On the implementation of thermal bridge calculations in the Belgian building code

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Abstract:
Numerical tools for two-dimensional or three-dimensional heat transfer are readily available to the building professional to calculate the thermal transmittance of thermal bridges. However, designers need appropriate limits to compare the predicted performance and decide whether it is necessary to improve the detailing. This paper presents a methodology and suggestion for such limiting values. For 5 building typologies all building envelope interfaces were evaluated. For each interface the design was modified to reflect 'business-as-usual', 'standard', or 'thermal bridge avoidance' approach, and the overall impact was evaluated for different insulation levels. The resulting limiting values differ as a function of thermal bridge geometry and take into account the technical feasibility of the requirements. However, when such limits are introduced in a building code, this would imply that every single building envelope interface in every project needs to be simulated. Hence, there is a clear need for a straightforward methodology for the building practice to handle thermal bridge evaluation. In this paper the Belgian approach is presented, which uses easy to apply rules of thumb to check whether a specific building envelope interface is code-compliant. These rules of thumb are based on extensive simulations, and can be applied using only the geometrical information and thermal conductivities of building nodes. Finally, an approach is presented to implement this methodology in an overall heat loss calculation that can cope with different types of input (code-compliant, non-code-compliant, and numerically simulated).

Keywords:
Thermal Bridge, Heat Loss Calculation, Building Code, Numerical Simulations

1. Introduction

The Energy Performance of Buildings Directive (EPBD) in Europe has entailed a standardised energy calculation method and mandatory software in Belgium that was implemented in 2006. As the EPBD did not explicitly require to account for energy loss due to thermal bridge effects, a comprehensive methodology was only developed in 2010 on a national level and implemented in 2011. The main goal was to provide a pragmatic approach that allows an easy implementation by building practitioners. Based on a selection of case-studies it was found that even rather simple residential buildings easily comprise over 30 different building envelope interfaces. The number of point thermal bridges, or situations where important 3D effects come into play is more sensitive to the specific definition. Consequently, a correct calculation would require dozens of building nodes to be simulated in numerical software, an accurate measurement of building envelope length and number of point thermal bridges, and as well, a system to check the accuracy of the simulations and calculations. Such a methodology would entail a large burden on the building industry. In the Belgian context a simplified approach was developed that allows to take the additional energy loss into account, with a reasonable trade-off between accuracy and feasibility. For more literature on thermal bridges and an overview of thermal bridge software, please refer to the Final Report of the European ASIEPI-project (Erhorn et al, 2010). EN ISO 10211 provides guidelines to calculate complex thermal bridges by a linear (W/m.K) or point (W/K) heat transmission coefficient, which is subsequently multiplied with the respective length and number for a specific building. For the majority of European countreis, the detailed calculation of thermal bridges according to this standard is an accepted option to to account for thermal bridge associated energy losses. Other European countries have developed more simplified approaches. The most simplified method is by adding a correction factor ΔU to the U-value of the different envelope areas to take thermal bridging into account (e.g. The Netherlands, Germany, Poland, Spain). More precise, but often still simplified, is the use of tabulated values for specific details or the application of a thermal bridge atlas (e.g. Denmark, France, Germany, Spain) (Roels et al., 2011).
In Belgium, a different approach was developed. Firstly, the typical impact of thermal bridges on energy loss was evaluated for a range of building geometries and building envelope interface design principles. Subsequently, specific limits for linear thermal transmittance were set that take into account geometric and technical boundary conditions. Thirdly, simplified rules of thumb were developed for the building industry, for which detailed simulations were done to ensure that these in fact entail limited additional heat losses in accordance to the linear thermal transmittance values. Finally, an overall approach was developed to incorporate additional energy losses due to thermal bridges in the building code, while maintaining the flexibility to choose a

detailed numerical approach, simplified rules of thumb, default values for poorly designed thermal bridges, or a combination thereof.

