Thermography as a main tool in analysis of thermal bridges effects

asst.prof. Bojan Milovanović

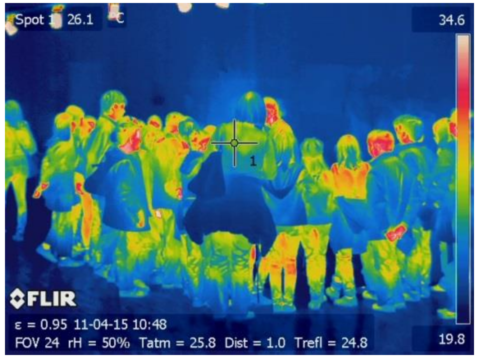
SVEUČILIŠTE U ZAGREBU
GRAĐEVINSKI FAKULTET
UNIVERSITY OF ZAGREB
FACULTY OF CIVIL ENGINEERING

INFRARED THERMOGRAPHY

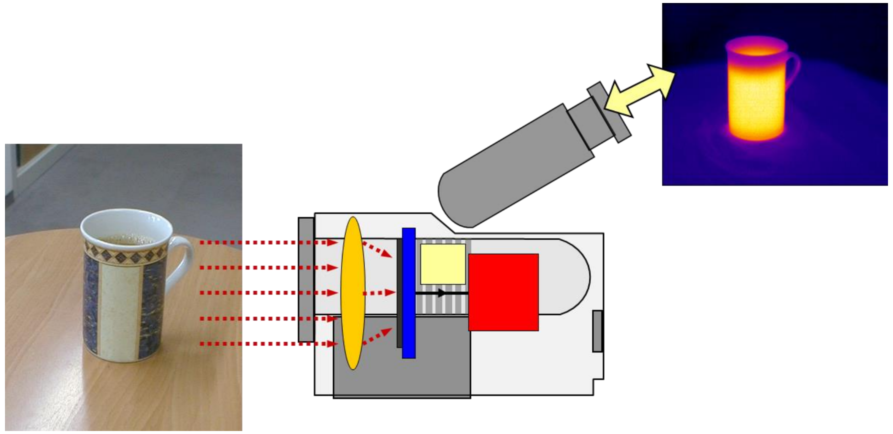
Introduction – IR thermography

Infrared (IR) thermography is a noncontact method of measuring temperature changes across the surface of the observed object.

- It is based on the measurement of the IR radiation intensity which is being emitted from the object.
- The camera converts invisible infrared radiation into a visible image.
- in the form of temperature field by usind Stefan-Boltzmann law for real bodies



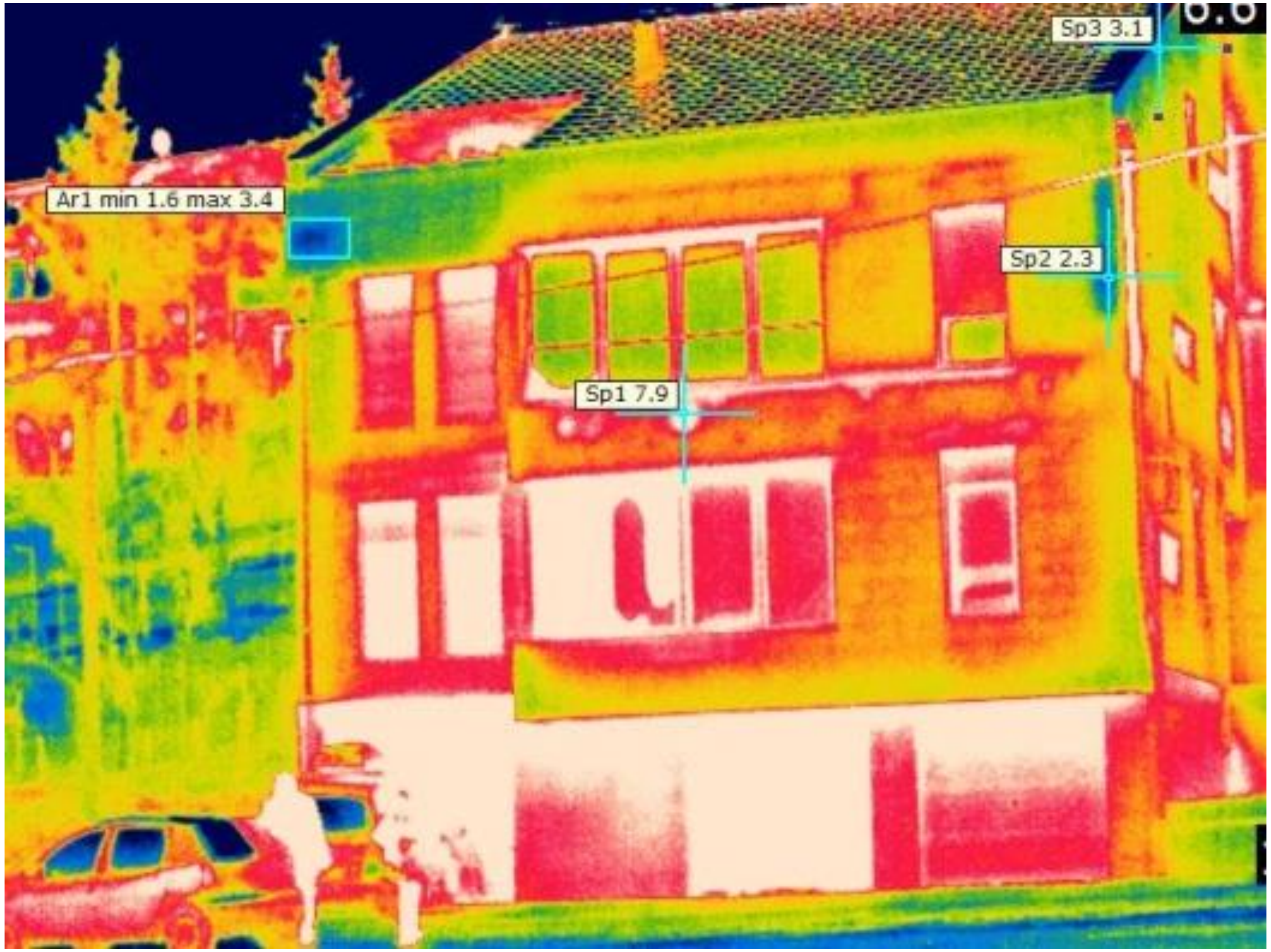
$$W_{uk} = \varepsilon \cdot \sigma \cdot T^4$$

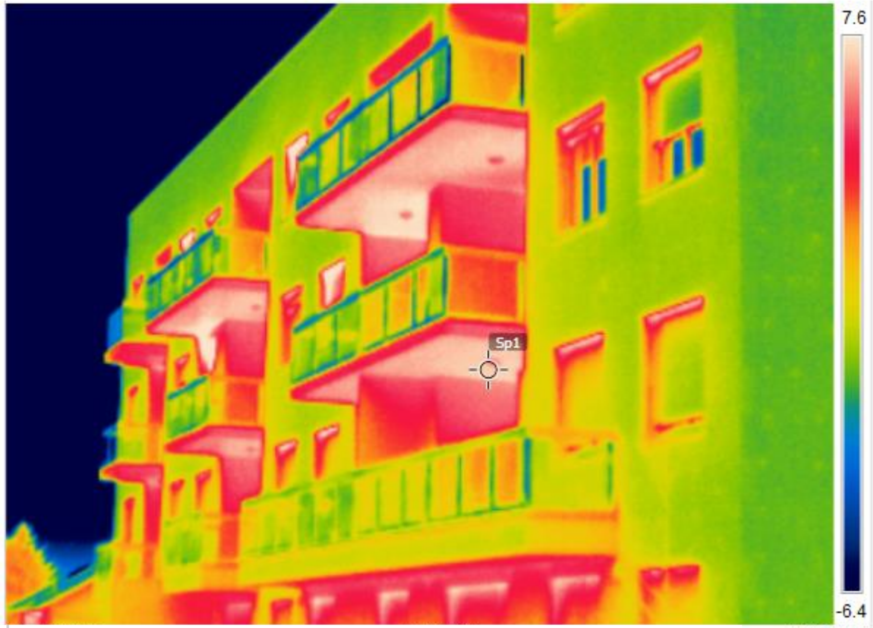


Thermogram

- Usual depiction of IRT results
  - Image depicts the incident radiation on the IR detector.

- Thermogam is visual representation of temperature changes on the surface
  - ONLY when relevant calculations and compensations are performed with detected radiation





IR_0267.jpg FLIR E60 49037646

Measurements	°C
Sp1	7.1

Parameters

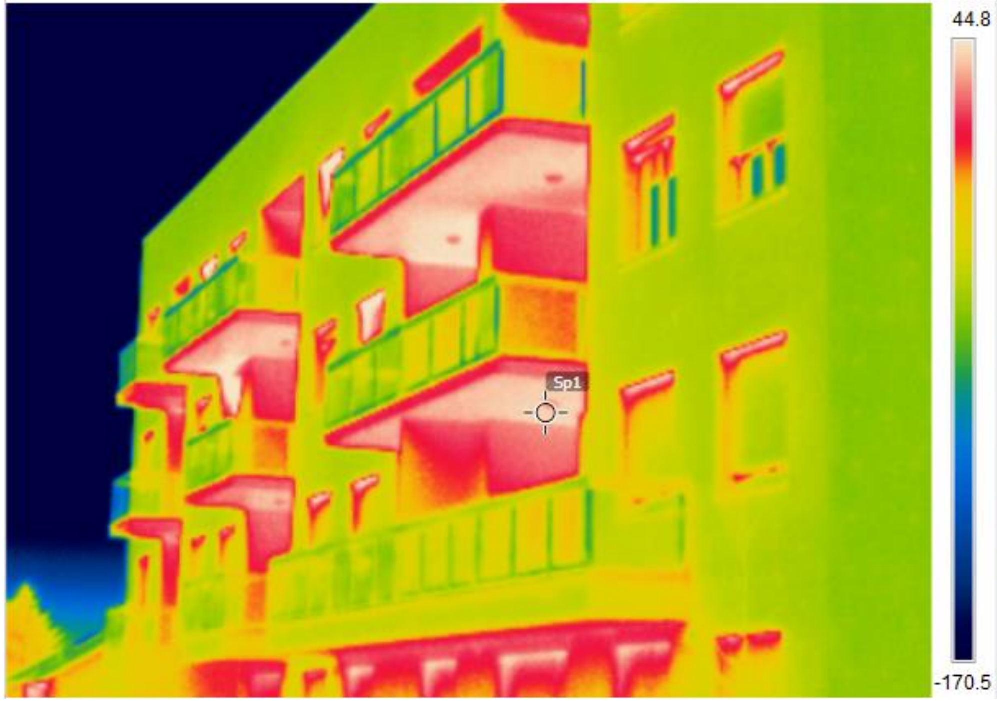
Emissivity	0.95
Refl. temp.	5 °C
Distance	20 m
Atmospheric temp.	10 °C
Ext. optics temp.	20 °C

IR_0267.jpg FLIR E60

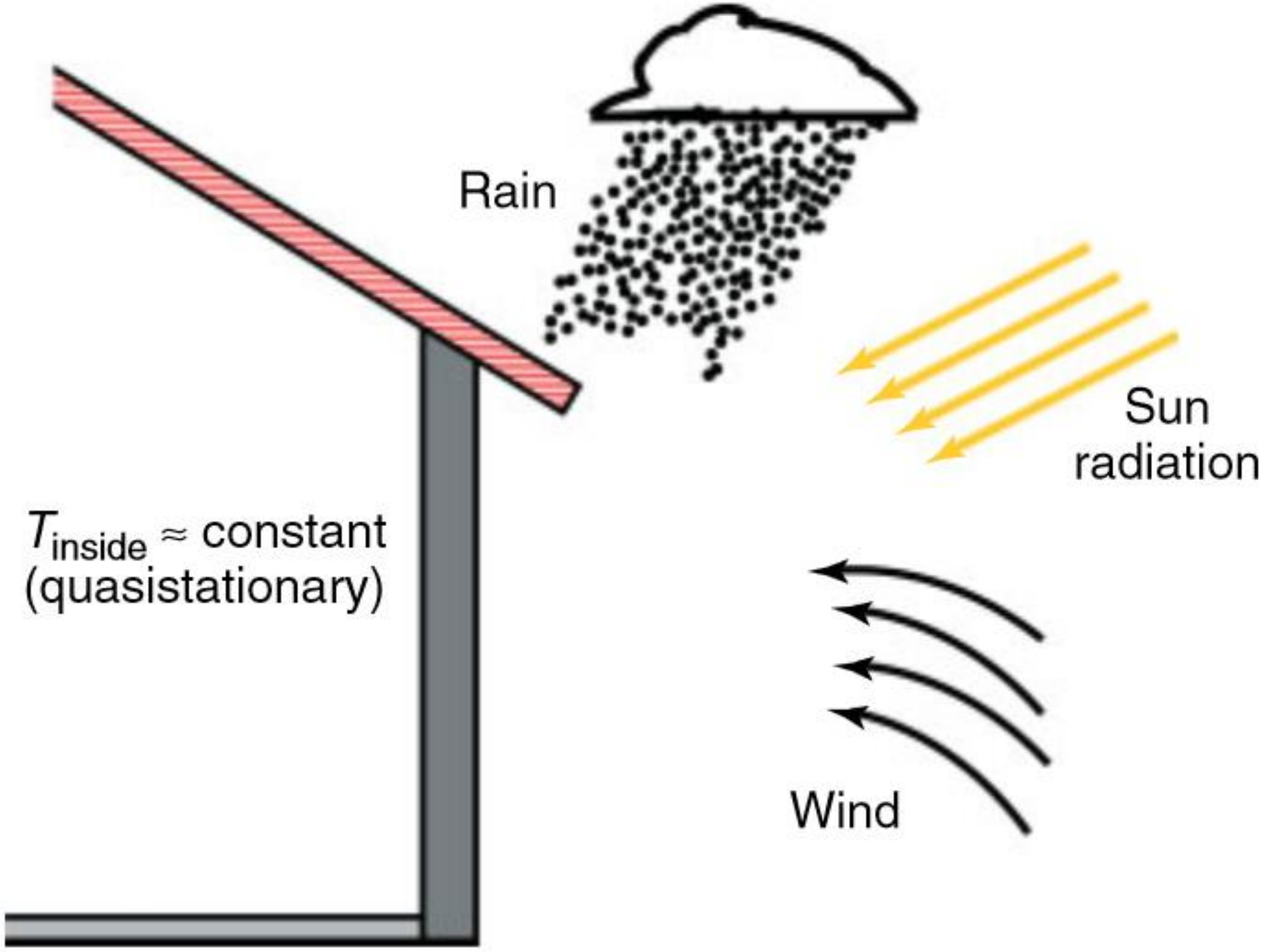
Measurements	°C
Sp1	39.0

Parameters

Emissivity	0.05
Refl. temp.	5 °C
Distance	20 m
Atmospheric temp.	10 °C
Ext. optics temp.	20 °C



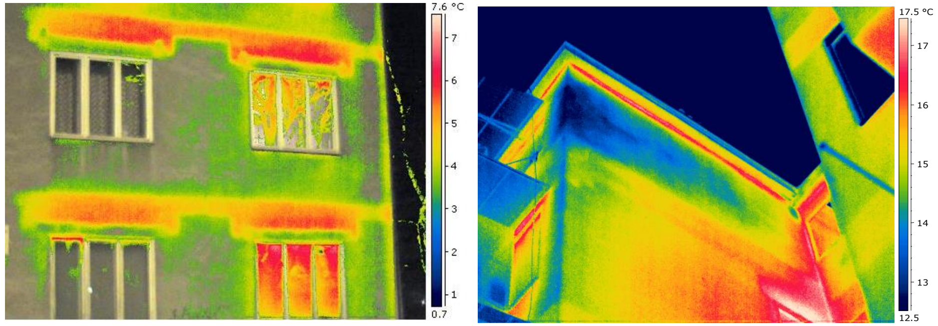
Measurement „context” is very important



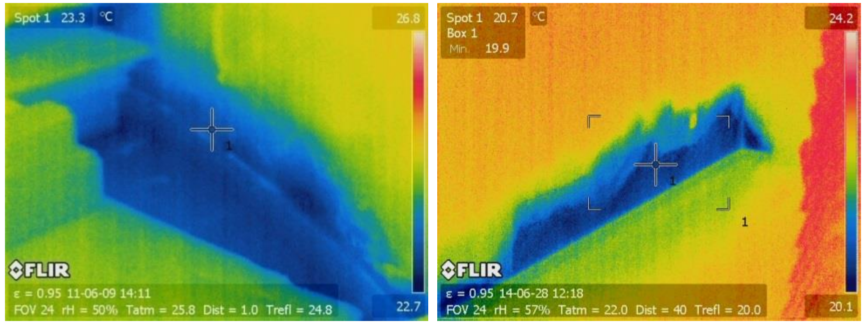
IR thermography in buildings

- Often used for:

