Sensitivity analyses of thermal bridges: confrontation with the new Belgian EPB-methodology

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SUMMARY:
As governments continue to impose more and higher energetic requirements for buildings, they also need better assessment-tools to take into account as many parameters as possible. This results in continuous developments of new calculation methods and softwares, where a balance has to be found between practicality and accuracy.

To answer this problem, specifically with regard to the thermal bridges, the three Belgian regions developed a new and common pragmatic approach for assessing thermal bridges, confronting them either to simple basic rules of thumb or to maximal heat transmission coefficients, depending on the type of junction. While thermal bridges that don't meet the requirements are sanctioned, thermal bridges that perform better can be taken into account to lower the calculated heat-losses.

For this project, several very common thermal bridges were selected. Sensitivity analyses are carried out for the different parameters, such as dimensions and thermal conductivity of the components. The calculated heat transfer coefficients are confronted with the boundary-('limit-')values and the default-values of the new methodology. Nevertheless, these analyses weren't meant as a test for the methodology. They aim at allowing designers to quickly assess their common building details to the new regulation, without having to do preliminary numerical simulations of each individual thermal bridge. They also help them to better understand the correlations between the parameters of the building detail and the resulting heat transmission coefficients. The challenge that rose, was to summarize the results in pragmatic, straight-forward formats.

1. Introduction

Calculating the thermal transmittance of a building is the first step towards estimating its heating consumption. With today's knowledge and software, thorough calculations of thermal transmittance of whole buildings are possible. Nevertheless, one of today's challenges is to hand over pragmatic tools for those calculations to the architects and other building-practitioners. Those tools are necessary for the building sector not only to make the accurate energy-calculations themselves more cost-effective, but also to ease the understanding of the basic rules of good practice within applied building physics. Both of these goals are necessary steps towards increasing the level of energy efficiency of new buildings on a large scale and that is what policy-makers aim at through e.g. the Energy Performance of Buildings Directive (EPBD).

Within existing official tools for energy-performance-assessment of buildings, the implementation of thermal-bridges often remains difficult. The difficulty relies in the balance that has to be found between the accuracy of the calculation and the amount of work necessary to take the thermal bridges into account. The three Belgian regions developed a common methodology to address this challenge (EPB-Annex IV: Handling of building-nodes).

As this new methodology became compulsory in Flanders for all new EPB-calculations on 01-01-2011, there is a growing and urging demand for more information and indications on the influence of specific building nodes on the total thermal transmittance of a building, in agreement with the new calculation method. Not only the governmental instances and the educational institutes, but also private companies from within the building sector are currently building up their offers with respect to those demands. The results presented further fit within this framework, trying to offer some practical information and data, with focus both on the importance of thermal bridges as such, as well as on their effect with regard to the results of the improved calculation method.

2. Background

2.1 New Belgian EPB-method

The new regulation lets the EPB-assessor chose between three options for taking the thermal bridges into account. The first and most accurate option (‘option A’) consists of the compulsory full input of all individual thermal bridges (linear or point heat transmission coefficients, lengths or amounts), resulting in a overwhelming amount of work. At the other extreme resides the less accurate but quickest option (‘option C’): for each building one single, severe, default-penalty is added into the total transmittance of the building, taking into account all thermal bridges together, independently of the quality of the thermal design of the building details. Between these two extremes resides the third and innovative method (‘option B’). This last option is based on an easy assessment of the thermal bridges using basic, mainly visual rules of good thermal detailing. The thermal bridges are then taken into account in the EPB-calculation through predefined limit-values and default-values or calculated values, depending on the effort the user wants to make.

