Energy auditing - Trainings Program

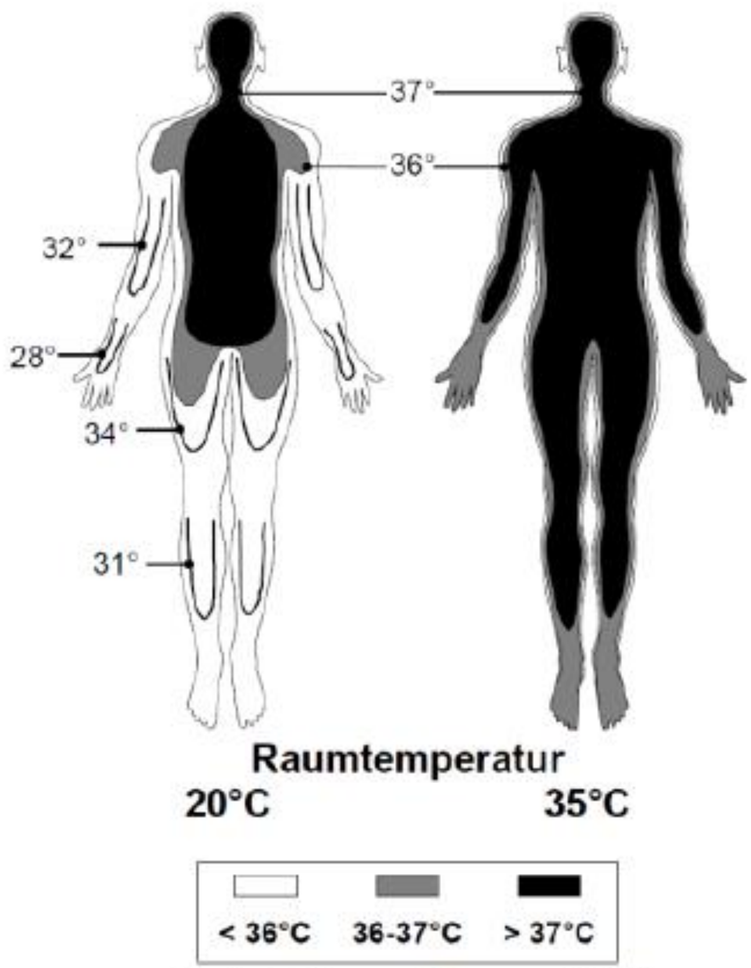
ENERGY AUDITS AND ENERGY EFFICIENCY DESIGN

23/11/2016

Overview

- Thermal comfort- theory in overview
- Impact of building elements and standards on thermal comfort, e.g. glass facade

Thermal comfort Introduction



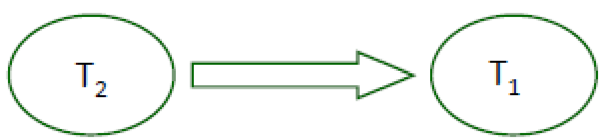
Quelle: Schierz und Krueger (2001)

- The core body temperature increases together with the indoor temperature. Heat is transferred between bodies with different temperature
- Optimal body core temperature ca. 37 °C
- The temperature „feel“ is dependent on age, weight, body type and constitiution , etc.

Second law of termodynamics; natural direction of heat flow is from hot to cold.

Heat transfer between objects:

- Conduction
- Convection
- Radiation



$(T_2 > T_1)$

Source: TU Wien, Institute Building physics & building Ecology

Thermal comfort
Subjective vs. Objective

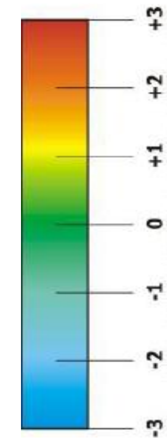
- Subjective
  - Simple questioners

- Objective
  - Comfort theory and measurements of comfort parameters
  - PPD (predicted percentage of dissatisfied) /PMV(predicted mean vote)
  - Psychometric charts

PMV
Predicted mean vote

The PMV index predicts the mean response of a larger group of people

+3 hot
+2 warm
+1 slightly warm
0 neutral
-1 slightly cool
-2 cool
-3 cold

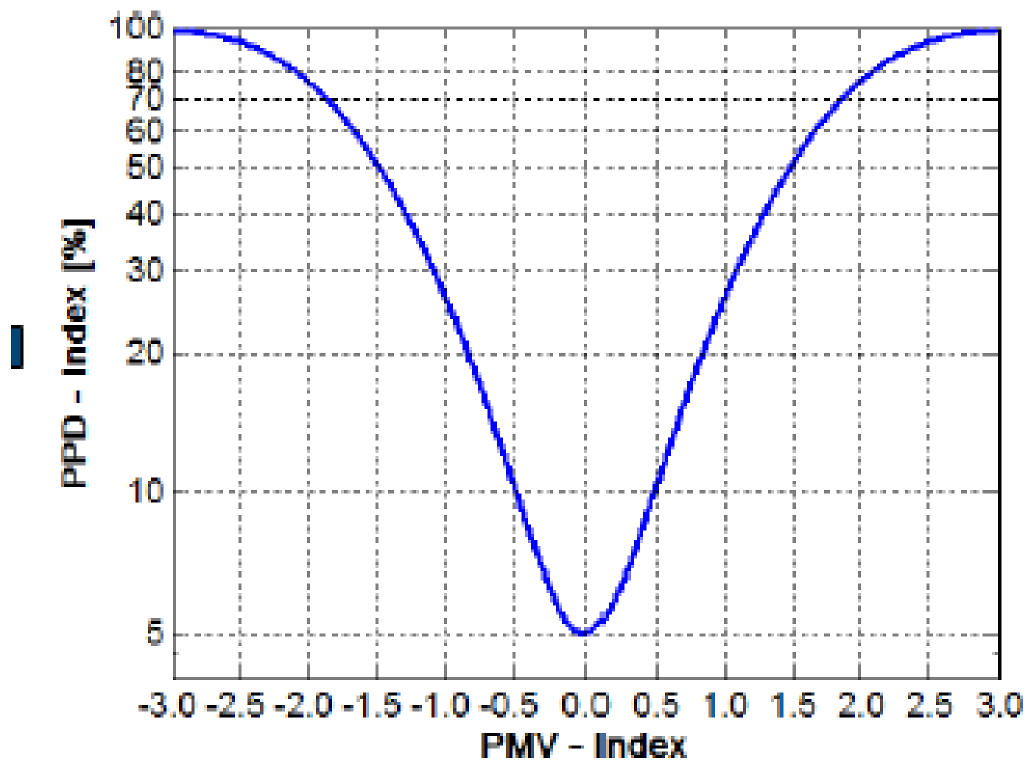


$$PMV = (0.303\, e^{-0.036M} + 0.028)\, L$$

M-metabolic rate
L- thermal load - the difference between the internal heat production and the heat loss to the actual environment - for a person at comfort skin temperature and evaporative heat loss by sweating at the actual activity level