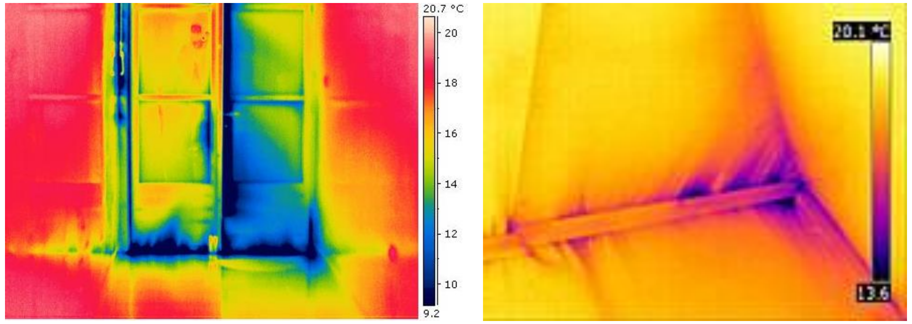
Detecting heat losses



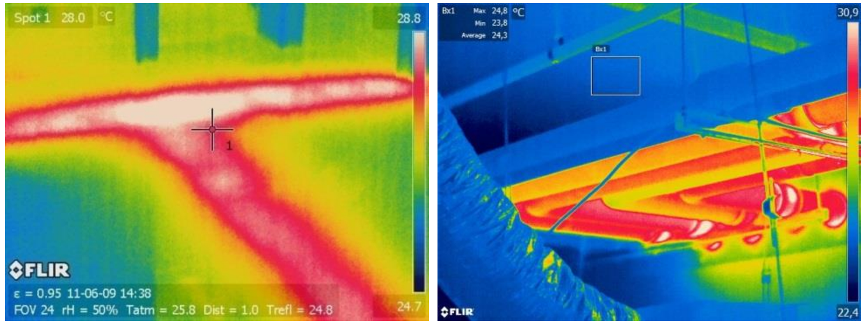
Detecting water leackages



Detecting air infiltrations

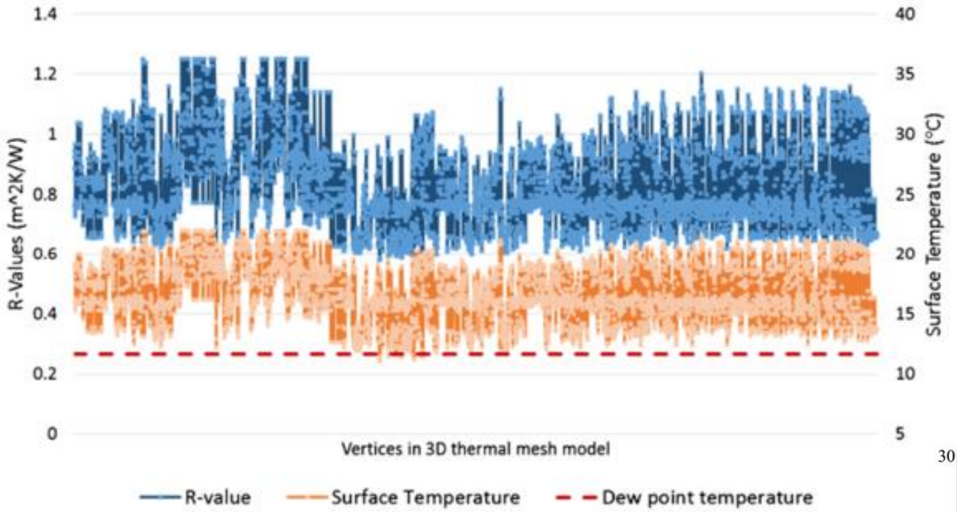


Control of HVAC systems



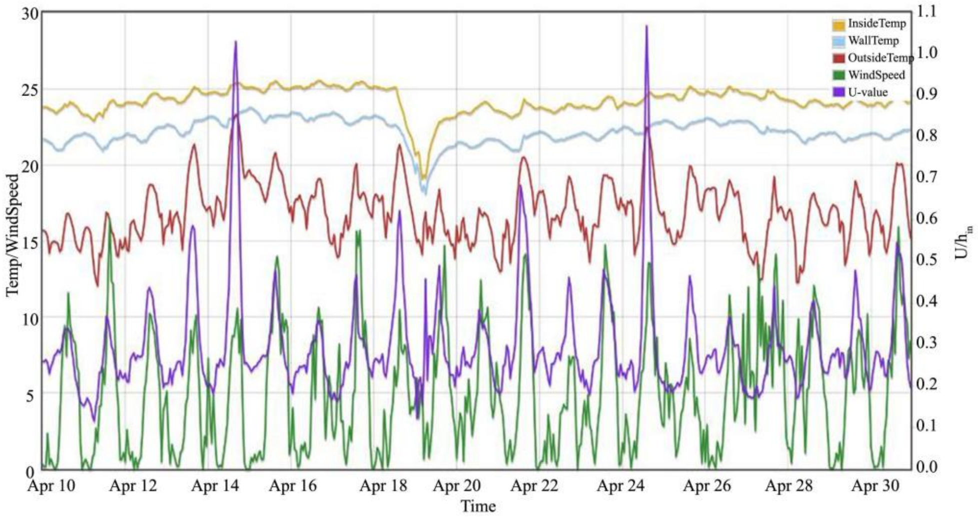
U-value using IRT

- Surface temperature and thermal resistance (R-value) of concrete blocks wall.



Source: Ham and Golparvar-Fard Visualization in Engineering 2014, 2:12

- Temperature and U-value of a brick wall.



Source: Sakkas et al. Non Intrusive U Value Metering, Open Journal of Energy Efficiency, 2015, 4, 28-35

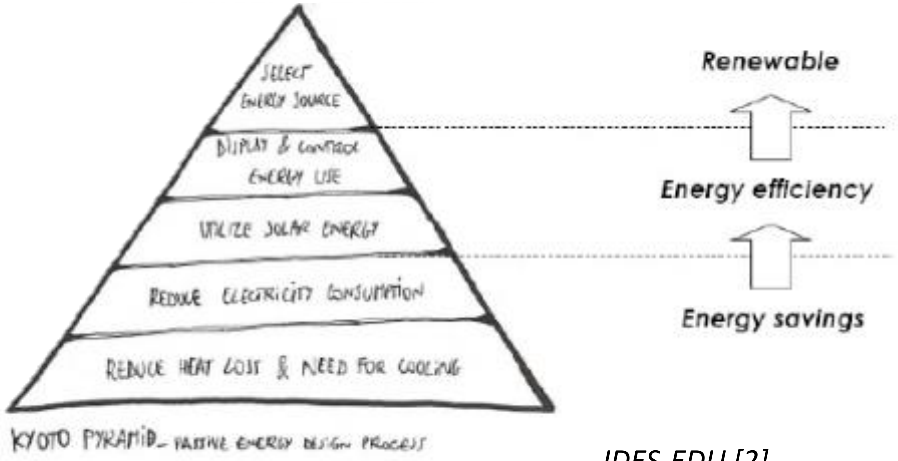
THERMAL ENVELOPE

Building envelope

Priciples of designing nZEB buildings and retrofitting to nZEB standard

Park City [1]

Building shape, zoning of room categories. **Well insulated and tight building envelope without thermal bridges.** Efficient heat recovery of ventilation air. Renewable sources of energy.



IDES-EDU [2]

COHERENCE OF MEASUERES in design and Step-by-step renovation approach

Thermal envelope

Requirements for thermal envelope

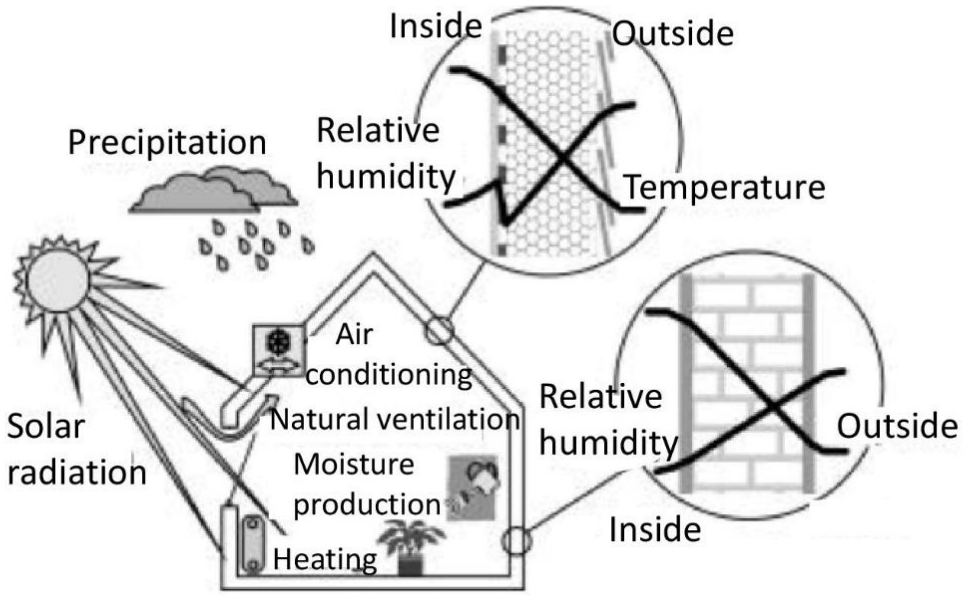
1) Quality of construction: good workmanship → damage free
2) Fire safety
3) Thermal bridges minimized
4) Airtightness ensured
5) Moisture-safe:
    - Control of water vapour diffusion (diffusion-impermeable and diffusion-permeable solutions) & Bulk-water run-off

WIDE RANGE OF THERMAL INSULATION MATERIALS AND SYTEMS AVAILABLE ON THE MARKET!

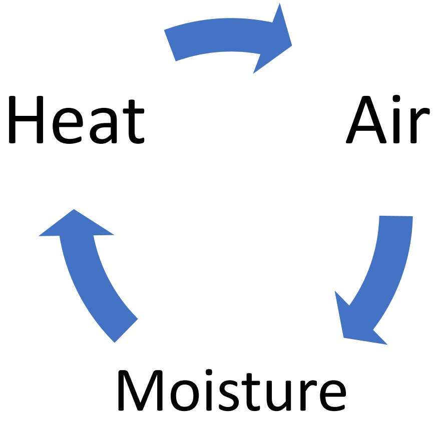
The proper selection and application depends from case to case (exterior or interior insulation, fire safety requirements, water presence etc.)!

Thermal envelope

Is thermal aspect of building envelope sufficient?



Holm, A. et al. [12]



Heat

Air

Moisture

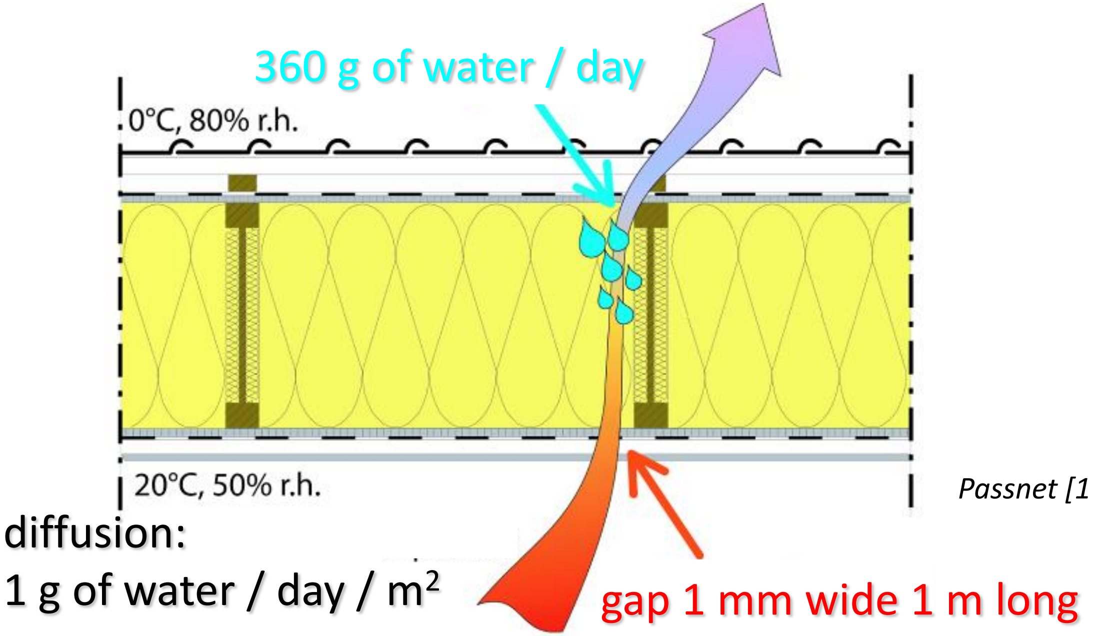
HYGROTHERMAL PERFORMANCE OF BUILDING ENVELOPE!

KEY GOAL: ensure **OPTIMAL** hygrothermal performance

- Prevent or reduce moisture entry into construction and ensure sufficient drying capacity → **moisture-safe and damage-free design**.
- Ensure **designed thermal performance** (U-value) of building components and **thermal comfort** in buildings.
- **Healthy indoor environment**.

Thermal envelope

Water vapour transport vs. Leakage in the Vapour barrier



Passnet [17]

Warm humid air goes into the insulation, condenses at cold zones (in case of dew-point temperature) in the construction and causes moisture damage.

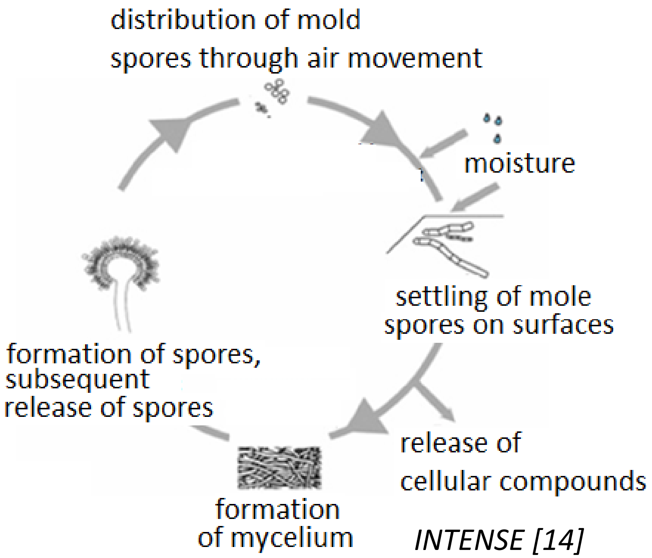
Air flow through leaks and thus also vapour flow, is 30 times greater at a 1 mm wide gap (leakage) than through diffusion per square meter.

