INSTITUTO SUPERIOR TÉCNICO
Universidade Técnica de Lisboa

Impact Assessment of Thermal Bridges on Residential Buildings Performance

Jorge Gustavo Marques Alface Pereira Valério

Extended Abstract

Jury

President: Prof. Dr. Jorge Manuel Caliço Lopes de Brito
Tutor: Prof. Dr. António Heleno Domingues Moret Rodrigues
Member: Prof. Dr. Daniel Aelenei

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Jorge Gustavo Pereira Valério

Instituto Superior Técnico, DECivil, Av. Rovisco Pais, 1049-001, Lisboa, Portugal

e-mail address: jgvalerio@gmail.com

1. INTRODUCTION

Energy consumption is one of the biggest problems of the nowadays world because it yields to the fastest run out of the fossil fuels, non-renewable natural resources, and contributes to the emission of greenhouse effect gases, responsible for serious environmental issues [1].

Buildings are one of the greatest energy consumers in the world, mainly because of comfortable room temperatures. Although in Portugal the energy spent with thermal comfort is lower than that spent in other countries, statistics show that this is growing, mainly because of the increase of the quality of life of the population and their demand for more comfort.

The need of saving energy in buildings, has led in Portugal, following what is being done in EU, to the approval of more and more restrictive regulations for thermal and energetic behaviour of the buildings. Recently, it was approved the Regulations on Characteristics of the Thermal Behaviour of Buildings (Regulamento das Características de Comportamento Térmico dos Edifícios, RCCTE) [2] and the system of energy certification for buildings.

Since there is a direct relation between energy consumption for climatization and the thermal insulation of buildings, building thermal regulations give a special focus on this relation so that the buildings can be more economical and energy efficient. Giving that building envelopes are not uniform in terms of thermal characteristics, which cause differently transfer rates, the way the thermal insulation is estimated and applied should not only concern current zones of elements but also specific zones of the construction, as it will be explained later. These zones are called thermal bridges, and, impact the weight they can have in heat exchanges through the environment and therefore the economical aspects, affect also the comfort, salubrity and constructions flaws by the gradient of temperatures and condensation phenomena on those areas. This work approach about these thermal bridges, following the aspects that are here enumerated.

2. AIMS AND METHODOLOGY

This work aims to evaluate the relevance of thermal bridges in the thermal performance of residential buildings and their contribution for the global energetic costs. To achieve the purpose of this work was be selected one apartment in which a diverse set of thermal and energetic analysis will be applied. To understand the effect of the thermal bridges in buildings along the years, the analysis will be also carried out for different constructions, to test the majority of types of construction in Portugal for the last decades. This work allows concluding on the impact of the regulations on the salubrity conditions in the interior of the buildings and their energetic costs. The evaluation of the characteristics of the thermal bridges was made on a computer application called Bisco [3]. This numerical application is based at finite elements and allows the user to implement a detailed model of the thermal bridges. For the estimation of the energetic needs of the apartment it was used the calculation method used in the most recent thermal regulation, where a great relevance is given to the thermal bridges in what concerns the heat losses to the surrounding environment.

3. DEFINITION OF THERMAL BRIDGE AND CALCULATION METHODOLOGY

Thermal bridge is the common name used to designate localized phenomenon of heat transfer arising on building envelopes. It consequence is the decreasing of the thermal resistance characteristics of those locations relatively to the current zone. This phenomenon is due to the existence of geometrical and material heterogeneities in building envelopes. In what concerns the physical phenomenon, at the zones of thermal bridges the lines of heat flows are not rectilinear, as it would be in a unidirectional process – Figure 1 and Figure 2 – but take the direction where the thermal resistance is lower.

This fact causes the thermal transmission in those areas transform in a bi- or tri-dimensional process. In practice, the thermal bridges have the effect of increasing the thermal exchanges with the environment, leading to an increase of the energy costs of the building, and a heterogeneous distribution of temperatures, specifically lower temperatures on the areas of discontinuous homogeneity of geometric or material characteristics. This effect contributes to the occurrence of condensation phenomena and development of fungus, which are responsible for important building pathologies.

