Thermal Bridges Catalogue

Passive House Institute

Passive House Institute

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References

Imprint and Disclaimer

1 Introduction

Goal of the study

The calculation of an energy balance is required for all buildings in the Passive House planning phase. To calculate the thermal heat losses through the envelope, the U-value is the commonly used concept, being an easy to handle and straightforward method. Thermal bridge effects, defined by the Ψ-value, occur for every building due to geometric effects (e.g. corners) or penetrations (e.g. balconies). One of the Passive House principles is “thermal bridge free-design”. As a result, thermal bridges due to penetrations and connections, which cause interruptions to the thermal envelope, need to be avoided. However, this principle cannot always be applied in practice and in cases such as retrofits or projects in seismic areas, different solutions must be found.

There are many factors which determine which thermal bridges have to be considered in detail and whether they can be estimated from tables or must be calculated individually. Since the Ψ-value changes according to the insulation thickness of a specific detail when the insulation thickness is varied, several calculations can be necessary.

In order to speed up the Passive House planning process and to reduce the costs and time needed for thermal bridge calculations, the Passive House Institute evaluated approximately 1.200 thermal bridges, varying a number of parameters that affect both the Ψ-value and the f_{Rsi} factor, relevant for hygiene reasons. The outcome is a catalogue of Ψ-values and f_{Rsi} factors for the different cases, which can be used to determine a value for a particular detail or to estimate the value of a similar case.

Architectural details

Two different solid wall construction systems were chosen for evaluation in all of the Passive House climate zones (Zones 1-7), according to the international EnerPHit criteria [1]. The two solid wall construction systems are:

A brick wall construction of 240 mm thickness and λ = 0.42 W/(mK), as typically found in European building stock. The uninsulated wall shows an U-Value of about 1.30 W/(m²K).

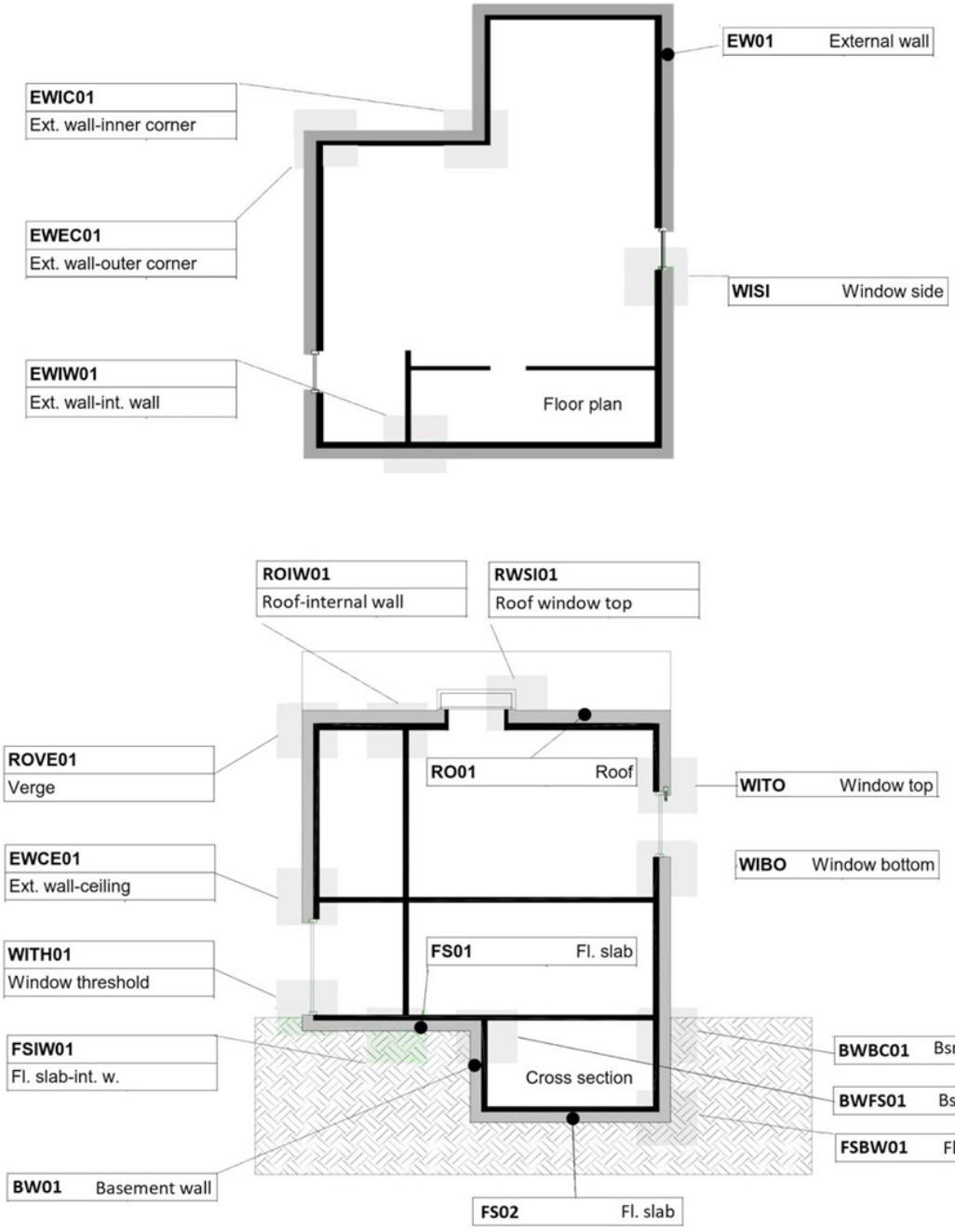
A concrete wall construction of 120 mm thickness and λ = 2.10 W/(mK), as very often found in developing countries. The uninsulated wall shows an U-Value of about 4.00 W/(m²K).

Please keep in mind that the two construction systems chosen for the research represent average qualities or geometries of the components. Thickness and thermal conductivity of brick or concrete walls in specific projects may differ and the thermal bridge coefficients of the connection details needs to be evaluated accordingly. For example, in concrete constructions in Germany thicker wall thicknesses and the use of reinforced concrete (λ = 2.3 W/(mK)) are common.

Connection details were calculated for insulation thicknesses increasing in 25 mm steps (roughly 1 inch), starting with 0 mm of insulation (the existing building wall) up to 400 mm of insulation.

The graduations in insulation thickness were applied to both construction types (brick wall and concrete wall). The lambda value of the insulation was also varied and λ = 0.025 W/(mK), λ = 0.035 W/(mK) and λ = 0.045 W/(mK) were used for the study to allow a quick estimation of the Ψ-value of the connection.

The scope of this study only includes improvements which do not modify the underlying nature of the wall structure. Retrofits or new buildings in seismic areas require solutions such as thermal breaks in the wall structure, but these cannot be practically applied. In these situations, the most practical solution is to apply flanking insulation to reduce the thermal bridge effect caused by the penetrations in the insulation layer e.g. a balcony. In non-seismic areas thermal breaks should be considered as solutions to reach the “thermal bridge free-design” goal.



