Thermal Bridges Catalogue
Passive House Institute

Passive House Institute

Sinfonia

Contents

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 and comfort 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.

Connection Details Examined

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:

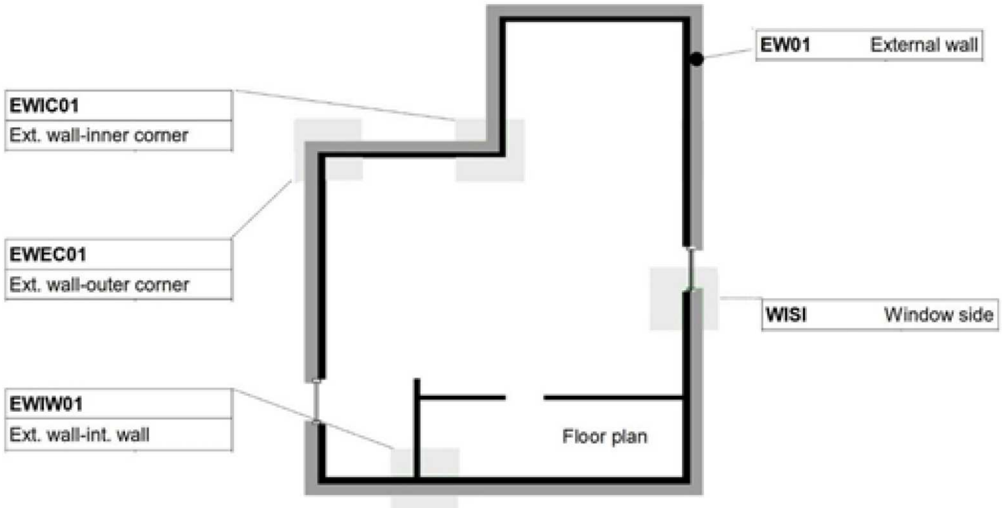
• **A brick wall construction** of 240 mm thickness and λ = 0.42 W/(mK), as typically found in European building stock. The uninsulated wall shows an U-Value of about 1.30 W/(m²K).

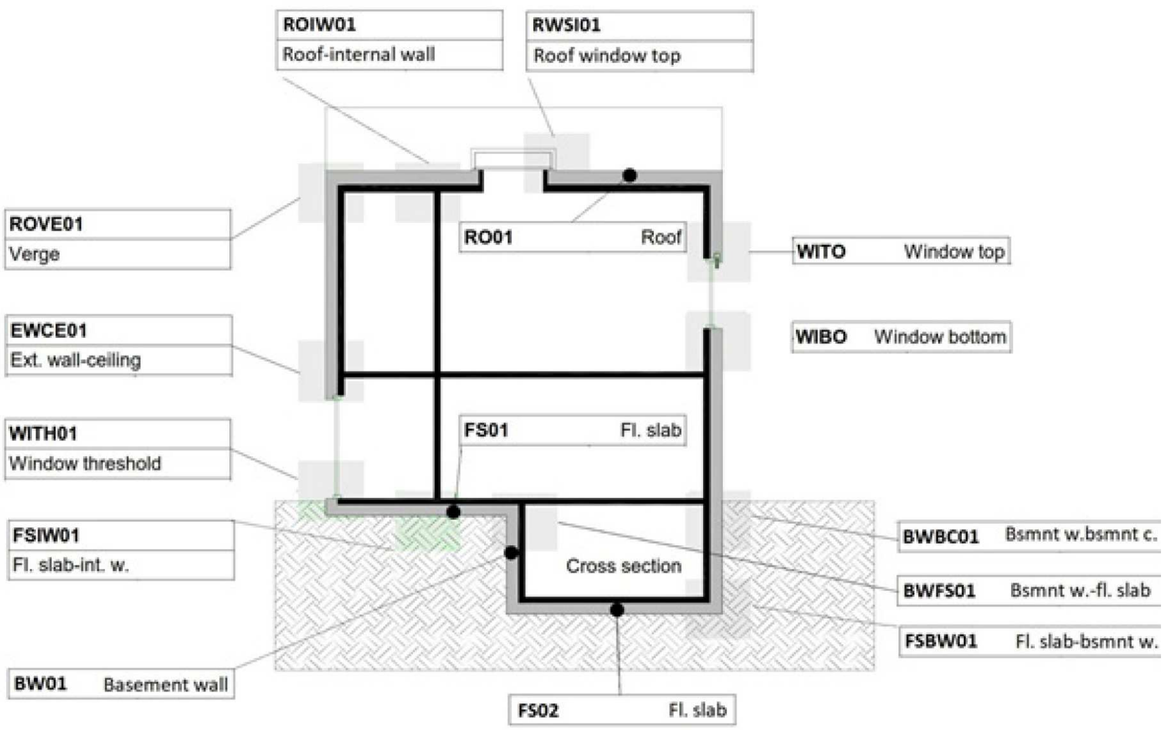
• **A concrete wall** construction of 120 mm thickness and λ = 2.10 W/(mK), as very often found in developing countries. The uninsulated wall shows an U-Value of about 4.00 W/(m²K).

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.





