

2. Building envelope

*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

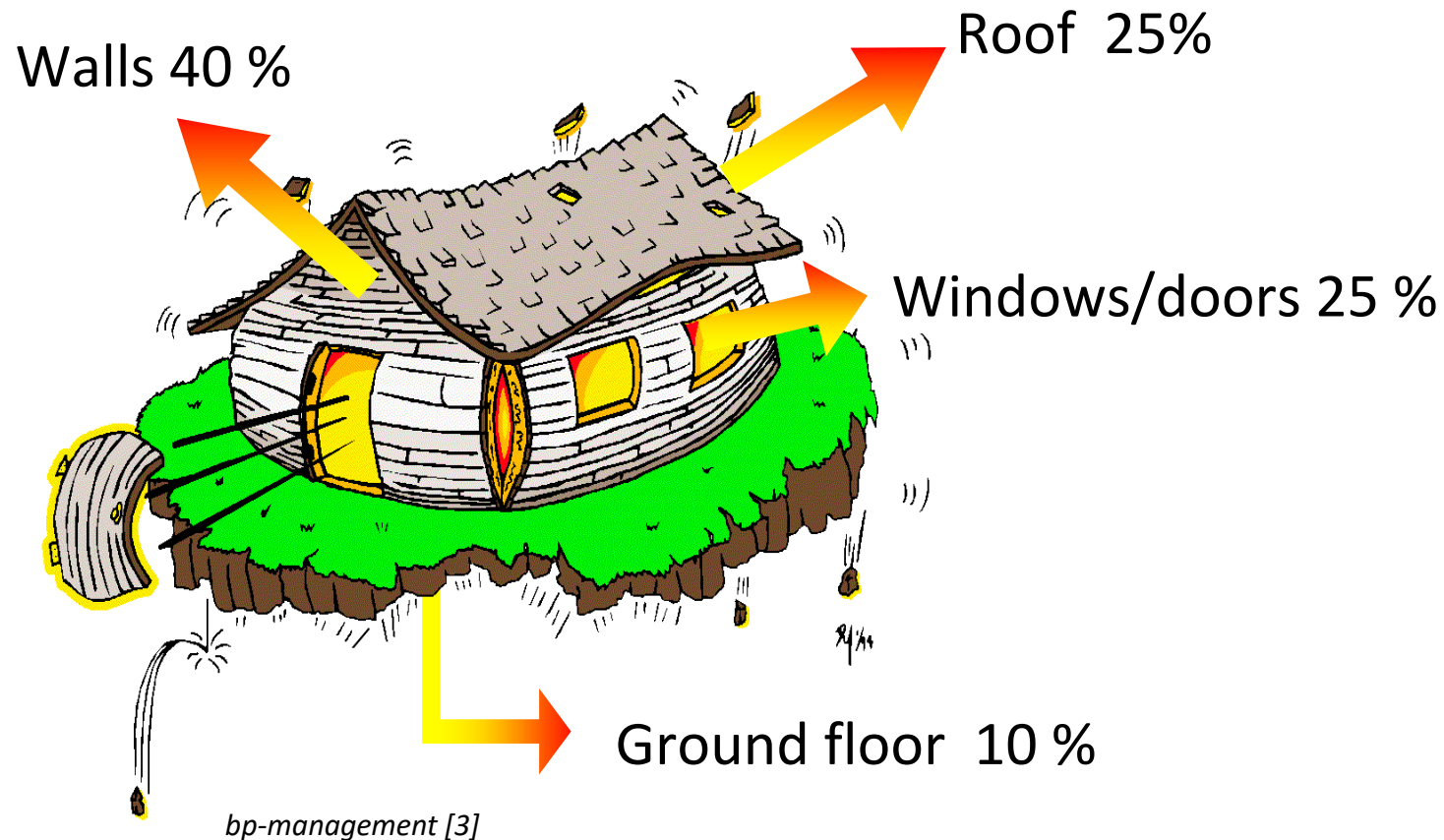
Thermal insulation fundamentals

Why it matters, which materials to use, how to determine it

Building Envelope



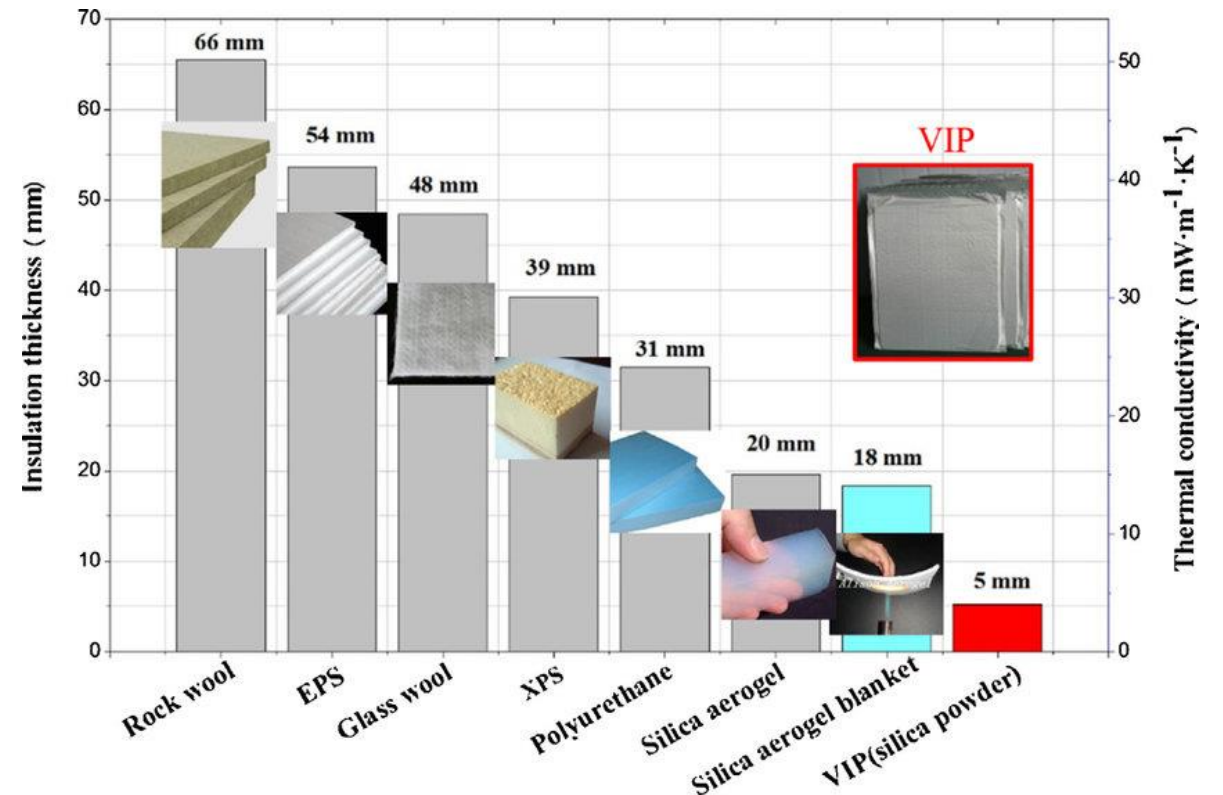
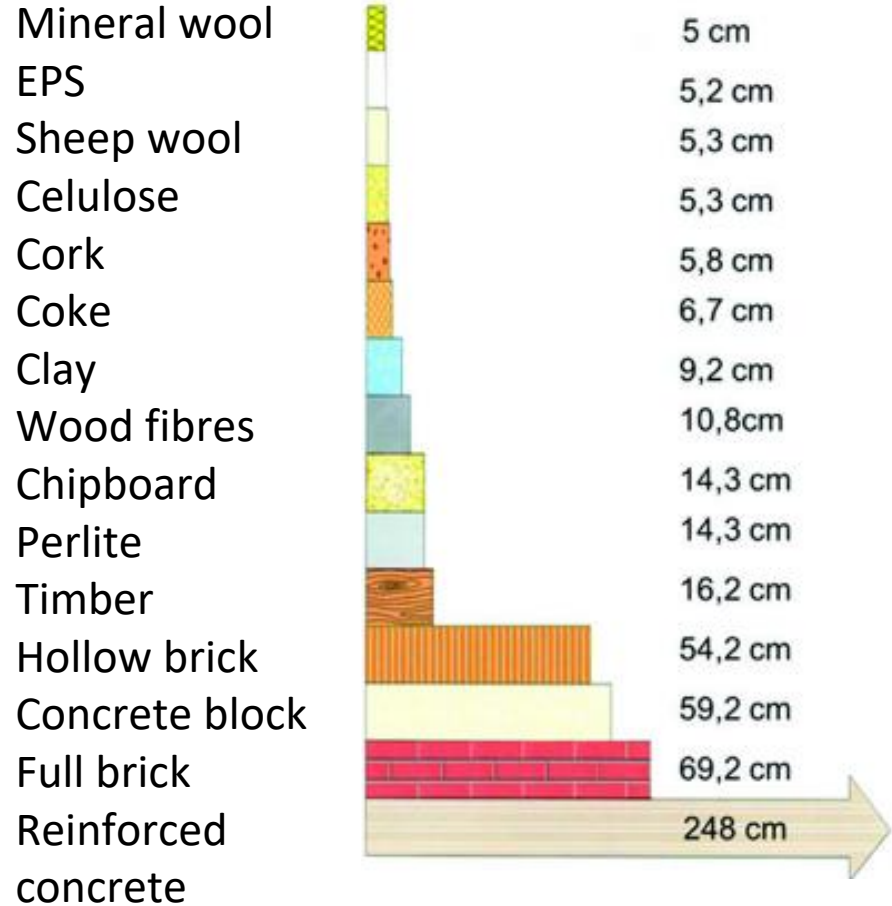
Distribution of heat losses through building envelope components



Opaque building components, especially walls, have a great ENERGY SAVING POTENTIAL!

HOW?

