The “Insulated” Slab Edge Discontinuity

An “insulated” slab edge detail showing the 50mm of XPS (arrow) below the termimesh that has been parged to the slab edge below the base plate of the timber frame.

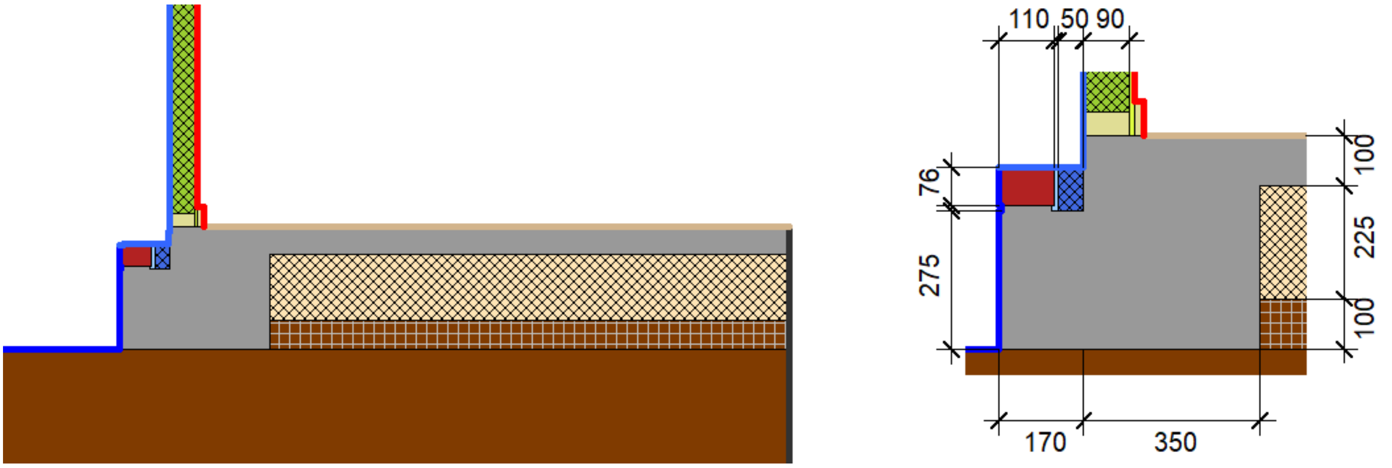
This is insulated in theory but actually achieves essentially nothing in reality. This is particularly the case when used with the also (essentially) uninsulated waffle pod slab.

The 2D heat flow analysis demonstrates just how poorly this slab and slab edge detail performs and it is not adequate in the cold climate of Canberra to avoid a high risk of mould in this corner.

I have assumed the use of a waffle pod with voids rather than solid, although there is actually very little difference in the performance. Either way this slab is not even close to being adequate insulated for this climate, even taking into account the reduction in heat loss to the ground.

The effective R value when all of the concrete beams that are formed in the voids between the pods are accounted for is actually only R0.41(m^2K)/W. Even though it is made with EPS which has an excellent thermal conductivity of as low as 0.032W/mK the concrete beams which only has a thermal conductivity of 2W/mK derates the whole slab (pods and beams) value.

A clearer view of the insulation relative to the slab edge with XPS (arrow) exposed.



The cross-sectional model of the "insulated" slab and slab edge showing timber frame wall, brick veneer wall and, slab with the waffle pods, fill and ground.

A close up of the detail.

In this case the wall will be constructed with insulation in the timber frame and a ventilated cavity between this and the brick veneer with no additional insulation to adjoin the XPS against the slab edge.

This may reasonable for most climates in Australia but not appropriate for the cold climate that this house is built in (Canberra).

We will start to see why I make this statement but be warned it is a little less intuitive (don’t worry it is to professionals involved in this work as well) than previous papers and a lot more involved in understanding the differences that I am outlining. You will have to read it more than once.

This is between an appropriately insulated slab construction for cold climates against what the legal minimum the NCC allows and the reality of how it actually performs. This is not able to be meaningfully accounted for in the NatHERS energy model (other than nominally 0.2 Star improvement) as it is never modelled to understand if it actually is worth the cost.

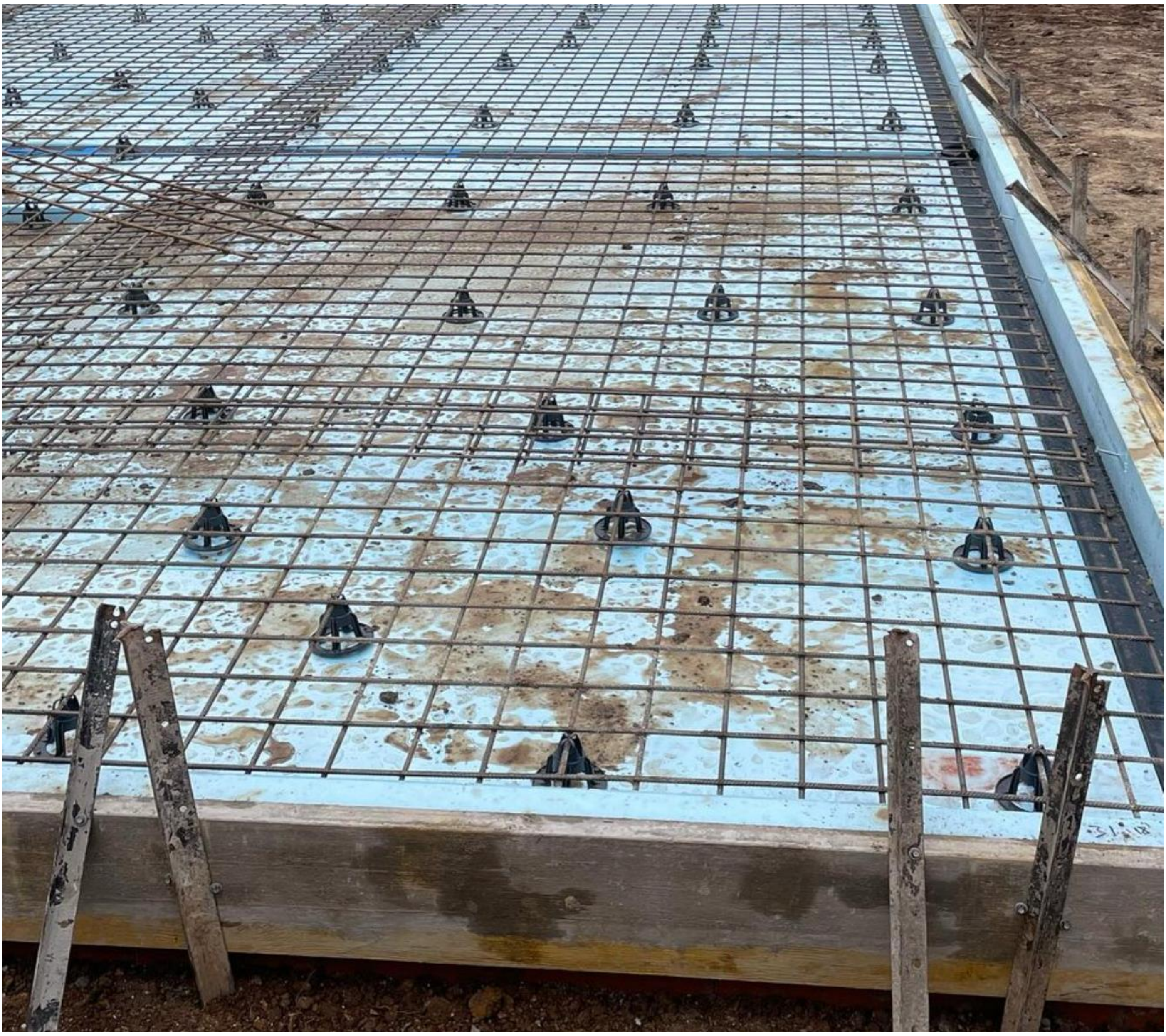
An appropriate detail for a thermally broken slab and slab edge in Canberra.

This detail uses Foamglas (black) as the load bearing thermally broken connection of the wall to the footings and is rated at >600kPa. This material is 60% recycled glass content and achieves a thermal conductivity of 0.041W/mK. The blue material is XPS and achieves a thermal conductivity of 0.033W/mK and is rated to 350kPa of compressive load. This is a Passivhaus suitable slab detail for Canberra.

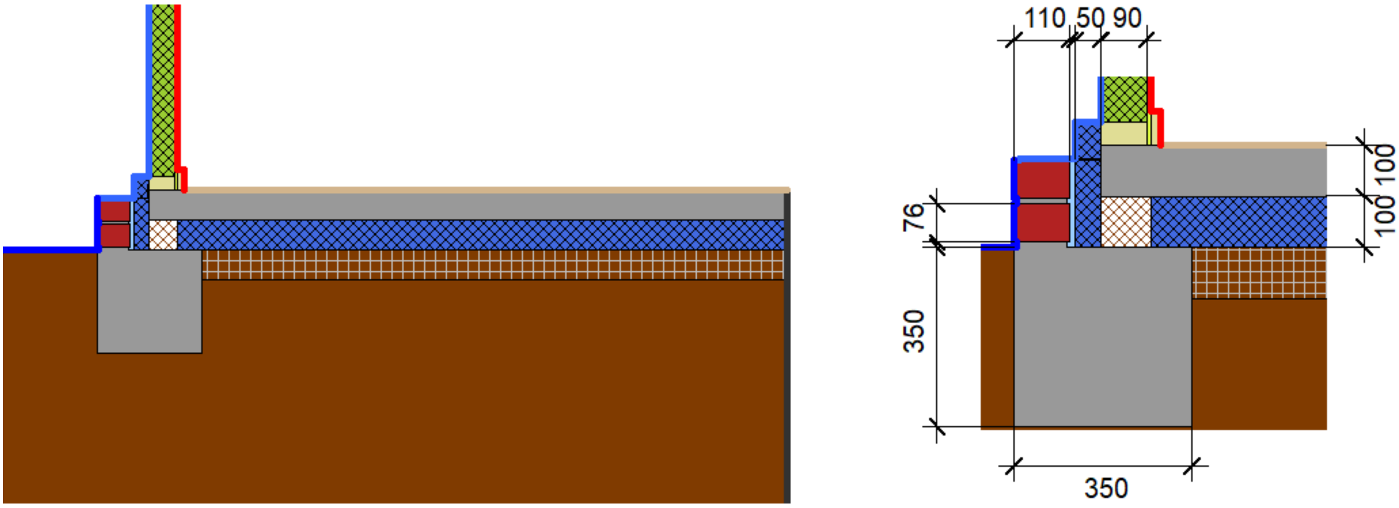
By comparison the brick, mortar and concrete all have a thermal conductivity of around 2.000W/mK, that is the heavy thermal mass material is some 50-60 times more thermally conductive.