NOTE! **Not all leaks necessarily lead to moisture damage.**

Thermal envelope

What if building envelope solution is not moisture safe?

dspInspections [13]



INTENSE [14]

1) Mould growth is directly linked with indoor air humidity and surface temperature. The lower the surface temperature of the wall, the moister the surface of the building component.
2) Mould spores are natural allergens. After repeated contact they can trigger allergies in susceptible people

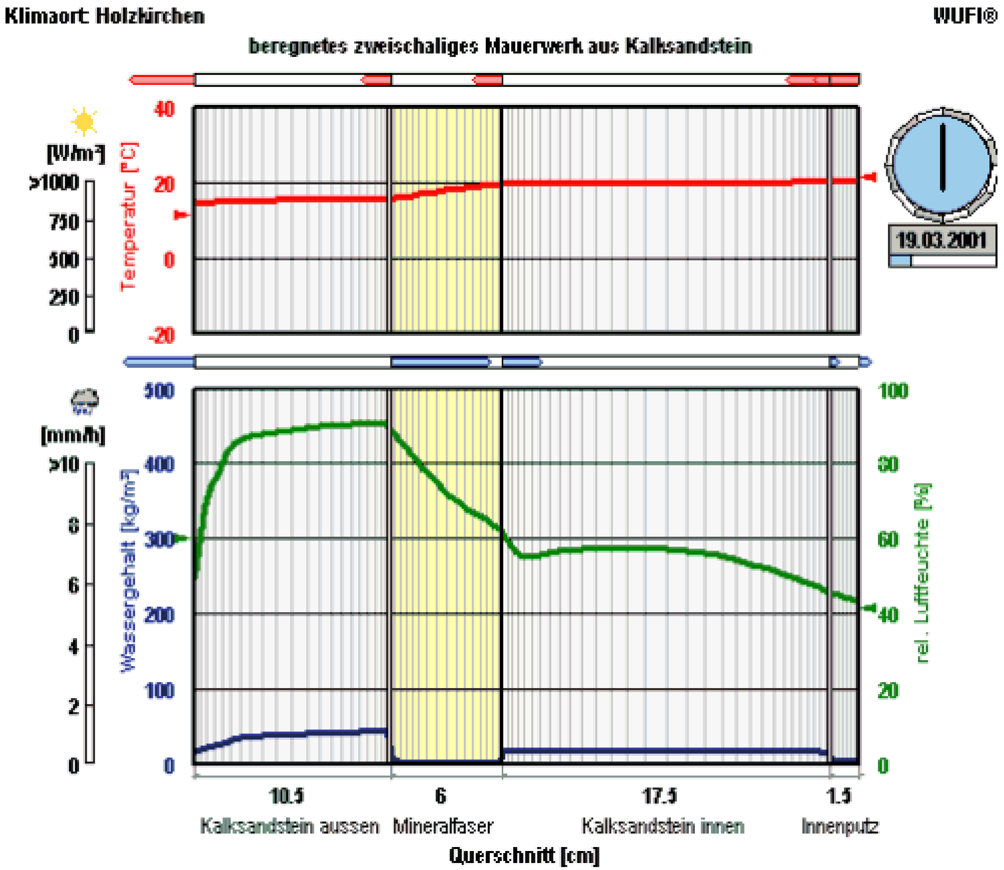
Assessment of hygrothermal performance

How to assess overall hygrothermal performance of building components?

Dynamic methods – HAM (Heat, Air and Moisture) models (transient calculations)

Especially it is important to assess hygrothermal performance of:

- New materials and systems being developed
- Building envelopes going through deep energy renovation
  - change of existing dynamic hygrothermal equilibrium
- Designing new high-performing building envelopes



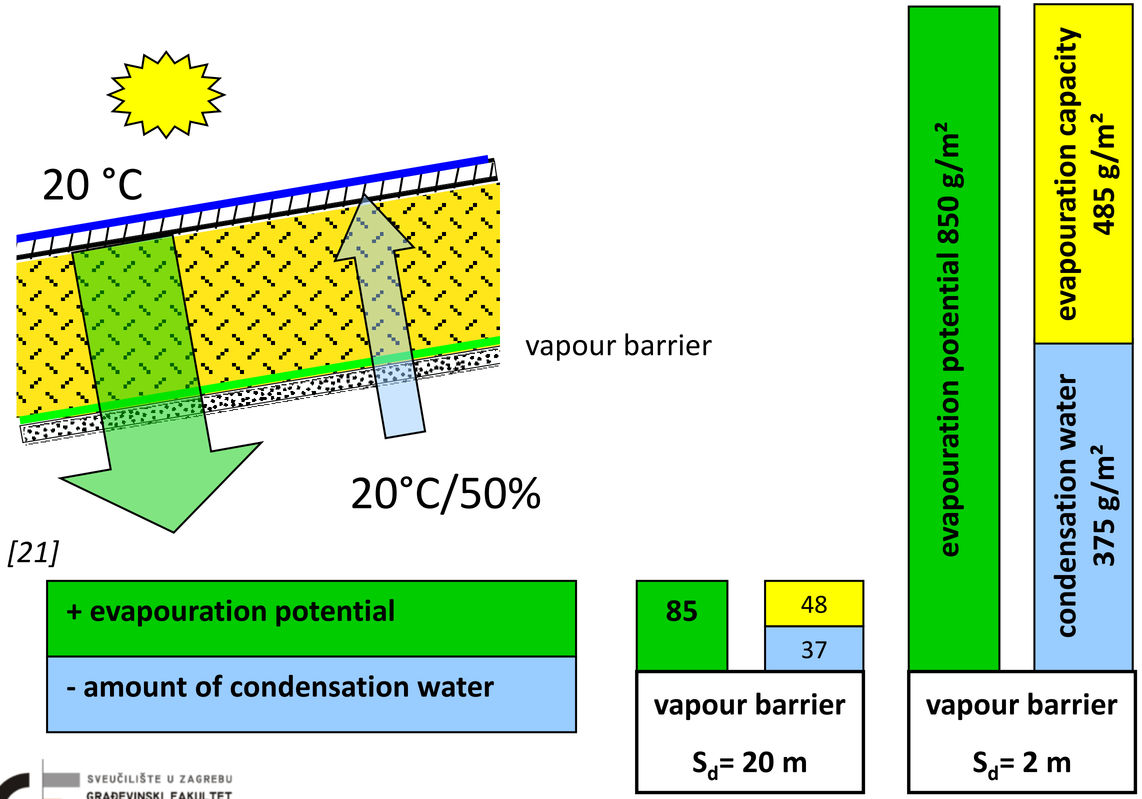
WUFI [25]

Thermal envelope

Balance vapour-tightness and drying/evaporation capacity

Vapour-tight on the outside! But also on the inside?

The heating of the roof surface due to the sun's radiation leads to increased diffusion of the condensation water back into the interior.



INTENSE [21]

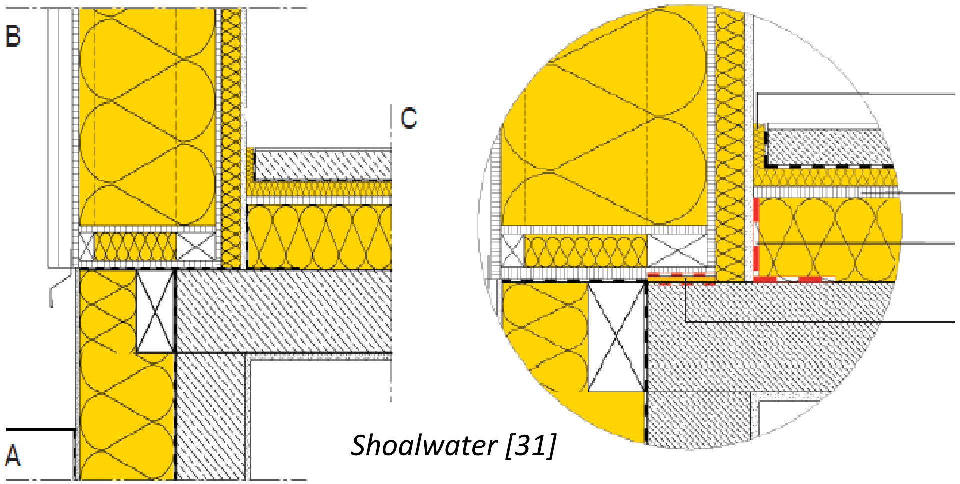
HAVE IN MIND:

If exterior is vapour tight, then…

- **interior membrane is as tight as necessary** (to limit amount of condensation water)
- **interior membrane is as open as possible** (to achieve high evapouration capacity).

Wooden structures

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**.
4) **Control diffusion of water vapor**



Sound insulating strip

Chipboard for uniform load distribution

Sealing tape, sealed airtight

Adhesive tape

Shoalwater [31]

Detail of connection wall – floor above unheated basement

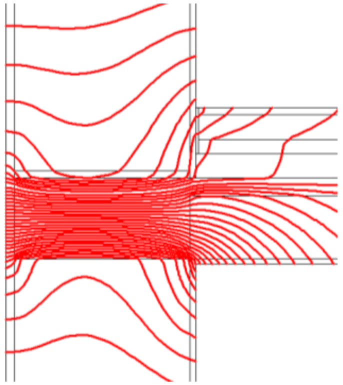
Salopek, D. et. al [30]

Perimeter insulation of concrete foundation

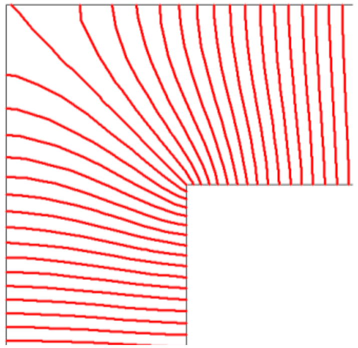
THERMAL BRIDGES

Thermal bridge

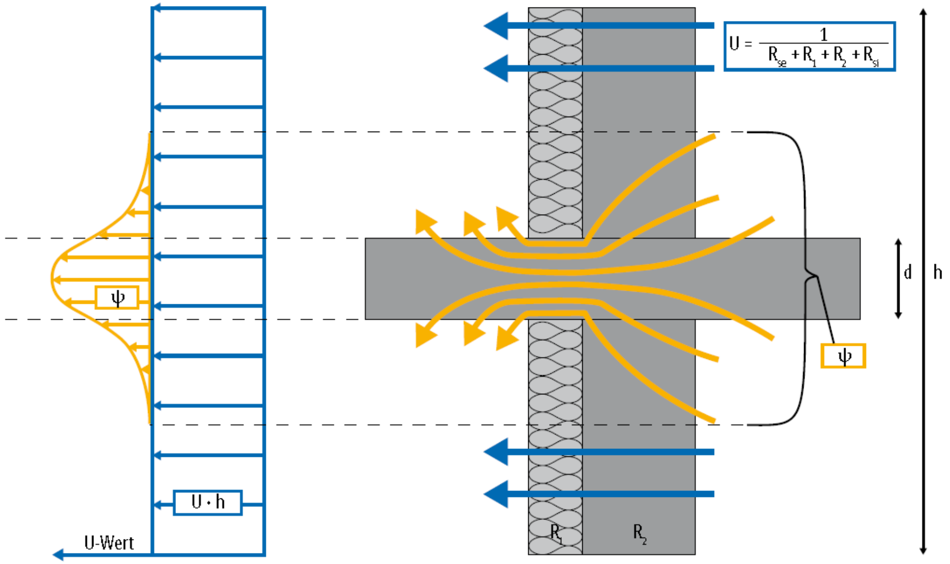
- A thermal bridge is an area of a building construction which has a significantly higher heat transfer than the surrounding materials. It occurs because of change in material, change in thickness and change in geometry of the building element.



Source: B. Milovanović [3]



Source: B. Milovanović [3]

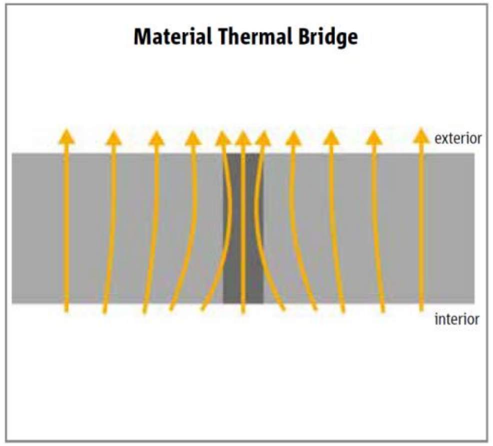


Source: Schöck Ltd [4]

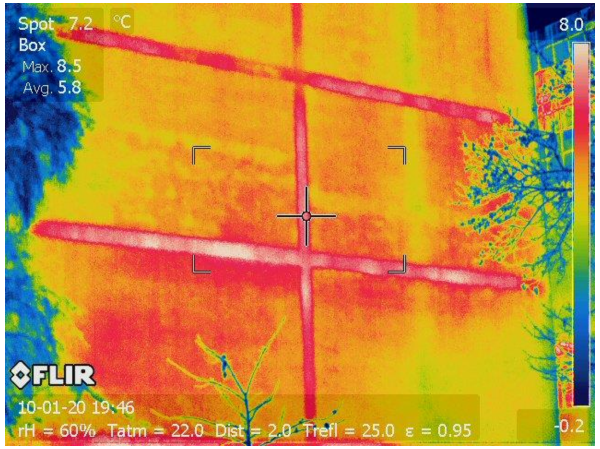
Types of thermal bridges

1) Material thermal bridge

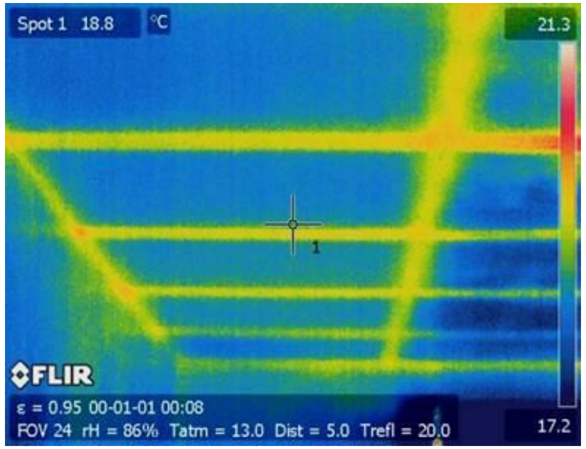
- The most obvious kind of thermal bridge occurs when a thermally conductive element passes through an insulating layer.
- A typical example would be anchor bolts penetrating a layer of insulation.



Source: Schöck Ltd [4]



Source: B. Milovanović [3]

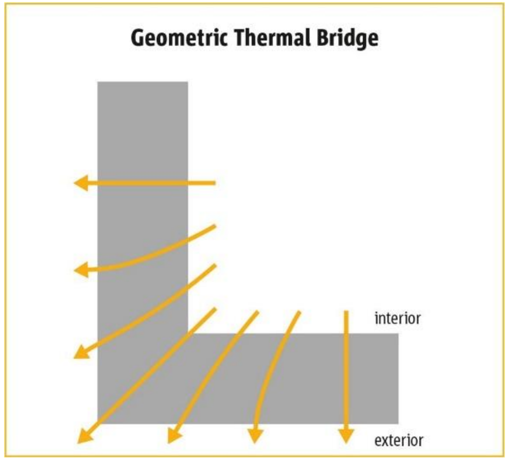


Source: B. Milovanović [3]

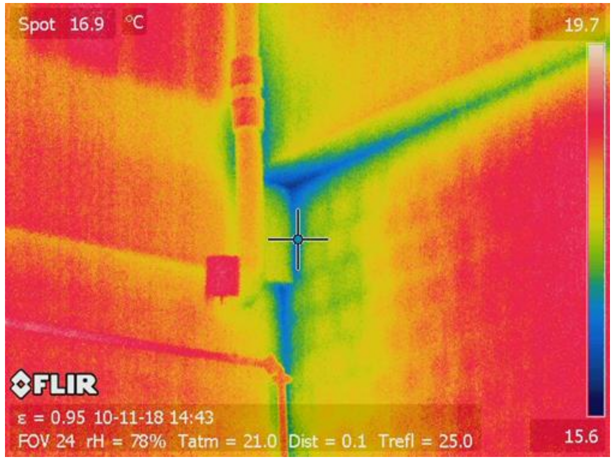
Types of TB

2) Geometric thermal bridge

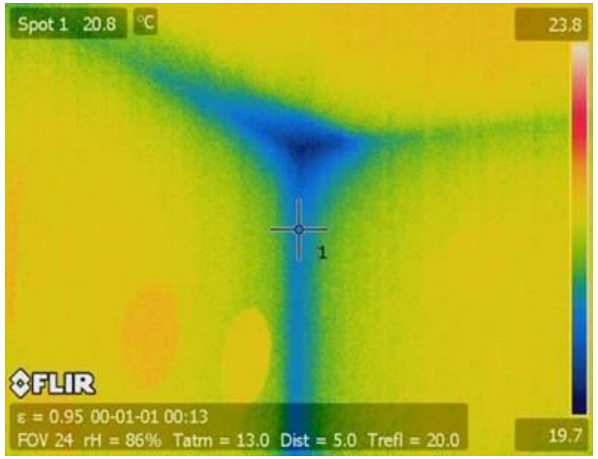
- Geometric thermal bridges can occur when the heat-emitting surface is larger than the heat absorbing surface.
- Building corners are a typical example.



