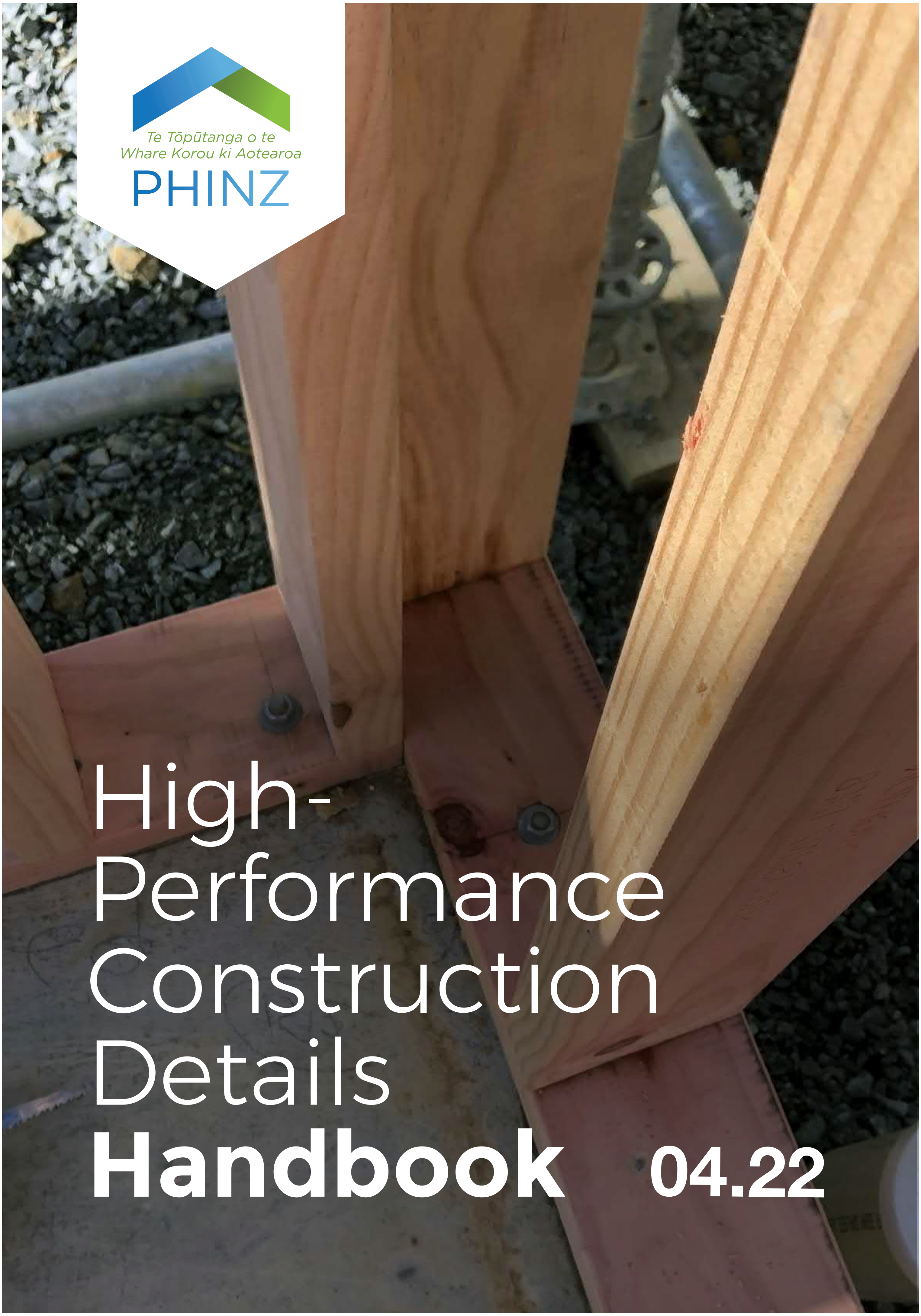
Te Tōpūtanga o te Whare Korou ki Aotearoa

PHINZ



High-Performance Construction Details **Handbook**

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About this report

Project

LR12313: Thermal performance of houses is in the detail – providing tested details that deliver

Title

PHINZ High-Performance Construction Details Handbook

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This report and CAD files of all the details included are freely available to download from the PHINZ website at: passivehouse.nz/hpcd-handbook/

Abstract

This handbook brings together selected high-performance construction details from residential projects successfully built in New Zealand. Out of all the details from every Passive House project certified in this country, the most useful Elements and Junctions were selected and analysed thermally in detail to ISO standards. CAD data for these generic details is provided, along with R-value calculations plotted for the Elements and thermal bridge performance in terms of PSI and fRSI values provided for the Junctions. Selected commonly-built details (those that only comply with Building Code minimums) are also included for the sake of comparison.

Making these high-performance details freely available will assist the building industry to design and build more energy-efficient and thermally-comfortable homes for New Zealanders. Further, the information contained in this handbook will be of considerable vaue to council consenting officials as they review increasing numbers of high-performance building projects.

Reference

Quinn, Jason E., "PHINZ High-Performance Construction Details Handbook," 2022

Disclaimer

This publication is provided to inform professionals of the thermal performance, cost and carbon of these details. The authors of this publication have used their best efforts to provide accurate and authoritative information in regard to the subject matter covered. The authors, Sustainable Engineering Ltd and Passive House Institute NZ (PHINZ) make no warranty of any kind, expressed or implied, with regard to the information contained in this work. The information presented must be used with care by professionals who understand the implications of what they are doing. If professional advice or other expert assistance is required, the services of a competent professional should be sought. The authors, Sustainable Engineering Ltd and PHINZ shall not be liable in the event of incidental or consequential damages in connection with, or arising from, the use of the information contained in these details/publication. The views expressed herein do not necessarily represent those of any individual contributor. Nothing in this publication is an endorsement of any proprietary building envelope system or particular assembly product.

Weathertightness details (ref. New Zealand Building Code clause E2) shown are for illustration. They are not guidance on how to construct weathertight buildings as this project is focused on thermal performance. It is recommended that readers consult relevant and current technical publications alongside using this handbook. Take advice from consultants with appropriate qualifications and refer to appropriate authorities with regard to envelope design, assembly fabrication and construction practices. Further, seek specific information on the use of envelope-related products and follow the instructions of envelope assembly manufacturers. Any construction project must comply with the New Zealand Building Code.

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Passive House Institute NZ Te Tōpūtanga o te Whare Korou ki Aotearoa

When we first conceived of the idea for this publication in 2018, we imagined a small collection of construction details representative of completed Passive House projects in Aotearoa NZ. We hoped to enable newcomers to begin designing their first Passive House project with this valuable knowledge sharing.

We contacted Jason Quinn about authoring the publication as he was the only accredited Passive House certifier in the country at the time. In this role, he saw and assessed almost all the Passive House construction details being used across the country. It was a pleasant surprise to find Jason had a similar publication in mind also.

When we started to develop our project proposal, we sought input from David Dowdell at BRANZ. He encouraged us to look beyond the Passive House community and consider how this publication could contribute to the wider industry. David was also instrumental in the carbon and cost information being included for the details. The project could enable and catalyse the design and construction of high thermal performance houses across the whole industry. At the same time, it could also increase carbon literacy and, importantly, support low-carbon construction.

And now, as this project comes to fruition, the construction industry in Aotearoa NZ is on the cusp of change. Awareness of the need for better quality houses and the need to respond to climate change in the construction industry is growing fast. Thermal performance of houses is no longer just the concern of Passive House practitioners and building scientists. The Ministry for Business Innovation and Employment, Kāinga Ora – Homes and Communities, BRANZ and NZ Green Building Council all have programmes and work underway to develop and support higher thermal performance houses and low-carbon construction.

This publication reflects that. It contains much more than Passive House construction details: a whole host of high thermal performance details and information to support their uptake on houses anyone designs and constructs. And we sincerely hope that this is exactly what happens: that the details in this handbook are widely used and adopted across the whole industry.

It's been a tremendous effort from the whole team of people involved—just like the creation of a high thermal performance house–and we are very proud of the outcome. We hope it serves the industry well.

—Elrond Burrell, Chair of the Board PHINZ

Foreword

Homes are special places. They are places full of memories and places to build new memories. They should be snug, safe sanctuaries that keep us cosy and healthy.

But for far too many New Zealanders, our homes don't keep us safe and healthy. They are not sanctuaries. They are cold, damp, unhealthy places, which can all too often saddle the least well-off New Zealanders with hefty household bills as they try to heat a poorly insulated place.

And, despite far too many homes being cold, the carbon pollution from our homes are making the earth too hot. Research has found that a typical new Kiwi home emits five times as much carbon pollution as we can afford to stay within 2C of warming. Five. Times.

Presiding over this sorry state of affairs is our woeful, internationally criticised Building Code. There's a litany of areas where the Building Code fails. Some much needed changes are needed for better insulation requirements, inclusion of air tightness and thermal bridging standards, improved ventilation, requirements to mitigate overheating, efficiency standards for all energy uses, and energy performance modelling and reporting.

Change is coming however. All of us, working together, to improve the standard of our homes for all New Zealanders, can feel the momentum behind our growing movement.

And the publication of this book is a key part of making this change happen.

Making this information freely available will surely help architects and designers include higher performing details for warmer, drier houses that are cheaper to run. The inclusion of carbon calculations should help all of us in the sector to slash the carbon associated with building products and materials.

Many congratulations to the team at PHINZ and everyone who worked on this important publication.

—Andrew Eagles
CEO, NZ Green Building Council

Preface

New Zealand has a well-documented legacy of cold, damp and mouldy homes. New buildings constructed to the current NZBC Clause H1 Energy Efficiency settings are low-performing by international standards.

There is increasing recognition internationally and in New Zealand of the need to improve the thermal performance of buildings. The benefits are many: increased energy efficiency, improved indoor environment, health and comfort and mitigation of greenhouse gas emissions.

Lifting our standards for buildings of all kinds is a vital and necessary part of our response to curb climate change. I strongly advocate for and work to bring about better performing buildings. I'm a building scientist—and also a citizen and a father. I care about improving our buildings for the sake of those who occupy them, but also because of the benefits delivered to society as a whole.

The community of Passive House certified designers, consultants and tradespersons has grown significantly in the past five years. We have successfully designed and built the hardest projects: single-family, stand-alone homes. The next step is winning institutional backing, so as to build large public and commercial buildings to higher standards of energy performance and quality. The larger the volume of the building, the easier and cheaper it is to achieve Passive House standards. Cost is not a barrier.

Several of us in the Passive House community conceived of the need for this book a few years ago and I'm glad of the support of PHINZ, the building industry and collaborators that have made it possible. It is a book for readers from many different disciplines—architects and designers, engineers, council consenting officials and regulators—but who share a focus on improved building quality.

Slab on-ground Elements updated from the previous edition (2021)

This released version of the PHINZ HPCD has updated the slab-on-ground R-values from the previous versions of the HPCD handbook. Previous versions of this handbook should no longer be used.

We're on the cusp of radical change and I look forward to you being part of it.

—Jason Quinn
Director, Sustainable Engineering Ltd
CMEngNZ IntPE(USA)
Passive House Designer and Certifier

Introduction

This publication gives design and construction professionals practical tools they can use to exceed the minimum standards of the New Zealand Building Code. It will also support building consent officials who are increasingly encountering projects that include high-performance Alternative Solutions. It shows how a range of New Zealand buildings have been designed and built to improve occupant health and comfort and radically reduce the financial and carbon cost of heating and cooling.

Timber frame buildings, as they have been typically built in New Zealand, have well-known limitations that result in poor thermal performance. This includes excessive thermal bridging, especially in corners and internal-to-external wall junctions; and inadequate design of skillion roofs, such that good thermal performance is virtually impossible to achieve using current practice.

At the same time, there are barriers to market entry of better products and construction methods. This is an outcome of the Acceptable Solutions/Alternative Solutions pathway set down in the Building Code. It varies between councils and even individual projects but specifying superior components and details has risked delay and its associated costs at the consenting stage. This must change. This resource you are reading is intended to do just that.

The industry hasn't had publicly available, proven construction details that can deliver improved thermal performance and building quality: but it does now with the publication of this document. The need for this handbook is self-evident. The Passive House Institute of New Zealand (PHINZ) routinely receives requests for resources or guidance with construction details. This valuable knowledge and experience with high-(thermal) performance design does exist, but until now it's been locked up in specific Passive House projects and architectural/design practices.

This handbook is for any professional and any project that wants to go beyond the Building Code's Acceptable Solution for thermal performance. It is based primarily on details from successful New Zealand Passive House buildings but its use and value is not restricted to projects that aim for this gold standard of energy efficiency and occupant wellbeing.

For the sake of comparison, standard practice details are also included. Seeing familiar business-as-usual examples alongside new, high-performance details graphically illustrates how changes in construction practice significantly improve thermal performance. In turn, interior cold spots are reduced or removed and along with that, the risk of mould.

What's inside

The publication has 101 details, both elements (1D details) and junctions (2D details with heat transfer calculation and 3D details with psi and chi values). Included are:

- walls (plus door and window penetrations)
- roofs and
- floors, including both suspended floors and slab foundations.

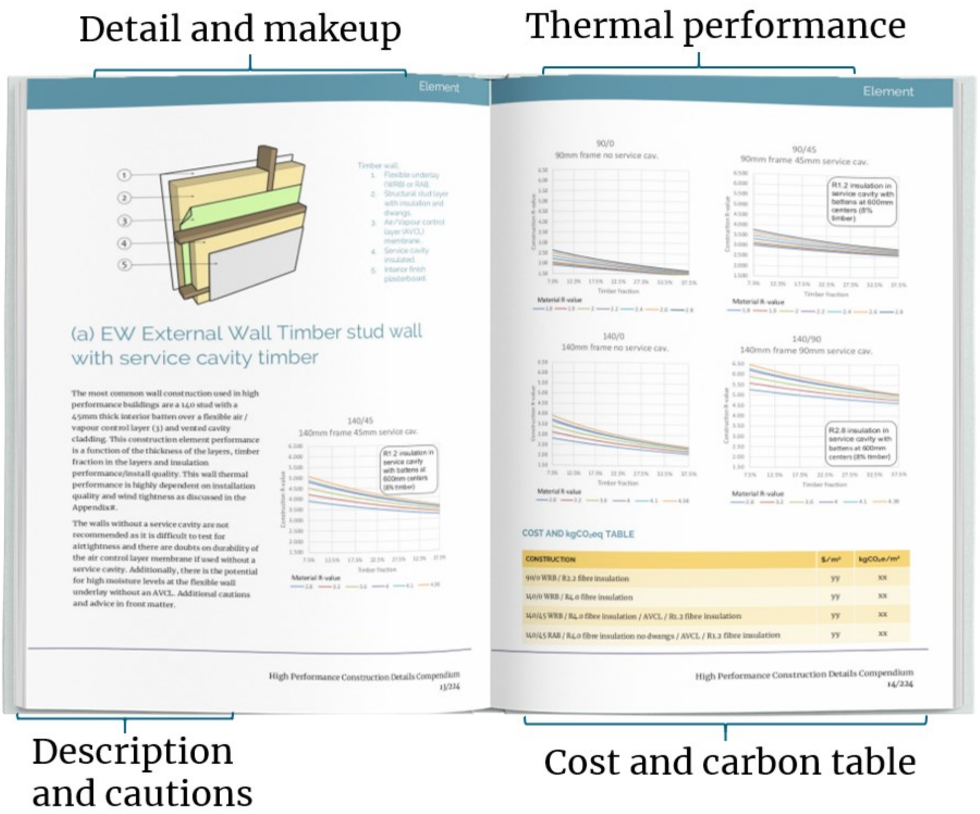


Figure 1: Understanding the Element pages.

A number of construction types are included:

- timber framing
- insulated concrete forms
- structural insulated panels and
- even one straw bale wall element.

The details are not theoretical; they have been successfully used in built projects in this country and demonstrate advanced practice already in use. The drawings contain generic products and materials that represent a broad spectrum of what is locally available. Due to the generic nature of the details, external moisture (Building Code clause E2) data is not provided; that technical advice is specific to individual products.

Elements vs junctions

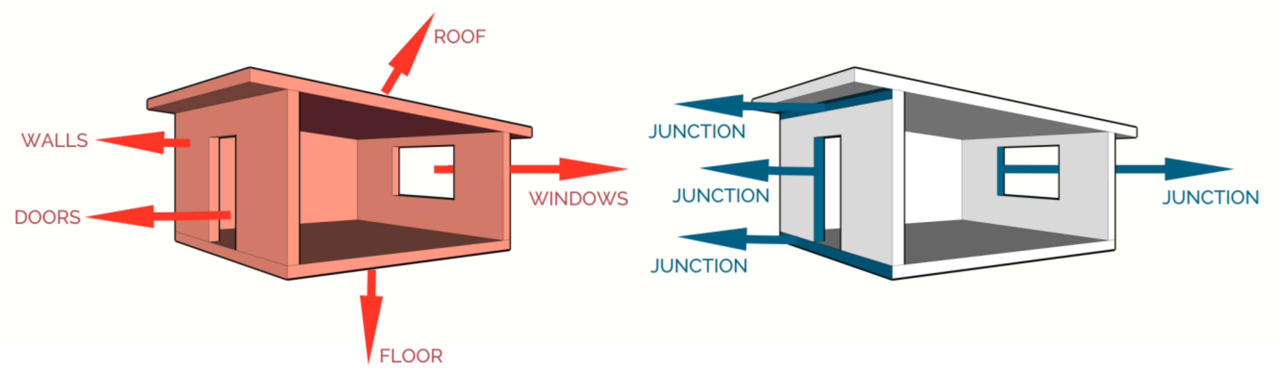


Figure 2: Elements (left) vs Junctions. High-performance buildings require Junction performance for sufficiently accurate predictive thermal modelling.

Both the Building Code and the New Zealand Green Building Council thermal performance (energy) modelling requirements are based on wall, roof, floor and window areas. These parts of the building fabric are *Elements.*

But as projects move towards higher thermal performance, Junctions become critical. Elements in high-performance buildings have such high R-values that the *Junctions* between them also need to be calculated: where the wall meets the slab for instance, or a window install detail. Beyond simple thermal performance, thermal bridges at Junctions should be checked for the minimum surface temperature factor or fRSI at the Junction.

Slab on-ground a special case

NZBC H1/VM1 references ISO 13370 as a means for demonstrating compliance of floor slabs. Since the ISO method uses internal dimensions and includes heat loss from the slab edge, the calculated R-values cannot be used with PHPP. Slab-on-ground floor Elements H & I R-values have been calculated using the ISO method and the Elements J & K ones have been calculated using some additional simplifications to the ISO method. This is discussed in more detail here [Thermal envelope connection to the ground]

$$Minimum\ Temperature\ Factor = \frac{Minimum\ interior\ surface\ temperature - External\ temperature}{Interior\ air\ temperature - External\ temperature}$$

This ratio is used as a simple indicator of mould risk with lower numbers indicating higher risk. New Zealand climates range from warm to cool-temperate and the [PHI Passive House Standard Building Criteria] sets different fRSI requirements accordingly. See Table 1 on page 25.

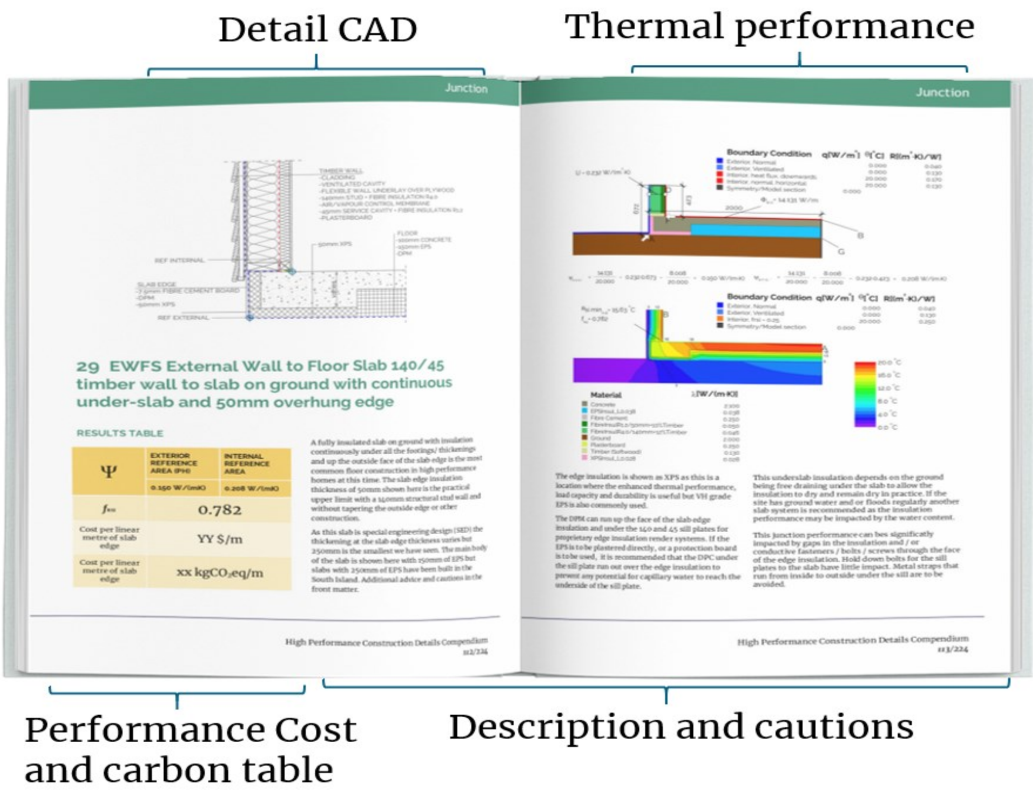


Figure 3: Understanding the Junction pages.

Looking to the future

In the longer term, this project and its outcomes will inform and support MBIE's [Building for Climate Change programme] and associated revisions to the Building Code. Current initiatives suggest the government has two main priorities in relation to construction: ensuring better quality homes (warmer and drier, plus cheaper to run) and mitigating climate change.

Building for Climate Change will require buildings with very high thermal performance. The first step to achieving this is *modelling* thermal performance (often called energy modelling).

A word of caution

A designer can take details from this handbook and incorporate them into a standard project to make incremental improvements to thermal performance. But: attempting to deliver a "high-performance" home that aims for significant improvements over Building Code without predictive thermal modelling is inadvisable. There is considerable risk of serious overheating and unnecessary cost, especially in warmer climate zones.

Building enclosure fundamentals

The point of higher thermal performance details is to reduce heat loss. However, with less energy flow through these details, drying potential is reduced. In order to have the same or better durability, drying potential must be increased. Adding insulation reduces heat loss but done incorrectly, it can increase the risk of interstitial condensation.

On top of this, our current practice assemblies are not durable enough and can fail international mould criteria[1]. They do not appear to be failing wholesale but if they are borderline, adding more insulation without increasing drying potential could cause mould to arise. It is important to model both retrofits and new designs to prevent such problems. The starting point is a clear understanding of building control layers.

Building control layers: a primer

The control layers are found in a building's enclosure. They are what separates the inside environment from the 'natural' environment outside. The enclosure includes everything from the paint on the outside of the wall cladding to the finish surface on the inside (including any wall-mounted mirrors). Sometimes the building enclosure is called the building envelope.

[11] Overton, G., BRANZ SR344 "Vapour Control in New Zealand Walls," 2016

There are four main control layers in a building's enclosure:

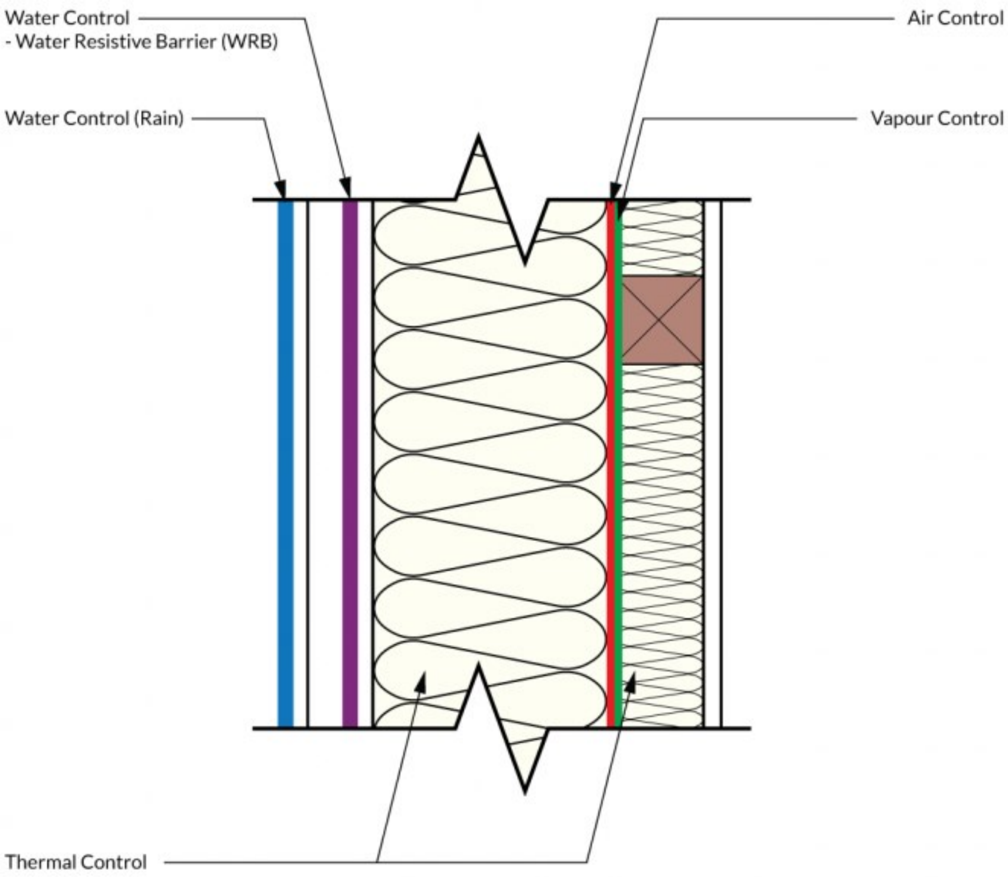


Figure 4: Four main control layers in a building's enclosure.

• **Water Control Layer(s)**

The external water control layer is the most important of the four as it keeps rain out of the building. It sheds the majority of incident rain load before it has a chance to penetrate further into the assembly. The second water control layer or 'water resistive barrier' provides a non-absorptive drainage path should any incident water bridge the cavity. Failures of both of these layers can be catastrophic which is why a cavity is usually adopted to provide some redundancy. 'Leaky building syndrome' failures with small leaks over a long period of time proved the most damaging, as they were not evident inside the dwelling.

• **Air Control Layer**

The air control layer prevents air leaking through the building enclosures. There have been many documented failures[2] caused by air leakage from the building interior carrying moisture into the walls and roof structures, where it then condensed and caused damage. The primary damage mechanism from interior moisture is air-carried moisture over vapour diffusion. The Elements that follow all have a specified AVCL to prevent this.

[2] Aggravated thermal bridging Malcolm Cunningham - 1 December 2011, *Build* 127
Too much moisture in the roof By Stephan Rupp and Dr Manfred Plagmann - 1 June 2018, *Build* 166
Solar fan reduced roof moisture By Stephan Rupp and Dr Manfred Plagmann - 1 June 2020, *Build* 178
Simulating school roof cavity Issue By Stephan Rupp and Stephen McNeil - 1 December 2015, *Build* 151

In New Zealand, failure of the air control layer is the cause of the much publicised problem of school roofs leaking when it is sunny. Residential and office building roofs have failed in climate zones as diverse as Wellington, Auckland and Queenstown for the same reason.

Walls can fail for similar reasons of air leakage of internal moist air but have less night sky cooling as the view factor is less and walls tend to leak less air. This is because roofs tend to have more penetrations (for example, downlights) or very air permeable suspended ceilings plus a fairly constant Δp of a few Pa.

• **Vapour Control Layer**
The vapour control layer manages moisture levels in the assembly by moderating vapour flow due to vapour diffusion through the building assembly. Most vapour control layers also increase the assembly's drying potential by becoming more permeable to vapour when the local RH is high. Vapour control layers moderate how moisture transfers directly through *materials,* as distinct from moisture carried on air leakage. Often the same physical layer controls air *and* vapour (eg plywood or AVCL membrane) but this is not necessarily the case.

Buildings in colder climates are more prone to condensation mainly because they require more insulation. In general, increasing the level of insulation in building assemblies reduces drying potential because less energy passes through the assemblies. And with many modern materials and assemblies not allowing as much vapour flow as traditional materials (eg plywood sheathing compared to weatherboards), the risk of condensation in well-insulated assemblies is increased further.

The key takeaway is that the drying potential of building assemblies must keep up with increased insulation levels.

• **Thermal Control Layer**
The thermal control layer is the least important of the four control layers with regard to building durability. However it receives the most attention due to a cultural focus on saving money on heating and increasing thermal comfort in traditionally cold homes. Water, air and vapour control layers must be defined and implemented correctly first. Only then is it suitable to pay attention to the thermal control layer. Thermal performance is a function of the thickness of the layers, timber fraction in the layers and insulation performance/install quality. This wall thermal performance is highly dependent on insulation installation quality as thermal bypass can reduce the wall performance by 30% or more[3].

All of New Zealand, despite the climatic range, is considered a heating climate: one in which more energy is required for active heating versus active cooling. In general, in heating climates, the air and vapour control layers should be inside, or mostly inside, the thermal control layer. This prevents moist interior air from contacting surfaces that are cold (due to being outside the thermal control layer) and then condensing. Note that the outside surface of the thermal control layer is often referred to as the thermal envelope.

Here are the most important considerations, in order to prevent thermal bypassing.

1. The thermal control layer is contiguous (eg at the roof wall Junction and around the windows to the insulation gap between the glass) and that it lines up.
2. There is no windwashing through the insulation.

[3] Siddall, Mark, "Thermal Bypass – The impact of natural and forces convection upon building performance," Green Building Magazine, (2009).

3. The insulation is fitted tightly without gaps.

How to fit the four control layers together

The four control layers must completely wrap around the building enclosure, including underneath. At every Junction in the building, the designer must understand how the control layers are kept continuous across the detail. If it is not understood at the design stage and communicated clearly via drawings, it will not be built correctly and will not function properly.

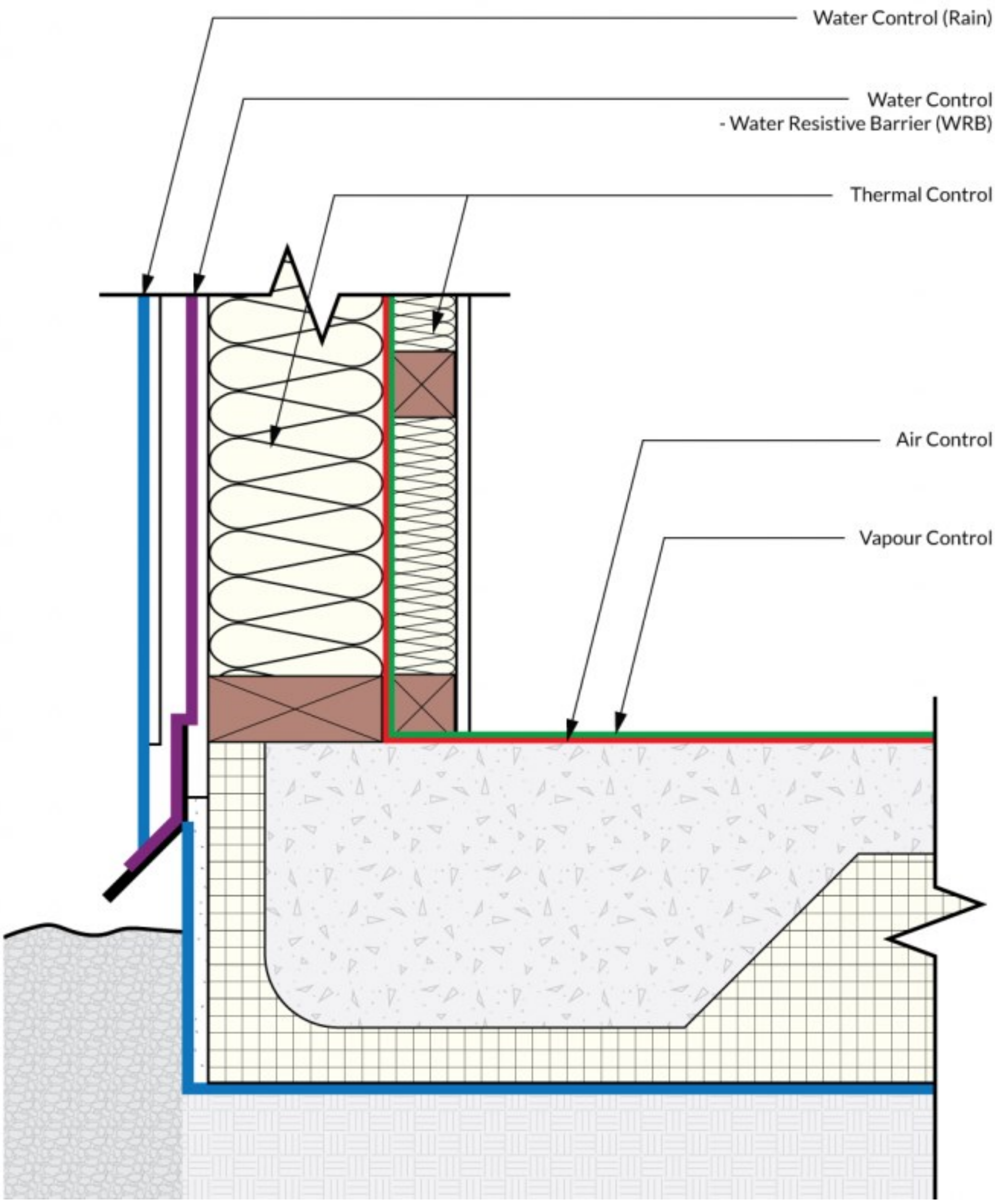


Figure 5: shows the four control layers where a wall joins a floor Junction. The concrete slab is acting as an air and vapour control layer (AVCL) (no membrane or coating is needed).

1. The exterior weather resistive barrier (purple) runs down to join the water control layer on the slab.
2. The air control layer (red) joins the top surface of the concrete slab to the inside surface of the air-tight membrane in this wall.
3. The vapour control layer (orange) is, in this case, at the same point in the wall assemblies.
4. The thermal control layer is contiguous, except for the point at the timber bottom plate.

Many common wall/roof constructions are moisture flow-through assemblies, designed to dry in both directions. This is good practice and should be encouraged. Throughout New Zealand, care must be taken with specifying impermeable layers such as vapour barriers. In general, the permeability of the control layers should increase from the interior to the exterior surface of the building. In other words, resistance to moisture transport by diffusion should be lower at the outer edge of the building. This applies to all heating climates.

Insulated service cavity

The design must specify good continuous control layers across all the sections and details. These layers then need to be installed correctly and protected from the occupants. The most common approach is to test the air vapor control layer (AVCL) as early as possible during construction, when there is still an opportunity to repair it if necessary. In practical terms, this requires a service cavity.

A service cavity is most commonly a secondary insulation layer usually to the inside of the structural Elements and the AVCL. It contains the wiring and plumbing in order to keep penetrations of the AVCL to a minimum. The service cavity can be left uninsulated but is usually insulated. Commonly, the AVCL is tested for air leakage before insulating the service cavity or installing the interior finish.

A wall service cavity is typically constructed by fixing 45x45mm timber battens to the inside of a flexible or rigid AVCL. The battens can be spaced to ideally suit the installation of insulation and mounting the interior finish lining; they are not structural. Wiring—and less commonly plumbing—is run in the service cavities in the walls. Unless recesses are designed into the air/vapour control layer, 45mm is the minimum for switch/outlets. A thinner service cavity is possible, but it increases the complexity of the AVCL as well as reducing the thermal benefit of the service cavity.

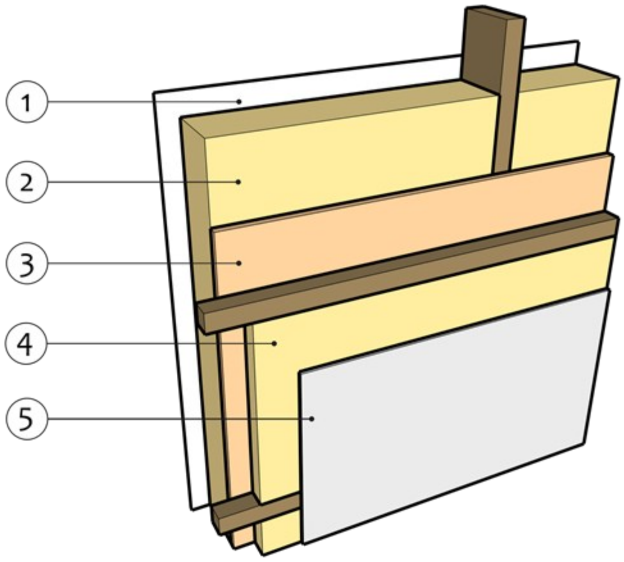


Figure 6: Element showing (4) 45mm service cavity to the inside of the rigid AVCL (plywood in this image).

For ceilings, the service cavity size starts at 35mm, with some builders preferring quite large cavities. Where needed, at least 120mm is recommended, to allow routing 90mm ducting below the air/vapour control layer. It should be noted that for the MVHR to achieve optimal efficiency the ductwork must be located inside the thermal envelope. The most common location to do this is inside the ceiling service cavity.

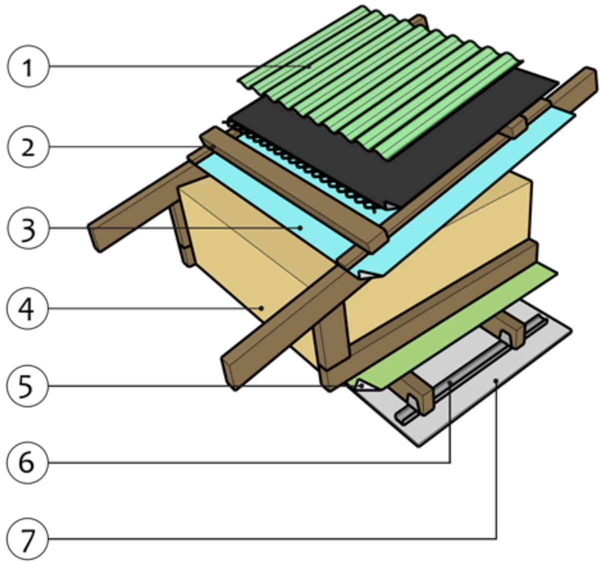


Figure 7: Element showing (6) timber blocking and metal batten system forming a ceiling service cavity.

fRSI explained

Thermal bridges are problematic if not managed for two reasons. The amount of heat loss is understood and quantifiable. Thermal bridges also lead to lower localised surface temperatures, which can be problematic from a moisture perspective. The details that follow include a surface temperature factor (fRSI) value, a metric which can then be assessed against a criterion for the risk of condensation and mould growth at the thermal bridge (for example, where a window joins the adjoining wall). This section explains what this number is, why it is used, alternatives and limitations.

fRSI is a dimensionless number between one and zero. Both 1.0 and 0.0 are impossible results[4] but the higher the number the better the result. Acceptable results depend on the climate zone (see Fig. 18 below).

A rough rule of thumb when it comes to mould is, "cold spots equal mould spots". If a surface is colder than the room, it cools the air immediately adjacent to it, raising the local relative humidity as a consequence. As an example, let's assume the warm and dry air inside a typical New Zealand home in the winter is 20°C and 60% relative humidity (RH). If the window sill is 15°C, the relative humidity at the sill's surface is >80%, high enough for mould growth to be likely. Note that fRSI is a constant, construction-specific value. It is independent of any temperature difference between indoor and outdoor climate.

To thoroughly assess mould risk is a little more complicated, because it involves the materials, the amount of time at high relative humidity and moisture storage capacity of the surface.

Best practice in assessing building assembly moisture durability and resistance to mould growth is to simulate the heat and moisture transfer over time. This is called hygrothermal modelling and it is performed using software like WUFI ®. The results are then evaluated using ANSI/ASHRAE Standard 160-2016, (Criteria for Moisture-Control Design Analysis in Buildings), which specifies criteria for predicting, mitigating and reducing moisture damage to the building envelope depending on climate, construction type and HVAC system operation.

Alternate approaches, like surface temperature comparison, are simplified and only consider the interior surface while not as accurate it is far quicker and thus less expensive to calculate.

A reasonable approach is to first calculate the surface temperature factor (fRSI) using Flixo or THERM for critical Junctions. The result can then be compared to the current PHI fRSI limits for the appropriate climate zone. This is relatively quick. If the assembly/detail is marginal, a more accurate check with WUFI is recommended (either the one- or two-dimensional versions).

Note that passing the PHI published fRSI moisture criteria does not mean the *building assembly* will not support mould growth internal to the construction assembly, as it is only valid for the internally exposed surface. Moisture inside the building assembly depends on convective air and moisture movement as well as storage and transmission (vapour permeability and capillary) in the materials and can be quite complicated to assess.

[4] fRSI 1 would mean the internal surface temperature at the thermal bridge is identical to the temperature of the rest of the building. This would be an excellent outcome but is physically impossible to achieve.

There is no requirement in the Building Code to meet the PHI fRSI moisture criteria. However, if the assembly fails this measure, it should be redesigned for the sake of occupant health and comfort and building durability.

The surface temperature criteria or surface temperature factor or minimum temperature factor (fRSI) should meet or exceed the PHI table of critical values. These critical values are region specific. The fRSI is a simple ratio using the indoor air temperature, outdoor air temperature, and the surface temperature.

$$Minimum\ Temperature\ Factor = \frac{Minimum\ interior\ surface\ temperature - External\ temperature}{Interior\ air\ temperature - External\ temperature}$$

The fFSI value has been calculated for each Junction detail in the handbook. Check the minimum fRSI value that applies to the climate zone where a specific project is located and whether the Junction meets that requirement.

To calculate fRSI, first model the Junction using ISO10211:2007 as would be done to calculate the thermal bridge coefficient. Then change the internal surface air film resistance to 0.25 m^2K/W. Find the minimum temperature and calculate the minimum temperature factor. Changes to the Junction's insulation level or geometry etc will in many cases require new calculations. This process is discussed here on the author's website.

fRSI is not a function of the temperatures used in the analysis for ISO10211:2007 calculations, as air cavity thermal conductivity is defined in ISO6946:2007 standard as only a function of direction of heat flow and thickness and not a function of temperature. fRSI of window frame assemblies with air cavities will change with external temperatures for ISO10077-2:2012 calculations, air cavity thermal conductivity is defined as a function of temperature (and cavity dimensions, surface emissivity and view factor).

Table 1: Minimum temperature factor fRSI=0.25 m2K/W required for each NIWA climate zone at the station altitude. The climate zone and thus the fRSI requirements also vary with altitude as the average temperatures typically drop by 0.6C per 100m of elevation gain. fRSI requirements from PHI Passive House Standard Building Criteria.

fRSI	TMY	Station	Territorial Local Authorities
0.55	NL	Kaitaia	Far North, Whangarei, Kaipara
0.55	AK	Auckland	Rodney, North Shore City, Waitakere City, Auckland City, Manukau City, Papakura, Franklin, Thames-Coromandel
0.65	HN	Ruakura / Hamilton aero	Hauraki, Waikato, Matamata-Piako, Hamilton City, Waipa, Otorohanga, South Waikato, Waitomo
0.55	BP	Tauranga	Western Bay of Plenty, Tauranga, Whakatane, Kawerau, Opotiki
0.65	RR	Rotorua	Rotorua
0.65	TP	Turangi / Taupo	Taupo, Ruapehu, northern Rangitikei
0.55	NP	New Plymouth	New Plymouth, Stratford, South Taranaki, Whanganui
0.55	EC	Napier	Gisborne, Wairoa, Hastings, Napier City, Central Hawke's Bay
0.65	MW	Paraparaumu	Southern Rangitikei, Manawatu, Palmerston North City, Horowhenua, Kapiti Coast
0.65	WI	Masterton	Tararua, Upper Hutt City, Masterton, Carterton, South Wairarapa
0.65	WN	Wellington	Porirua City, Hutt City, Wellington City
0.65	NM	Nelson	Tasman, Nelson City, Marlborough, Kaikoura
0.65	WC	Hokitika	Buller, Grey, Westland
0.65	CC	Christchurch	Hurunui, Waimakariri, Christchurch City, Banks Peninsula, Selwyn, Ashburton, Timaru, Waimate
0.70	QL	Queenstown	Queenstown-Lakes
0.70	OC	Lauder	Mackenzie, western Waitaki, Central Otago
0.70	DN	Dunedin / aero	Eastern Waitaki, Dunedin City, Clutha
0.70	IN	Invercargill	Southland, Gore, Invercargill City
0.65	CI	Waitangi	Chatham Islands (non-NIWA hourly file)

Two important assumptions underpin the analysis of surface temperature:

- the building is ventilated building properly—preferably a mechanical ventilation system with heat recovery (MVHR) or at least continuous extraction; and
- no bulk water leakage into the assembly.

Otherwise, conditions would depend so heavily on occupant behaviour or external water penetration that accurate predictions are impossible. For example, if the entire building is always very humid, mould can develop no matter how well-designed the building. Similarly, if the roof/wall leaks, problems will arise no matter which assembly is chosen.

Timber fractions

In order to accurately predict the heat loss of a building, the most important parameters to get correct are the performance of the large Elements in the building: walls, roofs, floors. Calculation of these performance values depends upon accurately estimating the amount of timber in the construction. If 20% timber in the wall assembly is assumed, but it's actually 50%, the heat loss model will be wrong.

H1/VM1 clause 2.1.3.3 requires: (abridged)

> *The construction R-values of building elements shall be calculated as follows:*
>
> *b) For framed walls, the R-value shall include the effects of studs, dwangs, top plates and bottom plates, but may exclude the effects of lintels, sills, additional studs that support lintels and sills, and additional studs at corners and junctions;*

The thermal bridge calculations account for the timber immediately at the Junction. This means if a slab-edge calculation shows the bottom plate, the bottom plate timber is accounted for in the thermal bridge and does not need to be added to the timber content of the wall. This works the same for the windows sills, jambs and heads.

This handbook's details assume the sill is a single 45mm thick timber, while the jamb has two 45mm thick studs. The head is assumed to have a 140 mm thick timber lintel. The figure below shows the timber highlighted in red which does *not* need to be accounted for in the wall timber content, provided the thermal bridge calculations have been calculated and included in the overall assessment of the building.

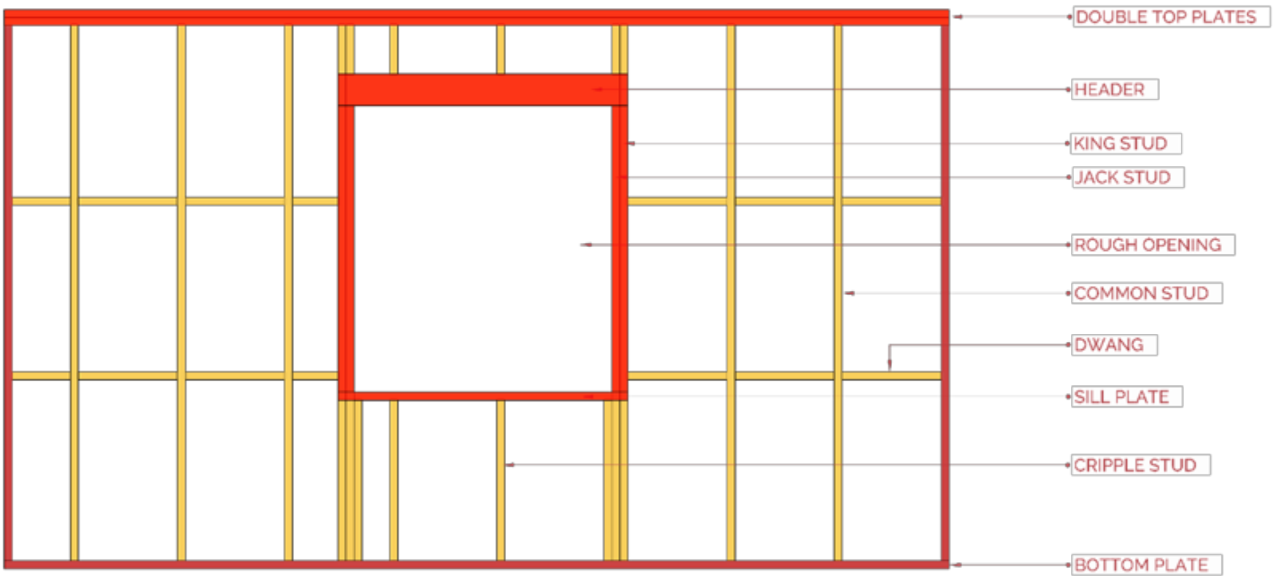


Figure 8: Timber to count with a 140mm tall timber lintel - accounted for in the thermal bridge of the window head.

If there is additional timber beyond that accounted for in the thermal bridge calculation, either a new thermal bridge calculation needs to be completed or the additional timber can be accounted for in the wall timber content fraction. Figure 9 below shows a much taller lintel then the standard 140mm and this would likely need to be accounted for in the wall timber content.

The additional studs underneath the window and the dwangs/nogs etc *need to be included* in the wall timber content. (Beacon Pathways' recent report on measured timber content in walls showed >30% timber fraction for typical pre-nailed frames[5].)