Different thermal insulation materials



Liang, Y. et al. [6]

Thermal envelope



High-tech thermal insulation materials



Berkeley Lab [7]

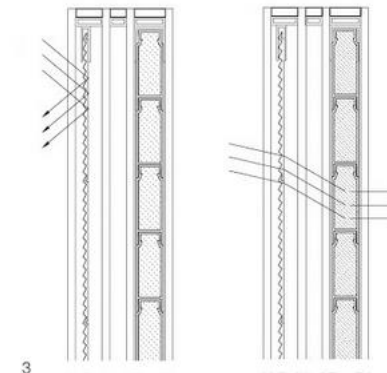
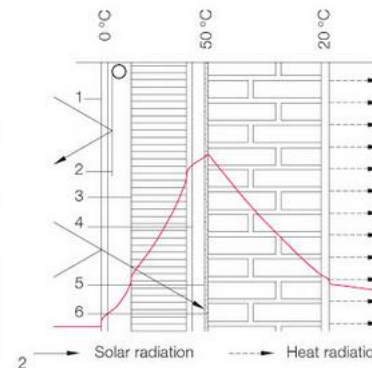
Aerogel („frozen smoke”):
 $\lambda < 0.024 \text{ [W/(mK)]}$



Phase Change Materials, PCM:
 thermal energy storage



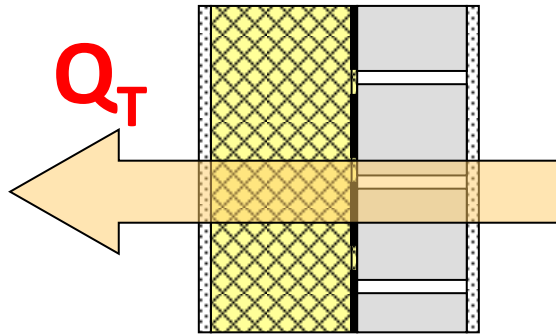
Vacuum Insulated Panel, VIP:
 $\lambda = 0.00576 \text{ [W/(mK)]}$



Transparent thermal insulation,
 TWD: use of solar energy for
 heating in conjunction with an
 opaque external wall

Pfundstein, M. Et al. [8]

Quantification of heat loss through thermal envelope → **TRANSMISSION LOSSES**

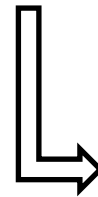


SEEDpass project [9]

$$Q_T = \boxed{A * U * b_T} * G_t$$

A = Area of thermal envelope
 U = U-value
 b_T = Temperature-correction factor
 G_t = Heating degree hours

$$H_T = \underbrace{\sum b_j A_j U_j}_{\text{Areas of thermal envelope}} + \underbrace{\sum b_j \Psi_j l_j}_{\text{Linear thermal bridges}} + \underbrace{\sum b_j X_j}_{\text{Point thermal bridges}}$$

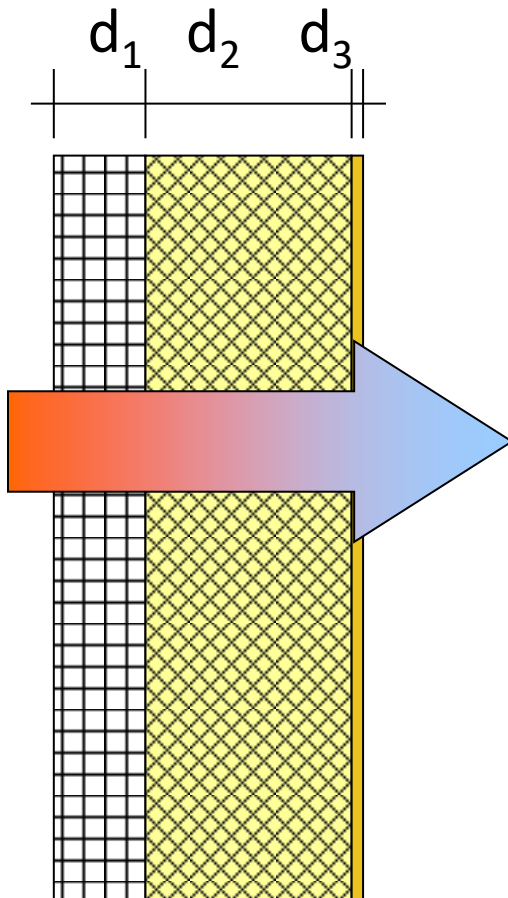


- Opaque Elements → **Walls, Roof, Slab**
- Transparent Elements → **Windows**

Thermal envelope



U-values of homogeneous building elements (EN ISO 6946)



$$U = \frac{1}{R_T} = \frac{1}{R_{si} + d_1/\lambda_1 + d_2/\lambda_2 + d_3/\lambda_3 + R_{se}}$$



U = U-value [$W/(m^2K)$]

R_T = Total thermal resistance [$(m^2K)/W$]

R_{si} = Internal surface resistance [$(m^2K)/W$]

d_i = Layer thickness [m]

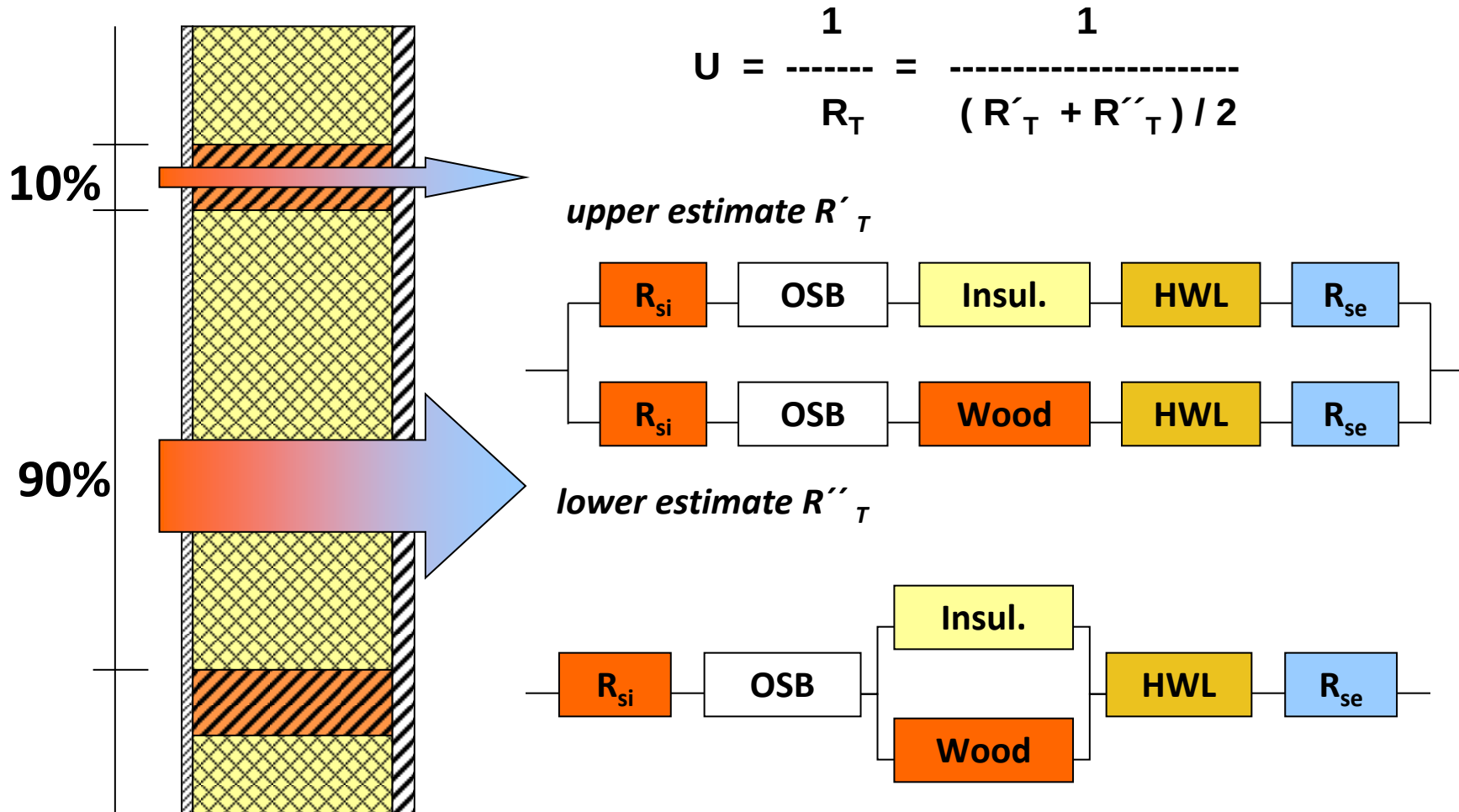
λ_i = Thermal conductivity of layer [$W/(mK)$]

R_{se} = External surface resistance [$(m^2K)/W$]

Thermal envelope



U-value of inhomogeneous building elements (EN ISO 6946)

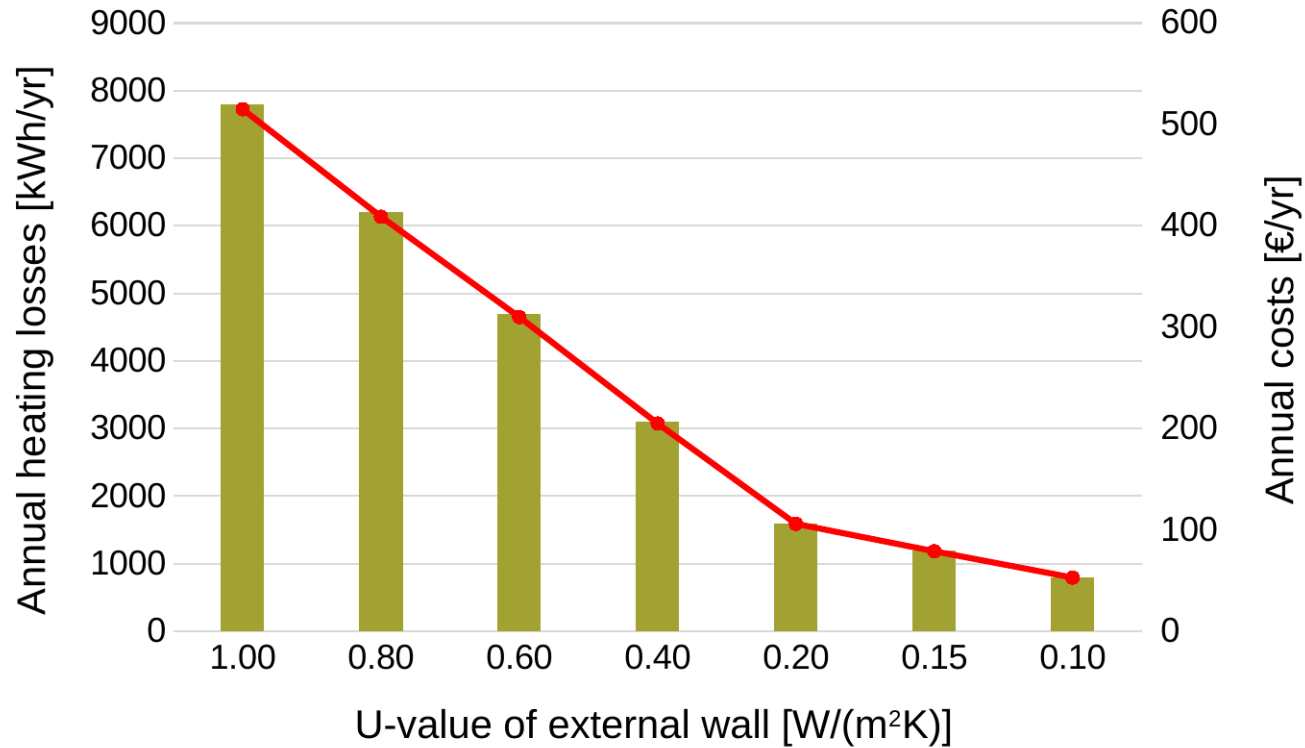


CEPH Project [4]

