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Thermal performance evaluation of fiber-reinforced polymer thermal breaks for balcony connections

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ABSTRACT

The potential effects of high-performance fiber-reinforced polymer thermal breaks for balcony connections on the thermal losses and heating needs of a typical residential building in Switzerland were investigated. In an optimized form, these new thermal breaks have a linear thermal transmittance of $\psi \leq 0.10$ W/mK. The reduction of the total transmission losses via these optimized thermal breaks through the building envelope remained modest. If however losses through the thermal bridges are related to those through the opaque envelope elements only, the latter were reduced by up to 18% for an optimum envelope. If furthermore these losses are related to the heating needs of a building with an optimum envelope, their magnitude is reduced by 41% if ψ is decreased from 0.30 (recommended value from SIA) to 0.10 W/mK. In attempting to approach the goal of zero-energy buildings with zero heating needs, the thermal losses through thermal breaks can thus have a significant effect.

1. Introduction

Since July 2012, the EU requires that member states (including Croatia, Norway and Switzerland) implement the amended version of the Energy Performance Building Directive (EPBD), so that by 31 December 2020, all new buildings are nearly zero-energy buildings (NZEB) [1]. The EPBD describes the nearly net-zero energy building as a building that has a very high energy performance [2], which signifies buildings with minimized heating needs, but not at the expense of indoor comfort. Therefore special attention should be paid to the optimization of every building element, so that good internal comfort is guaranteed and energy waste due to poor design is avoided.

Critical regions of the building envelope constitute the thermal bridges, created by every interruption of the insulation layer and generally in zones with reduced thermal resistance [3], which affect both energy consumption and indoor comfort. Multidimensional heat flows are generated at these locations, in addition to the heat flow normally transmitted through the building envelope. Furthermore, a high risk of condensation and mold growth exists in thermal bridge regions due to the low internal superficial temperature, with a negative impact on the structure and indoor environmental quality [4]. Since thermal bridges are such a critical issue, the different energy policies implemented in Europe consider them in their requirements for energy-efficient buildings as shown for instance in Switzerland's energy policy, SIA [5] and MoPEC [6], and in two of the most prevalent European energy standards, MINERGIE [7] and Passivhaus [8].

The building codes and standards primarily focus on requirements concerning the performance of the building envelope, of which thermal bridges are a part. The Swiss code SIA 380/1 proposes two methods for the evaluation and optimization of the envelope's energy performance; the global and the punctual methods. While in the global method no requirements are established regarding thermal bridges, the punctual method prescribes limit values and target values for the thermal transmittance, ψ, of the envelope elements. In the case of balcony connections these values are $\psi = 0.30$ W/mK and $\psi = 0.15$ W/mK, respectively. Furthermore, the Swiss building code SIA 180 [9] requires the evaluation of the critical superficial humidity and internal temperature in order to avoid condensation or mold growth risk. Finally, MoPEC requirements concerning thermal bridges are based on SIA 380/1.

The energy standards in Switzerland, MINERGIE apply similar requirements concerning thermal bridges to the SIA codes. In the basic MINERGIE standard the limit value ($\psi = 0.30$ W/mK) must be met if the punctual method is used. In MINERGIE-P and MINERGIE-A only the global method is applied and thus no requirements are prescribed for thermal bridges. The German Passivhaus standard has stricter requirements concerning thermal bridges. The evaluation of the thermal transmittance through the thermal bridges according to EN ISO 10211 [10] and/or EN ISO 1007 [11] is required. Concerning thermal bridges created in balcony connections, the thermal bridge correction factor is limited to $\Delta U = 0.025$ W/m^{2}K while, if a value of $\Delta U = 0.01$ W/m^{2}K is complied with, the balcony

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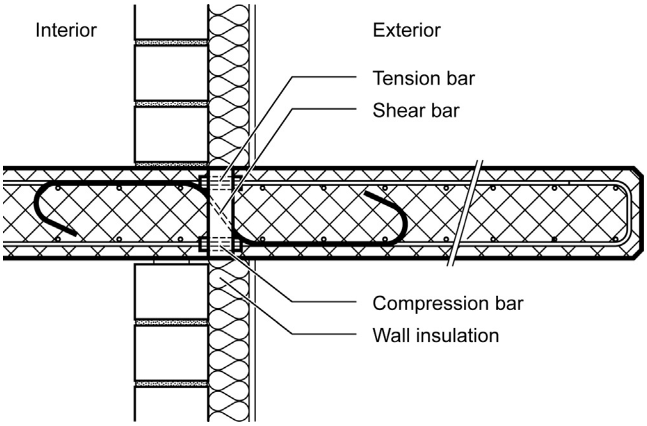

Fig. 1. Typical thermal break with steel bars currently used for balcony connections [15].

connection is considered as ″thermal bridge free″. In addition, the temperature factor, f_{rsi}, should not exceed the minimum value for mold growth risk [12].

