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Reducing heat losses – first step toward nZEB

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Abstract. Energy consumption for space heating and air conditioning holds a significant share in the total energy consumption, among them residential and tertiary buildings being on the first places. This strong energetic dissipative character of different elements of the building envelope offers multiple possibilities of intervention aiming to reduce the heat losses. The Romanian requirements concerning the elements evaluating conformity with the Standard C107-2010 and the Order no.2641/2017 are given with a focus on thermal bridges influence aside with a short description of different ways to estimate this influence in EU countries. The paper presents in general, concepts to be used in order to achieve the nZEB standard developed by the Energy Performance of Building Directive having in mind a mitigation of greenhouse gases, GHG emission. In this context, is presented the role of balcony elements as undesirable “heat exchanger” and this thermal bridge is depicted together with some ways to avoid this inconvenience.

1. Introduction

Energy consumption in the residential sector holds a relative significant share being responsible for the Greenhouse Gases, GHG emission, specifically the carbon dioxide, CO₂ contributing to the climate change. Reducing the climate change effects implies some measures and technical issues necessary to be implemented by professionals to improve the energy efficiency of buildings. In this context, the energy auditor holds a role to play not only when certifying the energy performance of buildings but also in case of consultancy given to architects during the design phase.

Improving the energy efficiency needs a high level of thermal insulation and airtightness as part of design process of new buildings, and an effort to renovate the existing ones based on clear principles, too. Traditional design and practice have been concentrated on the envelope insulation, i.e. on exterior walls, the floor and the roof of buildings aiming to reduce their thermal transmittance, U. Thermal bridging is an important consideration in case on nearly Zero Energy Building design.

Until recently little attention was paid to heat losses involved by joining elements and by building openings, resulting in uncontrolled air infiltration. Without measures limiting thermal bridges from joining elements, and a better envelope sealing, the share of heat losses caused by them tends to increase, as the insulation standards have evolved, in the context of the renovation of the building envelope aiming to a better efficiency. To highlight the significance of thermal bridges it must be pointed out that the effect of the thermal bridges on the energy requirement can equal, or even exceed, the energy provided by the solar collectors for domestic hot water, which is beyond the current concerns of the general public.

As a result, it is not sufficient to estimate the U-value for main parts of walls, roofs and floors, being necessary to consider the non-repeated thermal bridges.



Researches have shown that about 30% of the total heat loss of building envelopes result from thermal bridges, and annual CO₂ emissions can be reduced by up to 10% through the use of the enhanced construction details and an improved airtightness. Therefore, it is necessary as far as possible the design and execution of works to be based on the principles that lead to improved performance by over 85% in the case of lintels, the joints between walls and floor, ceiling and wall and of the gable respectively [1].

2. Compliance of the building thermal performance with the Romanian requirements

The Romanian Standard C107-2010 [2] defines a limit for the annual energy demand for heating, Q measured in kWh/(m² year)

$$Q < QN \quad (1)$$

In case of residential buildings this limitation depends on the surface area to volume (A/V) ratio and it makes a distinction that refers to the design contracting date: before, or after January 1, 2011, as depicted in figure 1.

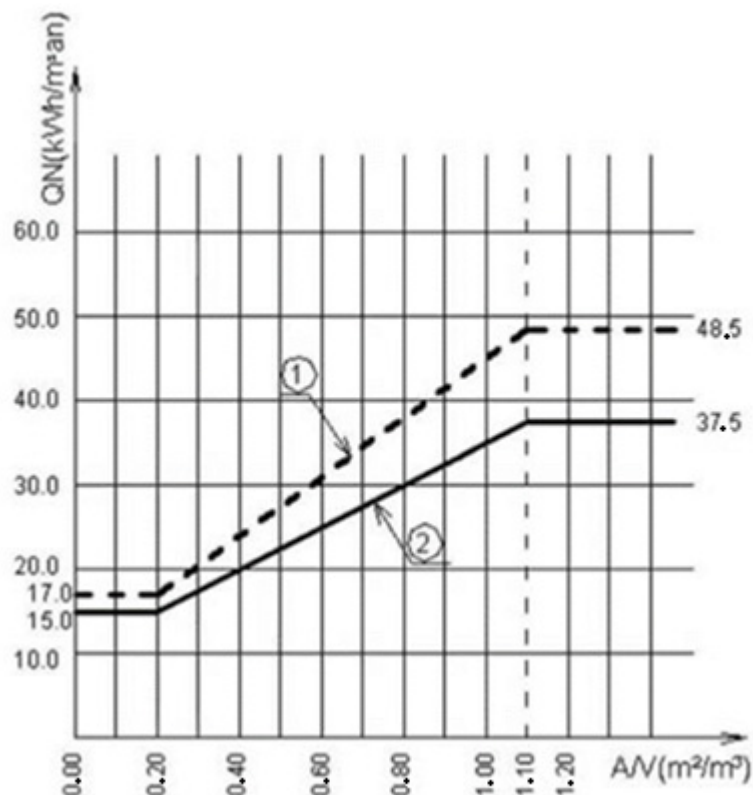


Figure 1. The Annual normative energy demand for heating QN , in case of residential buildings correlated with the Surface area to volume (A/V) ratio: 1 – before January 1, 2011; 2 – after January 1, 2011.

