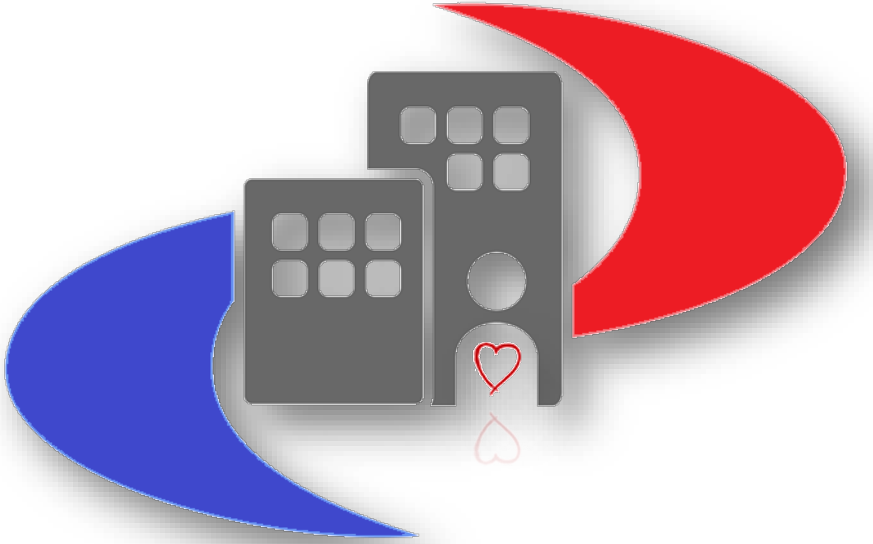
EPFL



CIVIL - 450: THERMODYNAMICS of COMFORT in BUILDINGS

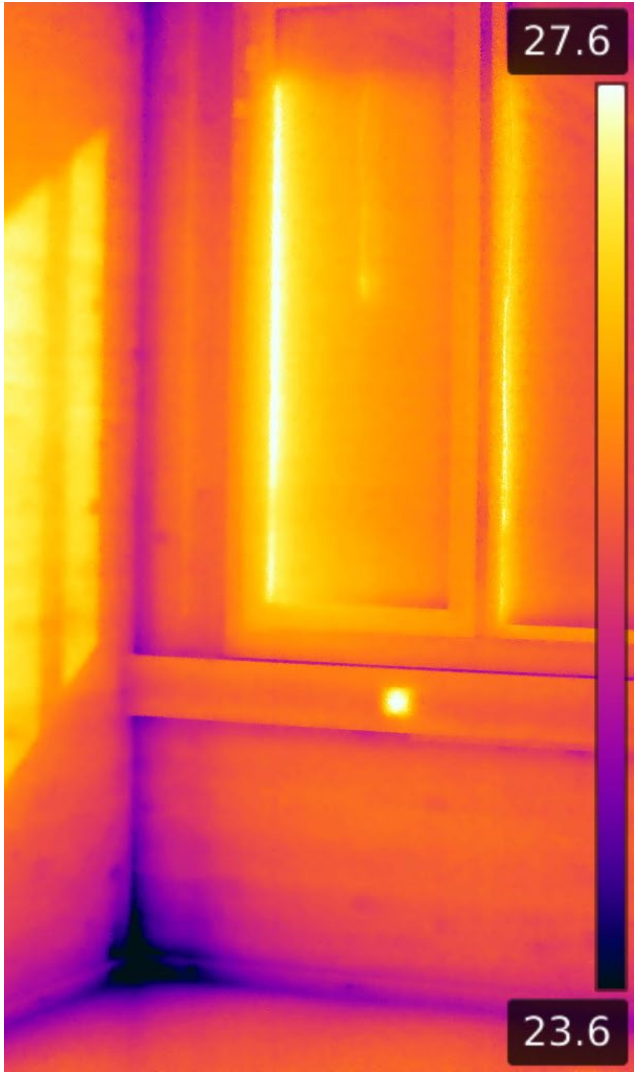
Assist. Professor
Dolaana Khovalyg

Lecture 01:
Course Overview.
Intro to Thermal Comfort and Human Thermoregulation

21 February 2025

EPFL

Assist. Prof. Dolaana Khovalyg



CONTENT:

- Introduction to the course
- Subjective evaluation of the thermal environment
- Intro into human thermoregulation
- Review of comfort requirements
- Class activity

Course Instructor

From Femmes de Science Project:
https://portraits-professeures-epfl.ch/en/portraits/

❑ **Dolaana KHOVALYG, Assist. Professor**
dolaana.khovalyg@epfl.ch

- Head of **the Laboratory of Integrated Comfort Engineering (ICE)**
- **Research focus**: energy efficient buildings, building physics, personalized comfort systems, thermal conditioning of people, well-being and comfort of building occupants
- **Teaching activities**: CIVIL-309 "*Urban Thermodynamics*", ENG-445 "*Energy and Comfort in Buildings*", CIVIL-450 "*Thermodynamics of Comfort in Buildings*"

Advancing human comfort studies, the design and control of occupant-centered thermal systems

Integrated Comfort Engineering Laboratory

More details on the ICE activities online: https://www.epfl.ch/labs/ice/

Thermodynamics of Buildings

Assist. Prof. Dolaana Khovalyg

Buildings are Exhibition Halls filled with Wonders of Thermodynamics:

- Around and across the building envelope
- In ventilation and heat recovery ventilation
- In space heating/cooling (supply and generation)
- In hot water production and delivery
- Around on-site electricity generation systems
- Around the human body…..everywhere around!

Fluids:

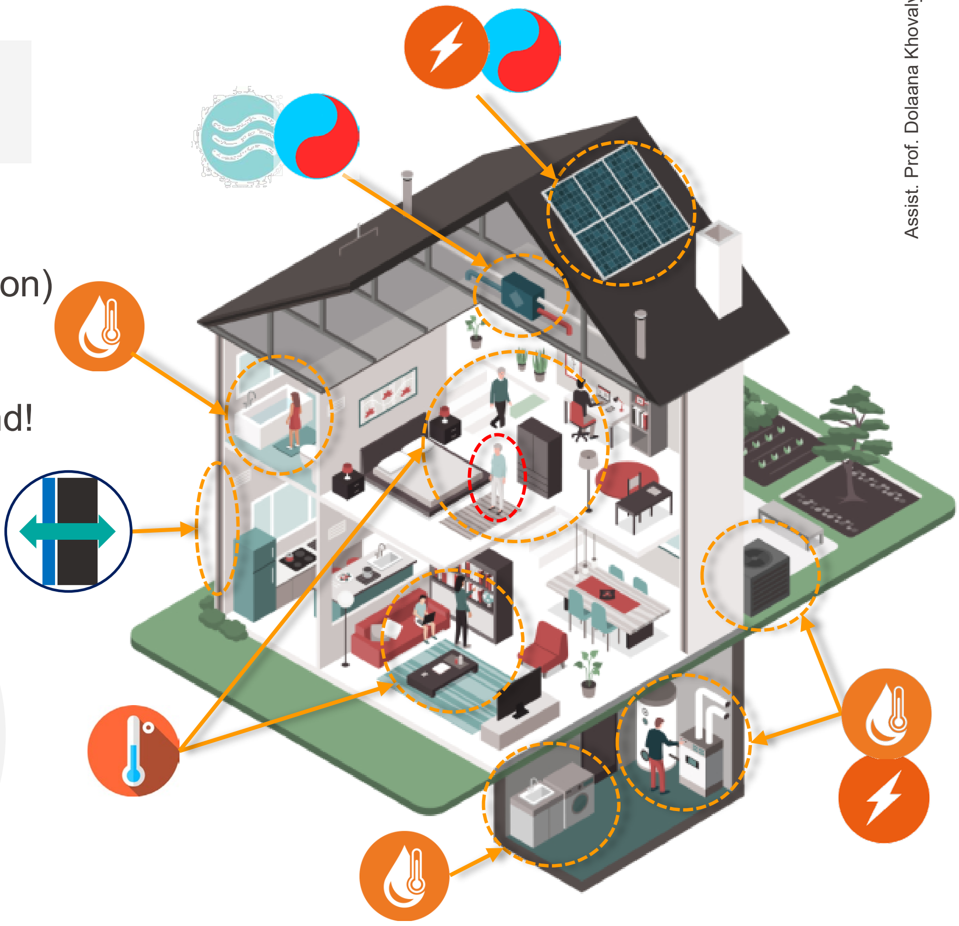
- Air
- Water
- Refrigerants
- Glycol
- Blood

States:

- Single-phase
- Two-phase

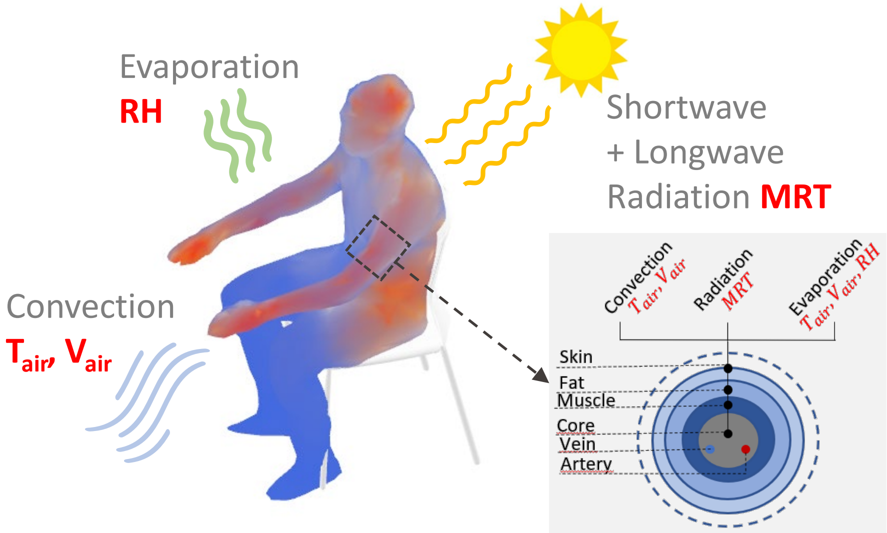
Processes:

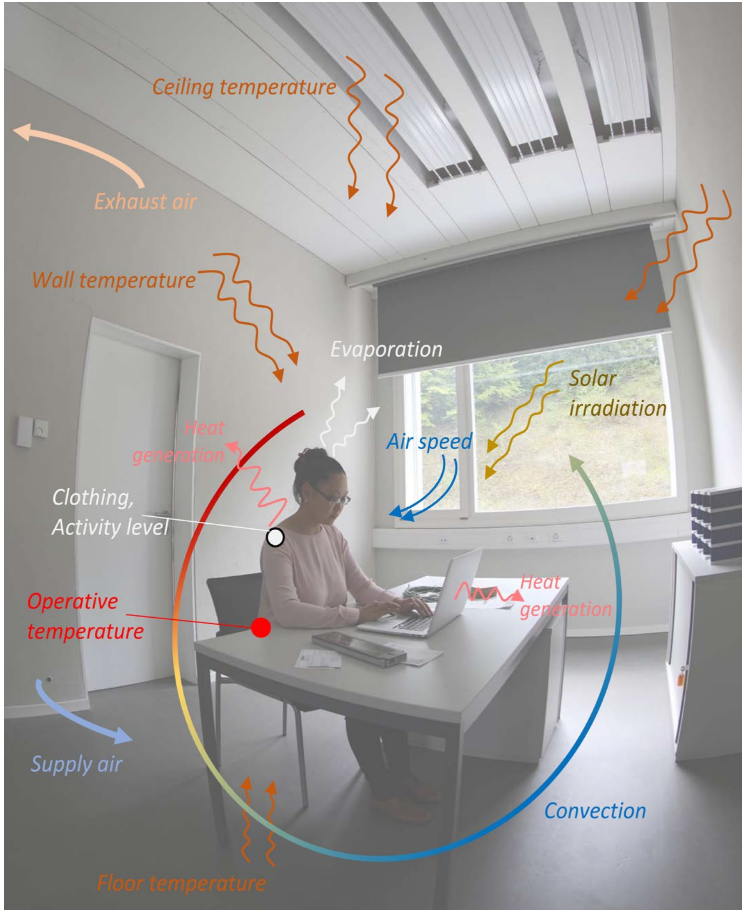
- Evaporation
- Condensation



What is CIVIL-450 about?

- Analysis of **thermal energy transfer** within **the built environment**
- **Levels**: human level, room level, building level
- Detailed characterization of **driving mechanisms** for **heat exchange** between **the human body** and **the surrounding environment** and **their connection with subjective perception** of **comfort**





What is "COMFORT"?

