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Limiting windows offset thermal bridge losses using a new insulating coating

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HIGHLIGHTS

- Co-simulation is used; coupling a 2D heat transfer code developed in MATLAB with EnergyPlus.
- Windows offset thermal bridges energy load constitutes around 2-8% of the total house load.
- Applying the coating reduces the windows offset thermal bridge load by about 24% to 50%.

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ABSTRACT

Thermal bridges are weak areas of the building envelope in which they can significantly increase the energy load of houses. In this study, we tackle the thermal bridges resulting from windows offset from exterior walls. First, we present an innovative insulating coating which can be used to limit thermal bridge effects. Second, we compute the cooling/heating load coming from the windows offset thermal bridges of a typical French house before and after adding the insulating coating. Third, we compare the time lag and decrement factor when the 2D heat transfer effects of the thermal bridge are taken into consideration. The methodology is to incorporate 2D heat transfer into a whole building energy simulation program. This is done through co-simulation between a 2D heat transfer model developed in MATLAB and the building energy simulation software EnergyPlus using the software BCVTB. This latter enables us to link the two programs and allow them to exchange data at each simulation time step. Results showed that the windows offset thermal bridges energy load percentage of the total house load constitutes around 2–8% depending whether exterior walls have interior insulation or not. Applying 1 cm and 2 cm of the coating on these thermal bridges reduces the windows offset energy load by about 24–50%. Concerning time lag and decrement factor, we obtain high values for decrement factor and low values for the time lag for wall positions near the thermal bridge. Applying the coating decreases, significantly, the decrement factor and increases the time lag.

1. Introduction

In France, the share of the building sector is about 43% of the total energy consumption and 25% of carbon dioxide emission [1]. France has already adopted the objective of reducing its energy consumption and greenhouse gas emissions by a factor of four to five by the year 2050 as a part of its national strategy for sustainable development, introduced in June 2003, and its climate plan, introduced in July 2004 [1]. Also, to cope with the new thermal regulations (RT 2012) which limits the primary energy consumption for new buildings to 50 kW h/m^2 per year (this includes heating, cooling, lighting, water heating, and ventilation), and also requires a better thermal comfort through limiting overheating during summer season, it is crucial to find solutions to reduce energy consumption and enhance thermal comfort. Super-insulating materials, such as silica aero-gels and vacuum insulation are one of the promising techniques to be used in building envelopes to obtain the desired objectives.

Thermal bridges are weak areas of the building envelope, where heat can find its path through them penetrating the well-insulated walls. Moreover, the innovative technologies for modern buildings (for instance, silica aerogels based materials and vacuum insulation panels) induce thermal bridge effects that cannot be neglected

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Nomenclature

k	thermal conductivity (W/(m K))
c	specific heat (J/(kg K))
ρ	density (kg/m^3)
T	temperature (K)
x	x-coordinate (m)
y	y-coordinate (m)
t	time (s)
h	convective heat transfer coefficient (W/(m^2 K))
L	length (m)
W	width (m)
q	heat flux (W/(K))
$\dot{m}$	volumetric flow rate (m^3/h)
$\varnothing$	time lag (h)
f	decrement factor
η	efficiency
subscripts	
i	Layer i
in	inside
o	outside
e	east
w	west
n	north
s	south

[2]. According to the French Scientific and Technical Centre for Building Research (CSTB), thermal bridges can increase the thermal load of a house by 20% [3]. Furthermore, Kosny and Kossecka [4] showed that the calculation of a thermal resistance of a wall, neglecting the thermal bridge effects and adopting the one-dimensional approach, could also lead to an overestimation greater than the 44%.

A lot of research has been carried out concerning the effect of thermal bridges on energy consumption [5,6], thermal comfort [7], and cost [8]. Also, other studies have focused on conducting sensitivity analysis to identify the main important design variables affecting the heat losses through different types of thermal bridges [9,10].