Later, in 2017 the Order no. 2641 specified the maximal annual energy consumption from non-renewable sources $q_{an, max}$ as 153 kWh/(m² year) for low-rise residential buildings (ground floor and no more than 3 stories), and 117 kWh/(m² year) for buildings higher than ground floor and 3 stories, respectively.

Considering the thermal insulation of a building envelope, the Standard C107-2010 and the Order no. 2641/2017 [3] both require that thermal insulation overall coefficient, G , related to the building-as-a-whole, to be limited by the normative overall coefficient of thermal insulation of the building, GN :

$$G < GN \quad (2)$$

The thermal insulation overall coefficient, G , expressed in $W/(m^3K)$, depends on the surface area to volume (A/V) ratio, and on the mean thermal resistance, R_m , and on the number of air changes per hour, ACH:

$$G = \frac{A/V}{R_m} + 0.34 \cdot ACH \quad (3)$$

The normative values of the overall coefficient GN are tabulated in the Standard C107-2010 and in the Order no. 2641/2017 being a function of the surface area to volume (A/V) ratio and having the number of floors, N as parameter. Figure 2 presents in a graphical form these tabulated values, GN and the calculated values G must be under the curve corresponding to the number of floors, N .

As can be noted, the surface area to volume (A/V) ratio, has higher values for single-family houses than in case of multifamily buildings. As a result, to keep $G < GN$ – the requirement of the standard – makes necessary a better insulation for single-family houses, i.e. higher values for the mean thermal resistance, R_m is necessary.

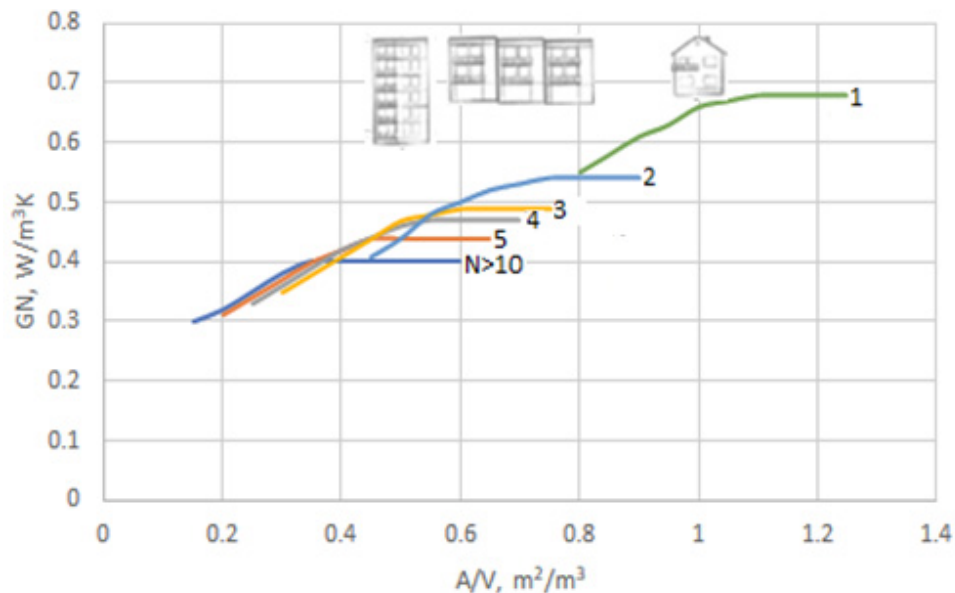


Figure 2. The normative overall coefficient GN correlated with the surface area to volume (A/V) ratio and having the number of floors, N as parameter.

Besides the above requirement, $G < GN$, the thermal resistance, R' of different elements of the building envelope must respect the condition

$$R' > R'_{min} \quad (4)$$

where R' refers to the corrected value that takes into consideration the influence of thermal bridges and the normative values for R'_{min} in case of different building elements are specified by C107-2010 and by the Order no. 2641/2017, being presented in figure 3.

Thermal bridges result in an overall reduction in thermal resistance of the envelope element with a higher heat transfer / heat leaks associated with increased carbon emissions, and a thermal discomfort.

Thermal bridges can occur in different locations of an envelope, usually at junction between elements of the envelope, like balcony-wall, slab-grade, floor-wall, roof or ceiling-wall, window, or door-wall etc.

Thermal bridges are characterized by two- or three-dimensional heat transfer, with fluctuations of temperatures, meaning a non-steady-state process.

To avoid calculation difficulties of such a complex model the concept of thermal bridge was introduced. Thermal bridging is an important consideration in Low energy Building design. It has been estimated that up to 30% of the heat loss in a well-insulated building is through these non-repeating thermal bridges.