*"A condition that allows a person **to operate optimally**"*

*"**Absence of discomfort** due to environmental conditions, feeling of well-being"*

*"Comfort is the absence of **discomfort**. It is when a person is in **a sense of well-being**"*

- **COMFORT** – a state of ***physical ease*** and ***freedom*** from **pain** or **constraint** (Dictionary)
- **THERMAL COMFORT** "…***the condition of mind*** *that* ***expresses satisfaction*** *with the* ***thermal environment*** *and is assessed* *by* ***subjective evaluation***" (ASHRAE 55, ISO 7730)

Assist. Prof. Dolaana Khovalyg

Course Information - Overview

TEACHING METHODS:

- **5 lectures** on **theoretical background** regarding the human energy balance, thermal comfort, exergy and energy analysis in the built environment
- **2 laboratory activities** at the ***EPFL-Fribourg campus*** at the facilities of *the Laboratory of Integrated Comfort Engineering* and *Smart Living Lab*

STUDENT ACTIVITIES:

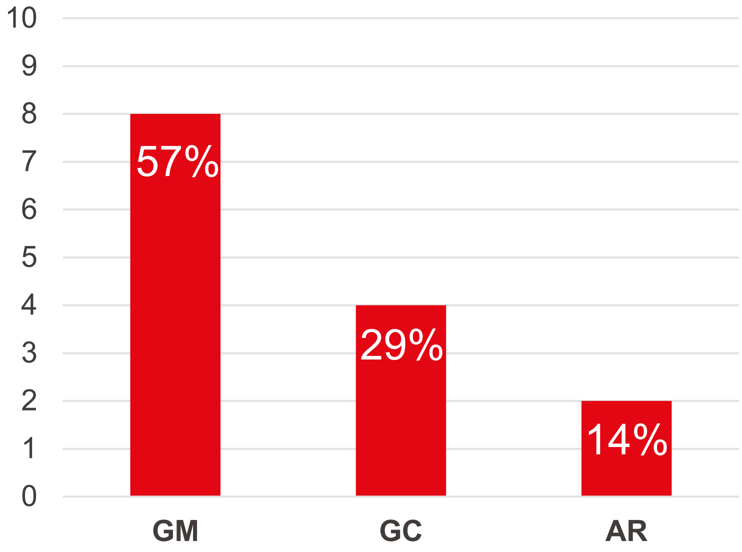
- Attend lectures and laboratory activities
- Work in groups, data analysis and interpretation, reporting, and presentation
- **Groups** of **3-4 students** (at least **1 female** per group) should be formed **by Week 3**

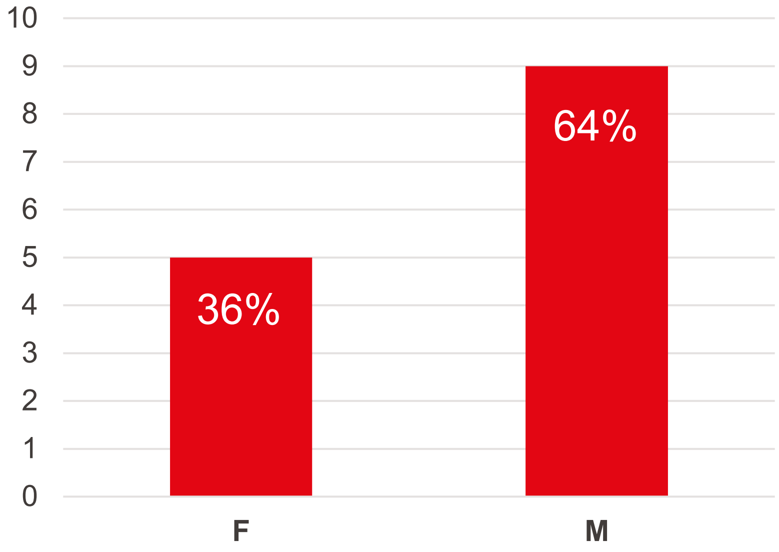
ASSESSMENT METHOD:

The grading is based on the following activities:

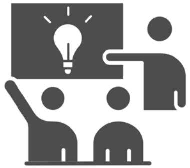
- **Presentation** and **report** on the **lab work #1**: **50% (15+35)**
- **Presentation** and **report** on the **lab work #2**: **50% (15+35)**

Course Information - Class Population





Course Information - Schedule



Classroom GC D0 386 is on the Lausanne campus

WEEK	Date	Content	Location
1	21.02.2025	Intro to thermal comfort and human thermoregulation	GC D0 386
2	28.02.2025	Human body energy balance	GC D0 386
3	07.03.2025	Exergy analysis in the built environment (*guest lecture*)	GC D0 386
4	14.03.2025	Lab #1 in Fribourg (climatic chamber). Measurements and instrumentation.	EPFL-Fribourg
5	21.03.2025	Group work on Lab #1	GC D0 386
6	28.03.2025	Group work on Lab #1	GC D0 386
7	04.04.2025	Invisible radiant heat: transparent & translucent building elements and their effect on comfort (*guest lecture*)	GC D0 386
8	11.04.2025	Lab #1 presentations, reports submission	GC D0 386
9	18.04.2025	Good Friday (holiday)	No class
10	25.04.2025	Easter break	No class
11	02.05.2025	Lab #2 in Fribourg (building prototype)	EPFL-Fribourg
12	09.05.2025	Building-environment interaction and energy balance	GC D0 386
		Group work on Lab #2	
13	16.05.2025	Group work on Lab #2	GC D0 386
14	23.05.2025	Group work on Lab #2	GC D0 386
15	30.05.2025	Lab #2 presentations, reports submission. Course summary and course evaluation.	GC D0 386

Course Information – Guest Lecturer

Forrest MEGGERS, Associate Professor

- Director of the **C.H.A.O.S. lab** - *Cooling and Heating for Architecturally Optimized Systems*
- Andlinger Center for Energy and the Environment, **Princeton University** (USA)
- Founder of **CHAOSense** https://www.chaosense.com/ and **ClearlyCool** https://www.clearly-cool.com/
- More details: https://soa.princeton.edu/content/forrest-meggers

Make sure to attend his exciting lectures on March 7 and April 4!

Lab #1 facility – Climatic Chamber ICE (Fribourg)

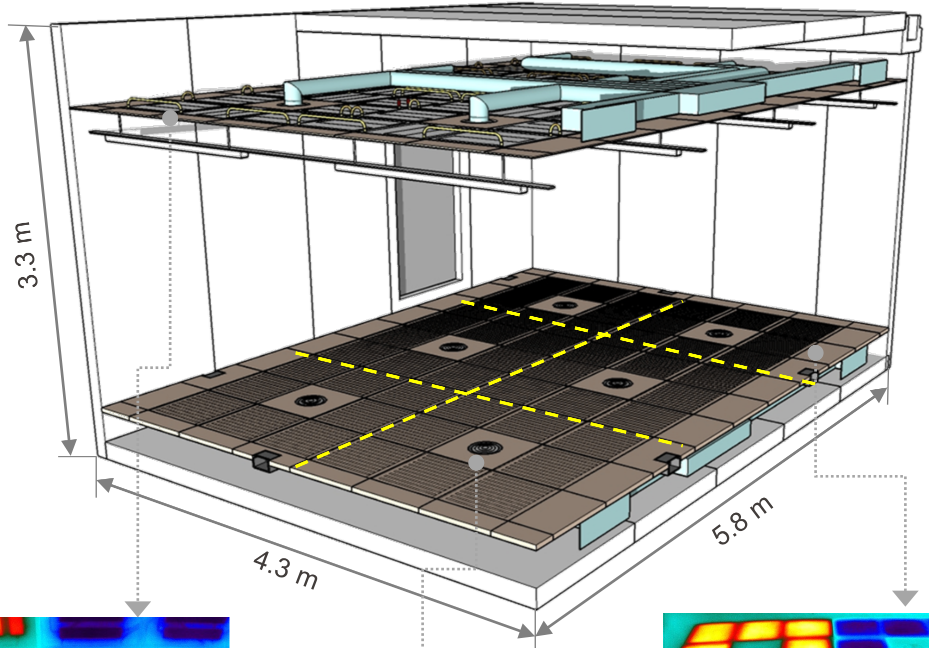
More info online: https://www.epfl.ch/labs/ice/research-facilities/

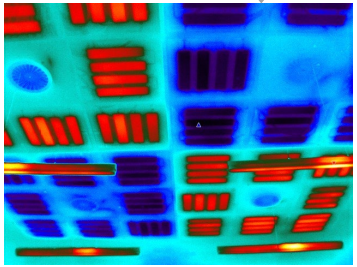
Lab #1 facility – Climatic Chamber ICE (Fribourg)

- An **air-tight** enclosure
- Size (useful volume):
  5.8 x 4.3 x 2.5(h) m³

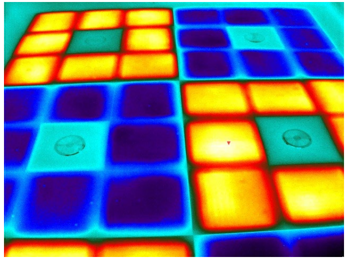
Operational range of parameters:
- Temperature range: **+15…+35°C**
- Relative humidity: **20..80%**
- Lighting intensity: **100-700 lux**
- Ventilation rate:
  0.5 - 10 ACH (30-600 m³/h)

Specific characteristics:
- Air supply: **ceiling/floor** (1-6 combination of diffusers)
- Radiant heating/cooling: **ceiling/floor** independent loops on the floor/celling)
- **Ultra** supply filtration
- SIEMENS controls, **BACnet** protocol



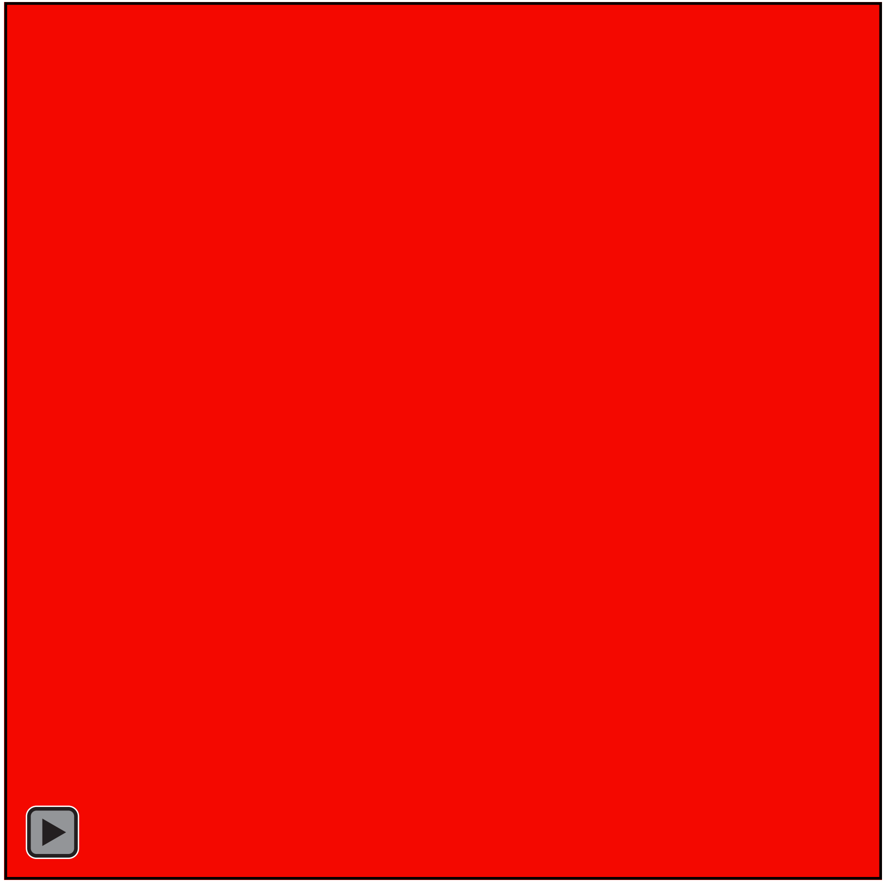

Radiant ceiling


Air diffuser


Radiant Floor

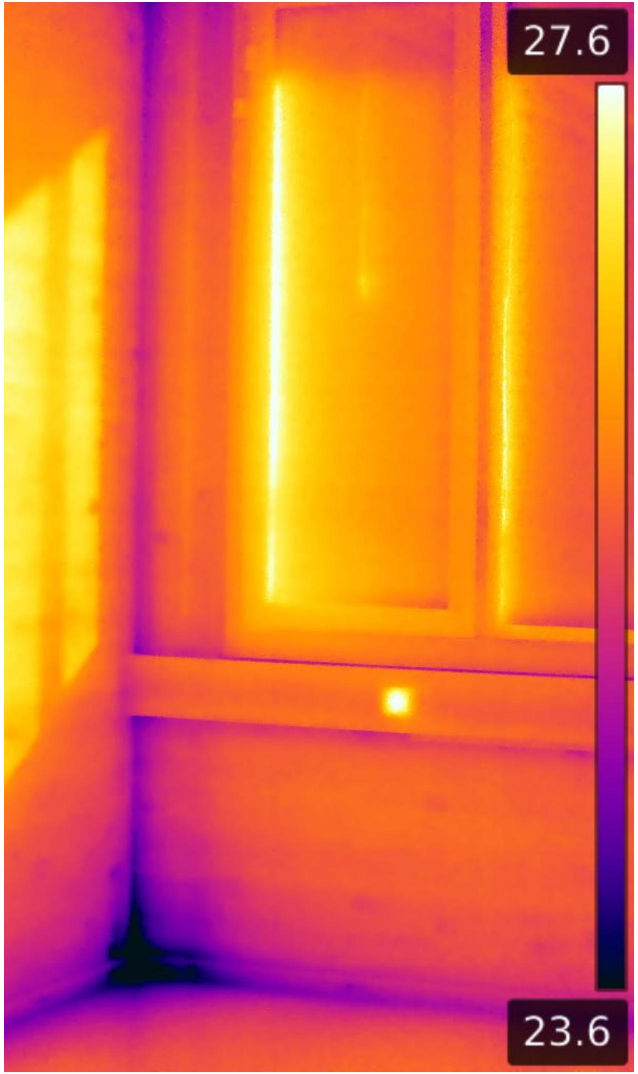
Assist. Prof. Dolaana Khovalyg

Lab #2 facility – Building Prototype CELLS (Fribourg)



Virtual Tour: https://building2050-rdi.epfl.ch/virtualtour/slldemo/

Assist. Prof. Dolaana Khovalyg



CONTENT:

- Introduction to the course
- **Subjective evaluation of the thermal environment**
- Intro into human thermoregulation
- Review of comfort requirements
- Class activity

Subjective Indoor Environment Evaluation

- **Indoor environment in a building may be classified (per EN 15251) by:**

  - Criteria used for **energy calculations** (*new* buildings)
  - **Whole year computer simulations** of the **indoor environment** and **energy performance** (*new* and *existing* buildings)
  - **Long term measurement** of **selected parameters** for **the indoor environment**
  - **SUBJECTIVE RESPONSES FROM OCCUPANTS** (*existing* buildings)

Standard ISO 10551:2001
"Assessment of the influence of the thermal environment using subjective judgement scales":

The following introductory questions shall be posed:

— before applying the perceptual scale: "How are you feeling (at this precise moment)?" (followed by the replies from the scale);

— after the response given on the perceptual scale, and immediately before applying the evaluative scale: "Do you find this...?" (followed by the replies from the scale);

— after the response given on the evaluative scale, and immediately before the application of the preference scale: "Please state how you would prefer to be now" (followed by the replies from the scale).