The only way to satisfy the limit or target values for thermal bridges is to homogenize the thermal resistance throughout the building envelope [13]. With regard to thermal bridges created in balcony connections in concrete or masonry structures, the industrial sector proposes a variety of balcony thermal breaks, which interrupt the heat flow towards the external environment by adding an intermediate insulation layer between the internal floor and the balcony slab, as shown in Fig. 1. For the majority of thermal breaks, the load transfer from the balcony's cantilever to the main structure occurs through stainless steel bars, which penetrate the insulation layer and still have a high thermal conductivity. Table 1 summarizes the thermal conductivity of the most commonly used materials in such connections (according to EN ISO 10456:2007 [14]). Depending on a variety of parameters (wall thermal transmittance, diameter of bars, number and distance of elements, etc.), the thermal performance of these elements, evaluated by the linear thermal transmittance, ψ, varies between 0.11 and 0.35 W/mK (according to manufacturer data sheets). However, the lowest values can only be achieved for very small overhangs (if U-values of the walls of 0.10 W/m^{2}K according to MINERGIE-P or NZEB are aimed at). ψ-values for typically used balconies (projections of 1.2–1.5 m) are then around 0.25–0.30 W/mK and therefore meet the Swiss limit value, but not the target value.

New materials exist nowadays with much improved thermal properties, see Table 2, which could replace existing conventional ones and improve the performance of thermal breaks. Keller et al. [15] studied a new hybrid element, in which the lower stainless steel reinforcement was replaced by a compression-shear glass-fiber reinforced polymer (GFRP) element, which improved the thermal performance by 26% compared to the pure steel solution [16]. However, the remaining tension steel bars were still leading to significant losses. Even better thermal properties than those of glass fibers are offered by aramid fibers, see, Table 2, and combined with high-performance insulation materials e.g. aerogels, thermal transmittances of ψ = 0.10 W/mK, far below the SIA target value, can be achieved.

Table 1
Thermal conductivity of commonly used materials in thermal breaks [15].

Material	λ (W/mK)
Reinforcing steel	50
Reinforcing stainless steel	17
EPS foam	0.032–0.040
XPS foam	0.025–0.040
Mineral wool	0.030–0.035

Table 2
Thermal conductivity of aramid and glass fibers and aerogel materials.

Material	λ (W/mK)
Aramid fibers	0.04[a]
Glass fibers	1.0[a]
Aerogel (insulation)	0.013[b]

[a] Values from Swiss-Composite [28].
[b] Values from Cabot [29].

The objective of this work is to evaluate the possible impact of such an improved and optimized thermal break on the energy balance of a typical residential building in Switzerland's environmental conditions. In a case study the thermal losses through the balcony connections are estimated and compared to the total transmission losses and the heating needs. Three different thermal transmittances are taken into account, ψ = 0.30, 0.15 and 0.10 W/mK, corresponding to the SIA limit and target values and to an optimized FRP thermal break, respectively. For each value, three different envelopes are considered, corresponding to the MINERGIE and MINERGIE-P standards as well as to an optimized envelope according to NZEB requirements. In a MINERGIE or MINERGIE-P envelope, the losses through thermal bridges can always be compensated by optimizing other building elements e.g. using more efficient glazing types or thicker insulation. However, when the envelope cannot be optimized any further and all the elements exhibit the best currently attainable performance, the real impact of thermal bridges on the building's energy consumption can be estimated. The impact of thermal losses through balcony connections will thus be quantified for optimally performing thermal breaks and building envelopes as well.

2. Case study and general assumptions

A typical two-story residential building was selected for the analysis, as shown in Fig. 2. The building was assumed as being situated in Pully, one of the eastern suburbs of Lausanne, located on the shores of Lake Geneva. The altitude was selected as being 461 m where data were available from a meteorological station. On the ground floor were a kitchen, a living room and subsidiary rooms, while on the first floor were four rooms and a bathroom, see Figs. 3 and 4. A balcony and a projecting roof were designed around the first floor, which served as protection against weather conditions. The energy reference area (ERA) according to SIA 380/1 was 180 m^2 and the total building height was 7.1 m (external dimensions, see Fig. 5). The ERA is defined as the total sum of the horizontal surfaces (external dimensions) that are included inside the thermal envelope. The orientation of the building and the

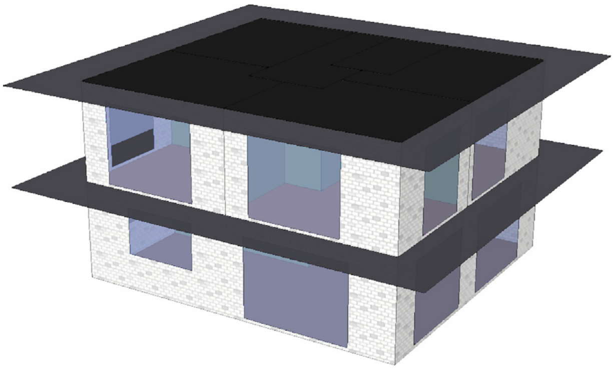

Fig. 2. 3D visualization of case study building.