Assessing the use of simplified and analytical methods for approaching thermal bridges with regard to their impact on the thermal performance of the building envelope.

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Abstract: *Thermal bridges have received much attention during the last decades, due to their role on the formation of the energy needs on one hand and the on-going objective for building energy efficiency on the other. Due to their complex nature, thermal bridge effect is taken into account by the linear thermal transfer coefficient Ψ. Values of Ψ can be determined by detailed numerical calculations, tabulated data or default values. The accuracy provided by each method is different and analogous to the difficulty and the burden of its implementation. In the current study, the uncertainties introduced by these methodologies are assessed by comparing the magnitude of the thermal bridge effect, calculated according to these methods on o typical building located in the Mediterranean climate. The results reveal not only the precision of each methods but also indicates the necessity of using an analytical or a simplified approach in such constructions.*

Key words, Thermal insulation of buildings, thermal bridges, energy performance

Introduction

Thermal bridges have received much attention during the last decades, due to their role on the formation of the energy needs on one hand and the on-going objective for building energy efficiency on the other. The influence of linear thermal bridging on the energy efficiency of the building envelope is taken into account by the linear thermal transfer coefficient Ψ W/(m·K). Values of Ψ can be determined by analytical numerical calculations, thermal bridges catalogues or default values. Numerical calculations are conducted with the help of 2-D thermal analysis and finite-element software tools and are rarely employed during the building design phase due to the time consuming and complex nature of their calculation. In most cases, catalogues of thermal bridges are often used, which show the Ψ values for different configurations of the building elements, given that, typically the Ψ values vary with reference to the layers that compose the building elements in conjunction, as well as the position, the width and the properties of the thermal insulation. Default values of linear thermal transmittance are usually given for fixed parameters of typical constructional details and are used for estimating roughly the thermal bridging effect.

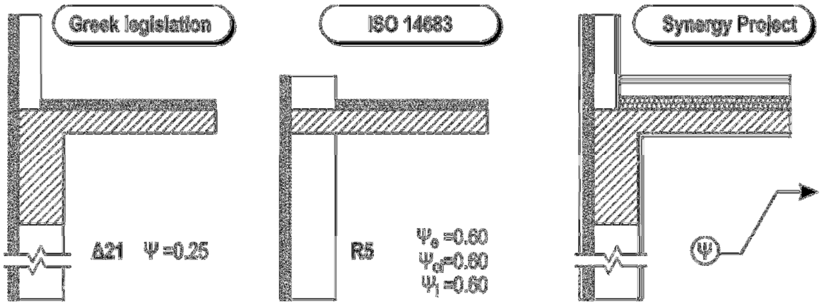
It is obvious that the accuracy provided by each method is different and analogous to the difficulty and the burden of its implementation. In the current study, the uncertainties introduced by these methodologies are assessed; more specifically, the thermal bridging effects encountered in a specific building are estimated following four different methodologies:

- the detailed, numerical calculation, which has derived from the elaboration of the research project SYNERGY [1], as a representative of the finite-element, numerical approach,
- the national catalogue of thermal bridges foreseen by the Greek Regulation for building energy performance, in the relative technical guide [2]
- the default values provided by ISO 14683 [3].
- the surcharge on the U-value approach, proposed by ISO 13790 for existing buildings [4]

The first methodology is the most accurate having the least simplifications, but involves a significant calculation time and effort that is quite impossible to follow is typical building studies. In this study, it is based on the use of the finite element analysis software package ANSYS in order to simulate the actual heat flow and the linear thermal transmittance in steady-state conditions at the junction of adjacent building elements. All assumptions concerning the length of each simulated element, minimum calculation cell dimensions and boundary conditions are according to the ISO 10211[5]. An exception is that, in this method, the simplification of neglecting the influence of "secondary layers" is not taken into account. In all other methods, only the thermal insulation layer, the pillar or slab, walls and windows are considered, where other layers like plaster, floor layers, bitumen layers etc. are ignored according to the ISO 10211(figure 1). In this method, not only all these layers are considered, but also the thickness of the insulation layer on horizontal and on vertical building elements have been calculated for all possible combinations, in order to determine the effect of this parameter to the overall thermal bridge effect.

