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Thermal stress & Thermal confort

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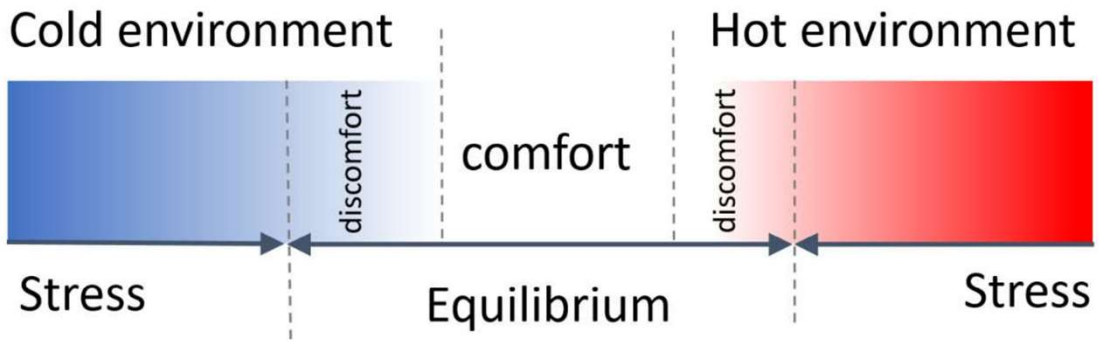
Exposure situations
Mechanisms
Health effects
Assessment

Thermal stress and thermal comfort

Thermal balance

- Thermal equilibrium is maintained in various environments through physiological and behavioral adaptation (homeothermy)



Heat stress – exposure situations

Occupational exposure

- Industrial processes with specific heat sources
  Foundries, glass factories, bakeries, kitchen chemical industry…Confined areas
- Confined areas in hot and/or moist environments
  Underground work, wearing heavy protective equipment
- Outdoor work during hot days
  Building work, agriculture…

	permanently exposed	exposed >25 of the time
Cold exposure	4	21
Hot exposure	6	23

Prevalence of heat exposure among EU workers [%]

Heat stress – exposure situations

General population

- Extreme heat, Heat waves
  > 30-35 °C during the day
  > 20°-25°C at night
  3 consecutive days

- Vulnerable individuals
  Elderly, young children, people with mental illness, drug and alcohol abusers

- Intense physical activity

Heat stress – mechanism

Thermal homeostasis

- Balance between the internal heat (metabolic) production and external losses

$$H = C_{res} + E_{res} + K + C + R + E$$

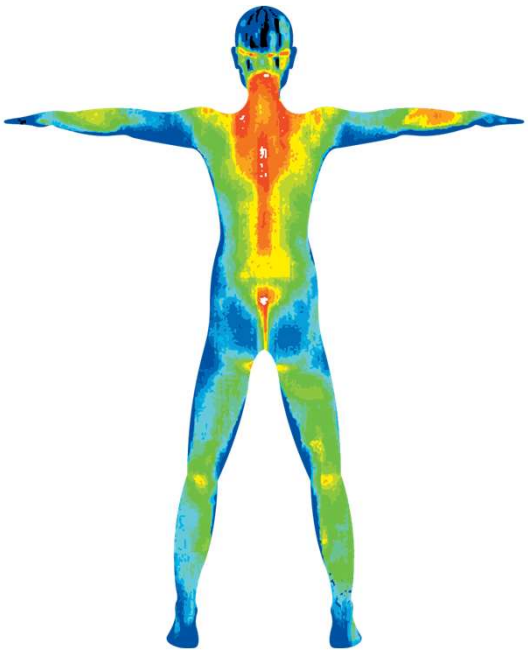
H: internal heat production
Cres: convection in the respiratory tract
Eres: evaporation from the respiratory tract
K: conduction at skin level
C: convection at skin level
R : radiation at skin level
E : evaporation from the skin

The heat produced by the human body must be expended to prevent overheating !

