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University of Antwerp
Faculty of Applied Engineering

# Sustainable and Resilient Infrastructure and Buildings

## 1 February 2022 – 30 April 2022

# Energy performance of buildings in terms of their sustainability

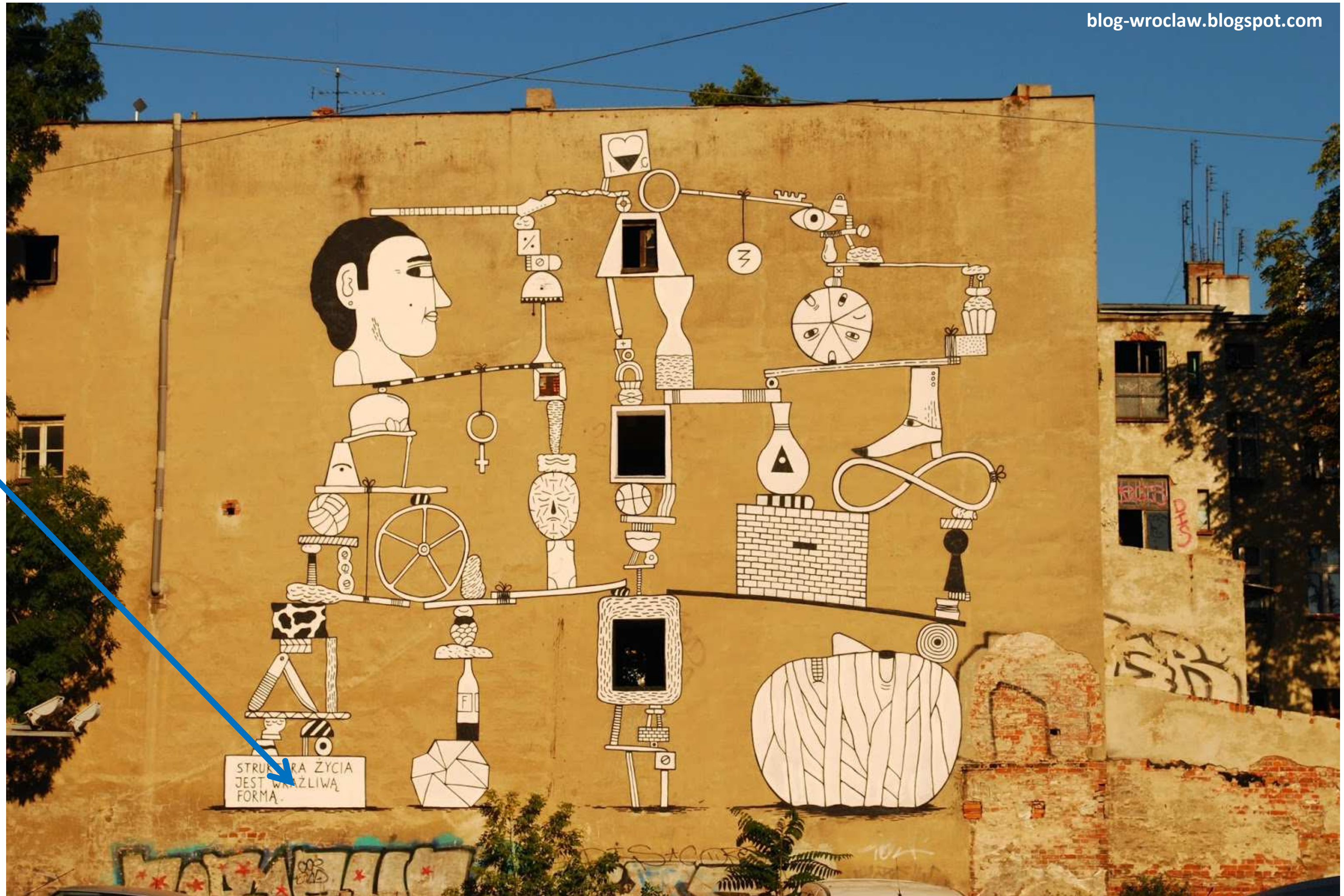

**Łukasz Nowak, Dr Eng.**

**Wrocław University of Science and Technology**

# Schedule

- Energy demand in buildings
- Levels of building energy performance
- Impact of external parameters on building energy performance
- Impact of internal parameters on building energy performance
- Summary

**THE STRUCTURE OF LIFE IS A SENSITIVE FORM**


Building is also
a sensitive form…

…from an energy
point of view.

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# Energy demand in buildings

**EU** index — **Usable energy** e.g. heating load, cooling load

**EK** index — **Final energy** (Site energy)

**EP** index — **Primary energy** (Source energy)

Net energy needed to create proper comfort of use in the building (for heating, cooling, ventilation, DHW)

- Architecture + construction energy efficiency
- Building energy performance (e.g. passive house, low energy building)

Fuel or energy needed to be supplied to the building HVAC systems to maintain comfort of use with systems efficiency taken into account

- HVAC systems efficiency
- Running costs

Non-renewable energy needed to be taken from the environment and to be supplied to the building as a fuel.

- Building environmental footprint
- $CO_2$ emission
- Fulfillment of technical regulations

# Levels of building energy performance

- Standard building (meets the technical regulations) e.g. in Poland:

  $U_C < U_{C\,(max)}$ — thermal transmittance of the building partitions

  $EP \leq EP_{max}$ — primary energy index

- Low-energy building:

  $EU_H \leq 40$ kWh/($m^2$year) — usable energy index for heating

- Passive building

  $EU_H \leq 15$ kWh/($m^2$year) — usable energy index for heating

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# Levels of building energy performance

- nZEB and ZEB (*near Zero Energy Building / Zero Energy Building* )

  the amount of energy consumed is:
  - in nZEB buildings - slightly greater than produced,
  - in ZEB buildings - should be equal to the produced one.
- Plus-energy building
- Autonomous building (self-sufficent)
- …

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# Why the building architecture/structure design is here important?

Adding power makes you faster on the straights. Subtracting weight makes you faster everywhere.

— *Colin Chapman* —

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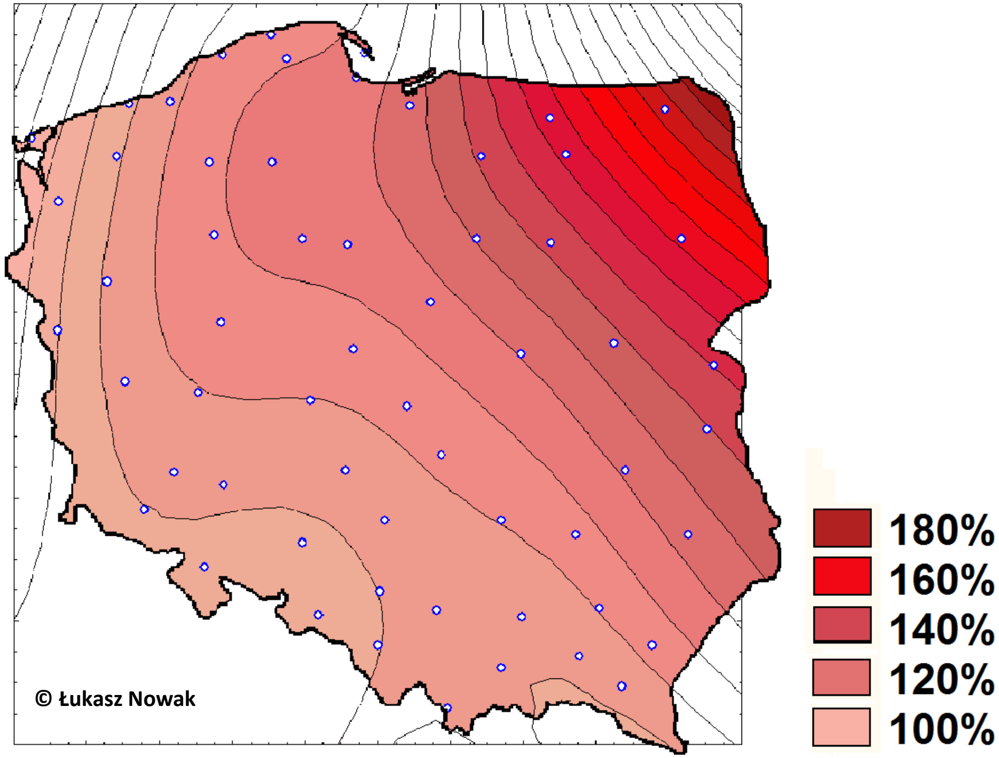
# Impact of external parameters

## Climate and location

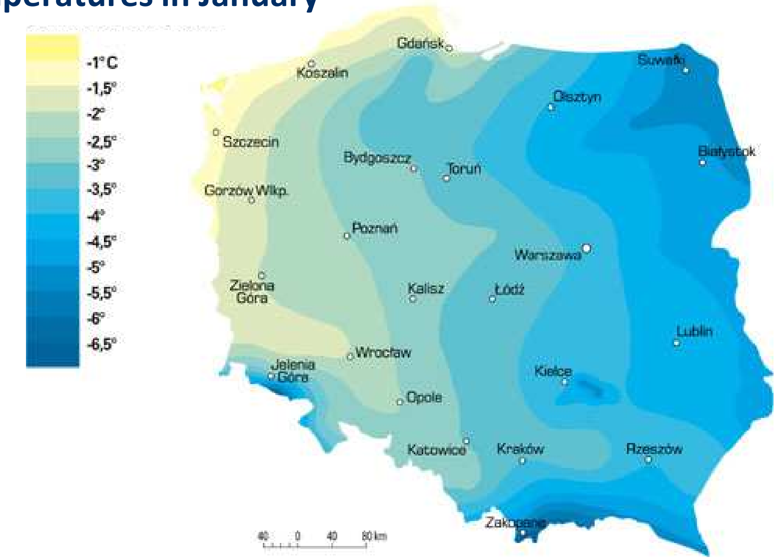
- the topography significantly influences insolation, the microclimate of a given area, and thus the thermal balance of buildings
- the building should be properly located in relation to the local earth, wind and solar conditions, including:
  - landform,
  - slope,
  - location in relation to the wind rose,
  - location in relation to the directions of the world.
- topography, geological structure, water reservoirs, type of flora or even other buildings may influence local atmospherical changes and create different microclimatic conditions.