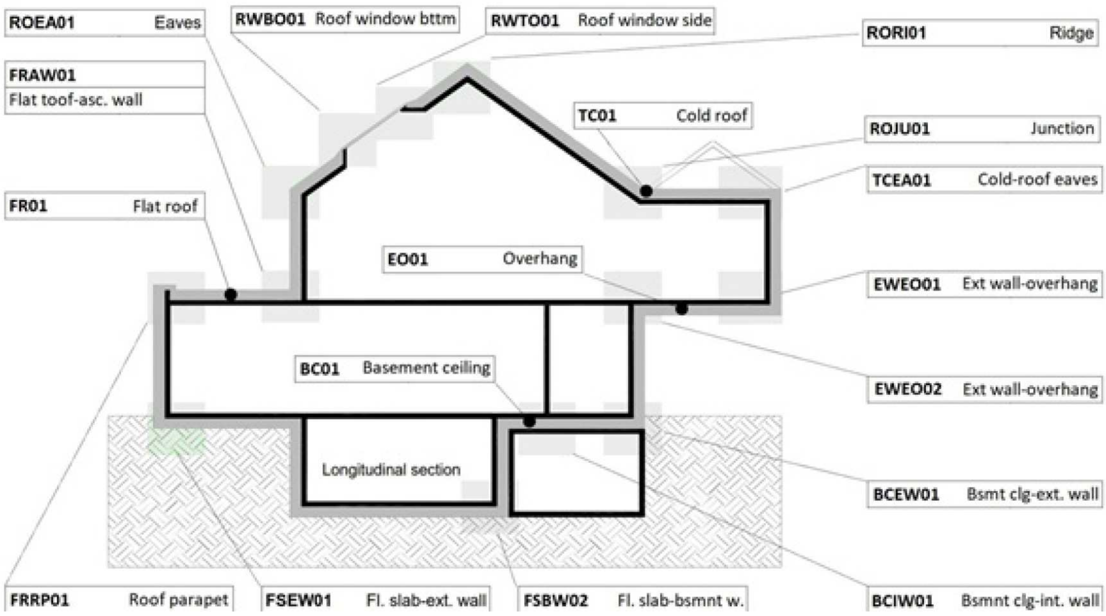


Figure 1: Floor plan, cross section and longitudinal section showing the typical connections in a building and the codes assigned in the "Criteria and Algorithms for Certified Passive House Components: Opaque construction systems" [2].

Energy, Hygiene and Efficiency Parameters

The connections were evaluated to determine two parameters:

- Ψ-value, for an energy evaluation of the detail;
- f_{Rsi} factor, for a hygiene and efficiency 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 and Efficiency 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 Rsi = 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 and an efficiency criterion were 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 efficiency criterion establishes the minimum f_{Rsi} factor that needs to be reached to ensure thermal comfort. Fanger's theory [3] explains that one of the causes of thermal discomfort is radiant temperature asymmetry in the room. The Passive House standard is defined to reach comfort class A [4]. These temperature limits are translated into f_{Rsi} limits for opaque components in the efficiency criterion.

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

No	Climate	Hygiene criterion f_{Rsi} = 0.25 m²K/W	Efficiency criterion f_{Rsi} = 0.25 m²K/W
01	Artic	0.80	0.90
02	Cold	0.75	0.88
03	Cold-Temperate	0.70	0.86
04	Warm-Temperate	0.65	0.82
05	Warm	0.55	0.74
06	Hot	-	0.74
07	Very Hot	-	0.82

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

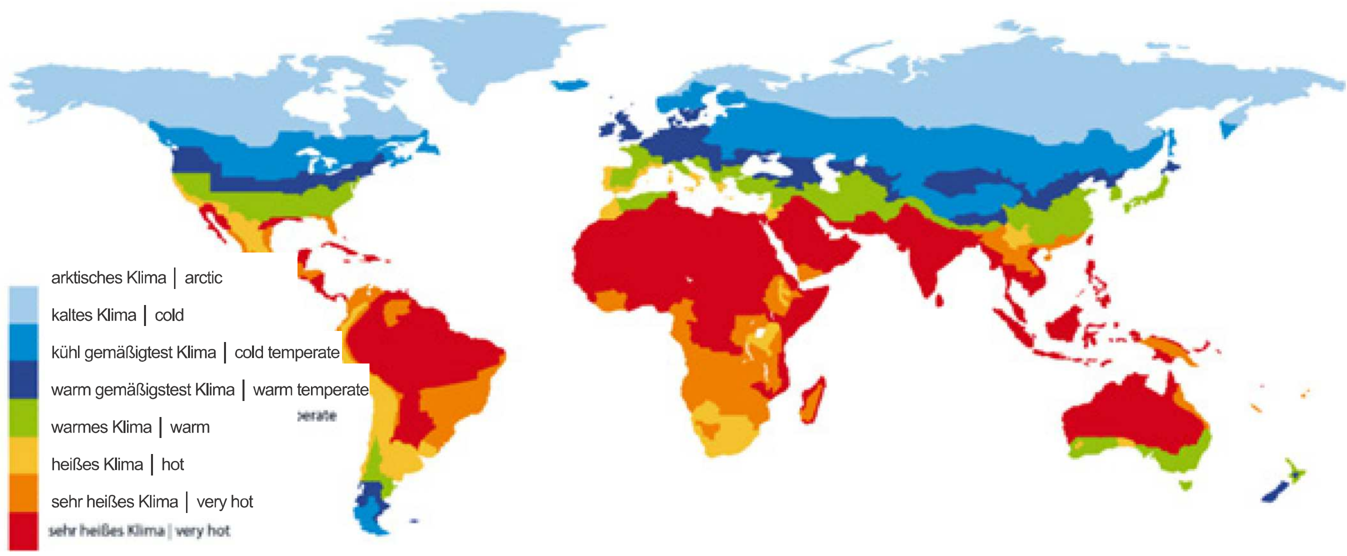
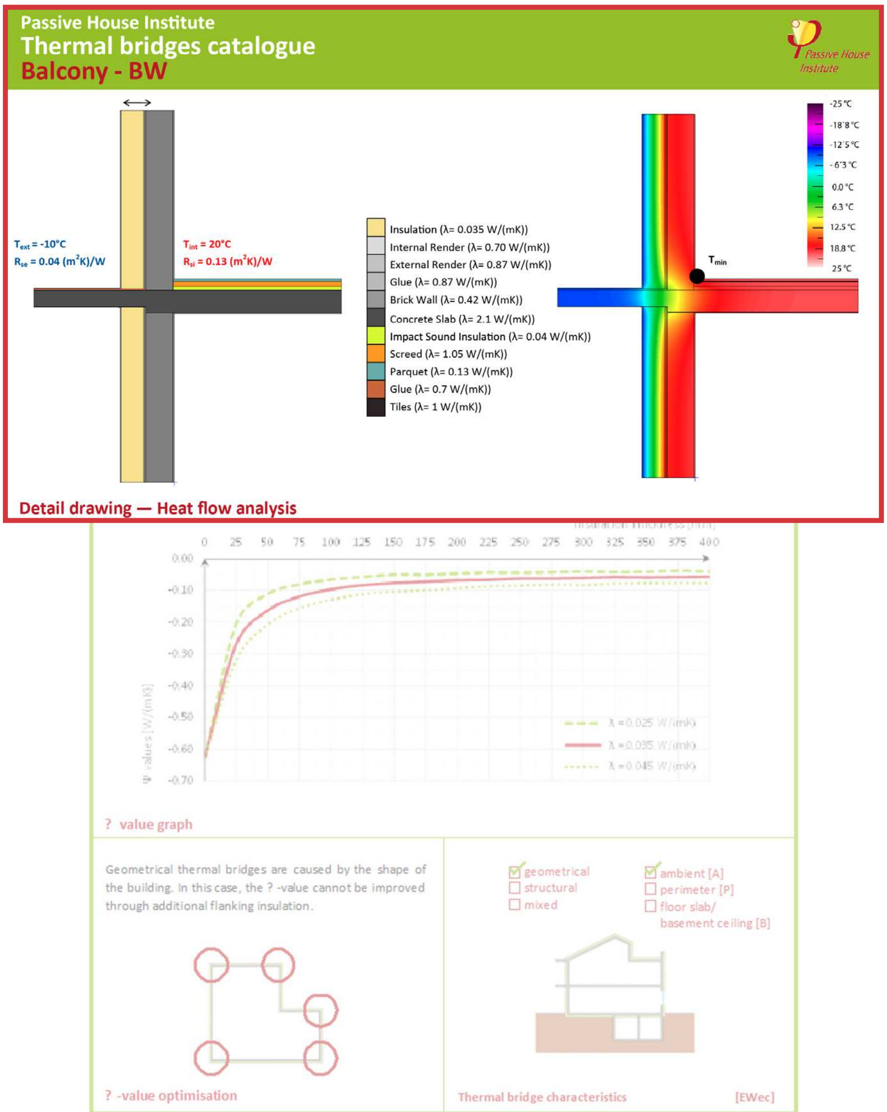