PPD
predicted percentage of dissatisfied

Predicted Percentage Dissatisfied - PPD - index is a quantitative measure of the thermal comfort of a group of people at a particular thermal environment



Thermal comfort

- Main influencing parameteres of thermal comfort
  - Temperature (Air, Surface, Asymmetry)
  - Radiant temperature
  - Relative humidity
  - Air speed/turbulance
  - Activity (metabolic rate)
  - Clothing (clo-value)

Thermal comfort
Metabolic rate

- Expresseion of heat emission per m²

  1 met= 58.1 W/m2=50kcal/(h m²)

  For a 1,73m tall man,70 kg, AD= 1,8 m²

$$A_D = 0.202 m^{0.425} l^{0.725}$$

where

A_D = DuBois surface area, m^2
m = mass, kg
l = height, m

Source: TU Wien, Institute Building physics & building Ecology

Thermal comfort
Metabolic rate

Table 4 Typical Metabolic Heat Generation for Various Activities

	W/m²	met*
Resting		
Sleeping	40	0.7
Reclining	45	0.8
Seated, quiet	60	1.0
Standing, relaxed	70	1.2
Walking (on level surface)		
3.2 km/h (0.9 m/s)	115	2.0
4.3 km/h (1.2 m/s)	150	2.6
6.4 km/h (1.8 m/s)	220	3.8
Office Activities		
Reading, seated	55	1.0
Writing	60	1.0
Typing	65	1.1
Filing, seated	70	1.2
Filing, standing	80	1.4
Walking about	100	1.7
Lifting/packing	120	2.1

Source: 2005 ASHRAE Handbook – Fundamentals

Thermal comfort
Clothing factor (clo)

- Describes the thermal isolation of clothing
- 1 clo = 0,155 m^2K/W
- ISO 7730,ISO 9920 list of specific values

Table C.1 — Thermal insulation for typical combinations of garments

Work clothing	I_{cl}		Daily wear clothing	I_{cl}	
	clo	$m^2 \cdot K/W$		clo	$m^2 \cdot K/W$
Underpants, boiler suit, socks, shoes	0,70	0,110	Panties, T-shirt, shorts, light socks, sandals	0,30	0,050
Underpants, shirt, boiler suit, socks, shoes	0,80	0,125	Underpants, shirt with short sleeves, light trousers, light socks, shoes	0,50	0,080
Underpants, shirt, trousers, smock, socks, shoes	0,90	0,140	Panties, petticoat, stockings, dress, shoes	0,70	0,105
Underwear with short sleeves and legs, shirt, trousers, jacket, socks, shoes	1,00	0,155	Underwear, shirt, trousers, socks, shoes	0,70	0,110
Underwear with long legs and sleeves, thermo-jacket, socks, shoes	1,20	0,185	Panties, shirt, trousers, jacket, socks, shoes	1,00	0,155
Underwear with short sleeves and legs, shirt, trousers, jacket, heavy quilted outer jacket and overalls, socks, shoes, cap, gloves	1,40	0,220	Panties, stockings, blouse, long skirt, jacket, shoes	1,10	0,170
Underwear with short sleeves and legs, shirt, trousers, jacket, heavy quilted outer jacket and overalls, socks, shoes	2,00	0,310	Underwear with long sleeves and legs, shirt, trousers, V-neck sweater, jacket, socks, shoes	1,30	0,200
Underwear with long sleeves and legs, thermo-jacket and trousers, Parka with heavy quilting, overalls with heave quilting, socks, shoes, cap, gloves	2,55	0,395	Underwear with short sleeves and legs, shirt, trousers, vest, jacket, coat, socks, shoes	1,50	0,230

Source: ISO 7730

Western Balkans Investment Framework WBIF

ces CLEAN ENERGY SOLUTIONS

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Thermal comfort
Clothing factor (clo)

Table C.1 — Thermal insulation for typical combinations of garments

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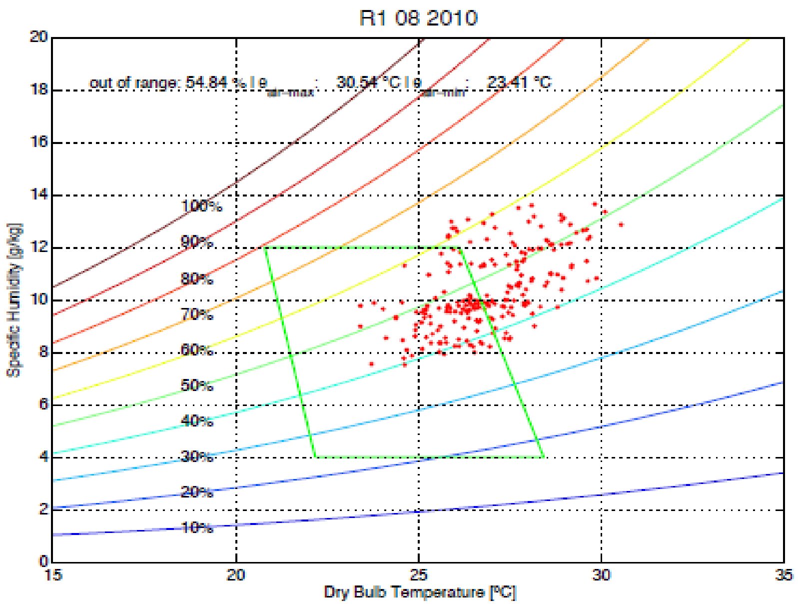
Source: ISO 7730