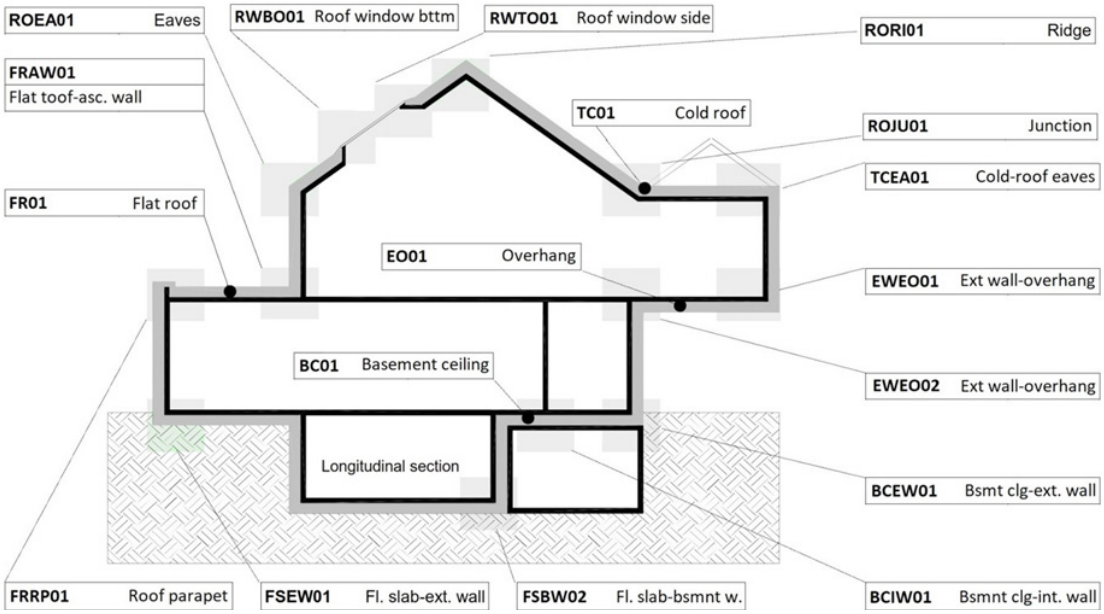


Figure 1: Floor plan, cross section and longitudinal section showing the typical connections in a building and the codes assigned in the “Criteria and Algorithms for Certified Passive House Components: Opaque construction systems” [2].

The connections were evaluated to determine two parameters:

- Ψ-value, for an energy evaluation of the detail;
- f_{Rsi} factor, for a hygiene evaluation of the detail.

Energy Evaluation

The Ψ-value is a means to evaluate the linear heat losses that occur through the connection caused by a thermal bridge effect. In a Passive House, the aim is to reach Ψ ≤ 0.01 W/(mK), which means “thermal bridge free design”. However, there is no limit for the Ψ-value that would prevent the building being defined as a Passive House. The Ψ-value must be taken into account when calculating the total transmission losses through the envelope, because it will have an influence on the overall energy balance.

Hygiene Evaluation

For each connection, the minimum surface temperature was calculated as well. The results are displayed through the f_{Rsi} factor, which is determined as follows:

$$f_{Rsi} = \frac{(\theta_{si} - \theta_e)}{(\theta_i - \theta_e)}$$

where θ_{si} is the minimum interior surface temperature, θ_e is the minimum outside temperature (assumed to be -10°C) and θ_i is the interior temperature (assumed to be 20°C). The θ_{si} is calculated considering R_{si} = 0.25 (m²K)/W as the internal surface resistance.

The f_{Rsi} factor is the parameter chosen to easily identify the risk of mould growth and condensation.

A hygiene criterion was established for each climate zone. The hygiene criterion identifies the minimum f_{Rsi} factor that a component can tolerate in relation to the risk of mould growth.

The f_{Rsi} factor limit in each climate zone for the hygiene criterion according to the “Criteria and Algorithms for Certified Passive House Components: Opaque construction systems” [2] are as follows:

No	Climate Zone	Hygiene criterion ($f_{Rsi = 0.25\ m^2K/W}$)
01	Artic	0.80
02	Cold	0.75
03	Cold-Temperate	0.70
04	Warm-Temperate	0.65
05	Warm	0.55
06	Hot	-
07	Very Hot	-

The Climate Zones are defined according to the map shown in Figure 2.

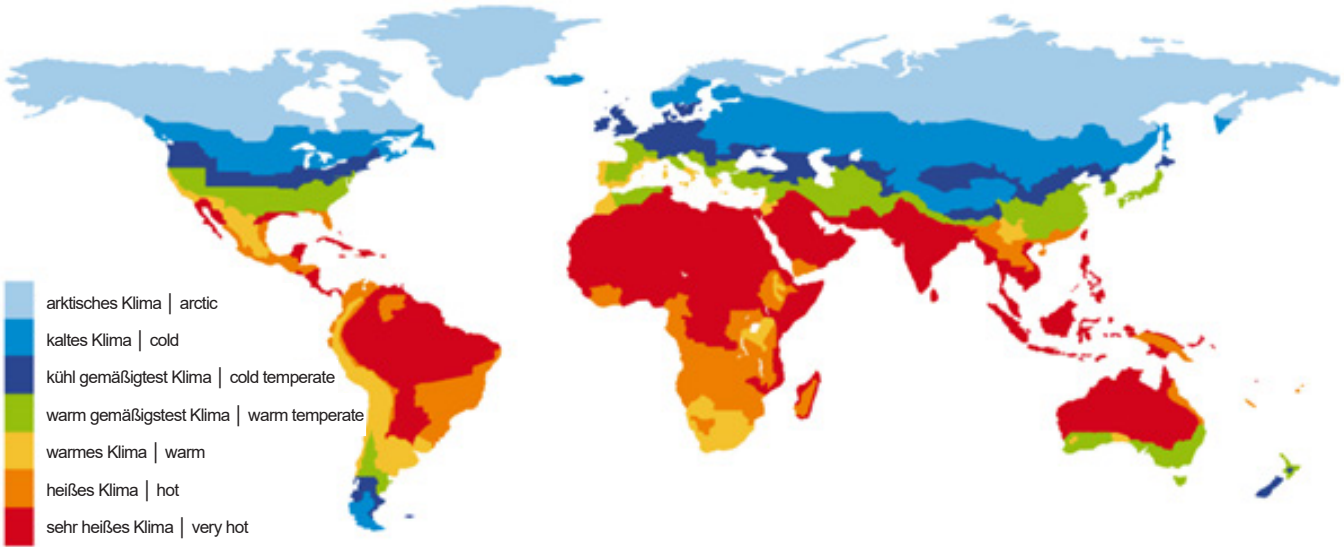
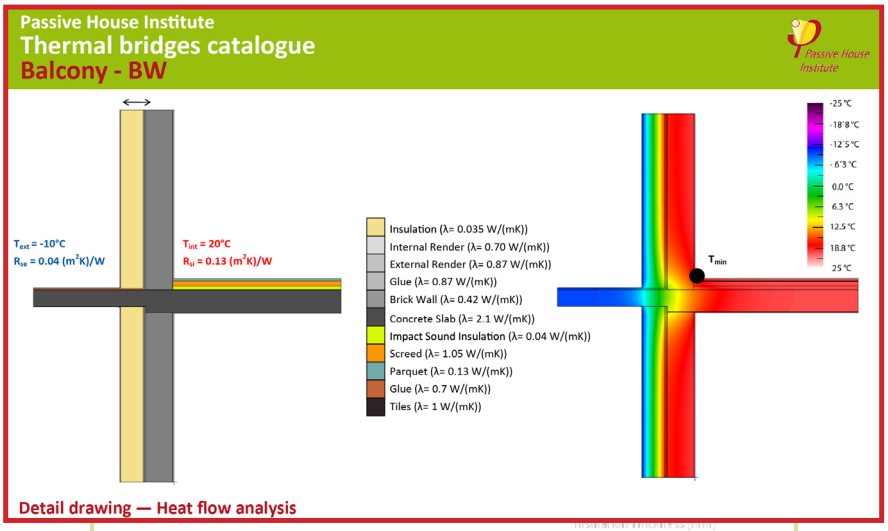
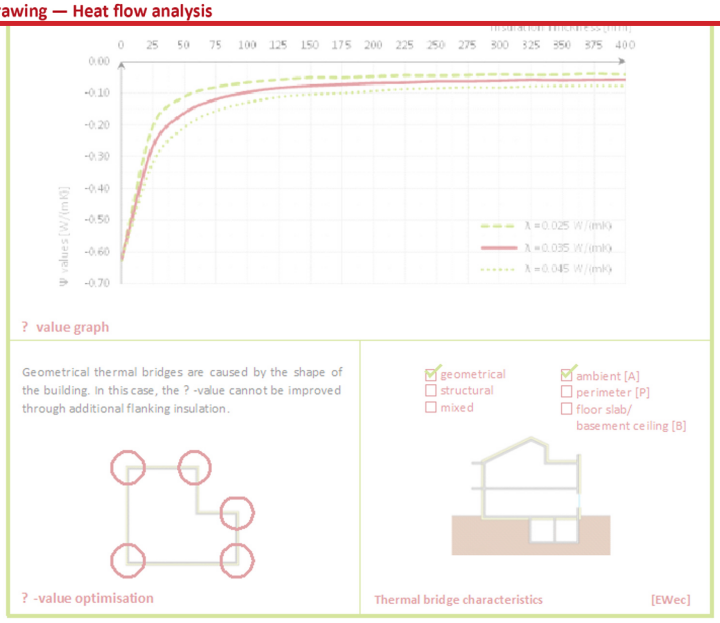