The national catalogue of thermal bridges foreseen by the Greek Regulation is in full accordance to the ISO 10211. A large number of linear thermal transmittance is presented for a variety of building elements junctions, covering the most common construction cases found in Greek buildings. The linear thermal transmittance values are a result of analytical calculations like the first scenario, but for predetermined thermal insulation layer thickness. Additionally, only the most significant layers have been taken into account (concrete, brick blocks, thermal insulation and window frames).

Similar is the case of default, tabulated data presented in ISO 14683. The difference, relative to the previous scenario, is that this catalogue is significantly shorter, containing only the most representative cases. In order to use the catalogue, one has to make significant simplifications, like selecting geometries with limited similarity to the one under investigation. On the other hand, this catalogue is provided more like an example in order to develop national catalogues adjacent to each country's building characteristics, and less that a complete reference table.



insulation thickness (wall) \ insulation thickness (roof)	0.05	0.06	0.07	0.08	0.10
0.02	0.019	0.026	0.028	0.028	0.021
0.03	0.084	0.093	0.097	0.098	0.098
0.04	0.114	0.124	0.129	0.132	0.132
0.05	0.127	0.138	0.144	0.147	0.149
0.06	0.130	0.141	0.147	0.152	0.155
0.07	0.127	0.138	0.145	0.150	0.154
0.08	0.119	0.130	0.138	0.143	0.148
0.10	0.093	0.105	0.114	0.120	0.127

Figure 1. Example of simplification of the building elements in the examined methodologies and corresponding calculated linear thermal transmittance

Finally, the fourth method, this on applying a surcharge of 0.1 W/(m²·K) on the U-value of every opaque element, excluding elements in contact to the ground, is used mainly in existing, older buildings in the case of energy audits, since in most cases the actual construction characteristics are unknown or difficult to describe.

Methodology

All these methods are used in order to calculate the linear thermal transmittance factor of every linear thermal bridge of the building's envelope, the average building U-value and the breakdown of heat loss according to the national thermal insulation methodology of a typical Greek multifamily building (Figure 2).

