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Energy and cost evaluation of thermal bridge correction in Mediterranean climate

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ABSTRACT

In the cold climate of continental Europe the correction of thermal bridges in buildings is a mandatory issue, as in these areas they produce not only heat losses but frequently also condensation and mould growth.

In mild Mediterranean climate thermal bridges also cause an increase in energy consumption, but usually do not present condensation effects. In Italy, the current regulations for new buildings only recommend but do not impose the thermal bridge correction, which usually needs extra costs during construction and refurbishment phases.

This paper presents a study on the effects of thermal bridges for two building types (terraced houses and semi-detached houses) and three current envelope solutions in Italian climate, which may be considered representative of mild Mediterranean climate. The buildings are characterised by reinforced concrete frameworks and clay block walls; the thermal performance of the envelopes complies with Italian regulations for new constructions. In a first step the impact of thermal bridges on both heating and cooling energy demand is studied; then the economic convenience of correcting such thermal bridges is assessed by calculating the discounted payback period referred to the additional costs of construction and refurbishment.

1. Introduction

A thermal bridge is a building element where a significant change in the thermal resistance occurs compared to that of the envelope, due to the presence of materials with a higher thermal conductivity, as well as to the change in the geometry of the fabric, as in the case of the junction between roofs, floors, ceilings and walls [1]. As a result, a multidimensional heat flow is locally generated, which adds to the heat flow normally transmitted through the envelope surfaces; this means that thermal bridges increase winter heat losses and summer heat gains.

Furthermore, the local reduction of the thermal resistance yields a decrease in the temperature of the inner surface over the thermal bridge during the heating season, which might cause condensation and mould growth; this would imply the deterioration of the building materials and a reduction of the indoor air quality.

In the literature, linear and point thermal bridges are defined. A linear thermal bridge occurs at the junction between two or more elements of the building envelope: in this case, it is possible to identify an axis along which the orthogonal section of the thermal bridge does not change. A point thermal bridge is located where the continuity of the insulation is locally interrupted in one point, such as at three-dimensional corners.

The effect of the point thermal bridges is often neglected in the analyses aimed at defining the building energy performance. On the contrary, linear thermal bridges are accounted for through a linear thermal transmittance (ψ value), defined as the steady heat transfer per unit of length and per unit of temperature difference between the two environments [1]. Therefore, the overall heat transfer through a bi-dimensional component of the building envelope (wall, roof, floor) can be assessed as in Eq. (1), where the sum refers to all the linear thermal bridges associated with the component:

$$\dot{Q} = \left(U \cdot S + \sum_j \psi_j \cdot l_j \right) \cdot (T_i - T_o) \tag{1}$$

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Nomenclature

Variables

CD	building cooling demand (kWh year^{-1})
COP	coefficient of performance of the chiller (–)
l	length of the thermal bridge (m)
PE	primary energy demand (kWh year^{-1})
Q	thermal power (W)
S	surface (m^2)
T	temperature (°C)
U	surface thermal transmittance ($\text{W m}^{-2}\,\text{K}^{-1}$)

Greek letters

ψ	linear thermal transmittance ($\text{W m}^{-1}\,\text{K}^{-1}$)
η	efficiency (–)

Subscripts

el	electricity
i	indoor
o	outdoor

Eq. (1) may also be rewritten in a different form (see Eq. (2)); here, the effect of the thermal bridges is represented by an additional thermal transmittance ΔU, defined as in Eq. (3):

$$\dot{Q} = (U + \Delta U) \cdot S \cdot (T_i - T_o) \qquad (2)$$

$$\Delta U = \frac{1}{S} \cdot \sum_j \psi_j \cdot l_j \qquad (3)$$

2. Regulations and previous experiences

Several studies have investigated into the impact of thermal bridges on the energy performance of a building. A first study was conducted in Greece on a typical three-storey apartment building with an open ground-floor space (pilotis) and a flat roof; the façades are composed by two brick layers with interposed insulation (5-cm expanded polystyrene) [2]. The study shows that the correction of the thermal bridges, mainly carried out by the installation of a 3-cm layer of extruded polystyrene on the outer surface of the concrete beams and pillars, can reduce the building annual heating load of about 29%; on the contrary, their effect on the cooling load is negligible.