# Impact of external parameters

## Location and heating energy demand



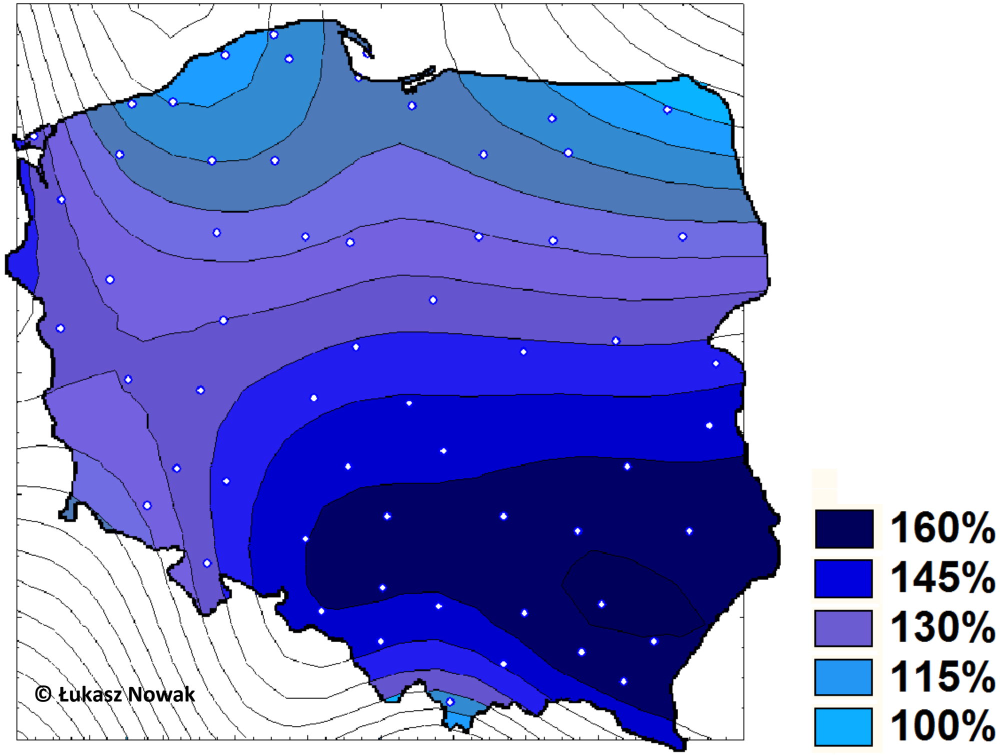

Mean ambient air temperatures in January



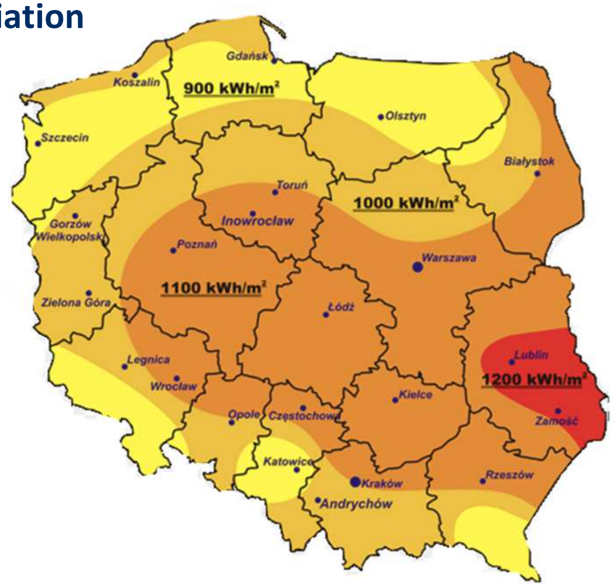

The impact of the location in Poland of a single family building designed in accordance with Polish technical regulations for 2021 on the change in its energy demand for heating

# Impact of external parameters

## Location and cooling energy demand




Global solar
horizontal irradiation




**The impact of the location in Poland of a single family building designed in accordance with Polish technical regulations for 2021 on the change in its energy demand for cooling**

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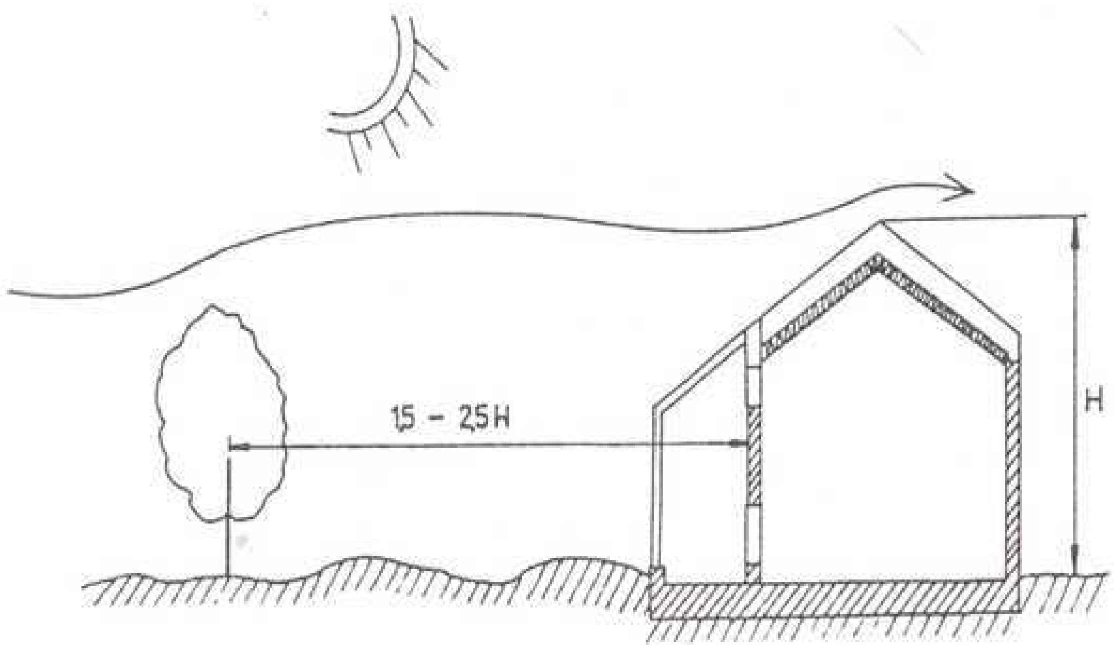
# Impact of external parameters

## Wind sheltering

How to provide?

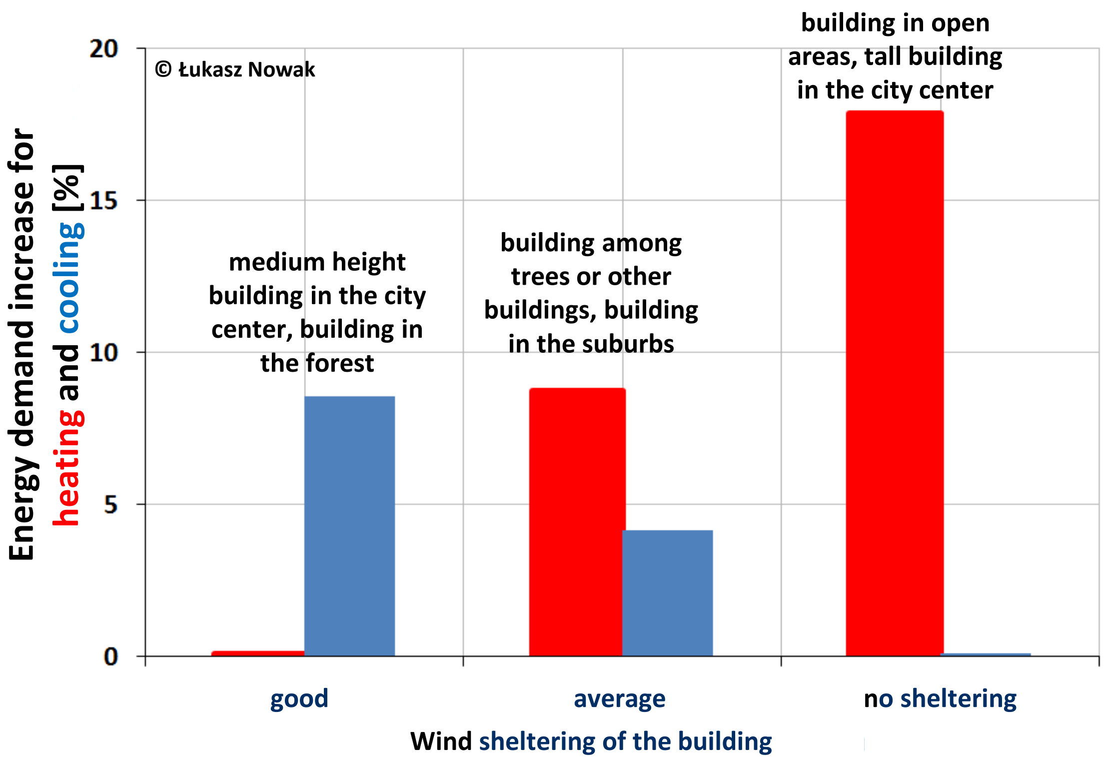
- protective forests,
- auxiliary buildings,
- earth slopes,
- screens and fences (2 ÷ 3 m),
- hedges (2 ÷ 4 m),
- planting with trees (6 ÷ 12 m),
- earth embankments.




**The windshield MUST allow air to circulate - otherwise, a negative pressure is created on the leeward side, resulting in strong air turbulence, which causes greater heat loss.**

# Impact of external parameters

## Wind sheltering and heating / cooling




The impact of the wind sheltering of a building designed in accordance with technical regulations for 2021 on the change in its energy demand for heating and cooling

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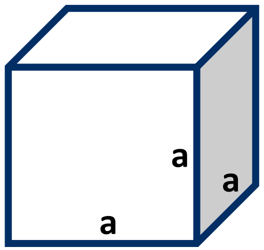
# Impact of internal parameters

## Geometry

**The geometry of building enclosure is usually the result of many design assumptions, i.e .:**

- **geometry and size of building site,**
- **building function,**
- **or formal conditions (technical regulations).**

**The shape coefficient A/V is the ratio of the surface area of its external partitions to the building heated/cooled volume.**




**For a = 1 m**

$A = 6a^2 = 6\ m^2$
$V = a^3 = 1\ m^3$
$A/V = 6.0\ m^{-1}$

**For a = 2 m**

$A = 6a^2 = 24\ m^2$
$V = a^3 = 8\ m^3$
$A/V = 3.0\ m^{-1}$

**For a = 8 m**

$A = 6a^2 = 384\ m^2$
$V = a^3 = 512\ m^3$
$A/V = 0.75\ m^{-1}$

**The larger the area of the partitions surrounding the building, the greater the heat loss through the building envelope, which means a compact building geometry is advantageous.**

