The Effect of Thermal Bridge Junctions Between Pillars and Walls in the Energy Demand of Buildings in Warm Climate

David Bienvenido-Huertas(✉), María Victoria Montes, Carlos Rubio-Bellido, and Jacinto Canivell

University of Seville, 41012 Seville, Spain
jbienvenido@us.es

Abstract. Currently, the building stock is energy inefficient. Consequently, the residential sector is one of the main sources emitting Greenhouse Gases, mainly due to the poor thermal performance of envelopes. Thermal bridges are among those envelope elements where heat losses or gains take place. A previous study highlighted the importance of controlling the linear thermal transmittance in junctions, such as slab fronts. However, there is a lack of studies analysing the thermal bridges of pillars and their effect on the energy demand of buildings located in warm climate zones. This study therefore analyses how the linear thermal transmittance of pillars affects the building energy demand. For this purpose, a case study located in Seville was analysed in 3 different climatic scenarios (current, 2050, and 2100). The case study was simulated with 3 different designs of junctions between pillars and walls. The linear thermal transmittance was determined using a two-dimensional simulation, and the energy demand was determined using EnergyPlus. The results of this study confirm the importance of controlling the thermal bridges of pillars and their impact on the energy demand.

Keywords: Thermal bridges · Pillars · Junctions · Linear thermal transmittance · Energy demand · Climate change

1 Introduction

Existing buildings have a high energy consumption which generates serious effects on the environment [1, 2]. For this reason, the European Union has set a series of goals to achieve a low-carbon economy by 2050 [3]. Among these goals, reduction values of carbon dioxide emissions are established in various sectors. As for the building sector, emissions should be reduced by 90% [3].

To achieve this goal, the main reason of energy consumption in buildings should be addressed: the use of HVAC systems [4, 5]. To reduce this type of energy consumption, different energy saving measures, such as the use of systems with a better performance or the building envelope improvement, could be performed in buildings. Regarding the envelope, controlling its thermal properties is of great importance to reduce energy

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consumption [6–8]. Highly effective thermophysical properties for the envelope allow the building energy demand to be significantly reduced [9]. The envelope is generally made up of a series of layers of different materials and thicknesses determining its thermal resistance. However, there are zones in the envelope where the junction between various elements causes a thermal bridge. A thermal bridge is understood as the part of the envelope presenting variations in its thermal resistance due to the junctions of materials with different thermal resistances [10].

These thermal bridges are responsible for generating heat losses in winter and heat gains in summer [11, 12], with variations of up to 30% in the heating demand [13]. The reason is that the thermal bridge can increase up to 35% the thermal transmittance value of a wall [14]. As a result, due to both the lowest thermal resistance and the associated energy losses, the analysis of thermal bridges influences the building energy demand [15, 16] and the determination of energy saving measures that should be implemented.

There are various studies in the scientific literature analysing the effect of certain typologies of thermal bridges in the energy behaviour of buildings, such as reinforced concrete structures [17, 18], curtain walls [19] or ceilings [20]. Nevertheless, there is a lack of studies analysing the effect of improving thermal bridges on the junctions of pillars and façades in corners. Also, there are few studies conducted in warm climates. For this reason, the goal of this study is analysing the energy behaviour of various building solutions considering this type of junctions and applied to a case study located in a warm region. To do this, an actual case study with problems of heat losses in this type of thermal bridge was selected, and the existing design was compared to other two building solutions. The case study was in Seville, which has a Csa class according to Köppen-Geiger climate classification [21]. The linear thermal transmittance was obtained through two-dimensional simulations performed according to ISO 10211:2007 [10], whereas the energy demand was obtained through simulations performed with EnergyPlus.

2 Methodology

2.1 Case Study and Energy Simulation

To carry out this research, an existing case study in Seville was selected. The building is a single-family dwelling from 2008. After analysing it through infrared thermography, heat losses were found in the thermal bridge of pillars and walls in corners (see Fig. 1 (a)). The analyses were conducted according to EN 13187:1998 [22].

The use of this case study allowed therefore to have a building appropriate to the needs of this research. For its energy simulation, a thermal model was designed in Design-Builder appropriate to the characteristics of the building. As its technical documentation was available, its dimensions and design characteristics could be accurately known. In this regard, one of the most important aspects was to know the thermal properties of the façade (see Table 1).