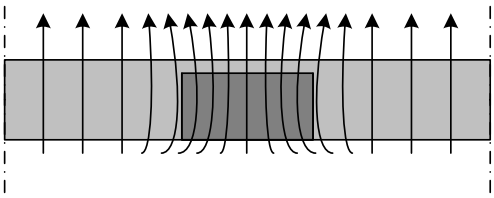


Figure 1 – Thermal bridge due to the transition of different material (concrete column)

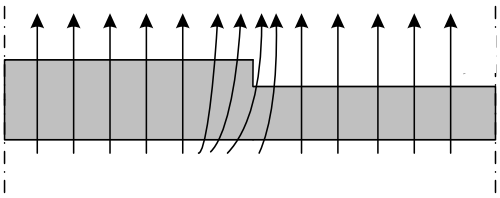


Figure 2 – Thermal Bridge due to variations of thickness

4. HEAT TRANSFER ANALYSIS

The evaluation of the energy losses through the thermal bridges is not, in terms of principle, different from the method of calculation of a heat flow, which always includes a coefficient associated to a temperature gradient. So, relatively to the heat flow associated to the thermal bridge, a coefficient (ψ) is introduced so that, when multiplied by the temperature gradient, gives the correct rate of heat transfer originated by the temperature gradient. To simplify the calculations, this coefficient is given per unit length of thermal bridge and not per unit area – as the thermal coefficient is – and the heat flow through one thermal bridge is given by:

$$Q = \psi\, B\, (\theta_i - \theta_e) \quad [W] \tag{1}$$

where B is the linear dimension of the thermal bridge.

The main difficulty of this method is in the determination of the coefficient ψ. To solve this problem the norm EN ISO 10211 [4] established de rules to modulating a thermal bridge in numerical applications using finite differencing or finite elements and the related computation of the coefficient ψ from this kind of applications. To show the evaluation of the coefficient ψ , the construction detail of Figure 3 and Figure 4 is taken as reference, which represents a thermal bridge separating two environments where the temperature gradient is $\Delta\theta = \theta_i - \theta_e$.

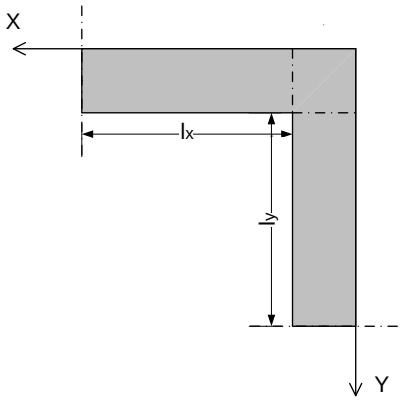


Figure 3 – View in XY plane

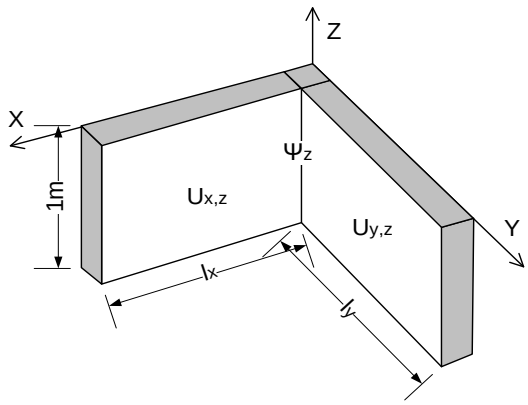


Figure 4 – Tri dimensional detail of a thermal bridge in an edge zone

The coefficient ψ is given by:

$$\Psi_z = L^{2D} - \sum U_i \times l_i \tag{2}$$

where:

L^{2D} is the coefficient of thermal transmission of the construction detail that separates the indoor and outdoor environment, calculated by the bi-dimensional model;

U_i is the coefficient of thermal transmission of the uni dimensional element **i** that separates the two environments (current zone);

l_i is the length, within the geometrical bi-dimensional model, where **U_i** is applied.

Whereas $\sum U_i \times l_i$ could be obtained easily, the same does not happen with L^{2D}. The computation of this coefficient implies a bi-dimensional process of heat transfer which can be solved by an appropriate numerical algorithm that uses finite difference. Although it is possible a manual calculation of that coefficient, it is better to use a computer application with a smaller effort and a greater precision, like the Bisco [3] code used in this work.