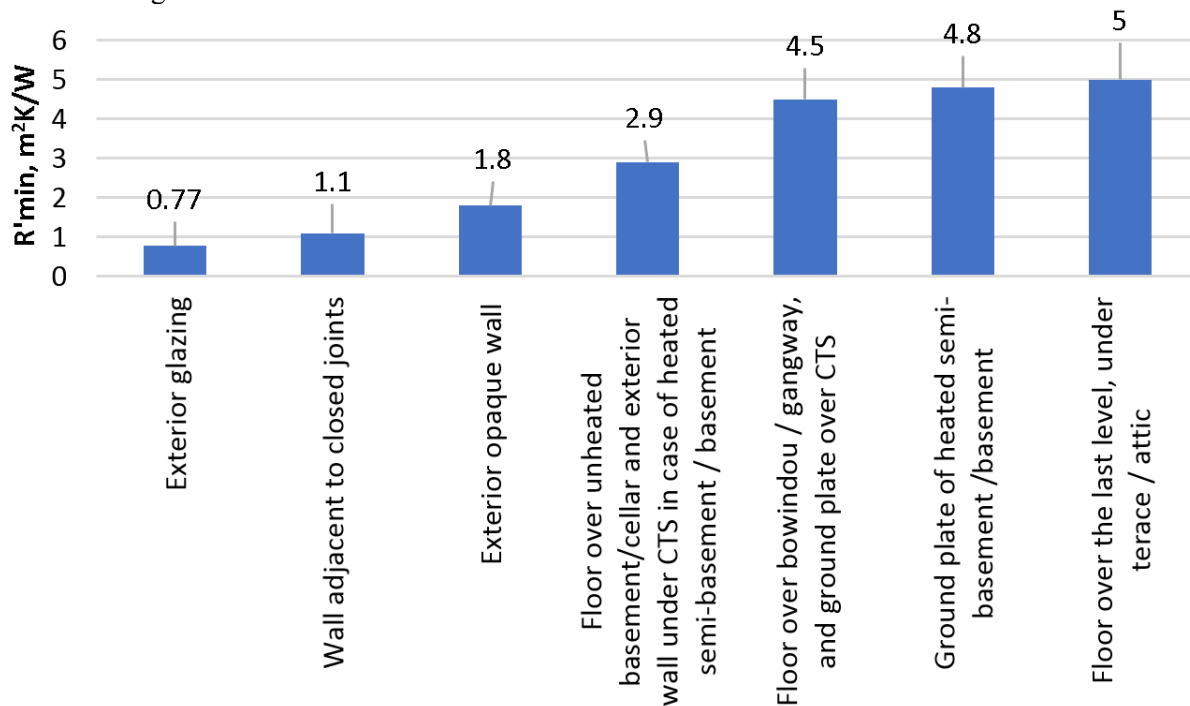


Figure 3. The normative values for corrected thermal resistance, R'_{min} specified by the Standard C107-2010 and by the Order no. 2641/2017.

3. Thermal bridges and insulation

The corrected thermal resistance, R' as a reverse value of the transmittance, U' can be written as

$$U' = \frac{1}{R'} = \frac{1}{R} + \frac{1}{R_{\psi}} + \frac{1}{R_{\chi}} \quad (5)$$

where, besides the unidirectional (or repeating) thermal resistance, R some other two elements are considered: Thermal resistance of linear (or non-repeating) thermal bridges, R_{ψ} , and Thermal resistance of point thermal bridges, R_{χ} , measured in m²K/W and defined as

$$R_{\psi} = \frac{A}{\sum(\psi l)} \quad (6)$$

$$R_{\chi} = \frac{A}{\sum \chi} \quad (7)$$

A linear thermal bridge adds an extra heat flow to the unidirectional one being specific for building elements junction like corners (floor-to-wall junction, balcony-to-wall or wall-lintels /jambes), or in case of the openings (windows, doors) installed in walls.

As mentioned before equation (6) the Thermal resistance of a linear thermal bridge, R_{ψ} , depends on the linear thermal transmittance, ψ expressed in W/(m K), and on its length, l .

Dividing the surface area A of the envelope by the sum of ψl calculated for all thermal bridges existing on this surface results in a value representing the resistance of linear thermal bridges, R_{ψ} . Cantilevered balconies and exposed slab edges are the most critical thermal bridges in a building envelope.

In case of a point thermal bridge, occurring in one spot, energy losses are caused by elements that penetrate the insulating layer, like anchor bolts, or curtain wall supports, fastening elements, steel balconies etc. The point thermal transmittance, χ specific for every situation is measured in W/K.

Considering that thermal bridges can result in additional heat losses, that impact the amount of energy required to heat a space in cold climates, it is obvious the necessity to prevent thermal bridges by creating thermal breaks.

From figure 4 it can be noticed that a thermal resistance of a linear thermal bridge, R_ψ having the same magnitude as the unidirectional thermal resistance, R will reduce to one half the corrected thermal resistance, R' when compared to R (factor r).

In case of a cumulated R_ψ being only 50% of R the corrected thermal resistance, R' will be lowered to about 35% of the unidirectional thermal resistance, R (point thermal bridges was neglected in this evaluation). As a result, heat will follow this low-resistance path resulting in higher heat losses.

