BUILDING PHYSICS

Linear heat transmission (thermal bridges) Thermal capacity

Part 1

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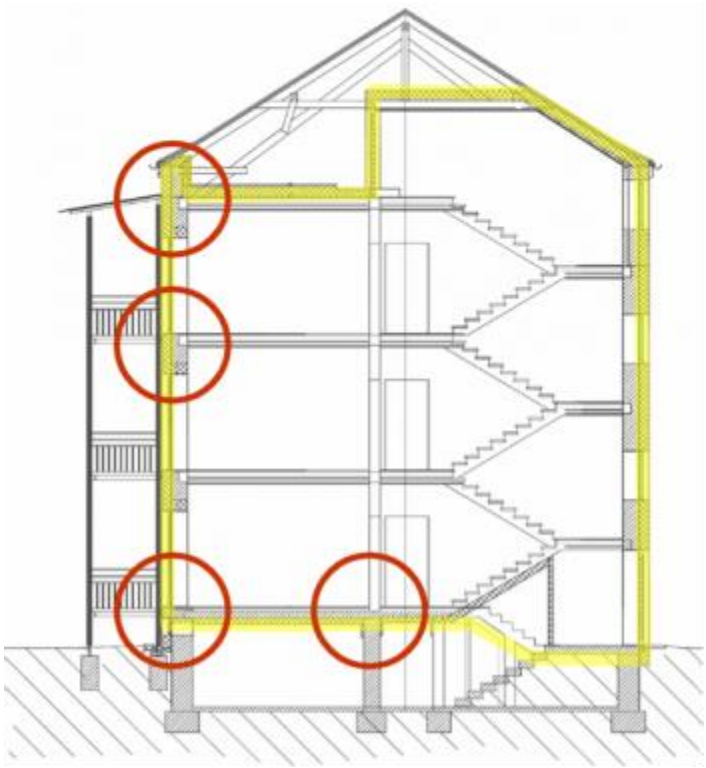
Outline

Thermal bridges introduction
Self-scale temperature
Application of self-scale temperature
Apparent thickness
Temperature distribution of a wall corner
Thermal bridges definition and types
Point Loss

Thermal Bridges
introduction

THERMAL BRIDGE is a component, or assembly of components, in a building envelope through which **HEAT IS TRANSFERRED** at a substantially **HIGHER RATE** than through the surrounding envelope area, also **temperature is** substantially **different** from surrounding envelope area.



Thermal bridges are junctions **where insulation is not continuous** and **causes heat loss**. One of the main problems is that, thermal bridges have more **impact on the loss percentage** if the house is not well insulated.

A thermal bridge occurs when there is a gap between materials and structural surfaces. The main thermal bridges in a building are found **at the junctions** of facings and floors, facings and cross walls; facings and roofs, facings and low floors. They also occur each time there is a **hole** (doors, windows, loggias…). **These are structural thermal bridges**. These thermal bridges vary in importance according to the type of wall or roof (insulated or not).

Thermal Bridges
introduction

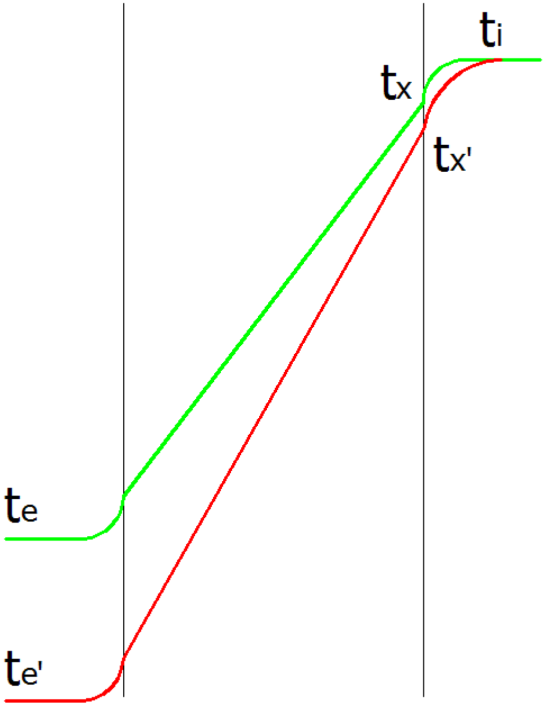
In a building that is **not properly insulated**, thermal bridges represent low comparative losses (usually below 20%) as total losses via the walls and roof are very high (about >1W/m^{2}K).

However, when the walls and roof are **well insulated**, the percentage of loss due to thermal bridges becomes high (more than 30%) but general losses are very low (less than 0.3 W/m^{2}K).

That is why in low energy consuming buildings, it is important to have very high thermal resistances for walls and roofs to have low heat losses via the junctions.

A wall or floor almost always consists of **several components** pasted, screwed or mechanically assembled together. If they are not well designed, these assembly systems can produce **thermal bridges** within the system, hence their name **of integrated thermal bridges**.

Self-scale temperature
definition



Self scale (unit less) temperature is for generalizing critical temperature data (t_x) from ambient temperatures (t_i, t_e)

<u>Critical surface temperatures are given on self-scale.</u> The zero point of the self-scale is the outdoor temperature, the unit is the difference between the indoor and outdoor air temperature.

Thus, in point x the temperature measured on self-scale

$$\Theta_x = \frac{t_x - t_e}{t_i - t_e}$$

$$\Theta_x \approx \Theta'_x$$

Properties of self-scale temperature Θ (theta):

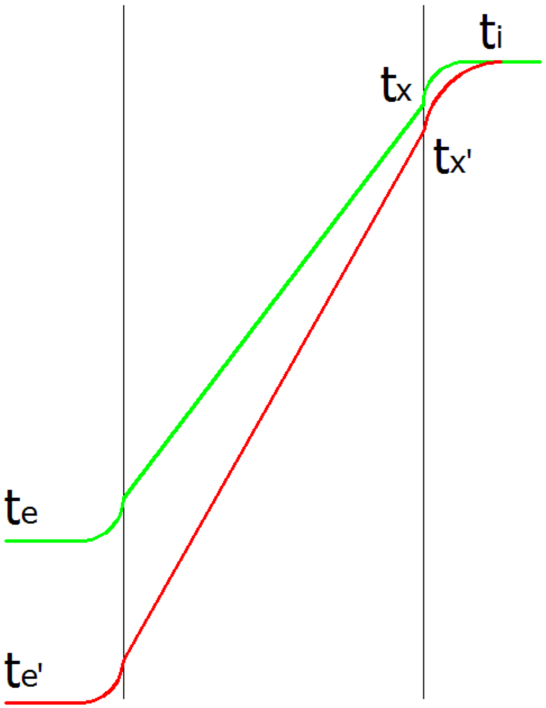
$$-1 \leq \Theta \leq 1$$

Use of self scale: Estimation of the internal surface temperature by change of external one.