Heat stress – mechanism

Environmental factors

- Ambient temperature (Ta)
  Influence convection, conduction and evaporation process
  $\sim\Delta T$
- Radiant temperature (Tr)
  Influence radiation (hot surface, sunlight)
  $\sim\Delta T^4$
- Relative humidity (RH)
  Influence evaporation and convection
  $\sim e^{-RH}$
- Air speed (V)
  Convection
  $\sim\sqrt{V}$



Source: American College of Clinical Thermology

Heat stress – Individual factors

Internal heat production (H)

- depending on metabolic activity

Activity intensity	Examples	Energy produced [W/m^2]
Rest	Sleeping, resting	65
Light	Sitting, office work	100
Moderate	Walking, hand/arm work	165
High	Climbing stairs, running	230
Very high	Whole body intense activity (e.g. digging a trench)	290

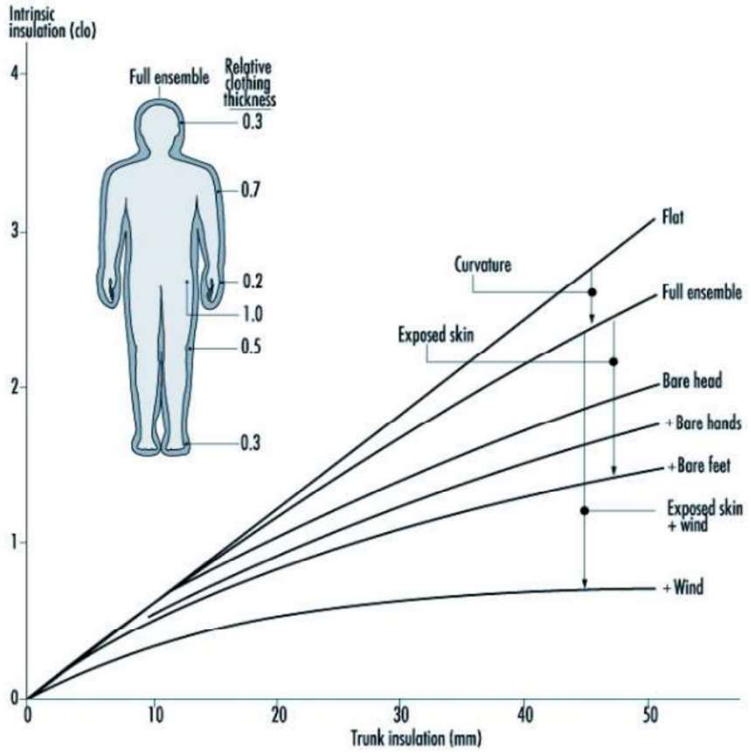
Heat stress – individual factors

Thermal insulation

- Hindering heat exchanges through clothing insultation
- Thermal insulation clothing unit [clo]

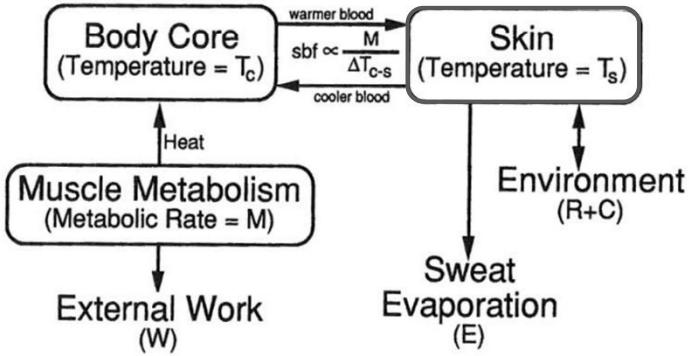
  1 clo = 0.155°C m^2 W^{-1}

Clothing	Insulation [clo]
T-shirt	0.09
Light skirt	0.15
Knitting	0.28
Coat	0.6
Boots	0.1



Heat stress – mechanisms

Modelling heat balance



ISO 7933

- Core temperature maintained through convention and evaporation

	Situation 1	Situation 2
Wind	1 m/s	1 m/s
T air	20°C	35°C
T rad	25°C	63°C
Metabolism	300 W	300 W
required sweat flow	**144 g/h**	**823 g/h**