Regarding the use and internal loads of the building, the usage profile defined by the Spanish Building Technical Code (in Spanish, CTE [23]) was used. This profile is generic and representative of the use of buildings in most building stock designed according to criteria of the CTE. Table 2 indicates the setpoint temperatures defined in the CTE, and Table 3 indicates the percentage contributions of the internal loads. It

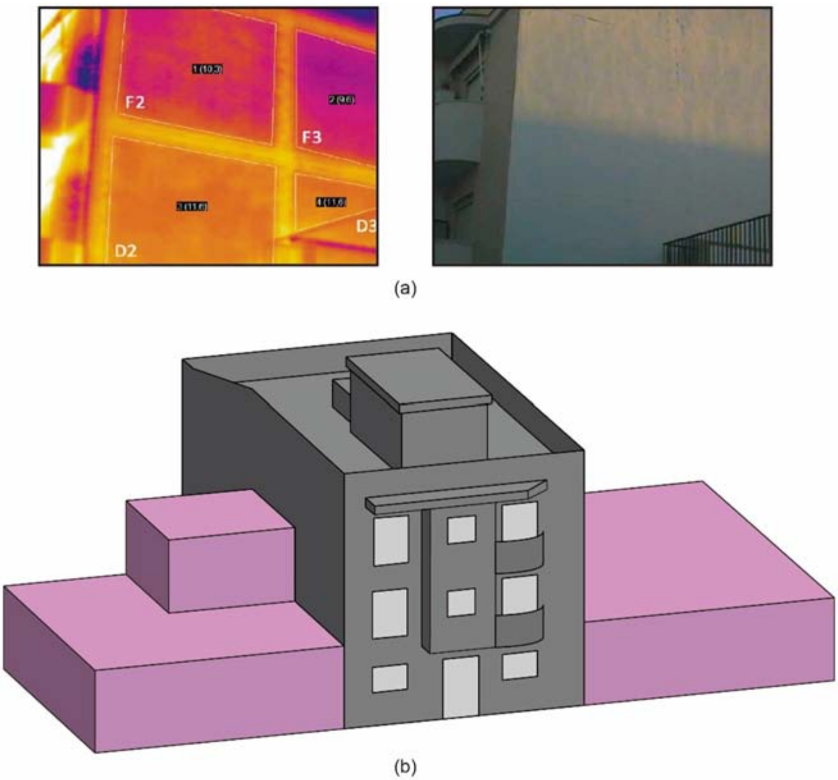

Fig. 1. Case study of the Research: (a) thermographies conducted in which heat losses can be seen through the thermal bridge between pillars and walls, and (b) 3D scheme of the case study.

Table 1. Layer thickness and thermophysical properties of the building façade.

Layers	Thickness [mm]	Thermal conductivity [W/(mK)]	Thermal resistance [(m^{2}K)/W][a]
Cement mortar	10	0.70	–
Perforated brick	110	0.59	–
Cement mortar	10	1.30	–
PUR insulation	20	0.03	–
Air gap	40	–	0.18
Hollow brick	50	0.44	–
Gypsum plaster	10	0.40	–

[a]Thermal resistance obtained from ISO 6946 [27].

is important to note that the maximum load for equipment and lighting is 4.40 W/m^2, whereas for the latent and sensitive occupancy are 1.36 and 2.15 W/m^2, respectively. As the variable analysed in the energy simulations was the energy demand, it was not necessary to consider special performance requirements for the HVAC system of the case study.

Table 2. Setpoint temperatures in the case study.

Setpoint temperature	Month	Hour						
		1–7	8	9–15	16–18	19	20–23	24
Cooling	Jan.–May	–	–	–	–	–	–	–
	Jun.–Sep.	27	–	–	25	25	25	27
	Oct.–Dec.	–	–	–	–	–	–	–
Heating	Jan.–May	17	20	20	20	20	20	17
	Jun.–Sep.	–	–	–	–	–	–	–
	Oct.–Dec.	17	20	20	20	20	20	17

Table 3. Percentage of loads in the case study.

Load	Hour						
	1–7	8	9–15	16–18	19	20–23	24
Occupancy	100	25	25	50	50	50	100
Occupancy (weekend)	100	100	100	100	100	100	100
Equipment	10	30	30	30	50	100	50
Lightning	10	30	30	30	50	100	50

Climate files were obtained through METEONORM. As for the climate files for 2050 and 2100, the climate change scenario of the Intergovernmental Panel on Climate Change (IPCC) was selected [24]. In this sense, the scenario A2 was selected because it is one of the scenarios which has the greatest effects of climate change [24]. It is also the scenario most used in other similar research studies [25, 26].