Figure 2: Assignment of the regions with identical requirements, based on studies by Passive House Institute.

2 Instructions

How to read the catalogue





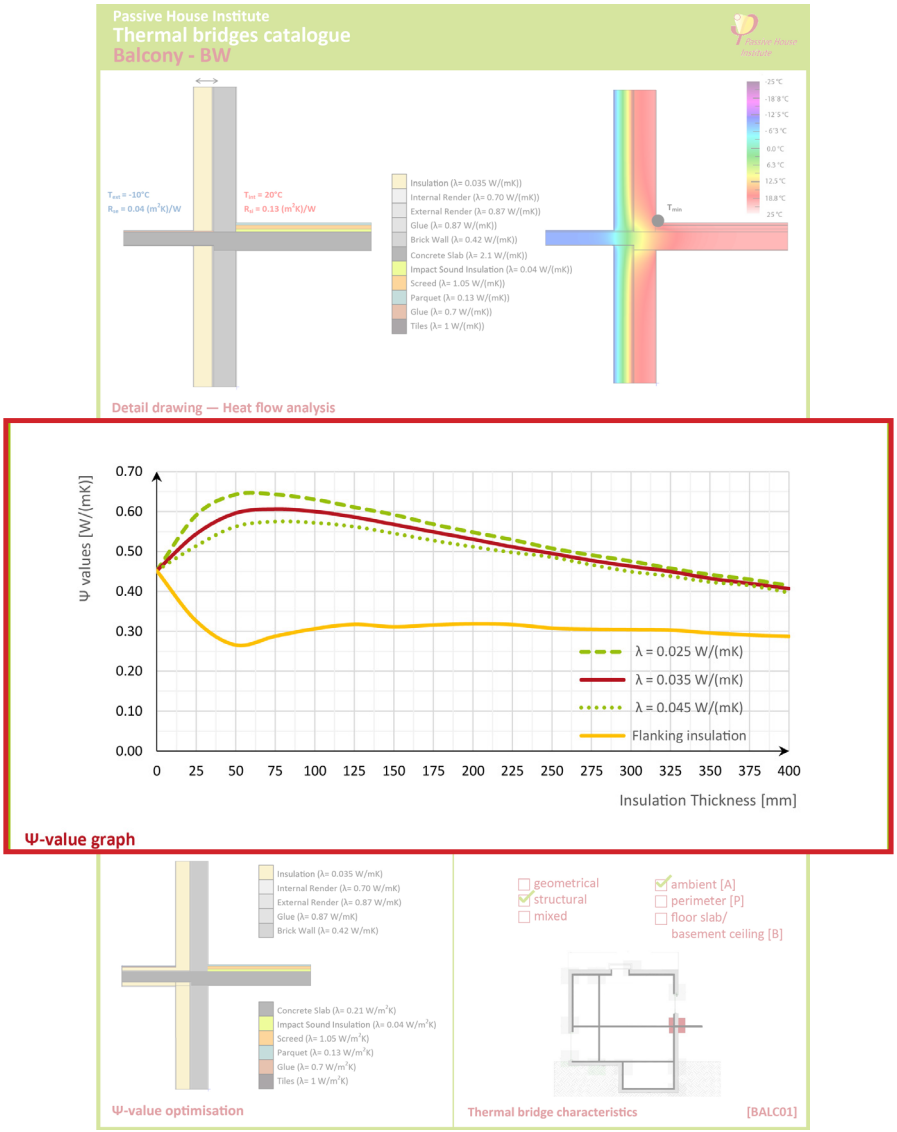
Detail drawing

The analysed connection is reported with specifications about the materials of the assemblies and the boundary conditions assigned to the internal and external surfaces for the thermal bridge calculation (temperature [°C] and surface resistance [W/(mK)]). The figure reported in this section of the catalogue sheet shows the connection geometry when a 200 mm insulation layer is applied.

Heat flow analysis (200 mm insulation thickness)

The connection is shown with a colour infrared diagram. The outside temperature is indicated in blue (-10 °C) and the internal temperature in red (20 °C). A scale is reported to easily identify the relation between each colour and the temperature in the component (-25 to 25°C).

The point on the interior surface with the lowest temperature is marked in the diagram. The value of the minimum temperature depends on the thickness of the insulation layer in the assembly.

