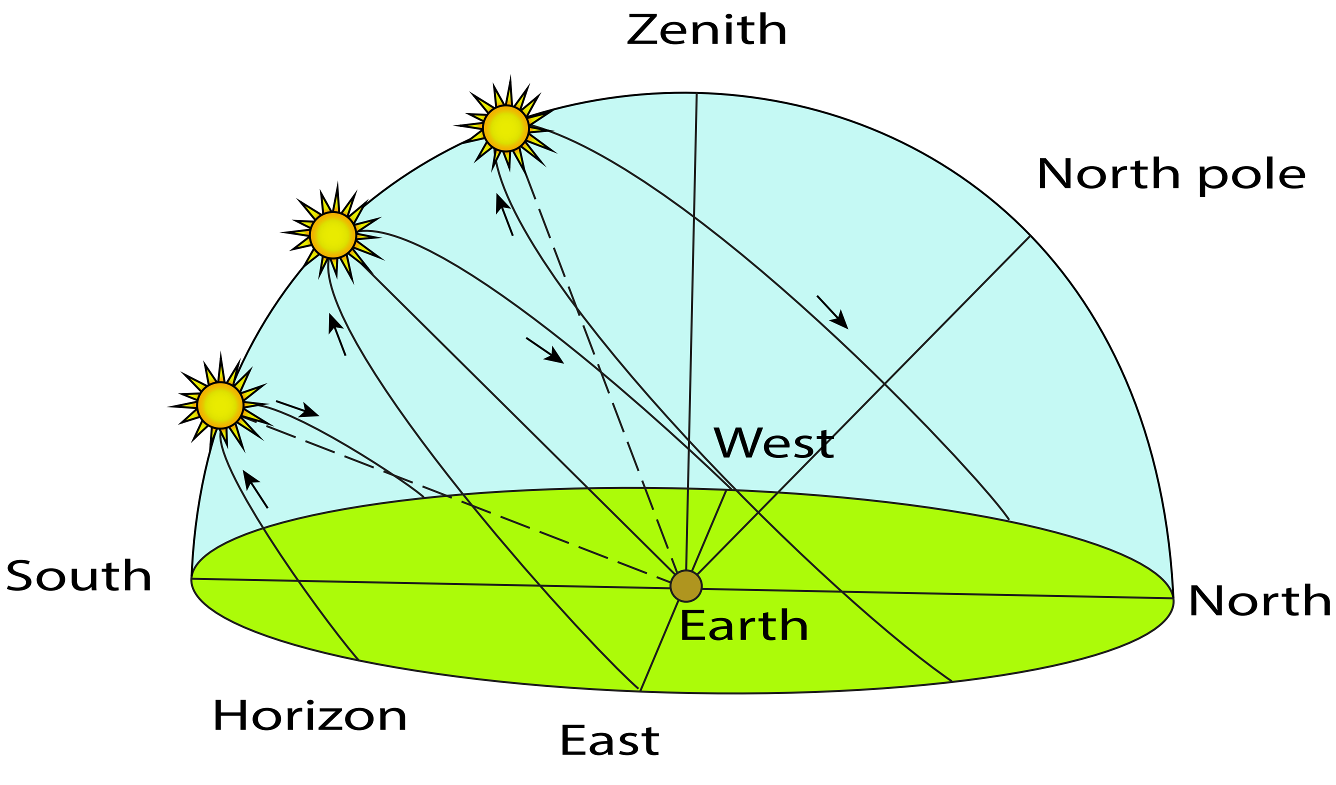
Building physics - heat and humidity



SZÉCHENYI 2020

PÉCSI TUDOMÁNYEGYETEM
UNIVERSITY OF PÉCS

László Fülöp

Building physics - heat and humidity

Pécs

2019

The Building physics - heat and humidity course material was developed under the project EFOP 3.4.3-16-2016-00005 "Innovative university in a modern city: open-minded, value-driven and inclusive approach in a 21st century higher education model".

László Fülöp

Building physics - heat and humidity

Pécs

2019

A Building physics - heat and humidity tananyag az EFOP-3.4.3-16-2016-00005 azonosító számú,
„Korszerű egyetem a modern városban: Értékközpontúság, nyitottság és befogadó szemlélet egy 21. századi felsőoktatási modellben” című projekt keretében valósul meg.

BUILDING PHYSICS
Heat and Humidity

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Main fields of heat and humidity technologies in architecture

Thermal comfort

- Comfort in buildings in winter
- Comfort in buildings in summer

Energy consumption required to achieve the comfort needs (affects the environmental quality!)

- Heating energy
- Cooling energy

Consistency issues

- Vapour condensation within the structures
- Vapour condensation on the surface of the structures
- Mould growth on the surface

CEN CR 1752 standard (1998)

Ventilation for buildings

Design criteria for the indoor environment

Categories of the indoor environment

A high level of expectations

B medium level

C moderate but acceptable level

Standards are not compulsory in the EU.
Typical application: offices.
Construction and rental fee of offices of higher comfort level is higher. Pays back if the fee of the workforce is high due to more efficient work and less illness leave.

Example design criteria for spaces in various types of building

Type of building/space	Activity W/m^2	Category	Operative temperature °C		Maximum mean air velocity [a] m/s	
			Summer (cooling season)	Winter (heating season)	Summer (cooling season)	Winter (heating season)
Single office Landscape office Conference room Auditorium Cafeteria/restaurant Classroom	70	A	24,5 ± 1,0	22,0 ± 1,0	0,12	0,10
		B	24,5 ± 1,5	22,0 ± 2,0	0,19	0,16
		C	24,5 ± 2,5	22,0 ± 3,0	0,24	0,21 [b]
Kindergarten	81	A	23,5 ± 1,0	20,0 ± 1,0	0,11	0,10 [b]
		B	23,5 ± 2,0	22,0 ± 2,5	0,18	0,15 [b]
		C	23,5 ± 2,5	22,0 ± 3,5	0,23	0,19 [b]
Department store	93	A	23,0 ± 1,0	19,0 ± 1,5	0,16	0,13 [b]
		B	23,0 ± 2,0	19,0 ± 3,0	0,20	0,15 [b]
		C	23,0 ± 3,0	19,0 ± 4,0	0,23	0,18 [b]

[a] The maximum mean air velocity is based on a turbulence intensity of 40 % and air temperature equal to the operative temperature according to 6.2 and Figure A.2. A relative humidity of 60 % and 40 % is used for summer and winter, respectively. For both summer and winter a lower temperature in the range is used to determine the maximum mean air velocity.

[b] Below 20 °C limit (see Figure A.2).

EN 15251:2007 standard

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

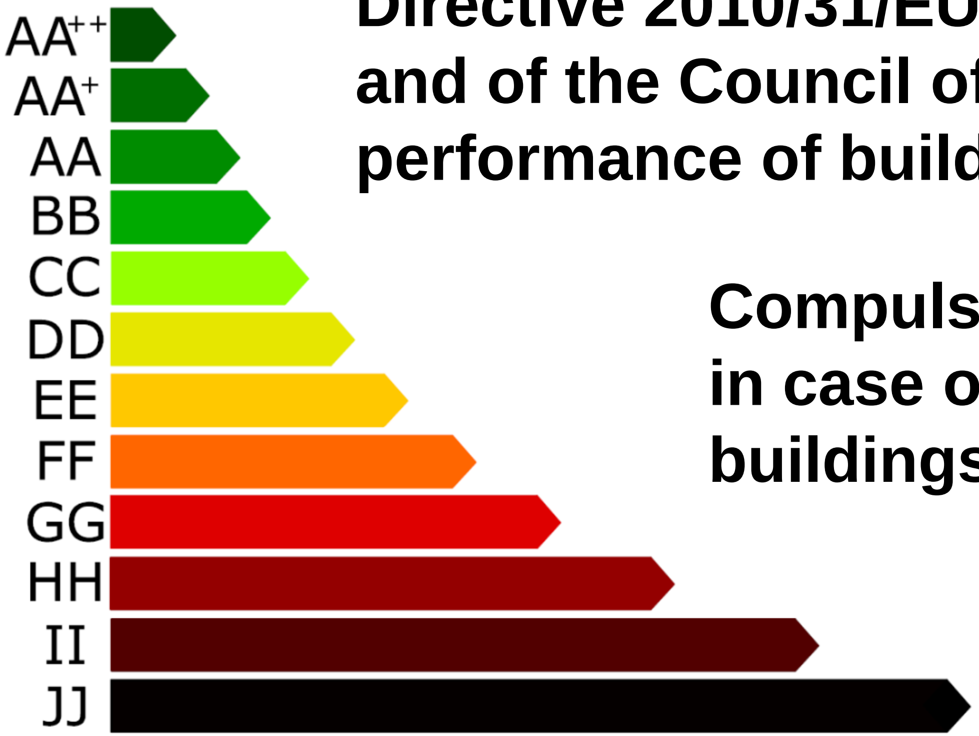
Category	Explanation
I	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons
II	Normal level of expectation and should be used for new buildings and renovations
III	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

Energy certificate of buildings

Background

Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.

Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)



Compulsory in Hungary from 2012 in case of new buildings, or buildings to be sold or let out.

Building of better energy performance is more valuable, easier to sell

Consistency, wetting issues

Mould (fungus) growth on the surface

Rot inside the building structure

Fundamental ways of heat transfer

- Conductance $$q = \frac{(T_1 - T_2)}{R} \quad [W/m^2] \qquad R = \frac{d}{\lambda}$$
- Convection $$q = h \cdot (T_1 - T_2) \quad [W/m^2]$$
- Radiation $$q = C_{1\rightarrow 2} \left\{ \left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right\} \quad [W/m^2]$$

Where:

d thickness [m] λ thermal conductivity (also marked as k) [W/mK]

h convective heat transfer coefficient (also marked as α) [W/m^{2}K]

$C_{1\rightarrow 2}$ radiative exchange factor [W/m^2 K^4]

Thermal transmittance through a multi-layer structure

(complex heat transfer from air to air)

Boundary conditions: one-dimensional, steady-state, source-free

Convective heat transfer resistance on the surface: $R = \frac{1}{h}$

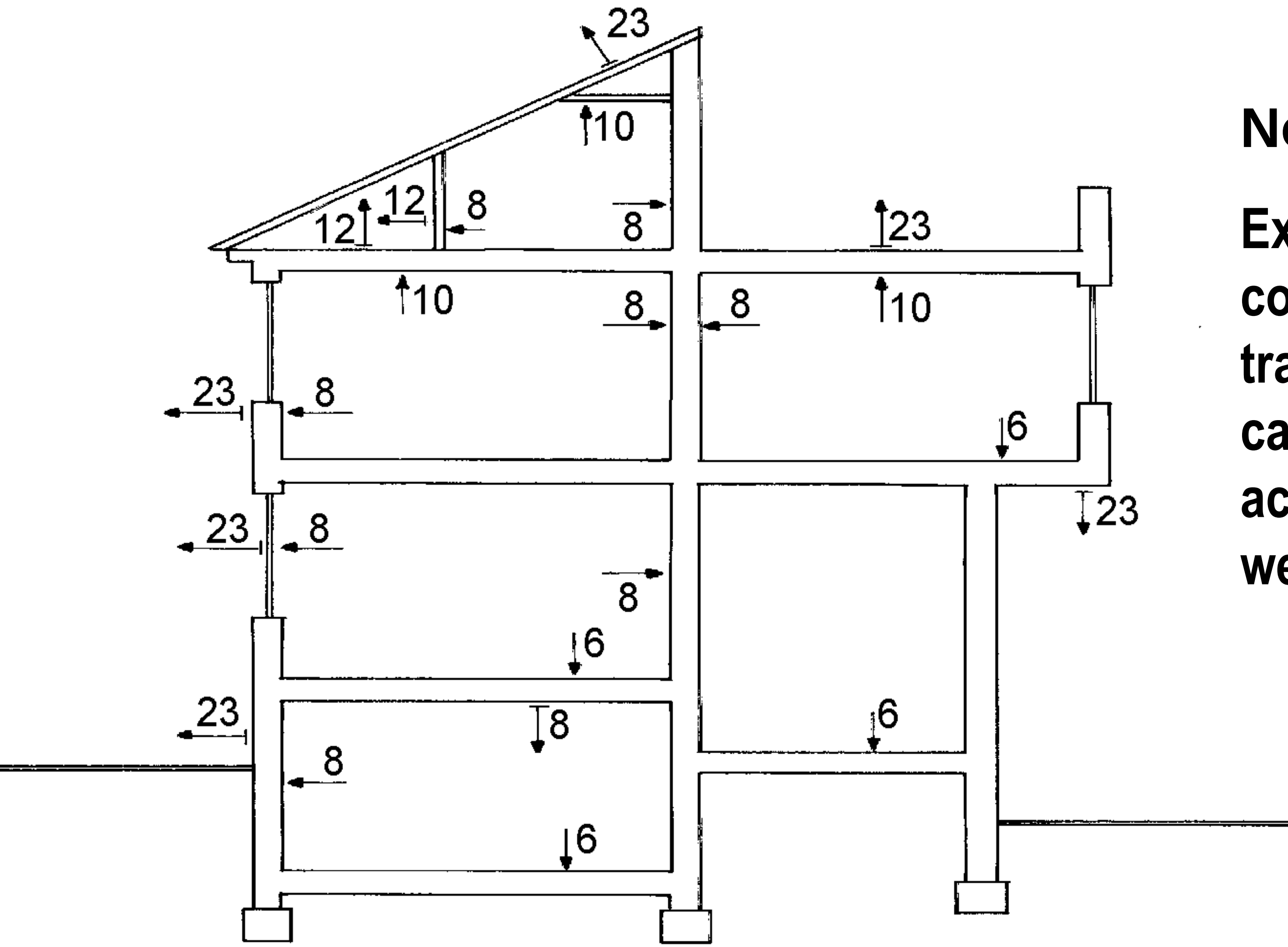
Thermal resistance of a layer: $R = \frac{d}{\lambda}$

Total thermal resistance: $R_{total} = \frac{1}{h_i} + \sum \frac{d_j}{\lambda_j} + \frac{1}{h_e}$

Thermal transmittance coefficient: $U = \frac{1}{R_{total}} \left[W / m^2 K \right]$

(Also marked as *k*)

Convective heat transfer coefficient [W/m^{2}K]



Note:

External convective heat transfer coefficient can be 24 or 25 too according to the weather conditions

5.3.1 Unventilated air layer

EN ISO 6946:1996

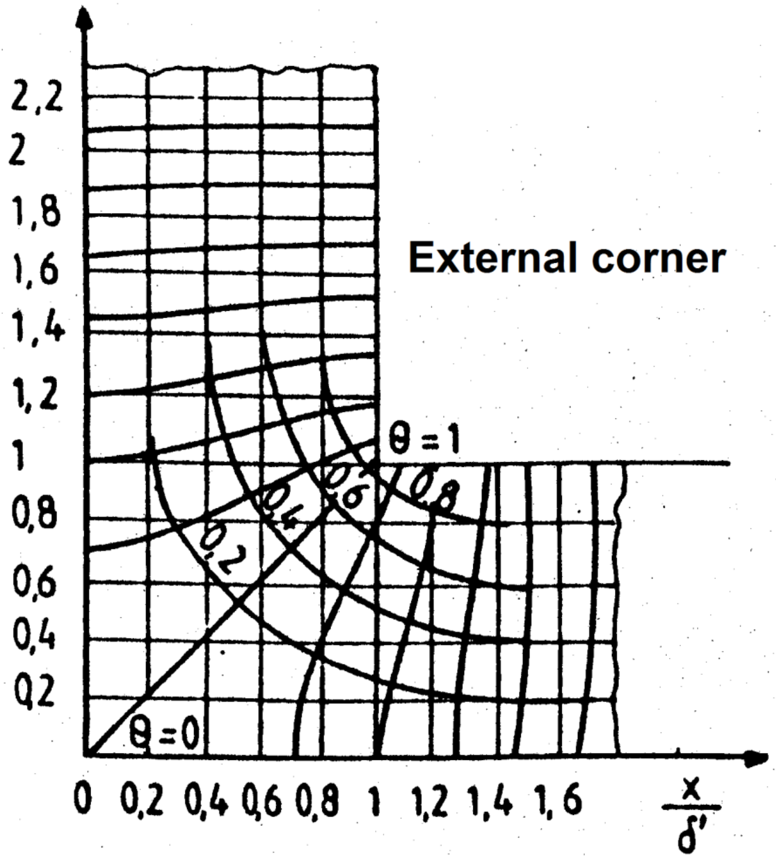
An unventilated air layer is one in which there is no express provision for air flow through it. Design values of thermal resistance are given in table 2. The values under "horizontal" apply to heat flow directions ±30° from the horizontal plane.

Table 2 - Thermal resistance (in $m^2 \cdot K/W$) of unventilated air layers: high emissivity surfaces

Thickness of air layer mm	Direction of heat flow		
	Upwards	Horizontal	Downwards
0	0,00	0,00	0,00
5	0,11	0,11	0,11
7	0,13	0,13	0,13
10	0,15	0,15	0,15
15	0,16	0,17	0,17
25	0,16	0,18	0,19
50	0,16	0,18	0,21
100	0,16	0,18	0,22
300	0,16	0,18	0,23

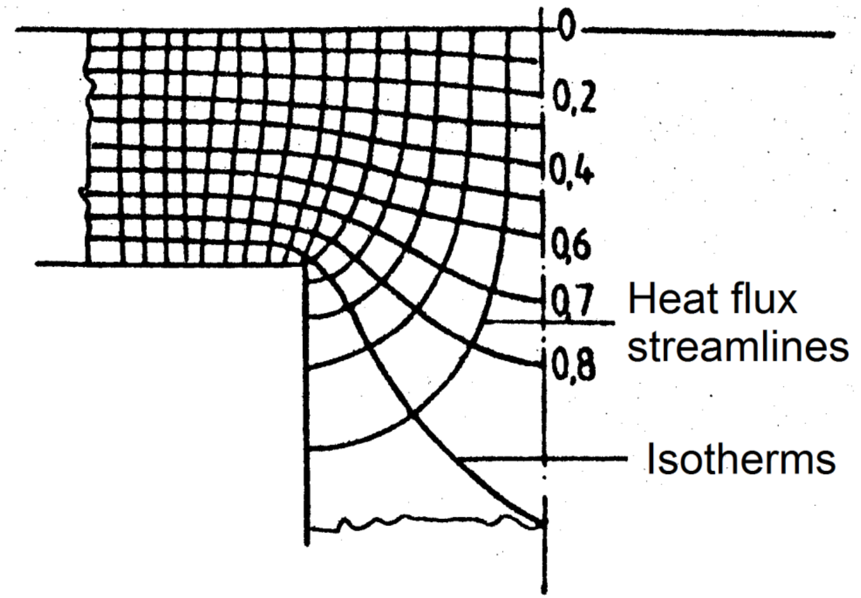
NOTE - Intermediate values may be obtained by linear interpolation.