Source: Schöck Ltd [4]



Source: B. Milovanović [3]

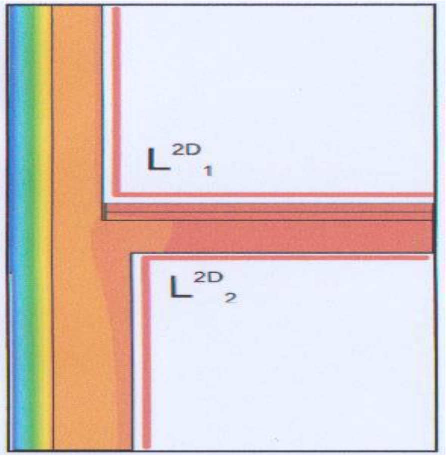


Source: B. Milovanović [3]

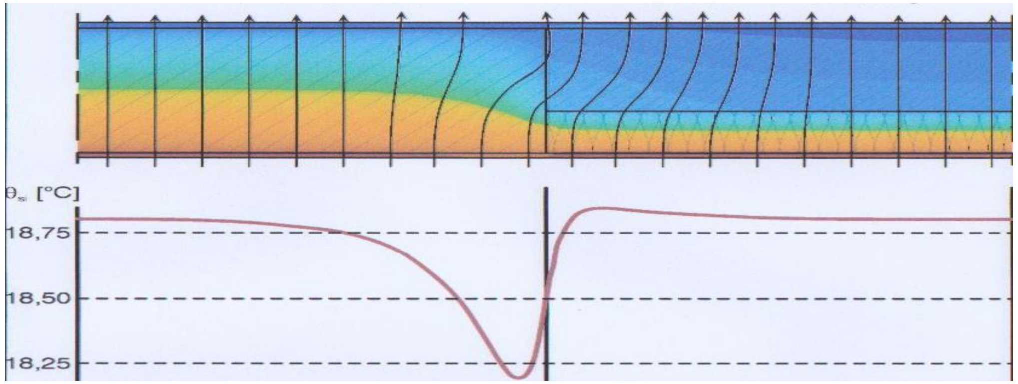
Types of thermal bridges

3) Combined thermal bridges

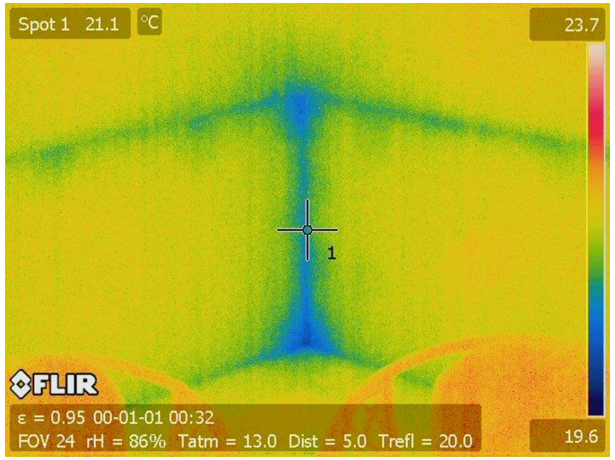
- These thermal bridges occur due to the change in the thickness of the building material.
- In the cross-section in which the change occurs, a sudden fall in the temperature of the inner surface occurs (Figure below).



Source: B. Milovanović [3]



Source. B. Milovanović [3]



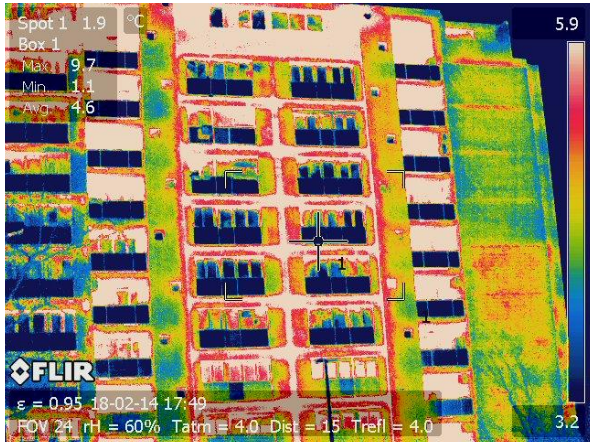
Source: B. Milovanović [3]

Quantification of linear TB

1) **Linear Heat Transmittance coefficient ψ [W/(mK)]** quantifies the influence of the line thermal bridge (increase in heat flow transfer) on the total heat flow.
   - **Ψ is equal to the increase of the stationary heat flow through the linear thermal bridge, relative to the undisturbed area.**

Source: B. Milovanović [3]

Source: B. Milovanović [3]



Source: B. Milovanović [3]

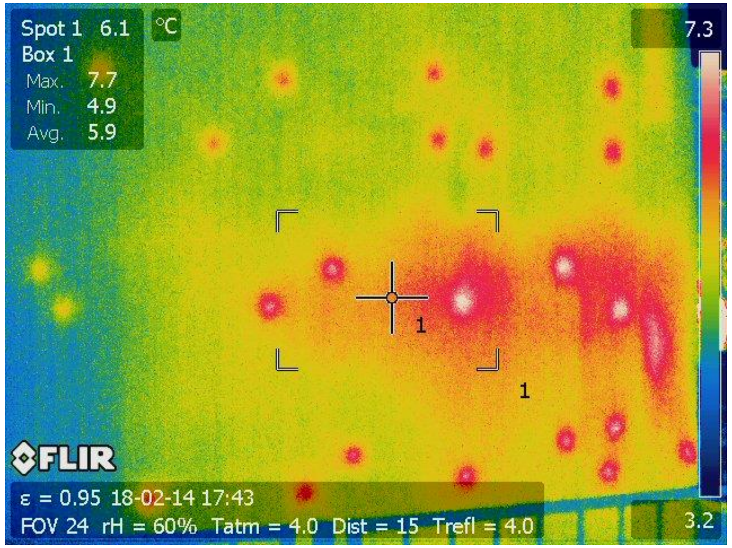
Quantification of point TB

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 heat flow through the point thermal bridge, relative to the undisturbed area.**

Source: B. Milovanović [3]

Source: B. Milovanović [3]

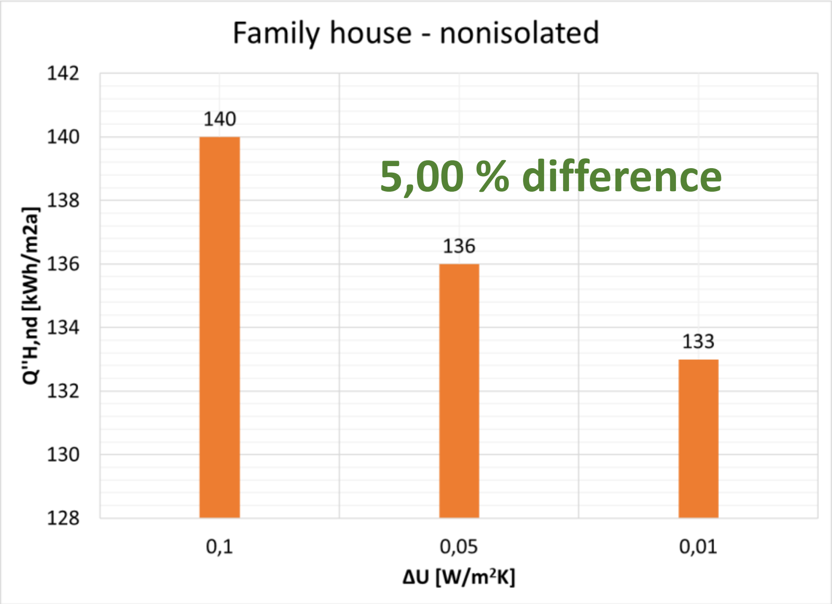


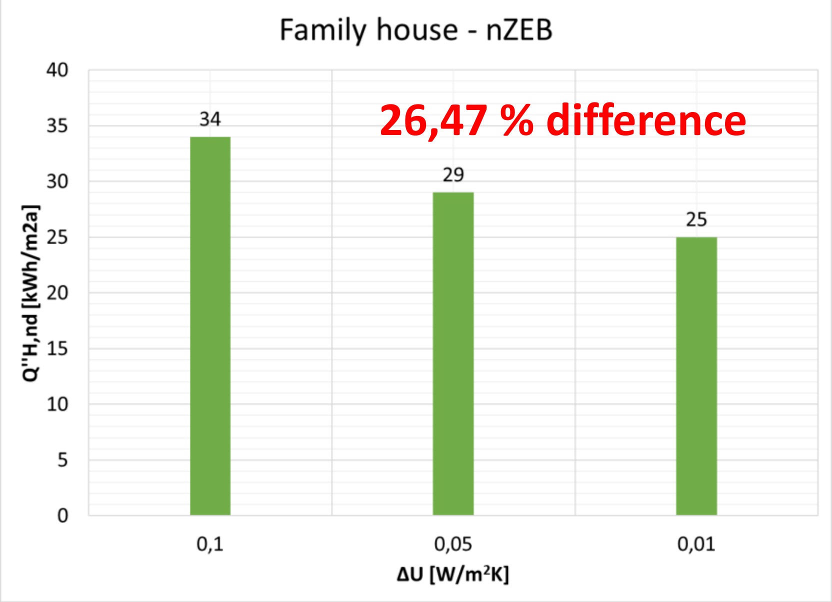
Source: B. Milovanović [3]

Additional heat losses due to TB

1) in the context of energy balancing, thermal bridges can be depicted as follows:
   - by using a general thermal bridge value $\underline{\Delta U = 0{,}10\ \mathrm{W/(m^2K)}}$ (EnEV),
   - by using a reduced thermal bridge value $\underline{\Delta U = 0{,}05\ \mathrm{W/(m^2K)}}$ (DIN 4108),
   - by using a reduced thermal bridge value $\underline{\Delta U = 0{,}01\ \mathrm{W/(m^2K)}}$.

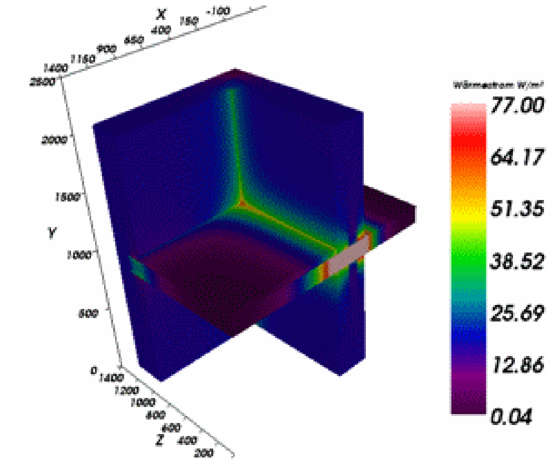
2) **For nZEB and Passive House buildings, the use of thermal bridge additions is not advised because they lead to overestimation of the heat losses!**



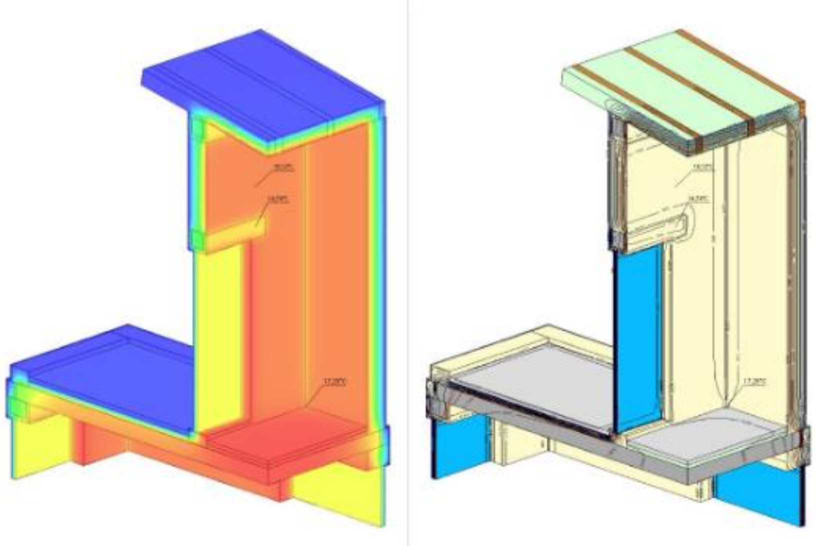


Modeling of thermal bridges

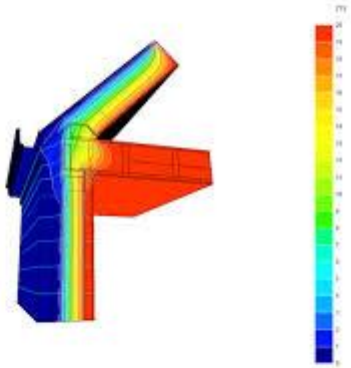
- The calculations are based on 2 mathematical methods:
  - **Finite element method (FEM) which can be used for all materials, and**
  - **Finite difference method (FDM) which is only valid for isotropic materials.**
- Some of the computer programs used for analysis of TBs are:
  - **HEAT 3D, Psi-Therm 3D, AnTherm 3D, BKI, Mold, DIANA FEA…**



Source: AnTherm [9]



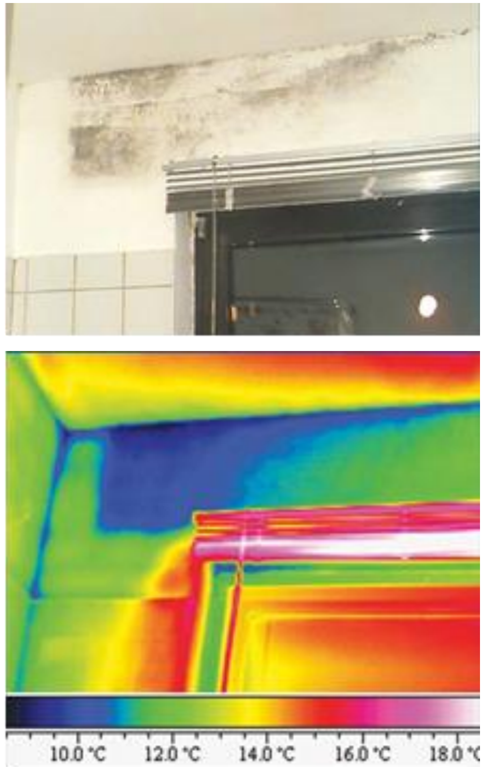
Source: Psi-Therm 3D [10]



Source: Thermodicht [11]

Consequences of TB

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…)



Source: B. Milovanović [3]

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

Consequences of thermal bridges

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]

WINDOWS

General function of windows

The heating and cooling demands depend significantly on

- glazing type and size,
- window orientation and
- whether shading is implemented or not.

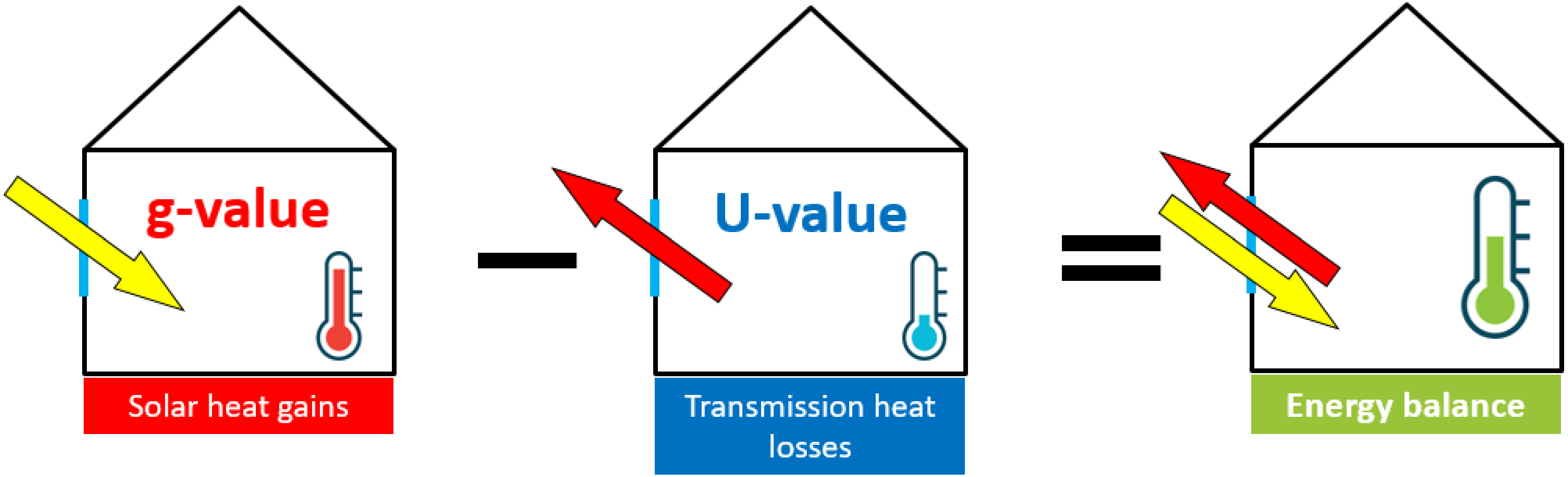
Windows can reduce the electric lighting by providing natural light.

