Calculating linear thermal bridges in Passive Houses with THERM

Who should read this?

In writing this document, I had a reader in mind who was previously trained in the use of THERM, but need to brush up on some of the finer details of thermal bridge modelling/calculations. Some people may have obtained experience with thermal bridge modelling by other means, and may find this document useful as well, but if you are an absolute beginner: this is neither a comprehensive introduction to all things thermal bridges nor a general initiation to using THERM!

What are thermal bridges

For the intelligent use of thermal bride modelling software, we should recap some important concepts. Thermal bridges are gaps in your strategy to keep the temperature of the indoors separated from the outdoors. For thermal bridges to matter, your building envelope needs to be reasonably well insulated. Do not bother with preventing or calculating thermal bridges if the building you are dealing with is poorly insulated. You only need to worry about bridges, if it is otherwise difficult to cross to the other side.

We differentiate between geometrical thermal bridges, that occur due to a larger surface area on the outside compared with the surface area on the inside, as it happens e.g. at exterior corners, and structural, material related thermal bridges, where a material with higher thermal conductivity bridges materials with low thermal conductivity, e.g. a concrete beam in an insulation layer.
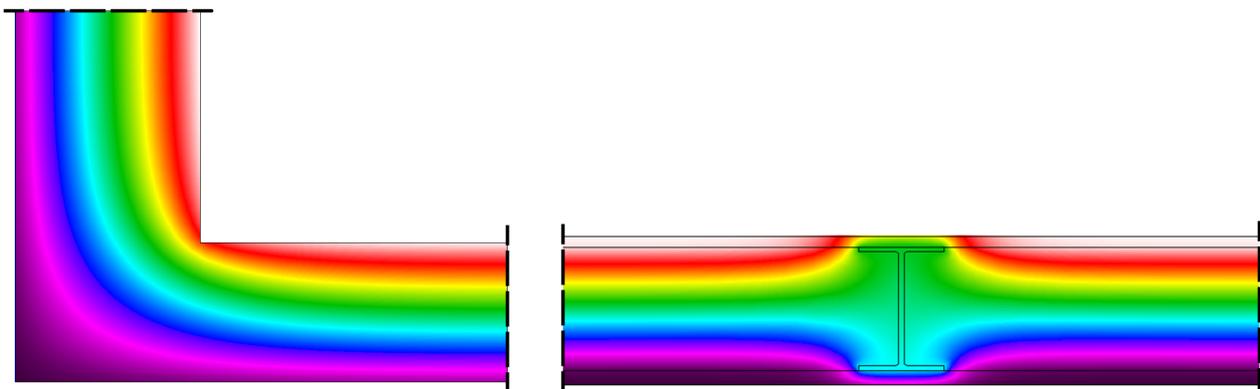

Figure 1: Geometrical thermal bridge (left) and structural thermal bridge (right)

Note: if the material that bridges a typical insulation layer (0.040 W/(mK)) has a thermal conductivity not exceeding 0.250 W/(mK) e.g. timber, the thermal bridge effect will likely be

negligible. This is not to say that the timber content in an insulation layer does not matter. It does for the one-dimensional heat loss, but the additional heat loss at a joint containing such a bridging material will be small.

Apart from linear thermal bridges, which are the topic of this document, punctiform thermal bridges, like wall ties that bridge an insulation layer, may also need to be taken into consideration. Typically, this is done using a Δ U-value that needs to be calculated from data provided by the manufacturer for the product in use, or e.g. for columns penetrating an insulation layer under a floor slab, modelled in 3 dimensions. Punctiform thermal bridging is therefore not further discussed in this document.

Why should thermal bridging be avoided

A thermal bridge is a short-cut for thermal energy. Everyone likes a short-cut, so rather than taking the designed path, heat will take the shortest route to escape to the outside. The consequences of thermal bridges are however more dire than just losing a few kilowatt-hours of warmth: the inner surface around a thermal bridge will get cold, which is why moisture in indoor air is likely to become sufficiently saturated to allow mould growth on these surfaces. If the extent of the thermal bridge is large, e.g. a steel lintel in an otherwise reasonably well insulated wall, discomfort may also be a concern. That is why thermal bridges need to be designed out of well insulated building envelopes.
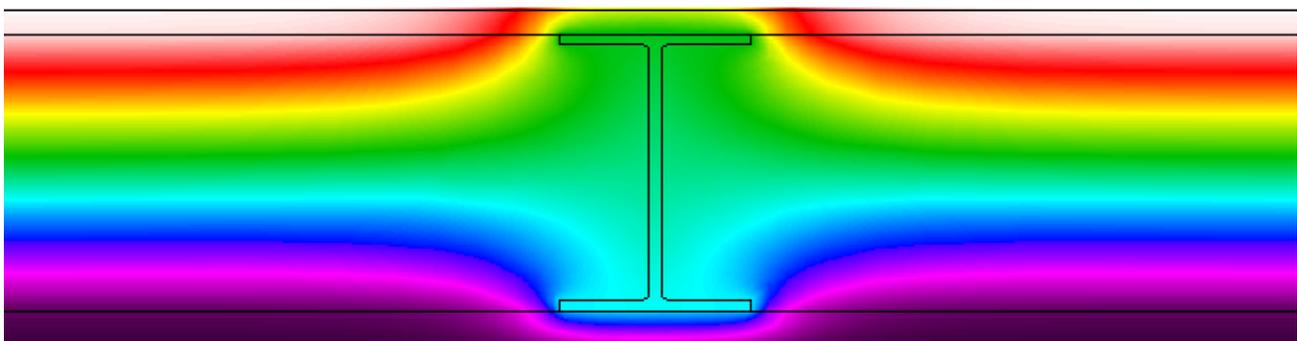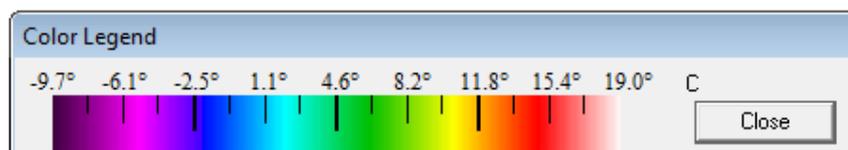

Figure 2: Low interior surface temperatures can be a result of thermal bridging

Ψ-value (psee-value)

The Ψ-value indicates the additional heat loss incurred at linear thermal bridges. This is additional to the one-dimensional heat loss that can easily be calculated using U-values (which may include the impact of regularly occurring thermal bridges, e.g. timber studs in an insulated timber frame wall), and multiplying the thus obtained U-values with the area of building element in question. While U-value calculations give the loss factor for one-dimensional heat flow (from inside-out in one direction), for thermal bridge modelling, you are either looking for the effect of two-dimensional

heat flow (at right angle joints), or the effect of gaps in the alignment of two or more elements you already have data for, e.g. a wall and a window, or the effects of metals or other highly conductive materials bridging an insulation layer, in other words: situations that cannot accurately enough be reflected with U-value calculations alone. Two-dimensional heat flow simulations for linear thermal bridges obtained in THERM are typically accurate enough for Passive House purposes, and three-dimensional models are hardly ever required.