Multi-dimensional heat transfer



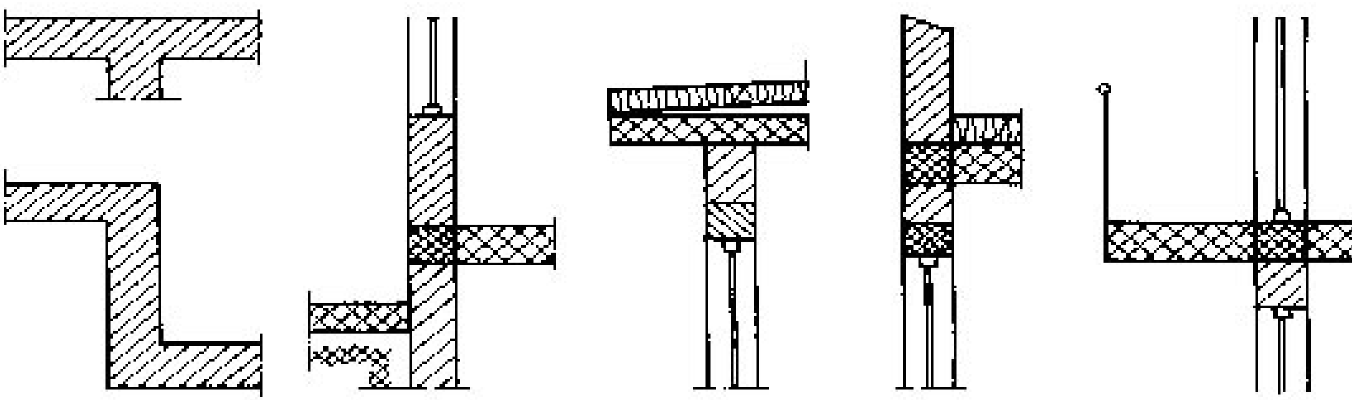
External corner

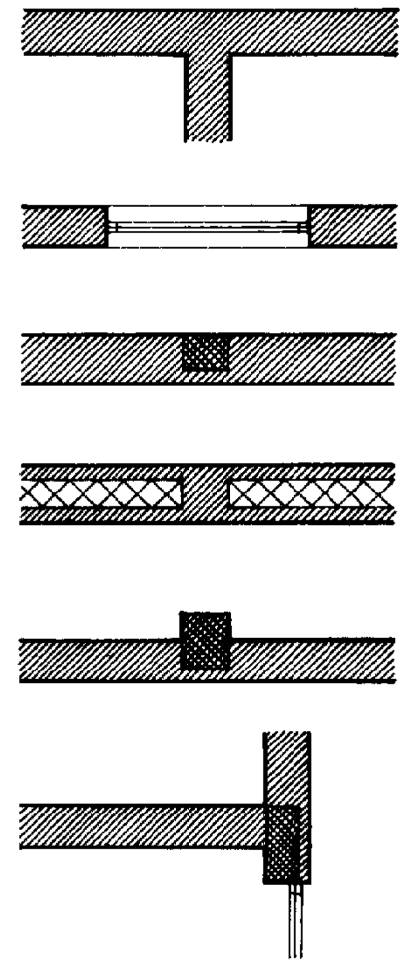
Half of a symmetrical T-junction



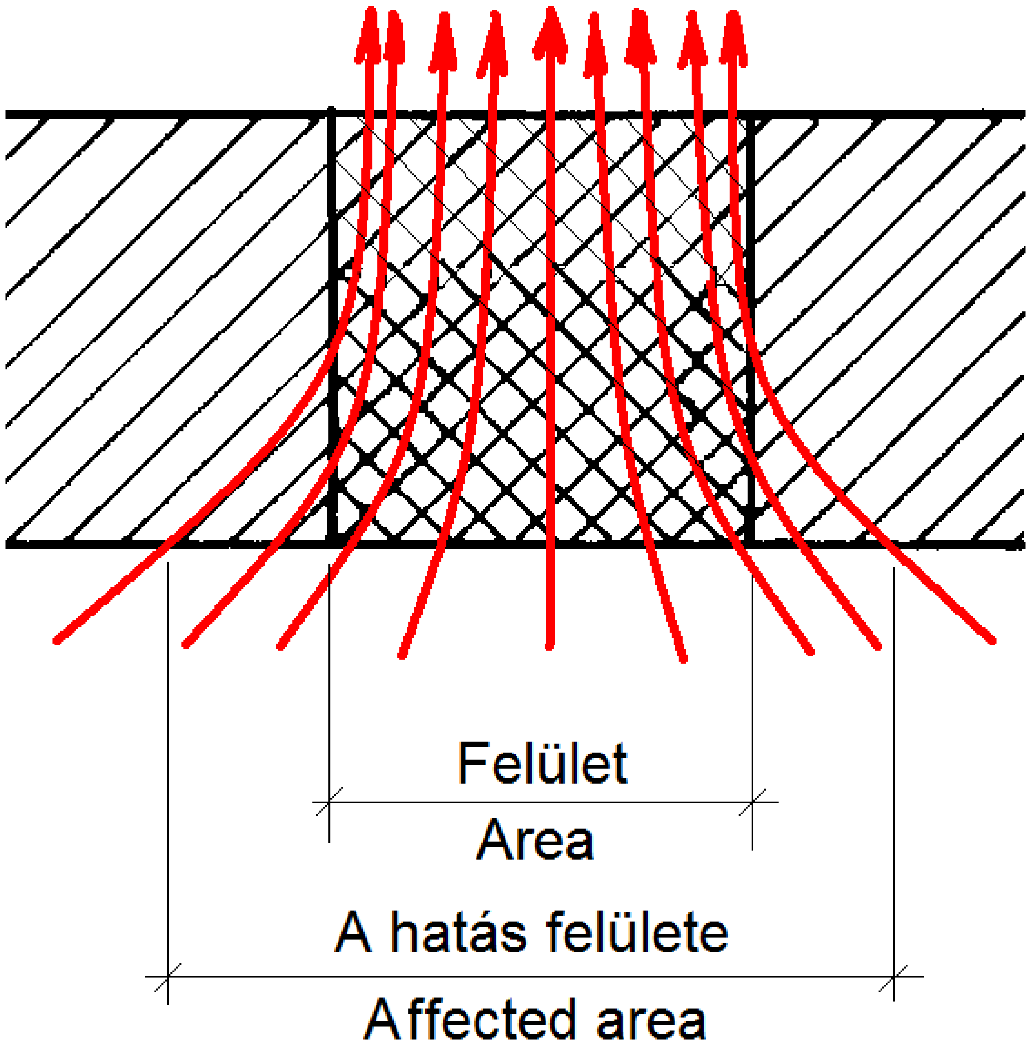
Examples of thermal bridges

Also called cold bridge





Structural thermal bridge

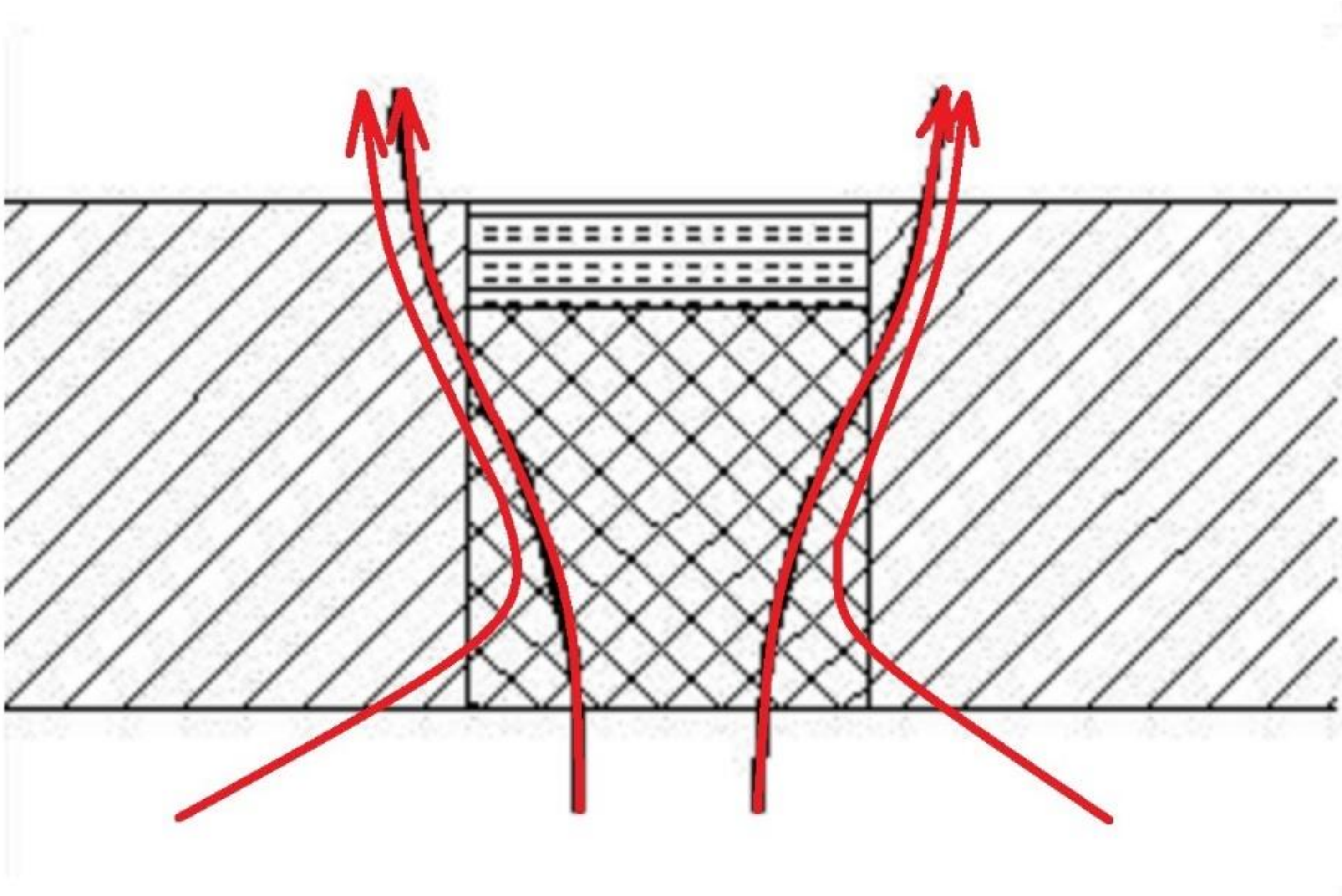


Heat flux follows the less resistance

The affected area (surface) is larger than the actual area (surface)

Consequence: surface proportional calculations underestimate the extra heat flux across the thermal bridge

Insulated structural thermal bridge

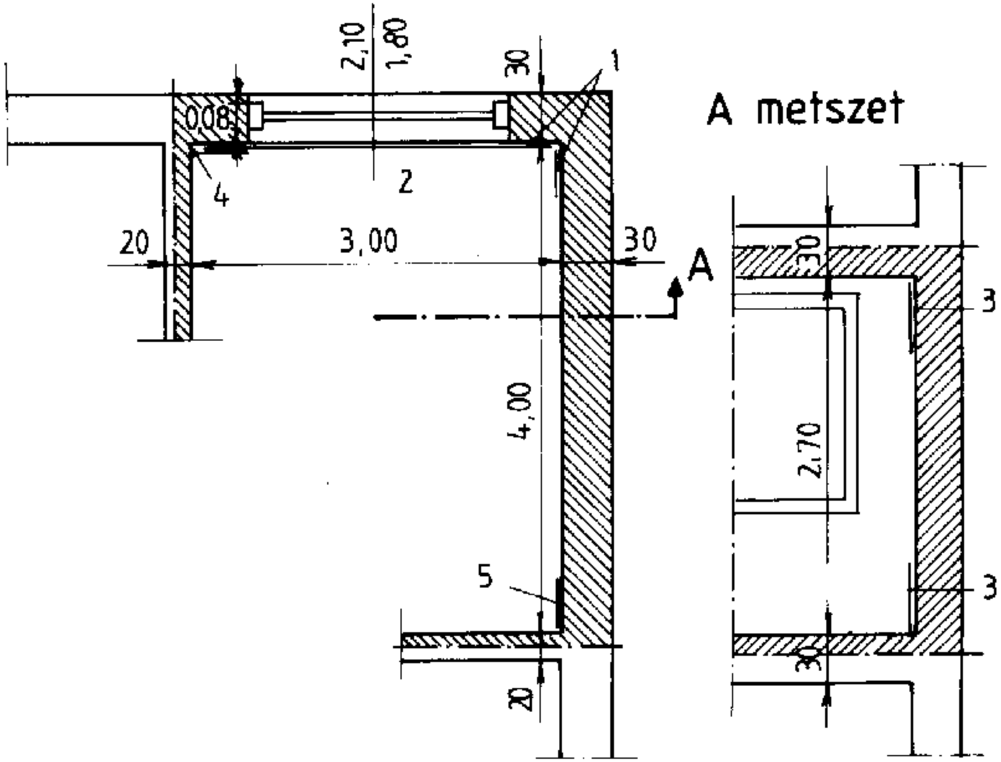


Heat flux bypasses the thermal insulation

Insulation on the structural thermal bridges

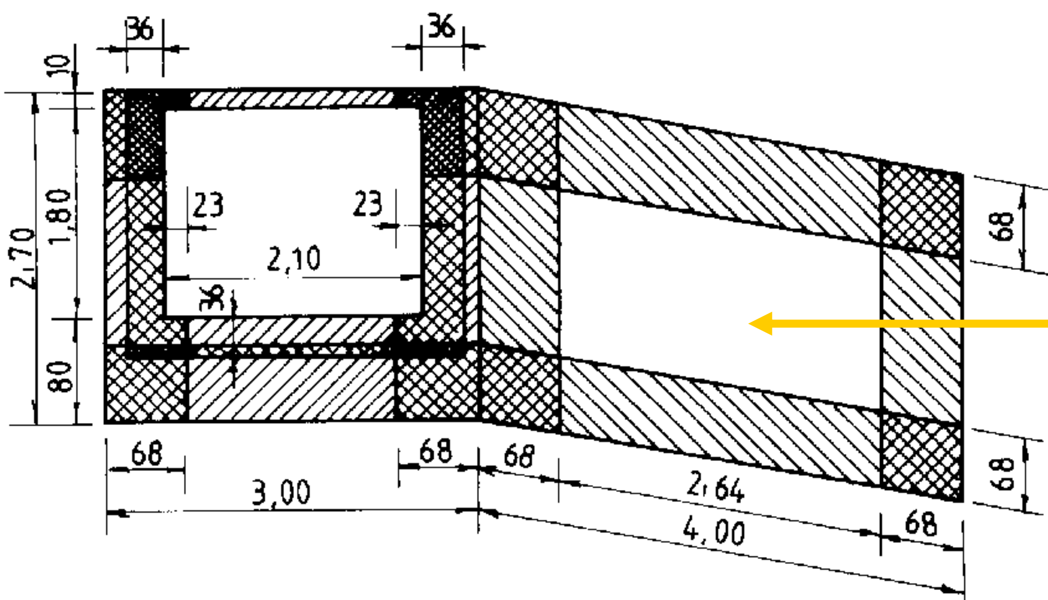
Insufficient thermal insulation on the structural thermal bridges


Mould (fungus) growth



Thermal bridges

The hatched area is affected by the thermal bridge resulting in increased heat flux



Thermal bridge free area

Linear thermal transmittance coefficient (Ψ) [W/mK]

All extra heat transfer concentrated into a line, edge, like a corner. These values are based on two-dimensional numerical modelling in accordance with ISO 10211.

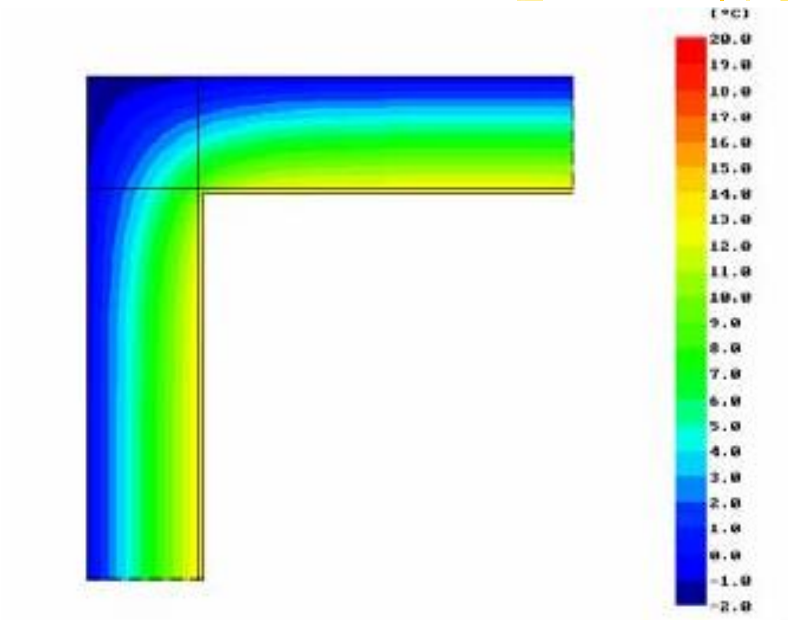
Heat flow rate in the steady state divided by length and by the temperature difference between the environments on either side of a thermal bridge.

They generally represent the maximum effects of thermal bridging.

Extra heat transfer through the thermal bridge:

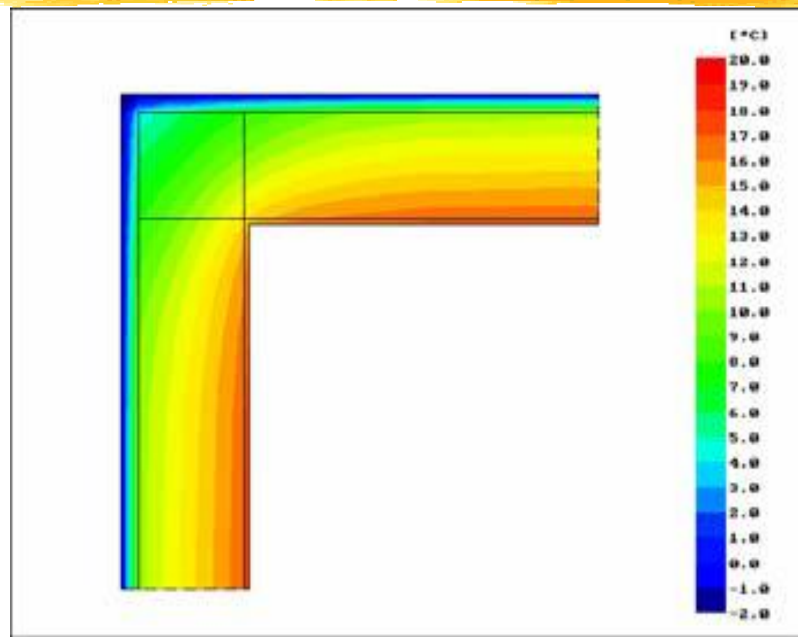
$$q_{tb} = l \cdot \Psi$$

Thermal bridge analysis by computer modelling - corner



B30 large hollow brick with plaster

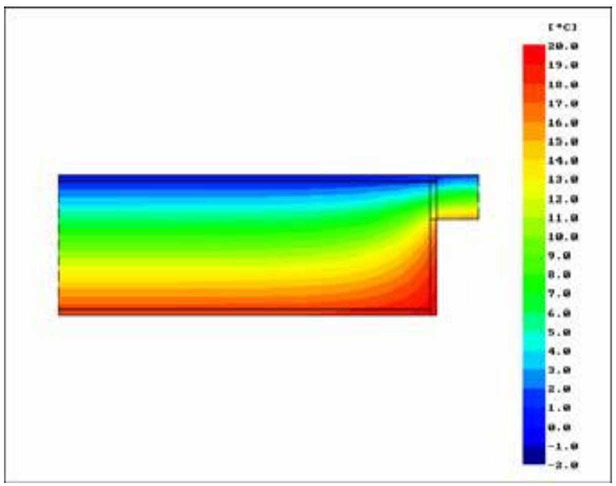
λ_{B30} = 0,64 W/mK
$\lambda_{plaster}$ = 0,34 W/mK
Ψ = 0,15 W/mK
t_x = 10,7°C (t_e = -2°C)
t = 14,2°C (t_e = -2°C)
Heat flux: 62,4 W/m²

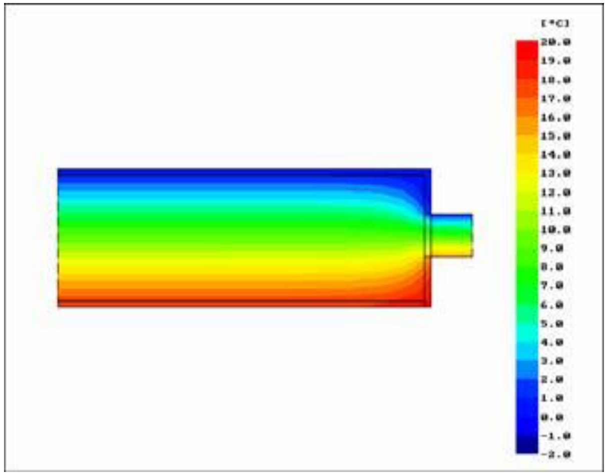


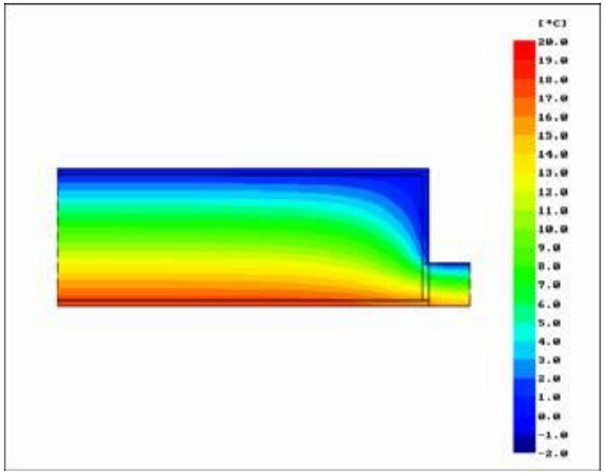
B30 brick plus 5cm expanded polystyrene outside

λ_{B30} = 0,64 W/mK
λ_{polyst} = 0,054 W/mK
Ψ = 0,19 W/mK
t_x = 14.8°C (t_e = -2°C)
t = 17.3°C (t_e = -2°C)
Heat flux: 30,5 W/m²

Thermal bridge analysis by computer modelling – effect the location of window in the wall

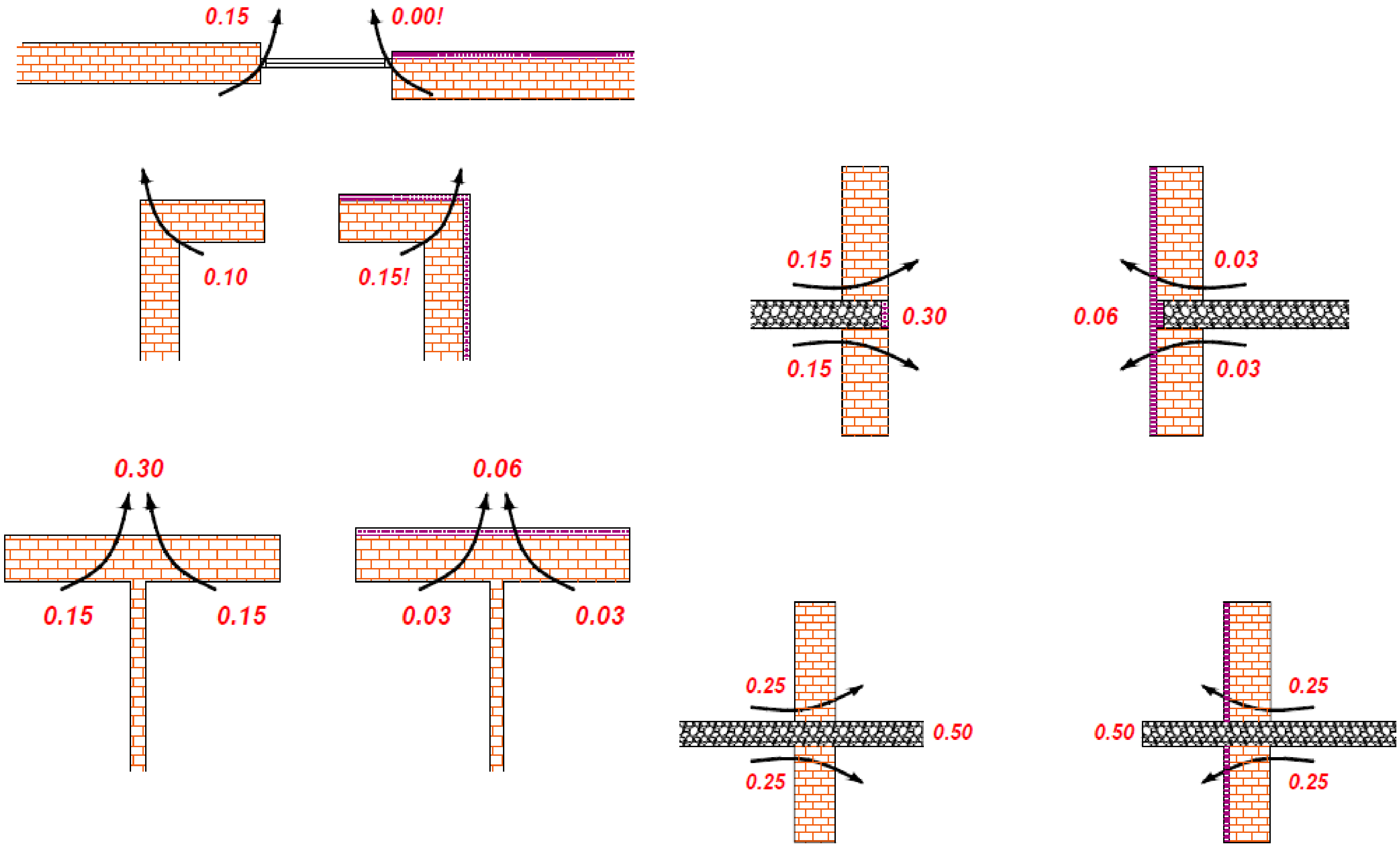




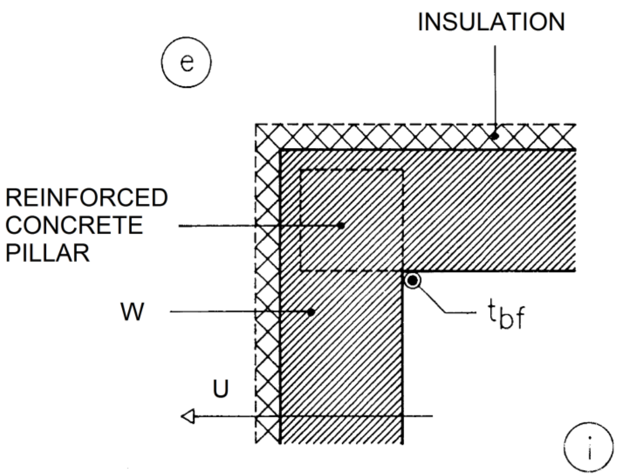


It is more favorable on the outside plane

Linear thermal transmittance coefficients



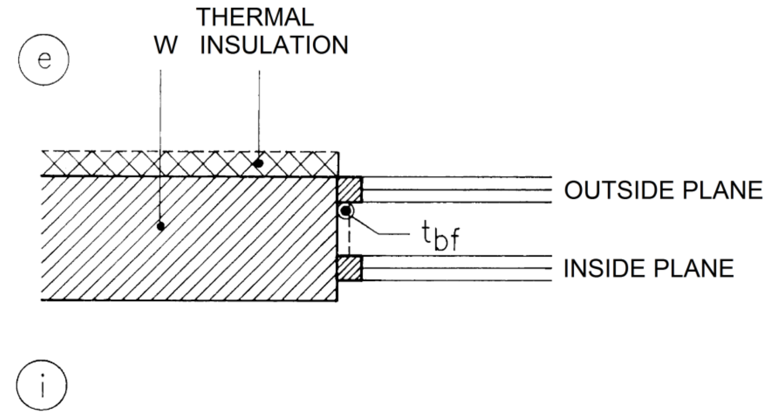
EXTERNAL WALL - POSITIVE CORNER



EXTERNAL WALL		WALL (W)				INSULATED WALL (W+I)		
PILLAR (RC)		YES		NO		YES	NO	
U-value of the wall (W/m²K)		⩽0,65	>0,65	⩽0,65	>0,65			
Thermal resistance of wall and insulation	$R_I < R_W$						+	
	$R_I > R_W$					+		+
Ψ (W/mK)		0,17	0,20	0,09	0,14	0,24	0,08	0,14
$\Theta \left(= \frac{t_{bf} - t_e}{t_i - t_e}\right)$		0,65	0,53	0,70	0,64	0,82	0,86	0,84