Figure 2: Assignment of the regions with identical requirements, based on studies by the PHI.

2 Instructions

How to read the catalogue



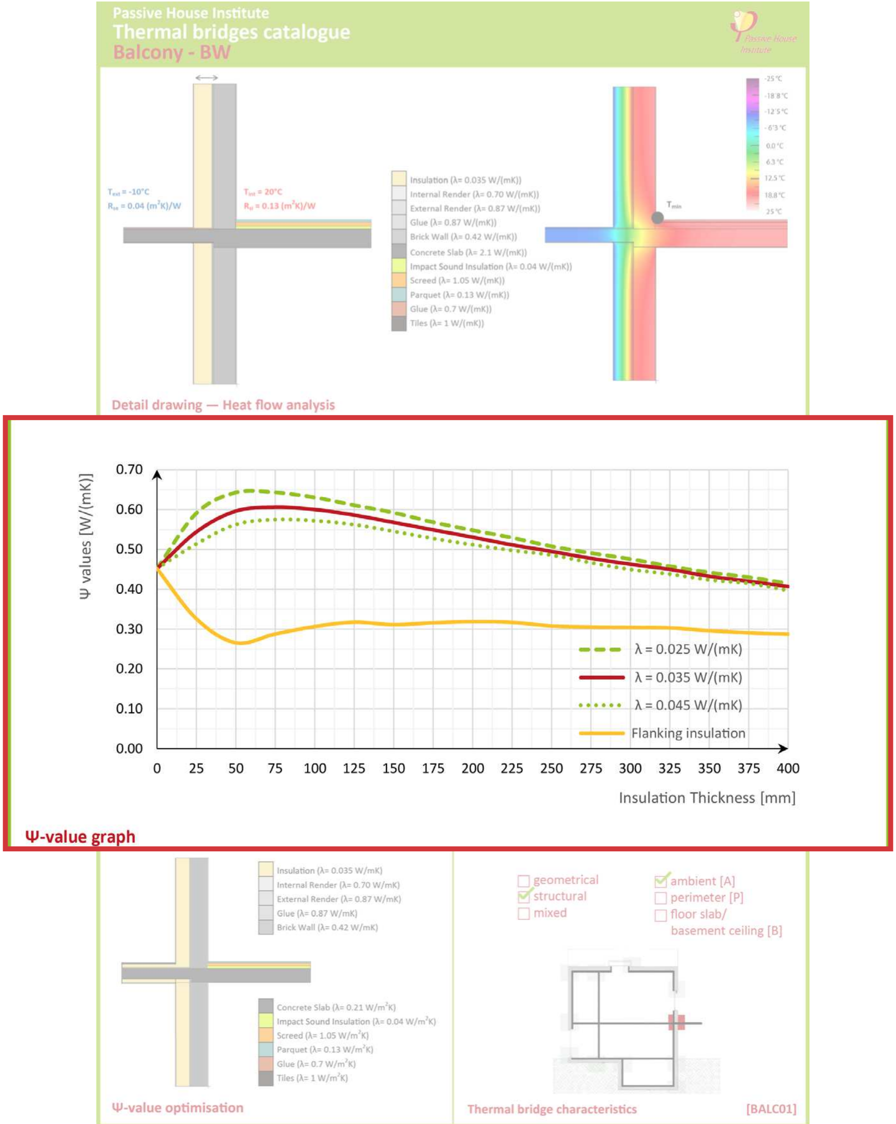
Detail drawing

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

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.