Ψ-value with interior dimensions

If you calculate the one-dimensional heat loss using interior dimensions for the building element, you have to calculate the Ψ-value at every exterior coner of the building to obtain the total heat loss of the building. This is time-consuming and not recommended – but some Building Codes, for example the NZBC, are using internal dimensions nonetheless. Luckily, Passive House does not.

Ψ-value with exterior dimensions

When you use exterior dimensions to calculate the one-dimensional heat loss, as you do for Passive House certification, you are counting exterior corners twice. In doing so, you are likely to slightly overestimate the effect of geometrical thermal bridges. This allows you to forego any thermal bridge calculations at exterior wall corners. You may however perform them to obtain a more realistic assessment of the heat loss at exterior corners. With wide walls, you likely get negative Ψ-value in this case that you may deduct from your calculated one-dimensional heat loss. Note: all thermal bridge values for certification purposes need to be referenced to exterior dimensions!

What is THERM

Let's begin with what THERM is not: it's not a CAD programme. Drawing in THERM is cumbersome. That said: as with everything else, it gets easier with practice. It is a fantastic simulation engine to calculate thermal bridge effects, though. And it is free as in free lunch.

THERM is currently provided by LBNL, but will become open source software next year. There's hope that some developers may invest time to improve the input options as a result. Everything else is pretty good already.

How to use THERM

To model your detail in any thermal bridge software, first of all some abstraction is needed. Thin membranes up to 1 mm e.g. can be left out. Everything beyond internal and external air (e.g. external cladding behind a ventilated cavity, or anything that would not form part of the U-value calculation) can be neglected, too.

As you cannot model in 3D, you usually either slice your joint vertically or horizontally, depending on what you are after.

If you cut vertically, there may be parts of the building element that do not appear in your model (e.g. timber studs in a wall). If the structural members are made of timber, then those inhomogeneous layers can be "homogenised", that is: a material is created that has the thickness and thermal conductivity proportionally of the insulation plus timber in the wall. As an example: if the wall has insulation with a thermal conductivity of 0.040 W/(mK), bridged by timber (0.13 W/(mK)) to 10%, then the homogenised thermal conductivity is 0.040*0.9+0.130*0.1= 0.049 W/(mK).

This new material could be called "homogeneous fill" and be drawn in section between liners.

Irregular timber members, and all timber you cut through, like e.g. bottom plates however would need to be drawn as timber regardless. The extra lintel around a window for example, or any other timber that is not covered with the U-value calculation for the building element about to be joined. A bottom or top plate could be covered in the U-value calculation, but it is cleaner to include timber you directly cut through in your model, and subsequently account for these bits in your U-value calculation.

In a horizontal cut, you would rather draw each stud between insulation instead. You will not see top and bottom plates in this case, or any dwangs. Most likely, though, these can simply be left out of considerations for the thermal bridge.

ISO 10211:2007 requires to extend your model at least to the greater of 1 m and three times the thickness of the flanking element concerned each side of the joint or central element. Should you be interested in the thermal bridge effect of regularly occurring elements at fixed distances, e.g. steel studs in the insulation layer, you can cut your model on the symmetry axis instead. Those instructions apply if your joint borders air on all sides. If one or all of the surfaces of the joint in question border the ground, a large chunk of the ground needs to modelled as well to account for the thermal resistance of the ground.

Surfaces have to get boundary conditions assigned. The film-coefficient (the inverse of the applicable surface resistance) are based on the heat flow direction and values from ISO 6946:2007.

With practice, the easiest way to draw the already abstracted building assembly in THERM is entering coordinates using the number pad on your keyboard. Alternatively, you may underlay a bitmap drawing (carefully check the scale if you do this), or import a dxf drawing. Caveats for the latter: dxf drawings must only contain closed polygons (no fill), and be saved in R12 or R13 version - the import will surely fail otherwise.

The predefined setting in THERM (Options → Preferences) are mostly OK for our purposes. Make sure that you are using SI units, and that the Snap Settings are what you want. The only change you need to make is in the Drawing Options tab: set the drawing size to 5000x5000 mm. This will be large enough for most models bar models with contact to the ground.

Drawing in THERM

Drawing geometry is best done using the num pad of your keyboard. Click somewhere on your drawing board, and key in vectors (in mm) from this point. A Step Size window should pop up as soon as you hit a num pad key.
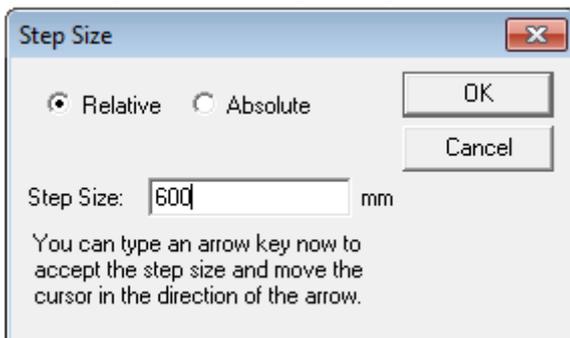
Enter the distance from the previously clicked point (Relative), and using the arrow keys, gives the direction. Confirm with the Return key.

Start by selecting either the polygon or rectangle buttons. With a rectangle, you can enter two values in sequence to fix the far corner. Note: do not use the mouse once you have set the start point, as this will relocate it, and everything will go pear-shaped!

Figure 3: Step size window

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Entering materials

THERM comes with a pre-populated material library. None of the values in there are of much use to us. It is therefore advisable to create a new material library. Start by renaming the old material.lib in your THERM folder into material_LBNL.lib. THERM will complain when you try and start it without the material.lib, but do not worry, things will work out.