5. THERMAL ANALYSIS

To evaluate the thermal impact and consequent condensation risk of thermal bridge zones, some important parameters can be set to prevent this phenomenon and associated pathologies. Within these parameters are the well-known *Surface Temperature Factor* and the *Heterogeneity Surface Temperature Factor*, whose are calculated with the temperatures shown in figure 5.

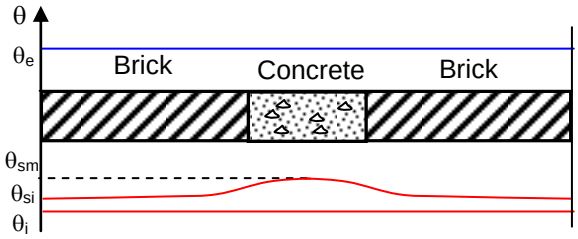


Figure 5 - Variation of temperature in the parameter inside one wall

The *Surface Temperature Factor* is the non dimensional parameter, calculated for any point at the interior surface, is given by [5]:

$$\mu_s = \frac{\theta_{si} - \theta_e}{\theta_i - \theta_e} \tag{3}$$

where θ_i,θ_e and θ_{si} are, respectively, the indoor temperature, outdoor temperature and internal surface temperature.

The minimum value occurs over the thermal bridge and, according to Figure 5, it will be given by:

$$\mu_{sm} = \frac{\theta_{sm} - \theta_e}{\theta_i - \theta_e} \tag{4}$$

This value, as being catalogued for a given thermal bridge, allows the calculation of the minimum temperature that occurs for any pair of values θ_i e θ_e. As lower as the surface temperature factor is, higher is the risk of condensation and growth of fungus. With the goal of preventing condensations, minimums values for the *Surface Temperature Factor* are recommended for each type of building, as shown in Table 1 [6].

Building type	Minimum μ_s
Storage buildings	0,30
Offices, retail premises	0,50
Residential buildings and schools	0,75

Sports halls, kitchens, canteens (buildings with un-flued gas heaters)	0,80
Buildings with high humidity e.g. swimming pools, laundries, breweries	0,90

Table 1 - Minimum values for the "*Factor of Superficial Temperature*" to prevent condensation reactions.

The *Surface Temperature Factor* can also be found in the scientific literature with a slightly different definition, that is:

$$\mu_s^* = \frac{\theta_i - \theta_{si}}{\theta_i - \theta_e} \tag{5}$$

In this case, as greater as the index is, greater is the risk of condensation. This index, defined as in equation 5, appears frequently associated with another in recommendations to prevent the condensation phenomena. This additional index is known as *Heterogeneity Surface Temperature Factor* and is defined as [7]:

$$\mu_h = \frac{\theta_i - \theta_{sm}}{\theta_i - \theta_{si}} \tag{6}$$

This index gives the measure of drifting of the temperature of the thermal bridge in comparison with its value on the current zone. To avoid the appearance of resulting from condensations, or the occurrence of termophoresis on the surfaces, it is recommended that, in winter conditions, the factors μ_s^* and μ_h do not be greater than [7]:

$$\mu_s^* < 0{,}25$$
$$\mu_h < 2{,}0$$

6. CASE STUDY

For the study cases it was used the apartment represented in *hatch* in Figure 6. Its construction solutions were chosen among those commonly applied in Portugal during the 80's, the 90's and nowadays. These solutions have different thickness for the external walls, some have air cavity and thermal insulation, others don't. Along the work it is made a detailed description of the solutions used. The apartment is located in a building in Cascais, at an urban area. Its architecture is very regular in all fronts, with windows and balcony in the front façade and with the other façades connecting directly to neighbor buildings. The building is located in the climatic zone I_1-V_1 [2].