Or to put it more clearly these concrete and clay materials are not at all useful in terms of insulation. They are useful as a floor material, and if left uncovered provide some useful thermal mass to buffer temperature extremes.

If you don’t allow the temperature to move outside of a comfortable zone then there is little benefit gained from this exposed thermal mass, that is another topic to explore.



The slab is formed as usual but with the slab edge insulation in situ when poured and with no gaps (no discontinuity) between any of the insulation that is both under and to the side of the concrete.



The cross-sectional model of the Passivhaus slab, and slab edge showing wall, slab and ground.

The finished slab with the top of the XPS (edge) insulation left visible. In this case it will actually be built with continuous with woodfibre board directly attached to the outside of the 90mm timber frame that will sit on the edge of the slab beside the XPS.

The critical detail is that there is continuous insulation around the whole of the slab bottom and edge (and then the wall and finally the roof) there is no concrete in contact with the ground or the air. Any discontinuity of the insulation around the concrete would result in a thermal bridge.

A thermal bridge is where material that has a high thermal conductivity (or low thermal resistivity) interrupts the insulation material. In this situation any concrete that is in contact with the ground or the air.

This thermal bridging is clearly shown in the following thermal bridge analysis models in the “insulated” slab edge example.

The first model is the “insulated” slab the second is the Passivhaus with external brick veneer added to better visually match the “insulated slab construction – it is actually irrelevant to the performance of the junction.

The temperatures of the bricks demonstrate that they add no difference to the performance of the slabs (or walls) as these are outside the thermal insulation layer and only serve the purpose of protecting the building from rain, this is true of any cladding material that has a ventilated cavity behind them. This is now the only way you are allowed to build a wall in Canberra (and climate zones 6, 7 and 8).

A quick tutorial for understanding 2D heat flow analysis. These are showing the heat flowing through cross sections of the slab and wall of the building (as well as the ground).

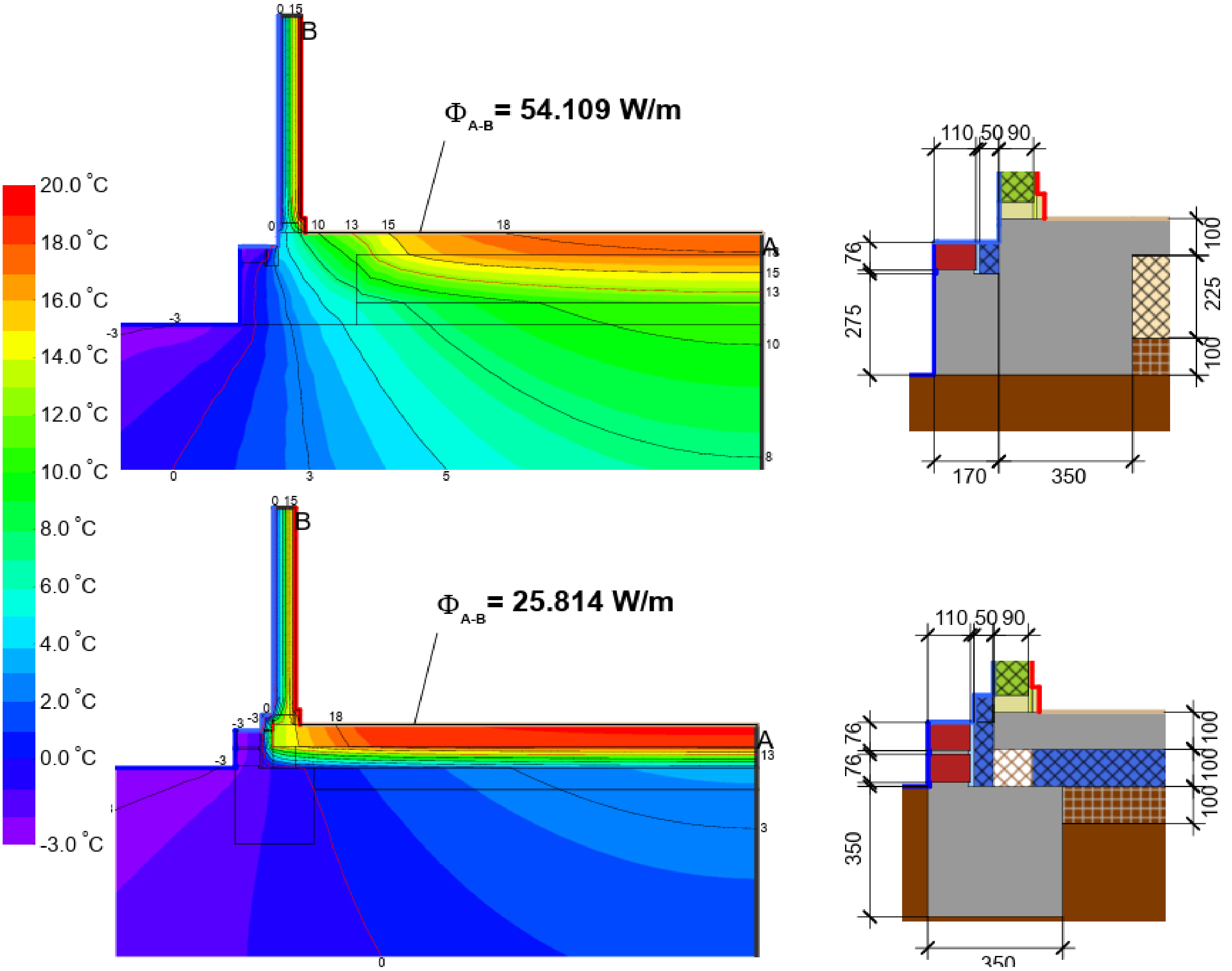
The temperature at each point in the construction is represented by both colour (key on the far left) as well as the black lines running through the model which are called isotherms (iso = same, therm = temperature) these are also with the temperature noted at the ends.

In this model the outside is on the left/bottom and is at either -3ºC (Canberra cold climate) and the inside on the right/top at 20ºC. The outside is set at 80% and inside at 50% relative humidity.

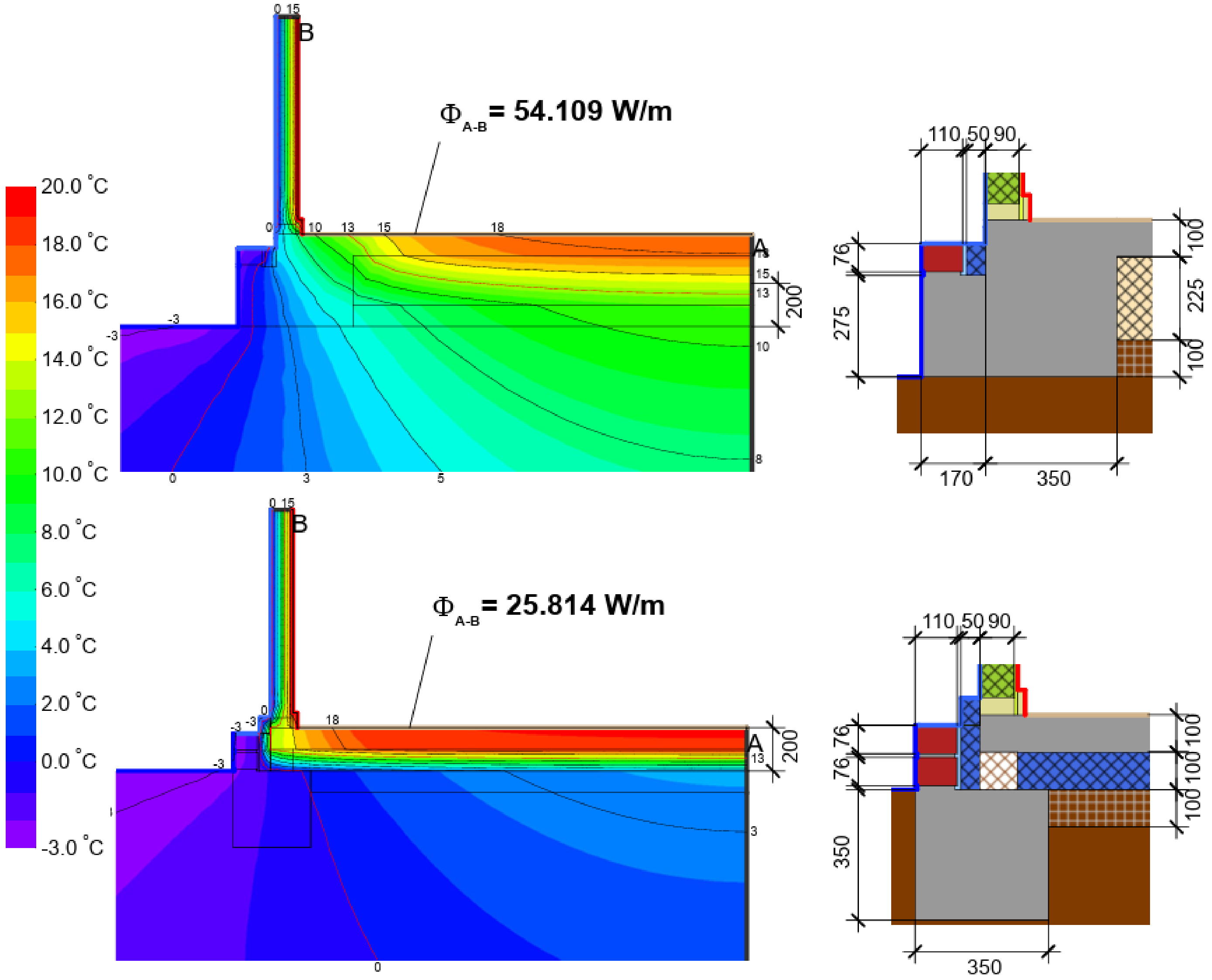
Materials that are more insulative will show the isotherms running parallel, straight and closer together, see within the XPS insulation in the lower Passivhaus slab and also the insulated wall in both models.