Psychometric chart



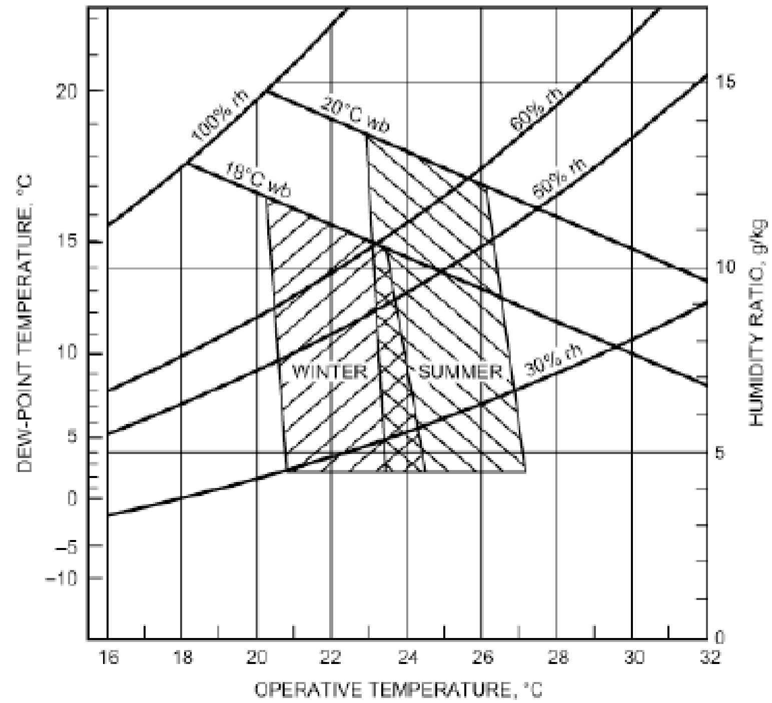


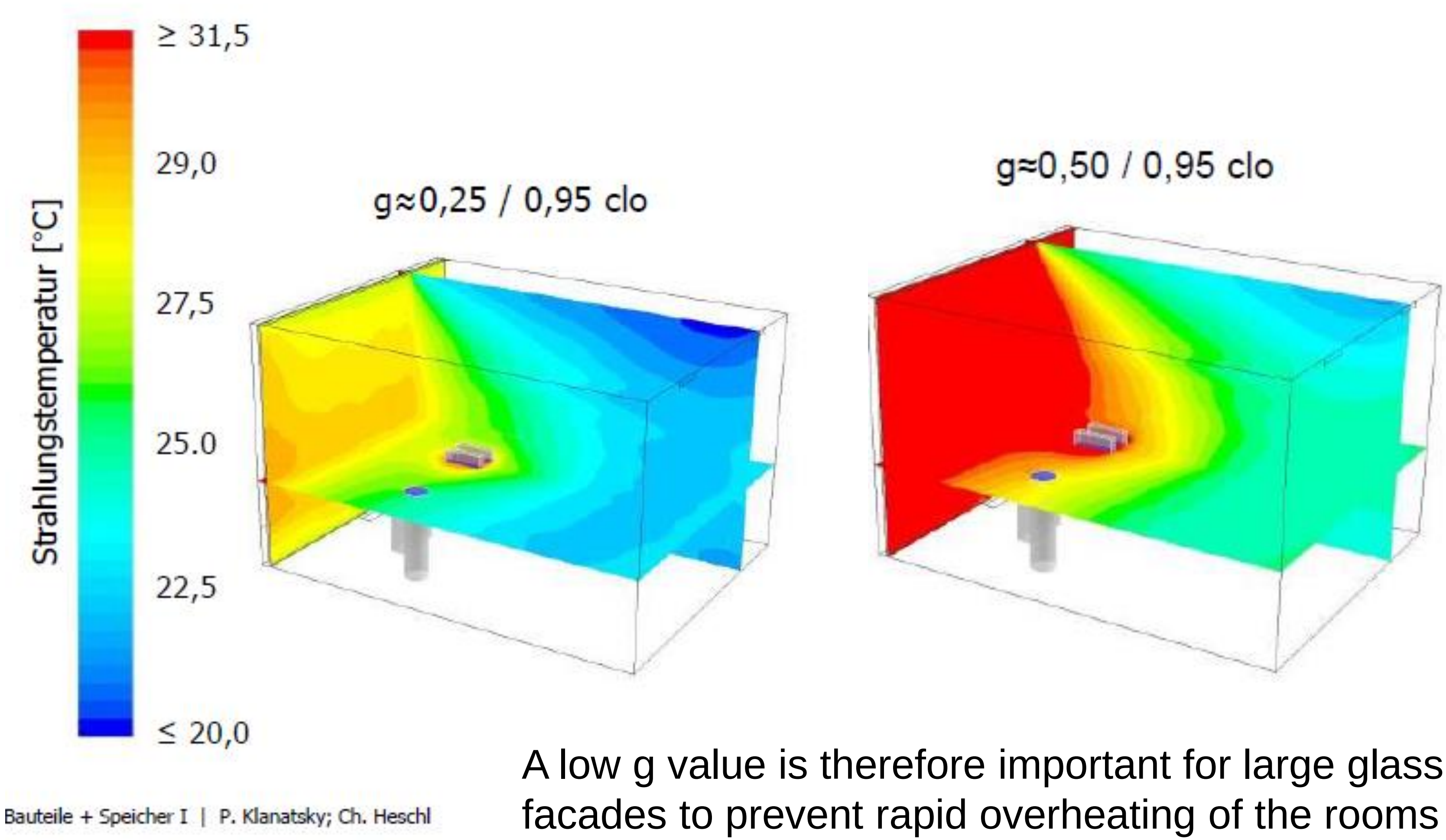
Fig. 5 ASHRAE Summer and Winter Comfort Zones
(Acceptable ranges of operative temperature and humidity for people in typical summer and winter clothing during primarily sedentary activity.)