EXTERNAL WALL - WINDOW

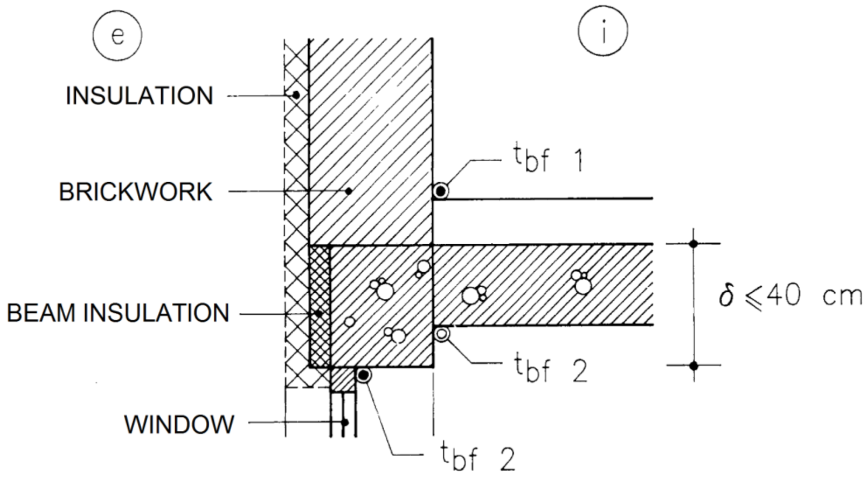
Ackn. Dr. Laczkovits (1991)



EXTERNAL WALL		WALL (W)				INSULATED WALL (W+I)			
Window location		OUTSIDE PLANE		INSIDE PLANE		OUTSIDE PLANE		INSIDE PLANE	
U-value of the wall (W/m²K)		⩽0,65	>0,65	⩽0,65	>0,65	⩽0,65	>0,65	⩽0,65	>0,65
Thermal resistance of wall and insulation	$R_I < R_W$					+		+	
	$R_I < R_W$						+		+
Ψ (W/mK)		0,17	0,25	0,24	0,29	0,09	0,21	0,12	0,26
$\Theta \left(= \frac{t_{bf} - t_e}{t_i - t_e}\right)$		0,66	0,58	0,57	0,53	0,85	0,80	0,67	0,60

EXTERNAL WALL - INTERNAL SLAB

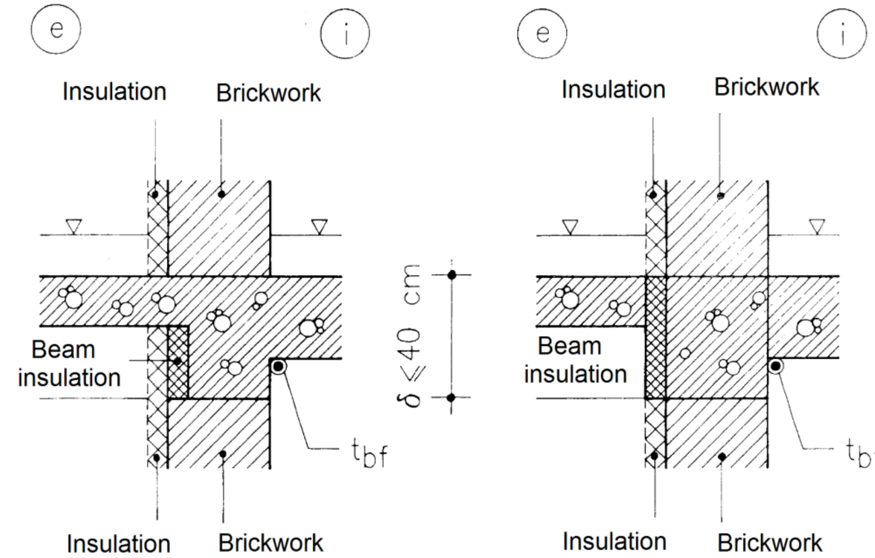
Ackn. Dr. Laczkovits (1991)



$$\Psi = \Psi_1 + \Psi_2$$

External wall upper floor		Brickwork				Brickwork with ext. insulation		
External wall lower floor		Brickwork		Window		Brickw	Window	
U-value of the wall (W/m² K)		$\leqslant 0,65$	$>0,65$	$\leqslant 0,65$	$>0,65$			
Thermal resistance of wall and insulation	$R_I < R_W$					+	+	
	$R_I > R_W$							+
Ψ (W/mK)	Ψ 1	0,06	0,08	0,08	0,08	0,13	0,13	0,13
	Ψ 2	0,21	0,28	0,39	0,33		0,40	0,56
$\left(\frac{t_{bf}-t_e}{t_i-t_e}\right)$	Θ 1	0,86	0,73	0,85	0,67	0,90	0,90	0,90
	Θ 2	0,81	0,73	0,75	0,70		0,73	0,65

EXTERNAL WALL - INTERNAL SLAB - EXTERNAL SLAB



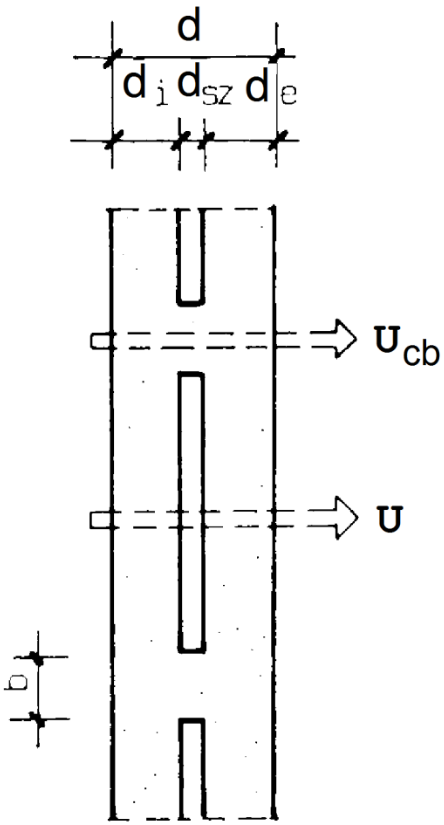
Slab without thermal break

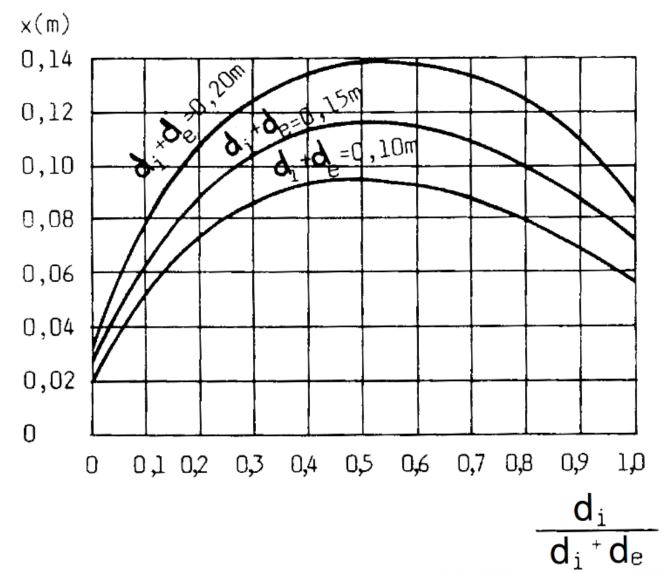
Slab with thermal break

External wall	Brickwork		Brickwork with ext. insulation	
Slab without thermal break	+		+	
Slab with thermal break		+		+
2Ψ (W/mK)	0,63	0,31	0,70	0,32
$\Theta \left(=\frac{t_{bf}-t_e}{t_i-t_e}\right)$	0,66	0,75	0,79	0,83

Linear thermal transmittance coefficient of reinforced concrete beams, ribs

Ackn. Dr. Laczkovits (1991)

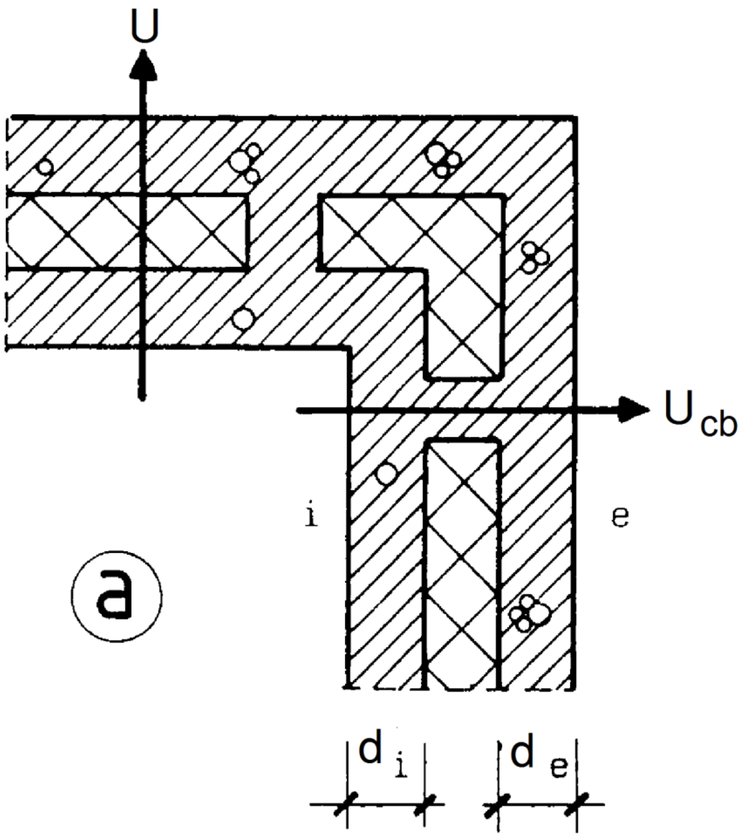




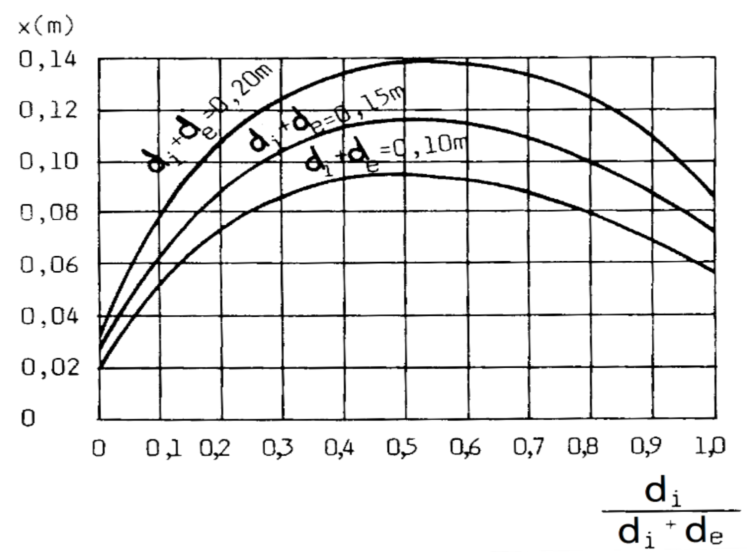
$$\Psi = U_{cb} \cdot b + (U_{cb} - U) \cdot x \quad (W/mK)$$

Linear thermal transmittance coefficient of reinforced concrete beams, ribs

Ackn. Dr. Laczkovits (1991)

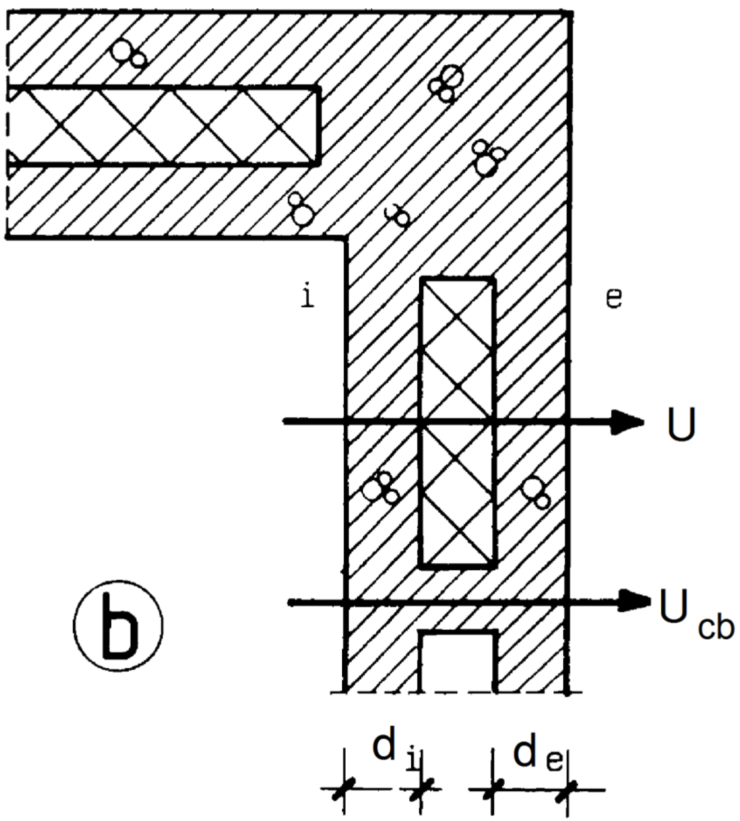


$$\Psi = 0{,}6 \cdot U \cdot d_i$$

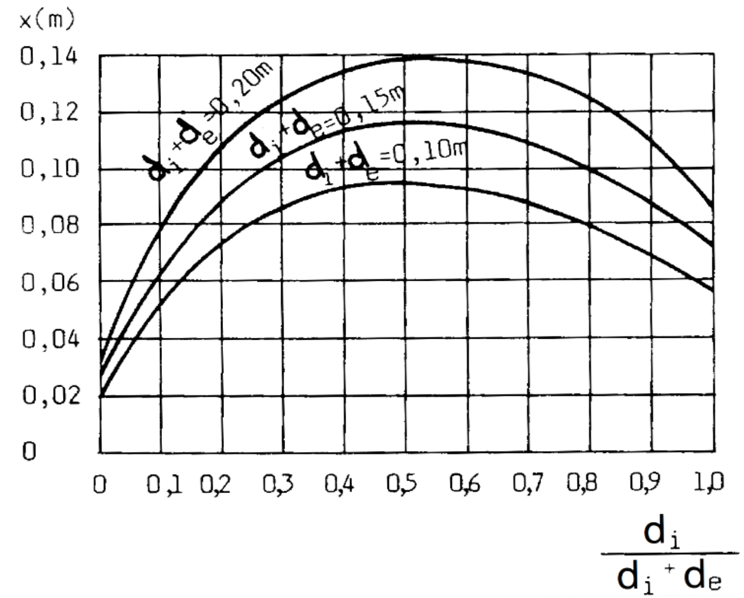


Linear thermal transmittance coefficient of reinforced concrete beams, ribs

Ackn. Dr. Laczkovits (1991)



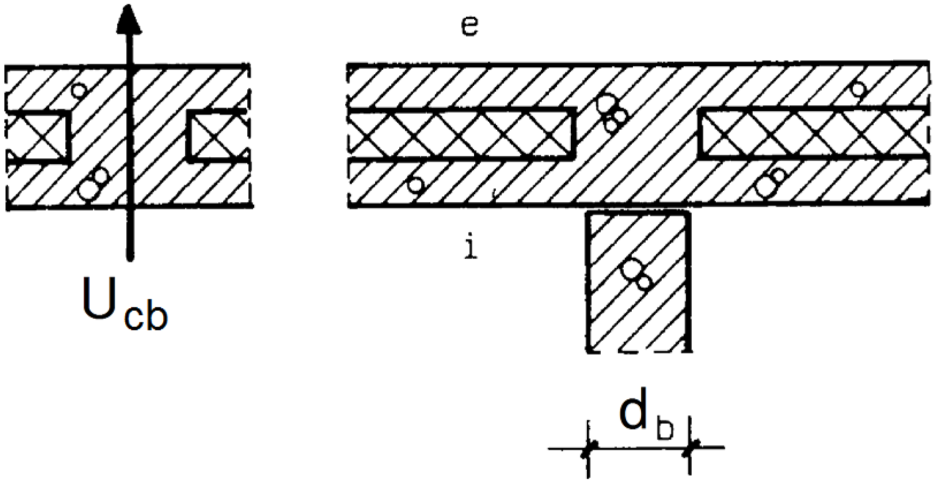
$$\Psi = 0{,}85\left[0{,}7 \cdot U \cdot d_i + (U_{cb} - U) \cdot \frac{x}{2}\right]$$



Linear thermal transmittance coefficient of reinforced concrete beams, ribs

Ackn. Dr. Laczkovits (1991)

$$\psi = 0{,}4 \cdot U_{cb} \cdot d_b$$



Thermal bridge standards

ISO 10211:2017 Thermal bridges in building construction
- **Heat flows and surface temperatures**
- **Detailed calculations**

ISO 10211-2:2001 Thermal bridges in building construction
- **Heat flows and surface temperatures**
- **Linear thermal bridges**

ISO 14683:2017 Thermal bridges in building construction
- **Linear thermal transmittance**
- **Simplified methods and default values**

ISO 10211:2017
Thermal bridges in building construction

ISO 10211 sets out the specifications for a three-dimensional and a two-dimensional geometrical model of a thermal bridge for the numerical calculation of:

- heat flows, in order to assess the overall heat loss from a building or part of it;
- minimum surface temperatures, in order to assess the risk of surface condensation.

These specifications include the geometrical boundaries and subdivisions of the model, the thermal boundary conditions, and the thermal values and relationships to be used.

ISO 10211 is based upon the following assumptions:

- all physical properties are independent of temperature;
- there are no heat sources within the building element.

ISO 10211 can also be used for the derivation of linear and point thermal transmittances and of surface temperature factors.

ISO 14683:2017 Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values

Scope

This document deals with simplified methods for determining heat flows through linear thermal bridges which occur at junctions of building elements.

This document specifies requirements relating to thermal bridge catalogues and manual calculation methods.