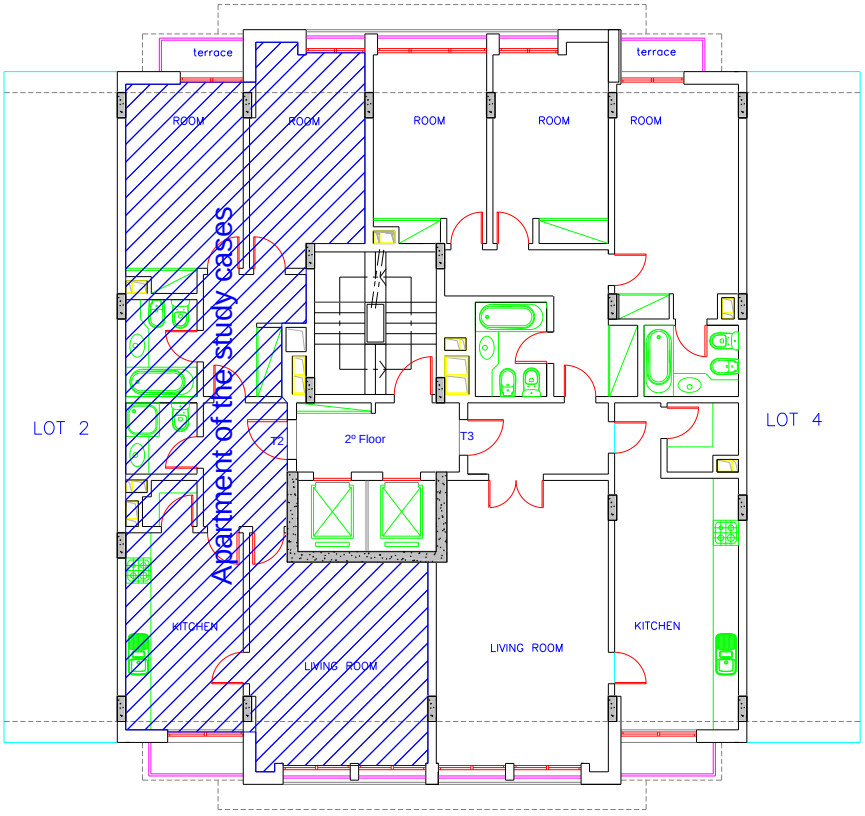


Figure 6 - 2º Floor plan and the apartment studied

The following table (Table 2) shows the construction solutions that are characteristic of each time period, together with the main details of thermal bridges, and the correspondent U-values and ψ-values that result from the Bisco program [3] and RCCTE [2]. Also, the values taken by the thermal indices previously defined are presented.

