

3. Thermal bridges

*Airtightness, thermal insulation, **thermal bridges**, condensation, ventilation, cost-in-use and windows*

ZEPHIR training session | Train-the-Trainers pilot programme (Day 3)

Dolni Rakovets (Bulgaria), 28 September to 2 October 2026

Dr. Phys. Francesco Nesi | ZEPHIR Passivhaus Italia



**Co-funded by
the European Union**

Project 2025-1-BG01-KA210-VET-000362824

"Let's build ecologically together"

SECTION 1

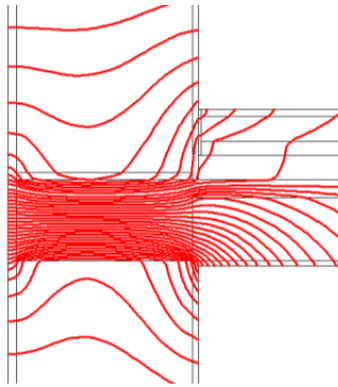
Thermal bridges fundamentals

Linear and point thermal bridges, how to avoid them, common mistakes and consequences

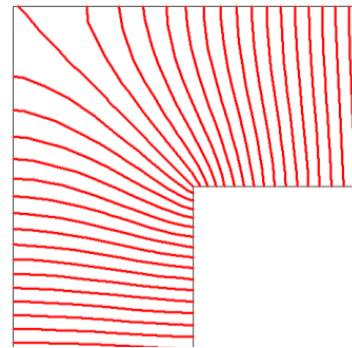
Thermal Bridge - Introduction



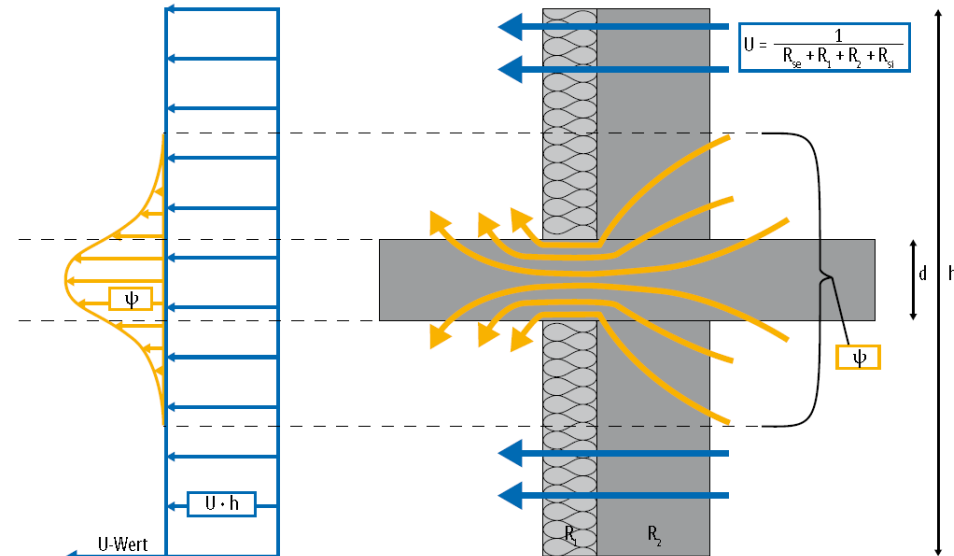
A thermal bridge is an area of a building construction which has a significantly higher heat transfer than the surrounding materials. It occurs because of change in material, change in thickness and change in geometry of the building element.



Source: B. Milovanović [3]



Source: B. Milovanović [3]



Source: Schöck Ltd [4]

Thermal Bridge - General concept



Replacing materials with high thermal conductivity

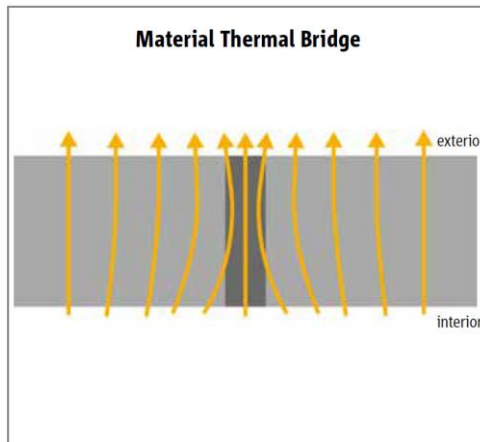
Materials with high thermal conductivity	λ [W/(mK)]	Replacement with low thermal conductivity	λ [W/(mK)]
reinforced concrete	2,2	expanded polystyrene (EPS)	0,031
structural steel	50	expanded polystyrene (EPS)	0,031
carbon steel	50	high strength stainless steel	15
Compression bar made of carbon/stainless steel	50/16	High strength concrete	0,8

Classification and quantification of thermal bridges

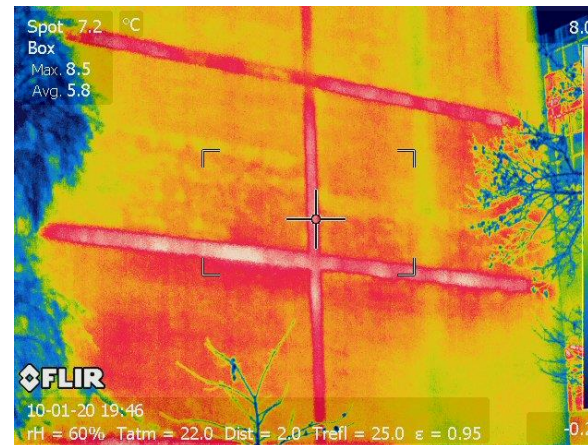
Types of thermal bridges

1) Material thermal bridge

- The most obvious kind of thermal bridge occurs when a thermally conductive element passes through an insulating layer.
- A typical example would be anchor bolts penetrating a layer of insulation.



Source: Schöck Ltd [4]



Source: B. Milovanović [3]



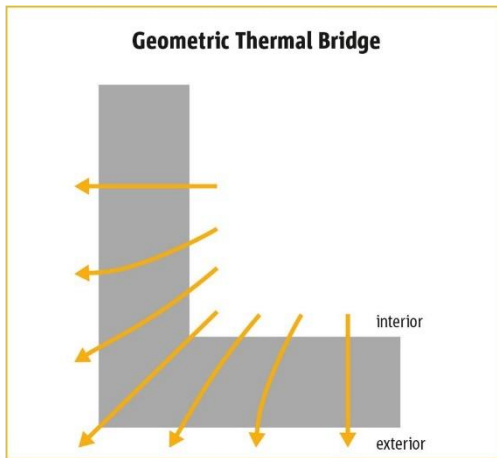
Source: B. Milovanović [3]

Classification and quantification of thermal bridges

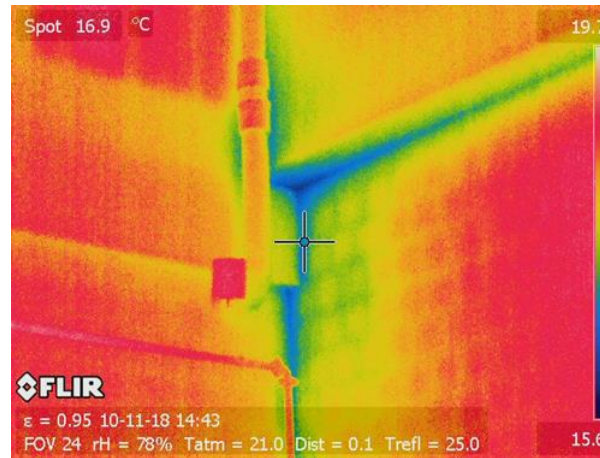
Types of thermal bridges

2) Geometric thermal bridge

- Geometric thermal bridges can occur when the heat-emitting surface is larger than the heat absorbing surface.
- Building corners are a typical example.



Source: Schöck Ltd [4]



Source: B. Milovanović [3]



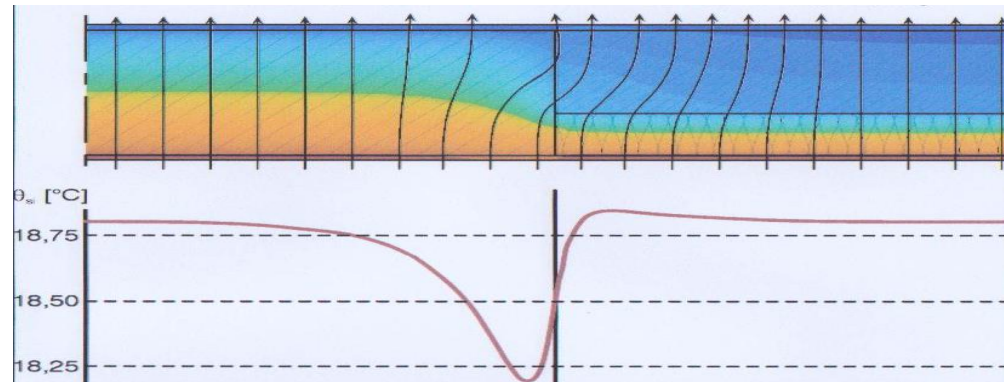
Source: B. Milovanović [3]

Classification and quantification of thermal bridges

Types of thermal bridges

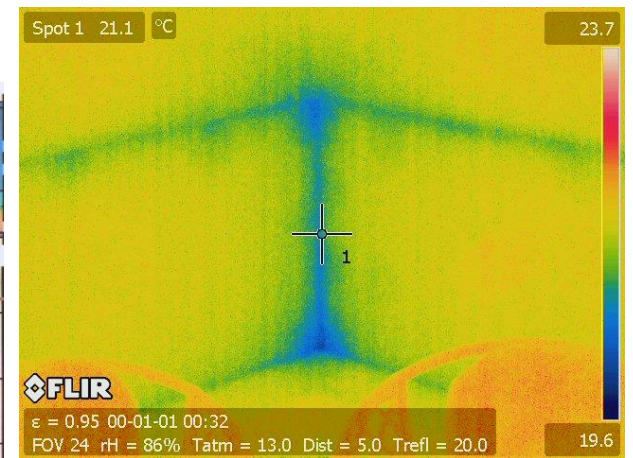
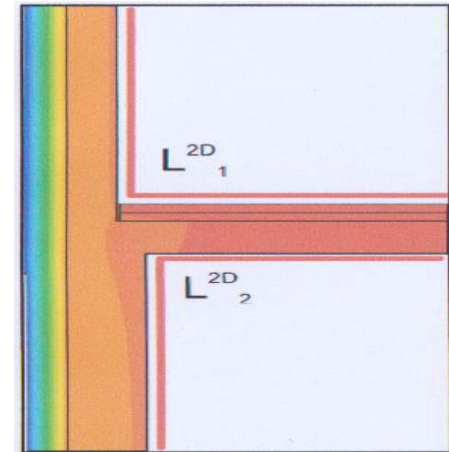
3) Combined thermal bridges

- These thermal bridges occur due to the change in the thickness of the building material.
- In the cross-section in which the change occurs, a sudden fall in the temperature of the inner surface occurs (Figure below).



Source: B. Milovanović [3]

Source: B. Milovanović [3]



Source: B. Milovanović [3]

Classification and quantification of thermal bridges

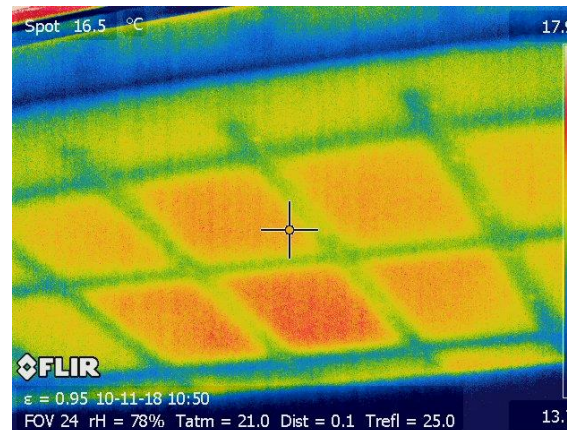
Types of thermal bridges

4) Structural thermal bridges

- A structural thermal bridge may occur whenever there is a structural connection.
- Linear thermal bridges are disturbances in the continuity of the thermal envelope that can occur along a certain length of the envelope.



Source: Schöck Ltd [4]



Source: B. Milovanović [1]



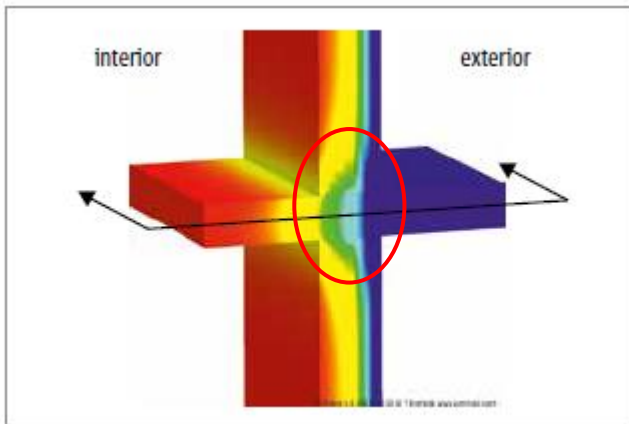
Source: B. Milovanović [1]

Classification and quantification of thermal bridges

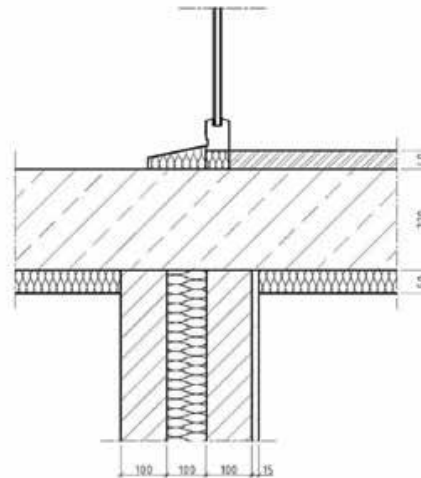
Types of thermal bridges

4) Structural thermal bridges – linear thermal bridges

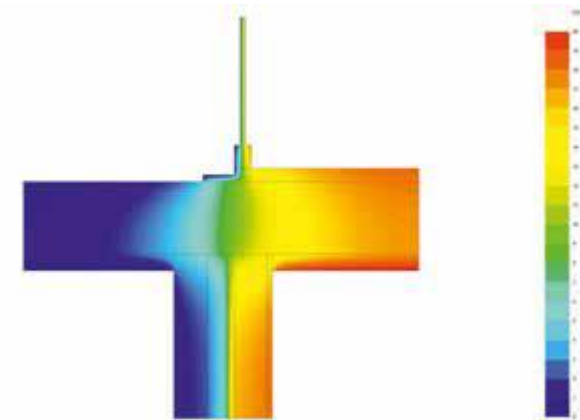
- The energy losses incurred by a **linear thermal bridge** are quantified by the linear thermal transmittance ψ (“psi”).



