02.01_PH-SUMMER SCHOOL

THERMAL COMFORT

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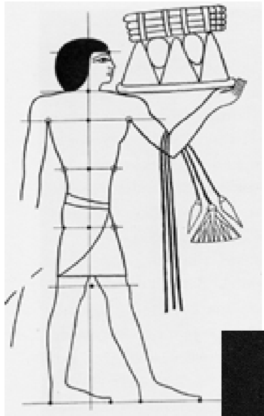
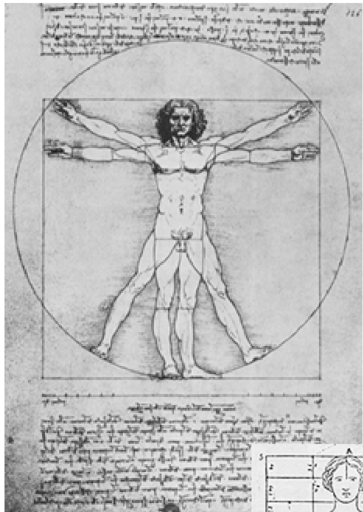
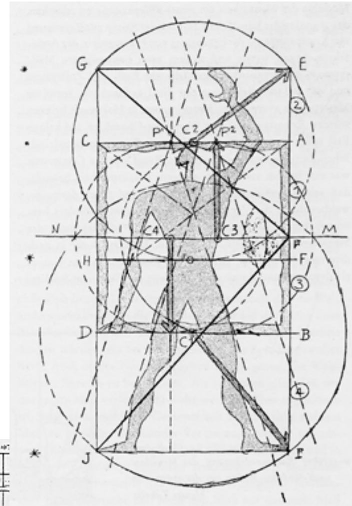
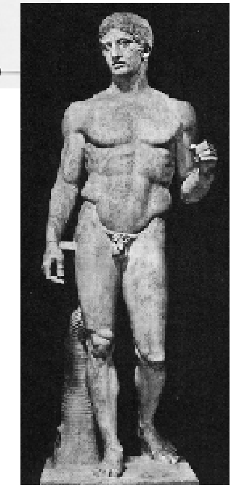
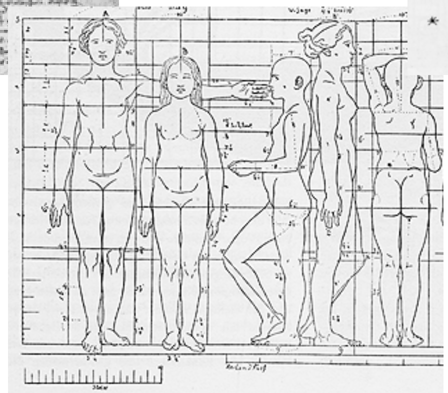
Language support: William GALLAGHER, Rob McLEOD, Michael WILLIAMS
Date: 2009-07-18

In the centre – man / woman

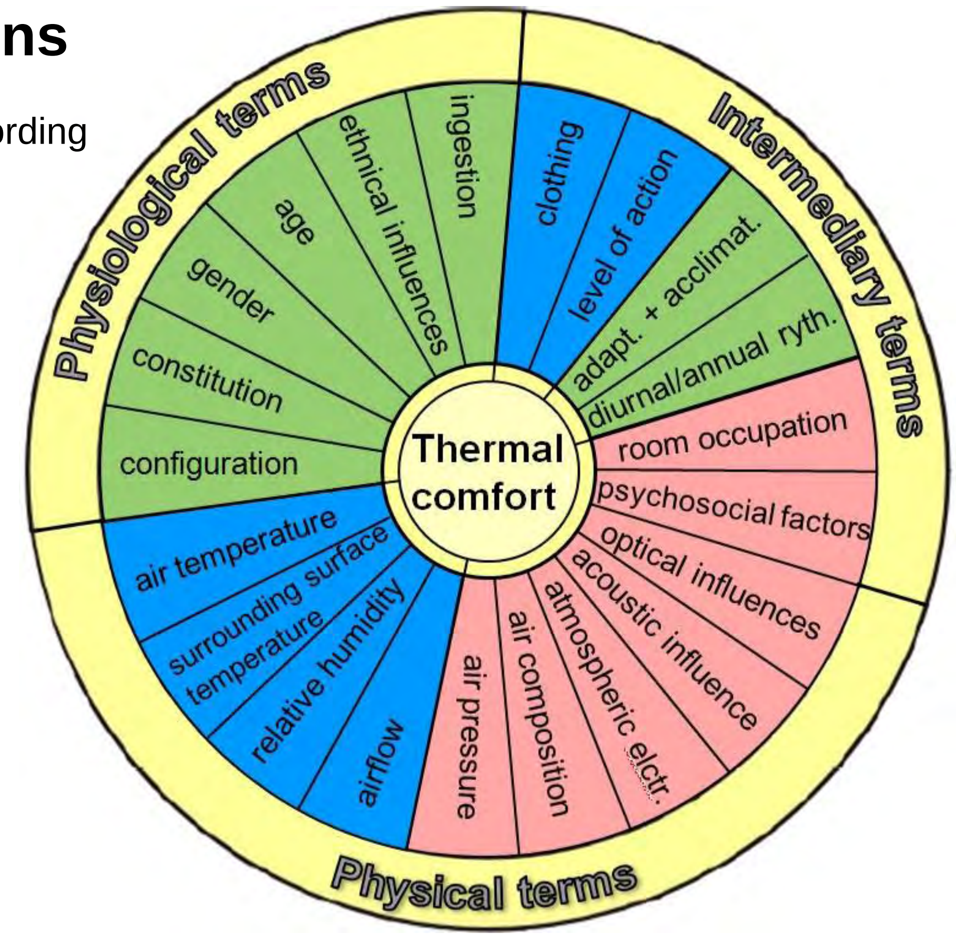






Source: kusem.de/lk/prop/prop

Comfort conditions

The thermal comfort is according to physiological, physical and intermediary conditions

- **Primary and dominating factors**
- **Additional factors**
- **Secondary and suspected factors**



Comfort values (Frank):

Factors Influencing Thermal Comfort

- Air Temperature (Dry-Bulb)
- Relative Humidity
- Air Velocity
- Radiation (Mean Radiant Temperature)
- Metabolic Rate
- Clothing Insulation

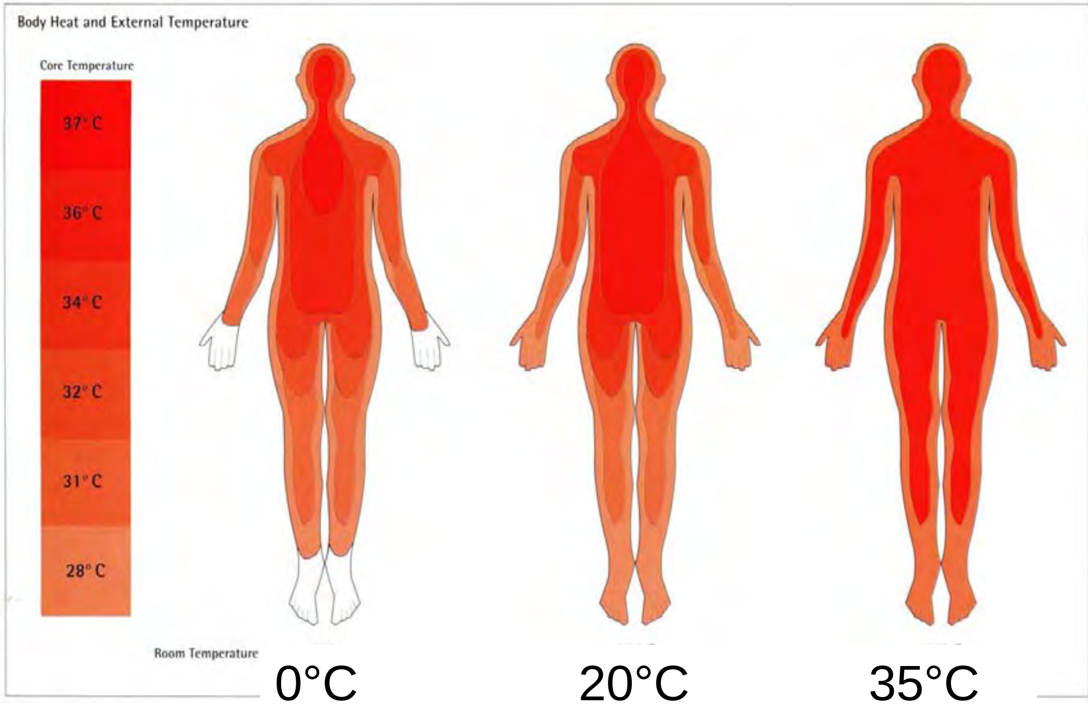
Source: http://personal.cityu.edu.hk/~bsapplec/newpage312.htm