Materials that are less insulative (more conductive) will distort the lines and move them further apart. This can be seen in the concrete and earth where it spreads the lines. The heat loss is measured in heat flow, W/m or Watts per metre.

"Insulated" Slab Edge / Passivhaus Insulated Slab and Edge



"Insulated" Slab Edge / Passivhaus Insulated Slab and Edge



	Material	λ[W/(m·K)]
🟥	Clay Brick	1.000
⬜	Concrete, reinforced (with 1% of steel)	2.100
▦	Gravel	2.000
🟫	Ground	2.000
🟨	Plasterboard	0.250
🟩	Stainless Steel Termimesh Austenitic	20.000
🟨	Timber (Softwood) (1)	0.130
▨	Waffle Pod EPS/Conc beam SE Equivalent	0.410
▩	Wall R2.5/ 90mm 13.6% Timber	0.048
▩	XPS DCT GA 300	0.033
🟦	Slightly ventilated air cavity *	
	* Simplified approach	

	Boundary Condition	θ[°C]	R[(m²·K)/W]
🟦	Exterior, Normal -3C	-3.000	0.040
🟦	Exterior, Ventilated -3C	-3.000	0.130
🟫	Interior, heat flux downwards	20.000	0.170
🟥	Interior, normal, horizontal	20.000	0.130
⬛	Symmetry/Model section		

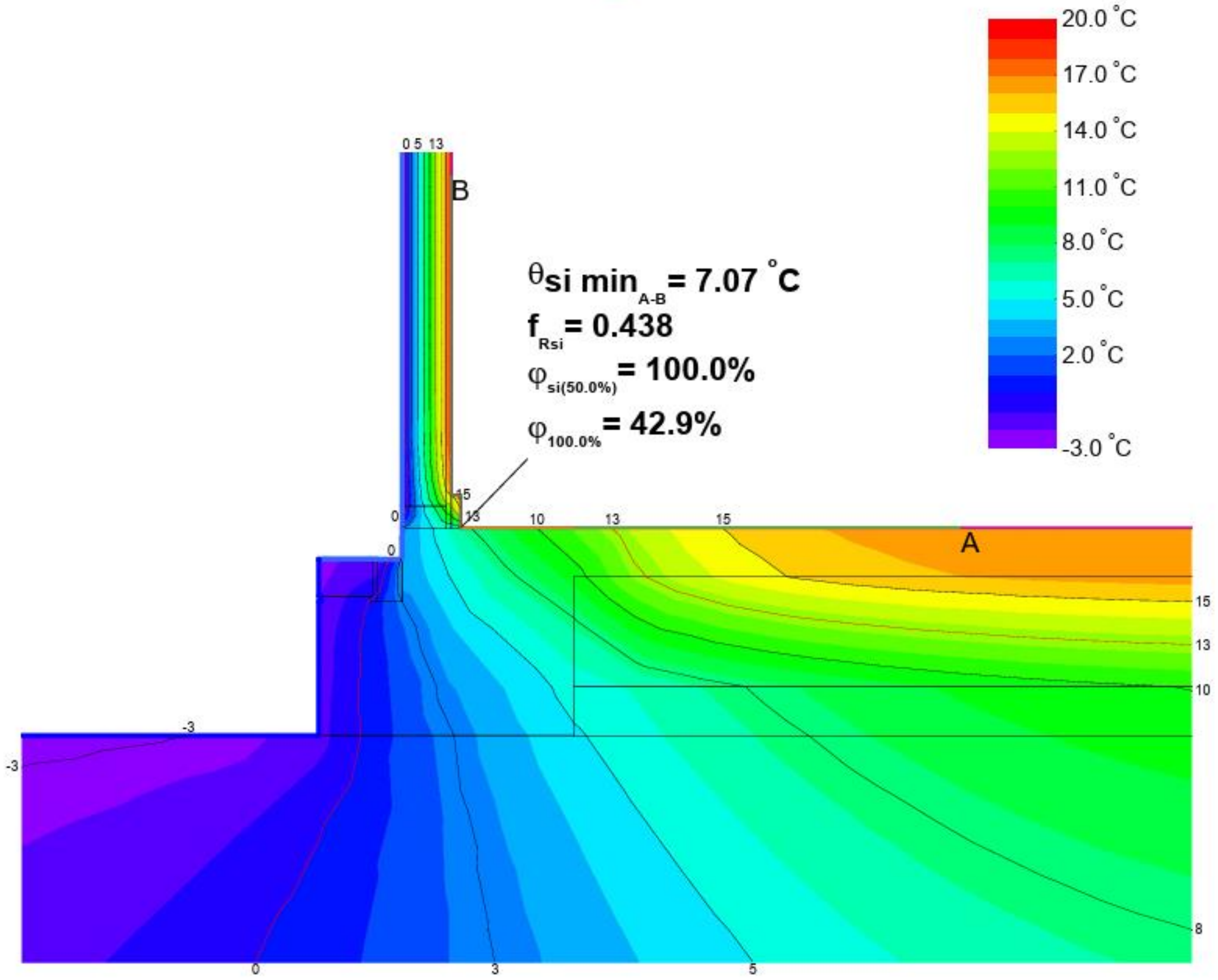
	Material	λ[W/(m·K)]
🟥	Clay Brick	1.000
⬜	Concrete, reinforced (with 1% of steel)	2.100
▨	Foamglas	0.035
▦	Gravel	2.000
🟫	Ground	2.000
🟨	Plasterboard	0.250
🟩	Stainless Steel Termimesh Austenitic	20.000
🟨	Timber (Softwood) (1)	0.130
▩	Wall R2.5/ 90mm 13.6% Timber	0.048
▩	XPS DCT GA 300	0.033
🟦	Slightly ventilated air cavity *	
	* Simplified approach	

	Boundary Condition	θ[°C]	R[(m²·K)/W]
🟦	Exterior, Normal -3C	-3.000	0.040
🟦	Exterior, Ventilated -3C	-3.000	0.130
🟫	Interior, heat flux downwards	20.000	0.170
🟥	Interior, heat flux horizontal	20.000	0.130
⬛	Symmetry/Model section		

The direct comparison of the two slabs modelled to show the total heat flow from inside to outside the building (to the ground and air).

The “insulated” slab allows more than twice as much heat to flow through it to the ground and air outside the building. The “insulated” slab is effectively R1.1 the Passivhaus slab is effectively R3.1. This is before accounting for the additional heat loss through all the additional materials that make up the junction (the footing and wall bottom plate).

"Insulated" Slab Edge 90mm Wall fRsi



$\theta_{si\ min_{A-B}} = 7.07\ ^{\circ}C$

$f_{Rsi} = 0.438$

$\varphi_{si(50.0\%)} = 100.0\%$

$\varphi_{100.0\%} = 42.9\%$

Material	λ[W/(m·K)]
Clay Brick	1.000
Concrete, reinforced (with 1% of steel)	2.100
Gravel	2.000
Ground	2.000
Plasterboard	0.250
Stainless Steel Termimesh Austenitic	20.000
Timber (Softwood) (1)	0.130
Waffle Pod EPS/Conc beam SE Equivalent	0.410
Wall R2.5/ 90mm 13.6% Timber	0.048
XPS DCT GA 300	0.033
Slightly ventilated air cavity *	

