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A building thermal bridges sensitivity analysis

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HIGHLIGHTS

- ▶ Heat transfer through the most typical thermal bridges is analyzed through a finite difference method.
- ▶ The linear thermal transmittance for a large number of design parameters is catalogued.
- ▶ Non-linear regression models of the most typical thermal bridges are identified.
- ▶ A sensitivity analysis of the most relevant design parameters is carried out.

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ABSTRACT

Along with the entry into force of the new European Directive 2010/31/EU on the Energy Performance of Buildings (EPBD recast), each Member State has the responsibility of supporting activities for the construction of nearly zero energy buildings with a very high energy performance. In order to achieve the new EU directive targets, designers, in addition to having to use innovative building components, also have to pay more attention to the construction details which mostly affect building envelope heat losses. It is therefore necessary not only to properly design structural nodes, in order to minimize such energy losses, but also to identify accurate numerical methods in order to appreciate the benefits of a proper design. A sensitivity analysis based on an extensive study of the linear thermal transmittance value of many types of thermal bridge, based on the methodology specified in EN ISO 10211, has been carried out in the presented work. After having defined the input design variables and considering a range of variation for each of them for the linear thermal transmittance evaluation, a non-linear regression model has been specifically developed for each analyzed thermal bridge, considering the output values of a numerical code as data set. In order to perform the sensitivity analysis a significant and representative number of cases have been generated, using a sampling technique. The ANOVA–FAST method has been performed, on the basis of the obtained results, in order to assess the contribution of each input design variable to the deviation of the linear thermal transmittance for each kind of thermal bridge.

1. Introduction

1.1. Influence of thermal bridges on building energy performance

With the entry into force of European Directive 2010/31 on the Energy Performance of Buildings (EPBD recast) [1], each Member State is required to draw up national plans to increase the number of nearly zero-energy buildings. Moreover, starting from European Directive 2002/91/CE, the Italian national legislation on building energy efficiency (Legislative Decree no. 192/2005, Legislative Decree no. 311/2006) has led to an improvement in opaque and transparent envelope performance.

In order to achieve the objectives of the EPBD recast, the designer is required on one hand to use innovative envelope components, while on the other hand to pay greater attention to construction details.

In fact, the mere addition of an insulation layer only reduces the one-dimensional heat flow, but does not significantly decrease the multi-dimensional one, if no attention has been paid to the heat flow through thermal bridges. Although it is not possible to obtain general results concerning the weight of thermal bridges on the energy needs of buildings, several studies have presented numerical results for different cases. A 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 of two brick layers with interposed insulation [2]. The study shows that the double brick wall construction widely used in Greece is affected to a great extent by thermal bridges. Even if the actual construction presents high insulation levels, the heating need can be 30% higher than the one calculated without taking into account the thermal bridge effects. Cappelletti et al. [3] have shown that the weight of thermal

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Nomenclature

Symbols

B'	characteristic dimension of the floor (m)
b_{tr}	temperature reduction factor (–)
e	width (m)
H	overall heat transfer coefficient (W K^{-1})
l	length (m)
L_{2D}	thermal coupling coefficient from bi-dimensional calculation (W m^{-1} K^{-1})
q	heat flow per meter length (W m^{-1})
R	thermal resistance (m^2 K W^{-1})
S	thickness (m)
SI	sensitivity index
U	thermal transmittance of a building component (W m^{-2} K^{-1})

Greek symbols

θ	air temperature (°C)
λ	thermal conductivity (W m^{-1} K^{-1})
ψ	linear thermal transmittance (W m^{-1} K^{-1})

Subscripts

adj	adjacent, adjusted
b	balcony
calc	calculated
e	external
fl	floor
fr	frame
gr	ground
i	internal
int	intermediate
ins	insulation layer
m	mean
mas	masonry
*M*1	internal masonry
*M*2	external masonry
p	pillar
pred	predicted
r	roof
se	external surface
si	internal surface
tr	transmission
w	wall

bridges on building energy needs for space heating can reach 67% for a building with a double brick wall (U = 0,15 W/(m^2 K)) in a typical Italian climatic zone. A collection of interesting studies has been reported in [4]. The impact of thermal bridges on the energy quality of a building has also emerged from a study carried out in the Czech Republic: the case study was a residential building with brick walls and wooden frame windows. From the same study it is highlighted that the relative impact of the thermal bridges on the annual energy needs varies from 7%, for typical houses of the seventies to 28%, for modern high-quality houses. The impact of thermal bridges on the heating energy needs of different European Member States is generally as high as 30% [4]. Moreover, the more a building envelope is insulated, the more thermal bridges play a relatively increasing role in the global heat losses and consequently in the energy needs for space heating.

A study on the effects of thermal bridges in an Italian climate has been carried out on two building types (terraced houses and semi-detached houses) and three envelope configurations by Evola et al. [5]. The results show that the correcting thermal bridges is an effective way of reducing the primary energy heating demand (25% for terraced houses, 17.5% for semi-detached house), but only a slight improvement – about 3.5% – can be achieved in the cooling performance of the building. The overall annual energy savings is about 8.5%, but a cost analysis has shown that the savings determined by correcting thermal bridges are not sufficient to recover the additional construction and refurbishment costs.

Some studies focus on window thermal bridges giving practical and technical solutions to minimize their effect on building thermal losses. Thermal bridging has been evaluated through three different window systems commonly used in buildings in hot regions, by Ben-Nakhi [6] by means of the linear thermal transmittance (ψ) approach. The results show that the classical window system, which is the most common in Kuwait, is affected by significant thermal bridging and that this effect should be considered in building design. Some practical methods used to reduce the ψ value for the classical window system were also evaluated in this paper. The influence of thermal bridges on the performance of windows has also been analyzed by Cappelletti et al. [7] for the case of clay walls with external and cavity insulation. The results pointed out a consistent reduction of up to 70–75% in linear thermal transmittances when the window is moved from the internal to the external position. This decrease mainly depends on the position of the insulating layer installed in the window hole.

Hence, in order to minimize thermal bridge energy losses, it is necessary not only to design the structural nodes properly, but also to identify accurate methods to calculate heat losses, in order to make it possible to appreciate the benefits induced by a correct design.

1.2. Existing methods for the calculation of energy losses through thermal bridges

In this paper the thermal bridging effect is evaluated by means of the linear thermal transmittance approach. Since this parameter is calculated under stationary conditions, it is generally applied for building energy need assessment through quasi-steady state methods in the framework of energy performance technical standards and regulations. The use of linear thermal transmittance approach presents some limitations for building energy simulations (BESs); therefore the aim of this paper is not to implement it in dynamic energy simulation codes.

The heat exchange through thermal bridges can be calculated using the different methodologies specified in the relevant technical standards [8,9], which present both simplified and detailed methods to calculate thermal losses through thermal bridges under steady-state conditions.

Italian Technical Specification UNI/TS 11300-1 [10], *for existing buildings, in the absence of reliable project data or more accurate information, for some building types*, considers a percentage increase of the overall heat transfer coefficient by transmission ($H_{tr,adj}$), while European Standard EN 12831 [11] introduces a corrected thermal transmittance of building element, taking into account linear thermal bridges through an increase of the thermal transmittance of the element. Both documents mention EN ISO 14683 standard as the main reference for the calculation of heat transfer through the thermal bridges in all the remaining cases.

In the cases of linear thermal bridges, and in the absence of specific data, EN ISO 14683 standard [8] provides the use of default