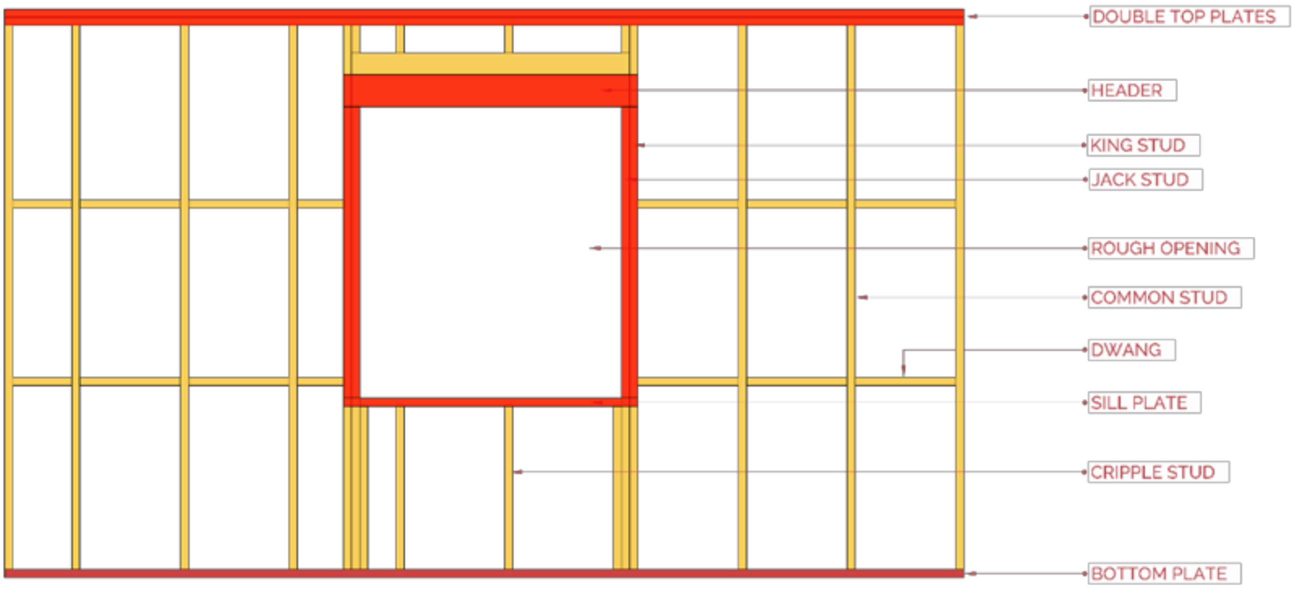


Figure 9: Timber to count with a 240mm tall timber lintel. This additional timber beyond 140mm needs to be added to the wall timber fraction.

5 BRANZ ER53 Measuring the extent of thermal bridging in external timber-framed walls in New Zealand (August 2020)

Cost and Carbon

Capital cost and embodied carbon needs to be considered when designing and building high-performance buildings. Our clients will keep us focused on cost and MBIE's Building for Climate Change programme will focus the industry on the embodied carbon. To help us make good choices early in the design process, all of the Elements and many of the Junctions are costed and the embodied carbon calculated.

Cost

— Lindsay Wood

Each detail is estimated as a combined cost of the materials and labour needed to construct the detail. The costs are in $NZD (at 2020 material and labour rates), exclude GST and are estimated as $/m², and $/m respectively. They do not include contractor's or contingency margins, consenting or professional fees, special plant or preliminary and general ("P&G") items (except for formwork as described below).

To reduce distortions due to edge effects (eg, surplus building wrap or inefficient joist spacing), the approach has been to estimate very large quantities of generic construction (typically 10,000m² of floor plan, or 1000m of Junction length) and then reduce the resultant totals to /m² or /m figures.

Effort has been made to align estimates with code requirements (especially NZS 3604:2011) and common construction practice, but the wide variety of possible circumstances mean that this should be taken as indicative rather than assured.

All estimates assume a level building platform, non-expansive soils with 100 kPa minimum safe bearing capacity and straightforward builder's access and site management. Cost rates reflect those for a conventional lump sum contract.

Constant usable space: It is desirable that variable details are measured to try to achieve the same usable room sizes and ceiling heights and this approach has been adopted here where viable. However, this can be impractical to achieve in the present context of estimating individual details, especially for some specific elements. Thus, a potential variation of wall thickness (eg between 90mm framing and 300 I-Joist with service cavity) would have significant cost and carbon implications for overall building size and associated floor and roof areas (notionally another 10%, or 10-15 m², on an average house). Similarly, for different under-slab insulation thicknesses, there are also variations in excavation, hardfill etc in order to leave the same ground-level-to-floor-level dimension. For variable roof construction, ceiling heights are in the main kept constant. (In real projects, such considerations might also have a bearing on things such as boundary clearances.)

Such integrated or whole-of-building estimating is largely beyond the scope of this project but they should be factored in when making overall cost or carbon comparisons as their impacts may be substantial.

Comparison not aggregation: The primary purpose of these estimates is to enable general comparison between HPCD construction and standard construction and, in some cases, between variants of those. This in turn assists in relating thermal, energy and carbon impacts of detail selection to the corresponding cost implications. The cost estimates do not claim to be all-inclusive for the details they cover, nor are they suitable for aggregation to estimate overall building costs.

Materials: Quantities are generally based on well-established formulae incorporating commonly accepted wastage factors (see also "wastage" below).

Where possible, prices are derived from builders' merchant's rates (current as at December 2020) with discounts suited to a medium-sized residential builder. This applies to the great bulk of materials. Otherwise, rates are derived from the most reliable source available.

Labour: Builder's carpentry labour has been based on a rate of $60/hour, being a representative average across the various skill levels. Labour quantum is derived from accepted labour factors ("labour constants") with some adaptation for complexity, novelty etc.

Subtrades: Due to the nature of the details, few subtrades are estimated. They are only included where they are an intrinsic part of the pricing needed for comparison (eg, roofing, wallboard stopping or painting) and are estimated with labour and materials rates combined. Such rates come from specific trade operators, Resilienz's own knowledgebase, or from sources such as *QV costbuilder*.

No building services have been estimated, except spouting associated with eaves details.

Wastage: Although most products have conventional wastage factors, some wastage is dependent on that measured for other products (eg, fixings for flooring incorporate the wastage built into the flooring material itself), and some are based on general allowances rather than wastage factors. (Please note the way wastage is used in costing is not identical with that for carbon calculations.)

Apart from wastage, formwork comprises the only material measured that is not to remain in the finished building. This has been measured in some detail and assumes a proportion of reuse (typically 50% for normal construction and 75% for waffle/pod slabs).

Regional variation: There are considerable regional variations across materials and labour, site and code requirements, building practices, and even aspects of carbon footprinting. These have been adopted to try to make each category representative in a way that assists comparison *within* that category, but should not be taken as consistent *between* categories. Thus, embodied carbon has all been calculated for Zone 1 (Auckland), but foundations are not based on Auckland's expansive clay soils; and while material costs are representative of those in major provincial centres, exposure and wind zones are notional approximations that potentially fit a wide range of locations.

Reliability generally and fixings specifically: Because estimates for main building (carpentry) work are prepared in considerable detail, with current rates, and on well-proven software, there can be good confidence in underlying general reliability. However, variations (such as in sites, building practices, codes and technology) mean that assumptions and approximations are inescapable.

In estimating Elements there has been a general allowance for typical complexities *within the aspects of construction already being measured* (e.g., for a percentage of bracing linings in walls) but no allowance for subtrades (such as building services), that may or may not occur in such Elements.

To enhance suitability for estimating details separately, timber has been estimated as site-cut and assembled. Thus, labour and wastage suit in-situ frame construction rather than prenailed frames.

Special engineering design (SED) input is more commonly required for HPCD details compared to standard details, but corresponding professional fees are not included in the estimates.

There are a few estimates of specialised or unconventional systems of construction such as straw bale and these are based on more broad-brush generic rates, with correspondingly lower accuracy.

Fixings deserve a special explanation as they may be complex, often offer multiple choices and are frequently impracticable to estimate with precision. In Resilienz’s experience, common practice is a blend of specific fixings measured to suit, plus an allowance per metre squared depending on the nature of the building. This is at best an approximation, but becomes even more so when broken down into allowances per Element or Junction, as is the case here. Thus, while we have given these careful consideration, and have endeavoured to be consistent in our approach, we highlight the higher level of approximation that applies to quantities and costs associated with fixings.

Changes in rates: These estimates have been prepared in late-2020/early-2021 during the global Covid-19 pandemic. The NZ economy was unexpectedly buoyant and causing notably increasing costs in the construction sector. These increases have not been fully captured in these estimates, and as a rule this means that the intended comparisons should remain valid, but overall costs less so.

Please note that factors used in carbon calculations are also subject to variation, primarily due to progressive refinement of available data, but potentially also due to new practices or technologies.

Carbon

—David Dowdell

Explanation of the carbon footprint figures contained in the details

Each detail in this document includes its embodied carbon footprint. This estimates the potential climate change impact, due to emission of greenhouse gases, emitted due to construction of the detail.

For element details, the carbon footprint is expressed per metre squared and for Junction details, it is expressed per linear metre.

The scope of the carbon footprint calculation includes manufacture, transport and installation of materials (LCA modules A1 to A5), and therefore does not include any potential emissions beyond construction (for example, due to any ongoing maintenance and replacement of materials during the building service life, and deconstruction/demolition at the building end-of-life).

Carbon footprints are, by convention (but not always), calculated by taking the mass of a material and multiplying it by a material-specific embodied carbon factor, in units of kg CO_2eq/kg (for example). The kg CO_2eq is calculated using global warming potentials (GWP). GWP reflects additional atmospheric radiative forcing relative to a reference gas (carbon dioxide) over a specific timeframe, which is typically 100 years. This timeframe is important because the GWP of greenhouse gases vary depending on the timeframe considered for their derivation. For example, a greenhouse gas with a shorter atmospheric life such as methane has a higher GWP over a shorter timeframe of say, 20 years, in comparison with its GWP over 100 years. Note that carbon dioxide, because it is the reference gas, has a GWP of 1.

Therefore, calculated carbon footprints in this document are an estimate of the additional radiative forcing in the Earth's atmosphere over a 100 year period due to manufacture of the materials in the details and their construction in a building.

This has an implication for bio-based materials and, in particular, timber and engineered woods. Since the full life cycle of the building in which the details may be used is not within the scope of this document, a conservative approach has been adopted in which carbon dioxide removed from the atmosphere (through photosynthesis) to provide temporary carbon storage in these materials is excluded from the tables containing the carbon footprint calculations. This removal of carbon dioxide from the atmosphere reduces additional radiative forcing that contributes to climate change. If timber or engineered wood is produced from sustainable forestry (for example, FSC or PEFC certification), then this removal of atmospheric carbon dioxide can be included in a carbon footprint assessment.

Here, we do not know if these materials will be sourced from certified sustainable forestry, nor does the carbon footprint calculation include the timeframe over which the sequestered carbon will remain temporarily stored in the detail, and what happens to it afterwards (for example, a proportion may continue to be stored in landfill following demolition, or it may be combusted, releasing the stored carbon back to the atmosphere as carbon dioxide).

Therefore, a statement is separately provided in each detail (where relevant) which quantifies the potential benefit of this temporary carbon storage assuming the Element or Junction detail remains in-place in a building for 100 years.

Data quality for the calculation of the carbon footprints can vary considerably depending on the source(s) of underlying data used. Where possible, data from relevant Environmental Product Declarations (EPDs) are used, for example, registered on EPD Australasia (epd-australasia.com). In the absence of such data, generic data are used, as well as scenarios representing activities such as logistics to the construction site. For further information about data, Appendix A of the BRANZ SR418 study report can be downloaded at branzfind.co.nz/.

Further notes

- Part of the carbon footprint calculation includes a provision for logistics to the construction site, which varies depending on specific conditions such as the source of material, location of the build and mode of transport. For the carbon footprint calculations in this document, generic transport distances for Auckland are used, summarised in the "Construction transport (module A4)" datasheet available at branz.co.nz/buildinglca under "Data".
- There are remaining data gaps in the carbon footprint calculation, such as operation of a construction site office, use of power tools and disposal of packaging waste. These are likely to be of lower significance. Additionally, employee transport to manufacturing and construction sites is excluded.

How to use the detail calculations to assess overall heat transfer in buildings

This chapter is for those professionals who are already using energy modelling software, very likely architects, designers and building scientists who are certified Passive House designers and consultants familiar with using the Passive House Planning Package or other energy modelling software. Training and certification is available through PHINZ for those interested in extending their skills. Otherwise, projects can hire a consultant to work alongside the architect or designer in order to feed data about energy performance back into the design.

To use the cost and carbon calculations, it is straightforward to add up the total amount of each Element and Junction used in the project.

The thermal performance is slightly more complicated to assess. Calculate the overall building heat loss, consider which details need to be improved and by how much and finally check surface temperatures to ensure cold/mouldy surfaces are not being created. Element performance is calculated using ISO6946:2007, which is a one-dimensional calculation similar to NZS4214:2006, except for the slab on-ground Elements which include the edge losses see later Thermal envelope connection to the ground.

The detailed thermal calculations provide data on performance, surface temperatures and thermal comfort. (Note that thermal comfort is a complicated topic and outside the scope of this handbook[6].)

Calculate the overall building heat loss either by entering the thermal performance values into an energy modelling tool or by way of simple hand calculations that estimate the overall heat transfer for the building. This chapter will lay out the steps in this hand calculation process, taking a simple building as an example. It will also outline which details are needed—and which are not.

Reviewing the calculations for the example building is the quickest way to understand the impacts of the different Elements and Junctions details.

In timber-framed buildings on a concrete slab (the most common construction in New Zealand) prioritise:

- Use the timber fraction that will actually[7] be built for the roof and walls.
- Understand the area-to-perimeter ratio for the concrete slab on-ground and how the edge and under-slab insulation impacts that.
- Evaluate the most significant thermal bridges from Junctions. These are typically window installations, wall-to-floor and midfloor junctions. Using the pre-calculated thermal performance

[6] PHPP addresses thermal comfort for windows using a conservative methodology that combines the PSI install, frame, glass edge (spacer) and glass to create an installed window U-value to compare to an overall U-value limit. ISO7730 or ASHRAE55 (largely equivalent) offer a calculation methodology that can be used for more general thermal comfort calculations.
[7] The timber fraction is often higher than the design team estimates see BRANZ ER53(2020).

values, select the appropriate Junctions for your project and understand how they impact on building performance.

It is not unusual to have projects focus on the wrong items. Examples include spending a lot of money on a very good slab-edge detail, when better outcomes would have been achieved by spending much less money on a good window install.

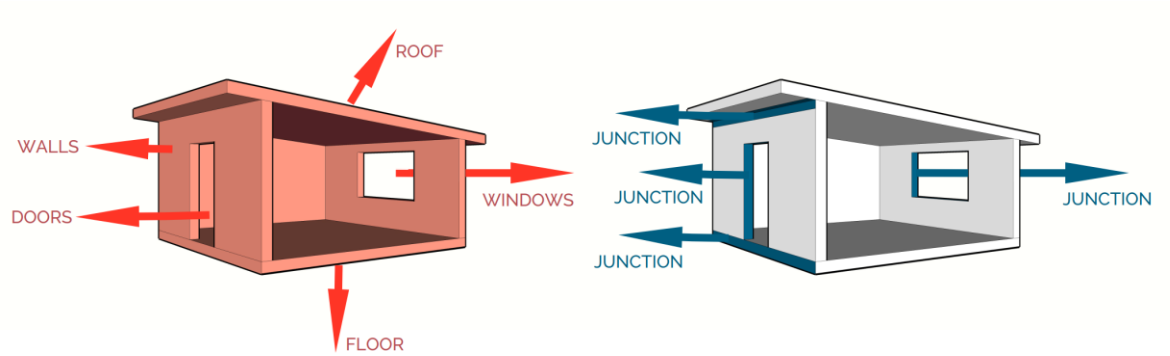


Figure 10: Building elements and junctions contribute to the overall heat transfer.

Our example for the purpose of illustration is a simple bach-like structure, shown in the figure below. It has six surfaces: roof, floor and four walls. The windows and doors complete the thermal envelope. To model its heat loss, we must understand the heat loss from the area-based Elements (eg six surfaces and the windows and doors).

These can be modelled with sufficient accuracy by using an area-based R-value for each Element for low-performance buildings and existing practice for H1 calculations performed to satisfy the Building Code.

But it's not enough to include only the heat loss through the Elements in high-performance buildings. The additional heat loss at the junctions (for example the installation of windows into the wall) is large enough that the results can be wrong by 5-10%. This error is large enough that a client could be misled as to the building's performance. Instead, more detailed thermal analysis is required: the thermal bridge value must be calculated. This is typically done using ISO 10211:2007 and can be complicated. Fortunately, once the thermal bridge value is calculated, it is relatively simple to apply the value to the performance model and it will be accurate enough for a high-performance building.

Junction heat loss is important in high-performance buildings because the Element heat loss has been reduced significantly. Thermal bridge values are correction factors which account for the Junctions. Using a thermal bridge atlas or this handbook, it is possible to manually calculate the impacts of thermal bridges and quite quickly experiment with alternatives. Calculating thermal bridges separately from the Elements of the building means the same calculation can be applied across multiple projects, speeding the design process.

Thermal bridges explained

Thermal bridge calculations are of two types.

Length-based thermal bridges, eg between a wall and floor slab where the bridge runs along the Junction between the wall and slab. These are PSI (ψ) values expressed in W/(mK), Watts per metre-Kelvin.

Quantity based thermal bridges, eg a steel beam poking out of an insulated wall to support a balcony. These are CHI (χ) values expressed in W/K, Watts per Kelvin.

The overall heat loss of a building is a function of the area-based Elements and the length- or quantity-based Junctions. The total heat loss of the building can be written as a simple equation using R-values (or U-values) for the Element area-based heat losses:

$$\sum \frac{Areas(m^2)}{R\left(m^2K/_{W}\right)} + \sum \psi\left(\frac{W}{mK}\right) \times Lengths(m) + \sum \chi\left(\frac{W}{K}\right) \times quantity = Heat\ Transfer\left(\frac{W}{K}\right)$$

or

$$\sum U\left(\frac{W}{m^2K}\right) \times Areas(m^2) + \sum \psi\left(\frac{W}{mK}\right) \times Lengths(m) + \sum \chi\left(\frac{W}{K}\right) \times quantity = Heat\ Transfer\left(\frac{W}{K}\right)$$

This will become clearer as we apply the calculations to our example building. But first, it's necessary to clarify what areas and lengths are measured. The first step to understanding the areas: know where the thermal envelope of the building is located. This is simple with a six-sided cube but is more complicated in a more typical complex building shape.

The illustration below depicts a relatively small building with skillion roof, a ventilated attic, a knee wall and attached garage. These elements can confuse where the thermal envelope is located —it's the surface that separates the conditioned from unconditioned spaces. Unconditioned garages and basements are classified as unconditioned spaces even though they are warmer than the outside temperature. Once the walls and floors of these unconditioned spaces are properly insulated, they act much more like outside in terms of both temperature and fluctuations.

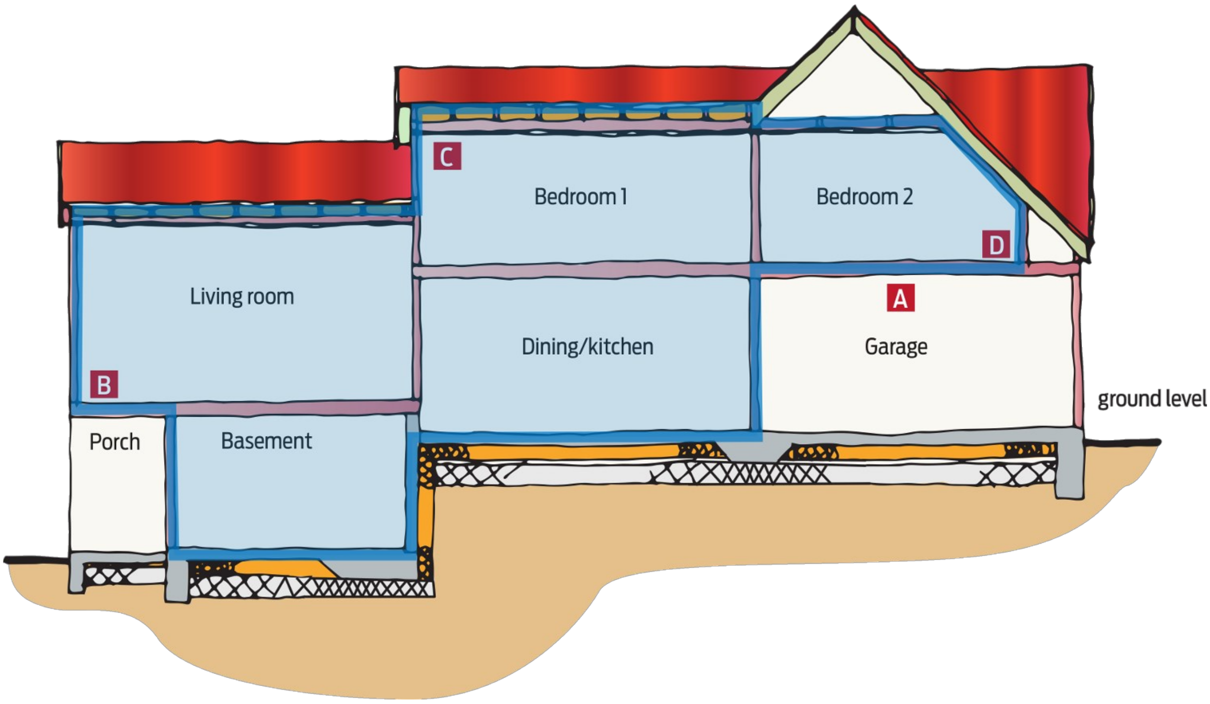


Figure 11: The thermal envelope is the surface between conditioned and unconditioned space. Illustration from *Build 159 34 Design Right Thermal Envelope Basics*.

Next, it is important to know exactly where the heat transfer surface is located. This will affect the areas measured and this is significant because the heat loss is the area of the Element divided by the R-value. The New Zealand Building Code notionally used to use internal dimensions for H1 calculations by referencing NZS 4218: 2009 "Thermal insulation – Housing and small buildings" but this has been removed in all H1 Version 5 (29Nov2021) documents.

Figure 12 shows the three ways typically used to measure building dimensions in order to calculate heat loss: internal dimensions, overall internal dimensions or external dimensions. Each system selects different points to measure between. Using external dimensions produces the largest area and so its thermal bridge correction value will be correspondingly the smallest. Passive House methodology exclusively uses external dimensions. In this case most thermal bridge Junctions in timber-framed buildings can be neglected (provided the regularly repeating timber content is accounted for in the construction R-value) as they will be small or negative.[8]

If internal dimensions are used, most Junctions will be a positive thermal bridge and would require calculation. The author recommends using external dimensions for all calculations, but this handbook also provides the value for overall internal dimensions. Note that the slab-on-ground Elements R-values are calculated using the default R-value calculation method in ISO 13370 and are therefore referenced to internal floor dimensions. Using ISO 13370 and internal dimensions means the R-values calculations are consistent with international best practice and more useful than just the schedule and calculation methods of H1/AS1. The slab-on-grade R-

[8] Negative thermal bridges are common using external dimensions. This is because you are using slightly larger areas to estimate the heat loss from the building. When you calculate the actual heat loss at the Junction you can find the thermal bridge value is negative. This simply means that your estimated heat loss is slightly too high and the thermal bridge corrects this downwards.

values are not intended to be used with PHPP so have not been referenced to the overall external dimensions that are used with PHPP and therefore cannot be used with PHPP.

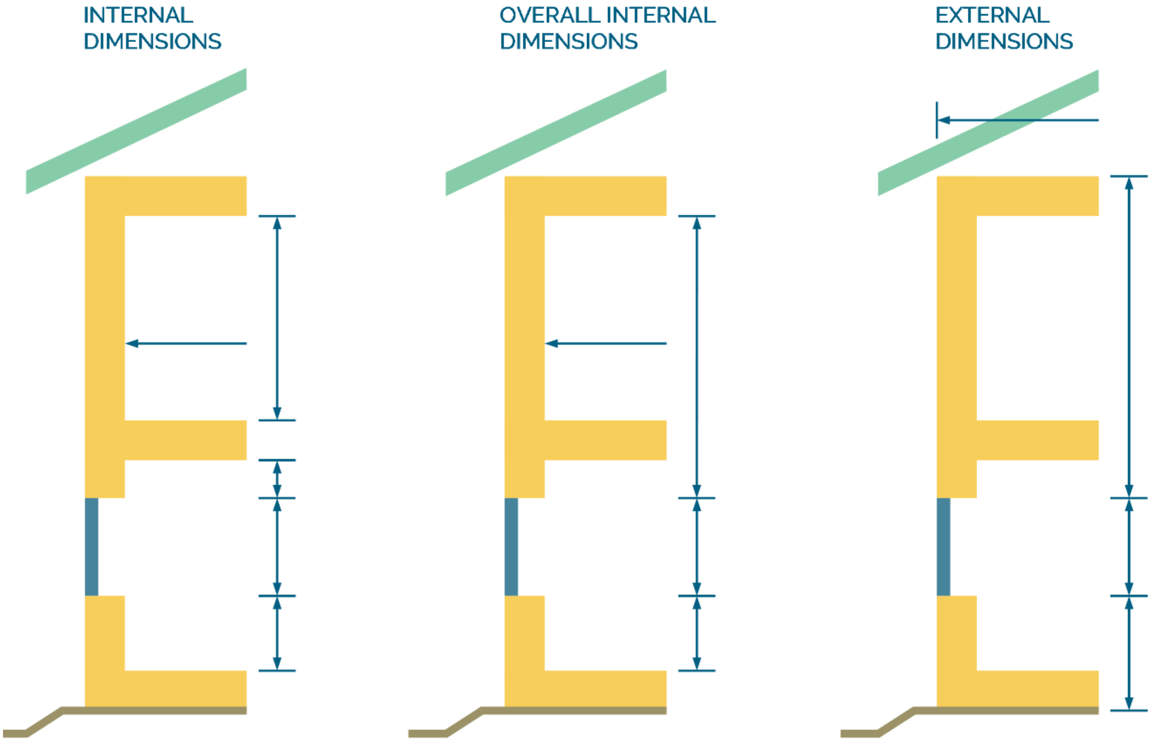


Figure 12: Area of the thermal envelope is measured using one of the following three systems normally used for component dimensioning: internal dimensions, internal overall dimensions or external dimensions. NZBC uses internal or internal overall depending on the project. The area is largest when using external areas and this area measurement is required for use in PHPP and the NZGBC V5 ECCHO tool based on PHPP. Illustration based on Berggren et al 2018.

Pick one dimension system for calculating thermal bridges in your energy model and use it consistently. This is an important and it is fundamental to choose which approach is being taken (inside dimensions or outside dimensions) and be consistent. External dimensions are recommended.

Let's consider two example corners to explore the implications of different dimension systems. Note that this matters most in the case of a complex building shape.

In Figure 13 below, the graphic on the left shows an *external wall*, with the exterior surface shown in light blue. External dimensions measure from the very outermost point of the corner. This means the thickness of the wall is counted twice when the areas are added up, producing the smallest possible thermal bridge ψ value (negative in this case, -0.15 W/(mK)). In contrast, using internal dimensions would produce a result of 0.10 W/(mK).

The graphic on the right shows the *internal corner of an external wall*. External dimensions produce the smallest area and the correspondingly largest thermal bridge ψ value (0.10 W/(mK)) compared with -0.10 W/(mK) if calculated using internal dimensions.

If the external reference area is used, it is not necessary to calculate the corner thermal bridges because the internal corners are offset by the external corners. This reduces the overall amount of analysis required for typical timber structures, saving time and effort.

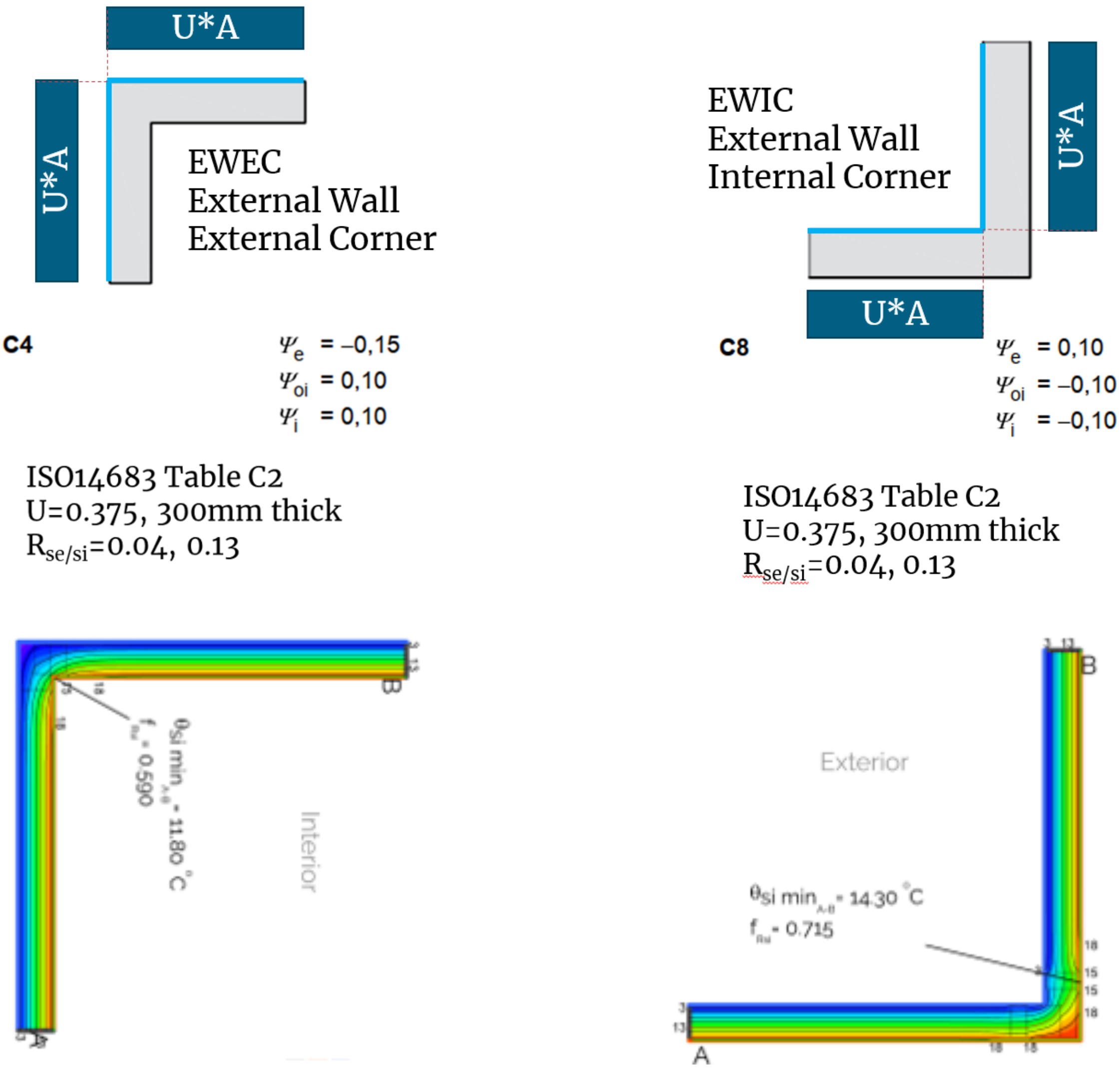


Figure 13: Thermal bridge values for corners and dimension systems.

Thermal envelope connection to the ground

The final factor to consider when defining the thermal envelope is the thermal envelope connection to the ground. If the building has a slab on-ground or a suspended floor, the heat loss is reduced due to the ground's thermal resistance. This reduction in heat loss can be significant and the calculation of this reduction is handled differently depending on how the result is to be used.

For both NZBC and PHPP, the first step is to define the perimeter. This is the length of wall between conditioned and unconditioned space. Figure 14 below shows the perimeter for a moderately complicated building. (Note that the wall between the (unconditioned) garage and the heated interior of the home is part of the perimeter in this example[9].) The perimeter length will be slightly different for NZBC and PHPP as the NZBC will measure the perimeter at the inside of the external wall and PHPP will measure to the external surface.

Next, determine the slab on-ground area which will then be the area inside of the perimeter (either internal or external). Divide the floor area by the perimeter to produce the area-to-perimeter ratio, A/P. (Passive House uses the term B'/2 for the floor non-dimensional width: A/P = B'/2). The A/P ratio is used because the benefit of the ground thermal resistance is primarily a function of the A/P ratio for a given ground conductivity and climate and not a function of the area of the floor. The generic floor R-values presented in the tables in H1/AS1 Appendix F use the default ISO 13370:2017 practice of the R-value being defined in terms of the overall internal slab area-to-perimeter ratio, rather than the external slab (full) dimensions.

Equation F.2 from H1/AS1 can be used to calculate the slab area-to-perimeter ratio from the slab's external dimensions.

$$\text{slab area} - \text{to} - \text{perimeter ratio} = \frac{A_{slab,external}}{P_{slab,external}} - \frac{wall\ thickness}{2}$$

The tables in H1/AS1 (or charts in this handbook) can then be used to look up the R-value for a floor with that floor area-to-perimeter ratio.

For PHPP the ground heat loss is calculated using specific inputs to the ground sheet which estimate the monthly heat loss based on the methodology in ISO13370:2007 and calculates monthly ground temperatures below the slab. PHPP then uses these monthly ground temperatures and the slab thermal transmittance along with slab edge and floor to ground thermal bridge PSI values to calculate the heat loss/gain from the ground. The Passive House approach splits the heat loss into wall to floor slab edge losses (multiplied by the perimeter) and the slab area losses (multiplied by slab area) following a similar pattern as the rest of the area and thermal bridge accounting used for the rest of the thermal envelope.

[9] If one of the walls were part of an adjoining building, such as in a duplex, this would not count as part of the perimeter as there would be no heat loss along this length.

For NZBC compliance the slab-on-ground R-value can be looked up in H1/AS1 (5th edition, Nov2021) Appendix F or the Elements H, I, J, K R-values are provided in this Handbook or, if the case is not available, the R-values can be calculated using H1/VM1 Appendix F methods (5th edition, Nov2021). This R-value represents the annual heat transfer (and thus is not appropriate to use in monthly or hourly energy models such as PHPP or EnergyPlus) and includes both the wall to floor slab edge losses and the slab area losses. The R-values in Elements H,I,J,K are two-dimensional numerical calculations using ISO 13370, and using ISO 10211 based geometrical models. The models used a floor width equal to half the characteristic dimension of the floor, and used overall internal dimensions (ignoring internal partitions, as per ISO 13789). The R-values in Elements J & K, the slab-on-ground floors with waffle pods (ie inhomogeneous construction) were calculated using a combination of simplified two & three dimensional numerical calculations. For Elements J, the two-dimensional calculations were further adjusted to closely match the corresponding cases in H1/AS1.

It is important to note that the wall to floor slab edge Junction PSI values for a given floor R-value (ie External Wall to Floor Slab perimeter Junctions) change only slightly with A/P ratio for reasonable values of A/P between 1.25 and 4 m. Because of this the Handbook has used an A/P ratio of 2m (external dimensions) for all Junction PSI calculations. [For more information see this technical article on the authors website.]

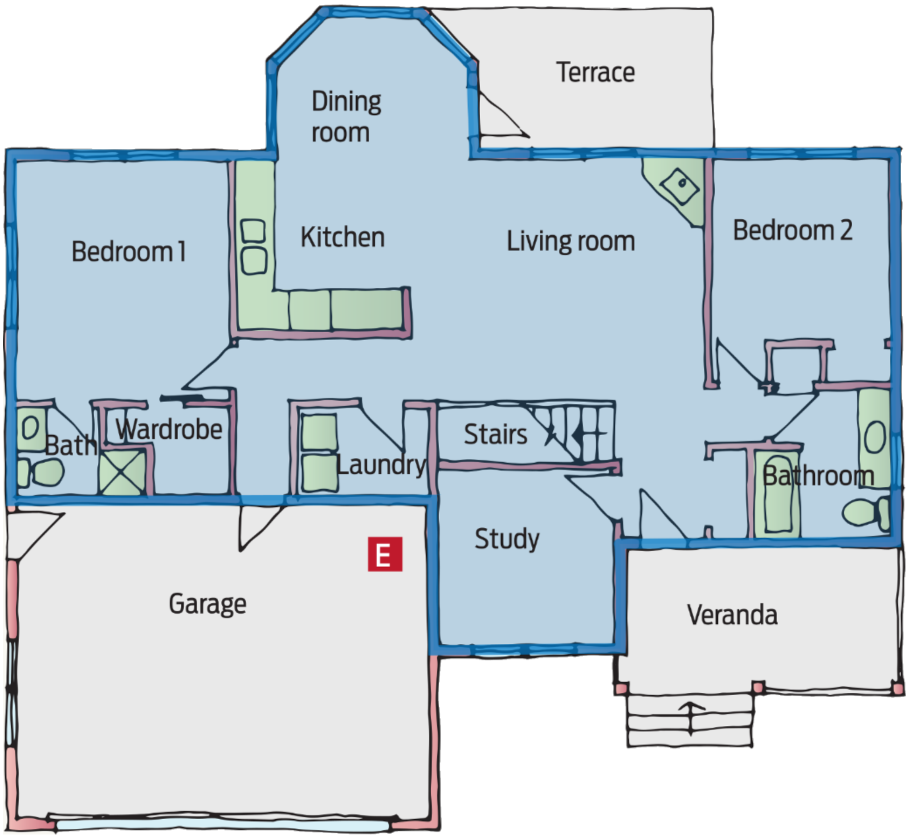


Figure 14: The perimeter is the length of wall between conditioned and unconditioned space. Illustration: BRANZ from *Build 159 34 Design Right Thermal Envelope Basics*.

Example building

By using the values in this handbook, we can look at an example building and estimate the impact of thermal bridges as we change the thermal envelope performance. This is not very accurate as dynamic effects and the length of the heating season is not assessed but does provide a reasonable estimate of the size of the impact of thermal bridging. A more accurate assessment would require an energy model using monthly (PHPP) or even hourly simulation (such as Energy Plus).

Figure 15 below shows an example simple building with the Junction thermal bridges highlighted. This example will illustrate current building practice, ie the typical performance and thermal bridge values found in house built to Building Code minimums prior to November 2021. The calculation method is intentionally similar to the calculation method in H1/AS1 (5^{th} edition, Nov2021) and the slab-on-ground heat loss includes the edge and area heat loss from the slab to be consistent with this. In PHPP you would calculate the slab-on-grade heat loss using an edge PSI value and the slab-on-grade construction.

The calculation process follows a similar approach to H1/AS1 (5^{th} edition, Nov2021) of dividing the building up into Elements with areas and R-values. This is then further refined by calculating Junction thermal performance values and lengths; These are *not* considered in H1/AS1 (5^{th} edition, Nov2021) for building code compliance.

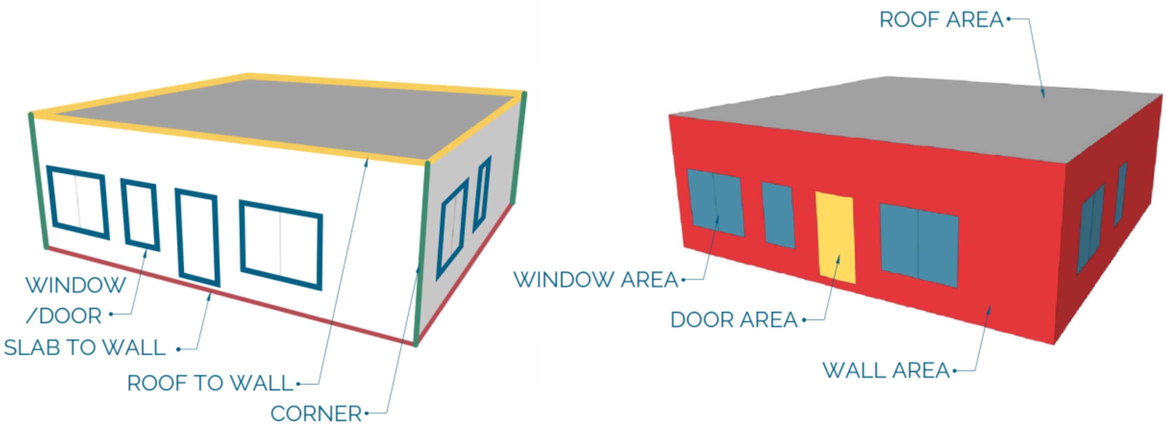


Figure 15: Example simple building with areas and junctions highlighted. Roof-to-wall length is shown in yellow; corner length in green; slab-to-wall length in red; and window/door-to-wall install length in blue.

The four-step process used to estimate the impact of thermal bridges is as follows.

1. Divide the building into Elements; Implicit in this step is choosing to measure exterior, internal or internal overall dimensions. (Don't get confused by slab-edge areas and midfloor Junction areas; these are most easily dealt with as Junctions not special constructions.)
2. Determine Element R-values using the Elements section of this handbook and building surface areas.

3. Measure the Junctions. Determine Junctions using ψ and χ values from this handbook, multiplied by lengths and quantity.
4. Determine the heat loss for the Elements and Junctions and percentage of total building heat loss.

The table below shows the calculations for the simple example building. The given timber fractions and insulation values for the Elements are taken from this handbook. The unexpected result is the large additional heat loss due to the window installation values. This is a result of the windows being installed outside of the thermal envelope and the large heat loss through the bottom of the frames to the ventilated cavity.

Note that the PSI value for the slab-on-ground edge can be used to estimate the heat loss from the slab edges alone. This could be useful to assess edge insulation and it's potential benefits. It is important to remember that the slab-on-ground R-values provided in Elements H to K include this edge heat loss.

Table 2: Example building current practice.

	Step 1	Step 2	Step 3	Step 4	
	Description	Area, length, quantity	Performance	Heat Loss Coefficient	% Total Heat Loss
Element		Area/Performance = Heat Loss Coefficient			
Roof/Ceiling	Truss at 900mm for 8% timber R3.2 Insulation - Element P	110 m²	R2.9	38 W/K	11%
Wall	90mm studs 22% timber R2.6 insulation - Element A	94 m²	R1.9	49 W/K	15%
Floor	Uninsulated concrete slab – 90mm stud wall H1/AS1 (5th edition, Nov2021) $A/P_{internal}$ = 2.6 from Table F.1.2.2F	110 m²	R1.1[10]	100 W/K	30%
Windows	Aluminium framed double glazed – NZS4218 ref value	30 m²	R0.26	115 W/K	35%
Doors	Aluminium door – NZS4218 ref value	2 m²	R0.18	11 W/K	3%
Junction (Thermal Bridge)		Length * Performance = Heat Loss Coefficient			
Roof-to-wall	Truss ceiling roof eaves to wall – Junction 56	42 m	-0.057 W/(mK)	-2.4 W/K	-0.7%
Wall-Corner	External wall external corner 90mm stud – Junction 5	12 m	0.020 W/(mK)	0.24 W/K	0.1%
Window-To-Wall	Window solid alum frame flush with cladding Junctions 61, 69, 76	90 m	0.247 W/(mK) averaged	22 W/K	6.7%
External Wall to Floor Slab	EWFS External Wall to Floor Slab - Stud wall 90mm stud current practice uninsulated slab no edge insulation; Junction 21	42m	0.223 W/(mK)	~~9.4 W/K~~	Included above in floor R-value
			Total Heat Loss	334 W/K	100%

Note the slab-on-ground R-value is not used in PHPP.

[10] Slab area-to-perimeter ratio $A/P_{external}=110/42=2.62$ m; Convert to $A/P_{internal}=2.57$ m using equation F.1 and F.2 from H1/AS1 (5th edition, Nov2021).

Note that when calculating heat loss using R-values, the heat loss is the area divided by the R-value (ie Heat Loss 1 = Area1/R1), while the heat loss for the thermal bridges is the ψ value multiplied by the length.

The table below shows the calculations for the same building but with higher performance assemblies. This is just over the (improved) window installation details.

If the U-value (1/R-value) of the Elements in the thermal bridge Junction calculation differ by more than 10% the PSI value may not be considered sufficiently accurate for Passive House Certification. If there is some margin in the building's overall performance, one approach is to add additional safety margin and use these pre-calculated values rather than modelling additional details.

Table 3: Example building with high-performance assemblies.

	Step 1	Step 2	Step 3		Step 4
	Description	Area, length, quantity	Performance	Heat Loss Coefficient	% Total Heat Loss
Element		Area/Performance = Heat Loss Coefficient			
Roof/Ceiling	Truss at 900mm for 8% timber R8.0 Insulation - Element P	110 m²	R7.8	14 W/K	13%
Wall	140mm studs 15% timber R4.0 / 45mm service cavity R1.2 insulation - Element A	94 m²	R4.4	21 W/K	20%
Floor	150mm EPS insulation under the concrete slab - Element H, Junction 29 $A/P_{internal}$=2.6	110 m²	R3.7	30 W/K	27%
Windows	uPVC high-performance 4:/16/4 double glazed low-e argon	30 m²	R0.77	39 W/K	36%
Doors	Insulated panel in uPVC frame	2 m²	R0.9	2.2 W/K	2%
Junction (Thermal Bridge)		Length * Performance = Heat Loss Coefficient			
Roof-to-wall	Truss ceiling roof eaves to wall raised heel truss – Junction 57	42 m	-0.057 W/(mK)	-2.4 W/K	-2.2%
Wall-Corner	External wall external corner 140/45mm no additional timber – Junction 8	12 m	-0.059 W/(mK)	-0.71 W/K	-0.6%
Window-to-Wall	Window uPVC frame recessed to centre of wall Junctions 67, 74, 81	90 m	0.065 W/(mK) averaged	5.9 W/K	5.4%
External Wall to Floor Slab	EWFS External Wall to Floor Slab 140/45 timber wall to slab on ground with continuous under-slab and 50mm overhung edge; Junction 29	42 m	0.206 W/(mK)	~~8.7 W/K~~	Included above in floor R-value
			Total Heat Loss	109 W/K	100%

Note the slab-on-ground R-value is not used in PHPP.

As building thermal performance improves and buildings become more complicated, the thermal impacts of Junctions become more important and hand calculations become difficult and potentially misleading. Figure 16 below is a building that has several foundation details, overhangs, conditioned basement space and steel reinforcing—all of which results in significant numbers of thermal bridge Junction details to calculate. The additional workload was significant as several details needed to be changed to meet performance targets.

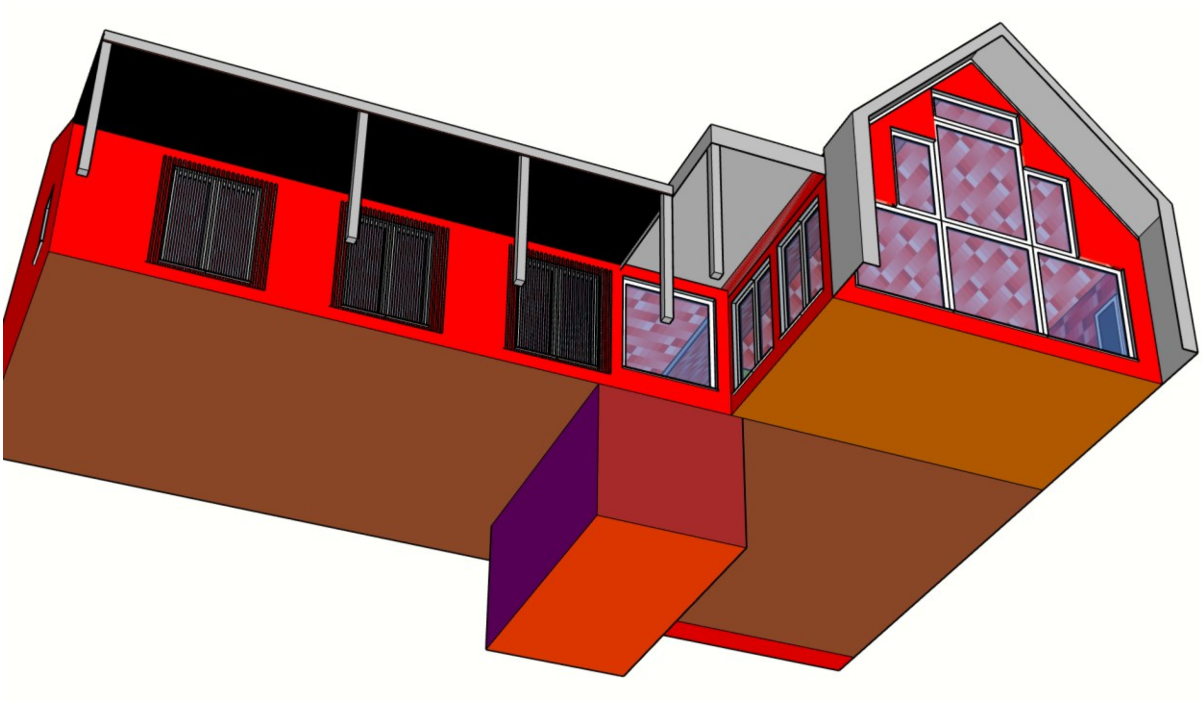


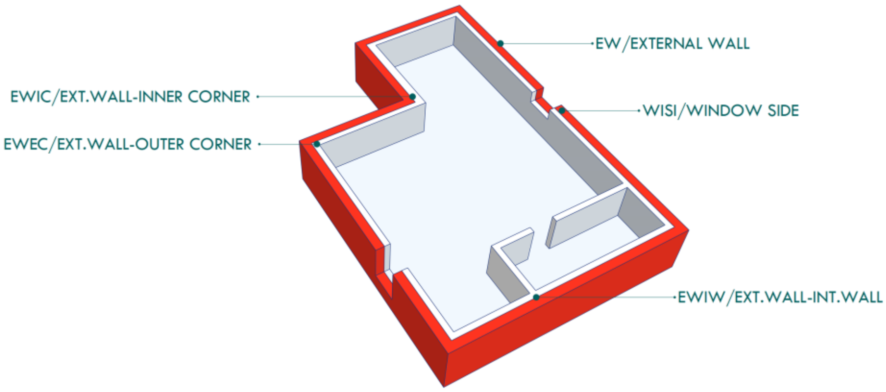
Figure 16: An example of a complicated building with an underground carpark, which has many thermal bridges Junctions. Even with good practice, they add significantly to the heat transfer.