Now create your own material.lib, starting with some generic materials and their thermal conductivities, as suggested in the PHPP manual:

Table 1: Selected thermal conductivities from the PHPP manual

Material	Thermal conductivity (W/(mK))
Concrete (reinforced)	2.1
Rubber	0.17
Carpet	0.06
Linoleum	0.17
Float glass	1
Aluminium	160
Mild steel	50
Stainless steel	17
Gypsum plasterboard	0.25
Cement screed	1.4
Sand-lime masonry	1
Softwood	0.13
Hardwood	0.18
Oriented strand board (OSB)	0.13
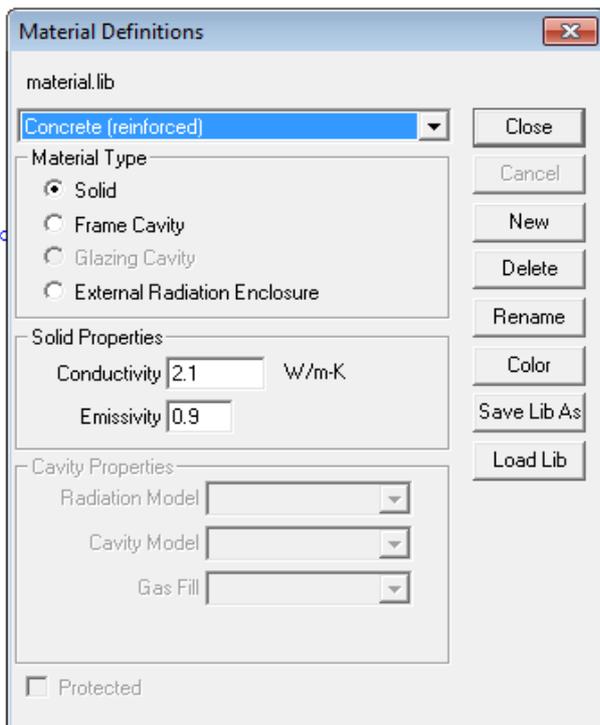
You will find a few more materials in the PHPP manual, but they are given with a range of thermal conductivities, so you will need to obtain applicable values for the materials that you intend to use from their manufacturers.

Creating a new material is easy: go to Libraries →Material library (or Shift+F4), click New and enter the values from the table above. The Emissivity will nearly always be around 0.9. You can use this as a default. Click on Color to associate a memorable color with the material and then Save Lib As material.lib.

Quickly draw a rectangle and select it. The drop-down menu at the top right should now offer you the new material.

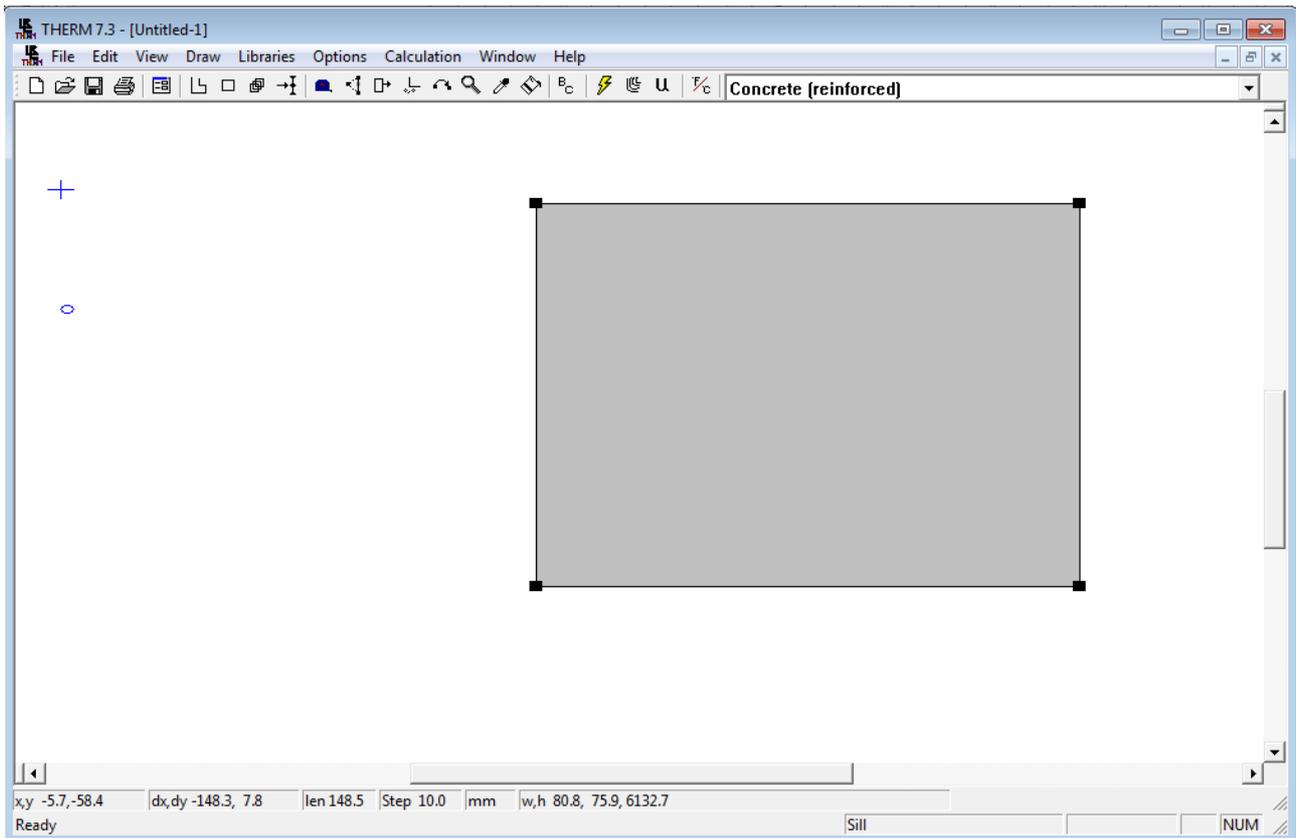*Figure 4: Create a new material in the Material Library*

Figure 5: Assign the new material with the drop-down menu

Boundary conditions

After you have finished drawing your geometry, you need to give THERM an indication of the heat flow direction. You do this by assigning boundary conditions. THERM comes with a library for these, but as with the material library, the pre-defined boundary conditions are unfit for our purposes. Rename the BC.lib into BC_LBNL.lib, and create your own BC.lib. The model to use is for our purposes always: Simplified.

Table 2: Suggested boundary conditions

Condition	Film coefficient (W/(m^{2}K))	Temperature (°C)
Exterior air	25.000	dtl
Exterior, ventilated	7.692	dtl
Exterior, ground	99999.000	dtl
Interior, horizontal	7.692	22
Interior, upwards	10.000	22
Interior, downwards	5.882	22
Interior, mould (all heat flow directions)	4.000	22
dtl = design temperature location; this can be obtained from cell BR14 in the Windows worksheet.		

Note: the film coefficient has to be the inverse of the surface resistance you use for your one-dimensional calculations. For Ψ-value and fR$_{si}$ calculations, it does not matter how temperatures

are set exactly, as long as there is a gradient, but temperatures as above for either case can be used. Obviously, if you perform fR_{si} calculations with the surface temperature obtained, you need to use exactly the same outdoor temperature that you used in your model in the fR_{si} formula. The mould film coefficient should not be used to determine the Ψ-value or comfort temperatures. Its use is exclusively for fR_{si} calculations, that is: to find interior surface temperatures.

Boundary conditions are assigned after you click the BC button. By default, all surfaces are set to adiabatic, but you only want this condition at your cut-off planes. Click other surfaces to assign your predefined boundary conditions.