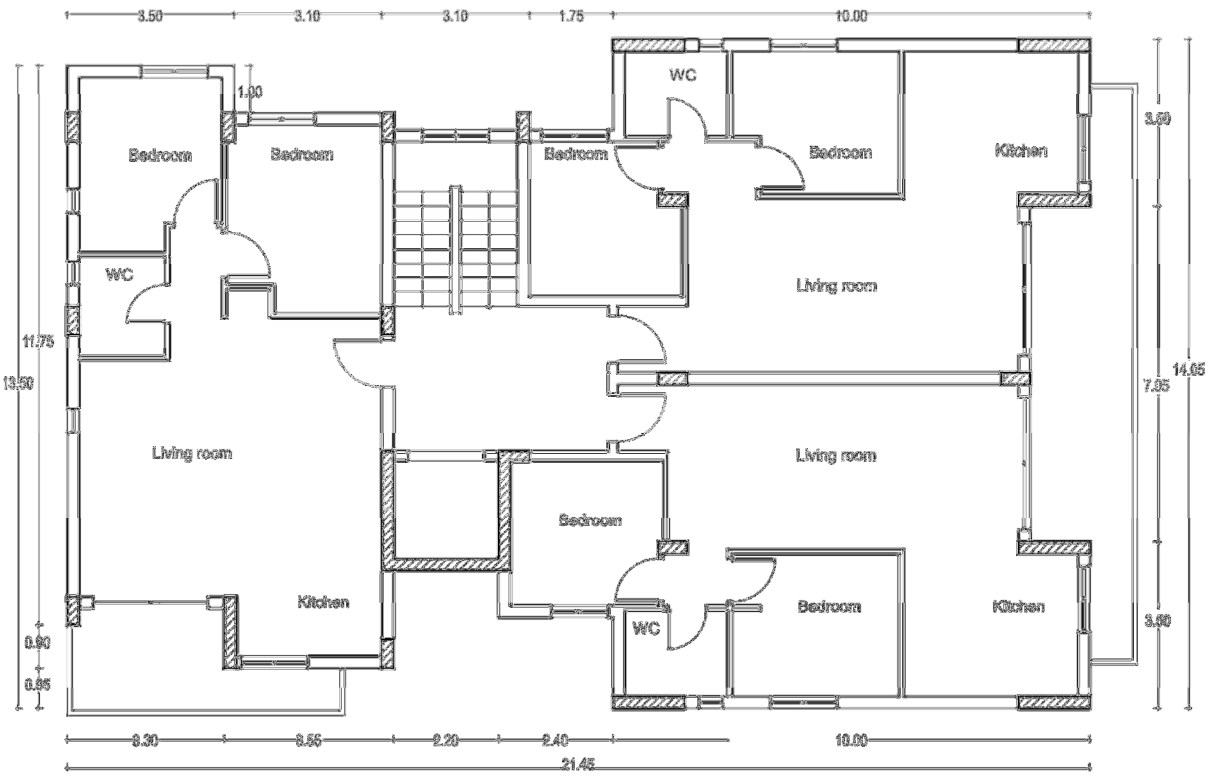


Figure 2. Floor plan of the typical multi-family building.

Like almost every building of the residential sector in Greece, the existence of balconies and other morphological characteristics of the envelope contribute to a relatively large proportion of heat loss due to thermal bridge, which can account for up to 30% or even higher of total thermal loss through the envelope [6]. Obviously, such a relatively large contribution to heat flows plays an important role in modern legislation requirements and are supposed to become even more significant in near future, where low or near-zero building principle demands accurate estimation of actual heat flows.

The results of each methodology, are presented for each of the four climatic zones in Greece, since actual thermal insulation requirements vary according to the climatic zone. The difference lies in the fact that the maximum allowed overall thermal transmittance of the envelope differs among climatic zones, being higher in the warm climatic zone (zone A) of southern Greece and lower in the colder zone of northern Greece (zone D). Thickness of insulation layers in every building element varies accordingly from 5 to 7 cm. Regarding the magnitude of thermal bridge effect, the different insulation thicknes of envelope elements in each zone, results in different linear thermal transfer coefficients in the analytical methodology, where in all other cases, the thickness of the insulation layer does not affect this, due to calculation assumptions.

Results

The comparison of the calculated heat flows does not only reveal the precision of each method –compared to the numerical method- but it indicates the necessity of using an analytical or a simplified approach in a the Mediterranean building constructions, where the thermal losses due to the existence of thermal bridges are significant, as the balconies interrupt the continuity of thermal protection.

Figure 3 presents the breakdown of thermal bridge heat transmission foe each of the examined methodologies. According to the results, the use of tabulated data from ISO 14683 can lead to the higher overestimation of thermal bridge effect. Depending on the level of insulation protection, in low thermal insulation requirements like those in zone A, the estimation error of this methodology can lead to a 94% overestimation in the typical building, while in better insulated buildings like those in zone D, the error is reduced to 69% but remains significant. The larger error is found in the estimation of horizontal thermal bridges, while vertical ones are underestimated by ISO 14683 methodology.

Tabulated data found in the Greek technical guides present a similar overestimation, but with a lower error varying from 86% to 63%, depending on the climatic zone. The more simple form of vertical thermal bridges, like those found in the corners of the building contributes to a small estimation error. On the contrary, the error of vertical thermal bridges is significant.