There are three ‘basic rules’ within ‘option B’. If a building node is in agreement with at least one of these three rules, that node is considered as ‘EPB-accepted’. EPB-accepted details don’t have to be taken into account separately in the calculation. There is already a fixed default-penalty incorporated in the overall thermal transmittance of the building, which takes into account the estimated effect of all thermal bridges of a building, on the assumption that they are well-designed, in agreement with the basic rules. That default-penalty is much lower than that within ‘option C’. On the opposite, if a detail doesn’t fit any of the three rules, it is considered as ‘not-EPB-accepted’ and has to be added separately in the calculation. That way, its effects add up to the above mentioned default-value on the total thermal transmittance. As all EPB-accepted nodes are already taken into account within that default-value, only an additional part of the linear heat transmission coefficient (Ψ_e [W/(m.K)]) has to be added, that of the not-EPB-accepted node in comparison to the Ψ-value of an EPB-accepted node. Therefore, the heat transmittance due to the individual building nodes is calculated as follow:

$$H = \sum_i \left(\psi_i - \psi_{\lim,i}\right) \cdot L_i \qquad (1)$$

Where Ψ_i linear heat transmission coefficient of the building node [W/(m.K)]
$\Psi_{lim,i}$ ‘limit-value’ for the linear heat transmission coefficient [W/(m.K)], found in a table from the new regulation, corresponding to the linear heat transmission coefficient of an EPB-accepted building node of a similar type (e.g. inner-corner, foundation, balcony)
L length of the building node [m]

This way, ‘good’ EPB-accepted nodes can –but don’t have to- be included through calculated values. When lower than the corresponding limit-values ($\Psi_{lim,i}$), taking into account their calculated Ψ-values can lower the estimated total heat transmittance of the building, thus rewarding good thermal design.

2.2 Project framework

In an attempt to help the building sector with this new regulation, a new project was launched. It aims at increasing the awareness and the understanding of thermal bridges within the building sector and tries to hand over information on common thermal bridges that could be used directly in EPB-reports in Belgium. Two sets of deliverables were developed.

The first set of deliverables consists of 72 common thermal bridges which fit the new ‘basic rules’ and thus are ‘EPB-accepted’. The details are not only given as limited ‘ready-to-use’ solutions, but are also accompanied by a note and graphical indications on why they fit those basic rules. This allows the reader to easily identify the degrees of freedom he has if he wants to adapt the detail to his needs, remaining within the margins of the corresponding basic rules.

The second set of deliverables consists of parameter-analyses for 17 frequently occurring, acceptable or good details. For each of these details, Ψ-values were calculated for a set of configurations with varying parameters such as thickness and λ-values of the insulating material. For thermal bridges that were ‘not-EPB-accepted’, these tabulated Ψ-values still lied consistently lower than the default-values, thus limiting the resulting penalty on the total thermal transmittance of the building. For some detail-configurations, the Ψ-values lied lower than the limit-values from the new regulation, thus allowing the user not only to limit the penalty, but even to improve the total thermal transmittance of the building by voluntarily taking into account these ‘better’ building nodes. This paper will present the main methodology and outputs from this second set of deliverables, the tabulated parameter-analysis.

3. Parameter analyses

3.1 Simulation parameters

Due to the available means, the amount of simulations had to be limited. Therefore the amount of analysed building nodes and design-solutions had to be limited, as well as the amount of values for each parameter of each building.

3.1.1 Building nodes

As a first selection criteria for the building nodes, those had to be relevant for as many building projects as possible. Therefore, only building nodes were selected that occur frequently and over relatively long distances. Furthermore, building nodes that are to dependant of specific product-characteristics to be generalised, were filtered out (e.g. junctions with window-frames). For further selection, two other criteria were taken into account: the possibility to design the node in accordance to one of the three basic rules and the possibility to reach a low linear heat transmission coefficient (Ψ_e [W/(m.K)]).