Characteristics of the human body

Body temperature:	36,5 - 37 °C
Basal metabolism (at complete quiet): Minimum heat production	70 W
Skin surface (statistically average):	1,7 - 1,9 m^2
Area-specific basal metabolism:	40 W/m^2
Middle skin temperature:	32-34 °C
Volume of the air breathed in:	0,5 - 9,0 m^3/h
Temperature of the air breathed out:	35 °C
Humidity of the air breathed out:	95 %
Composition of the air breathed in:	79 % N_2, 21 % O_2
Composition of the air breathed out:	79 % N_2, 17 % O_2, 4 % CO_2

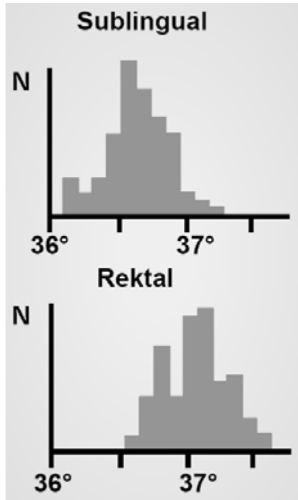
Source:

Temperature zones of the body



0°C 20°C 35°C

room temperature



Variation range in healthy population

Source: E.Niggli, Uni Bern

Thermal comfort

The feeling of comfort for human beings depends upon conditions affecting the thermal balance between the body and the environment. It is determined by:

- **Physical factors**

- **Physiological factors**

Thermal comfort

Physical factors:

- air temperature,
- temperature of the surrounding surfaces,
- relative humidity,
- air movement in the vicinity of the body,
- thermal resistance of the clothing

Physiologic factors:

- Weight and body height,
- Metabolism or heat production of the body

The metabolism or heat production of the body is affected through:

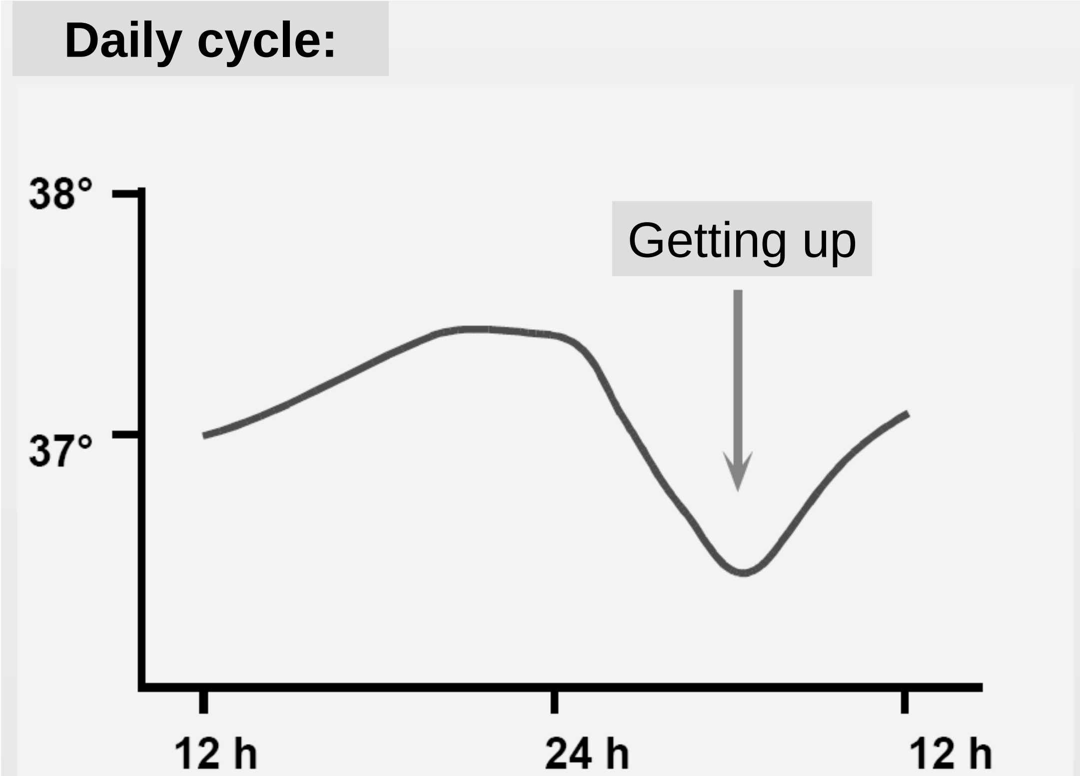
- Activity level
- Surface/Volume relation (baby - adult)
- Muscle mass / body fat ratio (sex)
- Relaxation degree
- Hormone balance
- Time of day
- Diet
- Chemical influences (Smoking, alcohol)
- ….

Heat production / temperature regulation (feeling) and sex

- The skin of a women is thinner and reacts faster on cold.
- On average the body of a slim woman consists of 25% fat and 25% muscles, slim men only have 10% body fat and 40% muscle mass.
- Muscles produce "heating“ better whilst body fat „insolates“ but can't produce heat.

Source: Susanne Schütte, VITAL

Heat production / diurnal cycle



Source: E.Niggli, Uni Bern

Heat production / Human heat emission at different activity levels

Activity	Heat emission		Metabolic Rate
	[W/m²]	[W]	[met]
sleeping	40	70	0,69
lying	46	80	0,80
sitting	58	100	1,00
standing	70	125	1,21
easy office work	70	125	1,21
standing easy activity	80	145	1,38
active office work	85	150	1,47
slow walking	125	210	2,16
heavy physical activity	165	300	2,84
fast walking	235	400	4,05
fast running	325	550	5,60
the hardest work	410	700	7,07

(1,0 met represents 58 W/m² heat emission (activity: sitting)

Source: DIN EN ISO 7730 and DIN 33403 T3

Heat balance /
Insulation values of the clothes

Clothing combination	Heat resistance		Heat transmission
	[m²K/W]	[clo]	[W/m²K]
naked	0	0	∞
Light clothes (short / shirt)	0,08	0,5	13,1
Clothes (shirt / trousers / socks)	0,1	0,65	10,0
normal working clothes	0,125-0,160	0,8 - 1,0	9,0 - 6,25
light sports clothes with jacket	0,160	1,0	6,25
strong clothes / pullover	0,200	1,25	5,0
heavy working clothes	0,210	1,3	4,8
clothes for cold weather with coat	0,250 - 0,300	1,6 - 2,0	4,0 - 3,3
clothes for coldest weather	0,45 - 0,60	3,0 - 4,0	2,2 - 1,7

1,0 clo is a heat resistance of 0,16 m²K/W (light sports clothes with jacket)

Source: Recknagel/Sprenger

Heat balance /

Insulation values of the clothes

Clothing combination	Clo	m2K/W
Naked	0	0
Shorts	0,1	0,018
Typical tropic clothing outfit	0,3	0,047
Light summer clothing	0,5	0,078
Working cloths	0,8	0,124
Typical indoor winter clothing combination	1,0	0,155
Heavy traditional European business suit	1,5	0,233

Source: http://personal.cityu.edu.hk/~bsapplec/heat.htm

Specific heat emission of the human body

- through **convection** from the body surface to the surrounding air
- through **transmission** from the body surface to solid objects
- through **heat transmission** from the body surface to the air film
- through **heat radiation** from the body surface the surrounding room surfaces
- through **evaporation** of water (humidity) from the skin
- through **breathing**
- through **secretions**

Heat emission –

The meaning of the variables are: (all units in Watt)

- H: internal heat production of the body,
- E_{diff}: latent heat transfer through the skin by diffusion,
- E_{l}: latent heat transfer by breathing,
- E_{s}: sensible heat transfer by breathing,
- E_{pe}: latent heat transfer by perspiration evaporation,
- R: radiative heat transfer from the surface of the clothing
- C: convective heat transfer through the clothing.

$$H - E_{diff} - E_{l} - E_{s} - E_{pe} = R + C$$

Source:

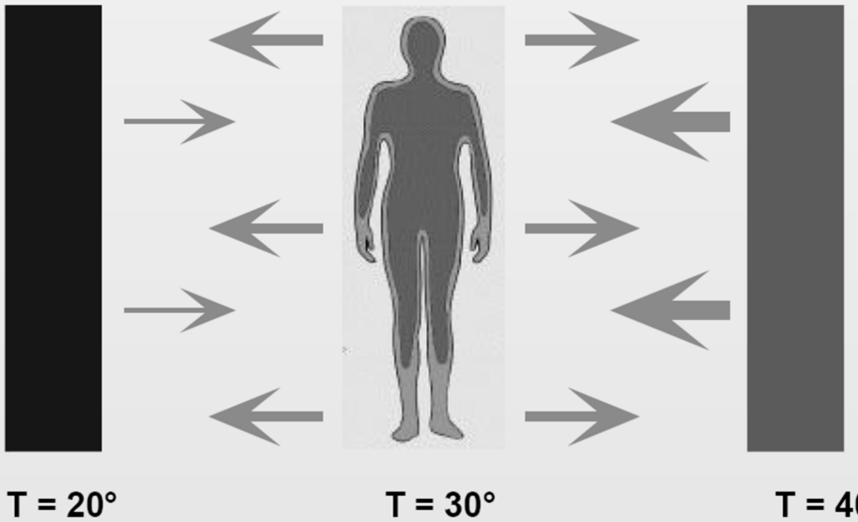
Specific heat emission of human

- **Average heat emission of human (clothed):**
  ~ 70 W/m² (~ 1 W / kg weight)