To determine Ψ-values

The Ψ-value is what's left over once you deduct from the total heat loss of your model the heat loss that you have already accounted for by multiplying the U-value with the area of the building element. As Passive House uses exterior dimensions, and therefore counts corners twice, this "added" heat loss may occasionally be negative.

The total heat loss for your model can be obtained from THERM as a U-factor, but only after you have tagged surfaces appropriately.

To do this, you need to first trim another library: the UFACTOR.lib. To this, this it is easiest to simply add tags you want, and delete tags you do not need.

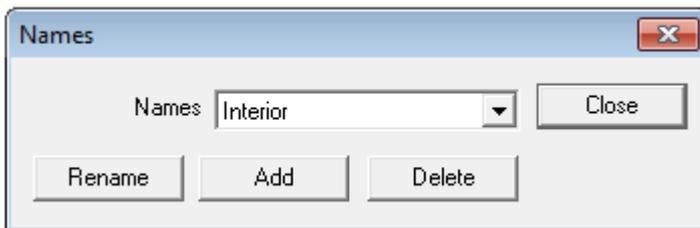Go to Libraries → Ufactor Names. This window pops up:

Figure 6: Add new U-factor tags

Click on Add, and type *Interior* in the next window. Confirm with OK. Repeat and type *Exterior*.

Delete all other names, and close. Occasionally, it makes sense to add other tags, but most situations should be covered with only two.

To avoid confusion: if you tag all interior and exterior surfaces, then the relevant U-factor multiplied by the total length of surfaces should be exactly the same. It is therefore not necessary to go with exterior surfaces in this instance, which means you can apply tags to the least number of surfaces (see Example 2). Remember, though, that the one-dimensional heat loss that you obtain by multiplying the U-values in PHPP with the applicable area of the building element will always be based on exterior dimensions.

One more important point: the U-value calculated for heat loss in PHPP and the U-value calculated to subtract the one-dimensional heat loss from the resulting total heat loss of the joint in your THERM model will likely not be the same, unless all layers of your building element are homogenous. That is because for inhomogeneous elements, you need to make a decision where to cut, and it would be comparing apples with oranges if you do not give THERM the opportunity to consider elements (as they are not drawn) that will need to be considered as regular thermal bridges in your one-dimensional heat loss calculations. The U-value calculation for obtaining the

Ψ-value must be in line with how you would calculate with only the parts drawn in THERM in your building element.

To recap: the Ψ--value accounts for linear heat loss, that is the extra heat loss occurring at the line where your building elements are joined. As the unit is W/(mK) it needs to be multiplied with the length of the joint, that is the extension along the X-axis for joints modelled in section, and the extension along the Y-axis for joints modelled in plan view.

Joints in contact with air

How your model needs to look depends on the central element you are after. If you are concerned about an internal floor that terminates in an external wall e.g. you cut through the wall along the Y-axis, and you get a wall section. For some situations, e.g. an assessment of a window in a wall, you will need both, cut along the Y and X axes.

Let's do a few examples. For all examples we go here with 22°C interior air temperature, and 0°C exterior air temperature.

Example 1: Intermediate floor in timber frame wall

7 mm plywood, 0.17 W/(mK)
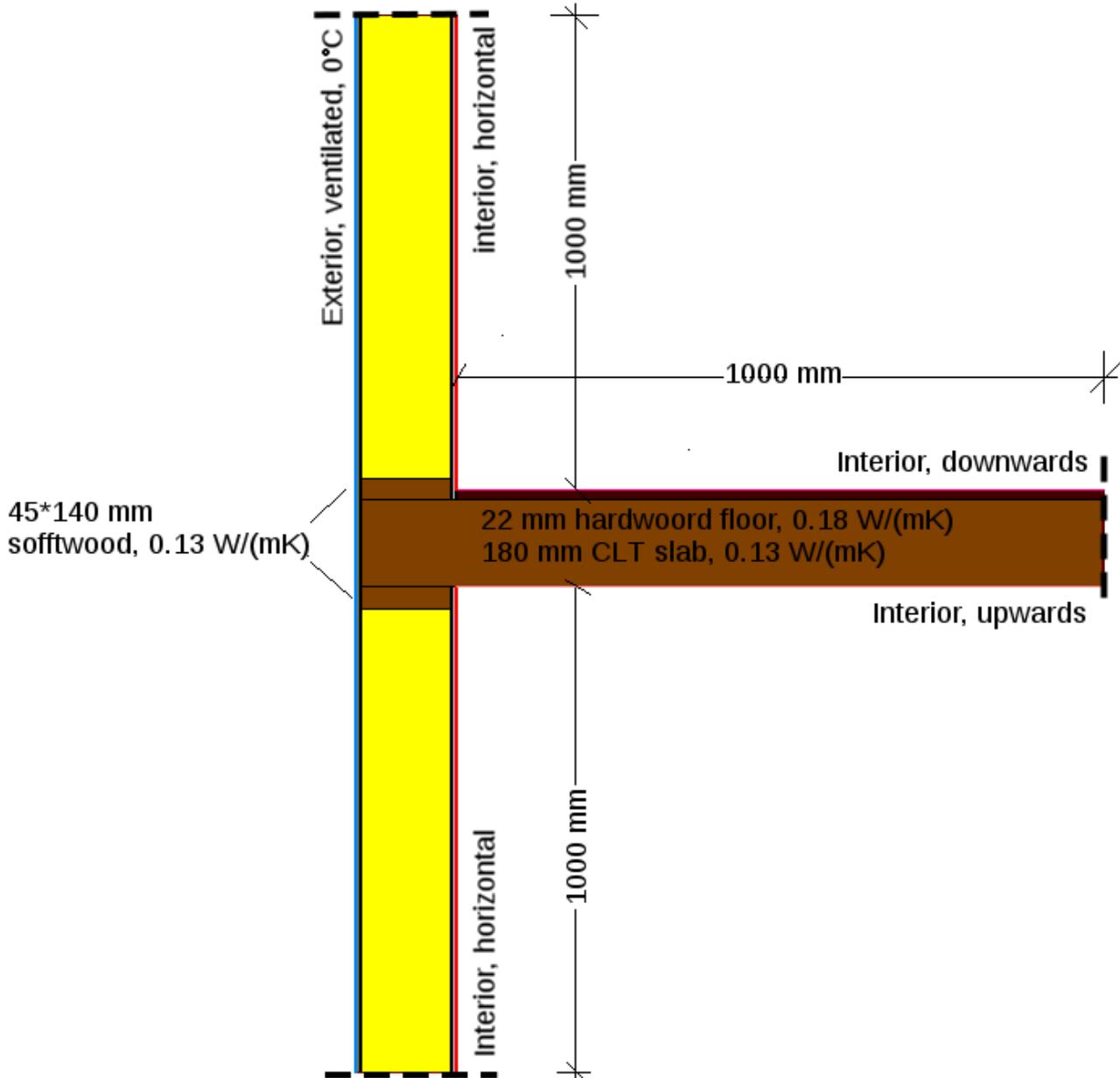140 mm insulation, 0.040 W/(mK)
10 mm gypsum plasterboard, 0.25 W/(mK)

Exterior, ventilated, 0°C

interior, horizontal

1000 mm

1000 mm

Interior, downwards

45*140 mm sofftwood, 0.13 W/(mK)

22 mm hardwoord floor, 0.18 W/(mK)
180 mm CLT slab, 0.13 W/(mK)

Interior, upwards

Interior, horizontal

1000 mm

Figure 7: Model intermediate floor

This is our model. A solid timber slab in a timber frame wall. What we cannot see in this section are the studs. They are 45 mm wide and at 600 mm centres. Our homogenised cavity layer therefore has a thermal conductivity of (0.040*(600-45)+0.13*45)/600 = 0.047 W/(mK).