Effective window design

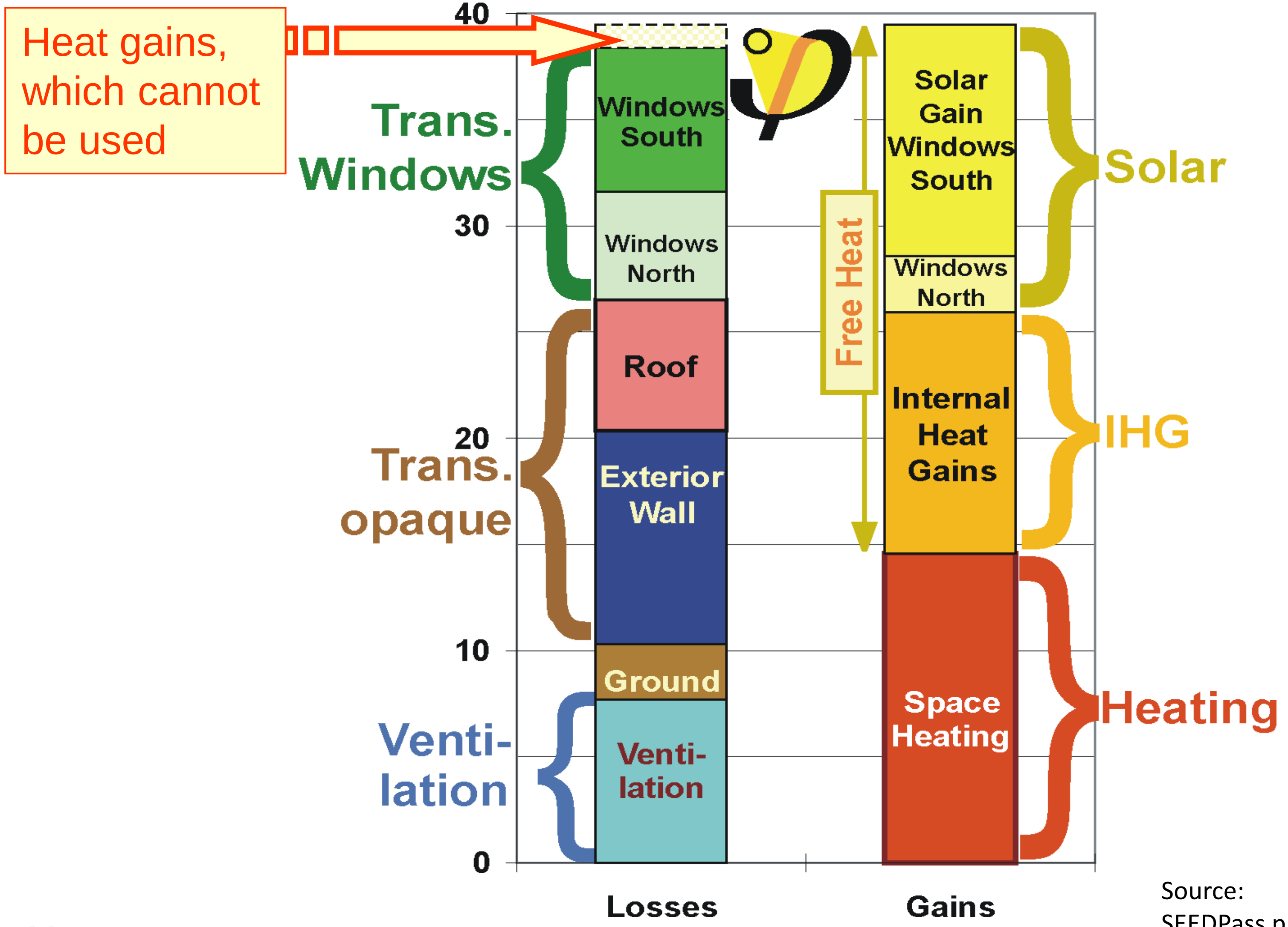
- a complicated process
- requires thorough investigation of the impact on heating, cooling and lighting.

Balancing heat losses and heat gains through windows

1) The U- and g-values are the most dominant factors affecting the annual energy performance.



Qualitative energy balance of a window



Source:
SEEDPass project, S. Pallantzas

An optimal energy balance for windows is therefore a **basic requirement** for nZEBs

General requirements for windows

Thermal transmittance (U_w - value)

0.75

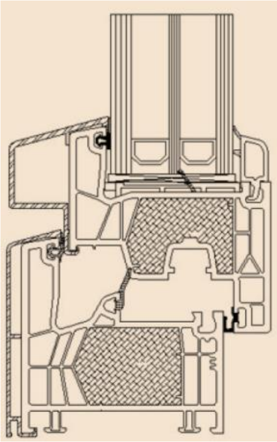
U_w [W/m²K]

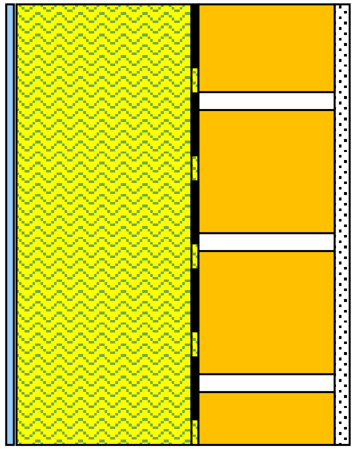
>>>>>

5 ×

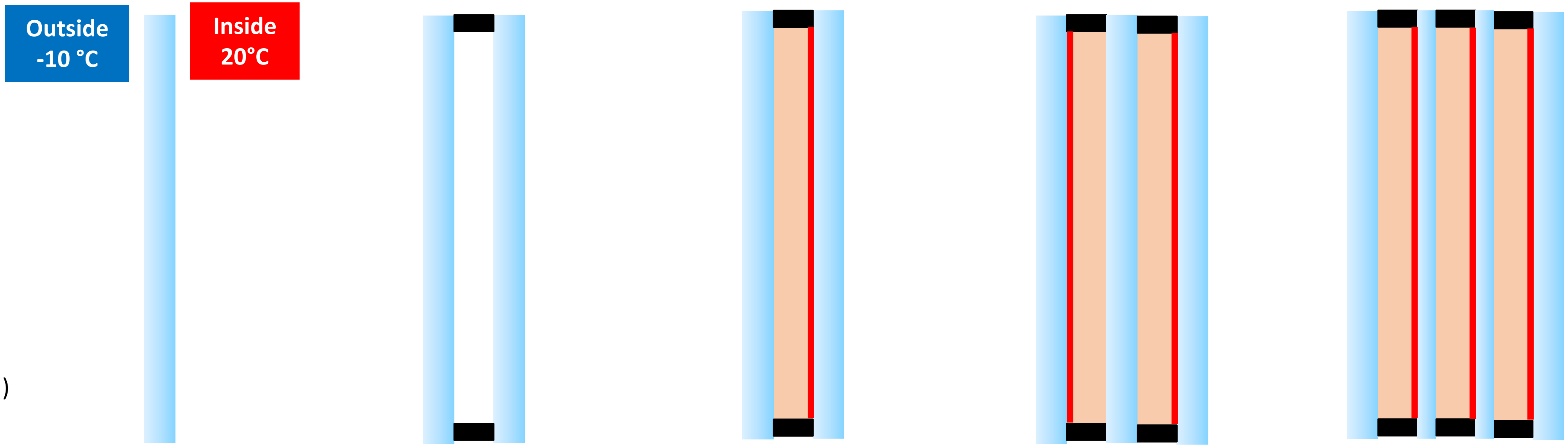
0.15

U [W/m²K]





Inner surface temperature



Source:
SEEDPass project, W. Hasper (PHI)

Glazing	Single pane	Double pane with air	Insulating glass units with low-e coating (pos 3) and Argon	Tripple insulating glass units with low-e coating (pos 2 & 5) and Argon	Quadrouple insulating glass units with low-e coating (pos 3, 5 & 7) and Argon
Glass U-value U_g [W/m²K]	5.8	2.7	1.1 – 1.3	0.53 – 0.75	0.36 – 0.44
Inner surface temperature (At -10 °C ambient & 20°C room)	-2.6 °C	9.5 °C	14.9 – 15.7 °C	17.1 – 17.9 °C	18.3 – 18.6 °C
Total transmittance g-value	0.87	0.78	0.62 – 0.71	0.49 – 0.60	0.43 – 0.57

U_W-value below 0.85 W/(m²K) for comfort reasons

- Lower U_w
- Higher inner surface temperatures
- Lower air movement
- BETTER COMFORT

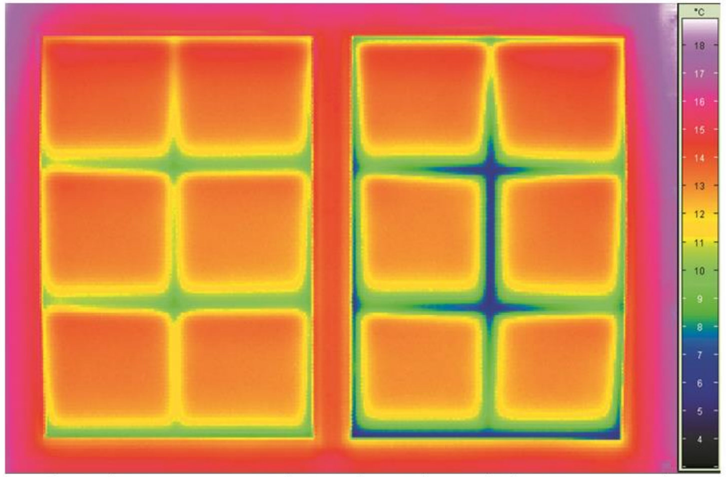
Glazing edge

SMALL COMPONENT, BIG IMPACT!

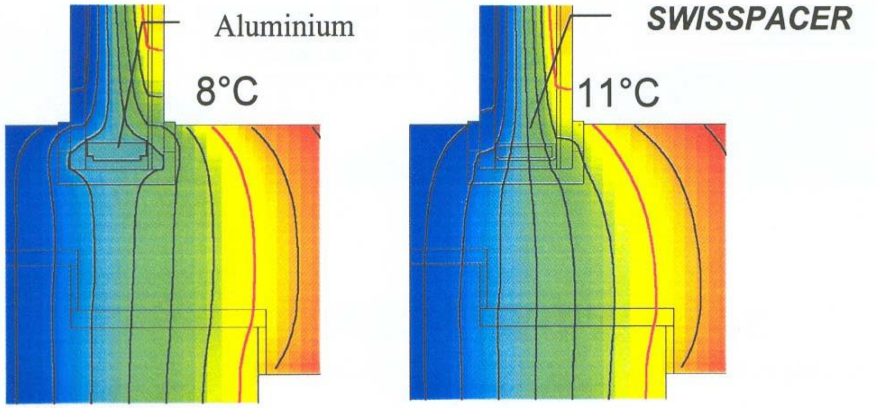
- Important to consider
- They restrict the energy around the perimeter of double (triple, quadrouple)-glazing,
- Lowers the U_w – value of windows and facades.

$$U_W = \frac{A_g U_g + A_f U_f + \boxed{l_g \Psi_g}}{A_g + A_f}$$


Image source:
- Swisspacer



Window with composite spacer bar / Window with aluminium spacer bar



Isotherms for: Θ_e = -5°C, Θ_i = +20°C

Rule of thumb

COLD CLIMATES:

Let the sunshine in!

HOT CLIMATES:

Keep the solar load out!

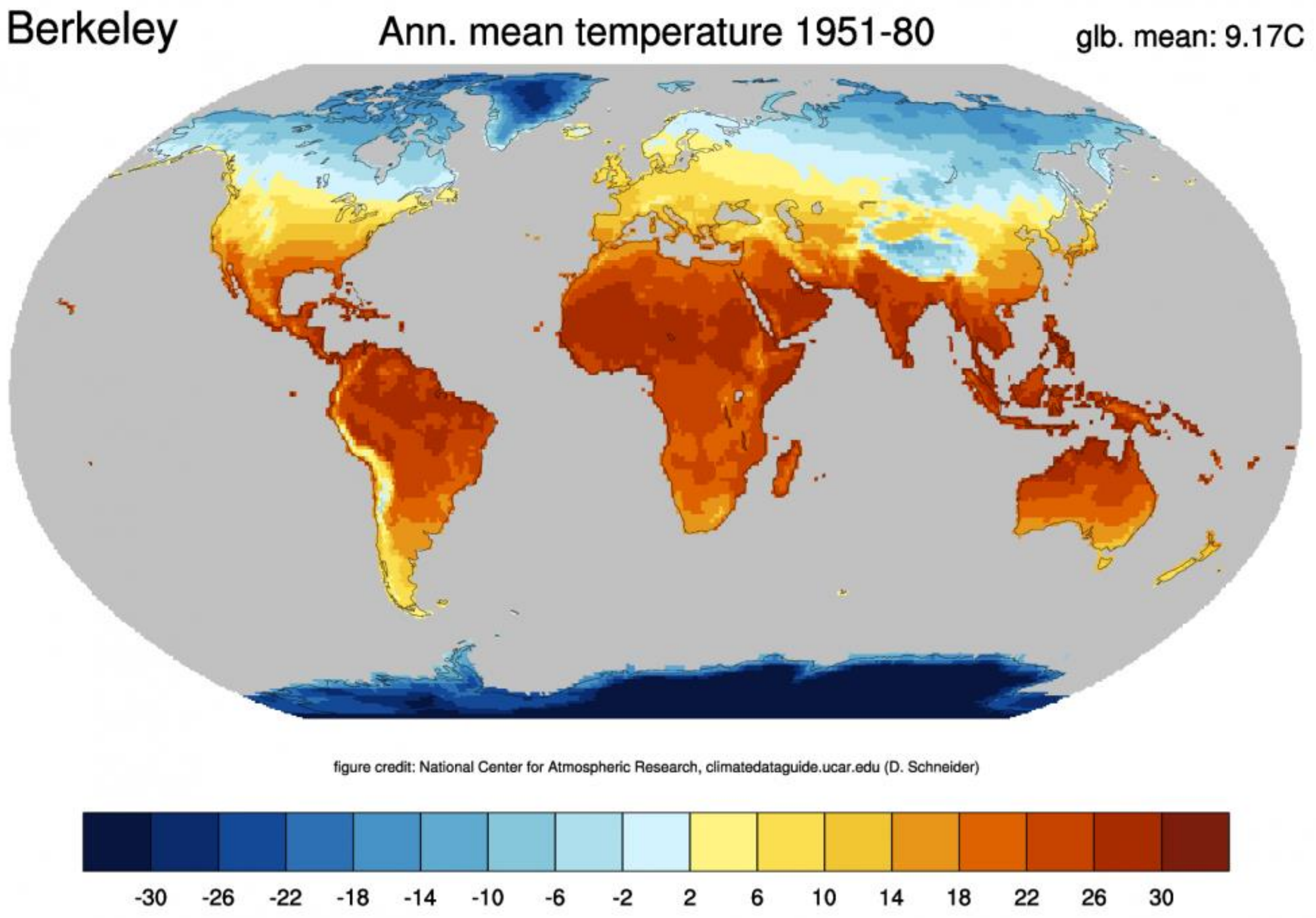
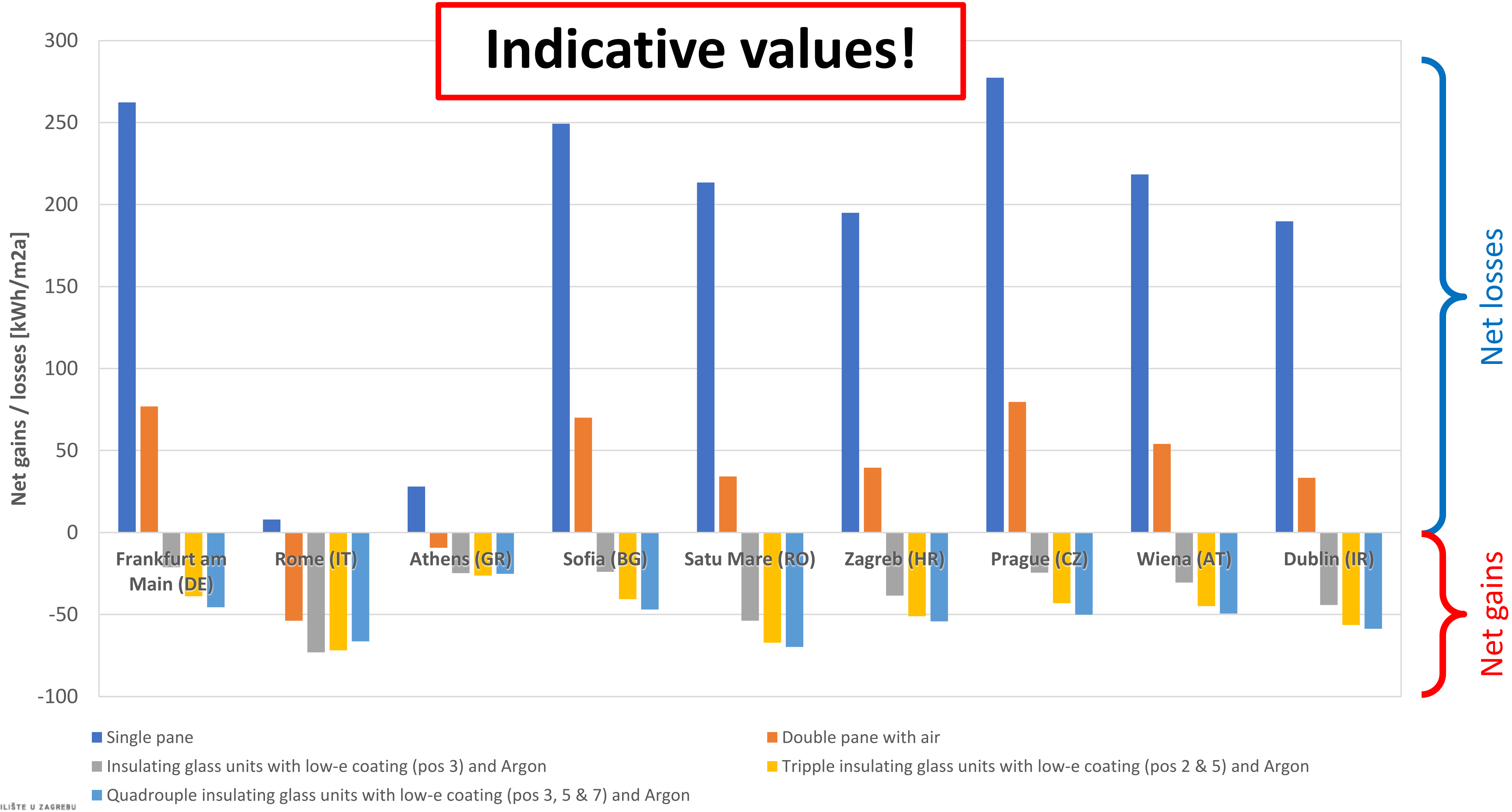