Thermal envelope



Potential for energy and financial saving



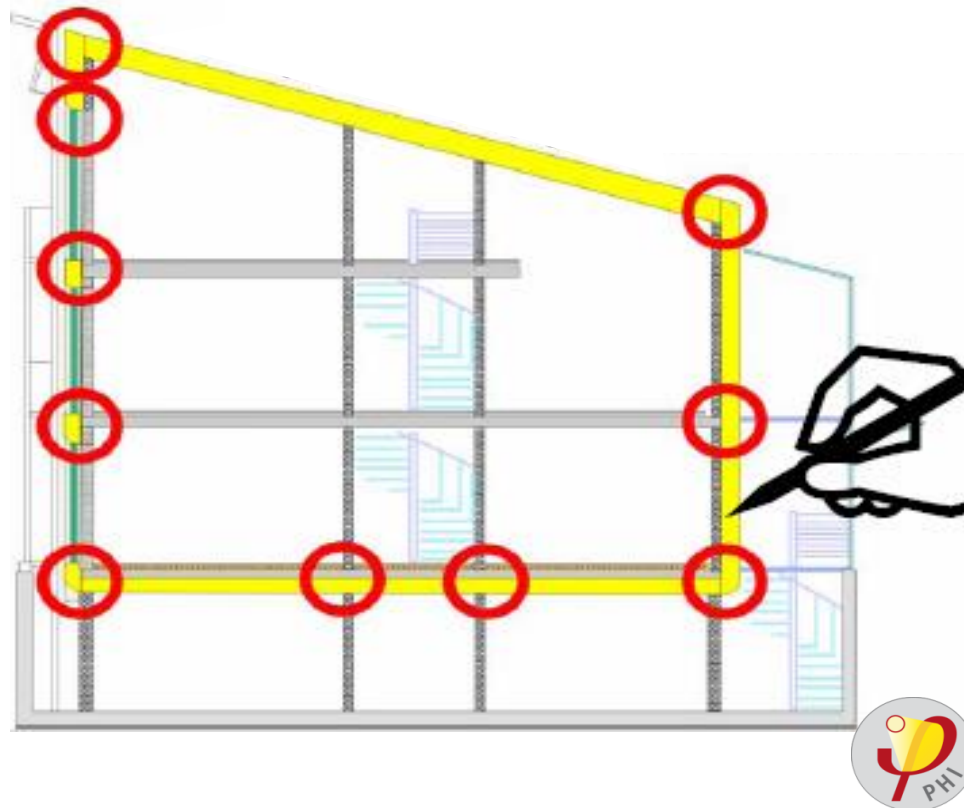
Example of a small single-family house with an external wall surface of 100 m²

Thermal envelope



Golden rule: „The Pencil Rule”

CONTINUITY : unbroken thermal envelope



In principle it should be possible to draw the insulation layer and the air tight membrane without „raising” the pencil.

Thermal envelope

Different construction tradition across Europe



SECTION 2

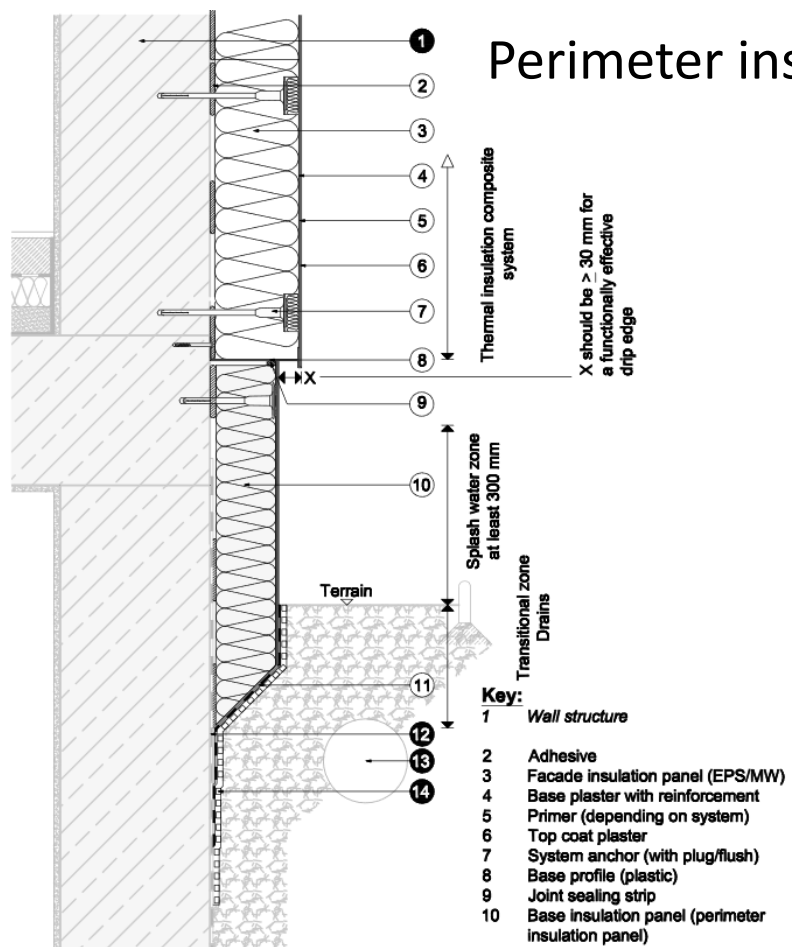
External thermal insulation

Foundations & floors, walls, roofs

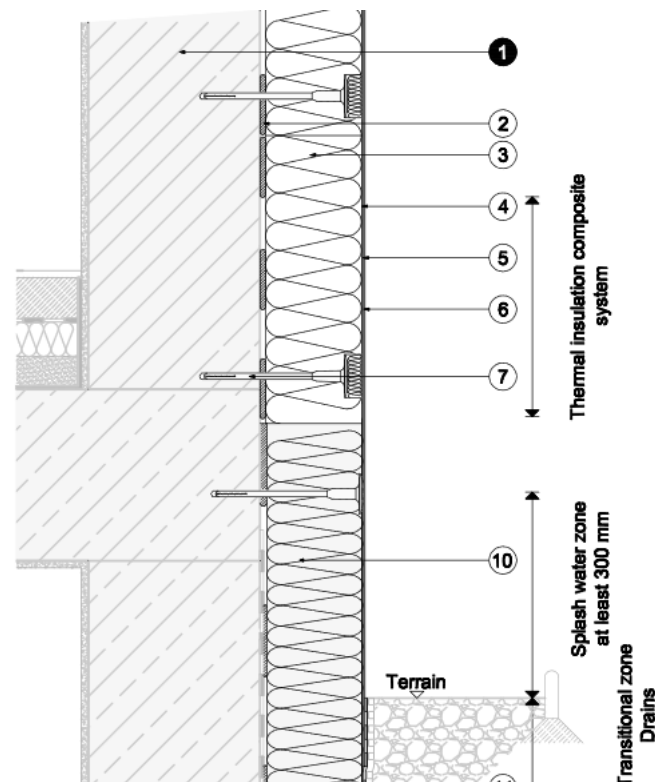
Insulation of existing foundations



Perimeter insulation: transition from the facade to the base area

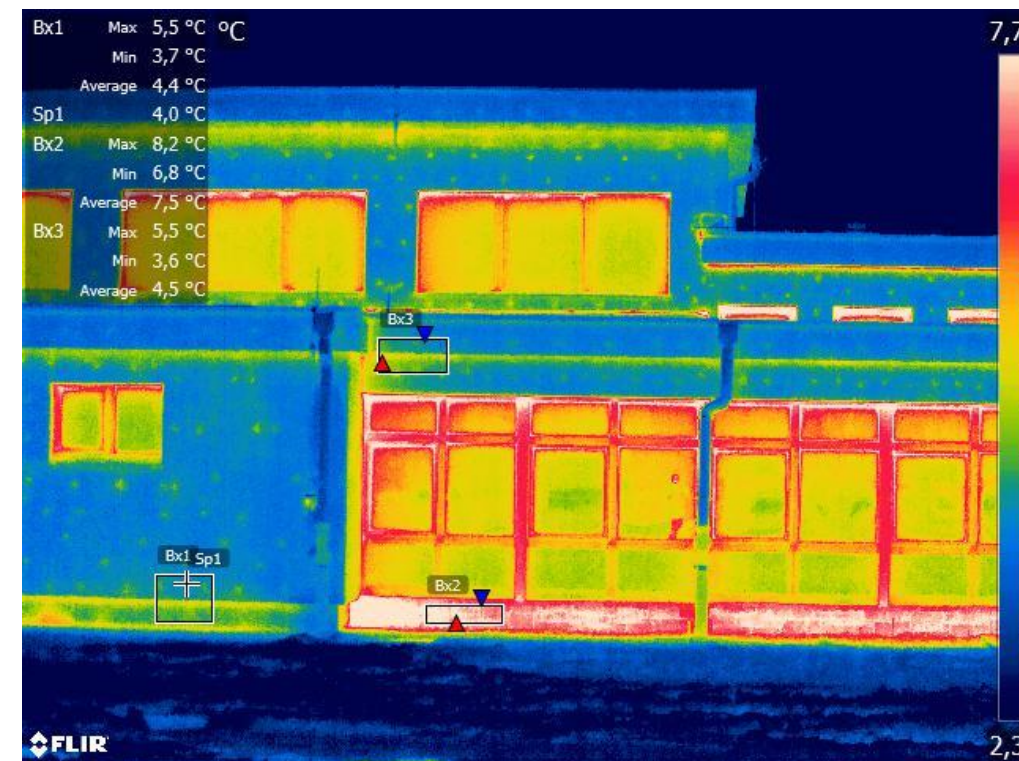


Undercut base



Flush base

EAE [29]

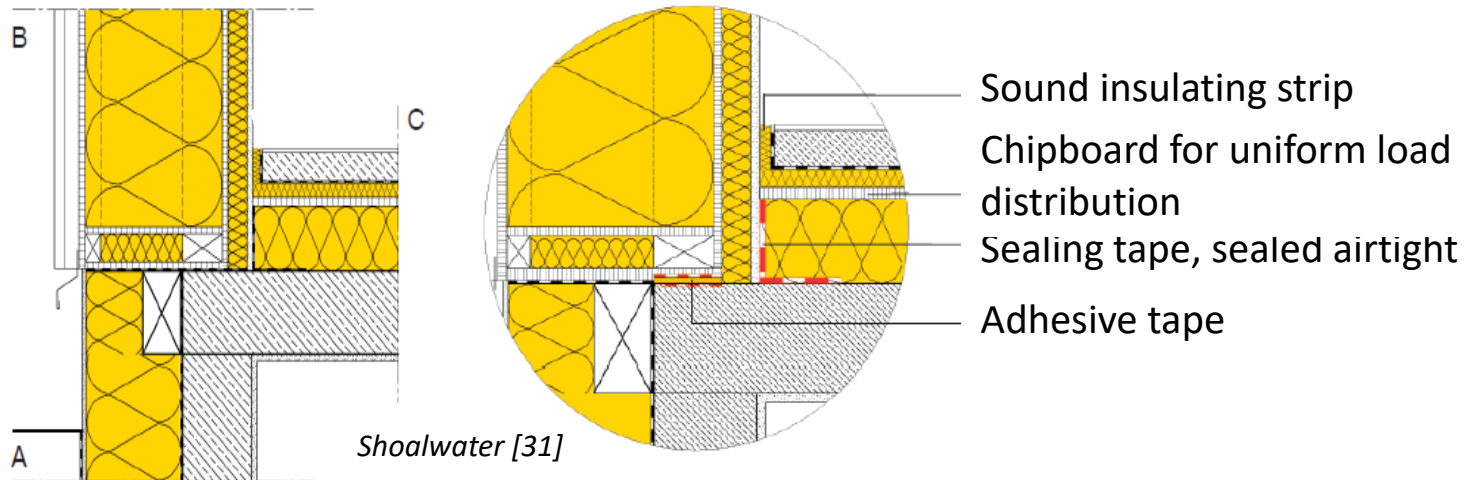


- Take care of thermal bridges!
- Material choice: XPS or foam glass

Insulation of foundations



- 1) Unbroken thermal envelope!
- 2) If possible, thermal insulation on exterior „cold” side.
- 3) Always ensure easy and quick drainage of rainwater by drainage around the foundation.



