



Methodology to be followed for calculation of equivalent thermal conductivities for Passive House construction system certification

Equivalent thermal conductivities in thermal modelling

In order to simplify the process of two- and three-dimensional thermal modelling of heat transfer coefficients of opaque components (both linear Psi-values and area-based U-values), it is often necessary to calculate equivalent thermal conductivities to take into account the effect of repeating thermal disturbances. These generally take the form of structural members that run in the direction parallel to the modelling plane, but can also be point thermal bridges or other linear elements that cannot be taken into account due to their geometry. Broadly speaking, these can be divided into the following:

1. Unidirectional heat loss elements (external walls, roofs and floors) with repeating disturbances;
2. Linear junctions with repeating disturbances at the point of connection;
3. Point connections (Chi-values) with regular distribution over the surface of a unidirectional heat loss element;
4. Balcony connections using proprietary thermal break products.

This appendix to the document Criteria and Algorithms for Certified Passive House Components: Opaque Construction Systems will detail the various approaches to calculation of equivalent thermal conductivities.

1. Unidirectional heat loss elements (external walls / roofs / floors) with repeating disturbances

Heat loss elements (external walls, roofs and floors) often feature repeating disturbances, e.g. a lightweight timber wall with regularly distanced vertical studs. When carrying out thermal modelling of vertical cross-sections of such framed constructions, e.g. the intersection between external wall and intermediate floor (see Figure 1, these disturbances run parallel to the modelling plane. These are known as ‘inhomogeneous layers’ and in order to model these accurately, a equivalent material must be created, the lambda value of which accounts for the correct proportions of timber and insulation present in the layer.

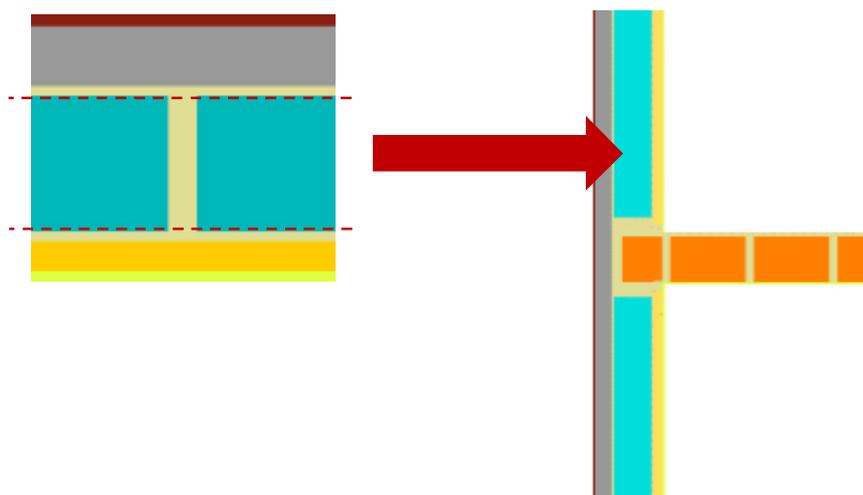


Figure 1 – Basic wall assembly, horizontal section (left), vertical section (right) with equivalent material in light blue

The standard approach to calculating the U-value where such geometry is present is given in ISO 6946, section 6.7.2, and leads to a reasonable degree of accuracy, however this is not sufficiently accurate for construction system certification as this is generally calculated to three decimal places, and can thereby lead to inaccurate Psi-values.

Using FEM calculation according to ISO 10211, the U-value can be calculated to a high degree of accuracy. Where only one inhomogeneous layer is present, the equivalent thermal conductivity of this can then be calculated simply by establishing the R-value of the full assembly in m²K/W and then subtracting the R-value of the boundary conditions and of each homogeneous layer until only the disturbed layer remains; the lambda value is then found by dividing the thickness of this layer in metres by the resistance.

The equivalent thermal conductivity can also be found within the modelling software by creating an additional, 'undisturbed' model of the wall, consisting of simple parallel layers with a single, theoretical, material to represent the inhomogeneous layer, i.e. (in this case) mineral wool insulation and steel.