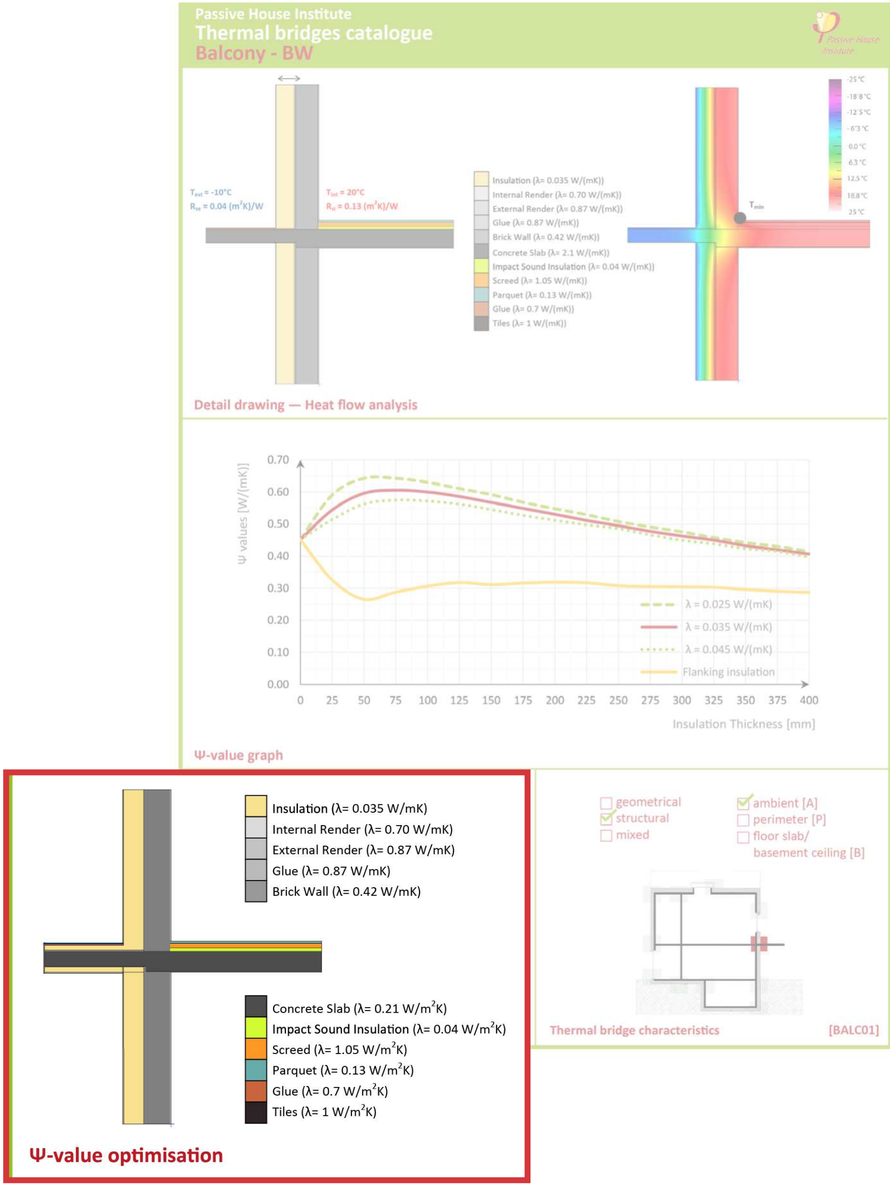


Ψ-value graph

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 optimization

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 and Nr.24 [5].

Thermal bridge characteristics

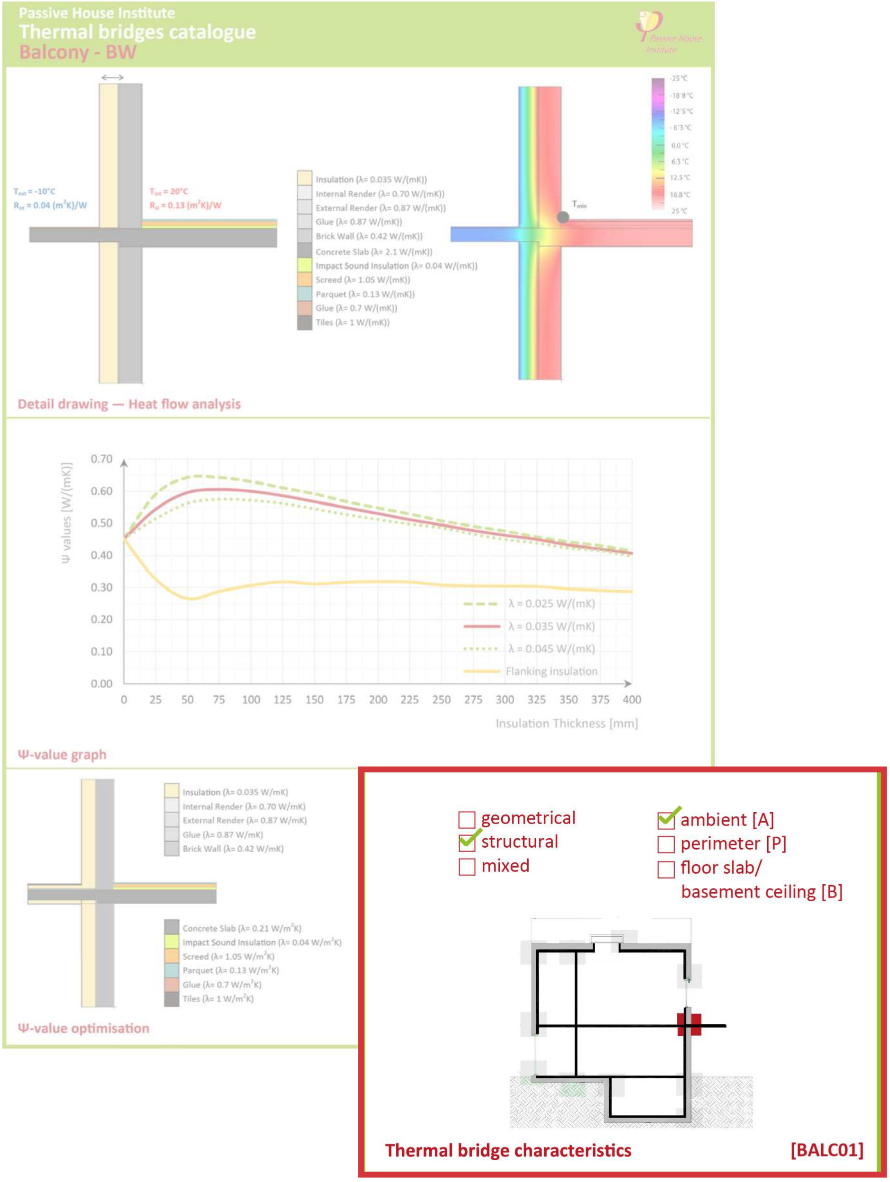
Each connection is identified through a code, as in the "Criteria and Algorithms for Certified Passive House Components: Opaque construction systems".

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.

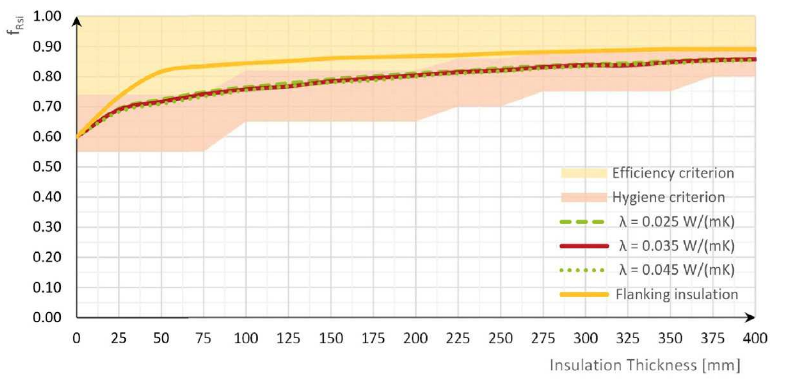
With reference to the classifications reported in PHPP, the thermal bridges are identified as follows:

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 (G_t [kWh/a]) to be taken into account in the final transmission heat losses balance.