Detail of connection wall: floor above unheated basement



Salopek, D. et. al [30]

Perimeter insulation of concrete foundation

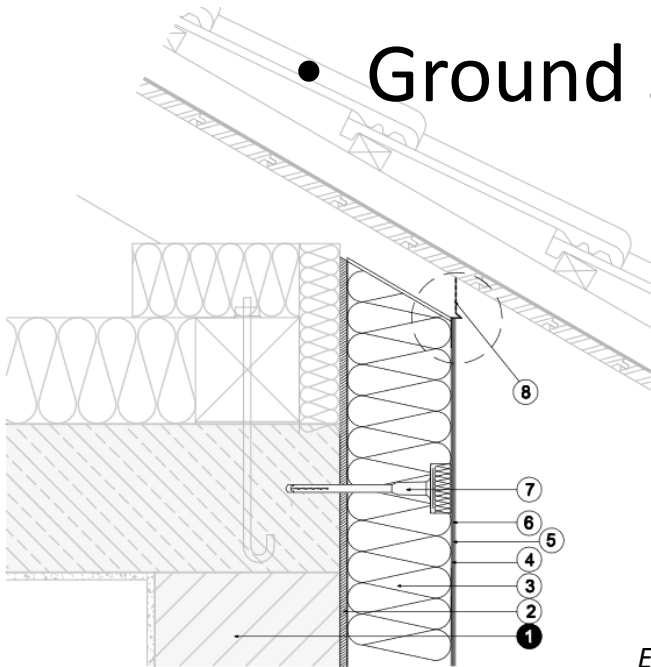
Floors that need to be thermally insulated



- Cold attic floor
- Floor above unheated basement
- Floor above surrounding external air
- Ground slabs



YTONG [33]



Key:

- 1 Wall structure
- 2 Adhesive
- 3 Facade insulation panel (EPS/MW)
- 4 Base plaster with reinforcement
- 5 Primer (depending on system)
- 6 Top coat plaster
- 7 System anchor (with plug/flush)
- 8 Roof connection profile

EAE [29]



Maistor Plus[34]



HUPFAS [32]

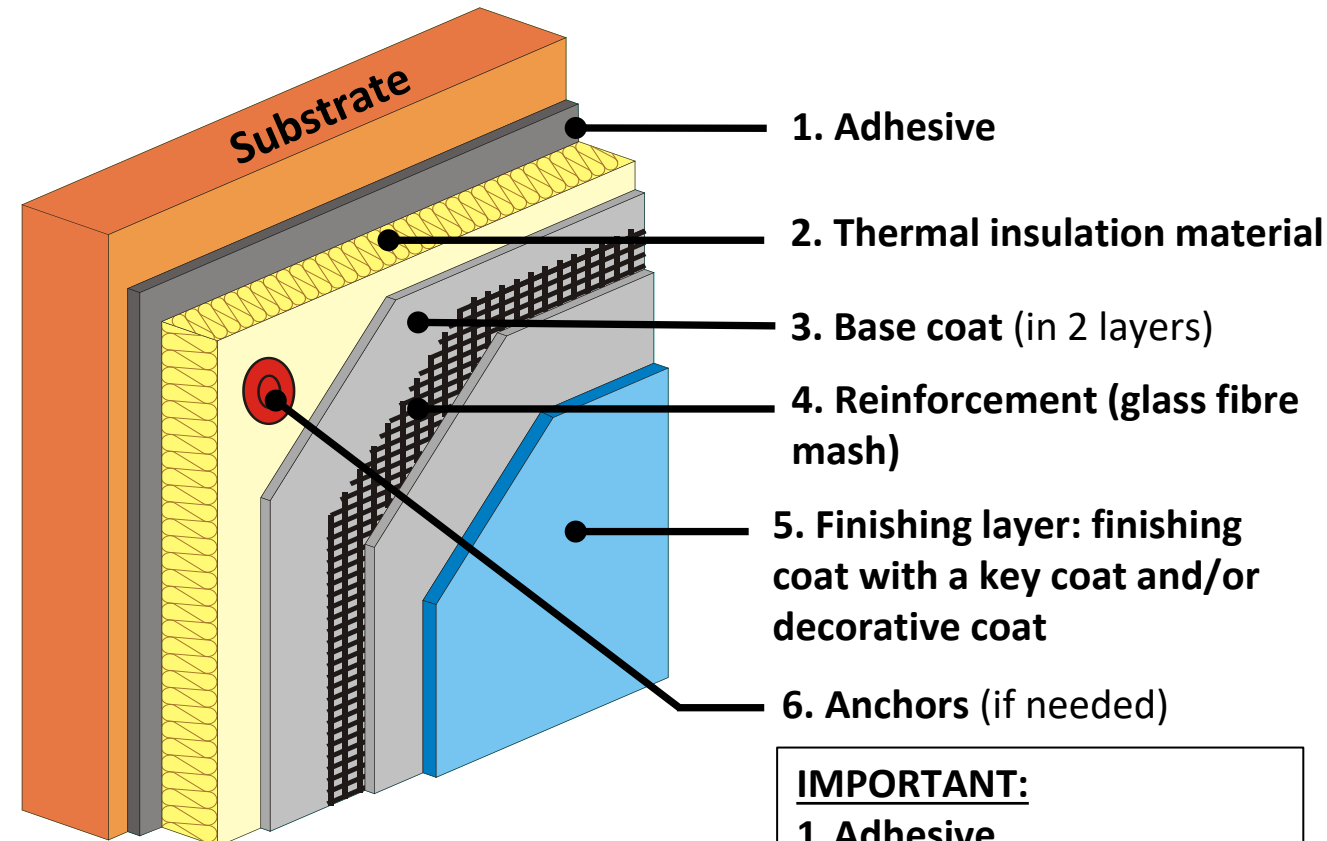
External thermal insulation: External walls



ETICS systems (**E**xternal **T**hermal **I**nsulation **C**omposite **S**ystem)

One of most commonly used systems for thermal enhancement of walls.

Thermal insulation material	Advantages	Disadvantages
Mineral wool	• <u>Vapour permeable</u> • Good reaction to fire • Good sound insulation	• 15-30% more expensive • More demanding for installation • Risk of damping
EPS-polystyrene	• Lower material price • Easier for installation • Greater choice of finishing layers	• <u>Less vapour permeable</u> • Weaker sound insulation • Weaker reaction to fire



IMPORTANT:

1. Adhesive
2. Reinforcement
3. Finishing layer have to be from the same producer

Phases of ETICS installation

1. Pre-treatment of the substrate + preparation works



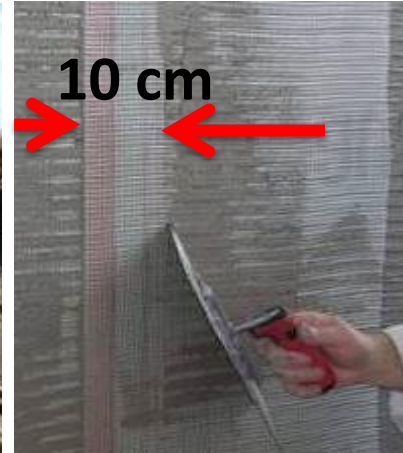
2. Bonding



3. Anchoring



4. Reinforcement



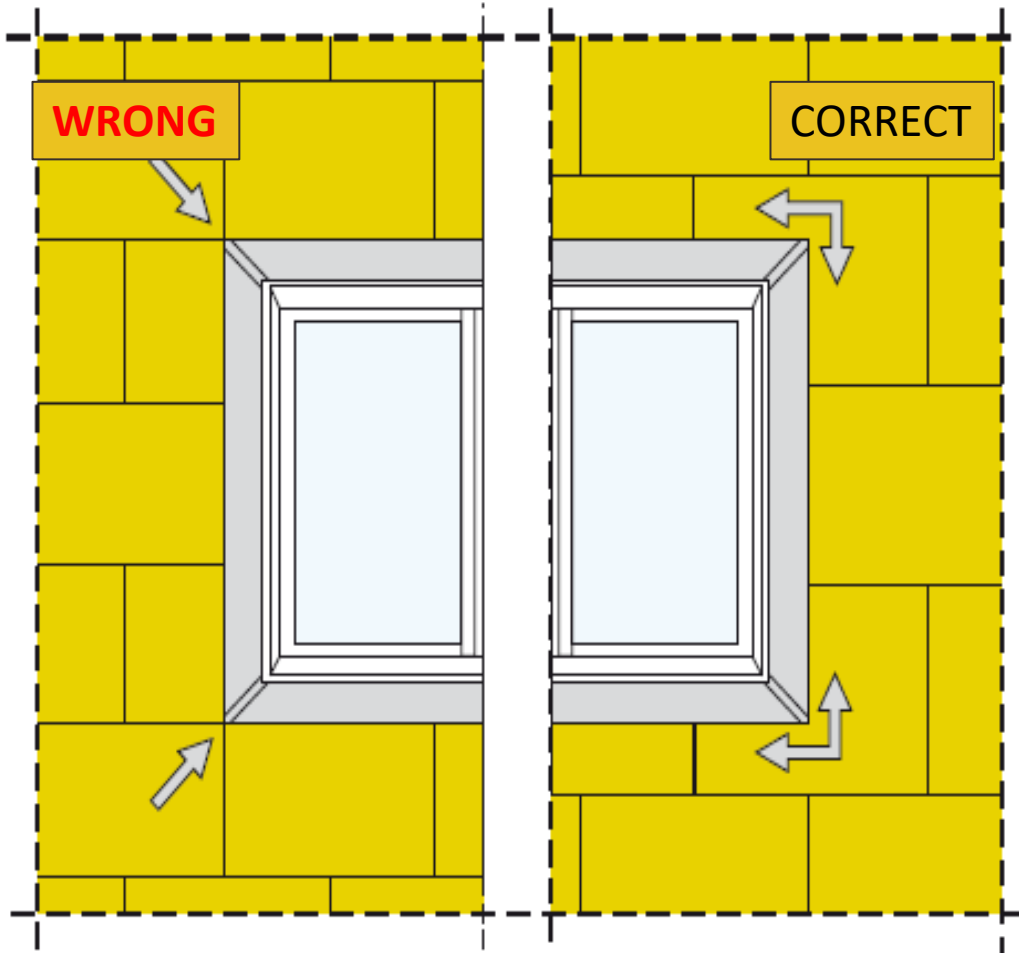
5. Finishing coat with primer and paint coating