Source: 2005 ASHRAE Handbook – Fundamentals

- Comfort area within a specific temperature/relative humidity rage

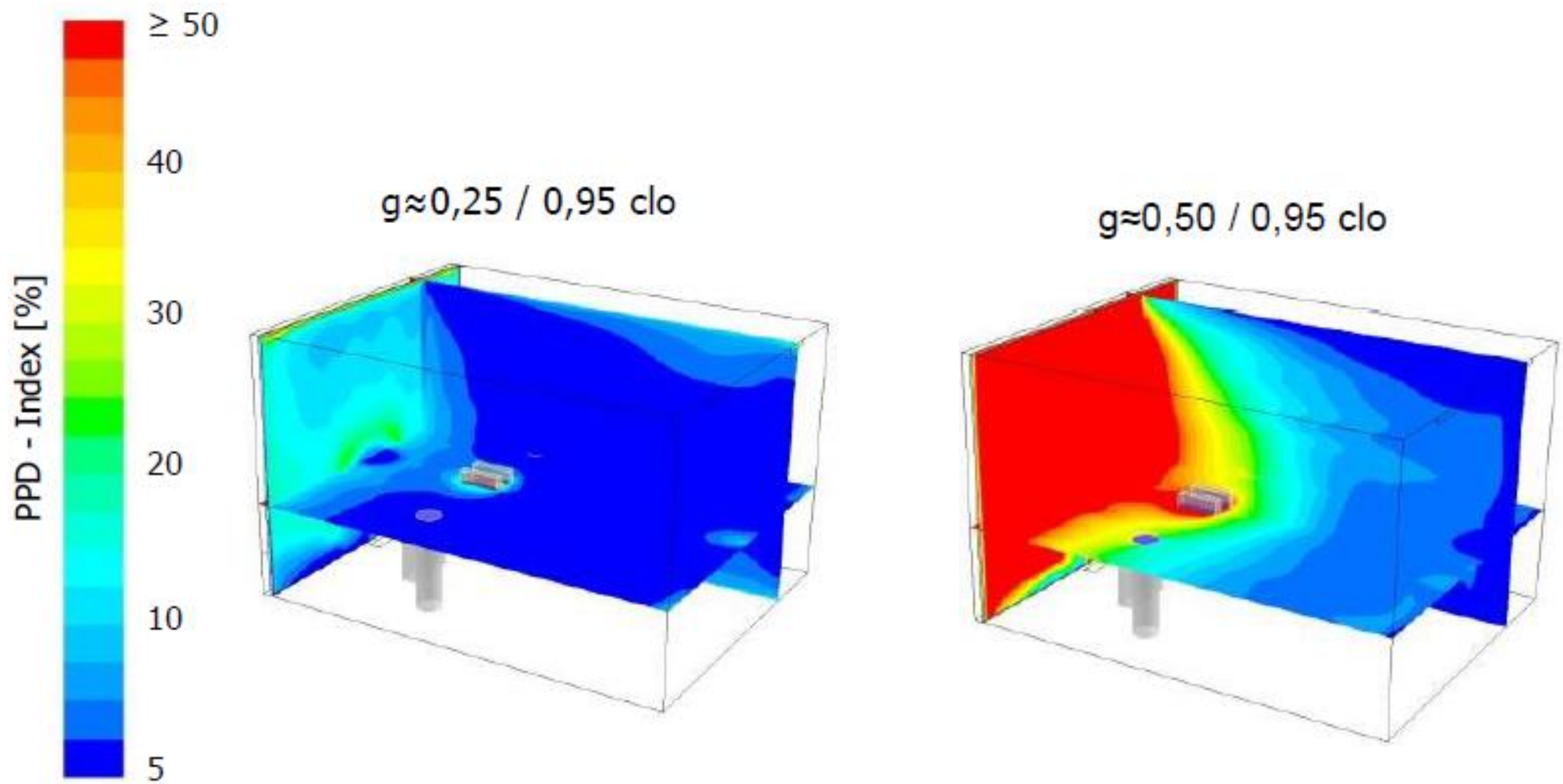
Thermal comfort

Impact of building elements



A low g value is therefore important for large glass facades to prevent rapid overheating of the rooms

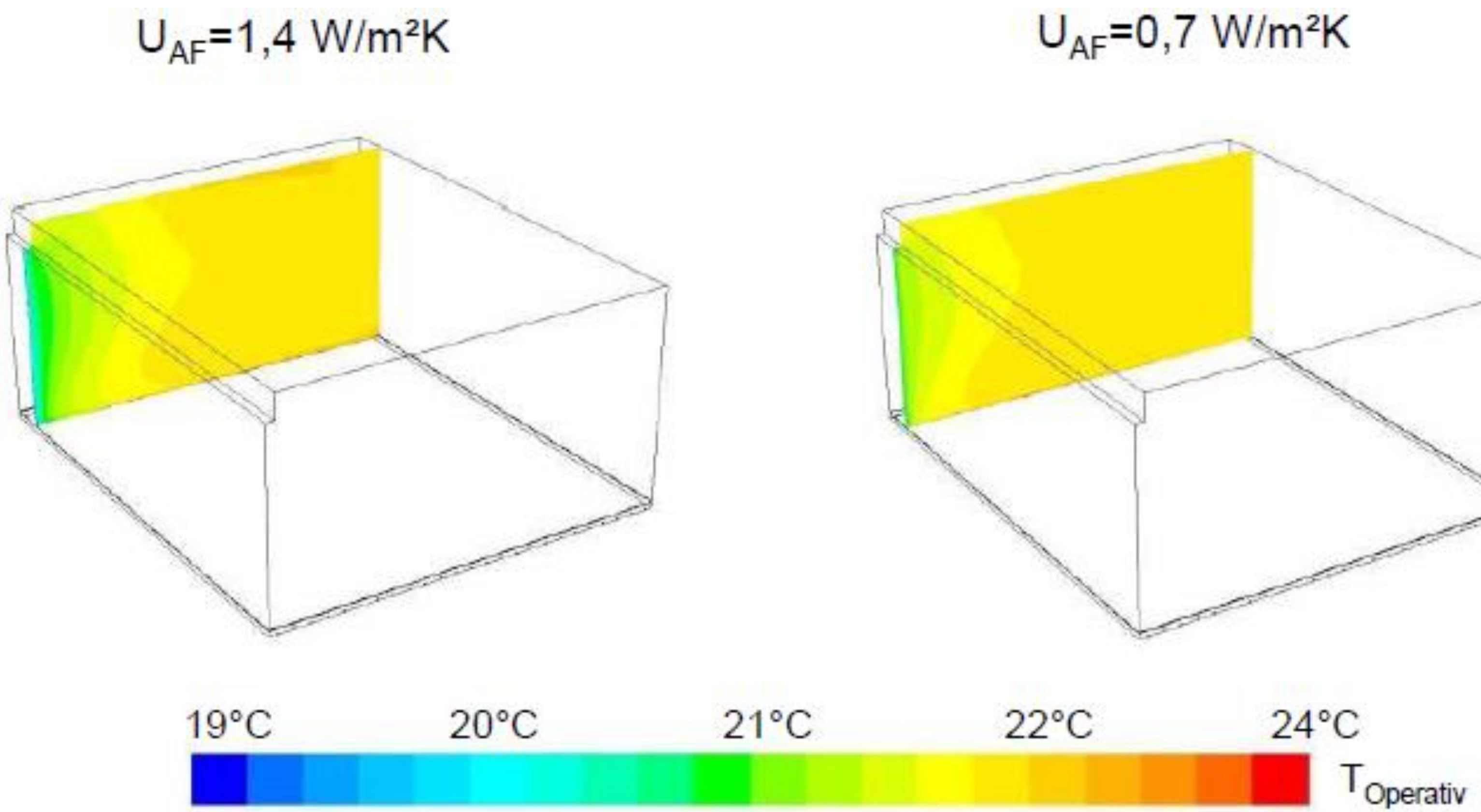
Thermal comfort
Impact of building elements-Glass facade