Source: Schöck Ltd [4]



Source: Schöck Ltd [4]



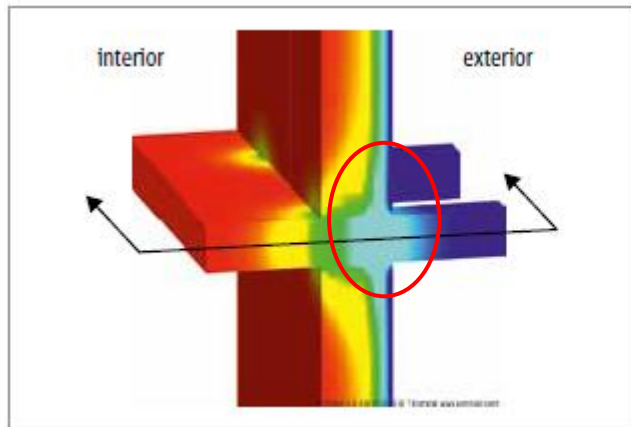
Source: Schöck Ltd [4]

Classification and quantification of thermal bridges

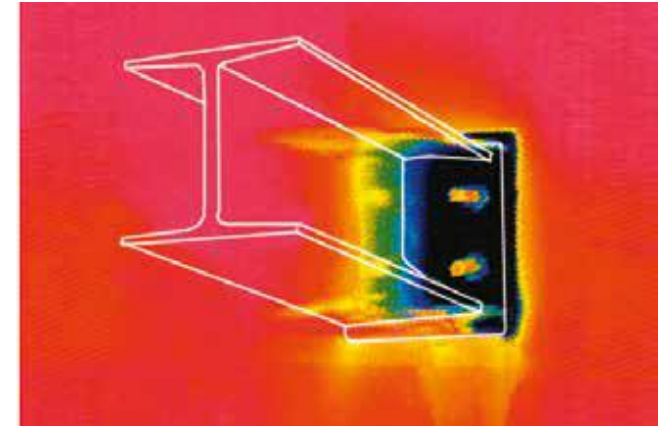
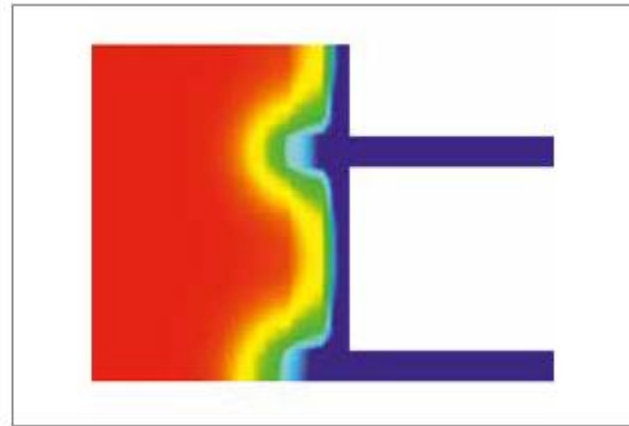
Types of thermal bridges

4) Structural thermal bridges – point thermal bridges

- The energy losses incurred by **point thermal bridges** are quantified by the point thermal transmittance χ (“chi”).
- Coefficient χ **must be calculated from a 3D model!**



Source: Schöck Ltd [4]



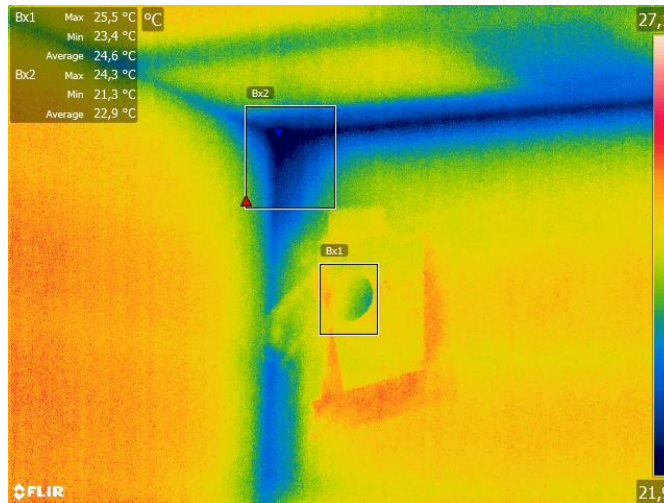
Source: Schöck Ltd [4]

Classification and quantification of thermal bridges

Types of thermal bridges

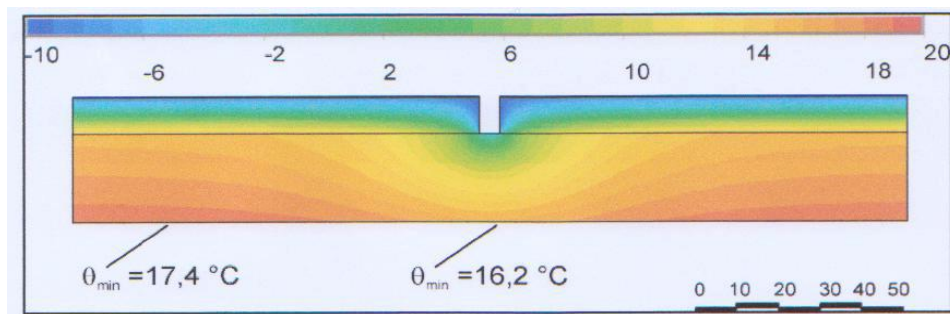
5) Convective thermal bridges

Source: B. Milovanović [3]

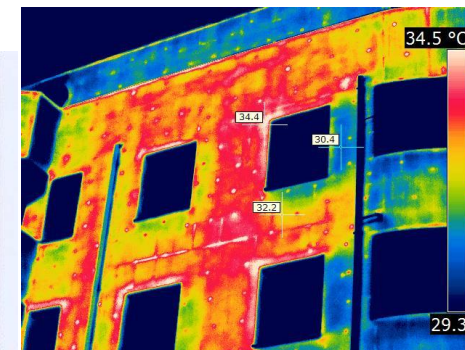


Source: B. Milovanović [3]

Air movements inside the construction cause convective thermal bridges!



Source: B. Milovanović [3]



Source: B. Milovanović [3]

Classification and quantification of thermal bridges

Quantification of linear thermal bridges

Linear Heat Transmittance coefficient ψ [W/(mK)] quantifies the influence of the linear thermal bridge (increase in heat flow transfer) on the total heat flow.

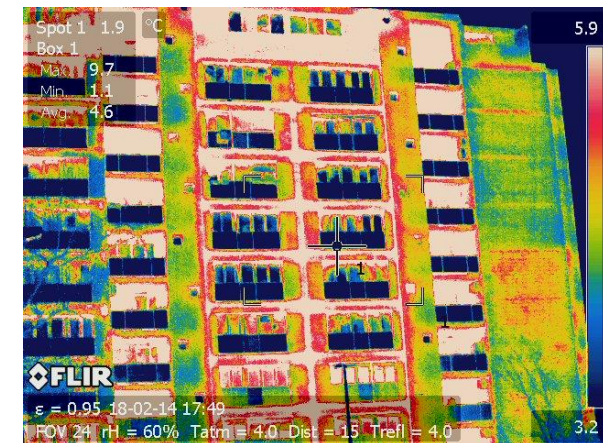
- Ψ is equal to the increase of the stationary 2D heat flow through the linear thermal bridge, relative to the undisturbed area.



Source: B. Milovanović [3]



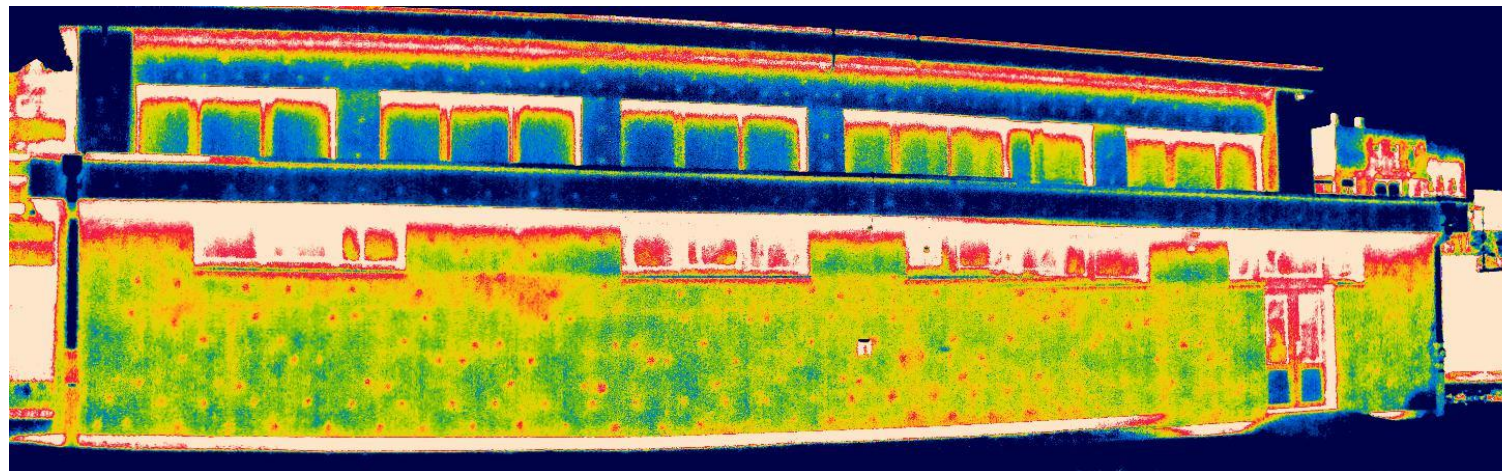
Source: B. Milovanović [3]



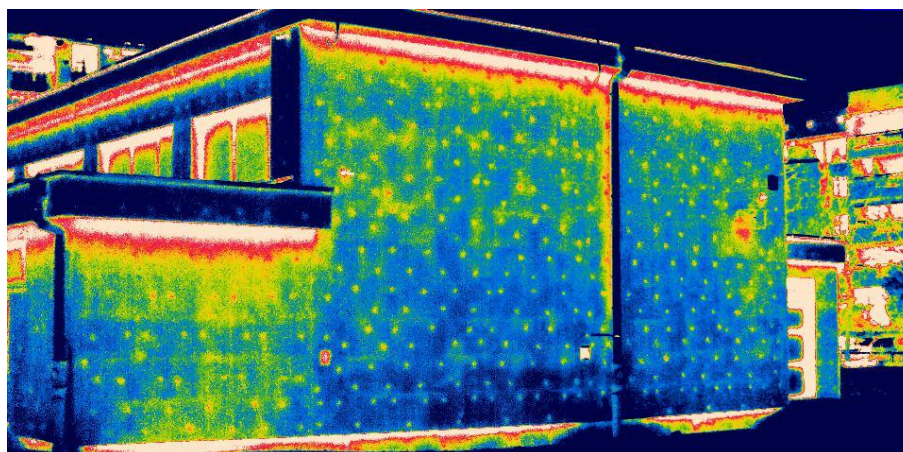
Source: B. Milovanović [3]

Classification and quantification of thermal bridges

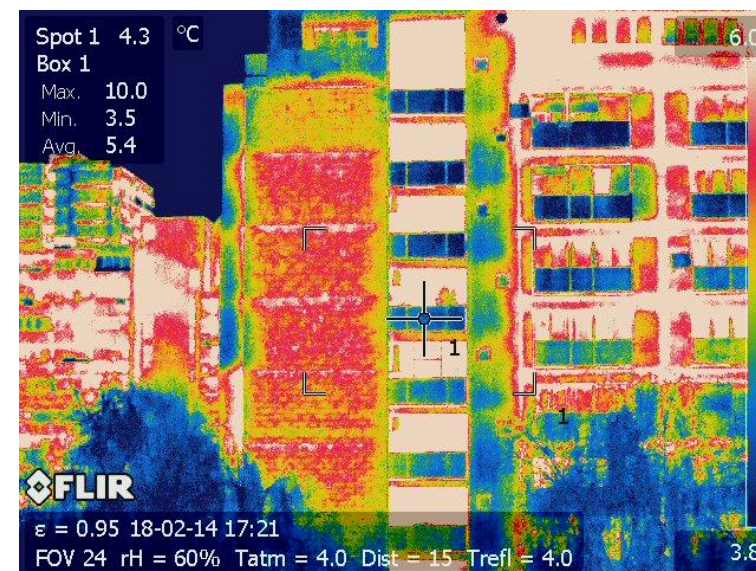
Examples of linear thermal bridges



Source:
B. Milovanović [3]