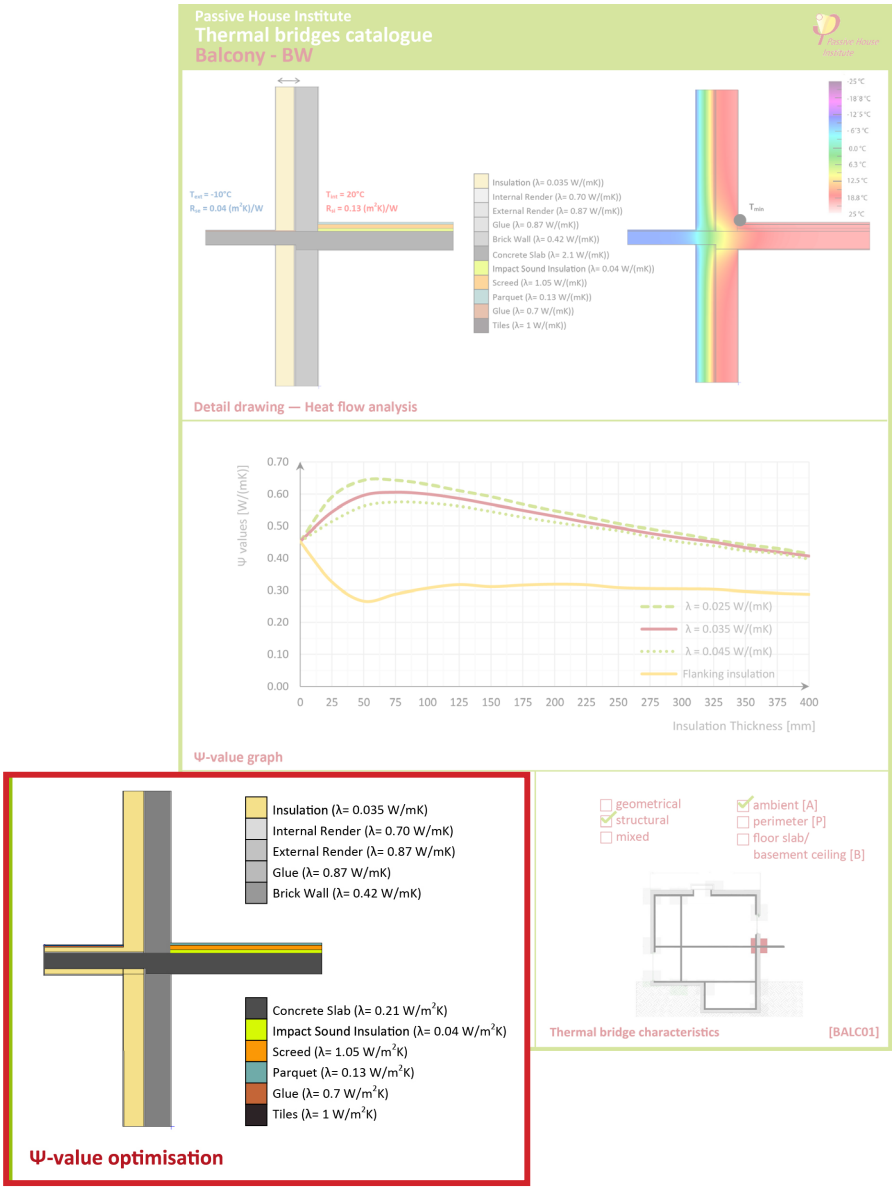


Ψ value graph

The graph reports the results of all the thermal bridge simulations for the detail. The insulation thickness applied to the components is on the x-axis. The Ψ-value results are on the y-axis.

The Ψ-values were calculated for different insulation thicknesses (from 0 mm to 400 mm) and for three different insulation conductivities (0.025 W/(mK), 0.035 W/(mK), 0.045 W/(mK)). The results are displayed in three curves on the graph.

When the detail can be improved through the addition of flanking insulation, the results of the simulations are displayed with a yellow curve. In these cases the details were simulated considering a flanking insulation layer with varying insulation thicknesses (0-400 mm). The insulation conductivity for the flanking insulation is assumed to be 0.035 W/(mK).



Ψ-value optimisation

When detail optimization is possible, a drawing showing how to apply the additional insulation is shown. Notice that thermal bridges created by a geometric effect cannot be improved. The optimal thickness of the flanking insulation is chosen according to the studies in “Protokollband” Nr.16 [3] and Nr.24 [4].

Thermal bridge characteristics

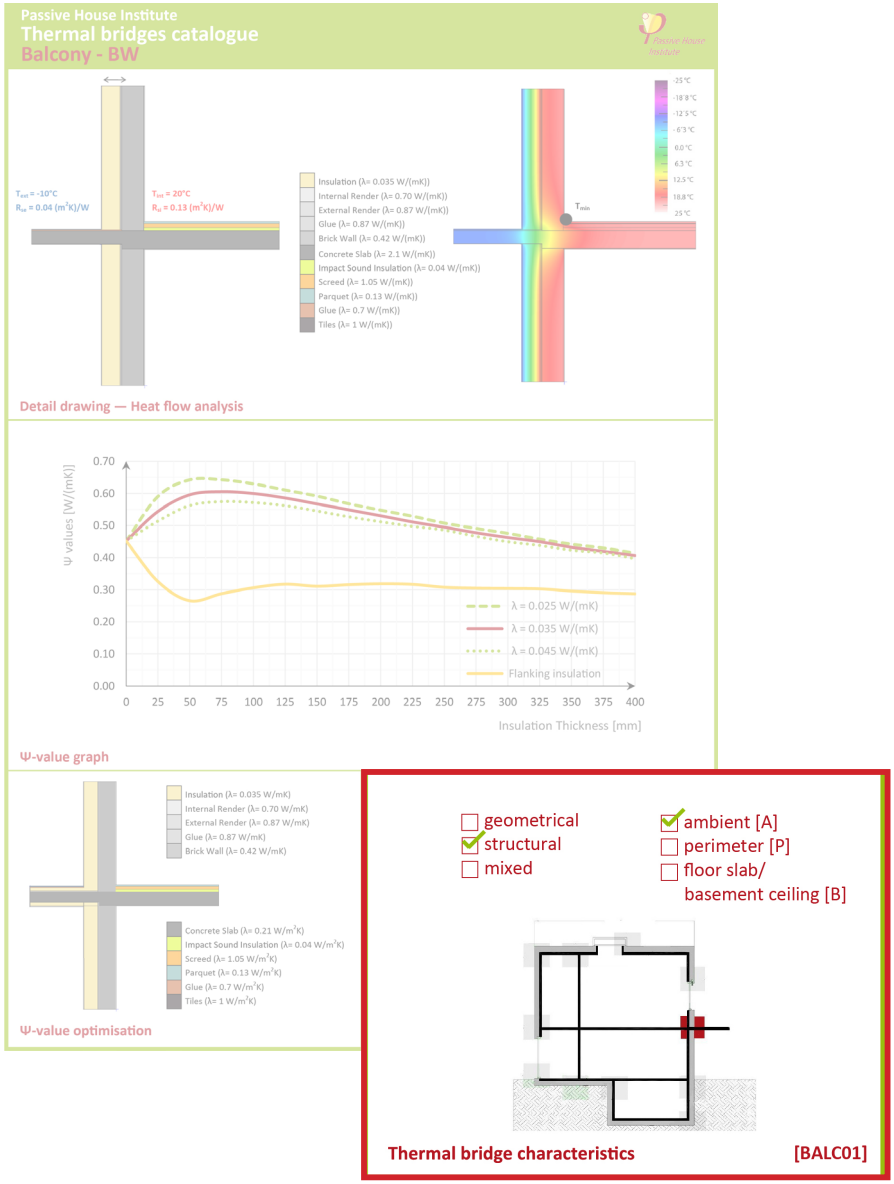
Each connection is identified through a code, as in the “Criteria and Algorithms for Certified Passive House Components: Opaque construction systems”.