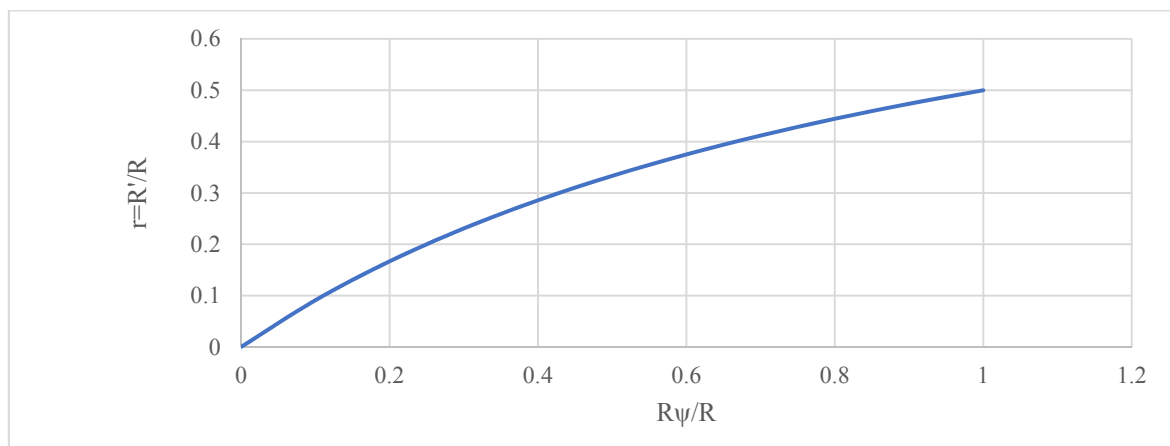


Figure 4. The influence of thermal resistance of a linear thermal bridge, R_ψ on the corrected thermal resistance, R' .

Heat loss is becoming significant when thermal bridges contribute to a lower thermal resistance of the envelope, as figure 5 shows.

Different linear thermal bridges have various influence on heat loss, depending on psi-value and on the corresponding length, but usually floor-to-wall and balcony-to-junction are on poll position followed by slab-on-grade, roof, or ceiling-to-wall junctions. Window-to-wall and door-to-wall junction can have a significant influence because of their number.

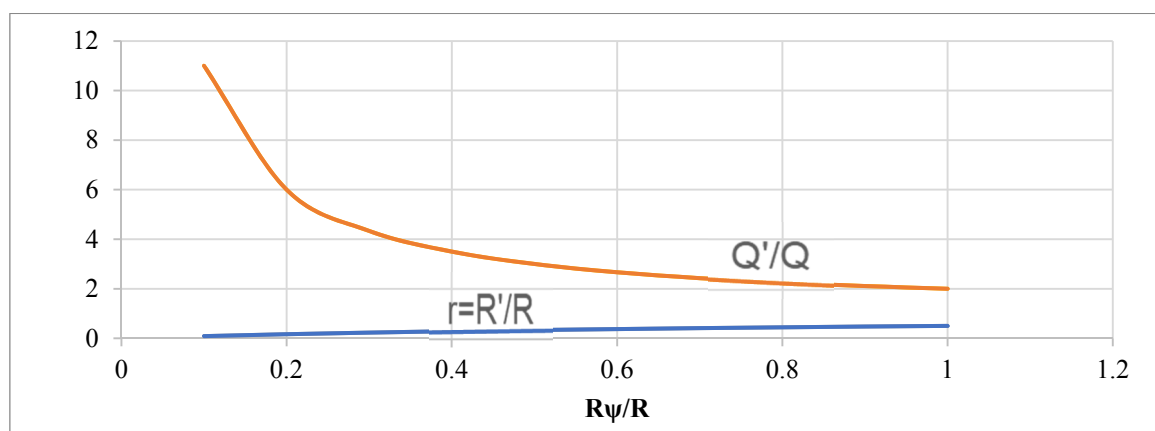


Figure 5. The thermal resistance of a linear thermal bridge, R_ψ is affecting the heat loss: the lower the R_ψ , the higher the heat loss Q' .

Evaluating the additional heat losses due to thermal bridges through the explicit method is the most accurate way but considering its tedious character it represents an important disadvantage. It is not only the evaluation of the lengths and the number of every type of thermal bridges, but the access to an atlas offering the psi-values is necessary too.

Reducing and avoiding thermal bridges is not only recommended but necessary. A continuous thermal insulation layer consisting of mineral wool, rigid foam, or polystyrene board is the first issue, which will be accompanied with double/triple pane windows with gas filler and low-emissivity coating for installed in thermally broken frames resulting from low conductivity material. Once the envelope is insulated the relative contribution of thermal bridges is amplified in the frame of the heat balance: ψ -values increase after the thermal insulation as a result of thicker layers near the thermal bridges [4]. Higher heat losses and lower temperatures on the adjacent interior surfaces will result with local condensation and a reduced comfort.

Lower temperatures inside the structure will be followed by supplementary stress in material elements with possible interstitial condensation resulting in damage due to humidity. Critical building elements are masonry lintels, floor-to-wall junctions, window-to-wall and door-to-wall junctions, steel studs and others.

Small buildings like single family houses having an unfavorable surface area to volume (A/V) ratio, need to be thermal bridge-free as much as possible. Cantilevered balconies are examples of critical thermal bridges involving expensive compensation measures and preventing high standards as the passive house.