The U-factor tag *Exterior* was assigned to the *Exterior, ventilated* boundary condition. As a result, we obtain a U-factor of 0.3418 W/(m²K) from THERM, after calculating ⚡ , and clicking on the U button.
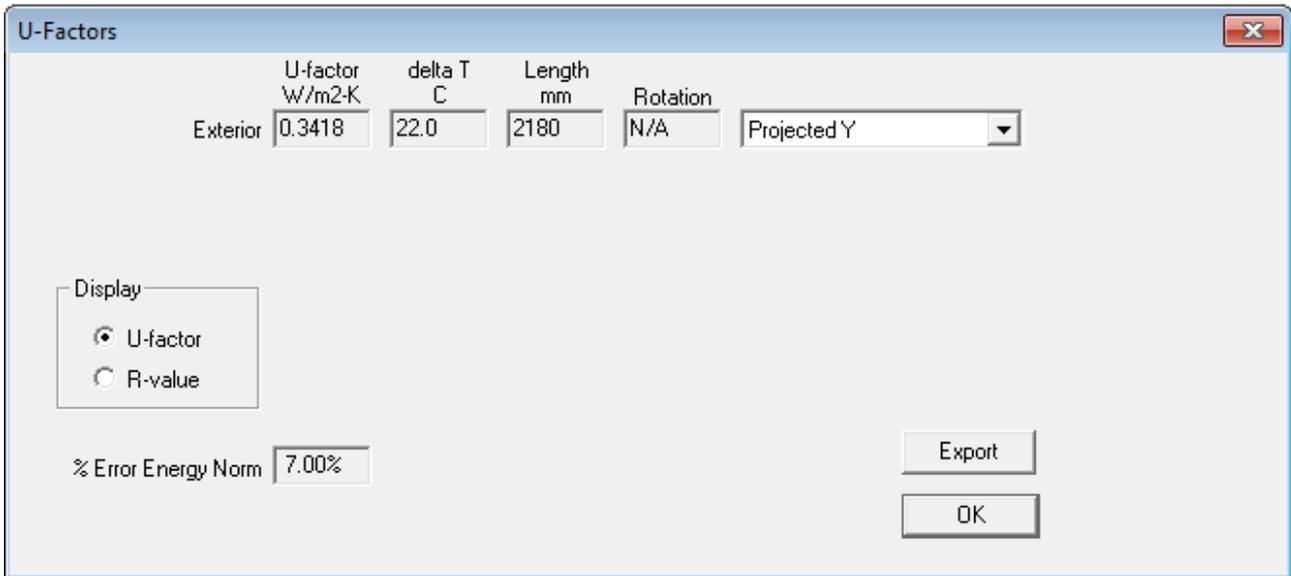
Figure 8: Obtaining the U-factor

There is no other logical option here but to look at heat flow through the Y-axis, so Projected Y is exactly what we are after.

We have to multiply the U-factor with the length (in m) to arrive at L_{2D}, the thermal coupling coefficient from two-dimensional calculation. 0.3418 W/(m²K)*2.18 m = 0.7451 W/(mK).

Now we need to deduct from this the U-value of the wall, or the heat loss we already knew – sort of.

*Table 3: Wall composition for intermediate floor model*

The top and bottom plates of the wall are regarded as parts of the regular wall construction. They have a proportion of 90/2180mm, or 4.1%.

The resulting wall U-value is 0.319 W/(m²K). Multiplied by the length of our wall using exterior dimensions, we get 0.319 W/(m²K)*2.18 m = 0.6954 W/(mK). 0.7451 W/(mK) - 0.6954 W/(mK) = 0.0497 W/(mK), which is our Ψ-value. This is what our U-value calculation has not told us about

heat loss through the wall. If we multiply this value with the length of the joint, we get the additional heat loss.

What if the floor was not solid timber? We would have to cut through it, using an homogenised value for the fill between the flooring and plasterboard below. If there is no insulation between the joists, the air in there can likely not be assumed as stagnant – things get complicated. To avoid this complication in the calculation of the Ψ-value - and thermal bridging, put insulation between the joists at the perimeter of the floor.

Example 2: Protruding wall corner
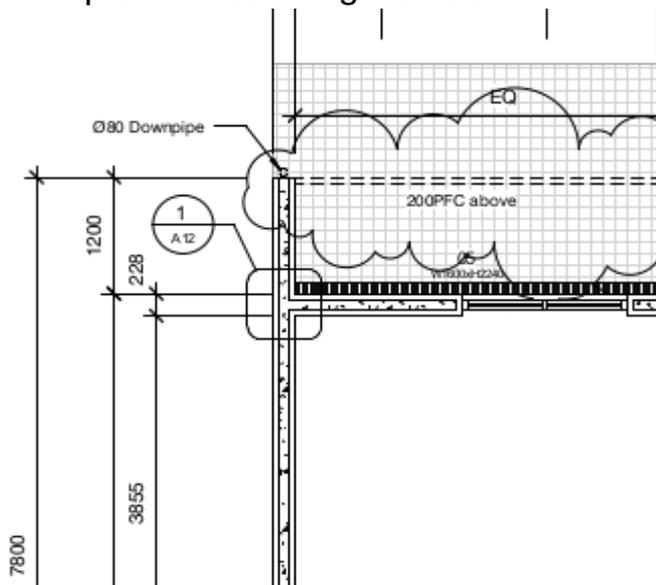
This is our situation, a wall that protrudes using insulated concrete form construction. There is no insulation at the head of the protruding wall. Is this a concern?

Figure 9: Protruding wall in plan

This is the wall construction:

Table 4: Wall composition for protruding wall model

Component Nr.	Component Label
2	ICF Wall

Internal Surface Resistance R_{si}: 0.13 m²K/W

Range 1	Range 2	Range 3	Thickness d in mm	Range 1	Range 2	Range 3
1. Gypsum plasterboard			10	0.250		
2. Expanded polystyrene			65	0.038		
3. Concrete (reinforced)			100	2.100		
4. Expanded polystyrene			65	0.038		
5. Exterior render			10	0.700		
6.						
7.						
8.						
9.						