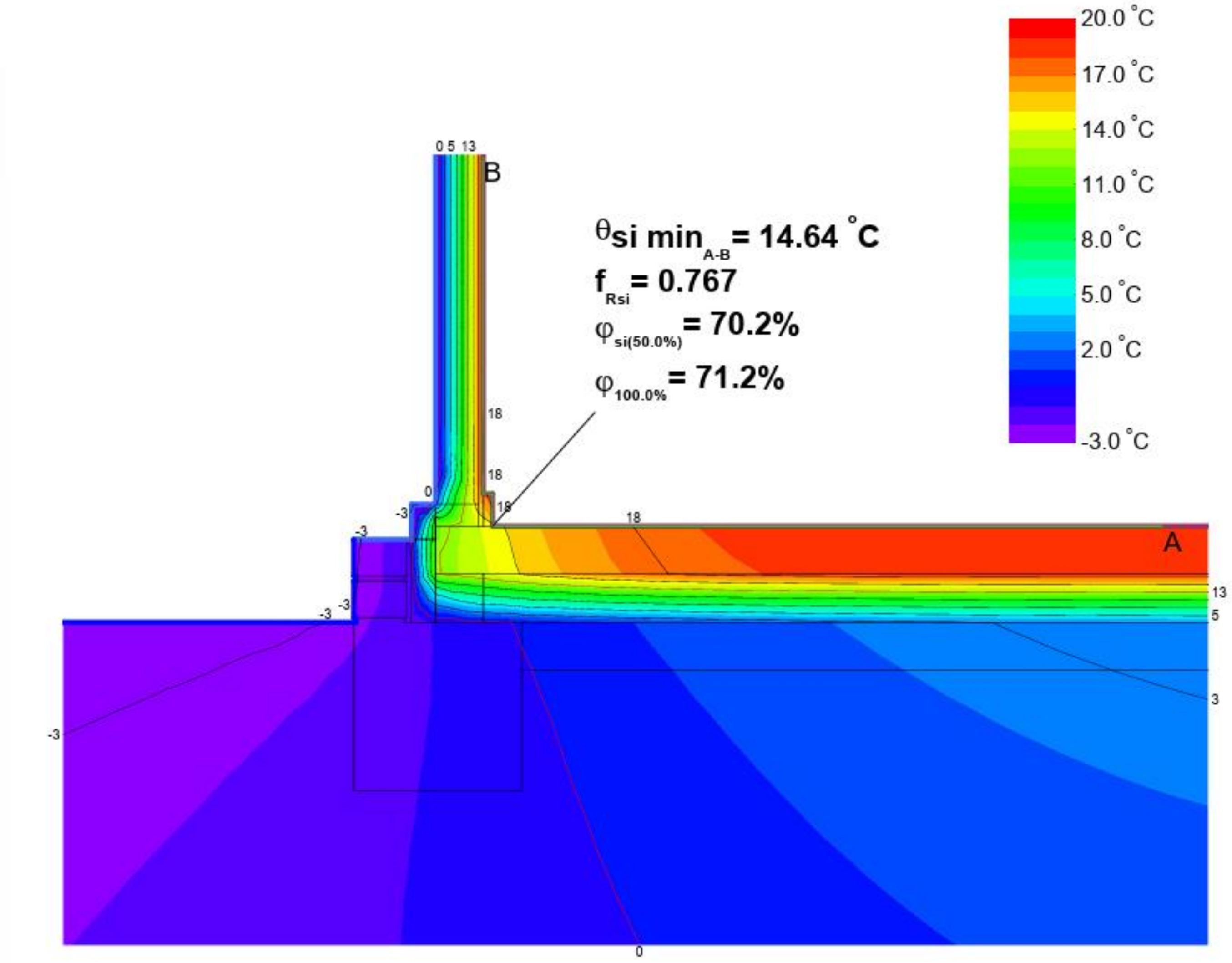
* Simplified approach

Boundary Condition	θ[°C]	R[(m²·K)/W]
Exterior, Normal -3C	-3.000	0.040
Exterior, Ventilated -3C	-3.000	0.130
fRsi 0.25	20.000	0.250
Symmetry/Model section		

Cold spots are mould spots, if any inside surface is too cold it will lower the relative humidity of the air nearby and if this is the case for too long it will support mould growth.

The minimum surface temperature (at the corner in this model) is just above 7°C, this point in the corner will have 100% relative humidity when it is 20°C and 50% relative humidity inside, it will actually reach this whenever the inside relative humidity is above 43% at 20°C.

Passivhaus Insulated Slab Edge 90mm Wall fRsi



$\theta_{si\ min_{A\text{-}B}} = 14.64\ ^{\circ}C$

$f_{Rsi} = 0.767$

$\varphi_{si(50.0\%)} = 70.2\%$

$\varphi_{100.0\%} = 71.2\%$

	Material	λ[W/(m·K)]
🟥	Clay Brick	1.000
⬜	Concrete, reinforced (with 1% of steel)	2.100
▨	Foamglas	0.035
▦	Gravel	2.000
🟫	Ground	2.000
🟨	Plasterboard	0.250
🟩	Stainless Steel Termimesh Austenitic	20.000
⬜	Timber (Softwood) (1)	0.130
▨	Wall R2.5/ 90mm 13.6% Timber	0.048
▨	XPS DCT GA 300	0.033
🟦	Slightly ventilated air cavity *	

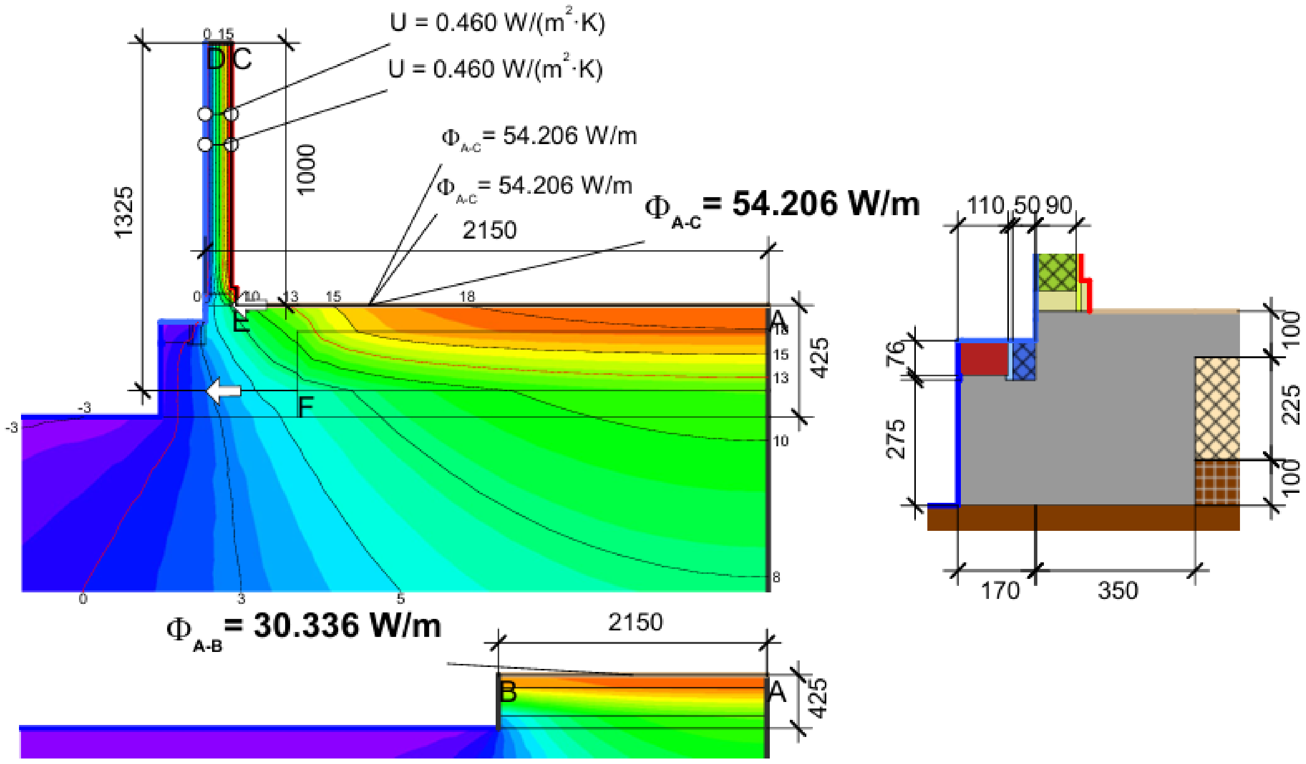
* Simplified approach

	Boundary Condition	θ[°C]	R[(m²·K)/W]
🟦	Exterior, Normal -3C	-3.000	0.040
🟦	Exterior, Ventilated -3C	-3.000	0.130
🟪	Interior, frsi = 0.25	20.000	0.250
⬛	Symmetry/Model section		

Warm spots are not mould spots, if the building is adequately insulated for the climate no inside surface will drop below the temperature that supports mould growth.

The temperature is always above 14°C at the corner (the coldest spot), it will only reach 100% humidity when inside the home is above 71% relative humidity.

"Insulated" Slab Edge 90mm Wall Psi



Internal dimensions additional heat loss

$$\psi_{A\text{-}E\text{-}C,*} = \frac{54.206}{23.0} - \frac{30.336}{23.0} - 0.46\cdot 1.0 = 0.578\ \mathrm{W/(m\cdot K)}$$

External dimensions additional heat loss

$$\psi_{A\text{-}F\text{-}C,*} = \frac{54.206}{23.0} - \frac{30.336}{23.0} - 0.46\cdot 1.325 = 0.429\ \mathrm{W/(m\cdot K)}$$

The more complex but nuanced way of understanding the relative difference between the two situations is to calculate a Psi value for the floor and wall junction.

The Psi value is a mathematical calculation that represents the additional heat loss for each metre length of the building perimeter that is due to the thermal bridging from all of the structural material in the “insulated” slab edge (the footing and wall bottom plate).