2.2 Determining the Linear Thermal Transmittance

To assess the effect of the thermal bridge, 3 different designs were analysed (see Fig. 2). The first design corresponds to the current design of the building, and the other two designs constitute two proposals to improve the performance of the junction. The advantage of these two new designs is that they could be applied to the building. Therefore, the results also aimed to analyse the actual possibilities of applying the measure. To determine the linear thermal transmittance (ψ), two-dimensional simulations were performed in HTFlux. The modelling of the thermal bridges was carried out according to the criteria included in ISO 10211:2007 [10]. In this sense, walls were cut at a distance of three times the thickness of the wall. The surface thermal resistances indicated in ISO 6946 were used as boundary conditions of the simulation [27]: 0.13 m^2K/W for the internal surface thermal resistance and 0.04 m^2K/W for the external surface thermal resistance.

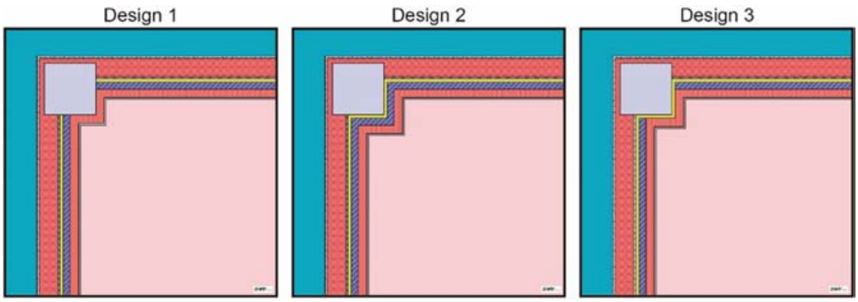

Fig. 2. Junction designs between the pillars and walls analysed in this research. Design 1 corresponds to the actual design of the building, and designs 2 and 3 are the improvement proposals.

3 Results and Discussion

Firstly, three designs of junction between pillars and walls were simulated to assess the existing differences between the linear thermal transmittance of the current design (design 1) and the two improvement proposals. Figure 3 represents the linear thermal transmittance values obtained by each design, showing that the linear thermal transmittance decreased considerably with the new designs, having the design 2 the lowest linear thermal transmittance. Whereas design 2 obtained a decrease of the linear thermal transmittance of 0.392 W/(mK), the decrease was slightly lower in design 3 (0.344 W/(mK)). Design 2 would be therefore the most recommended option for the decrease of the linear thermal transmittance, without considering other aspects resulting from the execution of the design and the economic cost of the measure.

After determining the design with the greatest decrease of the linear thermal transmittance, the energy saving achieved in the three scenarios considered in this research (current, 2050, and 2100) were studied. Figure 4 represents the monthly values of the heating and cooling energy demand obtained in the simulation process. The tendencies presented by the models simulated in each scenario were similar. However, differences between the two designs were found. The use of design 2 allowed slight decreases to be obtained in the energy demand. These decreases were greater in heating than in cooling.