As many building nodes could be designed in accordance with the basic rules or wouldn’t help to lower the calculated heat losses significantly, it was preferred to select fewer building details, allowing to extend the analyses for those details. Based on these considerations, 15 building nodes were selected for further parameter-analyses. They mainly consist of junctions between cavity-walls and foundations, between cavity-walls and roofs and between 2 cavity-walls. Those are the main basic exterior corners of a building, occurring over long and quickly measurable distances. For the junctions between exterior walls and foundations or flat roofs, different frequently used solutions were analyzed: using foam-glass to join both insulation layers or extend one insulation layer to wrap the thermal bridge as far as possible. TABLE 1 gives an overview of the main different building nodes that were analysed. Both the corresponding limit-values and default-values from the new regulation are mentioned as well as the minima and maxima that occurred for each parameter-analysis.

TABLE 1: Building nodes and linear heat transmission coefficients (Ψ [W/(m.K)])

Building nodes			linear heat transmission coefficient			
			Annex IV		Simulations	
code	*Junction: cavity wall...*	*Optimisation*	Ψ_{lim}	$\Psi_{default}$	*Min.*	*Max.*
Ext_WC	Forming an external corner	-	-0.10	0.05	[-0.22	-0.06]
Fund_1	On foundation	-	0.05	0.20	[-0.11	0.10]
Fund_2		Cellular glass	0.05	0.20	[-0.12	0.06]
GOS_01	On foundation (insul. under floor)	-	0.05	0.20	[-0.02	0.08]
KBS_07	On floor above basement	-	0.00	0.15	[-0.35	0.03]
KBS_08		Cellular glass	0.00	0.15	[-0.37	-0.01]
PSZ_01a	Supporting a flat roof (concrete)	-	0.00	0.15	[-0.12	0.07]
PSZ_06		Wrap insulation	0.00	0.15	[-0.12	0.04]
PSZ_07a		Cellular glass	0.00	0.15	[-0.15	0.01]
PSR_01	Supporting a flat roof (timber-frame)	-	0.00	0.15	[-0.12	0.07]
PSR_06		Wrap insulation	0.00	0.15	[-0.15	0.03]
PSR_07a		Cellular glass	0.00	0.15	[-0.17	0.02]
PRS_04	On a flat roof (timber-frame)	-	0.15	0.30	[0.07	0.26]
PZS_01a	On a flat roof (concrete)	-	0.15	0.30	[0.08	0.31]

3.1.2 Detail components

The main parameters for the different components are the thickness of the layers and their thermal conductivity (λ-values [W/(m.K)]). Not only did they have to enclose the most relevant values taking into account both present and future building practice, but the intervals between successive values also had to be small enough to make detailed analyses and differentiations possible.

The ranges between the smallest and highest values were chosen based on the common available or used values, taking also into account the current and future building-regulations and –objectives. Therefore, U-values [W/(m².K)] had to minimally stretch from the EPBD-minima to the values usually necessary for highly energy-performant buildings. For some material properties, default values were chosen as authorised for Belgian EPB-calculation (Transmission-reference-document 2010). A summary of the main variables and their chosen values is given in TABLE 2.

3.1.3 Simulation procedure

Simulations were carried out in accordance to EN ISO 10211. The multi-dimensional, finite-element calculations themselves were executed with the software Trisco v.11w. As the final parameter analyses consisted of more than 50.000 different building-details, the necessary codes to create the definitive simulation-files, import the results and create the outputs were programmed for this project in Visual Basic.

TABLE 2: Building components and parameter values

Component	EPB-max.	Min.	Max.	Layer	Thickness [mm]	λ [W/(m.K)]
Cavity wall	U <= 0.40 [W/m².K]	0.09	0.49	Insulation	60-80-100-120-140-160-180-200-220-240	0.020-0.027-0.035-0.045
				Inner-leaf	140	(0.200)-0.260-0.327
Pitched roof	U <= 0.30 [W/m².K]	0.15	0.37	Insulation	140-160-180-200-220-240-260-280-300-320	0.035-0.045
Flat roof	U <= 0.30 [W/m².K]	0.06	0.42	Insulation	80-100-120-140-160-180-200-240-280-320	0.020-0.027-0.035-0.045
Floor	R >= 1.00 [W/m².K]			Insulation	60-80-100-120-140-160-180-200-220-240	0.025-0.035-0.085