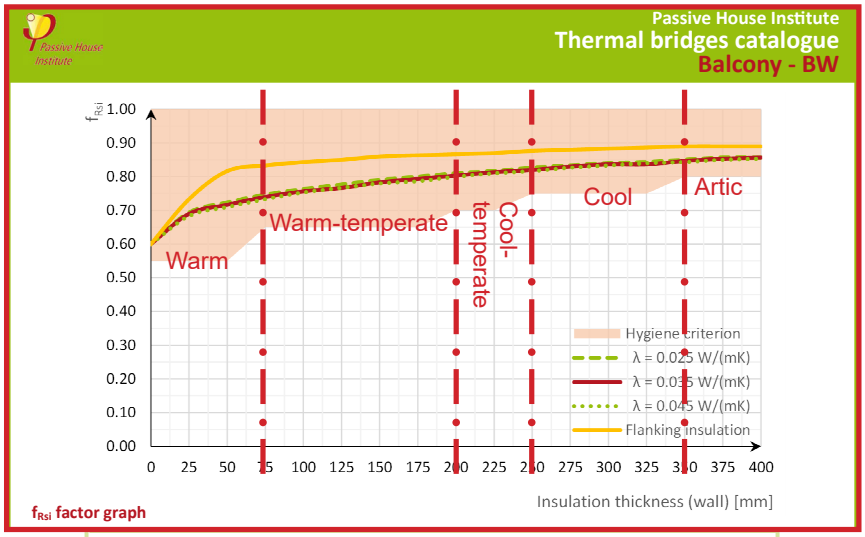
Thermal bridges can be classified as geometric (caused by a change in the shape of a component), structural (when there is a discontinuity in the material used), and mixed (when both geometric and structural discontinuities are present). For each connection, information about the category to which the connection belongs is reported.

With reference to the classifications reported in PHPP, the thermal bridges are identified as follows:

A) interior against ambient air;
B) interior against the ground or basement;
P) thermal bridge at the perimeter against the ground.

This classification is important for the calculation of the heat losses caused by the thermal bridge. In fact, different categories will lead to different degree-days (Gt [kWh/a]) to be taken into account in the final transmission heat losses balance.





The study of the Ψ-value showed remarkable behavior depending on the insulation thickness. First the Ψ-value increases to 0.65 W/(mK) for 50 mm of insulation and then it decreases by approximately 0.02 W/(mK) for every additional 25 mm of insulation. These results are for a reinforced concrete penetration (conductivity 2.1 W/(mK)) with a width of 150 mm.

The resultant Ψ-value is quite high for all of the cases and therefore, a correction for the thermal bridge through the addition of flanking insulation is required. It is applied on and under the balcony slab and is only 50 mm thick.

The internal surface temperatures of a balcony connection will fulfil the requirements of the hygiene criterion.

For the flanking insulation solution, the Ψ value reduces to approximately 0.30 W/(mK). Notice that in all of the cases studied the flanking insulation is 50 mm thick. When the wall insulation is 25 mm thick, the flanking insulation should be defined accordingly.

No.	Climate	U-value requirement	Ψ-value	Hygiene Criterion	f_{Rsi} factor
01	Arctic	0.09 W/(m²K)	0.43 W/(mK)	0.80	0.85
02	Cold	0.12 W/(m²K)	0.48 W/(mK)	0.75	0.83
03	Cool-Temperate	0.15 W/(m²K)	0.53 W/(mK)	0.70	0.8
04	Warm-Temperate	0.30 W/(m²K)	0.60 W/(mK)	0.65	0.76
05	Warm	0.50 W/(m²K)	0.60 W/(mK)	0.55	0.72
06	Hot	0.50 W/(m²K)	0.60 W/(mK)	-	0.72
07	Very Hot	0.25 W/(m²K)	0.59 W/(mK)	-	0.77
Existing Building		*4.00 W/(m²K)*	0.45 W/(mK)		0.60

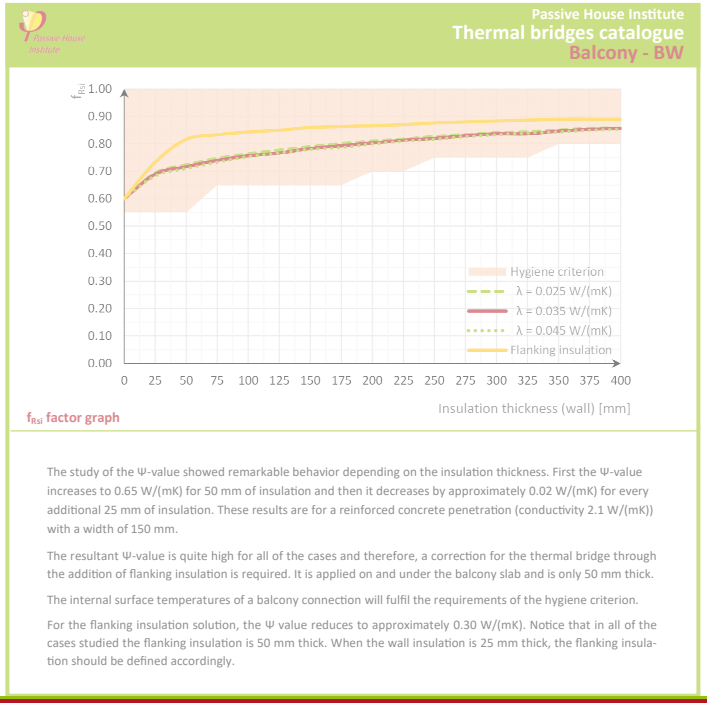
f_{Rsi} factor graph

The graph reports the results of the f_{Rsi} factor. The insulation thickness applied to the components is on the x-axis. The f_{Rsi} factor results are on the y-axis. The f_{Rsi} factor was calculated using the minimum internal surface temperature determined in each case.

The simulations were calculated for three different insulation conductivities (0.025 W/(mK), 0.035 W/(mK), 0.045 W/(mK)) and displayed through three different curves.

When the detail can be optimized through the addition of flanking insulation, the results of the simulations are displayed with a yellow curve. The insulation conductivity for the case is assumed to be 0.035 W/(mK).

The graph also shows an orange area, which represents the hygiene criterion. When a point of the curve lays in this area, it means that the hygiene criterion is fulfilled. The steps in the hygiene criterion areas represent five different climate zones. Considering the concrete wall and brick wall construction systems, when a certain insulation thickness is applied, a certain U-value can be determined. A step in the hygiene criterion area marks that the U-value minimum requirement is fulfilled according to the EnerPHit component method for a certain climate zone.