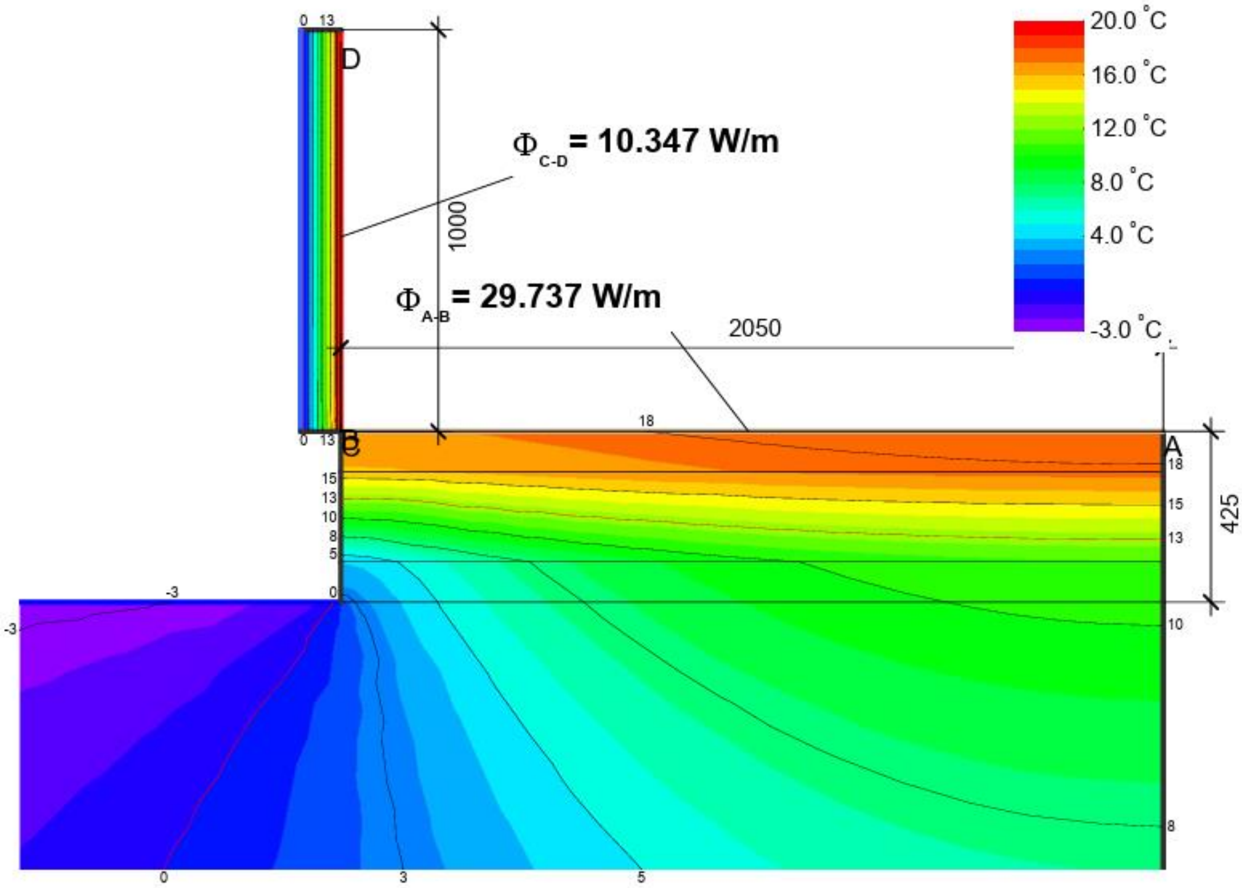
The top calculation is used in NatHERS modelling where internal dimensions of buildings are used to model heat loss.

The bottom calculation is what would be used in Passivhaus modelling where external dimensions of buildings are used.

The difference is showing that there is less additional heat loss to account for in Passivhaus modelling as use of external dimensions already accounts for more of the heat loss.

Then to clarify the difference in an energy model with the use of internal or external dimensions we can look at the heat loss through each wall and floor separately and then compare this with the reality of the whole construction including all of the junction that is just excluded.

"Insulated" Slab Edge 90mm Wall using Internal Dimensions



Internal dimensions heat loss 10.347W/m + 29.737W/m = 40.084W/m

Internal dimensions additional heat loss 54.109W/m - 40.084W/m = 14W/m

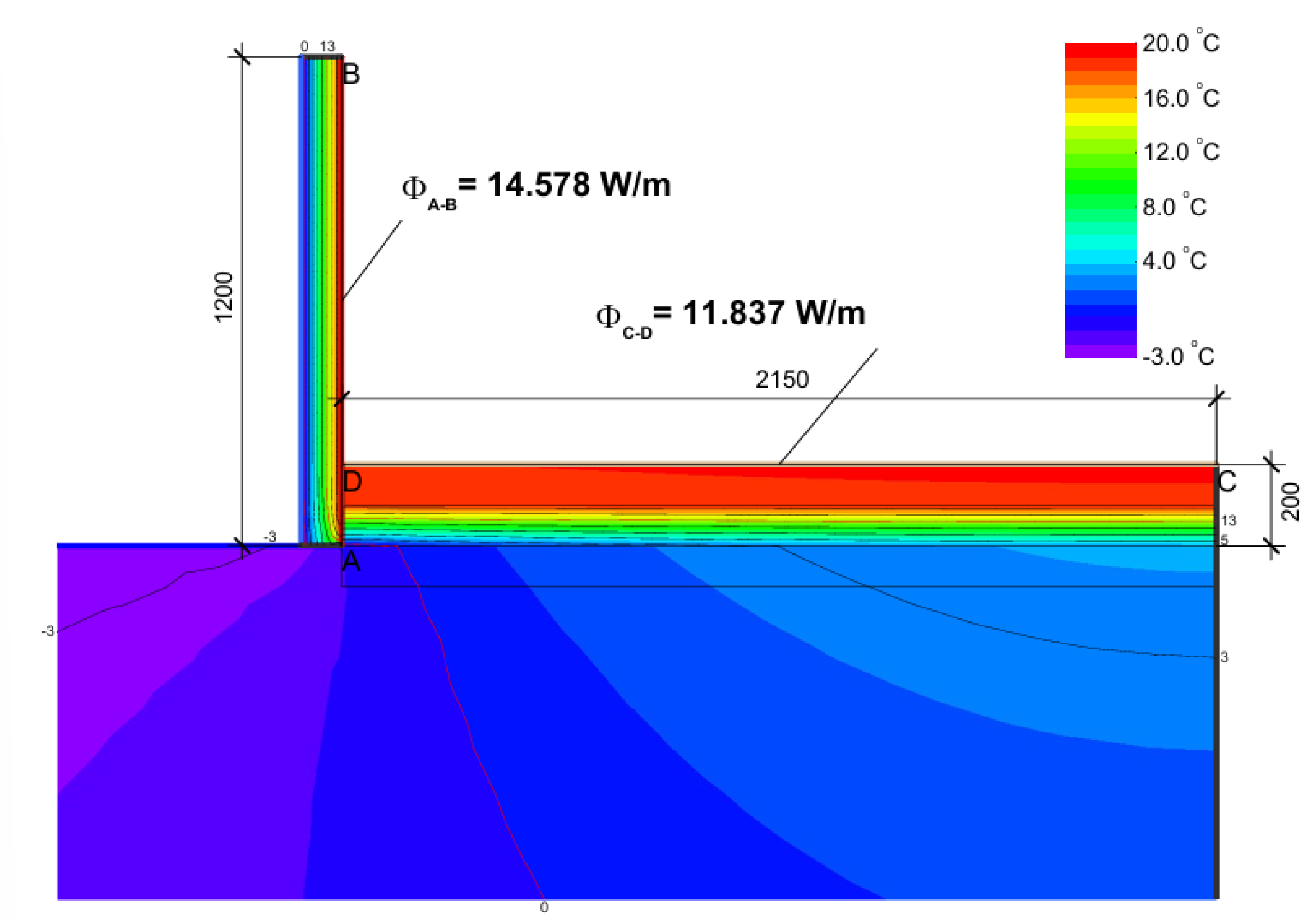
This is showing the way in which NatHERS accounts for heat loss of the building envelope using internal dimensions. It calculates that there is 40W/m of heat loss through this wall and floor.

When the actual building construction is modelled there is 54W/m (page 11) this a difference of 14W/m, from just this one junction. To be fair, in a well detailed timber framed building this is usually about the worst junction in the building.

That is unless, you have steel in the building that is going from outside to inside, which is very common, this is a far worse thermal bridge as steel is 25 times more thermally conductive than concrete. The use of steel within the thermal envelope will be explored in a further paper.

The next model is of the Passivhaus slab and the heat loss that is already accounted for in the PHPP model when using external dimensions.

Passivhaus Slab 90mm Wall using External Dimensions



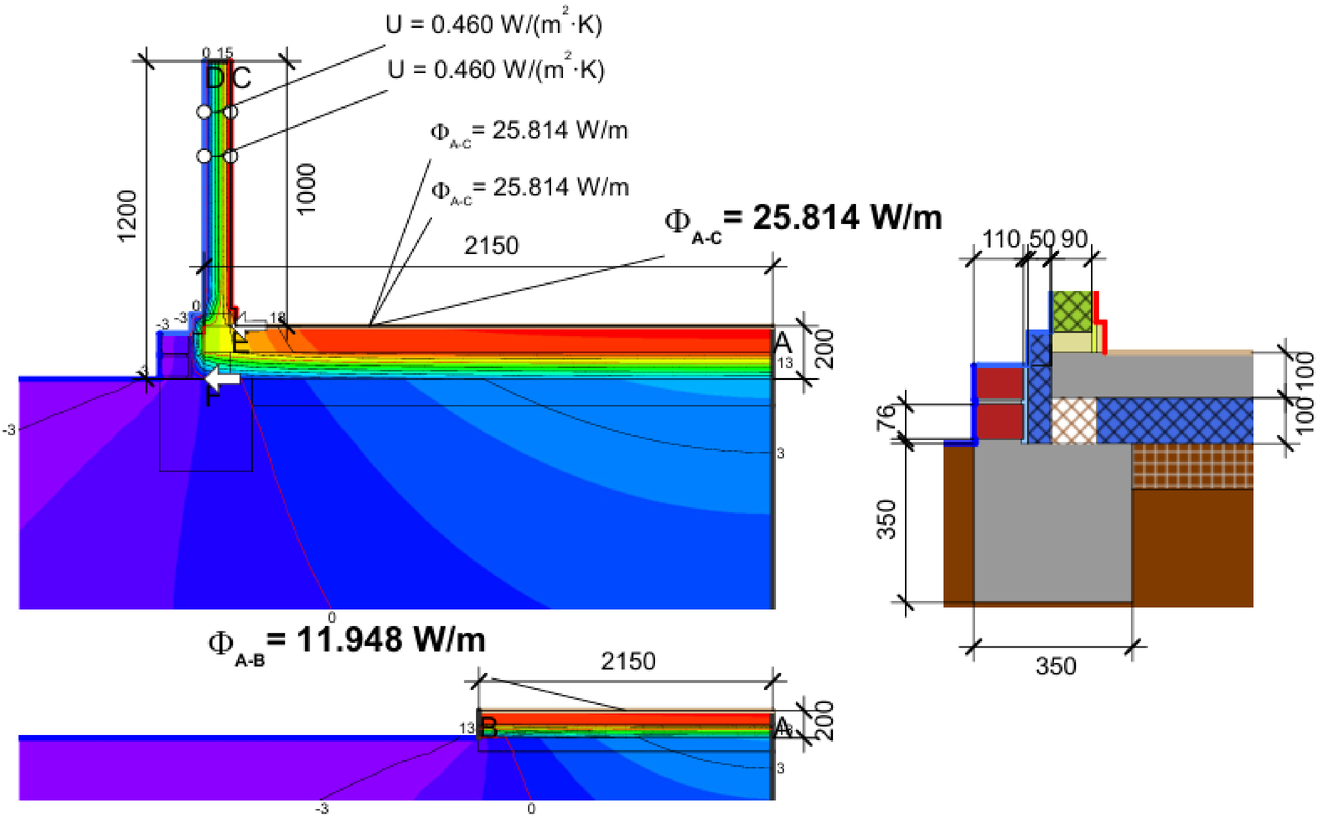
External dimensions heat loss 14.578W/m + 11.837W/m = 26.415W/m

External dimensions additional heat loss 25.814W/m - 26.415W/m = -0.601W/m

It can be seen that the heat loss through the wall element and the slab element actually over account for the total heat loss including the additional slab edge structure. That is the thermal bridge is negative, the model does not really need correcting. This is particularly the case as it is a very well continuously insulated junction, only these will show this lack of thermal bridging and accordingly little difference in the total heat flows when accounting for the junction, or not.