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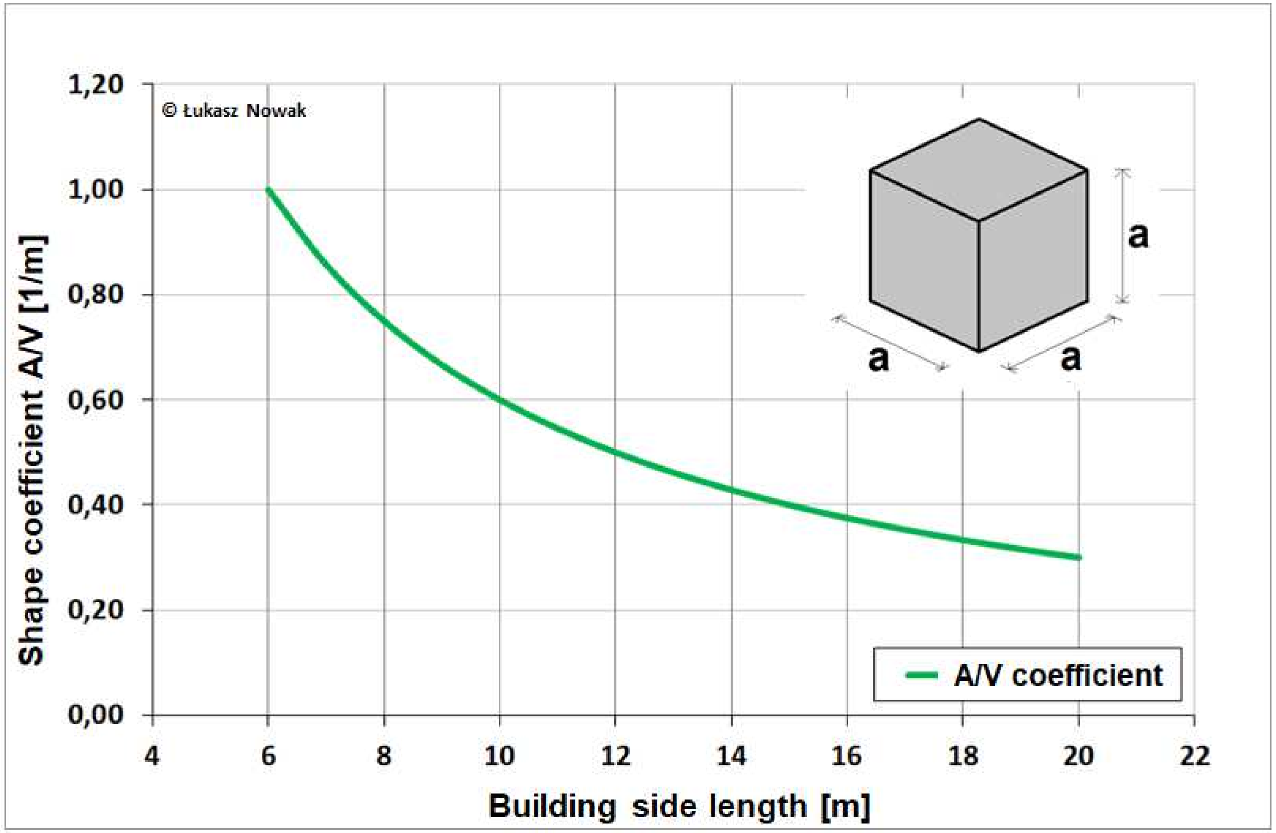
# Impact of internal parameters

## Geometry vs size



# Impact of internal parameters

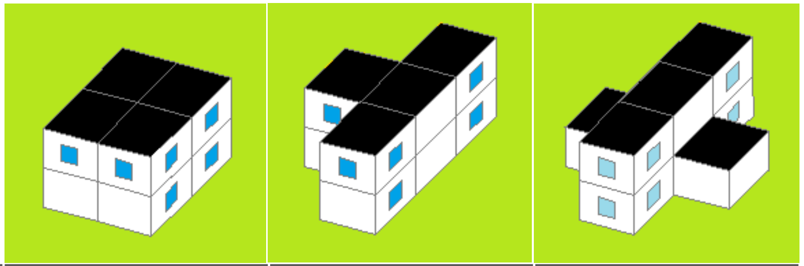
## Geometry and heating

© dreamstime.com

**Heat losses depend on the thermal insulation of the partitions and their area - the larger the area of the partitions and/or worse the thermal insulation properties, the greater the heat losses.**

**Shape coeffcient has bigger influence on energy performance in small buildings**

**GEOMETRY vs ENERGY DEMAND**



| Shape coefficient (A/V) | 0.71 | 0.81 | 0.89 |
|---|---|---|---|
| $EU_H$ index increase | | +11% | +17% |
| EP index increase | | +6% | +10% |

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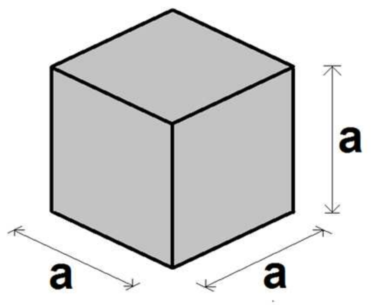
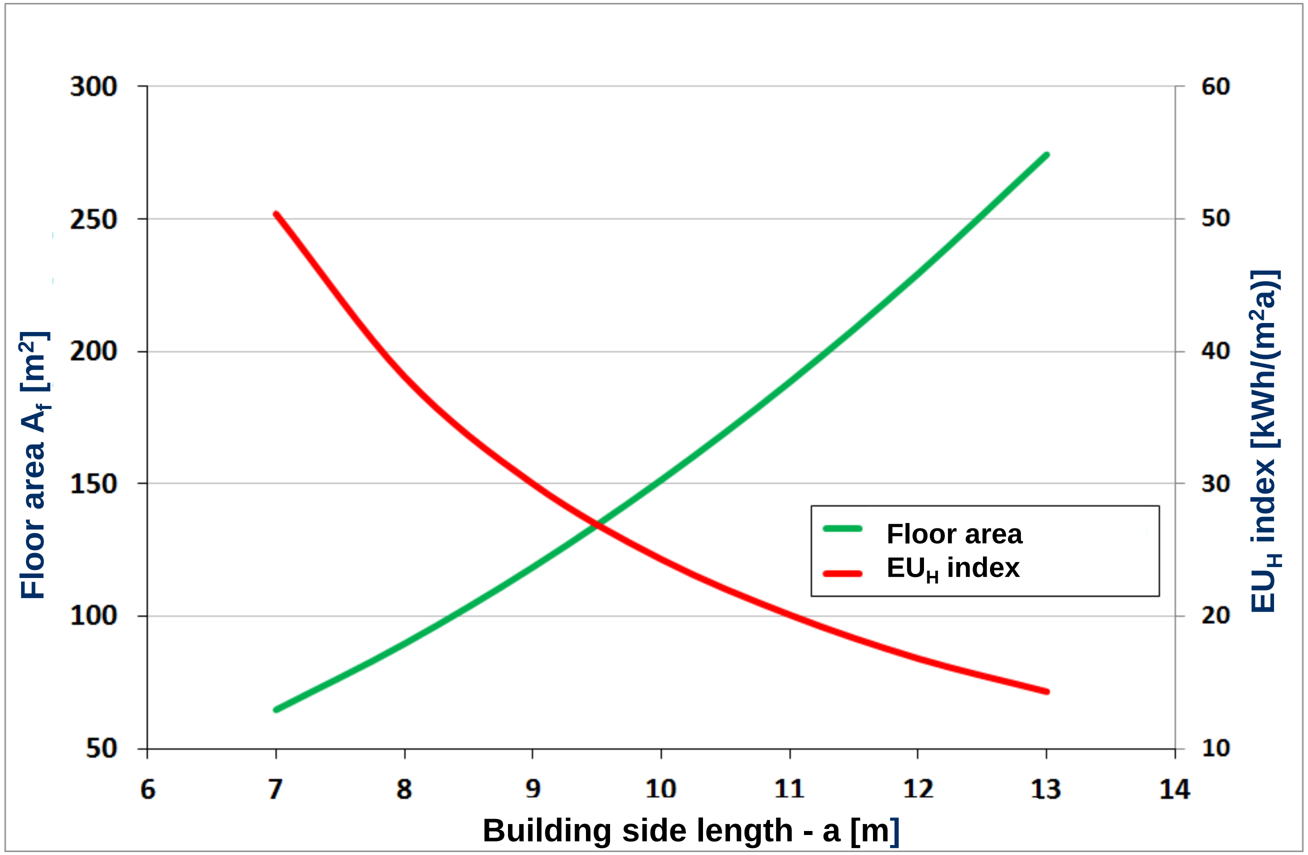
# Impact of internal parameters

## Size and heating




The impact of the size of a single family building designed as a cube on the usable energy index for heating

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# Impact of internal parameters

## Orientation and heating

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**Location:**

**Wrocław, Poland**

- **proper window placement (biggest window area oriented to the South)**

**$EU_H$ = 33.6 kWh/($m^2$a)**

- **wrong window placement (biggest window area oriented to the North)**

**$EU_H$ = 37.1 kWh/($m^2$a)**

**Increase:**

**+ 3.5 kWh/($m^2$a)**

**+ 10.4%**

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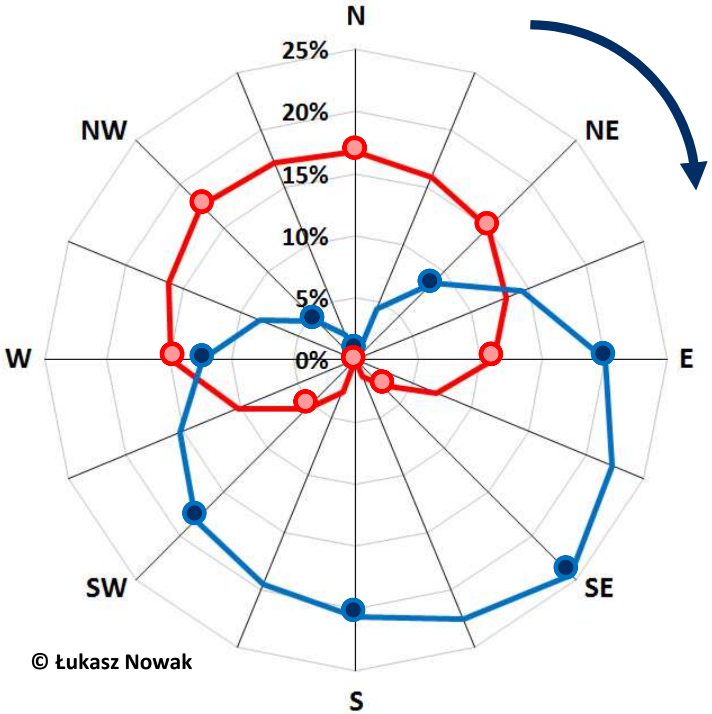
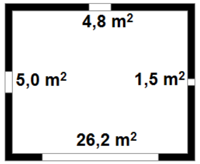
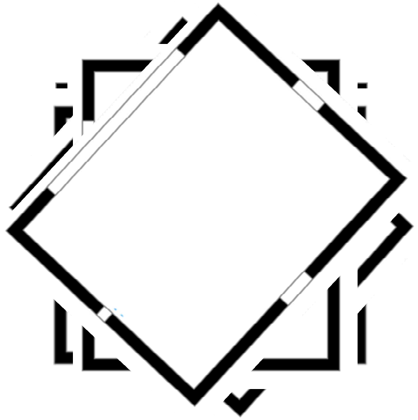
# Impact of internal parameters

## Orientation



**Increase in the energy demand for heating and cooling associated with the change of the location of the main, southern glazing of the building to a different direction.**

# Impact of internal parameters

## Room zoning and heating

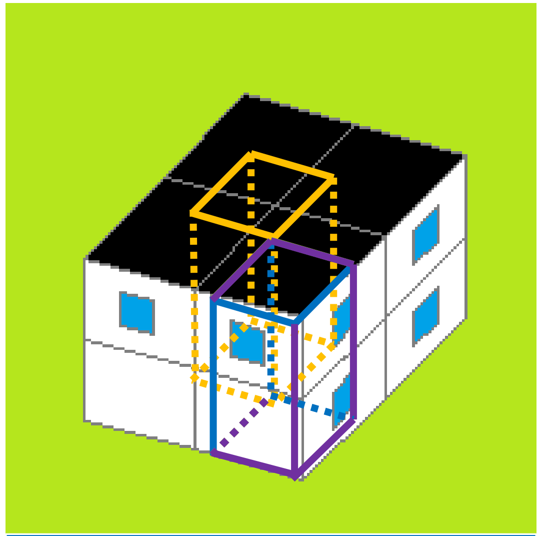
**We arrange the rooms (zones) in the building in such a way as to minimize heat transfer through the partitions, i.e. we are ZONING.**