Table

The table summarizes the main results for each climate zone. The limit U-value of the component is defined by the EnerPHit criteria. This translates into a certain insulation thickness, if the components (e.g. wall) are defined similarly to those used in this research (240 mm brick wall, 0.42 W/(mK); 120 mm concrete wall, 2.1 W/(mK)). The main element influencing the U-value of the component will be the insulation layer. Therefore, the results of this study can be used also to estimate the Ψ-value and f_{Rsi} factor of details with construction systems similar to the ones studied here. However, it is highly recommended to apply a safety margin to the values.

For each connection in which the wall component is characterized by a limit U-value, the Ψ-value and the f_{Rsi} factor are reported. The f_{Rsi} factor limit values to fulfil the hygiene criterion are reported in the table as well.

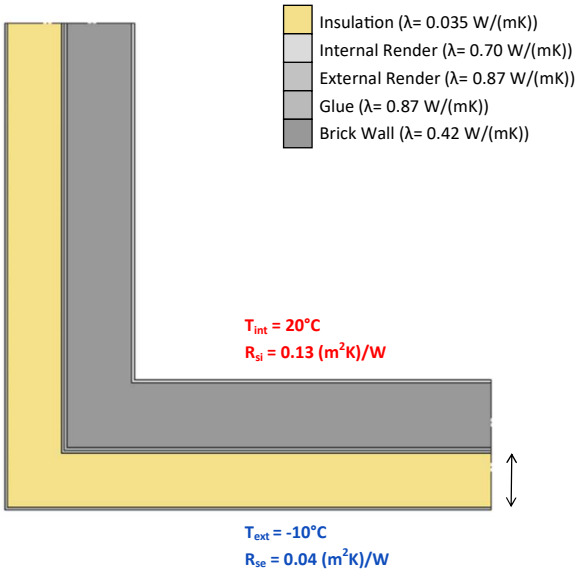
No.	Climate	U-value requirement	Ψ-value	Hygiene Criterion	f_{Rsi} factor
01	Arctic	0.09 W/(m²K)	0.43 W/(mK)	0.80	0.85
02	Cold	0.12 W/(m²K)	0.48 W/(mK)	0.75	0.83
03	Cool-Temperate	0.15 W/(m²K)	0.53 W/(mK)	0.70	0.8
04	Warm-Temperate	0.30 W/(m²K)	0.60 W/(mK)	0.65	0.76
05	Warm	0.50 W/(m²K)	0.60 W/(mK)	0.55	0.72
06	Hot	0.50 W/(m²K)	0.60 W/(mK)	-	0.72
07	Very Hot	0.25 W/(m²K)	0.59 W/(mK)	-	0.77
Existing Building		*4.00 W/(m²K)*	0.45 W/(mK)		0.60

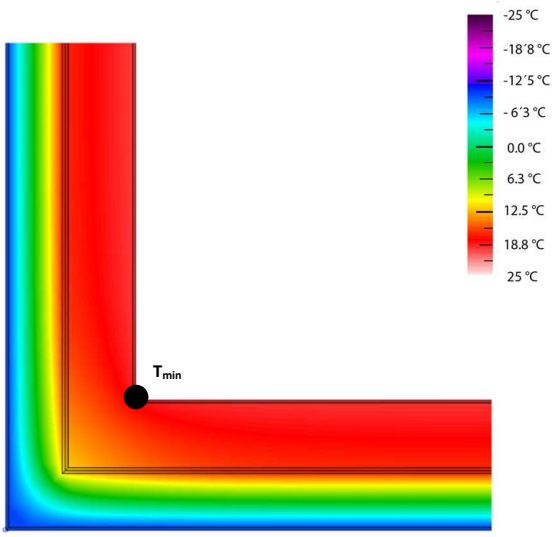
3 Catalogue

Passive House Institute

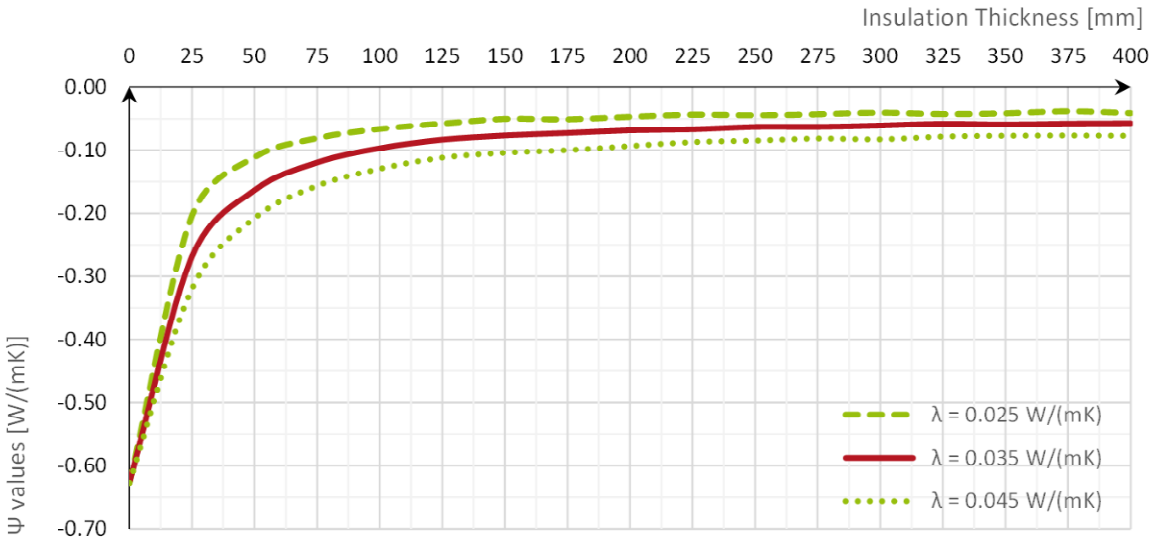
Thermal bridges catalogue

External wall – outer corner - BW





Detail drawing — Heat flow analysis



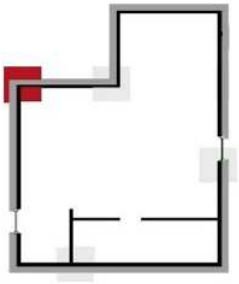
Ψ-value graph

Geometrical thermal bridges are caused by the shape of the building. In this case, the Ψ-value cannot be improved through additional flanking insulation.