2. Impact of thermal bridges on transmission heat loss

To create a better understanding of the relative importance of thermal bridges, the two-dimensional transmission heat loss resulting from all junctions encountered in five typical masonry cavity wall dwelling designs was quantified. The reference dwelling designs have been developed in the framework of a research project on the optimization of building envelopes and services for low-energy residential buildings. The five dwellings are all single-family houses with the same program (four-person families) and the same useful floor area, corresponding to national statistical figures. The dwellings only differ in typology and building compactness, ranging from a detached bungalow to a flat in a six-floor apartment building.

The transmission heat loss related to linear thermal bridges was analyzed for each of the dwellings. The building envelope consisted of traditional constructions that are most commonly found in the Belgian housing stock: insulated cavity walls, warm flat roofs with concrete floors, insulated cathedral ceilings with wood-frame structures, concrete ground floors and floors above grade, etc. To determine a representative linear transmittance for each junction, the two-dimensional heat loss was calculated assuming a thermal insulation thickness of 20 cm (≈ 0.2 W/m2·K). Note that for larger insulation thickness the linear thermal transmittance becomes rather stable, which allows a safe implementation when using standard values.

The analysis is based on three different scenarios with respect to the thermal quality of building details. The difference between the three scenarios is illustrated in Figure 1.

1. **Business as usual**. In this scenario, typical structural intrusions in the thermal insulation are present at window reveals, roof eaves, etc., but not at junctions between the façade and the inner walls and floors. This corresponds to poor building practice in Belgium.
2. **Standard**. In this scenario, the insulation layer is no longer interrupted around window junctions, but structural breaks at other locations (eaves, bearing walls, etc.) remain unsolved.
3. **Thermal bridge avoidance**. In this case, different techniques were applied to achieve continuous insulation over the building envelope. At all structural connections, specific thermal-break materials or components are present to minimize supplementary heat loss.

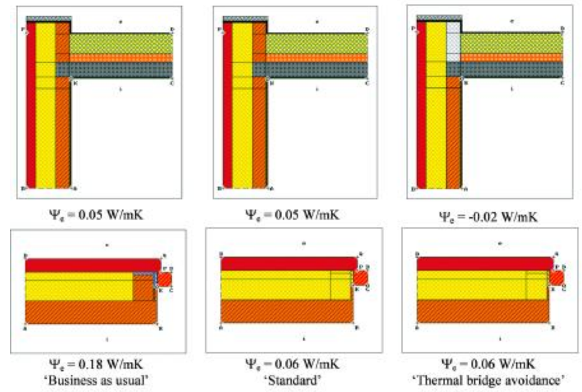

Fig 1: Typological examples (above: roof eaves; below: window reveal) of building junctions for three scenarios with respect to the thermal quality of building details.

The linear thermal transmittances of all building details have been calculated by means of Physibel software. The highest transmittance values are found at junctions where the insulation layer is intruded by a structural concrete floor, such as at balconies. The lowest (negative) values are found at exterior corners where the insulation layer is uninterrupted, such as at building corners and at roof eaves. However, for all detailing scenarios, the two-dimensional heat loss at window junctions is the largest compared to other junctions. Even when the window details are optimized (standard scenario), their influence is still about 40% of the total specific heat loss for all junctions.
Subsequently, the contribution of thermal bridges to the overall thermal transmittance of the buildings was calculated. The increase of the average thermal transmittance as a result of two-dimensional heat transfer at building junctions is given in Figure 2 for the five different reference dwellings.

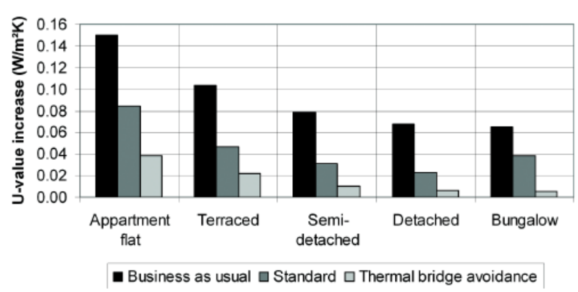

Fig 2: Contribution of building junctions to the average thermal transmittance of the building envelope as a function of the quality of constructional detailing.