By way of iteration, it is then possible to adjust the lambda value of the equivalent material within the parallel layers model to achieve the same heat flux (W/m, to 5 decimal places, or as high a possible level of accuracy), and thereby the same U-value as the original 'disturbed' model. This procedure is shown below in figure 2:

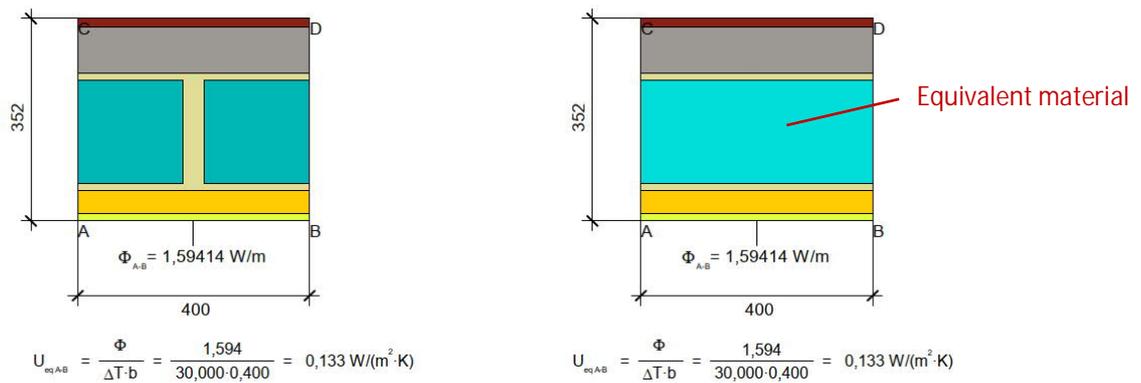


Figure 2 - Basic wall assembly, horizontal section. Right hand image showing equivalent material.

For those thermal modellers using Flixo Pro, the built-in 3d equivalent object tool leads to a reasonable degree of accuracy (based on the above example, within 0,001 W/(m²K)), however as previously this is not sufficient for certified construction systems. This approach may, however, be suitable for preliminary calculations or where the net heat flow is zero, e.g. to take into account repeating elements in an intermediate floor. In such cases both sides, above and below, are 'warm' and the prescribed FEM calculation cannot be carried out due to the lack of a temperature differential. In all cases, however, the stipulations set out in ISO 6946 6.7.2.1. (see above) must be met, otherwise three-dimensional FEM modelling according to ISO 10211 is necessary. Other thermal modelling softwares may also have similar functions, but these have not been tested by PHI.

Where multiple inhomogeneous layers are present and these run in the same direction, the same procedure can be followed – multiple steps are of course necessary in this case and the order of calculation should be from thinnest to thickest layer, as shown below in Figure 3:

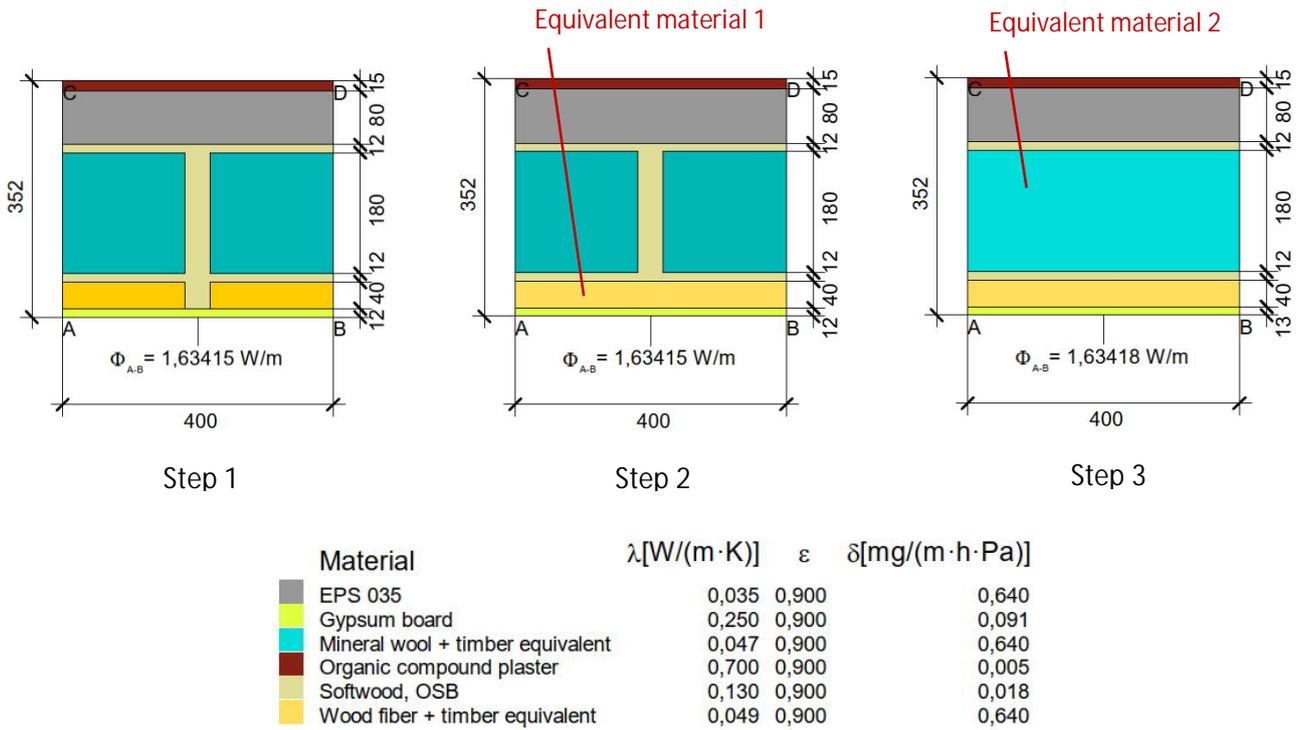


Figure 3 - Basic wall assembly, lightweight timber, horizontal section with timber stud in service cavity (left), equivalent material in service cavity (middle) and equivalent material in both cavities (right)

Step 1: Determine the heat flow of the original construction per FEM simulation (left in figure 3)

Step 2: Determine the equivalent conductivity of one of the inhomogeneous layers by iteration (center in figure 3)

Step 3: Calculate conductivity of the last inhomogeneous layer (right in figure 3)

Where multiple inhomogeneous layers are present and these run in opposite directions, however, three-dimensional modelling should be carried out using the same iterative process as above to determine the equivalent thermal conductivities. This procedure is shown below in figure 4:

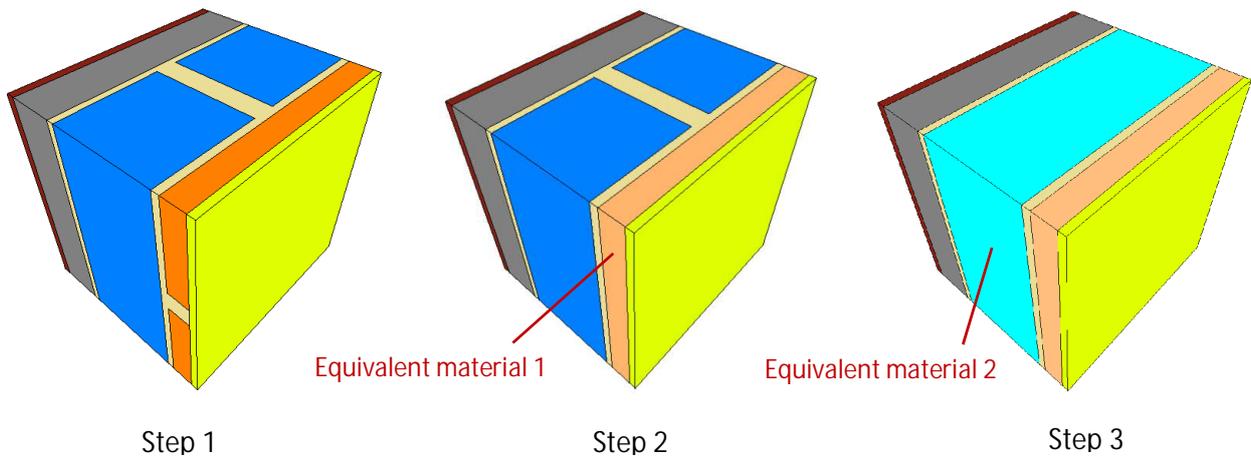


Figure 4 – Basic wall assembly, lightweight timber, three-dimensional thermal model with horizontal timber stud in service cavity (left), equivalent material in service cavity (middle) and equivalent material in both cavities (right)

Alternatively, where no 3D modelling software is available, it is possible to generate equivalent values for assemblies that do not include metal components using two-dimensional modelling in the following way, where the example of the assembly in figure 4 is used:

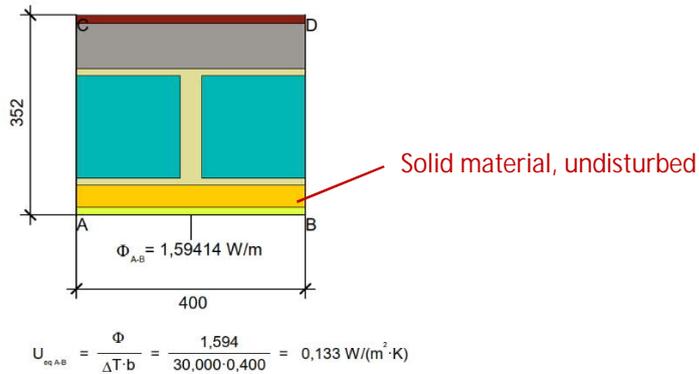
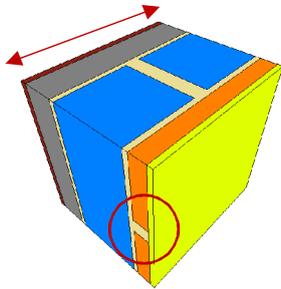


Figure 5 –Modelling the wall assembly

Step 1: model the wall assembly to planes of symmetry in the horizontal plane (see left), without (in this case) consideration of the horizontal timber member in the service cavity (see left, circled).

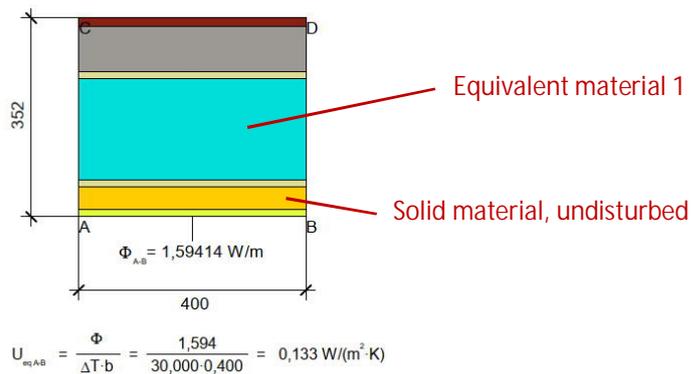


Figure 6 – Creating equivalent material 1

Step 2: create an equivalent material for the main cavity to consider (in this case) the thermal insulation and timber.