Subjective Indoor Environment Evaluation

Comfort Evaluation Approaches for Various Applications

Measurement Method		Nature of Application: Short-Term	Nature of Application: Long-Term
	Occupant Surveys	**Right-Now/Point-in-Time Survey (must survey relevant times and population):** • Binning (TSENS scores) leads to % comfort exceedance during period of survey. • Needs coincident temperature to extrapolate to full range of conditions. *(Used for research, problem diagnostics)*	**Occupant Satisfaction Survey:** • Survey scores give % dissatisfied directly. ("dissatisfaction" may be interpreted to start either below –1, or below 0). • Time period of interest can be specified to survey takers. *(Used for building management, commissioning, rating operators and real estate value, compliance with green building rating systems).*
	Environmental Measurements	**Spot Measurements, Temporary (Mobile) Sensors (must select a relevant time to measure):** • Use measurements to determine PMV (Sections 5.3.1, 5.3.3). • Use measurements to determine compliance with adaptive model (Section 5.4). *(Used for real-time operation, testing and validating system performance).*	**Logging Sensors over Period of Interest, or Trend Data from Permanently Installed (BAS) Sensors:** • Exceedance hours: sum of hours over PMV or Adaptive Model limits. • Binned exceedances may be weighted by their severity. • Instances of excessive rate-of-temperature change or of local thermal discomfort can be counted. *(Used for evaluating system and operator performance over time).*

Source: Standard ASHRAE 55-2017

Subjective Indoor Environment Evaluation

	1	2	3	4	5
Type of judgement	**Perceptual**	**Affective evaluation**	**Thermal preference**	**Personal acceptability**	**Personal tolerance**
Subject under judgement	**Personal thermal state**			**Thermal ambience**	
Wording	"How do you feel (at this precise moment)?" 7 or 9 degrees, from very (or extremely) COLD to very (or extremely) HOT	"Do you find it.......?" 4 or 5 degrees, from COMFORTABLE to very (or extremely), UNCOMFORTABLE	"Please state how you would prefer to be now" 7 (or 3) degrees, from (much) COLDER to (much) WARMER	"How do you judge this environment (local climate) on a personal level?" 2 degrees, GENERALLY ACCEPTABLE, GENERALLY UNACCEPTABLE	"Is it .....? 5 degrees, from perfectly TOLERABLE to INTOLERABLE

Source: Standard ISO 10551

How do you feel the temperature at this moment?

A. Hot

B. Warm

C. Slightly warm

D. Neutral

E. Slightly cool

F. Cool

G. Cold

Please login:

responseware.eu

Session ID: **civil450**

Do you perceive temperature at this moment?

Assist. Prof. Dolaana Khovalyg

A. Very comfortable

B. Comfortable

C. Slightly comfortable

D. Neutral

E. Slightly uncomfortable

F. Uncomfortable

G. Very uncomfortable

Please login:

responseware.eu

Session ID: **civil450**

Is the temperature acceptable for you at this moment?

A. Acceptable

B. Unaceptable

Please login:

responseware.eu

Session ID: **civil450**

Would you like to be...?

A. Colder

B. No change

C. Warmer

Please login:

responseware.eu

Session ID: **civil450**

EPFL

Are you experiencing the following sources of thermal discomfort?

A. Hot surfaces
B. Cold surfaces
C. Hot body parts
D. Cold body parts
E. Drafts

Please login:

responseware.eu

Session ID: **civil450**

Assist. Prof. Dolaana Khovalyg

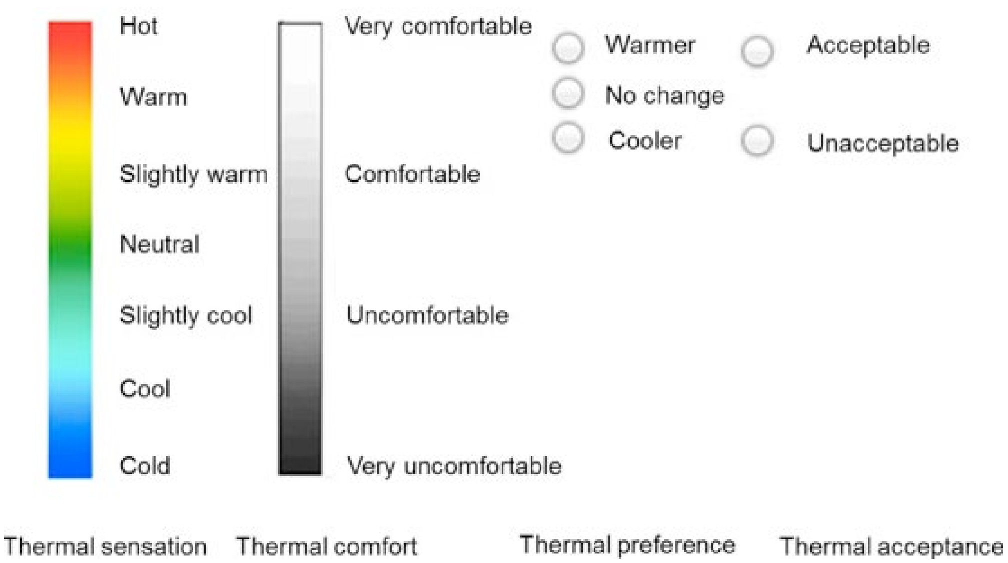
Subjective Indoor Environment Evaluation

A 7-degree scale shall be applied in the case of environments judged to be temperate (close to thermal neutrality or slightly hot or cold); a 9-degree scale shall be applied in the case of environments judged to be more intensely hot or cold. A practical limit between the two categories of environment is suggested at PMV = ± 2.

A symmetrical 7-degree two-pole scale, which can be extended to 9 degrees, comprising a central indifference point and two times 3 (or 4) degrees of increasing intensity.

Pole A	Degrees (− 4) − 3 − 2 − 1 of intensity	Point 0 of indifference	Degrees + 1 + 2 + 3 (+ 4) of intensity	Pole B

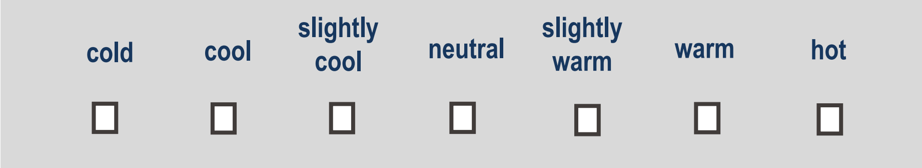
Scale	Thermal Sensation
+3	Hot
+2	Warm
+1	Slightly Warm
0	Neutral
-1	Slightly Cool
-2	Cool
-3	Cold



Source: ISO 10551

Subjective Indoor Environment Evaluation: Scales

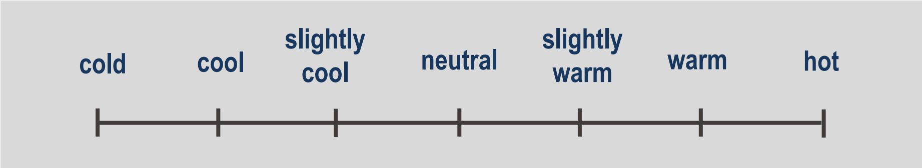
- **Categorical output**



PROS:
- Easy to compare to other studies, mostly used
- Easy to implement in survey tools

CONS:
- Not optimal for some statistical correlation analysis
- Loss of data when categorizing

- **Continuous output**

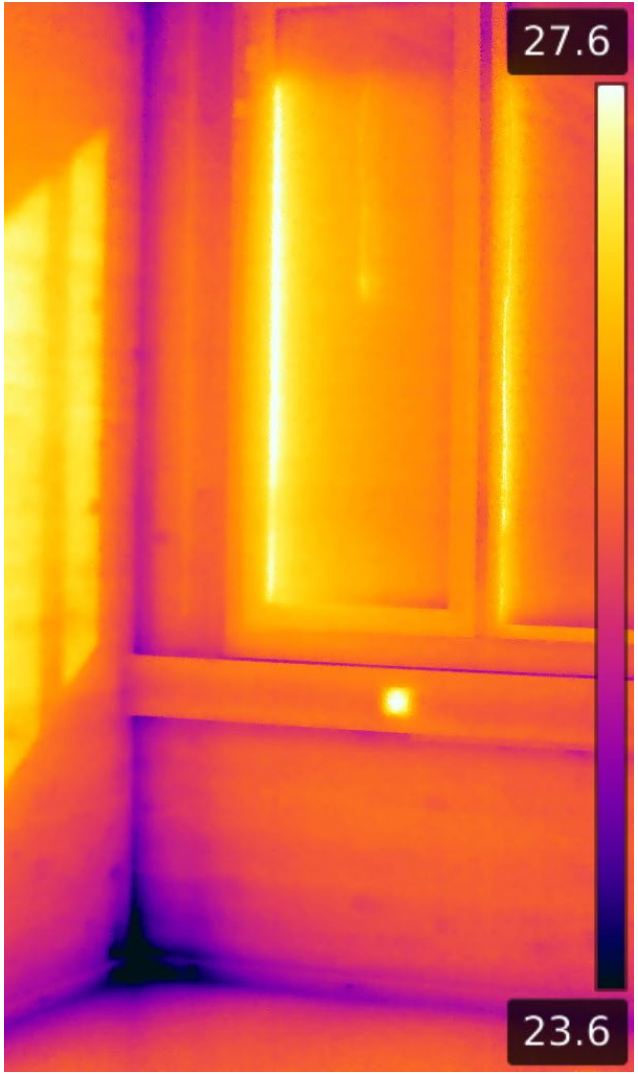


PROS:
- More detailed and useful for statistical analysis that require continuous data input

CONS:
- Longer post processing of data
- The distances between the nodes might not be representative and all equal (issue of «equidistance»)

- **Numerical output**

Assist. Prof. Dolaana Khovalyg



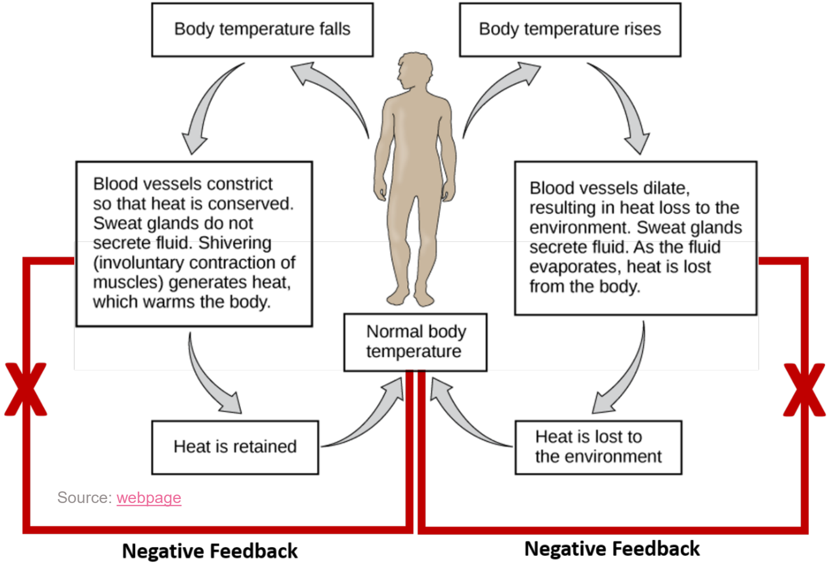
CONTENT:

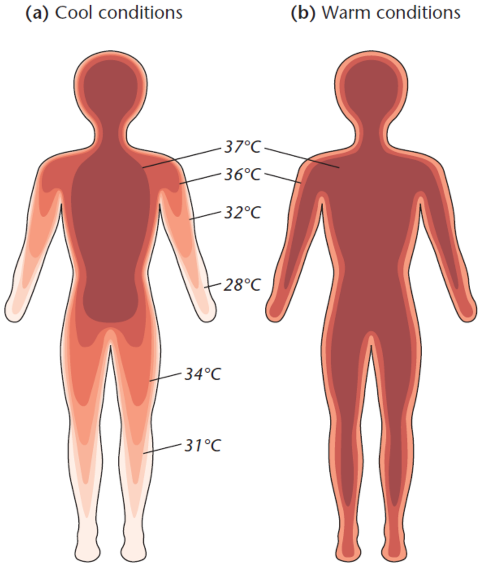
- Introduction to the course
- Subjective evaluation of the thermal environment
- **Intro into human thermoregulation**
- Review of comfort requirements
- Class activity

Assist. Prof. Dolaana Khovalyg

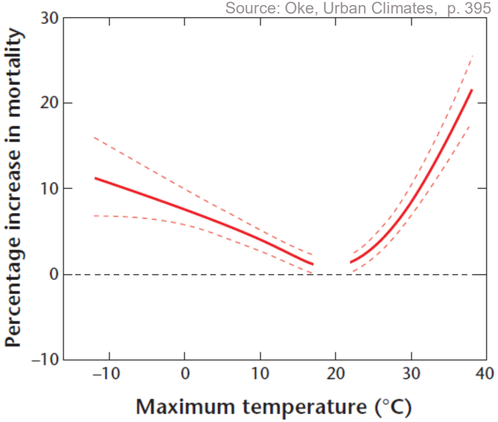
Human Thermoregulation

- The human beings are homeotherms therefore the body tries to maintain an internal temperature **~ 37°C**
- The mechanism of heat balance and temperature control is regulated by the **hypothalamus**
- The human body temperature can be used as *an indicator* of its thermal condition