figure credit: National Center for Atmospheric Research, climatedataguide.ucar.edu (D. Schneider)

Source:
National Center for Atmospheric Research: BEST

Let the sunshine in or not?

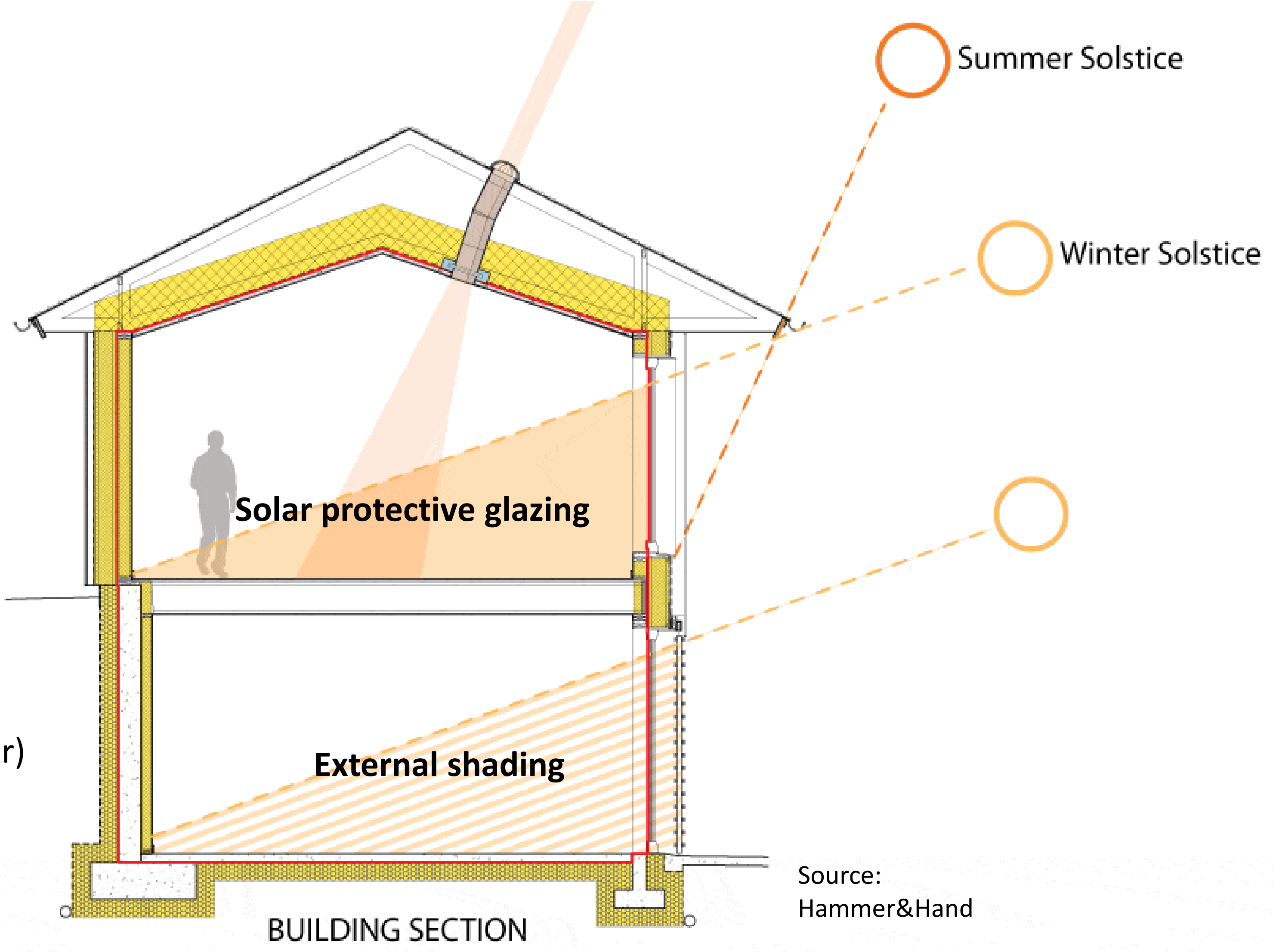

Indicative values!

Hot climates: Keep the solar load out!

- Suitable window size
  (All climates!)

- Exterior shading
  fixed elements and/or blinds
  → daylight redirection?
  (Climates with cold and warm season)

- Solar protective glazing
  (Locations with high solar loads throughout the year)

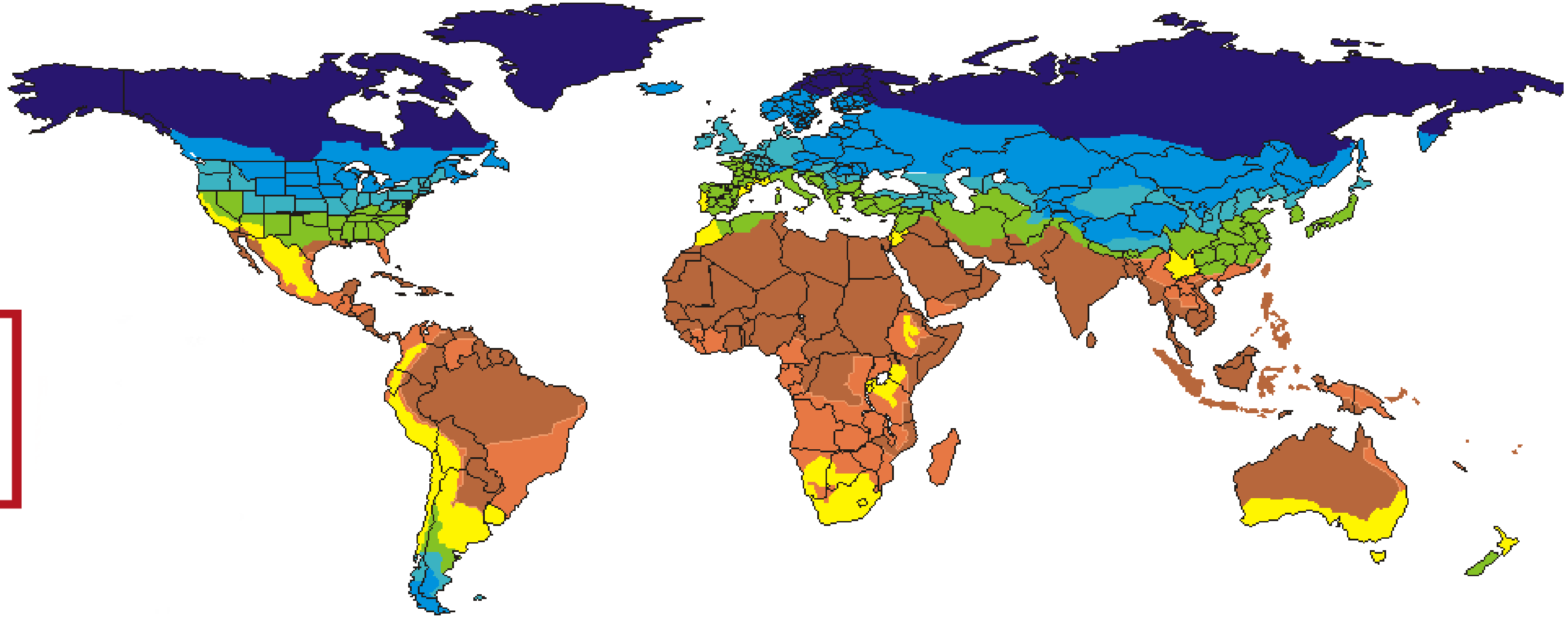


Source:
Hammer&Hand

Window requirements in different climate zones

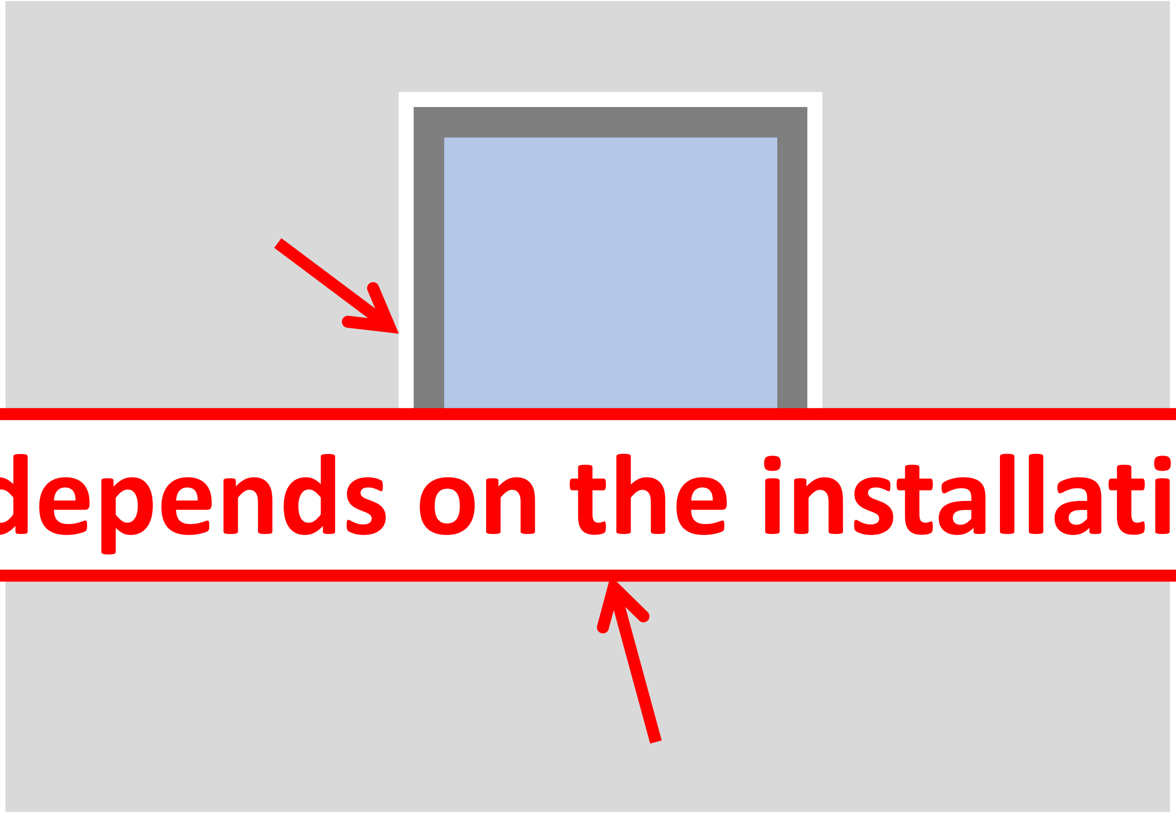
See: www.passiv.de | Certification | Components | Certification Criteria

	arctic	cold	Cool-temperate	Warm-temperate	Warm	hot	Extremly hot
Glazing type	Vacuum low-e	4-glazed low-e	3-glazed low-e	2-glazed low-e	2-glazed	2-glazed anti-sun	3-glazed anti-sun
Uw, installed MAX (vertical)	0.45	0.65	0.85	1.3	2.9	1.6	1.3



Source:
SEEDPass project, W. Hasper (PHI)

Window is a part of building's thermal envelope



It depends on the installation

Wall – complies to the design and/or regulatory requirements
Window – complies to the design and/or regulatory requirements
What about a Wall with the window ????

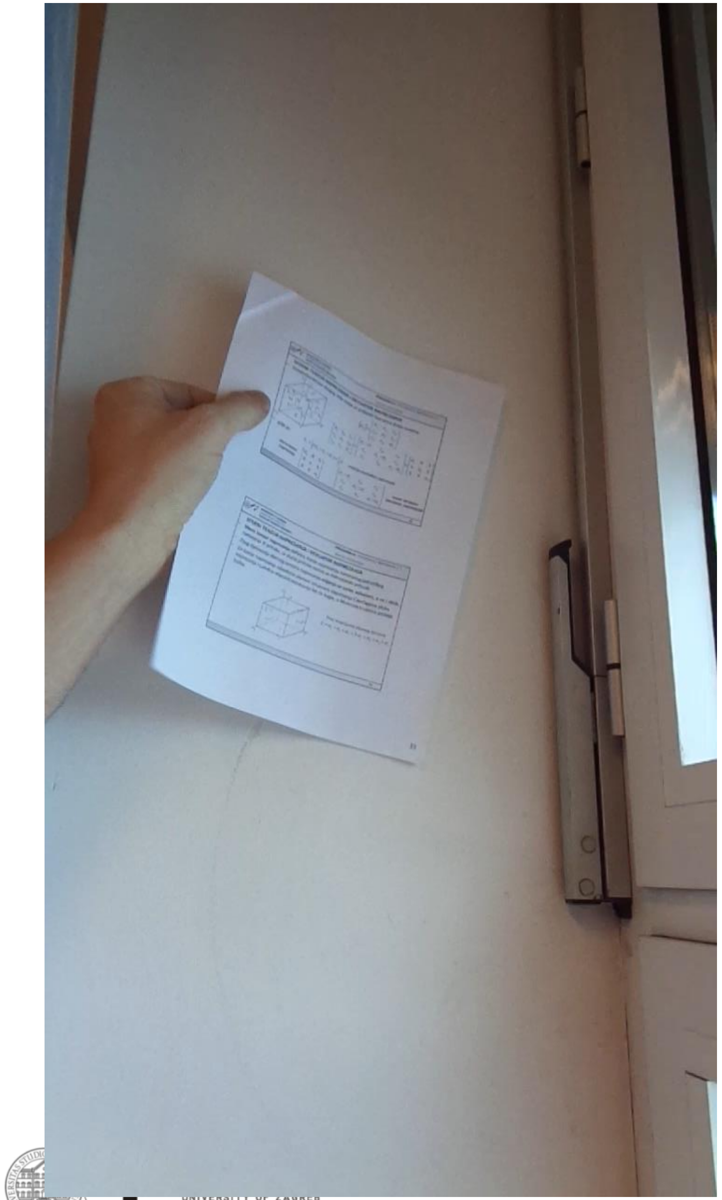
The installation is vital!