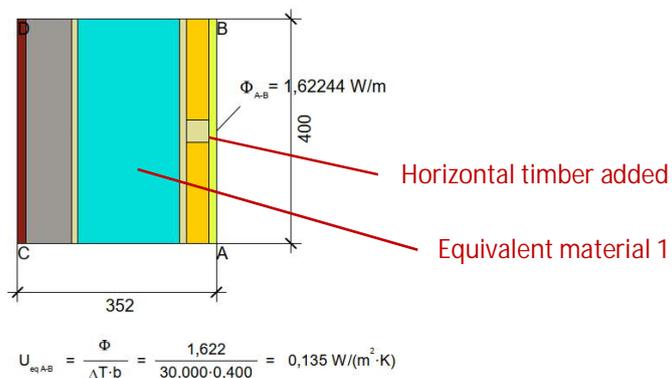
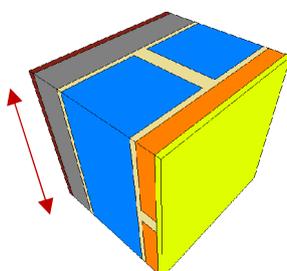
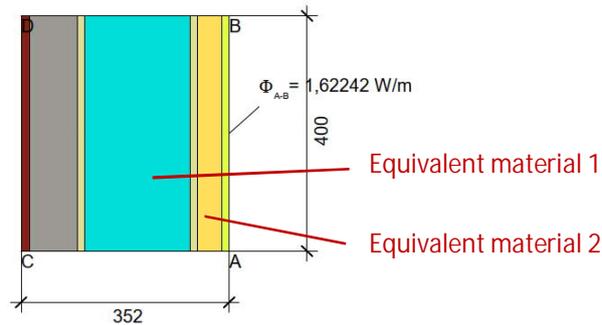


Figure 7 – Adding the timber member

Step 3: Model the wall assembly to planes of symmetry in the vertical plane (see left), using the equivalent material 1 for the main cavity, and adding the horizontal timber member into the service cavity. The U-value will thereby increase.



$$U_{\text{eq}A,B} = \frac{\Phi}{\Delta T \cdot b} = \frac{1,622}{30,000 - 0,400} = 0,135 \text{ W/(m}^2 \cdot \text{K)}$$

Figure 8 – Creating equivalent material 2

Step 4: Create an equivalent material for the service cavity to consider (in this case) the thermal insulation and timber.

This approach has been shown to be accurate to three decimal places when compared with the results of three-dimensional modelling of the same assembly.

It should be noted that the calculated equivalent thermal conductivities are in most cases 'context-specific', i.e. a result of the geometry and physical properties of the complete assembly and a determined value cannot simply be used in alternative assemblies. In such cases the process of equivalent thermal conductivity calculation should be carried out from the beginning.

2. Two dimensional connections with repeating disturbances at the point of connection

There are examples of two-dimensional connections where disturbances are repeating in one assembly or both and the two intersect and overlap, causing a complex detail at the point of connection that cannot be taken into account in a two-dimensional model – an example being the junction between an external wall and a timber roof, where the ends of the roof trusses penetrate the external wall insulation, as below:

In the above case, the thermal bridge effect of this junction is further intensified by the anisotropic properties of wood; at the point of the overhang, there is significant heat flow running in the direction of the fibres. The thermal conductivity of the wood here is then 0,29 W/(mK) rather than 0,13 W/(mK). In order to investigate the influence of this, several variants of this detail were examined within the framework of the EU-financed project UPStraw by means of 3D heat flow simulation.