Passive House Institute
Thermal bridges catalogue
Balcony - BW



f_{Rsi} factor graph

f_{Rsi} factor graph

The study of the Ψ-value showed a remarkable behavior depending on the insulation thickness. First the Ψ-values are increasing up to 0.65 W/(mK) till 50 mm insulation and then they are decreasing of about 0.02 W/(mK) every additional 25 mm of insulation. These results are referred to a steel concrete (conductivity 2.1 W/(mK)) penetration 150 mm width.

The Ψ-values obtained are quite high for all the cases; therefore, a correction of the thermal bridge though the addition of flanking insulation is needed. It is applied on and under the balcony slab and it is just 50 mm thick.

The internal surface temperatures of a balcony connection will fulfil the requirements of the hygiene criterion, but the efficiency criterion will be missed for almost any insulation thickness. With flanking insulation, also the efficiency criterion is met for any of the climate zones.

Thanks to this solution, the Ψ values are dropping drastically to around 0.30 W/(mK). Notice that in our simulations the flanking insulation is applied just from the case of 50 mm of insulation thickness.

No.	Climate	U-value requirement	Ψ-value	Hygiene Criterion	Efficiency Criterion	f_{Rsi} factor
01	Arctic	0.09 W/(m²K)	0.43 W/(mK)	0.80	0.90	0.85
02	Cold	0.12 W/(m²K)	0.48 W/(mK)	0.75	0.88	0.83
03	Cool-Temperate	0.15 W/(m²K)	0.53 W/(mK)	0.70	0.86	0.8
04	Warm-Temperate	0.30 W/(m²K)	0.60 W/(mK)	0.65	0.82	0.76
05	Warm	0.50 W/(m²K)	0.60 W/(mK)	0.55	0.74	0.72
06	Hot	0.50 W/(m²K)	0.60 W/(mK)	-	0.74	0.72
07	Very Hot	0.25 W/(m²K)	0.59 W/(mK)	-	0.82	0.77
Existing Building		*4.00 W/(m²K)*	0.45 W/(mK)			0.60

f_{Rsi} factor graph

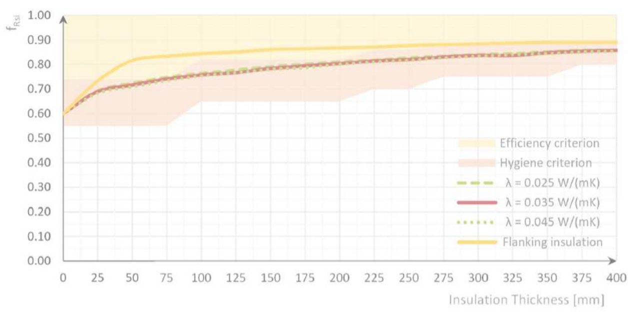
The graph reports the results of the fRsi factor calculated through the formula previously shown. The insulation thickness applied to the components lay on the x-axis. The fRsi factor results lay on the y-axis. The fRsi factor was calculated using the minimum internal surface temperature determined in 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 additional flanking insulation, the results of the simulations are displayed through a yellow curve. The insulation conductivity is assumed to be 0.035 W/(mK).

The graphs show also an orange area, which represents the hygiene criterion, and a yellow area, which represents the effi ciency criterion. When a point of the curve lays in one of these areas, it means that the corresponding criterion is fulfilled. Fulfilling the efficiency criterion implies fulfilling the hygiene criterion as well.

Passive House Institute
Thermal bridges catalogue
Balcony - BW



f_{Rsi} factor graph

The study of the Ψ-value showed a remarkable behavior depending on the insulation thickness. First the Ψ-values are increasing up to 0.65 W/(mK) till 50 mm insulation and then they are decreasing of about 0.02 W/(mK) every additional 25 mm of insulation. These results are referred to a steel concrete (conductivity 2.1 W/(mK)) penetration 150 mm width.

The Ψ-values obtained are quite high for all the cases; therefore, a correction of the thermal bridge though the addition of flanking insulation is needed. It is applied on and under the balcony slab and it is just 50 mm thick.

The internal surface temperatures of a balcony connection will fulfil the requirements of the hygiene criterion, but the efficiency criterion will be missed for almost any insulation thickness. With flanking insulation, also the efficiency criterion is met for any of the climate zones.

Thanks to this solution, the Ψ values are dropping drastically to around 0.30 W/(mK). Notice that in our simulations the flanking insulation is applied just from the case of 50 mm of insulation thickness.

No.	Climate	U-value requirement	Ψ-value	Hygiene Criterion	Efficiency Criterion	f_{Rsi} factor
01	Arctic	0.09 W/(m²K)	0.43 W/(mK)	0.80	0.90	0.85
02	Cold	0.12 W/(m²K)	0.48 W/(mK)	0.75	0.88	0.83
03	Cool-Temperate	0.15 W/(m²K)	0.53 W/(mK)	0.70	0.86	0.8
04	Warm-Temperate	0.30 W/(m²K)	0.60 W/(mK)	0.65	0.82	0.76
05	Warm	0.50 W/(m²K)	0.60 W/(mK)	0.55	0.74	0.72
06	Hot	0.50 W/(m²K)	0.60 W/(mK)	-	0.74	0.72
07	Very Hot	0.25 W/(m²K)	0.59 W/(mK)	-	0.82	0.77
Existing Building		*4.00 W/(m²K)*	0.45 W/(mK)			0.60

Table

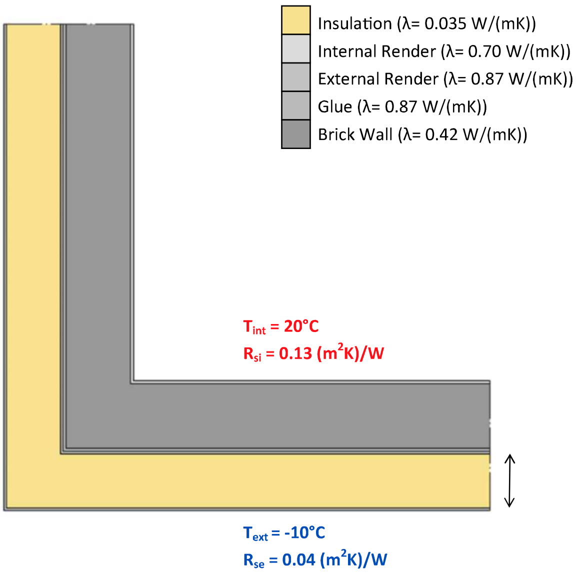
The table summarizes the main results for each climate zone. The limit U-value of the component is defined by the EnerPHit criteria, as previously explained. This translates into a certain insulation thickness, if the components (e.g. wall) are defined similarly as was used in this research (240 mm brick 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 here studied. It is highly recommended to apply a safety margin to the values, though.