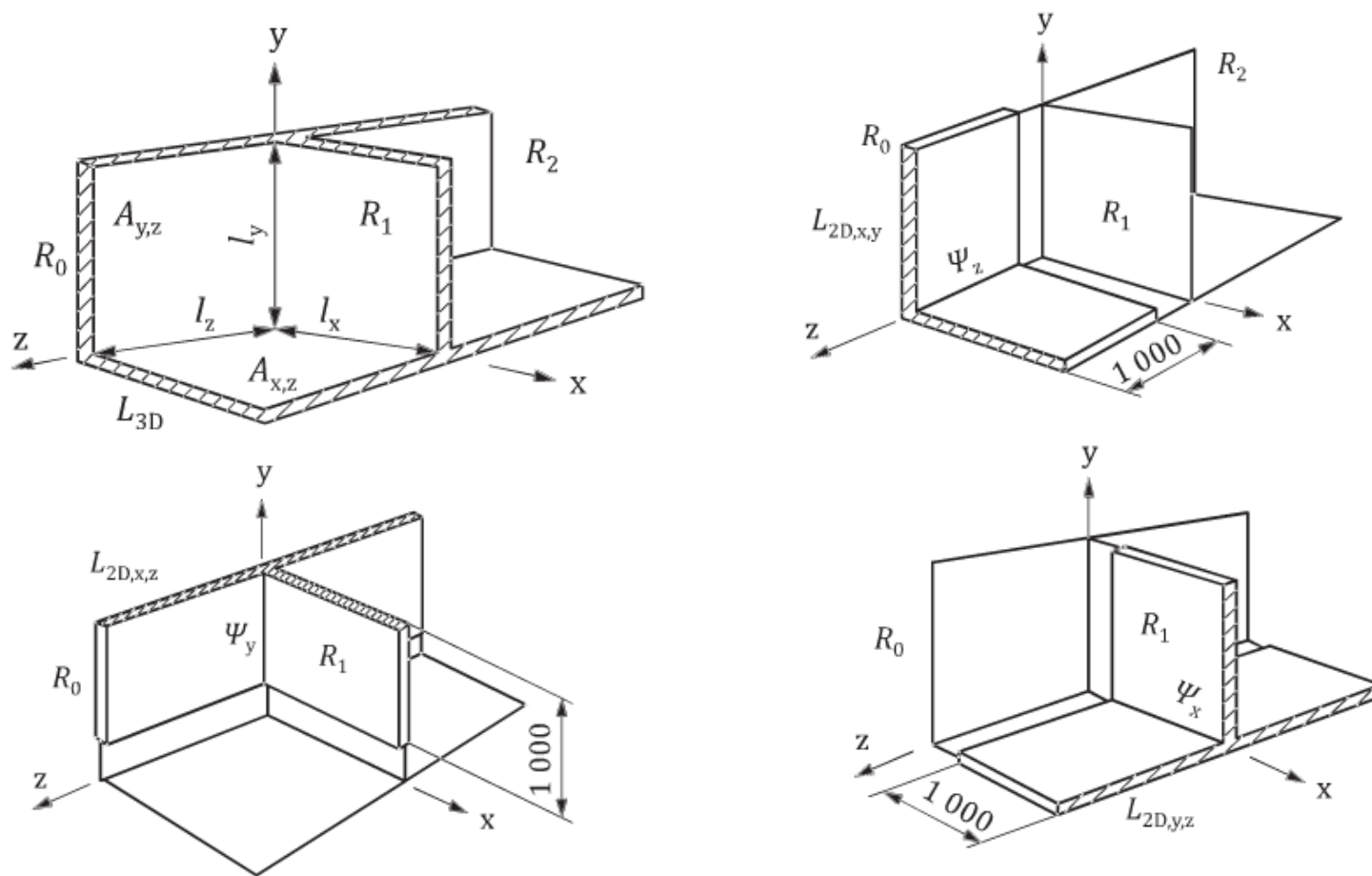
Source:
B. Milovanović [3]



Source:
B. Milovanović [3]

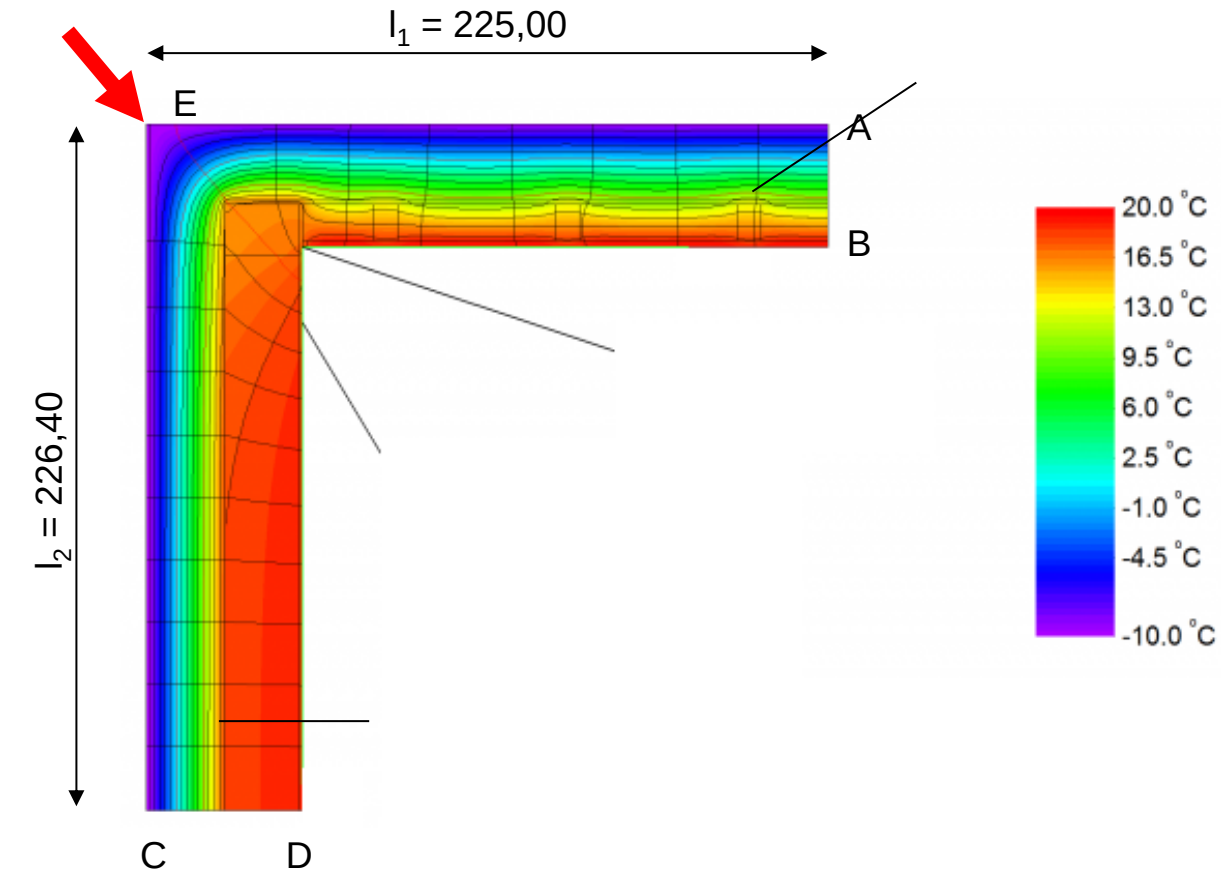
Classification and quantification of thermal bridges

Examples of the determination of linear and point thermal transmittances



Source: EN ISO 10211

Classification and quantification of thermal bridges

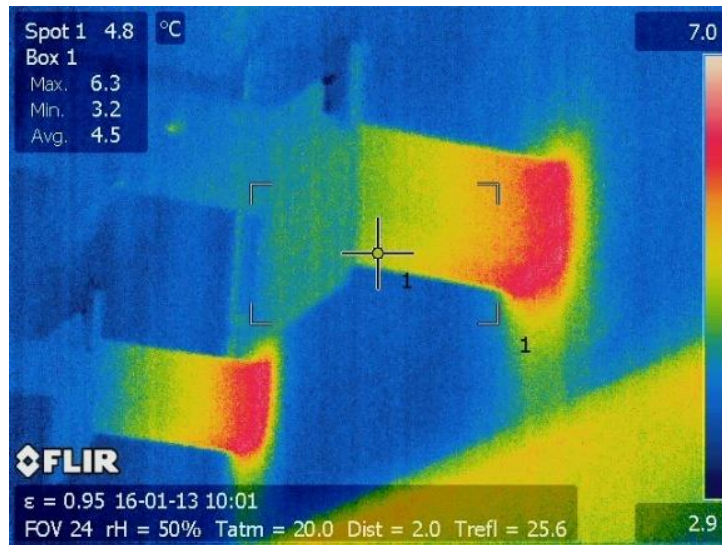


Source: Passipedia [5]

Classification and quantification of thermal bridges

Quantification of point thermal bridges

- 1) **Point thermal transmittance χ [W/K]** quantifies the influence of the point thermal bridge (increase of heat flow transfer) on the total heat flow.
 - χ is equal to the increase of the stationary 3D heat flow through the point thermal bridge, relative to the undisturbed area.



Source: B. Milovanović [3]



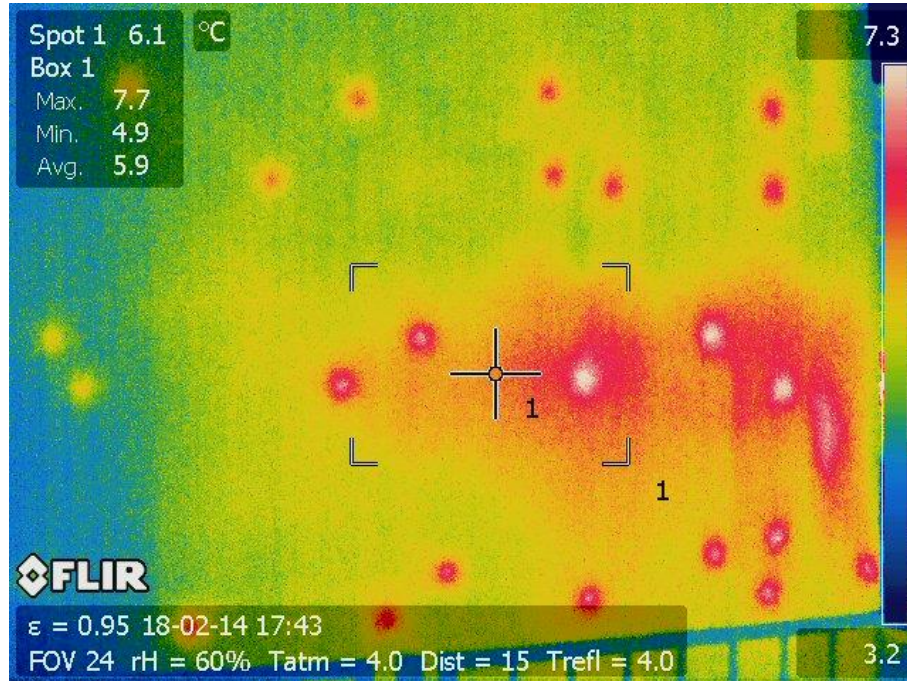
Source: B. Milovanović [3]



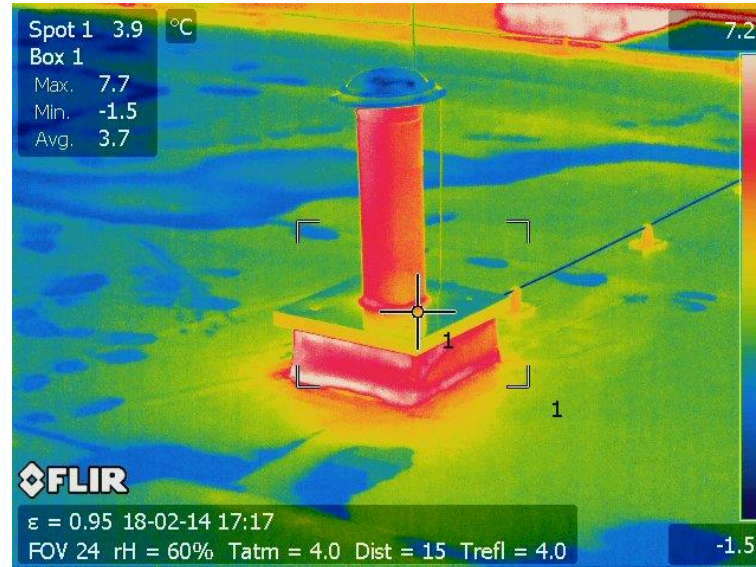
Source: B. Milovanović [3]

Classification and quantification of thermal bridges

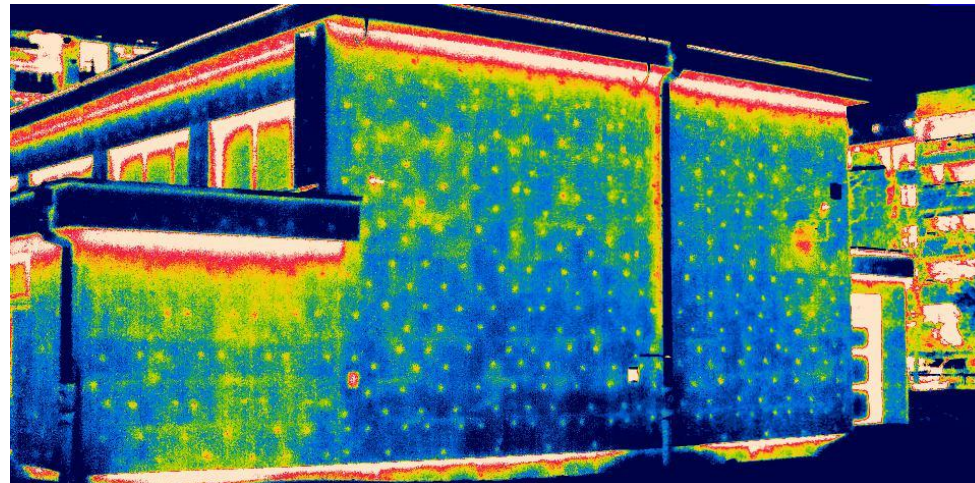
Examples of point thermal bridges



Source: B. Milovanović [3]



Source: B. Milovanović [3]



Source: B. Milovanović [3]