**Zoning is recommended when we have rooms/areas:**

- **with different design internal air temperatures,**
- **for different purposes,**
- **auxiliary, technical or economic,**
- **used at different times of the day or in different ways (daylight, internal profits),**
- **which are unconditioned (unheated/uncooled).**

**Basic rules for zoning in a building:**

- **in the middle of the building - zones heated to higher temperatures,**
- **from the outside, buffer zones (unheated),**
- **day (living) zone from the South,**
- **technical rooms or rooms not requiring daylight from the North**



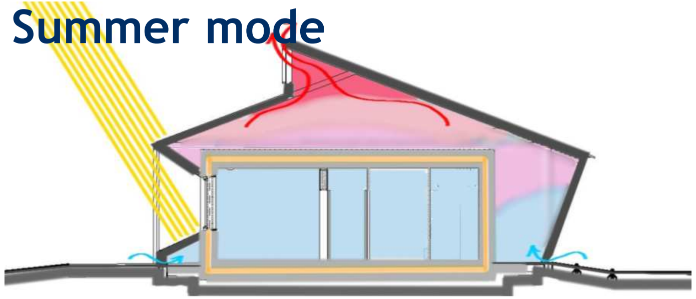
**ROOM ZONING VS ENERGY DEMAND**

| Bathroom placement | Inside | At corner |
|---|---|---|
| $EU_H$ index increase | | +4% |
| EP index increase | | +2% |

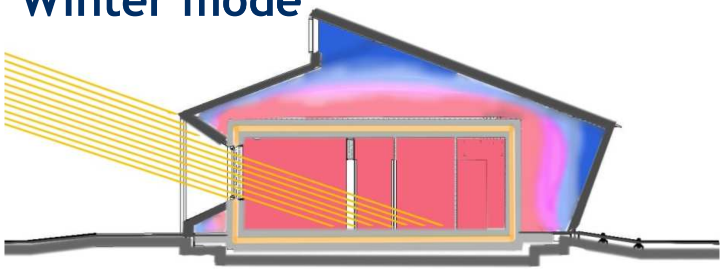
# Impact of internal parameters

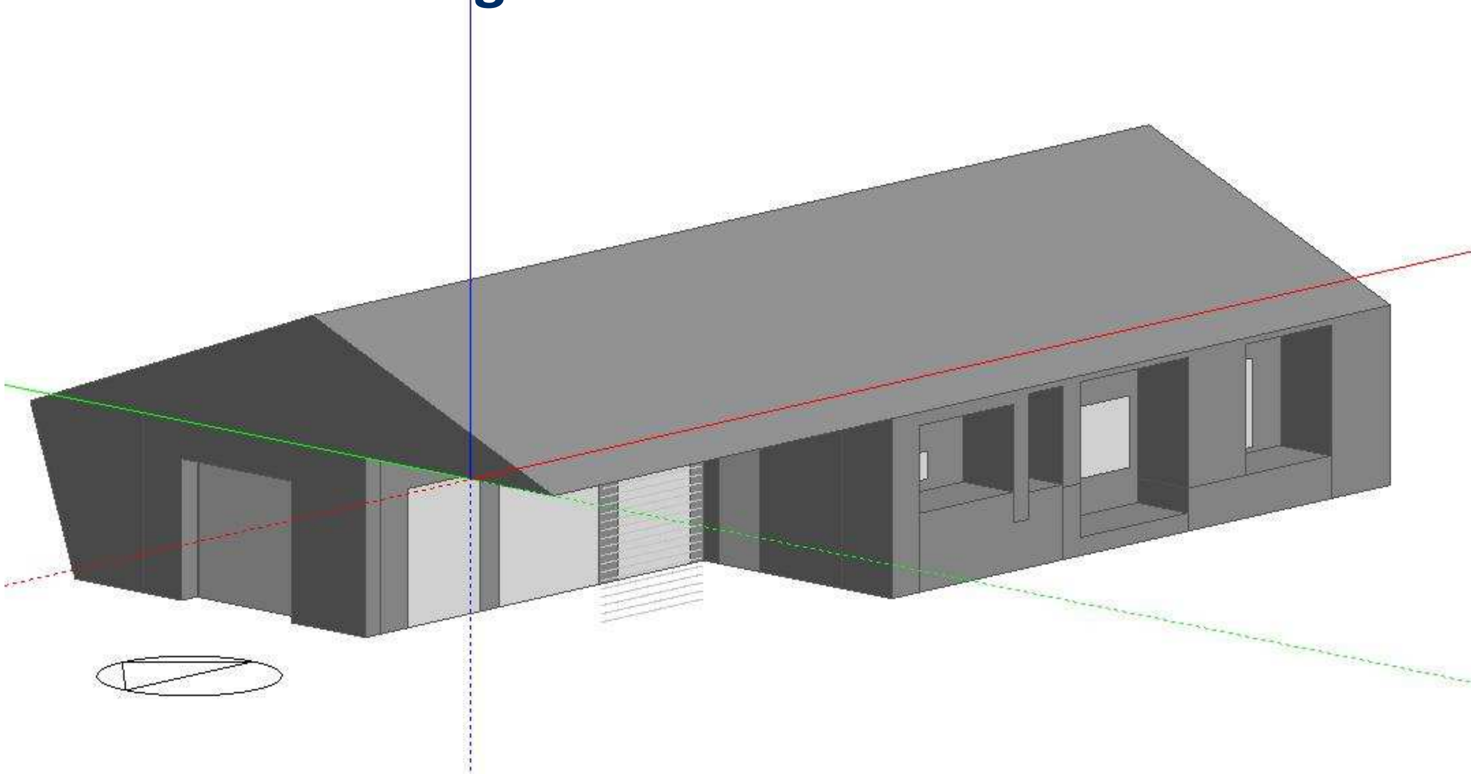
## Buffer zones – Double Skin Facade building

Summer mode



Winter mode





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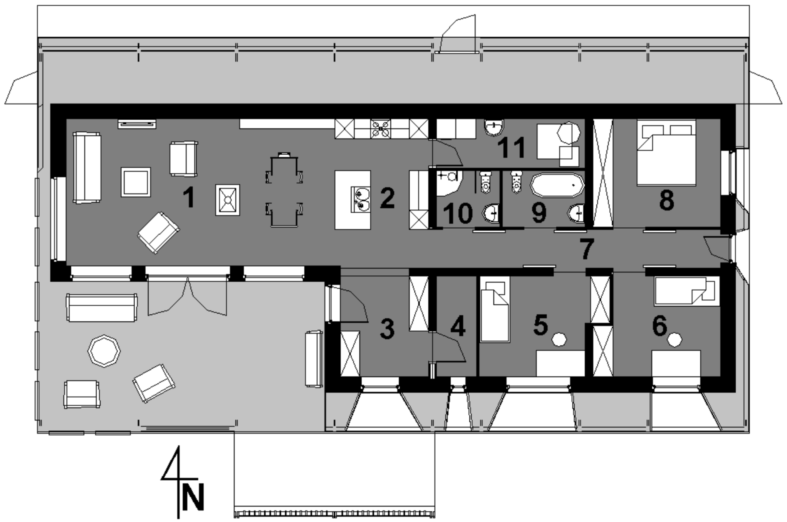
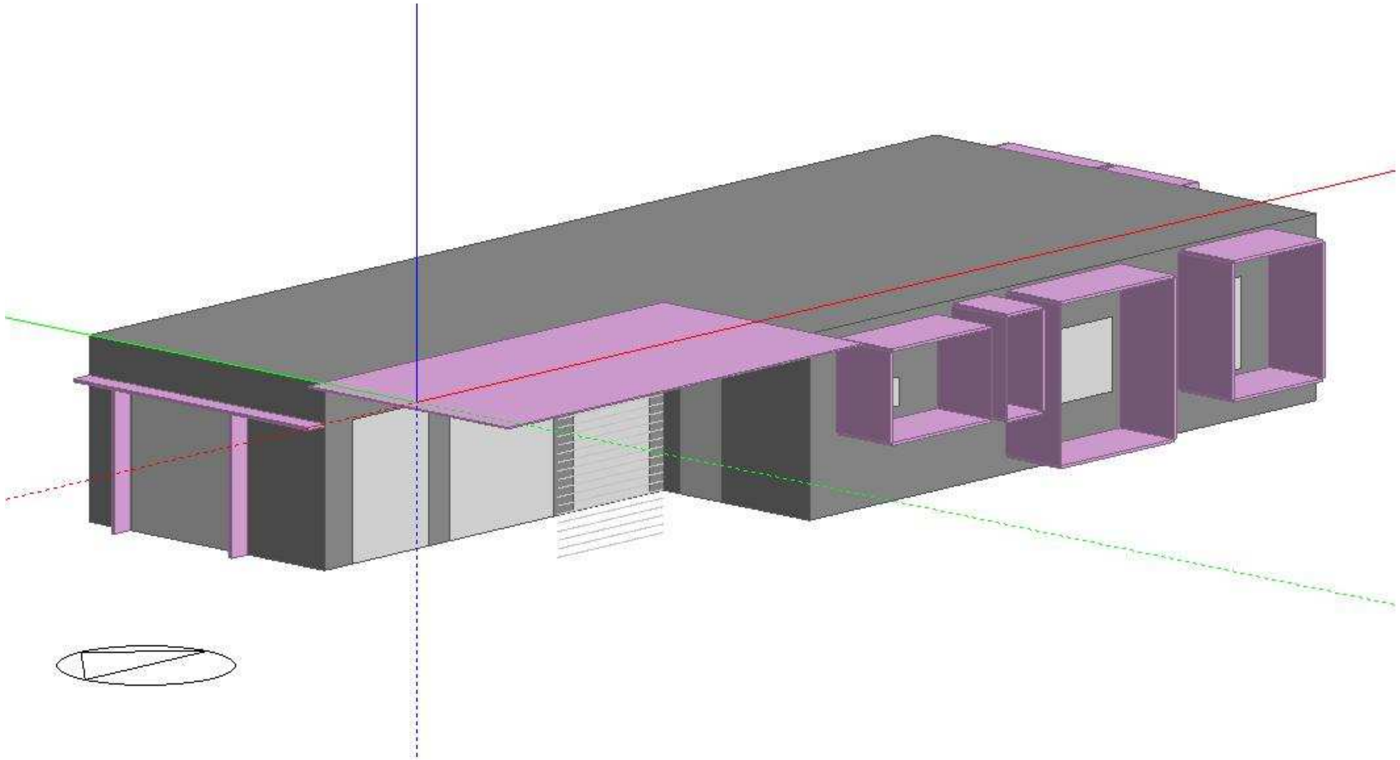
# Impact of internal parameters