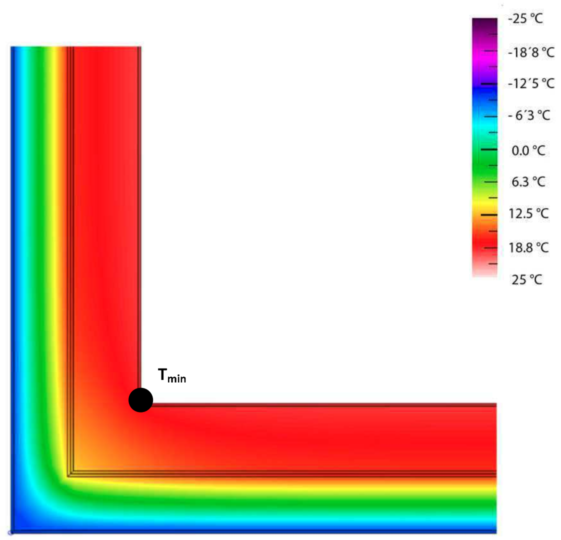
For each connection in which the wall component is characterized by a limit U-value, the Ψ-value and the f_{Rsi} factor are reported.

The f_{Rsi} factor limit values to fulfil the hygiene and efficiency criterion are reported in the table as well.

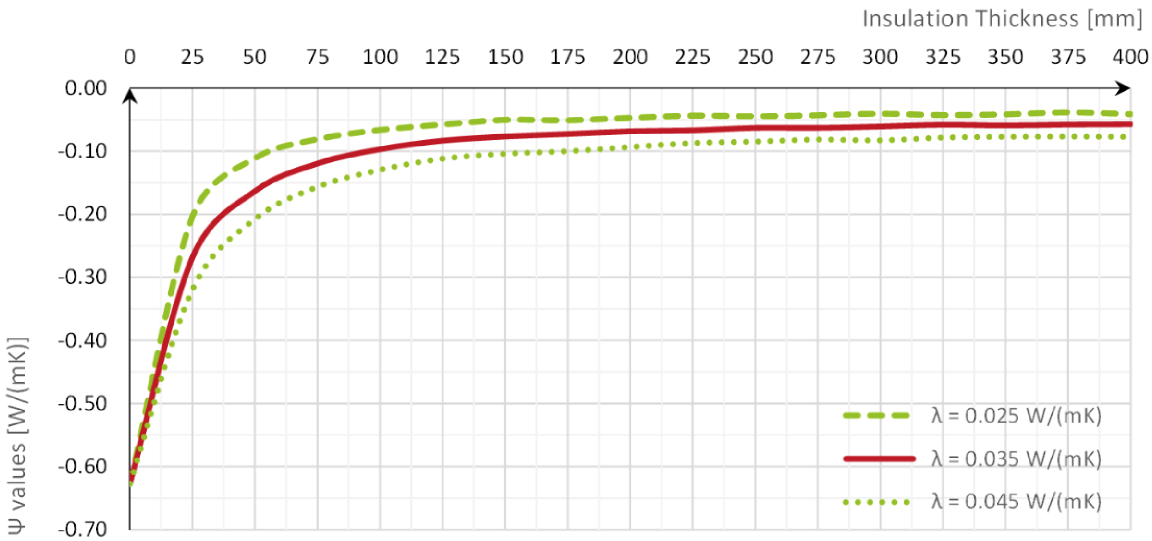
3 Catalogue

External wall – outer corner - BW





Detail drawing — Heat flow analysis



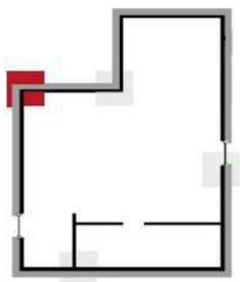
Ψ-value graph

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

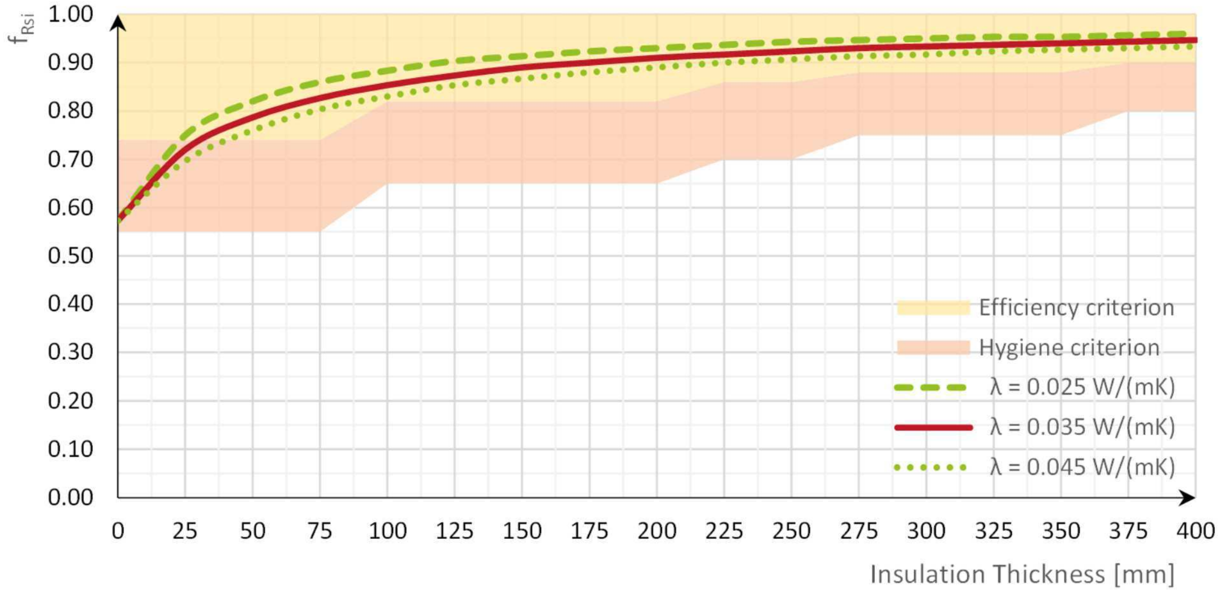
- ☑ geometrical
- ☐ structural
- ☐ mixed

- ☑ 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, as well as the efficiency criteria, for the certification of opaque building systems.