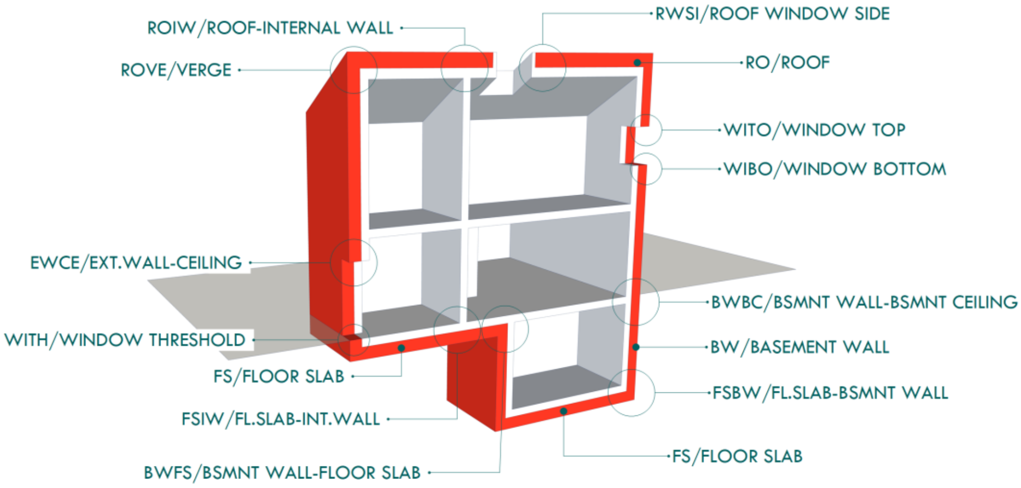
Out of scope

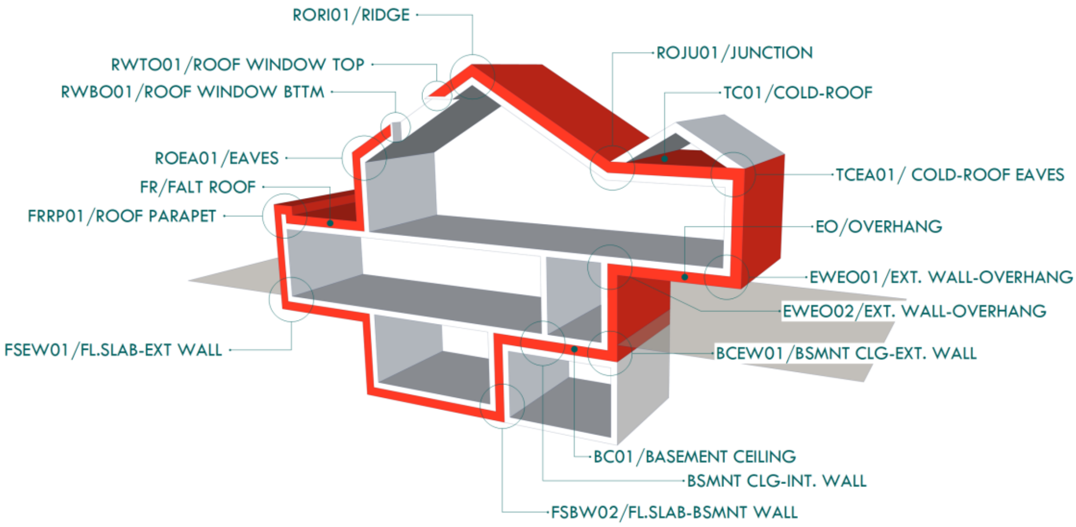
This handbook does not cover retrofits. Appropriately qualified professionals should be engaged to ensure moisture problems are not inadvertently created. Retrofitting interior insulation can be challenging and needs to be carefully considered. It is difficult to make interior insulation continuous across floor levels and wall intersections. It is also difficult to verify that internal air is unable to contact the interior side of the existing wall,. As this will typically be at a cooler temperature, the risk of moisture issues is increased. Controlling air leakage through the building enclosure (walls, ceiling and floor) is the first priority. Moisture diffusion may also be an issue. These are particularly difficult to address in retrofits and the solution must be carefully considered.

Weathertightness (ref. NZ Building Code clause E2) advice is not provided in this publication. The flashings and generic E2 provisions are for context only and specific advice on E2 is required on the basis of the specific materials used in the actual detail.

Element and Junction Abbreviations







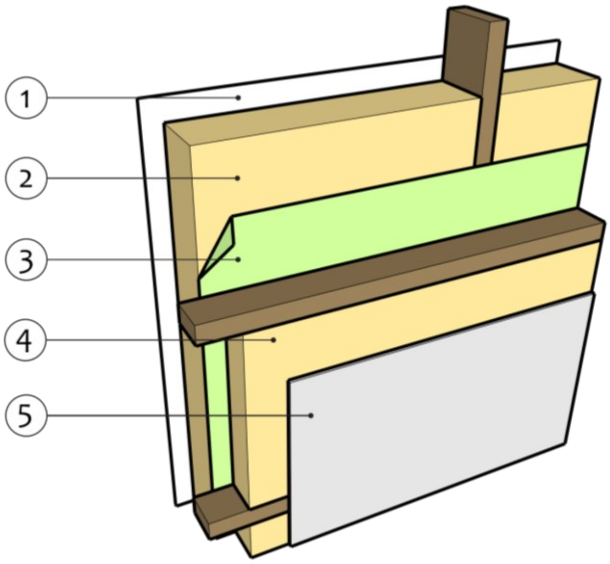
Elements or 1D assemblies are named with two letters

EW	External Wall
BW	Basement Wall
TC	Truss Ceiling (Cold Roof)
RO	Roof (Skillion or Shed Roof)
FR	Flat Roof
FS	Floor Slab on grade or Floor, Suspended timber
BC	Basement Ceiling
EO	External Overhang

Junctions are named with four letters

EWIC	External Wall – Inner Corner
EWEC	External Wall - External Corner
EWIW	External Wall to Internal Wall
EWCE	External Wall to Ceiling or Midfloor
EWEO	External Wall - Overhang
EWFS	External Wall to Floor Slab
EWFR	External Wall to Flat Roof
IWFS	Internal Wall to Floor Slab
WISI	Window Side (Jamb)
WITO	Window Top (Head)
WIBO	Window Bottom (Sill)
WITH	Window Threshold or Door Threshold
RWSI	Roof Window Side (Skylight Jamb)
RWTO	Roof Window Top (Skylight Head)
RWBO	Roof Window Bottom (Skylight Sill)
ROVE	Roof Verge
ROEA	Roof Eaves
ROIW	Roof to Internal Wall
ROJU	Roof pitch Junction
TCEA	Timber frame roof with (Cold) roof space Eaves
TCVE	Timber frame roof with (Cold) roof space Verge
FRRP	Roof Parapet
BWBC	Basement Wall - Basement Ceiling
BCEW	Basement Ceiling to External Wall
BCIW	Basement Ceiling to Internal Wall
BWFS	Basement Wall to Floor Slab

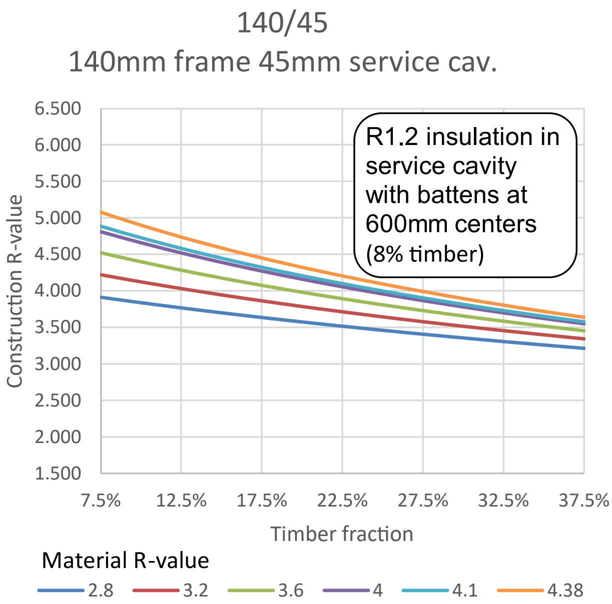
Elements

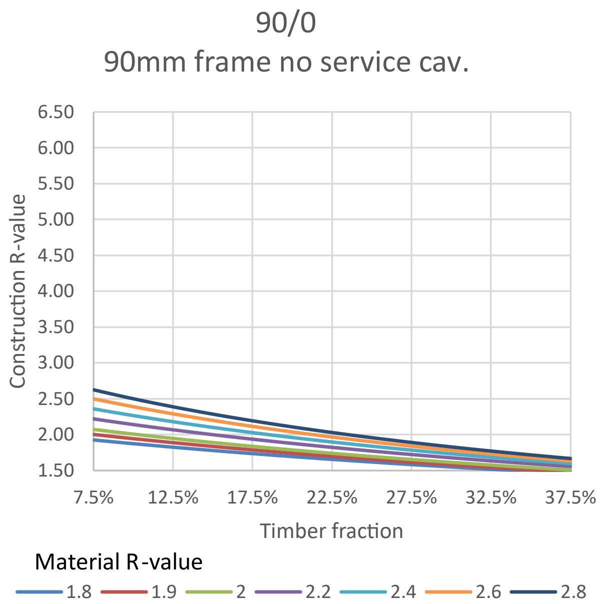


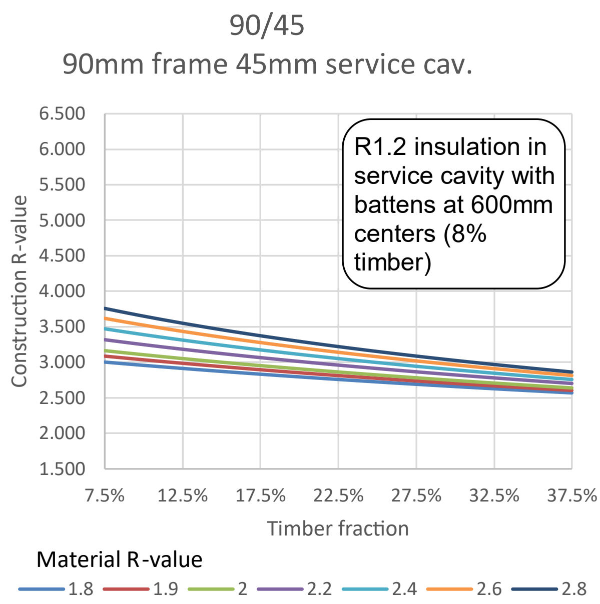
Timber wall:
1. Flexible underlay (WRB) or RAB
2. Structural stud layer with insulation and dwangs
3. Air/Vapour control layer (AVCL) membrane
4. Service cavity, insulated
5. Interior finish plasterboard

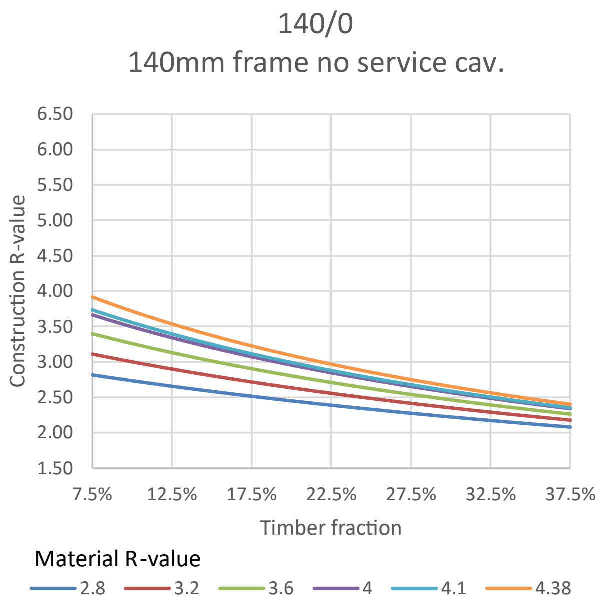
(a) EW External Wall timber stud wall with service cavity timber

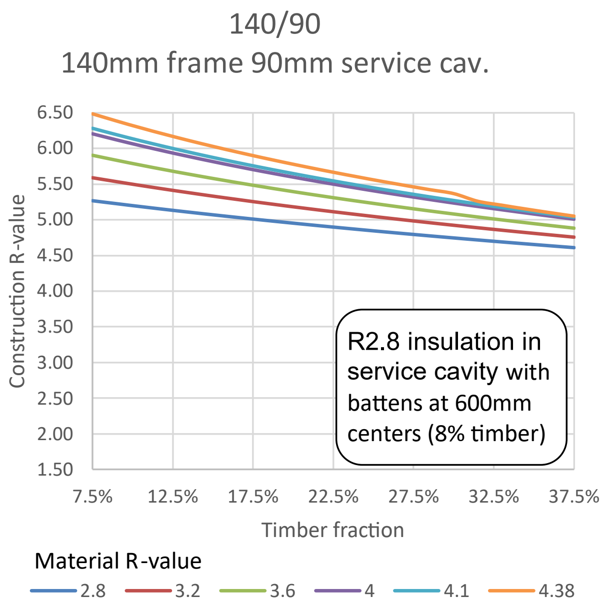
This is the most common wall construction used in high-performance buildings. It is composed of a 140mm stud with a 45mm-thick interior batten over a flexible air/vapour control layer and vented cavity cladding.





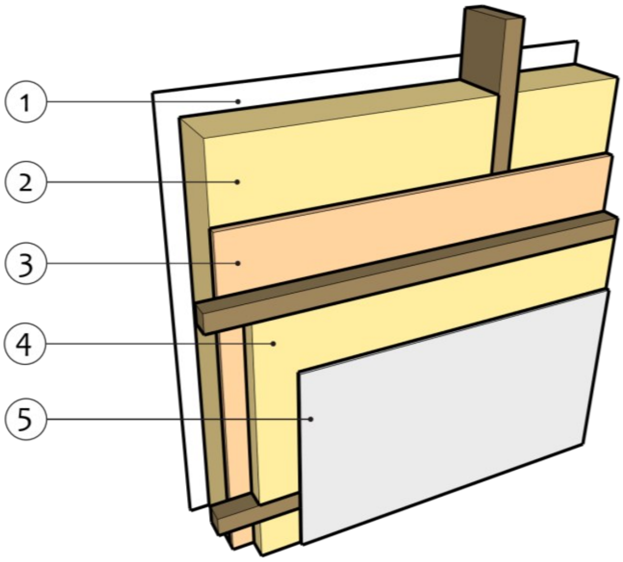






COST AND kgCO$_2$eq TABLE

CONSTRUCTION	$/m²	kgCO$_2$e/m²	Storage kgCO$_2$e/m²
90/0 WRB / R2.2 fibre insulation	342	20	38
140/0 WRB / R4.0 fibre insulation	376	24	45
140/45 WRB / R4.0 fibre insulation / AVCL / R1.2 fibre insulation	412	25	46
140/45 RAB / R4.0 fibre insulation no dwangs / AVCL / R1.2 fibre insulation	435	26	49



Timber wall:

1. Flexible underlay (WRB) or RAB
2. Structural stud layer with insulation and dwangs
3. Air/Vapour control layer (AVCL) plywood with junctions taped (also bracing)
4. Service cavity insulated
5. Interior finish plasterboard

(b) EW External Wall timber frame with plywood air control layer and with service cavity timber battens

Several New Zealand high-performance buildings have used this wall construction consisting of a 140mm stud with a 45mm-thick interior batten over a rigid OSB or plywood AVCL and vented cavity cladding.

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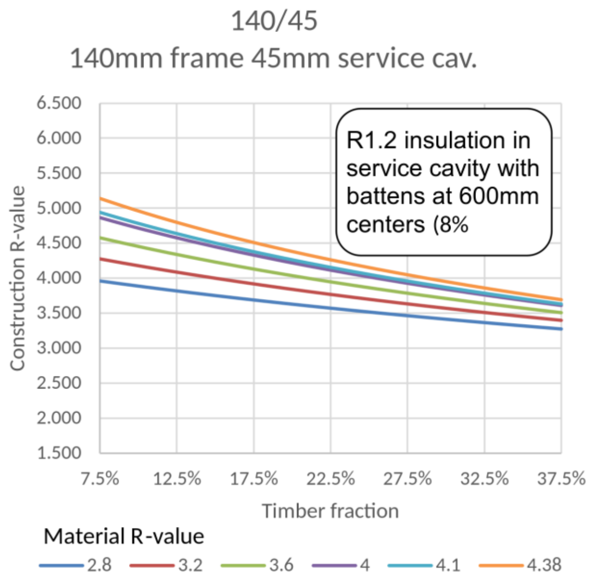
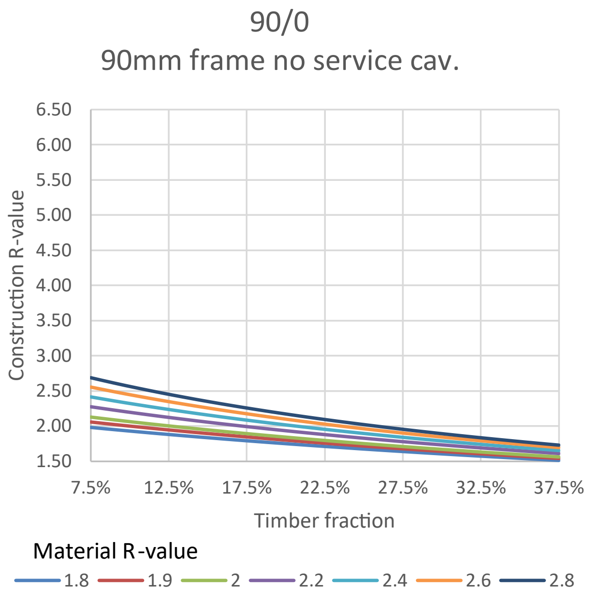
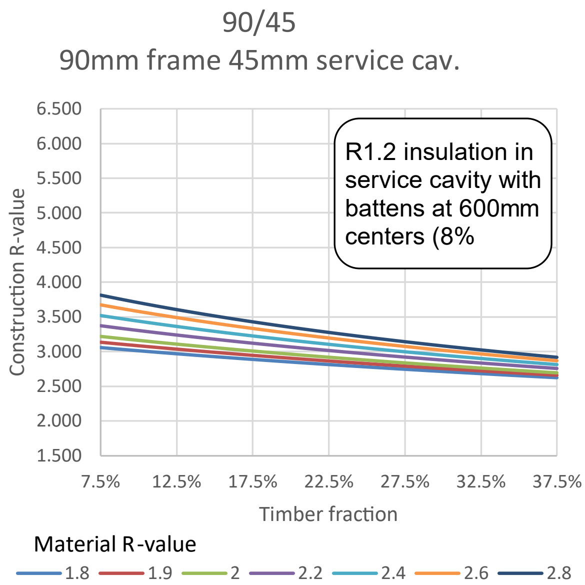
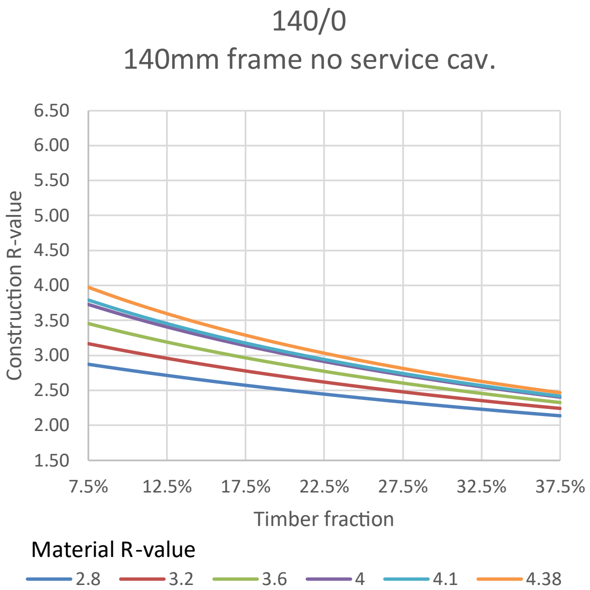
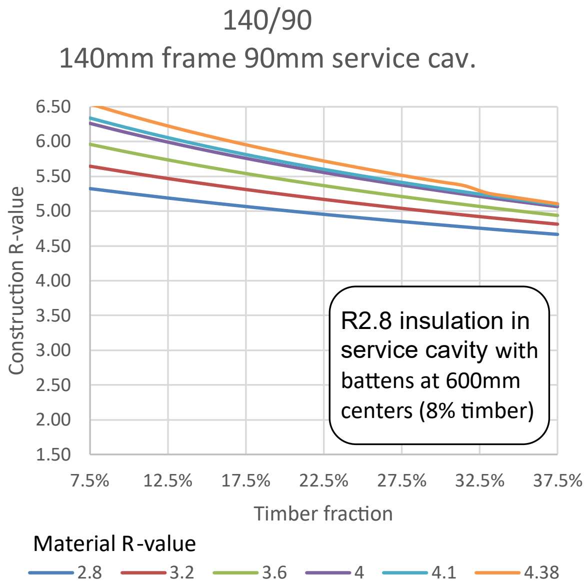




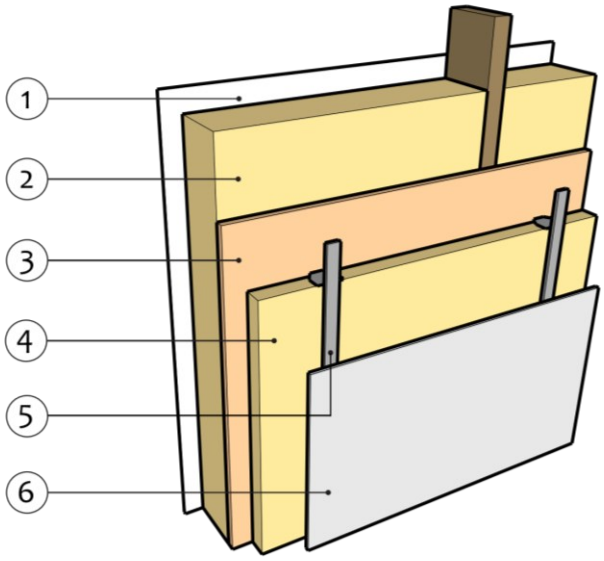






COST AND $kgCO_2eq$ TABLE

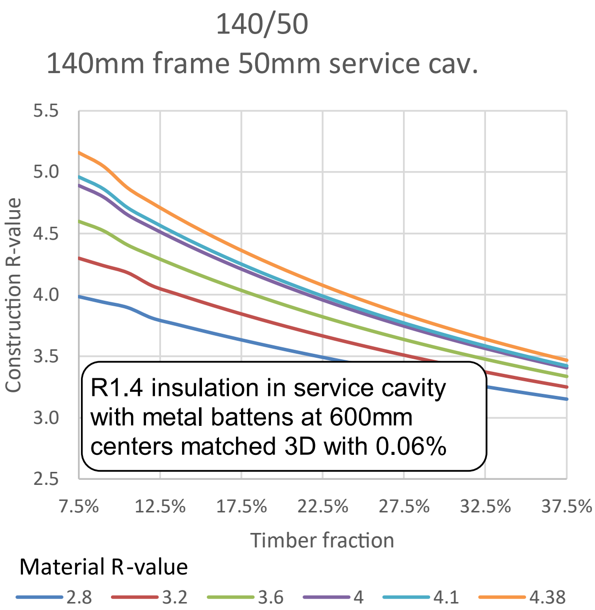
CONSTRUCTION	$/m²	$kgCO_2e/m^2$	Storage $kgCO_2e/m^2$
140/45 WRB / R4.0 fibre insulation no dwangs / AVCL / R1.2 fibre insulation	433	26	49
140/45 RAB / R4.0 fibre insulation no dwangs / AVCL / R1.2 fibre insulation	468	28	55

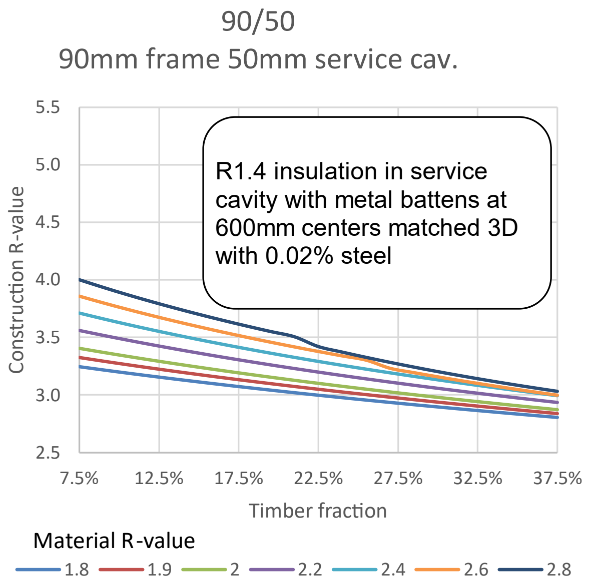


Timber wall:
1. Flexible underlay (WRB) or RAB
2. Structural stud layer with insulation and dwangs
3. Air/Vapour control layer (AVCL) plywood with junctions taped (also bracing)
4. Service cavity insulated
5. Metal batten system
6. Interior finish plasterboard

(c) EW External Wall timber frame with plywood air control layer and with metal batten service cavity

Several New Zealand high-performance buildings have used this wall construction of a timber stud structural/insulation layer with a 50mm-thick interior service cavity formed from a *metal* batten over a rigid OSB or plywood AVCL and vented cavity cladding. The performance shown here includes the thermal bridging of the steel brackets and battens calculated using ISO10211:2007 in a three-dimensional finite element model.

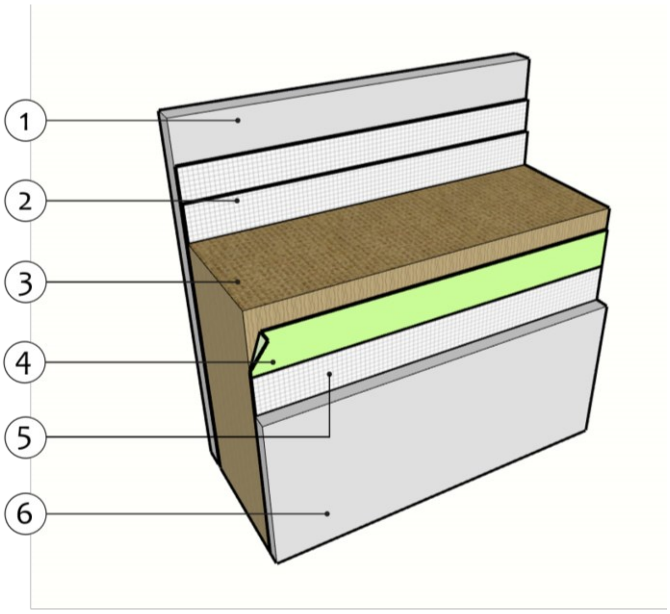




The steel bracket and batten impacts were calculated using ISO10211:2007 using UCanPSI (a three-dimensional finite element heat transfer software) as the primary heat transfer mechanism is the metal brackets rather than the metal battens. For this analysis, the compressed insulation around the batten is modelled as a 35mm-deep air pocket using ISO6946:2007. In thermal analysis using ISO6946:2007, such as that done with PHPP, the 50mm insulated service cavity thermal performance can be estimated using 0.03% steel bridging of the service cavity insulation layer.

COST AND kgCO_2eq TABLE

CONSTRUCTION	$/m2	kgCO2e/m2	Storage kgCO_2e/m²
140/50 WRB / R4.0 fibre insulation no dwangs / AVCL / R1.2 fibre insulation	478	30	48
140/50 RAB / R4.0 fibre insulation no dwangs / AVCL / R1.2 fibre insulation	515	32	54



Strawbale wall:

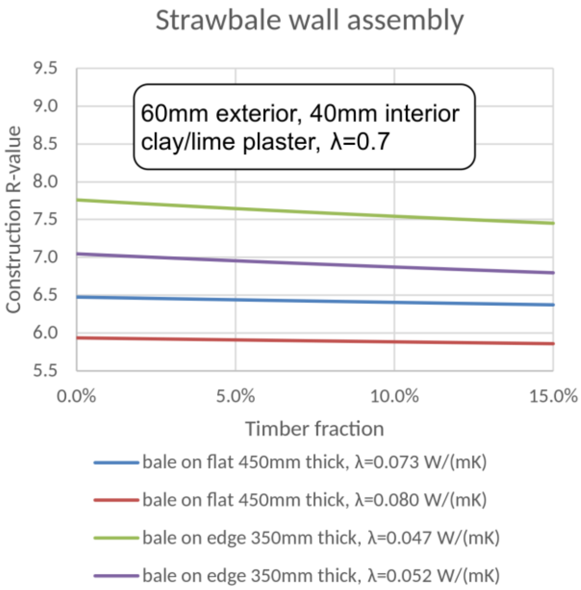
1. Exterior render
2. Mesh reinforcement for exterior render
3. Straw
4. Air/Vapour control layer (AVCL) if/as required.
5. Mesh reinforcement for interior render
6. Interior render/finish .

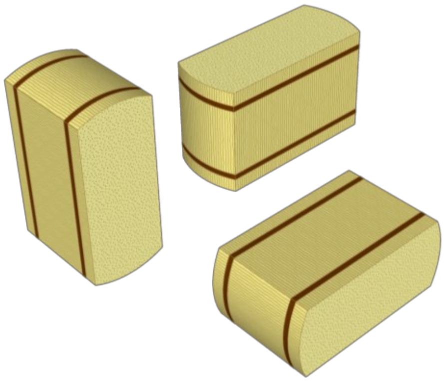
(d) EW External Wall Strawbale

Straw bale walls are a very low-carbon material and have excellent insulation properties. In New Zealand, they are typically combined with clay/lime plaster and deep overhangs.

Projects have been successful with passing the airtightness targets of PH without the interior membrane (4) and depending on the plaster alone. This is considered easier to build as the plaster 'keys' to the straw.

New Zealand has a set of earth building standards: NZS 4298:2020 "Materials and Workmanship for Earth Buildings", NZS 4297:2020 "Engineering Design of Earth Buildings" and NZS 4299:2020 "Earth Buildings Not Requiring Specific Design".



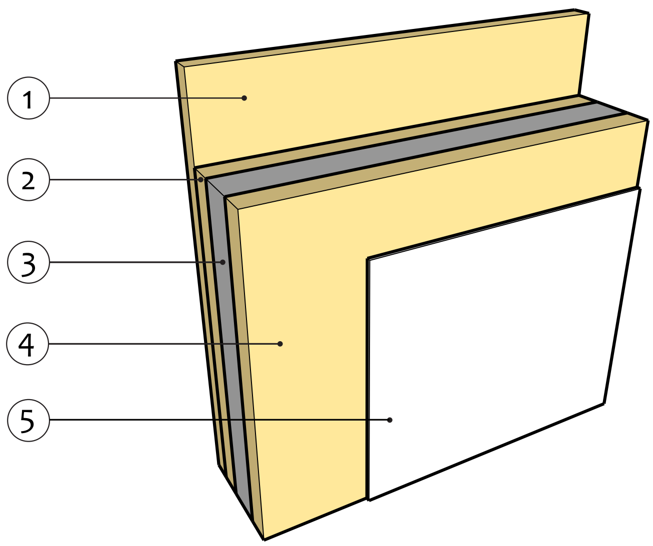


Note that the heat flow along the straw strands is higher than across them. This means the bales are more insulating when placed on-edge compared to flat, even though the bale laid flat is thicker. This is called anisotropic heat flow and is the reason that the different thermal conductivity values are used in the Element calculations. The common bale size is 900 mm long x 450 mm wide x 350 mm high (when placed flat). This means that the bales on edge are 350mm thick and on flat are 450mm thick.

There is a reasonable range of values for different densities of straw. For wheat straw and dry bulk density of approximately 100 kg/m3, values have been accepted by PHI (for Passive House Certification of a local project) at a rated value of 0.073 W/(mK) along the straw fibre and 0.047 W/(mK) perpendicular. These rated values include some margin for different moisture content and temperatures. ("2 0 2 0 / 17 2-string bales (small bales 0.36 m height, 0.48 m width and 1.2 m length with a density around 100 kg/m^3), the rated thermal conductivity λR can be assumed as 0.052 W/(mK) where thermal flux is perpendicular to the direction of the stalks, and 0.080 W/(mK) in the direction of the stalks." Source: IPHA–*Passive House Fact Sheet*.)

COST AND kgCO_2eq TABLE

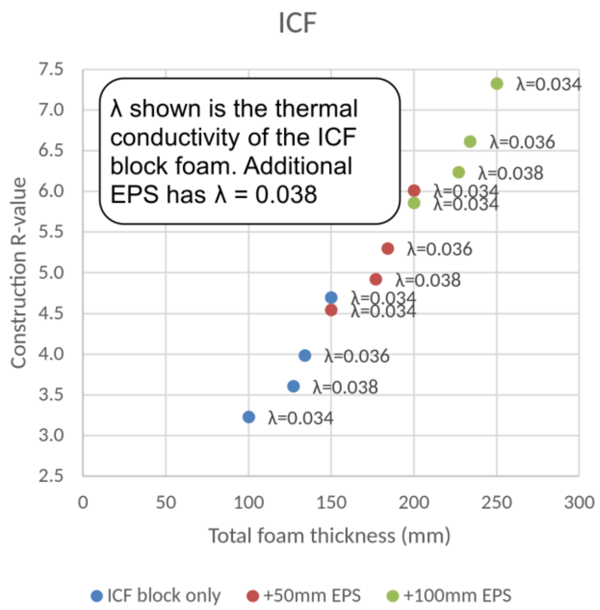
CONSTRUCTION	\$/m^2	kgCO_2e/m^2	Storage kgCO_2e/m^2
Lime-clay-sand plaster / bale on edge (350mm thick) no AVCL	725	23	76
Lime-clay-sand plaster / bale on edge (350mm thick) membrane AVCL	744	24	76



ICF wall:
1. Optional additional external rigid insulation (exterior cementitious render not shown)
2. ICF block outer insulation layer
3. Reinforced concrete structural layer
4. ICF block internal insulation layer
5. Interior finish plaster or plasterboard.

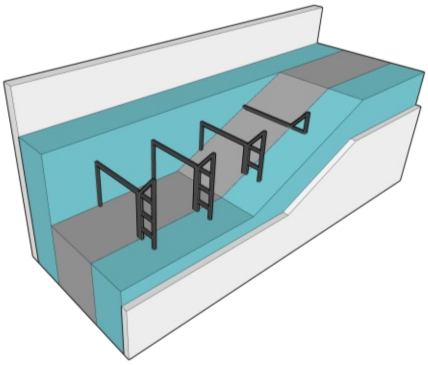
(e) EW External Wall ICF with optional external rigid insulation

ICF was a common solution for early Passive House projects. However, it does have a higher embodied carbon versus other construction methods due to the concrete and steel content.

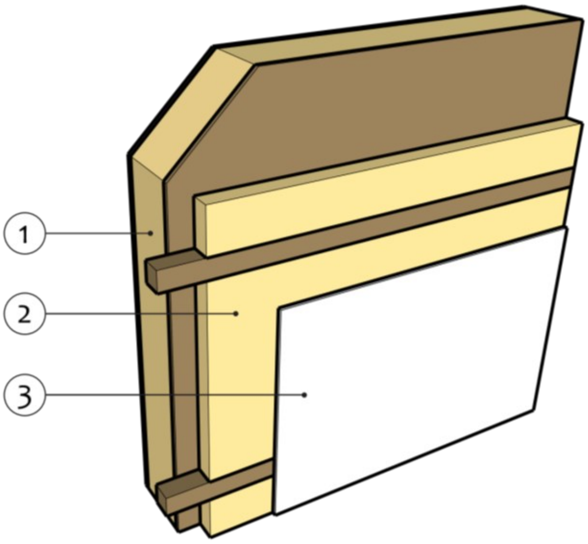


COST AND $kgCO_2eq$ TABLE

CONSTRUCTION	$/m²	$kgCO_2e/m^2$	Storage $kgCO_2e/m^2$
63.5mm EPS / 100mm structural concrete / 63.5mm EPS /plasterboard	460	99	3
67mm EPS / 100mm structural concrete / 67mm EPS /plasterboard	465	100	3
50mm EPS / 150mm structural concrete / 50mm EPS /plasterboard	537	117	3
100mm EPS / 150mm structural concrete / 50mm EPS /plasterboard	569	120	3



Detailed view of ICF showing the concrete and steel core with the plastic connectors holding the two sides of the blocks together; plaster outside and gypsum or plaster inside. Some ICF systems supply specialist foundations, midfloor and roof blocks.



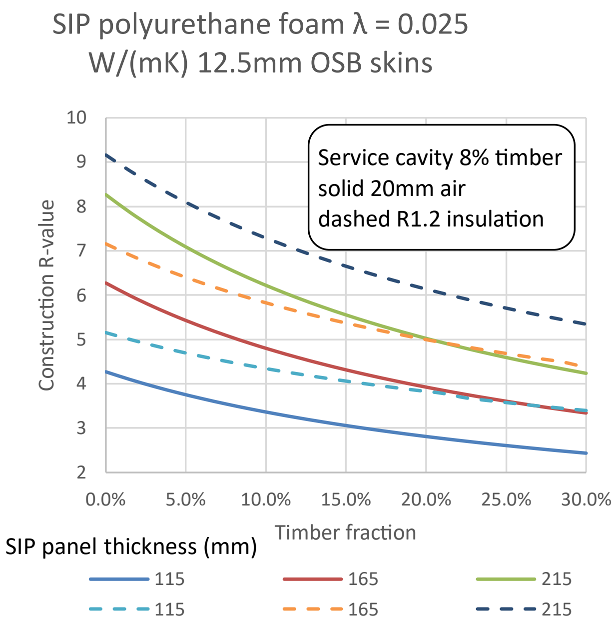
SIP wall:
1. SIP panel junctions taped on inside (flexible wall underlay not shown)
2. Service cavity insulated
3. Interior finish plasterboard

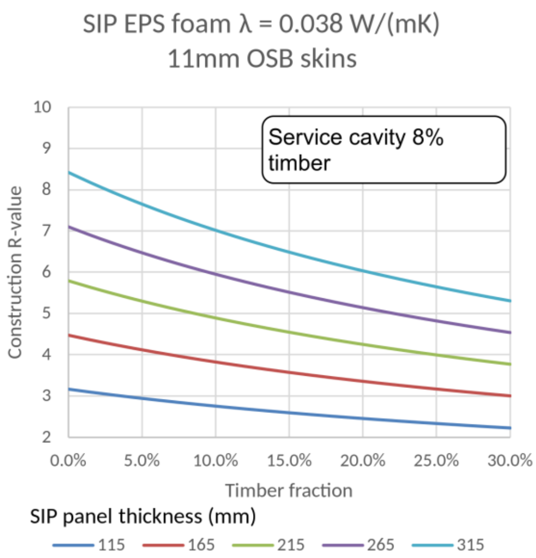
(f) EW External Wall SIP with timber batten service cavity

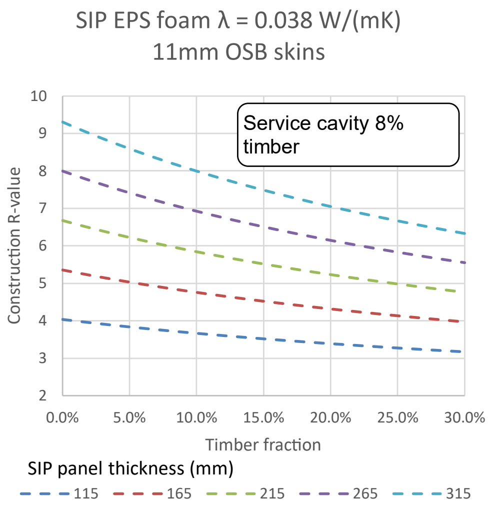
The construction performance of a SIP wall is primarily a function of the SIP thickness, SIP foam thermal conductivity and timber fraction in the SIP. The graph is for the main types of SIP sold/installed in New Zealand (solid lines are a 20mm air-filled service cavity and dashed lines are a 45mm R1.2 insulation service cavity, both with a minimal 8% timber content).

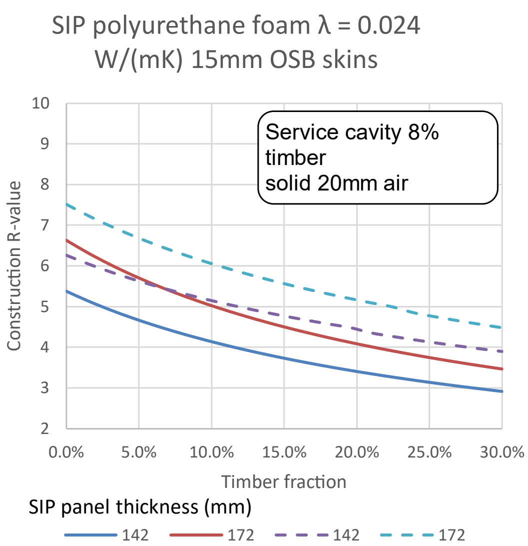
The interior face of the SIP acts as the AVCL. It must be airtight and this is most commonly achieved with airsealing tape. Failures of SIP roofs in very cold climates have been attributed to not sealing the interior face of the SIP (primarily the ridge).

SIP use the outer layer for structure and weathertightness is critical. This handbook recommends only using SIP walls with ventilated cladding and well-designed WRB and flashing details.



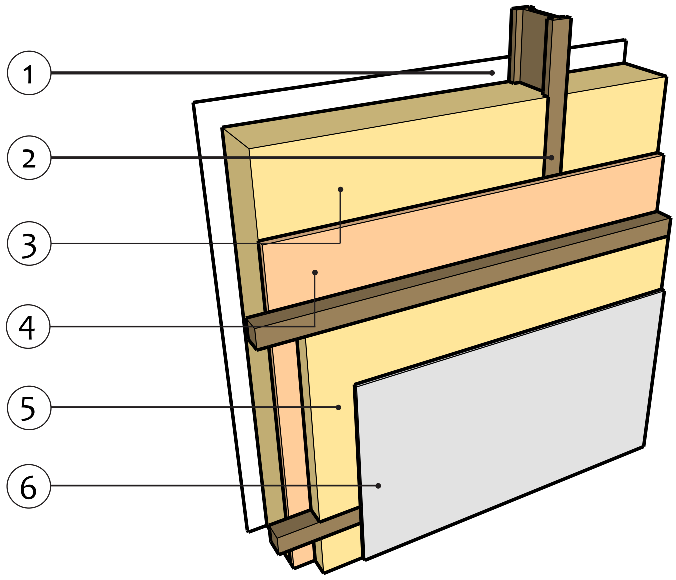






COST AND kgCO$_2$eq TABLE

CONSTRUCTION	$/m2	kgCO2e/m2	Storage kgCO$_2$e/m^2
165mm SIP (143mm EPS core) / 22mm battens / plasterboard	526	48	54
165mm SIP (143mm EPS core) / 45mm cavity R1.2 fibre insulation / plasterboard	562	49	56
165mm SIP (140mm PUR core) / 22mm battens / plasterboard	526	49	55
165mm SIP (140mm PUR core) / 45mm cavity R1.2 fibre insulation / plasterboard	558	50	57

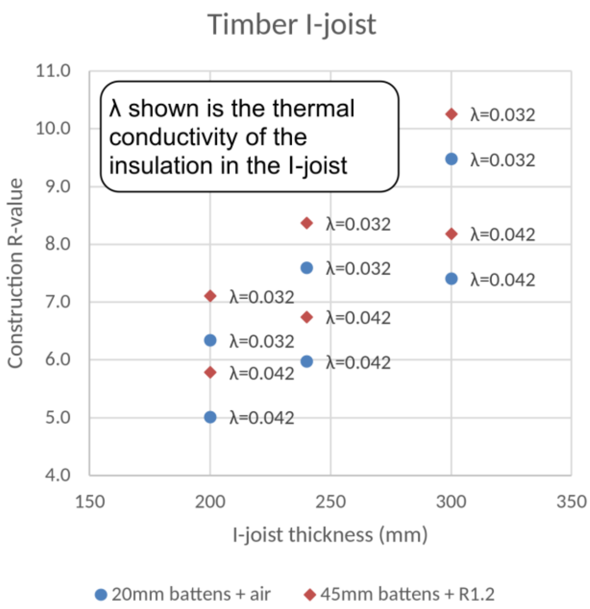


Timber I-joist wall:

1. Flexible wall underlay (WRB) or rigid air barrier (RAB)
2. Timber I-joist at 600mm, no dwangs
3. High density blown fibre insulation or fitted insulation fibre segments
4. Air/Vapour control layer (AVCL) plywood with junctions taped (also bracing)
5. Service cavity insulated
6. Interior finish plasterboard

(g) EW I-joist wall with plywood air control layer and service cavity

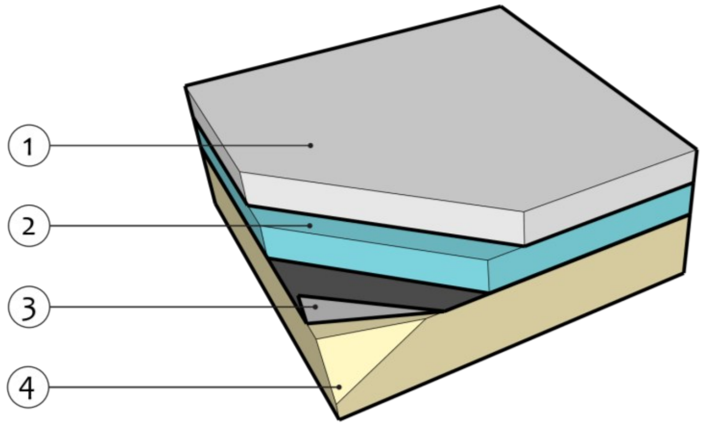
This construction Element performance is a function of the thickness of the layers, the timber fraction in the layers and insulation performance/install quality. This wall thermal performance is highly dependent on installation quality. As it can be very difficult to tightly fit cut segments of batt insulation, these walls are more usually insulated with high density blown fibre insulation ("loose fill").



COST AND $kgCO_2eq$ TABLE

CONSTRUCTION	$/m²	$kgCO_2e/m^2$	Storage $kgCO_2e/m^2$
WRB / 200mm I-joist blown fibre insulation / AVCL / 45mm R1.2 fibre insulated	504	32	48
RAB / 200mm I-joist blown fibre insulation / AVCL / 45mm R1.2 fibre insulated	541	34	54
WRB / 240mm I-joist blown fibre insulation / AVCL / 45mm R1.2 fibre insulated	527	34	49
WRB / 300mm I-joist blown fibre insulation / AVCL / 45mm R1.2 fibre insulated	623	42	48

The graph assumes, as stated in the figure, that the I-joists in the wall are 600mm on centre and have no dwangs/nogs. This results in very small timber fractions. All the walls in the graph have a 45mm insulated service cavity with R1.2 fibre insulation and 8% timber content.



Insulated concrete slab on ground:

1. Concrete
2. Rigid insulation
3. DPM
4. Blinding and ground

(h) FS Floor Slab on-ground with under-slab insulation

Adding a layer of EPS or XPS foam below the concrete is the most common approach to slab insulation in New Zealand. The PH projects with insulation below the slab have insulation continuously under the footer and up the edge of the slab as well. Details of the thermal conductivities and dimensions used are shown in the Junction(s).

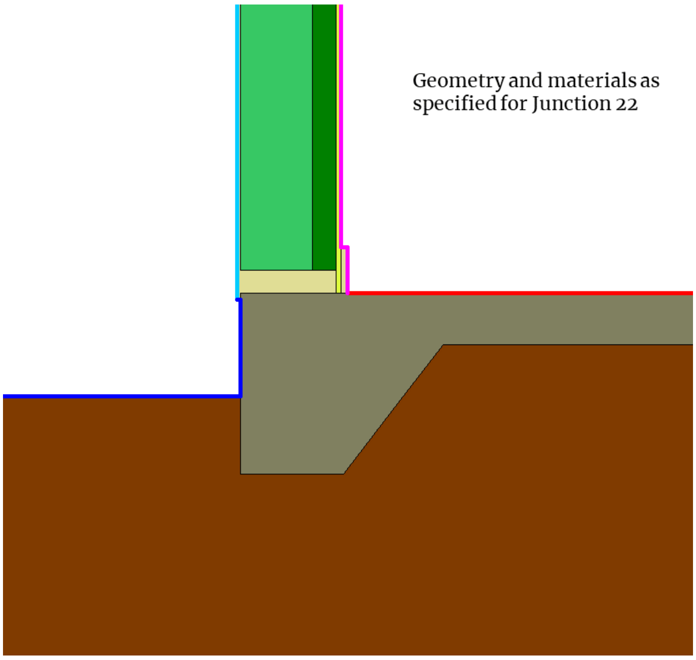
The R-value charts represent the floor heat loss as a function of the overall internal slab area-to-perimeter ratio. The R-values were calculated using ISO 13370 two-dimensional numerical calculations, and using ISO 10211 based geometrical models. H1/VM1 references the R-value calculation method from ISO 13370 as a means for demonstrating compliance. The R-values are referenced to internal dimensions, include the edge losses, and cannot be used with PHPP.