A collection of interesting studies is reported in [3]. Among these, a German demonstration project evaluates the energy performance of a two-family house with low thermal conductivity bricks, highly insulated roofs and basement slabs. The correction of sixteen linear junctions (external wall corners, window and door frame connections, roof–wall and slab–wall junctions) reduces the net energy demand for heating by 11.4 $\text{kWh m}^{-2}\,\text{year}^{-1}$ with respect to standard building solutions, leading to a final primary energy demand lower than 34 $\text{kWh m}^{-2}\,\text{year}^{-1}$. A France project on a new single family house with reinforced concrete framework in the climate of Paris is also proposed; nine different thermal bridges are analysed in detail, and various corrective techniques based on the thermal bridge rupture are suggested, showing that a reduction of the primary energy demand for heating between 11% and 24% can be achieved.

Furthermore, the growing impact of thermal bridges on the energy quality of the building also emerges from a study carried out in Czech Republic [3]. The case study is a residential building with brick walls and wooden frame windows; the relative impact of thermal bridges on the annual energy needs ranges from 7% for typical houses of the Seventies to 28% for modern high-quality houses.

However, despite their impact on the building energy demand for heating, the European Directive 2002/91/EC on the Energy Performance of Buildings does not explicitly mention any action against thermal bridges. Nonetheless, national regulations usually tackle this problem, even if at different levels. As an example, in Germany the national standards [4] impose that the impact of thermal bridging must be kept as low as possible. To take into account the thermal bridges shortly, an increase ΔU in the thermal transmittance of the building envelope as high as 0.10 $\text{W m}^{-2}\,\text{K}^{-1}$ must be introduced for standard new buildings; however, this term can be reduced to 0.05 $\text{W m}^{-2}\,\text{K}^{-1}$ if thermal bridges are corrected according to good practice examples mentioned in the regulation. In France, the ψ-value in new buildings should not exceed 0.65 $\text{W m}^{-1}\,\text{K}^{-1}$ for dwellings, 1 $\text{W m}^{-1}\,\text{K}^{-1}$ for apartment buildings and 1.2 $\text{W m}^{-1}\,\text{K}^{-1}$ for other buildings [5]; however, the actual respect of these constraints is usually not checked by the authorities.

In Denmark the same approach is followed: in new buildings, the maximum linear thermal transmittance ψ ranges from 0.06 $\text{W m}^{-1}\,\text{K}^{-1}$ for window fittings to 0.40 $\text{W m}^{-1}\,\text{K}^{-1}$ for foundations [3]. In Spain, the standards do not set a maximum ψ-value for thermal bridges, but a minimum value of the indoor surface temperature is imposed in order to avoid condensation risks [3].

Finally, in Italy national regulations do not impose a limit on the ψ-value [6]; however, if the additional thermal transmittance ΔU introduced in Eq. (3) exceeds by more than 15% the envelope thermal transmittance U, the effect of the thermal bridges cannot be neglected, and the overall transmittance ($U + \Delta U$) has to be compared with maximum acceptable values.

3. Review on calculation methods

Several methods are available to determine the linear thermal transmittance of a thermal bridge. As an example, the European Standard EN ISO 10211 [1] introduces an accurate numerical methodology for the description of the three-dimensional temperature distribution over the thermal bridge. However, its implementation is quite complex, and usually performed by means of appropriate software [7,8], thus making this approach not suitable for professionals, who are mostly interested in the overall building energy performance.

On the contrary, it might be easier and faster to refer to a thermal bridge atlas, where the ψ-values are reported for a large number of standard thermal bridges in easily comprehensible tables. The most common atlas is represented by the European Standard EN ISO 14683 [9], which contains seventy-six cases referring to eight typologies of thermal bridges (roofs, corners, intermediate floors, internal walls, slab-on-ground floors, suspended ground floors, pillars, window and door openings). Anyway, the number of cases is small if compared with the variety of solutions that can be identified in real buildings. Furthermore, the ψ-values suggested by the standard are calculated at reference conditions: as an example, the external walls considered in the standard are characterized by a thickness $s = 300$ mm and a thermal transmittance $U = 0.343\ \text{W m}^{-2}\,\text{K}^{-1}$. Consequently, the proposed ψ-value is as less precise as far we get from such reference conditions; however, these parameters are chosen in order to obtain ψ-values that are cautious overestimates of the thermal bridging effect.

The French Thermal Regulation published in 2006 contains, in one of its Annexes [10], a wide atlas of thermal bridges, with more than ten thousand cases. This atlas is characterized by a very high flexibility, as every building detail can be described with different wall thickness and thermal transmittance.

In Italy, an interesting approach is proposed in the national standard UNI 7357 [11], and exactly in its annex FA3 published in 1989.