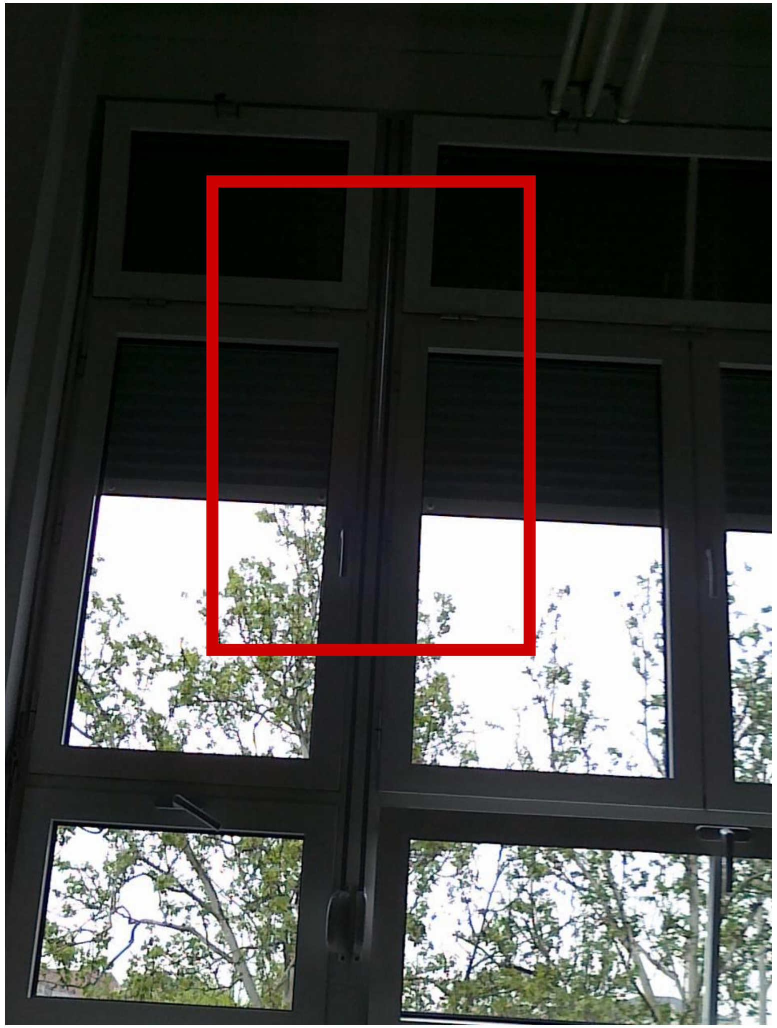
high performance window can only be as good as the install

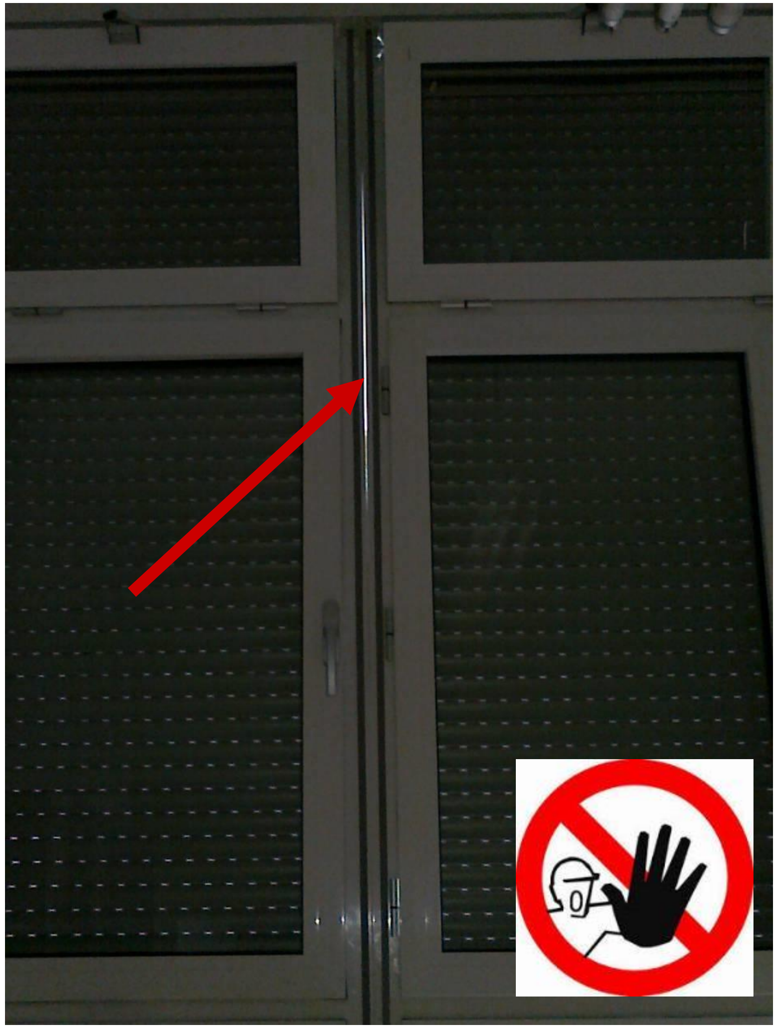
- The installation must address several key issues, it shall be :
  - structurally sound,
  - watertight,
  - airtight,
  - vapor smart and
  - increase the installed thermal performance of the window.

QUALITY MATTERS!