(Thermal Conductivity λ in W/(mK))

Thickness of Component: **250 mm**

Thermal Resistance of Unheated Space (e.g. Roof Space) R_u:

Area Ratio: 100.00%

External Surface Resistance R_{se}: 0.04 m²K/W
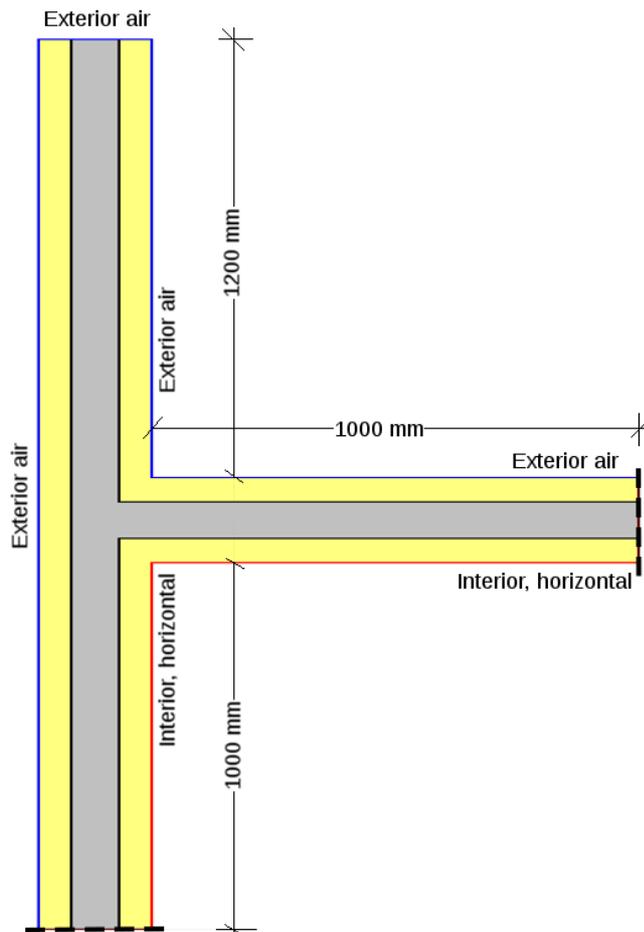
This is our model:

Figure 10: Model protruding wall

The U-factor tag *Interior* was assigned to the *Interior, horizontal* boundary condition. In this case, we are after Total length of the surfaces tagged *Interior*. As a result, we obtain a U-factor of 0.3179 W/(m^{2}K) from THERM, after calculating, and clicking on the U button.

We have to multiply the U-factor with the length (in m) to arrive at L$_{2D}$, the thermal coupling coefficient from two-dimensional calculation. 0.3179 W/(m^{2}K)*2.00 m = 0.6358 W/(mK).

Now we need to deduct from this the heat loss we already accounted for in PHPP. The U-value of the walls is 0.271 W/(m^{2}K), and the length we assigned to this in PHPP (remember: external dimensions!) was 2.50 m.

0.271 W/(m^{2}K)*2.50 m = 0.6775 W/(mK). 0.6358 W/(mK) - 0.6775 W/(mK) = -0.0417 W/(mK). This is the amount we overestimated the thermal bridge for, using exterior dimensions in PHPP. We may deduct this, multiplied by the height of this joint, from our overall heat loss.

Example 3: Window – wall joint

Ideally, you want to model a window-wall joint using the actual window, and some manufacturers provide you with windows to import into THERM. What if your manufacturer does not? You work with abstractions.

Abstraction number 1: the glass will have little impact on the window-wall joint thermal bridging, so we assume our window to be all frame. Abstraction number 2: the frame will have a distinct geometry, and may be constructed from extrusions. We assume it to be a rectangular board. The material of this board will have a thermal conductivity that reflects the U-value of the frame. The thickness of the board is the actual thickness of the frame.

Assume the U-value of the frame is known to be 1.10 W/(m^{2}K). The thickness of the frame is 75 mm. 1/1.1 W/(m^{2}K) = 0.909 m^2 K/W, which is the R-value of the frame. We need to deduct the surface resistance from this, as it is included in the frame U-value. 0.909 m^{2}K/W -0.04 m^2 K/W -0.13 m^{2}K/W = 0.739 m^{2}K/W. 0.075 m /0.739 m^{2}K/W = 0.102 W/(mK), which is the thermal conductivity of our equivalent board.

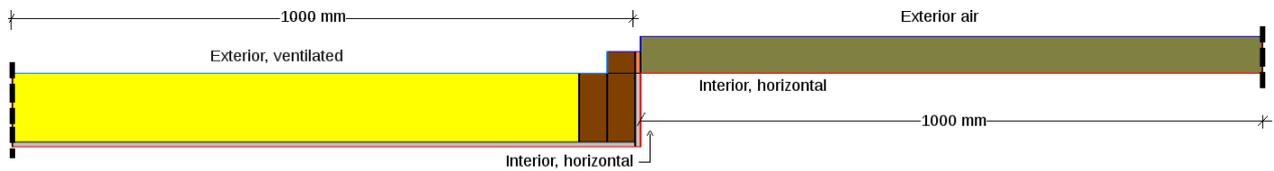This is our model – there is a 10 mm of expanding foam (0.040 W/(mK) between the batten and the window:

Figure 11: Window-wall model

The U-factor tag *Interior* was assigned to the *Interior, horizontal* boundary condition. In this case, we are after Projected X of the surfaces tagged *Interior*. As a result, we obtain a U-factor of 0.7482 W/(m^{2}K) from THERM, after calculating, and clicking on the U button.

We have to multiply the U-factor with the length (in m) to arrive at L$_{2D}$, the thermal coupling coefficient from two-dimensional calculation: 0.7472 W/(m^{2}K)*2.01 m = 1.5038 W/(mK).

Table 5: Wall composition for window-wall model

Now we need to deduct from this the heat loss we already accounted for in PHPP. The U-value of the wall is 0.286 W/(m^{2}K), and the length that applies to it is 1.00 m – with exterior dimensions, we would not have counted the gap filled with expanding foam as part of the wall. Note: the second stud is not part of the regular wall construction. It forms part of the thermal bridge. The U-value of the window is 1.10 W/(m^{2}K) and the length of the window is 1.01 m – the expanding foam is part of the window opening in our plan view. Considering all this we get: 0.286 W/(m^{2}K)*1.00 m = 0.286 W/(mK). 1.10 W/(m^{2}K)*1.01 m = 1.111 W/(mK). 1.5308 W/(mK) - 0.286 W/(mK) – 1.111 W/(mK)= 0.1069 W/(mK), which is a significant thermal bridge!

Joints in contact with the ground

When modelling thermal bridges in contact with the ground, the ground needs to form part of your model. As such, you always cut along the Y-axis.