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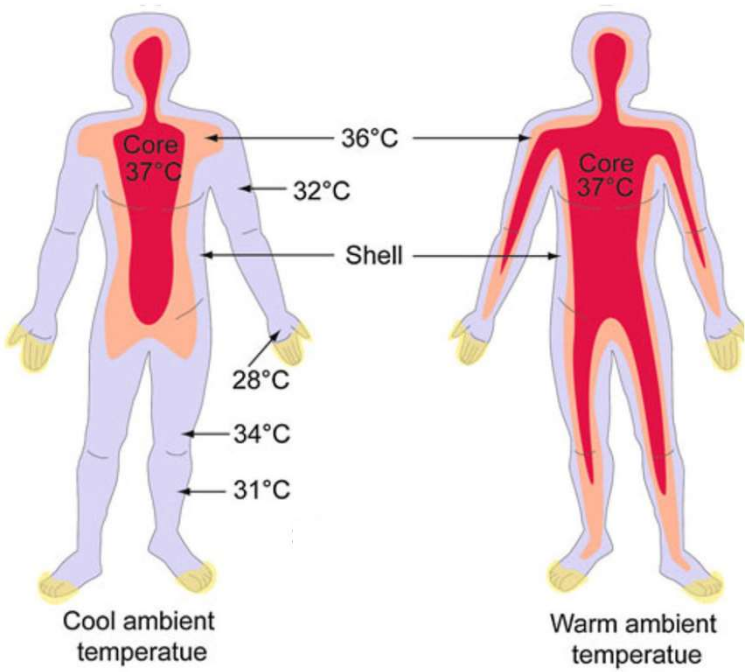
Heat stress – effects

Adaptative mechanism, thermoregulation

- Maintaining the body core temperature < 38°C
- Sweat regulation
- Vasodilation of peripheral blood vessels
- Acclimatization
  - Physiological adaptation process (~10 days)
  - More abundant and better distributed
  - Lower core temperature
  - Lower heart rate



Source: Matthew et al. 2011

Heat – Effects

Immediate effects

- Swelling (hands, feet), cramps (electrolyte imbalance)
- Increased core temperature, dehydration, syncope (drop in blood pressure)
- Heat stroke (inability to maintain heat balance), cardiac arrest

Delayed effects

- Sleep disorders, exhaustion
- Kidney disorders, metabolic regulation
- Mental health

Revealed: hundreds of migrant workers dying of heat stress in Qatar each year

As construction boom hits its peak ahead of Fifa World Cup, Guardian analysis shows workers toiling in potentially fatal temperatures

Dead at 24: did heat kill Doha World Cup worker Rupchandra Rumba?

A migrant worker at the construction site for the Al-Rayyan stadium, near Doha. Photograph: Tom Jenkins/The Guardian

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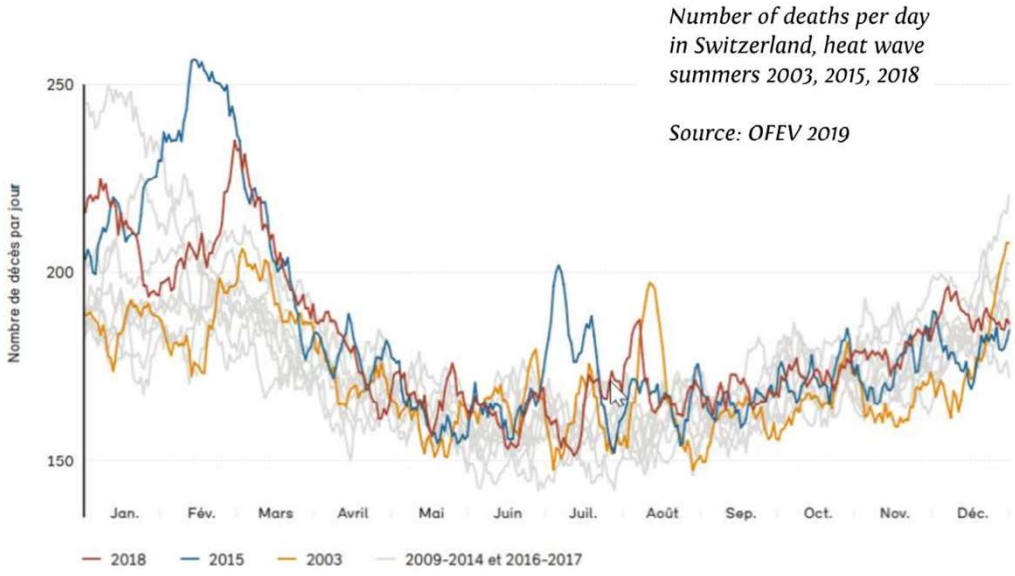
Heat – Effects

Mortality

- Increase of mortality in vulnerable populations
- Attracts attention during heat waves
- Moderate compared to winter mortality