The next model is of the Passivhaus slab and you will see the relative absolute size of the heat loss difference that is having to be accounted for when a slab is adequately insulated (continuously) by comparison with the “insulated” slab edge (page 11).

Passivhaus Slab and Edge 90mm Wall Psi



Internal dimensions additional heat loss

$$\Psi_{A\text{-}E\text{-}C,*} = \frac{25.814}{23.0} - \frac{11.948}{23.0} - 0.46\cdot 1.0 = 0.143\ \text{W/(m·K)}$$

External dimensions additional heat loss

$$\Psi_{A\text{-}F\text{-}C,*} = \frac{25.814}{23.0} - \frac{11.948}{23.0} - 0.46\cdot 1.2 = 0.051\ \text{W/(m·K)}$$

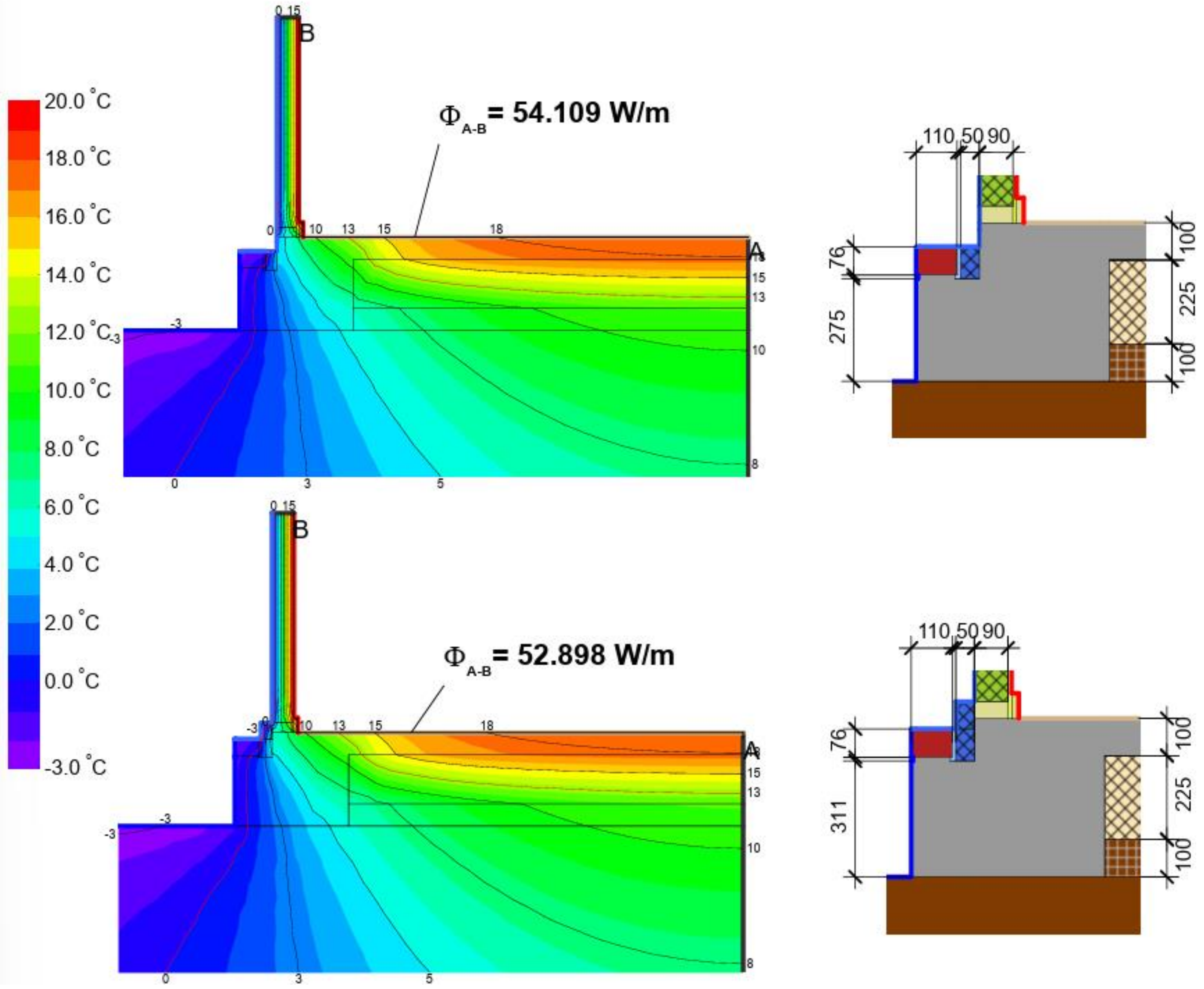
The difference is some 4-8 times less total heat loss to be corrected. Although this is deceptive as it is not comparing apples with apples as the slab in this Passivhaus situation has three times as much insulation as the “insulated” slab even though the wall is the same. The additional heat loss is relative to the performance of the wall and slab and so it is only really useful to compare in absolute terms the difference in internal and external dimensions (*you will need to re-read this and refer back to the previous few pages to make sense of this paragraph)*.

The most significant difference is of course the whole heat loss of the wall and slab modelled, this is 54W/m for the “insulated” slab and only 26W/m for the Passivhaus slab, it halves the heat loss.

I have then modelled variations of the “insulated” slab to try and mimic the Passivhaus slab performance with the addition of other bits of insulation to illustrate clearly the difference in approaches. Essentially, these are all relatively difficult and expensive to build and actually perform not that much better than not bothering with insulation at all.

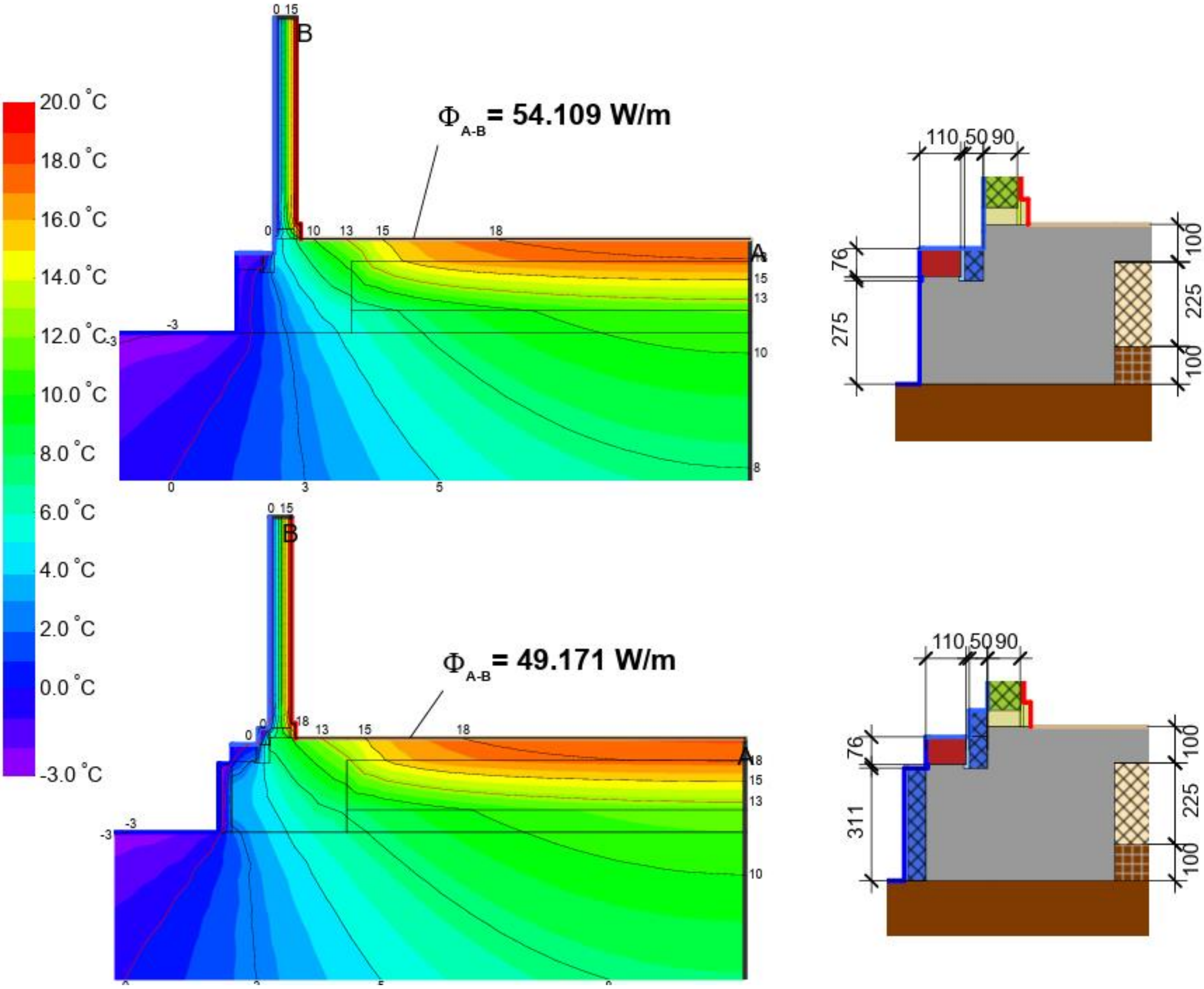
Insulation performance is unintuitive (and frustrating) in this way, even very small gaps lead to very large losses in performance. It needs to be designed with continuous insulation or modelled or it is uncertain just what value there is in adding any insulation.