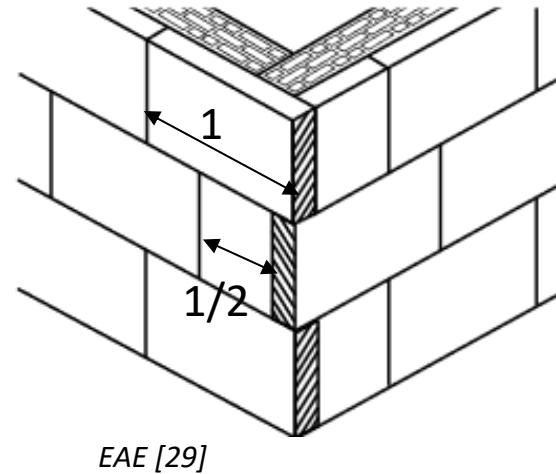
Each phase has its own specifics and it should be conducted respecting the professional guidelines!



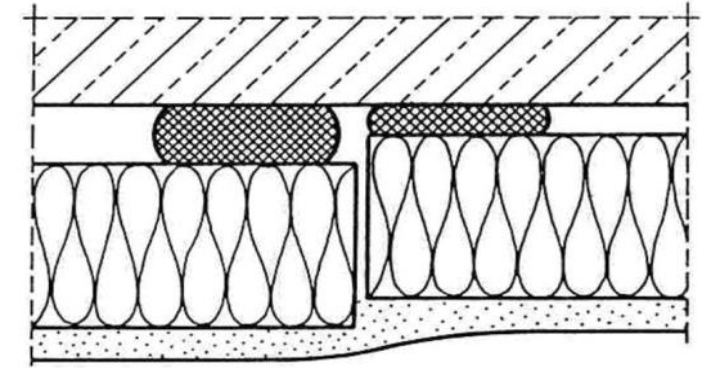
Bonding around windows, door and corners



HUPFAS [32]



EAE [29]



High risk of cracking (local strains).
 Grinding necessary (EPS and mineral
 wool lamella before reinforcing).
 Mineral wool boards are not grinded!

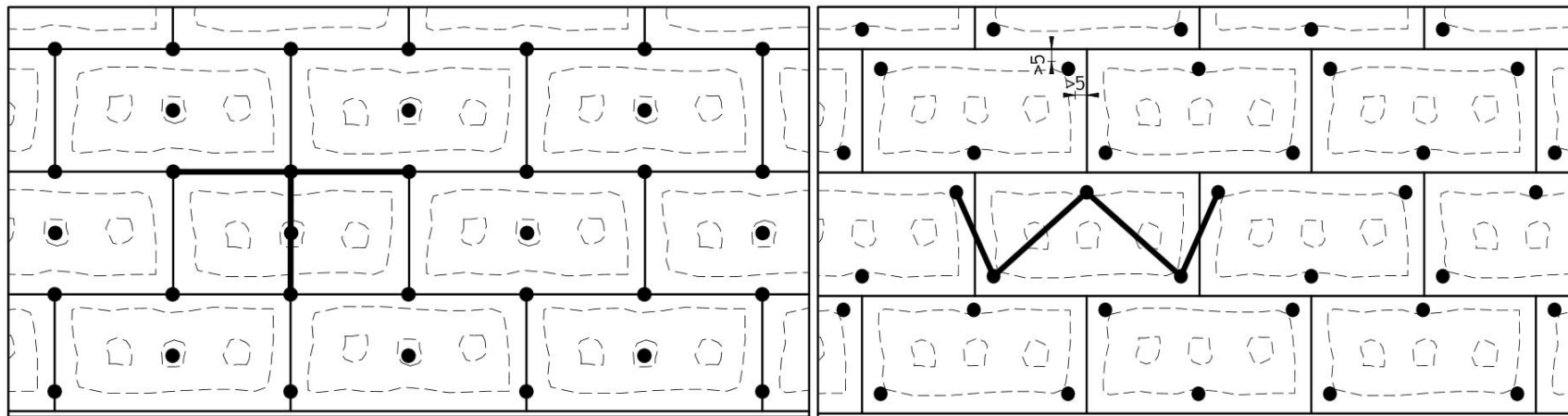
External thermal insulation: External walls



Anchors: how many and how to arrange them?

- 1) The number of anchors is determined by static calculations based on following parameters:
the wind zone, building height, the weight of ETICS system, substrate type, anchoring type...
- 2) When retrofitting existing buildings with substrate of questionable load capacity („pull-off” test)

T-scheme
EPS boards



W-scheme
**Mineral wool
boards**

HUPFAS [32]

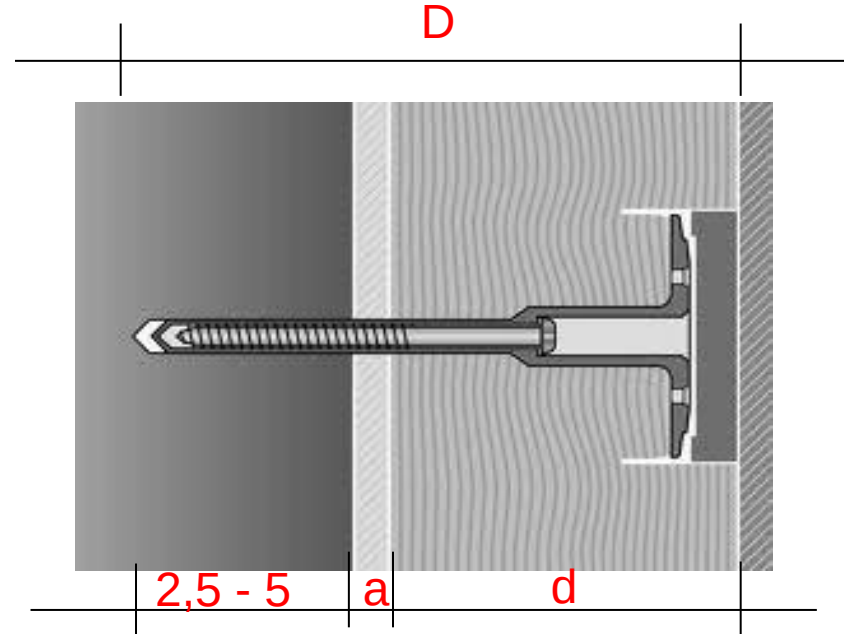
Anchors length calculation

$$\underline{D \text{ (cm)} = d + (2,5 \div 5) + a}$$

d = insulation thickness (cm)

+ (2,5 ÷ 5) cm, anchoring depth in substrate (depending on anchor producer)

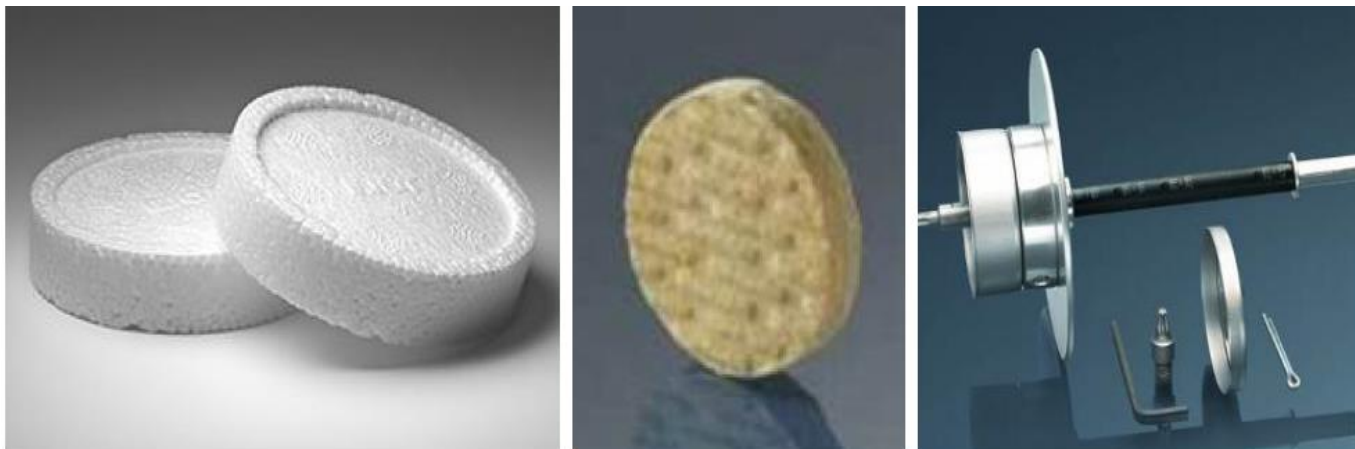
a = thickness of existing rendering and adhesive (cm)



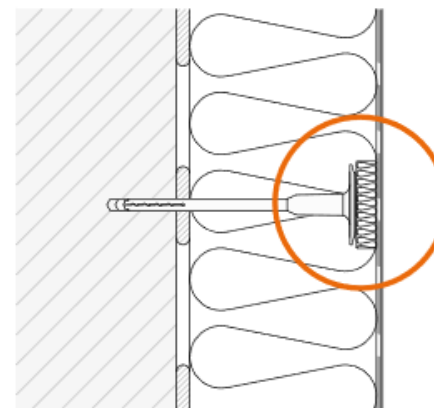
External thermal insulation: External walls



Anchor head countersunk into the insulation material



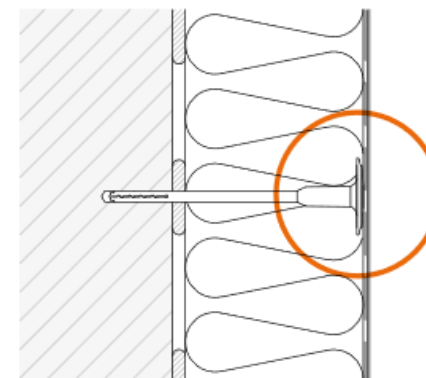
HUPFAS [32]