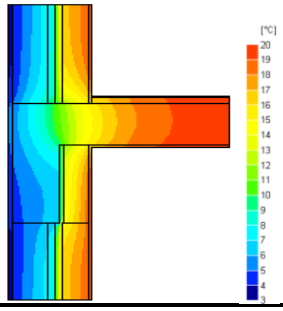
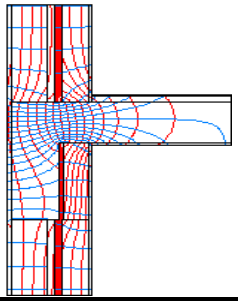
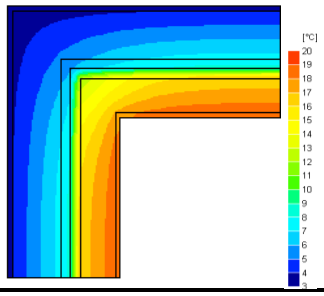
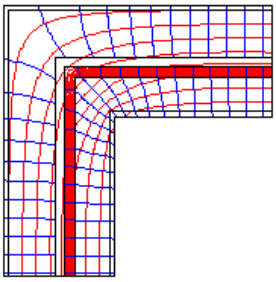
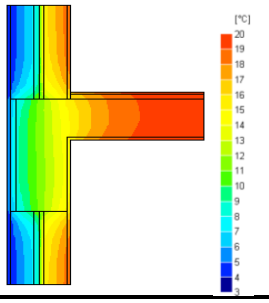
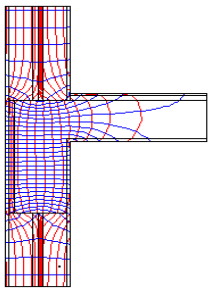
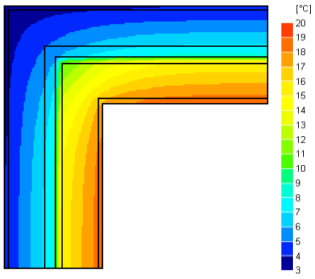
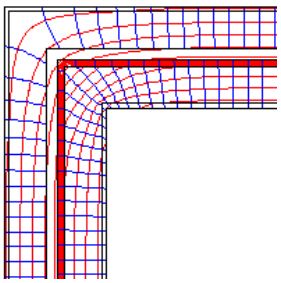
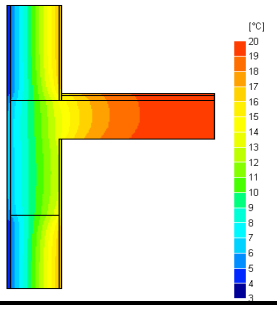
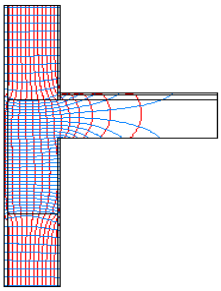
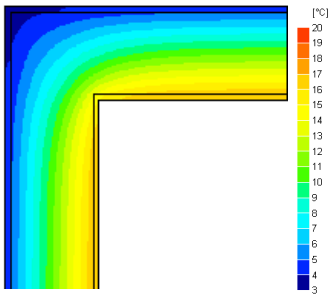
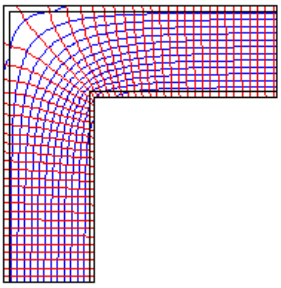
	Temperature Distribution	Isothermal lines and of heat flow	Results	
Beam – Currently			θ_e [ºC]	3,5
			θ_i [ºC]	20
			e_m [m]	0,35
			U current zone [W/m².ºC]	0,52
			$U_{plane\ thermal\ bridge}$ [W/m².ºC]	0,77
			L^{2D} [W/m.ºC]	1,03
			Ψ (RCCTE) [W/m.ºC]	0,25
			Ψ (BISCO) [W/m.ºC]	0,22
			μ_{SM}	0,73
			μ^*_S	0,061
			μ_h	4,5
Corner – Currently			θ_e [ºC]	3,5
			θ_i [ºC]	20
			e_m [m]	0,35
			U current zone [W/m².ºC]	0,52
			$U_{plane\ thermal\ bridge}$ [W/m².ºC]	-
			L^{2D} [W/m.ºC]	0,66
			Ψ (RCCTE) [W/m.ºC]	0,20
			Ψ (BISCO) [W/m.ºC]	0,14
			μ_{SM}	0,82
			μ^*_S	0,601
			μ_h	3
Beam – 90's			θ_e [ºC]	3,5
			θ_i [ºC]	20
			e_m [m]	0,30
			U current zone [W/m².ºC]	0,67
			$U_{plane\ thermal\ bridge}$ [W/m².ºC]	2,47
			L^{2D} [W/m.ºC]	1,49
			Ψ (RCCTE) [W/m.ºC]	0,25
			Ψ (BISCO) [W/m.ºC]	0,22
			μ_{SM}	0,73
			μ^*_S	0,061
			μ_h	4,5
Corner – 90's			θ_e [ºC]	3,5
			θ_i [ºC]	20
			e_m [m]	0,30
			U current zone [W/m².ºC]	0,67
			$U_{plane\ thermal\ bridge}$ [W/m².ºC]	-
			L^{2D} [W/m.ºC]	0,83
			Ψ (RCCTE) [W/m.ºC]	0,20
			Ψ (BISCO) [W/m.ºC]	0,16
			μ_{SM}	0,82
			μ^*_S	0,601
			μ_h	3
Beam – 80's			θ_e [ºC]	3,5
			θ_i [ºC]	20
			e_m [m]	0,25
			U current zone [W/m².ºC]	1,39
			$U_{plane\ thermal\ bridge}$ [W/m².ºC]	3,11
			L^{2D} [W/m.ºC]	2,15
			Ψ (RCCTE) [W/m.ºC]	-
			Ψ (BISCO) [W/m.ºC]	0,49
			μ_{SM}	0,61
			μ^*_S	0,18
			μ_h	2,33
Corner – 80's			θ_e [ºC]	3,5
			θ_i [ºC]	20
			e_m [m]	0,25
			U current zone [W/m².ºC]	1,39
			$U_{plane\ thermal\ bridge}$ [W/m².ºC]	-
			L^{2D} [W/m.ºC]	1,55
			Ψ (RCCTE) [W/m.ºC]	-
			Ψ (BISCO) [W/m.ºC]	0,16
			μ_{SM}	0,61
			μ^*_S	0,18
			μ_h	2,33