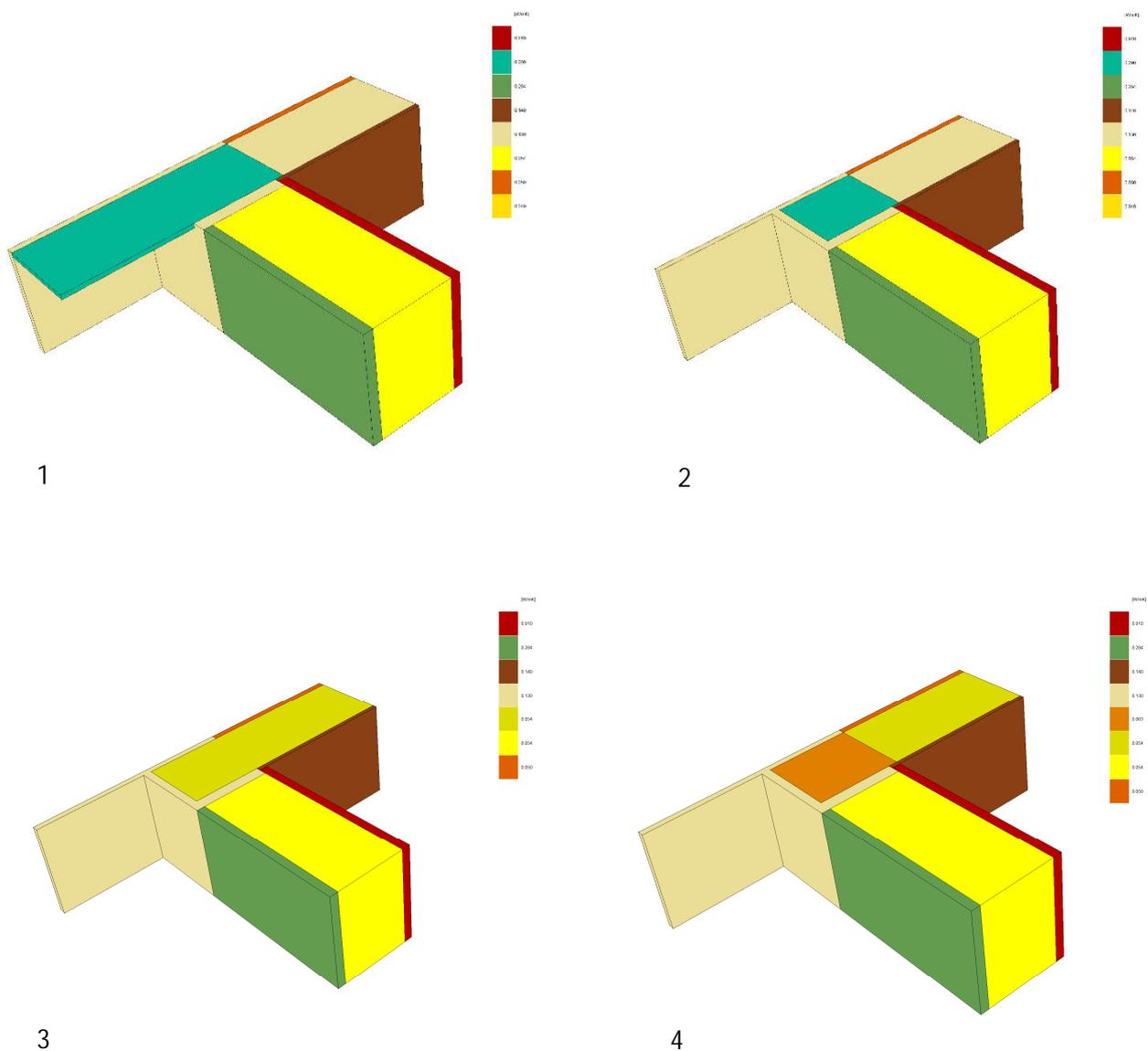


Figure 9 – Modelling of two-dimensional connections with repeating disturbances at the point of connection

In all variants, the wall is constructed from non-load-bearing straw and is assumed to have a U-value of $0.149 \text{ W}/(\text{m}^2\text{K})$. The roof is modelled with a slightly simplified structure and is also insulated with straw, achieving a U-value of $0.131 \text{ W}/(\text{m}^2\text{K})$.

The basic variant (1) is the eaves detail with a flat roof and projecting rafter. The thermal conductivity of the rafter in the area of the wall integration and the projection was set at $0.29 \text{ W}/(\text{mK})$. The flat roof was chosen because it allows a simpler grid to be formed. The linear thermal bridge was determined to be $-0.0661 \text{ W}/(\text{mK})$.

Variant 2 was calculated with the same structure, but without overhang. The linear thermal bridge determined in this way is $0.0662 \text{ W}/(\text{mK})$, which underestimates the thermal bridge by 0.18%. This corresponds to an additional point thermal bridge of the cantilevered rafter of $0.12 \text{ mW}/\text{K}$.

In variant 3, rafters and thermal insulation were substituted by a U-value equivalent material. The resulting thermal bridge of $-0.0696 \text{ W}/(\text{mK})$ underestimates the thermal bridge defined by the reference variant by 5.34%.