- Average heat emission of the head:
  ~ 115 W/m²
- Average heat emission of hands:
  ~ 75 W/m²
- Average heat emission of the soles of the feet:
  ~ 145 W/m²

1. The heat emission works through:

Heat radiation

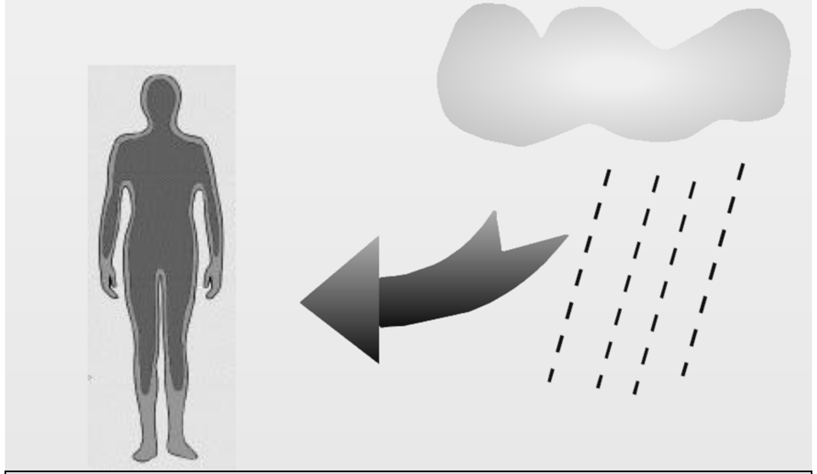


Heat emission (thermal output) and heat absorption (thermal input) by long-wave infrared radiation

Source: E.Niggli, Uni Bern

2. The heat emission works through:

Heat transmission and convection



- Boundary layer around skin: only transmission, there is no air movement.
  Clothes or hairiness thickens boundary layer.

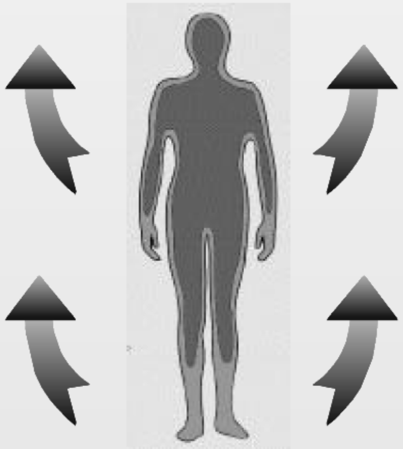
$$H = \Delta T * C * A$$

- Convection: Outside the boundary layer heat is transported without gradient.
- Heat emission is proportional to skin temperature and wind speed („wind chill factor“)

Source: E.Niggli, Uni Bern

3. The heat emission works through:

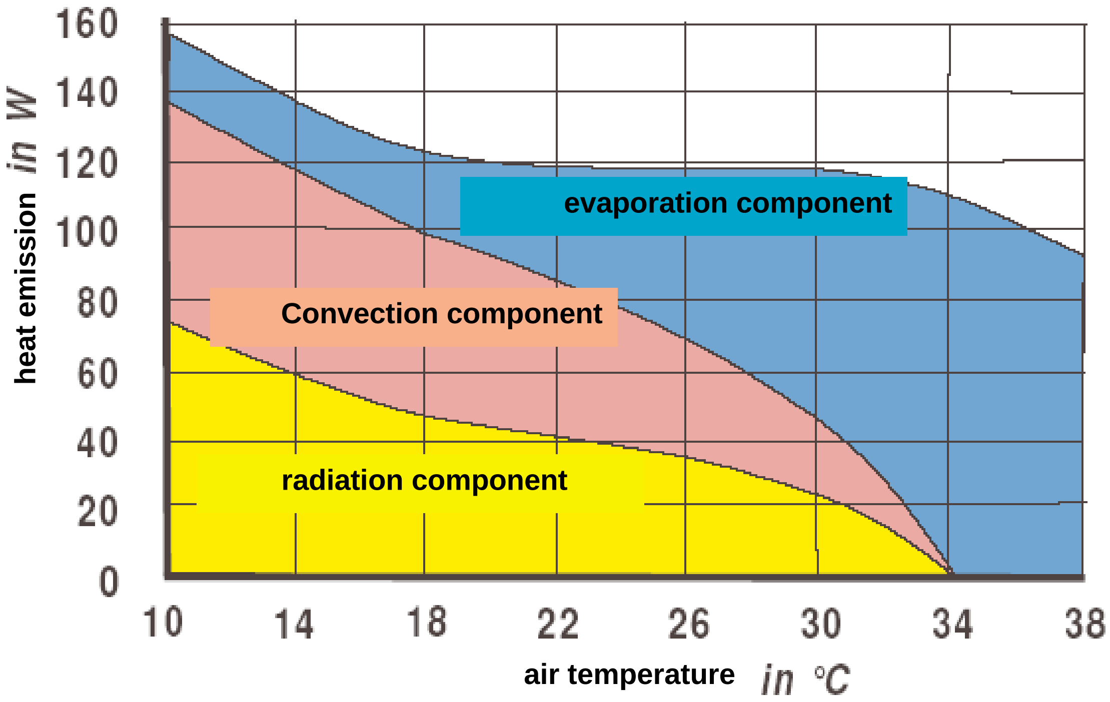
Wet or evaporation heat



- Heat emission (thermal output): 540 kcal / litre water
- „Perspiratio insensibilis“ – Perspiration/ transpiration is the evaporation trough skin and muscosa (0,4 – 1,0 l / d).
- Sweating: 1 – 4 l / h (for a short time) is a reserve mechanism of thermoregulation (evaporation heat)

Source: E.Niggli, Uni Bern

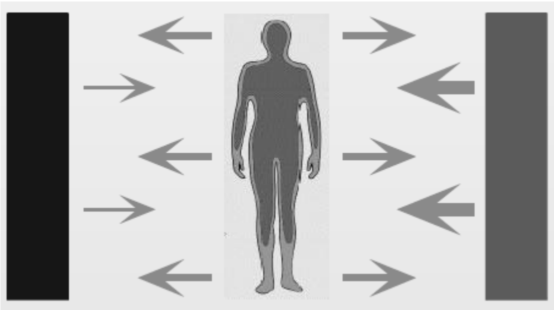
Heat emissions at rest as a product of air temperature (still air conditions)

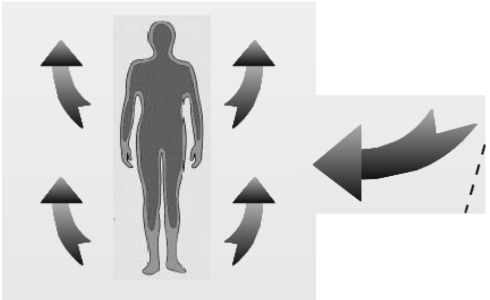


Source: nach Recknagel/Sprenger

The relevant influences are …

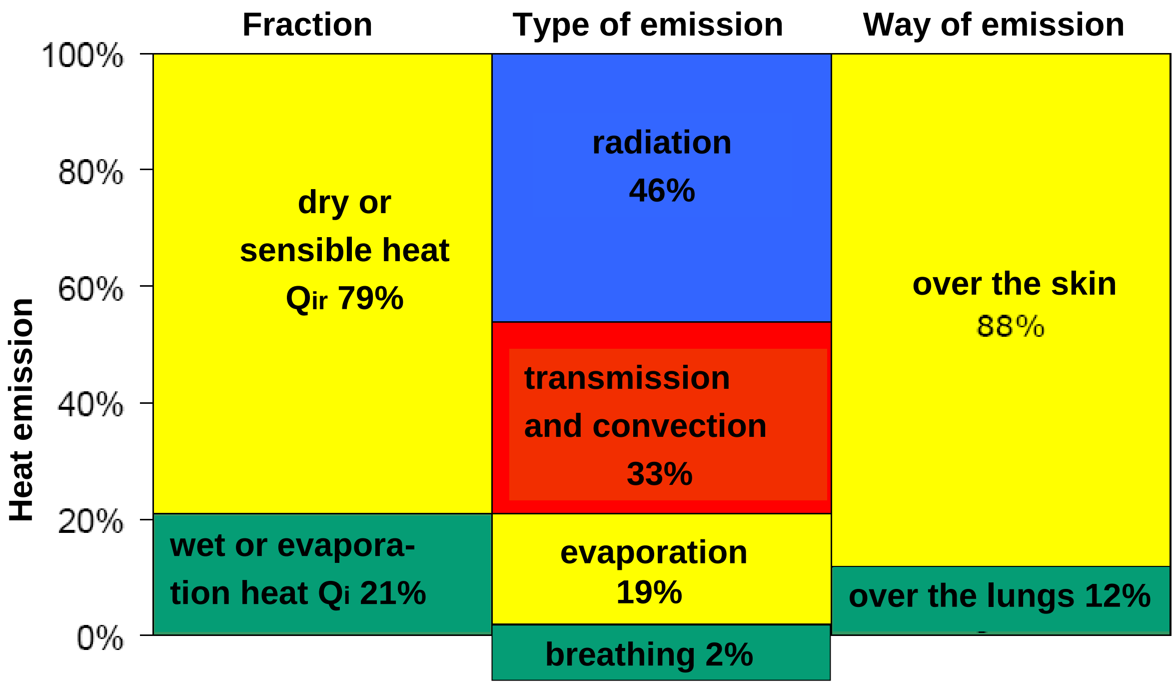
- temperature of surrounding elements (walls, ..)
- air movement / air temperature