Normative references

ISO 7345, Thermal insulation — Physical quantities and definitions

ISO 10211, Thermal bridges in building construction — Heat flows and surface temperatures — Detailed calculations

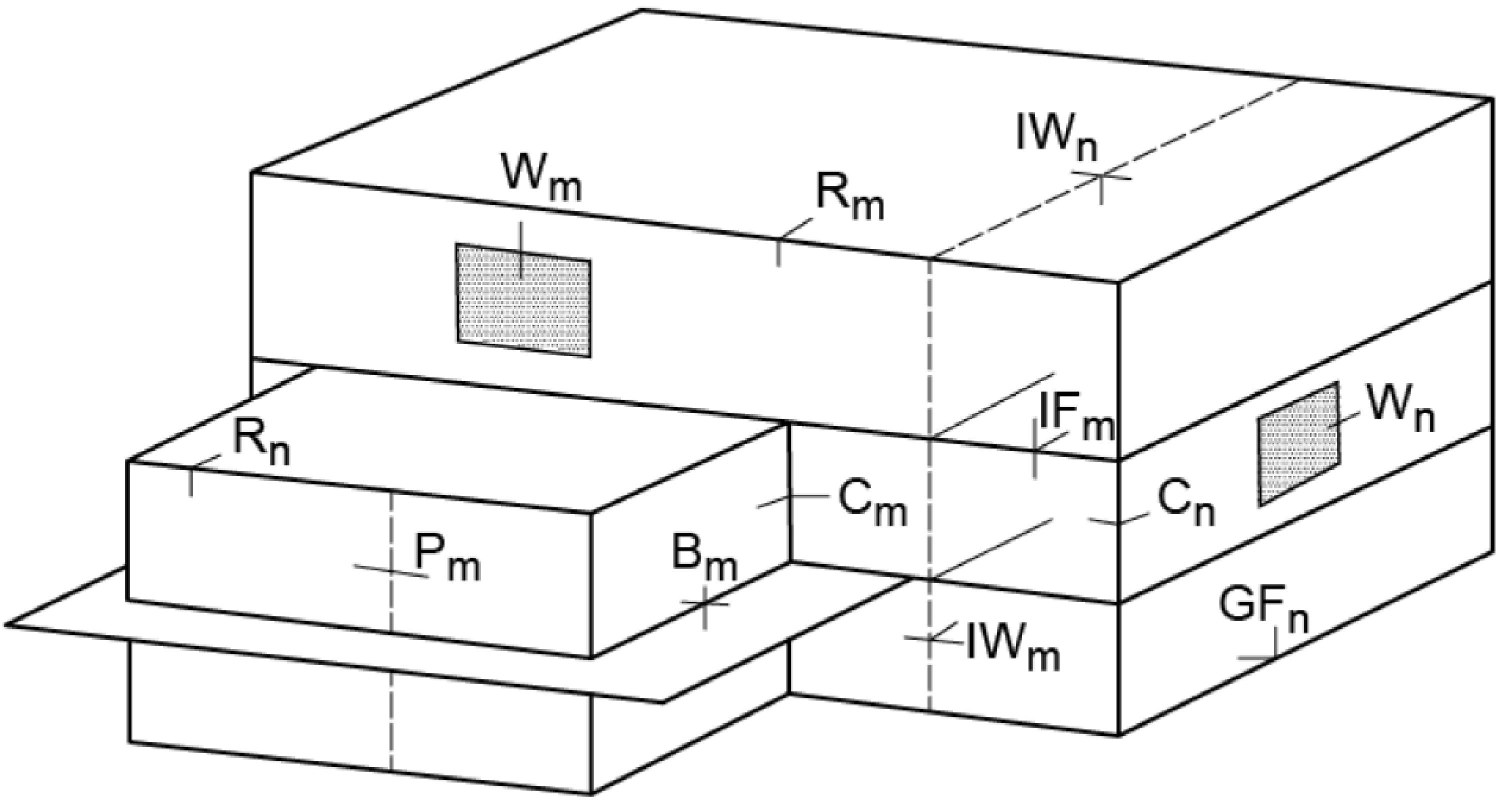
ISO 13370, Thermal performance of buildings — Heat transfer via the ground — Calculation methods

ISO 13789, Energy performance of buildings — Transmission and ventilation heat transfer coefficients — Calculation method

ISO 52000-1:2017, Energy performance of buildings — Overarching EPB assessment — Part 1: General framework and procedures

Linear thermal transmittance coefficients

ISO 14683:2017



Key

B_m, C_m, C_n, GF_n, IF_m, IW_m, IW_n, P_m, R_m, R_n, W_m, W_n locations of the thermal bridge

Figure C.1 — Sketch of a building showing the location and type of commonly-occurring thermal bridges according to the scheme given in Table C.2

Linear thermal transmittance coefficients

ISO 14683:2017 Example page

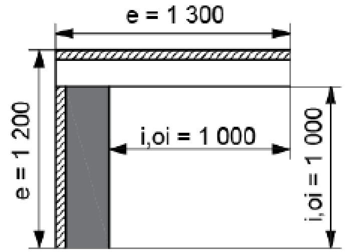
Table C.2 — Default values of linear thermal transmittance

Dimensions in mm; linear thermal transmittance in W/(m·K)

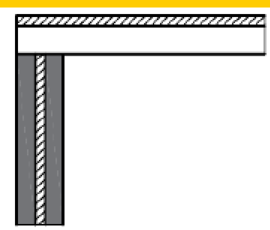
Wall	Lightweight wall (including lightweight masonry and timber frame walls)	Insulating layer	Slab/pillar	Window frame

Ψ_e based on external dimensions
Ψ_{oi} based on overall internal dimensions (in the middle of the wall)
Ψ_i based on internal dimensions

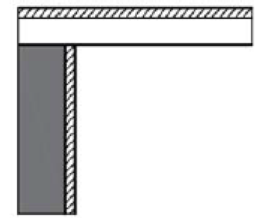
Roofs



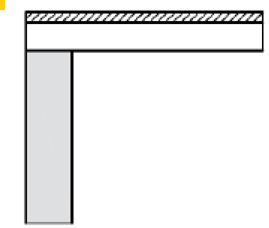
R1 Ψ_e = 0,30; Ψ_{oi} = 0,50; Ψ_i = 0,50



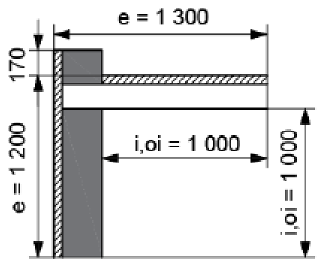
R2 Ψ_e = 0,50; Ψ_{oi} = 0,75; Ψ_i = 0,75



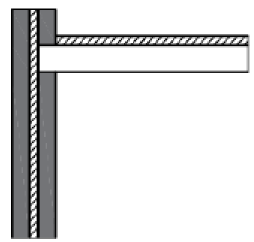
R3 Ψ_e = 0,40; Ψ_{oi} = 0,75; Ψ_i = 0,75



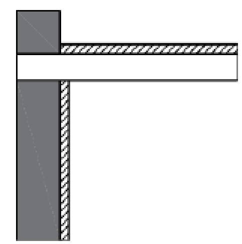
R4 Ψ_e = 0,40; Ψ_{oi} = 0,65; Ψ_i = 0,65



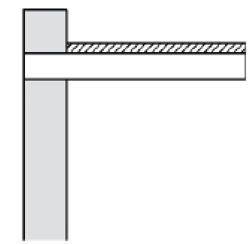
R5 Ψ_e = 0,60; Ψ_{oi} = 0,80; Ψ_i = 0,80



R6 Ψ_e = 0,50; Ψ_{oi} = 0,70; Ψ_i = 0,70



R7 Ψ_e = 0,65; Ψ_{oi} = 0,85; Ψ_i = 0,85



R8 Ψ_e = 0,45; Ψ_{oi} = 0,70; Ψ_i = 0,70

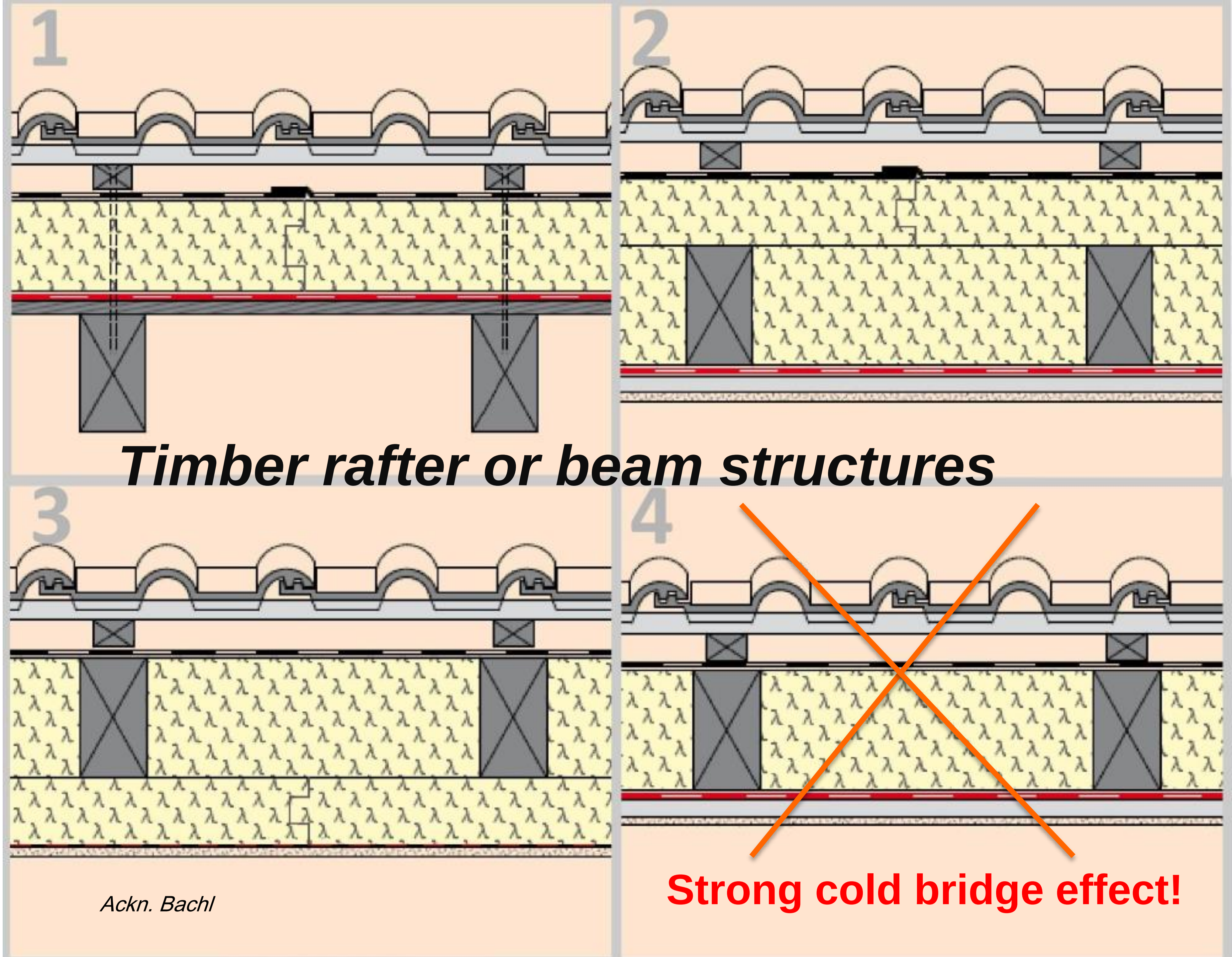
Point thermal transmittance
Steel rods through the thermal insulation
Average value of conductance proportional to cross-section is accepted

The heat transfer between the rod cover and the insulation is negligible compared to the heat transfer alongside the steel rods, the effect of the steel rods is calculated as the weighted average value of conductance proportional to surface that is the cross-section of the rods and the total Area.

Like if the rods were part of the thermal insulation.

$$\overline{\lambda} = \frac{A_{steel}\lambda_{steel} + A_{ins}\lambda_{ins}}{A_{steel} + A_{ins}}$$

Timber rafter or beam structures



Ackn. Bachl

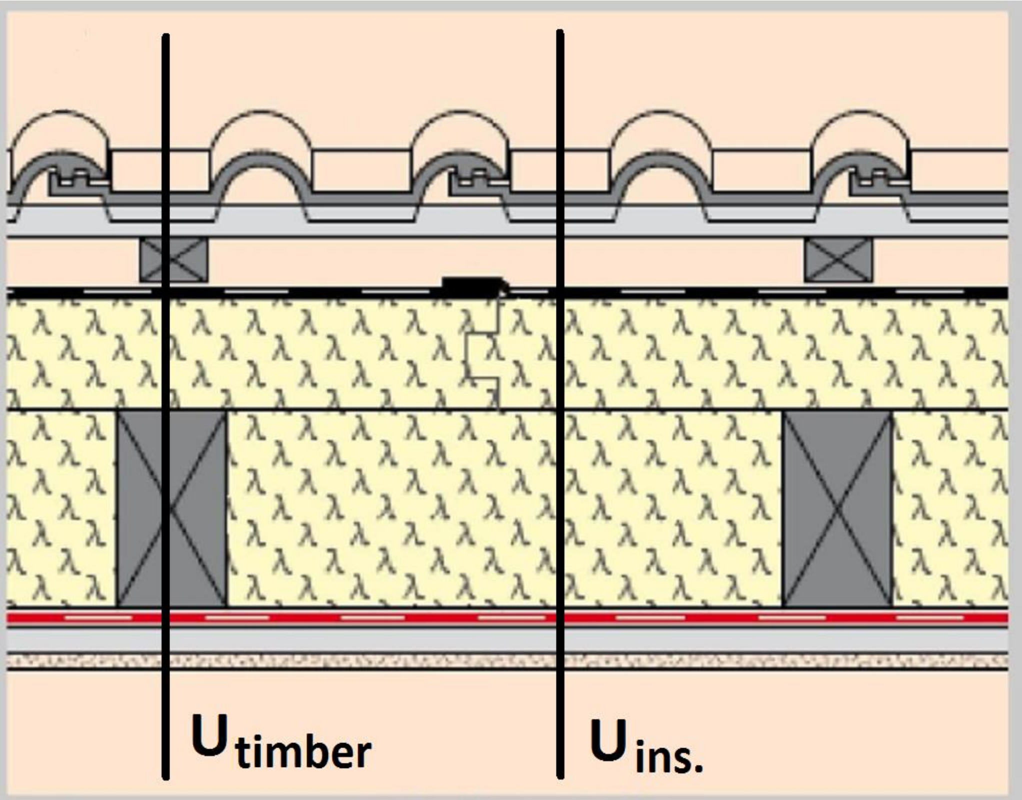
Timber structures

Weighted average U-value proportional to surface is acceptable

Thermal conductance of pine wood: 0,13 … 0,19 W/mK according to the density.

Load-bearing structures made of high density pine wood

A_{timber} = Area (surface) of the timber as seen from below

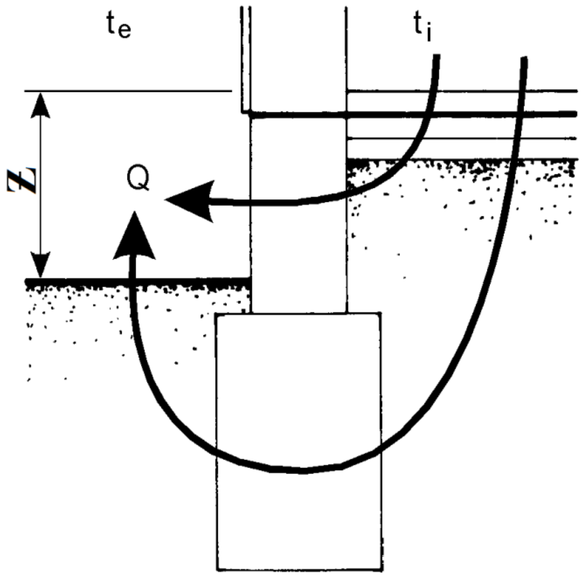


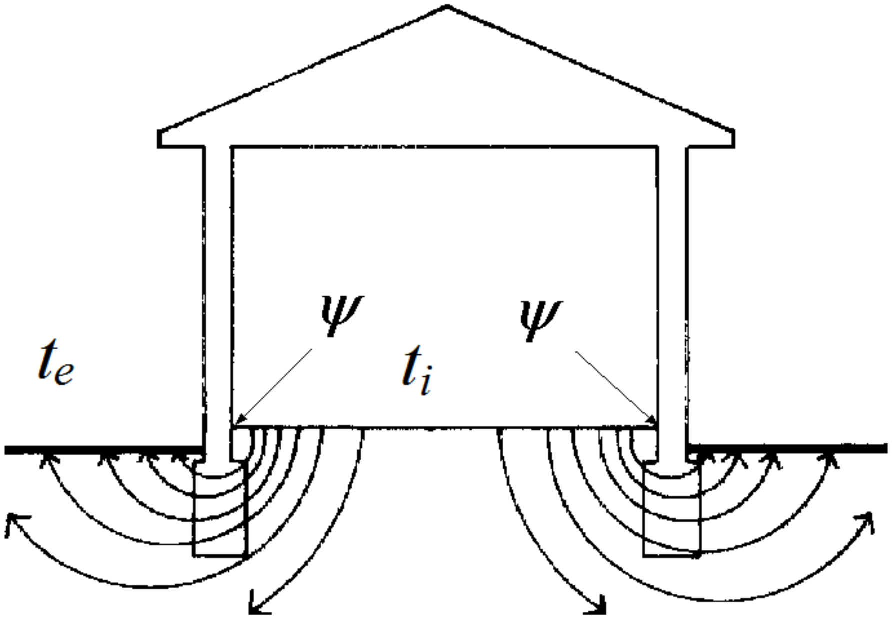
$$\overline{U} = \frac{A_{timber}\,U_{timber} + A_{ins}\,U_{ins}}{A_{timber} + A_{ins}}$$

Resultant thermal transmittance coefficient for comfort and mould (fungus) growth calculations

$$U_r = \frac{A \cdot U_{layer\,design} + \sum l_j \cdot \Psi_j}{A} \quad \left[W / m^2 K\right]$$

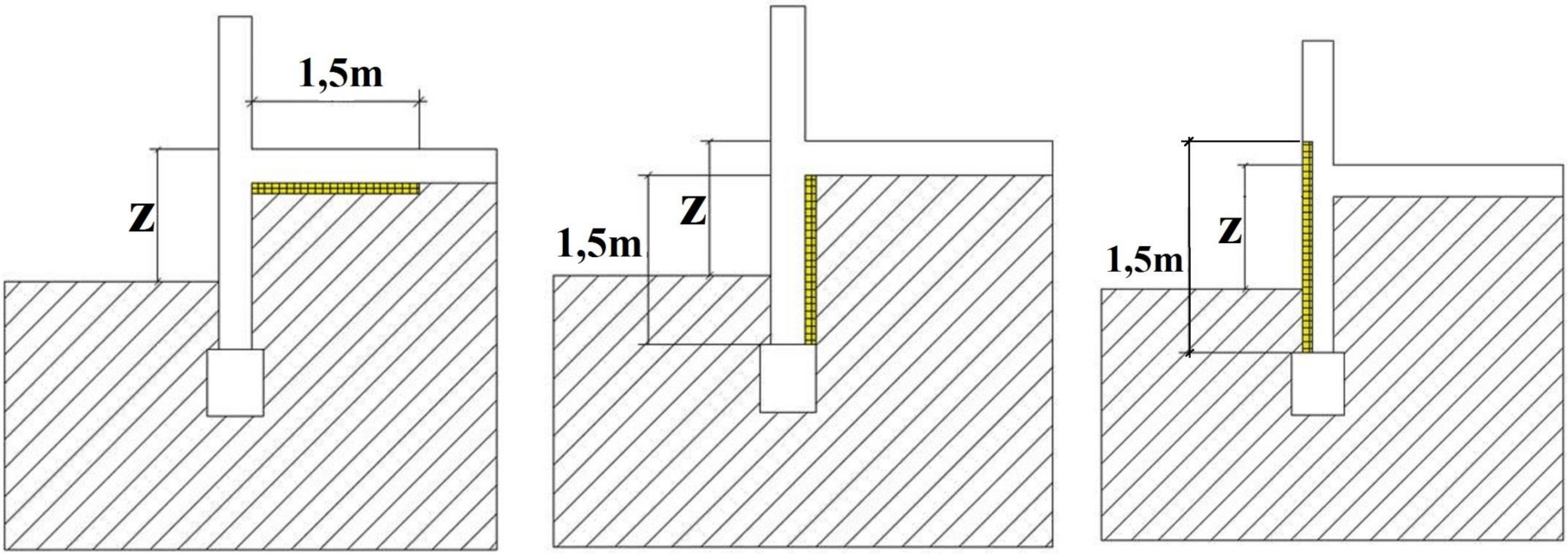
HEAT TRANSFER VIA GROUND
Slab-on-ground floor





The direction of the heat flux is from the room into the ambient, not the centre of the Earth. The heat flux is multi-dimensional. As a consequence, it can be calculated as linear heat transfer like thermal bridges. As opposed to usual thermal bridge calculation this linear heat transfer coefficient (Ψ) contains all heat fluxes not only the extra heat flux on the top of the heat flux of the surfaces.