Critical temperature (t_x) as a function of self scale:

$$t_x = t_e + \Theta_x (t_i - t_e)$$

Application of self-scale temperature
example 1



Based on measurements in a given construction internal temperature is t_i= 20 °C, the external temperature is t_e=-10 °C. At that temperature different the measured internal surface temperature is t_x=18 °C. Without considering thermal behavior (conduction, convection), by using self-scale estimate the internal surface temperature at $t_{e'}$ = -15°C external temperature!

Data:

t_i= 20 °C, t_e=-10 °C

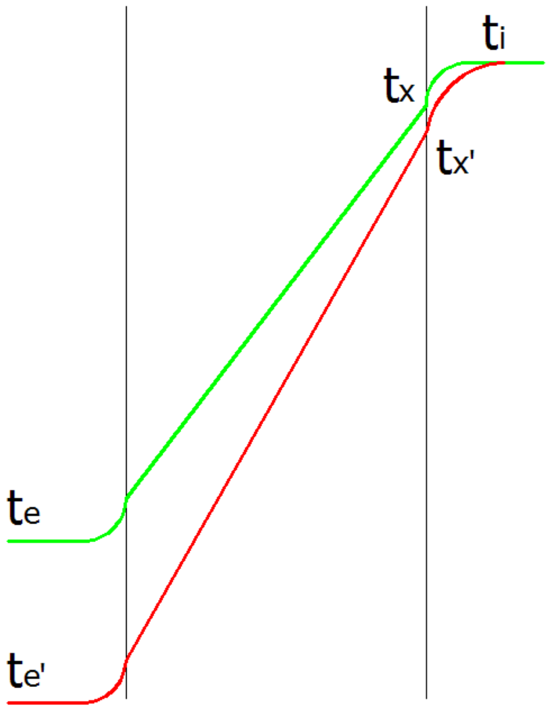
t_x=18 °C

$t_{e'}$=-15°C.

$t_{x'}$ =?

Application of self-scale temperature

example 1



By using self-scale definition, following equation can be developed:

$$\Theta = \frac{t_x - t_e}{t_i - t_e} = \frac{18-(-10)}{20-(-10)} = 0{,}93$$

Let us assume that even if external temperature changes self scale remains constant:

$$\Theta = \Theta' = 0{,}93$$

Thus for $t_{x'}$ self scale definition can be applied:

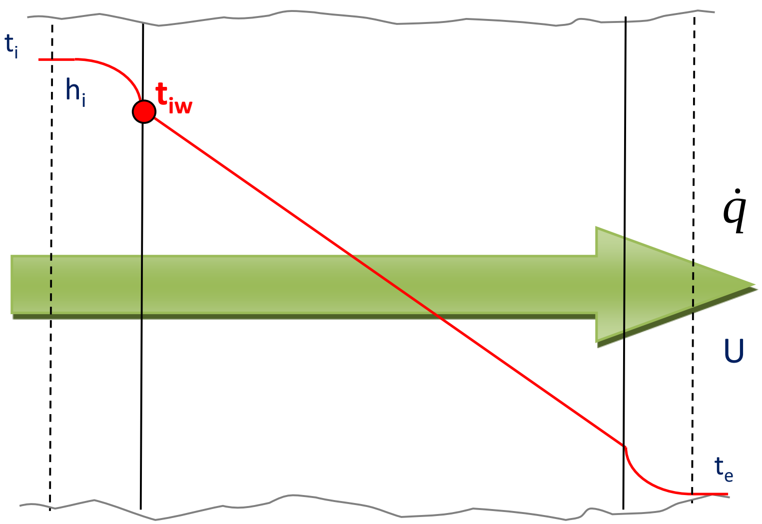
$$\Theta = \frac{t_{x'} - t_{e'}}{t_i - t_{e'}} = \frac{t_{x'} - (-15)}{20-(-15)} = 0{,}93$$

Only unknown is $t_{x'}$ thus:

$$t_{x'} = \Theta \cdot (t_i - t_{e'}) + t_{e'} = 0{,}93 \cdot 35 - 15 = 17{,}67\,°C$$

Application of self scale temperature

example 2 – surface temperature of a wall



By using self scale internal surface temperature equation can be developed easily. Based on equality of rate of heat flow the equation can be written:

$$\dot{q} = U \cdot (t_i - t_e) = h_i \cdot (t_i - t_{iw})$$

After reordering the equation:

$$\frac{(t_i - t_{iw})}{(t_i - t_e)} = \frac{U}{h_i}$$

Let's define self scale temperature as the internal temperature difference divided by the overall temperature difference:

$$\Theta = \frac{(t_i - t_{iw})}{(t_i - t_e)}$$

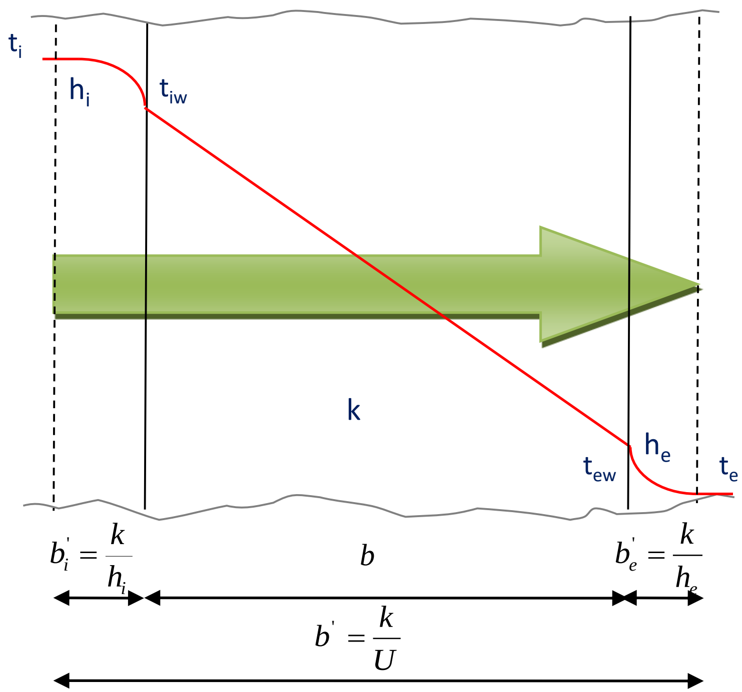
Thus

$$\Theta = \frac{U}{h_i}$$

Note that: in a particular case when U, h_i are known self scale temperature is constant, independent from any temperatures.