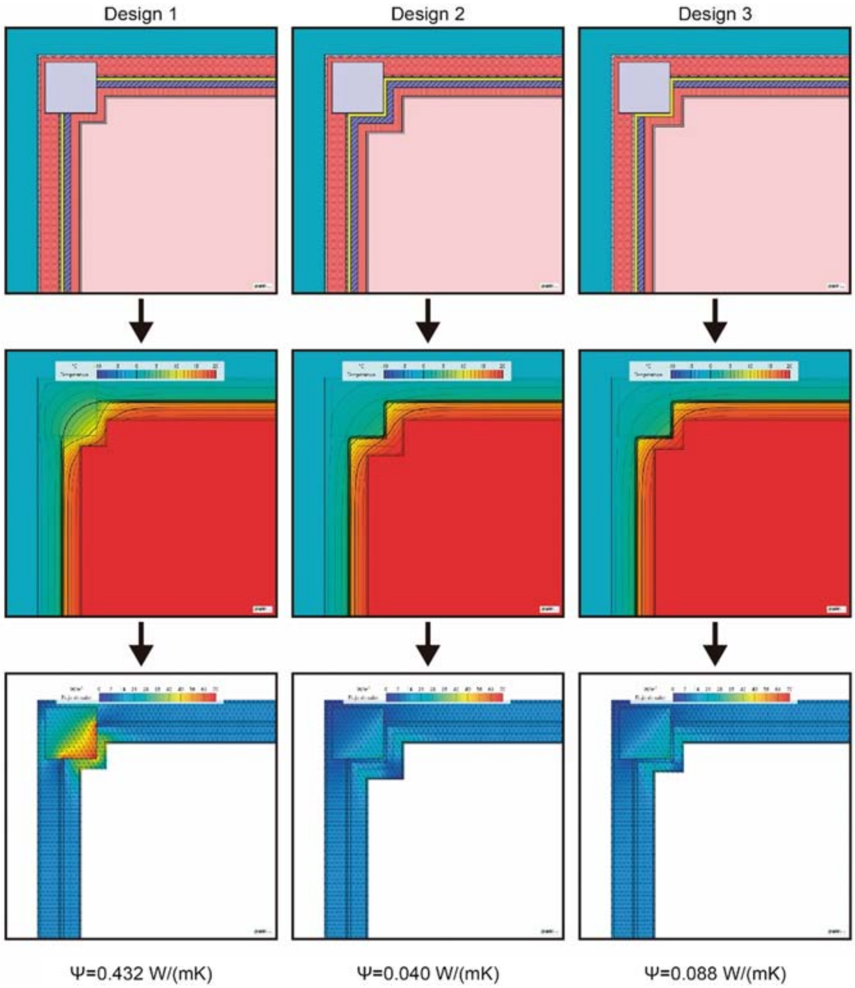

Fig. 3. Results of two-dimensional simulation obtained in HTFlux (isotherm and heat flux profiles) and the linear thermal transmittance value obtained.

Tables 4, 5 and 6 indicate the percentage deviations for the different periods considered and the obtained values of energy demand. As can be seen, the effect of design 2 on the monthly energy demand depended on the type of demand. In this sense, the monthly heating demand reached decreases of 298.87 kWh, whereas the monthly cooling saving reached maximum values of only 111.88 kWh.

Regarding future scenarios, the effect of design 2 on energy demands was similar to that of the current scenario. However, the progressive rise of external temperatures generated that the cooling energy demand was more and more high, thus significantly influencing the annual energy demand obtained in future scenarios (see Fig. 5).