PPD Index

Bauteile + Speicher I | P. Klanatsky; Ch. Heschl

Thermal comfort
Triple vs. double glazing

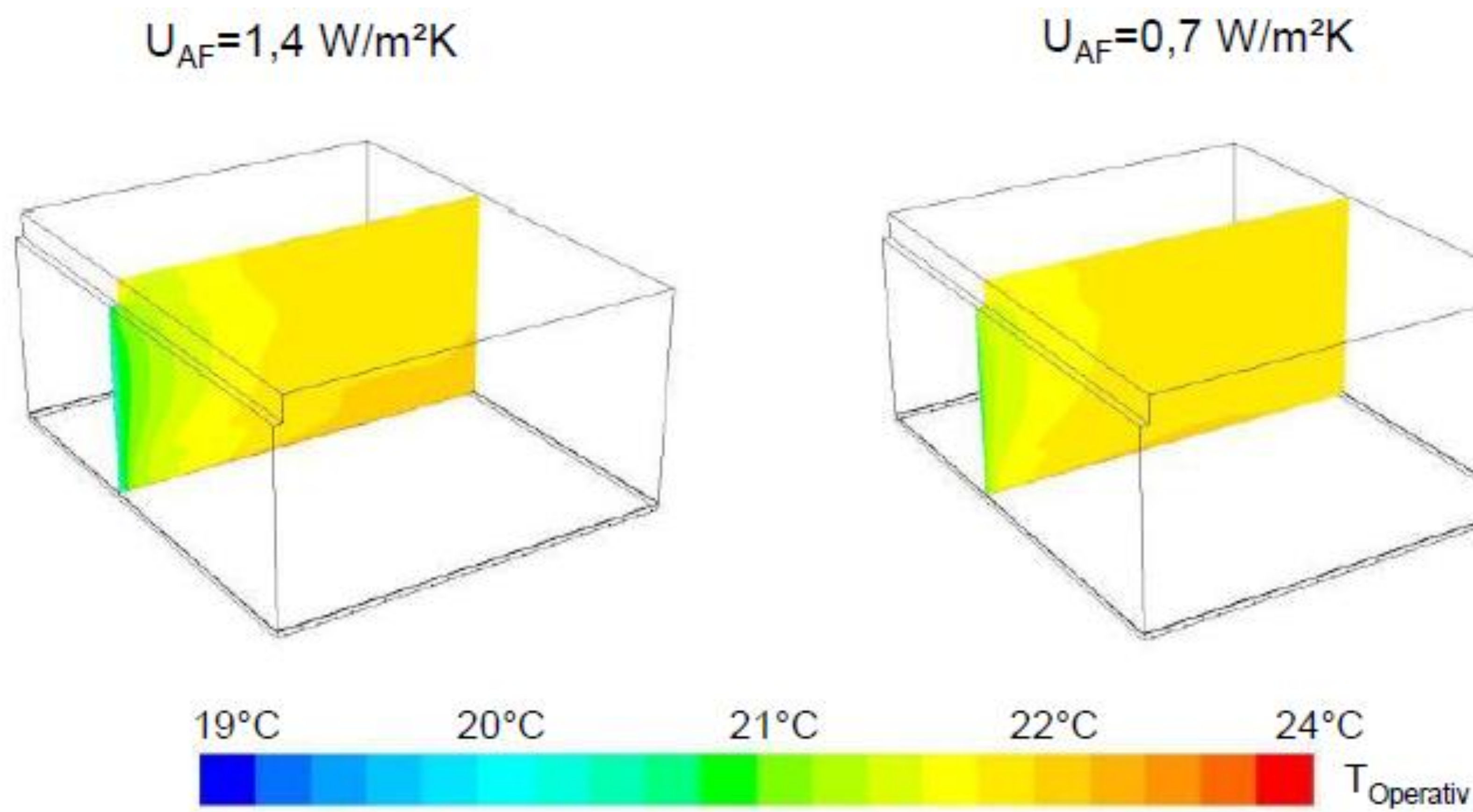


Example: glass facade with floor heating

Bauteile + Speicher I | P. Klanatsky; Ch. Heschl

Thermal comfort

Triple vs. double glazing



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Bauteile + Speicher I | P. Klanatsky; Ch. Heschl

Thermal comfort

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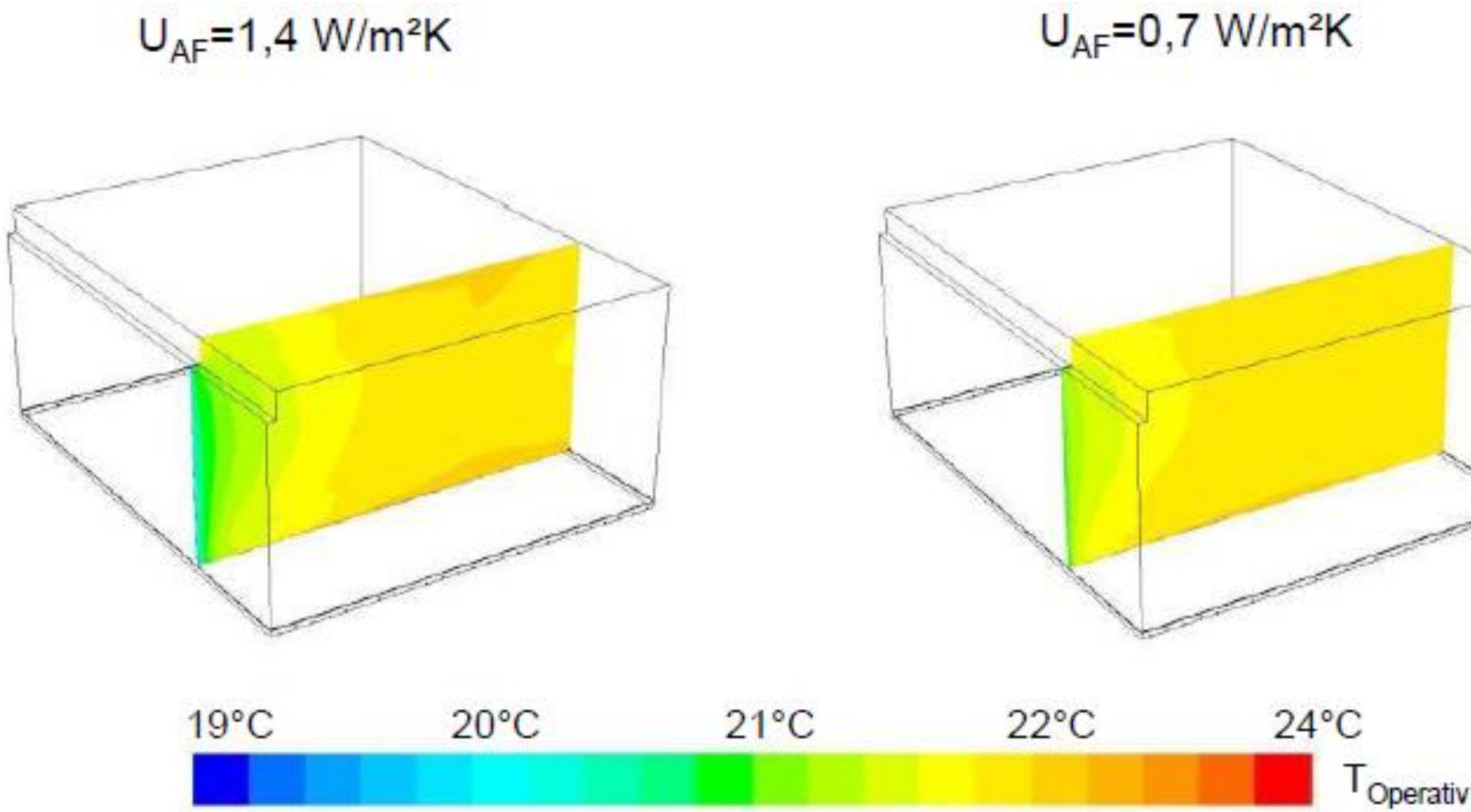

Example: glass facade with floor heating

Bauteile + Speicher I | P. Klanatsky; Ch. Heschl

Structure optimization measures

Optimization objectives:

- Reduction of heat loss through the building envelope
- Optimization of passive solar gains
- Optimized use of daylight
- Optimization of returns from PV and solar thermal
- Optimization of summer temperature behavior

↔ Relations ↔

Parameter:

- Compactness
- Portion of the south facade glazing
- Integration of PV and solar thermal components in south-facing exterior of the building envelope

Structure optimization measures

Relevant qestions:

- What architectural changes result from the advancement of the energy efficient building?
- How and where can the required space/room for renewable energy sources be provided?
- Which opposing interests do occur in the planning process?