SECTION 2

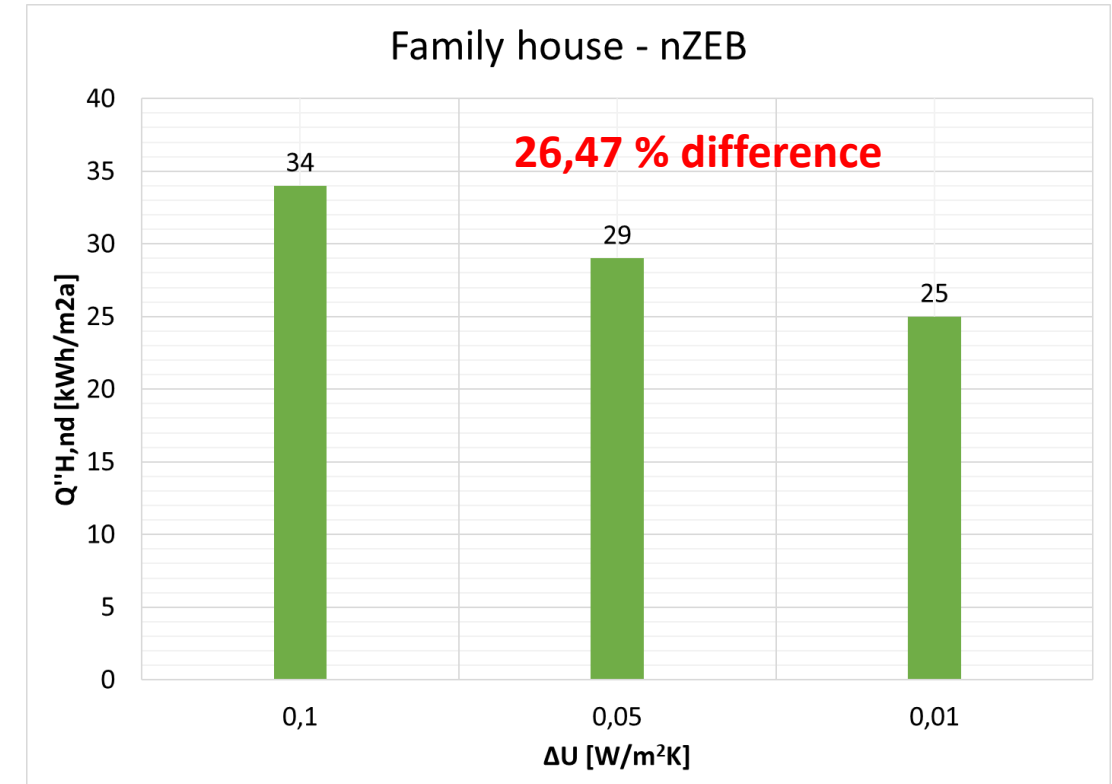
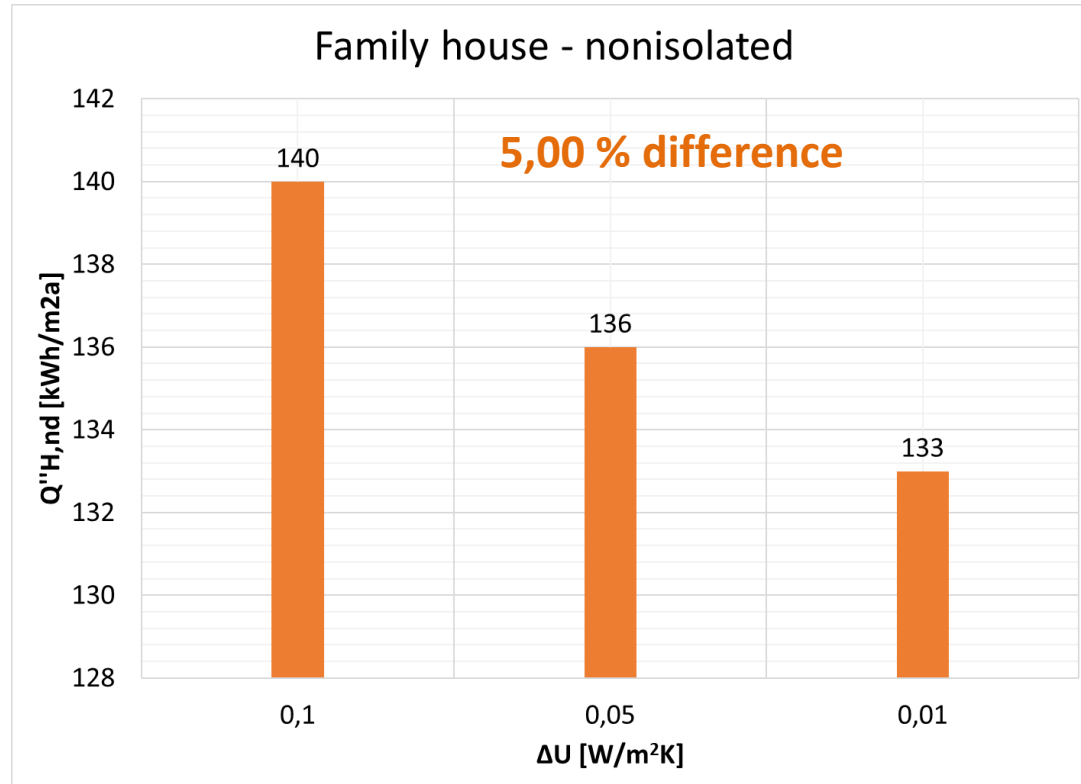
Influence of thermal bridges

How to reduce the impact of thermal bridges

Why thermal bridges matter



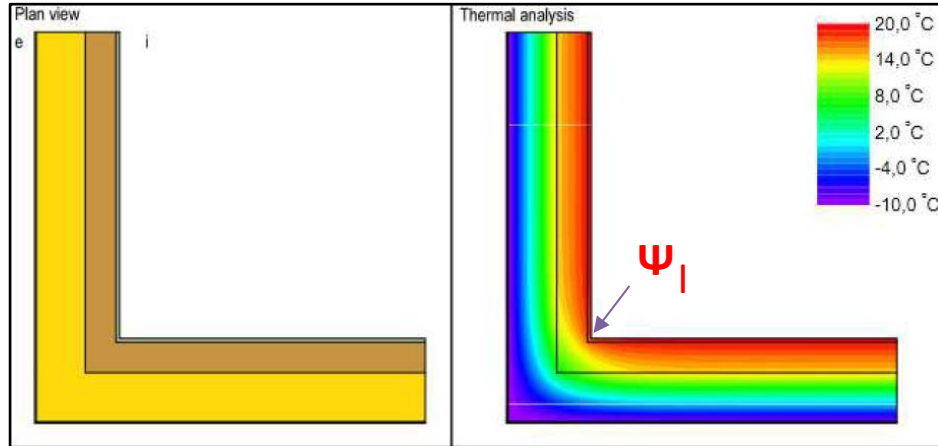
Additional heat losses



External wall/external corner

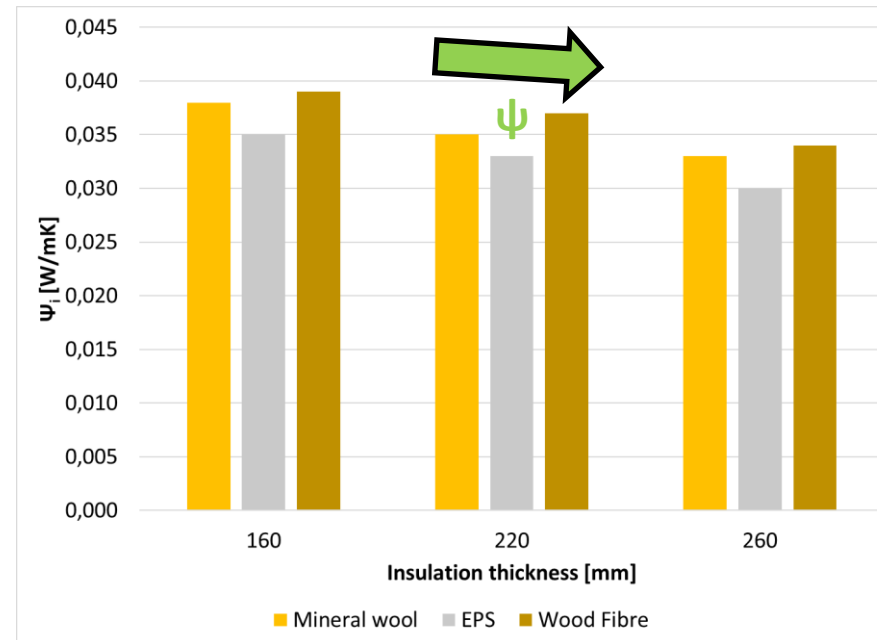
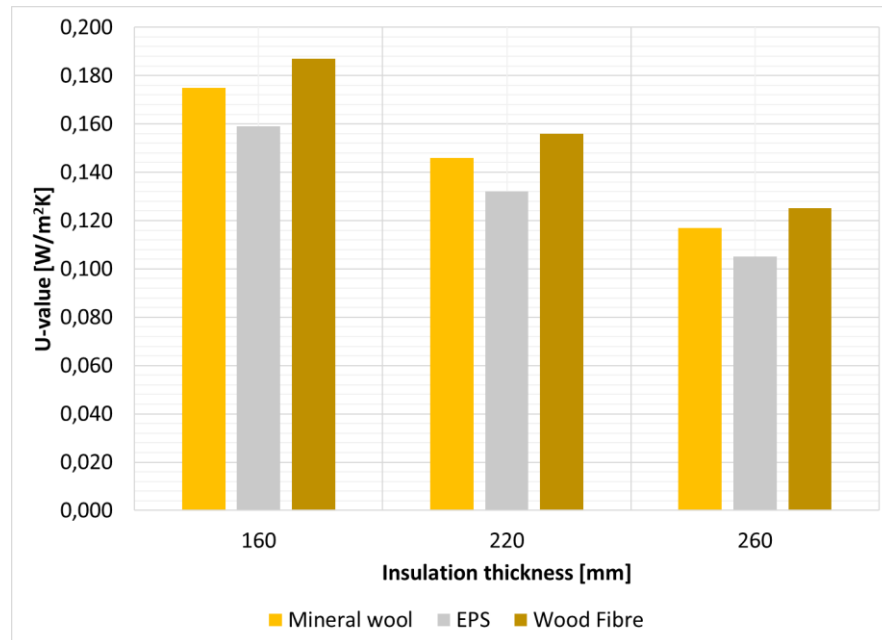


Thermal insulation thickness dependence on ψ -value



Component design		
Material	Thickness [mm]	λ [W/mK]
External wall e -> i		
Plaster	5,00	1,00
Thermal insulation	160,0/220,0/260,0	0,035/0,031/0,038
CLT	100,00	0,11
Fire-protection plasterboard	12,50	0,25

Lahti University of Applied Science [7]

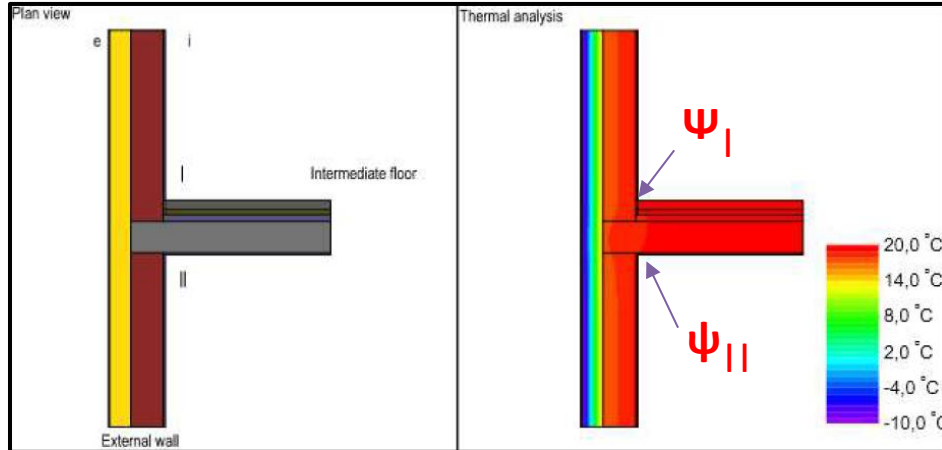


15 % less heat loss!

Intermediate floor



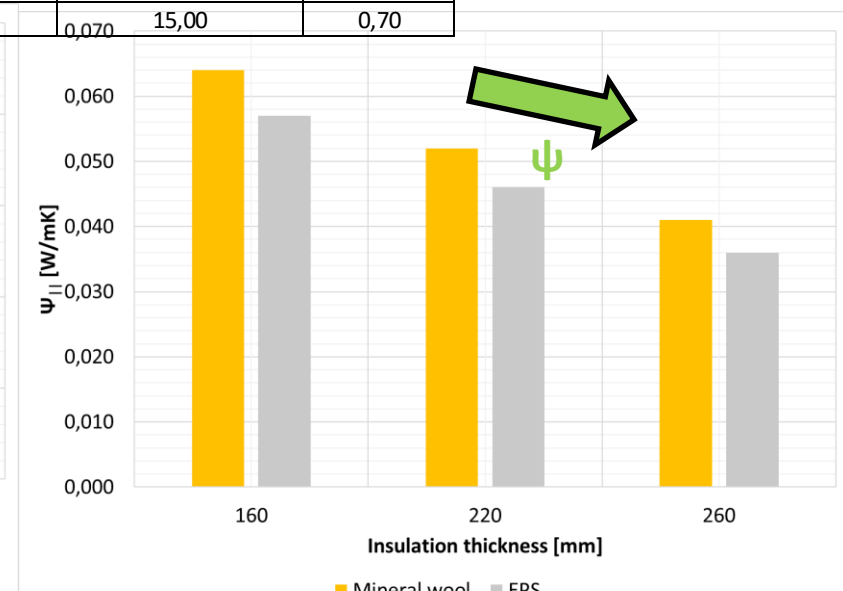
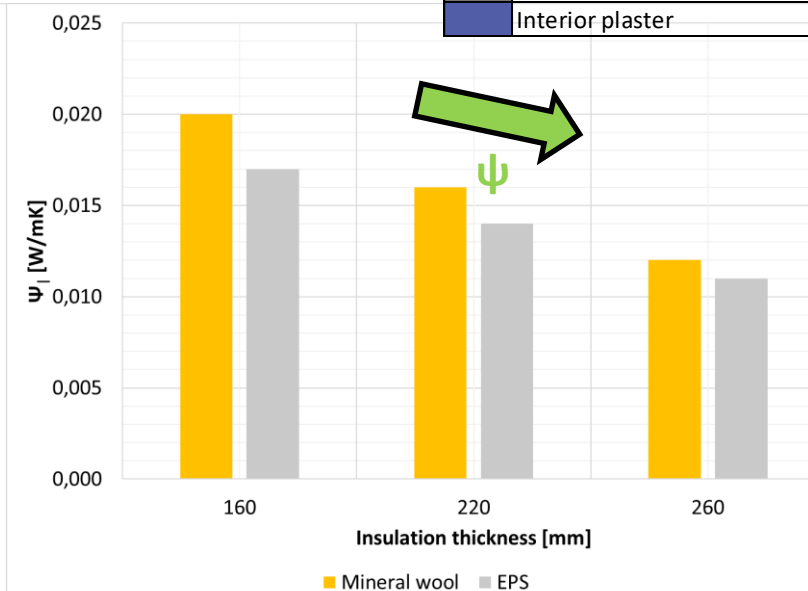
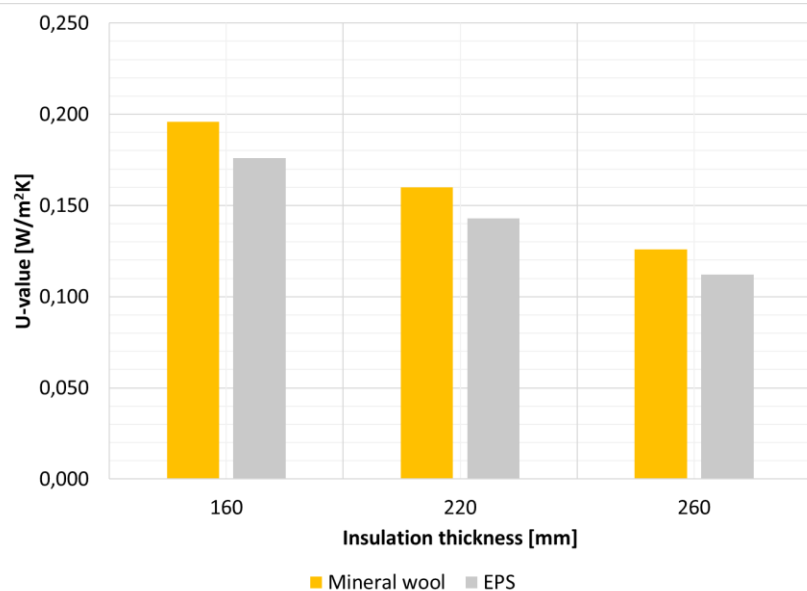
Thermal insulation thickness dependence on ψ -value