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Heat stress – assessment

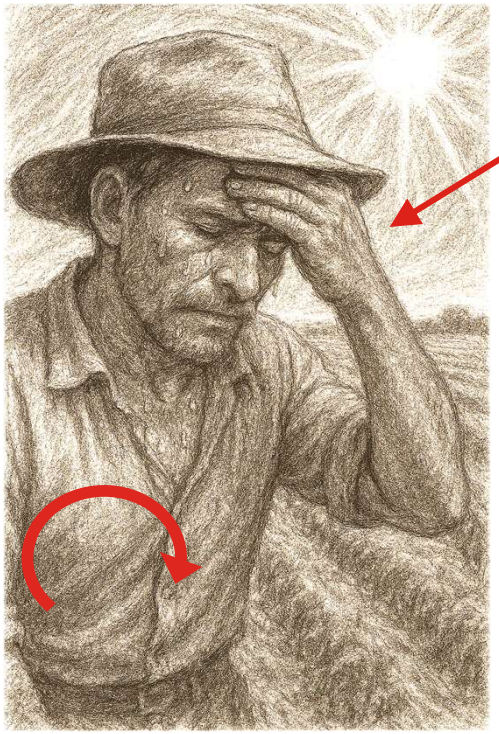
Strategy

Assessing heat stress

- Focused on environmental condition
- Temperature or **WBGT measurements**
- Meteorological data

Assessing heat strain

- Individual response (includes variability)
- Data protection issues
- Measuring sweating, skin temperature, heart rate



Heat Stress
Env. factors, heat exchange

Strain
Body response, core temperature, dehydratation

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Heat stress – assessment

WBGT measurement

Web Bulb Globe Temperature

- Adjusted temperature, taking into account the heat exchange mechanisms
- Empirical model
- Combines three temperature measurements

Without sunlight

$$WBGT = 0.3\,t_g + 0.7\,t_{nw}$$

With sunlight

$$WBGT = 0.2\,t_g + 0.7\,t_{nw} + 0.1\,t_a$$

T_g: globe temperature
T_{nw}: wet temperature
T_a: ambient temperature

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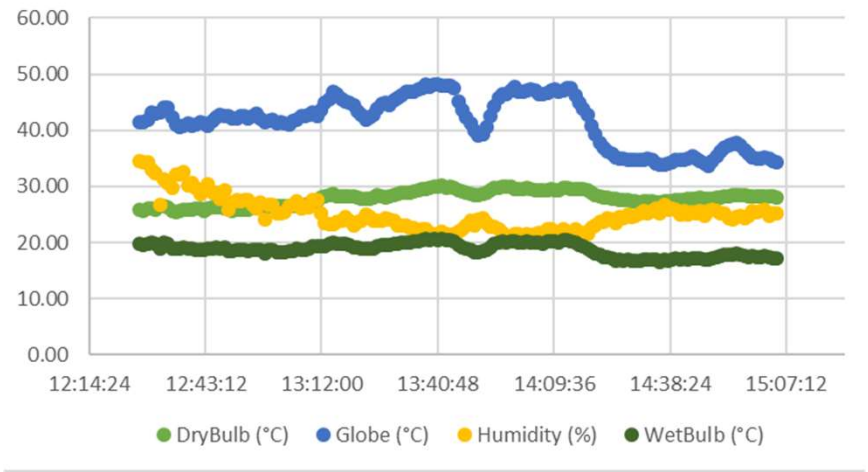
Heat stress – assessment

WBGT measurement

Field measurement

- Summer period
- Construction work



Preparation of slab formwork base

Heat stress – assessment

Thresholds expressed in WBGT temperatures

- Taking into account: physical activity, acclimatization and exposure time

	Metabolic rate, M		WBGT Reference value			
Metabolic Rate class	Related to a unit skin surface area W/m-2	Total (for a mean skin surface area of 1.8m2) W	Person acclimatised to heat °C		Person not acclimatised to heat °C	
0 (resting)	*M*≤65	*M*≤117	33		32	
1	65<*M*≤130	117<*M*≤234	30		29	
2	130<*M*≤200	234<*M*≤360	28		26	
3	200<*M*≤260	360<*M*≤468	No sensible air movement 25	Sensible Air movement 26	No sensible air movement 22	Sensible air movement 23
4	M>260	M>468	23	25	18	20

Reference values of WBGT heat stress index from ISO 7243 related to a maximum rectal temperature of 38°C

Source: Health and Safety Laboratory, UK

Case study

Mr. White at work

Mr. White works in a clothing cleaning company (laundry), which has a wet temperature of 32°C and a radiation temperature of 30°C.