Slab-on-ground floor
ways of thermal insulation



Linear thermal transmittance coefficient of slab-on-ground floor Ψ [W/mK]

Height difference between floor level and ground level	Resistance of the thermal insulation at least 1.5 m in width $R = \frac{d}{\lambda} \left[\frac{m^2K}{W}\right]$										
z (m)	Without insulation	0,20…0,35	0,40…0,55	0,60…0,75	0,80…1,00	1,05…1,50	1,55…2,00	2,05…3,00	3,05…4,00	4,05…5,00	5,05…6,00	6,05…7,00
-6,00	0	0	0	0	0	0	0	0	0	0	0	0
-6,00...-4,05	0,20	0,20	0,15	0,15	0,15	0,15	0,15	0,15	0	0	0	0
-4,00...-2,55	0,40	0,40	0,35	0,35	0,35	0,35	0,30	0,30	0,10	0,10	0	0
-2,50...-1,85	0,60	0,55	0,55	0,50	0,50	0,50	0,45	0,40	0,20	0,15	0,10	0
-1,80...-1,25	0,80	0,70	0,70	0,65	0,60	0,60	0,55	0,45	0,30	0,22	0,177	0,13
-1,20...-0,75	1,00	0,90	0,85	0,80	0,75	0,70	0,65	0,55	0,40	0,31	0,25	0,21
-0,70...-0,45	1,20	1,05	1,00	0,95	0,90	0,80	0,75	0,65	0,50	0,40	0,33	0,29
-0,40...-0,25	1,40	1,20	1,10	1,05	1,00	0,90	0,80	0,70	0,60	0,49	0,41	0,37
-0,20...+0,20	1,75	1,45	1,35	1,25	1,15	1,05	0,95	0,85	0,70	0,58	0,50	0,45
+0,25...+0,40	2,10	1,70	1,55	1,45	1,30	1,20	1,05	0,95	0,75	0,62	0,53	0,48
+0,45...+1,00	2,35	1,90	1,70	1,55	1,45	1,30	1,15	1,00	0,80	0,66	0,56	0,51

Linear thermal transmittance coefficient of ground contact wall

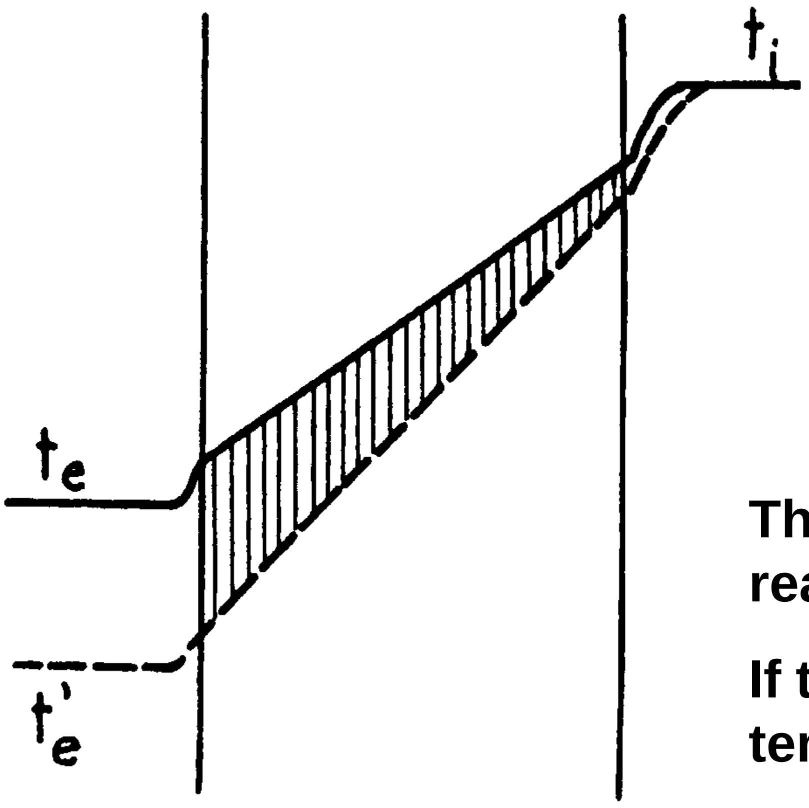
(One side is in heated room, other side contacted with the ground)

Ψ

[W/mK]

Height of ground contact wall (height difference between the ground level and the floor level) [m]		U-value of the wall								
		0,30... 0,39	0,40... 0,49	0,50... 0,64	0,65... 0,79	0,80... 0,99	1,00... 1,19	1,20... 1,49	1,50... 1,79	1,80... 2,20
...	-6,00	1,20	1,40	1,65	1,85	2,05	2,25	2,45	2,65	2,80
-6,00...	-5,05	1,10	1,30	1,50	1,70	1,90	2,05	2,25	2,45	2,65
-5,00...	-4,05	0,95	1,15	1,35	1,50	1,65	1,90	2,05	2,25	2,45
-4,05...	-3,05	0,85	1,00	1,15	1,30	1,45	1,65	1,85	2,00	2,20
-3,00...	-2,05	0,70	0,85	1,00	1,15	1,30	1,45	1,65	1,80	2,00
-2,00...	-1,55	0,55	0,70	0,85	1,00	1,15	1,30	1,45	1,65	1,80
-1,50...	- 1,05	0,45	0,60	0,70	0,85	1,00	1,10	1,25	1,40	1,55
-1,00...	-0,75	0,35	0,45	0,55	0,65	0,75	0,90	1,00	1,15	1,30
-0,70...	-0,45	0,30	0,35	0,40	0,50	0,60	0,65	0,80	0,90	1,05
-0,40...	-0,25	0,15	0,20	0,30	0,35	0,40	0,50	0,55	0,65	0,74
-0,40...		0,10	0,10	0,15	0,20	0,25	0,30	0,35	0,45	0,45

Thermal mass



- Temperature change results in energy change
- Heat stored or released:

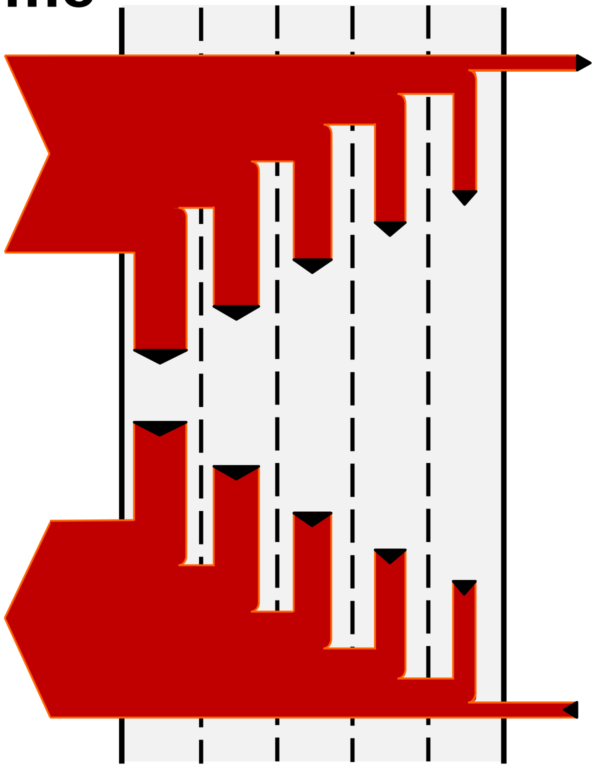
$$\Delta q = m \cdot c \cdot \Delta t$$

The temperature change on one side reaches a certain depth in a finite time.

If the temperature changes over time, the temperature distribution is not linear!

Daily heat storage cycle

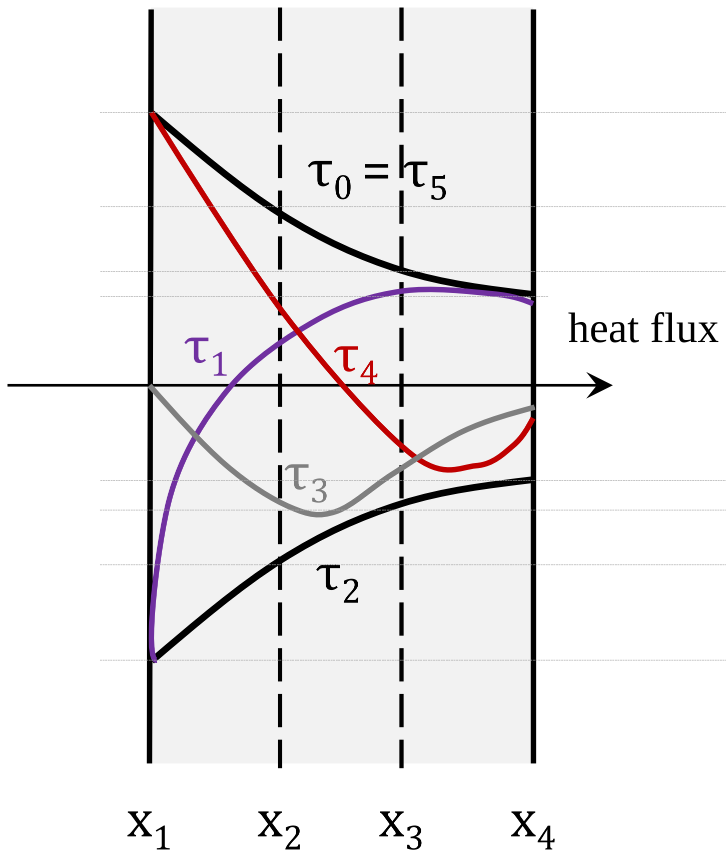
Daytime



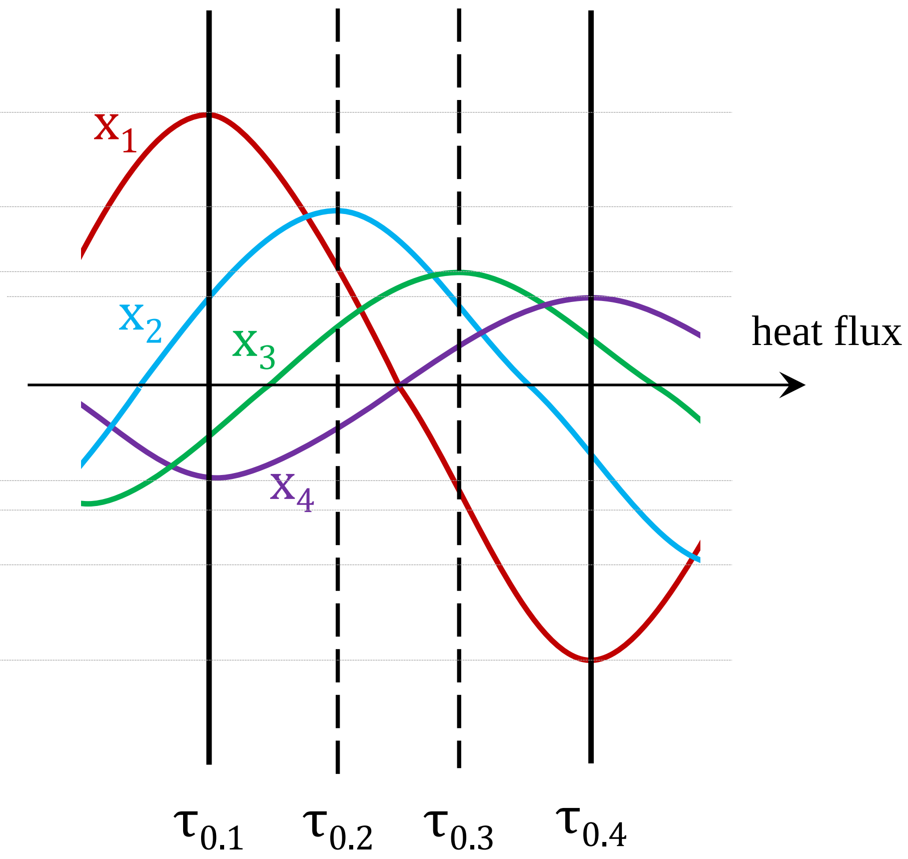
Nighttime

The structure absorbs some of the heat when the temperature rises and returns it when it cools down.

Temperature fluctuation in the structure by time



Temperature fluctuation by location

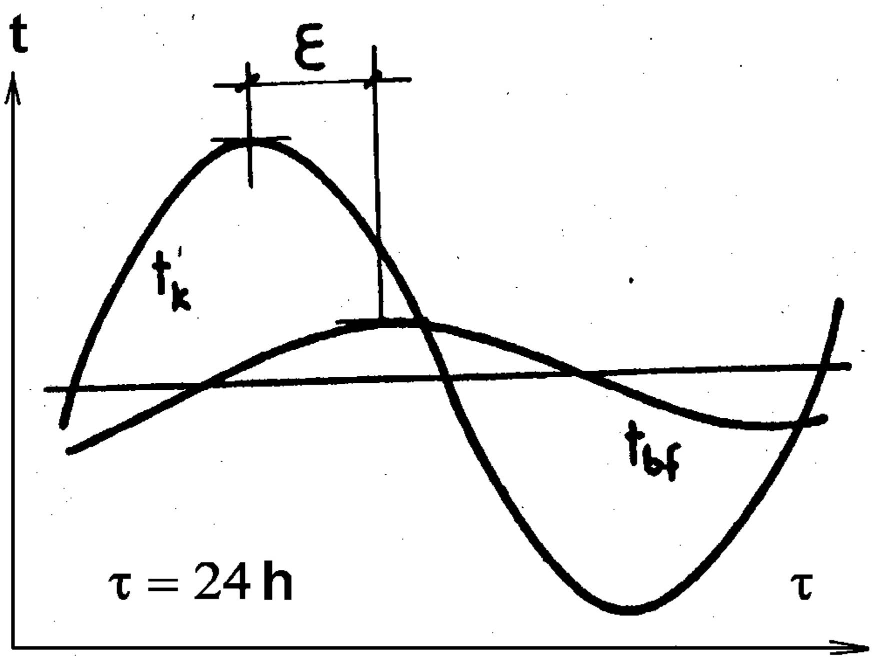


Temperature fluctuation by time τ_0

Attenuation, time lag (summer case)

It takes time to heat up the layers of heat flux in it's way. Therefore, the temperature fluctuation on the inner plane follows the swing of the inner plane temperature is delayed in time.

Time lag: distance of the same phase pints in time (ε)



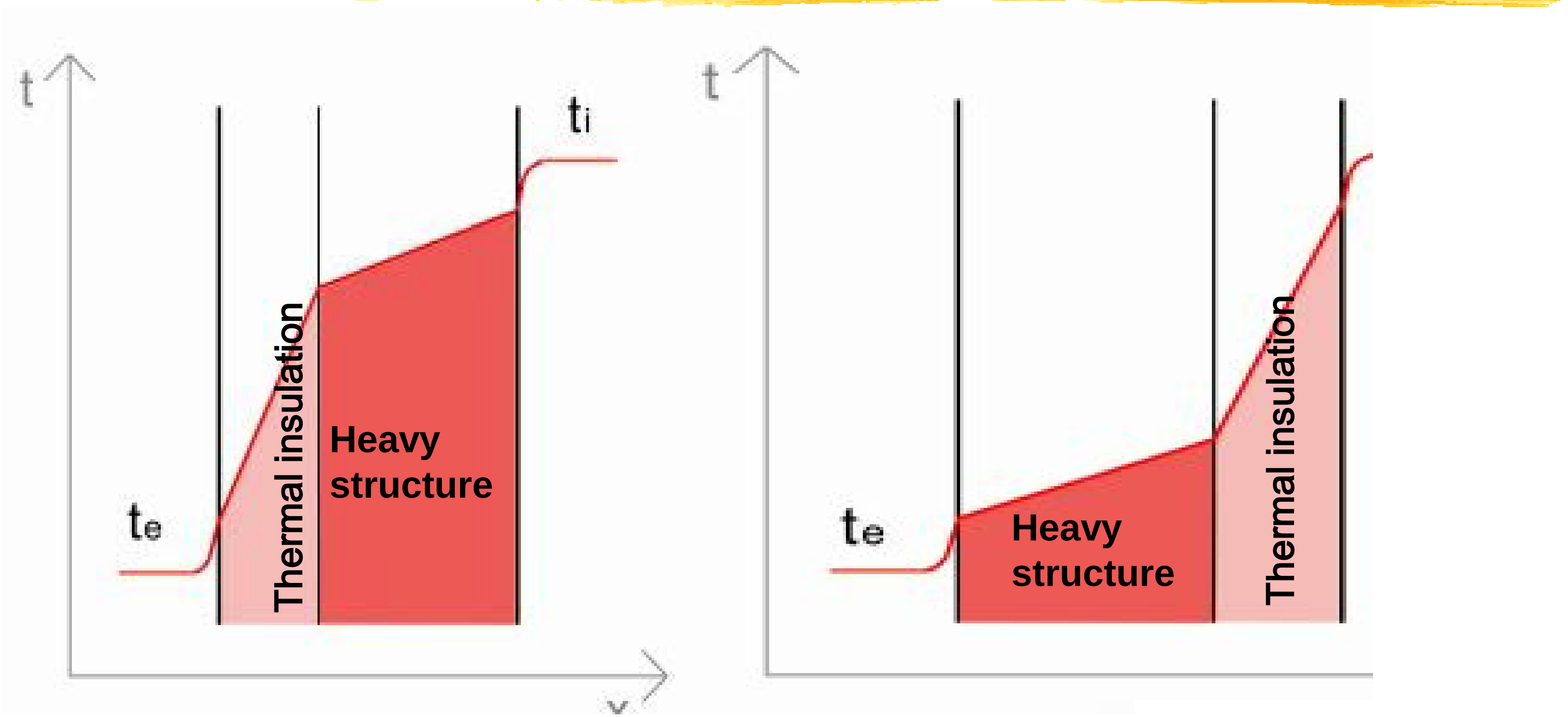
t'_k = surface temperature outside

t_{bf} = surface temperature inside

Amplitude outside: A_{tk}
Amplitude inside: A_{tbf}

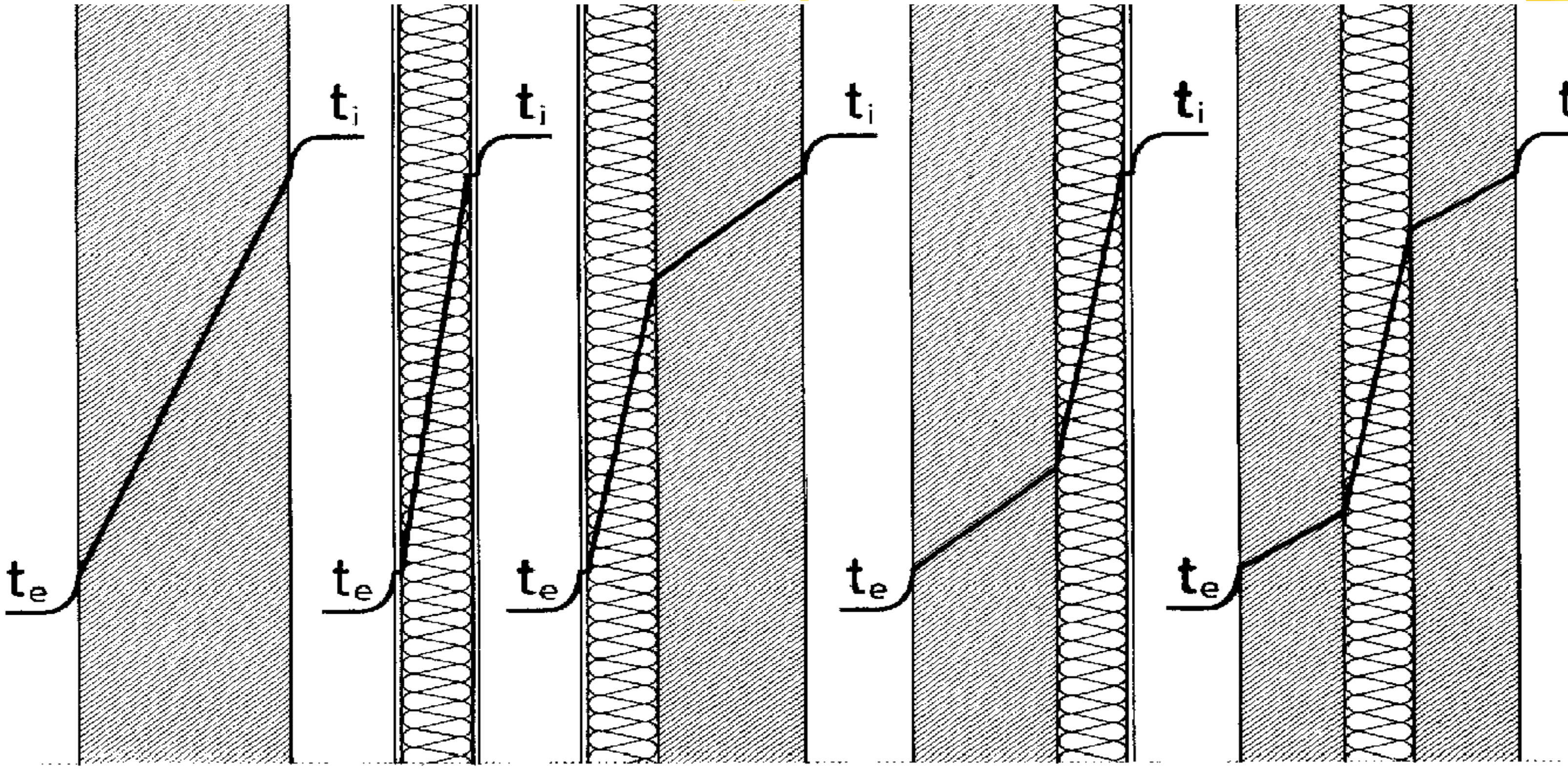
Attenuation factor: $\nu = \frac{A_{tk}}{A_{tbf}}$

The layer structure affects the effective heat storage



The stored heat is proportional to the area under the temperature profile curve. Internal thermal insulation excludes the heat storage mass from the building.

The layer structure affects the effective heat storage



Internal thermal insulation excludes the heat storage mass from the building, only the inner casing will work as thermal mass.

Thermal mass

The specific heat of the majority of (silicate-based) materials used in the construction industry
c = 0,84 … 0,95 kJ/kg K

Therefore, since the material type does not play a significant role in the amount of stored heat energy, instead of heat storage capacity (m · c) we only use heat storage mass (m).

The only exception is wood, which has a specific heat c = 1,7…3,0 kJ/kgK, therefore, a triple factor is used for heat storage

Thermal mass of structures Simplified method by CEN

Thermal mass is:

- **The first 10 cm from inside,**
- **Or, in case there is a thermal insulation before 10 cm is reached, then the thickness between the inner surface and the first insulating layer**
- **In case of partition wall, if the thickness is less than 20cm, then the distance between the inner surface and the centre line of the partition wall.**

Further reference: **CEN**/TC 89 **Thermal** performance of buildings and building components. ... Effects of **thermal mass**, ventilation, and glazing orientation on indoor air ...