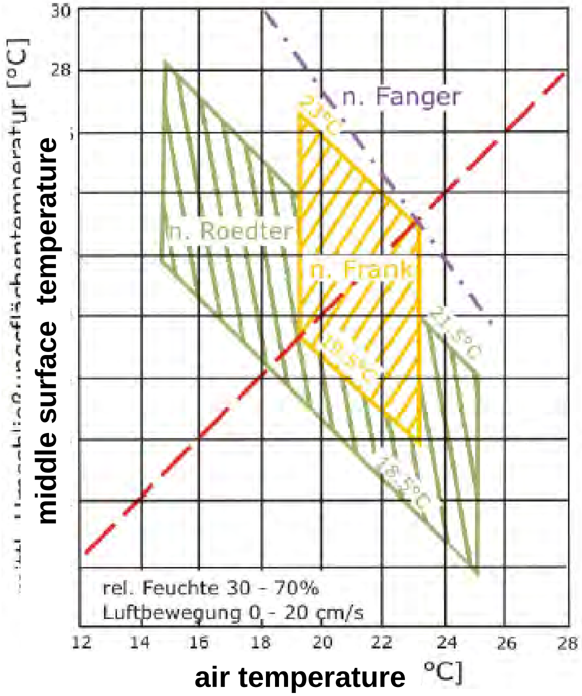
Source: E.Niggli, Uni Bern

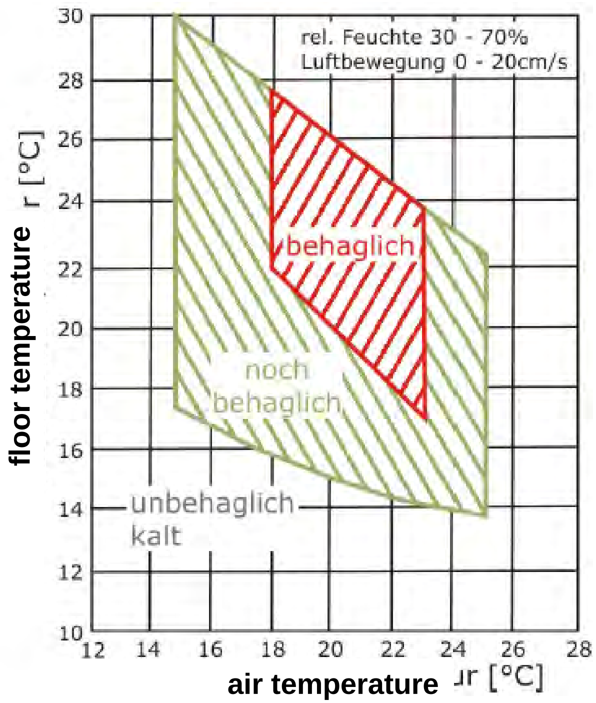
Sources of heat emissions from a human being at an air temperature of 20°C



Source: nach Recknagel/Sprenger

Comfort diagram I + II

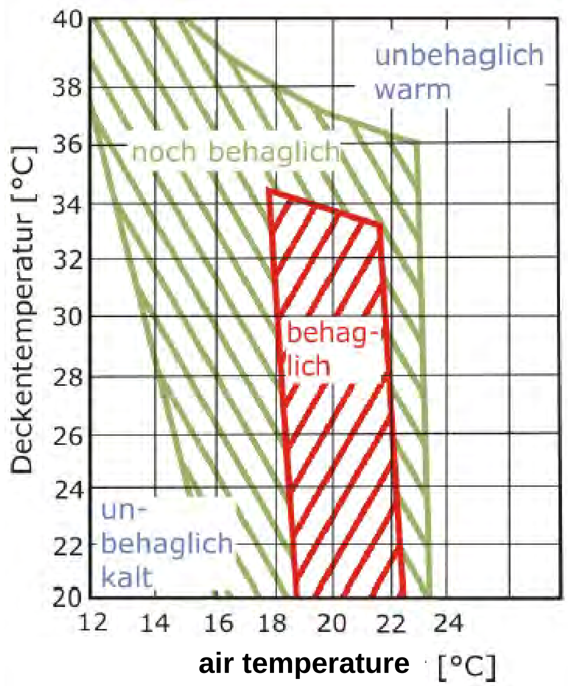


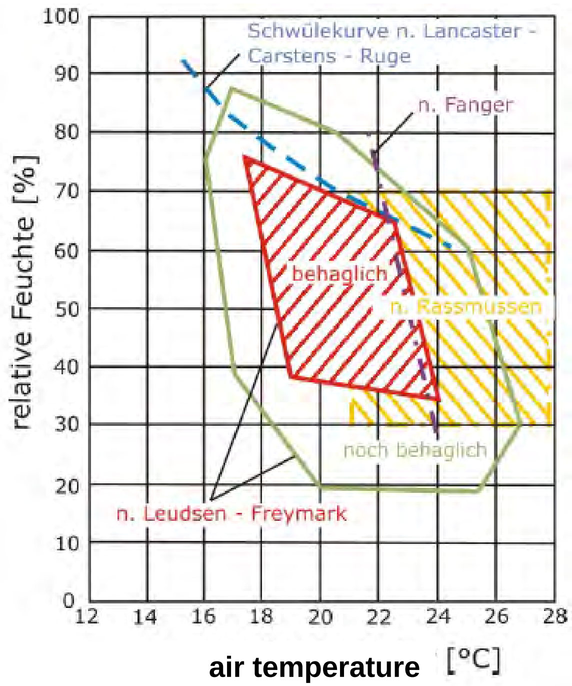


(valid for: relative humidity 30-70%, air velocity 0-20 cm/s, sitting activity, normal clothes)

Source: P.O.Fanger, Tech. University of Denmark

Comfort diagram III + IV

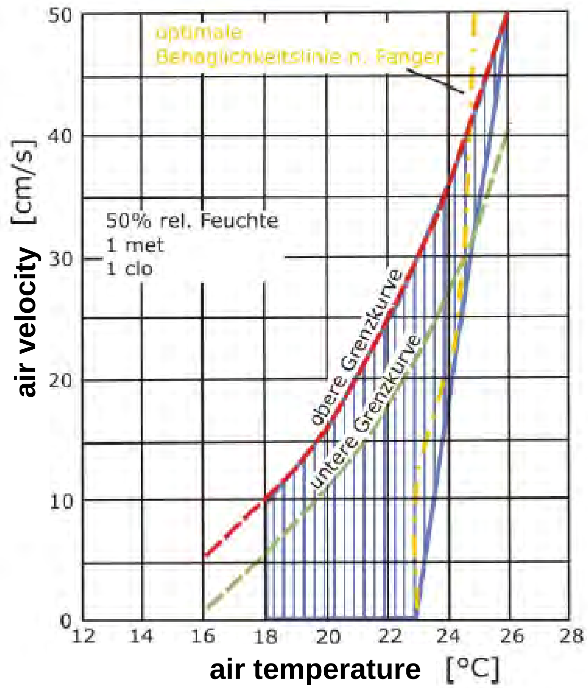


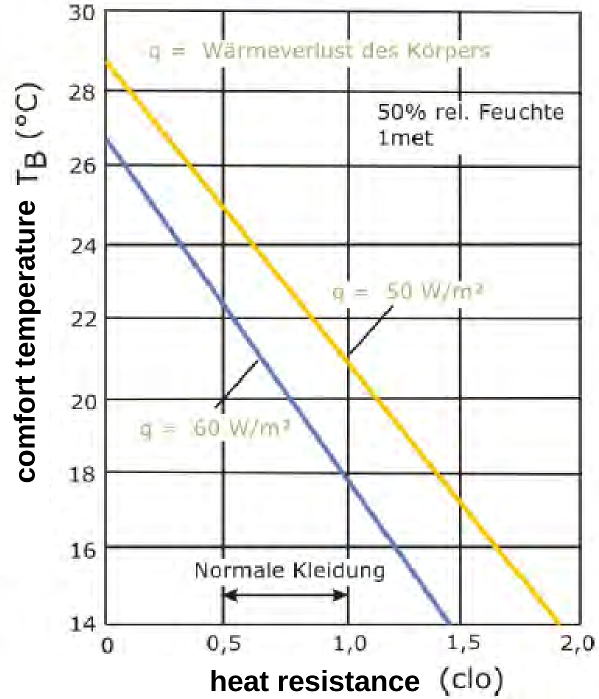


(valid for: relative humidity 30-70%, air velocity 0-20 cm/s, sitting activity, normal clothes)