3.1. Cantilevered balconies before and after wall insulation

Balconies as an extended surface through which occurs a heat exchange increases heat losses of the building: it works like a heat exchanger an undesirable one having higher temperatures in comparison with the near surfaces, as shown in figure 6.

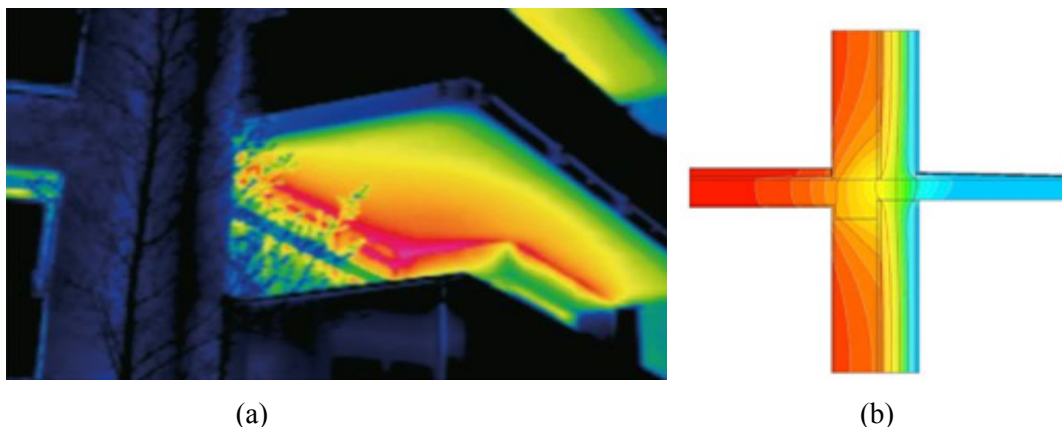


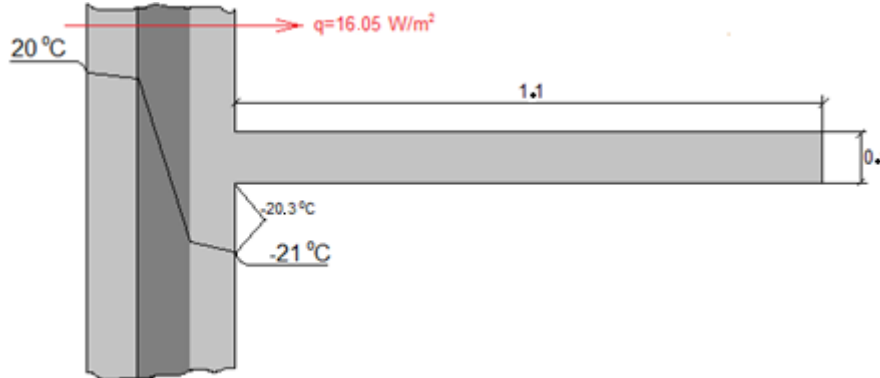
Figure 6. Thermal bridge of a balcony slab: a) infrared scan; b) numerical simulation.

This numerical example [5] is intended to show what changes occur in the balcony slab after insulating the façade wall on which it is connected. The slab having the dimensions shown in figure 7 (a) and being of the same length as the junction wall considered as of 10 m² was investigated through the finite difference method.

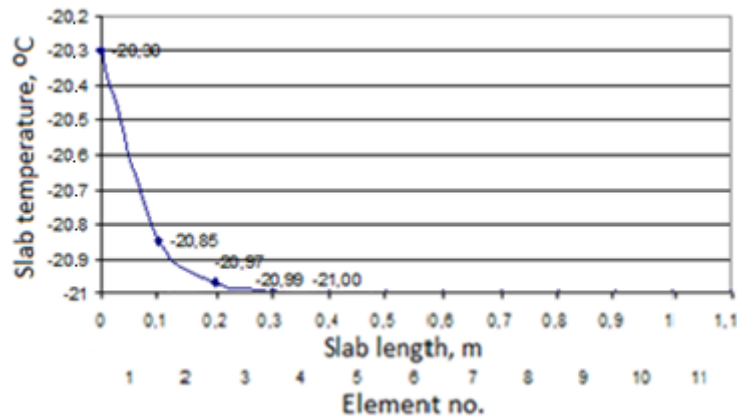
Temperatures and heat fluxes calculated for every element resulted after the discretization of the slab are shown in figure 7 (b) and 7 (c). The heat loss of the wall, before insulation is $Q_{w\ nonins} = 3.85$ kWh/day for a unidirectional thermal resistance, $R_{w\ nonins} = 2.56$ m²K/W (a 10 cm layer of mineral wool exists between the two concrete structure elements) and being exposed to an outside temperature of -21°C (Romania, Climatic zone IV) and the interior temperature of +20°C ($q = 16.05$ W/m²). In the same time the slab “extracts” from the building an amount of heat $Q_{s\ nonin} = 4.3$ kWh/day.