Ascione et al. [11] showed that approximate models of thermal bridges induce inaccurate interpretations and, consequently, inappropriate energy demands. They calculated the effect of the thermal bridges of a roof structure on the energy load of an office building using three different approaches for the thermal bridge representation; (a) a simplified scheme that considers an equivalent homogeneous structure, (b) a detailed subdivision in "in-series and "in parallel" layers, and (c) the real structure modeled by means of CFD studies. At First, using each of the three methods, the thermal transmittance of the roof was calculated. Then, these were implemented in a commercial code for the building energy dynamic simulation. The analysis was carried out in four different Italian climates. Results showed that the thermal transmittance of the roof varied greatly between the three approaches. The energy demand also was quite variable depending on the modeling strategy. The accurate interpretation of the thermal behavior of the composite structures (approach 3) leads to a lower energy load for winter conditions, with respect to the simplified model (approach 1), by about 20% in the South of Italy and about 13.5% in the North.

Al-Sanea and Zedan [12] studied the effect of the two dimensional heat transfer of an insulated wall cut by mortar joints under steady periodic conditions for the climate of Riyadh. They developed a computer model using the finite volume scheme. Transmission loads increased by 62% and 103% for mortar heights of 10 and 20 mm, respectively, compared to wall with no mortar joint effect.

Déqué et al. [13] calculated the heat losses due to walls intersections thermal bridges for a case study. They used the software Sisley to model the 2D heat transfer and they integrated the 2D models in the software Clim 2000 [14]. Results showed that building heat losses were more accurate by about 5–7% when taking the 2D effects into consideration.

Gao et al. [15] developed a low-order three-dimensional heat transfer model to account for additional losses of thermal bridges. Then, they developed a new "TYPE" in TRNSYS [16] in order to implement the thermal bridges effect into a whole building. This TYPE generates additional heat loss output with the reduced model. They showed that the additional thermal bridge heat losses in a room situated in the northern part of France for a 2 days simulation can reach 19%.

Berggren and Wall [17] presented the state of knowledge regarding thermal bridges among Swedish engineers and architects. A survey among Swedish engineers and architects was carried out in combination with comparative calculations of thermal transmittance through building envelopes with different external wall constructions and insulation thickness. It results from the survey that there is no clear practice/norm that can be identified regarding which measuring method is usually applied. Also, the study clearly shows the increasing role of thermal bridges in transmission heat transfer calculations when improving the building's energy performance. They showed that the relative (percentage) effect of thermal bridges increases when more insulation is used.

Martin et al. [18] conducted a series of tests in a guarded hot box testing facility to scrutinize the thermal bridge response. The characteristics of a pillar thermal bridge were studied in both steady and dynamic regime. Also, experimental results are compared to those obtained from simulations using numerical modeling approach.

Asdrubali et al. [19] proposes a methodology to perform a quantitative analysis of some types of thermal bridges, through simple thermographic surveys and subsequent analytical processing. From the simple measurement of the air temperature and the analysis of the thermogram, the thermal bridge effect can be estimated as a percentage increase of the homogenous wall thermal transmittance.

Most building energy simulation programs do not model the heat transfer in walls as two and three dimensional but rather consider it as merely one dimensional. This can lead to major deviations from the real load of the building especially for passive and low energy houses. We are concerned to tackle the effect of thermal bridges resulting from windows offset from exterior walls on the total load of the space and try to find solutions to limit the heat losses/gains through them as well as to enhance thermal comfort. If the outside wall surface is very well insulated, the heat will find its way through this thermal bridge.

In this study, we first present an innovative insulating coating based on (super)-insulating materials (silica aerogels) which can be used as a solution to limit thermal bridge effects and enhance thermal comfort. Second, we compute the cooling/heating load coming from windows offset thermal bridges and show how much it constitutes of the total load of a typical French house before and after adding the insulating coating on the thermal bridges. Third, we compare the time lag and decrement factor when the 2D heat transfer effects of the thermal bridge are taken into consideration with those obtained for the 1D heat transfer case.