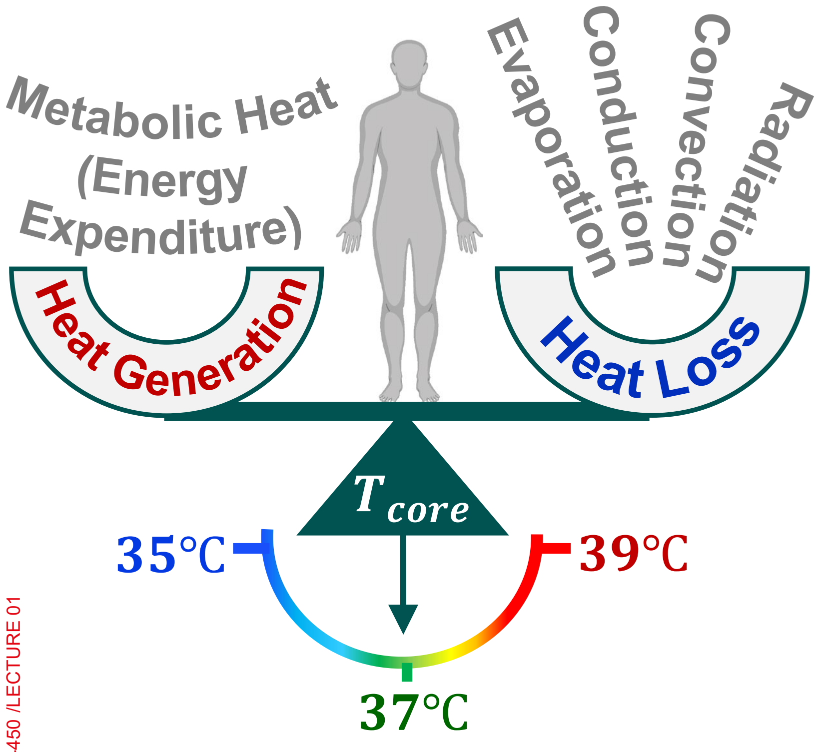


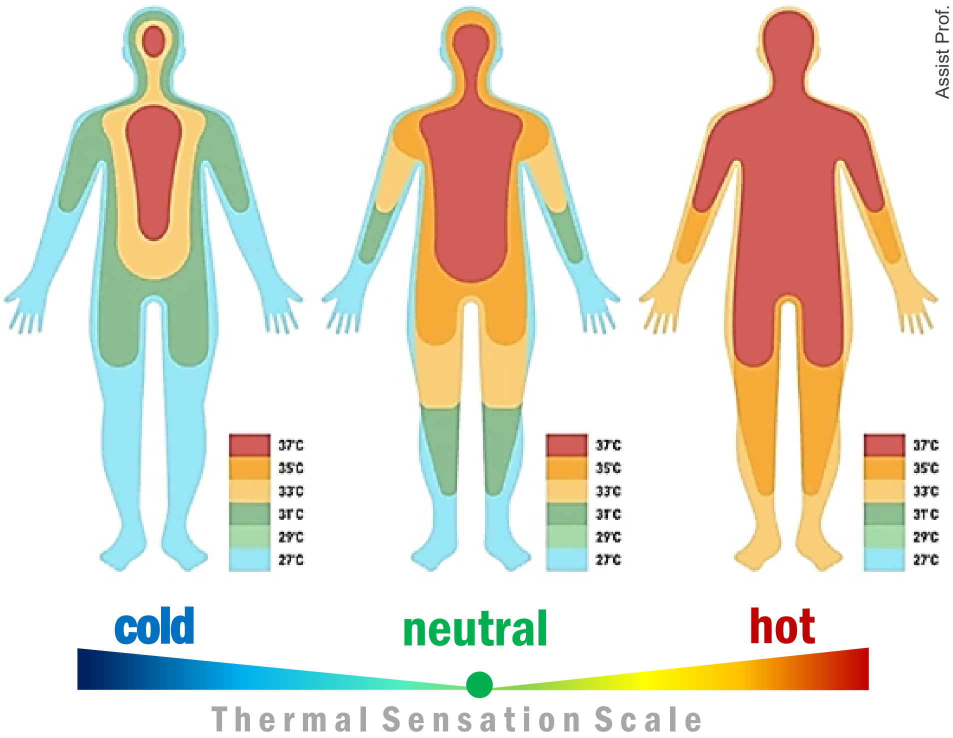
Source: Oke, Urban Climates, p. 395



Assist. Prof. Dolaana Khovalyg

Human Thermoregulation





Assist Prof. Dolaana Khovalyg

Human Metabolic Heat Generation

Assist Prof. Dolaana Khovalyg

$$\text{Food} + O_2 \rightarrow CO_2 + H_2O + \text{ATP} + \text{Heat}$$

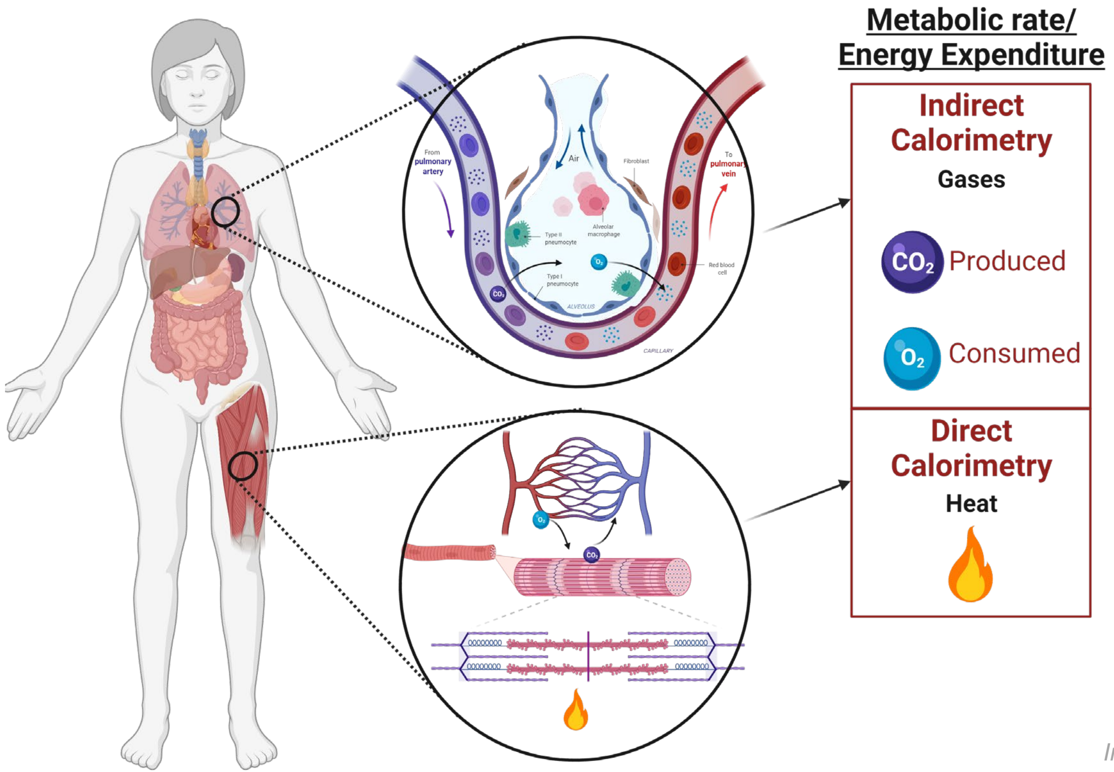


Image adopted from Y. Ravussin

Human Metabolic Rate

- **The rate** of **transformation** of **chemical energy** into ***heat*** and ***mechanical work*** by **metabolic activities of an individual**, per **unit** of **skin surface area**

Expressed in units of ***Met***, **1 *Met* = 58.2 W/m²** (*the energy produced per unit skin surface area of an average person seated at rest*)

$$Met = \frac{EE}{BSA} \cdot \frac{1}{58.2}$$

Activity type	*Met*	W/m²
Reclining	0.8	45
Seated, relaxed	1.0	58
Sedentary activity (office, dwelling, school, laboratory)	1.2	70
Standing, light activity (shopping, laboratory, light industry)	1.6	93
Standing, medium activity (domestic work, machine work)	2.0	116
Walking on level ground:		
2 km/h	1.9	110
4 km/h	2.8	165
5 km/h	3.4	200

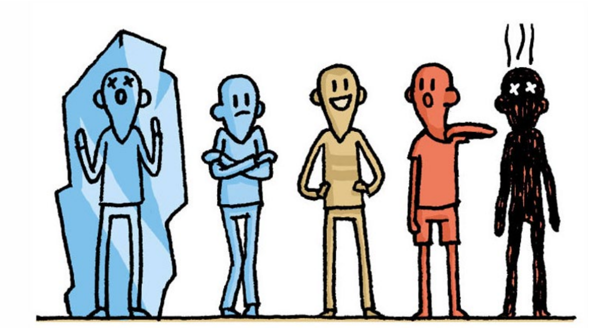
Source: Standard ASHRAE 55-2017

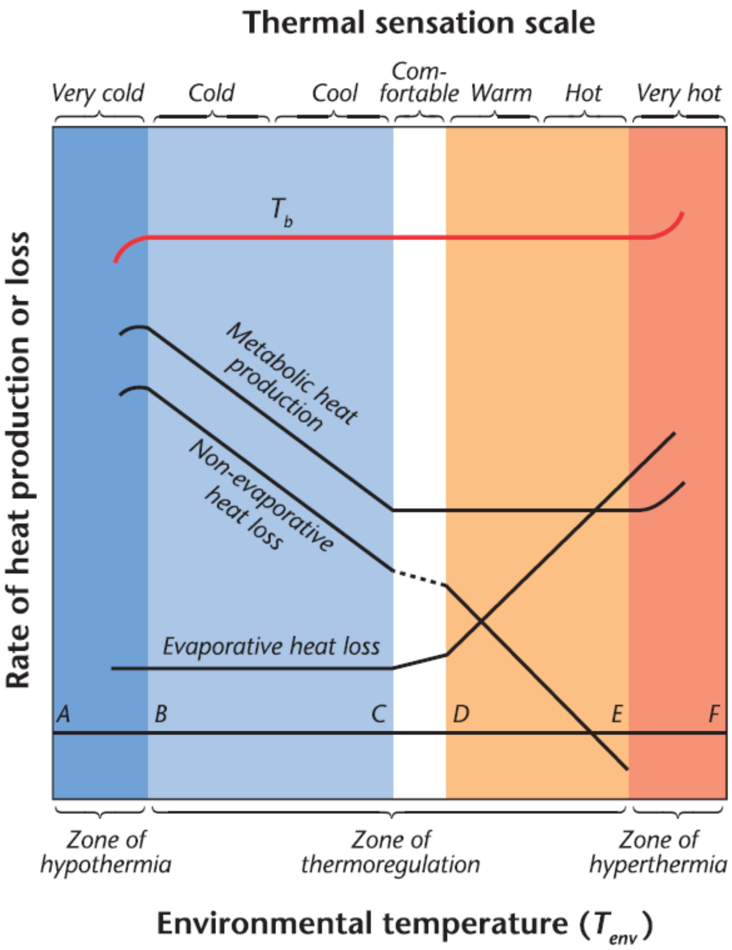
1 Met = **58.2** W/m²
Average BSA = **1.7** m²
Average BSA (males) = **1.9** m²

Human Thermal Comfort

- **THERMAL COMFORT** "…***the condition of mind*** *that* ***expresses satisfaction*** *with* ***the thermal environment*** *and is assessed* ***by subjective evaluation***" (ISO 7730, ASHRAE 55).

- **Thermal comfort** is achieved when **there is a balance** between **the generation of metabolic heat within the body** and **the loss of heat from the body** (via the mechanisms of *conduction*, *convection*, *radiation* and *evaporation)*.