**MINIMIZED POINT
THERMAL
BRIDGES!**

EAE [29]

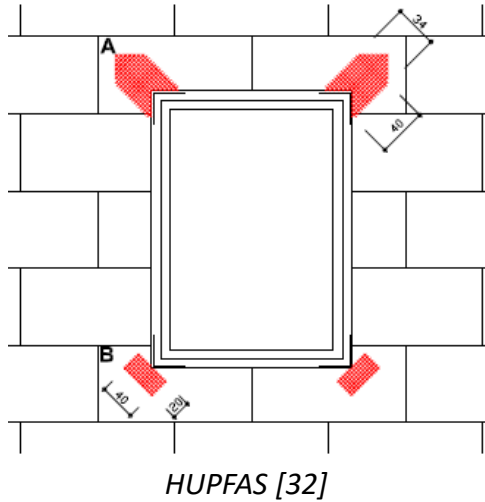
Anchor applied flush with the surface of the insulation material



External thermal insulation: External walls



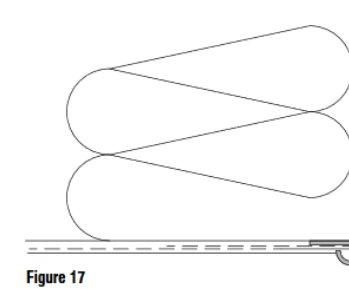
Diagonal reinforcements



Formation of edges, outer and inner corners



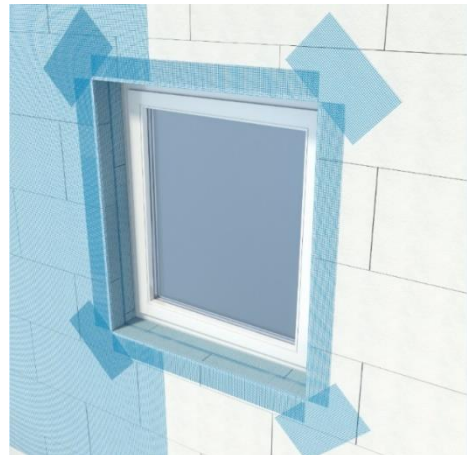
Formation of drip edges



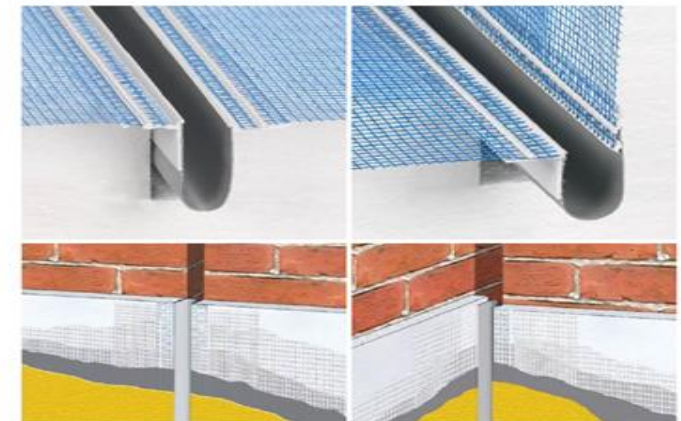
EAE [29]



Asb.sk [35]



Dilatations



Meister
Farben [36]

Critical details



Dosteba [37]



Don't forget the CONTINUITY of thermal envelope!

Lots of potential THERMAL BRIDGES that we need to address!

Selection of finishing coat

				
PLASTER:	Mineral	Silicate	Acrylic	Silicone
Water repellent	o	+	++	++
Vapour permeable	++	+	-	+
Dirt resistant	o	+	++	++
Elastic	-	o	++	+
Colour range	o	+	++	+

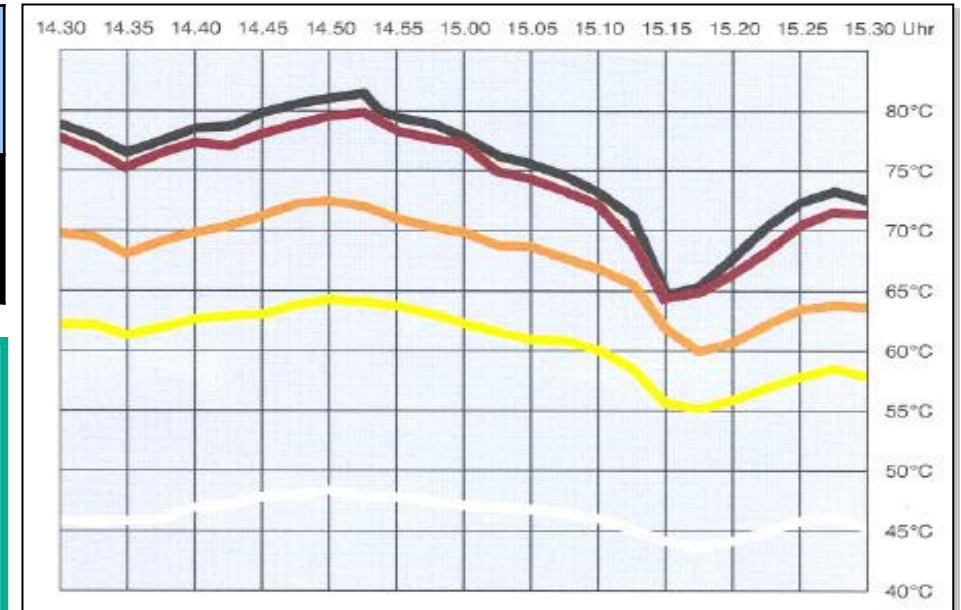
LEGEND: ++ very good + good o conditional good - poor

Colour of finishing coat

33°C	40°C	47°C
47°C	54°C	64°C

Dark colours are not recommended!!!

- | | |
|---------------------------------|-------------------------------------|
| •Acrylic and silicone plasters: | Light Reflectance Value $\geq 25\%$ |
| •Silicate plasters: | Light Reflectance Value $\geq 30\%$ |
| •Mineral plasters: | |
| Thin plasters (1,5 ÷ 4,0 mm): | Light Reflectance Value $\geq 50\%$ |



Construction damages on ETICS systems:

- **POOR WORKMANSHIP (90%):** each phase has to be carefully conducted!
- Low-quality and/or incompatible materials
- Working in inadequate conditions (rain, wind, low temperatures,...)
- Incompleted projects (without details or poor details)
- Absence of supervision in each phase of ETICS installation

Poor-practice examples....



Sabo, Ž. [38]



Škomrlj, D. [39]

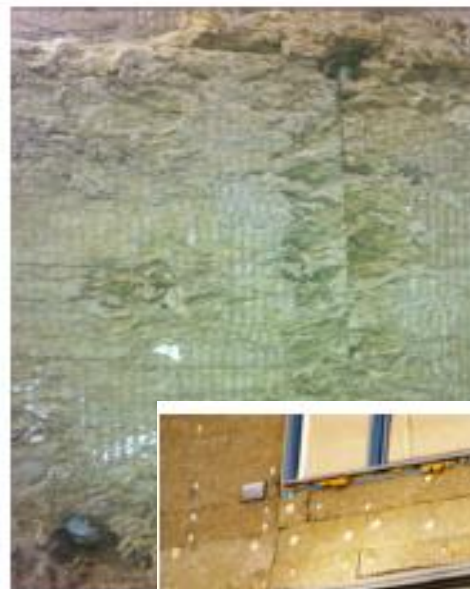
Poor-practice examples....



Škomrlj, D. [39]



Poor-practice examples....



**Damaged boards
should not be
used!!**



**Proper bonding
and anchors
should be used! As
well as anchoring
scheme!**



Poor-practice examples....



Gaps should be filled with the same insulating material, with the exception of a 3 mm narrow gaps (low-expansion polyurethane foam should be used)



Poor-practice examples....



sv-reckert [40]



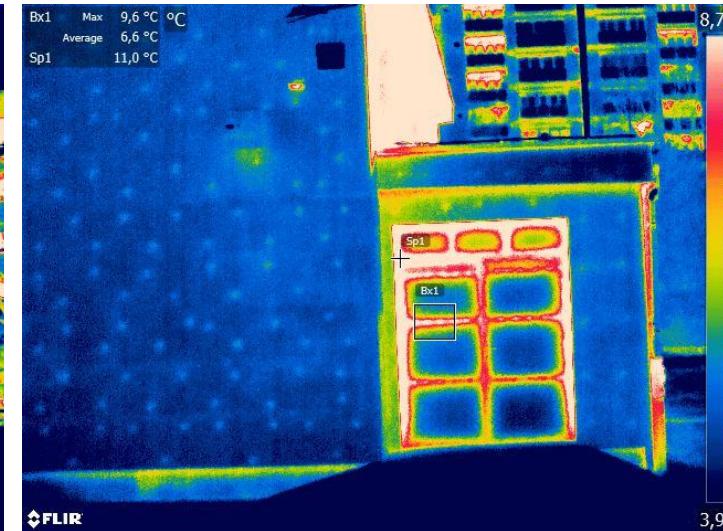
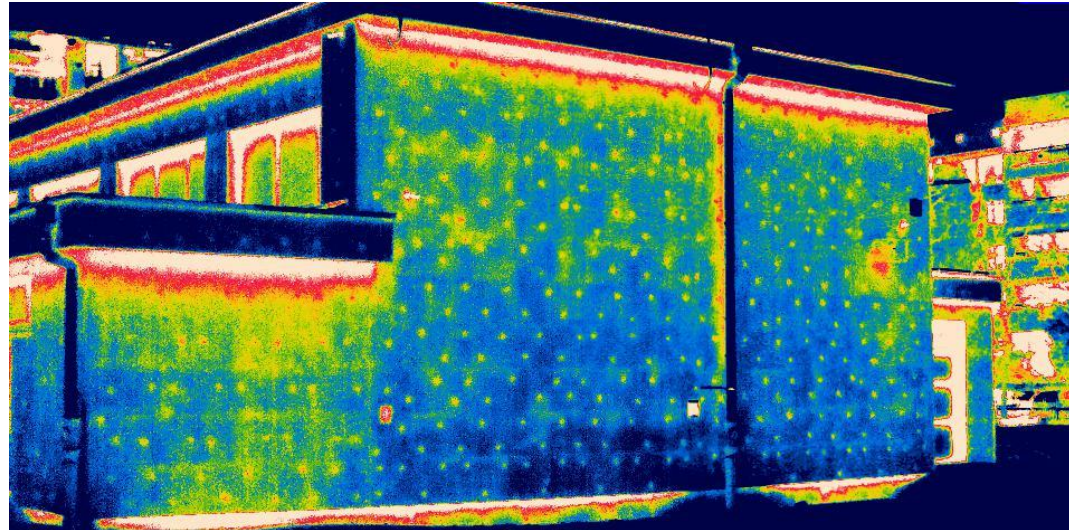
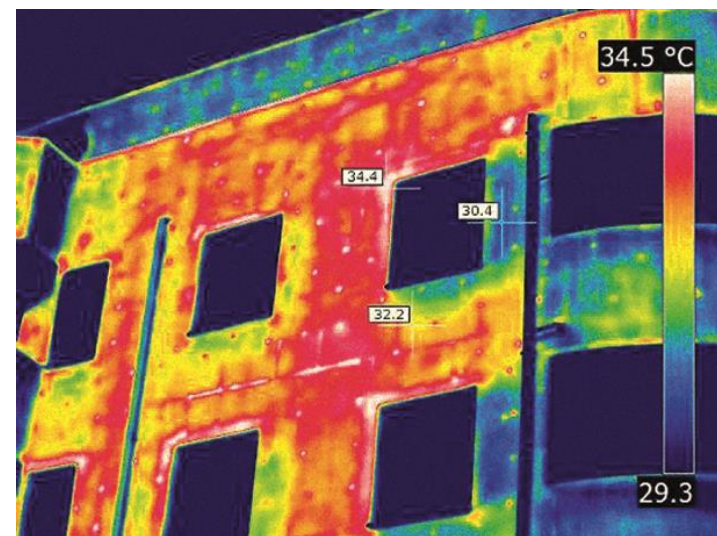
Diagonal reinforcement should be correctly installed!