Apparent thickness
definition

Most of the temperature change (which is a driving force of heat transmission) takes place in the boundary layer. A thin layer of an air is adjacent to the surface. The layer of the building material has certain thickness (b). The thickness of the boundary layer is b_i' and b_e' which is called **apparent thickness**. Overall apparent thickness can be defined by adding the apparent thicknesses to actual one. The physical meaning of **overall apparent thickness** is the **area where heat transmission takes place**:



$$b' = b_i' + b + b_e'$$

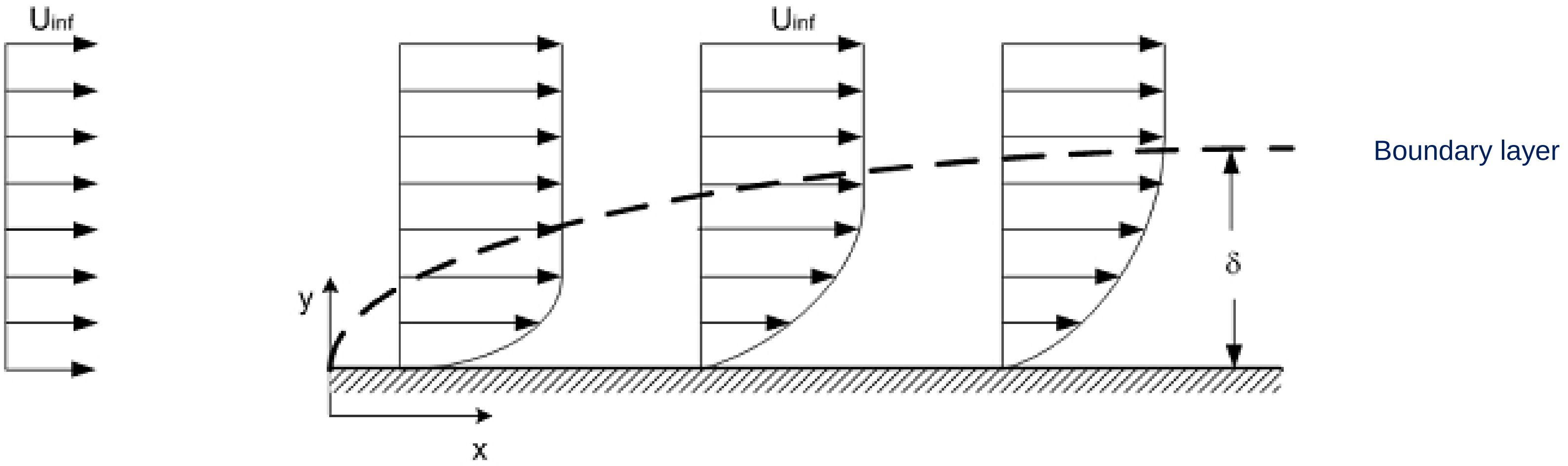
$$U = \frac{1}{\frac{1}{h_i} + \frac{b}{k} + \frac{1}{h_e}}$$