He is responsible for loading and unloading laundry. He spends about half of the workday doing this activity, and the other half on administrative tasks (order entry). He has been with the company for approximately 12 years.

Question (3.2a)

Is this work situation acceptable ?

Case-study solution

Question 3.2b

- Compute the WBGT (without sunlight) $\mathrm{WBGT} = 0.3\,t_g + 0.7\,t_{nw}$
- The equivalent temperature is: 31.4 °C
- This temperature is barely tolerable for light work (31.5°C), but not for medium or more intense work (considering ISO 7243).
- This would also be true according to the recommendations valid in Switzerland, as long as 50% of the work is done in a "cool" area.

Cold stress – exposure situation

Occupational exposure

- Artificial cold environments: refrigeration plants, food conservation, ice rinks
- Outdoor work in winter (altitude, extreme cold, wind)

General population

- Outdoor activities in winter (altitude, extreme cold, wind)
- Cold water exposure

Case study

Mr. White in holidays

Mr. White is on vacation in the mountains. He decides to climb to the top of the slopes on snowshoes (approx. 3,000 meters above sea level). He is wearing a full warm suit (face partly uncovered).

On the top of the slope, the air temperature is -10°C and the wind speed is 40 km/h.

Question (3.2b)

Is there a risk to Mr. White's health? Justify your answer based on the heat exchange mechanisms involved.

Cold stress – mechanisms

Heat exchange mechanisms

- Conduction, **convection**, radiation and evaporation

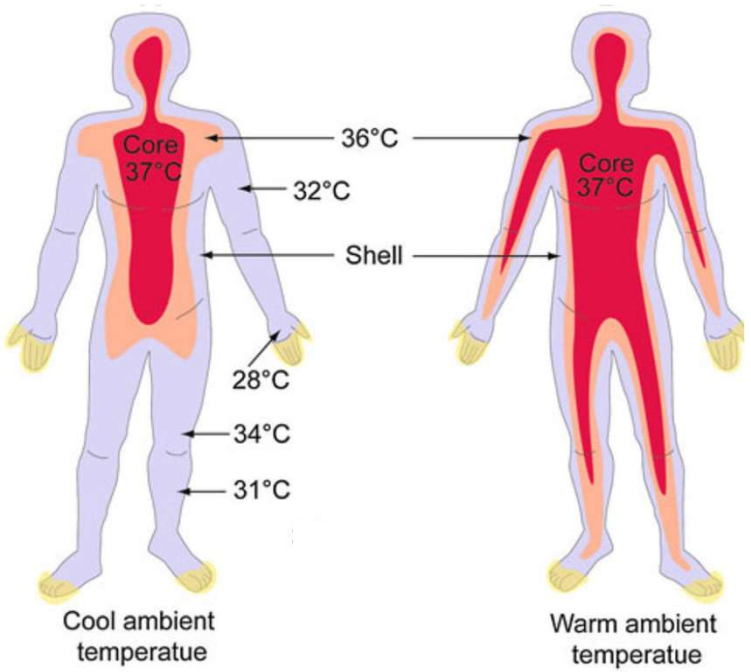
Key factors

- Exposure time
- Skin insulation
- Conductive medium (sweat, cold water)
- Wind

Cold stress – effects

Adaptative mechanism, thermoregulation

- Maintaining the body core temperature >36 °C
- Physiological
  - Vasoconstriction of the peripheric vessels
  - Heart rate ↗
  - Skin contraction
  - Shivering (local heat production)
- Behavioral
  - Dressing
  - Increasing physical activity



Source: Matthew et al. 2011

Cold stress – effects

Direct effect

- Frostbite
- Hypothermia
- Loss of manual dexterity
- Increase in reaction time
- Exhaustion