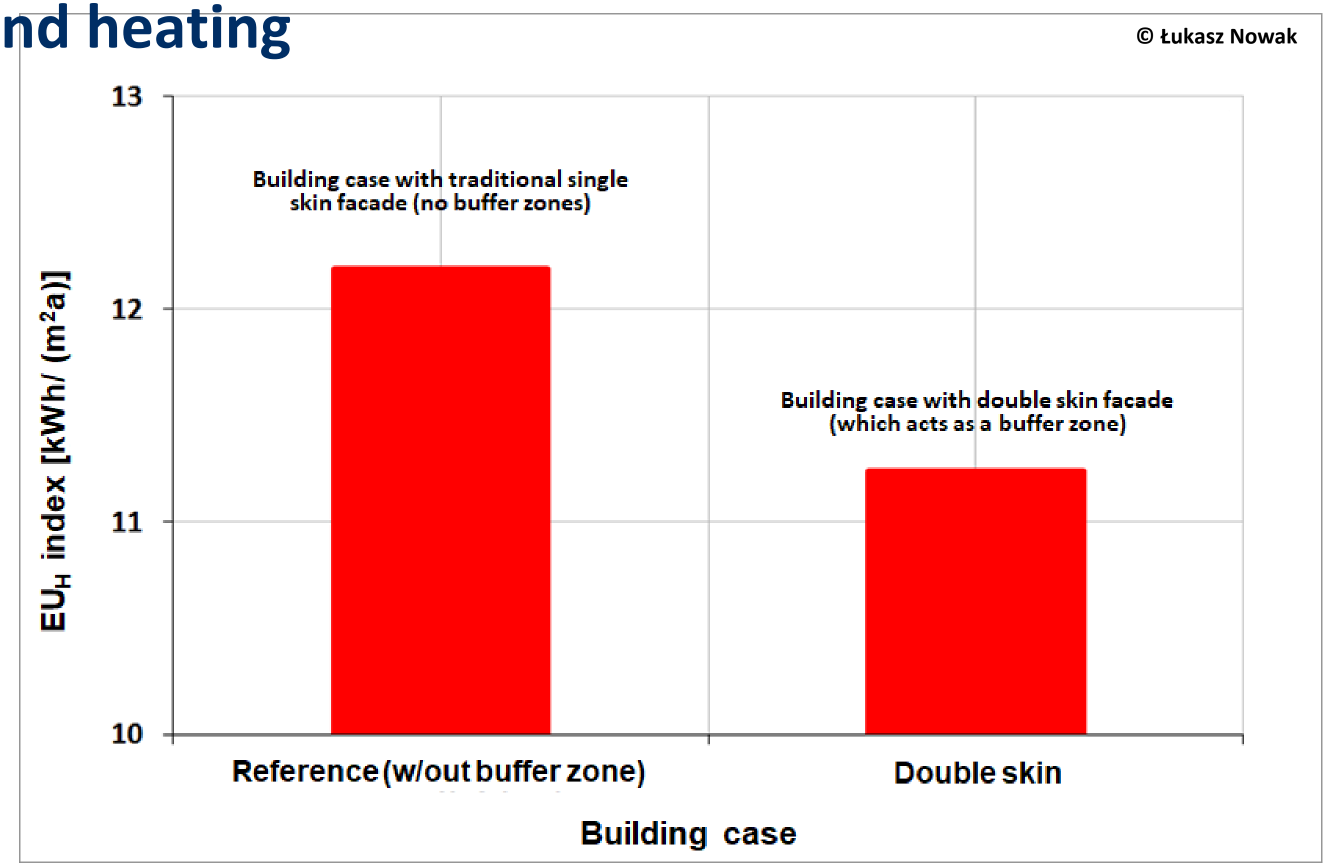
## Buffer zones



# Impact of internal parameters

## Buffer zones and heating

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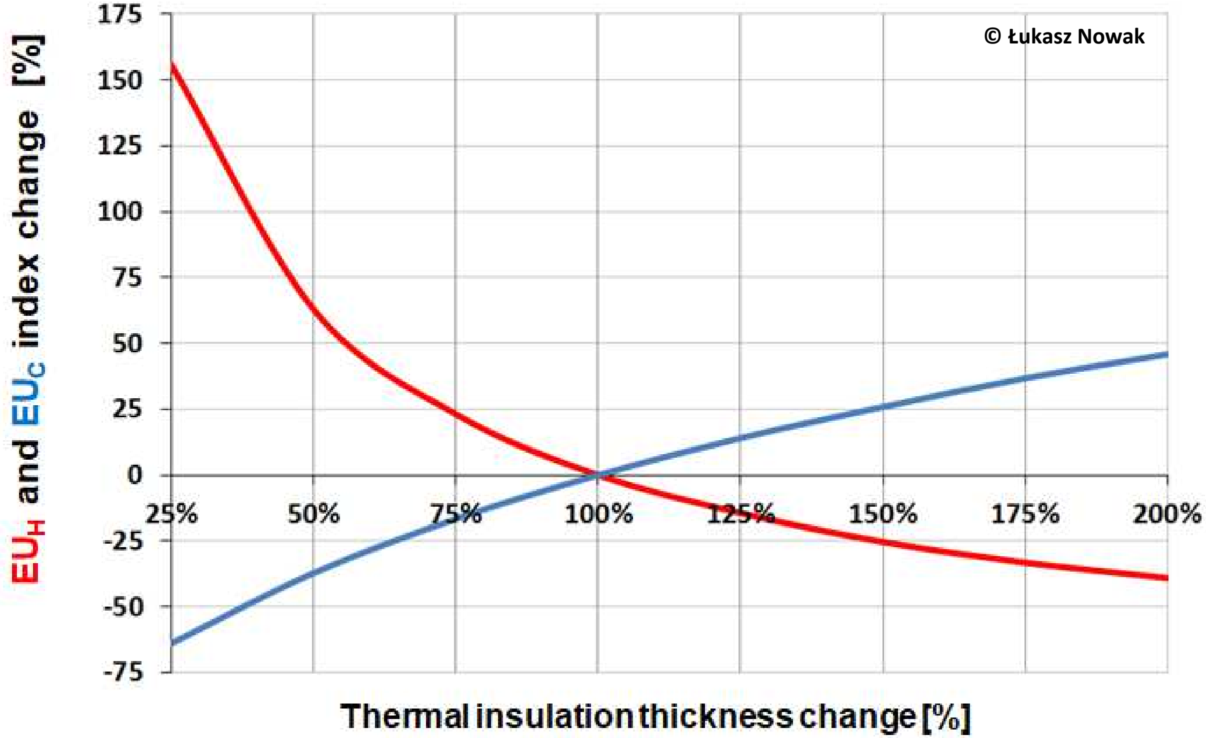
# Impact of internal parameters

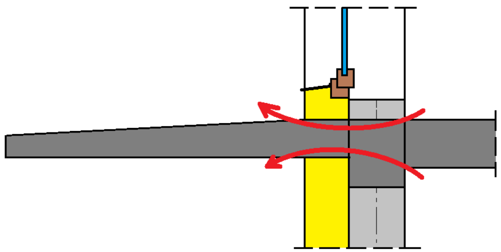
## Thermal insulation thickness



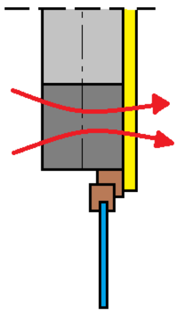
# Impact of internal parameters

## Thermal insulation and thermal bridges

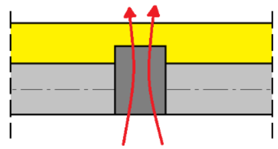
- **Breaking the continuity of the insulation,**



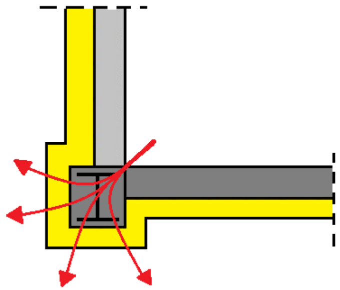
- **Local inclusion of elements/materials of high thermal conductivity,**



- **Reduction of thermal insulation thickness**



- **Complicated element geometry**



- **Incorrect design and/or execution decisions**

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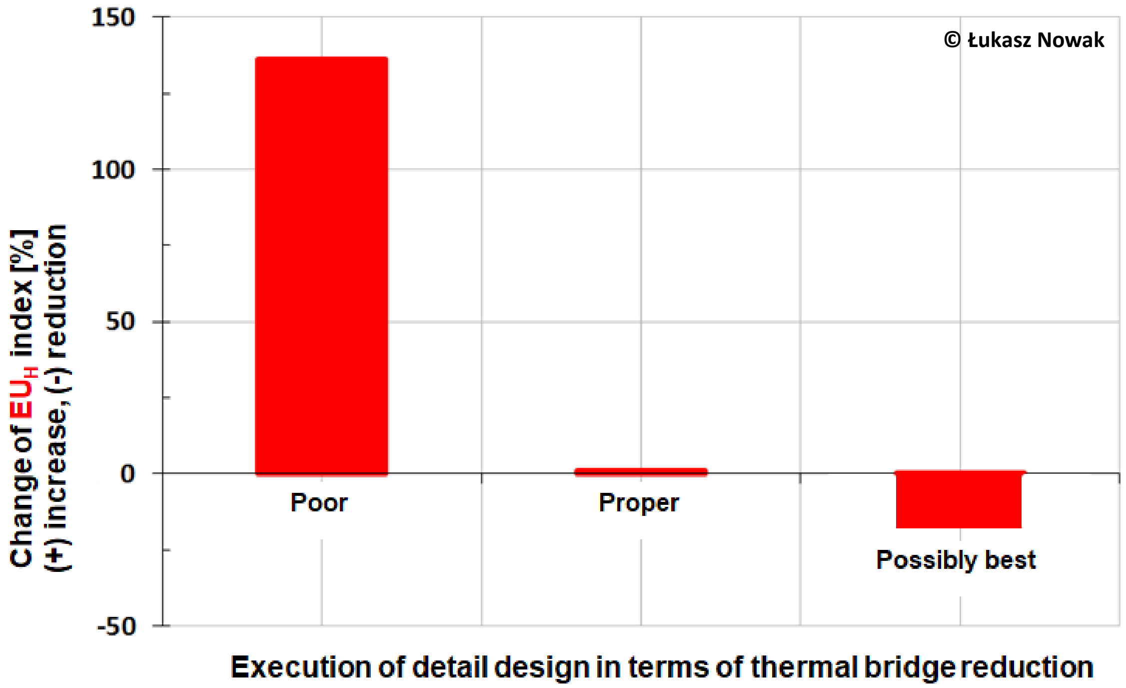
# Impact of internal parameters

## Thermal bridges and heating




- **thermal bridges practically cannot be eliminated - the designer's task is to minimize their impact (additional heat flow),**
- **it can be considered that if the thermal bridges in construction details will be:**
  - **up to 10% of transmission heat losses - these are good solutions,**
  - **up to 5% - very good solutions.**