Development of universal design recommendations:

➔ by representative model buildings
➔ based on model buildings according to building regulations and funding guidelines

Basis of estimating the Thermal Building behaviour:

Constant heat balance equation

With constant (i. e. **time independent**) view :

Heat losses = Heat gains

$$L_T \cdot (\Theta_i - \Theta_e) + L_V \cdot (\Theta_i - \Theta_e) = \Phi_s + \Phi_i + \Phi_h$$

(Mathematical representation)

Constant heat balance equation

$$L_T \cdot (\Theta_i - \Theta_e) + L_V \cdot (\Theta_i - \Theta_e) = \Phi_s + \Phi_i + \Phi_h$$

Transmission

Ventilation

Heat losses

$\mathrm{L_T} \cdot (\Theta_\mathrm{i} - \Theta_\mathrm{e})$ Transmission heat losses

$\mathrm{L_V} \cdot (\Theta_\mathrm{i} - \Theta_\mathrm{e})$ Ventilation heat losses

Unit: W

$$L_T \cdot (\Theta_i - \Theta_e) + L_V \cdot (\Theta_i - \Theta_e) = \Phi_s + \Phi_i + \Phi_h$$

Transmission

Ventilation

Factors of proportionality

L_T thermal (Transmission-) **Conductance** of building envelope

L_V **Ventilation conductance**

Unit: WK^{-1}

Boundary conditions

Θ_i Internal air temperature

Θ_e Ambient air temperature

Unit: K

Constant heat balance equation

$$L_T \cdot (\Theta_i - \Theta_e) + L_V \cdot (\Theta_i - \Theta_e) = \Phi_s + \Phi_i + \Phi_h$$

Heat gains

Φ_s Solar heat gains

Φ_i Heat gains caused by building use

Φ_h Heat gains caused by heating devices

Unit: W

Constant heat balance equation

$$L_T \cdot (\Theta_i - \Theta_e) + L_V \cdot (\Theta_i - \Theta_e) = \Phi_s + \Phi_i + \Phi_h$$

Applicabilities

- Heating load calculation
- Calculation of heating demand
- Calulation of summer behaviour

Climatic boundary conditions

Significant influences on the thermal building behaviour:

- ambient air temperature
- solar radiation

$$L_T \cdot (\Theta_i - \Theta_e) + L_V \cdot (\Theta_i - \Theta_e) = \Phi_s + \Phi_i + \Phi_h$$

Ambient air temperature

A) Instantaneous values

Designated use

Input values for the simulation of the thermal behaviour of buildings and building constructions

Most commonly used:

- hourly data over the year (8760 values)
- long-time monthly mean values should be garantueed by the test reference year
  ⟹ ***half-synthetic climate data (HSKD)***

Ambient air temperature

B) Mean values

Designed use

Input values for simplified calculation approaches (heat and energy demand)

Most commonly used:

- long-time monthly means (12 values)
- means are to built at least over 10 years (EN ISO 15927-4) ; default: 30 years (WMO)

Solar radiation

A) Instantaneous values

Designated use

Input values for the simulation of the thermal behaviour of buildings and building constructions

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- hourly data over the year (8760 values)
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Input values for simplified calculation approaches (heat and energy demand)

Most commonly used:
- long-time monthly means (12 values)
- means are to built at least over 10 years (EN ISO 15927-4) ; default: 30 years (WMO)

Design strategy: Minimizing heat losses

goal: **Reduction of heat power by reduction of heat losses**

$$\Phi_h = \underline{L_T \cdot (\Theta_i - \Theta_e)} + \underline{L_V \cdot (\Theta_i - \Theta_e)} - \Phi_s - \Phi_i$$

Transmissions heat losses

and / or

Ventilation heat losses

Design strategy: Minimizing heat losses

Reduction of transmission heat losses $$L_T \cdot (\Theta_i - \Theta_e)$$

$(\Theta_i - \Theta_e)$ depend on building use and climate

→ therefore **hardly alterable!**

L_T depends on U-values, areas, thermal bridges

→ **substantial suggestible** by the designer!

↓

Reduction of transmission heat losses necessitates design measures for **minimizing the transmission conductance** !

Design strategy: Minimizing heat losses

Reduction of the Transmission Conductance

$$L_T = \sum_i U_i \cdot A_i + \sum_j \psi_j \cdot l_j + \sum_k \chi_k$$

Design measures:

Reduction of the U-values – improved insulation

Reduction of areas – Minimizing the area of the building envelope
- Increasing the compactness of the building

Reduction of correction factors in view of thermal bridges – pain-taking design of building details!

Design strategy: Minimizing heat losses

Reduction of Ventilation heat losses $L_V \cdot (\Theta_i - \Theta_e)$

L_V Depends on the required hygienic vetilation rate and on ventilation requirements caused by the prevention of mould growth

→ therefore (for present-day buildings) **hardly alterable!**

$(\Theta_i - \Theta_e)$ Depends on the temperature of the incoming air

→ **suggestible** by the designer !

↓

Reduction of ventilation heat losses necessitates design measures for **increasing the temperature of the incoming air**!

Design strategy: Minimizing heat losses

Increasing the temperature of the incoming air: $(\Theta_i - \Theta_e) \rightarrow (\Theta_i - \Theta_z)$

Design measures:

→ **Include ventilation heat recovery system!**
(outgoing air warms up incoming air)

→ **Incoming air is warmed up by soil-heat exchanger**
[heat is detracter from the soil (winter) / heat is absorbed by the soil (summer)]

↓

Reduction of ventilation heat losses necessitates **controlled ventilation** (ventilation system) and an **air-tight building envelope**!

Design strategy: Maximizing heat gains

goal: **Reduction of the heat demand by increasing heat gains**

$$\Phi_h = L_T \cdot (\Theta_i - \Theta_e) + L_V \cdot (\Theta_i - \Theta_e) - \underline{\Phi_s} - \underline{\Phi_i}$$

Solar heat gains

and / or

Heat gains caused by building use

Design strategy: Maximizing heat gains

Increase of heat gains

$\Phi_i = \Phi_P + \Phi_G$ Dependant on the building use

→ therefore **hardly alterable!**

Φ_S Dependant on kind, size and position of the windows

→ **substantial suggestible** by the designer!

↓

Enlarging internal heat gains necessitates design measures for **increasing solar heat gains**!

Design strategy: Maximizing heat gains

Calculation of heat gains caused by solar radiation:

Heat power caused by solar radiation incoming through the transparent part of the window:

$$\Phi_s = \boldsymbol{B} \cdot \boldsymbol{A}_g \cdot \boldsymbol{g} \cdot \boldsymbol{r} \cdot \boldsymbol{z}$$

Φ_s ... Heat gain inside the room [W]

$\boldsymbol{B}$ ... Solar irradiation[Wm^{-2}]

$\boldsymbol{A}_g$... Area of the glass [m^2]

$\boldsymbol{g}$ ... g-value

$\boldsymbol{r}$ ... Reduction factor for ***g***

(angle of incidence, soiling)

$\boldsymbol{z}$ ... Shading factor

Design strategy: Maximizing heat gains

Total solar energy transmittance

The total solar energy transmittance of a glass is that part of the solar irradiance inclining on the external surface of the glass, which takes effect as solar heat gain inside the room.