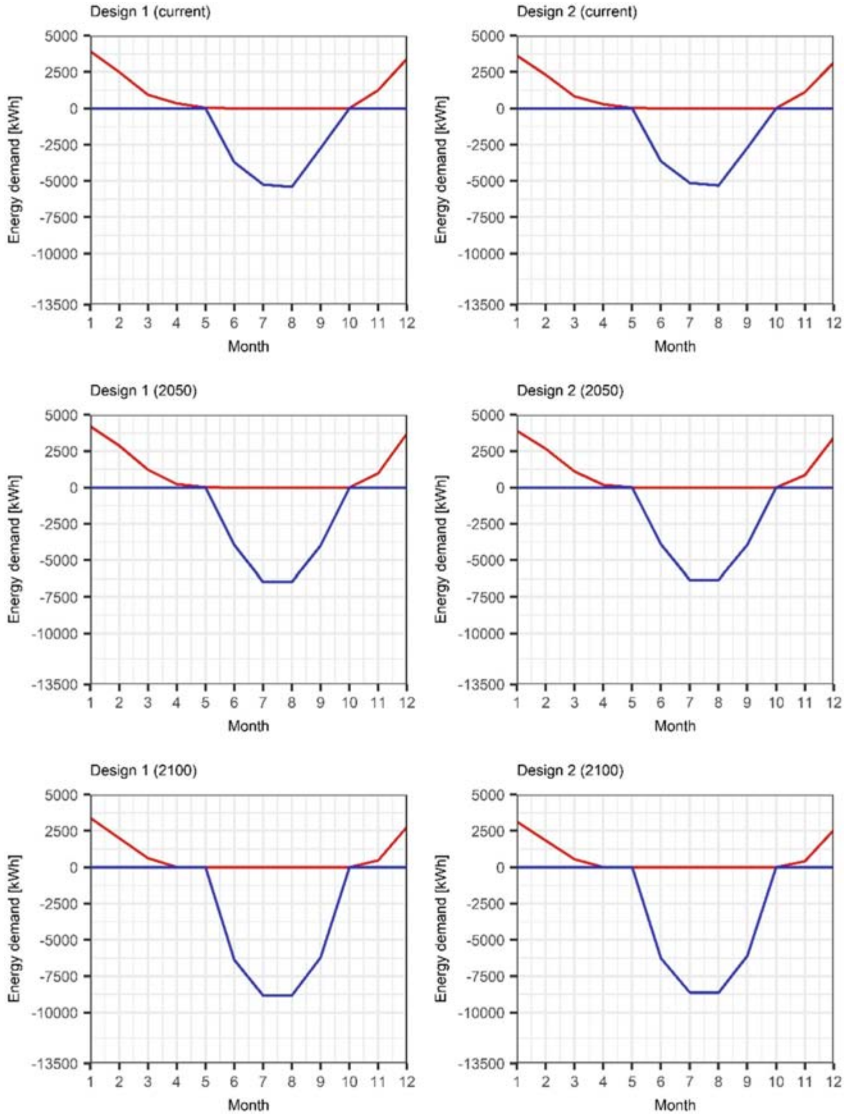

Fig. 4. Monthly building energy demand in the different scenarios considered (current, 2050, and 2100) using design 1 and design 2. The cooling energy demand is represented by the blue line, and the heating energy demand by the red line.

The decrease obtained in the total energy demand was low in all scenarios and with a decreasing tendency. In this regard, the decrease achieved in the total annual energy demand was 4.69% in the current scenario, 4.31% in 2050, and 3.64% in 2100. So, the improvement of the thermal bridge achieved low energy savings in the building in the different scenarios considered, with a higher incidence on the heating demand. These savings show the possible low economic profitability of carrying out energy improvement

Table 4. Differential of energy demand between design 1 and design 2 for the current period.

Month	Heating energy demand			Cooling energy demand		
	Design 1 [kWh]	Design 2 [kWh]	Energy saving [kWh]	Design 1 [kWh]	Design 2 [kWh]	Energy saving [kWh]
Jan.	3,927.93	3,629.06	298.87	0	0	–
Feb.	2,500.88	2,302.68	198.20	0	0	–
Mar.	928.75	823.52	105.23	0	0	–
Apr.	344.46	282.03	62.43	0	0	–
May.	37.85	27.99	9.86	0	0	–
Jun.	0	0	–	−3,702.53	−3,646.33	56.20
Jul.	0	0	–	−5,250.64	−5,138.76	111.88
Aug.	0	0	–	−5,409.39	−5,302.93	106.46
Sep.	0	0	–	−2,729.39	−2,716.05	13.34
Oct.	16.96	9.97	6.99	0	0	–
Nov.	1,260.19	1,114.69	145.50	0	0	–
Dec.	3,417.71	3,146.96	270.75	0	0	–

Table 5. Differential of energy demand between design 1 and design 2 for 2050.

Month	Heating energy demand			Cooling energy demand		
	Design 1 [kWh]	Design 2 [kWh]	Energy saving [kWh]	Design 1 [kWh]	Design 2 [kWh]	Energy saving [kWh]
Jan.	4,212.87	3,902.33	310.54	0	0	–
Feb.	2,880.90	2,661.48	219.42	0	0	–
Mar.	1,222.32	1,098.71	123.61	0	0	–
Apr.	233.44	185.06	48.38	0	0	–
May.	19.30	15.45	3.85	0	0	–
Jun.	0	0	–	−3,948.27	−3,902.54	45.73
Jul.	0	0	–	−6,473.60	−6,338.13	135.47
Aug.	0	0	–	−6,466.29	−6,336.14	130.15
Sep.	0	0	–	−3,992.82	−3,945.31	47.51
Oct.	5.59	2.58	3.01	0	0	–
Nov.	976.94	855.43	121.51	0	0	–
Dec.	3,713.64	3,430.19	283.45	0	0	–

Table 6. Differential of energy demand between design 1 and design 2 for 2100.