Source: P.O.Fanger, Tech. University of Denmark

Comfort diagram V + VI

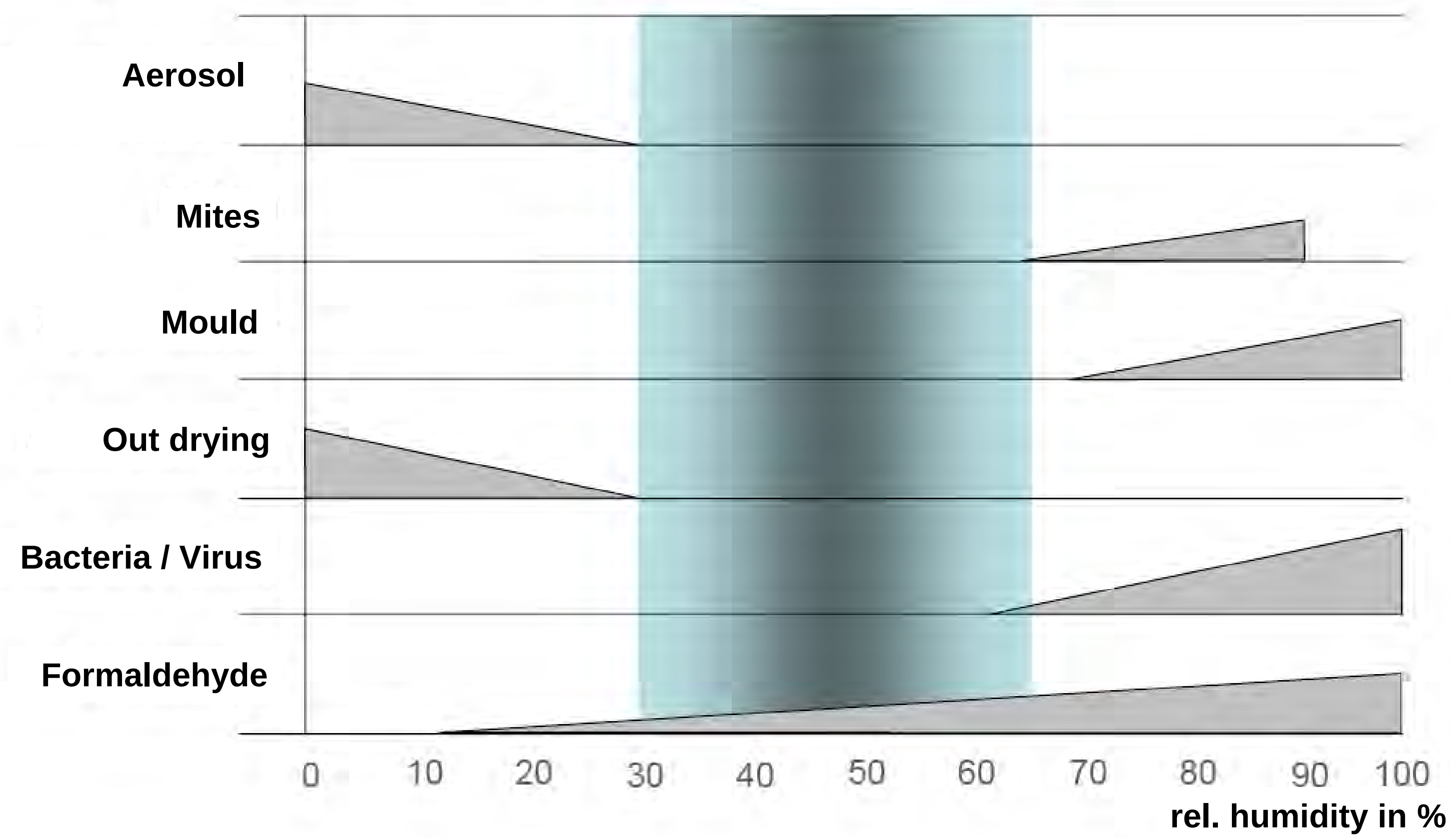




(valid for: relative humidity 30-70%, air velocity 0-20 cm/s, sitting activity, normal clothes)

Source: P.O.Fanger, Tech. University of Denmark

Area of comfort and relative humidity in %



Source: R. Lazzarin: Just a drop of water, Carel S.p.A., Ausschnitte in Refrigeration world, June 04 and Sep 04

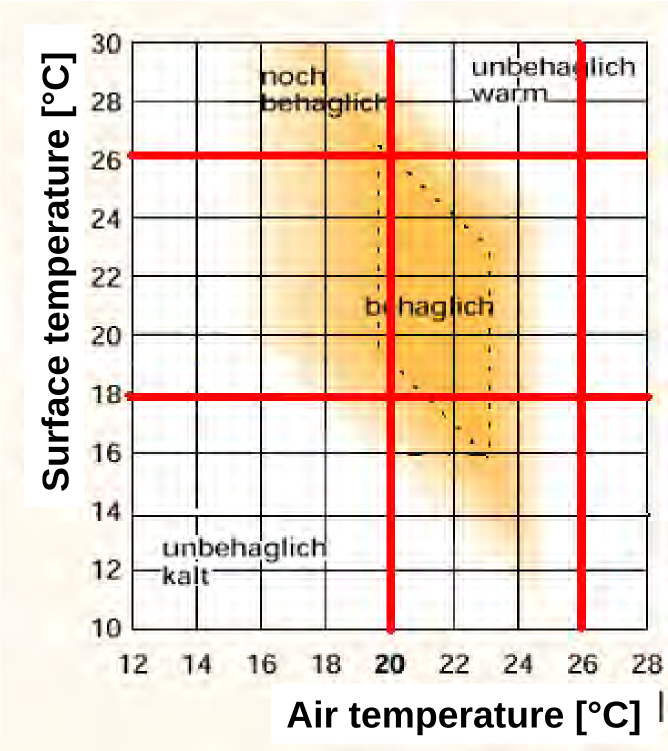
Area of comfort and relative humidity in %

- House dust mite

Main article: Asthma
Main article: Allergy

Source: http://de.wikipedia.org/wiki/Hausstaubmilbe

The „window“ of optimal comfort:



Surface - temperature: <26°C

Air- temperature: <25°C (night)
< 27°C (day)

Causes of local thermal discomfort

- Asymmetrical thermal radiation

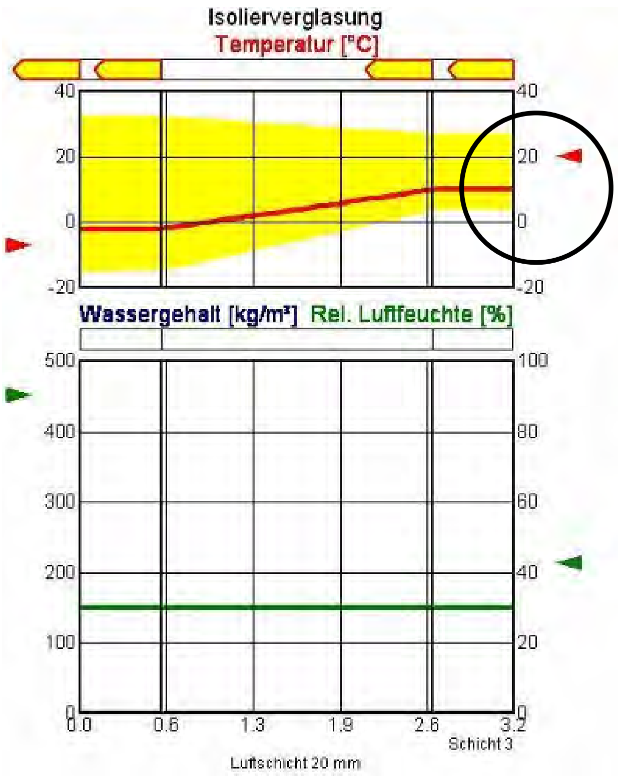
  (warm or cold floors / walls / ceiling) > 2,5 K

- Draft (air infiltration, air speed > 20 cm/sec)