The relative importance of building junctions on transmission heat loss increases when the building geometry becomes more compact. When insufficient attention is paid to the avoidance of thermal bridges, the contribution of building junctions to the overall thermal transmittance amounts to 0.06 to 0.15 W/m2·K. Compared to the current requirements in

Flemish building regulation, the construction details thus represent 13% to 17% of acceptable transmission heat loss. These results are obtained with the external building dimensions as a reference for the heat loss surface area. Of course, when internal dimensions are the reference, the heat transfer at building junctions becomes even more important. When attention is paid to thermal bridge avoidance in construction detailing, the contribution of building junctions to the thermal transmittance may be minimized to 0.01 to 0.04 W/m2·K. This represents only 1% to 4% of current transmission heat loss requirements. In low-energy building design. This quality of detailing is certainly necessary to obtain a sufficiently low average thermal transmittance of the building envelope.

3. Limits for linear thermal transmittance

Based on the analysis of thermal bridges for 5 different buildings in the previous section, a new set of limits for linear thermal transmittance was proposed, with limiting values adjusted to the geometrical typology of different junctions (table 1). When a building design meets this set of requirements, the effect of building junctions on transmission heat loss is limited to 0.02 W/m2·K for less compact buildings and to 0.05 W/m2·K for more compact buildings. As a result, the effect of thermal bridges on the thermal transmittance of the building envelope is less than 5%, except for the more compact building types. These figures are found when the limiting values for linear thermal transmittance proposed below are introduced in the analysis of the five reference dwellings.

External wall corners	**$\psi < -0.10$ W/mK**
Junctions at exterior corners	**$\psi < 0.00$ W/mK**
Junctions at interior corners	**$\psi < 0.15$ W/mK**
Balconies	**$\psi < 0.10$ W/mK**
Window junctions	**$\psi < 0.10$ W/mK**
Foundations	**$\psi < 0.05$ W/mK**
Other	**$\psi < 0.00$ W/mK**

Table 1. Limit values for linear thermal transmittance

These values can thus be used by the building industry to check whether a certain building node is well-designed. The results of numerical simulations are compared to these limiting values. The analysis showed that these performance limits are easily obtained at minimal cost.

Furthermore, these values can also be used as reference value to account for the impact of thermal bridges on the overall energy use of buildings. When the building code was adjusted to take the building nodes into account, an additional heat loss was automatically assigned for each building. As of that point, there was an increase in transmission heat loss in accordance with the values above. Because this supplementary heat loss is automatically calculated, the basis, reference energy calculation thus already assumes that building nodes entail additional heat loss, but as well, that all nodes meet the limits for linear thermal transmittance. By consequence, for the implementation of the thermal bridge effect in the energy calculation, all building nodes that meet the requirements are already accounted for.

4. Practical implementation

By integrating a default energy loss for building nodes, the additional work for the building industry can be significantly reduced. When a node meets the requirements, it is not even necessary to check the length, or the number of building nodes. Hence, the practical implementation has following goals:

- Check whether building nodes meet the requirements
- If not: calculate the linear thermal transmittance, and subtract the limit values (this part is already accounted for)
- If no calculation is done: apply a default conservative, high linear thermal transmittance.

However, the first aspect is not self-evident. To ensure that not every building node in every project needs to be calculated, simple rules of thumb were developed for the building industry. The system works as follows: first one needs to choose between 3 options.

- Option A: detailed method. Every node is numerically calculated, and there is a variable increase in transmission heat loss.
- Option B: pragmatic approach with 'EPB-accepted nodes'. The building nodes are classified into two categories: EPB-accepted, and the other. The first ones can be neglected, the second type entails a variable increase in total thermal transmittance, evidently smaller than the one for option A.
- Option C: there is a fixed penalty, i.e. a large value of 10W/K is applied to the overall thermal transmittance, which can add up to more than 30% for standard buildings.