No.	Climate	U-value requirement	Ψ- value	Hygiene Criterion	Efficiency Criterion	f_{Rsi} factor
01	Arctic	0.09 W/(m²K)	-0.06 W/(mK)	0.80	0.90	0.94
02	Cold	0.12 W/(m²K)	-0.06 W/(mK)	0.75	0.88	0.93
03	Cool-Temperate	0.15 W/(m²K)	-0.07 W/(mK)	0.70	0.86	0.92
04	Warm-Temperate	0.30 W/(m²K)	-0.10 W/(mK)	0.65	0.82	0.86
05	Warm	0.50 W/(m²K)	-0.15 W/(mK)	0.55	0.74	0.79
06	Hot	0.50 W/(m²K)	-0.15 W/(mK)	-	0.74	0.79
07	Very Hot	0.25 W/(m²K)	-0.08 W/(mK)	-	0.82	0.88
Existing Building		*1.30 W/(m²K)*	-0.63 W/(mK)			0.57

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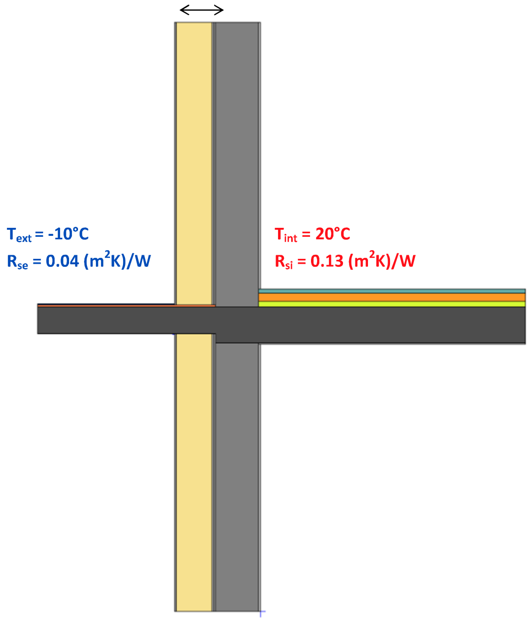
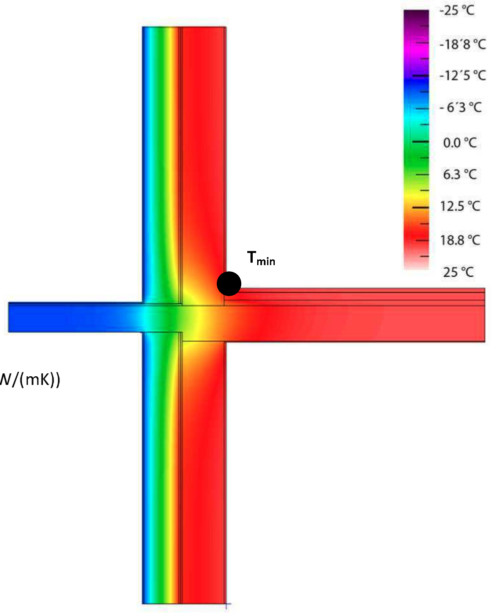
Thermal bridges catalogue

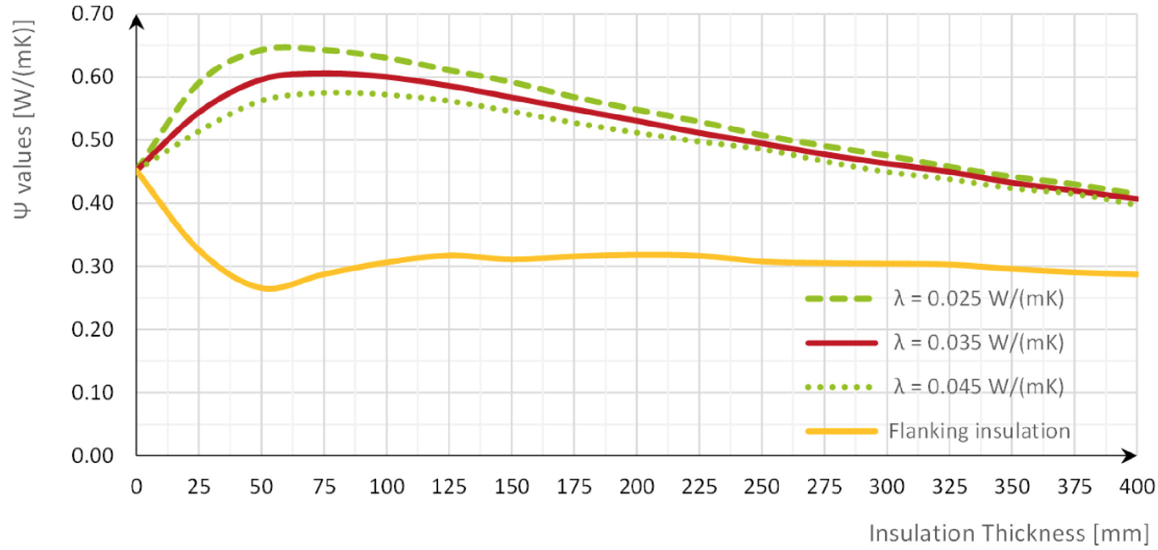
Balcony - BW



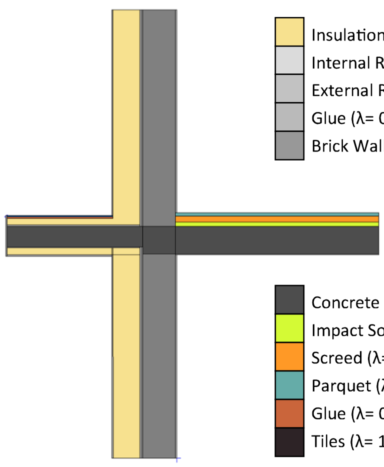
- Insulation (λ= 0.035 W/(mK))
- Internal Render (λ= 0.70 W/(mK))
- External Render (λ= 0.87 W/(mK))
- Glue (λ= 0.87 W/(mK))
- Brick Wall (λ= 0.42 W/(mK))
- Concrete Slab (λ= 2.1 W/(mK))
- Impact Sound Insulation (λ= 0.04 W/(mK))
- Screed (λ= 1.05 W/(mK))
- Parquet (λ= 0.13 W/(mK))
- Glue (λ= 0.7 W/(mK))
- Tiles (λ= 1 W/(mK))