In variant 4, another substitute material was introduced in the area of the ceiling integration, which differs from that of variant 3 by the choice of the thermal conductivity of wood with $0.29 \text{ W}/(\text{mK})$. In this configuration the linear thermal bridge is $-0.0647 \text{ W}/(\text{mK})$, thus the thermal bridge is overestimated by 2.06%. This method was used for the 2D calculations and is generally recommended.

3. Point thermal bridges (Chi-values) with regular distribution over the surface of a heat loss element

Point thermal bridges with regular distribution over the area of a heat loss element (external walls/roofs/floors), such as insulation anchors or facade anchors as below in Figure 10, need to be taken into account in the regular U-value:

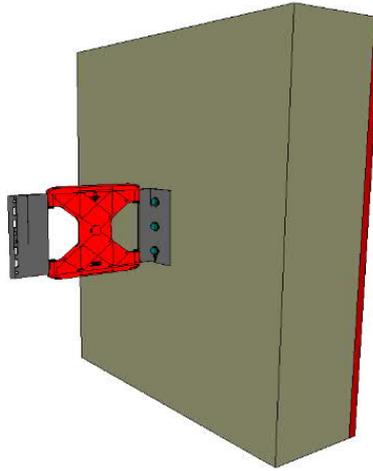


Figure 10 – Three-dimensional image of facade anchor, in this case FOX VT from the manufacturer Hilti Deutschland AG

For these disturbances where there is a definite density (x/m^2 - N.B. this figure can vary according to the location of the anchor on the building, e.g. for high-rise buildings, where the wind load on the upper floors is higher than on lower floors; if in doubt use the most conservative, 'worst case' value), the additional heat loss is considered through calculation of a ΔU (delta-U-value, $W/(m^2K)$) as detailed in ISO 6946, Appendix F, section 3.1. This is done by multiplying the point heat loss coefficient or χ -value (Chi-value, W/K) by the x/m^2 figure to find the surcharge, and then adding this to the U-value of the basic construction.

Please note that when such point thermal bridges feature in construction systems to be certified as Passive House Components, these values must be calculated by PHI unless they are simple EIFS system fasteners, in which case the values in Protokollband 35, Appendix A (available in the German language for purchase from the PHI) can be used, so long as the geometry and materials are comparable.

It is also possible to certify complex, proprietary façade anchors as Passive House components; please see the Passive House Institute website for the most up-to-date criteria. The full set of certified façade anchors, and all certified components, can be found on the Passive House Institute component database at:

<https://database.passivehouse.com/en/components/>

4. Balcony connections using proprietary thermal break products

The intersection between an external wall and a cantilevered balcony is often thermally broken using such products as shown below in figure 11 in order to reduce the linear heat loss coefficient and maintain an adequate interior surface temperature:

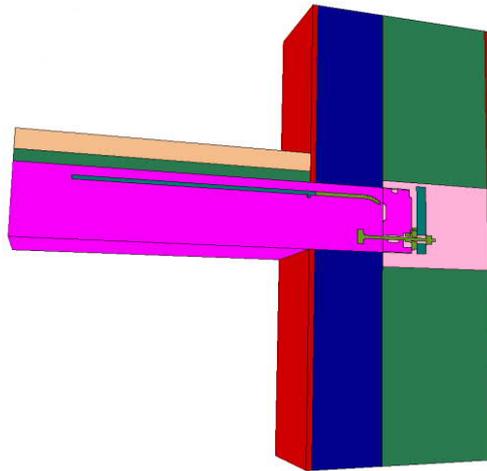


Figure 11 – Three-dimensional image of balcony connection using a thermal break, in this case QS10 180 from the manufacturer Schöck Bauteile GmbH

The thermal performance values are calculated following a similar approach to that described in 3., however due to their complex geometry, for Passive House and certified construction systems looking to use these equivalent thermal conductivities, the values must be calculated by PHI.