The g-value is comprised by the the radiation transmission factor τ_s and the secundary heat emission factor q_i :

$$g = \tau_s + q_i$$

The total solar energy transmittance is defined for solar radiation impinging perpendicular upon the glass.

Design strategy: Maximizing heat gains

Total solar energy transmittance for several glasses

Bezeichnung	U_g	τ_s	g
Einfach-Glas 6 mm	5.8	0.80	**0.83**
Zweifach-Isolierglas Klarglas 6-8-6	3.2	0.65	**0.71**
Zweifach-Isolierglas Klarglas 6-12-6	2.9	0.65	**0.71**
Zweifach-Isolierglas Klarglas 6-16-6	2.7	0.65	**0.72**
Zweifach-Verbundfenster Klarglas 6-30-6	2.7	0.65	**0.72**
Dreifach-Isolierglas Klarglas 6-12-6-12-6	1.9	0.53	**0.63**
Zweifach-Wärmeschutzglas beschichtet 4-16-4 (Luft) $\varepsilon \leq 0.05$	1.5	0.48	**0.61**
Zweifach-Wärmeschutzglas beschichtet 4-15-6 (Ar) $\varepsilon \leq 0.1$	1.3	0.47	**0.61**
Zweifach-Wärmeschutzglas beschichtet 4-12-4 (Kr) $\varepsilon \leq 0.05$	1.1	0.49	**0.62**
Zweifach-Wärmeschutzglas beschichtet 4-12-4 (Xe)	0.9	0.49	**0.62**
Dreifach-Wärmeschutzglas beschichtet 4-8-4-8-4 (Kr) $\varepsilon \leq 0.05$	0.7	0.29	**0.48**
Dreifach-Wärmeschutzglas beschichtet 4-8-4-8-4 (Xe)	0.5	0.29	**0.48**

Source: ÖNorm B8110-1

Design strategy: Maximizing heat gains

Reference values for the reduction factor

The reduction factor *r* lies in the range of 0,8 and 0,9 in winter time.

During summertime the reduction factor is dependant on the orientation of the glasses:

Orientierung	***r***
Süd	**0,65**
Ost /West	**0,80**
Nord	**0,70**

Design strategy: Maximizing heat gains

The shading factor z

Shadowing can strongly affect the heat gains caused by solar radiation:

Shadowing by

- skyline
- adjacent buildings
- shape of the building
- design of the facade
- blinds

Shading factor *z*: Reduction factor for irradiation

Design strategy: Maximizing heat gains

Shading devices: Venetian blinds, Sreens, outside awning blinds, sun sails, ...

Shading factor ***z***: Reduction factor for the g-value

Abschattungsvorrichtung	Abminderungsfaktor z
keine Abschattungsvorrichtung	**1,00**
Außenjalousie, Fensterläden mit Jalousiefüllung (beweglich, unterlüftet, Belichtung ohne künstliche Beleuchtung möglich)	**0,27**
Zwischenjalousie	**0,53**
Innenjalousie (je nach Farbe und Material)	**0,75**
beschattungswirksame Vordächer, Balkone und horizontale Lamellenblenden	**0,32**
Markisen (seitlicher Lichteinfall möglich)	**0,43**
Rolläden, Fensterläden mit voller Füllung	**0,32**
helle Innenvorhänge, Reflexionsvorhänge und Innenmarkisen	**0,75**
Bepflanzung	**0,50 bis 1,00**

Source: ÖNorm B8110-3

Design strategy: Maximizing heat gains

Enlargement of the solar heat gains

$$\Phi_s = B \cdot A_g \cdot g \cdot r \cdot z$$

Design measures:

- Enlarge the solar input by appropriate orientation of the windows (optimum for europe: south orientation)
- Appropriate dimensioning of the window areas
- Applicate glasses with high g-values
- Avoid shadowing during winter season / Enable shadowing in summer (design of facades / use of blinds)

Summer behaviour of rooms

Standards:

Guide lines with regard to calculation parameters:

→ **International standards (EN and/or ISO)**

Definition of acceptable summer temperatures:

→ **National standards**

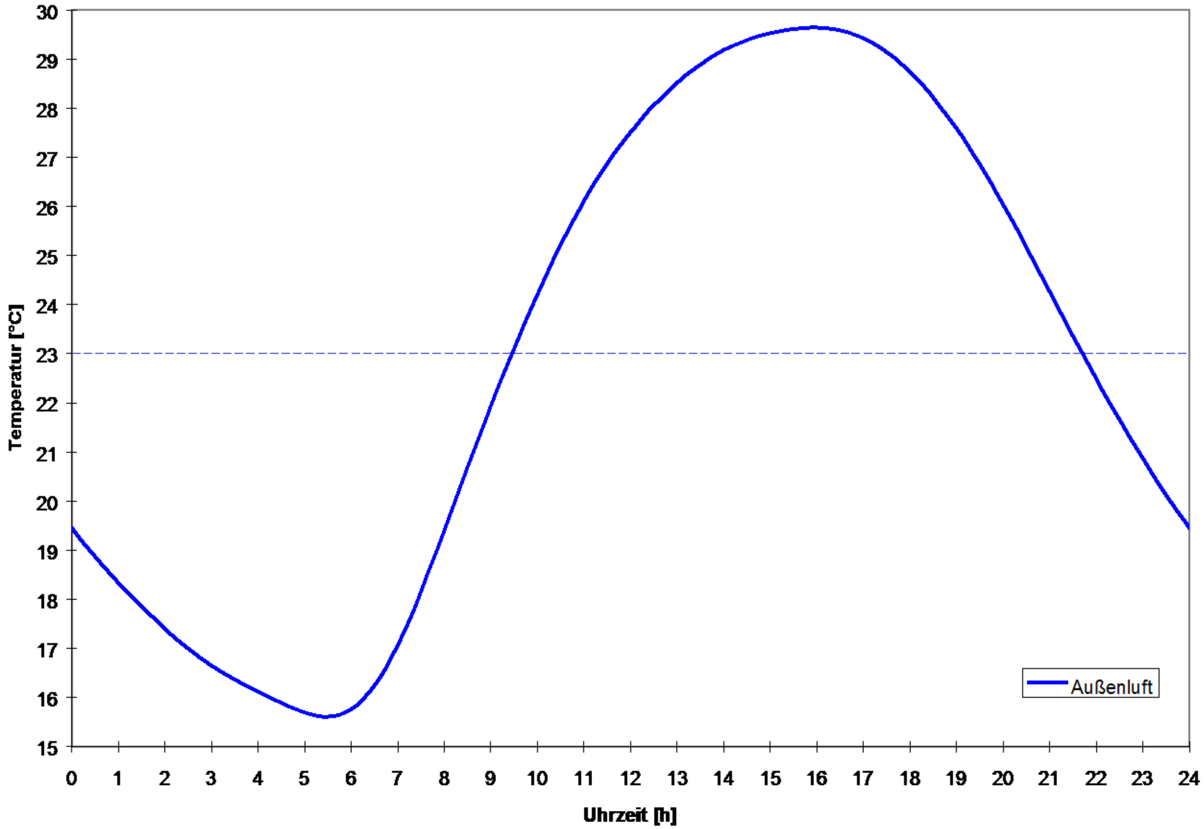
↓

Austria: ÖNorm B8110-3:1999

Definition of summer climate (Austria)