$$\frac{1}{U} = \frac{1}{h_i} + \frac{b}{k} + \frac{1}{h_e}$$

$$\boxed{\frac{k}{U} = \frac{k}{h_i} + b + \frac{k}{h_e} = b'}$$

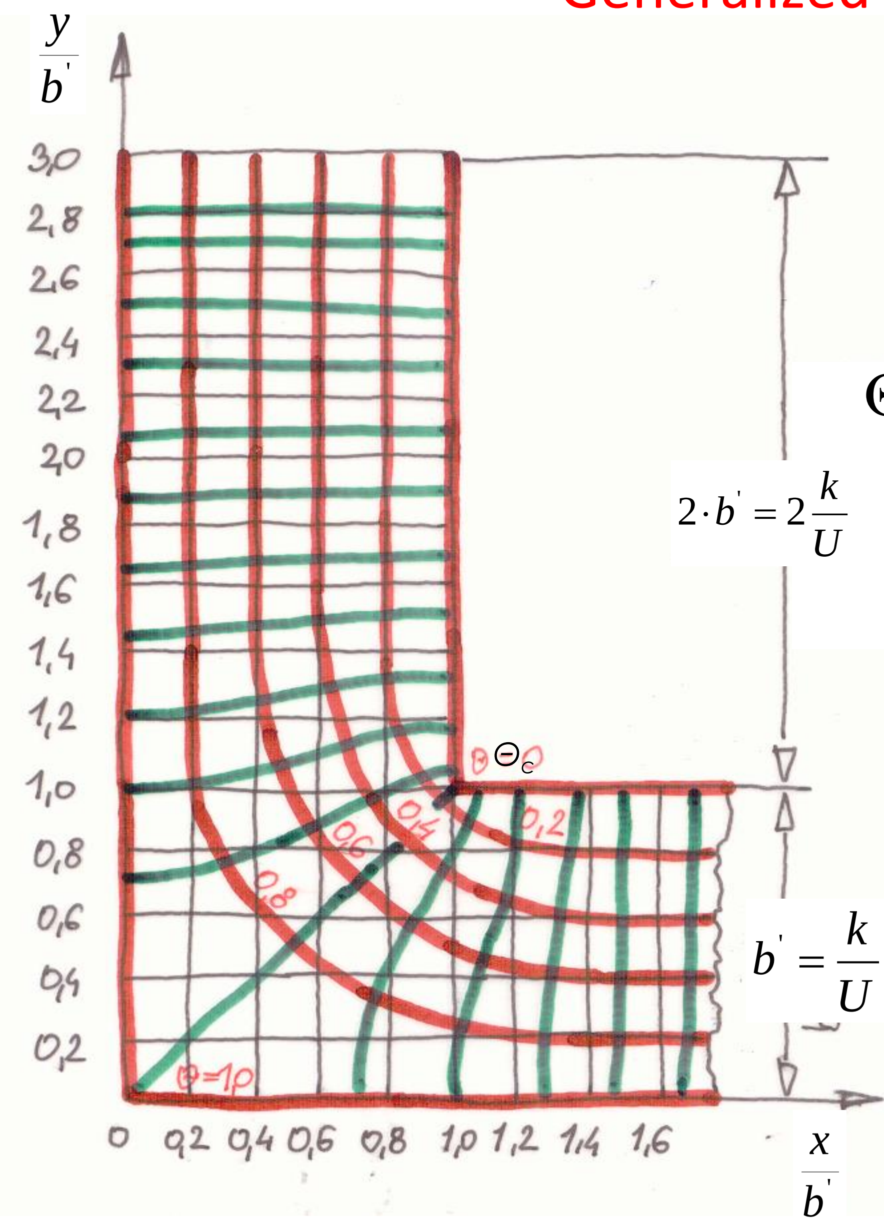
Apparent thickness

definition



Unit of the apparent thickness is meter (m). From the above equation it is clear that **apparent thickness depends on the rate of conduction and convection**. So apart from dimensional meaning it quantifies the heat conductions from and to the surfaces and conduction in the material.

Temperature distribution of a wall corner
Generalized isotherms



- A massive wall corner case can be generalized by applying a previously introduced **apparent thickness (b')** and **self-scale temperature**. Self scale defined as:

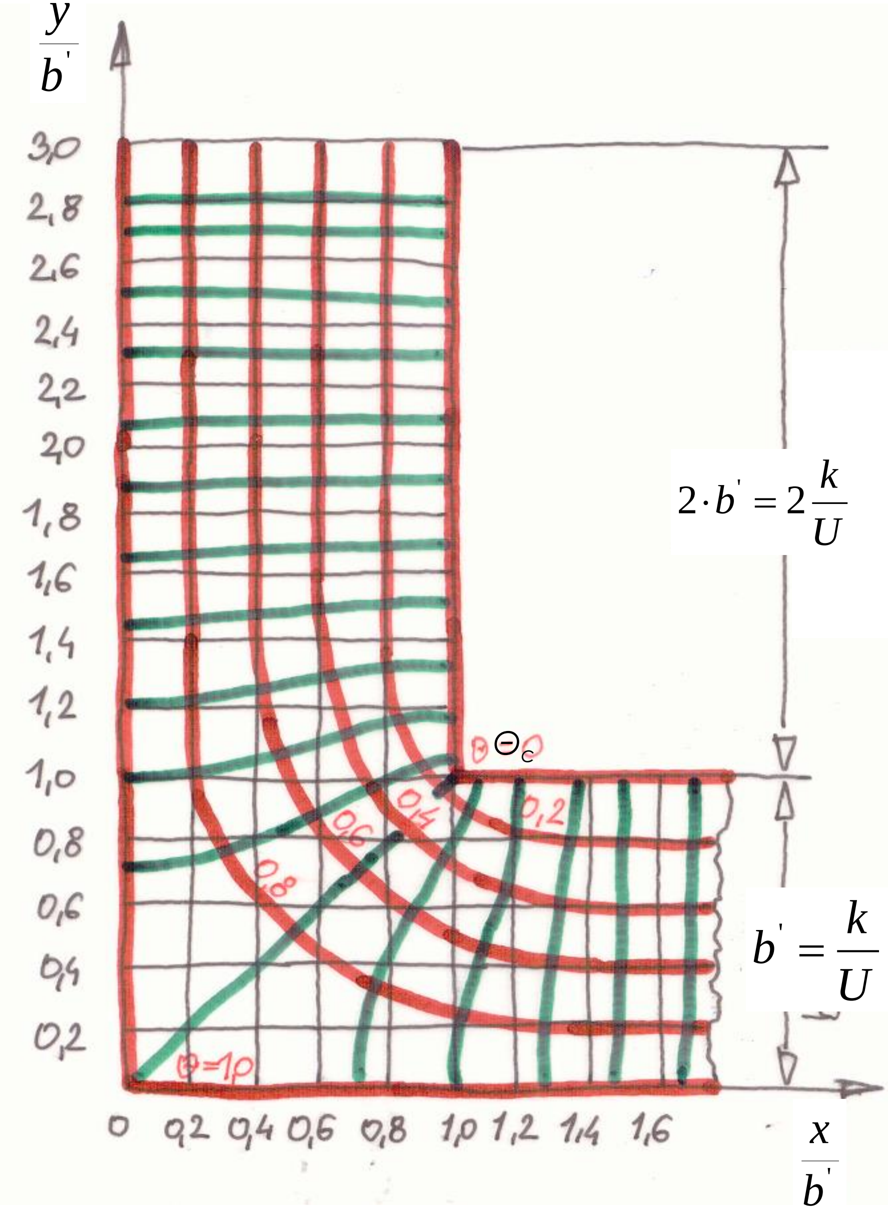
$$\Theta = \frac{(t_i - t)}{(t_i - t_e)}$$

where "t" represents a general temperature.

- Let us introduce a 2 dimensional coordinate system where the vertical axes is y/b' and horizontal axes is x/b' unit less dimensions. Note that in this case the dimensions also cover thermal properties – conduction an convection!
- In this coordinate system **general self-scale isotherms** (Θ – red lines)can be drawn. In this coordinate those self-scale **isotherms** generally covers any positive and negative wall corner cases.