As can be noted from figure 7 (b), almost the entire length of the slab is at the same temperature as the ambient one: only the temperature of the first three elements of the slab being in the vicinity of the

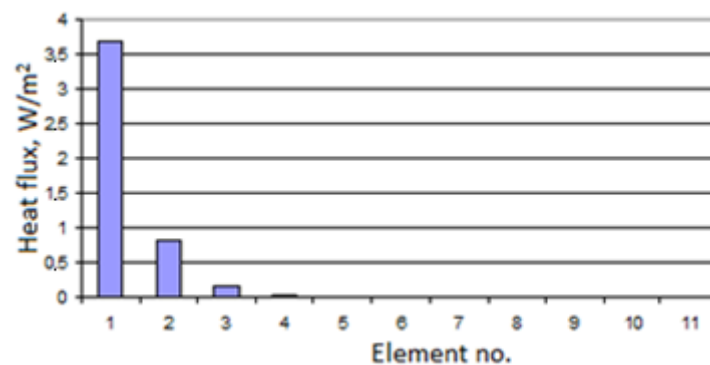
wall differ with less than one degree centigrade from the outside temperature. This means that the contribution of elements no. 5, 6...11 is negligible, only the first 3-4 elements being active in transferring heat.



(a)



(b)

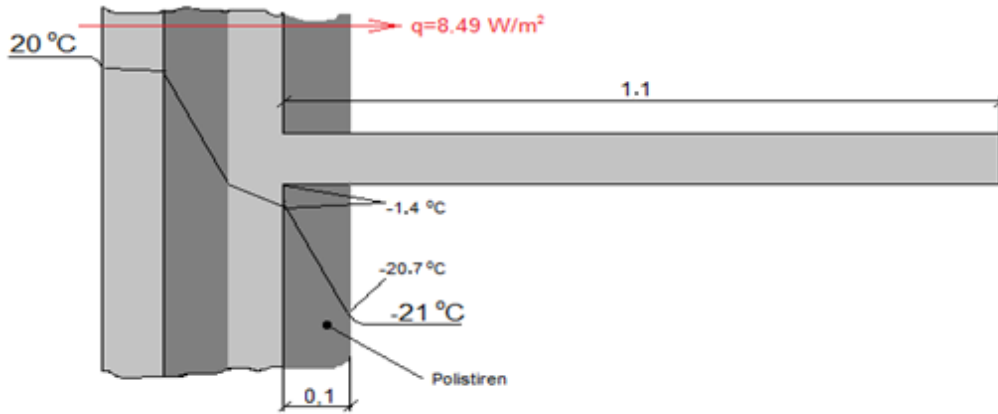


(c)

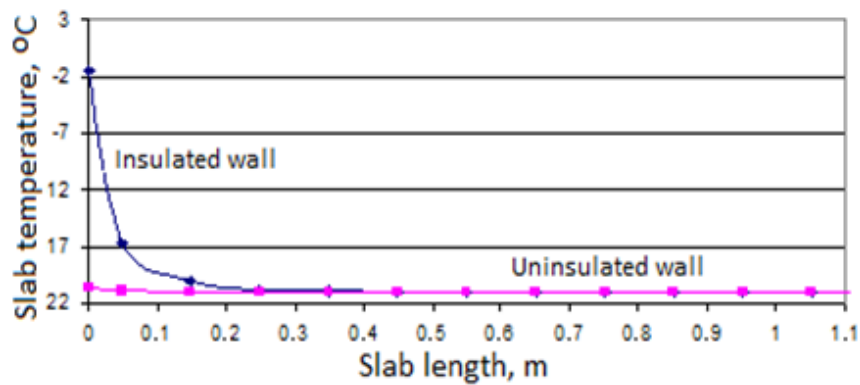
Figure 7. The balcony slab (a) and its temperature distribution (b), with the element corresponding heat flux (c) for the insulated wall.

After the insulation of the wall with 10 cm of polystyrene or mineral wool its thermal resistance is improved to $R_{w \text{ ins}}=4.83 \text{ m}^2\text{K/W}$ resulting in lower heat losses $Q_{w \text{ ins}}=2.0 \text{ kWh/day}$ that is almost the half of the previous case. Considering that wall insulation keeps the first element of the slab separated from the cold air, (i.e. no heat loss for this element) the temperature distribution in the slab is modified as depicted in figure 8 (b): higher temperatures compared to the previous situation when no insulation was