3.2 Results & output

Good design of thermal bridges is not only necessary to lower the heat-losses, but also to lower the risk for interior surface-condensation. As the risk for internal surface-condensation was negligible for the analysed details, the focus went to the calculation of the local 2- or 3-dimensional heat-losses. Further investigation went into possible ways to present the results, both for practical use in regard to the new regulation as well as for educational purposes, to help the understanding of the results and their causes.

3.2.1 Internal surface condensation

To assess risk for internal surface-condensation, the temperature factor was calculated for several thermal bridges. This was only carried out on a limited amount of thermal bridges, looking only at the worst thermal solutions (e.g. without foam-glass). When taking these building details into consideration for buildings with moderate indoor humidity (mainly newly built houses), no condensation risk was found as the temperature factors remained well above 0.7.

3.2.2 Linear heat transmission coefficients (Ψ_e [W/(m.K)])

The main goal of the parameter-analyses was to confront the results with the new regulation, helping the user to find good thermal solutions for his building nodes and allowing him to take those into account in the EPBD-calculation of the building. Once the simulation-results are available, the challenge resides in finding the best presentation format. Four possible presentation formats were elaborated.

The first and most precise, but less practical format, is the complete tabulated overview of all numerical parameters and results of each simulation, put together for each building node. As for most building nodes between 2.400 and 6.400 variations were simulated, based on the different values for each parameter, this approach is only relevant as a final database and as a basis for further 'graphical' translations.

The second, most visual approach, consists of making charts. The precision of values deduced from reading printed charts might sometimes be questionable, but charts are often the most understandable translation of parameter-analyses for educational purposes as they show the correlations between the different parameters and the linear heat transmission coefficients. As for most details, more than 5 parameters were varied, even 3-dimensional charts with multiple lines cannot present the total complexity of the problem. Interactive charts were made as study-objects, letting the user make a two-dimensional chart, after fixing a minimum amount of variables and choosing the variables for X- and Y-axes. An example of such a charts is given for detail PSZ_01a in FIG. 1, showing both the linear heat transmission coefficients in comparison to the (maximal) limit-value and the temperature factor. The non-linearity of the correlations between the Ψ-values and the different parameters is clearly illustrated, as opposed to correlations for the temperature-factor. Considering the different λ-values for the insulation- and masonry-layers, 48 (=4x4x3) sets of charts would be necessary to present the results of all the variations of PSZ_01a.