"Insulated" Slab Edge / Adjusted "Insulated" Slab Edge



This model adjusts the slab edge insulation to extend above the bottom plate of the wall as it does in the Passivhaus model. This additional 100mm of insulation reduces the heat loss by 2%, it is only slightly addressing the gap in the insulation layer of the whole rest of the slab edge and footing base.

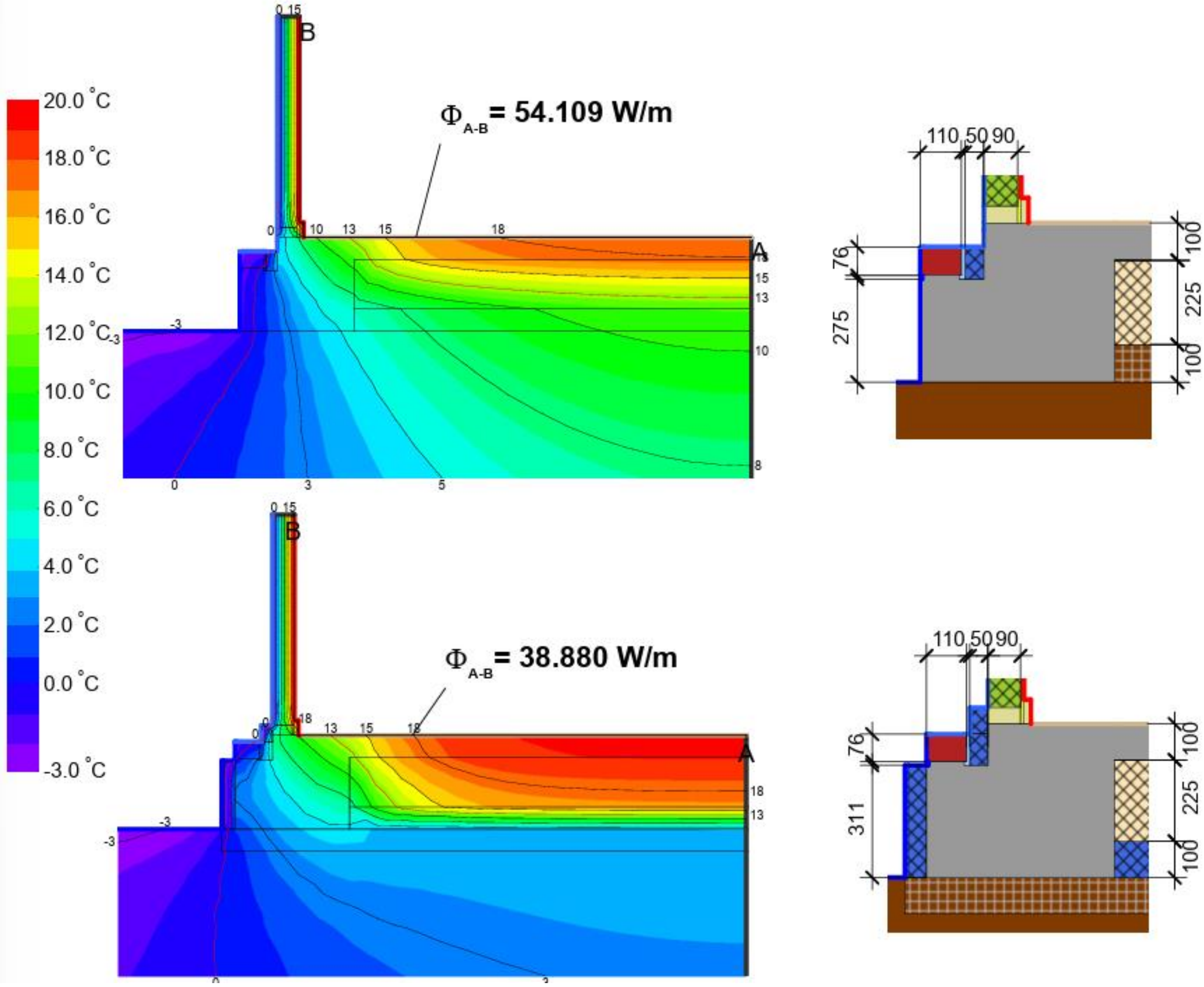
"Insulated" Slab Edge / Adjusted "Full Insulated" Slab Edge



This model then adds slab edge insulation to the outside of the slab edge that is exposed to the air and it gains a 9% reduction in heat loss.

This would still not probably be worthwhile doing for the cost of the materials, the additional labour against the performance and carbon cost of energy additionally leaking out of the building.

"Insulated" Slab Edge / "Full Insulated" Slab and Slab Edge



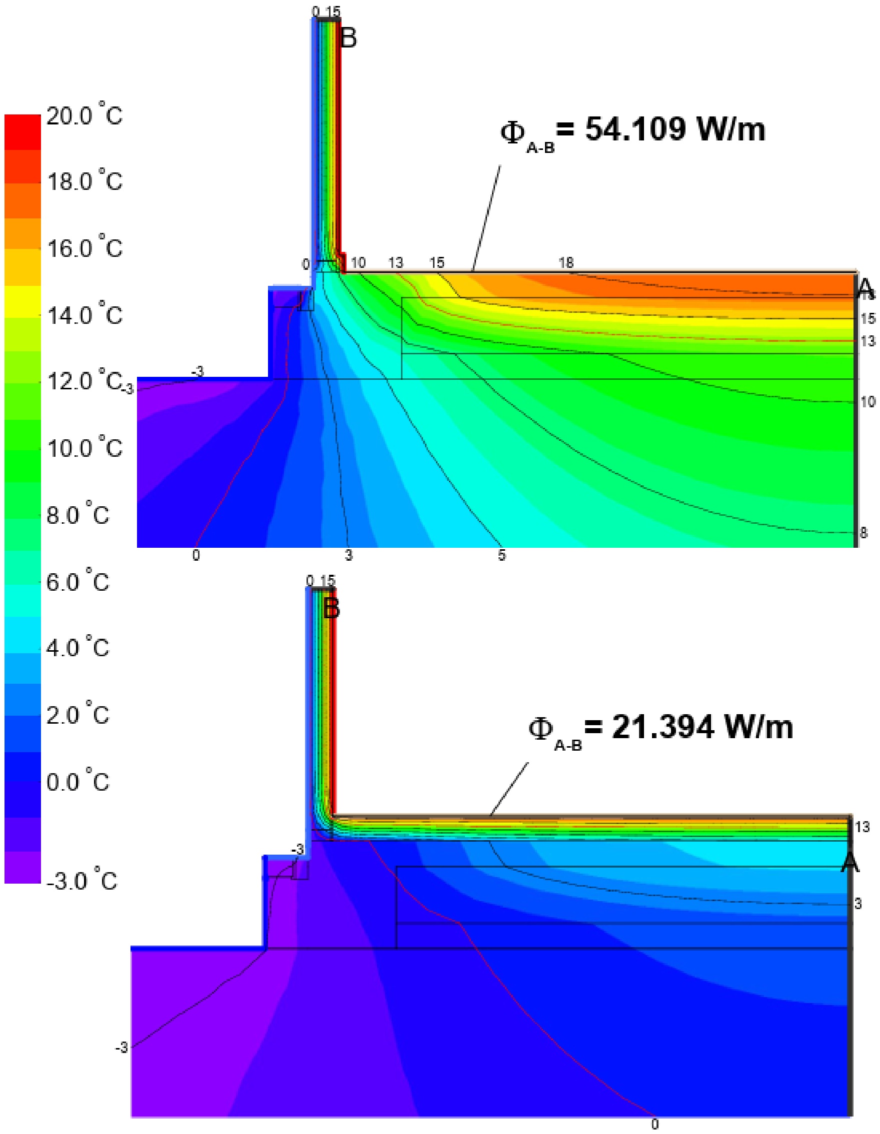
This model has 100mm of XPS insulation added under the slab in addition to the 50mm of XPS added to the slab edge. This does show a significant reduction in heat loss performance of 28%.

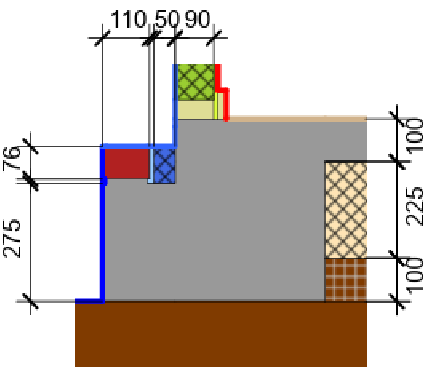
The issue of the slab footing being entirely uninsulated to the ground is the real thermal bridge problem.

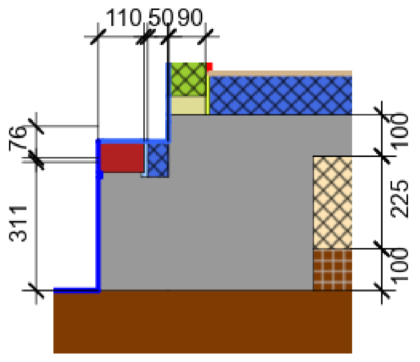
Again, the cost of the material and additional labour (and embodied carbon of these materials) may not ever be offset by the additional energy used to offset the heat loss.