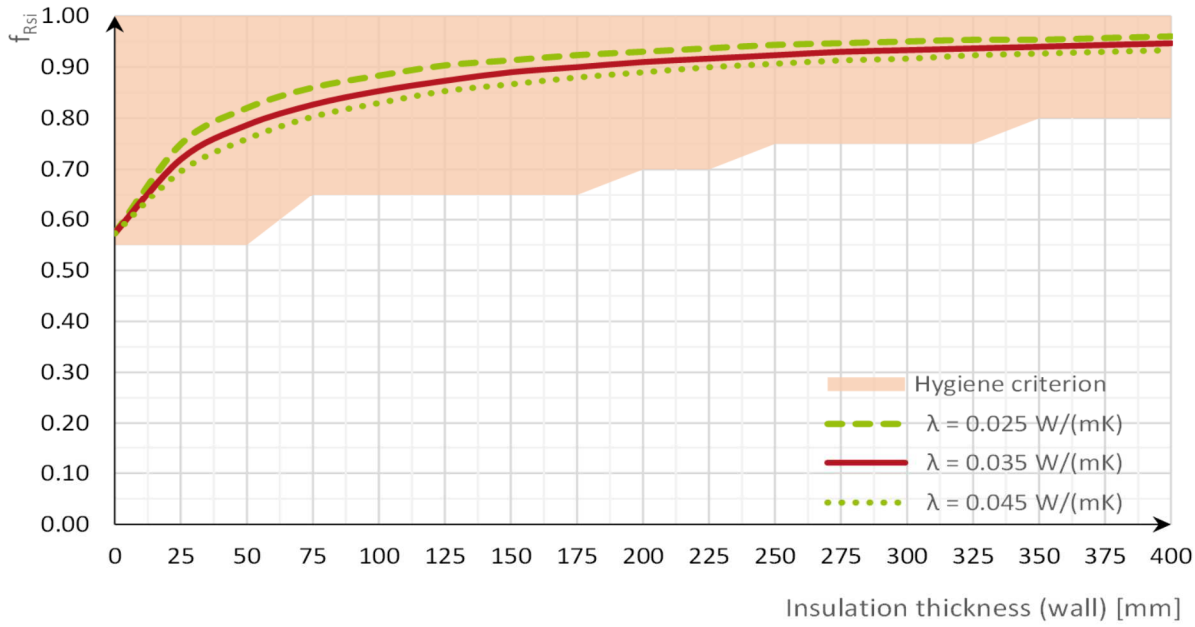
Ψ-value optimisation

- [x] geometrical
- [ ] structural
- [ ] mixed

- [x] ambient [A]
- [ ] perimeter [P]
- [ ] floor slab/ basement ceiling [B]



Thermal bridge characteristics [EWEC01]



f_{Rsi} factor graph

The Ψ-value of the uninsulated external corner is quite good (negative, therefore a bonus in the energy balance calculation), approximately a factor of 10 times better than the Ψ-value of typical Passive House Components in Central Europe. However, this positive effect will be negated by the bad performance of the uninsulated wall. The Ψ-value of the internal wall corner (not shown here) gets better (lower) with every inch of insulation.

The examination of the surface temperatures for this connection shows that insulation thicknesses of 50 mm or more fulfil the hygiene.

No.	Climate	U-value requirement	Ψ- value	Hygiene Criterion	f_{Rsi} factor
01	Arctic	0.09 W/(m²K)	-0.06 W/(mK)	0.80	0.94
02	Cold	0.12 W/(m²K)	-0.06 W/(mK)	0.75	0.93
03	Cool-Temperate	0.15 W/(m²K)	-0.07 W/(mK)	0.70	0.92
04	Warm-Temperate	0.30 W/(m²K)	-0.10 W/(mK)	0.65	0.86
05	Warm	0.50 W/(m²K)	-0.15 W/(mK)	0.55	0.79
06	Hot	0.50 W/(m²K)	-0.15 W/(mK)	-	0.79
07	Very Hot	0.25 W/(m²K)	-0.08 W/(mK)	-	0.88
Existing Building		*1.30 W/(m²K)*	-0.63 W/(mK)		0.57

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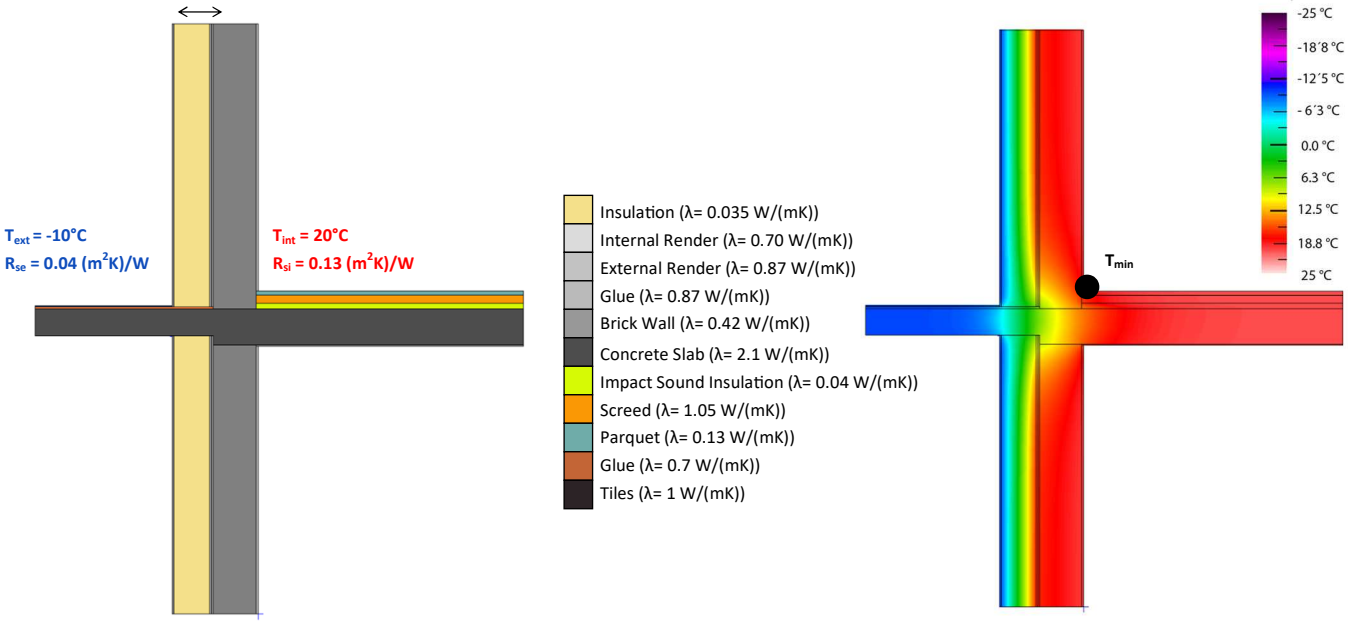
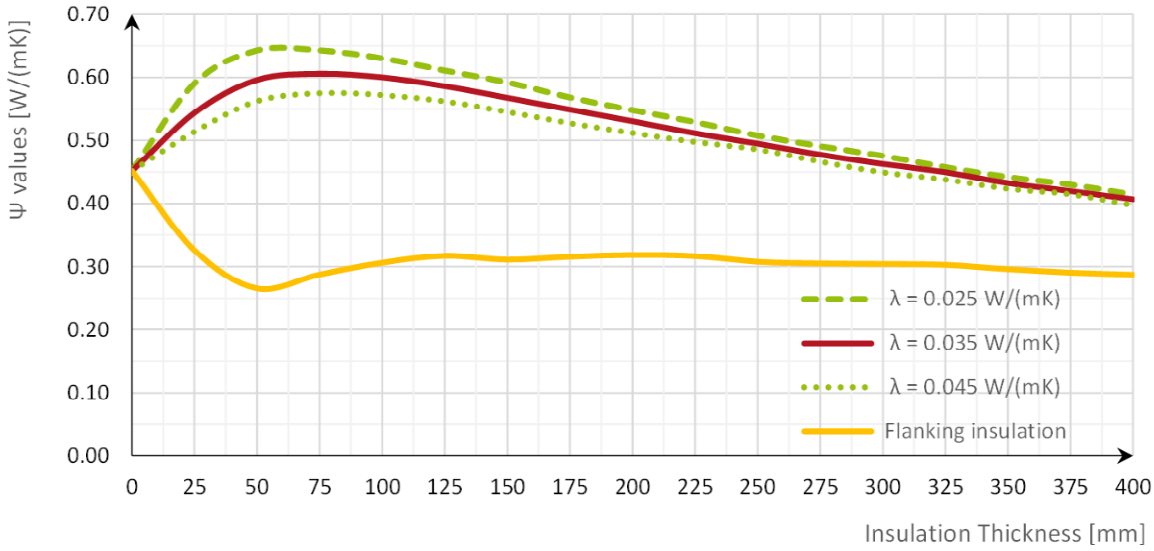
Thermal bridges catalogue