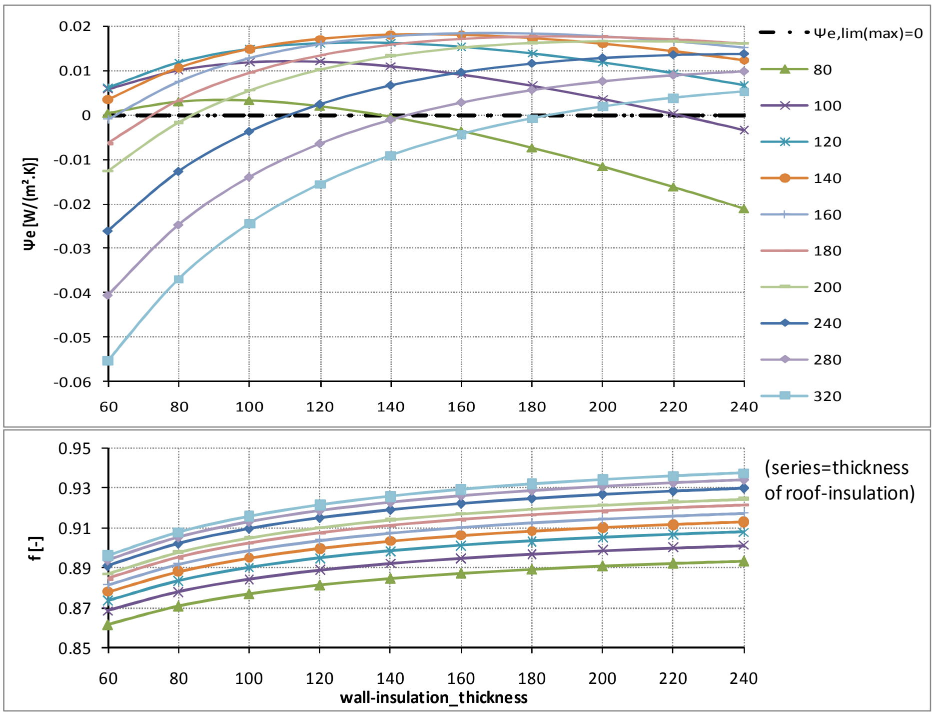

FIG. 1 Detail PSZ_01a (<u>parameters:</u> wall-inner-leaf_λ = 0.327W/m.K ; wall-insulation_λ = 0.035 W/m.K ; roof-insulation_λ = 0.035 W/m.K ; roof-insulation_thickness [mm]: see series, wall-insulation_thickness [mm]: see X-axis)

The third and new approach was developed specifically to be used when making the EPBD-calculation. It consists of tables showing which values the different parameters must have to reach a linear heat transmission coefficient lower or equal to the limit-value for that building-node. It also gives Ψ-values that can be used directly in the EPBD-calculation. This new approach is discussed further under 3.2.2.1.

As a last, integrated presentation-mode, the first three presentation forms might be made accessible in a more interactive way through e.g. an internet-application, giving directly the correct chart, the conditions to fulfil the limit-value and a Ψ-value that might be used in the EPBD-calculation. This is momentarily under investigation and development, but not by the authors of this paper.

3.2.2.1 Tabulated results

The third and new presentation form consists of tables that are different for each building detail, but formatted in a consistent graphical and textual way, in an attempt to deliver a usable and pragmatic interface for the results, that could also be printed out. For each building detail, one table is made for each type of inner-leaf of the cavity-wall as the first parameter to be chosen. The X-axes sums the subsequent parameter: the thickness of the cavity-wall-insulation. The Y-axes shows the thickness of the insulation layer of the second building component forming the junctions (the roof or the floor). Within each cell of the table, the conditions are mentioned for which the simulated Ψ-values were lower or equal to the limit-value. The focus for these rules lies on the remaining main parameters, those being the corresponding intervals of λ-values for both insulation-layers.