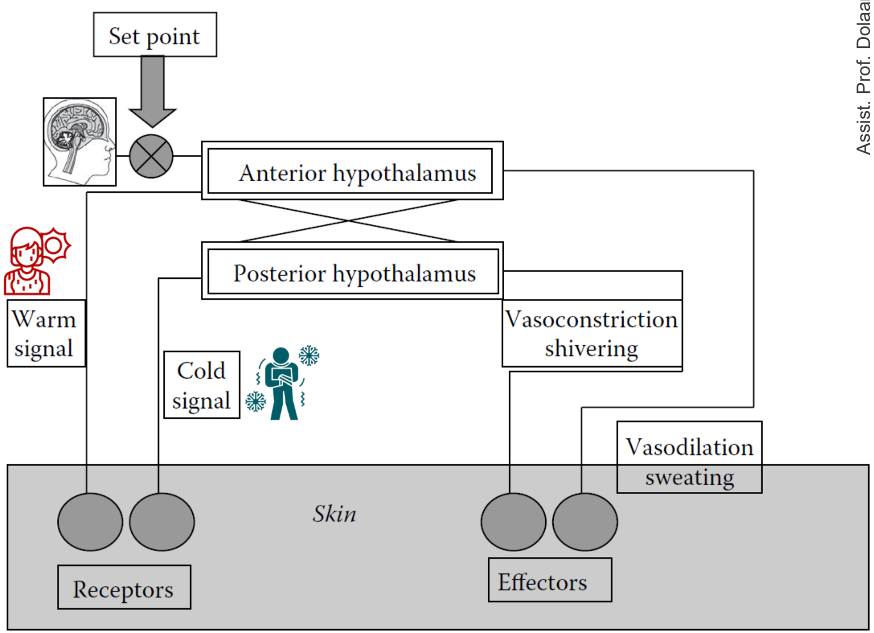




Source: Oke, Urban Climates, p. 394

Human Thermoregulation: Modeling Overview

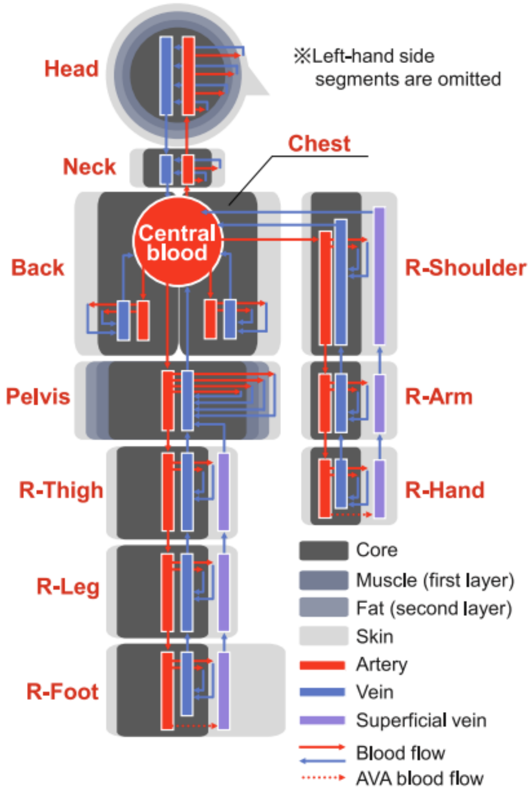
- **When human thermoregulation is modeled, it can be divided into 2 parts:**
  - **Passive system** simulates *physical human body* and *models heat transfer* within *the human body*, and *between the human body* and its *environment*. The passive system is *controlled* by the human body's active system.
  - **Active system** simulates the human body's *regulatory responses* of vasoconstriction, vasodilation, shivering and sweating.

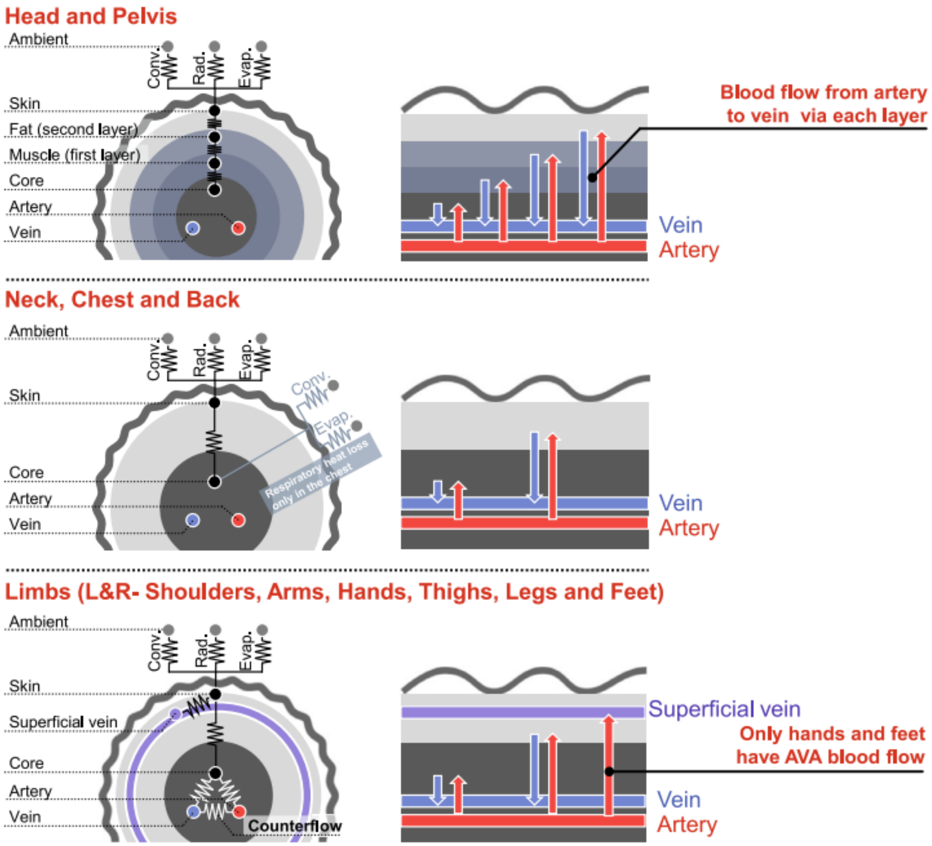


Parsons, K. (2014). *Human thermal environments: the effects of hot, moderate, and cold environments on human health, comfort, and performance*. CRC press.

Human Thermoregulation: Passive System Modeling

Assist. Prof. Dolaana Khovalyg

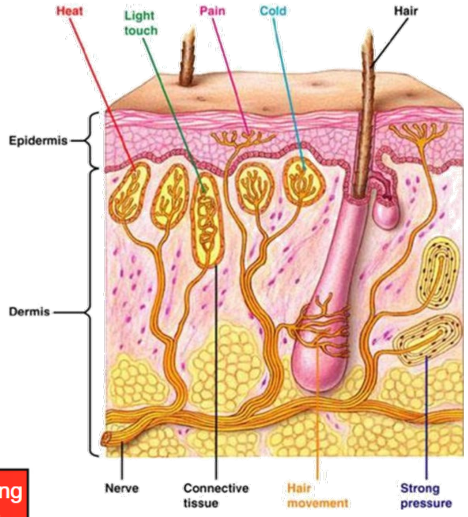


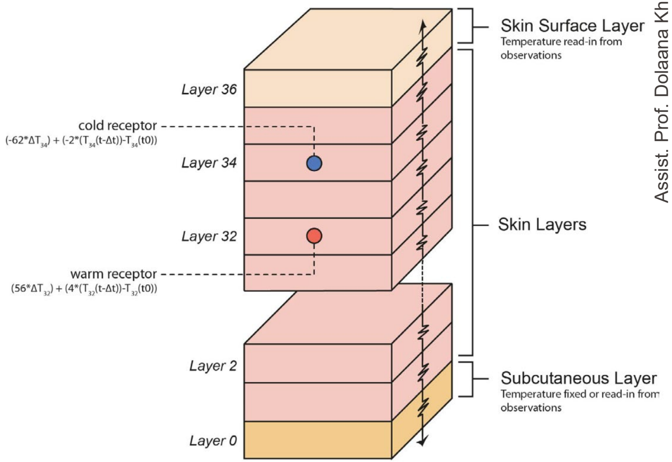


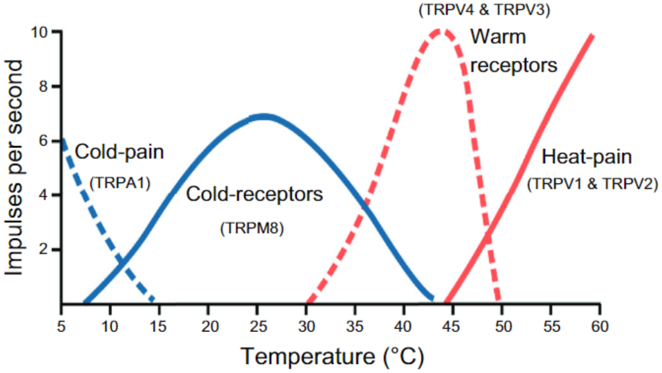
Takahashi et al. (2015) *Thermoregulation model JOS-3 with new open source code*, DOI: 10.1016/j.enbuild.2020.110575

Human Thermoreceptors

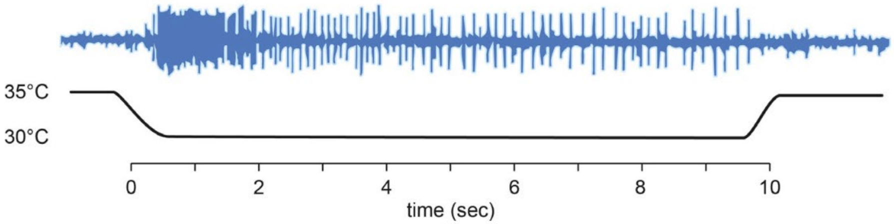
- **Thermoreceptors** can be separated into receptors for **warmth** and **cold** detection
- **Cold receptors** located **closer to the skin surface** than **warm receptors**
- Warm receptors will turn up their signal rate when they feel warmth







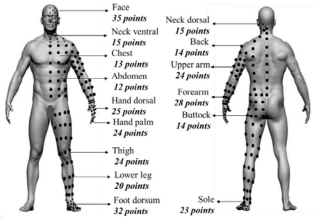
The dynamic and static response profile of a cold thermoreceptor recorded in a human subject during sudden cooling:

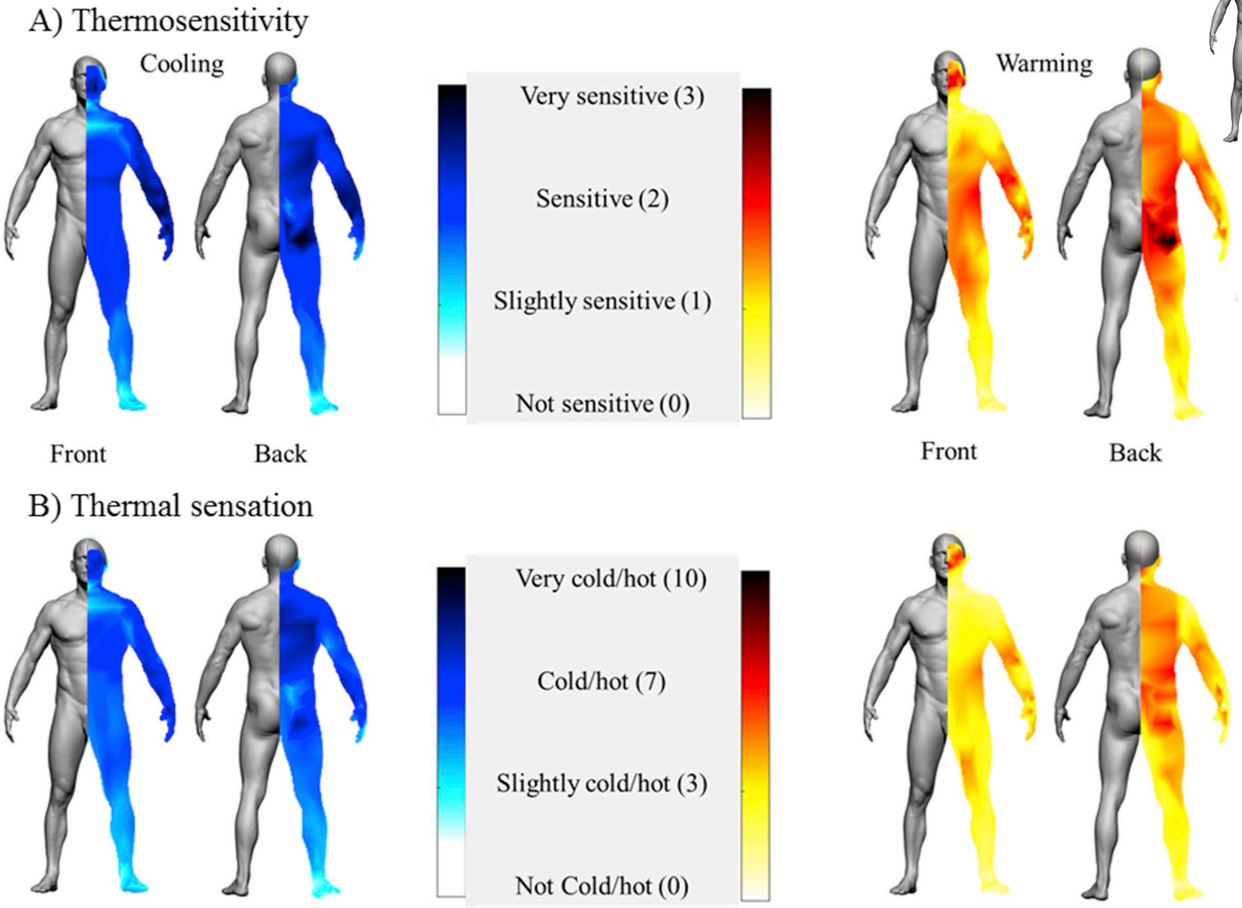


Parkinson et al. (2021), DOI: 10.1111/ina.12859

Assist. Prof. Dolaana Khovalyg

Human Thermal Sensitivity





Luo et al. (2020), High-density thermal sensitivity maps of the human body. DOI: https://doi.org/10.1016/j.buildenv.2019.106435