Table 2 – Summary of the results of the thermal analysis

7. ANALYSIS OF RESULTS

In a thermal analysis context we can observe that the regulation appeals to many simplifications and approaches, but that they are realistic (Table 2). The priced values of the coefficient of linear thermal transmission (Ψ) in the RCCTE [2] are sufficiently next to the real values, gotten with resource to program BISCO [3]. But simplifications exist as it is the case of the corner, where distinction between the existence or non-existence of concrete column does not exist, the value priced being higher than the real one in the situation without concrete column. This higher value allows to contemplate the situation with concrete column that will have a higher value of Ψ. Relatively to the occurrence of condensations it is verified that in nowadays as in the 90's its occurrence is less probable, being the thermal bridge created by the linking of the beam with the floors and façade the one where the values are closer to the minimums and thus with a higher probability of condensation. In buildings made in the 80's the probabilities of occurrence of condensations are very high, not only in the case of the thermal bridge created by the beam as well as in the servant for the corner. In any of these cases the parameters are significantly lower than the minimum values which increases the probability of occurrence of condensations and of associated pathologies.

Analyzing the results from the 80's to nowadays (Figure 7 and Figure 8), it can be seen a significant reduction not only on the global thermal losses (GTL) but also on the needs of useful energy for heating (NAQ). The fact that mainly contributes to this reduction was the approval of regulations more restrictive that concern several environmental and energetic aspects. During the 80's there were no regulations for the thermal behavior and energy costs of buildings. The first legislation about this topic appeared during the 90's with the old RCCTE (Portuguese law Nº40/1990) [8], and more recently, during 2006, this was up-to-dated (RCCTE Portuguese law Nº80/2006) [2], with the incorporation of the more recent advances in building thermal processes and environmental requirements.

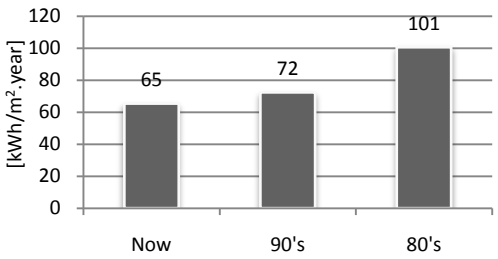


Figure 7 – Global thermal losses (GTL) [kWh/year]

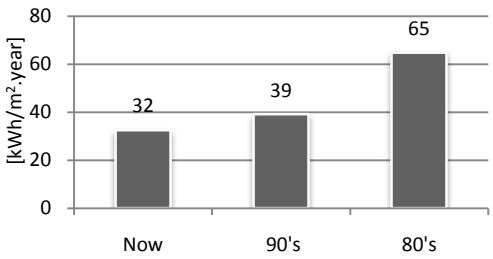


Figure 8 – Needs of useful energy for heating (NAQ) [kWh/year]

Figure 7 and Figure 9 allow to make an analysis not only in absolute values but also in comparative terms. It can be observed that the significance of the thermal bridges losses between the 80's and the 90's increased even though in absolute values it decreased. This fact is related to the increase of thermal insulation on the common areas, which enhances the "transmission marginal" effect of the thermal bridge areas. It comes to evidence that the insulation offered by these thermal bridges is not enough to oppose such effect. The

significance of the thermal bridges in relation to the global thermal losses and energy needs show a trend to increase together with the level of insulation. During the last decade it was made an effort to contradict this reality giving more attention to the insulation and to the calculus of the thermal bridges. This carefulness has led to very positive results on the plane thermal bridges, but has not been so effective on the linear thermal bridges. The losses from the linear thermal bridges have been almost constant in time compared to the global thermal losses (GTL) and heating energy needs that have been decreasing significantly. This means that the importance of the linear thermal bridges has increased relatively to the global losses and to the plane thermal bridges losses (Figure 10). At the 90's it was given a greater importance to the thermal bridges when compared with the other decades.