Lahti University of Applied Science [7]

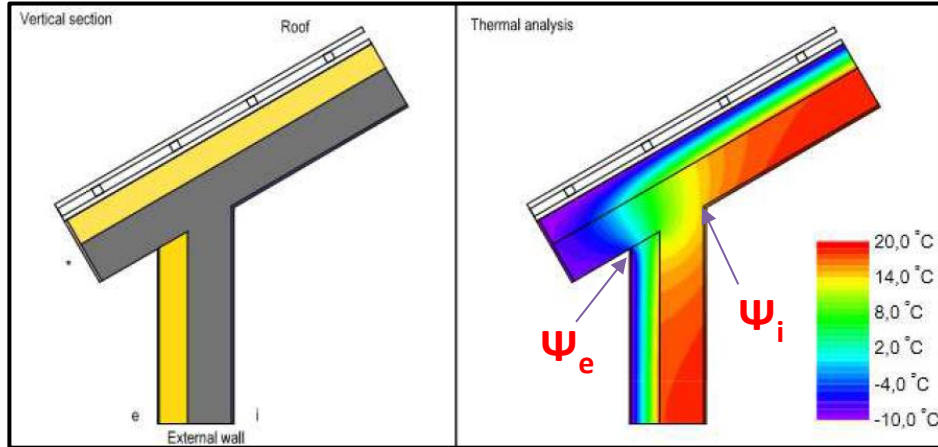
Component design		
Material	Thickness [mm]	λ [W/mK]
External wall e -> i		
Exterior plaster	10,00	1,00
Thermal insulation	160,0/220,0/260,0	0,035/0,031
Brick masonry	250,00	0,76
Interior plaster	15,00	0,70
Component design		
Material	Thickness [mm]	λ [W/mK]
External wall i -> 		
Cement screed	70,00	1,33
Sound insulation (mineral wool)	40,00	0,035
Gravel fill	50,00	0,70
Reinforced concrete (1 % steel)	240,00	2,30
Interior plaster	15,00	0,70

40 % less heat loss!



Sloped roof

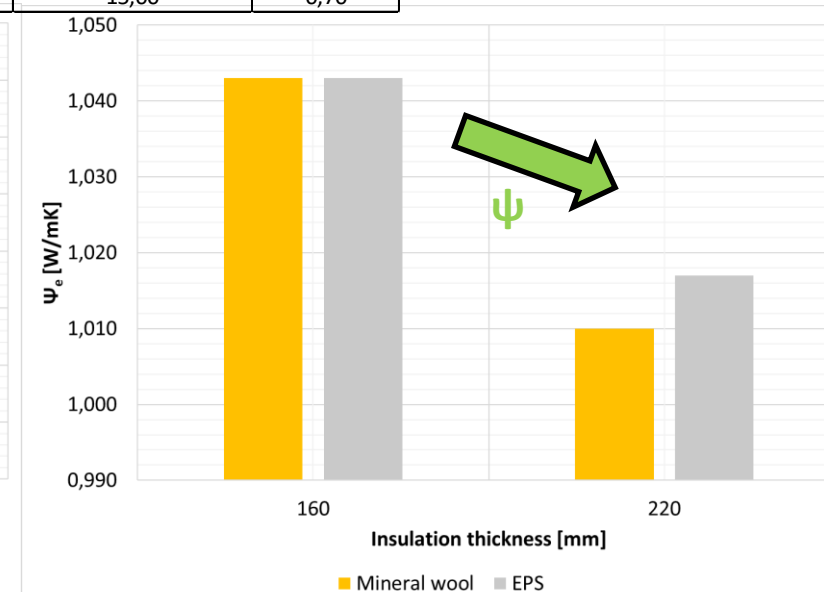
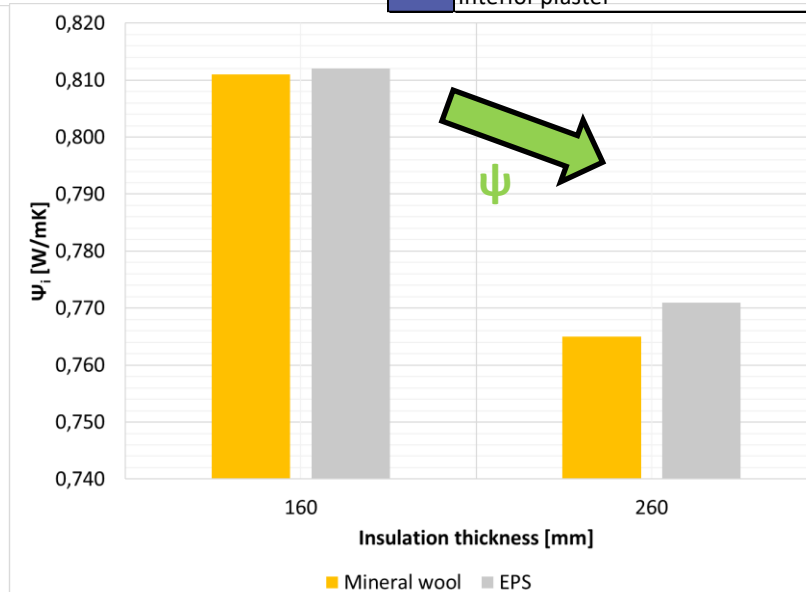
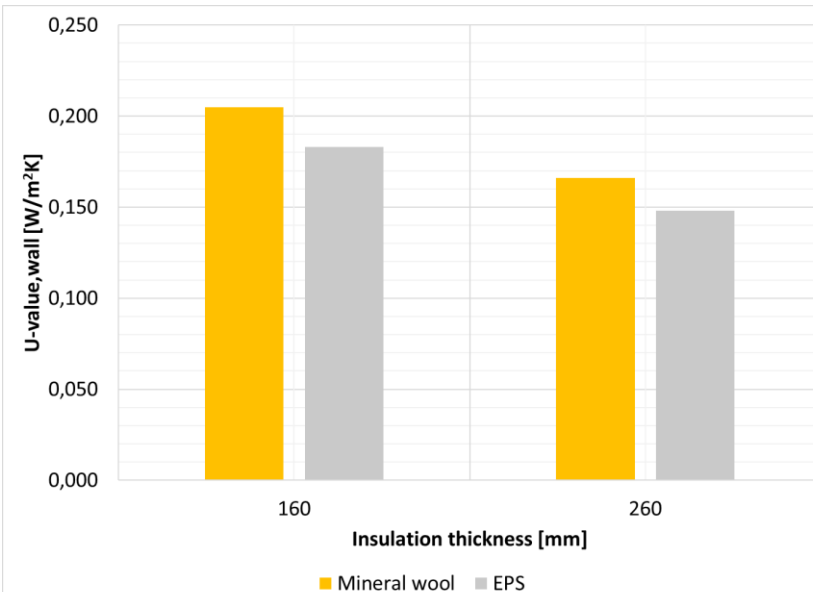
Thermal insulation thickness dependence on ψ -value



Lahti University of Applied
Science [7]

Component design		
Material	Thickness [mm]	λ [W/mK]
External wall e -> i		
Exterior plaster	10,00	1,00
Thermal insulation	160,0/260,0	0,035/0,031
Reinforced concrete (1 % steel)	250,00	2,30
Interior plaster	15,00	0,70
Component design		
Material	Thickness [mm]	λ [W/mK]
Roof e -> i		
Roof tiles	30,00	--
Wooden battens (roof latting)	50,000	0,130
Wooden battens (counter latting)	30,00	0,13
Mineral wood, rafters (e=800,0 mm)	160,00	0,04
Interior plaster	15,00	0,70

5 % less heat
loss.

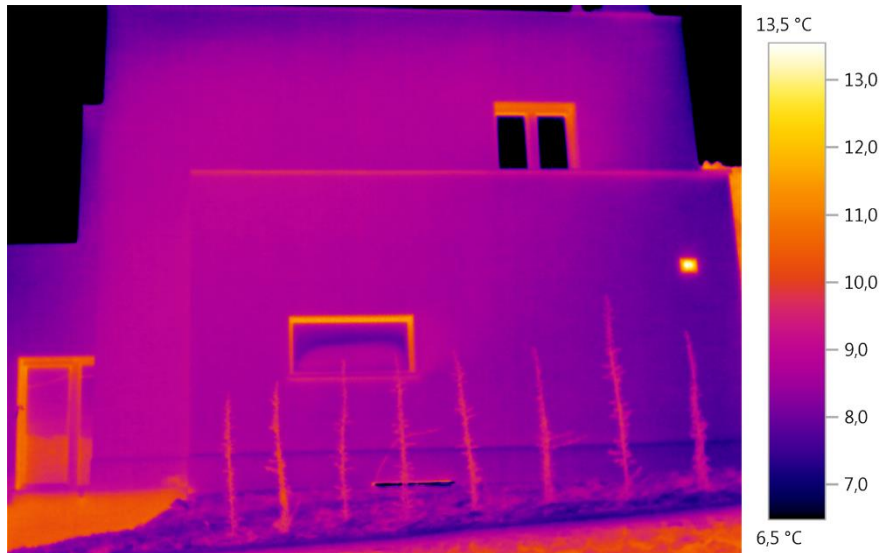


Thermal bridge free design

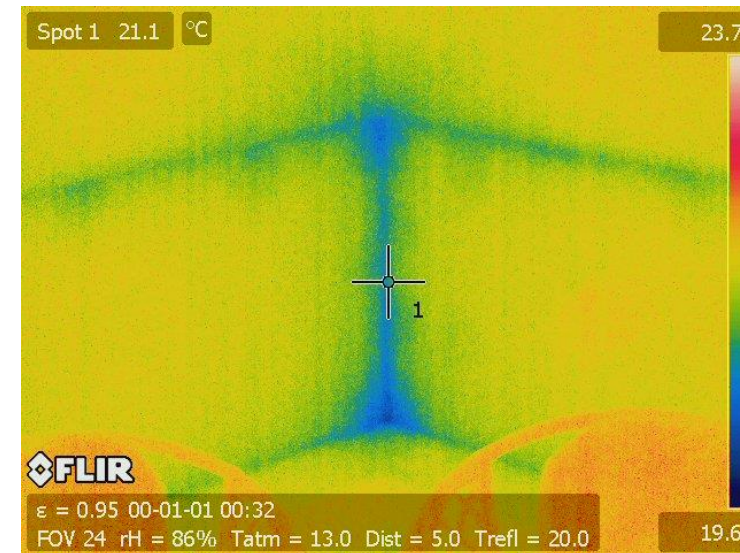


“Thermal bridge free design” can be defined as follows: **the contributions provided by thermal bridging are smaller than or equal to zero:**

In retrofit difficult to achieve, but important to try when cost effective, due to comfort and hygienic issues.



Source: B. Milovanović [3]



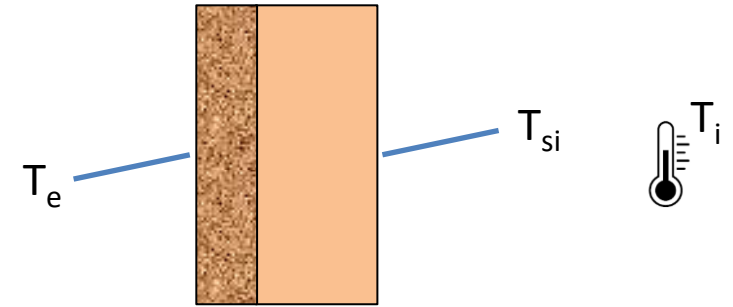
Source: B. Milovanović [3]

Modeling of thermal bridges

Characterization of TB due to room surface temperature

- 1) Temperature on the surface of TB on the side of the room is characterized by **temperature factor** at the internal surface:

$$f_{Rsi} = \frac{T_{si} - T_e}{T_i - T_e}$$



- 1) The aim is to calculate the minimal surface temperature and determine its location to estimate the risk of surface condensation.

Modeling of thermal bridges

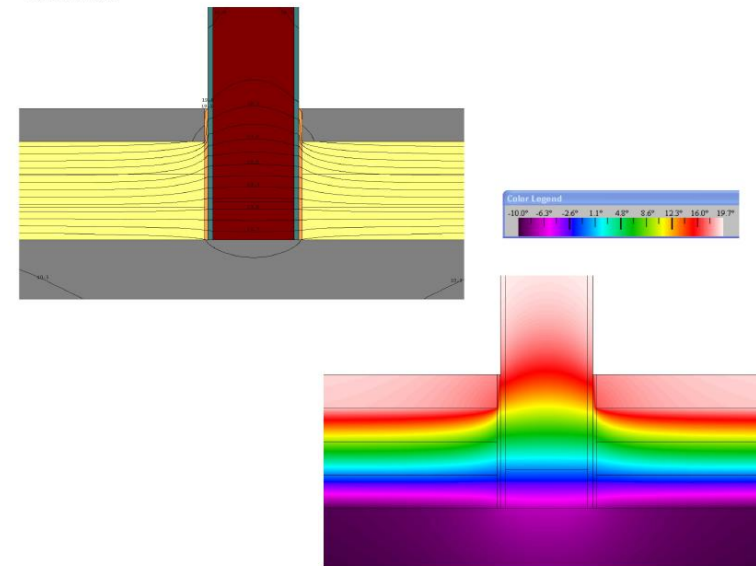


Characterization of TB due to room surface temperature

- Evaluation?
- Method of resolution?