Temperature distribution of a wall corner

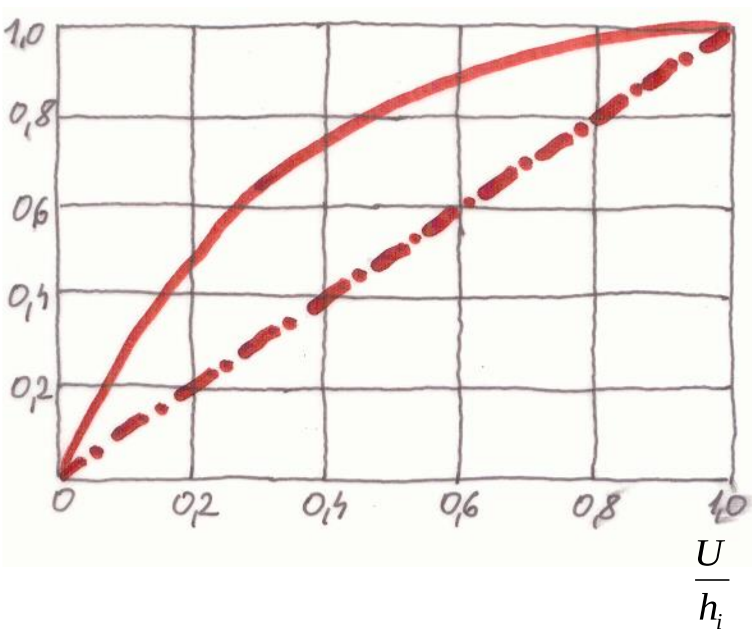
Generalized isotherms

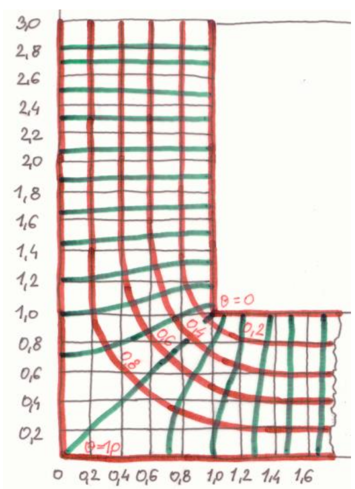


- In a case of positive **wall corner critical (lowest) temperature occurs right at the corner (Θ_c)**
- Based on the enclosed figure it is clear that out of 2·b' area there is no effect on isotherms by wall corner geometry. Thus concerning thermal bridge effect 2·b' area is considered. Within the considered area so called **form factor** is defined: form factors represents the additional heat loss because of thermal bridge effect. For wall corner form factor is FF=1.18
- **Green lines represents heat flow lines** on the enclosed figure. A number of lines per each directions represent heat rate through the building element

Temperature distribution of a wall corner
Critical temperature

$$\Theta_C = \frac{(t_i - t_C)}{(t_i - t_e)}$$





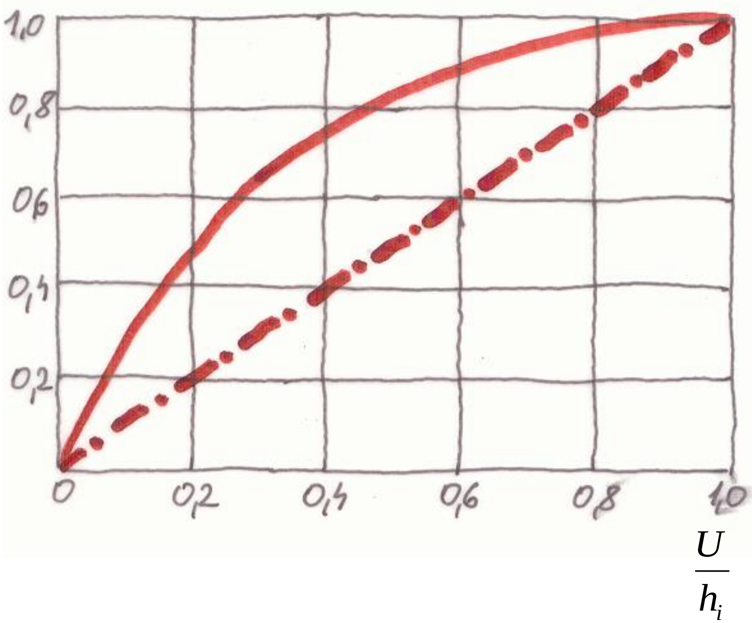
- Often only a **critical temperature** is important. That is because concerning **surface condensation** the lowest temperature is considered during the calculation. From the previous self-scale isotherms graph another graph can be developed. Let us define a **self-scale for the temperature of a wall corner (critical temperature):**

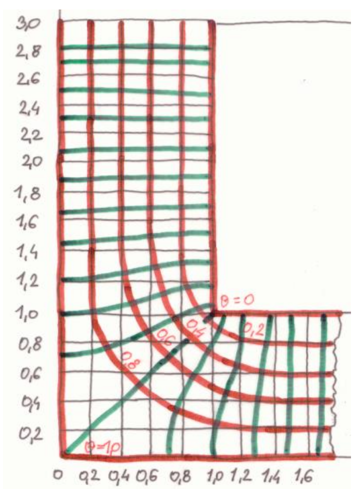
$$\Theta_C = \frac{(t_i - t_C)}{(t_i - t_e)}$$

- The horizontal axes is the overall heat transfer coefficient (U) divided by the internal surface convection coefficient (h_i). Note that: this fraction represents the ratio of overall heat and surface heat transmission. This fraction also does not have unit.

Temperature distribution of a wall corner
Critical temperature

$$\Theta_C = \frac{(t_i - t_C)}{(t_i - t_e)}$$





In this coordinate system general corner temperature graph can be drown, which is valid for any massive and multilayer walls (continuous red line).

The <u>surface temperature of a wall is a 45 degree straight line</u> in the Θ_C - U/h_i coordinate system (red dot line).

The **temperature of the corner** at any given temperature overall differences is:

$$t_C = t_i - \Theta_C (t_i - t_e)$$

Similar graphs can be developed for any other cases, like “T” junction, window perimeter etc.

Temperature distribution of a wall corner
Example: Estimation of a corner temperature

- Internal temperature is 20˚C, external temperature is -10˚C, internal surface convection coefficient is 10W/(m^2K), external surface convection coefficient is 25W/(m^2K), conduction coefficient of a massive wall is 0.5W/(mK), thickness of the wall is 30cm.

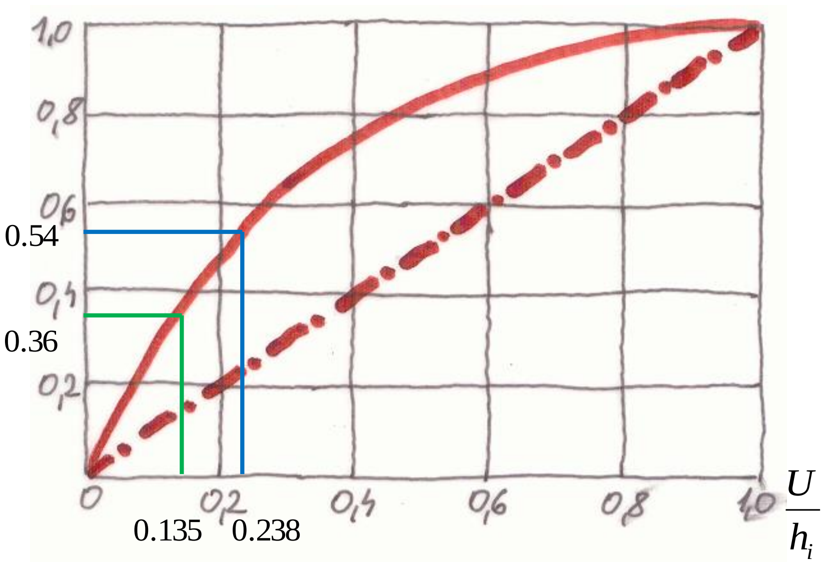
- Estimate the wall corner and the internal wall temperature by using an enclosed self-scale diagram for a corner and planar section of a wall **(A)**.