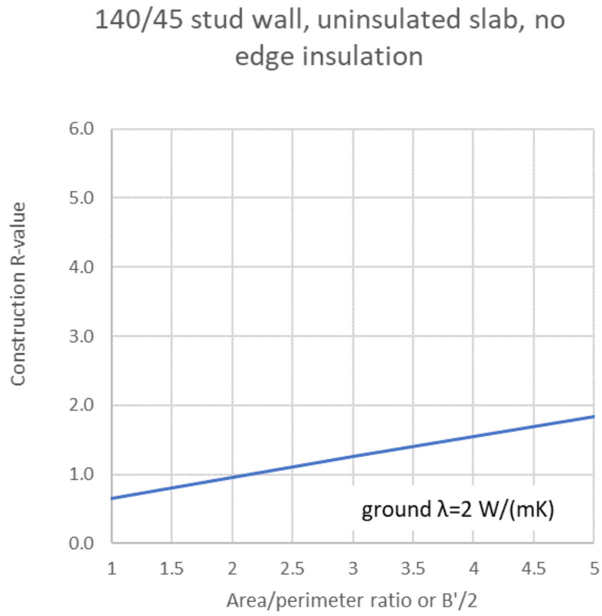
The top surface of the concrete slab is 200 mm above the ground level next to the slab.

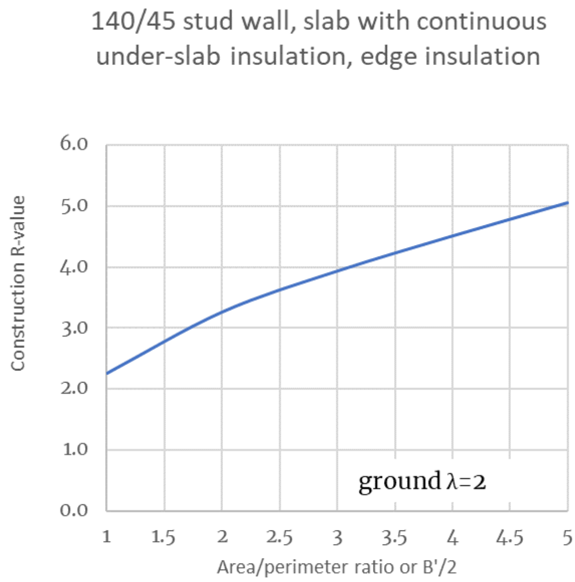
In warmer climates, uninsulated slabs with edge insulation could be appropriate but the risk of mould issues should be checked.

Cost and carbon table values are for the overall slab area excluding the slab edge and need to have the slab edge detail cost and carbon added to allow comparison (ie 10x10m slab would need 100sqm of cost and carbon from these Element tables here and 40m of cost and carbon from the slab edge Junction).

The insulated slab has the same materials and geometry as Junction 29. XPS (λ=0.028 W/(mK)) insulation 50mm thick on the edge and under the footer and 150mm thick EPS (λ=0.038 W/(mK)) under the entire core of the slab. Floor covering neglected.

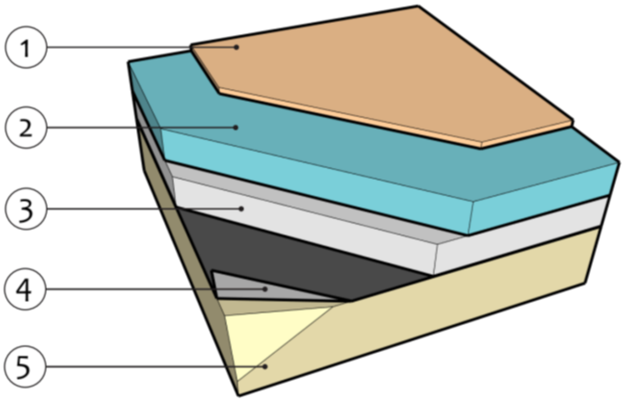






COST AND $kgCO_2eq$ TABLE

CONSTRUCTION	$/m²	$kgCO_2e/m^2$	Storage $kgCO_2e/m^2$
No insulation	96	50	0
50mm S-grade EPS	101	51	0
150mm S-grade EPS	121	55	0
250mm S-grade EPS	148	60	0



Top-insulated concrete slab on ground:

1. Subfloor plywood or timber panel (finish floor/carpet not shown)
2. Rigid insulation
3. Concrete
4. DPM
5. Blinding and ground

(i) FS Floor Slab on-ground with top-of-slab insulation

Building a conventional slab on-ground and then insulating on top is becoming more common in New Zealand. Insulating on top of the slab does lower the thermal mass in the building, which has a small but noticeable impact on overall heating energy consumption (not included here) and potentially a larger increase in overheating. Details of the thermal conductivities and dimensions used are shown in the Junction(s).

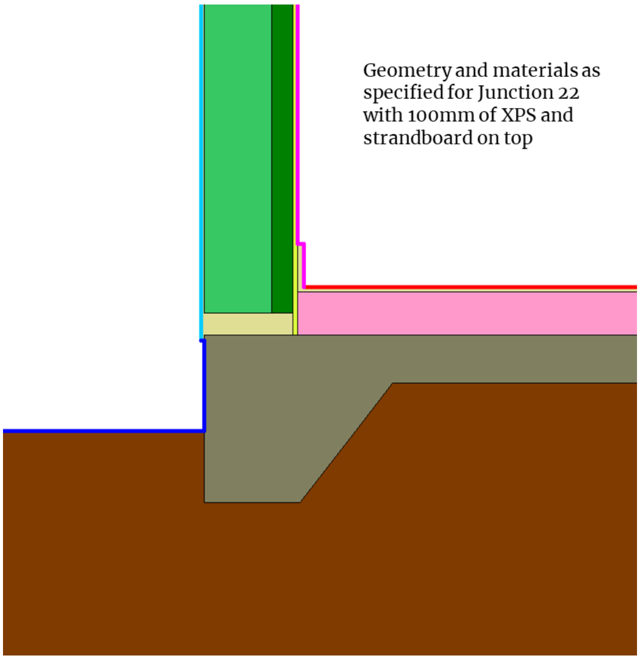
The R-value charts represent the floor heat loss as a function of the overall internal slab area-to-perimeter ratio. The R-values were calculated using ISO 13370 two-dimensional numerical calculations, and using ISO 10211 based geometrical models. H1/VM1 references the R-value calculation method from ISO 13370 as a means for demonstrating compliance. The R-values are referenced to internal dimensions, include the edge losses, and cannot be used with PHPP.

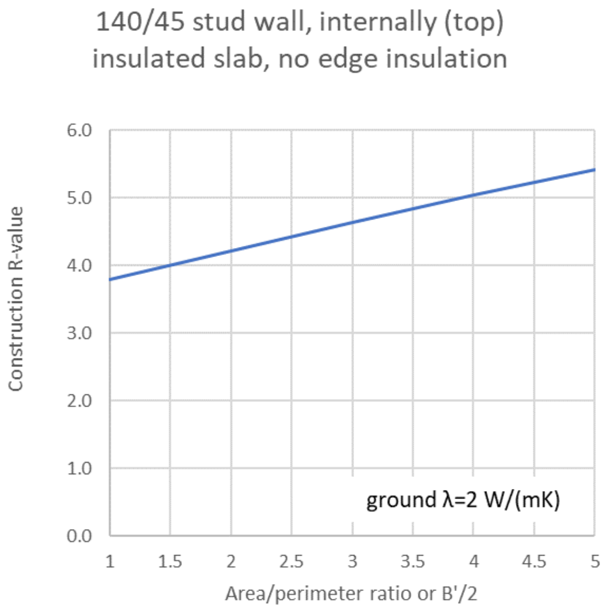
The top surface of the concrete slab is 200 mm above the ground level next to the slab.

Use of fibre insulation above the slab is generally not recommended due to spills of liquid getting into the insulation, as well as possible internal moisture issues in summer.

Strand board or plywood λ=0.13 W/(mK) and 20mm thick is included in all calculations.

Cost and carbon table values are for the overall slab area excluding the slab edge and need to have the slab edge detail cost and carbon added to allow comparison (ie 10x10m slab would need 100sqm of cost and carbon from these Element tables here and 40m of cost and carbon from the slab edge Junction).

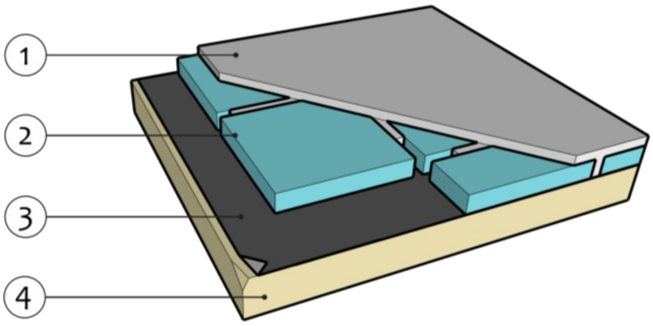




Slab internally insulated (top) with 100mm XPS λ=0.028 W/(mK) and 20mm λ=0.13 W/(mK) strandboard. Floor covering neglected.

COST AND $kgCO_2eq$ TABLE

CONSTRUCTION	$/m²	$kgCO_2e/m^2$	Storage $kgCO_2e/m^2$
40mm PIR [λ=0.022 W/(mK)]	208	69	17
80mm PIR [λ=0.022 W/(mK)]	234	73	17
100 mm XPS [λ=0.028 W/(mK)]	258	75	17
150mm XPS [λ=0.028 W/(mK)]	298	80	17



Concrete waffle pod slab:
1. Concrete slab and ribs
2. Foam pods (solid or hollow)
3. DPM
4. Blinding and ground

(j) FS Floor Slab Waffle pod slab on-ground

Adding EPS foam pods below the concrete and leaving concrete ribs/footer in contact with the ground between the pods is a very common approach to slab on-ground insulation and stiffening of slabs in New Zealand. Details of the thermal conductivities and dimensions used are shown in the Junction(s).

The R-value charts represent the floor heat loss as a function of the overall internal slab area-to-perimeter ratio. The R-values were calculated using ISO 13370 two-dimensional numerical calculations, and using ISO 10211 based geometrical models. The 2D calculations used a geometric model simplified by replacing the pods and ribs with an homogenous material with a constant thermal conductivity calculated using a simplified 3D model of the pods and ribs.

The R-values are referenced to internal dimensions, include the edge losses, and cannot be used with PHPP.

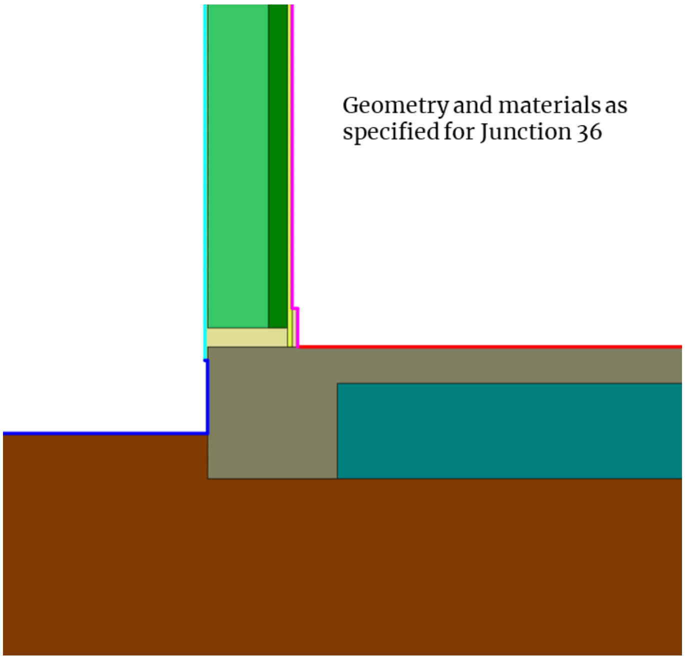
The top surface of the concrete slab is 200 mm above the ground level next to the slab.

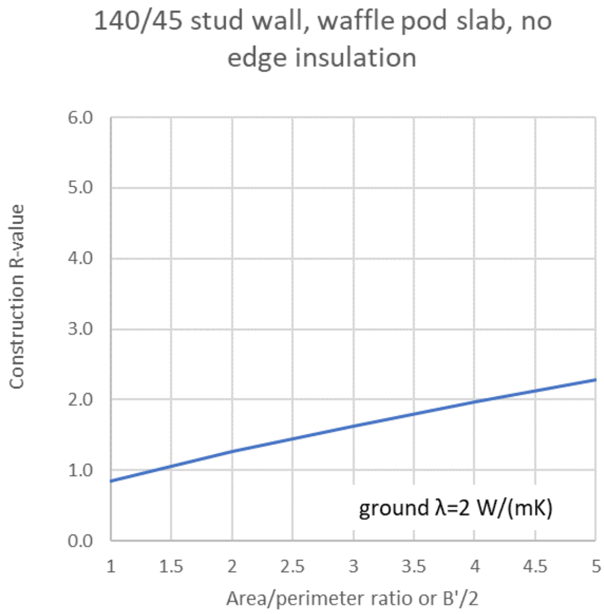
Note that 100 mm concrete ribs at 1200 mm centres in the field of the slab have been assumed.

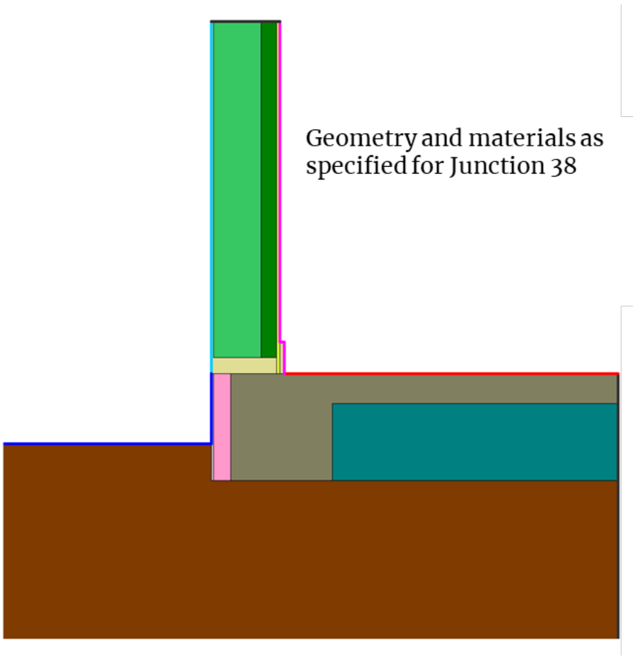
In warmer climates, uninsulated slabs with edge insulation could be appropriate but the risk of mould issues should be checked.

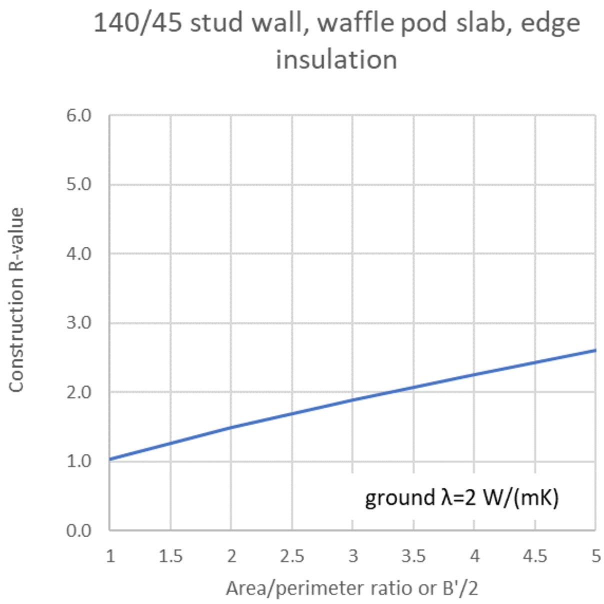
Cost and carbon table values are for the overall slab area excluding the slab edge and need to have the slab edge detail cost and carbon added to allow comparison (ie 10x10m slab would need 100sqm of cost and carbon from these Element tables here and 40m of cost and carbon from the slab edge Junction).

The insulated slab has the same materials and geometry as Junction 38. XPS (λ=0.028 W/(mK)) insulation 50mm thick on the edge and 220mm moulded pocket pods with 100mm concrete ribs at 1200mm centres under the entire core of the slab. Floor covering neglected.



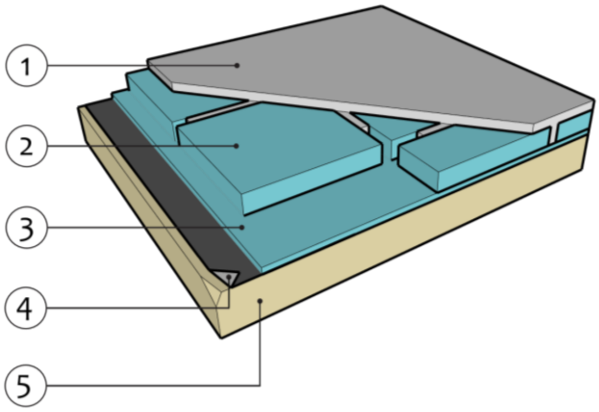






COST AND $kgCO_2eq$ TABLE

CONSTRUCTION	$/m²	$kgCO_2e/m^2$	Storage $kgCO_2e/m^2$
220mm moulded pocket pod	129	64	0
220mm solid EPS pod	153	75	0
300mm moulded pocket pod	138	68	0
300mm solid EPS pod	172	82	0



Concrete waffle pod slab:
1. Concrete slab and ribs
2. Foam pods (solid or hollow)
3. Rigid insulation under pods and ribs
4. DPM
5. blinding and ground

(k) FS Floor Slab waffle pod slab on ground with continuous under-slab insulation

This is an extension of Element J. Additional foam insulation has been added under the foam pods, concrete ribs/footer and to the slab edge to fully insulate them. This has been done in several certified Passive House projects. Details of the thermal conductivities and dimensions used are shown in the Junction(s).

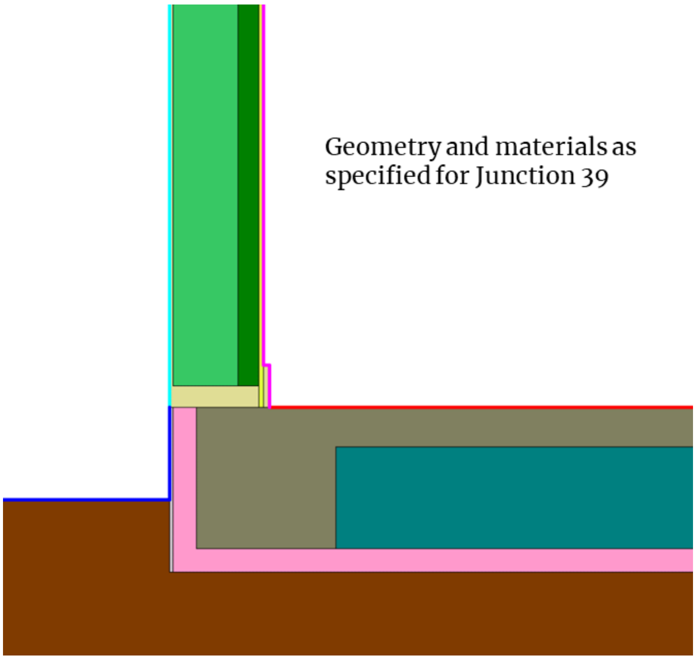
The R-value charts represent the floor heat loss as a function of the overall internal slab area-to-perimeter ratio. The R-values were calculated using ISO 13370 two-dimensional numerical calculations, and using ISO 10211 based geometrical models. The 2D calculations used a geometric model simplified by replacing the pods and ribs with an homogenous material with a constant thermal conductivity calculated using a simplified 3D model of the pods and ribs.

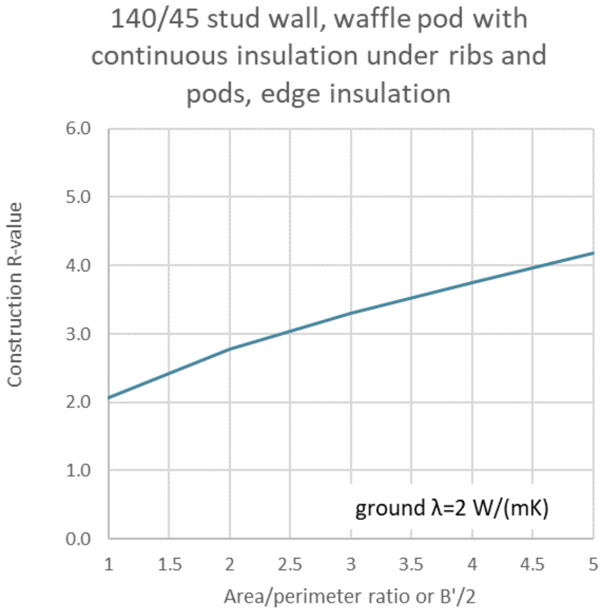
The R-values are referenced to internal dimensions, include the edge losses, and cannot be used with PHPP.

The top surface of the concrete slab is 200 mm above the ground level next to the slab. Note that 100 mm concrete ribs at 1200 mm centres in the field of the slab have been assumed.

In warmer climates, uninsulated slabs with edge insulation could be appropriate but the risk of mould issues should be checked.

Cost and carbon table values are for the overall slab area excluding the slab edge and need to have the slab edge detail cost and carbon added to allow comparison (ie 10x10m slab would need 100sqm of cost and carbon from these Element tables here and 40m of cost and carbon from the slab edge Junction).

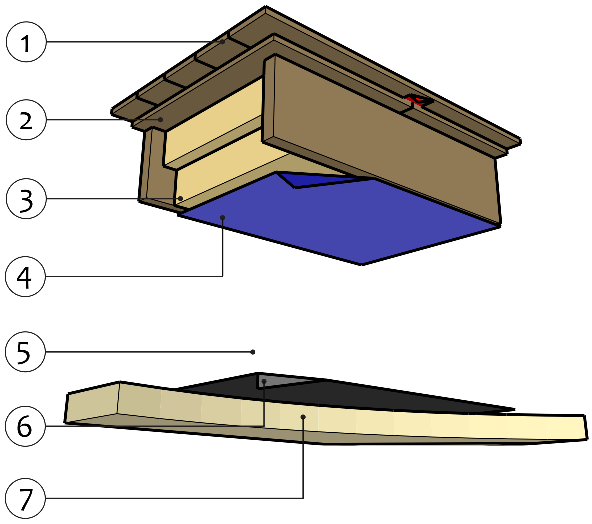




The insulated slab has the same materials and geometry as Junction 39. XPS (λ=0.028 W/(mK)) insulation 50mm thick on the edge and under the entire core of the slab with 220mm moulded pocket pods with 100mm concrete ribs at 1200mm centres on top of the XPS. Floor covering neglected.

COST AND $kgCO_2eq$ TABLE

CONSTRUCTION	$/m²	$kgCO_2e/m^2$	Storage $kgCO_2e/m^2$
220mm moulded pocket pod 30mm EPS	138	65	0
220mm moulded pocket pod 50mm EPS	140	66	0
220mm moulded pocket pod 100mm EPS	155	69	0
220mm moulded pocket pod 50mm XPS	173	69	0



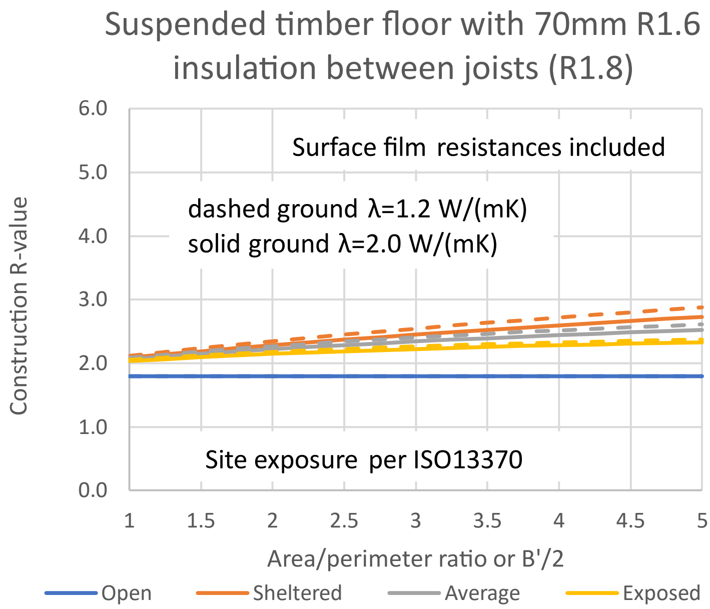
Suspended timber floor:

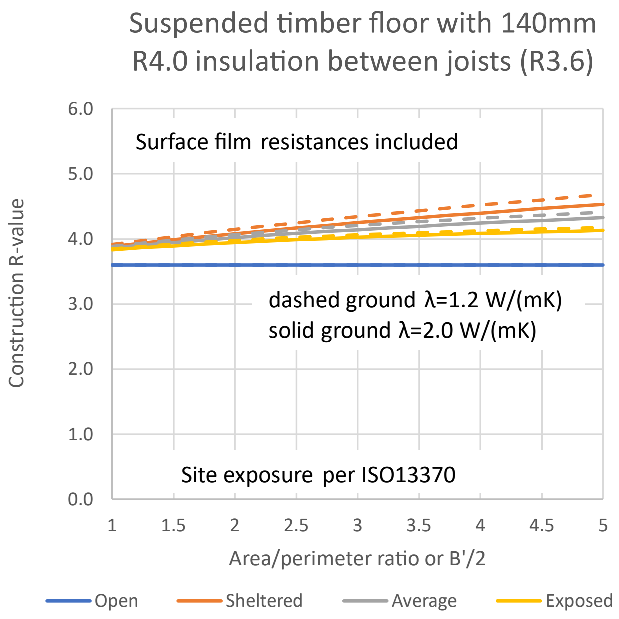
1. Interior finish floor timber or carpet (not included in cost/carbon)
2. Sub-floor timber panel or plywood junctions taped
3. Timber joists and fibre insulation
4. Windwash protection membrane (optional timber battens not shown)
5. Ventilated sub-floor space
6. DPM
7. Ground

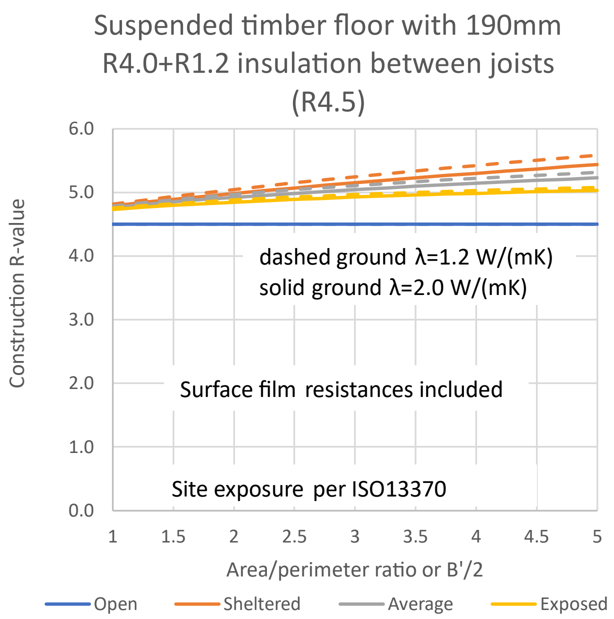
(l) FS Floor Slab suspended timber floor

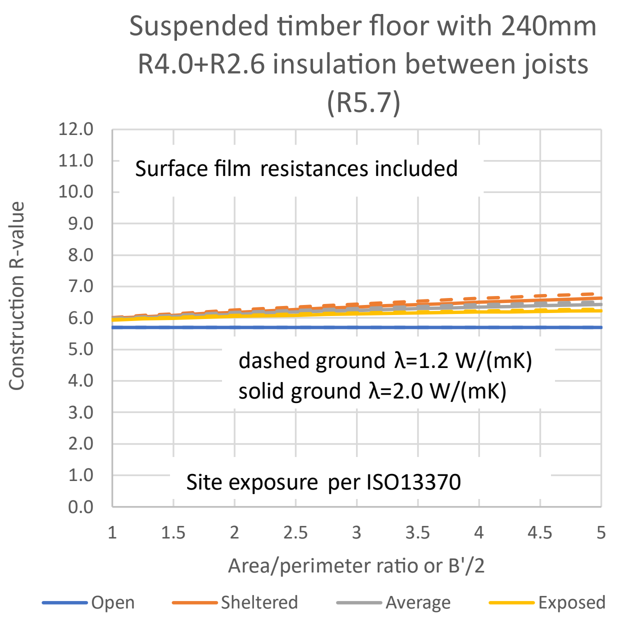
Suspended timber floors have been used successfully on many high-performance buildings. Thicker floor joists than standard are often required to fit the thickness of insulation needed but this can allow for fewer rows of piles/bearers.

The graphs show several building site/floor exposures. Open is a pole house or floor completely open to the outside environment. Sheltered, average and exposed refer to the site exposure to wind and assume minimum floor ventilation to NZBC (ie NZS 3604:2011 requires sub-floor vent openings of at least 3,500 mm² per m² of floor area).





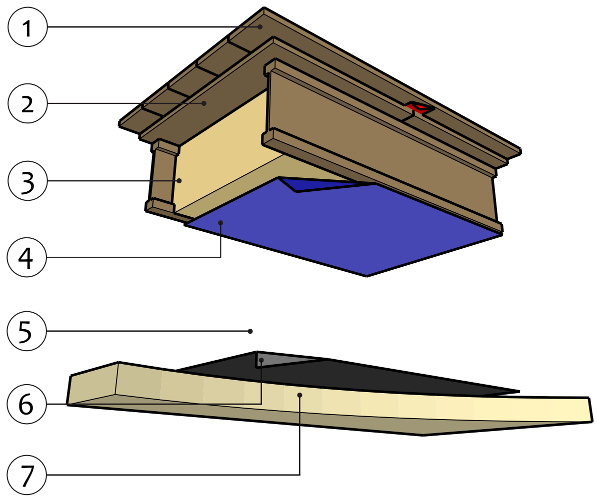




Analysis used a timber content in the floor at 12%. Floor R-value excludes the finish flooring but includes 20mm of wood board [λ=0.13 W/(mK)].

COST AND kgCO_2eq TABLE

CONSTRUCTION	$/m²	kgCO_2e/m²	Storage kgCO_2e/m²
140mm joists at 450mm with R1.6 fibre insulation	207	33	38
140mm joists at 450mm with R4.0 fibre insulation	227	34	38
190mm joists at 600mm with R4.0+R1.2 fibre insulation	237	37	40
240mm joists at 600mm with R4.0+R2.6 fibre insulation	274	39	49



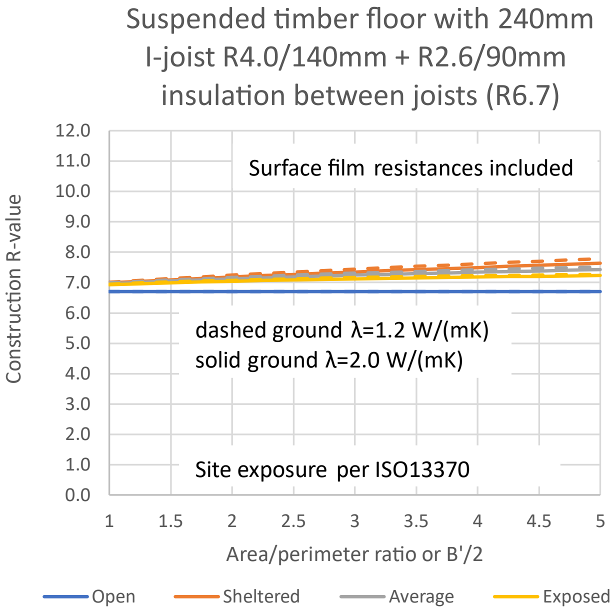
Suspended I-joist timber floor:

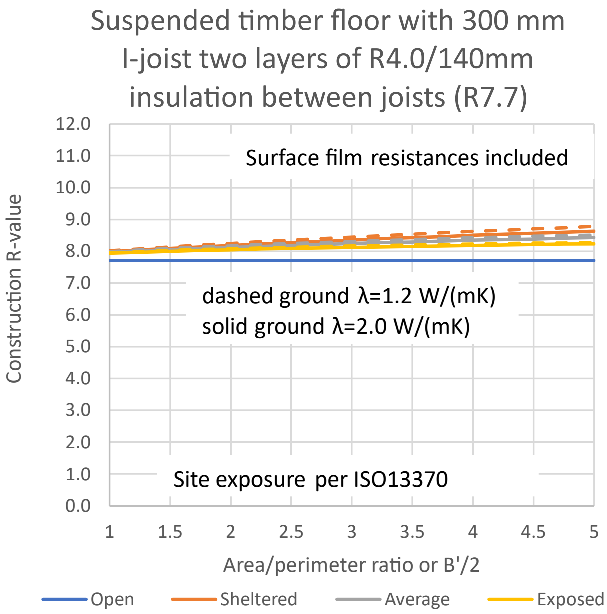
1. Interior finish floor timber or carpet (not included in cost/carbon)
2. Sub-floor timber panel or plywood junctions taped
3. Timber I-joist and fibre insulation
4. Windwash protection membrane (optional timber battens not shown)
5. Ventilated sub-floor space
6. DPM
7. Ground

(m) FS Floor Slab I-joist suspended timber floor

Suspended timber I-joist floors allow thicker floors than standard builds, which fit the required thickness of insulation and reduce the timber fraction for increased performance.

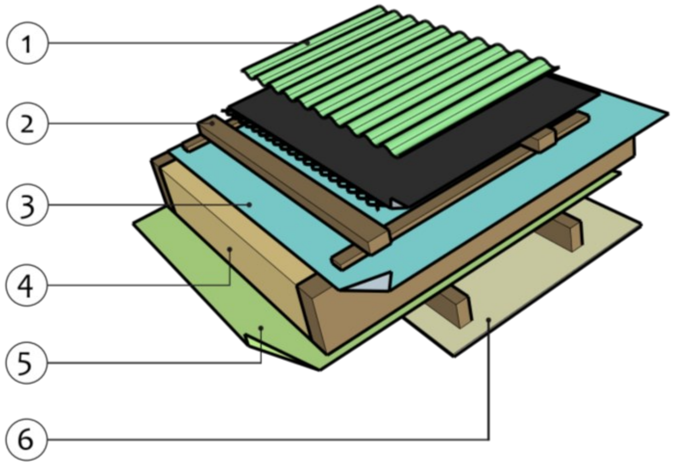
The graphs show several building site/floor exposures. Open is a pole house or floor completely open to the outside environment. Sheltered, average and exposed refer to the site exposure to wind and assume minimum floor ventilation to NZBC (ie NZS 3604:2011 requires sub-floor vent openings of at least 3,500 mm² per m² of floor area).





COST AND $kgCO_2eq$ TABLE

CONSTRUCTION	$/m²	$kgCO_2e/m^2$	Storage $kgCO_2e/m^2$
200mm I-joist 45mm flange at 600mm R2.6/110mm +R2.6/90mm fibre insulation	324	37	37
240mm I-joist 45mm flange at 600mm R4.0/140mm +R2.6/90mm fibre insulation	339	38	38
300mm I-joist 45mm flange at 600mm 2x R4.0/140mm fibre insulation	361	42	45

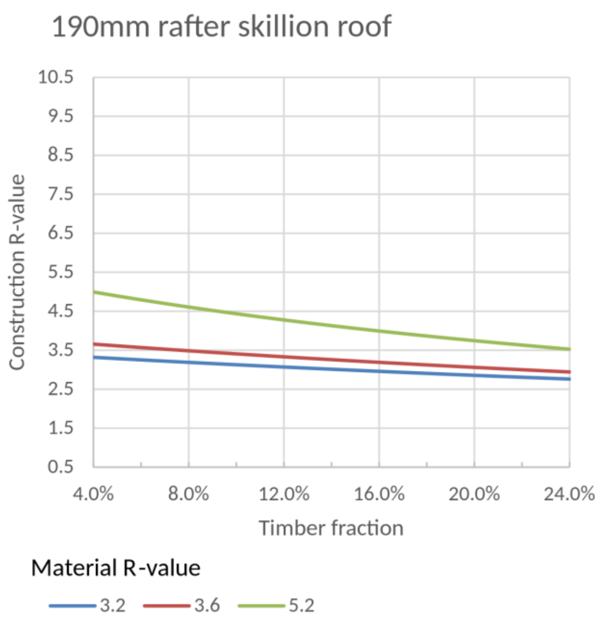


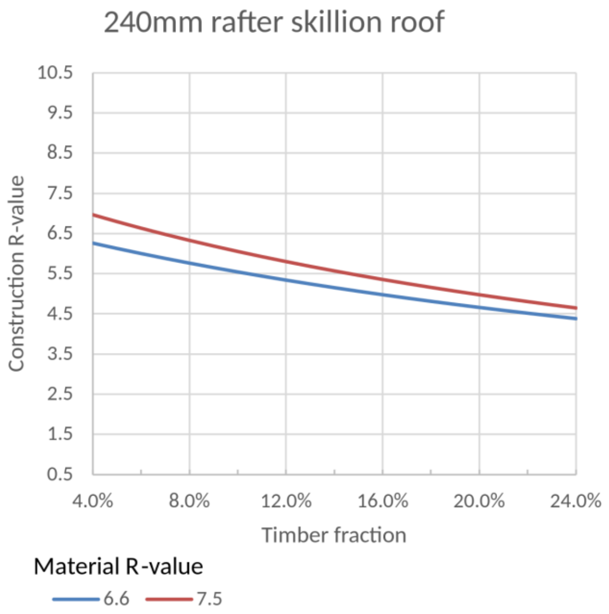
Skillion roof timber rafters:

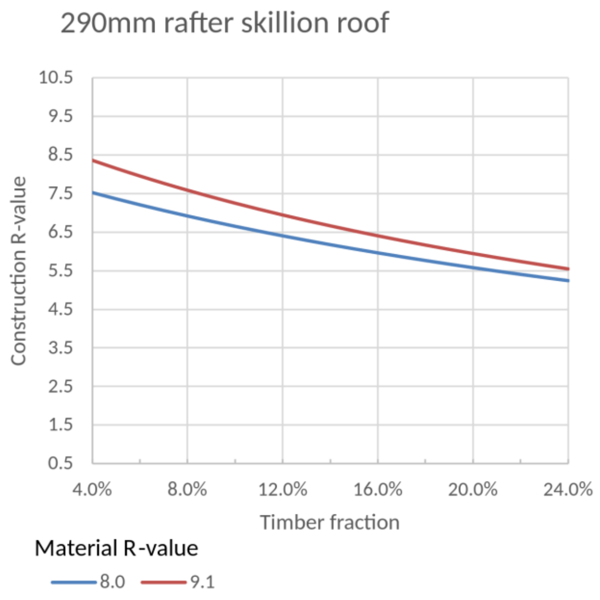
1. Roofing, underlay and safety mesh
2. Counter batten and purlin (ventilated)
3. Roof underlay vapour open membrane
4. Timber rafters and fibre insulation fully filling the rafters
5. Air/Vapour control membrane
6. Interior finish plasterboard with optional service cavity.

(n) RO Roof Rafter skillion roof with membrane air control layer and service cavity

This high-performance skillion roof assembly uses counter battens and an upper roof underlay directly over the rafters in order to fully fill between the rafters with insulation. This allows any condensation from under the steel to drain outside of the building and allows moisture which diffuses or leaks through the AVCL to dry to the outside through the roof underlay.

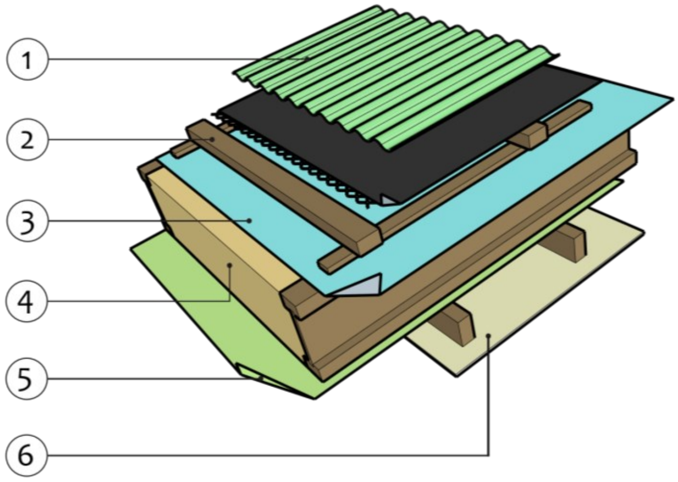






COST AND $kgCO_2eq$ TABLE

CONSTRUCTION	$/m²	$kgCO_2e/m^2$	Storage $kgCO_2e/m^2$
190mm rafter at 900mm current practice R3.2 fibre insulation – no counter batten or item 3 second underlay	232	32	20
190mm rafter at 900mm R4.0/140mm + R1.2/50mm fibre insulation	260	34	21
240mm rafter at 900mm R4.0/140mm + R2.6/90mm fibre insulation	275	35	23
290mm rafter at 900mm 2x R4.0/140mm fibre insulation	286	37	26

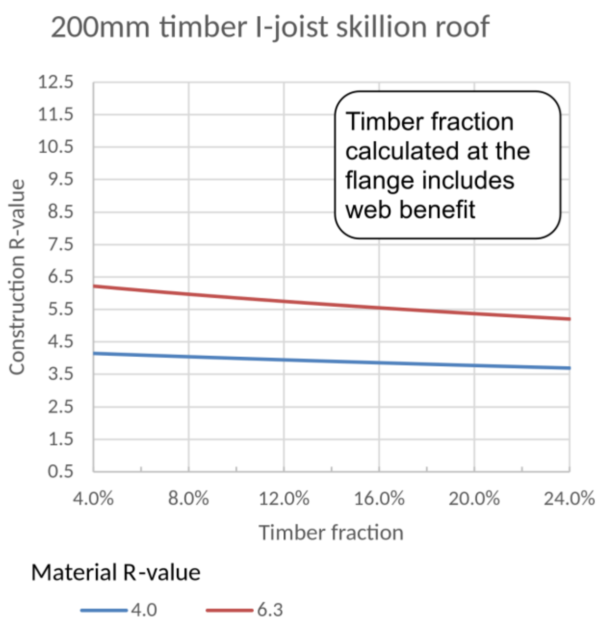


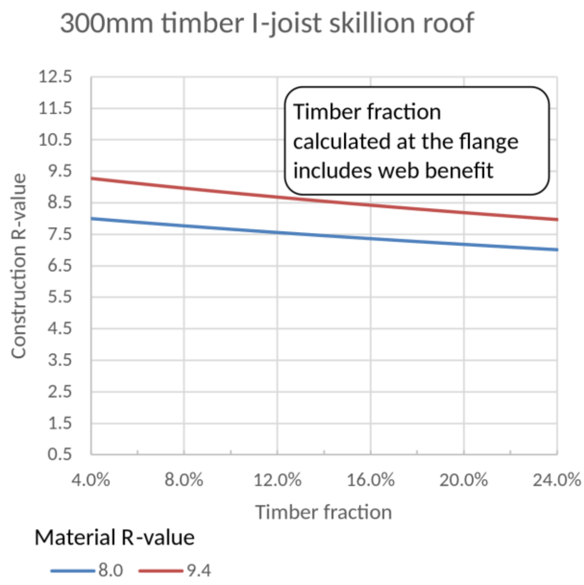
Skillion roof timber I-joist rafters:

1. Roofing, underlay and safety mesh
2. Counter batten and purlin ventilated
3. Roof underlay vapour open membrane
4. Timber I-joist rafters and fibre insulation fully filling the rafters
5. Air/vapour control layer membrane
6. Interior finish plasterboard with optional service cavity.

(o) RO Roof I-joist skillion, membrane air control layer and service cavity

This high-performance skillion roof assembly uses counter battens and an upper roof underlay directly over the I-joist rafters in order to fully fill between the rafters with insulation. This allows any condensation from under the steel to drain outside of the building and allows moisture which diffuses or leaks through the AVCL to dry to the outside through the roof underlay.

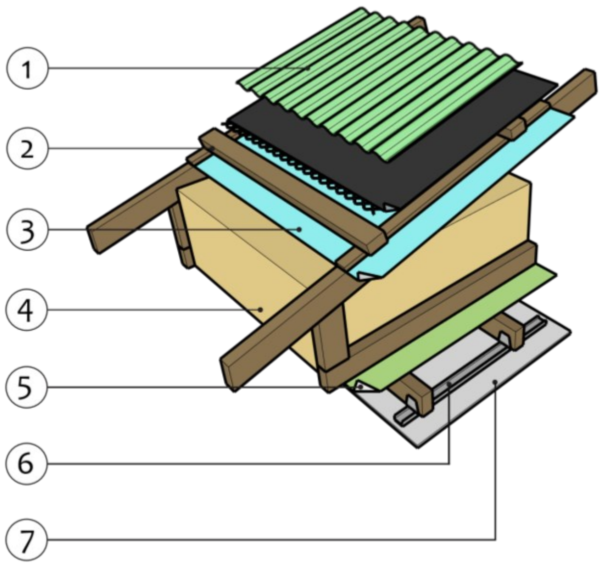




It is time-consuming to fit insulation batts tightly between the I-joist but this is necessary to prevent thermal bypass.

COST AND $kgCO_2eq$ TABLE

CONSTRUCTION	$/m²	$kgCO_2e/m^2$	Storage $kgCO_2e/m^2$
200mm I-joist 900mm centres; R4.0 (195mm thick) fibre insulation	318	40	27
240mm I-joist 900mm centres; R2.6/90mm and R4.0/140mm insulation	333	45	33
300mm I-joist 900mm centres; 2 layers R4.0/140mm insulation	340	46	33
360mm I-joist 900mm centres; dense pack 28 kg/m^3 fibre insulation	425	58	34

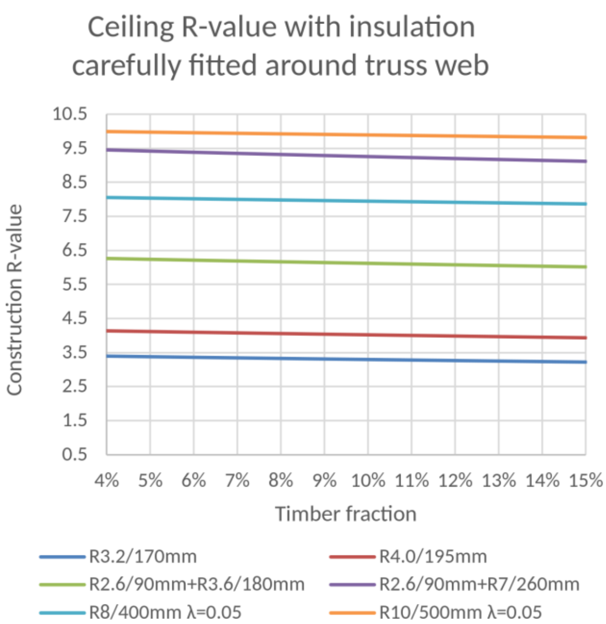


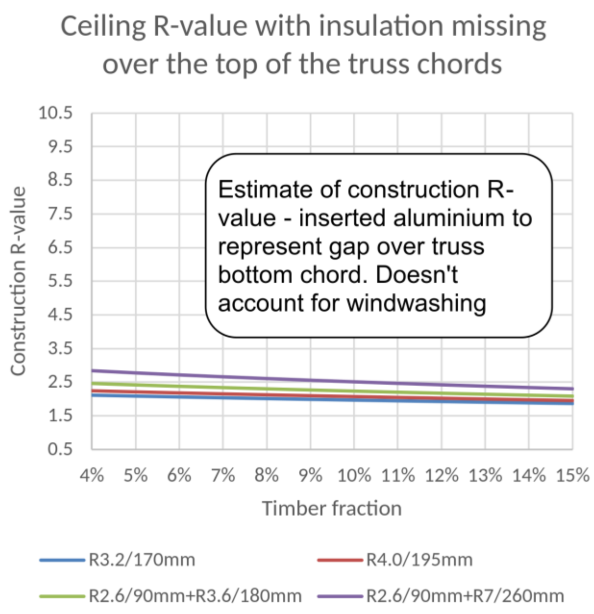
Timber truss roof:

1. Roofing, underlay and safety mesh
2. Counter batten and purlin (ventilated)
3. Roof underlay vapour open membrane
4. Timber truss and fibre insulation ventilated
5. Air/vapour control layer membrane
6. Service cavity timber blocking with steel batten system shown
7. Interior finish plasterboard

(p) TC Truss Ceiling timber frame ventilated roof space, membrane air control layer and service cavity

This is most common roof insulation assembly as it is generally the least expensive to build. High-performance buildings with this assembly typically specify a raised heel truss, which allows the full insulation thickness to be maintained over the top plate of the exterior walls, an AVCL in direct contact with the insulation and a service cavity. This ceiling thermal performance is highly dependent on insulation installation quality as discussed previously and shown in the graphs below.

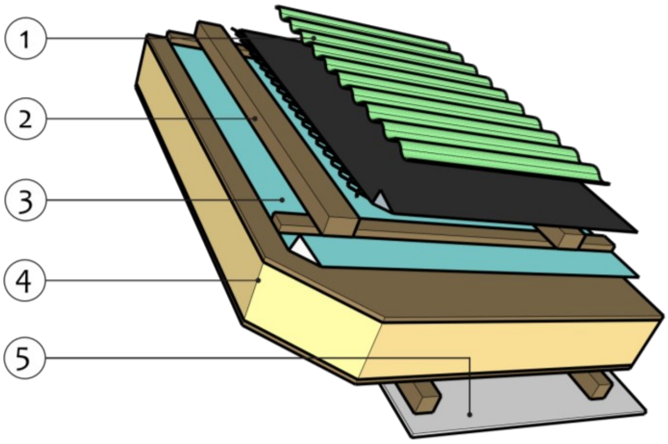




This graph of construction R-value assumes that the area over the truss bottom chords is an open-air gap to the ventilated attic and any heat entering this gap will quickly rise up and out of the building by air convection. Carefully fitting insulation around the truss webs to prevent gaps or using loose fill insulation is recommended.