Source: J. Schurr [12]

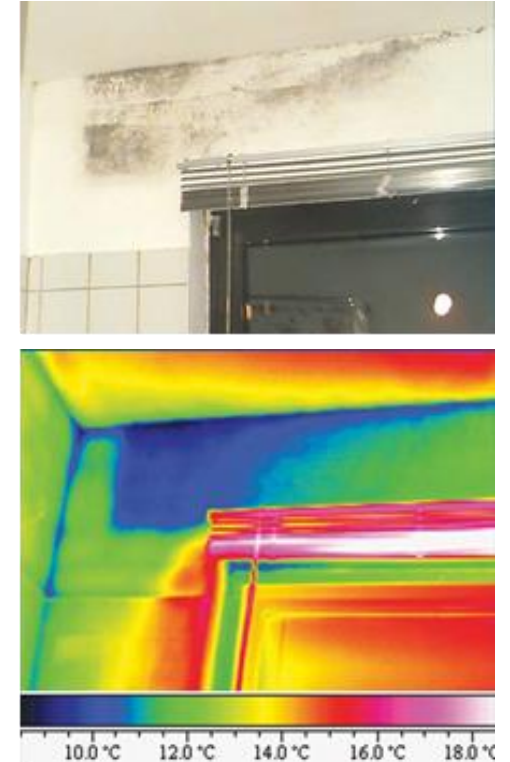


Consequences of thermal bridges



- 1) increased heat losses through building envelope during winter,
- 2) condensation of water vapor on the surface
- 3) formation of fungus / mold
- 4) destruction of building components due to corrosion
- 5) increased dust buildup on the wet surfaces
- 6) cracks caused by different thermal expansion of materials
- 7) destruction of building components due to freezing
- 8) segregation of plaster and wallpaper
- 9) increase in thermal conductivity of insulating materials
- 10) efflorescence on material surfaces (stone, concrete...)

➤ Grater degree of heat insulation of the building means greater condensation risk around the area of the thermal bridge.



Source: B. Milovanović [3]

Consequences of thermal bridges

Reasons for damage due to condensation around TBs

- 1) Buildings without thermal insulation (TI) - adverse effects of TBs are not very pronounced
- 2) Buildings with high, continuous thermal insulation (TI) - effects of TBs are very pronounced



Source: HDI [13]



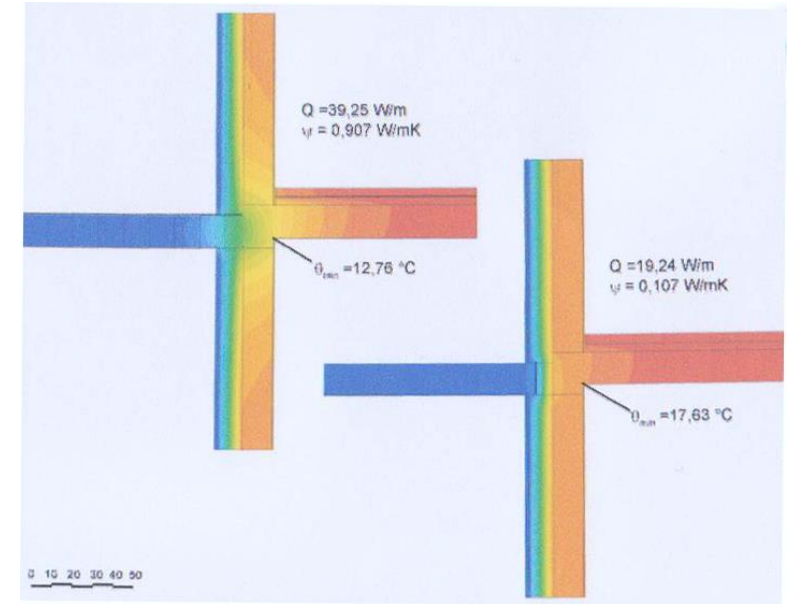
Source: B. Milovanović [3]

Consequences of thermal bridges



Example – condensation and dew point temperature

- 1) **left:** an unprotected thermal bridge made by the floorboard of the cantilever balcony.
 - Floor area temperature of the lower room is **only 12,76 °C**.
 - **Condensation will happen with 55-60% RH!**
- 2) **right:** the cantilever concrete slab is thermally separated from the wall.
 - Floor area temperature of the lower room is **17,63 °C**.
 - **Lower risk of condensation (it can still happen!)...**



Source: B. Milovanović [3]

Air temperature [°C]	Dew point temperature [°C] in relation to relative humidity										
	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
20	9,3	10,7	12,0	13,2	14,4	15,4	16,4	17,4	18,3	19,2	20
22	11,1	12,6	13,9	15,1	16,3	17,4	18,4	19,4	20,3	21,2	22
25	13,9	15,3	16,7	18,0	19,1	20,3	21,3	22,3	23,2	24,1	25
30	18,4	20,0	21,4	22,7	23,9	25,1	26,2	27,2	28,2	29,1	30

Ways and means for reducing the impact of TBs



Linear thermal bridges

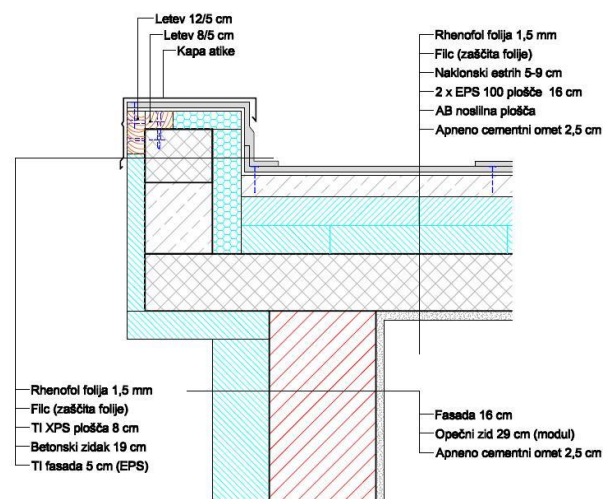
By thermally insulating all concrete surfaces that penetrate the main thermal insulation layer, i.e. building envelope.

- i.e. construction of a secondary thermal layer, the so-called „packing system”.

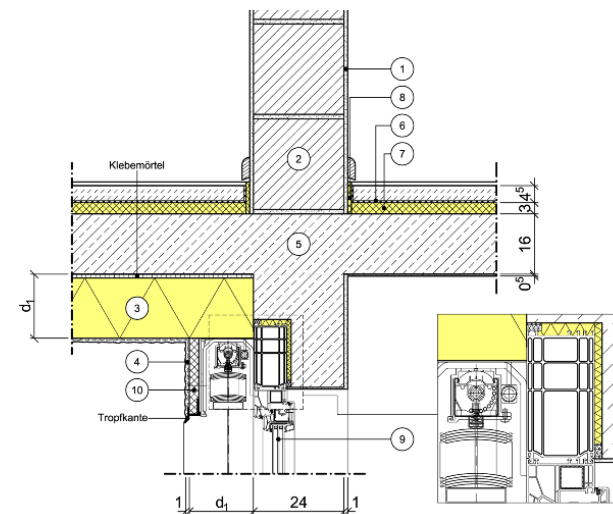
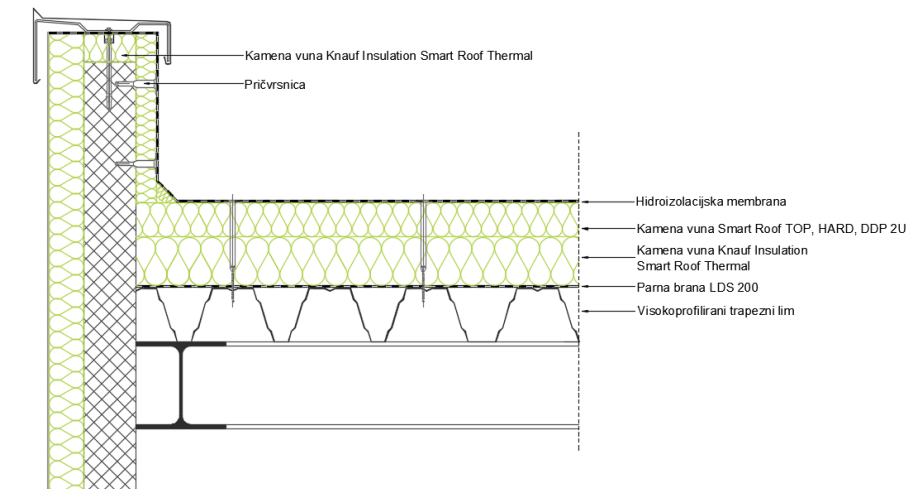
Source: B. Milovanović [3]



Source: Eps Attika [14]



Knauf Insulation [15]

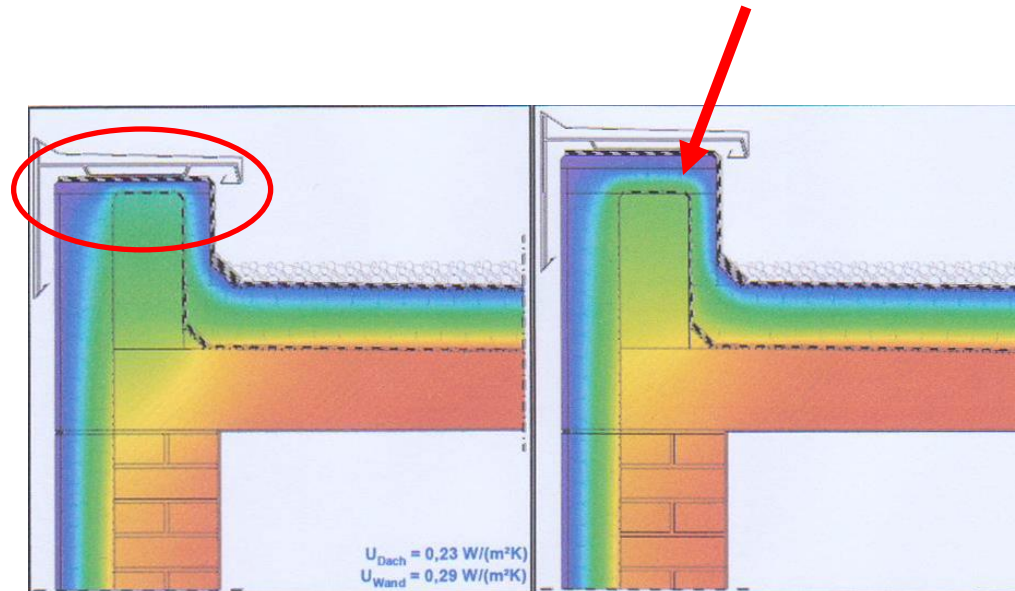


Source: Planungsatlas WDV [16]

Ways and means for reducing the impact of TBs

Example: The importance of correct parapet insulation

- 1) **left:** parapet with **discontinued heat envelope**
 - with linear Heat Transmittance coefficient of **$\psi = 0,23 \text{ W/(mK)}$** .
- 2) **right:** parapet with a **continuous heat envelope** (protection by "packing" system)
 - with linear heat transmittance coefficient of only **$\psi = 0,11 \text{ W/(mK)}$** .



$$U_{\text{WALL}} = 0,29 \text{ W/(m}^2 \text{ K)}$$

$$U_{\text{ROOF}} = 0,23 \text{ W/(m}^2 \text{ K)}$$

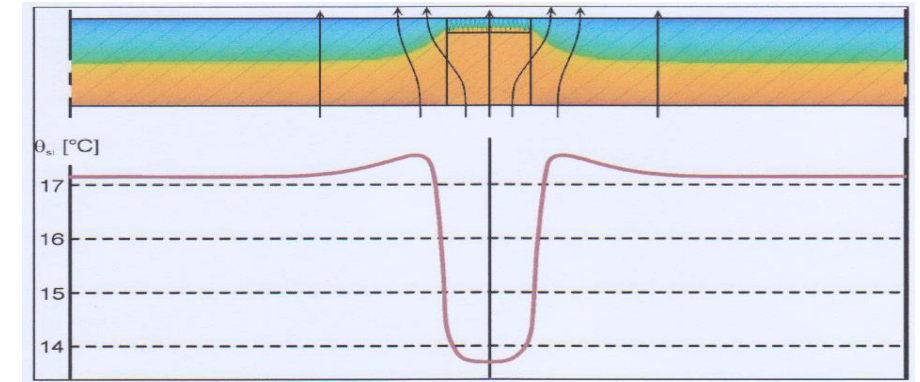
Source: B. Milovanović [3]

Ways and means for reducing the impact of TBs

Example: TB additionally insulated

1) External insulation

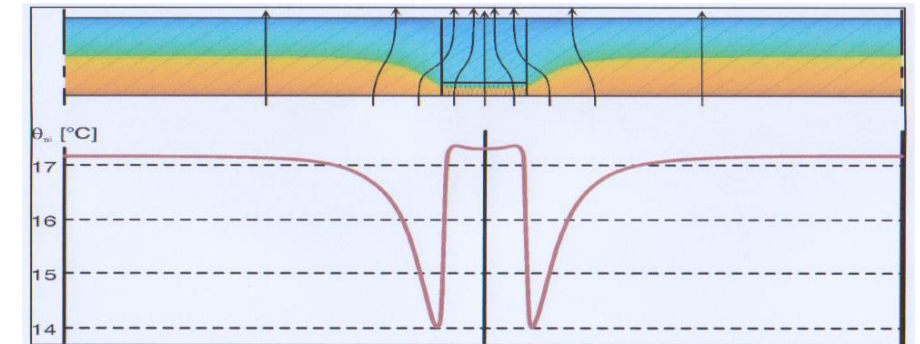
- internal surface temperature is lower by about 3 °C,
- thermal attenuation is concentrated along ring beam center line.



Source: B. Milovanović [3]

2) Internal insulation

- internal surface temperature is also lower by about 3 °C,
- thermal attenuation is separated into 2 zones along ring beam center line.



Source: B. Milovanović [3]

Ways and means for reducing the impact of TBs

Comment on the position of additional thermal insulation

1) From the previous example it can be observed that:

- **the position** of the additional thermal insulation layer of the TB affects only the temperature field on the inside of the building part,
- **and it does not affect** the difference in surface temperature, because they are the function of thermal resistance which, in both cases, is the same.