- Repeat the calculation if internal surface convection due to blocking effect at the corner is reduced to 5 W/(m^2K)**(B)**

Temperature distribution of a wall corner

Example: Estimation of a corner temperature

$$\Theta_C = \frac{(t_i - t_C)}{(t_i - t_e)}$$



	A	B
ti (°C)	20	20
hi (W/m²K)	10	5
k (W/mK)	0.5	0.5
b (m)	0.3	0.3
he (W/m²K)	25	25
te (°C)	-10	-10
U (W/m²K)	1.35	1.19
U/hi (-)	0.135	0.238
Teta (-)	0.36	0.54
tc (°C)	9.2	3.8
tiw (°C)	15.9	12.9

Input data: $h_i = 10$; $t_i = 20$;
$h_e = 25$; $t_e = -10$;
$k=0.5$; $b=30$;

Solution:

A:

$$U = \frac{1}{\frac{1}{h_i} + \frac{b}{k} + \frac{1}{h_e}} = \frac{1}{\frac{1}{10} + \frac{0.30}{0.5} + \frac{1}{25}} = 1.35$$

$$\frac{U}{h_i} = \frac{1.35}{10} = 0.135$$

From the graph: $\Theta_C\,(U/h_i)= 0.36$ thus by reordering the self-scale equation for t_C,t_{iw}:

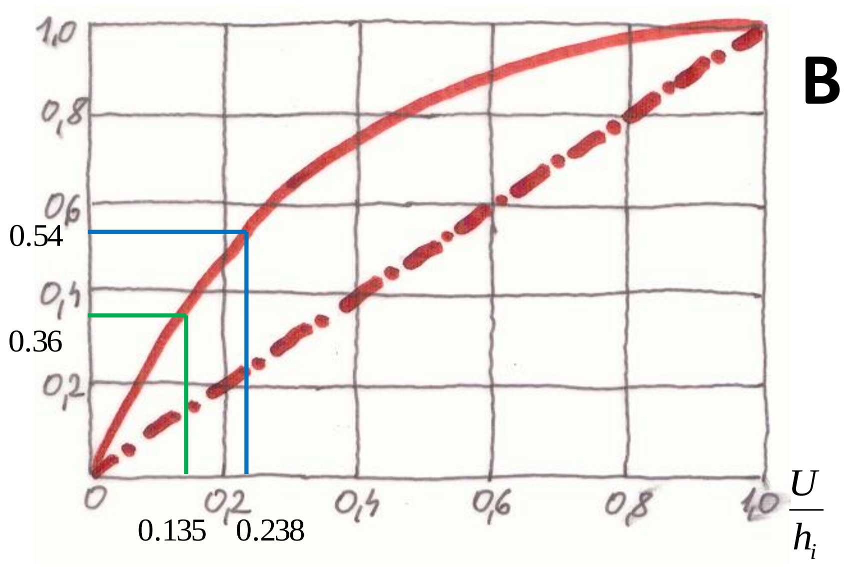
$$t_C = t_i - \Theta_C (t_i - t_e) = 20 - 0.36 \cdot 30 = 9.2°C$$

$$t_{iw} = t_i - U/h_i\,(t_i - t_e) = 20 - 0.135 \cdot 30 = 15.9°C$$

Temperature distribution of a wall corner

Example: Estimation of a corner temperature

$$\Theta_C = \frac{(t_i - t_C)}{(t_i - t_e)}$$



B:

$$U = \frac{1}{\frac{1}{h_i} + \frac{b}{k} + \frac{1}{h_e}} = \frac{1}{\frac{1}{5} + \frac{0.30}{0.5} + \frac{1}{25}} = 1.19$$

$$\frac{U}{h_i} = \frac{1.19}{5} = 0.238$$

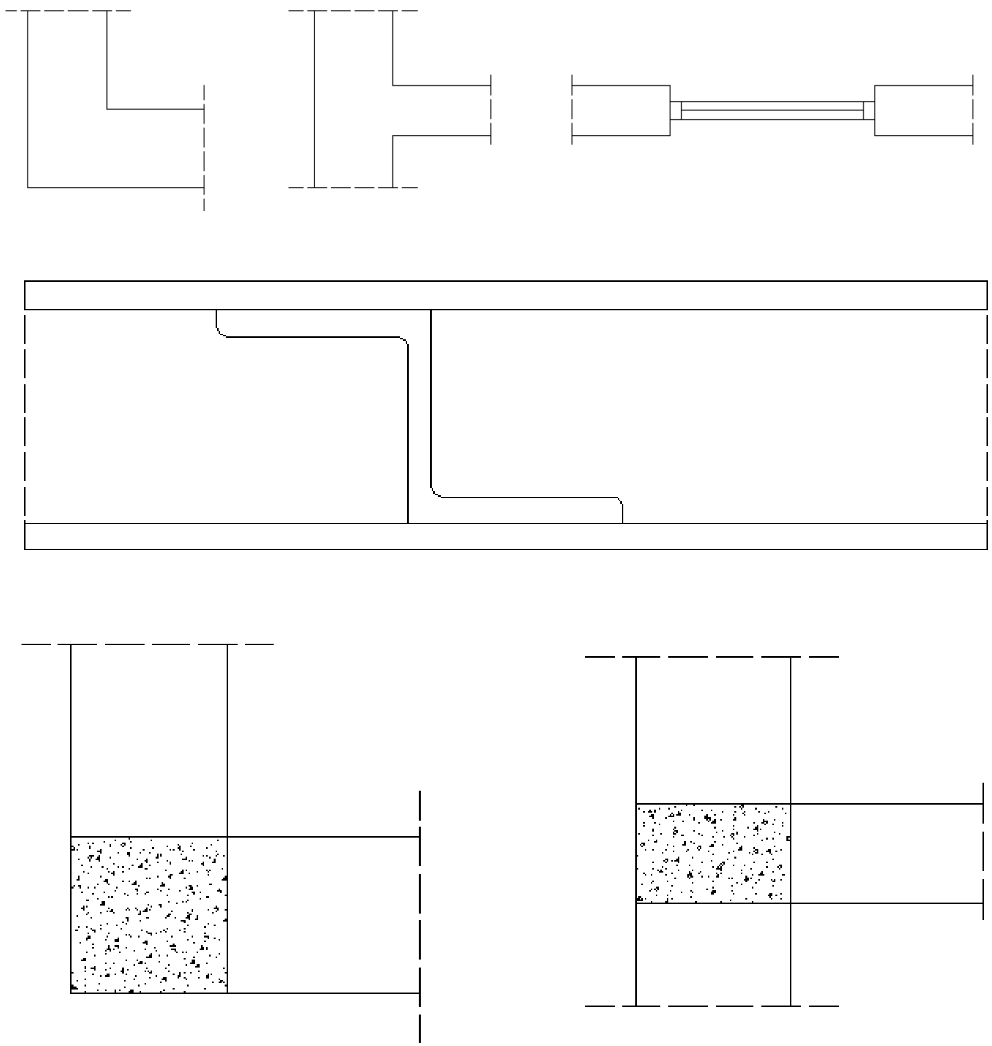
	A	B
ti (°C)	20	20
hi (W/m^{2}K)	10	5
k (W/mK)	0.5	0.5
b (m)	0.3	0.3
he (W/m^{2}K)	25	25
te (°C)	-10	-10
U (W/m^{2}K)	1.35	1.19
U/hi (-)	0.135	0.238
Teta (-)	0.36	0.54
tc (°C)	9.2	3.8
tiw (°C)	15.9	12.9