More likely it is the case that the users of the building would just accept a slightly lower operating temperature inside the building and colder feet (12ºC in the corner)! And, of course, a greater risk of mould!

"Insulated" Slab Edge / "Insulated" Slab Edge and Top







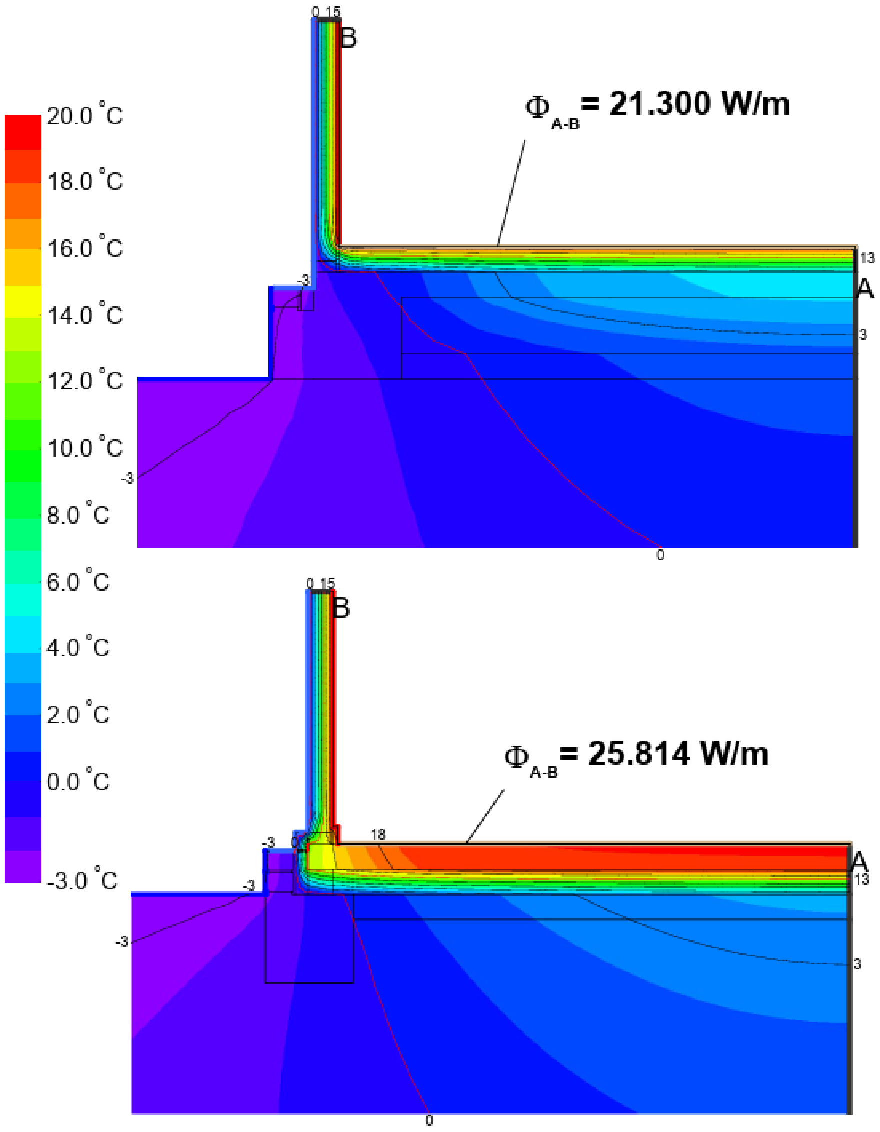
This is the first iteration of additional insulation that would be worthwhile considering. In this model there is 100mm of XPS added on top of the slab. This achieves a 60% reduction in heat loss and is actually better performing than the Passivhaus slab!

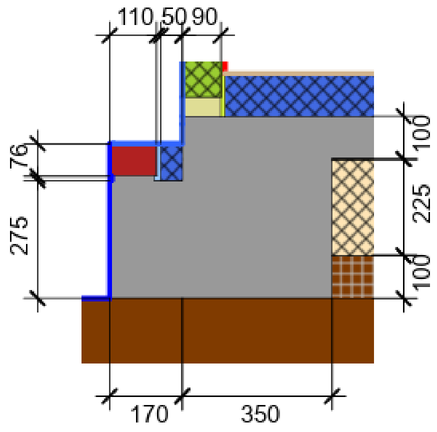
The temperatures show just what a continuous layer of insulation achieves, there is no thermal bridging of any material (aside from the small interruption of base plate of the wall frame). The original slab edge insulation is, of course, irrelevant, it is outside of the thermal insulation layer.

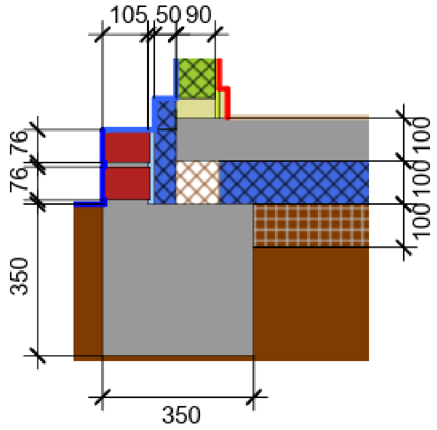
This may be suitable for a cold climate where heat loss is the number one consideration in the performance of the building – it depends on the other design decisions made. In warm or hot climates this is going to work against you in increasing how much cooling energy you need to keep the inside comfortable.

Now the drawback of this approach is that the thermal mass of the concrete is now outside of the building and therefore of no use in moderating the temperature fluctuations inside the building. But you would have warm feet and no risk of mould in the corners! However, if you build with appropriate insulation and air leakiness you don't have fluctuating temperatures inside that then need thermal mass to work anyway. Note that the Passivhaus slab almost achieves the same performance with the thermal mass of the slab inside.

"Insulated" Slab Edge and Top / Passivhaus Slab and Edge







The final comparison of the best performing waffle pod slab (insulated on top or internally) against the Passivhaus slab. The Passivhaus slab actually has a 17% increase in heat loss, although it has 52% less heat loss than the base case "insulated" slab edge example.

The other considerations of upfront (embodied) carbon are really important here. If you are happy with an exposed slab the Passivhaus slab really saves unnecessary heat loss energy as well as providing a finished floor surface. You can have your cake and eat it too! (if you like concrete cake)

If you used the waffle pod and then insulated internally you would lose 17% less heating energy at this junction but you would have used the additional carbon of the waffle pod manufacture and then the other materials needed to form the floor inside. This is likely yellow tongue, and timber or fibre cement sheeting and tiles, glues etc (you could do the calculations to understand this in real terms). Or if you really wanted the thermal mass (and exposed concrete) you could pour a topping slab inside! There are lots of reasons people build the way they do, I hope that this may serve to ask questions about the decisions you might make and why.

In fact (IMO), the best way to build is probably not with concrete (and steel reinforcing) at all, these materials are a significant part of the worlds carbon emissions. A raised timber floor is far less embodied carbon, performs far better and is entirely suitable for the light weight timber framing that we commonly use.

Notes

This modelling was conducted in Flixo a finite element 2D heat transfer modelling software that is able to accurately understand the heat flow of constructions in two dimensions such as wall and floor junctions, or in this case the slab edge. Flixo models to the ISO 10211 standard. This tool is the benchmark tool of this type available today.

The modelling parameters are set to represent a generic cold climate with an external temperature of 0^{o}C and 80% relative humidity (RH) and an internal of 20^{o}C and 50%RH. Altering these parameters won't change the wall or floor thermal transmittance (U-value) or it's inverse the thermal resistance (R-value) but will change the models representing the heat flow to understand the risk of condensation and mould (f_{Rsi}).

The f_{Rsi} is a relatively robust metric that describes the risk of condensation in a construction. This metric uses the lowest internal surface temperature and consequential relative humidity at that point on the surface to understand the risk of mould growth. There are of course more rigorous methods to assess this risk (WUFI being one of these softwares) but this should not be necessary in most scenarios, rather just design the construction to provide an appropriate level of risk with the other methods of managing this risk being also considered.

The performance values of the waffle-pod slab came from Sustainable Engineering who modelled this with a 3D finite element 3D heat transfer tool to obtain an accurate real-world performance figure for this construction type (here). Also, the truism I borrowed "cold spots equal mould spots" came from this source. If you want to understand how to build a better building, just read everything on the website (perhaps twice or three times).

I have used a 90mm timber stud frame with R2.5 insulation. The waffle pod slab is 225mm with a 100m slab and 50mm of XPS slab edge insulation. The Passivhaus slab uses 100mm of XPS insulation and the foamglas blocks. The Passivhaus slab detail comes from Craftbuilding in Canberra (here).

The "insulated" slab detail actually comes from an 8-Star rated new build also in Canberra. The details it uses are (generally) far better than standard construction, but this one is not worth doing for the reasons discussed in the paper. All of this detail is not considered in the NatHERS star rating, certainly not such that it is able to reflect the reality of the slab edge insulation.

The motivation behind writing this paper is personal. I have trained in building science (via Passivhaus) and also Building Design as well as having built buildings (and things) all of my life. I have interrogated many projects and understood what works, what doesn't (what is practical) and largely have leveraged the wealth of shared learnings, experience from around the world and most particularly used all of this to then make use of the tool Flixo. It quite simply tells you precisely what you need to do to make a junction work and just how well it will work in that climate. Most critically how much risk of cold spots that equal mould spots the junction has due to the way it is detailed. Otherwise, you may spend money building things that don't work or are not worth doing.

Across the way in Aotearoa New Zealand, they build slabs that are fully insulated, and they have to additionally contend with earthquakes. There is no reason that we shouldn't already do the same, it's no harder, the NatHERS modelling just has to be capable of discerning the actual difference that this can make to a building in any climate, but it can't. This is an example of such a system, I have no affiliation nor am I recommending this product but I am demonstrating that it is better than we currently do and it is available in Australia today.