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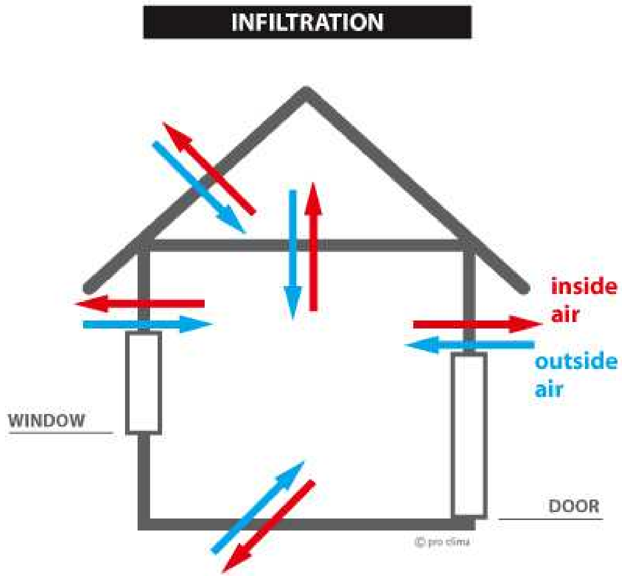
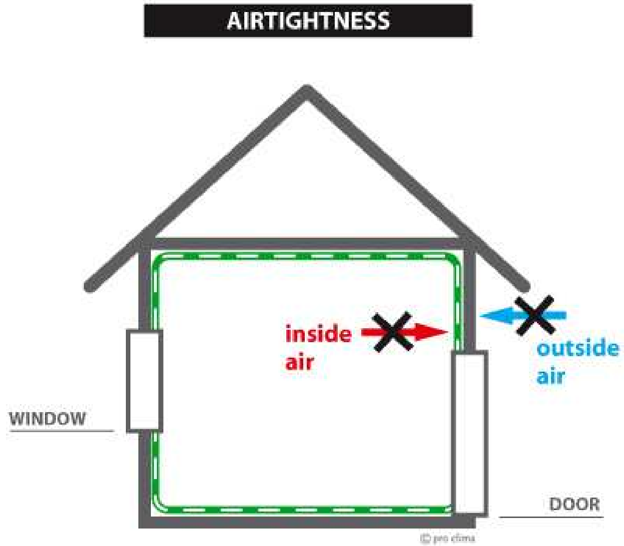
# Impact of internal parameters

## Airtightness




Uncontrolled air movement through the building envelope.




Preventing uncontrolled air movement (infiltration) through the building envelope.



**Airtightness - building parameter related to uncontrolled infiltration or exfiltration of air due to the presence of micro-leaks in the building envelope (cracks, leaks in joints, gaps, etc.).**

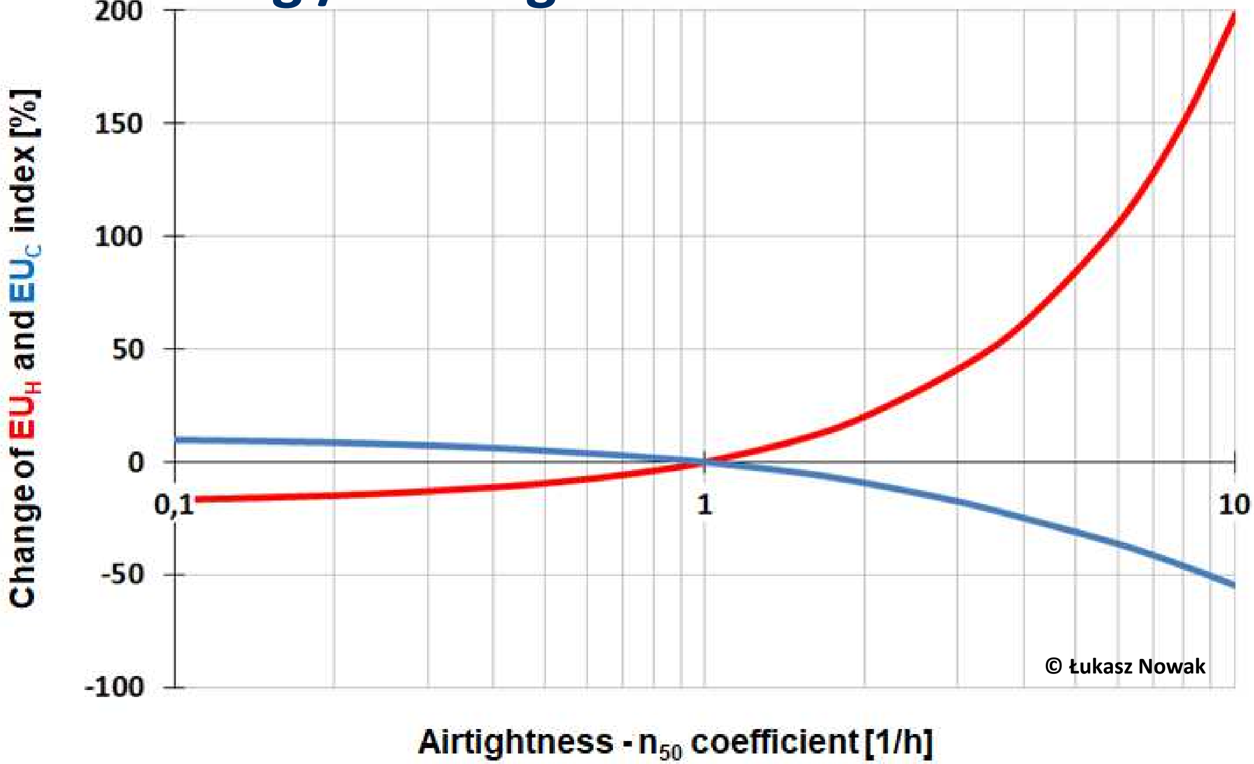
# Impact of internal parameters

## What causes air leakage?

- incorrect adjustment of locks on windows and balcony doors,
- bad installation of windows or external doors - failure to use a sealing system,
- lack of internal plasters,
- unheated attic flaps with no seals,
- electrical and plumbing connections, wall switches, electrical sockets and lighting points (no hermetic boxes),
- cracks and holes in the mortar in the external partitions,
- poorly made connections of the vapor barrier foil in the roof.

# Impact of internal parameters

## Airtightness and heating / cooling



# Impact of internal parameters

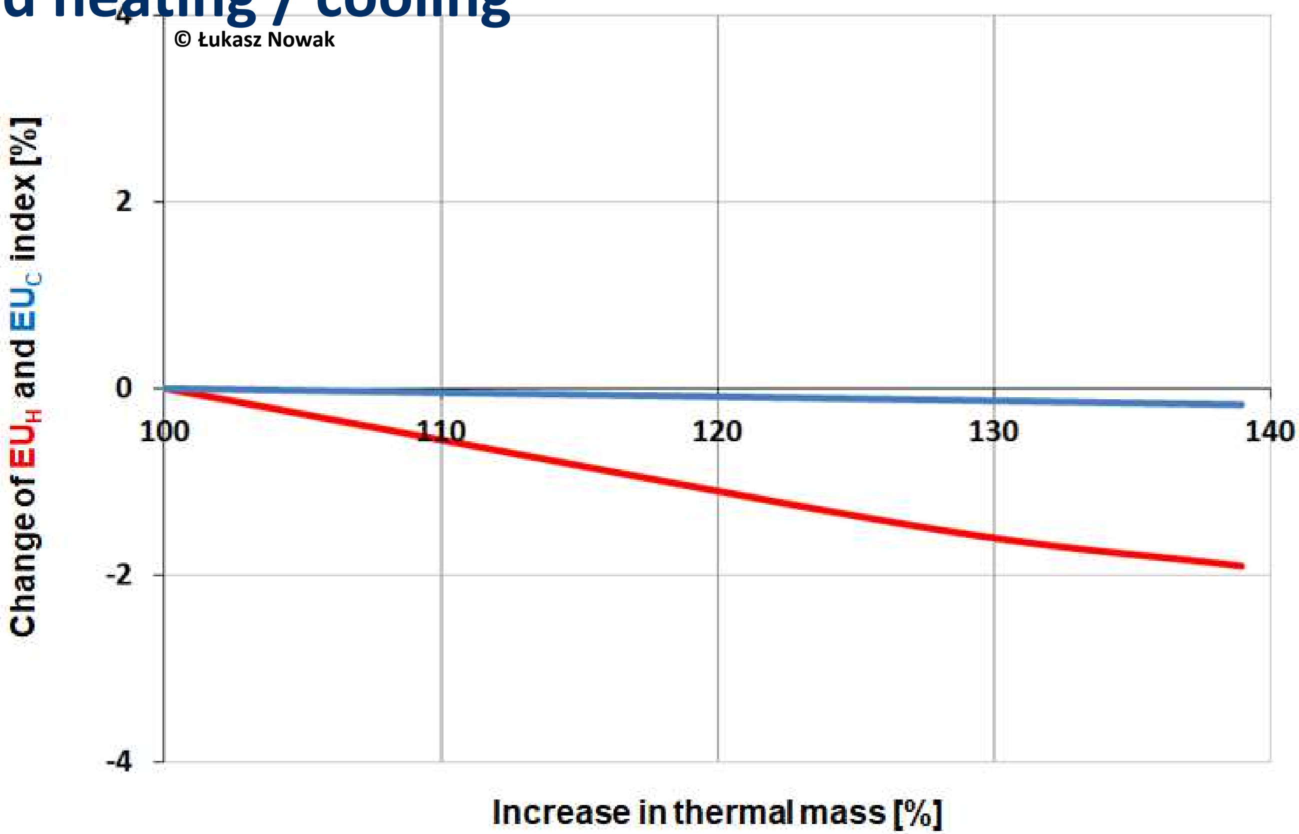
## Thermal mass

**Heat capacity =** Material density × Specific heat × Material layer thickness × Internally measured partition area

- the idea of operation - consists in "charging" (heating up) or "discharging" (cooling down) the thermal mass of the building
- it is useful when there are large fluctuations in temperature outside and/or inside
- the thermal mass should be exposed to direct sunlight (radiant heat from the sun) - it is then up to 3-4 times more effective than convection mass (solar heat transferred by warm air flow)