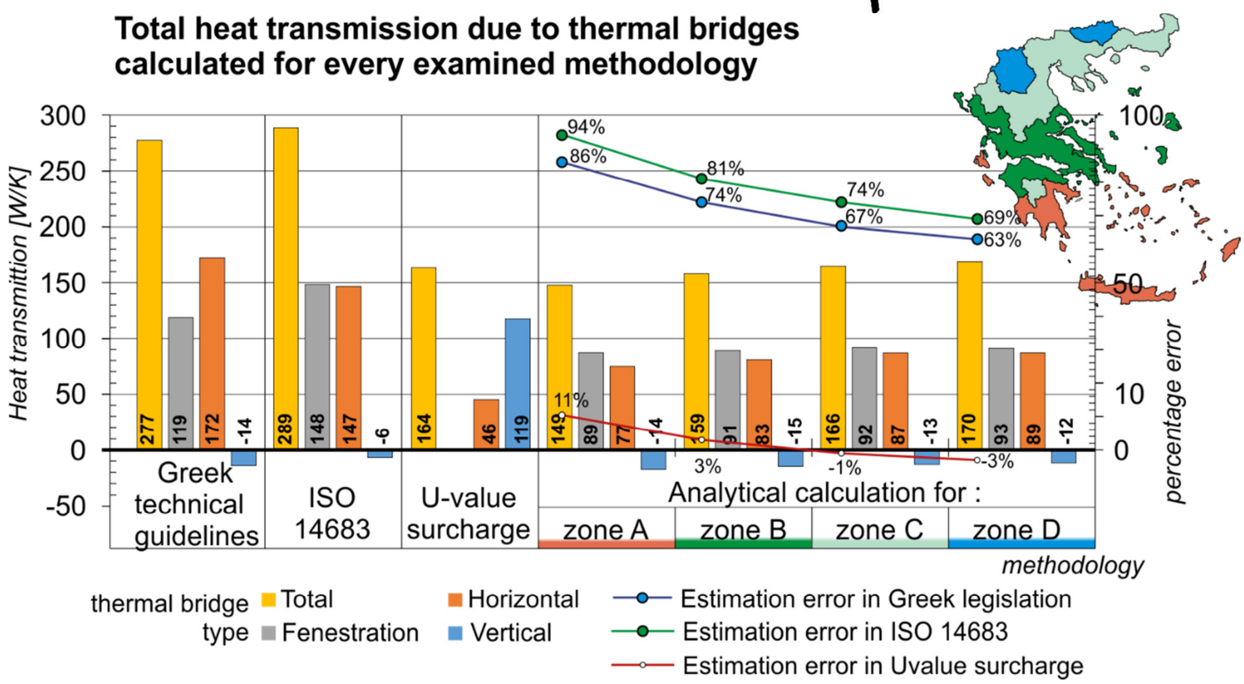


Figure 3. Breakdown of thermal bridge heat transmission according to all examined methodologies

Finally the methodology that surcharges the U-value of opaque elements despite being the simplest among the studied here, proves to be relatively accurate on overall heat transmission in the examined building, since it has a small estimation error, underestimating the actual heat flows. Unfortunatelly, this accuracy is related mainly to the specific characteristics of the study and can be considered as a random result. This is quite obvious from the breakdown of these heat flows, where vertical thermal bridges are highly overestimated and horizontal thermal bridges underestimated.

From these results, it is obvious that simplified methodologies that neglect the actual layers of the building elements and are not related to actual insulation layer thickness, tend to highly overestimate actual heat flows due to thermal bridge effect. When these heat flows are calculated using the more accurate, analytical methodology, the magnitude of thermal bridging is analogous to the level of insulation protection. This is expected, since heat flow in the area of a thermal bridge is relatively unaffected by the insulation thickness. In highly insulated buildings this magnitude is a larger portion of overall heat flows [7].