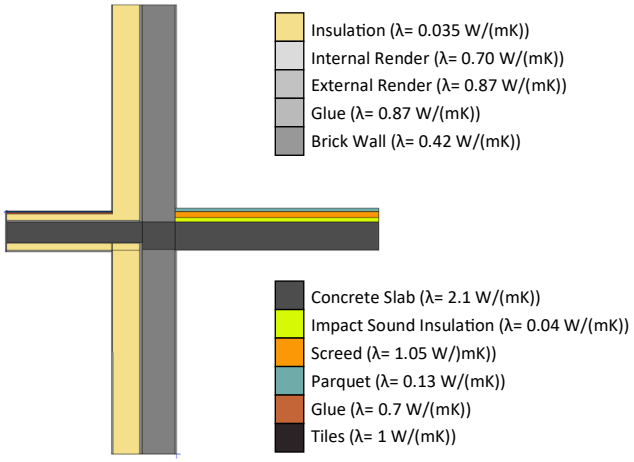
Balcony - BW



Detail drawing — Heat flow analysis



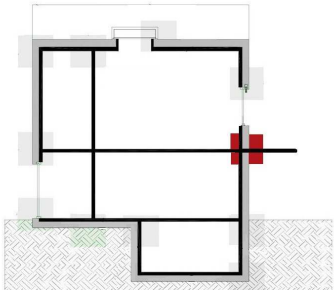
Ψ-value graph



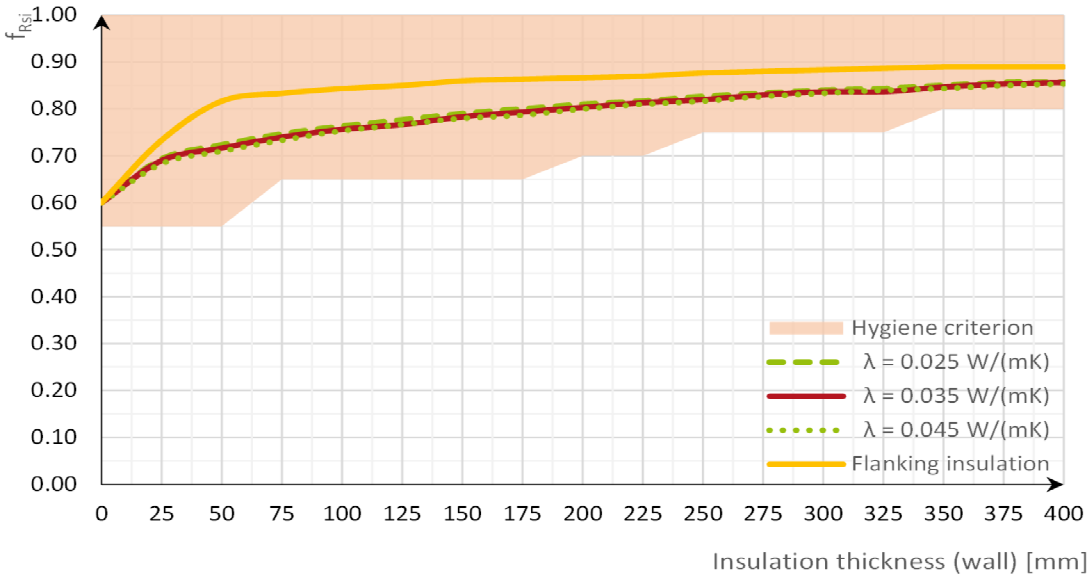
Ψ-value optimisation

☐ geometrical
☑ structural
☐ mixed

☑ ambient [A]
☐ perimeter [P]
☐ floor slab/ basement ceiling [B]



Thermal bridge characteristics [BALC01]



f_{Rsi} factor graph

The study of the Ψ-value showed remarkable behavior depending on the insulation thickness. First the Ψ-value increases to 0.65 W/(mK) for 50 mm of insulation and then it decreases by approximately 0.02 W/(mK) for every additional 25 mm of insulation. These results are for a reinforced concrete penetration (conductivity 2.1 W/(mK)) with a width of 150 mm.

The resultant Ψ-value is quite high for all of the cases and therefore, a correction for the thermal bridge through the addition of flanking insulation is required. It is applied on and under the balcony slab and is only 50 mm thick.

The internal surface temperatures of a balcony connection will fulfil the requirements of the hygiene criterion.

For the flanking insulation solution, the Ψ value reduces to approximately 0.30 W/(mK). Notice that in all of the cases studied the flanking insulation is 50 mm thick. When the wall insulation is 25 mm thick, the flanking insulation should be defined accordingly.

No.	Climate	U-value requirement	Ψ-value	Hygiene Criterion	f_{Rsi} factor
01	Arctic	0.09 W/(m²K)	0.43 W/(mK)	0.80	0.85
02	Cold	0.12 W/(m²K)	0.48 W/(mK)	0.75	0.83
03	Cool-Temperate	0.15 W/(m²K)	0.53 W/(mK)	0.70	0.8
04	Warm-Temperate	0.30 W/(m²K)	0.60 W/(mK)	0.65	0.76
05	Warm	0.50 W/(m²K)	0.60 W/(mK)	0.55	0.72
06	Hot	0.50 W/(m²K)	0.60 W/(mK)	-	0.72
07	Very Hot	0.25 W/(m²K)	0.59 W/(mK)	-	0.77
Existing Building		*4.00 W/(m²K)*	0.45 W/(mK)		0.60

Register to

to have access to the full version of the

Thermal Bridges Catalogue

References

[1] Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard, Passive House Institute, 2016.

[2] Criteria and Algorithms for Certified Passive House Components: Opaque construction systems, Passive House Institute, 2015.

[3] Arbeitskreis kostengünstige Passivhäuser, Protokollband Nr. 16: Wärmebrückenfreies Konstruieren. Passivhaus Institut, Darmstadt, 1999 [Research Group Cost-efficient Passive Houses, Volume 16: Thermal bridges free-design. Passive House Institute, Darmstadt, 1999].

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mail@passiv.de
www.passivehouse.com

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Soraya López García

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