From the graph: $\Theta_C\,(U/h_i)$= 0.54 thus for t_C ,t_{iw}:

$$t_C = t_i - \Theta_C (t_i - t_e) = 20 - 0.54 \cdot 30 = 3.8°C$$

$$t_{iw} = t_i - U/h_i\,(t_i - t_e) = 20 - 0.238 \cdot 30 = 12.9°C$$

Thermal Bridges
Definition and Classification of thermal bridges



Multi-dimensional steady state heat flow: thermal bridges

In real building elements the criteria of the one dimensional heat flow is often not fulfilled.

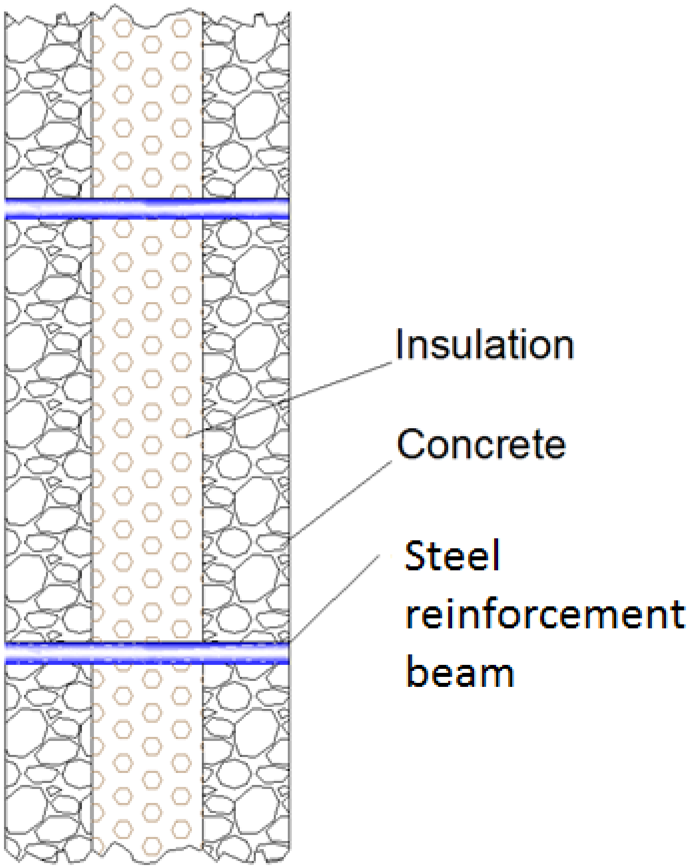
Everywhere when the border differs from the plan parallel planes, **two or three–dimensional heat flows develop**. These special parts are called **thermal bridges**.

They are the consequences of the:

- Geometric form,
- The combination of materials of different conductivities.

Point Loss

Modification of conduction coefficient in thermal points

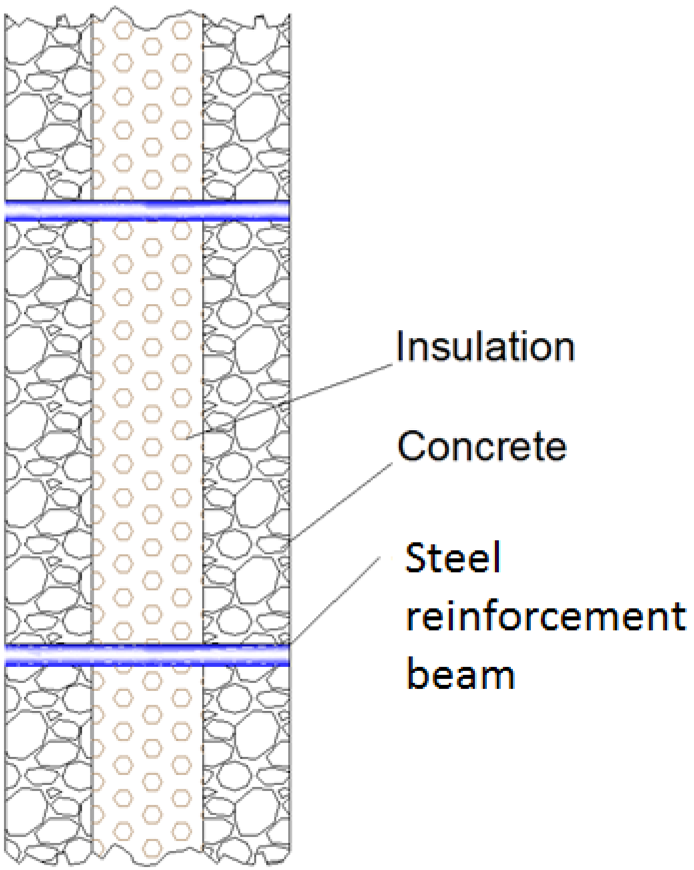


$$k_r = \frac{k_{ins}(1+\kappa)A_{ins} + k_{steal}A_{steal}}{A_{ins} + A_{steal}}$$

- The steal metal beam which piercing through the insulation modifies its conduction coefficient
- Assumption:
  - There is no heat transfer perpendicular to the metal beam
- Used model:
  - Equation of area weighted average
- Other examples:
  - Reinforced nerves (i.e.: attic)
  - Insulation in between timber construction (i.e.: rafter)
  - Perpendicular reinforcement in balcony
  - Etc.