External thermal insulation: External walls



What human eye can't detect, infrared can! (Quality control)



Hygrothermal requirements are fulfilled by using:

1) Roof membranes (air and moisture control)



2) Thermal insulation (thermal protection)



HUPFAS [32]
GUTEX [44]

3) Compressed tapes or coatings

Insulating pitched roof



Additional layer of thermal insulation above rafters



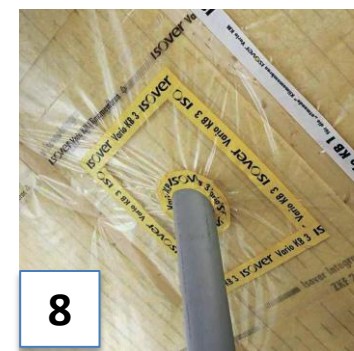
- 1) Installation of soft mineral wool between rafters
- 2) Extra layer of rigid mineral wool boards above rafters
- 3) Installation of watertight and vapour-permeable membrane
- 4) Overlapping and sealing of watertight and vapour-permeable membrane
- 5) Option: instead of rigid mineral wool boards additional layer of rigid PIR boards with integrated membrane can be installed or an open-to-diffusion natural material with no membrane – this can be proved through a dynamic hygrometric simulation

HUPFAS [32]

Insulating pitched roof



Additional layer of thermal insulation under rafters



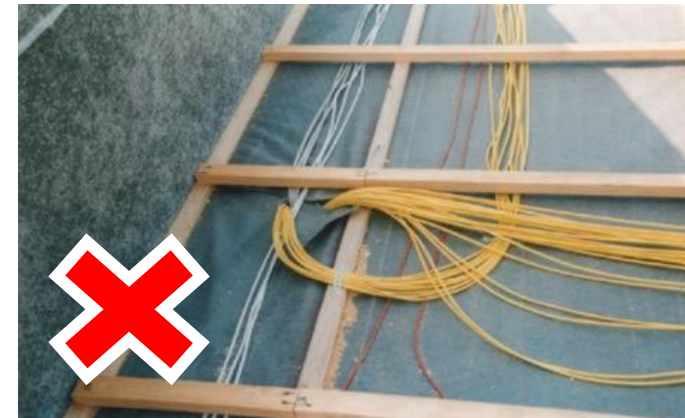
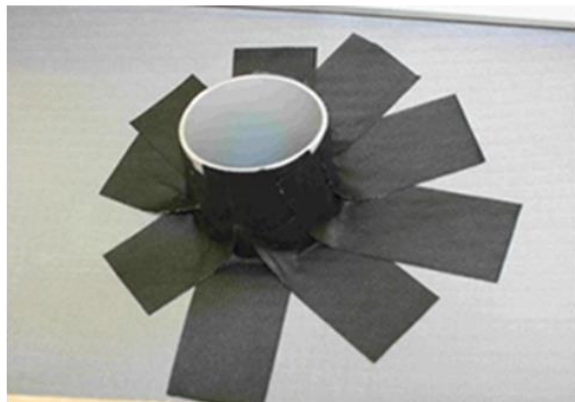
Moje potkrovlje [45]

Insulating pitched roof: reflective foils



skyTech [46]

Insulating pitched roof: details, details, details...



Moje potkrovlje [47]

All penetrations need to be properly sealed!



Insulating pitched roof: poor-practice examples



Westfalen-blatt [49]

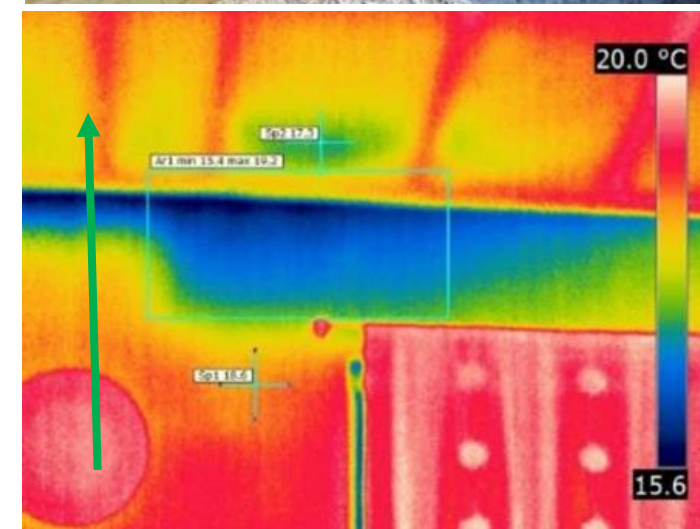
Moist and rot insulation
and timber roof structure



Energie-experten.org [50]



a24e [48]

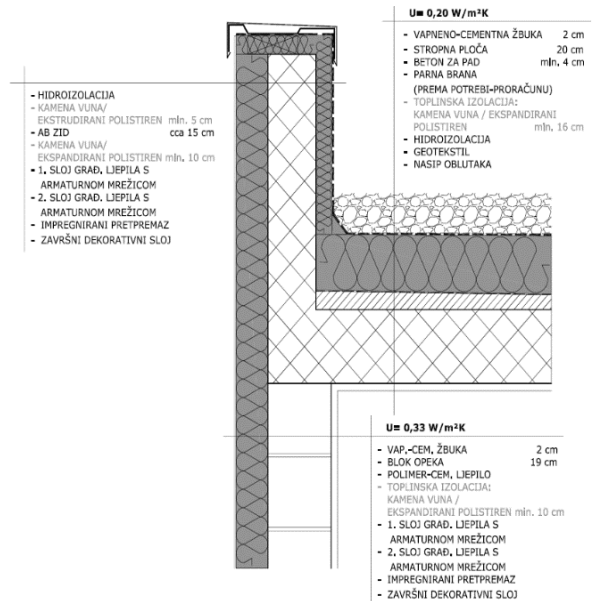
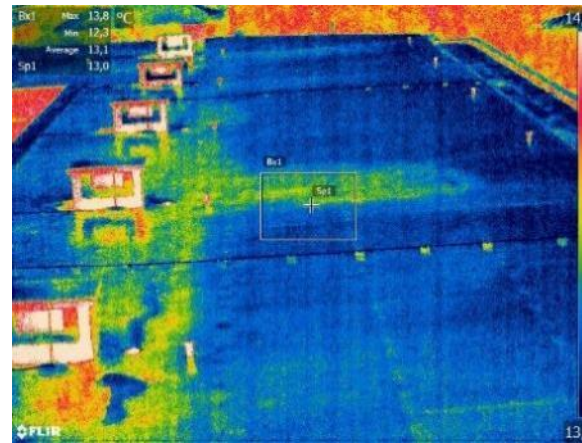
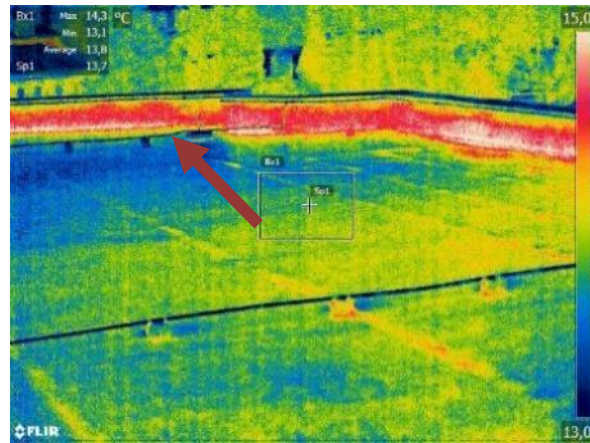


Insufficient thermal insulation between
rafters + no additional thermal insulation

Insulating flat roof



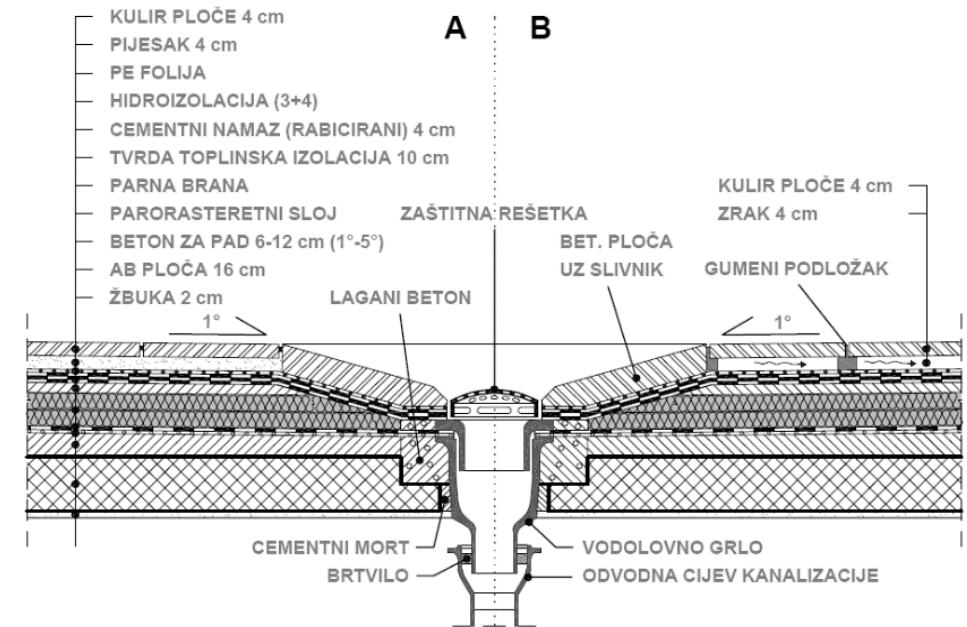
HUPFAS [32]