Thermal mass of a room / building

Total heat storage mass in the heated space:

$$M = \Sigma\ A_j \cdot m_{f\,j}\ [kg]$$

Specific heat storage of the room / building (ép):

Thermal mass per heated floor area ***(A)***

$$m_{f\,ép} = \frac{M}{A}\,[kg/m^2]$$

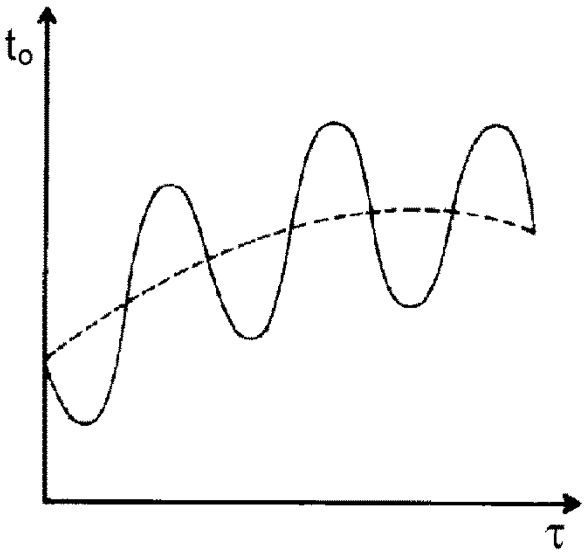
Classification by thermal mass:

- heavy, if $\boldsymbol{m_{f\,ép}} \geq 400$ kg/m^2

- lightweight, if $\boldsymbol{m_{f\,ép}} < 400$ kg/m^2

Effect of the thermal mass (capacity)

The high thermal mass (capacity) reduces the temperature swings

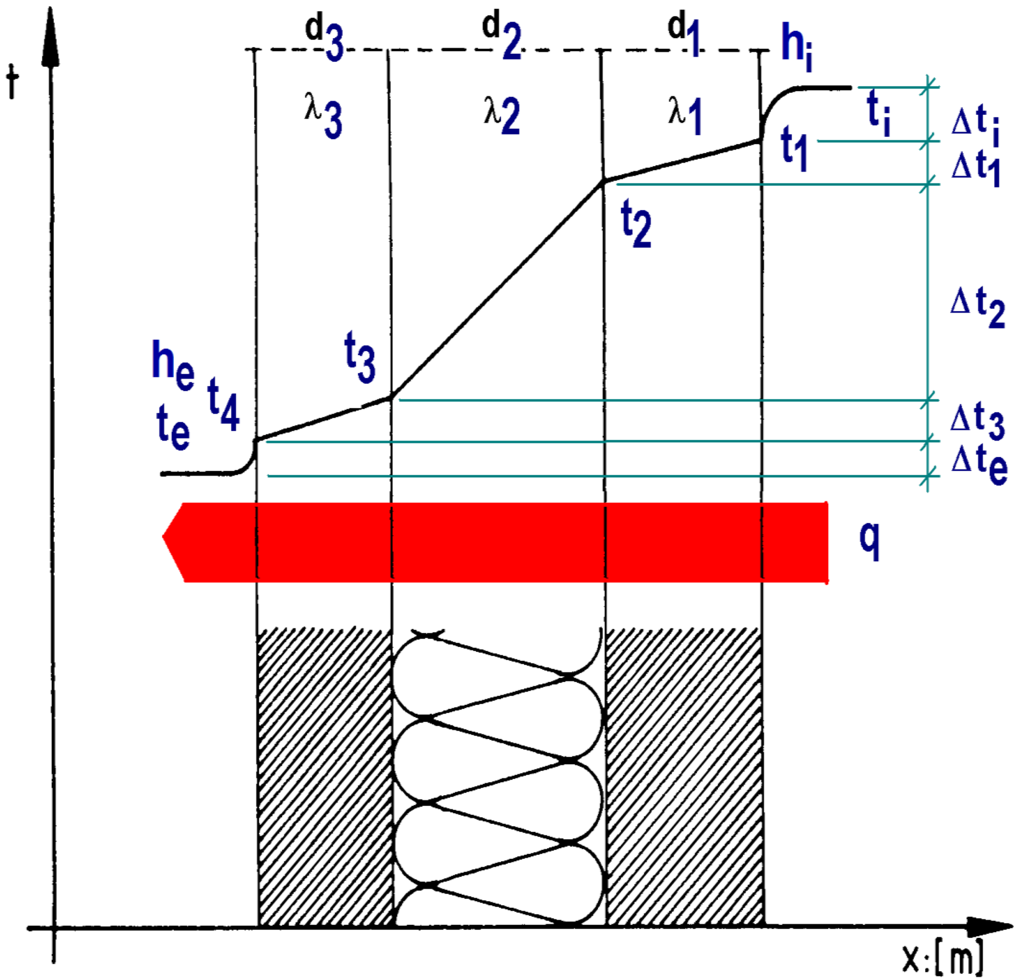


- **In summer it is beneficial because it slows down the warming. (Cool with cooler air at night to work well.)**
- **In winter, it is advantageous for intermittent heating, because the fluctuation will be smaller. If the heating is continuous and its temperature changes, it will only affect the control setting.**
- **In case of occasionally used building it is disadvantageous in winter (eg weekend house)**

Consistency, humidity issues

Temperature profile within a structure

Boundary conditions: one-dimensional, steady-state, source-free



$$q = h_i \cdot (t_i - t_1)$$

$$q = \lambda_1 / d_1 \cdot (t_1 - t_2)$$

$$q = \lambda_2 / d_2 \cdot (t_2 - t_3)$$

$$q = \lambda_3 / d_3 \cdot (t_3 - t_4)$$

$$q = h_e \cdot (t_4 - t_e)$$

$$q = U \cdot (t_i - t_e)$$

$$q \cdot \Sigma R = (t_i - t_e)$$

$$q \cdot 1 / h_i = q \cdot R_i = (t_i - t_1)$$

$$q \cdot d_1 / \lambda_1 = q \cdot R_1 = (t_1 - t_2)$$

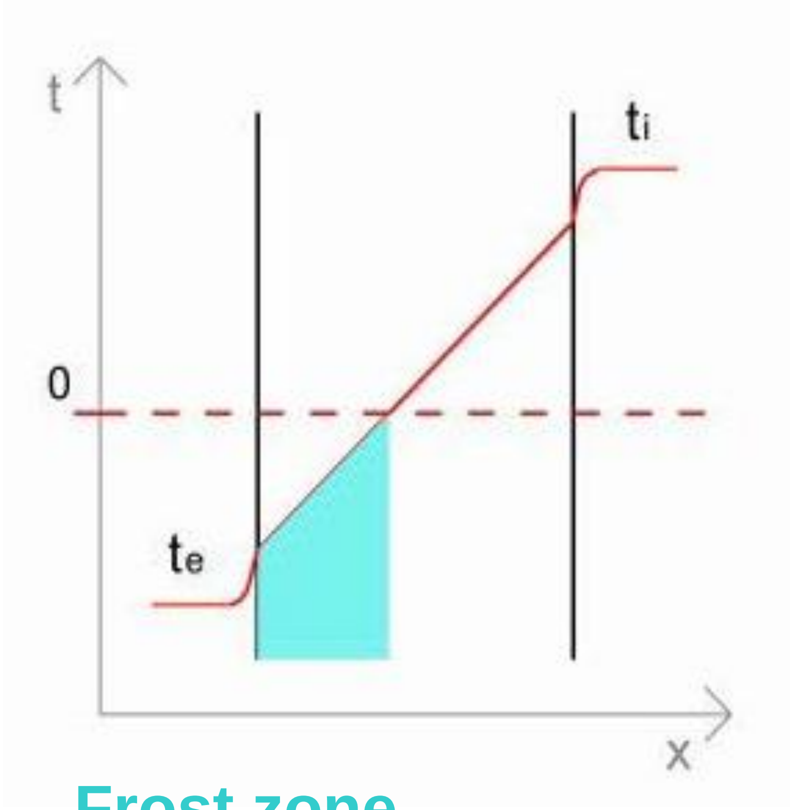
$$q \cdot d_2 / \lambda_2 = q \cdot R_2 = (t_2 - t_3)$$

$$q \cdot d_3 / \lambda_3 = q \cdot R_3 = (t_3 - t_4)$$

$$q \cdot 1 / h_e = q \cdot R_e = (t_4 - t_e)$$

Conclusion: temperature drop in each of the layers: $q \cdot R_n = \Delta t_n$

Frost zone within a structure



Frost zone

Humid Air
Water vapour in air

Water vapour is a key constituent of the atmosphere and plays a significant role in radiative and thermodynamic processes that affect the evolution of the atmospheric state through time.

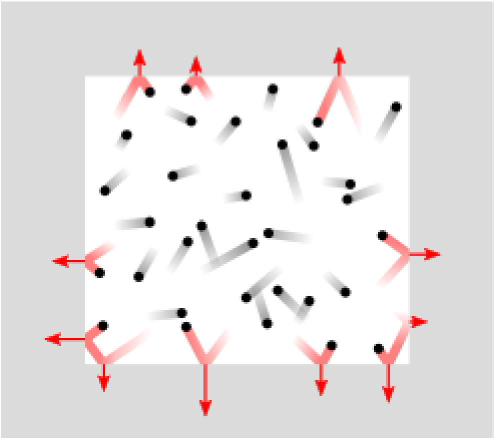
Typically water vapour is represented by the variable specific humidity, the amount of water vapour in the mixture of water vapour and dry air, in both analysis of the atmospheric state as well as various physically based models describing the evolution of the atmospheric state.

Pressure

Pressure as exerted by atoms or molecules colliding with the inner walls of a container.

Collisions and the resulting forces are shown in red.

Pressure is the sum of the collisional forces.



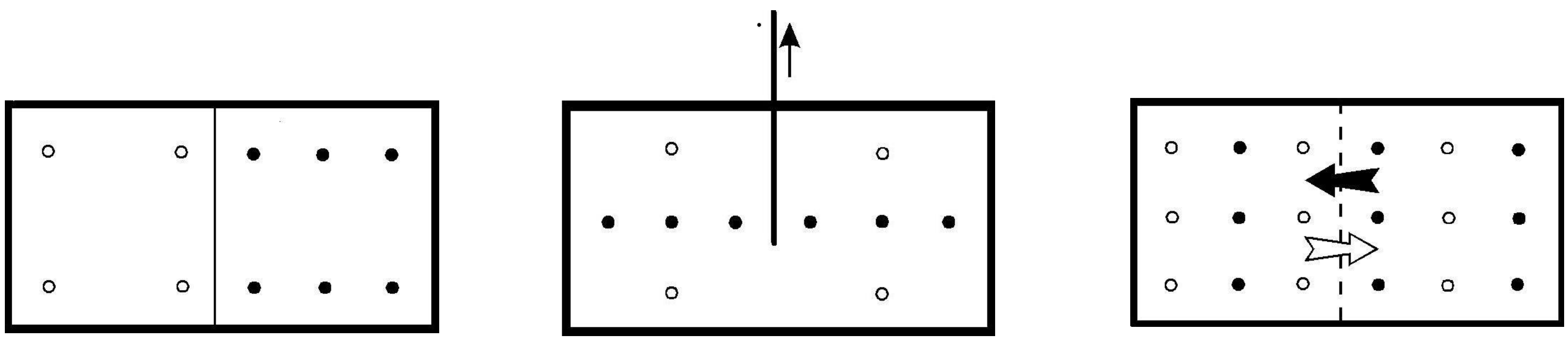
Diffusion

Diffusion is the process of two gases mixing together, if both stored in the same container.

They will spread out evenly, resulting in a solution (homogeneous mixture)

Gas mixture

Air: mixture of dry components and vapour. All components seek even distribution in the volume available.



The pressure is proportional with the number of molecules.

In a mixture of non-reacting gases, the total pressure exerted is equal to the sum of the partial pressures of the individual gases: $p_{total} = p_n + p_m$ (Dalton law)

Saturation and relative humidity

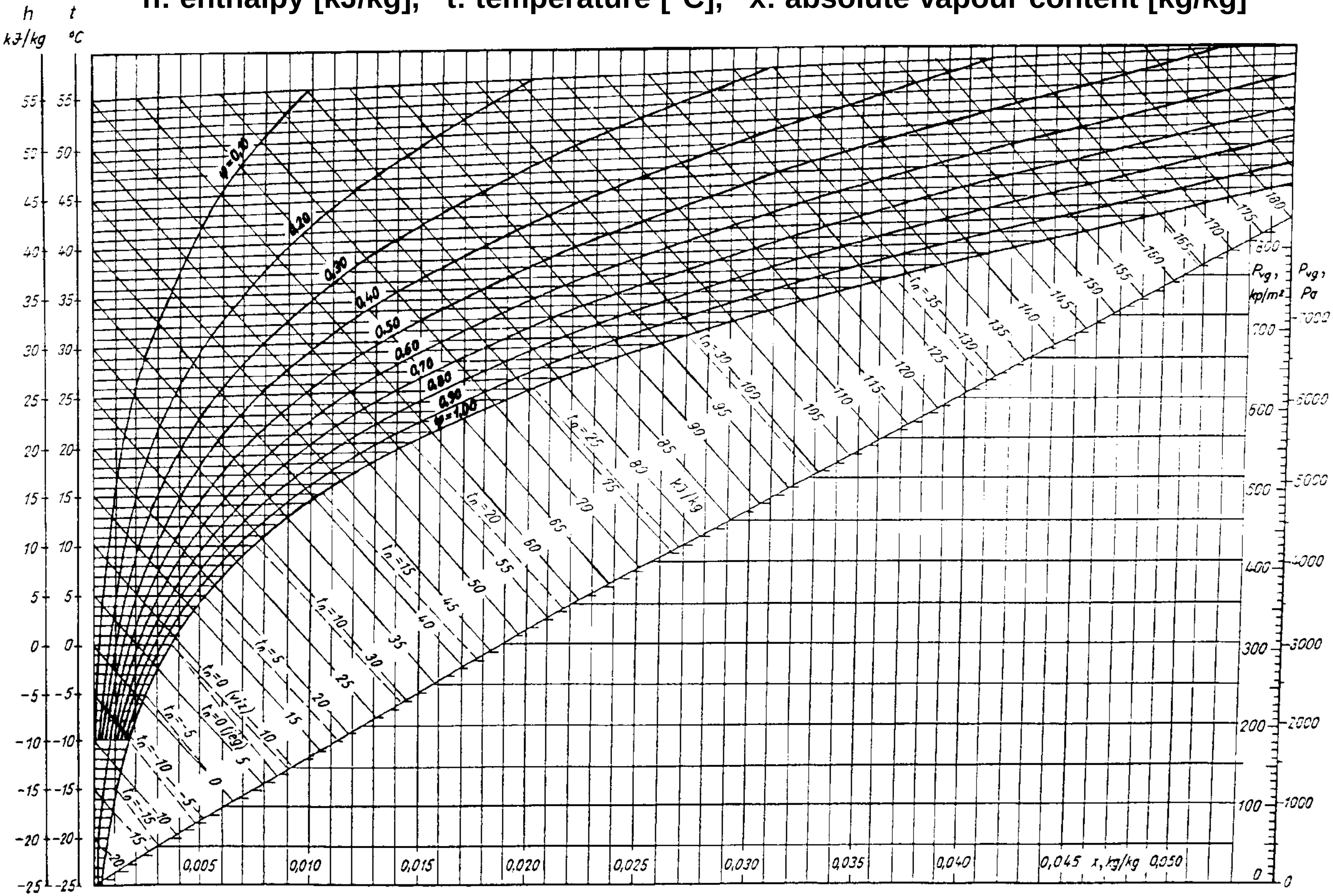
<u>Part saturation pressure (dew point):</u> the maximal partial pressure (vapour content) the air can keep. Temperature dependent.

<u>Relative humidity:</u> Relative humidity may be defined as the ratio of the water vapour density (mass per unit volume) pressure to the saturation water vapour density or pressure, usually expressed in percent:

$$\varphi = \frac{p}{p_s} \cdot 100[\%]$$

Mollier h-x diagram

h: enthalpy [kJ/kg], t: temperature [°C], x: absolute vapour content [kg/kg]

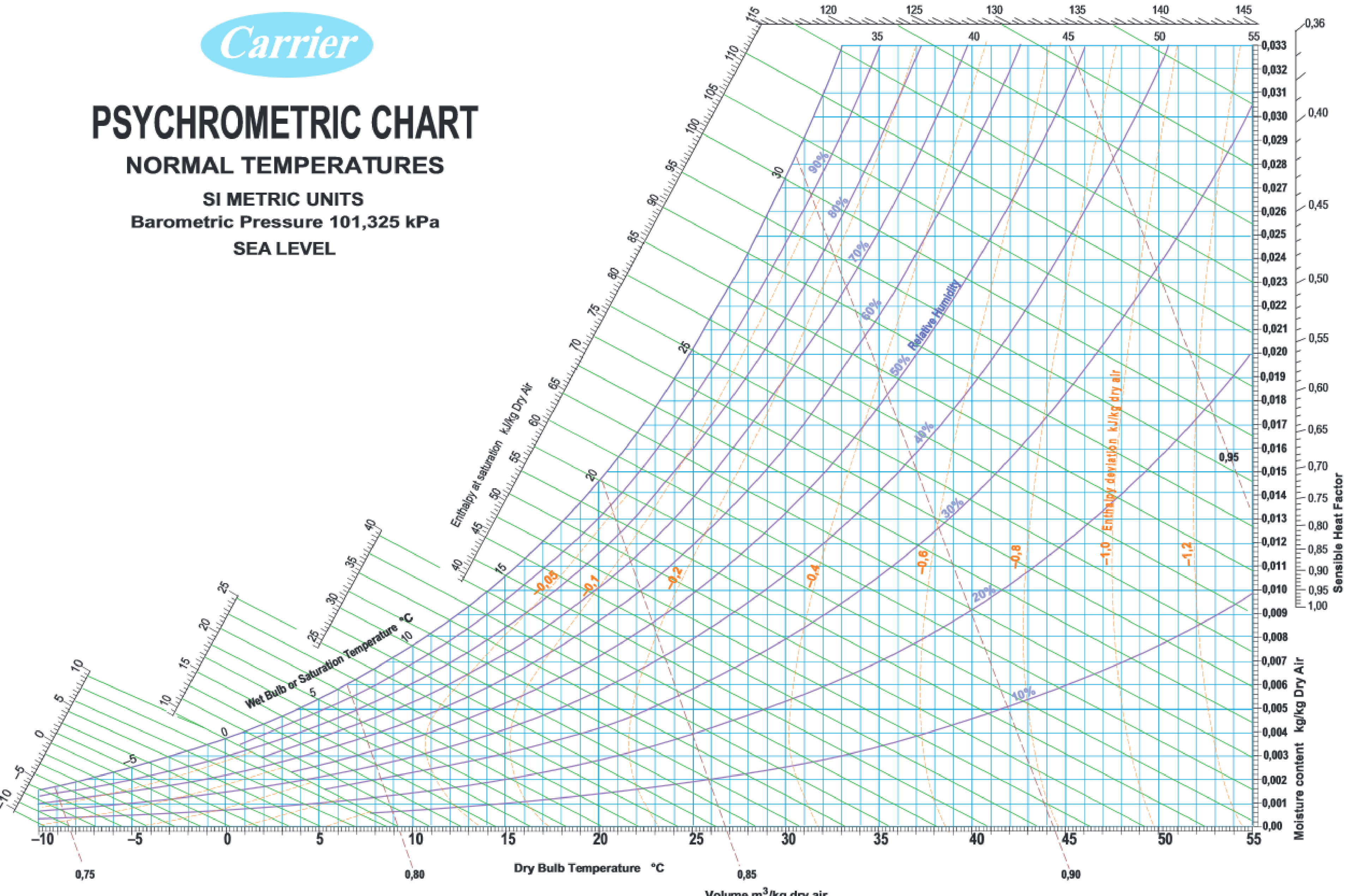


Carrier

PSYCHROMETRIC CHART

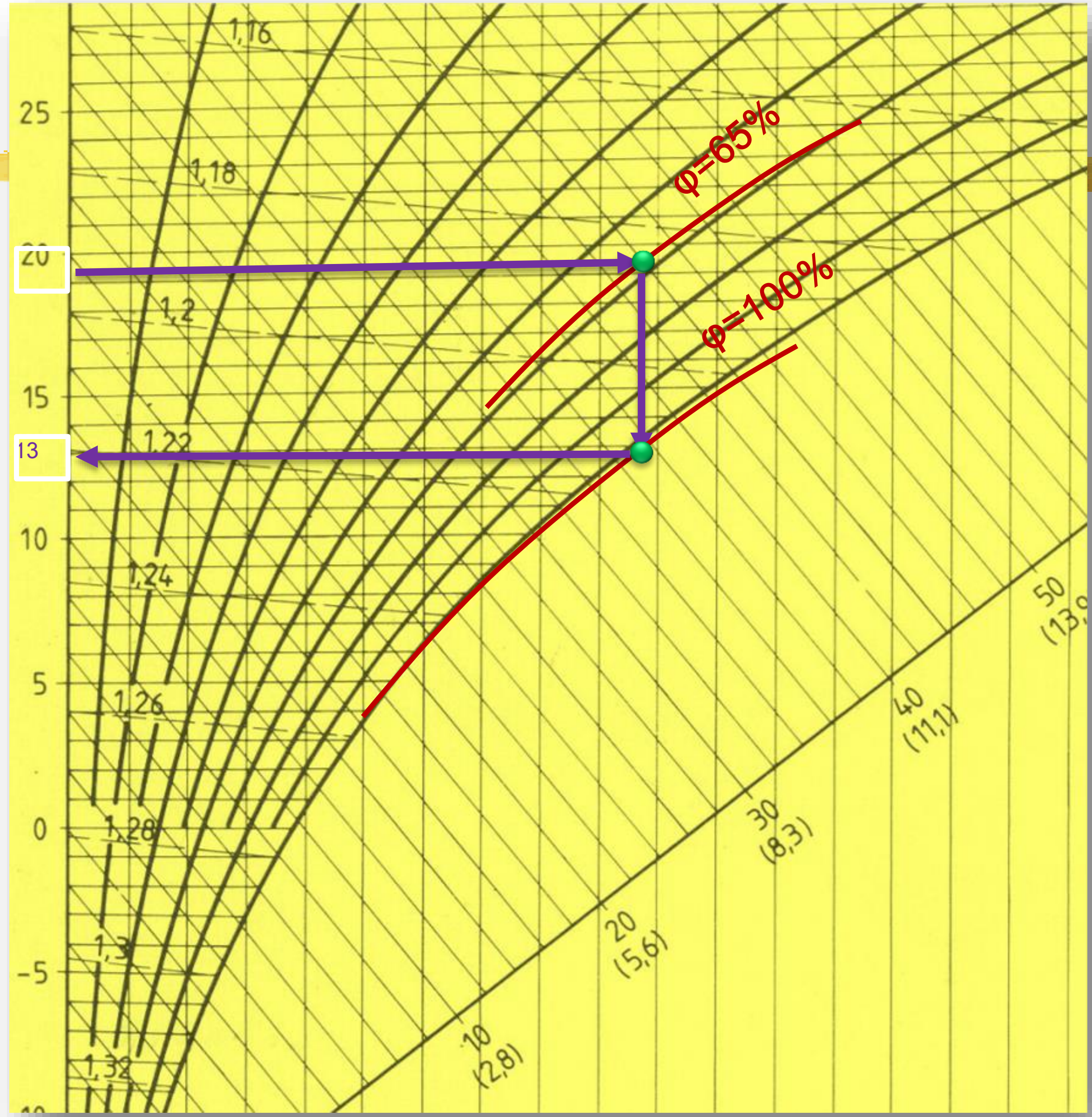
NORMAL TEMPERATURES

SI METRIC UNITS
Barometric Pressure 101,325 kPa
SEA LEVEL



Below 0°C, Properties and Enthalpy Deviation Lines Are For Ice

Condensation on the surface



Inside temperature of the surface

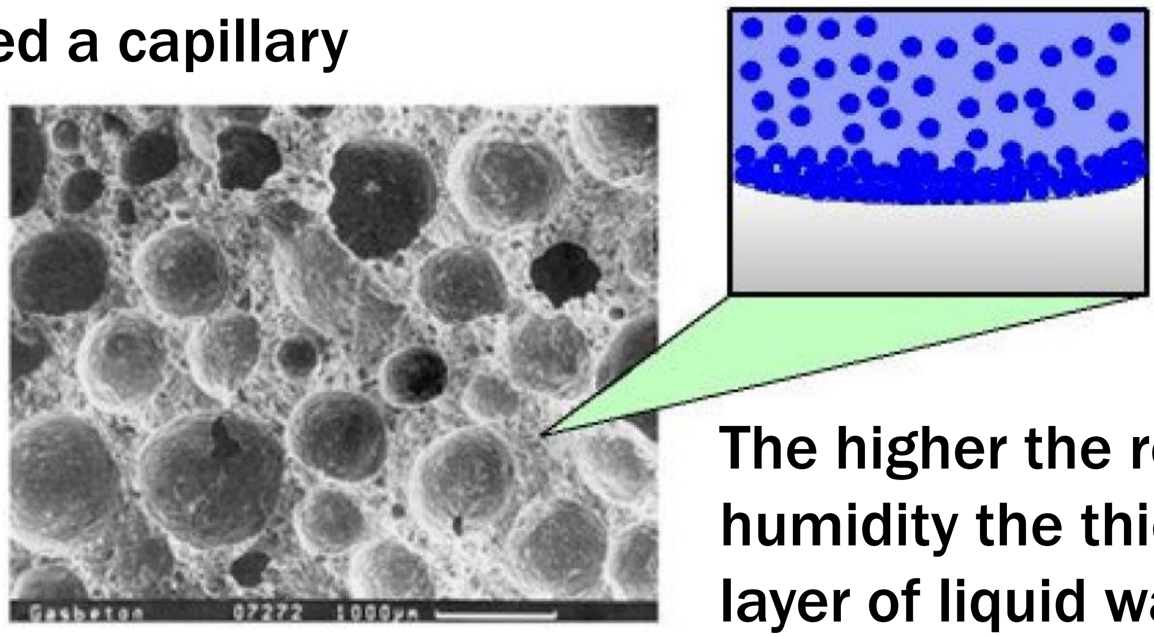
$$t_{surface} = t_i - \frac{U_R}{h_i}(t_i - t_e)$$