# Impact of internal parameters

## Thermal mass and heating / cooling

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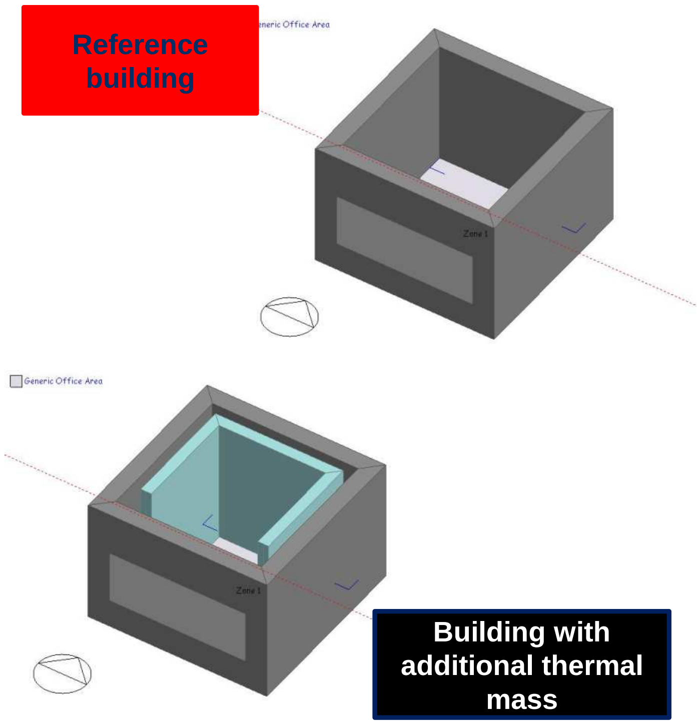
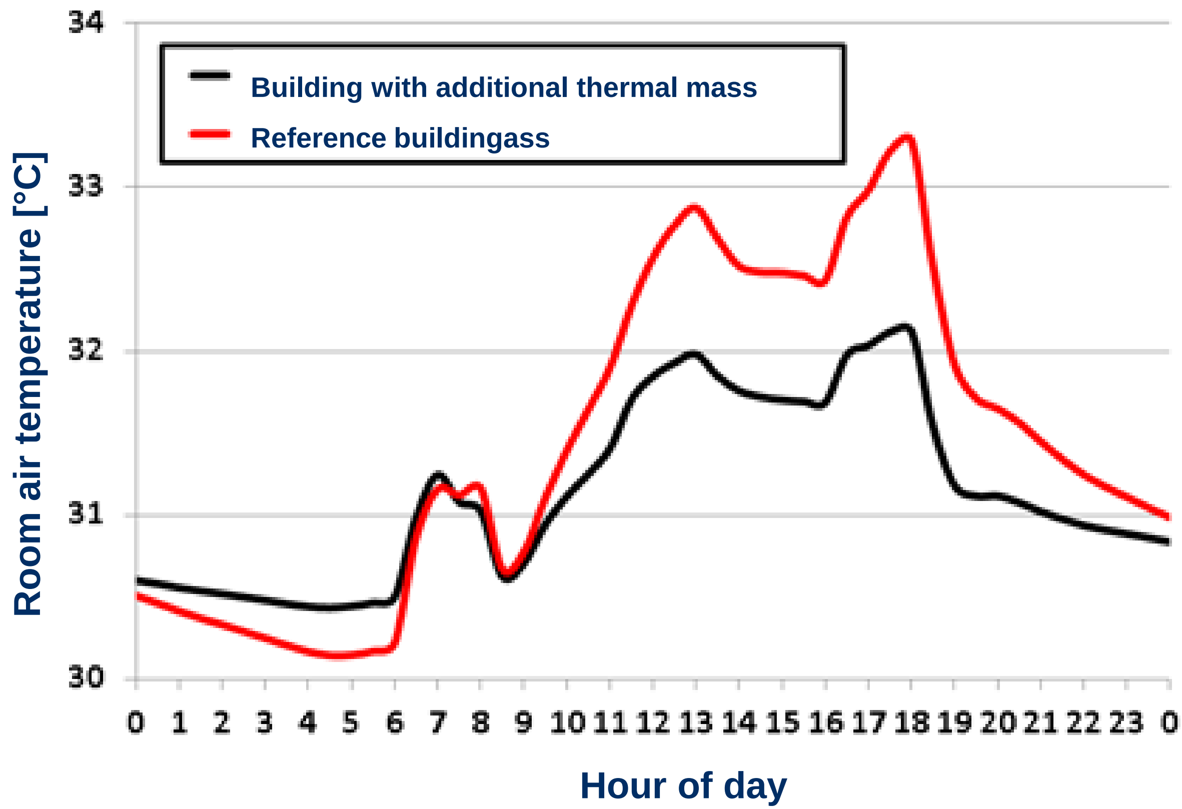
# Impact of internal parameters

## Thermal mass

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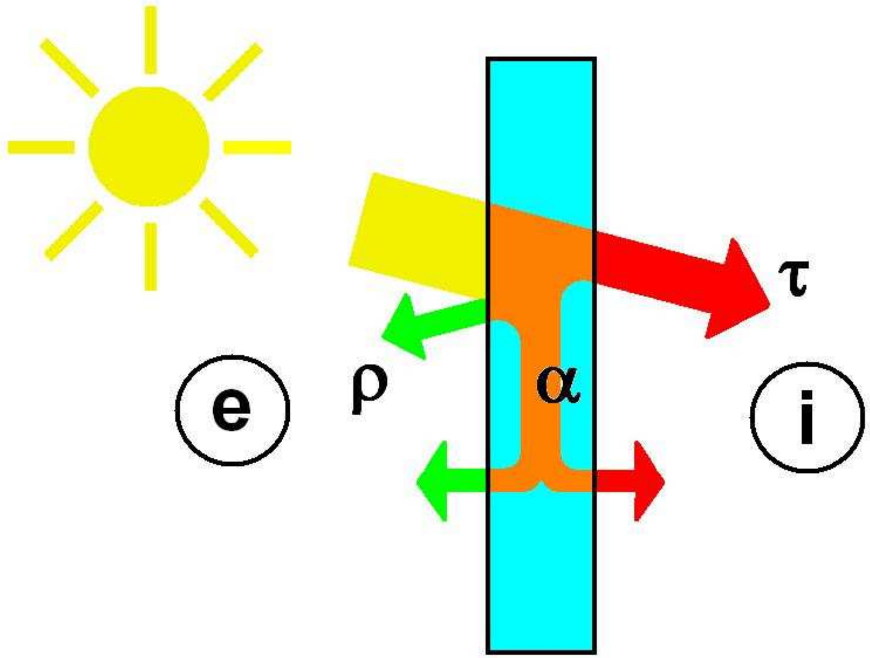
# Impact of internal parameters

## Glazing properties - introduction

***„...from an energy and environment viewpoint, it is well understood that the glazed component of a building is, at the same time, the weakest and the strongest element...”***

**(Clarke J.A., Janak M., Ruyssevelt P., 1996)**



# Impact of internal parameters

## Glazing properties – main parameters

- g or SHGC (*Solar Heat Gain Coefficient*) [-]
  Total Solar Transmittance coefficient
- DST (*Direct Solar Transmittance*) [-]
  Direct Solar Transmittance coefficient
- LT (*Light Transmittance*) [-]
  Light Transmittance coefficient
- $U_g$ (but for whole window its $U_w$) [W/(m²K)]
  Thermal transmittance coefficient for glazing set

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# Impact of internal parameters

## Glazing properties – other parameters

| | |
|---|---|
| **Thermal insulation** | |
| Thermal transmittance coefficient for glazing set | $U_g$ [W/(m²K)] |
| Thermal transmittance coefficient for frame | $U_f$ [W/(m²K)] |
| Thermal transmittance coefficient for window | $U_w$ [W/(m²K)] |
| Linear thermal transmittance coefficient for frame- glazing thermal bridge | $\Psi_g$[W/(mK)] |
| **Solar energy transmittance** | |
| Solar heat gain coefficient | SHGC [-], g [-], SF [-], TST [-], TSET [-] |
| **Daylight transmittance** | |
| Light transmittance coefficient | LT [-], VT [-], $T_V$ [-] |
| **Airtightness (air infiltration)** | |
| Air infiltration coefficient | a [$m^3$/(mhdaPa$^{2/3}$)] |
| **Acoustic insulation** | |
| Weighted sound redution index | $R_w$ [dB] |
| Spectrum adaptation term for pink noise | C [dB] |
| Spectrum adaptation term for traffic noise | $C_{tr}$ [dB] |
| **Others** | |
| Frame material, Window size and geometry, Frame share, Number of wings, Opening type etc. | |

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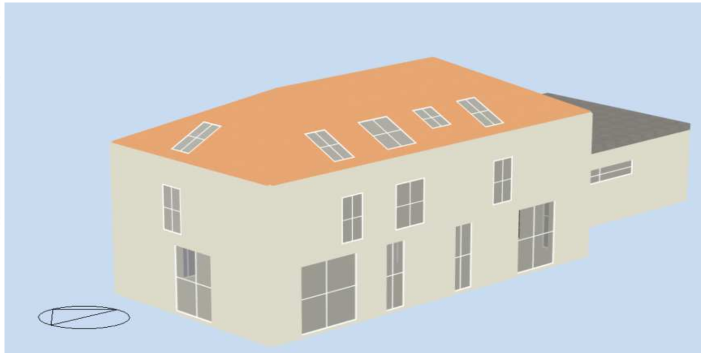
# Impact of internal parameters

## Glazing properties – window area

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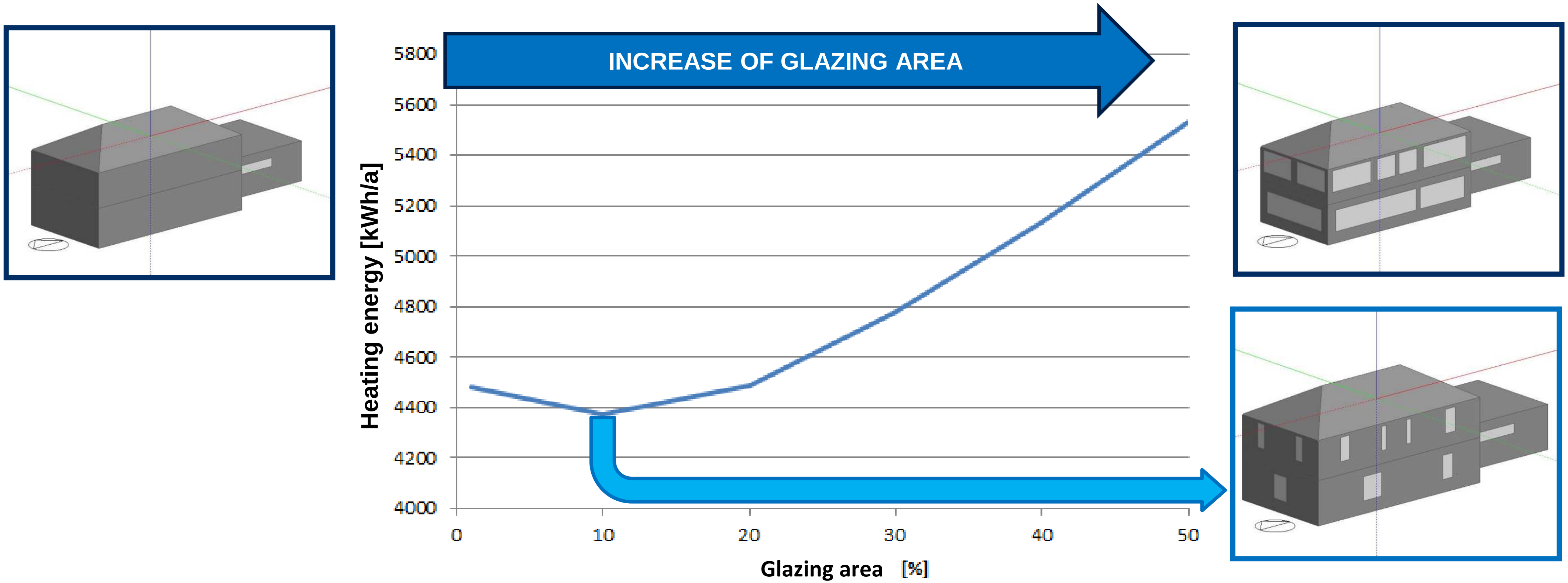
# Impact of internal parameters