Point loss

Example: Calculation of equivalent conduction coefficient

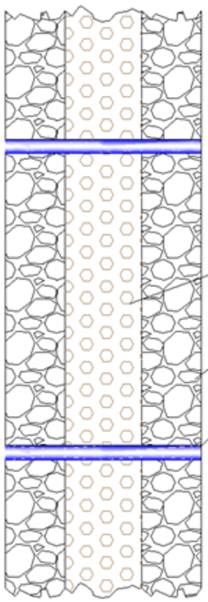


Modify U-value for thermal points

A. A sandwich panel includes an 80mm EPS slab between two reinforced concrete layers. In 1m^2 elevation area there are 4 steel ties 16mm diameter, penetrating the polystyrene. Calculate the U-value including the effect of the thermal points.

B. Calculate the U-value without thermal point.

Point loss
Example: Calculation of equivalent conduction coefficient



Data (thickness and conduction coefficient)

1 Reinforced concrete 0,15m; 1,55W/mK

2 Expanded Polystyrene 0,08m; 0,04W/mK

3 Reinforced concrete 0,15m; 1,55 W/mK

Area: $A=1m^2$

Surface convection coefficients: $h_i=8W/m^2K$, $h_e=25\ W/m^2K$

Resistance: $R_i=1/8=0{,}125m^2K/W$, $R_e=1/25=0{,}04m^2K/W$

Conduction coefficient for steel: k = 58 W/mK

The inbuilt coefficient for polystyrene in between reinforced concrete:

$\kappa=0{,}42$ $k_d=k_0*(1+\kappa)=0{,}04*(1+0{,}42)=0{,}0568$ W/mK

$$k_r = \frac{k_{polystyrene}(A - A_{steel}) + k_{steel}A_{steel}}{A}$$

$$\boxed{k_r = 0{,}1032\ \frac{W}{mK}}$$

$$A_{steel} = 4\left(\frac{D}{2}\right)^2 \pi = 4\frac{D^2}{4}\pi = 0{,}016^2\pi = 0{,}0008m^2$$

$$\frac{A_{steel}}{A} \approx 0$$

Point loss
Example: Calculation of equivalent conduction coefficient

A:

$$U_r = \frac{1}{\frac{1}{h_i} + \frac{b_{reinf.conc.}}{k_{reinf.conc.}} + \frac{b_{polystyrene}}{\bar{k}_r} + \frac{1}{h_e}} = \frac{1}{\frac{1}{8} + \frac{0.3}{1.55} + \frac{0.08}{0.1032} + \frac{1}{25}} = 0.88 \frac{W}{m^2 K}$$

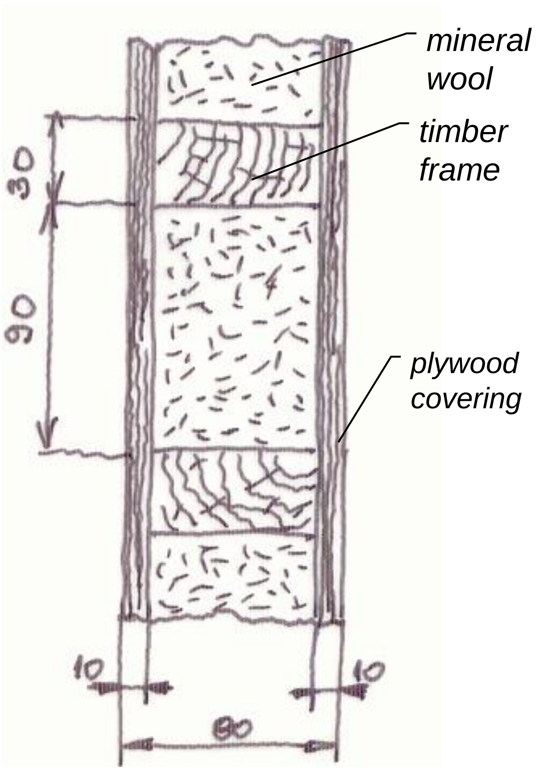
36%

B:

$$U = \frac{1}{\frac{1}{h_i} + \frac{b_{reinf.conr.}}{k_{reinf.conr.}} + \frac{b_{polystyrene}}{\bar{k}_{polystyrene}} + \frac{1}{h_e}} = \frac{1}{\frac{1}{8} + \frac{0.3}{1.55} + \frac{0.08}{0.0568} + \frac{1}{25}} = 0.565 \frac{W}{m^2 K}$$

Timber frame

Example: Estimation of an equivalent U-value



Example:

Estimate an overall heat transfer coefficient of an enclosed timber construction for an **area of 1,2 m²**. Conduction coefficient of a **plywood** covering is 0.12 W/mK, **timber frame** is 0.18 W/mK, **mineral wool** insulation is 0.04 W/mK. Internal and external surface convection coefficient is 8 W/m^2K and 25 W/m^2K.

Timber frame
Example: Estimation of an equivalent U-value

Result:

$$\bar{k}_r = \frac{k_{wool}A_{wool} + k_{timber}A_{timber}}{A_{wool} + A_{timber}} = \frac{0.04 \cdot 0.9 \cdot 1 + 0.18 \cdot 0.3 \cdot 1}{0.9 \cdot 1 + 0.3 \cdot 1} = 0.075 \frac{W}{mK}$$

$$U_r = \frac{1}{\frac{1}{h_i} + \frac{2 \cdot b_{plyw.}}{k_{plyw.}} + \frac{b_{wool}}{\bar{k}_r} + \frac{1}{h_e}} = \frac{1}{\frac{1}{8} + \frac{2 \cdot 0.01}{0.12} + \frac{0.06}{0.075} + \frac{1}{25}} = 0.88 \frac{W}{m^2K}$$