U_R **= the effect of the thermal bridges combined into the thermal transmittance coefficient**

$$U_R = \frac{A * U_{rt} + \sum \psi * l}{A} \left[{W}/{m^2K} \right]$$

The surfaces of capillaries can store liquid water

A series of linked pores are called a capillary

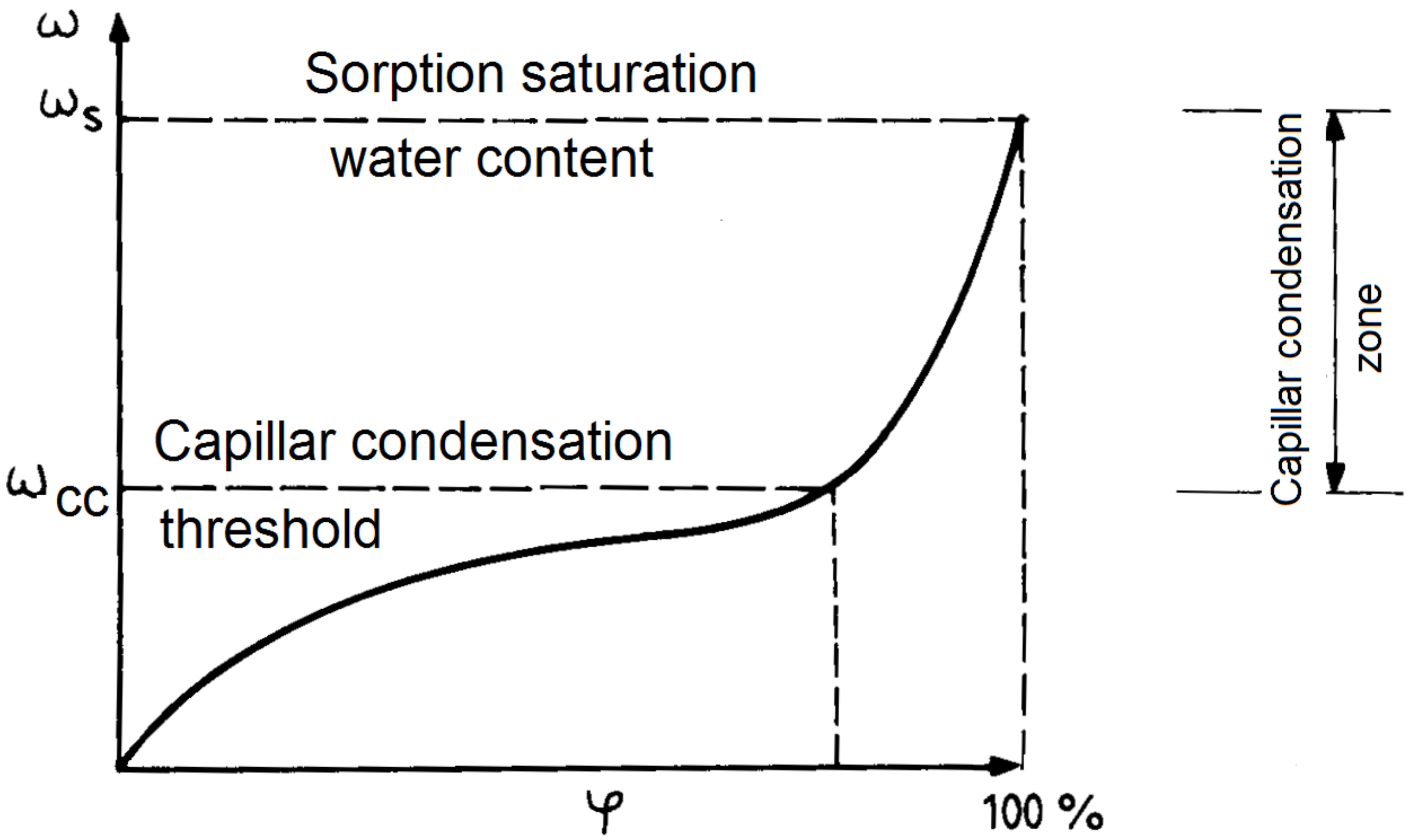


The higher the relative humidity the thicker is the layer of liquid water.

Liquid water can be found in a particular capillary of a porous material due to water vapour condensing on its surfaces as relative humidity levels change within it.

Moisture storage function of porous materials

Sorption isotherm



Moisture penetration, vapour diffusion

Boundary conditions: one-dimensional, steady-state, source-free

Vapour conductivity: δ [g / s Pa m]

Vapour transfer resistance between the surface and the air is negligible

Vapour transfer resistance : $R_v = \frac{d}{\delta}$ [s Pa m² / g]

More than one layers: $\sum R_v = \frac{d_j}{\delta_j}$

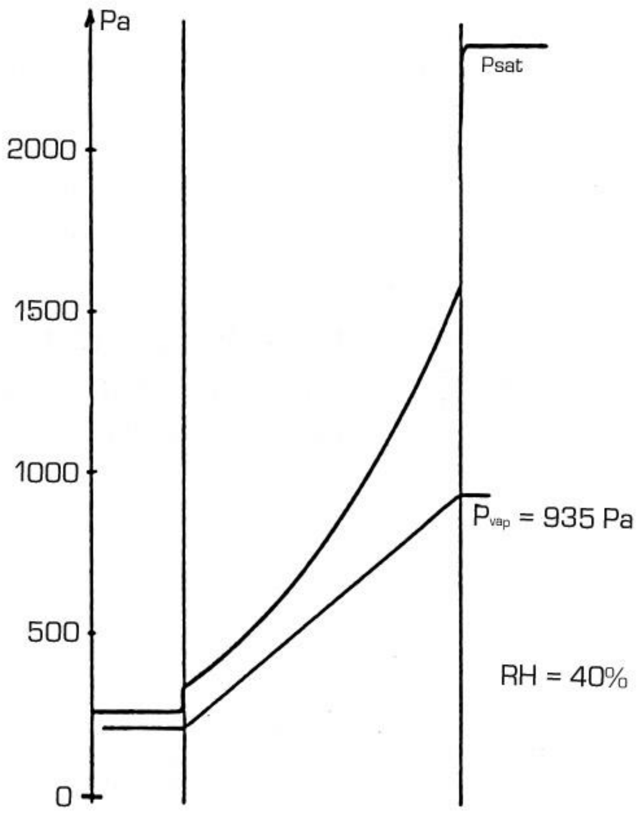
Vapour transfer flux: $g = \frac{p_i - p_e}{\sum R_v}$ [g / s m²]

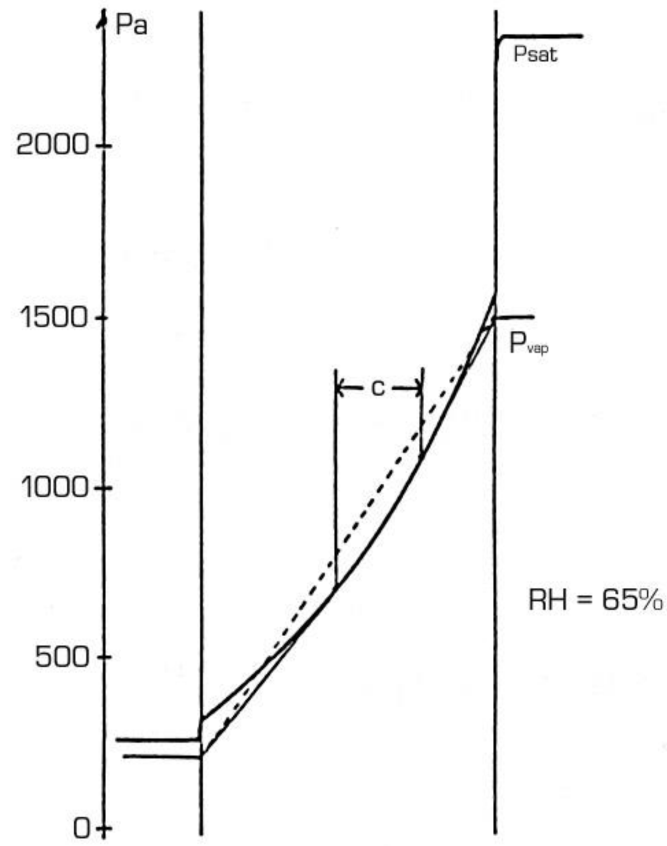
Where: g = vapour flux

Pressure drop in each of the layers: $\Delta p_n = g \cdot R_{v\,n}$

Design exterior air conditions in general: $t_e = -2^oC \quad \varphi = 90\%$

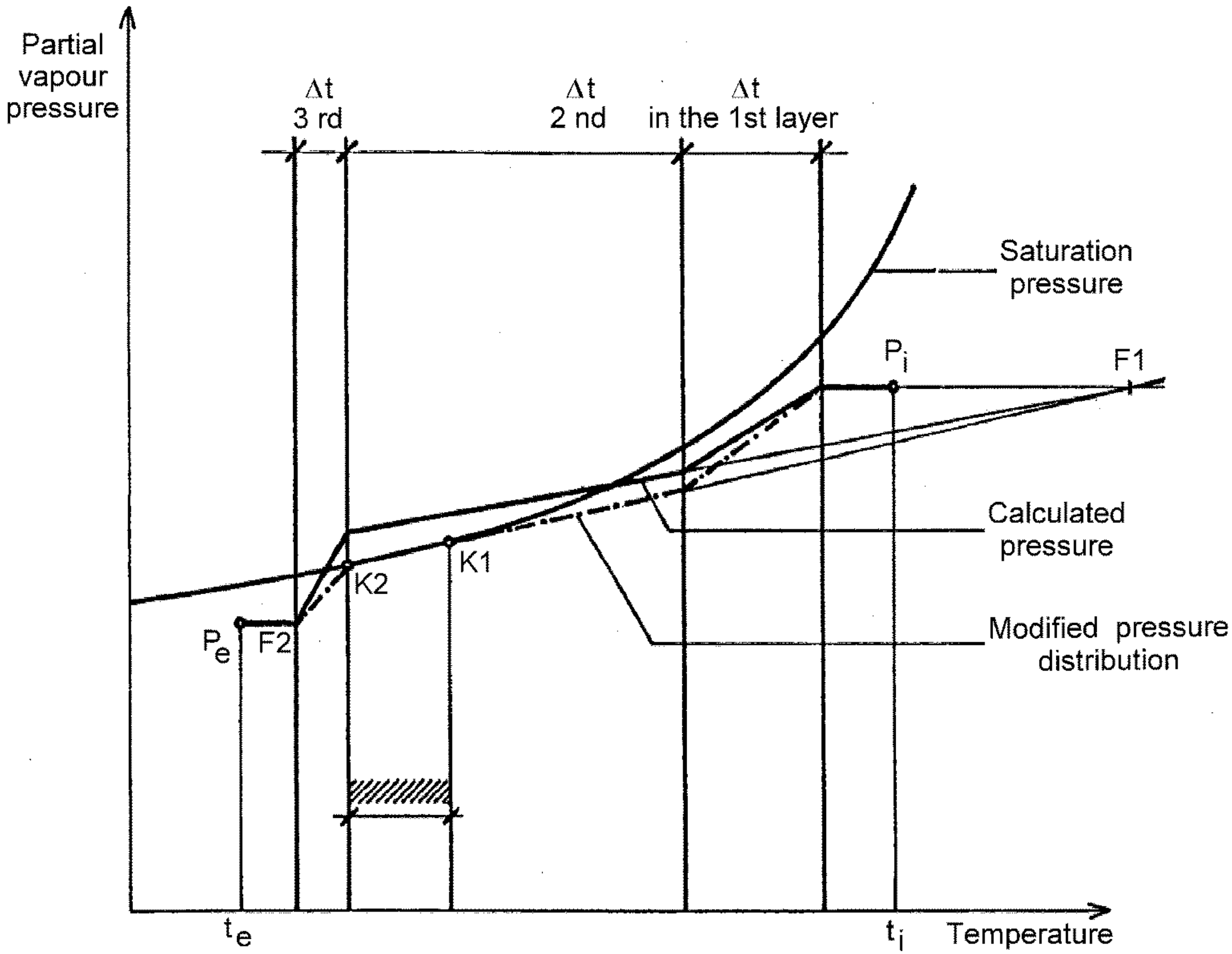
Protection against humidity





- ⌘ Condensation from humid air infiltration
- ⌘ Reaching of dew-point
- ⌘ Assessing the condensation risk

Drawing of the modified partial pressure diagram



The partial pressure newer excides the saturation pressure!

Calculation of the vapour subsidence time:

Reading „ω" from the sorption isotherm: initial and equilibrium ($\varphi_{initial}$ = 60%)

Increase of saturation in a structural layer:

$$\Delta\omega = \omega_{equilibrium} - \omega_{initial} \qquad [m\%]$$

The specific mass of a layer: $m = d \cdot \varrho$ [kg/m²]

Increase of water condensed in a layer:

$$\Delta m_v = \frac{m \cdot \Delta\omega}{100} \qquad [kg/m^2]$$

Increase of the total water content :

$$\sum \Delta m_v = \Delta m_{v1} + \Delta m_{v2} \ldots \Delta m_{vn} \qquad [kg/m^2]$$

Vapour subsidence time

$$\tau_t = \frac{\sum \Delta m_v}{g} \qquad [days\ or\ hours]$$

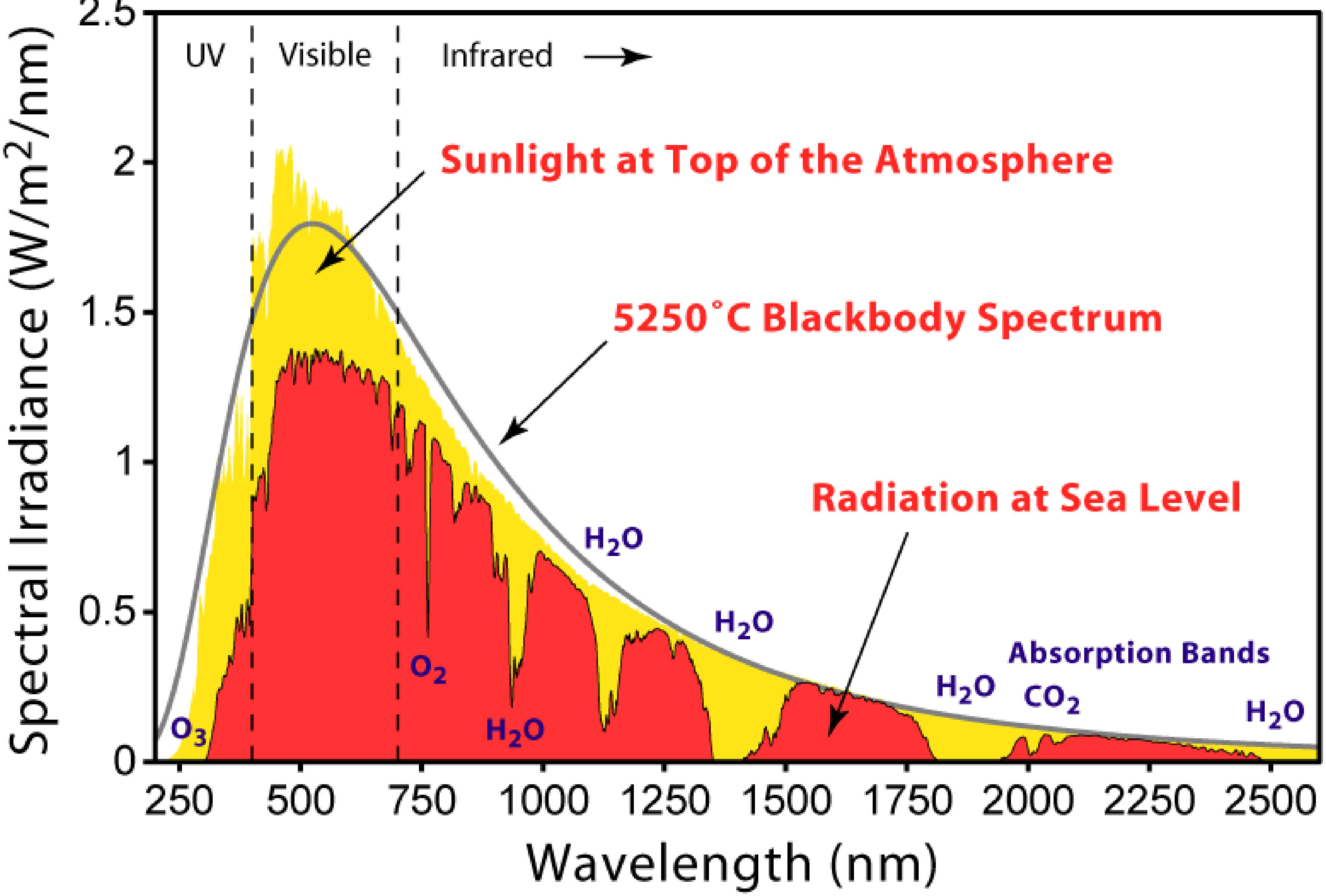
If the charging time is longer than the heating period (182 days in HU), the total saturation will not be reached.

If it is less than the heating period , then the structure must be modified!