COST AND $kgCO_2eq$ TABLE

CONSTRUCTION	$/m²	$kgCO_2e/m^2$	Storage $kgCO_2e/m^2$
Current practice – truss at 900mm R3.2 fibre insulation. No AVCL, counter batten or item 3 underlay	190	37	18
Truss at 900mm R3.2 fibre insulation	263	40	23
Truss at 900mm R2.6/90mm + R3.6/180mm fibre insulation	281	42	24
Truss at 900mm R2.6/90mm + R7.0/260mm fibre insulation	289	42	21

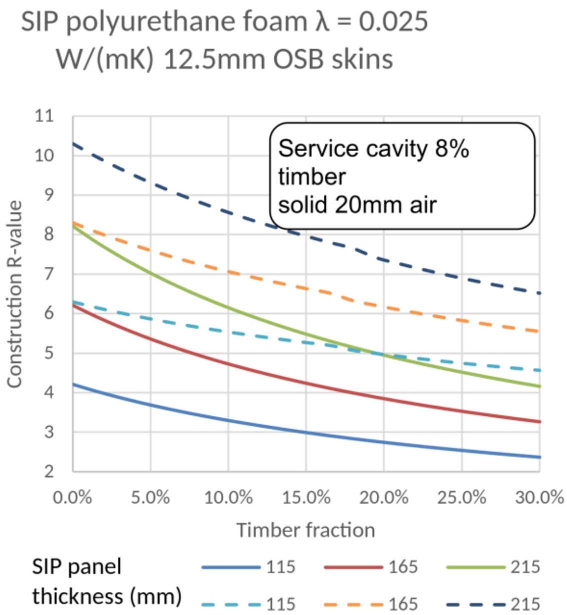


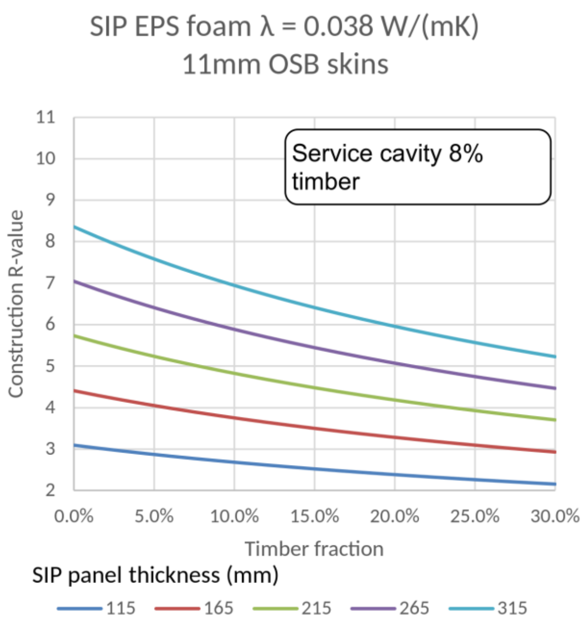
Skillion SIP roof

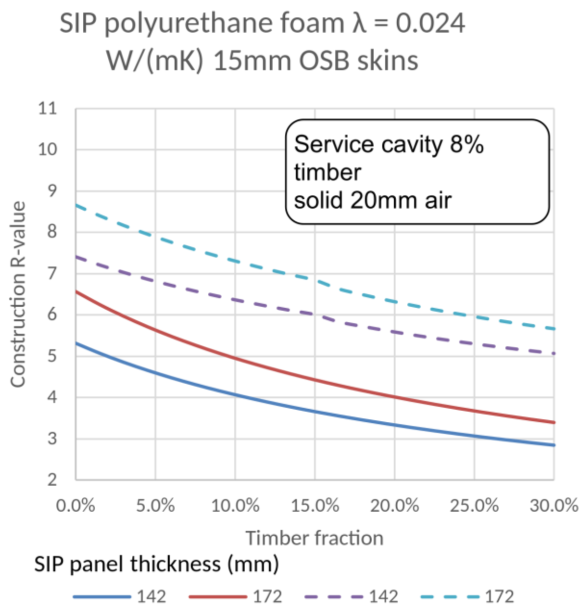
1. Roofing, underlay and safety mesh
2. Counter batten and purlin (ventilated)
3. Roof underlay vapour open membrane
4. SIP interior junctions taped for air/vapour control
5. Interior finish plasterboard with optional service cavity.

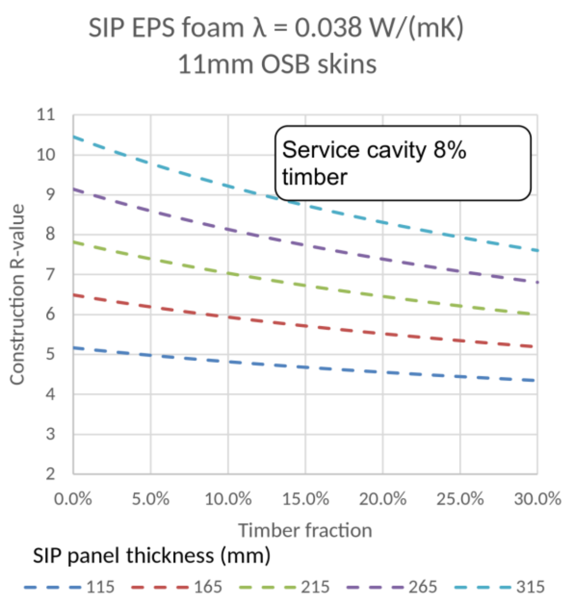
(q) RO Roof SIP with service cavity

The construction performance of a SIP roof is primarily a function of the SIP thickness, SIP foam thermal conductivity and timber fraction in the SIP. The graphs are for the main types of SIP used in New Zealand. Solid lines are 20mm air-filled service cavity and the dashed lines are for a 45mm R1.2 insulation service cavity, both with a minimal 8% timber content.





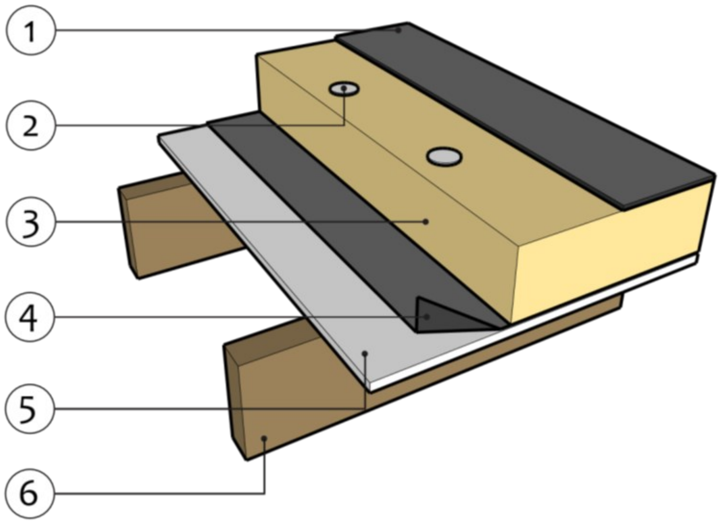




Note PUR core assumes HFO blowing agent other older blowing agents can result in significantly higher embodied carbon.

COST AND $kgCO_2eq$ TABLE

CONSTRUCTION	\$/m²	$kgCO_2e/m^2$	Storage $kgCO_2e/m^2$
215mm SIP (193mm EPS core) / 45mm battens / plasterboard	636	66	44
265mm SIP (243mm EPS core) / 45mm battens / plasterboard	635	70	43
165mm SIP (140mm PUR core) / 45mm battens / plasterboard	618	63	42
215mm SIP (190mm PUR core) / 45mm battens / plasterboard	633	67	45



Membrane on rigid insulation warm roof:

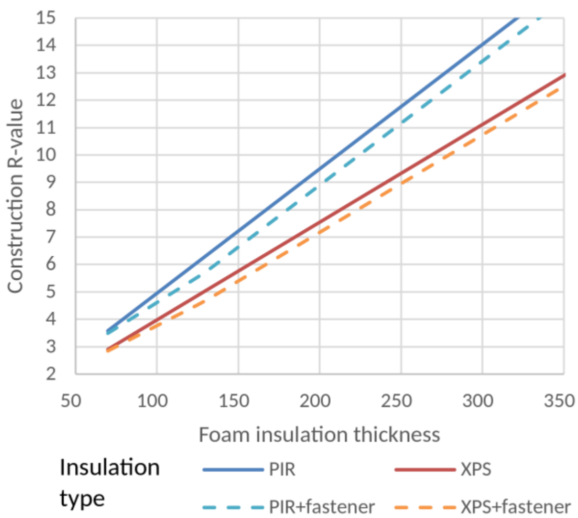
1. Roof membrane (watertightness layer)
2. Mechanical fasteners (optional)
3. Rigid insulation
4. Air/vapour control membrane layer
5. Structural roof deck plywood shown (steel option)
6. Roof structure timber rafters shown (steel option)

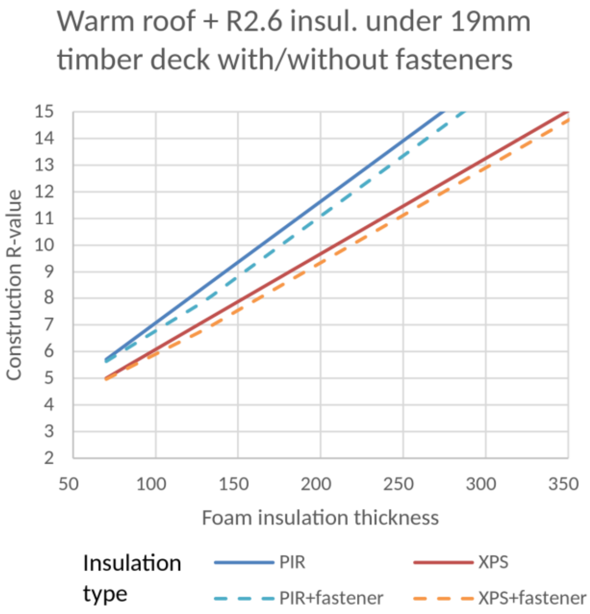
(r) FR Flat Roof warm roof

Warm roofs use insulation above the roof structure. This keeps the entire structure warm and, coupled with the installation of an AVCL, results in a roof assembly that is relatively insensitive to interior moisture levels. Insulating the exterior of the roof assembly also allows the use of steel structural elements with less risk of thermal bridging. A full AVCL below the warm roof insulation is recommended in all climates.

Note that it is good practice to install the warm roof insulation in multiple layers and offset the seams so that convection does not occur in the seams between the insulation panels. Air gaps in the warm roof system are not recommended.

Warm roof assembly on 19mm timber deck with and without fasteners





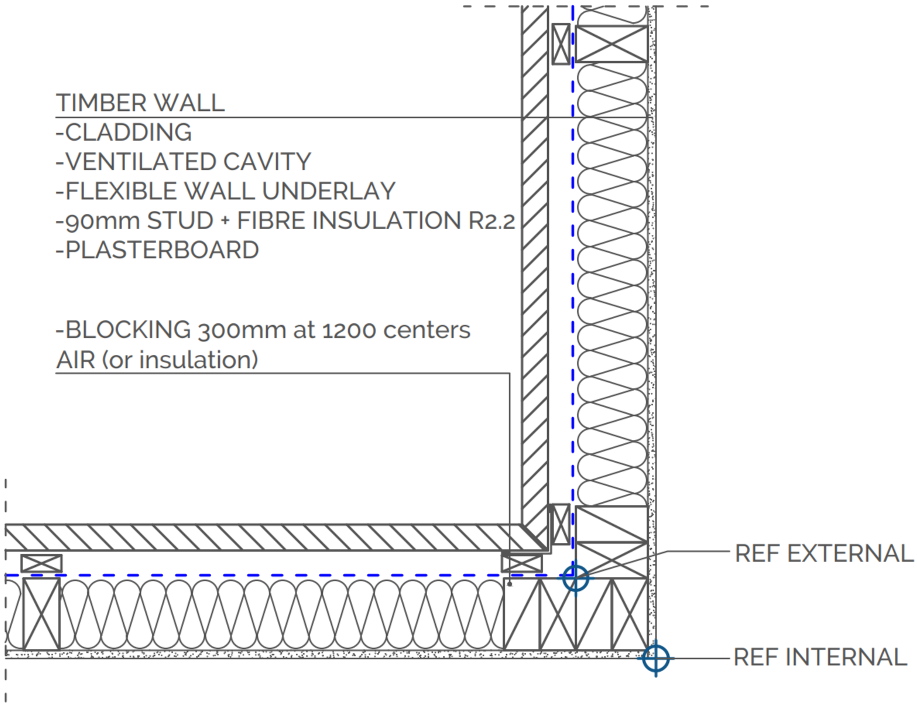
Fastener impact on thermal performance is calculated using ISO6946:2007 Annex D. Full thickness (non-countersunk) fasteners should be avoided. Countersunk fasteners have an impact on overall performance but are recommended along with fully adhered systems. Graph assumes 3.5 fasteners per sqm and 6.3mm steel screw countersunk 60mm , and then the countersunk depth increased so the steel screw is a maximum of 100mm long.

Timber fraction in the R2.6 layer is assumed to be 12%.

COST AND kgCO_2eq TABLE

CONSTRUCTION	$/m²	kgCO_2eq/m²	Storage kgCO_2eq/m²
70mm PIR (Polyisocyanurate)	460	40	39
80mm PIR (Polyisocyanurate)	460	40	39
100mm PIR (Polyisocyanurate)	482	41	39
200mm PIR (Polyisocyanurate)	581	46	39

Junctions



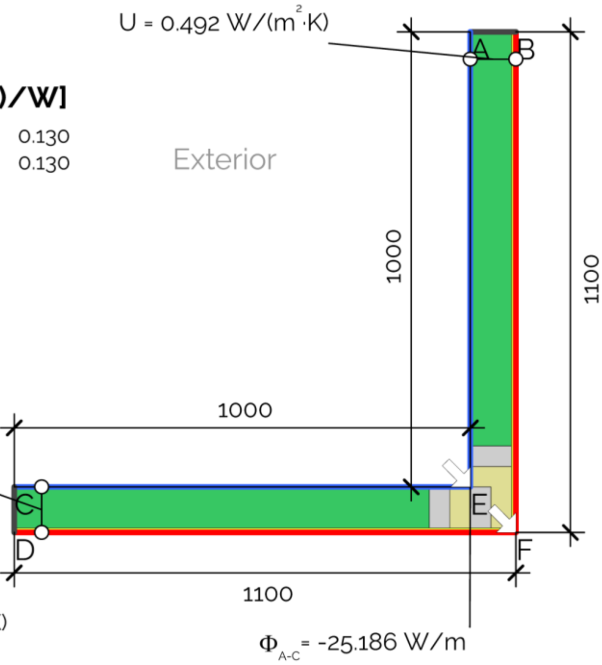
1 EWIC External Wall – inner corner 90mm stud wall current practice

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.274 W/(mK)	0.176 W/(mK)
f_{RSI}	0.715	
Cost	$76 per linear metre	
Carbon	7 $kgCO_2e/m$	
Carbon Storage	8 $kgCO_2e/m$	

This detail represents a current practice timber stud wall with uninsulated gaps between blocking in the corner. Excessive heat loss occurs due to the corner geometry, timber, blocking and air spaces in the corner.

Improved thermal bridge values may be achieved by insulating between the blocking with carefully fitted fibre insulation.



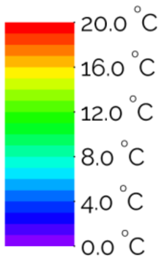
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, ventilated		0.000	0.130
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

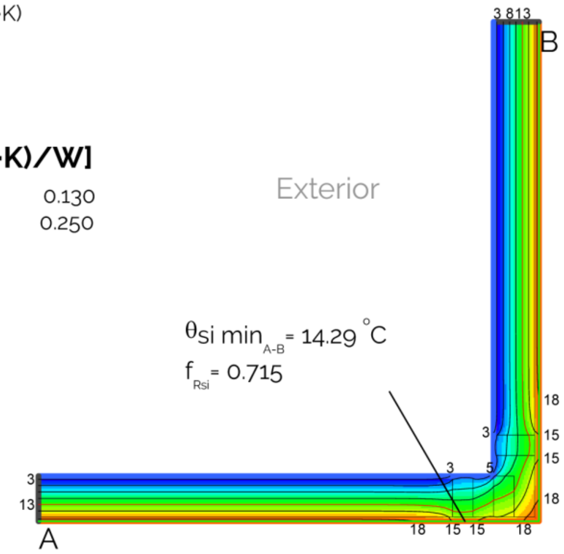
Material	λ[W/(m·K)]
Air90mm+25%Timber	0.400
FibreInsulR2.2/90mm+12%Timber	0.052
Plasterboard	0.250
Timber (Softwood)	0.130

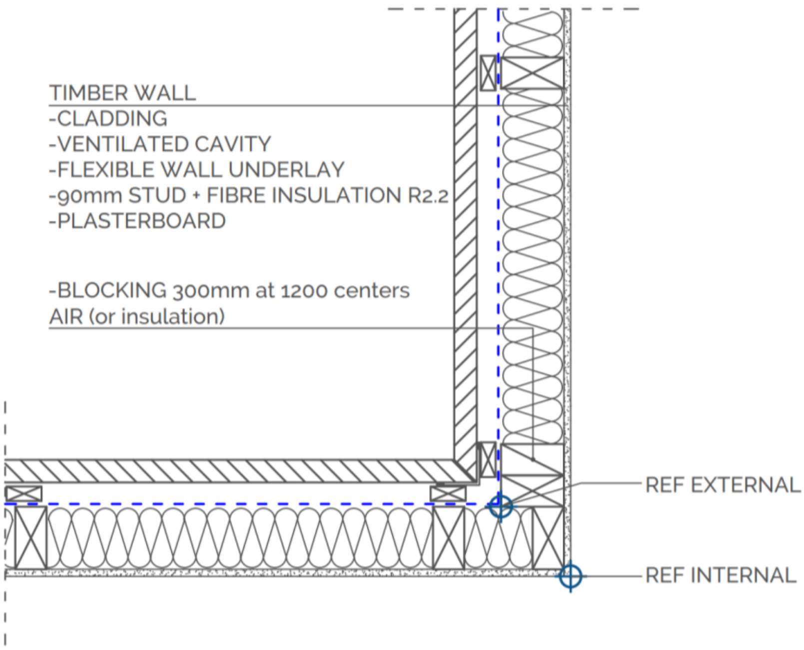
$$\psi_{A\text{-}E\text{-}C} = \frac{25.186}{20.000} - 0.492 \cdot 1.000 - 0.492 \cdot 1.000 = 0.274 \text{ W/(m·K)}$$

$$\psi_{D\text{-}F\text{-}B} = \frac{25.186}{20.000} - 0.492 \cdot 1.100 - 0.492 \cdot 1.100 = 0.176 \text{ W/(m·K)}$$

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		







2 EWIC External Wall – Inner Corner 90mm stud wall reduced timber

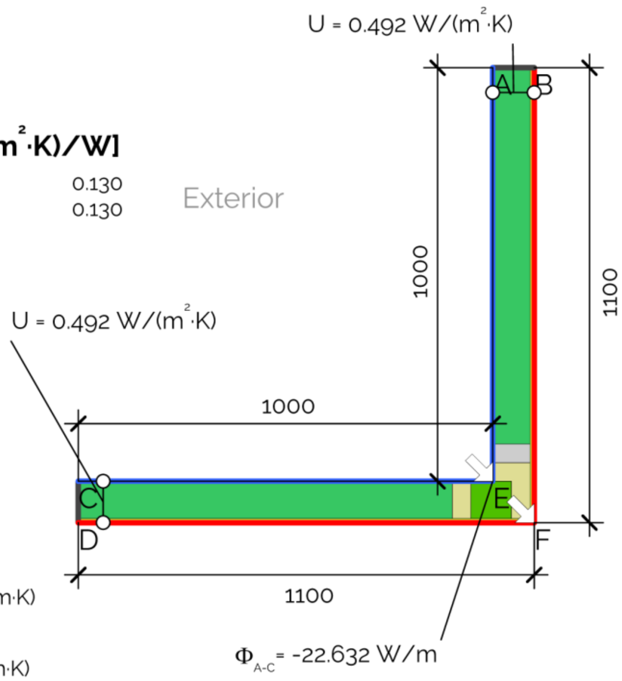
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.147 W/(mK)	0.048 W/(mK)
f_{RSI}	0.715	
Cost	$69 per linear metre	
Carbon	7 $kgCO_2eq/m$	
Carbon Storage	7 $kgCO_2eq/m$	

One option to improve the performance of current 90mm timber stud wall construction is to reduce the additional blocking at the corner. This two-stud corner offers improved thermal performance as insulation can be installed to fill nearly all of the cavities. The one remaining blocking/air section in grey was added for cladding attachment. Use of structural cavity battens would allow insulation of all the cavities.

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

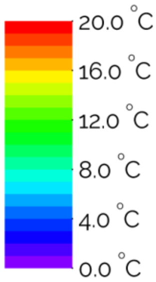
Material	λ[W/(m·K)]
Air90mm+25%Timber	0.400
FibreInsulR2.2/90mm	0.041
FibreInsulR2.2/90mm+12%Timber	0.052
Plasterboard	0.250
Timber (Softwood)	0.130

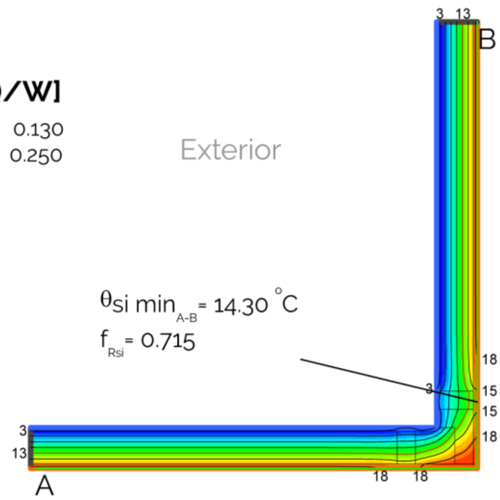


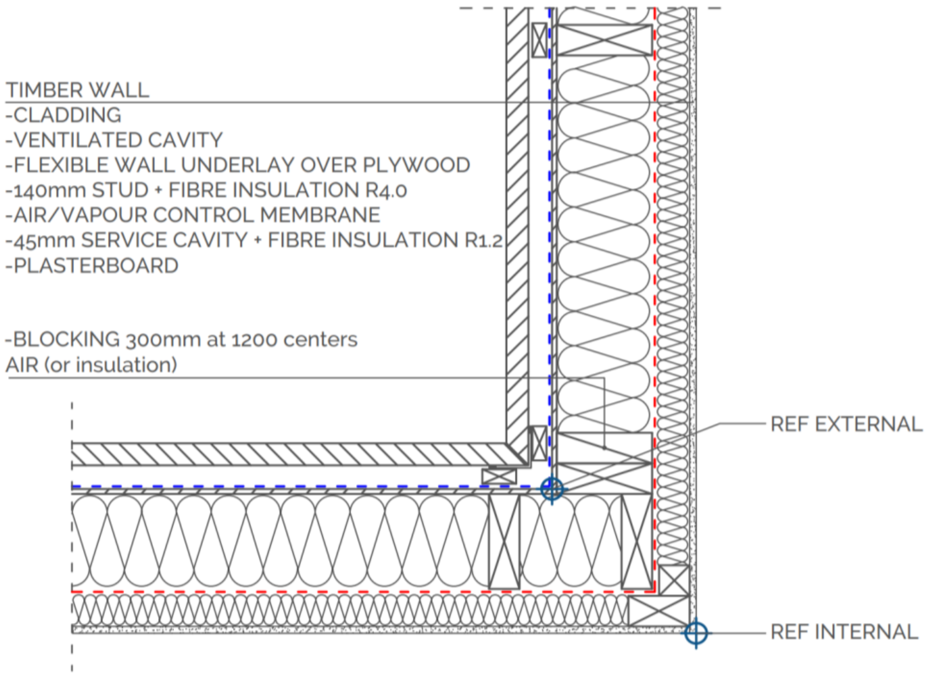
$$\Psi_{A\text{-}E\text{-}C} = \frac{22.632}{20.000} - 0.492 \cdot 1.000 - 0.492 \cdot 1.000 = 0.147\ \mathrm{W/(m \cdot K)}$$

$$\Psi_{D\text{-}F\text{-}B} = \frac{22.632}{20.000} - 0.492 \cdot 1.100 - 0.492 \cdot 1.100 = 0.048\ \mathrm{W/(m \cdot K)}$$

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		







3 EWIC External Wall – Inner Corner 140/45 stud wall current practice timber

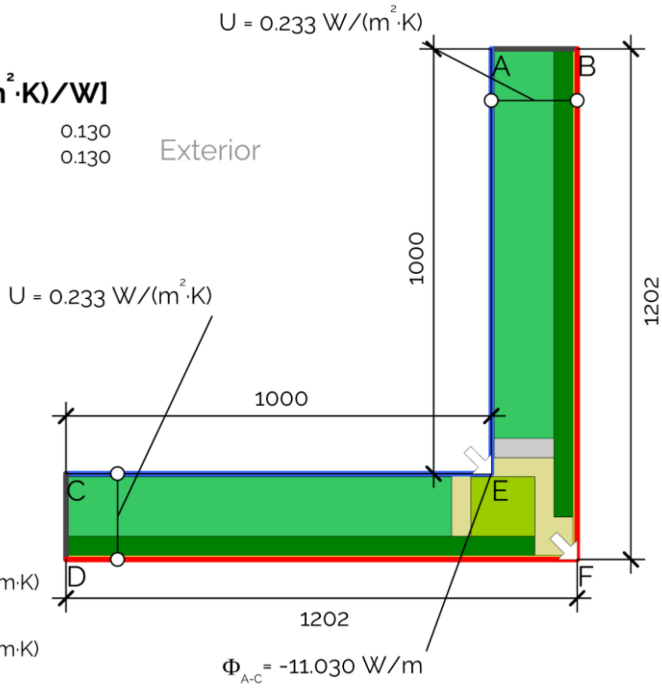
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.086 W/(mK)	-0.008 W/(mK)
f_{RSI}	0.902	
Cost	$167 per linear metre	
Carbon	13 $kgCO_2eq/m$	
Carbon Storage	21 $kgCO_2eq/m$	

The most common high-performance construction system is a 140mm structural stud wall with dwangs/nogs removed by using plywood for shear bracing and an interior insulated service cavity. The one remaining blocking/air section in grey was added for cladding attachment. Use of structural cavity battens would allow insulation of all the cavities.

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

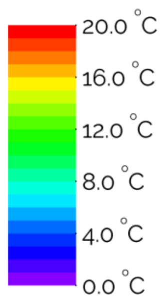
Material	λ[W/(m·K)]
Air140mm+25%Timber	0.600
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm	0.035
FibreInsulR4.0/140mm+12%Timber	0.046
Plasterboard	0.250
Timber (Softwood)	0.130

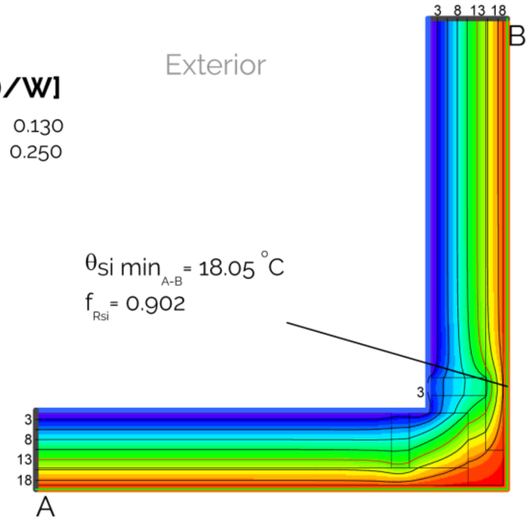


$$\psi_{A-E-C} = \frac{11.030}{20.000} - 0.233\cdot1.000 - 0.233\cdot1.000 = 0.086 \text{ W/(m·K)}$$

$$\psi_{D-F-B} = \frac{11.030}{20.000} - 0.233\cdot1.202 - 0.233\cdot1.202 = -0.008 \text{ W/(m·K)}$$

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		





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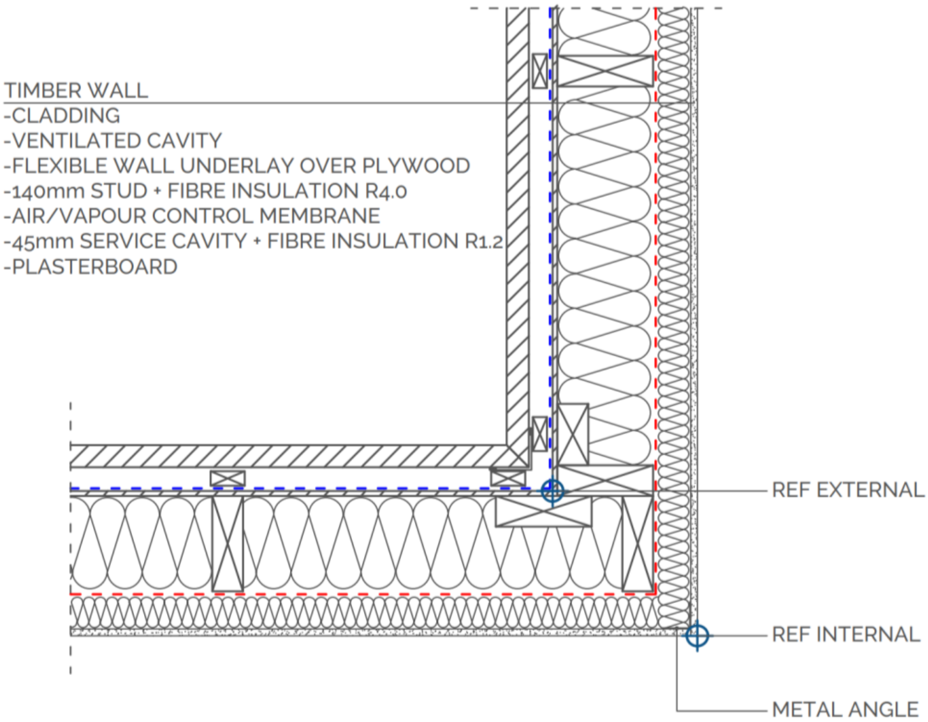


4 EWIC External Wall – Inner Corner 140/45 stud wall no extra timber

RESULTS TABLE

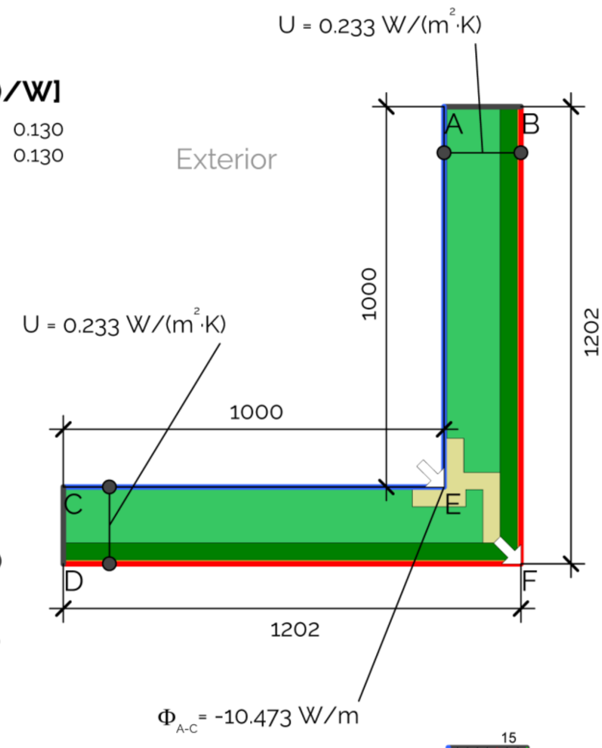
Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.058 W/(mK)	-0.036 W/(mK)
f_{RSI}	0.936	
Cost	$152 per linear metre	
Carbon	12 $kgCO_2eq/m$	
Carbon Storage	21 $kgCO_2eq/m$	

This is an improved version of the most common high-performance construction system: a 140mm structural stud wall with dwangs/nogs removed by using plywood for shear bracing and an interior insulated service cavity. Blocking “on the flat” has been added for cladding attachment while still allowing full insulation of all cavities.

This is close to the least thermal bridge that can be achieved with timber stud construction and external wall–inner corner geometry.

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

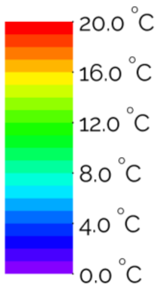
Material	λ[W/(m·K)]
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
Plasterboard	0.250
Timber (Softwood)	0.130

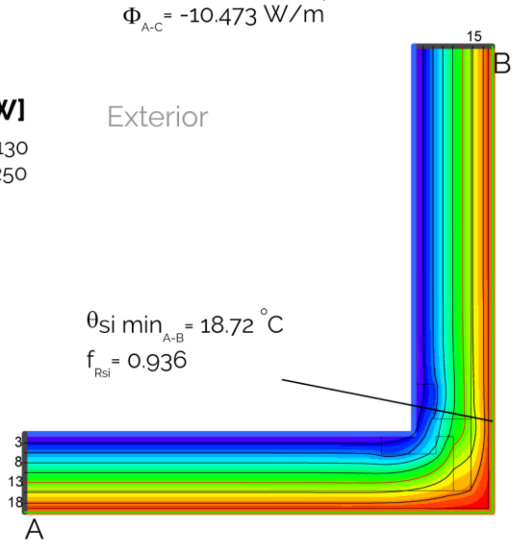


$$\psi_{A\text{-}E\text{-}C} = \frac{10.473}{20.000} - 0.233 \cdot 1.000 - 0.233 \cdot 1.000 = 0.058\ W/(m \cdot K)$$

$$\psi_{D\text{-}F\text{-}B} = \frac{10.473}{20.000} - 0.233 \cdot 1.202 - 0.233 \cdot 1.202 = -0.036\ W/(m \cdot K)$$

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		





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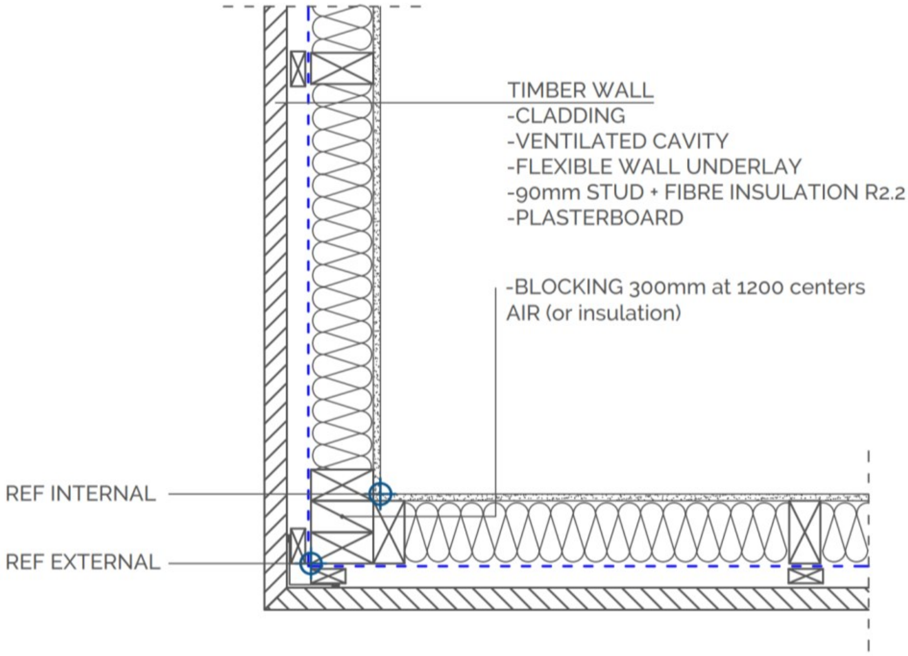


5 EWEC External Wall - External corner 90mm stud wall current practice

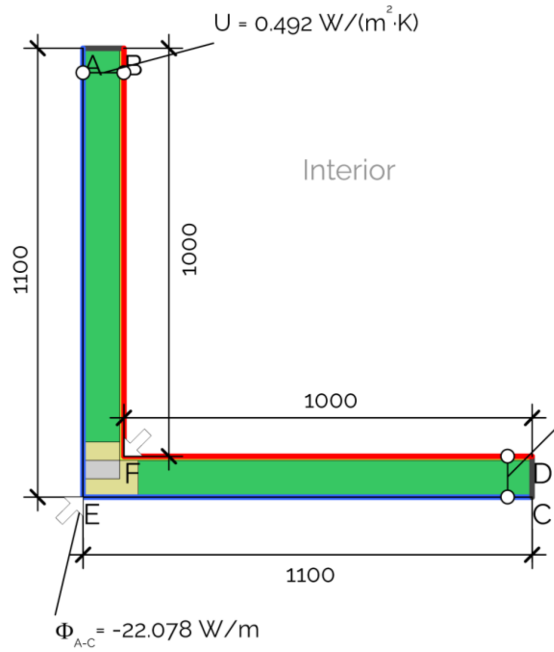
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.021 W/(mK)	0.119 W/(mK)
f_{RSI}	0.590	
Cost	$71 per linear metre	
Carbon	7 $kgCO_2eq/m$	
Carbon Storage	11 $kgCO_2eq/m$	

This detail represents a current practice timber stud wall with un-insulated gaps between blocking in the corner. Excessive heat loss occurs due to the corner geometry, timber, blocking and air spaces in the corner.

Improved thermal bridge values may be achieved by insulating between the blocking with carefully fitted fibre insulation.

Notice the low fRSI value of 0.59 meets the PHI fRSI criteria for Warm climate zones like Auckland but does not meet the fRSI criteria in the remainder of New Zealand.

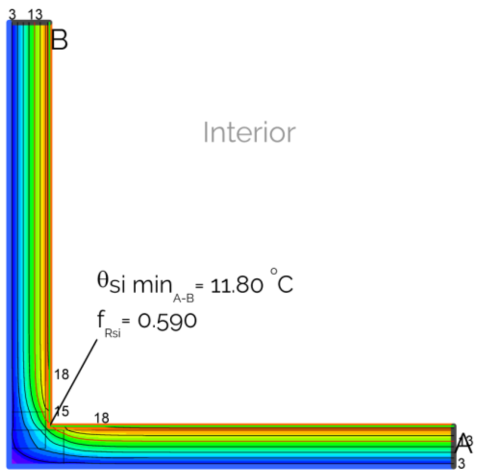


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

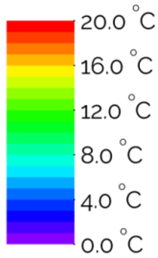
Material	λ[W/(m·K)]
Air90mm+25%Timber	0.400
FibreInsulR2.2/90mm+12%Timber	0.052
Plasterboard	0.250
Timber (Softwood)	0.130

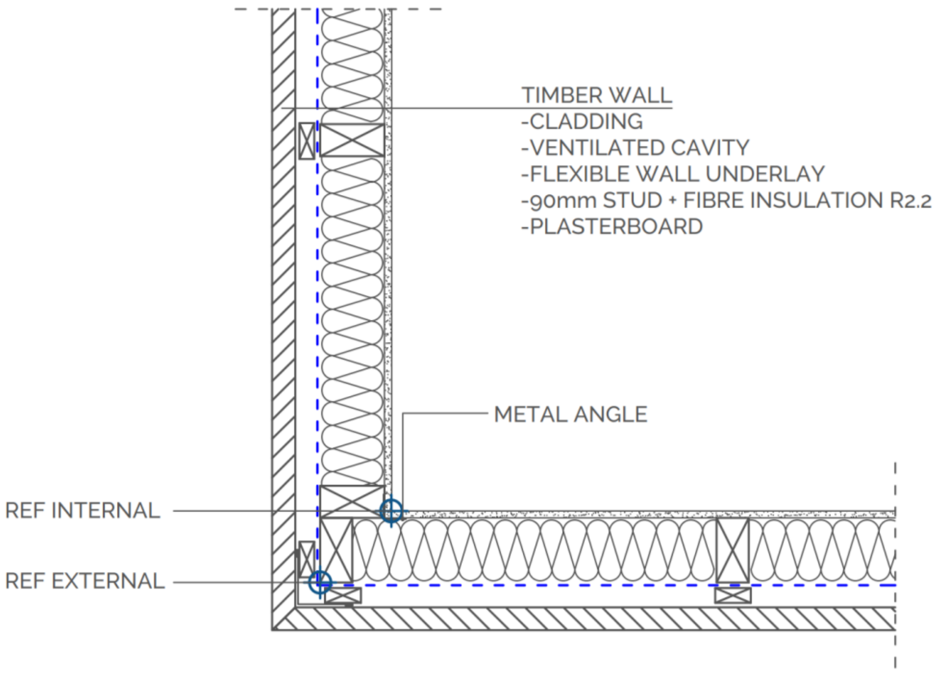
$$\Psi_{A\text{-}E\text{-}C} = \frac{22.078}{20.000} - 0.492 \cdot 1.100 - 0.492 \cdot 1.100 = 0.021\ \text{W/(m·K)}$$

$$\Psi_{D\text{-}F\text{-}B} = \frac{22.078}{20.000} - 0.492 \cdot 1.000 - 0.492 \cdot 1.000 = 0.119\ \text{W/(m·K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



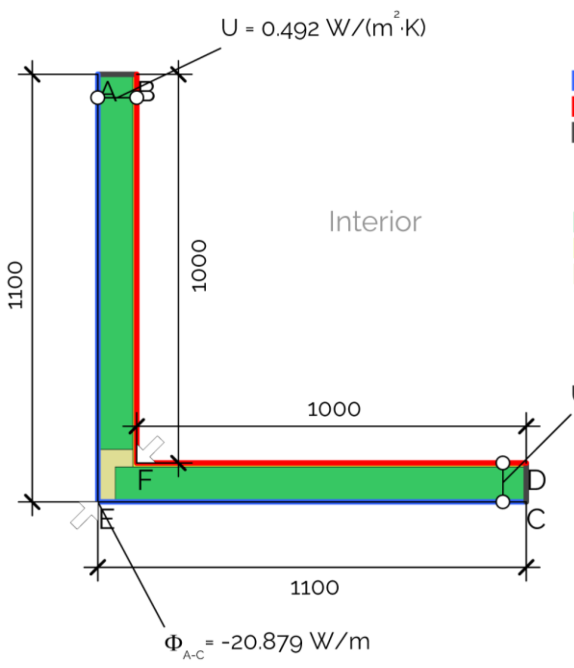


6 EWEC External Wall - External corner stud wall 90mm two stud corner

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	-0.039 W/(mK)	0.059 W/(mK)
f_{RSI}	0.727	
Cost	Not calculated	
Carbon	Not calculated	

Reducing the additional blocking at the corner is one way to improve the thermal performance of a typical 90mm timber stud wall construction. A two-stud corner means insulation can be installed to fill all of the cavities. This is most commonly done with a metal angle to allow fixing of the plasterboard.

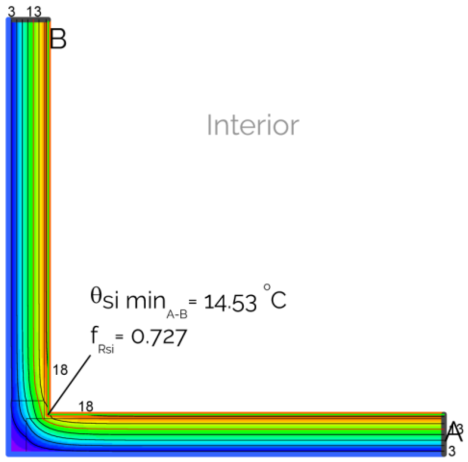


Boundary Condition	**q[W/m²]**	**θ[°C]**	**R[(m²·K)/W]**
Exterior, Ventilated		0.000	0.130
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

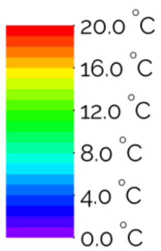
Material	**λ[W/(m·K)]**
FibreInsulR2.2/90mm+12%Timber	0.052
Plasterboard	0.250
Timber (Softwood)	0.130

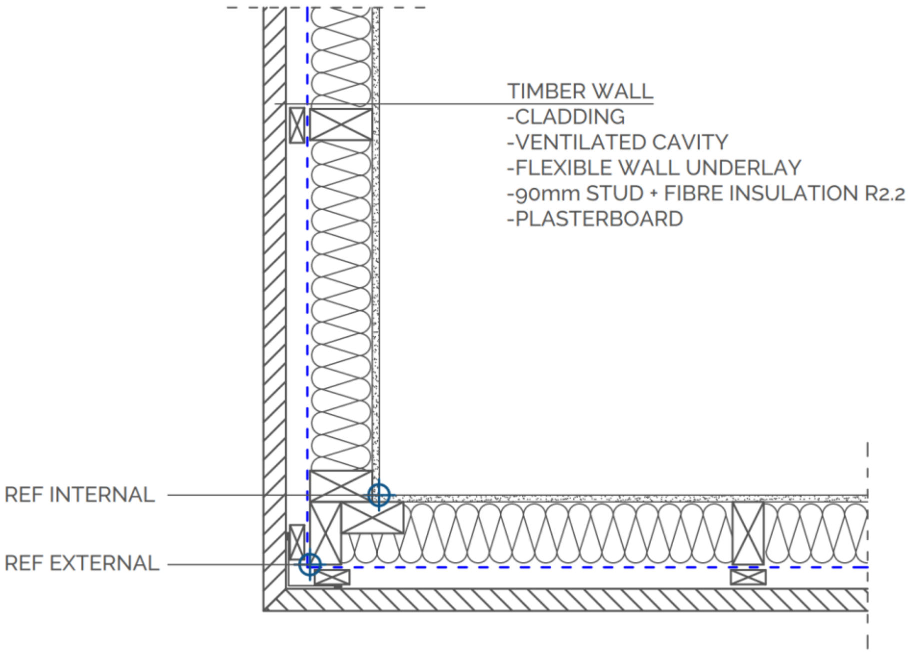
$$\Psi_{A-E-C} = \frac{20.879}{20.000} - 0.492 \cdot 1.100 - 0.492 \cdot 1.100 = -0.039 \text{ W/(m·K)}$$

$$\Psi_{D-F-B} = \frac{20.879}{20.000} - 0.492 \cdot 1.000 - 0.492 \cdot 1.000 = 0.059 \text{ W/(m·K)}$$



Boundary Condition	**q[W/m²]**	**θ[°C]**	**R[(m²·K)/W]**
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



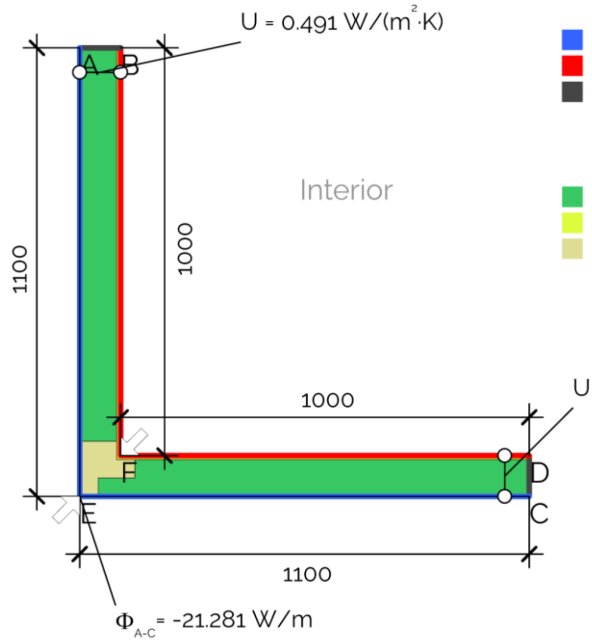


7 EWEC External Wall - External corner stud wall 90mm two stud ('California Corner')

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	-0.018 W/(mK)	0.080 W/(mK)
f_{RSI}	0.679	
Cost	Not calculated	
Carbon	Not calculated	

Rotating one stud at the corner to provide blocking for the internal plasterboard is another way to improve thermal performance of a 90mm timber stud wall construction. This three-stud corner means insulation can be installed to fill all of the cavities. It is common in California, USA.