fund_1; Ψ-lim=0.05 [W/(m.K)]_Table 1 : λinnerleaf = 0.327 [W/m.K]										
	thickness wall-insulation [mm]									
thickness floor-insulation [mm]	60	80	100	120	140	160	180	200	220	240
60	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.05)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)	λwall-ins = [0.027], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.035 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.07)	λwall-ins = [0.027], AND λfloor-ins = [0.085] -or- λwall-ins = [0.035 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.08)	λwall-ins = [0.035], AND λfloor-ins = [0.085] -or- λwall-ins = [0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.09)	λwall-ins = [0.035], AND λfloor-ins = [0.085] -or- λwall-ins = [0.045], AND λfloor-ins = [0.035 ; 0.085] ---------- (Ψ <= 0.09)	λwall-ins = [0.045], AND λfloor-ins = [0.085] ---------- (Ψ <= 0.09)	λwall-ins = [0.045], AND λfloor-ins = [0.085] ---------- (Ψ <= 0.10)	λwall-ins = [0.045], AND λfloor-ins = [0.085] ---------- (Ψ <= 0.10)	- not EPB-accepted - ---------- (Ψ <= 0.10)
80	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.04)	λwall-ins = [0.020], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.07)	λwall-ins = [0.027], AND λfloor-ins = [0.085] -or- λwall-ins = [0.035 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.08)	λwall-ins = [0.027], AND λfloor-ins = [0.085] -or- λwall-ins = [0.035], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.08)	λwall-ins = [0.035], AND λfloor-ins = [0.085] -or- λwall-ins = [0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.09)	λwall-ins = [0.035], AND λfloor-ins = [0.085] -or- λwall-ins = [0.045], AND λfloor-ins = [0.035 ; 0.085] ---------- (Ψ <= 0.09)	λwall-ins = [0.045], AND λfloor-ins = [0.085] ---------- (Ψ <= 0.09)	λwall-ins = [0.045], AND λfloor-ins = [0.085] ---------- (Ψ <= 0.09)	λwall-ins = [0.045], AND λfloor-ins = [0.085] ---------- (Ψ <= 0.10)
100	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.03)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.05)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.035 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.07)	λwall-ins = [0.027], AND λfloor-ins = [0.085] -or- λwall-ins = [0.035 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.08)	λwall-ins = [0.027], AND λfloor-ins = [0.085] -or- λwall-ins = [0.035], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.08)	λwall-ins = [0.035], AND λfloor-ins = [0.085] -or- λwall-ins = [0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.09)	λwall-ins = [0.035], AND λfloor-ins = [0.085] -or- λwall-ins = [0.045], AND λfloor-ins = [0.035 ; 0.085] ---------- (Ψ <= 0.09)	λwall-ins = [0.035 ; 0.045], AND λfloor-ins = [0.085] ---------- (Ψ <= 0.09)	λwall-ins = [0.045], AND λfloor-ins = [0.085] ---------- (Ψ <= 0.09)
120	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.02)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.04)	λwall-ins = [0.020], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.035 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.07)	λwall-ins = [0.027], AND λfloor-ins = [0.085] -or- λwall-ins = [0.035 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.08)	λwall-ins = [0.027], AND λfloor-ins = [0.085] -or- λwall-ins = [0.035], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.08)	λwall-ins = [0.027 ; 0.035], AND λfloor-ins = [0.085] -or- λwall-ins = [0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.08)	λwall-ins = [0.035], AND λfloor-ins = [0.085] -or- λwall-ins = [0.045], AND λfloor-ins = [0.035 ; 0.085] ---------- (Ψ <= 0.09)	λwall-ins = [0.035], AND λfloor-ins = [0.085] -or- λwall-ins = [0.045], AND λfloor-ins = [0.035 ; 0.085] ---------- (Ψ <= 0.09)
140	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.01)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.03)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.05)	λwall-ins = [0.020], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.07)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.035 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.07)	λwall-ins = [0.027], AND λfloor-ins = [0.085] -or- λwall-ins = [0.035 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.07)	λwall-ins = [0.027], AND λfloor-ins = [0.085] -or- λwall-ins = [0.035], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.08)	λwall-ins = [0.027 ; 0.035], AND λfloor-ins = [0.085] -or- λwall-ins = [0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.08)	λwall-ins = [0.035], AND λfloor-ins = [0.085] -or- λwall-ins = [0.045], AND λfloor-ins = [0.035 ; 0.085] ---------- (Ψ <= 0.08)
160	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.01)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.03)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.04)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.05)	λwall-ins = [0.020], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.035 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.07)	λwall-ins = [0.027], AND λfloor-ins = [0.085] -or- λwall-ins = [0.035 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.07)	λwall-ins = [0.027], AND λfloor-ins = [0.085] -or- λwall-ins = [0.035], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.08)	λwall-ins = [0.027], AND λfloor-ins = [0.085] -or- λwall-ins = [0.035], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.08)
180	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.00)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.02)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.04)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.05)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.05)	λwall-ins = [0.020], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.035 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.07)	λwall-ins = [0.020 ; 0.027], AND λfloor-ins = [0.085] -or- λwall-ins = [0.035 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.07)	λwall-ins = [0.027], AND λfloor-ins = [0.085] -or- λwall-ins = [0.035 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.07)
200	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= -0.01)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.01)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.03)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.04)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.05)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.05)	λwall-ins = [0.020], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.035 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.07)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.035 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.07)
220	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= -0.02)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.01)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.02)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.03)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.04)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.05)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.05)	λwall-ins = [0.020], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)
240	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= -0.03)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.00)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.02)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.03)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.04)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.04)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.05)	λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.05)	λwall-ins = [0.020], AND λfloor-ins = [0.035 ; 0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)