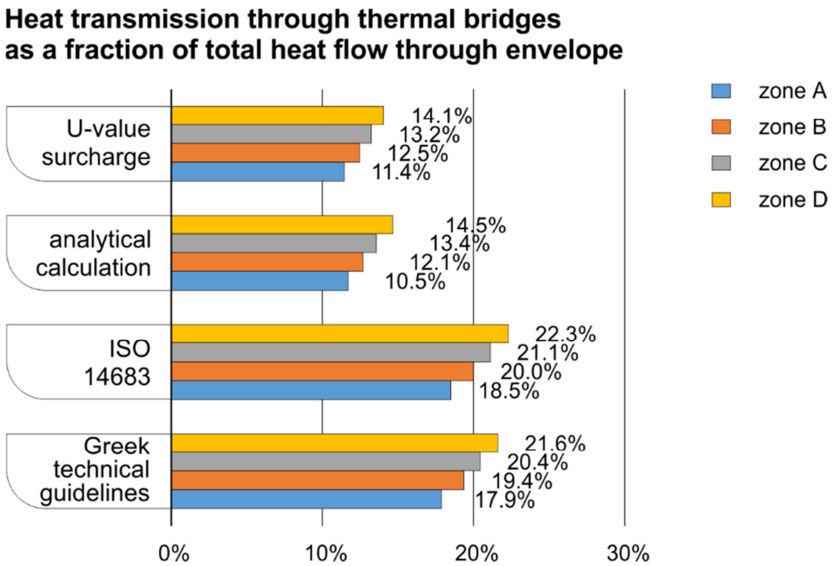


Figure 4. Percentage participation of thermal bridge heat transmission on overall heat transmission through the building's envelope.

The portion of heat flows due to thermal bridge to overall heat flows through the building's envelope is presented in figure 4. The presented error of up to 86% in existing methodology in Greece could be insignificant if thermal bridges was a minor heat flow. Although, the presented building is not among those were thermal bridges account for even up to 30% of overall heat flows, still their role cannot be neglected. According to national methodology applied to the selected building, thermal bridges are responsible for 18% to 21% of total heat flows, depending on the climatic zone. The application of the tabulated data of ISO 14683 presents similar results. The more accurate analytical method decrease these values to 15% and 11% respectively. Although a 10% error in estimating heat flows could be accepted some years ago, where applied methodologies were not very demanding, nowadays and especially in the near future, such an error in one of the more easy to estimate heat flows, like conduction heat flows, introduces a significant uncertainty regarding the tools we use to achieve low-energy and sustainable buildings.

Conclusions

The application of different methodologies to estimate the linear thermal bridge effect on a typical apartment building, shows that although all these methodologies are according to European standards, results differ by large amount. The most common approach to use pre-calculated, tabulated data for a variety of building elements tent to significantly overestimate the role of thermal bridges, by almost doubling their magnitude. In better insulated buildings, like these in the colder climatic zone of Greece, the error decrease but still cannot be neglected.

Surprisingly, the simplest methodology of surcharging the U-value of opaque elements, results in an estimation of the thermal bridge effect magnitude that is closest to the analytically calculated values. Unfortunately, the analysis done here cannot support that this method could successfully replace more complex methods. On the contrary, despite the total heat flow due to thermal bridges, the relative heat flows due to horizontal, vertical and fenestration thermal bridge are rather accidental and cannot be scientifically supported.

If national requirements were more demanding, similar to these in northern Europe, then the error would be expected to decrease even more. In that case, the application of relevant standards might be more accurate.

The use of accurate, numerical methods can be considered as not realistic in building studies since they could increase significantly the cost, time and complexity of the study. Unfortunately, in the case of the Mediterranean climate, the direct application of the other, simplified methodologies and standards should be reconsidered since the overestimation is not in accordance with modern methodologies that seek a more accurate estimation of heat flows and energy consumption. A more extended study is needed in order to adjust these standards to the national thermal insulation requirements. In that way, the estimation of thermal bridge effect could more realistic and could better support the need of improving methodologies aiming to design or verify the energy performance of buildings.

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