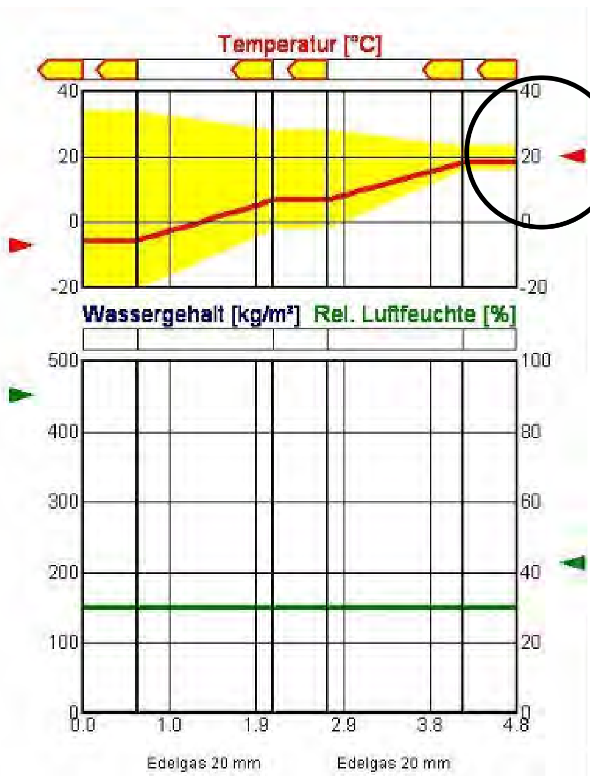
- Vertical air temperature stratification
  - For a standing person (> 2 K)
  - For a sitting person (> 1,5 K)

Development of High Quality Glazing in 20 Years

(1980) u = 2,30 W/m2K

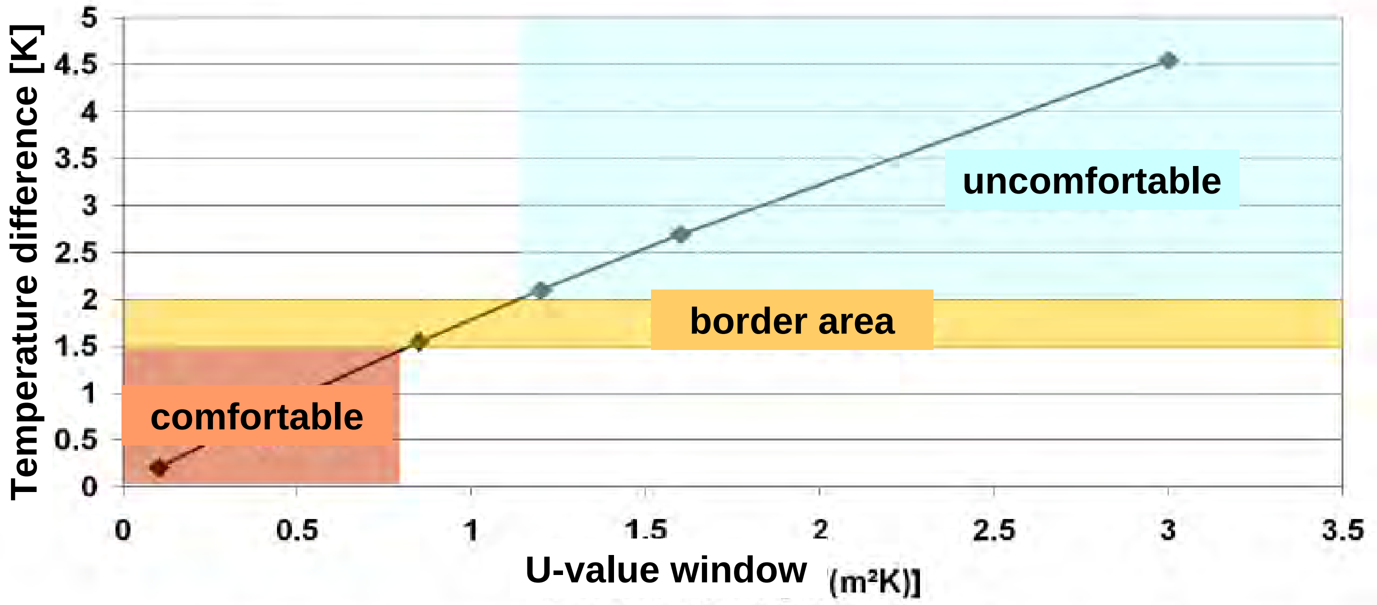


(2000) u = 0,70 W/m2K



Source: O. Pankratz / WUFI

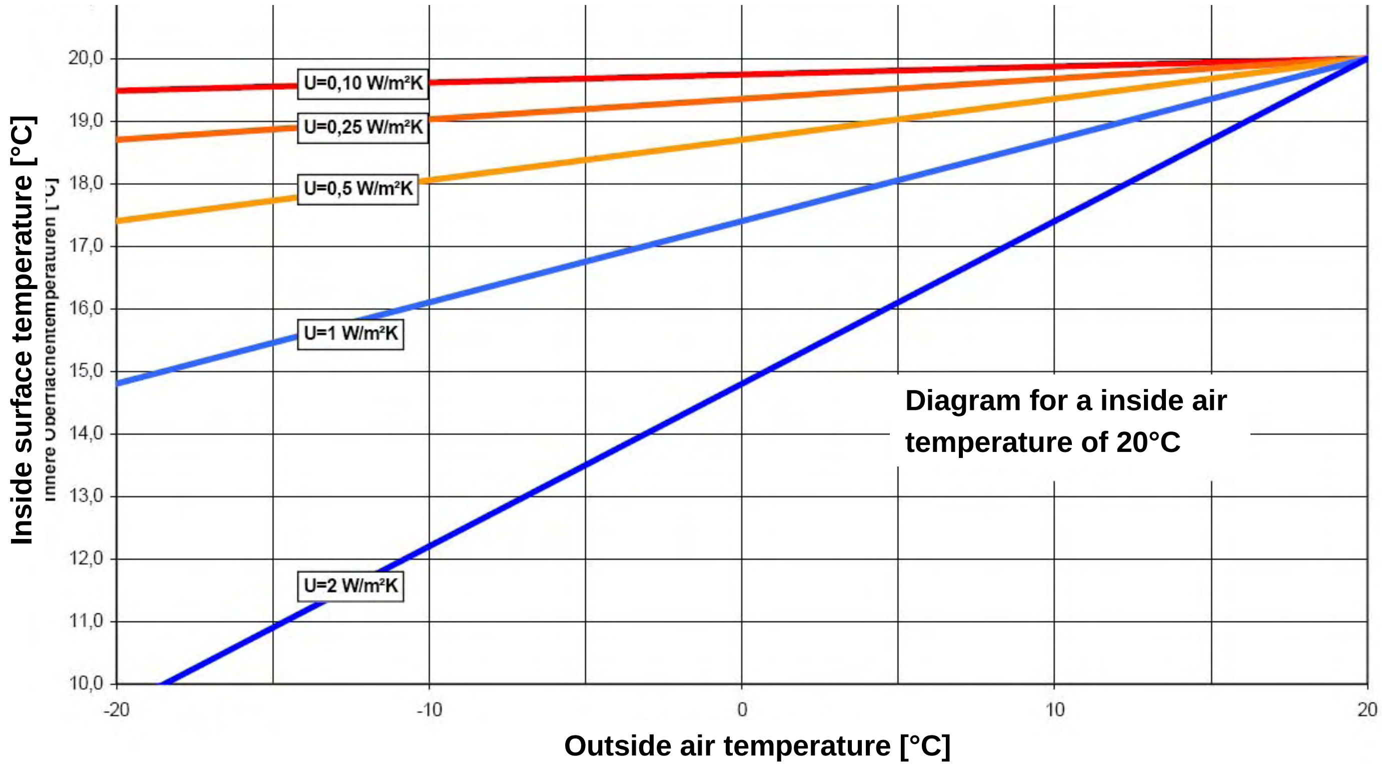
Influence of the U-value to the inside surface temperature difference



Temperature range between 0,1 and 1,1 high, 0,5 m in front of the window for 2,10 m high windows with different U-values

Source: HINWIN Hochwärmedämmende Fenstersysteme: Untersuchung und Optimierung im eingebauten Zustand, Anhang zum Teilbericht A, Picture 51, PHI

Influence of the U-value to the inside surface temperature



Source: P. Holzer, Donau Universität Krems

Comfort: Temperatures

Feeling of room temperatures

$$t_{felt\ temperature} = \frac{t_{room\ air} + t_{mean\ surfaces}}{2}$$

Source: ÖNORM EN 12831:2003

Passive house is comfort

Our comfort feeling is influenced from the difference of the surface temperatures of the surrounding walls.