Vulnerable groups

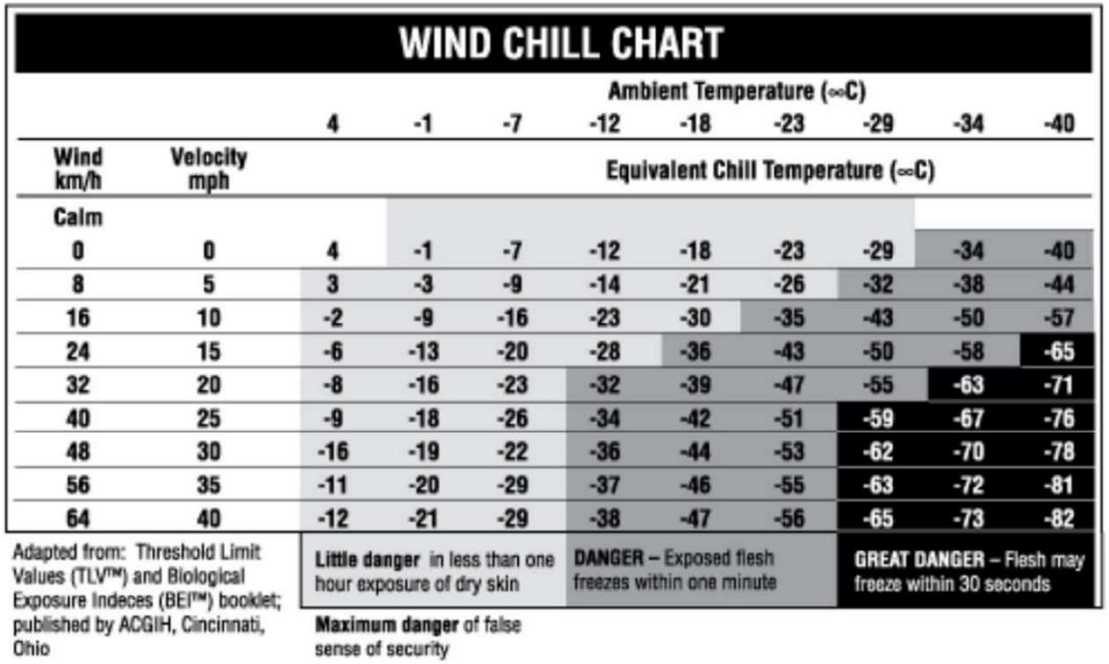
- Pregnant women
- Cold-induced asthma
- People:
  - Over 55 years old
  - With chronic diseases: cardiovascular, diabetes, hypertension,…
  - Suffering from white fingers disease (Raynaud's syndrome)

https://www.handsurgeryresource.net

Cold stress – assessment

The Wind hill chart

- Acute cold exposure, unprotected skin
- Equivalent temperature



WIND CHILL CHART

Wind km/h	Velocity mph	Ambient Temperature (∞C) 4	-1	-7	-12	-18	-23	-29	-34	-40
		Equivalent Chill Temperature (∞C)								
Calm										
0	0	4	-1	-7	-12	-18	-23	-29	-34	-40
8	5	3	-3	-9	-14	-21	-26	-32	-38	-44
16	10	-2	-9	-16	-23	-30	-35	-43	-50	-57
24	15	-6	-13	-20	-28	-36	-43	-50	-58	-65
32	20	-8	-16	-23	-32	-39	-47	-55	-63	-71
40	25	-9	-18	-26	-34	-42	-51	-59	-67	-76
48	30	-16	-19	-22	-36	-44	-53	-62	-70	-78
56	35	-11	-20	-29	-37	-46	-55	-63	-72	-81
64	40	-12	-21	-29	-38	-47	-56	-65	-73	-82

Adapted from: Threshold Limit Values (TLV™) and Biological Exposure Indeces (BEI™) booklet; published by ACGIH, Cincinnati, Ohio

Little danger in less than one hour exposure of dry skin

Maximum danger of false sense of security

DANGER – Exposed flesh freezes within one minute

GREAT DANGER – Flesh may freeze within 30 seconds

Thermal confort

- High inter-individual variability
- No “one-size fits all” thermal conditions
- Typically recommended in offices