FIG. 2a: Example of tabulated results: overview for detail Fund_1 (masonry-type: λ_innerleaf=0.327 W/(m.K)) (detailed cells: see FIG.2b,c,d)

λwall-ins = [0.020 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.02)	λwall-ins = [0.020], AND λfloor-ins = [0.085] -or- λwall-ins = [0.027 ; 0.045], AND λfloor-ins = [0.025 ; 0.085] ---------- (Ψ <= 0.06)	- not EPB-accepted - ---------- (Ψ <= 0.10)

FIG.2b :Example GREEN cell (all variations are EPB-accepted) (highest Ψ-value <= Ψ_lim)

FIG.2c: Example GREY cell (some variations are EPB-accepted) (highest Ψ-value > Ψ_lim)

FIG.2d: Example RED cell (no variation is EPB-accepted) (highest Ψ-value > Ψ_lim)

To ease the lecture of the tables, a colour-code was implemented. Cells for which no combination gives a resulting Ψ-value lower or equal to the limit-value are coloured in red. These are the combinations that will always result in an increase of the total heat transmittance. Cells for which all combinations give resulting Ψ-values lower or equal to the limit-value are coloured in green. These are the combinations that will always result in an lowered total heat transmittance. All other cells are coloured in shades of gray. For these cells the real Ψ-values can be lower or higher than the limit-value, depending on the used insulation material. For these gray cells, the conditions are written to have Ψ-values lower or equal to the limit-value. Furthermore, cells with identical conditions for the λ-values have the same shade of gray and, if adjacent, are grouped together within thicker cell-borders. This makes the tables 'cleaner' and makes it easier to find the correct conditions, even if the insulation-thickness lies between two values of the X- or Y-axes. FIG. 2 shows as an example the result for detail Fund_1.

Furthermore, for each cell, the highest Ψ-value from the corresponding simulations is mentioned. This might be considered as a 'safe' estimation of the Ψ-value of that building detail, regardless of the λ-values of the insulation layers (within the simulated range). As such, those values can be used in the EPBD-calculations, even if the detail doesn't fulfil the 'conditions' mentioned in that cell. As shown in TABLE 1, these Ψ-values are often considerably lower than the corresponding default-values (with some rare exceptions for the interior corners formed by exterior cavity-walls on flat roofs, PRS_04 and PZS_01a). Negative Ψ-values can occur for some construction nodes, mainly at external corners as the external dimensions are used to calculate the referential one-dimensional heat-transfer.

4. Conclusions

The challenge for taking thermal bridges into account in EPB-calculations resides in the development of good calculation methods, combining both accuracy of calculation and positive incentives for good thermal detailing while remaining pragmatic in everyday's building practice. Within the EPBD-framework, many countries found their own way to address this challenge. Within the Belgian context, a new methodology was developed, trying to find a new balance between the existing extremes. Through its first set of deliverables, it tries to offer some usable and common examples of how to implement the basic rules of this new methodology. Through its second set of deliverables, it aims at giving directly implementable Ψ-values by translating results from parameter-analyses in a pragmatic and communicative way, allowing the user to make better choices when detailing his building nodes and allowing him to take those improvements into account in his EPB-calculations without having to learn to use and own specialised software.

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