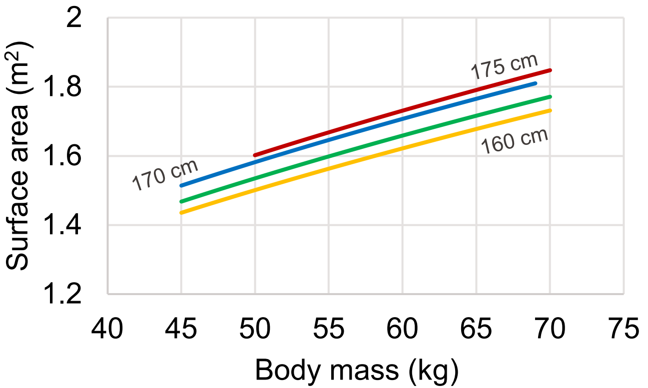
Assist. Prof. Dolaana Khovalyg

Human Skin Properties

- **Surface area of the body A_{body}** in **m²** (DuBois formula):

$$A_{body} = 0.007184 \cdot M^{0.425} \cdot H^{0.725}$$

M (kg) – human body mass, H (cm) – human height

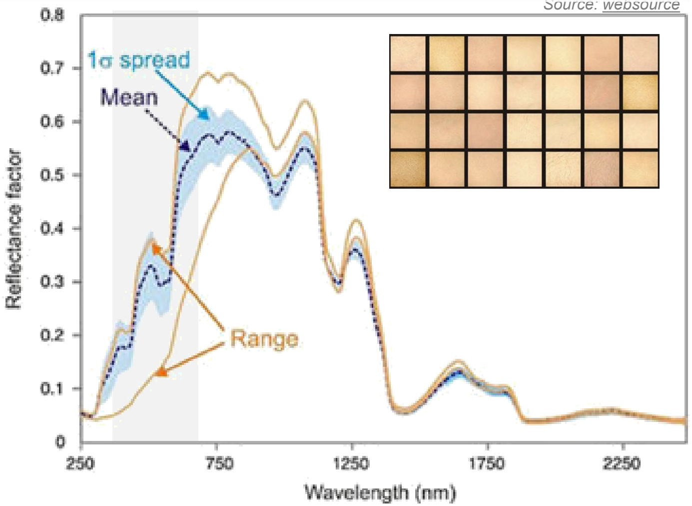


- **"Average" human body parameters:**

  M = 70 kg, H = 165 cm, r_{body}= 0.12 m

- **Reflectivity** of **human skin,** depending on pigmentation (melanin) and skin blood flow (hemoglobin)**, regulates *absorption* of radiation**:
  - Varies from 0.15 (dark) - 0.35 (light) at 0.4-0.7 μm (visible wavelength)
  - Increases sharply to 0.6 between 0.8-1.2 μm
  - Drops at longer wavelengths (> 1.2 μm)

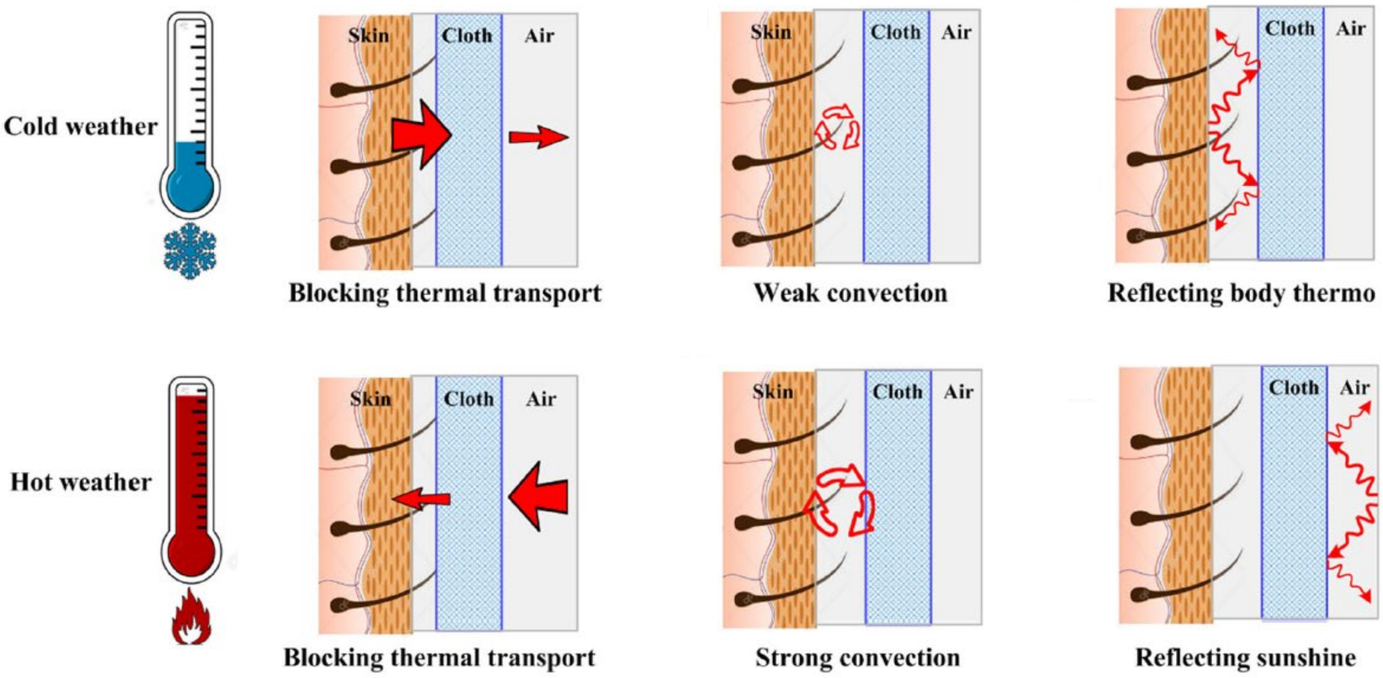
Source: websource



Assist. Prof. Dolaana Khovalyg

Clothing: Effect on Heat Losses from the Body

- **In cold weather**, clothing should *reduce* heat conduction, *minimize* heat convection, and *reflect* the heat radiation back
- **In hot weather**, clothing should *block* the heat conduction from the environment, *enhance* heat convection, and *reflect* heat radiation away from the clothed skin



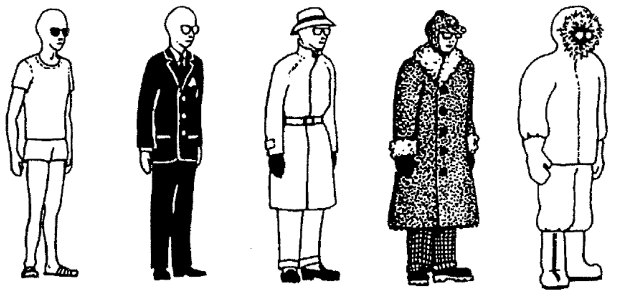
https://doi.org/10.1007/s10570-019-02534-6

Clothing: Thermal Resistance

Assist. Prof. Dolaana Khovalyg

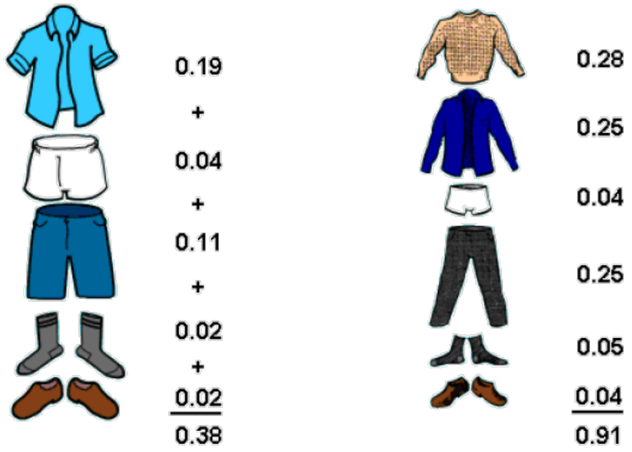
- Clothing creates **thermal resistance** R_{cl} $(\frac{m^2K}{W})$ between *body* and *environment*
- Various types of clothing vary in their **thermal resistance** I_{cl} (*insulative capacity*) measured in "*clo*"

$$R_{cl} = I_{cl} \cdot 0.155 \frac{m^2K}{W}$$



$0.5\ clo$ $1\ clo$ $2\ clo$ $3\ clo$ $6\ clo$

Insulation for the entire clothing: $I_{cl} = \sum I_{clu}$



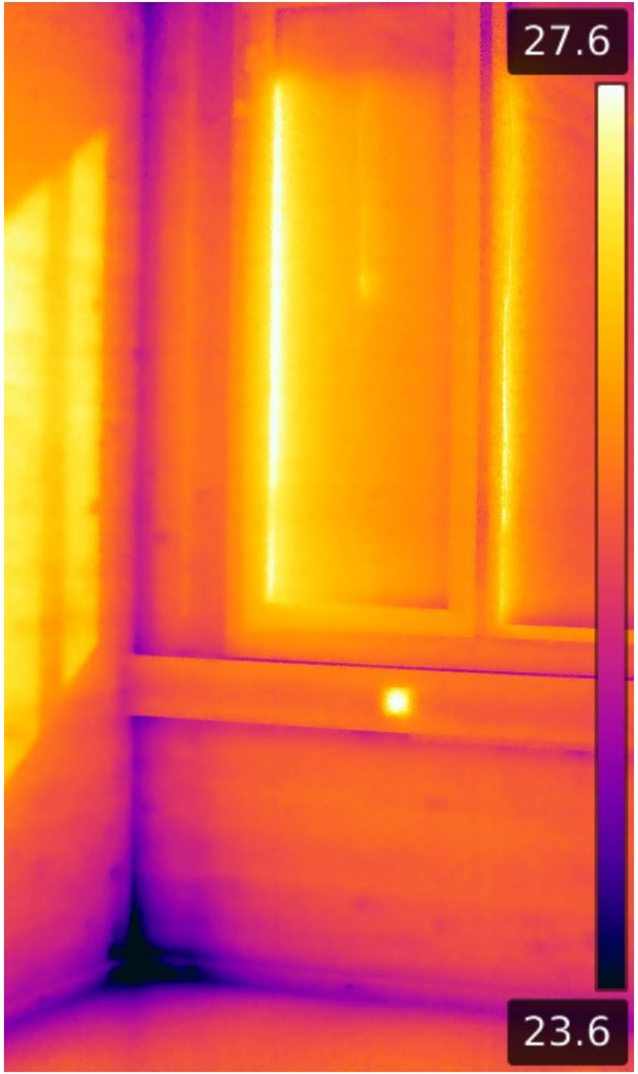
- **Clothing factor** f_{cl} - a ratio of the clothed surface area to that of the nude body

$$f_{cl} = \frac{A_{cl}}{A_{body}}$$

$for\ I_{cl} \leq 0.5$: $f_{cl} = 1 + 0.31 \cdot I_{cl}$

$for\ I_{cl} > 0.5$: $f_{cl} = 1.05 + 0.645 \cdot I_{cl}$

A_{cl} (m^2) – area of the human body covered with clothing



CONTENT:

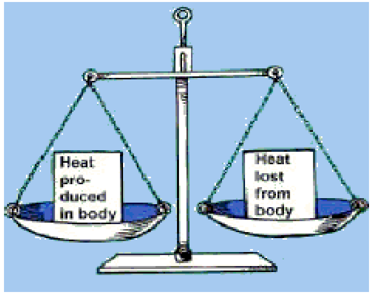
- Introduction to the course
- Subjective evaluation of the thermal environment
- Intro into human thermoregulation
- **Review of comfort requirements**
- Class activity

Criteria for Thermal Comfort

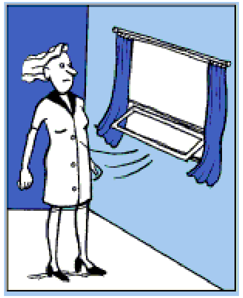
- **Thermal neutrality** for the body as a whole is a necessary, but *not sufficient condition* for thermal comfort.
- **Local thermal discomfort** due to *draught*, vertical *temperature gradient*, *radiant asymmetry*, or *warm* or *cold floors* may cause occupants to find **the thermal conditions unacceptable**.

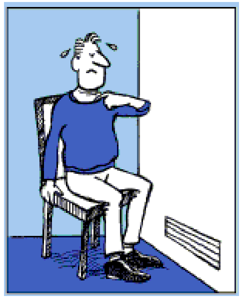
It is essential to evaluate thermal comfort in 2 steps:

1. Evaluate **overall body's thermal comfort**
2. Check that **there is no local discomfort**



+



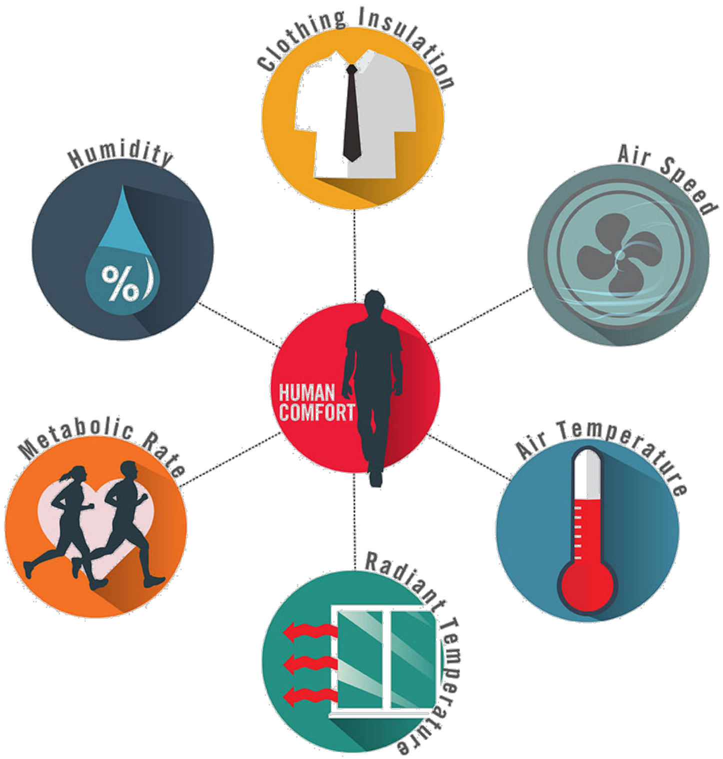


Assist. Prof. Dolaana Khovalyg

Thermal Comfort Models

- **PMV/PPD model:** Focus of Lecture 02
  - Considers **thermal comfort** as **a result** of **steady-state human body heat balance**
  - It is a function of **activity** (metabolic rate), **clothing insulation** and the **4 environmental parameters** (air temperature, mean radiant temperature, air velocity and air humidity.
  - Typically applicable for mechanically conditioned buildings