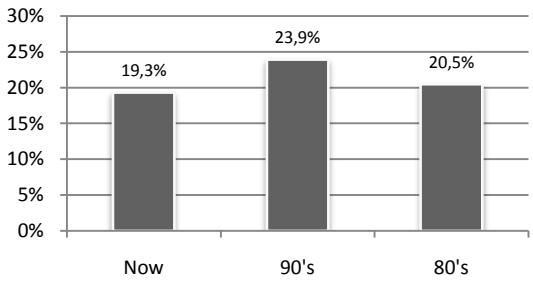


Figure 9 – Importance of thermal bridges in global thermal losses (GTL)

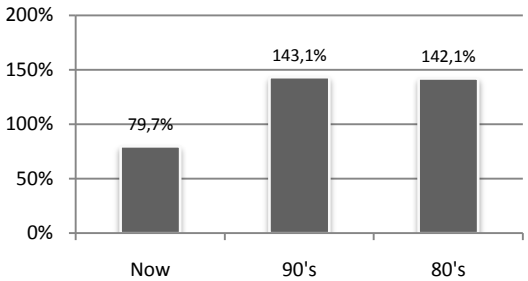


Figure 10 – Relation between plane thermal bridges losses and linear thermal bridges losses

A simple economic analysis was made to get a general quantification of the energy expenses per year, for a medium size apartment (T2 with 82 m^2), due to the thermal bridges losses (Figure 11). The values presented in Figure 11 correspond to take the electric energy as reference, with a price of 0,1077 €/kWh [9] and to consider that the inflation tax is approximately same some of the actualization tax. One verifies that a better insulation of the thermal bridges can give rise to a significant reduction of the expenses in energy, if one assumes that a building has a long useful life. Thus, it can be compensating the initial investment made in materials and labor to prevent the thermal bridges, and this investment is as much justifiable as one knows that the trend is for the increase of the energy cost.

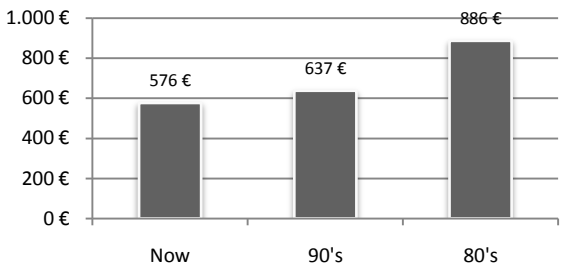


Figure 11 – Energetic costs due to thermal bridges for a medium size apartment (T2 with 82 m^2)

8. CONCLUSION

As first conclusion it can be stated that the thermal building regulation had a very positive effect in reducing the costs of energy consumption and, also, in minimizing thermal, salubrity and environmental problems. This fact was not only noticeable with the approval of the old RCCTE (Portuguese law Nº40/1990) [8], which was the first legislation on this theme, but also with the approval of the current RCCTE (Portuguese law Nº80/2006) [2], more adjusted to the new energy and environmental demands.

In this work it was verified that the importance of the thermal bridges depends on the insulation difference between the current areas and thermal bridges areas. Aiming to have a sustainable use of energy resources and good standards of comfort, it's not only needed an efficient insulation on the current areas but also on the thermal bridges areas. It has been proved that when the amount of insulation is increased in the current areas, the importance of the thermal bridges is amplified. In a situation with insufficient thermal insulation, the significance of the thermal bridges is less important due to the losses of the current areas. This was verified during the 80's, and it's the reason why it is only necessary to calculate the losses of the thermal bridges when insulation demands are higher.

It is demonstrated in this work that the amount of losses by thermal bridges are 20% of the global thermal bridges. This means that the thermal bridges have a big importance on the energy costs, thermal comfort, salubrity and economic - environmental expenses. It's a subject that should be carefully studied in order to prevent these effects. This is why the approved new regulation (RCCTE Portuguese law Nº80/2006) [2] has much higher requirements and demands than the older one (RCCTE Portuguese law Nº40/1990) [8], which was much simpler for being the first thermal legislation. With the increase of the world energy and environmental problems, it's natural for this subject to gain more and more importance.

Bibliography

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