  Temp: 19-21 °C

  RH: >20 %

  V_{air}: < 0.25 m/s

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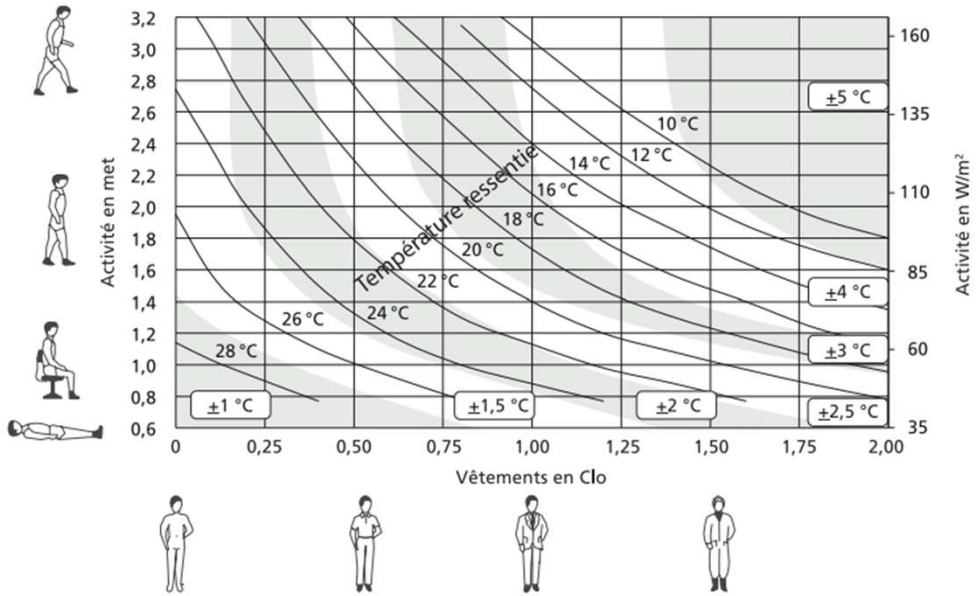
Thermal confort - assessment

- High inter-individual variability
- No “one-size fits all” thermal conditions



Source:
comments OLT3 and OLT4

50% humidity,
10% PPD,
<0.1 m/s air mvt

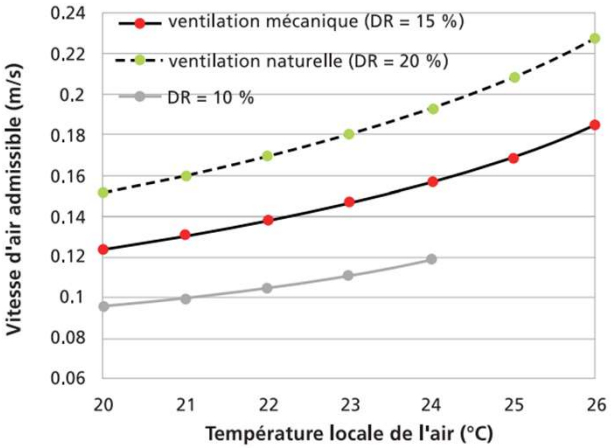
Thermal confort

- Ambiant temperature

  T_{amb}. =mean (T_{air}, T_{rad})

- Humidity
  - Large range, little perception of humidity variation
  - Winter 30-50% RH, Summer 40-60% RH

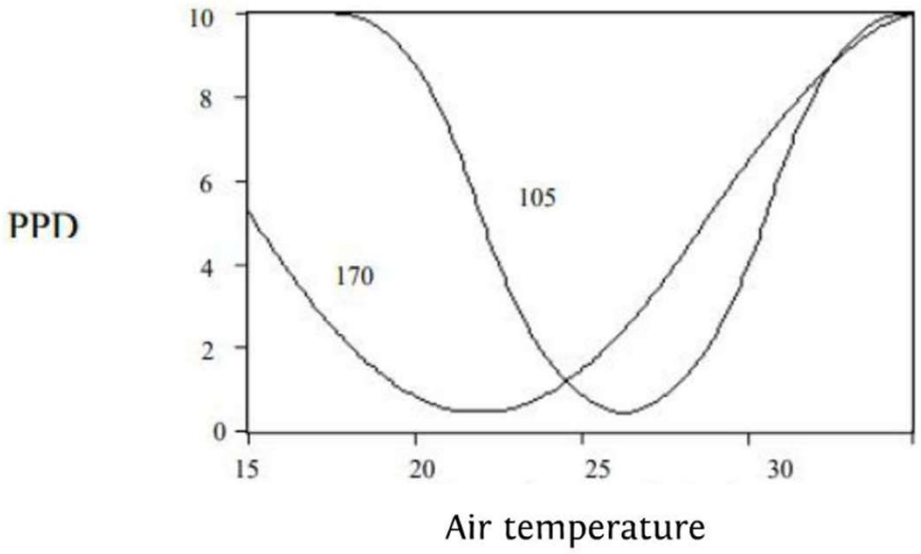
- Air movements
  - Draught rating
  - Air temp, air mvt, turbulence



Thermal comfort - PPD

- Comfort criteria based on the predicted number of dissatisfied

$T_{amb.} = \text{mean}(T_{air}, T_{rad})$



But:

Ideal ambient conditions means you have still 10% of dissatisfied

job dissatisfaction is a strong confounding factor