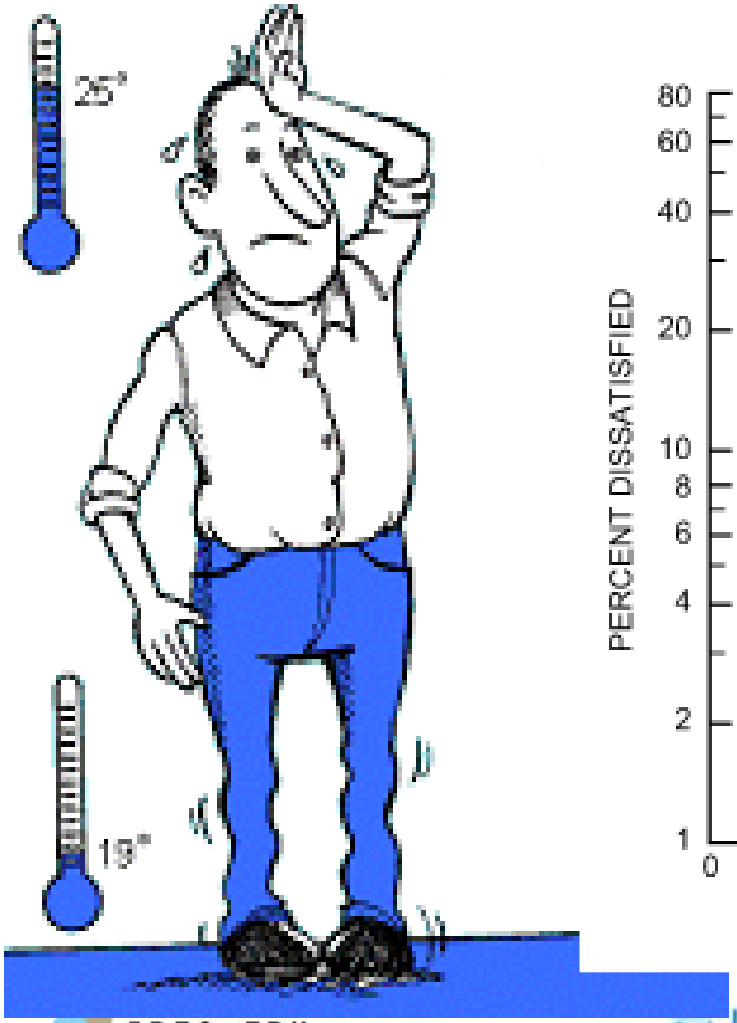
Radiant asymmetry - effect

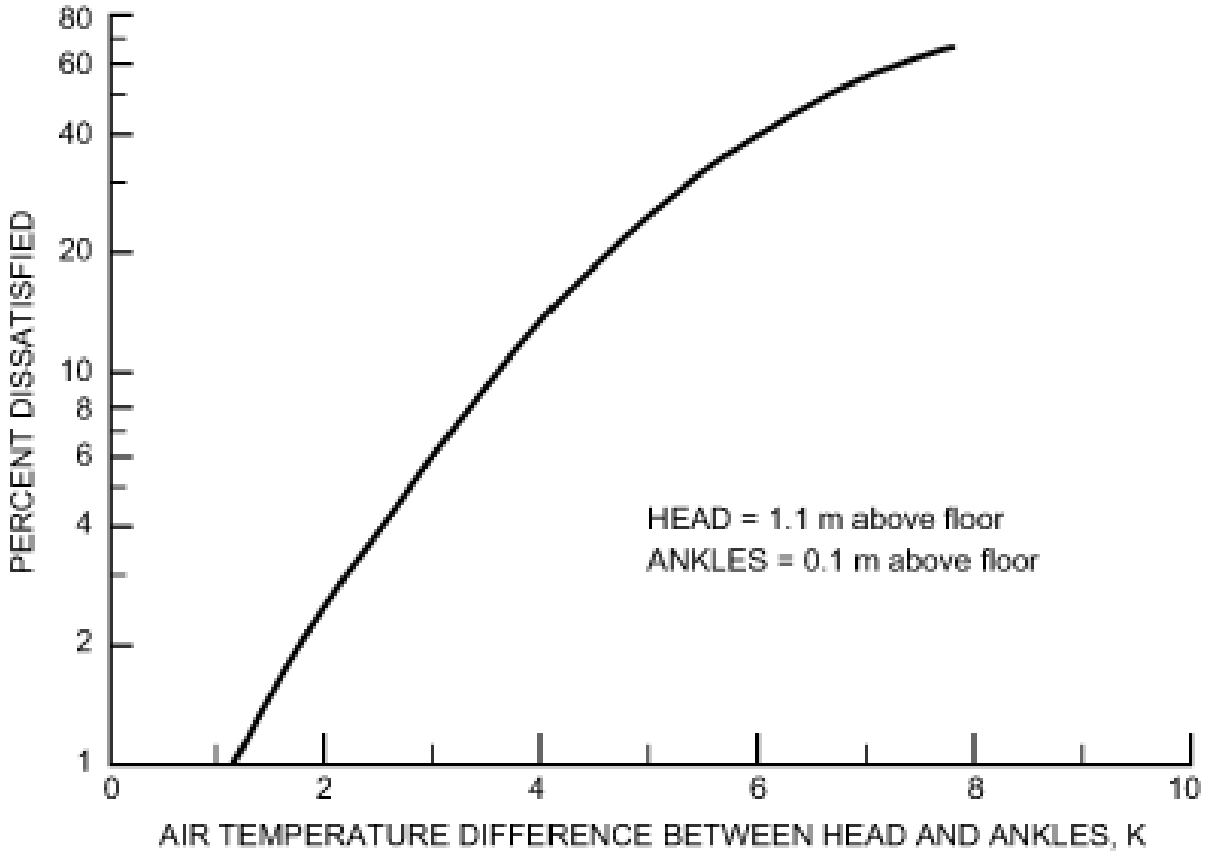




ASHRAE Handbook-Fundamentals

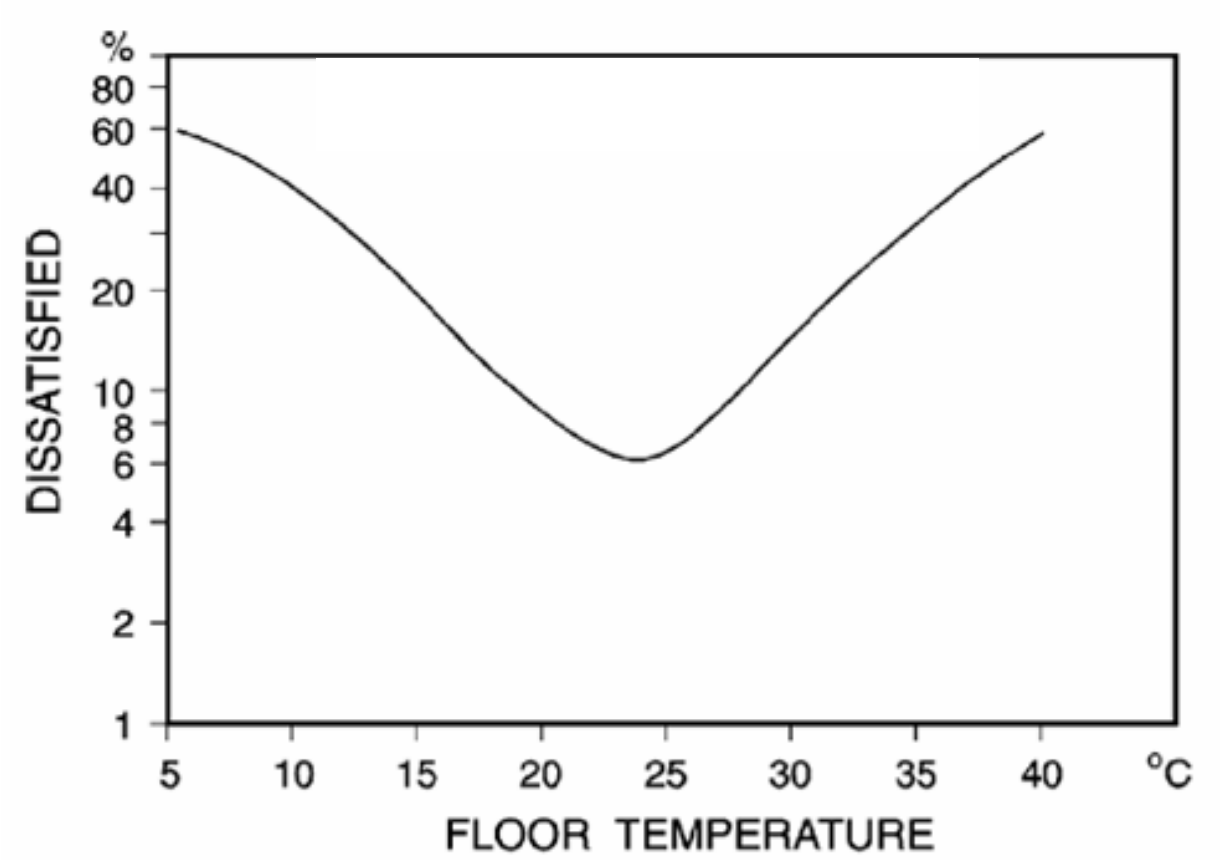
Vertical temperature gradient





ASHRAE Handbook-Fundamentals

Floor temperature

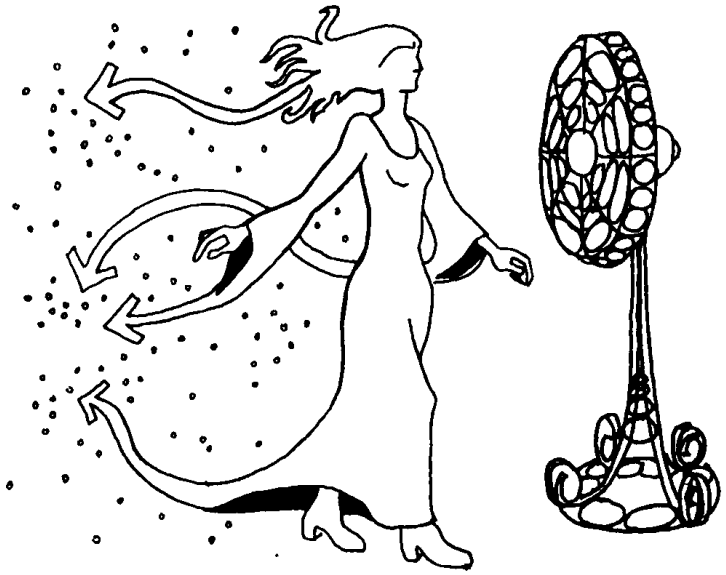


Local thermal discomfort

Air velocity

The speed of air flow should be 0,05-0.25 m / s, a higher speed may cause drafts

$$DR = (34 - t_l) \cdot (v - 0{,}05)^{0{,}62} \cdot (0{,}37 \cdot v \cdot Tu + 3{,}14)$$



The colder the air temperature is the slower air velocity should be

[Source: Ching & Adams (2003) *Guide technique et pratique de la construction,* p. 358]

Thank you the attention!

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