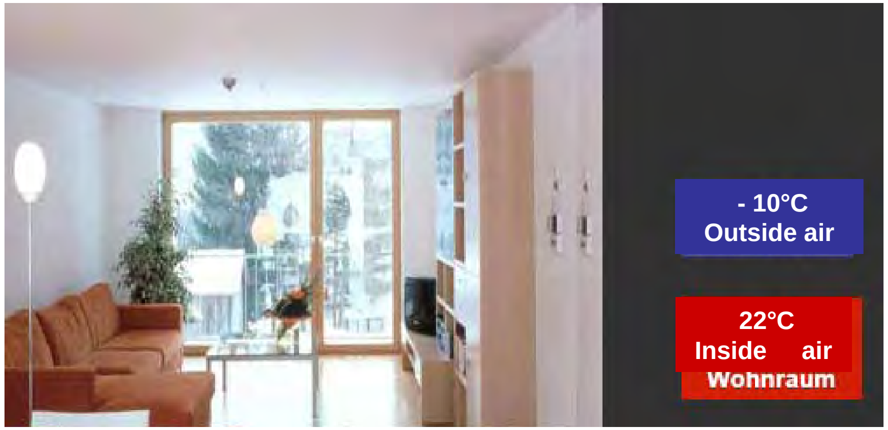
left semi space

right semi space

If this temperature difference (radiant symmetry) is less than 2.5 K we have a comfortable (cosy) living climate.

Source: Helmut Krapmeier, Energieinstitut Vorarlberg

Comfort: Radiation temperature - asymmetry



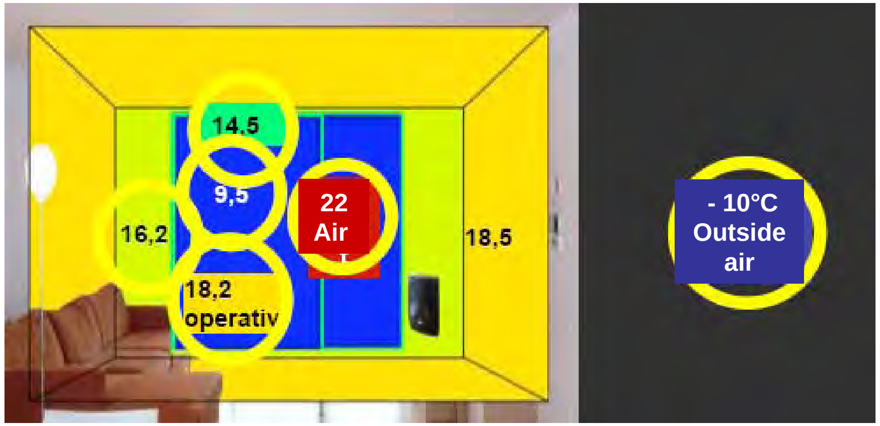
A living room:

In a new building?

In a redeveloped old building?

Source: Helmut Krapmeier, Energieinstitut Vorarlberg

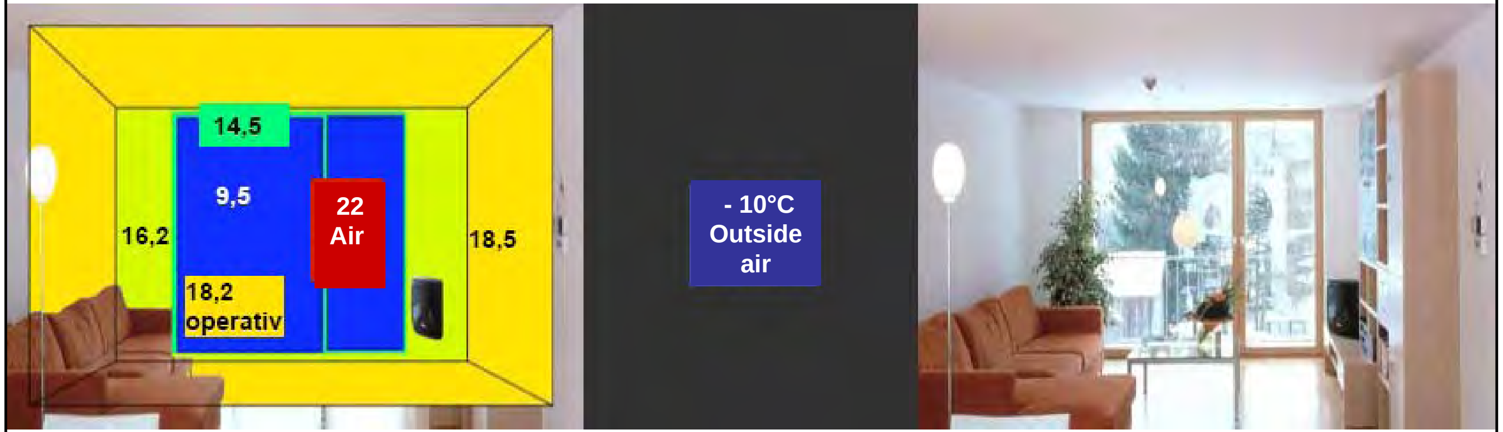
Comfort: Radiation temperature - asymmetry



Cold surfaces in badly insulated houses lead to asymmetrical radiation temperatures.

Source: Helmut Krapmeier, Energieinstitut Vorarlberg

Comfort: Radiation temperature - asymmetry



Cold surfaces in badly insulated houses lead to asymmetrical radiation temperatures.

Source: Helmut Krapmeier, Energieinstitut Vorarlberg

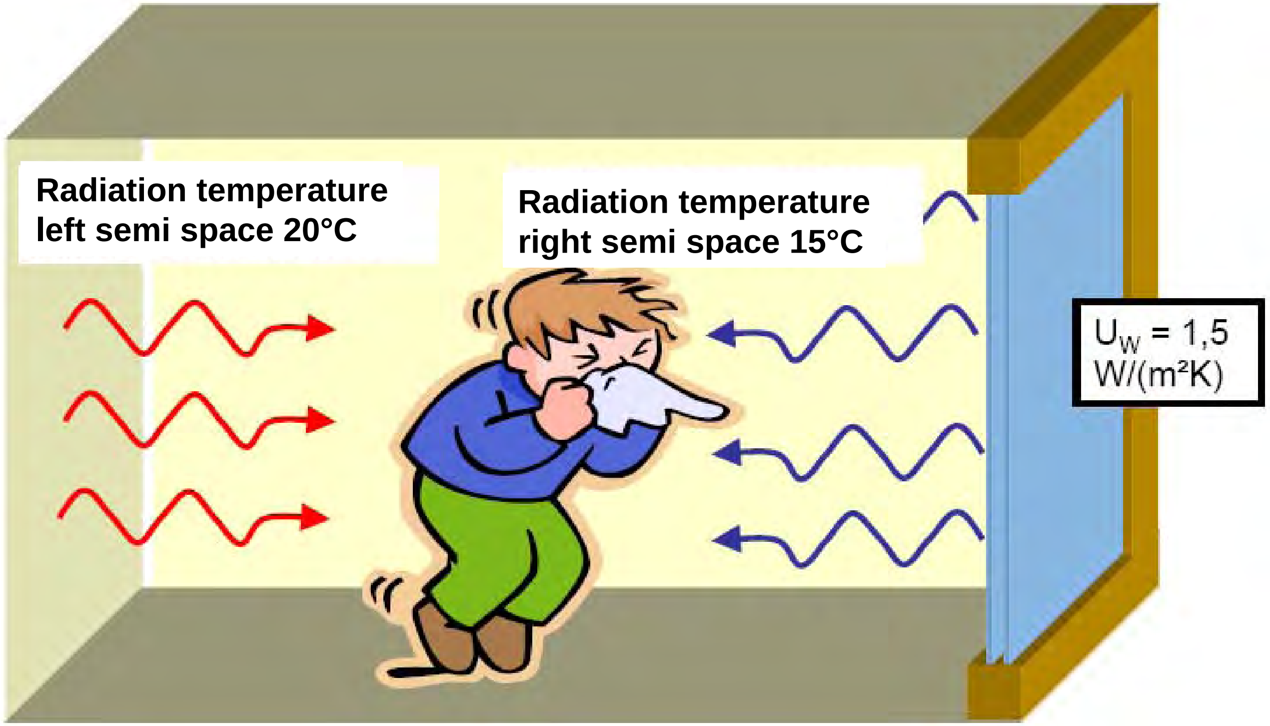
Comfort: Radiation temperature - asymmetry

Cold surfaces in badly insulated houses lead to asymmetrical radiation temperatures.

But in the passive house every surface is equal, moderatly warm as well as the windows. This results in a comfortable radiation climate.