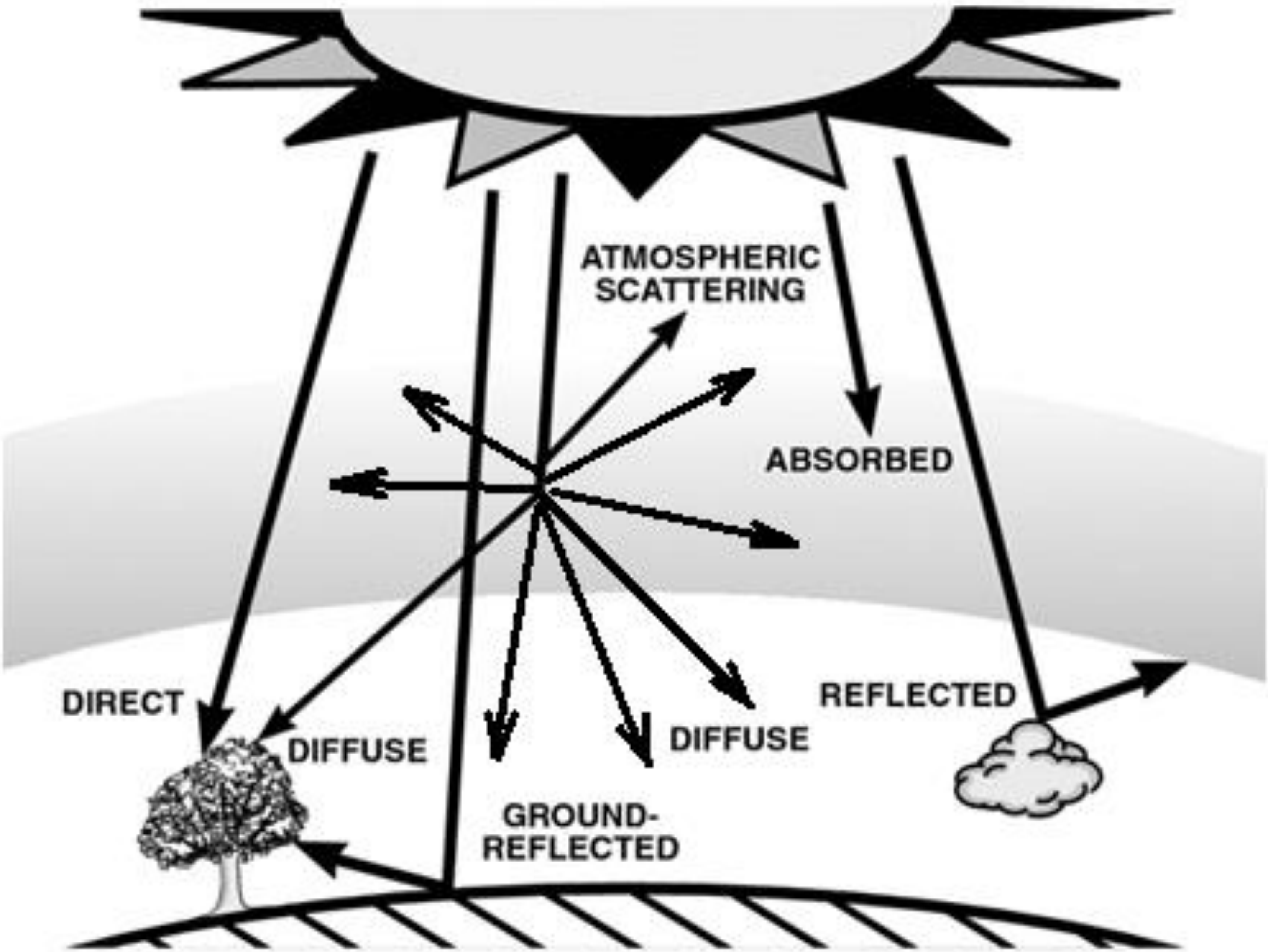
ENERGY BALANCE IN BUILDING

Energy loss and energy gain

Solar Radiation Spectrum



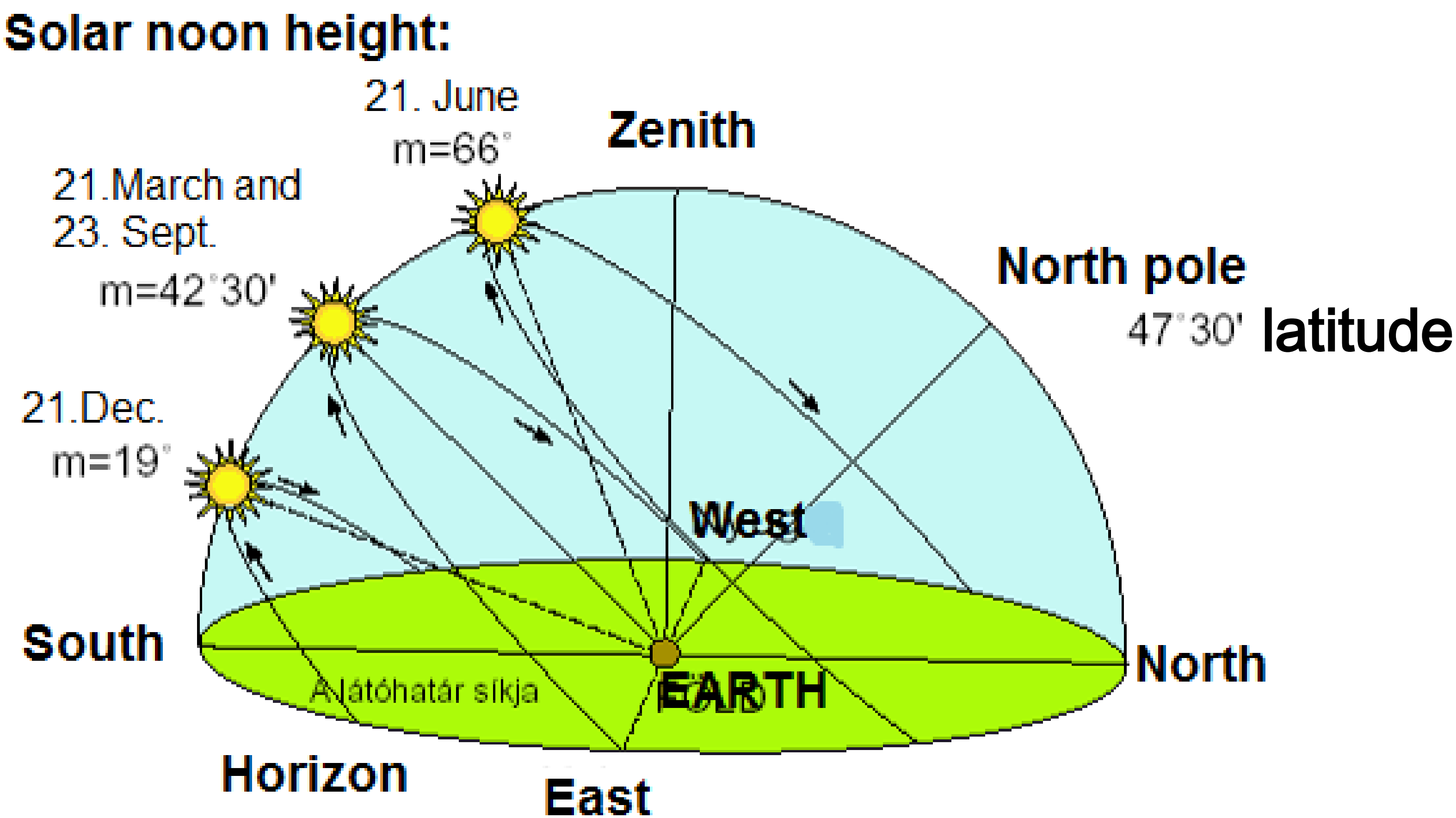
Components of solar radiation



STEREOGRAPHIC ECLIPTIC DIAGRAM

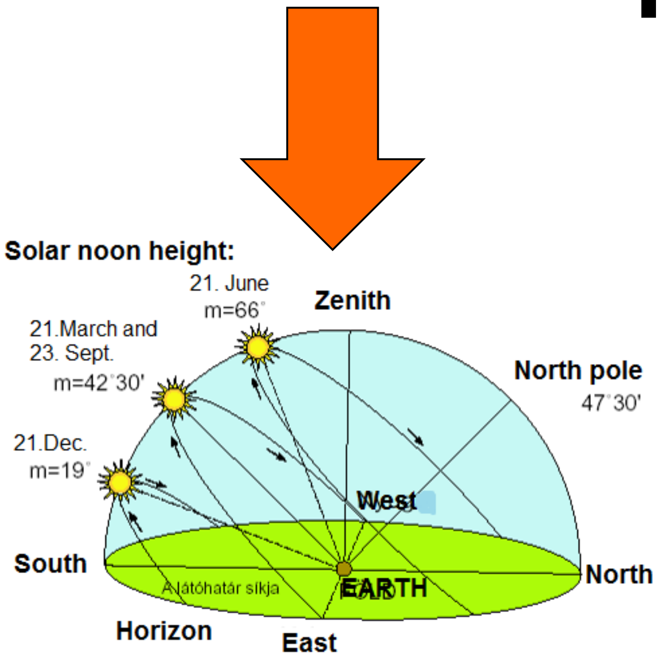
References:
Aladar Olgyay and Victor Olgyay: Solar Control and Shading Devices, Princeton University Press, 1957, 1976 ISBN 0-691-02358-1 ISBN 0-691-08186-7

Ecliptic

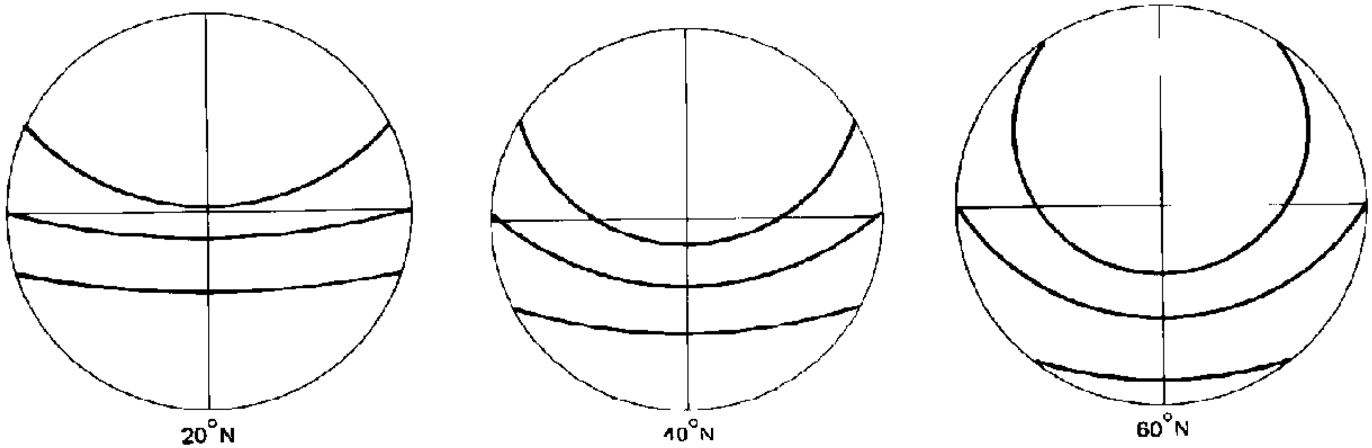


Solar noon height:
21. June
m=66°
Zenith
21.March and
23. Sept.
m=42°30'
North pole
47°30' latitude
21.Dec.
m=19°
West
South
A látóhatár síkja
EARTH
North
Horizon
East

Derivation of the stereographic ecliptic diagram

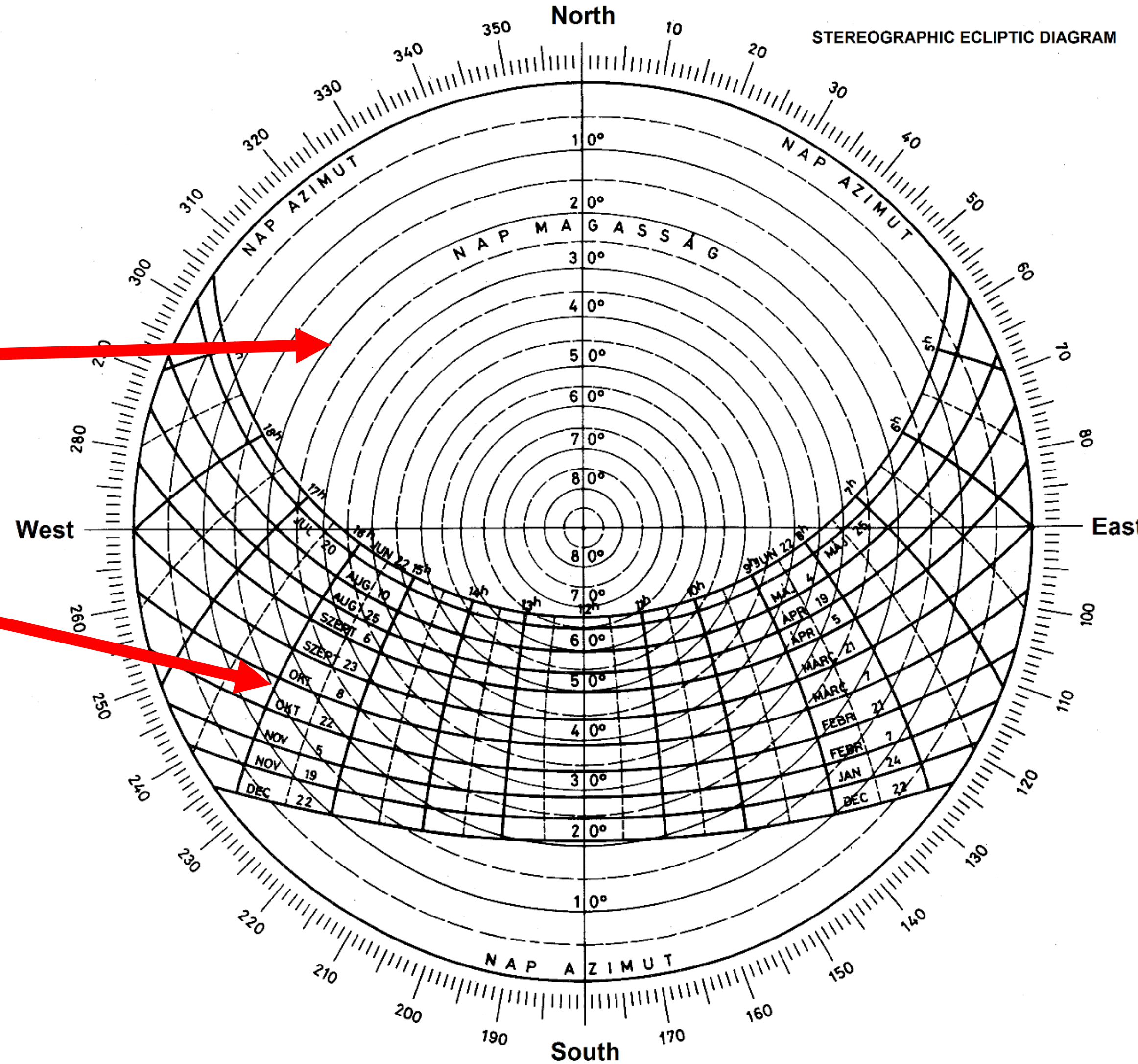


- Projecting the Sun’s apparent path to a horizontal plane
- Horizontal projection of the Sun’s apparent path depending on the latitude:



Stereographic ecliptic diagram

Adding the concentric circles of the Sun's height angles and the lines of the hours of the days

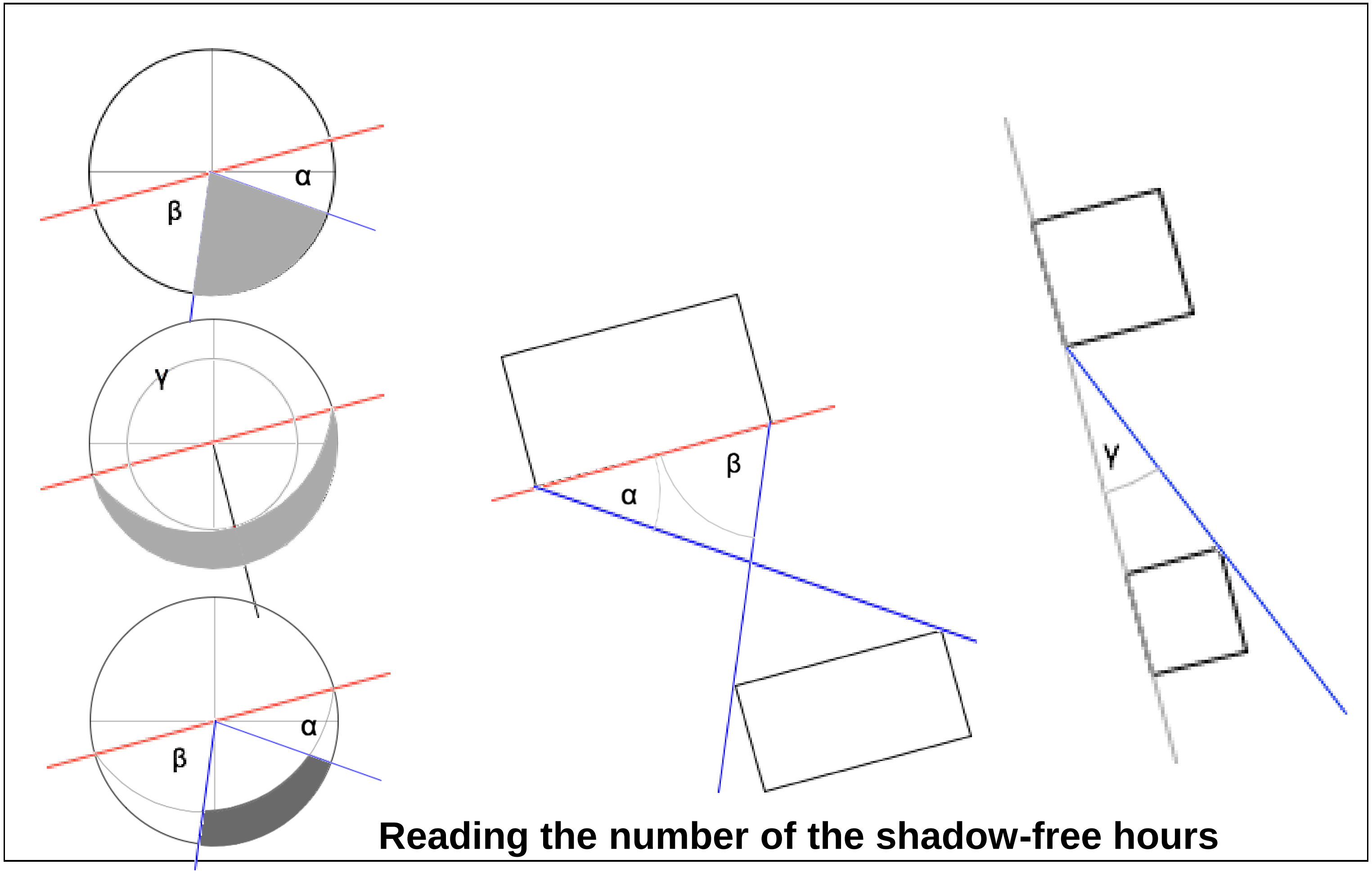


Drawing the shadow mask for a facade

Horizontal shadow mask

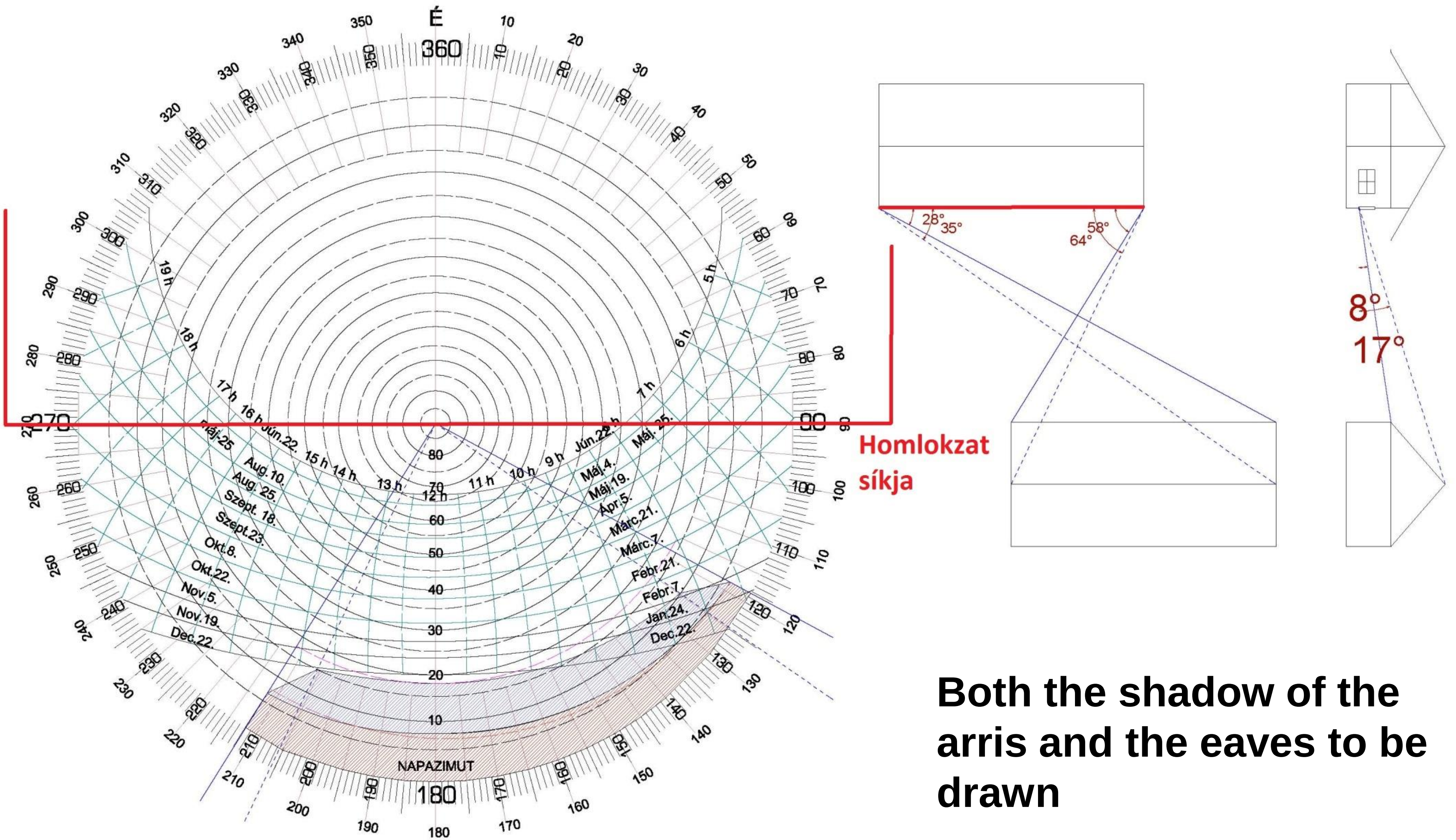
Vertical shadow mask

Aggregate shadow mask



Reading the number of the shadow-free hours

Pitched roof shadow mask



Both the shadow of the arris and the eaves to be drawn

Transmission heat losses
Heating Power

$$P_{tr} = (\Sigma\ A \cdot U + \Sigma\ l \cdot \Psi) \cdot (t_i - t_e)$$

Where:

A ***= Area***

U ***= Thermal transmittance coefficient***

l ***= Length of the cold bridge***

Ψ ***= Linear thermal transmittance coefficient***

t_i ***= air temperatures inside***

t_e ***= air temperatures outside***

Transmission heat losses
Heating Energy

$$Q_{tr} = (\Sigma\ A \cdot U + \Sigma\ l \cdot \Psi) \cdot H$$

Where:

A ***= Area***

U ***= Thermal transmittance coefficient***

l ***= Length of the cold bridge***

Ψ ***= Linear thermal transmittance coefficient***

$H = G/1000$

G = ***Degree Hours for the heating season [hK]***

Average DH in Hungary: 72000 hK

Transmission heat losses
Ventilation heat Power

$$P_{vent} = L \cdot \varrho \cdot c \cdot (t_i - t_e)$$

Where:

L = air flow (fresh air) [m^3/h]

ϱ = density of air [kg/m^3]

c = specific heat of the air [Wh/kg]

t_i = air temperatures inside [°C]

t_e = air temperatures outside [°C]

$\varrho \cdot c$ = 0,35 [Wh/m^3] at usual temperature range

Transmission heat losses
Ventilation heat Energy

$$Q_{vent} = L \cdot \varrho \cdot c \cdot H$$

Where:

L = air flow (fresh air) [m^3/h]

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$H = G/1000$

G = Degree Hours for the heating season [hK]

Average DH in Hungary: 72000 hK

$\varrho \cdot c$ = 0,35 [Wh/m^3] at usual temperature range

Heat balance of glazing in the heating season

⌘ **Transzmission heat loss of glazings in a heating season:**

$Q_{tr} = \Sigma A_{nominal} \cdot U_w \cdot H$

⌘ **Solar direct heat gain of glazings in a heating season:**

$Q_{sd} = \Sigma A_{tr} \cdot Q_{TOT} \cdot g \cdot \varepsilon$

Where:

A_{tr} = ***transparent area***

g = ***solar radiation transmission factor of the glazing***

ε = ***efficiency*** *(depends on the thermal mass of the building)*

Q_{TOT} = ***solar energy in the heating season***

Solar energy in the heating season in Hungary:

Orientation:	S	E-W	N, shadow
Q_{TOT} [kWh / m^2 a]	400	200	100