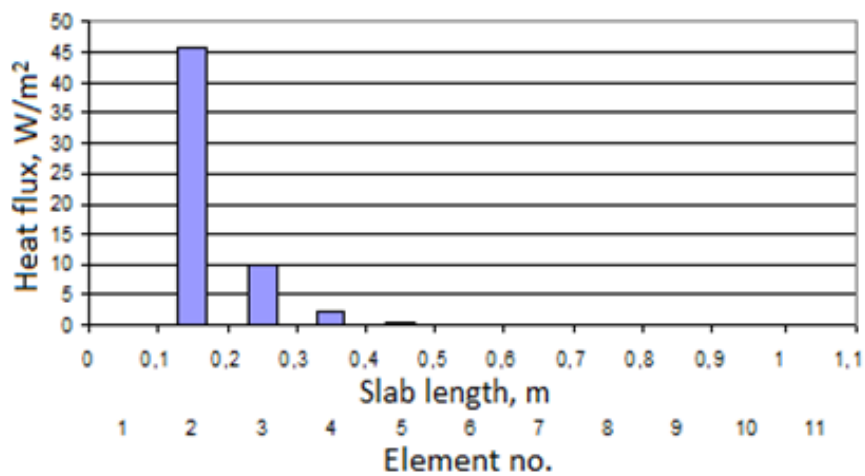
added (-1.4°C instead of (-20.3)°C for the first element, (-17)°C instead of 20.85°C for the second element). The heat flux through the insulated wall has been lowered to 8.49 W/m² instead of 16.05 W/m² in case of uninsulated wall. In the meantime, heat losses from the slab to the surrounding air increased, as a result of higher temperatures in the slab after insulating the junction wall. Figure 8 (c) shows.



(a)



(b)



(c)

Figure 8. The balcony slab (a) and its temperature distribution (b), with the element corresponding heat flux (c) for the insulated wall.

A comparison of heat fluxes per every element of the balcony slab is given in figure 9: if the first element has a heat flux of 3.70 W/m^2 before insulation of the wall, and after the insulation it became zero having no contact with the exterior cold air; but as a result of the higher temperature the second element has a heat flux of 45.05 W/m^2 instead of 0.82 W/m^2 .

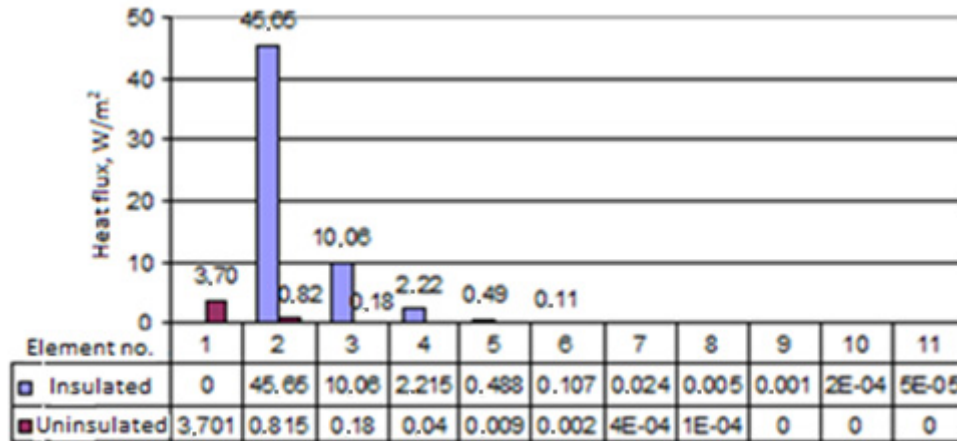


Figure 9. Heat flux of slab elements before and after the wall insulation.

Finally, insulating the wall its heat loss is lowered from 3.85 to 2.0 kWh/day , but this effort is not effective in case of the adjacent balcony slab, because of higher temperature inside the slab: the 4.30 kWh/day heat loss of the slab before insulation became 5.30 kWh/day , as shown in figure 10. In total only $8.15 - 7.3 = 0.85 \text{ kWh/day}$ is saved, that is about 10% , when only the wall is insulated.

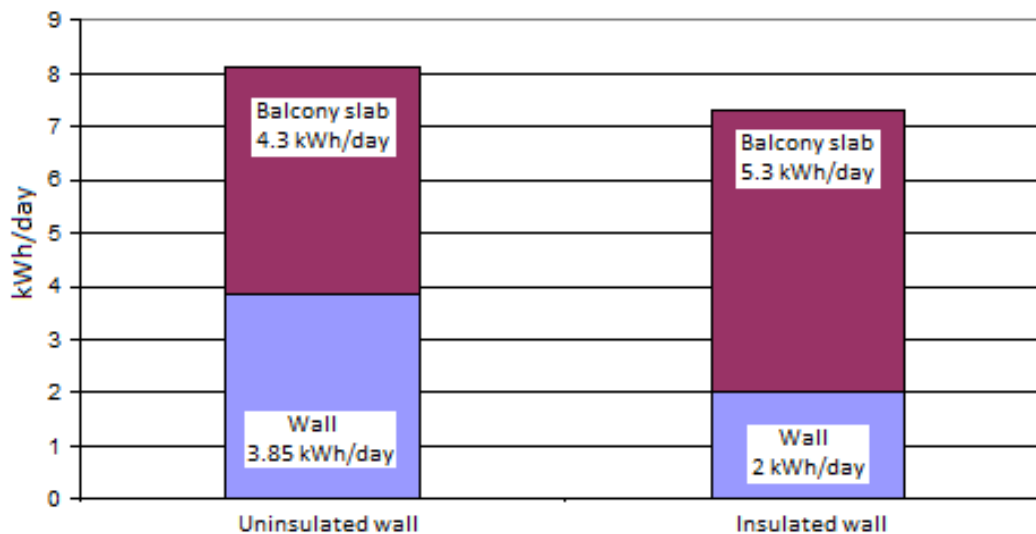


Figure 10. Heat losses of the balcony slab and of the wall before and after the insulation of the wall.