There are two options to approach this task: A) model the joint as is, and deduct one-dimensional heat loss taking the added resistance of the ground into account in the U-value of the element bordering the ground (you can pick this from the Ground worksheet in PHPP), or B) doing a two-step model. In the second step, the the U-value of the slab including the influence of the ground is modelled separately. Typically, this is the easier option. It also allows for changes in the geometry of the elements in contact with the ground. For example, if your building gets a bit thinner in the end, the otherwise obtained U-value to method A) of our slab will be not longer valid.
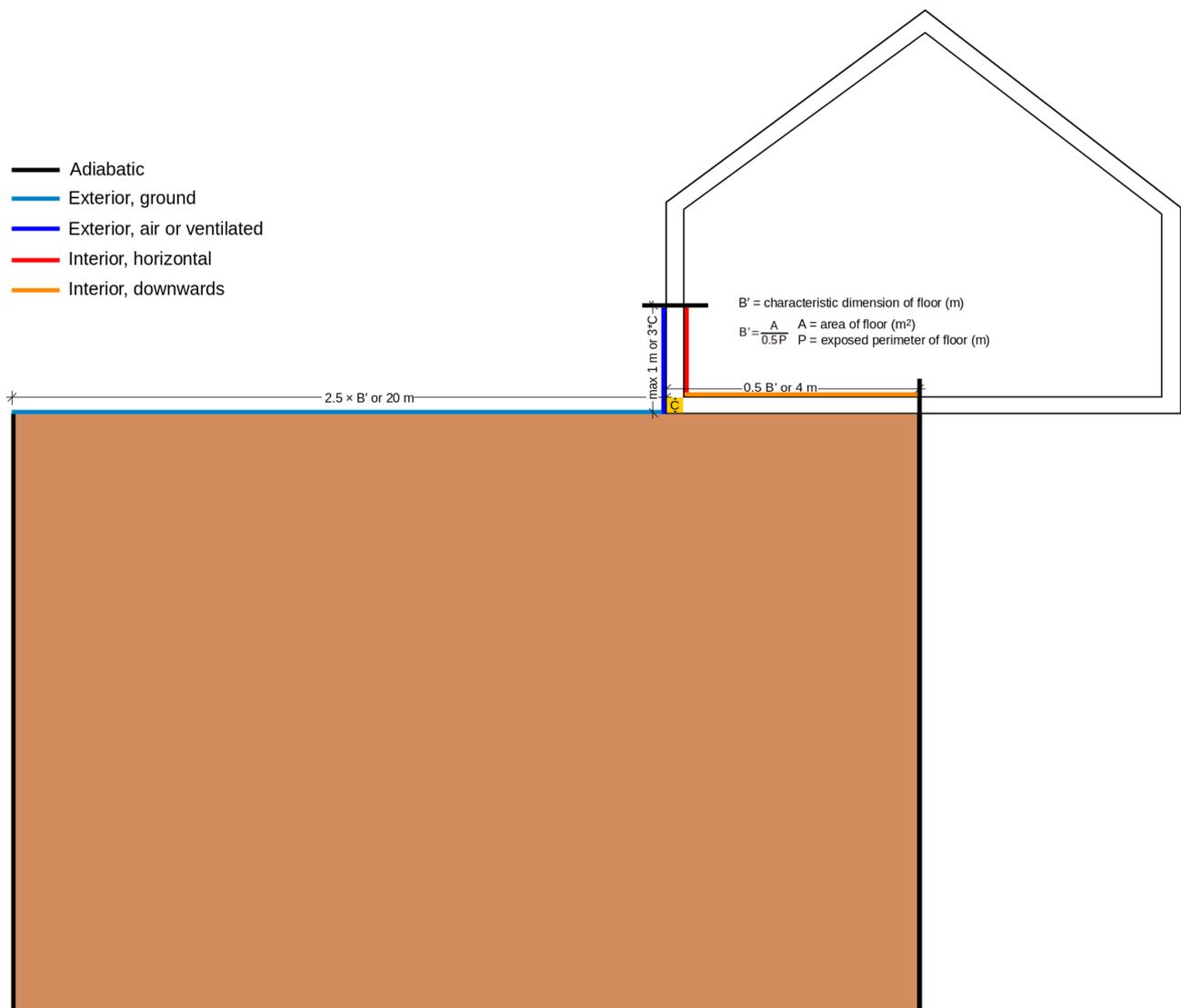
This is the general model:

Legend:
- Adiabatic
- Exterior, ground
- Exterior, air or ventilated
- Interior, horizontal
- Interior, downwards

B' = characteristic dimension of floor (m)

$$B' = \frac{A}{0.5\,P}$$

A = area of floor (m^2)
P = exposed perimeter of floor (m)

2.5 × B' or 20 m

max 1 m or 3°C

0.5 B' or 4 m

Figure 12: Modelling thermal bridges with ground contact

Note: deviating from ISO 10211:2007, all dimensions are taken to be from the exterior faces of the model to be congruent with the general PHPP approach. The thermal conductivity of the ground is assumed to be 2.0 W/(mK), which fits sand or gravel, unless better knowledge of the exact soil composition allows to narrow it down, e.g. 1.5 W/(mK) for clay or silt, and 3.5 W/(mK) for

homogenous rock.

Method A calculations require that the building's dimensions are fixed, and a result can be obtained from the Ground worksheet in PHPP; we are therefore doing a method B example in the following.

We are starting by modelling the situation as above.

Here are the U-value calculations for the wall and floor (without effect of the ground).

Table 6: Wall composition for wall-floor joint

Component Nr.	Component Label				
4	Wall for floor joint				

Internal Surface Resistance R_{si}: 0.13 m²K/W

	Range 1	Range 2	Range 3	Thickness d in mm	Thermal Conductivity λ in W/(mK) Range 1	Range 2	Range 3
1.	Gypsum plasterboard			10	0.250		
2.	Homogenised fill	Top/bottom plate		140	0.047	0.130	
3.							
4.							
5.							
6.							
7.							
8.							
9.							

Thickness of Component: **150 mm**

Thermal Resistance of Unheated Space (e.g. Roof Space) R_u :

Area Ratio: 95.50% | 4.5%

External Surface Resistance R_{se} : 0.13 m²K/W

Table 7: Floor composition for wall-floor joint

Component Nr.	Component Label				
5	Floor for wall joint				

Internal Surface Resistance R_{si} : 0.17 m²K/W

	Range 1	Range 2	Range 3	Thickness d in mm	Thermal Conductivity λ in W/(mK) Range 1	Range 2	Range 3
1.	Concrete (reinforced)			150	2.100		
2.	Foam glass			100	0.045		
3.							
4.							
5.							
6.							
7.							
8.							
9.							