Month	Heating energy demand			Cooling energy demand		
	Design 1 [kWh]	Design 2 [kWh]	Energy saving [kWh]	Design 1 [kWh]	Design 2 [kWh]	Energy saving [kWh]
Jan.	3,401.88	3,134.75	267.13	0	0	–
Feb.	2,011.41	1,837.36	174.05	0	0	–
Mar.	623.18	550.18	73.00	0	0	–
Apr.	19.61	11.66	7.95	0	0	–
May.	0.16	0.04	0.12	0	0	–
Jun.	0	0	–	−6,371.87	−6,255.36	116.51
Jul.	0	0	–	−8,828.43	−8,621.48	206.95
Aug.	0	0	–	−8,827.21	−8,629.28	197.93
Sep.	0	0	–	−6,213.47	−6,113.60	99.87
Oct.	0	0	–	0	0	–
Nov.	480.56	412.31	68.25	0	0	–
Dec.	2,781.38	2,552.72	228.66	0	0	–

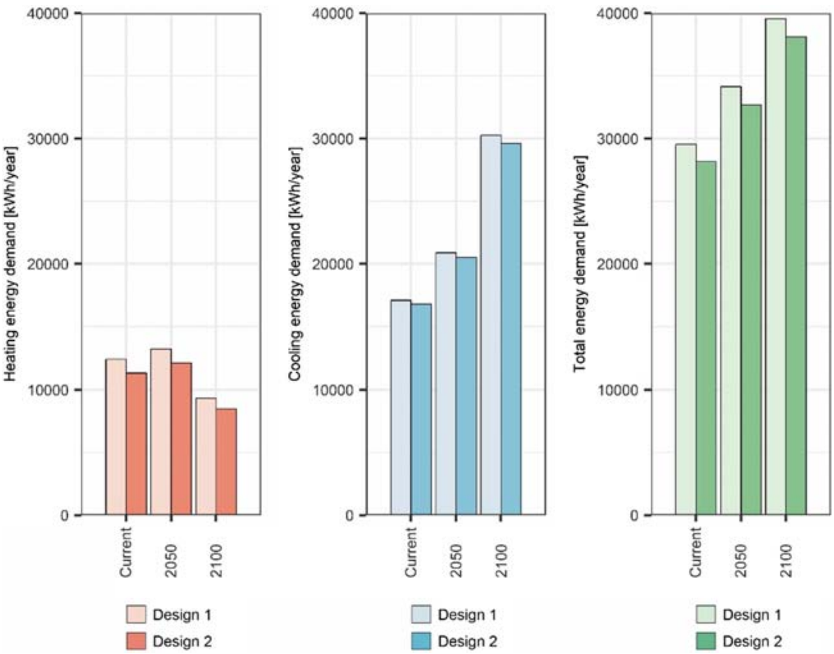

Fig. 5. Annual building energy demand in the different scenarios considered (current, 2050, and 2100) using design 1 and design 2.

measures in the existing buildings in warm climates to reduce the linear thermal transmittance in these thermal bridges. These results have a similar trend to that detected in a study of the slab front improvement in the same building [18], where it was detected how the decrease in linear thermal transmittance had a greater effect on the heating energy consumption than on the cooling energy consumption. However, the use of effective designs for these thermal bridges in new buildings are an opportunity due to the low impact produced. In addition, although the savings achieved are low, the effect generated by this low energy saving should be considered at a greater scale as little reductions could significantly affect the decrease of the environmental impact of the sector [28].

4 Conclusions

This research aimed at studying the effect of the thermal bridge of the junction of pillars and walls in corners on the energy demand of a case study located in a warm region. The analysis was conducted in a climate context with various scenarios. The results showed that the use of effective designs in the junctions led to significant decreases in the linear thermal transmittance. This decrease achieved decreases in the two types of building energy demand, although the saving in heating is greater than in cooling. As the energy demand with a higher incidence on the buildings of the zone is the cooling energy demand, the annual energy saving obtained is low and with a decreasing tendency in future scenarios.

Nevertheless, the effect generated by this low energy saving at a greater scale could have considerable decrease effects of the environmental impact caused by the building stock. Although the economic profitability of applying these designs in existing buildings is low (due to high payback periods), the use of these designs in new buildings would guarantee a building stock with a more efficient performance. It is also important to note that the results obtained are based on the analysis of a sole type of thermal bridge and in a climate zone. As other research studies have obtained similar energy saving percentages using other types of thermal bridges [18], future steps of this research will be focused on the combined analysis of different improvements of the linear thermal transmittance in buildings located in various regions and the economic assessment of their performance, so an accurate knowledge on the profitability of using effective designs for thermal bridges will be therefore available.

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