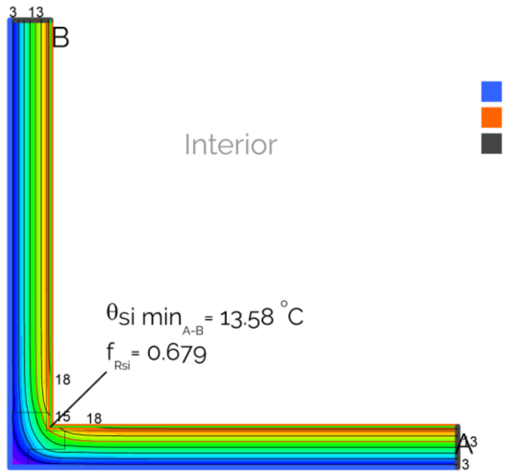


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

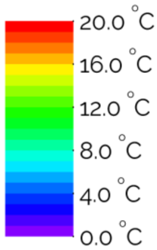
Material	λ[W/(m·K)]
FibreInsulR2.2/90mm+12%Timber	0.052
Plasterboard	0.250
Timber (Softwood)	0.130

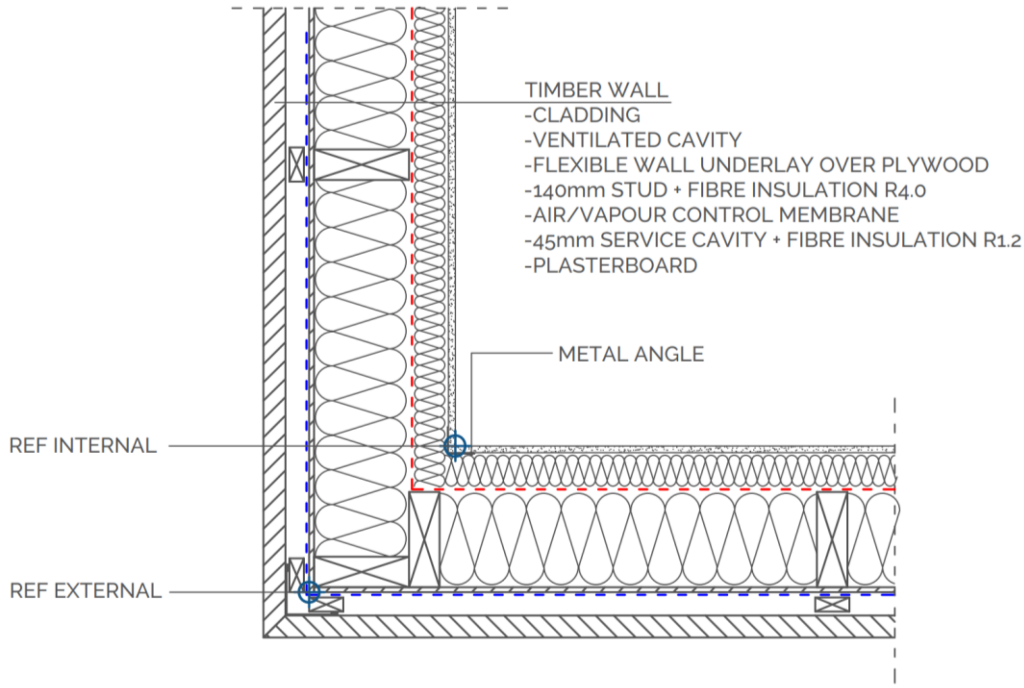
$$\Psi_{A\text{-}E\text{-}C} = \frac{21.281}{20.000} - 0.491 \cdot 1.100 - 0.492 \cdot 1.100 = -0.018 \text{ W/(m·K)}$$

$$\Psi_{D\text{-}F\text{-}B} = \frac{21.281}{20.000} - 0.492 \cdot 1.000 - 0.491 \cdot 1.000 = 0.080 \text{ W/(m·K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



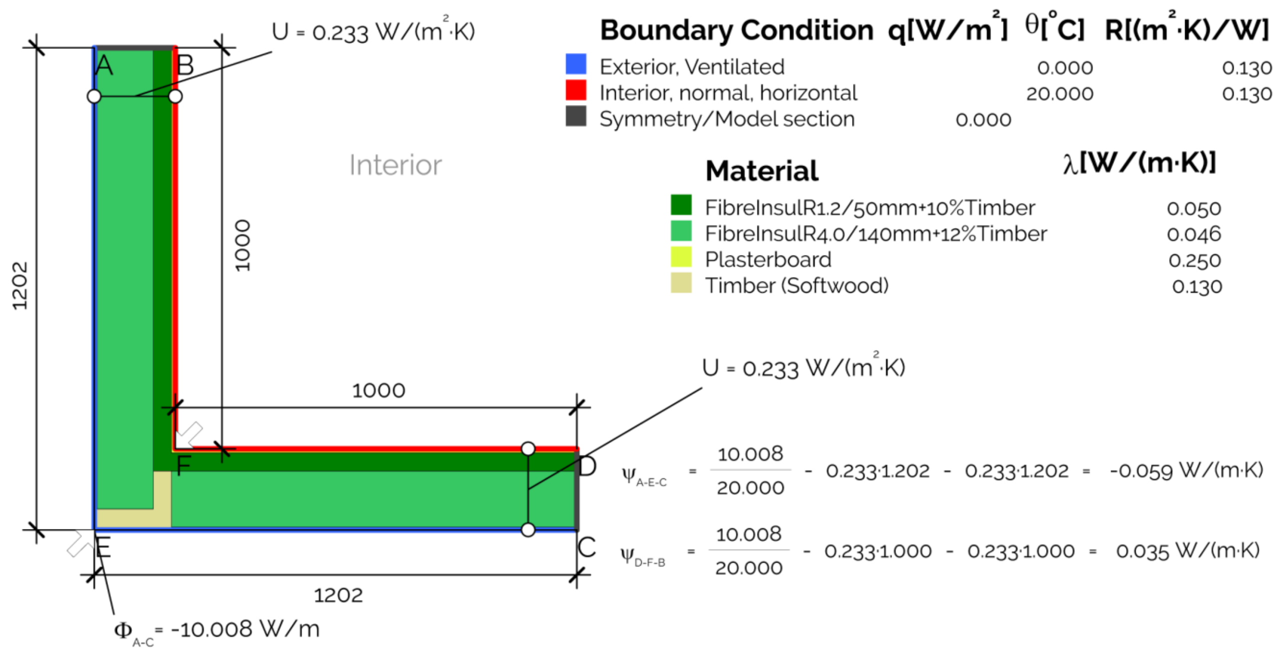


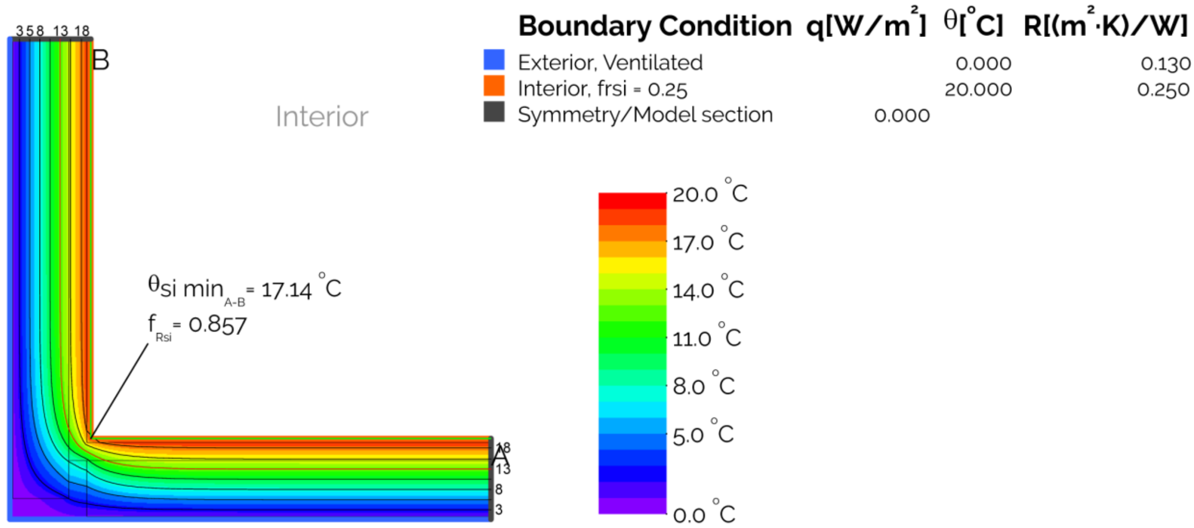
8 EWEC External Wall - External corner 140/45 stud wall no extra timber

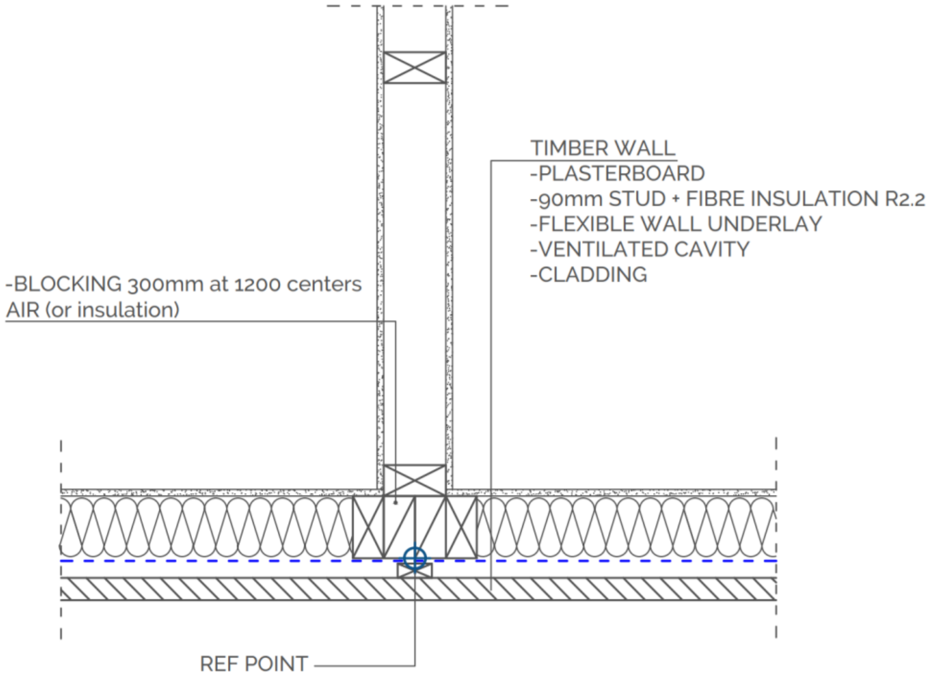
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	-0.059 W/(mK)	0.035 W/(mK)
f_{RSI}	0.857	
Cost	$34 per linear metre	
Carbon	3 $kgCO_2eq/m$	
Carbon Storage	5 $kgCO_2eq/m$	

The most common high-performance construction system is a 140mm structural stud wall with dwangs/nogs removed by using plywood for shear bracing and an interior insulated service cavity. This two-stud corner allow insulation of all the cavities. It produces the best performance achievable with standard timber stud construction as it has the least amount of timber.


U = 0.233 W/(m²·K)
A
B
Interior
1202
1000
1000
F
D
E
C
1202
U = 0.233 W/(m²·K)
Φ A-C = -10.008 W/m
Boundary Condition q[W/m²] θ[°C] R[(m²·K)/W]
Exterior, Ventilated 0.000 0.130
Interior, normal, horizontal 20.000 0.130
Symmetry/Model section 0.000
Material λ[W/(m·K)]
FibreInsulR1.2/50mm+10%Timber 0.050
FibreInsulR4.0/140mm+12%Timber 0.046
Plasterboard 0.250
Timber (Softwood) 0.130
ψ A-E-C = 10.008 / 20.000 - 0.233·1.202 - 0.233·1.202 = -0.059 W/(m·K)
ψ D-F-B = 10.008 / 20.000 - 0.233·1.000 - 0.233·1.000 = 0.035 W/(m·K)


3 5 8 13 18
B
Interior
θsi min A-B = 17.14 °C
f Rsi = 0.857
A
18
13
8
3
Boundary Condition q[W/m²] θ[°C] R[(m²·K)/W]
Exterior, Ventilated 0.000 0.130
Interior, frsi = 0.25 20.000 0.250
Symmetry/Model section 0.000
20.0 °C
17.0 °C
14.0 °C
11.0 °C
8.0 °C
5.0 °C
0.0 °C



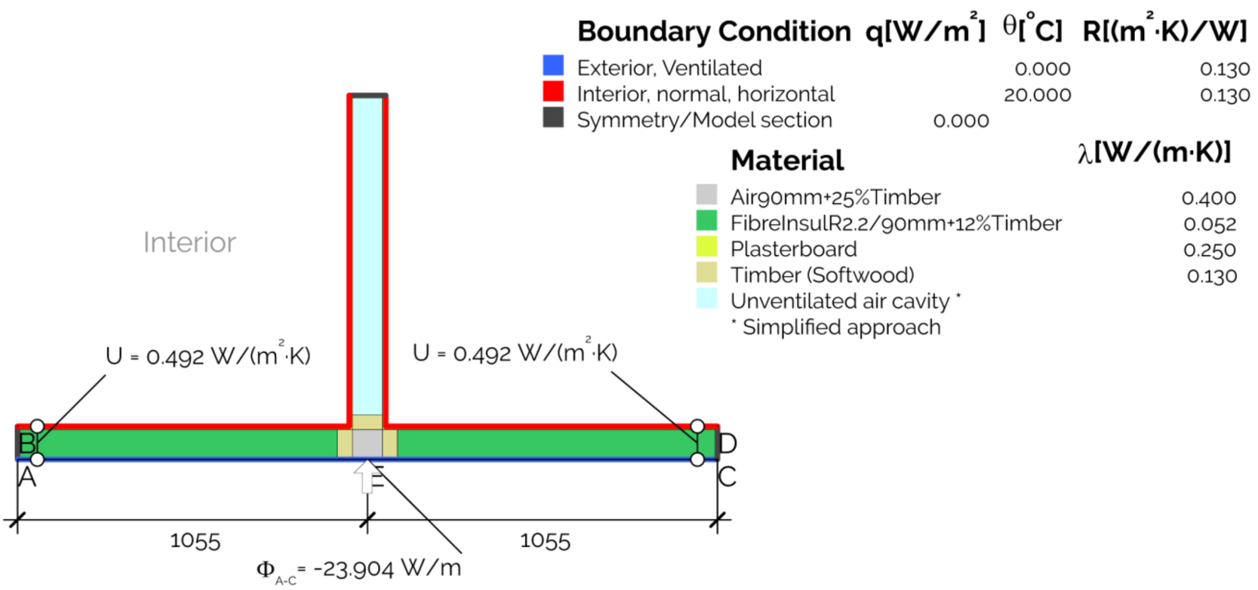
9 EWIW External Wall to Internal Wall - Stud wall 90mm stud current practice

RESULTS TABLE

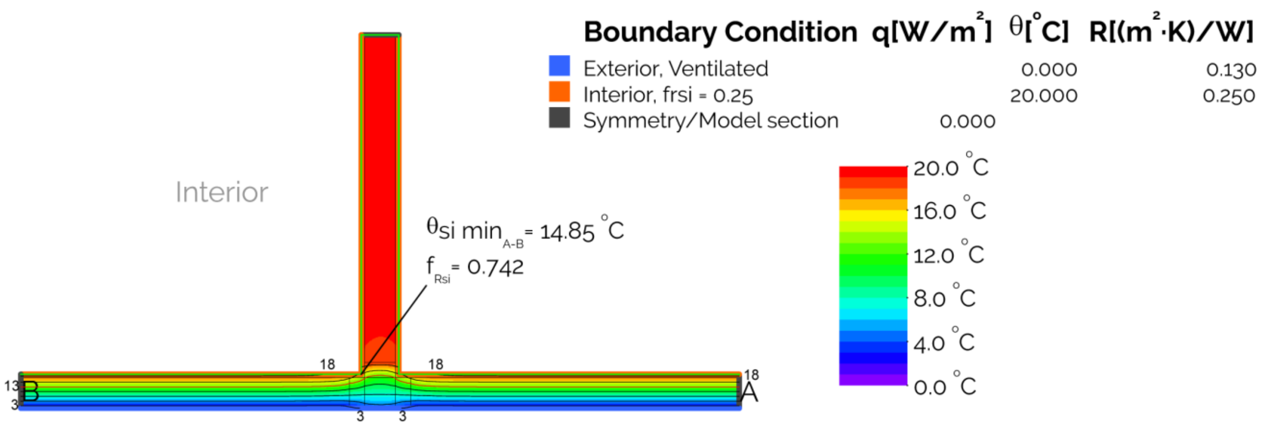
Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.156 W/(mK)	0.156 W/(mK)
f_{RSI}	0.742	
Cost	$68 per linear metre	
Carbon	3 $kgCO_2eq/m$	
Carbon Storage	8 $kgCO_2eq/m$	

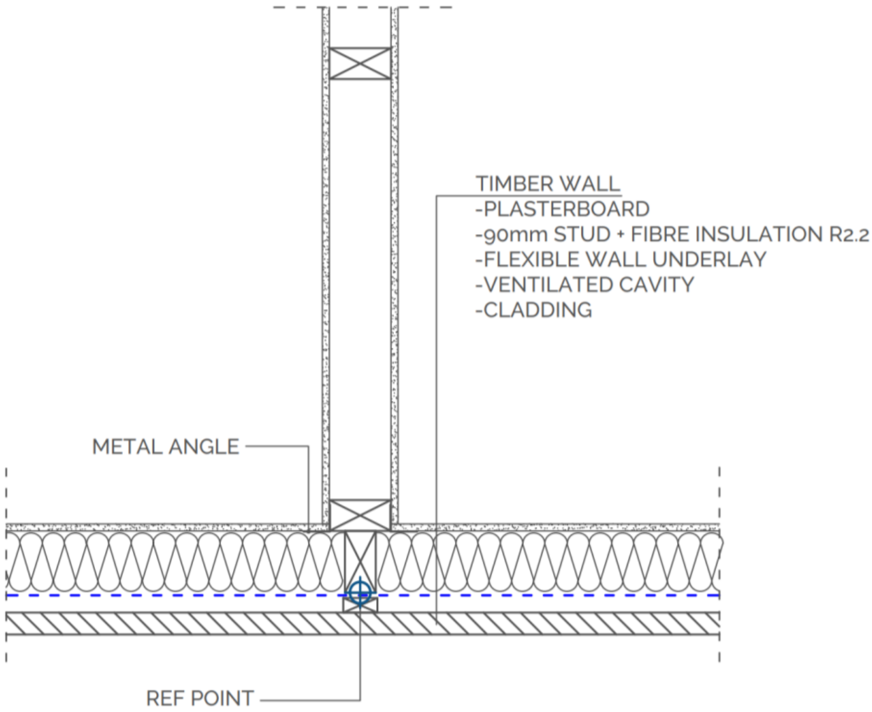
This detail represents a current practice timber stud wall with uninsulated gaps between blocking in an external wall to internal wall intersection. Excessive heat loss occurs due to the reduction in insulation, timber, blocking and air spaces in the intersection.

Improved thermal bridge values may be achieved by insulating between the blocking with carefully-fitted fibre insulation.



$$\psi_{A\text{-}E\text{-}C} = \frac{23.904}{20.000} - 0.492 \cdot 1.055 - 0.492 \cdot 1.055 = 0.156 \ \mathrm{W/(m \cdot K)}$$



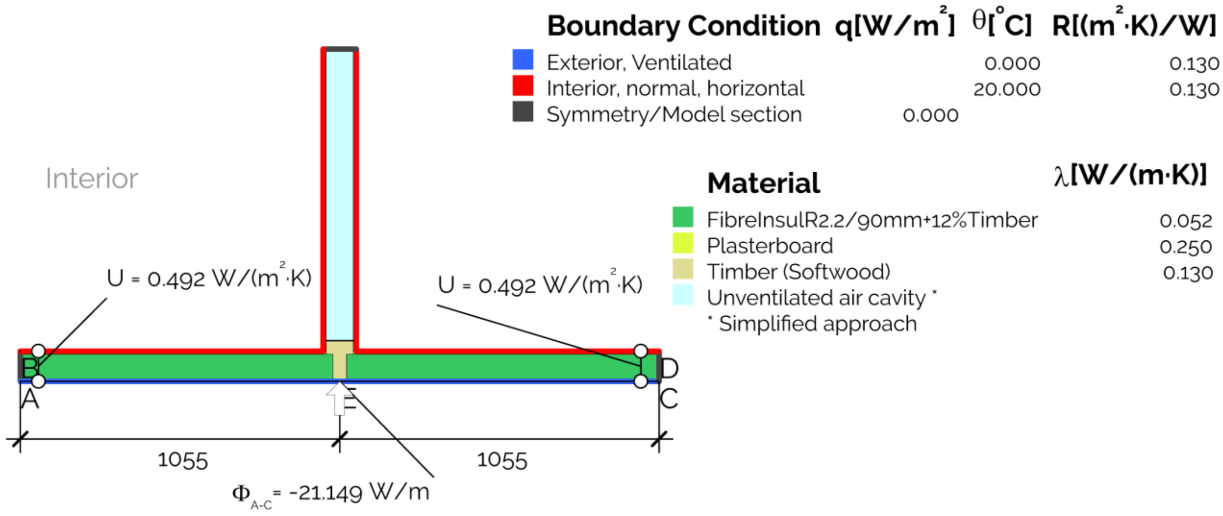


10 EWIW External Wall to Internal Wall - Stud wall 90mm stud studsaver

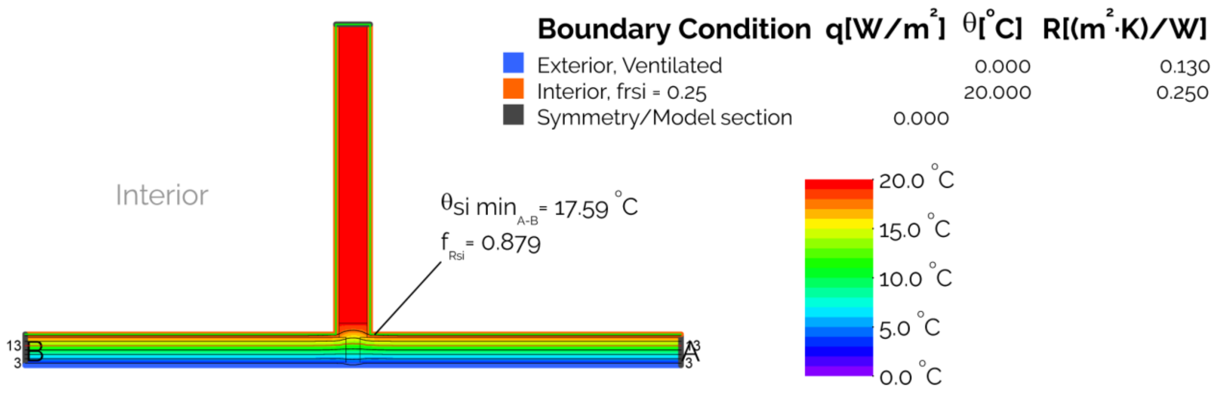
RESULTS TABLE

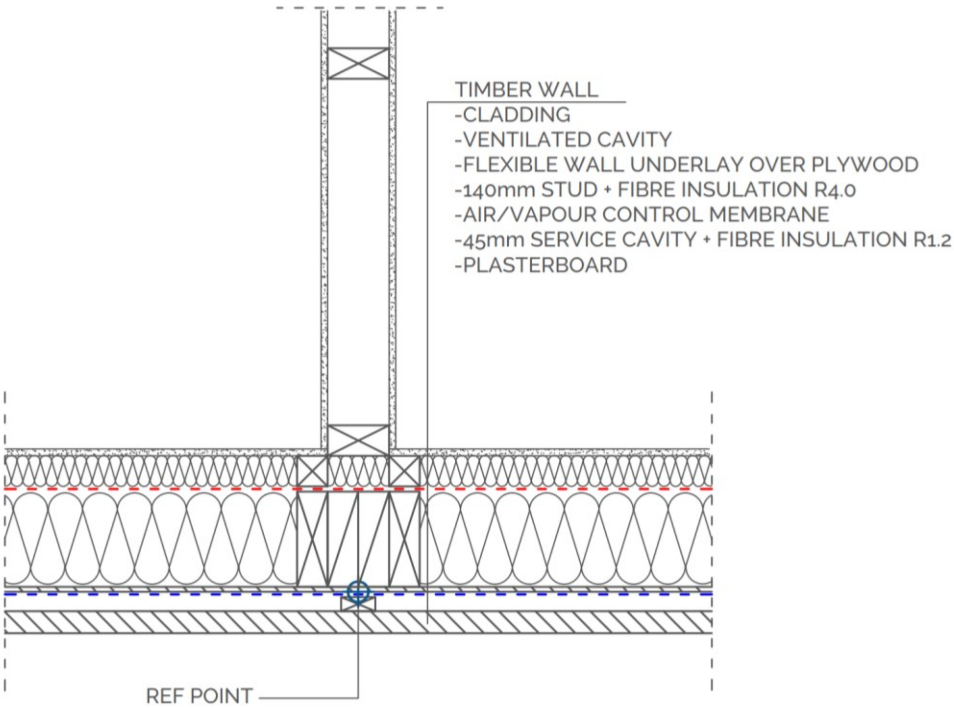
Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.018 W/(mK)	0.018 W/(mK)
f_{RSI}	0.879	
Cost	Not calculated	
Carbon	Not calculated	

This detail represents an improved-practice timber stud wall with minimal timber in an external wall to internal wall intersection. This allows the full insulation of all cavities, reduction in timber content and typically uses metal angles to provide fixing for the plasterboard.



$$\psi_{A\text{-}E\text{-}C} = \frac{21.149}{20.000} - 0.492 \cdot 1.055 - 0.492 \cdot 1.055 = 0.018\ W/(m \cdot K)$$



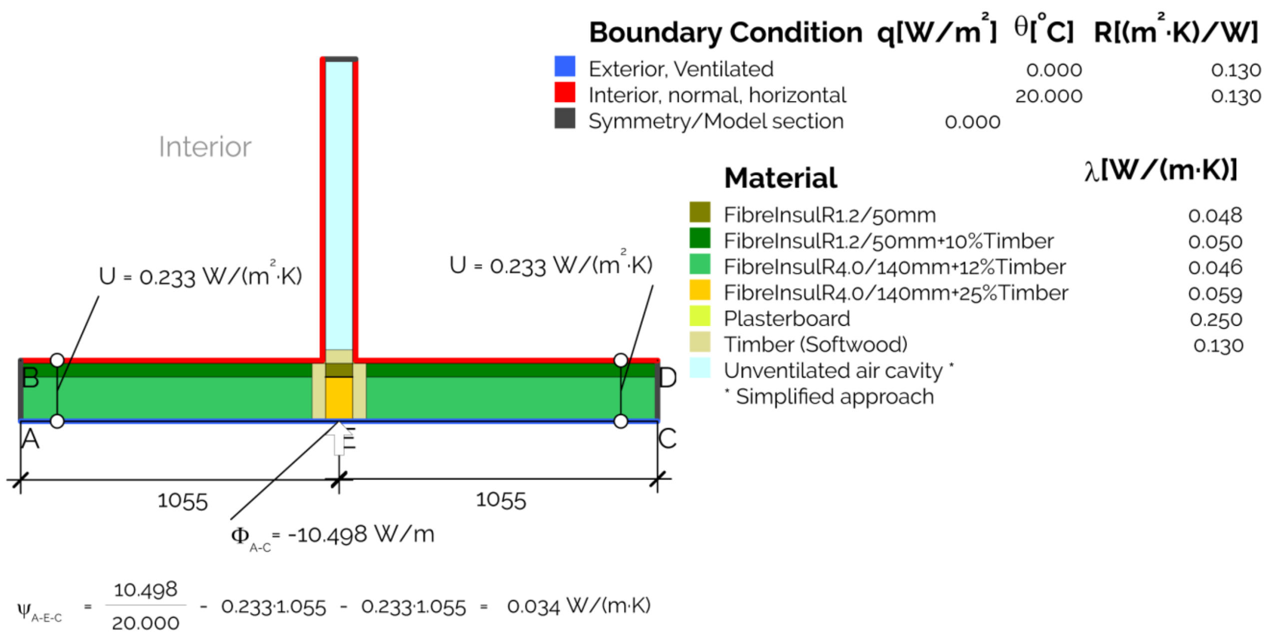


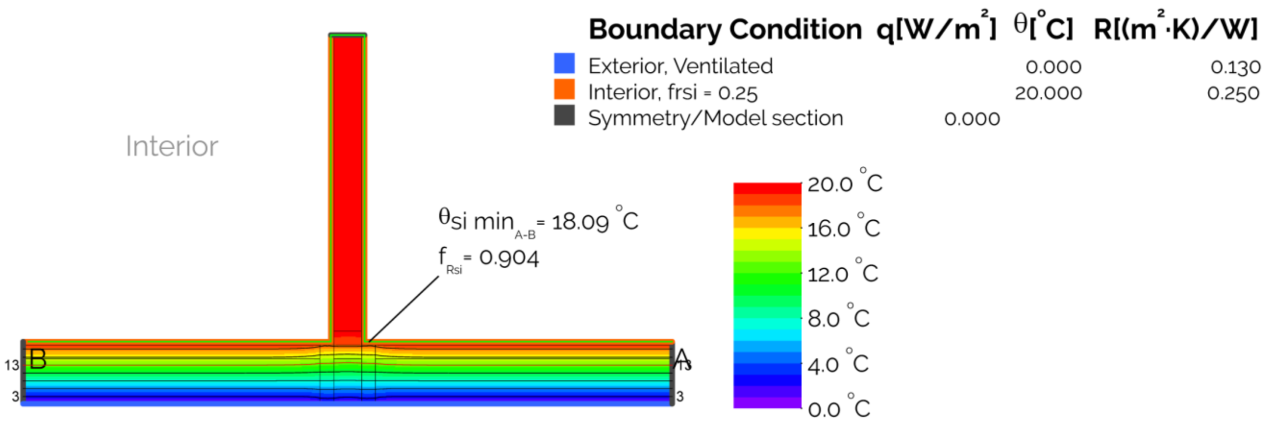
11 EWIW External Wall to Internal Wall 140/45 stud wall current practice timber

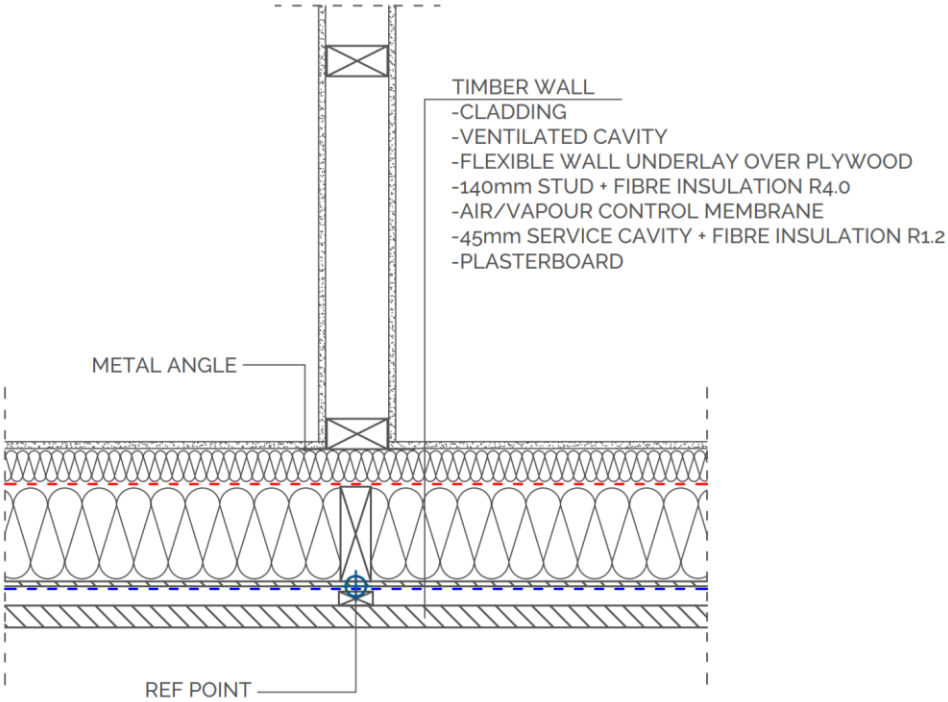
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.034 W/(mK)	0.034 W/(mK)
f_{RSI}	0.904	
Cost	$102 per linear metre	
Carbon	6 $kgCO_2eq/m$	
Carbon Storage	13 $kgCO_2eq/m$	

The most common high-performance construction system reviewed was a 140mm structural stud wall with dwangs/nogs removed by using plywood for shear bracing and an interior insulated service cavity. This detail with blocking and insulation of the cavities was the most common in the buildings reviewed.


Boundary Condition q[W/m²] θ[°C] R[(m²·K)/W]
Exterior, Ventilated 0.000 0.130
Interior, normal, horizontal 20.000 0.130
Symmetry/Model section 0.000
Material λ[W/(m·K)]
FibreInsulR1.2/50mm 0.048
FibreInsulR1.2/50mm+10%Timber 0.050
FibreInsulR4.0/140mm+12%Timber 0.046
FibreInsulR4.0/140mm+25%Timber 0.059
Plasterboard 0.250
Timber (Softwood) 0.130
Unventilated air cavity *
* Simplified approach
Interior
U = 0.233 W/(m²·K)
U = 0.233 W/(m²·K)
B
D
A
E
C
1055
1055
Φ A-C = -10.498 W/m
ψ A-E-C = 10.498 / 20.000 - 0.233·1.055 - 0.233·1.055 = 0.034 W/(m·K)


Boundary Condition q[W/m²] θ[°C] R[(m²·K)/W]
Exterior, Ventilated 0.000 0.130
Interior, frsi = 0.25 20.000 0.250
Symmetry/Model section 0.000
Interior
θsi min A-B = 18.09 °C
f Rsi = 0.904
B
A
13
3
20.0 °C
16.0 °C
12.0 °C
8.0 °C
4.0 °C
0.0 °C

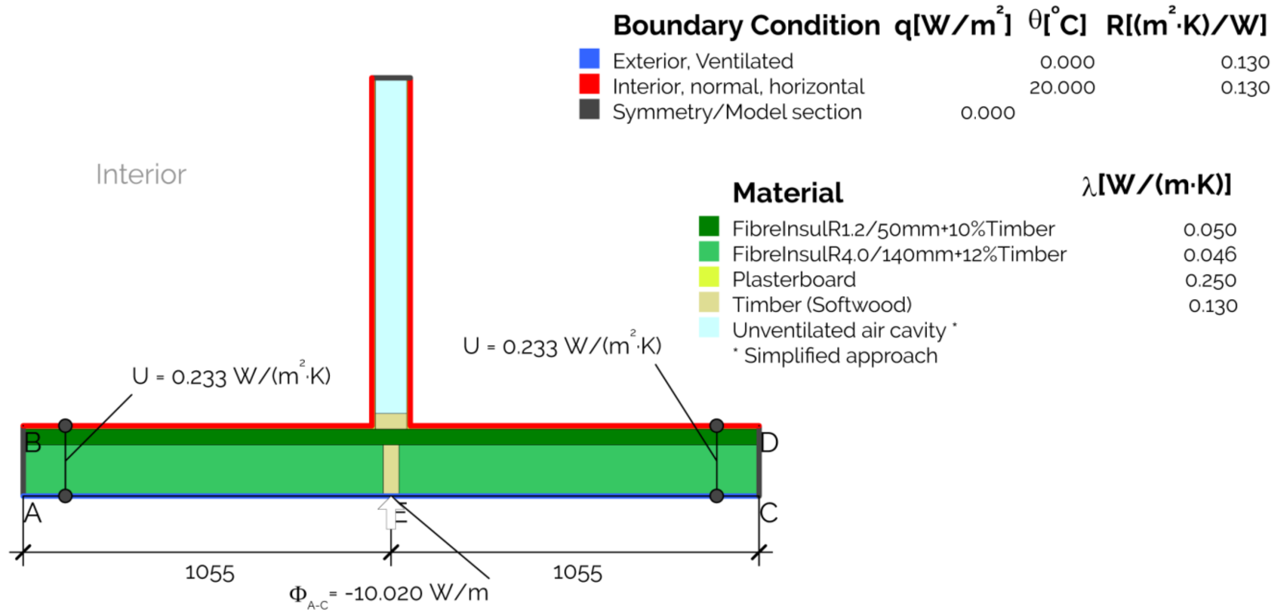


12 EWIW External Wall to Internal Wall 140/45 stud wall no extra timber

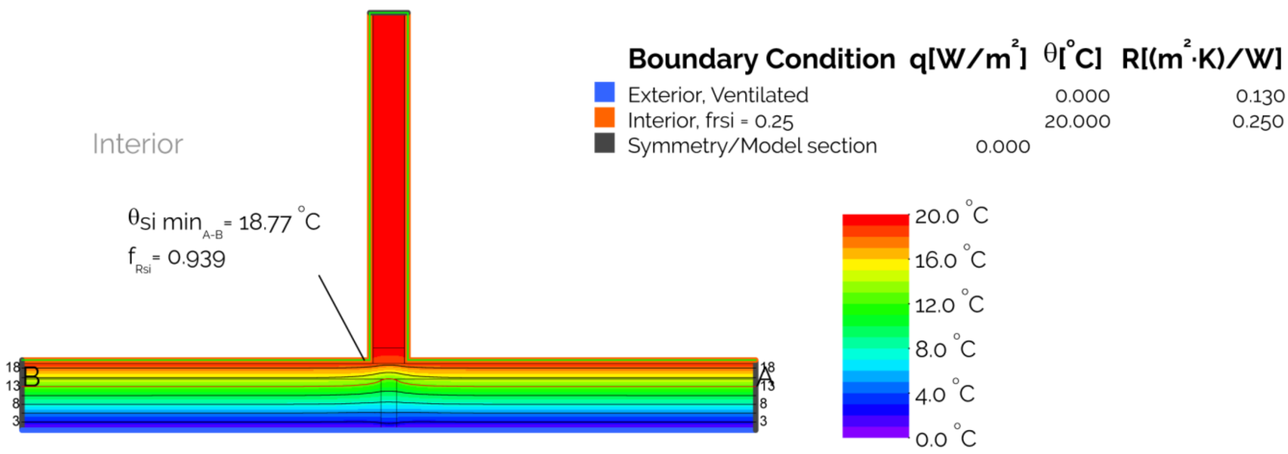
RESULTS TABLE

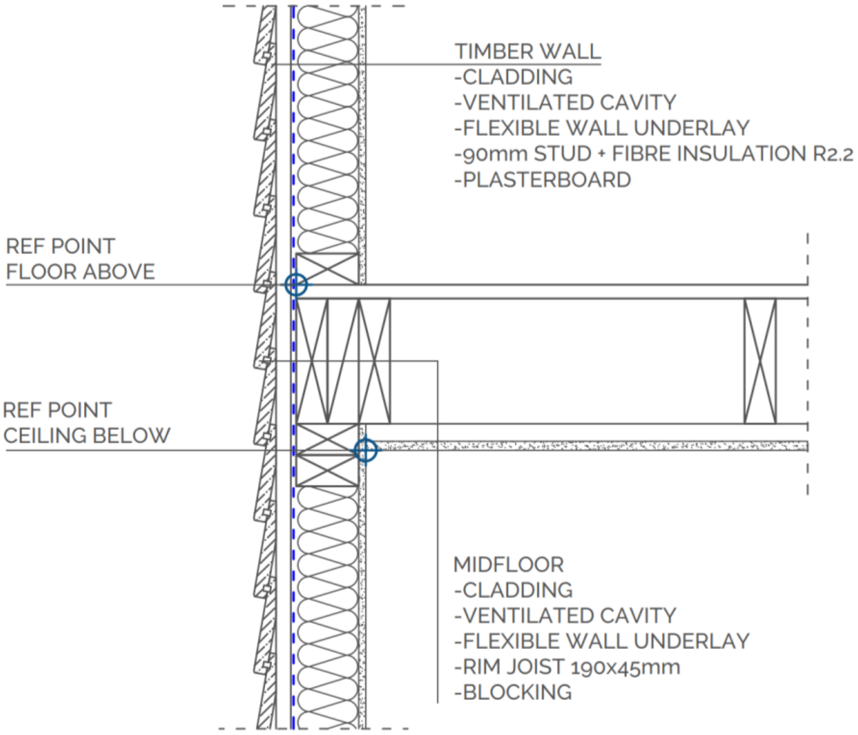
Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.010 W/(mK)	0.010 W/(mK)
f_{RSI}	0.939	
Cost	Not calculated	
Carbon	Not calculated	

The most common high-performance construction system reviewed was a 140mm structural stud wall with dwangs/nogs removed by using plywood for shear bracing and an interior insulated service cavity. This intersection shown allows insulation of all the cavities. It produces the best performance achievable with standard timber stud construction as it has the least amount of timber.



$$\psi_{A-E-C} = \frac{10.020}{20.000} - 0.233 \cdot 1.055 - 0.233 \cdot 1.055 = 0.010\ W/(m \cdot K)$$



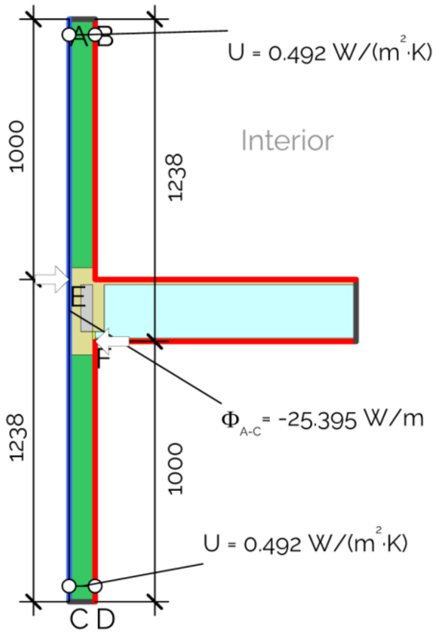


13 EWCE External Wall to Ceiling (Mid-floor) Stud wall 90mm stud current practice

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.167 W/(mK)	0.167 W/(mK)
f_{RSI}	0.780	
Cost	Not calculated	
Carbon	Not calculated	

This detail represents a typical, current practice timber mid-floor. Excessive heat loss occurs due to the corner geometry, timber, blocking and air spaces in the corner. Mid-floor performance can be improved by adding insulation between the blocking and additional insulation to the interior, as shown in the following details.



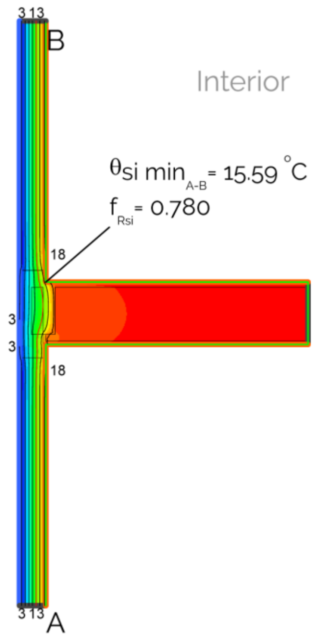
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
Air45mm+25%Timber	0.213
FibreInsulR2.2/90mm+12%Timber	0.052
Plasterboard	0.250
Timber (Softwood)	0.130
Unventilated air cavity *	

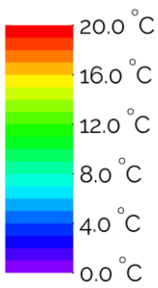
* Simplified approach

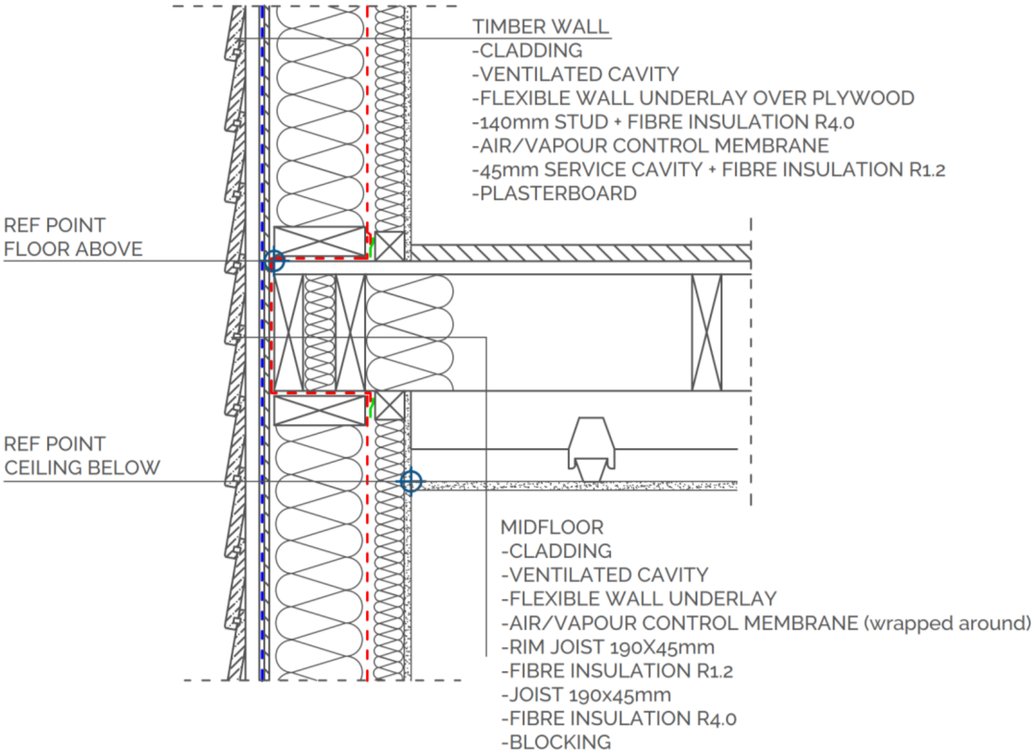
$$\Psi_{A-E-C} = \frac{25.395}{20.000} - 0.492 \cdot 1.000 - 0.492 \cdot 1.238 = 0.167 \text{ W/(m·K)}$$

$$\Psi_{D-F-B} = \frac{25.395}{20.000} - 0.492 \cdot 1.000 - 0.492 \cdot 1.238 = 0.167 \text{ W/(m·K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



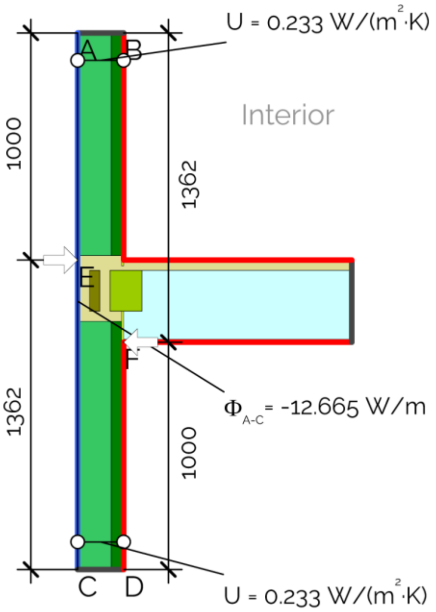


14 EWCE External Wall to Ceiling (Midfloor) 140/45 stud wall

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.084 W/(mK)	0.084 W/(mK)
f_{RSI}	0.894	
Cost	Not calculated	
Carbon	Not calculated	

The most common high-performance construction system reviewed was a 140mm structural stud wall with dwangs/nogs removed by using plywood for shear bracing and an interior insulated service cavity. This detail with blocking and insulation of the cavities was the most common in the buildings reviewed.



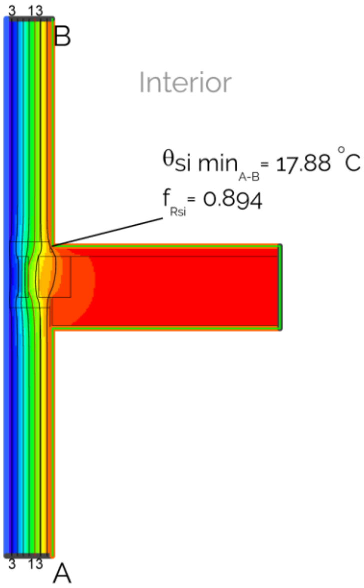
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
FibreInsulR1.2/50mm	0.048
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm	0.463
FibreInsulR4.0/140mm+12%Timber	0.046
Plasterboard	0.250
Timber (Softwood)	0.130
Unventilated air cavity *	

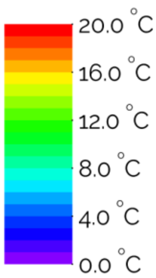
* Simplified approach

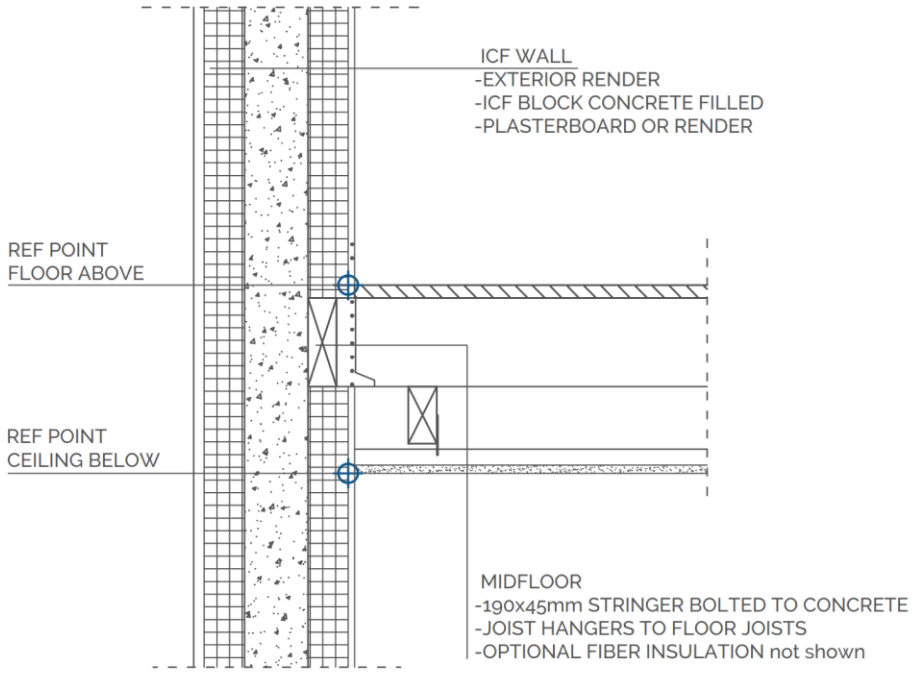
$$\psi_{A\text{-}E\text{-}C} = \frac{12.665}{20.000} - 0.233 \cdot 1.000 - 0.233 \cdot 1.362 = 0.084\ W/(m \cdot K)$$

$$\psi_{D\text{-}F\text{-}B} = \frac{12.665}{20.000} - 0.233 \cdot 1.000 - 0.233 \cdot 1.362 = 0.084\ W/(m \cdot K)$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



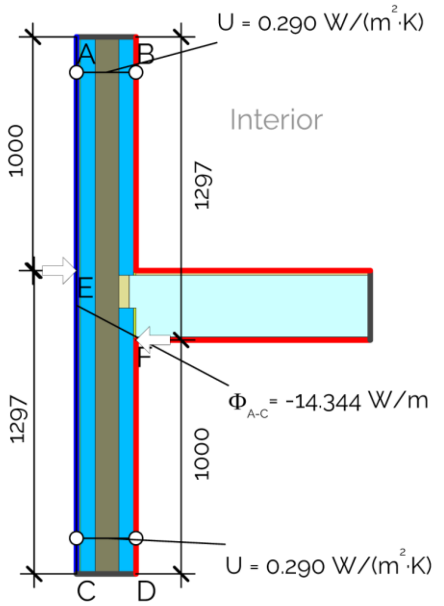


15 EWCE External Wall to Ceiling (Midfloor) ICF concrete midfloor

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.052 W/(mK)	0.052 W/(mK)
f_{RSI}	0.932	
Cost	Not calculated	
Carbon	Not calculated	

ICF walls are a common solution for high-performance buildings. This timber midfloor detail with a bolted joist was a common solution for the buildings reviewed.