Standardized climate:

Ambient air temperature: $\Theta_e \Rightarrow 23{,}0\,°C \pm 7{,}0\,K$



Definition of summer climate (Austria)

Standardized climate:

Solar radiation:

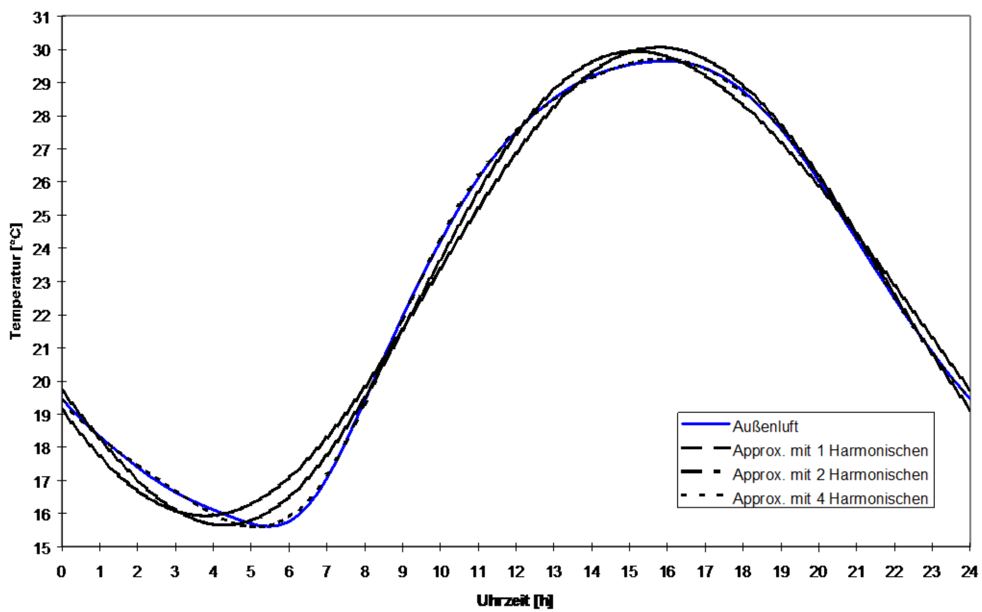
- **Haziness factors:** **Linke: 4,5**
  Reitz: 0,333
  Albedo: 0,2
- **Date: July 15**
- **location: building site** or **Vienna** (Hohe Warte)

Definition of summer building -behaviour (Austria)

Calculation method: periodic calculation

➡ **Period length:** 1 day (24 h)

➡ **Calculation model: Fourier-analysis**

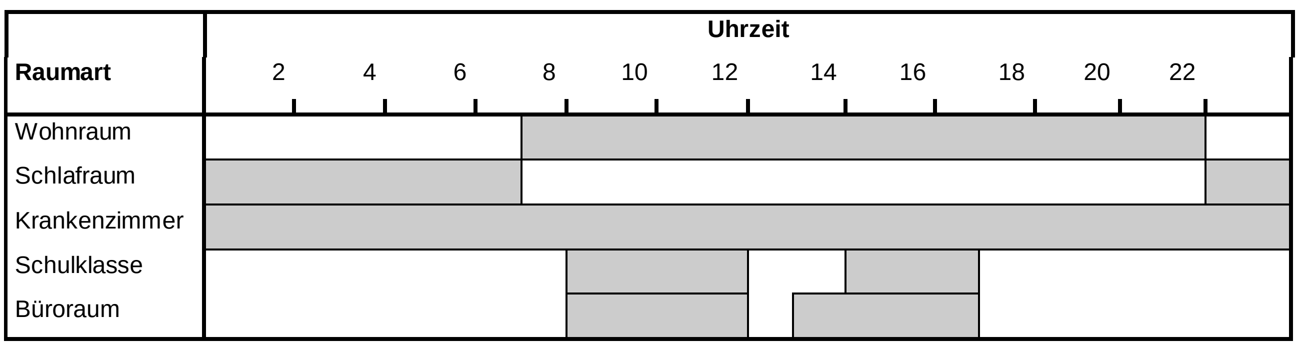


Definition of acceptable summer temperatures (Austria)

Standardized indoor climate:

A room fulfills the demands of standards with regard to its thermal summer behaviour, if the *operative temperature* does not exceed

- **27 °C for rooms used during day**
- **25 °C for rooms used during night**



Source: ÖNorm B8110-3

Methods of calculation summer behaviour

1. Hand calculation → **Daily mean of internal air temperature**

2. Standardized calculation according to ÖNorm B8110-3 (Austria) → **Yes/no – decision (rough estimate)**

3. periodic simulation

→

- **daily course of internal air temperature**
- **daily courses of surface temperatures**
- **daily cours of operating temperature**
- **depending on building building site, climate, Shading measures, ventilation strategies, …**

- **suitable for for proof of summer behaviour and**
- **optimization of internal summer climate**

Rough estimation of summer behaviour (hand-calculation):

$$L_T \cdot (\Theta_i - \Theta_e) + L_V \cdot (\Theta_i - \Theta_e) = \Phi_s + \Phi_i + \Phi_h$$

Constant calculation leads to the **daylу mean of the internal air temperature**:

$$\Theta_i = \Theta_e + \frac{\Phi_s + \Phi_i}{L_T + L_V} + \frac{\Phi_h}{L_T + L_V} \quad [°C]$$

$$\Delta\Theta$$

Rough estimation of summer behaviour (hand-calculation):

$$L_T \cdot (\Theta_i - \Theta_e) + L_V \cdot (\Theta_i - \Theta_e) = \Phi_s + \Phi_i + \Phi_h$$

Constant calculation leads to the **daylymean of the internal air temperature**:

$$\Theta_i = \Theta_e + \frac{\Phi_s + \Phi_i}{L_T + L_V} - \frac{\Phi_k}{L_T + L_V} \quad [°C]$$

$$\Delta\Theta$$

Rough estimation of summer behaviour (hand-calculation):

$$\Theta_i = \Theta_e + \frac{\Phi_s + \Phi_i}{L_T + L_V} - \cancel{\frac{\Phi_k}{L_T + L_V}}$$

Conclusions:

- Without cooling power the daily mean of indoor temperature is higher than the daily mean of ambient air temperature
- Increasing the internal heat leads to a higher daily mean of indoor temp.
- Reducing the transmission conductance – by means of better insulation – – leads to a higher daily mean of indoor temperature
- Enlarging the ventilation conductance – by means of increase of the Vetilation rate – leads to lower daily mean of indoor temperature

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