Thickness of Component: **250 mm**

Thermal Resistance of Unheated Space (e.g. Roof Space) R_u :

Area Ratio: 100.00%

External Surface Resistance R_{se} :

As always, thin membranes are disregarded. The reason a membrane is mentioned for the insulation under the slab is that the thermal conductivity for insulation material in direct contact with the ground must be assumed higher, as water may get in between the boards.

As we are not yet certain about the exact geometry of the floor, we simply go with 4 m for our cut-

off plane. The extend of the ground is therefore 20 m down from the cut-off plane, and 20 m to the left from the outer wall surface. Make sure that your drawing board fits these extensions!

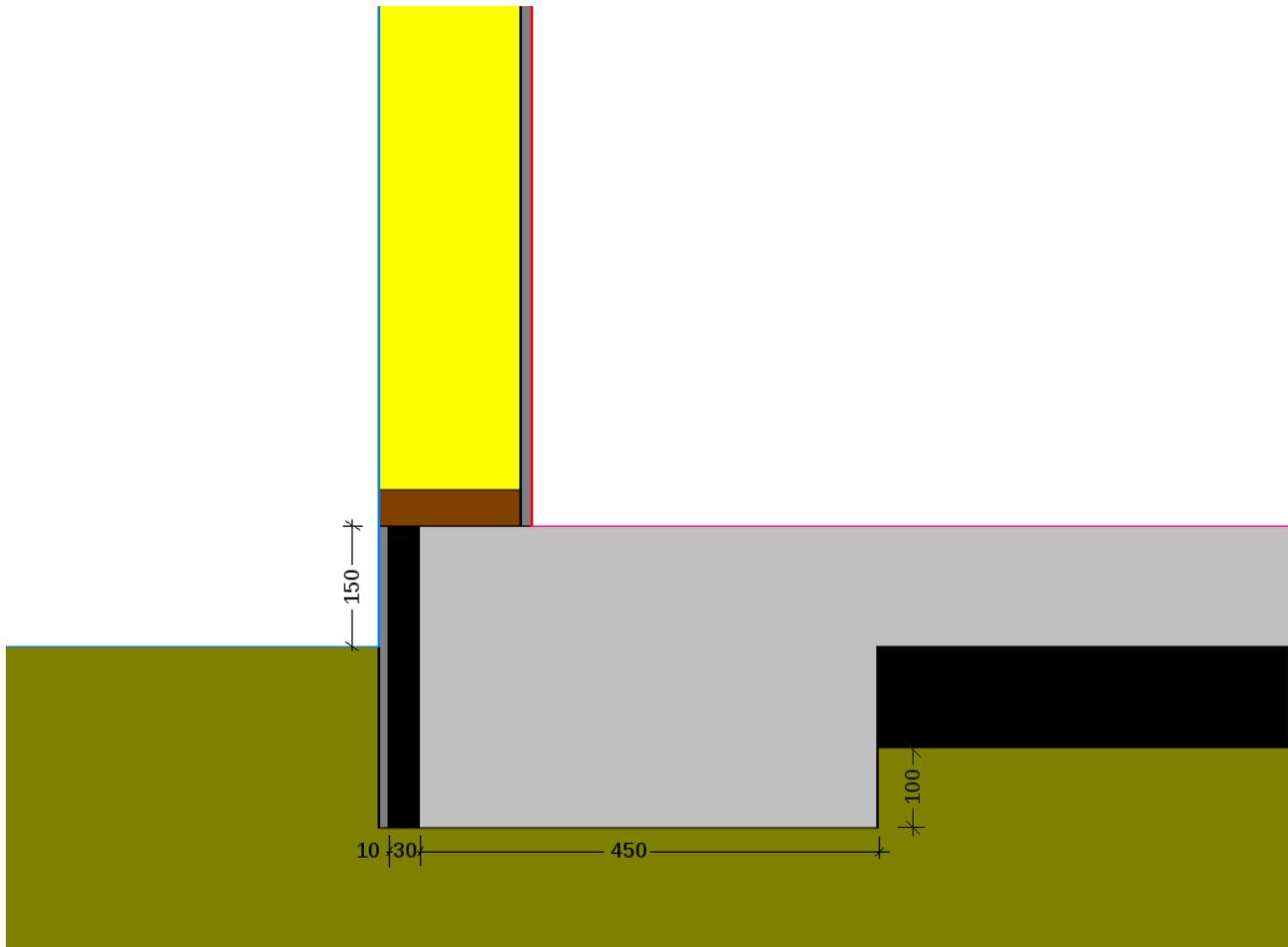This is our situation, zoomed in on the central element:

Figure 13: Zoomed-in wall-floor model

There is a 30 mm foam glass board at the perimeter of the foundation, protected by 10 mm of resinous render (0.70 W/(mK)). The bottom plate has again a height of 45 mm. The wall extends 1 m from the floor. All other dimensions can be taken from the U-value calculations. The full model needs to be in line with the instructions in Figure 14. The ground needs to extend 20 m below the insulation and 20 m to the left of the render. The wall was assumed to have a ventilated cavity exterior of it, but the render is directly exposed to air.

The U-factor tag *Interior* was assigned to the *Interior, horizontal* and *Interior, downwards* boundary conditions.

Referenced to Total length, we get a U-factor of 0.3768 W/(m^{2}K). Multiplied by the applicable length of 4.85 m we get 1.8275 W/(mK) as our L_{2D} result. It is easy to deduct the loss through the wall from this, but to know the loss through the floor, we need to consider the effect of the ground.

To do this, we can model our slab as a film coefficient on the ground. Even if the floor slab is not strictly on the same elevation line as the ground, we can assume it for this step to sit directly on the ground, as PHPP does the same for further calculations. The film coefficient we assume instead of the slab is the U-value of the floor, in our case 0.406 W/(m^{2}K).

We need to create a new boundary condition. You may call this "Slab for Method B". The temperature is set to 22°C again, and the film coefficient to the previously calculated U-value of the slab. The only other boundary condition we need to set is for the remainder of the ground surface. This shall be *Exterior, ground* again.

The U-factor tag *Interior* was assigned to the *Slab for Method B* boundary condition. The U-value for Total length is 0.2521 W/(m^{2}K) with an applicable length of 4 m (this includes the wall thickness - remember: exterior dimensions).

Now we have all ingredients for the Ψ-value calculation: the wall U-value is 0.336 W/(m^{2}K)*1.25 m (to underside of foam glass) = 0.420 W/(mK). The slab is 0.2521 W/(m^{2}K)*4.00 m = 1.008 W/(mK). 1.8275 W/(mK) - 0.420 W/(mK) – 1.008 W/(mK)= 0.3995 W/(mK), which is a significant thermal bridge!

Version 1b: 12 October 2016, Dr Kara Rosemeier

Please send any suggestions for improvement of this document to study@phanz.ac.nz.

You can learn more about Passive Houses and thermal bridge calculations by taking a course at Passive House Academy New Zealand: www.phanz.ac.nz