Adding insulation on the opaque surface of the walls is not effective to improve the thermal performance of a building, as shown before, if not inserted a thermal break between the exterior structure and the interior one.

The easy heat flow path around the insulation prevent minimizing the energy use and thermal bridges must be identified in order to be mitigated. In case of balconies, the exterior structure must be separated from the interior one by means of a thermal break like an expanded polystyrene block having a minimum thickness of 8 cm . Reinforcement bars connecting the exterior elements with the interior structure help

to transfer loads and reduce the heat transfer because of the low conductivity of stainless steel ($k=15 \text{ W/mK}$), figure 11.

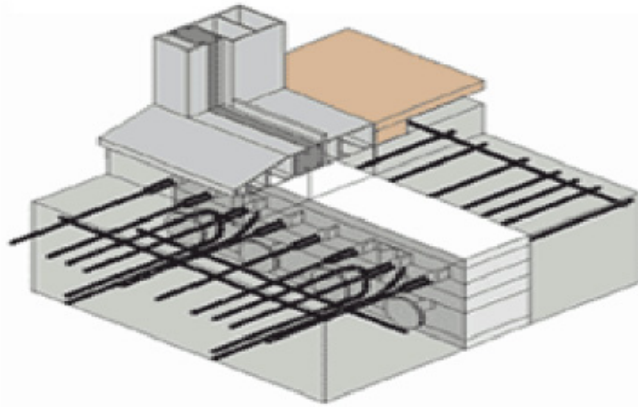


Figure 11. A thermal break (expanded polystyrene block) is inserted to separate the balcony slab from the interior structure.

4. U-values, Psi-values and y-values

Thermal bridge heat loss generally represents around 20% of the whole primary energy consumption of a low energy building. Reducing heat losses of a building requires the mitigation of the transmittance U' meaning to improve the thermal resistance of the envelope, not only the repeating one, R , but the linear thermal resistance, R_ψ too as shown before, equation (6). Considering the building as a free - point thermal bridges one, an identification of each linear thermal bridge followed by the evaluation of their thermal resistance R_ψ is necessary. Each linear thermal transmittance, ψ (numerical calculated values of psi with an accuracy of $\pm 5\%$, or extracted from thermal bridge catalogues, 20%) multiplied by every measured length are then summed up to get the transmission heat loss transfer coefficient:

$$H_{TB} = \sum(\psi \cdot l) \quad (8)$$

Instead of this cumbersome procedure some EU countries like Germany, The Netherlands, Poland and Italy use a more practical method to evaluate this transmission heat loss transfer coefficient:

$$H_{TB} = y \cdot \sum A_{ext} \quad (9)$$

The y-value is referred to what we call as an increment to the U-value denoted ΔU and A_{ext} meaning the total external heat loss area of the building:

$$y = U' - U = \frac{1}{R'} - \frac{1}{R} \quad (10)$$

The default y-value is 0.15 but can be reduced to 0.08 and by thermally modelling the junction details, conforming to at least Accepted Construction Details this figure can be get down to less than 0.04 to determine the total heat losses. Using the value of $y=0.04$ result in ranges of U-values for individual building elements as:

- floors 0.18 – 0.12 $\text{W/m}^2\text{K}$;
- walls 0.25 – 0.16 $\text{W/m}^2\text{K}$;
- roofs 0.13 – 0.09 $\text{W/m}^2\text{K}$.

The condition to have as a user-defined value for $y = 0.04$ is the aggregate percentage change from the respective target U-values should not exceed 20%. For example, if the wall U-value was increased 10% above the wall target U-value (0.22 instead of 0.20), then the roof U-value could be at most 10% below the roof target U-value (0.10 instead of 0.11), so the aggregate change would then be 20%. To keep the U-values for the building elements in the above mentioned range means to design the elements and the entire building in conformity with specific prescriptions established in those countries that adopted such heat losses reduction.

5. Conclusions

Energy Performance of Buildings Directive recently recast sets as a target for 2050 to limit the global warming by a GHG emissions mitigation of about 90% in comparison with those existing in 1990. The built environment responsible for approx. 40% of the total GHG emissions will support this target through the nearly Zero Energy Building concept, the first step being the reduction of the existing heat losses. Envelope insulation without a thermal bridge reduction is only a half-step, therefore the identification and the evaluation of their magnitude being necessary.

The usual way to evaluate the thermal resistance of a linear thermal bridge with accuracy of about 20% involving an atlas containing psi-values will have as a final point a “good practice” construction detail. This is a time-consuming issue that has been replaced by some EU countries through the y-value method meaning that the final target can be achieved by the designer only by using a set of prescribed construction details giving a “Thermal Bridge Free” building, which is a thermal bridge coefficient lower than 0.01 W/mK. Junction performance can be improved by: isolating the thermal bridge with insulation, changing the thermal bridge geometry, increasing the thermal bridge heat path, and changing the thermal bridge material.

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- [1] Enhanced Construction Details 2009 *Guidance on energy efficient construction* Energy Saving Trust
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