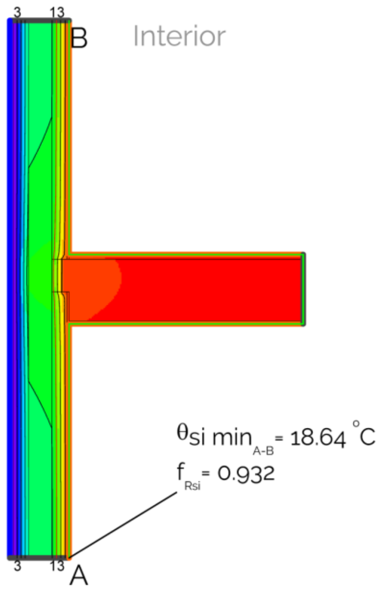
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
Concrete	2.100
Plaster, lime, sand	0.800
Plasterboard	0.250
RigidInsulationL0.04	0.040
Timber (Softwood)	0.130
Unventilated air cavity *	

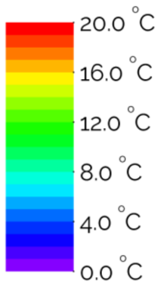
* Simplified approach

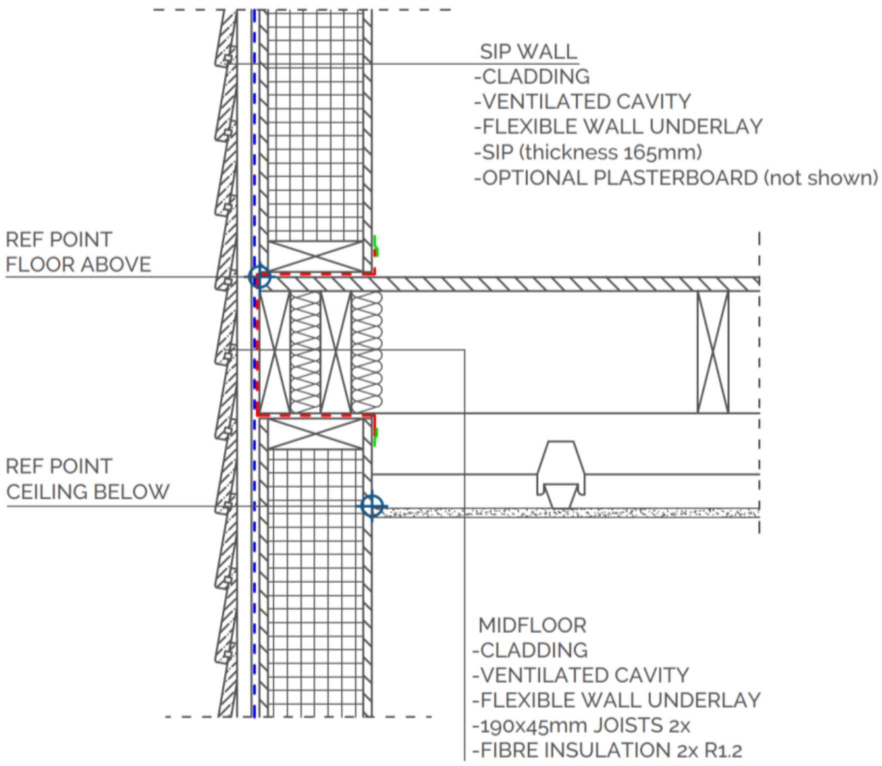
$$\psi_{A\text{-}E\text{-}C} = \frac{14.344}{20.000} - 0.290\cdot1.000 - 0.290\cdot1.297 = 0.052\ \mathrm{W/(m\cdot K)}$$

$$\psi_{D\text{-}F\text{-}B} = \frac{14.344}{20.000} - 0.290\cdot1.000 - 0.290\cdot1.297 = 0.052\ \mathrm{W/(m\cdot K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

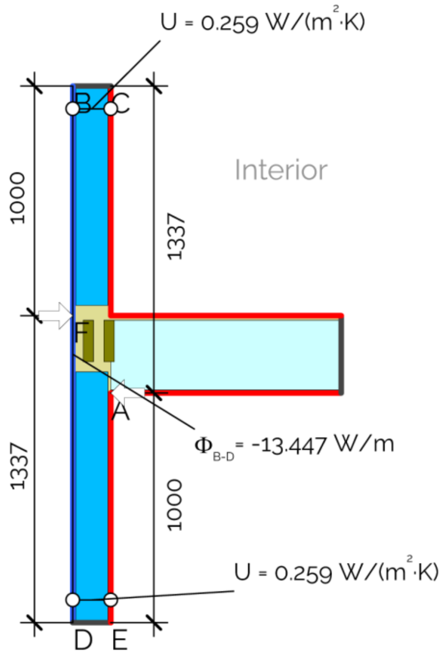




16 EWCE External Wall to Ceiling (Midfloor) SIP no service cavity timber midfloor

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.068 W/(mK)	0.068 W/(mK)
f_{RSI}	0.864	
Cost	Not calculated	
Carbon	Not calculated	



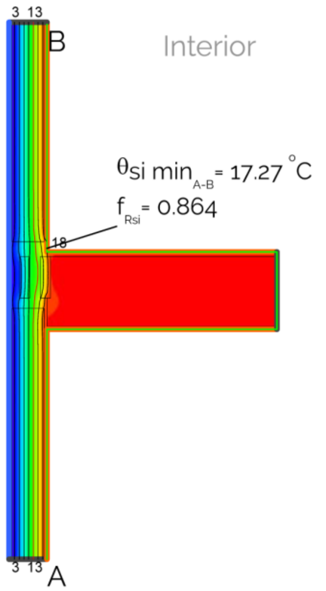
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
FibreInsulR1.2/50mm	0.048
Plasterboard	0.250
SIPCore_L0.041	0.041
Timber (Softwood)	0.130
Unventilated air cavity *	

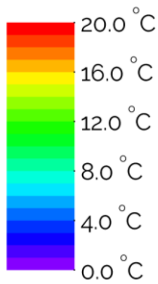
* Simplified approach

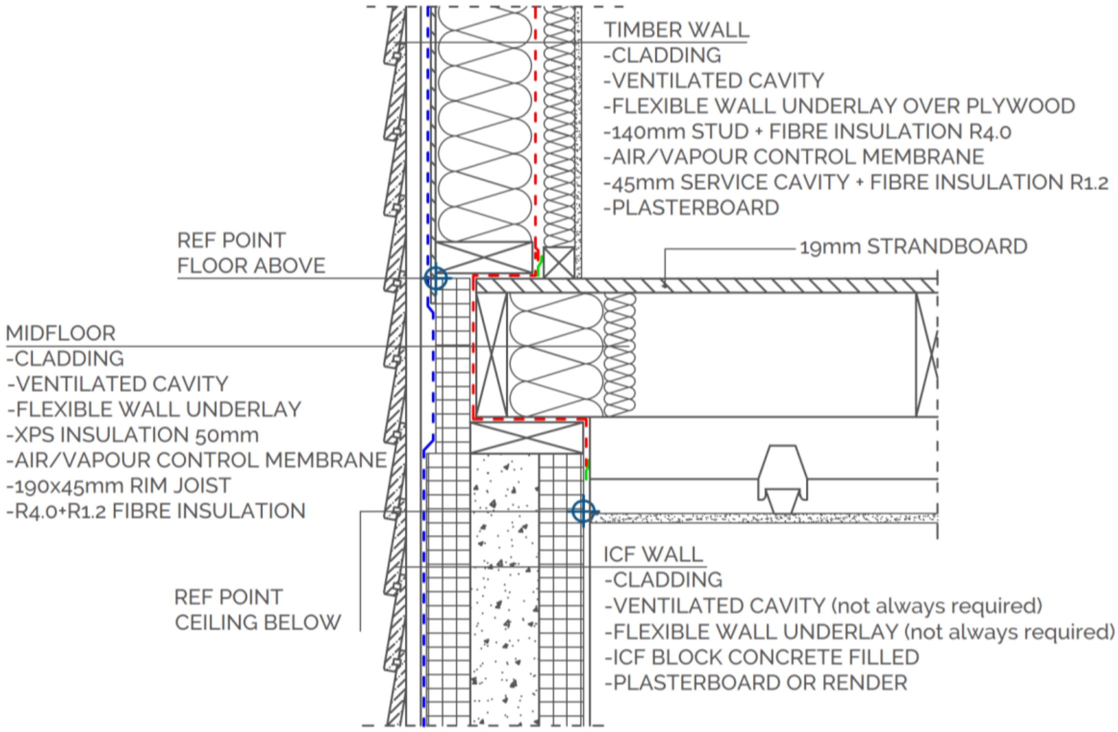
$$\Psi_{B-F-D} = \frac{13.447}{20.000} - 0.259 \cdot 1.000 - 0.259 \cdot 1.337 = 0.068 \text{ W/(m·K)}$$

$$\Psi_{E-A-C} = \frac{13.447}{20.000} - 0.259 \cdot 1.000 - 0.259 \cdot 1.337 = 0.068 \text{ W/(m·K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



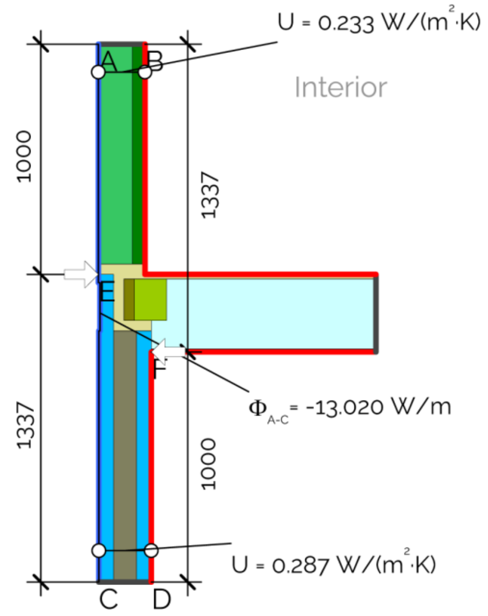


17 EWCE External Wall to Ceiling (Midfloor) ICF wall below, 140/45 wall above with timber midfloor

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.034 W/(mK)	0.053 W/(mK)
f_{RSI}	0.894	
Cost	Not calculated	
Carbon	Not calculated	

This combination of ICF walls on the lower or ground floor and timber-framed upper floor walls is a common solution for high-performance buildings. This timber midfloor detail bolted to an ICF lower floor wall was a common solution for the buildings reviewed.

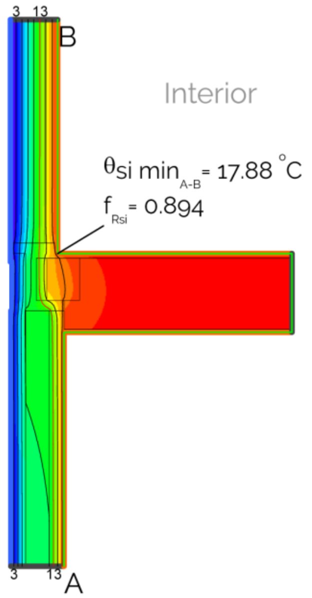


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

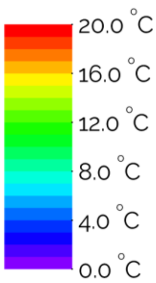
Material	λ[W/(m·K)]
Air204mmUnvent+12%Timber	0.990
Concrete	2.100
FibreInsulR1.2/50mm	0.048
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm	0.463
FibreInsulR4.0/140mm+12%Timber	0.046
Plasterboard	0.250
RigidInsulation	0.040
Timber (Softwood)	0.130

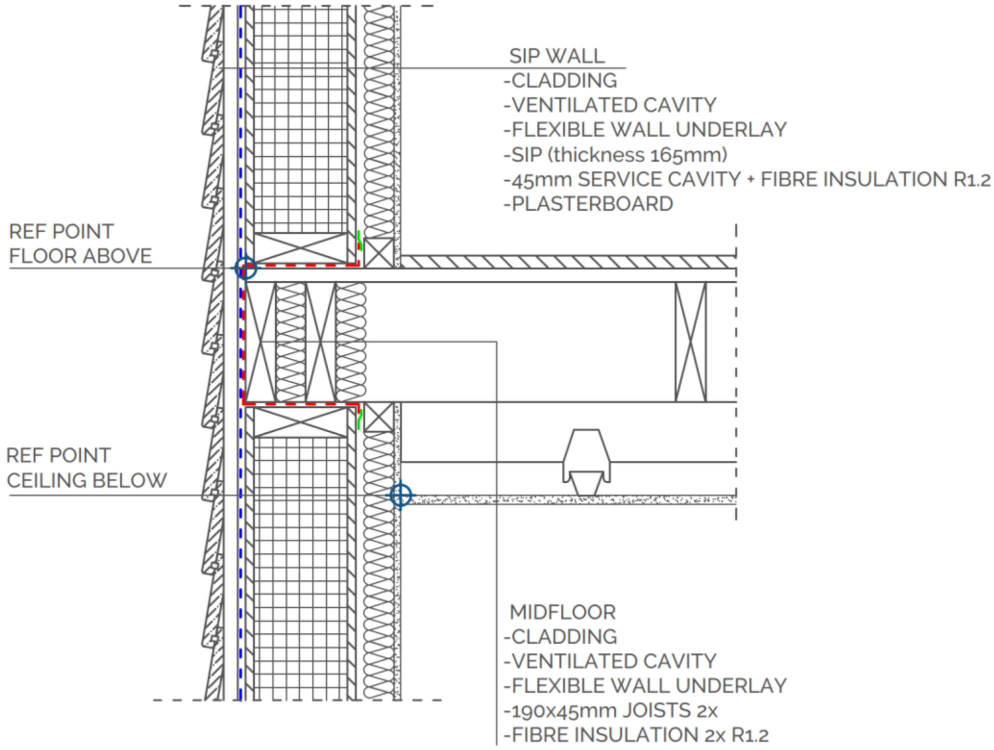
$$\psi_{A-E-C} = \frac{13.020}{20.000} - 0.233 \cdot 1.000 - 0.287 \cdot 1.337 = 0.034\ \mathrm{W/(m \cdot K)}$$

$$\psi_{D-F-B} = \frac{13.020}{20.000} - 0.287 \cdot 1.000 - 0.233 \cdot 1.337 = 0.053\ \mathrm{W/(m \cdot K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



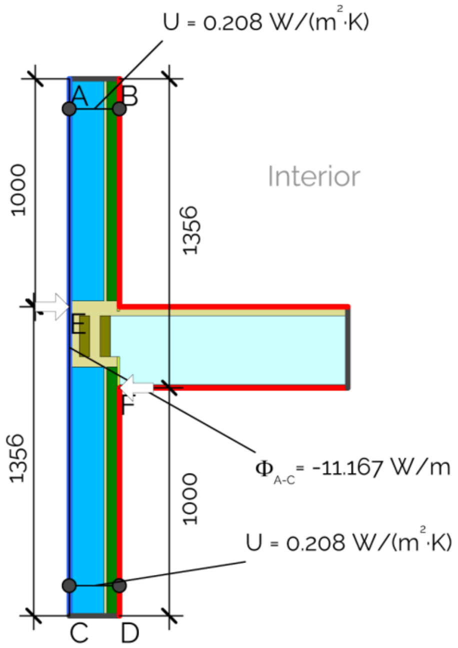


18 EWCE External Wall to Ceiling (Midfloor) SIP 45mm service cavity timber midfloor

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.068 W/(mK)	0.068 W/(mK)
f_{RSI}	0.927	
Cost	Not calculated	
Carbon	Not calculated	

SIP walls typically use a standard timber midfloor detail similar to that shown. Note the red AVCL wrapped around the outside of the midfloor rim joists to continue layer past the midfloor construction.



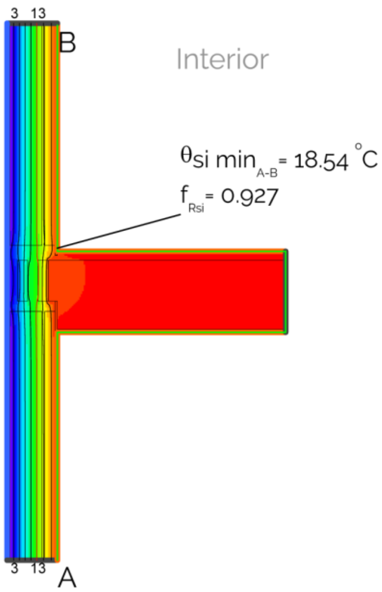
Boundary Condition	**q[W/m²]**	**θ[°C]**	**R[(m²·K)/W]**
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

Material	**λ[W/(m·K)]**
FibreInsulR1.2/50mm	0.048
FibreInsulR1.2/50mm+10%Timber	0.050
Plasterboard	0.250
SIPCore_L0.041	0.041
Timber (Softwood)	0.130
Unventilated air cavity *	

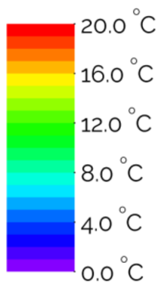
* Simplified approach

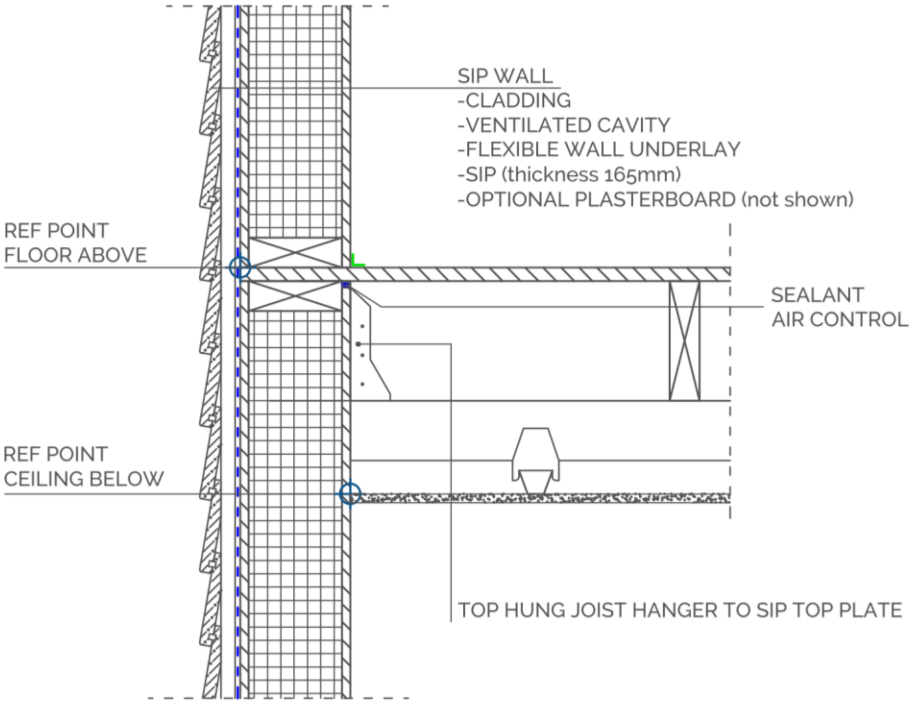
$$\psi_{A\text{-}E\text{-}C} = \frac{11.167}{20.000} - 0.208 \cdot 1.000 - 0.208 \cdot 1.356 = 0.068 \text{ W/(m·K)}$$

$$\psi_{D\text{-}F\text{-}B} = \frac{11.167}{20.000} - 0.208 \cdot 1.000 - 0.208 \cdot 1.356 = 0.068 \text{ W/(m·K)}$$



Boundary Condition	**q[W/m²]**	**θ[°C]**	**R[(m²·K)/W]**
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



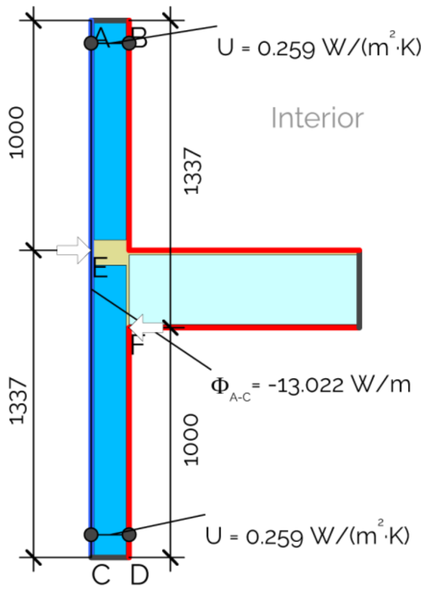


19 EWCE External Wall to Ceiling (Midfloor) SIP midfloor joist hangers

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.047 W/(mK)	0.047 W/(mK)
f_{RSI}	0.887	
Cost	Not calculated	
Carbon	Not calculated	

An improved SIP midfloor detail uses a top-hung joist hanger to reduce the interruption of the SIP wall reducing the thermal bridge value.



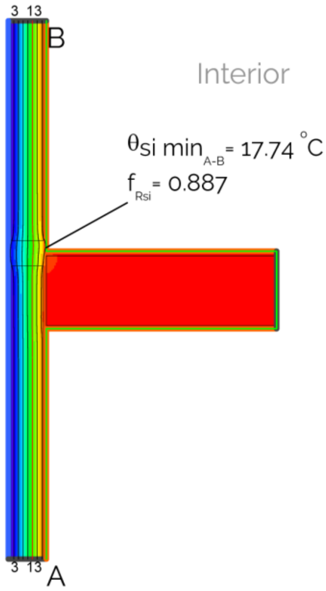
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
Plasterboard	0.250
SIPCore_L0.041	0.041
Timber (Softwood)	0.130
Unventilated air cavity *	

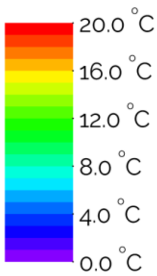
* Simplified approach

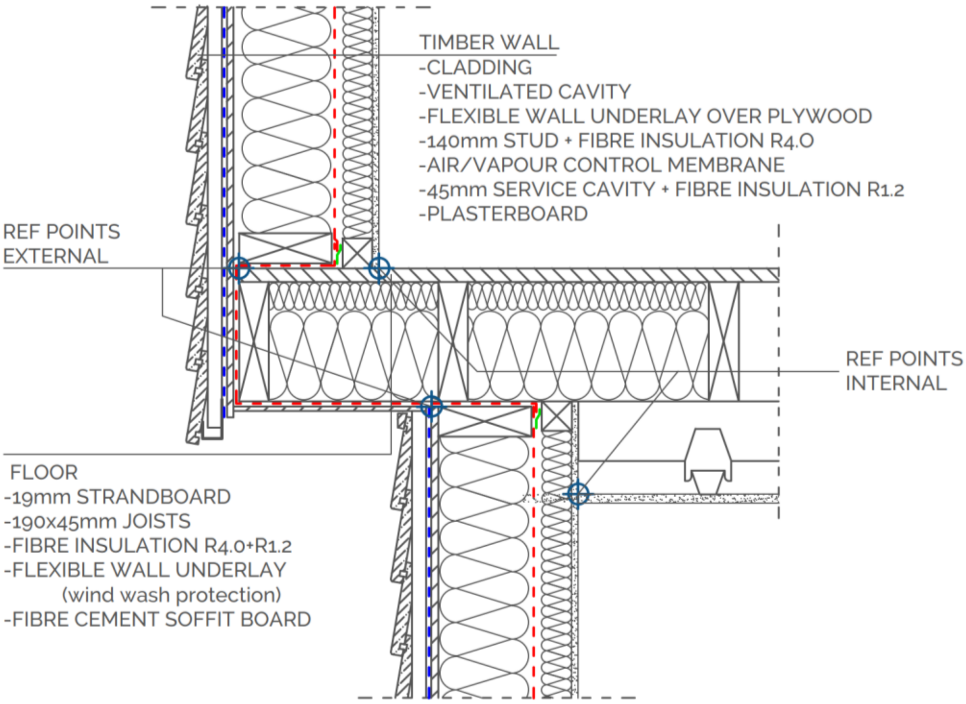
$$\psi_{A\text{-}E\text{-}C} = \frac{13.022}{20.000} - 0.259 \cdot 1.000 - 0.259 \cdot 1.337 = 0.047\ \mathrm{W/(m \cdot K)}$$

$$\psi_{D\text{-}F\text{-}B} = \frac{13.022}{20.000} - 0.259 \cdot 1.000 - 0.259 \cdot 1.337 = 0.047\ \mathrm{W/(m \cdot K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		





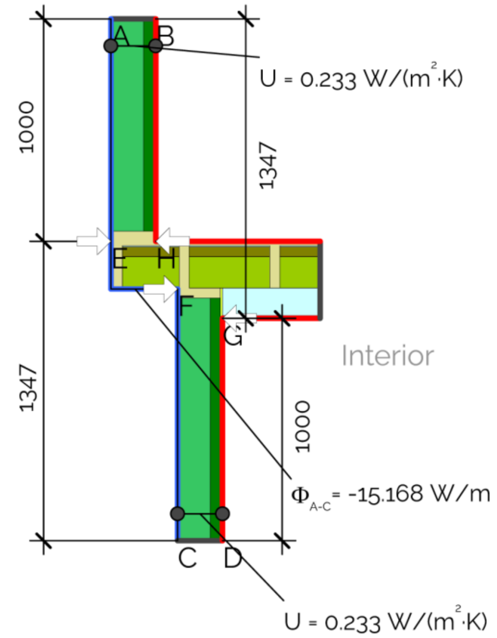
20 EWEO External Wall – Overhang 140/45 stud wall to timber cantilevered floor

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.212 W/(mK)	0.212 W/(mK)
f_{RSI}	0.772	
Cost	Not calculated	
Carbon	Not calculated	

Offsetting the floor areas can add significantly to the overall heat loss in a high-performance building. Compared to Junction 14, this detail has more than twice the midfloor heat loss and is comparable to an uninsulated slab edge.

Note that in the thermal bridge calculation, the small amount of soffit area heat loss is included in the thermal bridge value and thus is not included in the area-based heat losses.



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
Fibre Cement	0.250
FibreInsulR1.2/50mm	0.048
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm	0.463
FibreInsulR4.0/140mm+12%Timber	0.046
Plasterboard	0.250
Timber (Softwood)	0.130
Unventilated air cavity *	

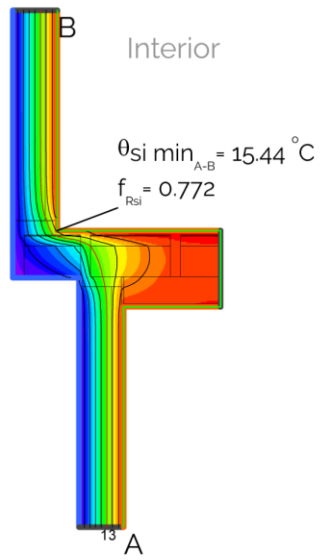
* Simplified approach

$$\psi_{A\text{-}E\text{-}C} = \frac{15.168}{20.000} - 0.233 \cdot 1.000 - 0.233 \cdot 1.347 = 0.212\ \text{W/(m·K)}$$

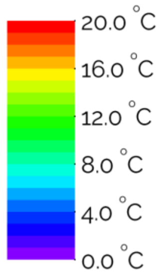
$$\psi_{A\text{-}F\text{-}C} = \frac{15.168}{20.000} - 0.233 \cdot 1.215 - 0.233 \cdot 1.132 = 0.212\ \text{W/(m·K)}$$

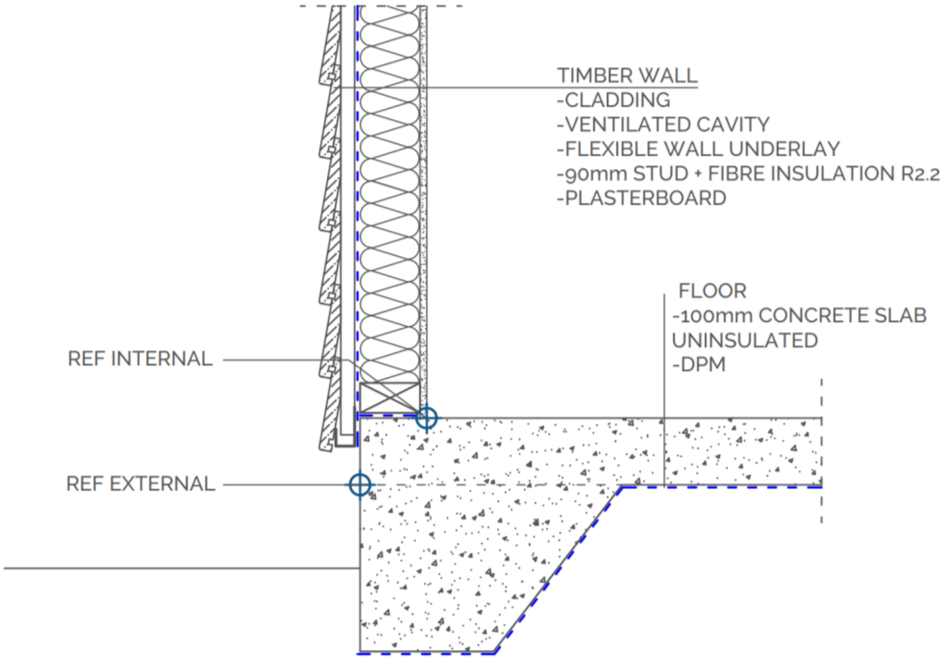
$$\psi_{D\text{-}G\text{-}B} = \frac{15.168}{20.000} - 0.233 \cdot 1.000 - 0.233 \cdot 1.347 = 0.212\ \text{W/(m·K)}$$

$$\psi_{D\text{-}H\text{-}B} = \frac{15.168}{20.000} - 0.233 \cdot 1.347 - 0.233 \cdot 1.000 = 0.212\ \text{W/(m·K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



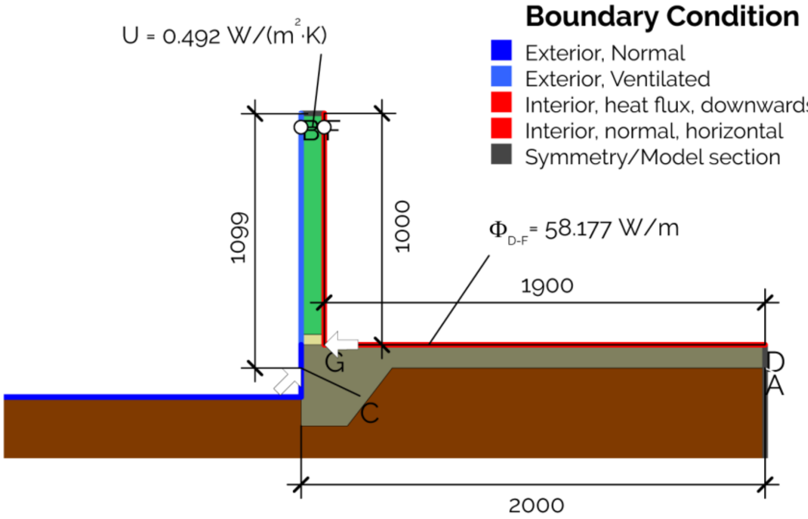


21 EWFS External Wall to Floor Slab - Stud wall 90mm stud current practice uninsulated slab no edge insulation

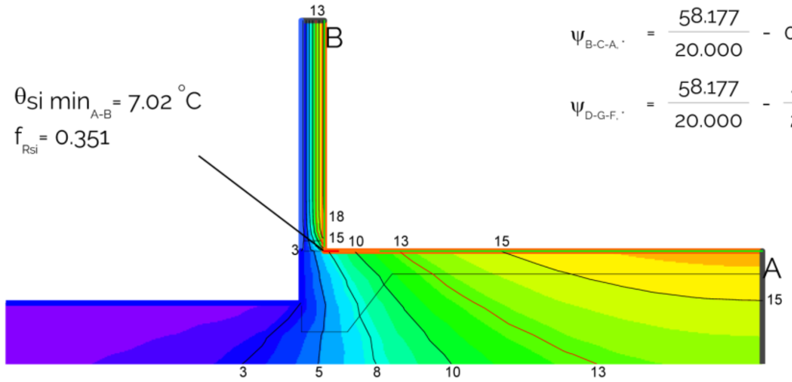
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.223 W/(mK)	0.272 W/(mK)
f_{RSI}	0.351	
Cost	$190 per linear metre	
Carbon	59 $kgCO_2eq/m$	
Carbon Storage	5 $kgCO_2eq/m$	

This detail represents a typical current practice slab edge with no edge insulation and no insulation below the concrete slab, along with a current practice 90mm timber stud wall.

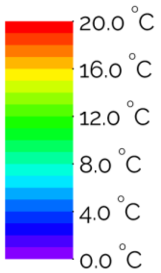


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		



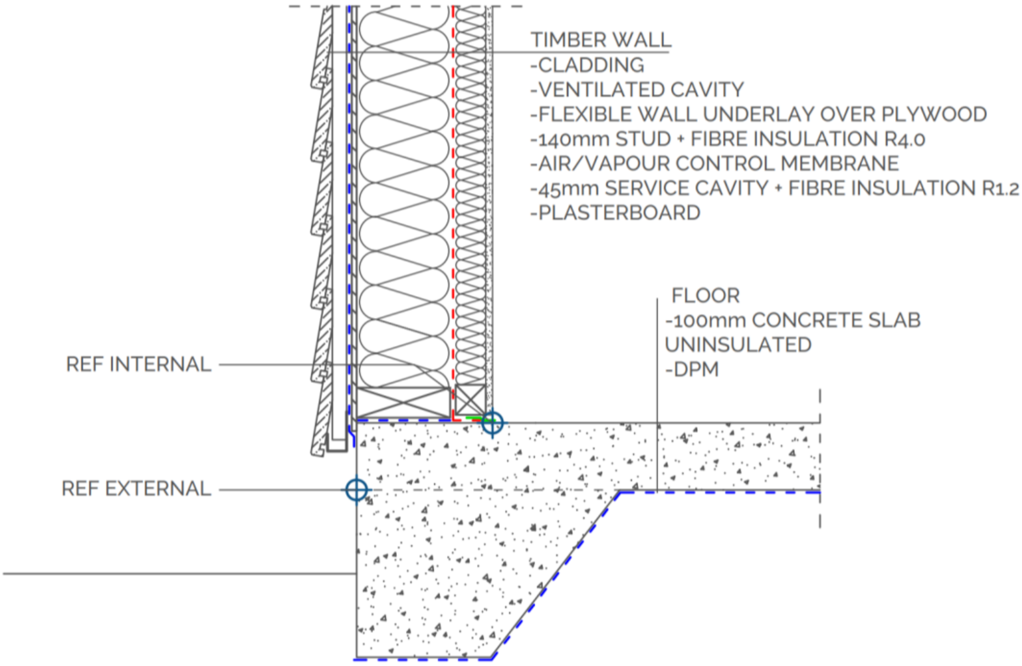
$$\psi_{B\text{-}C\text{-}A,\cdot} = \frac{58.177}{20.000} - 0.492 \cdot 1.100 - \frac{42.888}{20.000} = 0.223\ \text{W/(m·K)}$$

$$\psi_{D\text{-}G\text{-}F,\cdot} = \frac{58.177}{20.000} - \frac{42.888}{20.000} - 0.492 \cdot 1.000 = 0.272\ \text{W/(m·K)}$$



Material	λ[W/(m·K)]
Concrete	2.100
FibreInsulR2.2/90mm+12%Timber	0.052
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



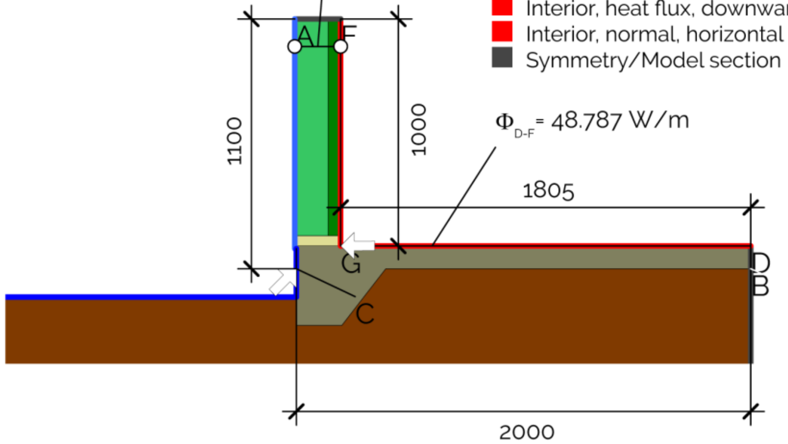
22 EWFS External Wall to Floor Slab - 140/45 stud wall uninsulated raft slab no edge insulation

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.039 W/(mK)	0.062 W/(mK)
f_{RSI}	0.427	
Cost	$199 per linear metre	
Carbon	62 $kgCO_2eq/m$	
Carbon Storage	5 $kgCO_2eq/m$	

This detail represents a typical current practice slab edge with no edge insulation and no insulation below the concrete slab, along with a high-performance wall. The additional wall thickness lowers the heat loss through the slab edge but the fRSI is still less than 0.55 required by the PHI criteria for Auckland.

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

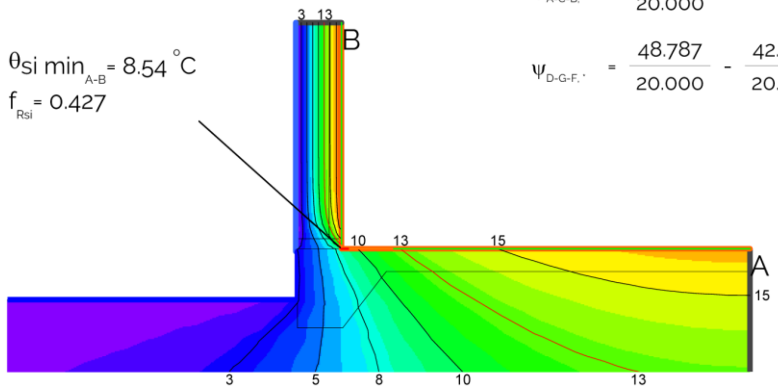


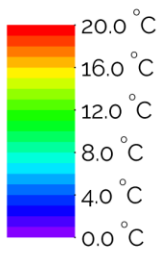
$$\Psi_{A\text{-}C\text{-}B,\cdot} = \frac{48.787}{20.000} - 0.233\cdot1.100 - \frac{42.888}{20.000} = 0.039\ \mathrm{W/(m\cdot K)}$$

$$\Psi_{D\text{-}G\text{-}F,\cdot} = \frac{48.787}{20.000} - \frac{42.888}{20.000} - 0.233\cdot1.000 = 0.062\ \mathrm{W/(m\cdot K)}$$

$\theta si\ min_{A-B} = 8.54\ ^\circ C$

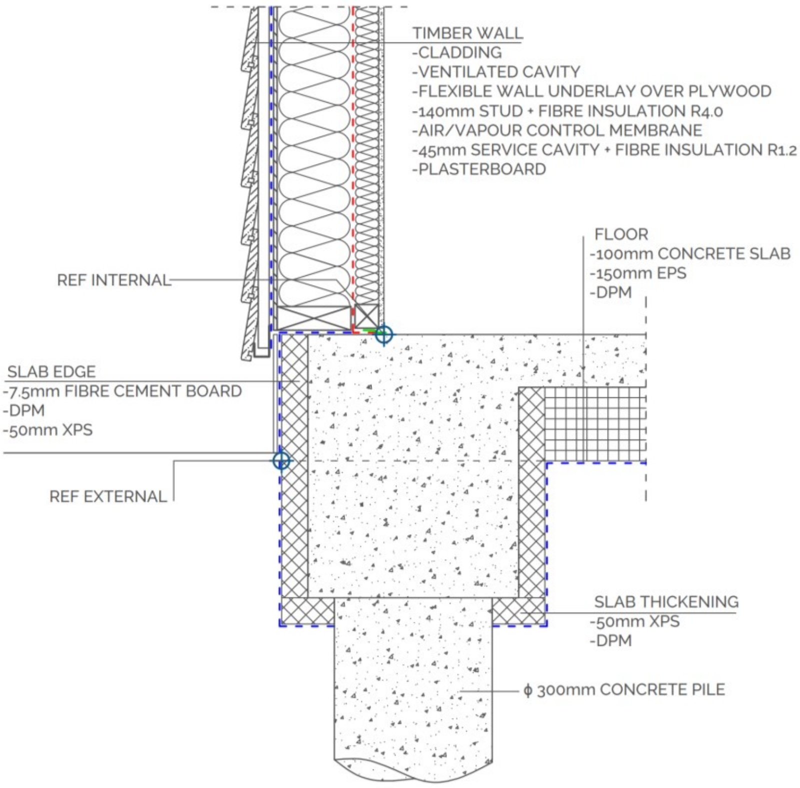
$f_{Rsi} = 0.427$





Material	λ[W/(m·K)]
Concrete	2.100
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



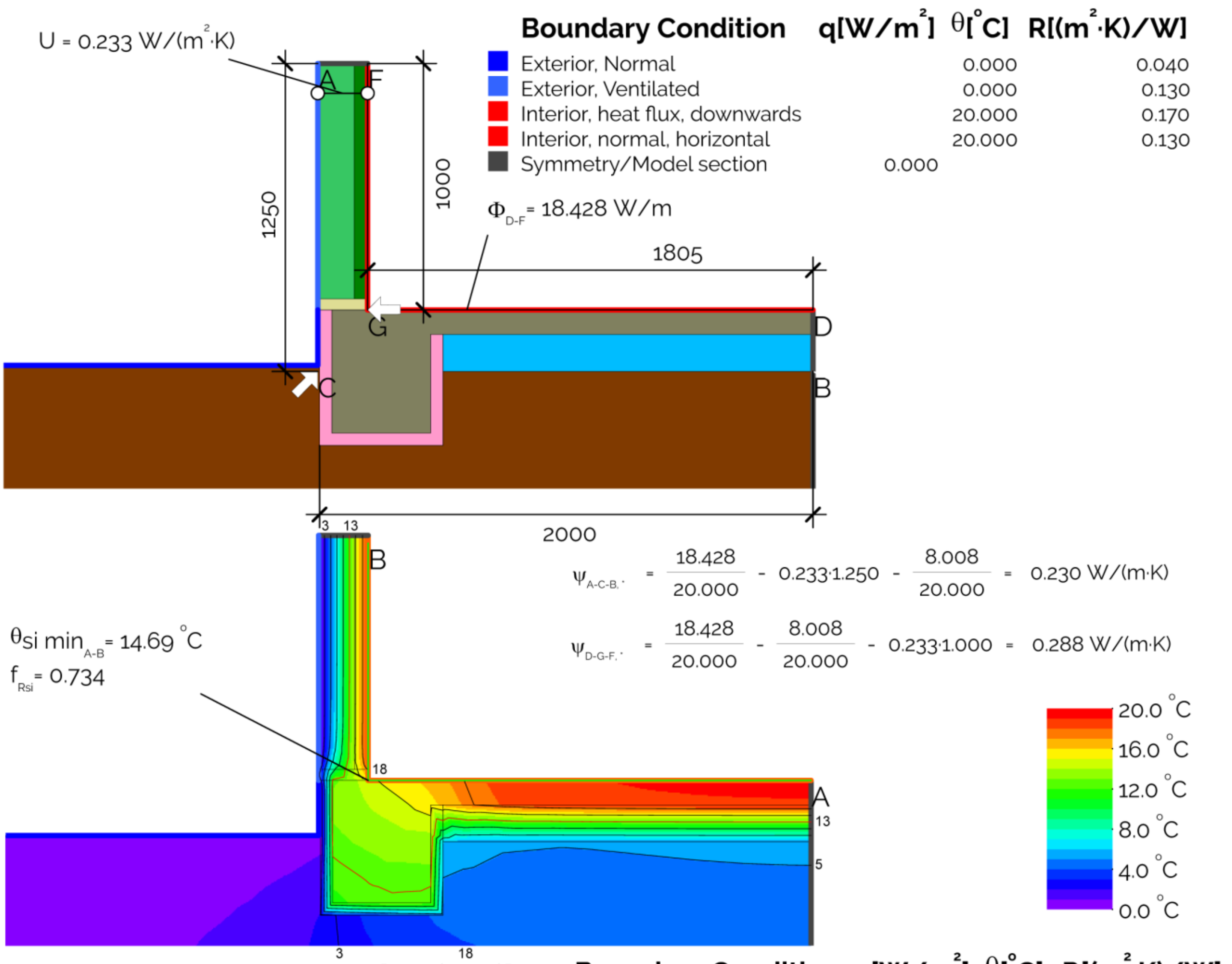
23 FSPile 3D - Concrete pile to insulated slab on ground

RESULTS TABLE

Ψ+X	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.230 W/(mK) + 0.11 W/K per χ	0.288 W/(mK) + 0.11 W/K per χ
f_{RSI}	0.68 from 3D	
Cost	Not calculated	
Carbon	Not calculated	

This slab edge thermal bridge for edge ground beam with concrete piles is a common solution for sites with poor bearing capacity soil.

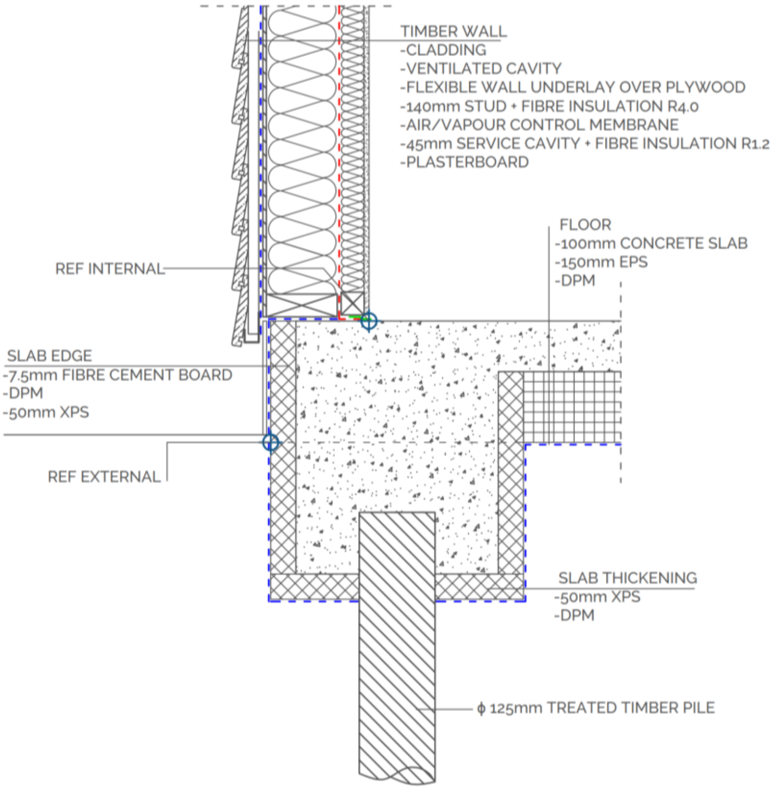
The heat loss out of this edge ground beam is a combination of the 2D PSI value and the 3D CHI value. A 3D model of the concrete pile shown at 1.2m centres yielded a CHI value of 0.11 W/K. The slab edge heat loss is the PSI value multiplied by the slab perimeter plus the CHI value multiplied by the number of concrete piles. The fRSI was also calculated in 3D and is a minimum of 0.68 on the centreline of the concrete pile. This is a lower fRSI than the 2D value of 0.73 and shows the impact of the concrete pile is high enough that it should be considered.



Material	λ[W/(m·K)]
Concrete	2.100
EPSInsul_L0.038	0.038
Fibre Cement	0.250
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130
XPSInsul_L0.028	0.028

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

These CHI values have been calculated using a 3D finite element model, using ISO10211:2007, for a section of the slab edge A/P=2m with and without the concrete pile.