Insulating flat roof: avoiding construction damage



- 1) Proper installation of flat roof components and special elements. Following guidelines provided by producers.
- 2) Especially:
 - connection of waterproofing membrane with other flat roof components.
 - proper drainage
 - proper installation of vapour barrier
 - minimization of thermal bridges



Insulating flat roof: poor-practice examples

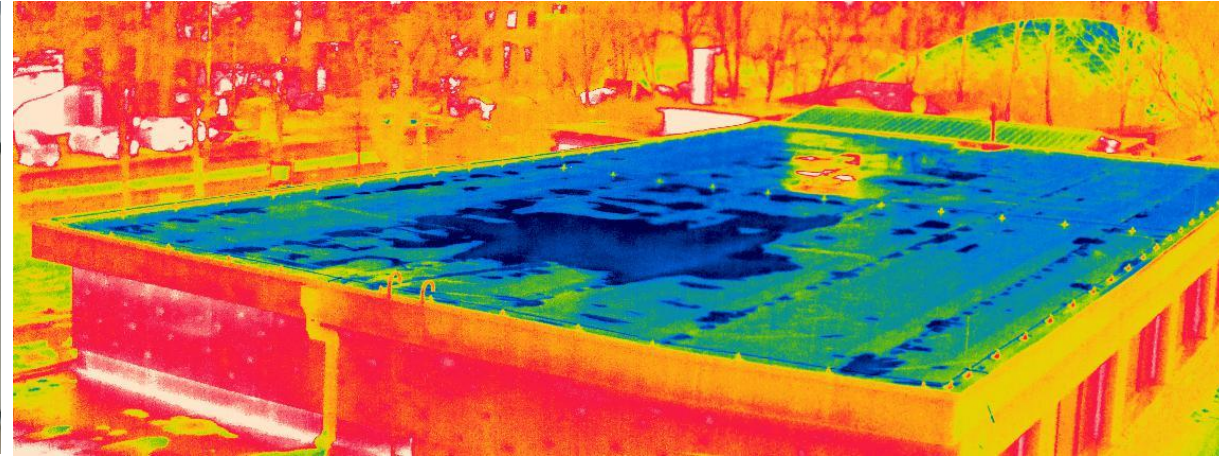


Clogged drain

FUNDA [51]



Damage of waterproofing membrane caused by UV radiation



Insufficient roof slope for adequate water drainage



Poor maintenance



Water leaks



Insulating flat roof: poor-practice examples



FIRE SAFETY!!

Selection of proper
thermal insulating
materials and
waterproofing
membranes!!



Zagreb.info [28]



Ćosić, B. [52]



Blog.dnevnik.hr [53]

Insulating flat roof: “green roofs”



Extensive green roof



Bauder [54]

1. Vegetation
2. Growth substrate
3. Filter layer
4. Accumulation and drainage layer
5. Protection layer and root barrier
6. Splitting layer

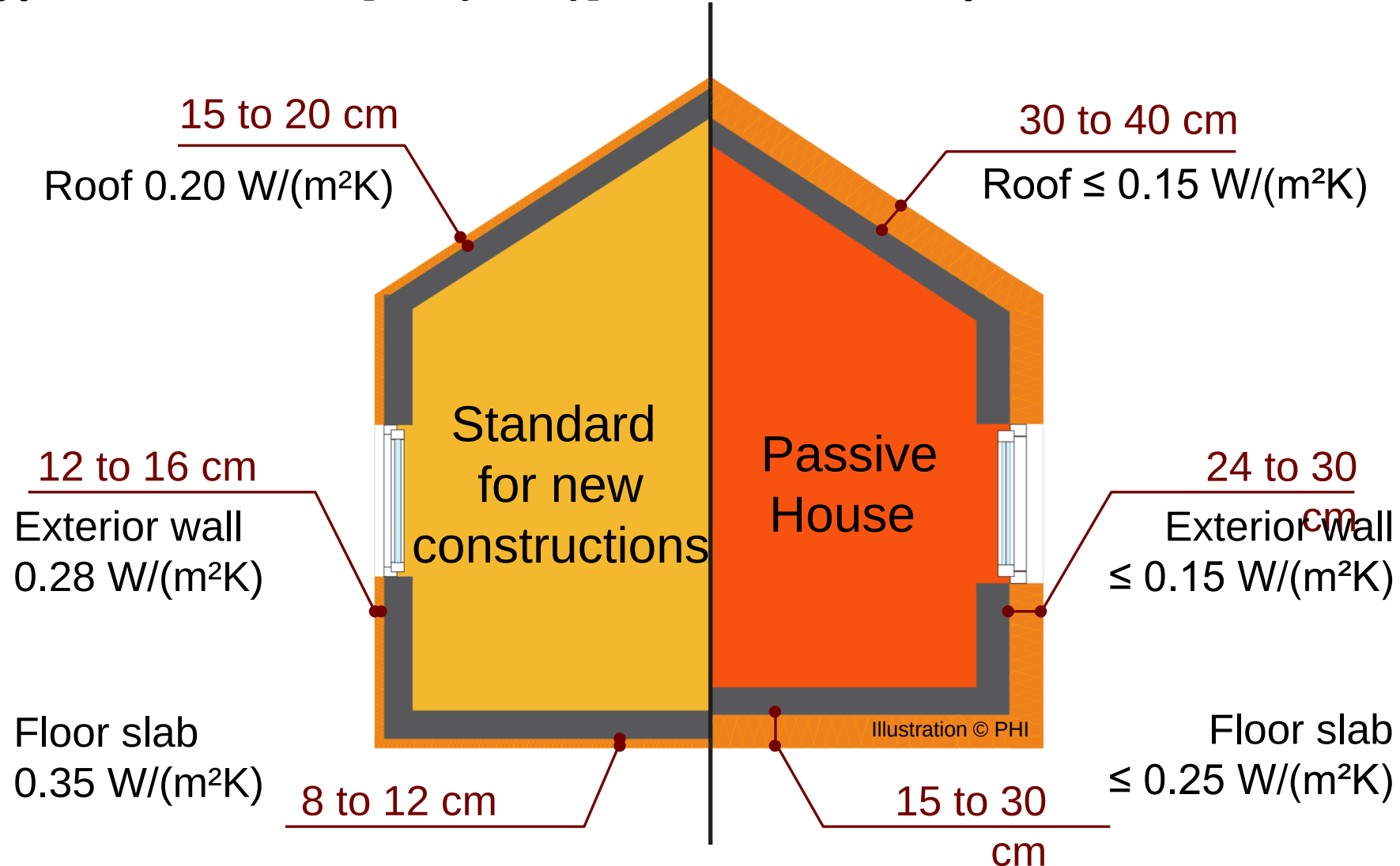
Intensive green roof



External thermal insulation



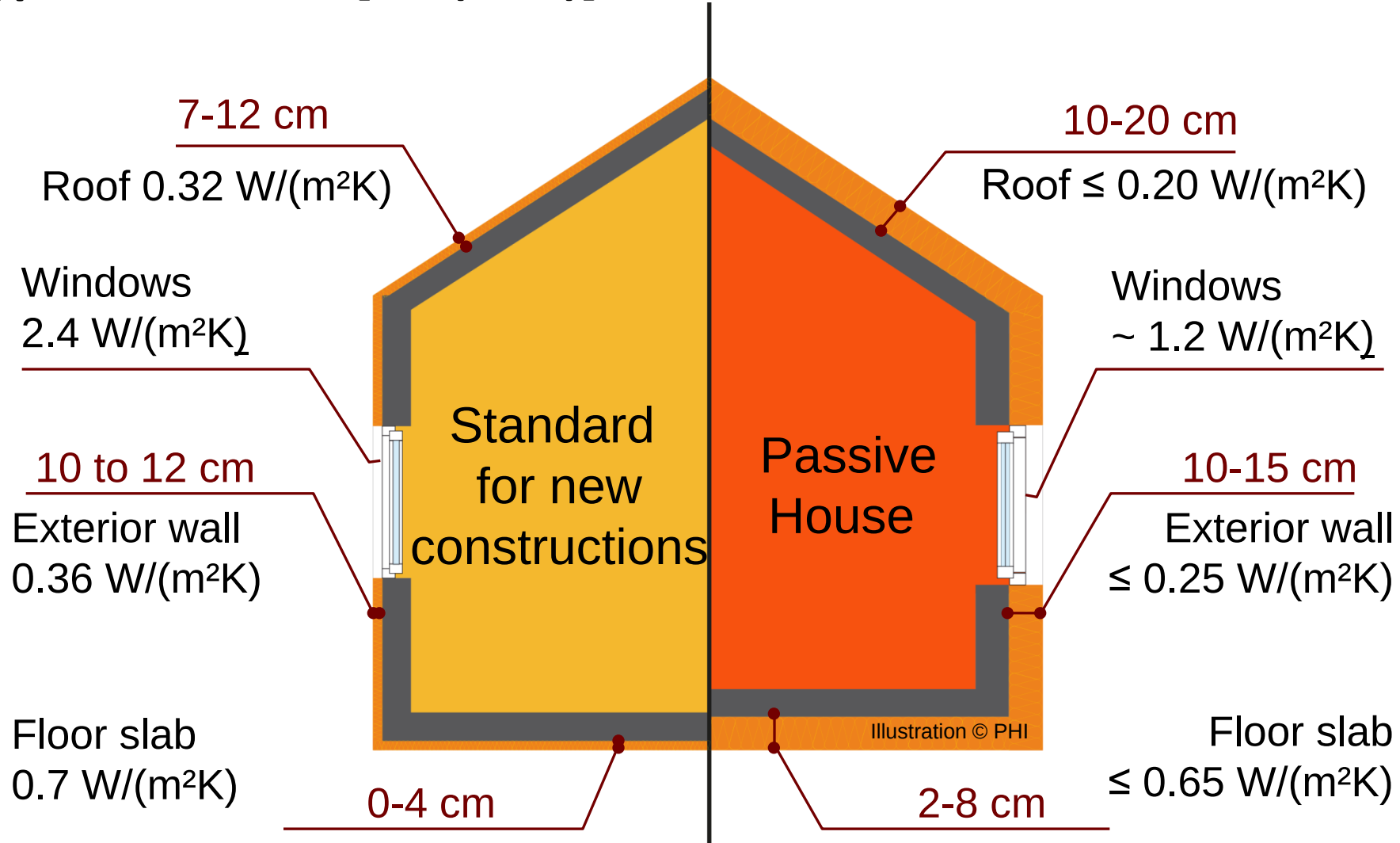
Typical U-values [$\text{W}/(\text{m}^2\text{K})$] in central Europe



Source: CPHT Course

External thermal insulation

Typical U-values [$\text{W}/(\text{m}^2\text{K})$] in Mediterranean climate



Source © ZEPHIR Passivhaus Italia: $f_T = 0.5$, reference climatic zone: Rome, $A/V = 0.9$

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.

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