## Glazing properties – window area

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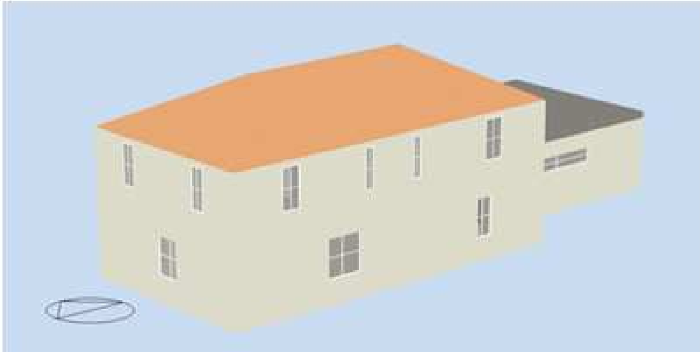
# Impact of internal parameters

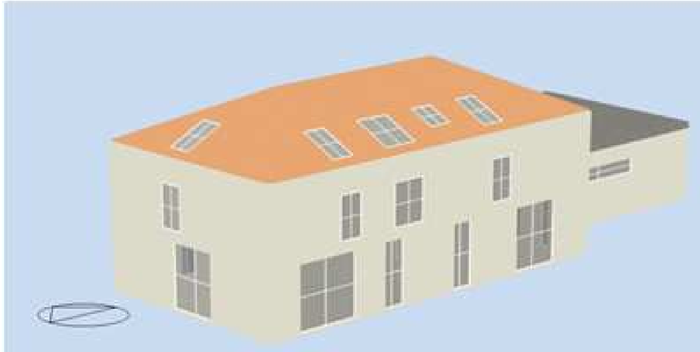
## Glazing properties

### Uniform glazing



| Facade part | Orientation | Partition area [m²] | Window area [m²] | Glazing percentage [%] |
|---|---|---|---|---|
| Walls ground floor | N | 35,5 | 3,6 | 10 |
| | W | 19,0 | 1,9 | 10 |
| | S | 35,5 | 3,6 | 10 |
| | E | 19,0 | 1,9 | 10 |
| Walls attic | N | 31,4 | 3,1 | 10 |
| | W | 16,8 | 1,7 | 10 |
| | S | 31,4 | 3,1 | 10 |
| | E | 16,8 | 1,7 | 10 |
| Roof | N | 36,5 | 3,6 | 10 |
| | W | 13,2 | 1,3 | 10 |
| | S | 36,5 | 3,6 | 10 |
| | E | 13,2 | 1,3 | 10 |
| | Average glazing percentage | | | 10 |

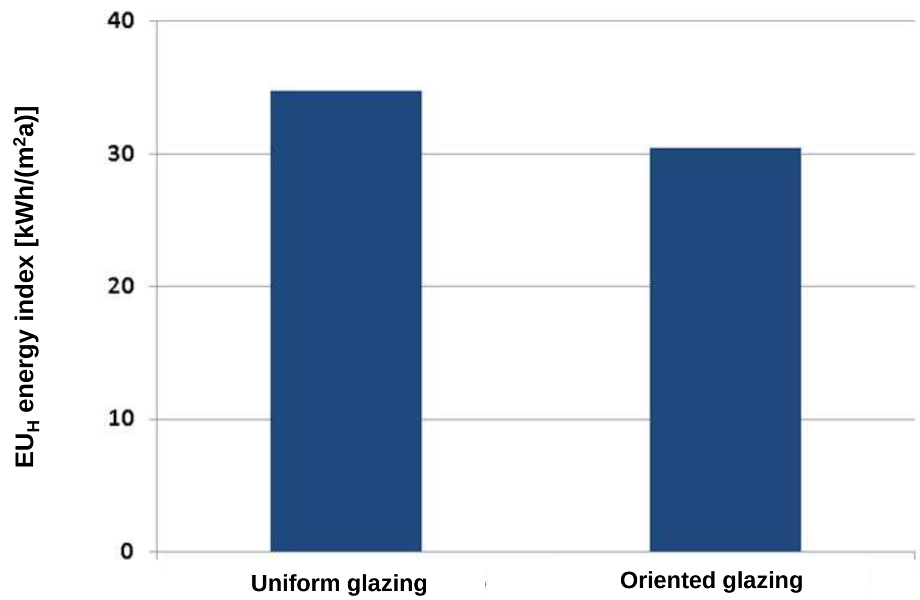
### Oriented glazing



| Facade part | Orientation | Partition area [m²] | Window area [m²] | Glazing percentage [%] |
|---|---|---|---|---|
| Walls ground floor | N | 35,5 | 2,8 | 8 |
| | W | 19,0 | 4,3 | 23 |
| | S | 35,5 | 14,0 | 40 |
| | E | 19,0 | 2,0 | 11 |
| Walls attic | N | 31,4 | 0,0 | 0 |
| | W | 16,8 | 1,3 | 8 |
| | S | 31,4 | 4,3 | 14 |
| | E | 16,8 | 1,3 | 8 |
| Roof | N | 36,5 | 0,7 | 2 |
| | W | 13,2 | 1,1 | 8 |
| | S | 36,5 | 4,5 | 12 |
| | E | 13,2 | 1,1 | 8 |
| | Average glazing percentage | | | 15 |

# Impact of internal parameters

## Glazing properties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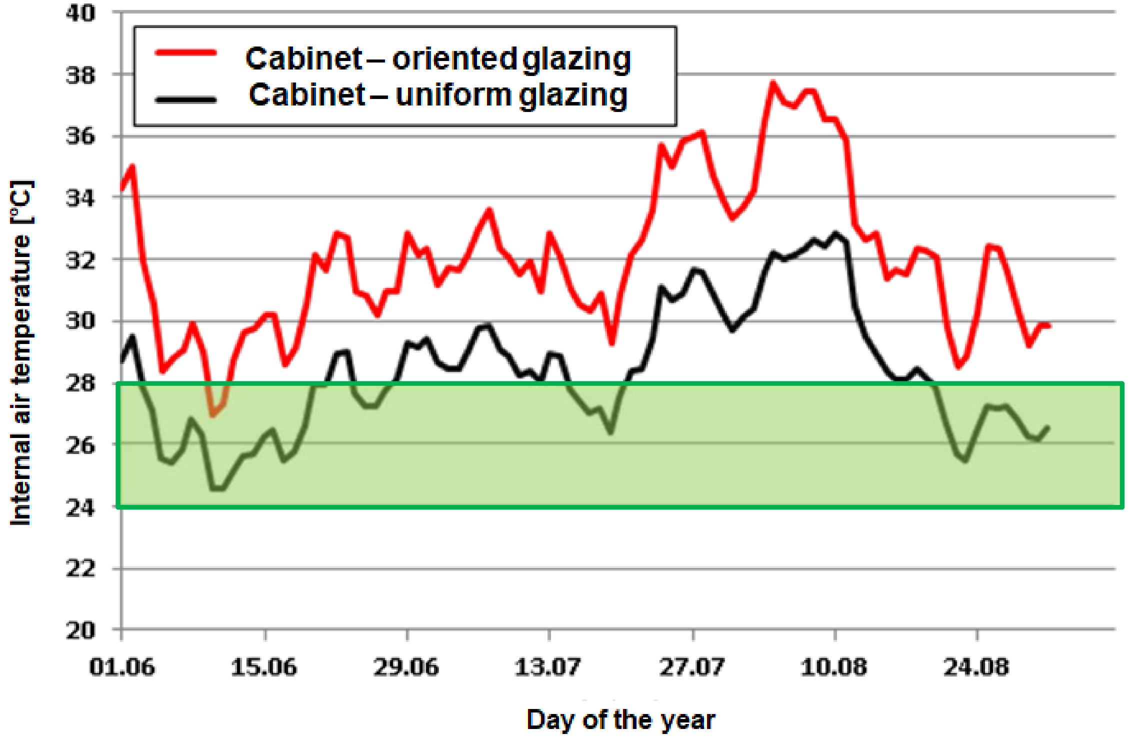
# Impact of internal parameters

## Glazing properties

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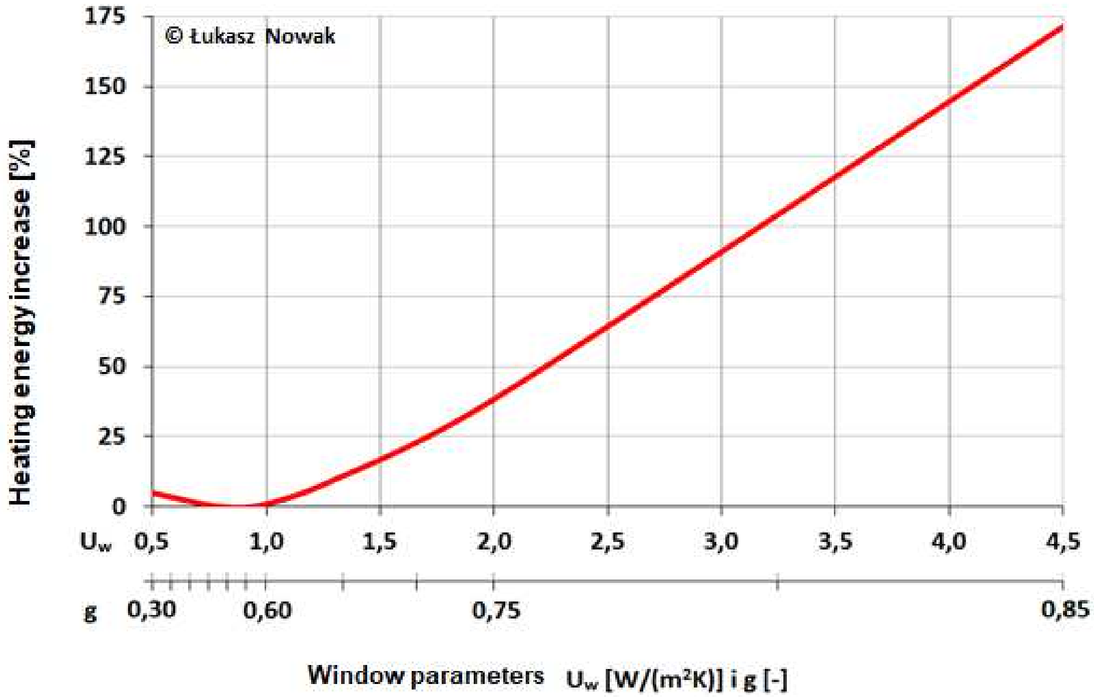
# Impact of internal parameters

## Glazing properties – window type (old, new and passive)

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# Summary

- **A building is a system of combined vessels - many decisions have an *impact on various design levels***
- **It is impossible to meet all of the goals at the highest level, but *a satisfactory level means no weak spots*.**
- **Many decisions have to be made *early in the design* process**

***Sustainability* is not a *Topic* but an *Attitude*.**

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# Design principles

- **K.I.S.S.** *Keep It Simple, Stupid.*
- **S.I.S.O.** *Shit in, Shit out.*
- **Cheap, Fast, Good** ...pick two

Blended Intensive Program

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# Sustainable and Resilient Infrastructure and Buildings

## 1 February 2022 – 30 April 2022

# Energy performance of buildings in terms of their sustainability


**Łukasz Nowak, Dr Eng.**

**Wrocław University of Science and Technology**