➤ **ATTENTION:** 

- **for the diffusion of water vapor** the position of the additional thermal insulation layer **is not unimportant**,
- a more favorable version is one **with external insulation** (for so-called normal climate).

Ways and means for reducing the impact of TBs

Possibilities to reduce the impact of point TBs - structural separation of the balcony

Prefabricated steel balconies



Source: B. Milovanović [3]

Stand alone balconies



Source:
B. Milovanović [3]

Ways and means for reducing the impact of TBs



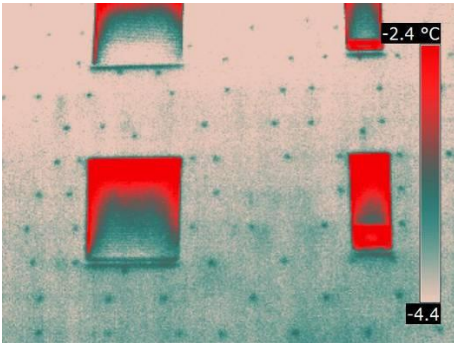
Point thermal bridges

Exclusion of the thermal bridge on metal couplings (dowels) of the ETICS system

- by inserting the "head" of the dowel into TI, or
- by using fasteners attached to the panel hinges



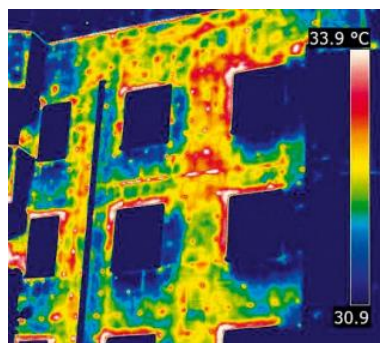
Source:
B. Milovanović [3]



Source:
Baupraxis [18]



Source:
HUPFAS [17]



Source:
HUPFAS [17]



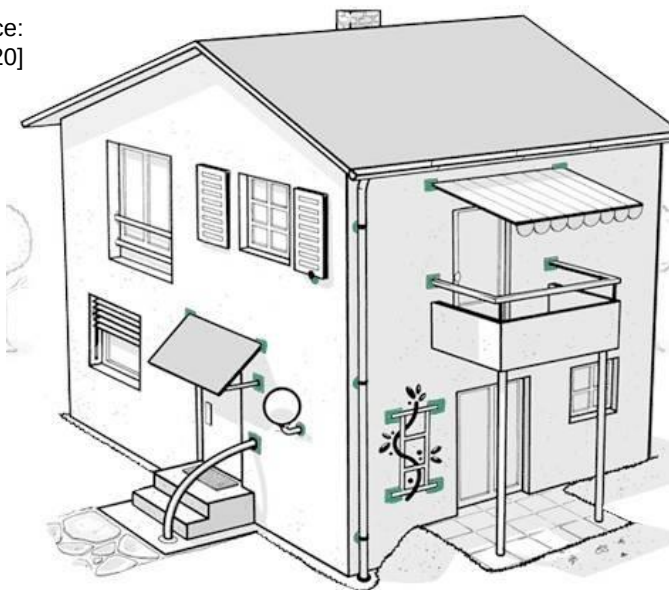
Source: Sto SE & Co. KGaA [19]

Ways and means for reducing the impact of TBs

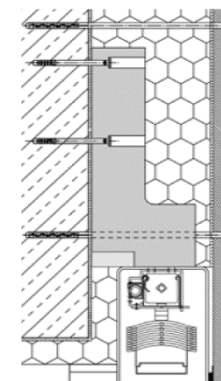
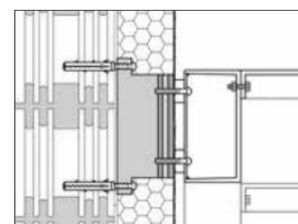


Point thermal bridges in facade systems - ETICS

Source:
Dosteba [20]



Prefabricated elements made of hard polyurethane foam and foam-shaped metal plates



Source:
Beck-Heun [21]

Elements for mounting external lighting fixtures



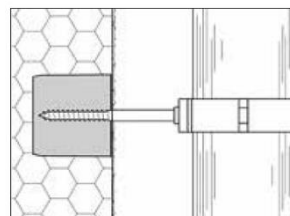
Source:
TIM [22]



Source:
ELDOLINE® [23]

Polypropylene prefabricated plate
Prefabricated cylinder made of very solid EPS

Source:
Sto [24]



Screw connection with TB break



Source:
Posaqualificata [25]

Source: B. Milovanović [1]

Ways and means for reducing the impact of TBs

Point thermal bridges in facade systems – ventilated facades

In cases of ventilated facades and metal supports, the point TB may be interrupted

- using ventilated facades made of **composite materials or glass fibers** with low thermal conductivity,
- using **Teflon or plastic substrates** whose low thermal conductivity contributes to reducing the impact of point thermal bridges.



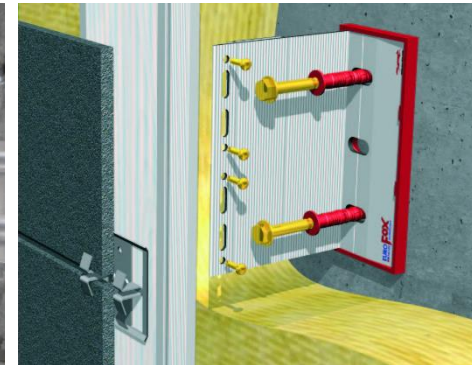
Source: B. Milovanović [3]



Source: Cascadia Clip [26]



Source: B. Milovanović [3]



Source: Budzirka [27]

Ways and means for reducing the impact of TBs



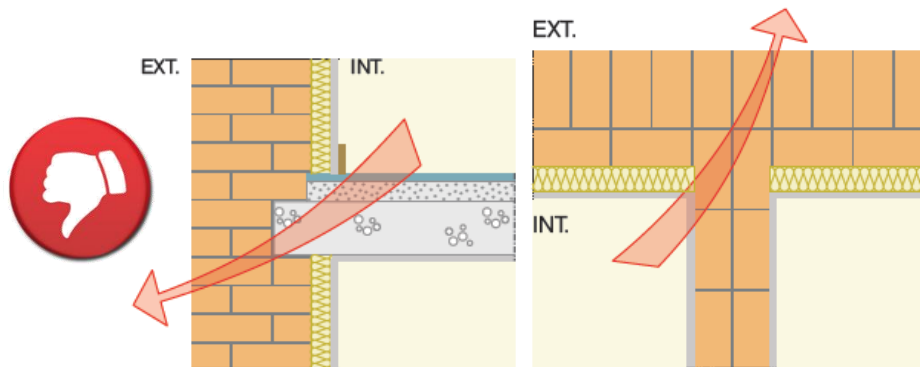
Auxiliary methods

The consequences of thermal bridges can be reduced by the following **auxiliary** methods:

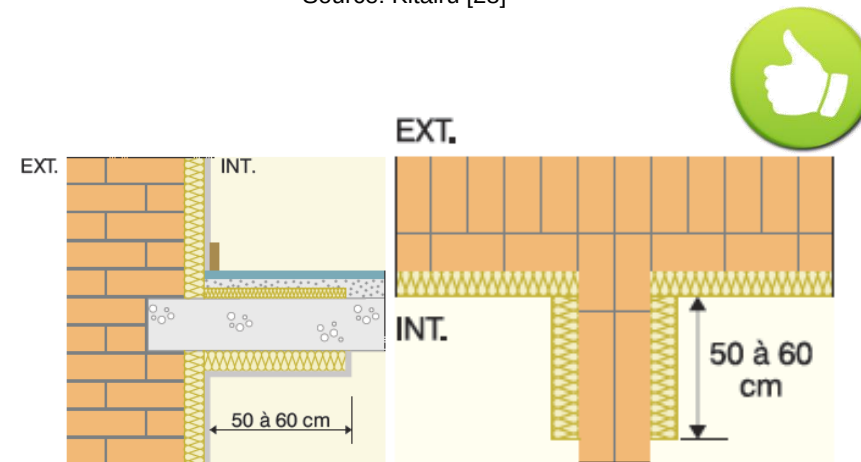
- indoor, **local sheathing of vulnerable zones** with secondary thermal layer,
- effective protection with the vapor barrier.



Source: Kitairu [28]



Source: Energie+ [29]

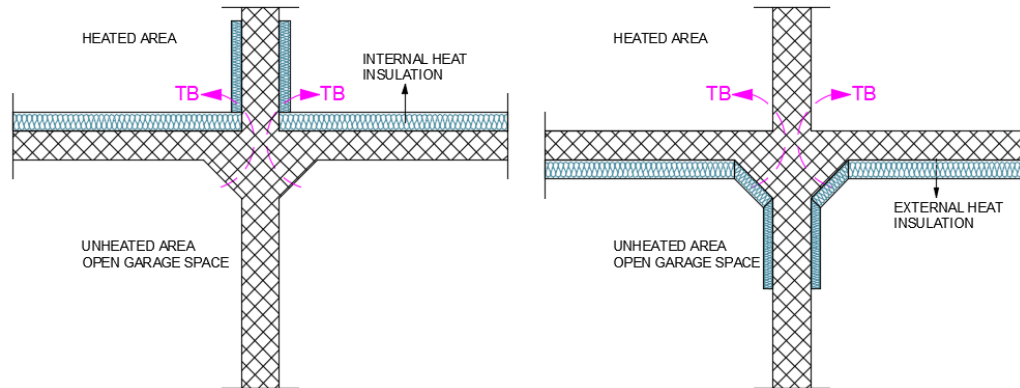


Ways and means for reducing the impact of TBs

Auxiliary methods

At the penetration of load-bearing columns through the slab above the non heated areas

- it is essential to partially cover column-slab connection with the secondary thermal insulation layer, which can be carried out on external or internal side.
- when the thermal separation is very problematic because of load-bearing reasons.
- when creating the shape of the column, flared column, the connection should provide space for the secondary thermal insulation layer.



Source: B. Milovanović [3]



Source: B. Milovanović [3]

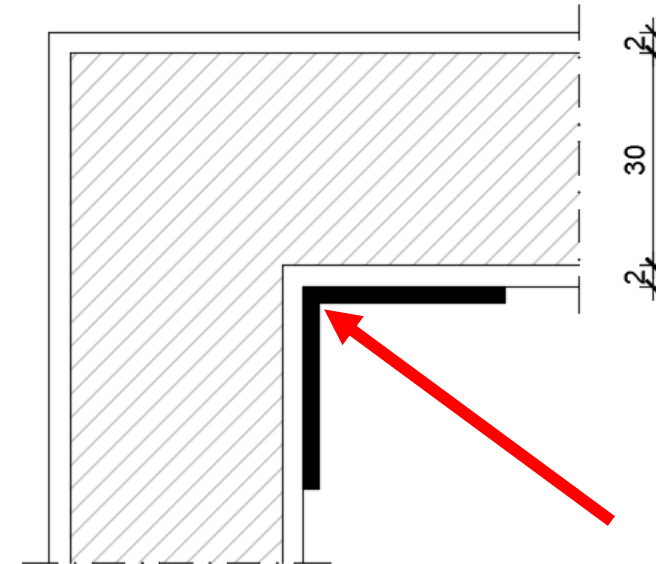
Ways and means for reducing the impact of TBs



Auxiliary methods

Passive protection of thermal bridges by partial coating

- preventing the thermal bridge in the corner of the room with an **additional inner thin coat** which is then coated with the aluminum foil on the outside,
- vapor barrier and reflector of long-wave radiation.



Source: B. Milovanović [3]

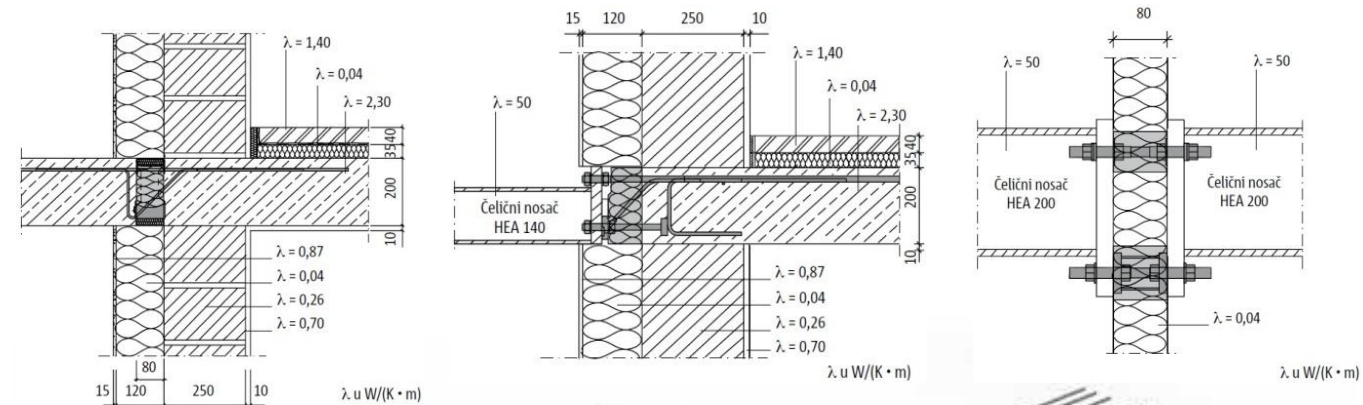
Ways and means for reducing the impact of TBs



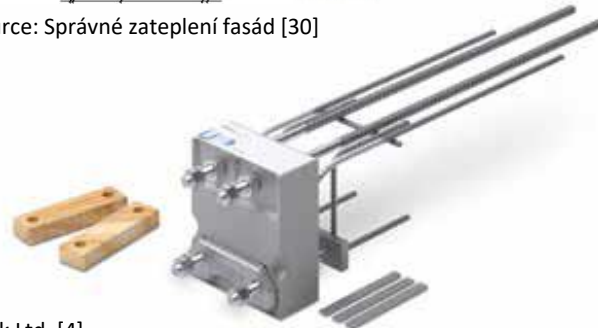
Physical separation of the structure

A load-bearing thermal insulating element consisting of load-bearing steel structures (reinforcement) and an EPS, XPS or MW insulating layer.