5. EPB accepter nodes

Option B with the EPB-accepted nodes is a pragmatic approach, which at the same time increases the awareness of good thermal detailing towards the building practitioners involved in the project. The basic rules are defined in such a way that designers, contractors and inspectors can - mainly in a visual way - check whether a detail fulfils the requirements to be an 'EPB-accepted' node. Essentially, the basic rules guarantee a continuous insulation layer within the building envelope.

<u>Basic rule 1: minimal contact length</u>

This rule requires that two connecting insulation layers need a sufficient contact length, which is at least half the thickness of the thinnest insulation layer. The contact length criterion followed from detailed calculations for all kind of different junctions, which showed that when the contact length is at least half the thickness of the thinnest insulation layer, the extra losses at the junction were minimal.

Basic rule 2: insertion of insulating element
When at a junction of two building envelope parts, it is not possible to bring the insulation layers within each element in contact with one another, an intermediate insulating element has to be foreseen that fulfils certain requirements:

- λ-value should be below 0.2 W/mK
- the thermal resistance R of the intermediate element has to be at least half the smallest thermal resistance of the adjacent insulation layers
- the contact length between insulating elements and adjacent layers has to fulfil basic rule 1

In practice, the majority of the connections and nodes appearing in the building envelope could be covered with an acceptable thermal performance level with basic rules 1 and 2. However, for some specific junctions where the continuity of the insulation layer cannot be guaranteed due to structural requirements (e.g. foundations bearing a heavy load, certain wall-floor connections and balconies), basic rule 1 and 2 are often not applicable. To avoid also for those details complex and time-consuming calculations, while still promoting a good thermal performance, a third rule has been added.

Basic rule 3: path of minimal thermal resistance
In those specific cases where basic rules 1 and 2 cannot be applied, the energy loss can be limited by ensuring a sufficiently long pathway from inside to outside. To determine the necessary length, different typical details have been numerically calculated to determine the linear heat transmission coefficient as a function of the length of the heat flow path. It was found that for different building nodes, a pathway of 1m was sufficient to ensure a reduced linear thermal transmittance that meets the limit values in table 1. Though certainly not the best option, at least basic rule 3 makes it possible to account for those situations where the only solution exists in wrapping insulation around the thermal bridge.

This set of three basic rules is defined in such a way that they can be easily communicated to the building industry and that details can be checked during design and construction phase without any additional calculations.

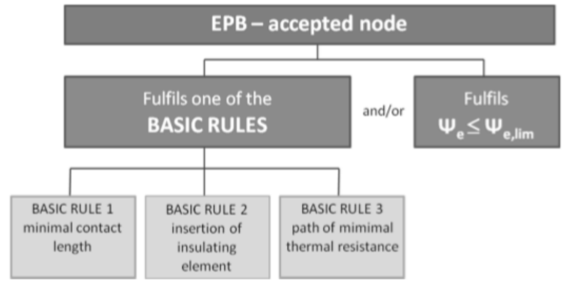

Fig 3: Different options to ensure that a certain building node is EPB-accepted

When for a specific project the majority of the building nodes meet the requirements, it is always possible that one or more nodes have a design which not allows to apply the simple rules. In that case, numerical simulations can be used to prove that in fact the limit values are obtained.

6. Conclusions

In this paper a methodology is presented to develop limiting values for the linear thermal transmittance of building junctions in order to minimize the influence of thermal bridges on transmission heat loss. First, the transmission heat loss resulting from all joints encountered in five reference dwellings with traditional masonry construction was quantified. From that, limit values were derived that account for geometry and technical feasibility. Based on those limiting values, simplified rules of thumb have been derived for the building industry, with a straightforward approach to implement it in practice. The practical experience in the building industry shows that the vast majority of buildings is checked for EPB-accepted nodes, and thus with little to no additional work for architects and contractors.

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