- **Adaptive comfort model:**
  - Considers **thermal comfort** as **a result of adaptation** (physiological, behavioural, psychological)
  - Establishes a *strong* relationship of the **comfortable temperatures** inside a building to **the mean temperatures prevailing outside the building**
  - Applicable for *naturally ventilated and "free-running"* buildings

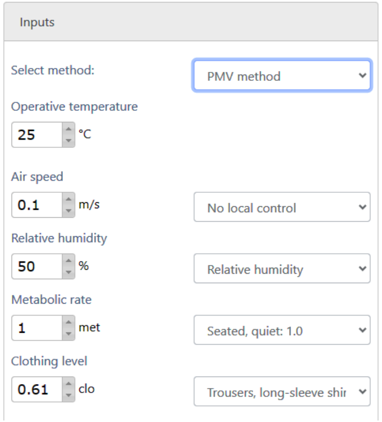


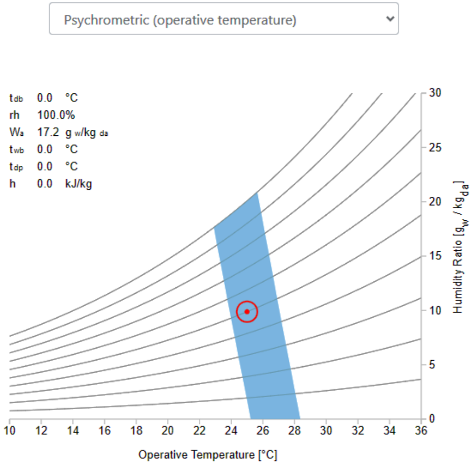
Source: Fanger, 1970, de Dear et al. (2013) Indoor Air

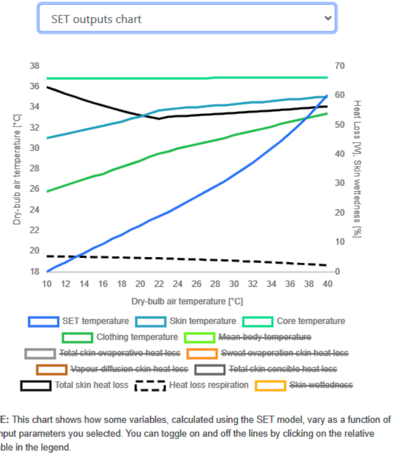
Thermal Comfort Models

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

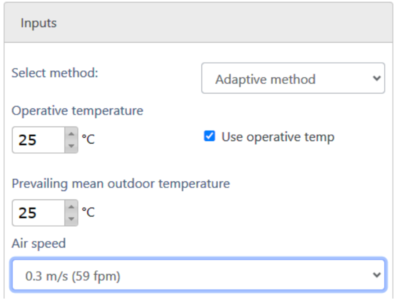
- **PMV/PPD model:**

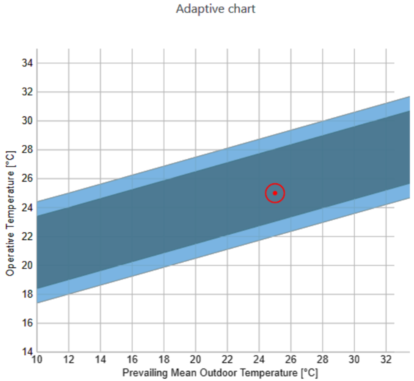




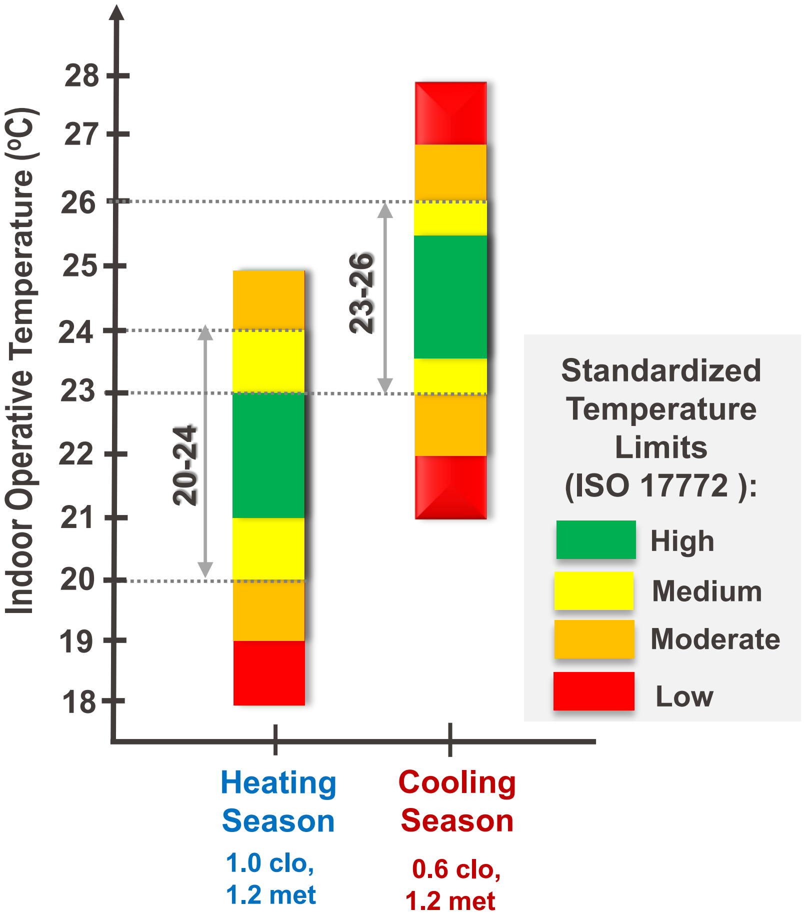


- **Adaptive model:**

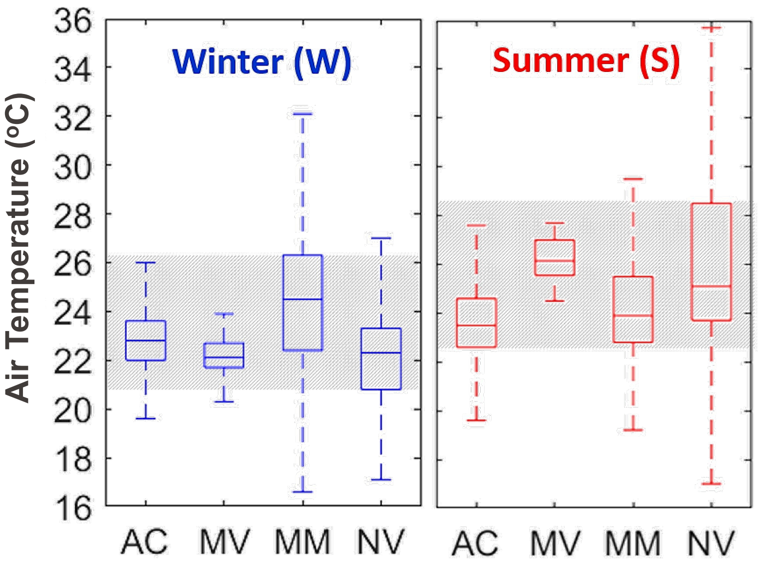




Thermal Comfort in Buildings: Current Practice



Air temperature variation
in differently conditioned buildings
(ASHRAE Global Thermal Comfort Database II)



AC – air-conditioned, **MV** – mechanically ventilated
MM – mixed mode, **NV** – naturally ventilated

Local Discomfort

- **Draught –**
  unwanted, **local cooling** of the skin *caused* **by air movement.** It is most prevalent when the whole-body thermal sensation is cool (below neutral). Draft sensation depends on air speed, air temperature, activity, and clothing.

- **Radiant temperature asymmetry –**
  The thermal radiation field about the body may be ***nonuniform*** due to **hot** and **cold surfaces** and **direct sunlight**. This ***asymmetry*** may cause local discomfort and reduce the thermal acceptability of the space

- **Vertical air temperature difference –**
  Thermal stratification that results in the air temperature at the **head level** *being warmer* than that **at the ankle level** may cause thermal discomfort. Thermal stratification in the opposite direction is rare.

- **Floor surface temperature (warm or cool floor) –**
  Occupants may feel uncomfortable due to contact with floor surfaces that are too warm or too cool. The temperature of the floor, rather than the material of the floor covering, is the most important factor for foot thermal comfort while wearing shoes.

Source: ASHRAE 55-2017

Draught Rate

Assist. Prof. Dolaana Khovalyg

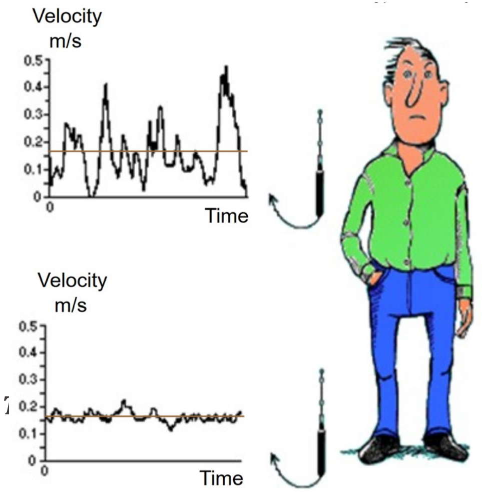
- ***Air currents*** can occur *near* *cold* & *hot* surfaces, near *ventilation inlets*, convective air current occur *naturally around the human body*

$$\boldsymbol{DR} = (34 - t_{op})(v_{a,mean} - 0.05)^{0.62}(0.37 \cdot v_{a,mean} \cdot \boldsymbol{Tu} + 3.14)$$

Operative temperature (°C) — t_{op}

Average air speed (m/s) — $v_{a,mean}$

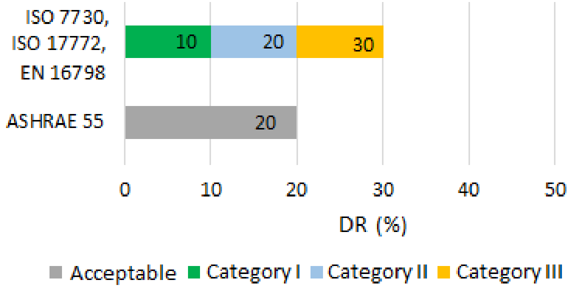
Turbulence intensity (%) — $Tu = v_{RMS}/v_{a,mean}$



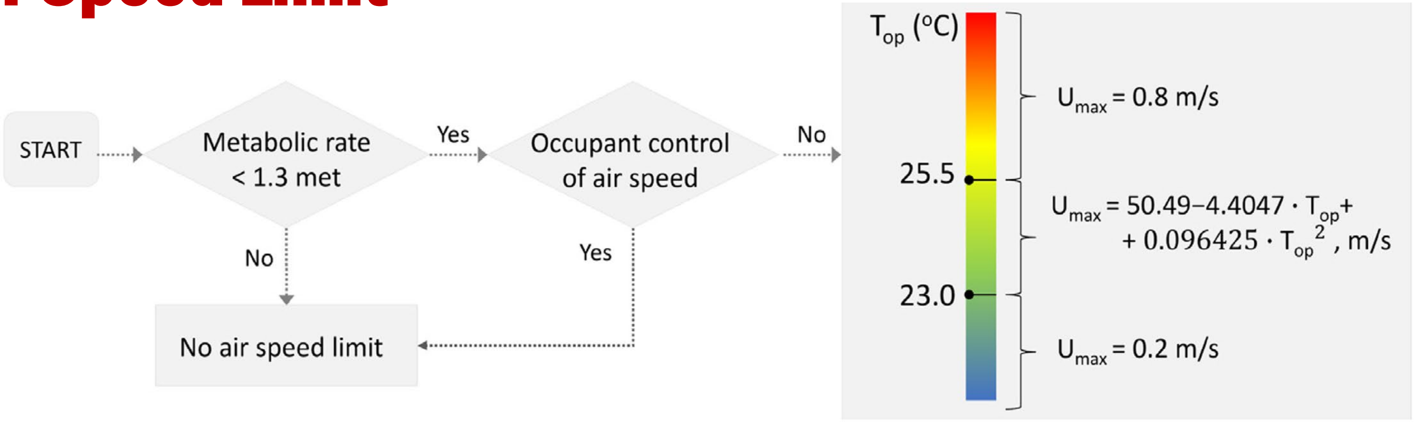
Acceptable maximum air speed to avoid draft:

Standard	Categories	U_{max} (m/s), summer	U_{max} (m/s), winter
ASHRAE 55	acceptable	0.8	0.15
ISO 17772, EN 16798	I	0.12	0.10
	II	0.19	0.16
	III	0.24	0.21

Standardized acceptable draft rate:

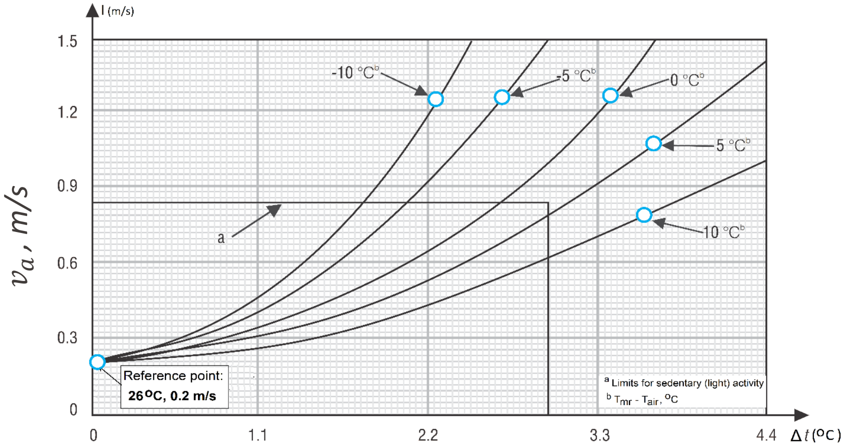


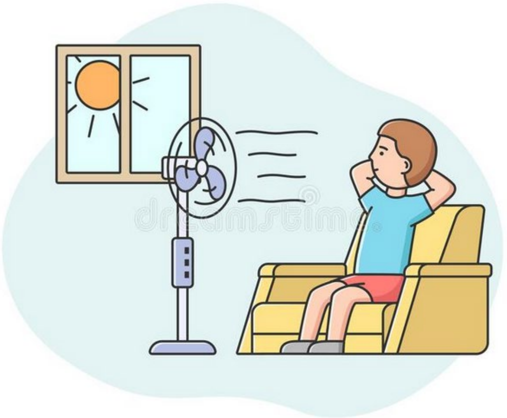
Air Speed Limit



Source: ASHRAE 55-2017

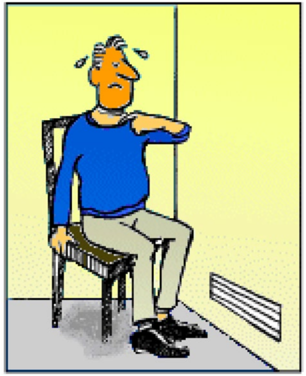
- **Air speed required to offset increased temperature (0.5 clo, 1.2 met):**

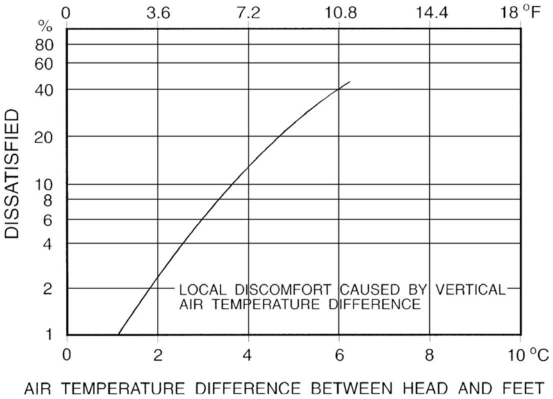


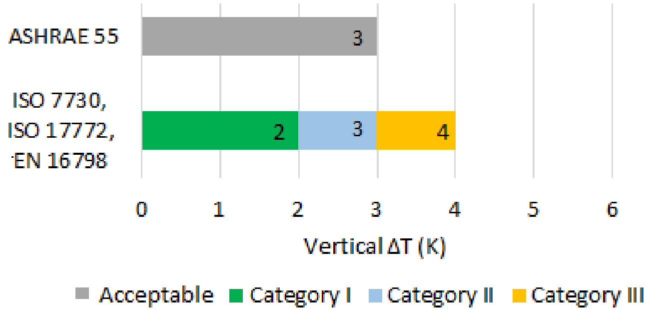


Assist. Prof. Dolaana Khovalyg

Vertical Air Temperature Difference

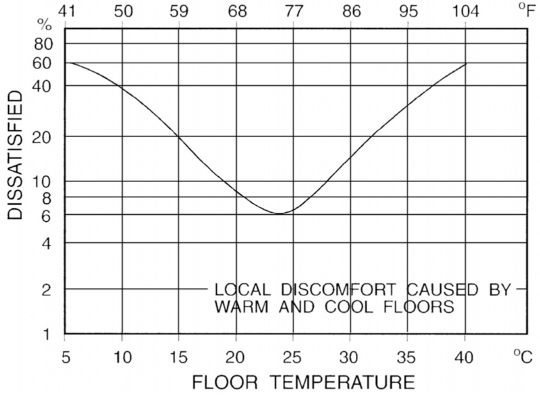


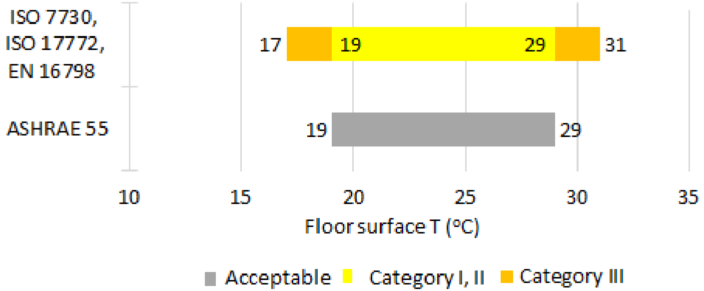




Assist. Prof. Dolaana Khovalyg

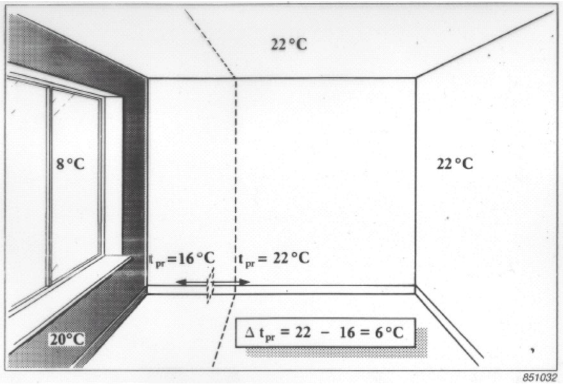
Floor Surface Temperature

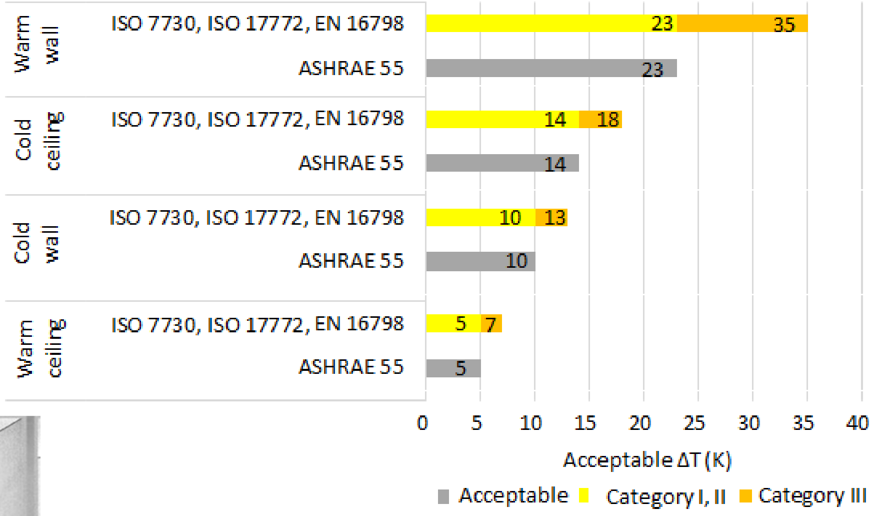


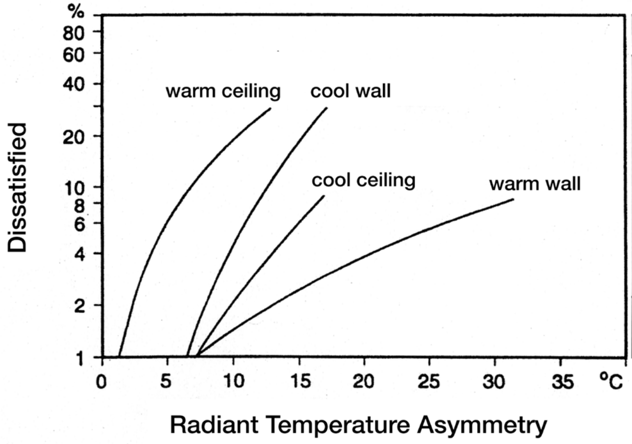


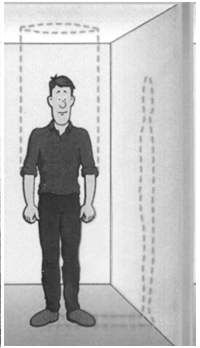
Radiant Temperature Asymmetry

- Characterized by *the difference* in the two half-room temperatures



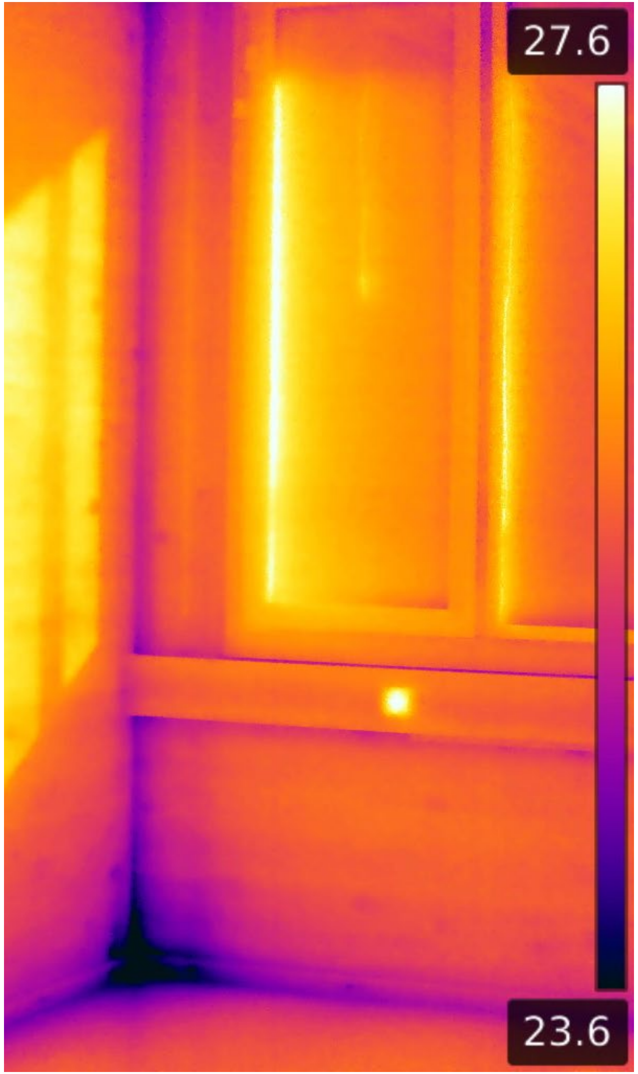






Assist. Prof. Dolaana Khovalyg

EPFL



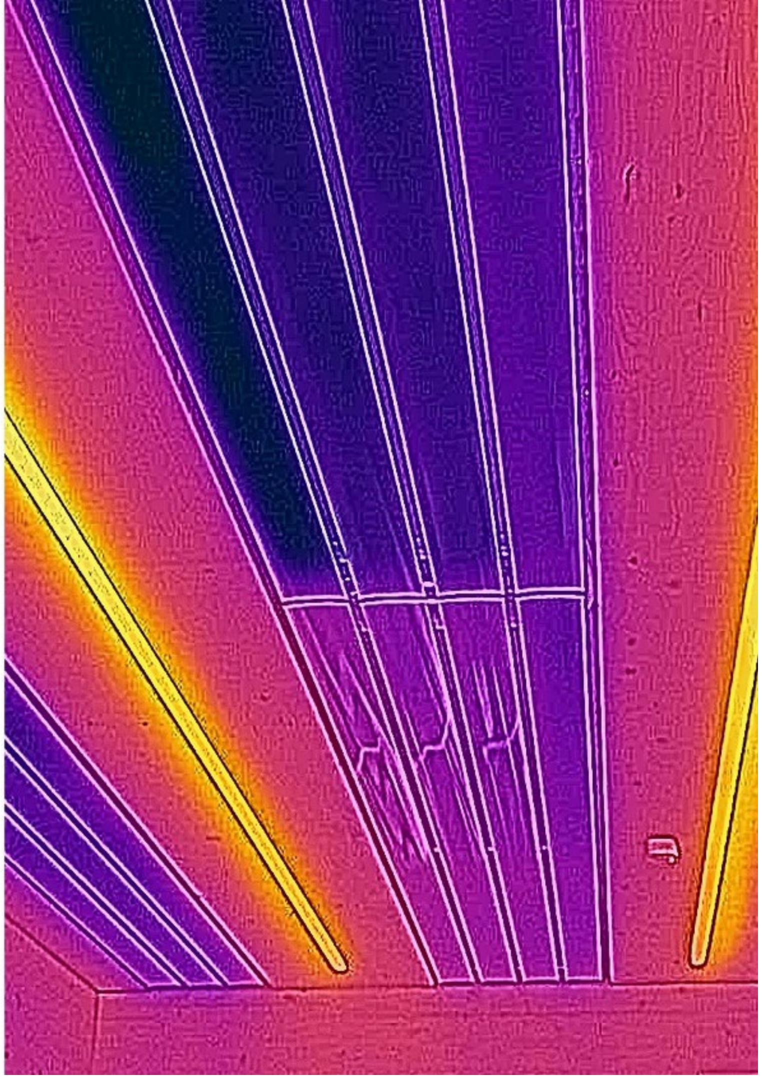
CONTENT:

- Introduction to the course
- Subjective evaluation of the thermal environment
- Intro into human thermoregulation
- Review of comfort requirements
- Class activity

ACTIVITY

- Observe your comfort and your environment
- Complete the COMFORT SURVEY
- Estimate your metabolic rate*
- Calculate total thermal insulation of your clothing ensemble*
- Compare *your thermal sensation vote* with *the predicted one* using the CBE Thermal Comfort Tool: https://comfort.cbe.berkeley.edu/
- Discuss with your neighbor:
  - The difference between predicted and actual thermal sensation vote
  - Effect of local discomfort (if any) on your thermal comfort

*Use data in the file "**ASHRAE 55_MET and CLO.pdf**"



Thank you for your attention

Dolaana Khovalyg
dolaana.khovalyg@epfl.ch