Source: Helmut Krapmeier, Energieinstitut Vorarlberg

Radiant temperature – asymmetry with “normal” windows

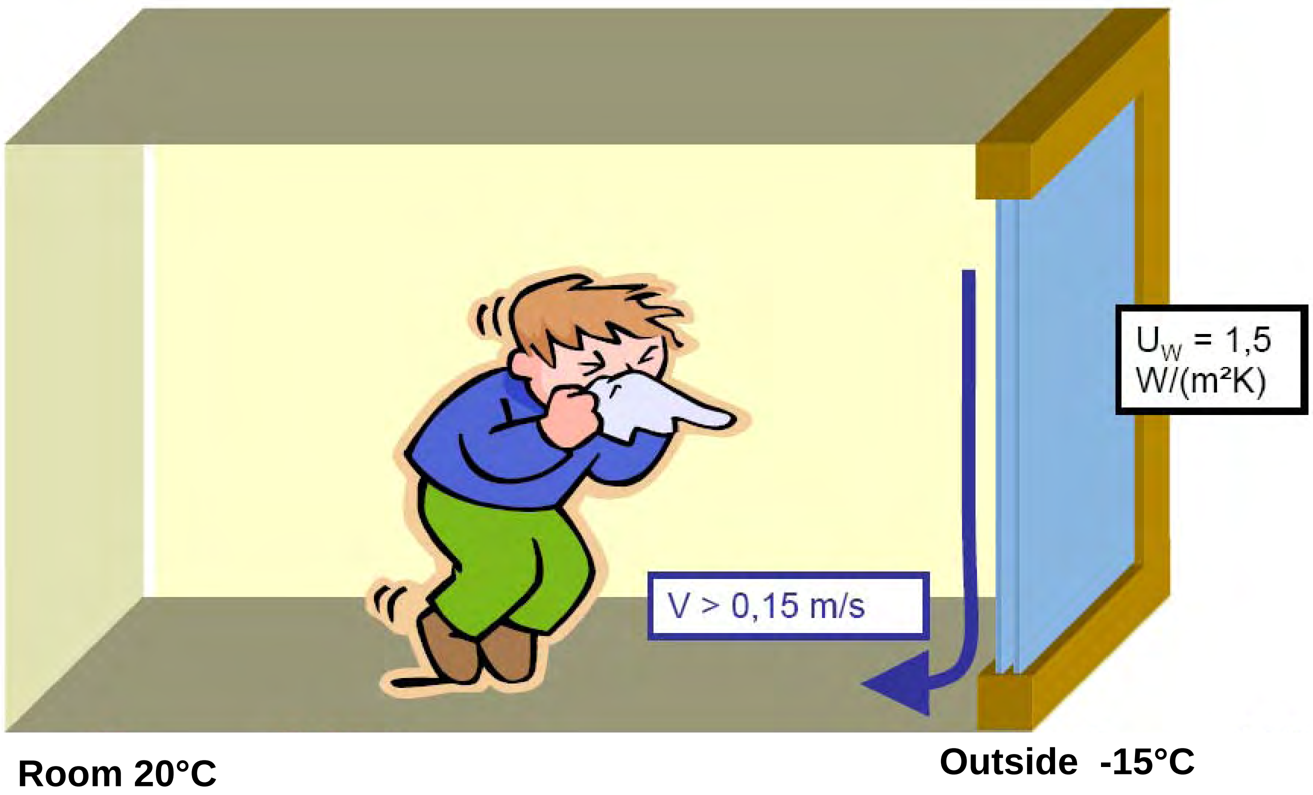


Room 20°C

Outside -15°C

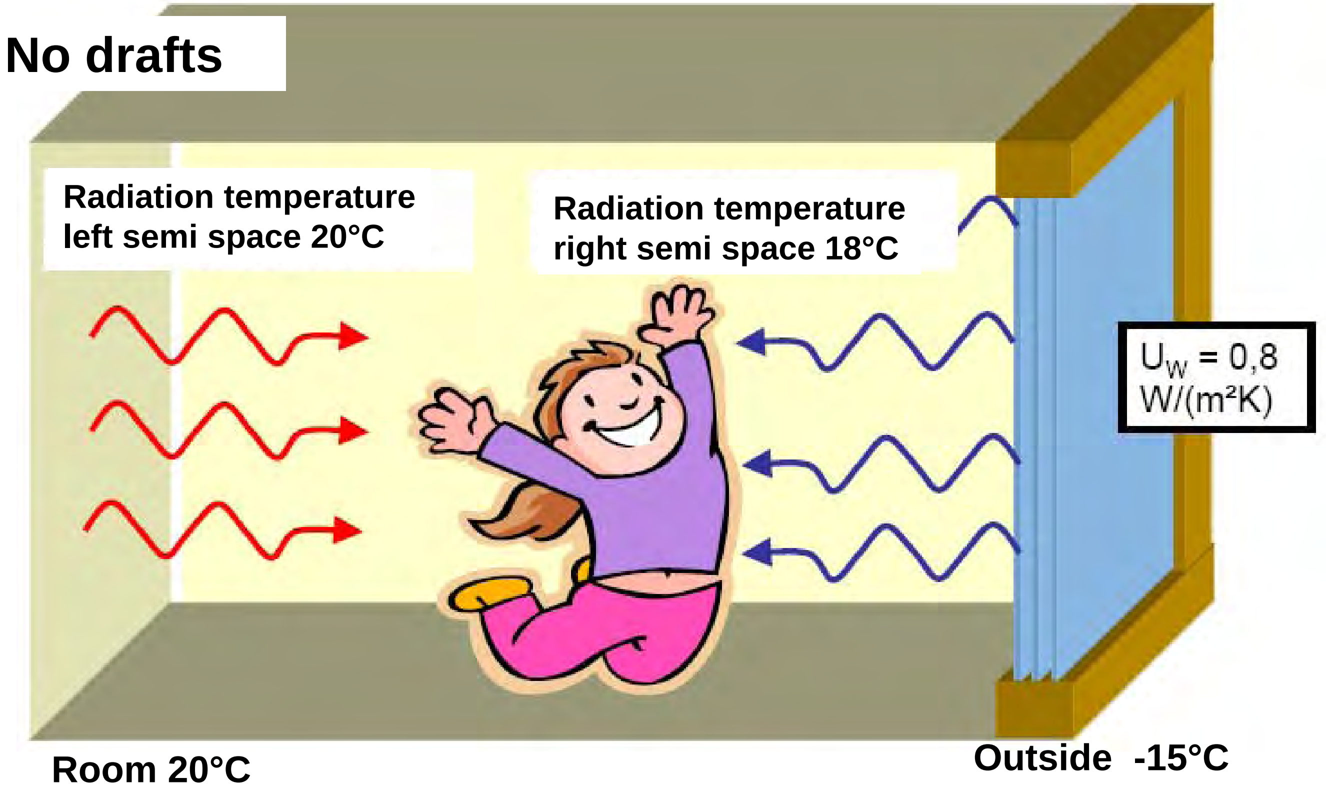
Source: Harald Krause, FH Rosenheim

Cold air flow – with “normal” windows

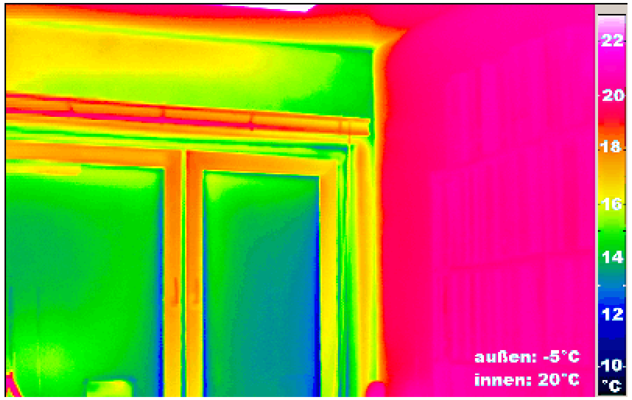


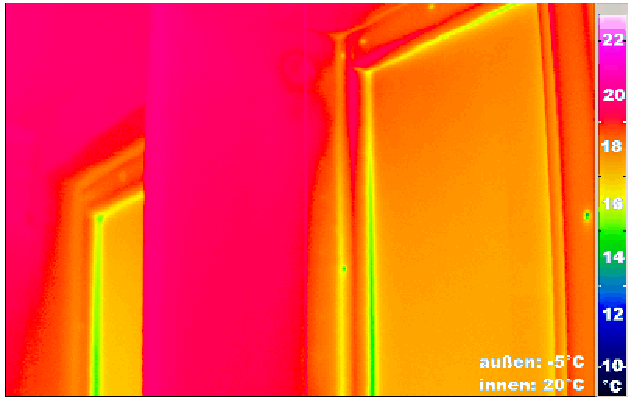
Source: Harald Krause, FH Rosenheim

Radiative temperature – asymmetry with PH-windows



Source: Harald Krause, FH Rosenheim





An old window: the middle surface temperatures are less than 14°C. Radiant temperature asymmetry causing draughts and a cold air mass.

IR-picture of a passive house window from the inside.
All surfaces are pleasantly warm (> 17°C): including frames and glazing. The temperature drops even on the edge of the glass no lower than 15° C.

Source: www.passivhaustagung.de/Passivhaus_D/Passivhaus_Behaglichkeit.html