A method to establish the equivalent thermal conductivity of such thermal breaks is given in the European Assessment Document EAD 050001-00-0301 (Load-bearing thermal insulating elements which form a thermal break between balconies and internal floors), in order that their effect can be calculated simply using two-dimensional FEM thermal modelling software to EN ISO 6946 EN ISO 10211. This method has been validated by PHI in a study commissioned by Schöck Bauteile GmbH in 2019. Figure 12 below shows how, according to the EAD, the geometry of the thermal break (vertical section) is converted into a simple quadrangle:

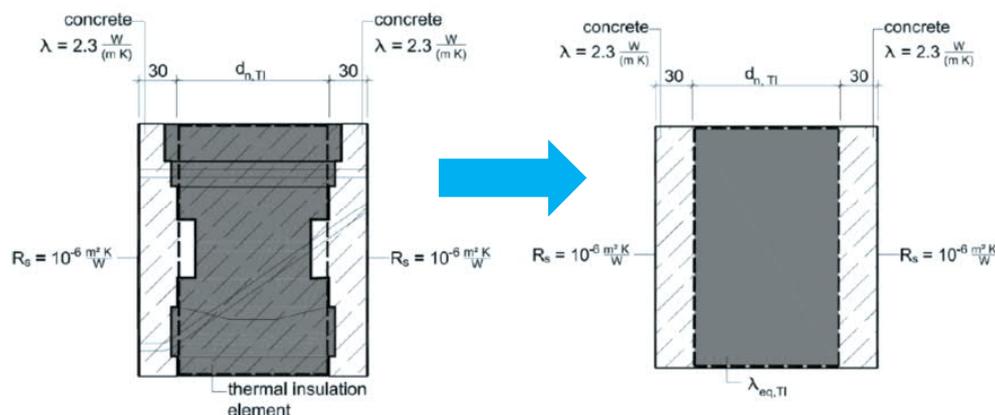


Figure 12 – Substitute model geometry according to EAD for two-dimensional thermal bridge calculation: Original geometry of the balcony element (left) e.g. simplified geometry (right) in between 6 cm concrete blocks.

The following formula can then be used to calculate the equivalent thermal conductivity:

$$\lambda_{eq, EAD} = \frac{\left[\frac{Q_{3D}}{\Delta T * h} \right]^{-1} - R_{se} - R_{si} - R_{con}}{d}$$

Where:

- Q_{3D} = Heat flow from the detailed three-dimensional simulation of the thermal break (see figure 13)
- ΔT = Temperature differential (20 K)
- R_{se} = Outside heat transfer resistance (10⁻⁶ (m²K)/W)
- R_{si} = Inside heat transfer resistance (10⁻⁶ (m²K)/W)
- R_{con} = Thermal resistance of concrete (0,06 m / 2,3 W/(mK) = 0,026087 (m²K)/W)
- h = Height of component (m)
- d = Depth of component (m)

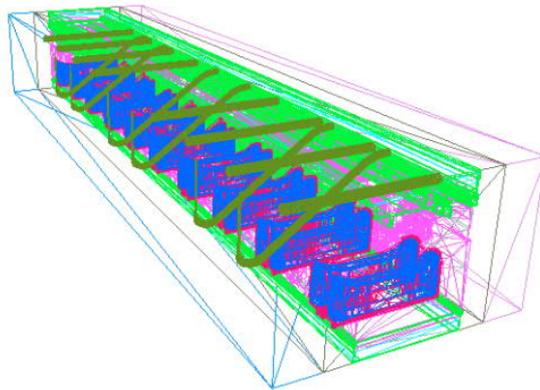


Figure 13 – Example simulation model for determining the equivalent thermal conductivity according to the EAD

The determination of characteristic values according to EAD provides for the use of a construction-independent calculation model, therefore the resulting value can theoretically be used in any assembly to achieve accurate results.

As with façade anchors, it is also possible to certify proprietary thermal breaks as Passive House components. Again, please see the Passive House Institute website for the most up-to-date criteria. Also as previously, the full set of certified thermal breaks, and all certified components, can be found on the Passive House Institute component database at:

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