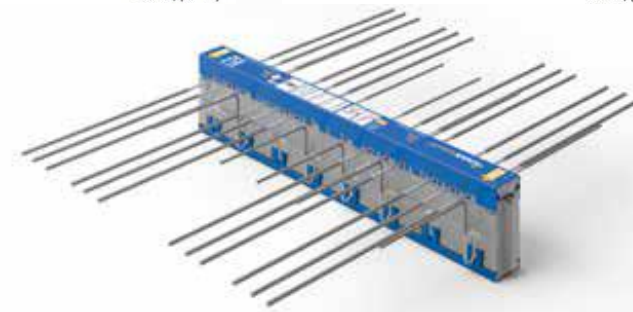
➤ Schöck Isokorb®, Halfen, ...



Source: Správné zateplení fasád [30]



Source: Schoeck Ltd. [4]



Source: Schoeck Ltd. [4]

Ways and means for reducing the impact of TBs



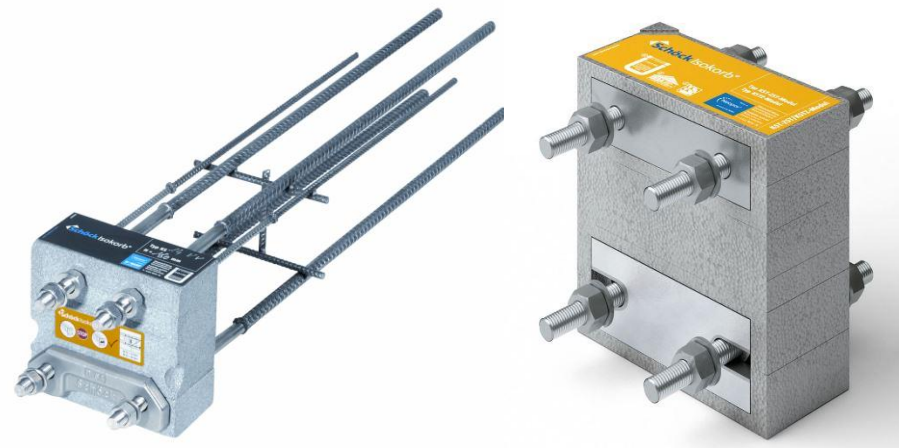
Physical separation of the structure

- mounted on prefabricated, assembled, cantilever balconies

Source:
Archiproducts [31]



- For fixation of steel elements, in concrete or steel structures



Source: Schoeck Ltd. [32]

Source: Schoeck Ltd. [33]

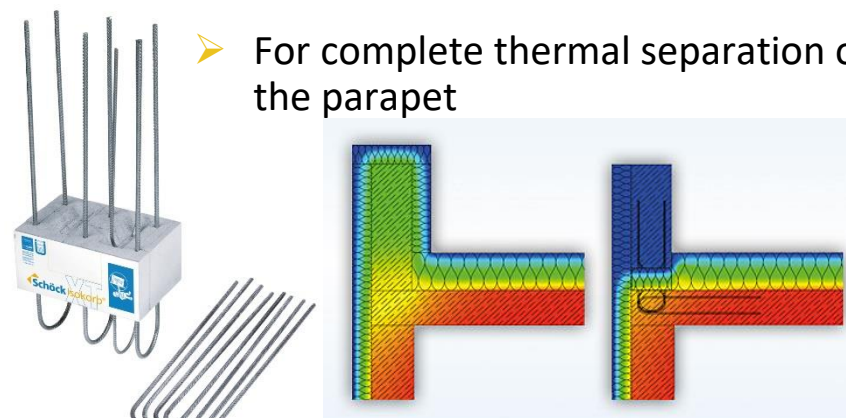
Source:
Laros [34]



- For installation in the first row of bricks above the foundation or basement

Source: B. Milovanović [1]

- For complete thermal separation of the parapet

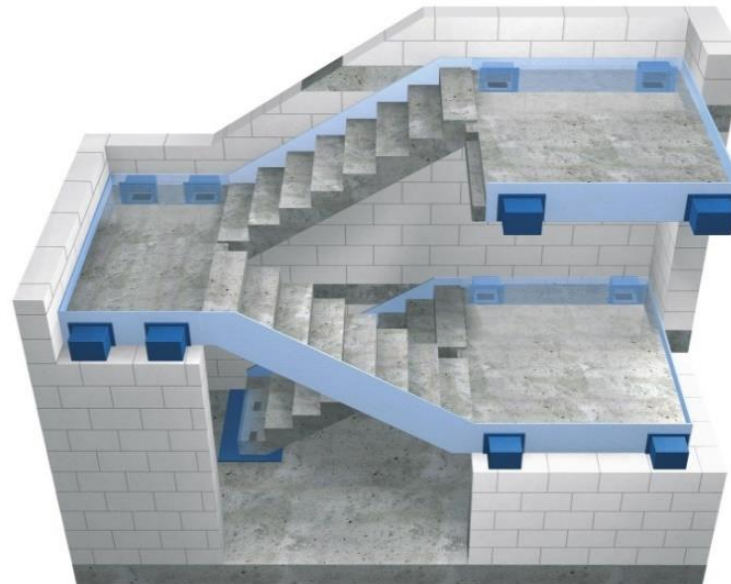


Source: BBA [35]

Source: Wohnet [36]

Structural separation of the staircase

- 1) Particular attention should be paid to staircases in residential buildings.
 - If the staircases are in non-heated areas, the junctions in which they are connected to the walls become places of increased heat loss, i.e. TBs.
- 2) Also, the noise on the staircases is very frequent, it is mainly an impact sound (noise).

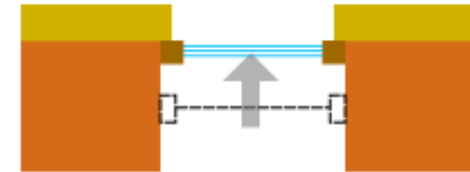


Source: Kornbrno [37]

Proper windows installation

- External insulation
 - if possible, it is desirable to bring the window forward to **align with the insulation layer** to a point where the insulation can overlap the frame.
- Internal insulation
 - the lining, together with the **vapor control layer should be returned into the window reveal** to be tightly **butted and sealed against the window frame**.

external insulation



internal insulation



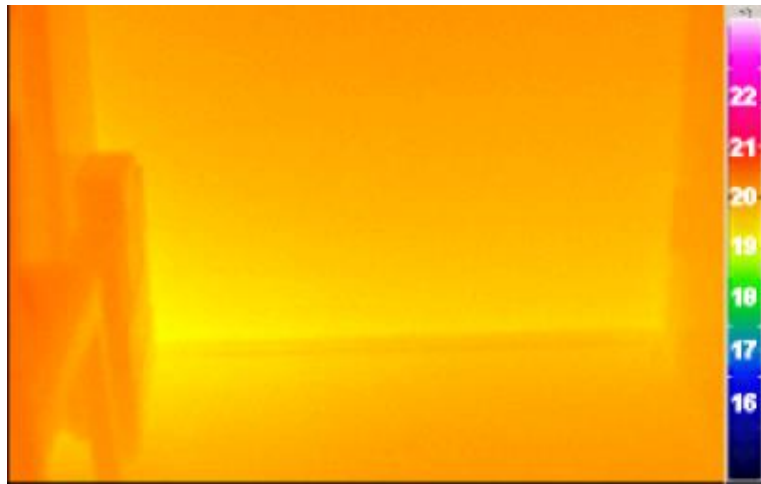
Source: GreenSpec [38]

Central points for Quality Assurance

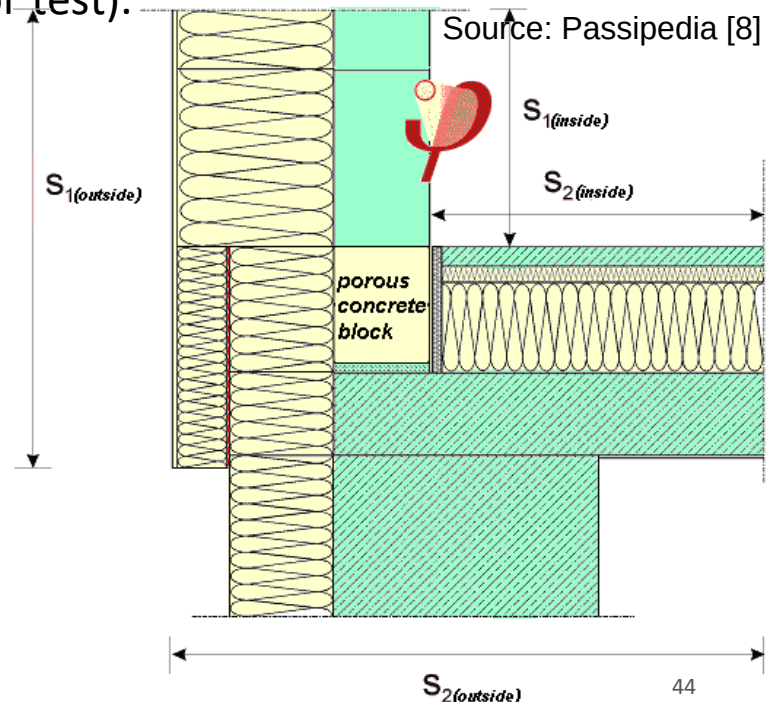
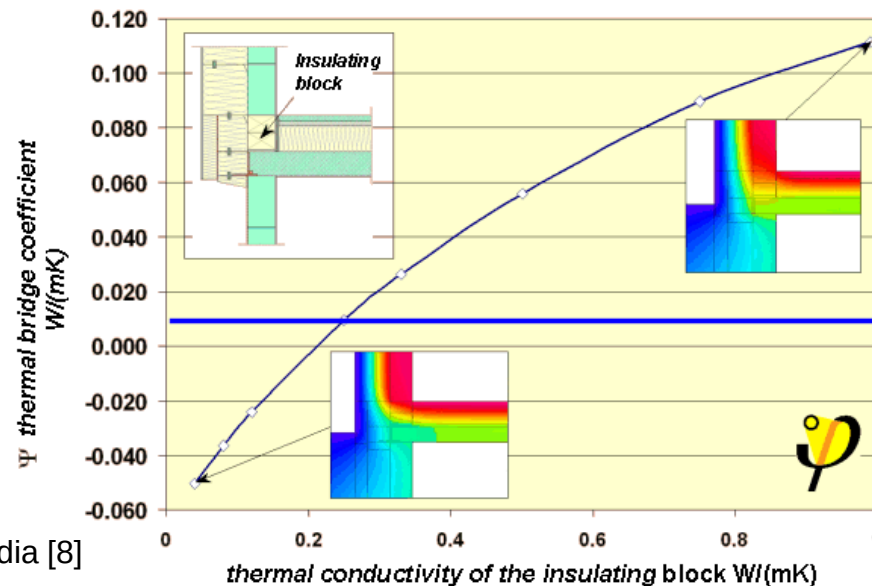
Low thermal bridge losses: thermal-bridge-free
Planning task: thermal-bridge-free design

- compliance with certificate,
- the calculation must also be comprehensible regarding to the design, and must be implemented at the site,
- quality check using infrared thermography (with Blowerdoor test).

Source: Passipedia [8]



Source: Passipedia [8]



Daily routine on site

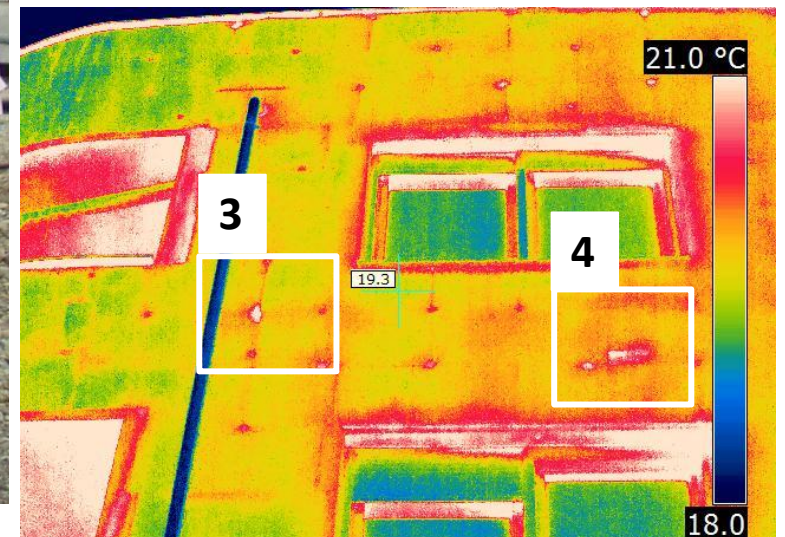
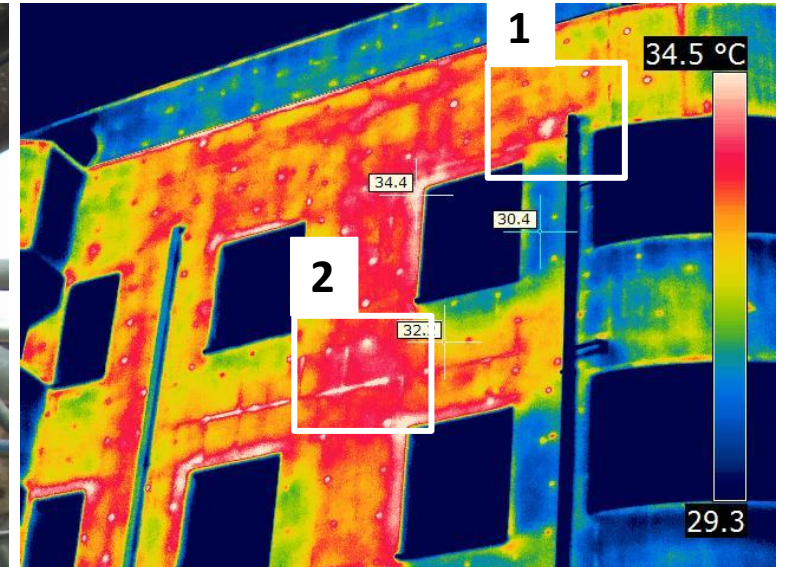
How is the handling of the insulation boards to be assessed?

10 mm wide crack
= Ψ -value 0,017 W/mK

U-value + 13 %



Source: B. Milovanović [3]



Source:

Schurr, J. [12]

Thank you.

Every detail shown here is a detail you will teach a craftsman.

State the problem, give the principle, show the wrong and the right example,
let them practise by hand, test it, document it.

Dr. Phys. Francesco Nesi | ZEPHIR Passivhaus Italia | f.nesi@zephir.ph | passivhausitalia.com

Funded by the European Union. Views and opinions expressed are those of the author only and do not necessarily reflect those of the European Union or EACEA. Neither can be held responsible for them.