Detail drawing — Heat flow analysis



Ψ-value graph

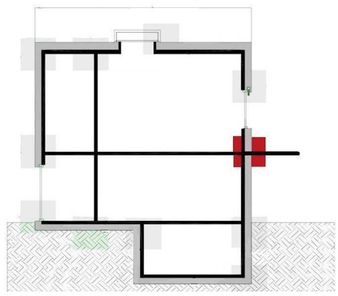


- Insulation (λ= 0.035 W/(mK))
- Internal Render (λ= 0.70 W/(mK))
- External Render (λ= 0.87 W/(mK))
- Glue (λ= 0.87 W/(mK))
- Brick Wall (λ= 0.42 W/(mK))
- Concrete Slab (λ= 2.1 W/(mK))
- Impact Sound Insulation (λ= 0.04 W/(mK))
- Screed (λ= 1.05 W/)mK))
- Parquet (λ= 0.13 W/(mK))
- Glue (λ= 0.7 W/(mK))
- Tiles (λ= 1 W/(mK))

Ψ-value optimisation

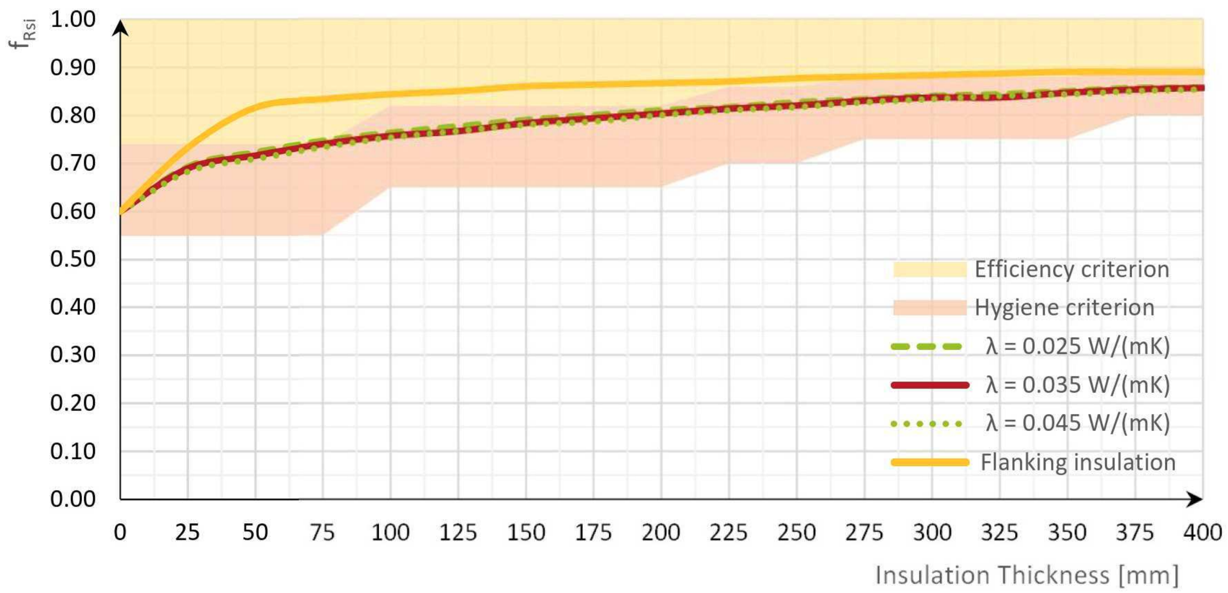
- [ ] geometrical
- [x] structural
- [ ] mixed

- [x] 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, but the efficiency criterion will not be satisfied for almost all insulation thicknesses. The efficiency criterion will be met for all climate zones with the addition of flanking insulation.

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	Efficiency Criterion	f_{Rsi} factor
01	Arctic	0.09 W/(m²K)	0.43 W/(mK)	0.80	0.90	0.85
02	Cold	0.12 W/(m²K)	0.48 W/(mK)	0.75	0.88	0.83
03	Cool-Temperate	0.15 W/(m²K)	0.53 W/(mK)	0.70	0.86	0.8
04	Warm-Temperate	0.30 W/(m²K)	0.60 W/(mK)	0.65	0.82	0.76
05	Warm	0.50 W/(m²K)	0.60 W/(mK)	0.55	0.74	0.72
06	Hot	0.50 W/(m²K)	0.60 W/(mK)	-	0.74	0.72
07	Very Hot	0.25 W/(m²K)	0.59 W/(mK)	-	0.82	0.77
Existing Building		*4.00 W/(m²K)*	0.45 W/(mK)			0.60

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] Fanger, P. Ole, “Thermal Comfort: Analysis and applications in environmental engineering”, 1970.

[4] ASHRAE Standard 55, 2010.

[5] Arbeitskreis kostengünstige Passivhäuser, Protokollband Nr. 24: Einsatz von Passivhaustechnologien bei der Altbau-Modernisierung. Passivhaus Institut, Darmstadt, 2003 [Research Group Cost-efficient Passive Houses, Volume 24: Use of Passive House technologies for refurbishments. Passive House Institute, Darmstadt, 2003].

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Scope of content and exclusion of liability

The "Thermal Bridges Catalogue" is intended to guide the Passive House Designers and Consultants to better understand the thermal bridge influence into the thermal energy balance and the typical Ψ-values of common connections in a building. The "Thermal Bridges Catalogue" was compiled with the greatest care and to the best of our knowledge and belief. However, no liability can be accepted for any content-related shortcomings or errors. Any liability for the accuracy and completeness of the contents and data and in particular for any damage or consequences arising from the use of the information presented here is therefore excluded

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