Poor window installation examples







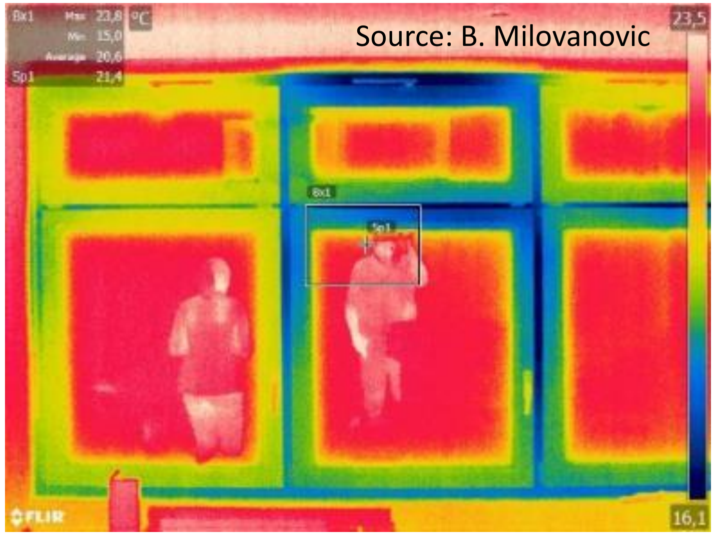
Poor window installation examples


Source: B. Milovanovic


Source: B. Milovanovic


Source: B. Milovanovic

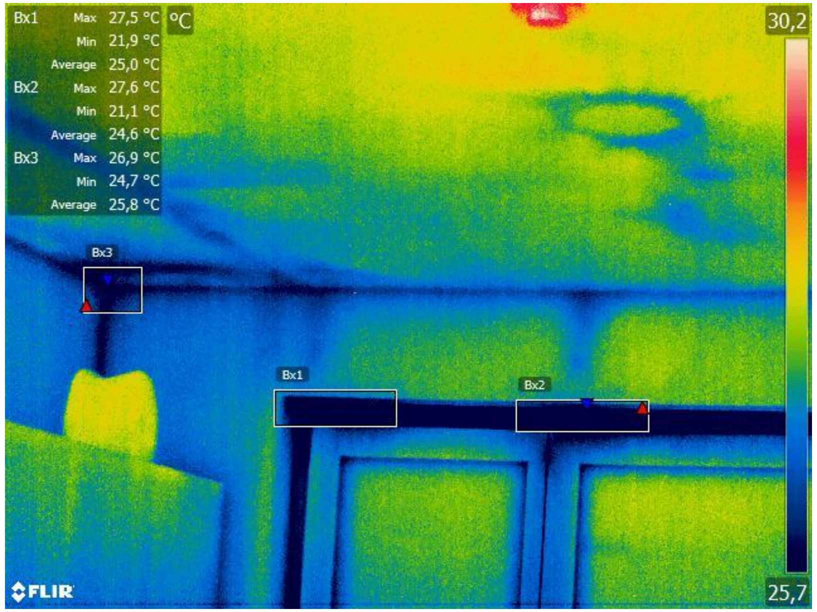

Source: B. Milovanovic

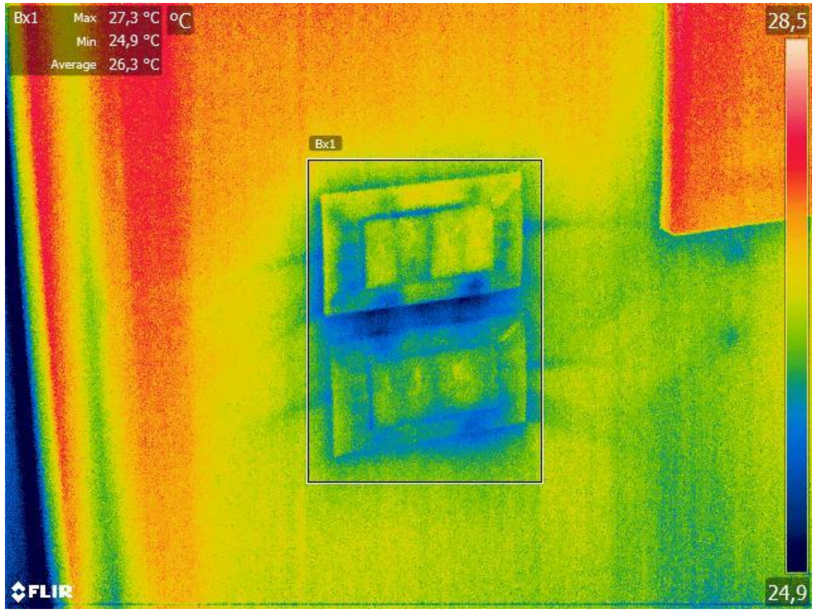

Source: B. Milovanovic

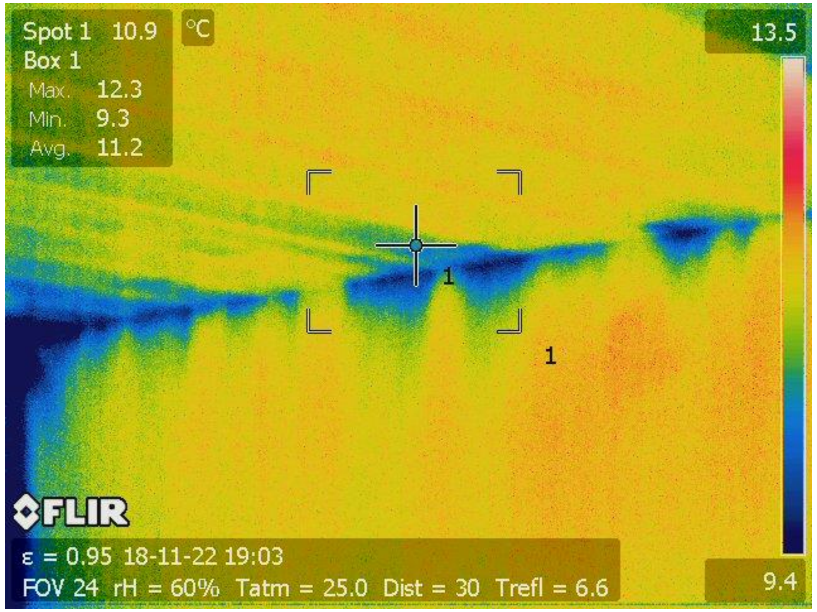

Source: B. Milovanovic

External thermal insulation

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

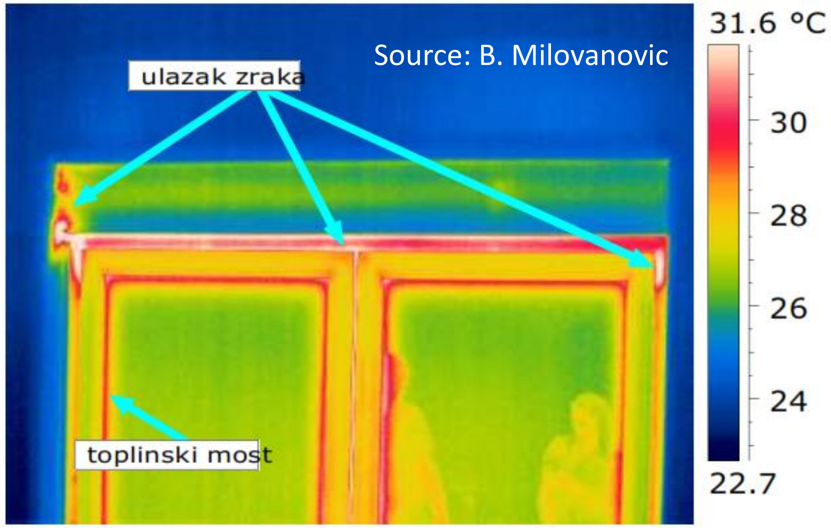


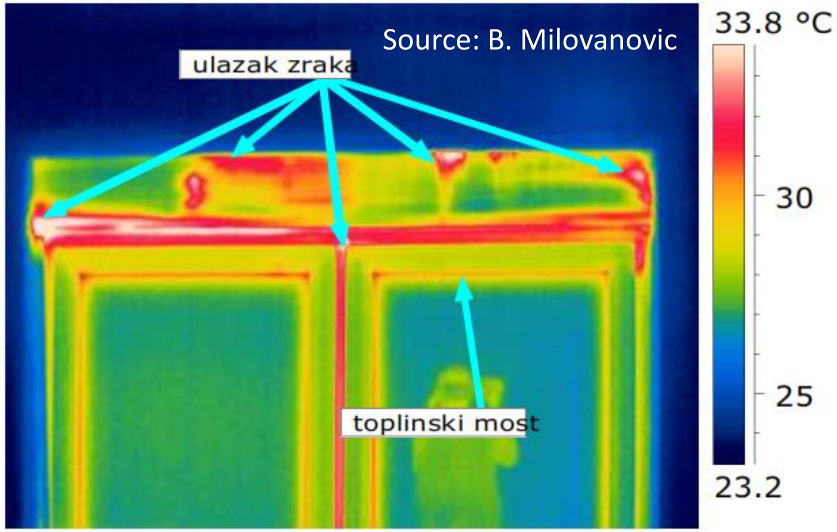


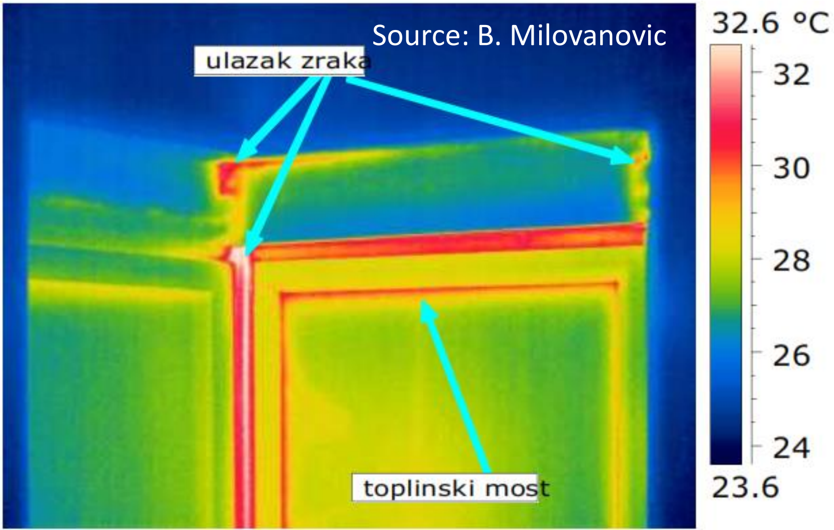


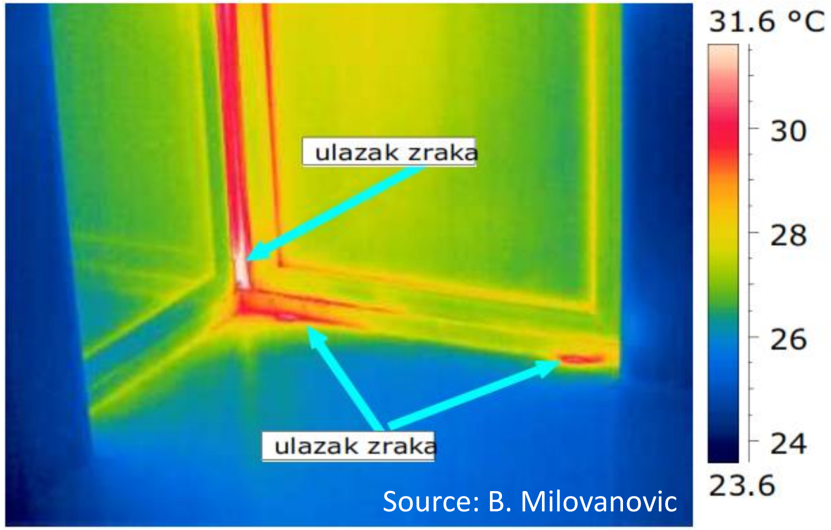
Quality control

Infrared thermography – during blower door test


Source: B. Milovanovic


Source: B. Milovanovic


Source: B. Milovanovic

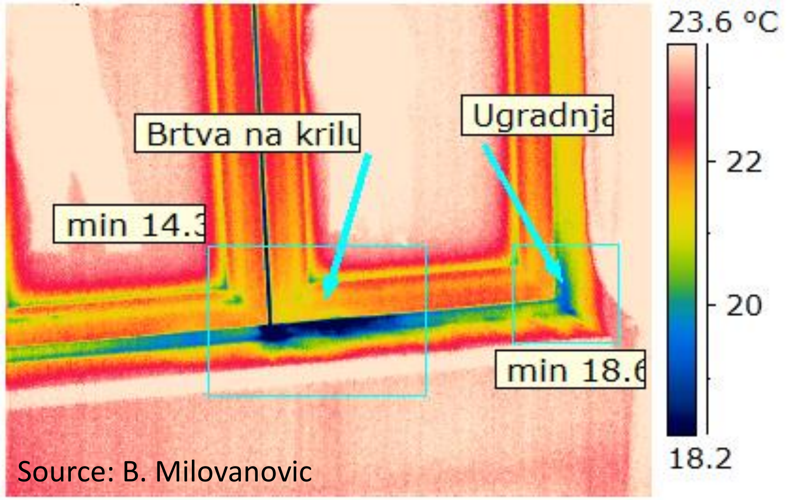

Source: B. Milovanovic


Source: B. Milovanovic

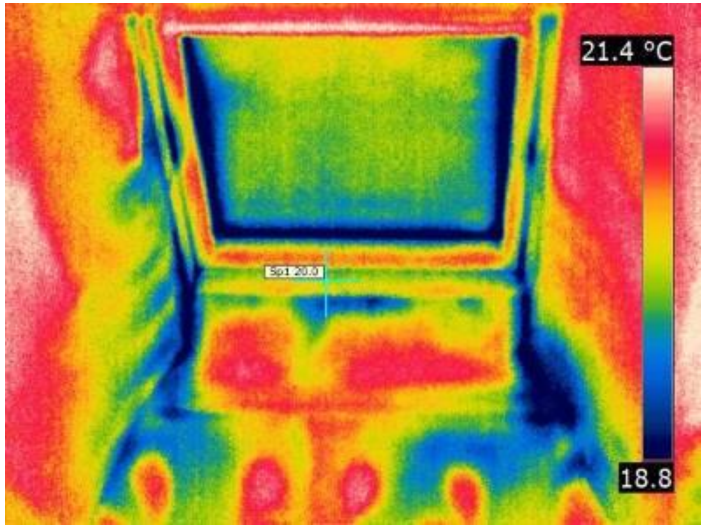
Quality control

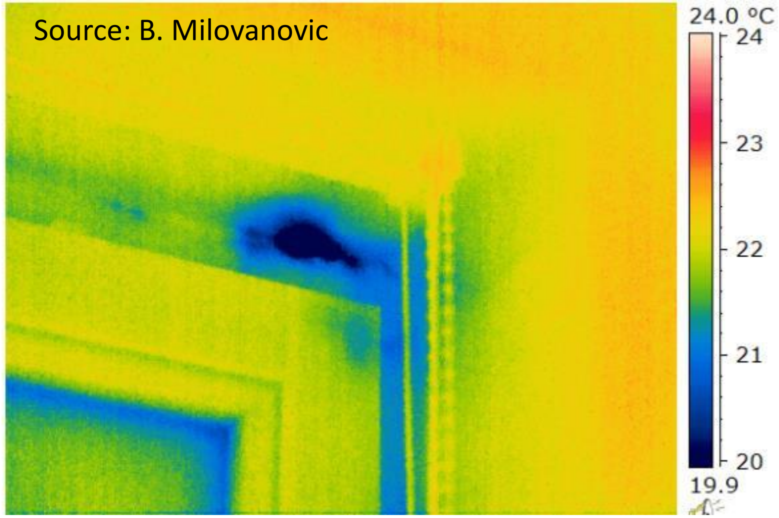
Fit-to-NZEB
Innovative training schemes for retrofitting to nZEB-levels

Infrared thermography – during blower door test

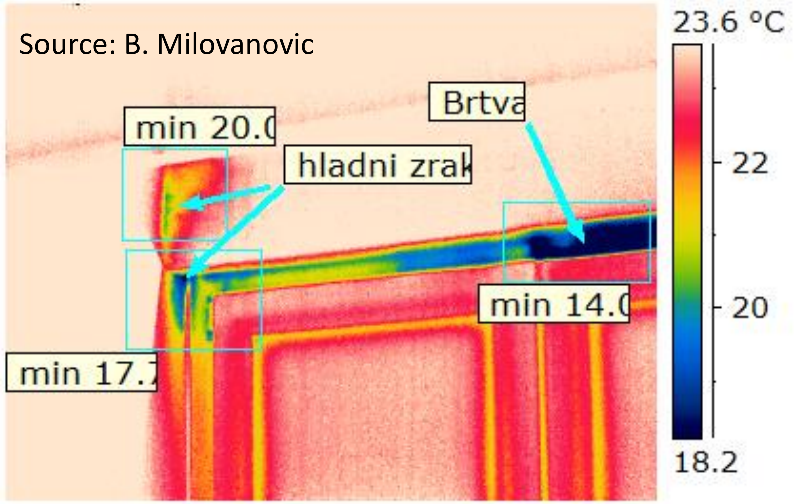


Source: B. Milovanovic

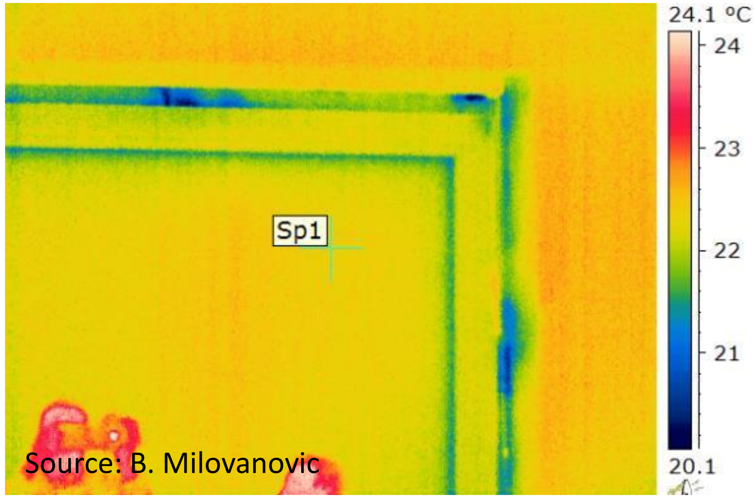




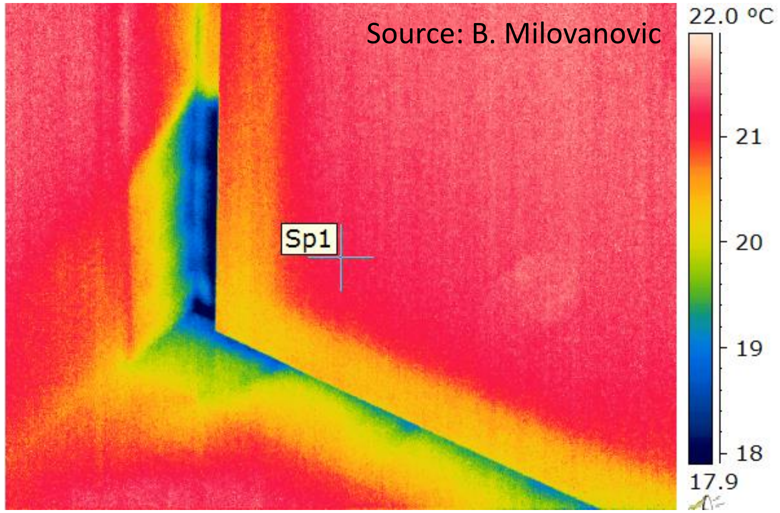
Source: B. Milovanovic



Source: B. Milovanovic



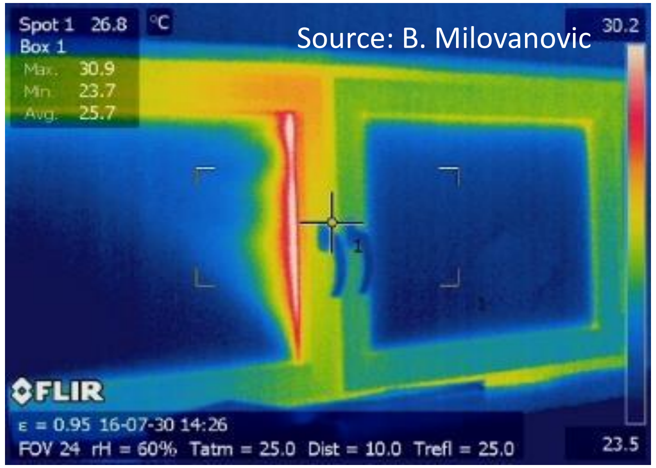
Source: B. Milovanovic



Source: B. Milovanovic

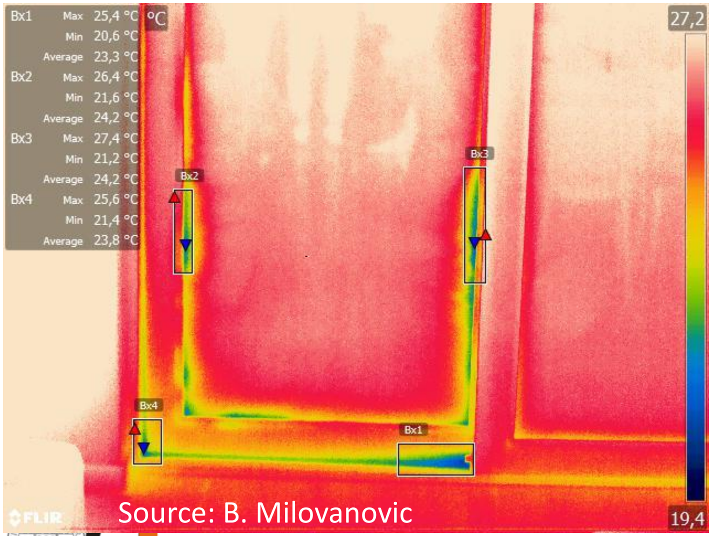
Poor window construction

- Sealing rubber missing



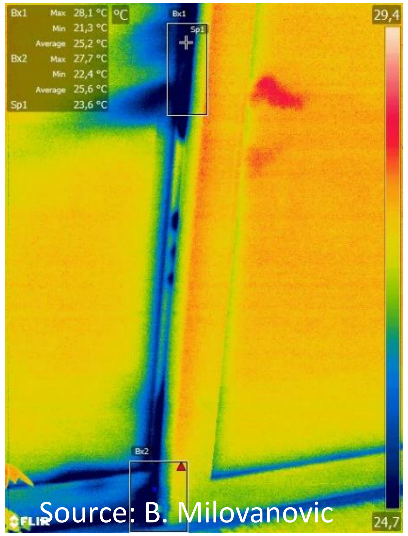
Source: B. Milovanovic

- Poor glazing – frame connection



Source: B. Milovanovic

- Sliding doors



Source: B. Milovanovic

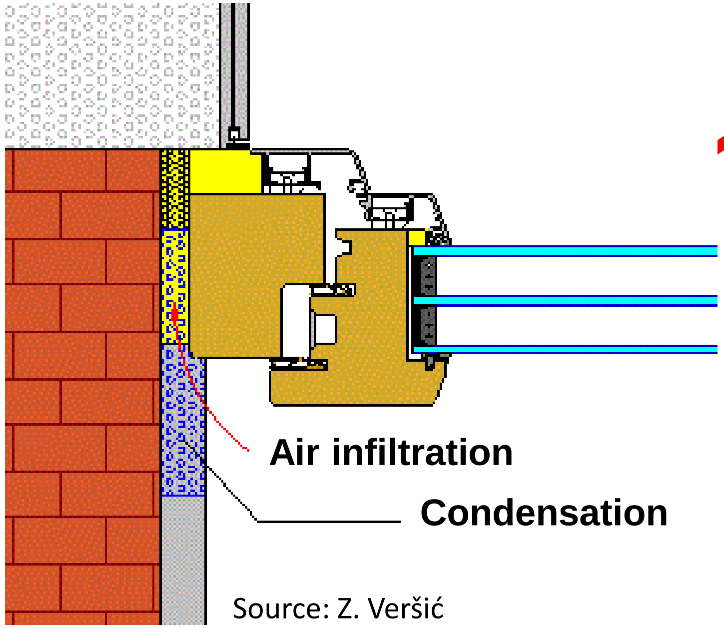
- Poorly installed sealing rubber

Source: B. Milovanovic

Source: B. Milovanovic

Consequences

- Poor window and/or roller shutter installation can result with moist walls and consequently mold growth



Source: Z. Veršić

Source: Z. Veršić

Source: B. Milovanovic

Source: B. Milovanovic

Consequences

1) Poor window design and/or construction can also result with water infiltration and/or condensation and consequently mold growth

Mold growth due to seal discontinuity

Source: B. Milovanovic

Source: B. Milovanovic

Source: Z. Veršić

Mold on the window frame

Source: Z. Veršić

Fit-to-NZEB

Innovative training schemes
for retrofitting to nZEB-levels

www.fit-to-nzeb.com

Koordinator: EnEffect

Center for Energy Efficiency EnEffect – Bulgaria

WP4 - Training programmes for institutions of higher education

- Razvoj novih programa edukacije koji su u **skladu s EQF razinama 6 i 7**
- Razvoj potrebnog **nastavnog sadržaja** (learning content):
  - Definirati programsku povezanost,
  - Nastavni materijali
    - Prezentacije,
    - Praktične vježbe
    - 3D vizualizacije
    - Video materijali
    - E-learning
    - Način provođenja ispita
- Provesti **barem 3 pilot edukacije**

© Passive House Academy

SVEUČILIŠTE U ZAGREBU
GRAĐEVINSKI FAKULTET
UNIVERSITY OF ZAGREB
FACULTY OF CIVIL ENGINEERING

Thank You for Your kind attention!

Bojan Milovanović
bmilovanovic@grad.hr