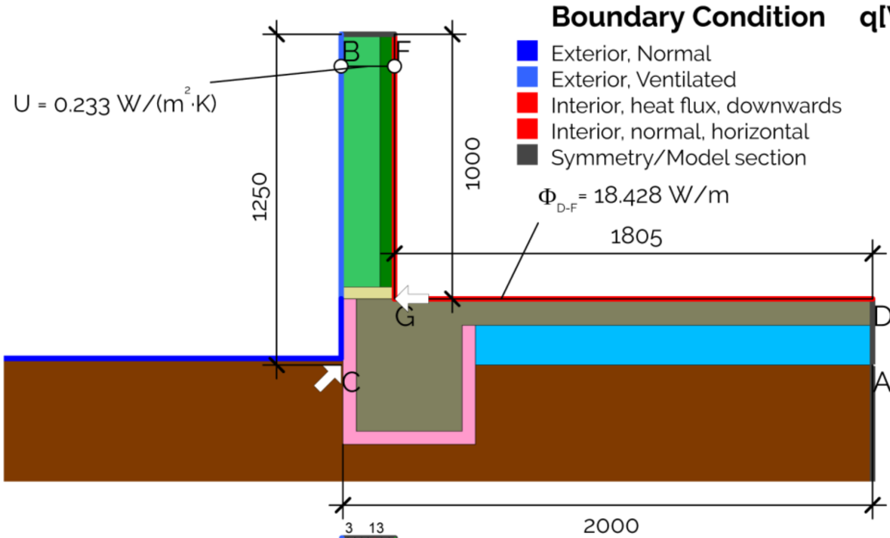
24 FSPile 3D - Timber pile to insulated slab on ground

RESULTS TABLE

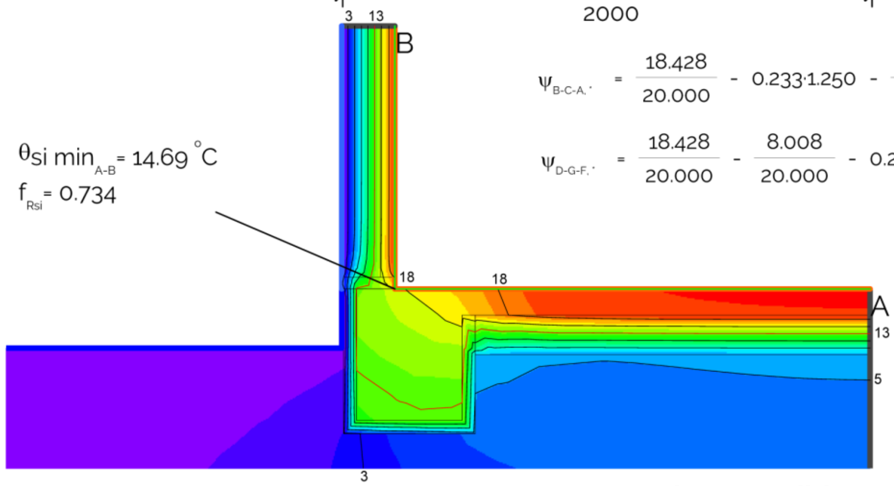
Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.230 W/(mK) + 0.003 W/K per χ	0.288 W/(mK) + 0.003 W/K per χ
f_{RSI}	0.735 from 3D	
Cost	Not calculated	
Carbon	Not calculated	

This slab edge thermal bridge for edge ground beam with timber piles is a common solution for sites with poor bearing capacity soil.

The heat loss out of this edge ground beam is a combination of the 2D PSI value and the 3D CHI value. A 3D model of the timber pile shown at 1.2m centres yielded a CHI value of 0.001 W/K. The slab edge heat loss is the PSI value multiplied by the slab perimeter plus the CHI value multiplied by the number of concrete piles. The fRSI was also calculated in 3D and is a minimum of 0.735 on the centreline of the timber pile (same as Flixo 2D calculation). Note the CHI value is so low that it can be disregarded.

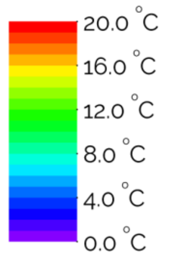


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		



$$\psi_{B-C-A} = \frac{18.428}{20.000} - 0.233 \cdot 1.250 - \frac{8.008}{20.000} = 0.230\ \mathrm{W/(m \cdot K)}$$

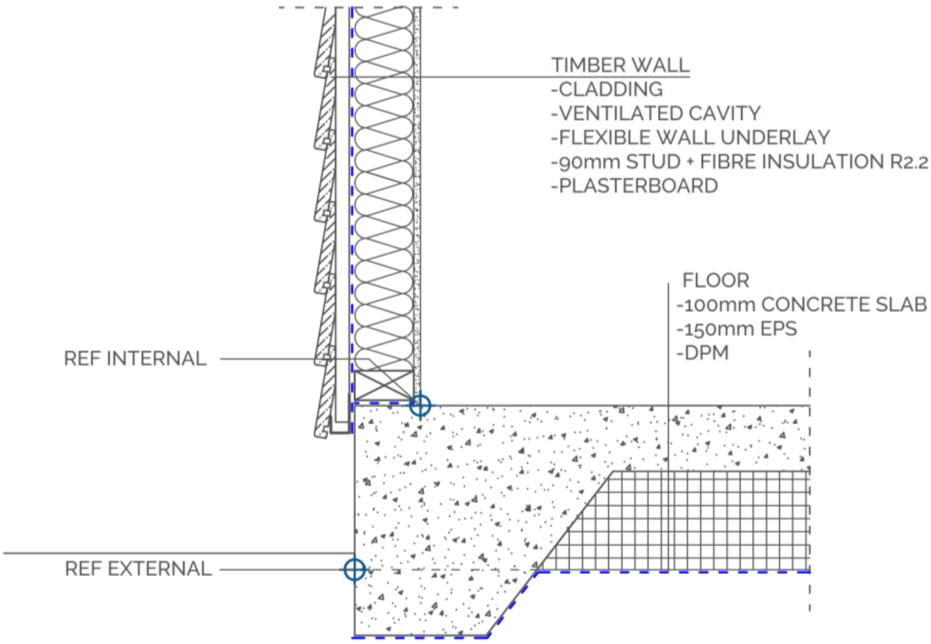
$$\psi_{D-G-F} = \frac{18.428}{20.000} - \frac{8.008}{20.000} - 0.233 \cdot 1.000 = 0.288\ \mathrm{W/(m \cdot K)}$$



Material	λ[W/(m·K)]
Concrete	2.100
EPSInsul_L0.038	0.038
Fibre Cement	0.250
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130
XPSInsul_L0.028	0.028

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

These CHI values have been calculated using a 3D finite element model, using ISO10211:2007, for a section of the slab edge A/P=2m with and without the timber pile.

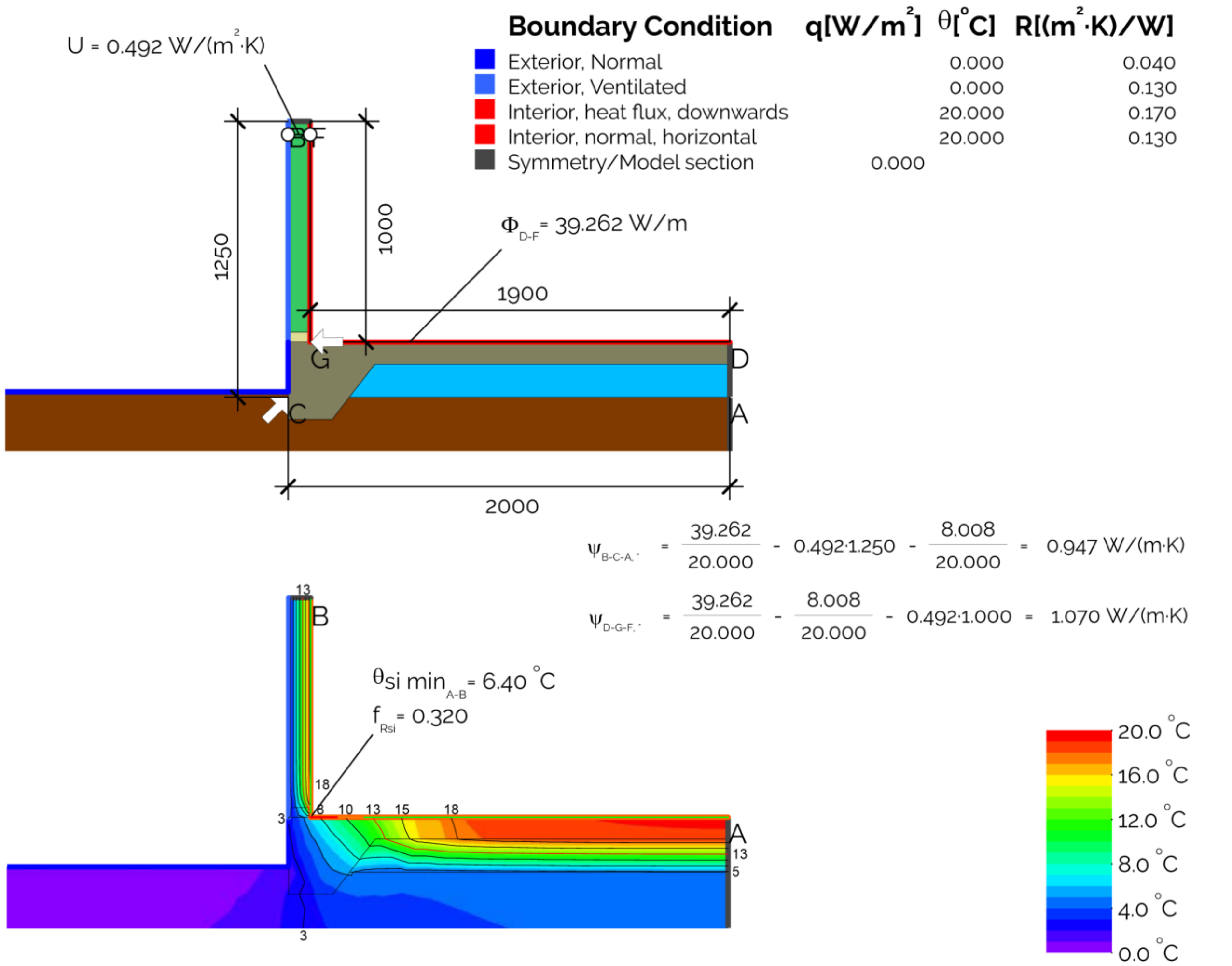


25 EWFS External Wall to Floor Slab - Stud wall 90mm stud current practice insulated raft slab no edge-insulation

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.947 W/(mK)	1.070 W/(mK)
f_{RSI}	0.320	
Cost	$180 per linear metre	
Carbon	57 $kgCO_2eq/m$	
Carbon Storage	5 $kgCO_2eq/m$	

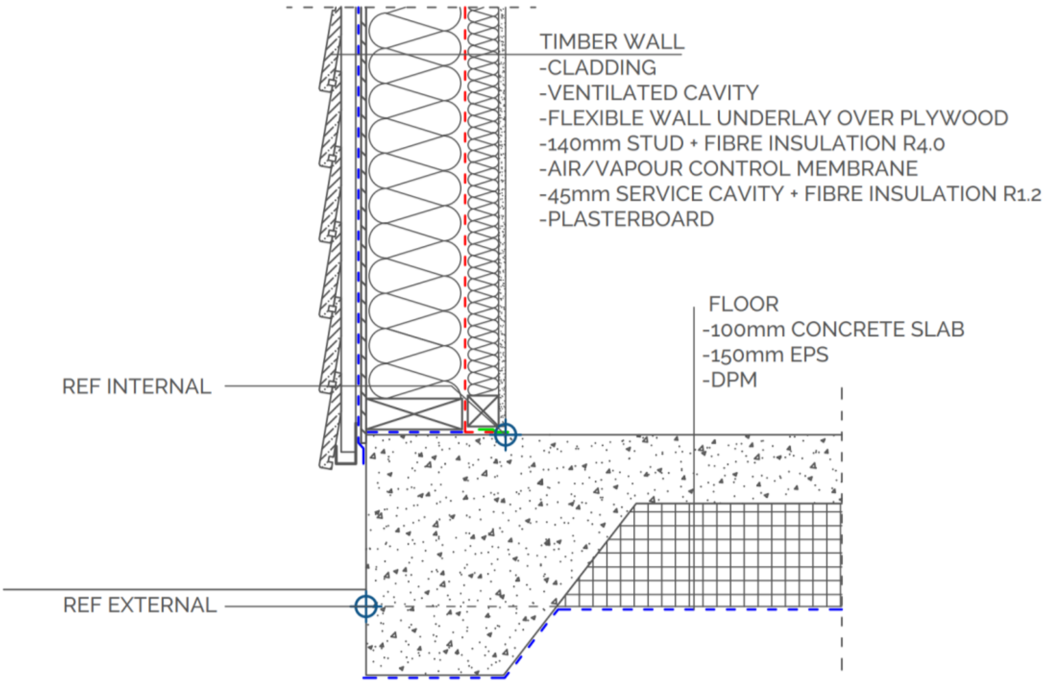
This detail represents a typical current practice slab edge with no edge insulation and a very high level of insulation below the concrete slab with a current practice 90mm timber stud wall. Excessive heat loss occurs due to the uninsulated edge and is primarily lost to the air.



Material	λ[W/(m·K)]
Concrete	2.100
EPSInsul_L0.038	0.038
FibreInsulR2.2/90mm+12%Timber	0.052
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

The performance of the slab edge can be improved by adding insulation to the exterior, as shown in the following details.

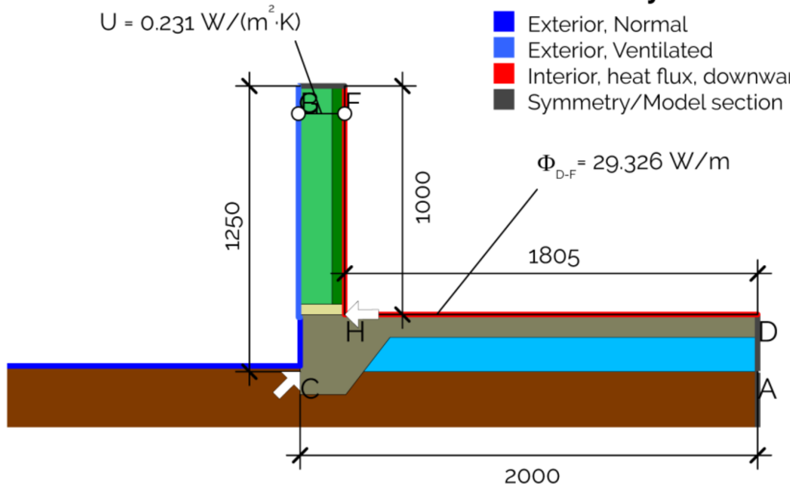


26 EWFS External Wall to Floor Slab - 140/45 stud wall insulated raft slab no edge insulation

RESULTS TABLE

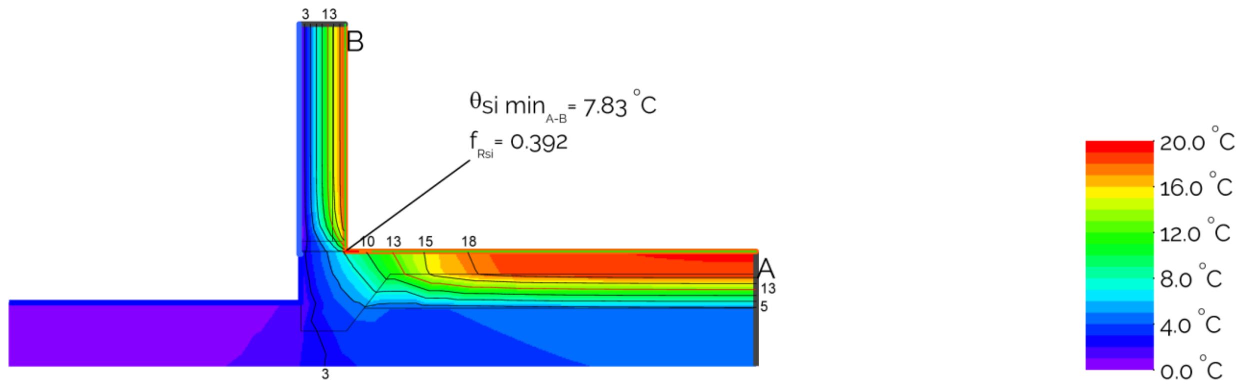
Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.778 W/(mK)	0.835 W/(mK)
f_{RSI}	0.392	
Cost	Not calculated	
Carbon	Not calculated	

This detail represents a typical current practice slab edge with no edge insulation and a very high level of insulation below the concrete slab, with a high-performance wall. Excessive heat loss occurs due to the uninsulated edge and is primarily lost to the air.



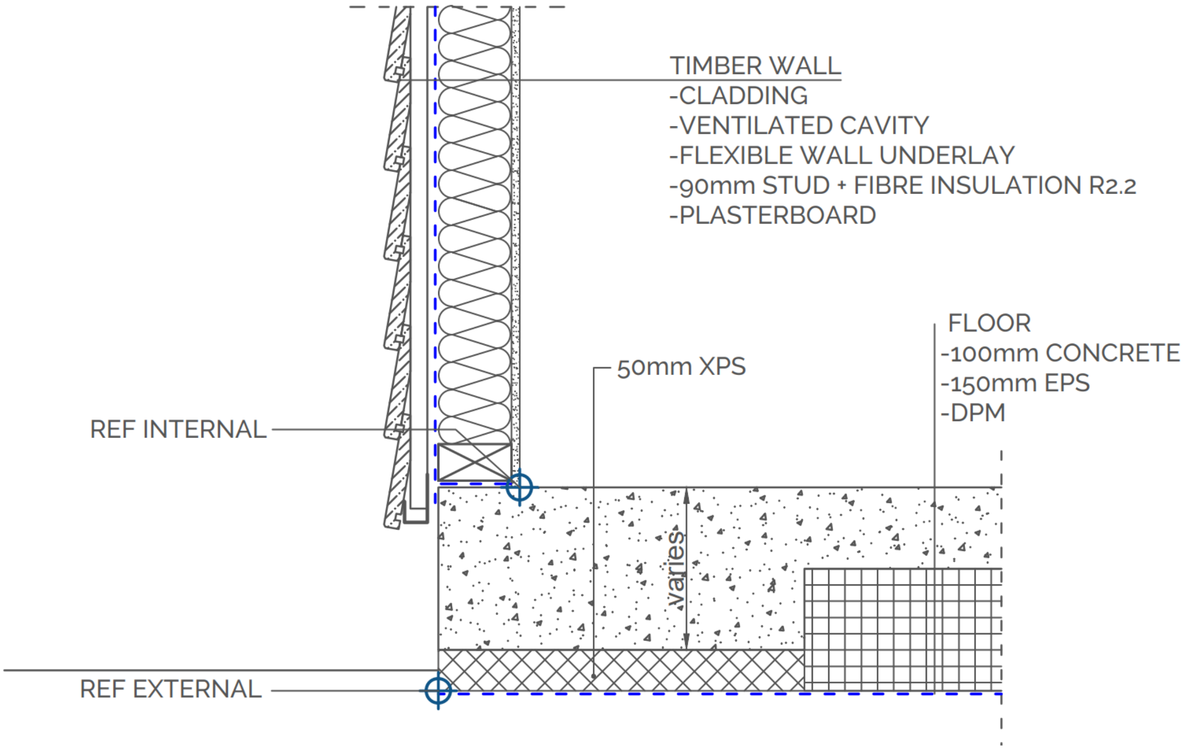
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Symmetry/Model section	0.000		

$$\psi_{G\text{-}C\text{-}A,*} = \frac{29.326}{20.000} - 0.231 \cdot 1.250 - \frac{8.008}{20.000} = 0.778\ W/(m\cdot K) \qquad \psi_{D\text{-}H\text{-}F,*} = \frac{29.326}{20.000} - \frac{8.008}{20.000} - 0.231 \cdot 1.000 = 0.835\ W/(m\cdot K)$$



Material	λ[W/(m·K)]
Concrete	2.10
EPSInsul_L0.038	0.03
FibreInsulR1.2/50mm+10%Timber	0.05
FibreInsulR4.0/140mm+12%Timber	0.040
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



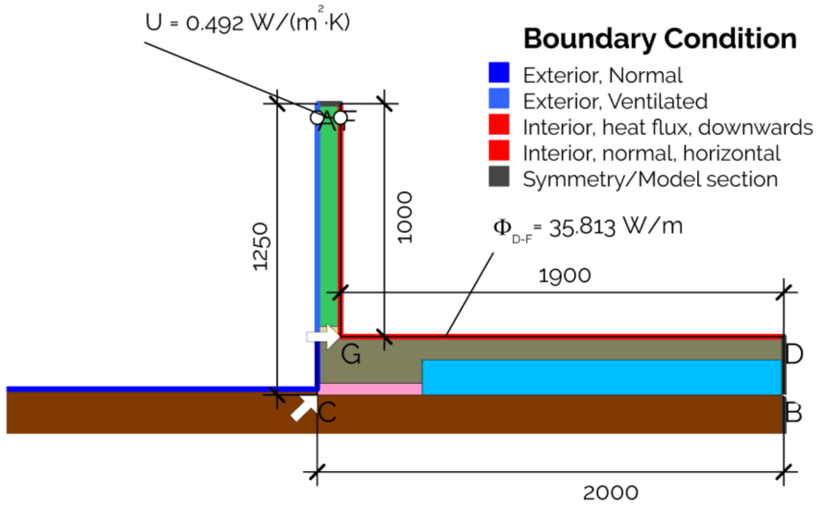
27 EWFS External Wall to Floor Slab - Stud wall 90mm stud current practice insulated raft slab and footer no edge insulation

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.775 W/(mK)	0.898 W/(mK)
f_{RSI}	0.387	
Cost	$226 per linear metre	
Carbon	61 $kgCO_2eq/m$	
Carbon Storage	6 $kgCO_2eq/m$	

This detail represents a typical current practice slab edge with no edge insulation but a high level of insulation under the footer and a very high level of insulation below the concrete slab, with a current practice 90mm timber stud wall. Excessive heat loss occurs due to the uninsulated edge and is primarily lost to the air.

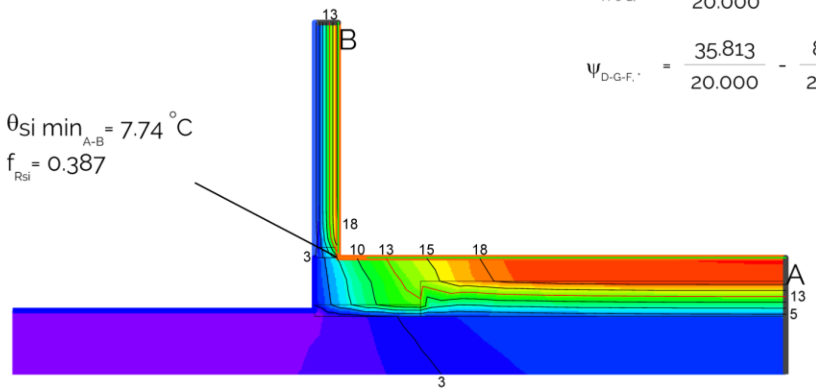
This detail was not used in any of the buildings reviewed and was included to show the heat loss reduction of insulation under the footer.

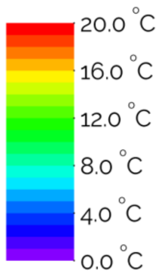


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

$$\Psi_{A-C-B,\cdot} = \frac{35.813}{20.000} - 0.492 \cdot 1.250 - \frac{8.008}{20.000} = 0.775\ \mathrm{W/(m \cdot K)}$$

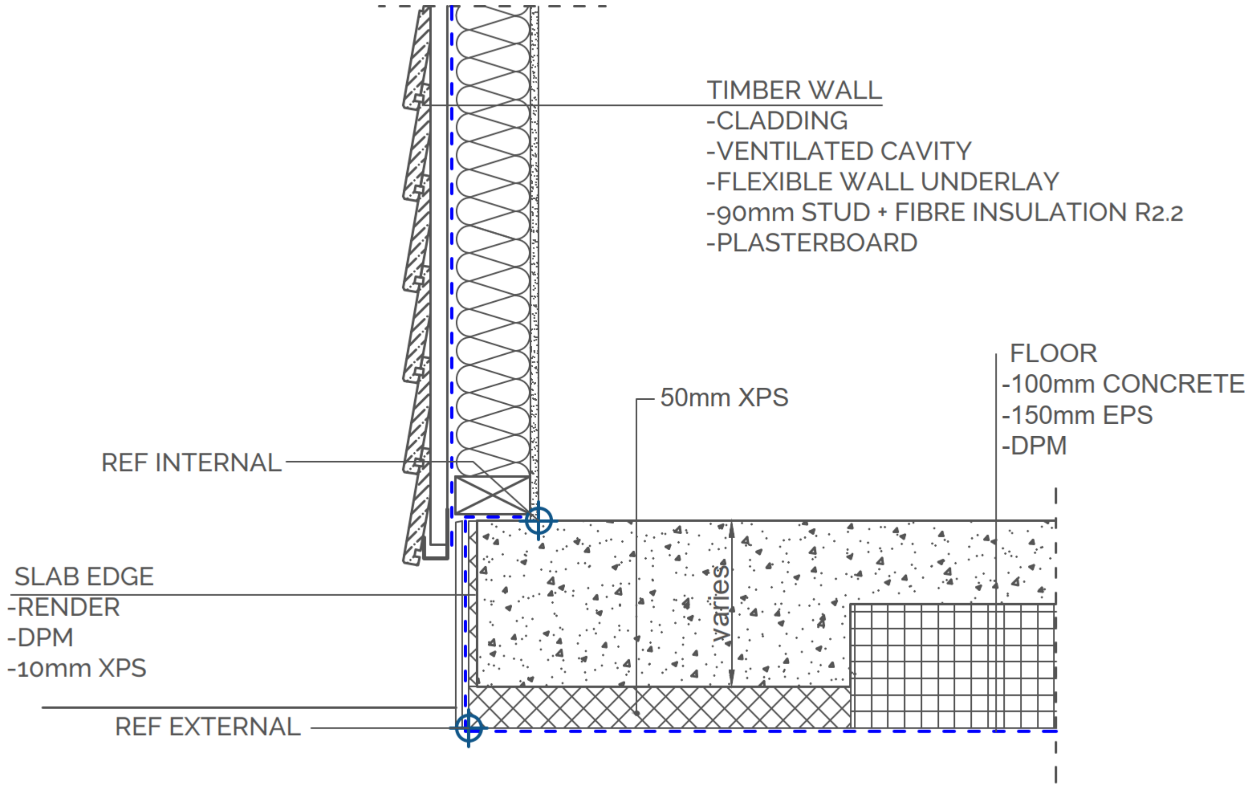
$$\Psi_{D-G-F,\cdot} = \frac{35.813}{20.000} - \frac{8.008}{20.000} - 0.492 \cdot 1.000 = 0.898\ \mathrm{W/(m \cdot K)}$$





Material	λ[W/(m·K)]
Concrete	2.100
EPSInsul_L0.038	0.038
FibreInsulR2.2/90mm+12%Timber	0.052
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130
XPSInsul_L0.028	0.028

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

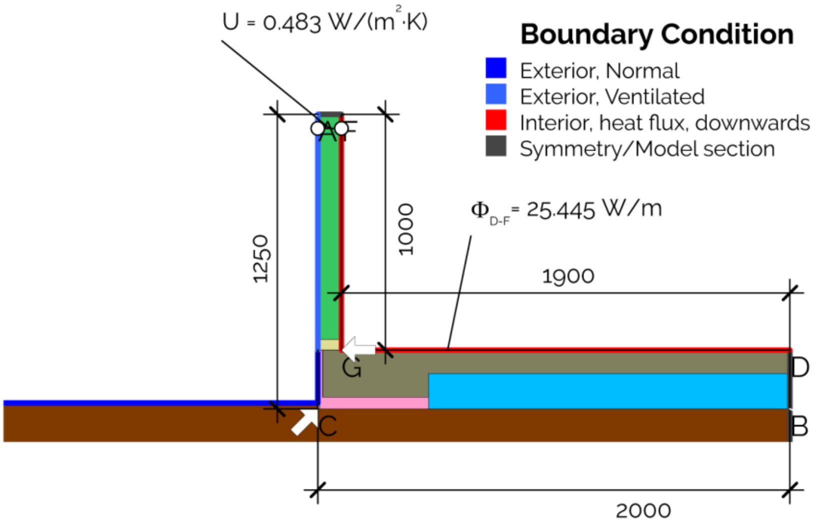


28 EWFS External Wall to Floor Slab - Stud wall 90mm stud current practice insulated raft slab edge insulation (20mm overhang)

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.268 W/(mK)	0.389 W/(mK)
f_{RSI}	0.679	
Cost	$250 per linear metre	
Carbon	65 $kgCO_2eq/m$	
Carbon Storage	6 $kgCO_2eq/m$	

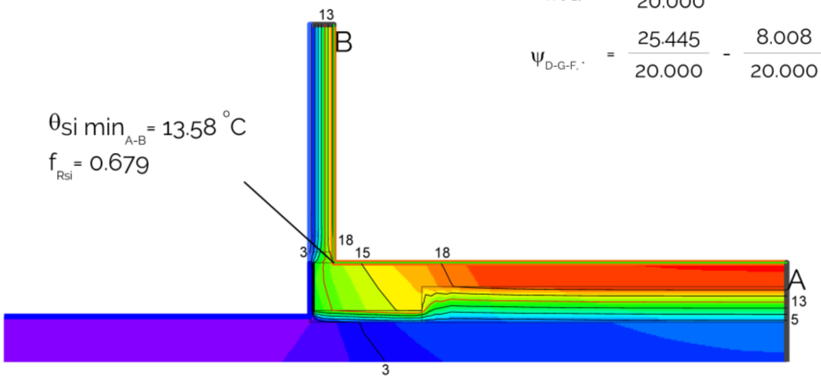
A fully-insulated slab on ground with continuous insulation under all the footings/thickenings and up the outside face of the slab edge is the most common floor construction in the high-performance buildings reviewed. The slab edge insulation thickness of 10mm shown here is the practical minimum without it breaking.

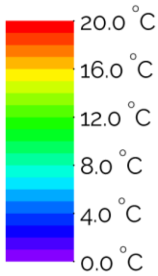


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Symmetry/Model section	0.000		

$$\Psi_{A\text{-}C\text{-}B,^*} = \frac{25.445}{20.000} - 0.483 \cdot 1.250 - \frac{8.008}{20.000} = 0.268\ \mathrm{W/(m\cdot K)}$$

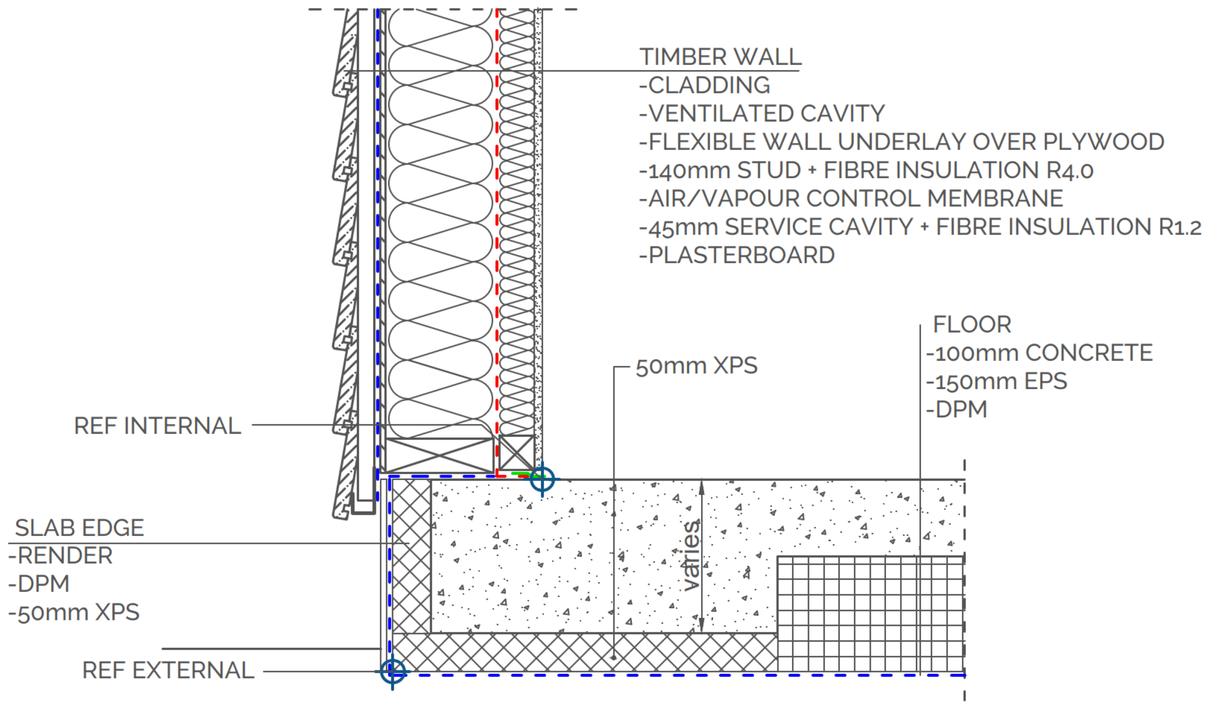
$$\Psi_{D\text{-}G\text{-}F,^*} = \frac{25.445}{20.000} - \frac{8.008}{20.000} - 0.483 \cdot 1.000 = 0.389\ \mathrm{W/(m\cdot K)}$$





Material	λ[W/(m·K)]
Concrete	2.100
EPSInsul_L0.038	0.038
Fibre Cement	0.250
FibreInsulR2.2/90mm+12%Timber	0.052
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130
XPSInsul_L0.028	0.028

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



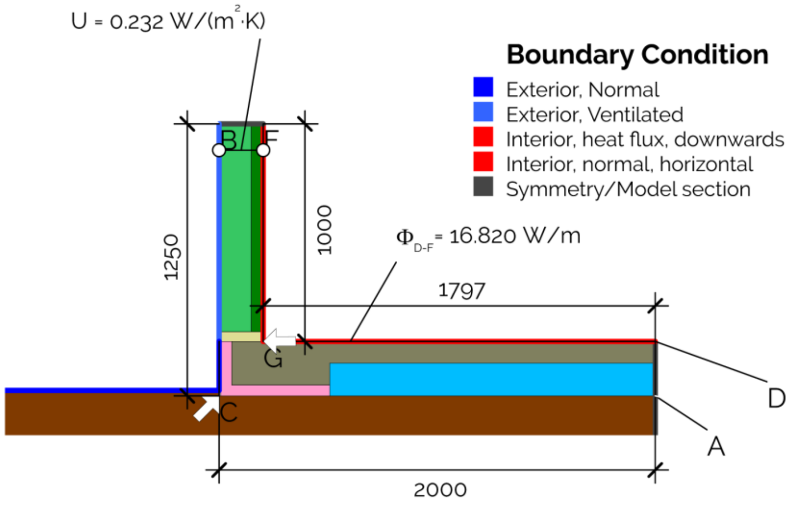
29 EWFS External Wall to Floor Slab 140/45 timber wall to slab on ground with continuous under-slab and 50mm overhung edge

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.150 W/(mK)	0.208 W/(mK)
f_{RSI}	0.782	
Cost	$265 per linear metre	
Carbon	69 kgCO$_2$eq/m	
Carbon Storage	6 kgCO$_2$eq/m	

A fully-insulated slab on ground with continuous insulation under all the footings/ thickenings and up the outside face of the slab edge is the most common floor construction in the high-performance buildings reviewed. The slab edge insulation thickness of 50mm shown here is the practical upper limit with a 140mm structural stud wall where the outside edge or other construction is not tapered.

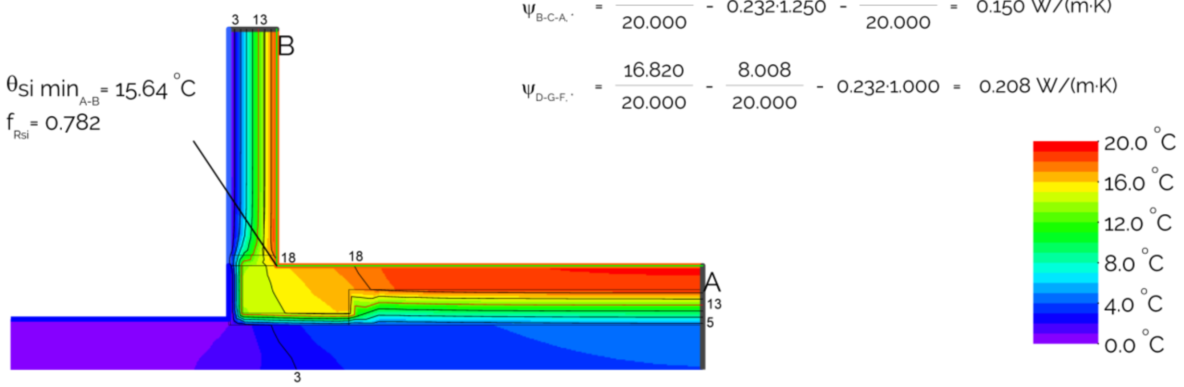
As this slab requires SED, the thickening at the slab edge thickness varies but 250mm is the smallest we have seen. The main body of the slab is shown here with 150mm of EPS but slabs with 250mm of EPS have been built in the South Island.



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

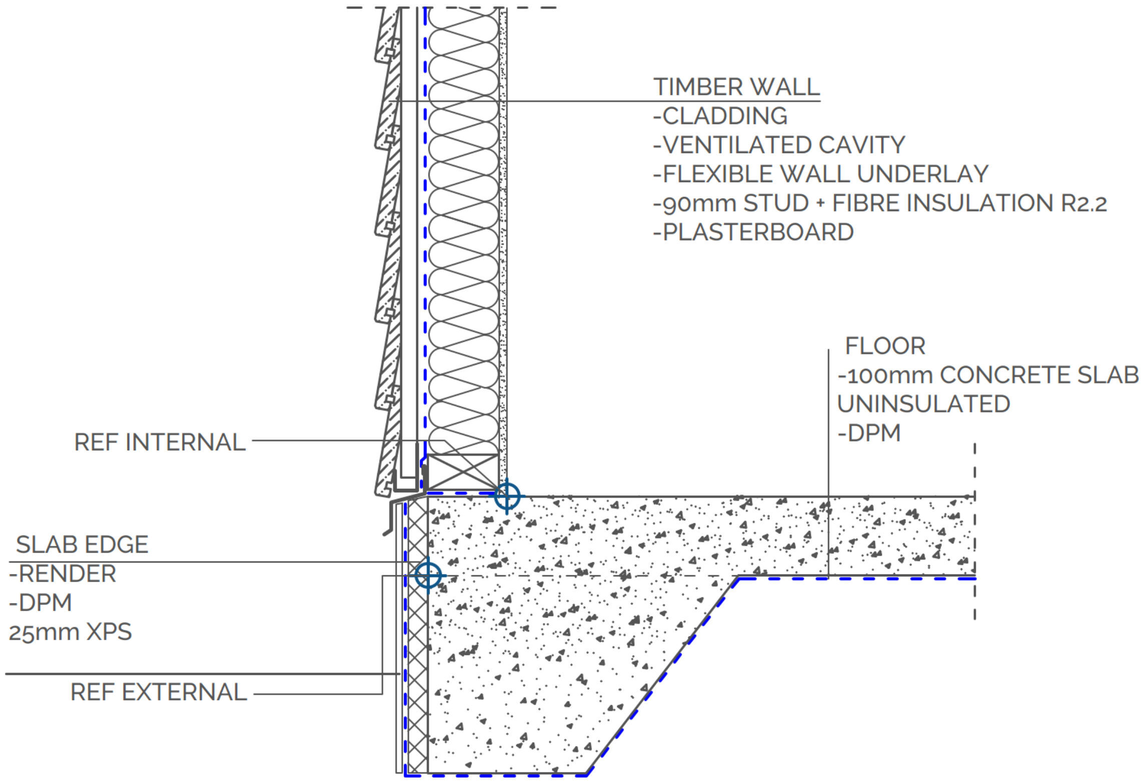
$$\psi_{B-C-A,\cdot} = \frac{16.820}{20.000} - 0.232 \cdot 1.250 - \frac{8.008}{20.000} = 0.150\ \mathrm{W/(m \cdot K)}$$

$$\psi_{D-G-F,\cdot} = \frac{16.820}{20.000} - \frac{8.008}{20.000} - 0.232 \cdot 1.000 = 0.208\ \mathrm{W/(m \cdot K)}$$



Material	λ[W/(m·K)]
Concrete	2.100
EPSInsul_L0.038	0.038
Fibre Cement	0.250
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130
XPSInsul_L0.028	0.028

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

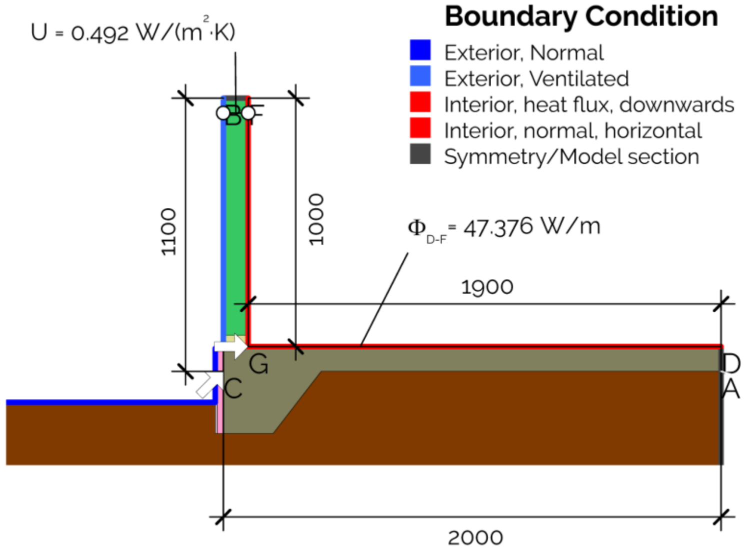


30 EWFS External Wall to Floor Slab - Stud wall 90mm stud current practice uninsulated slab edge insulation only

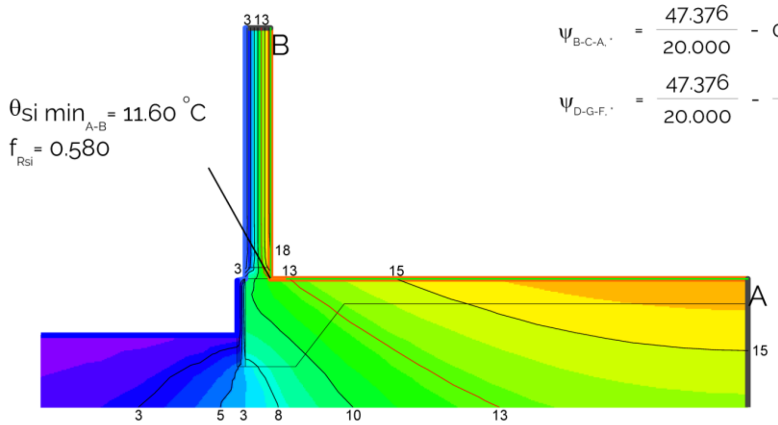
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	-0.317 W/(mK)	-0.268 W/(mK)
f_{RSI}	0.580	
Cost	$226 per linear metre	
Carbon	65 $kgCO_2eq/m$	
Carbon Storage	5 $kgCO_2eq/m$	

This detail represents a typical current practice slab with added edge insulation and no insulation below the concrete slab, with a current practice 90mm timber stud wall. This small amount of insulation significantly lowers the slab heat loss and increases the fRSI to above the 0.55 required by PHI for warm climates like Auckland.

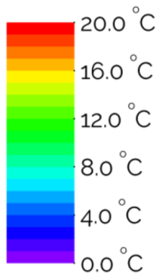


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		



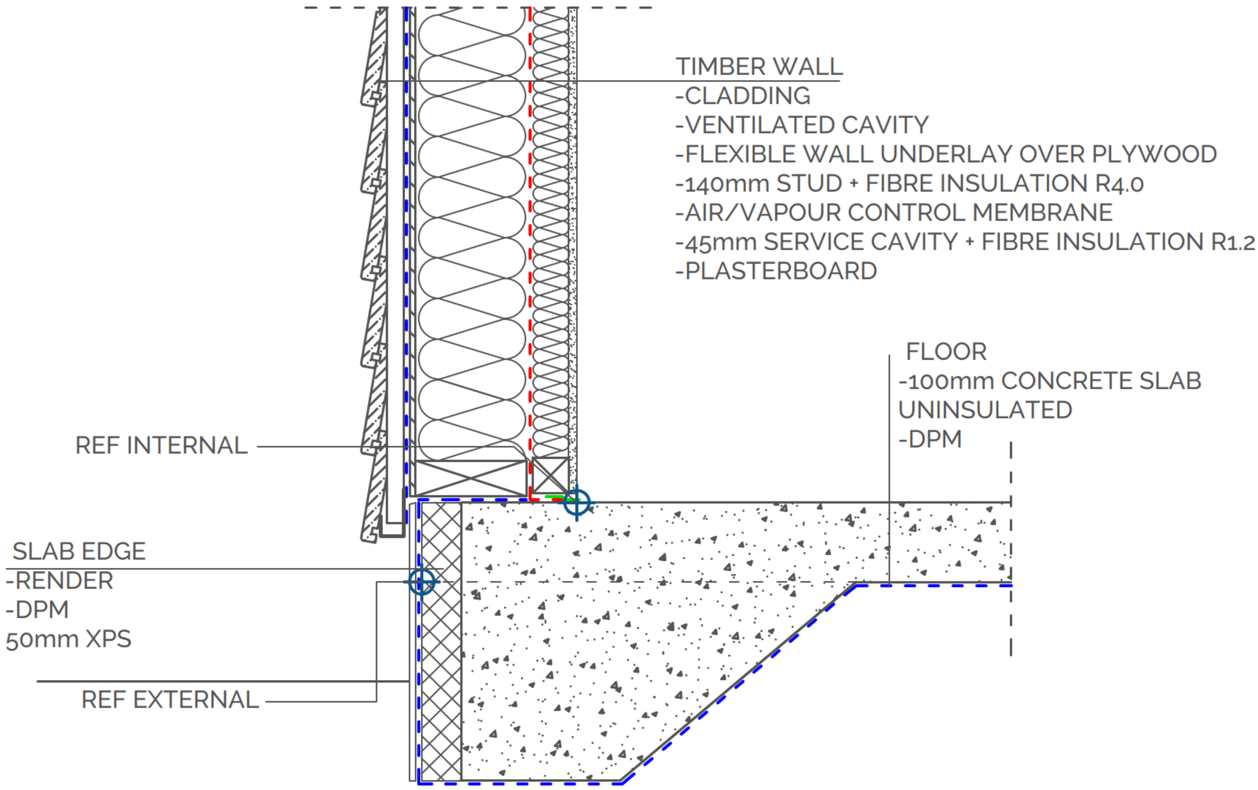
$$\Psi_{B\text{-}C\text{-}A,\cdot} = \frac{47.376}{20.000} - 0.492\cdot1.100 - \frac{42.887}{20.000} = -0.317\ \text{W/(m·K)}$$

$$\Psi_{D\text{-}G\text{-}F,\cdot} = \frac{47.376}{20.000} - \frac{42.887}{20.000} - 0.492\cdot1.000 = -0.268\ \text{W/(m·K)}$$



Material	λ[W/(m·K)]
Concrete	2.100
Fibre Cement	0.250
FibreInsulR2.2/90mm+12%Timber	0.052
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130
XPSInsul_L0.028	0.028

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



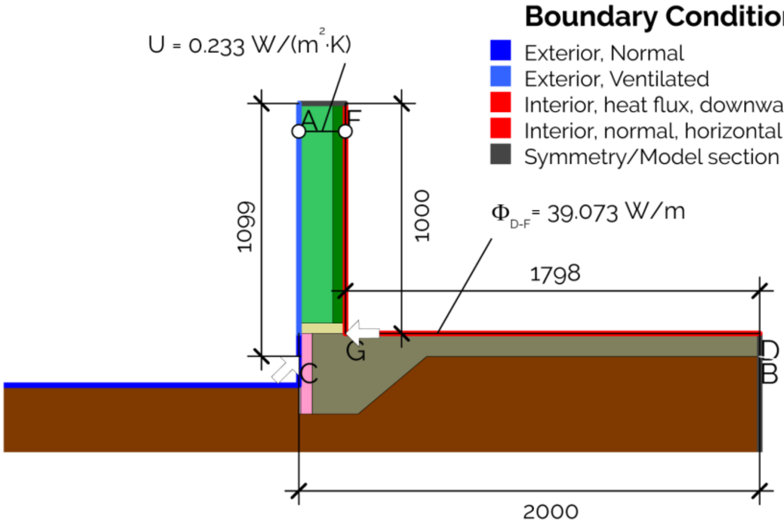
31 EWFS External Wall to Floor Slab - 140/45 stud wall uninsulated slab edge insulation only

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	-0.447 W/(mK)	-0.423 W/(mK)
f_{RSI}	0.629	
Cost	$242 per linear metre	
Carbon	69 $kgCO_2eq/m$	
Carbon Storage	5 $kgCO_2eq/m$	

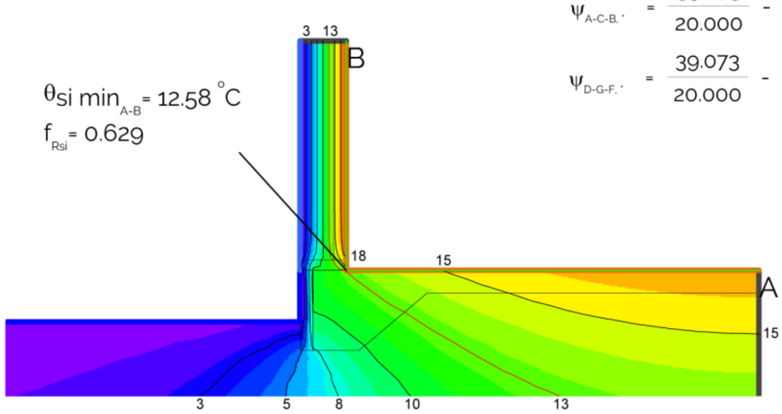
This detail represents a typical current practice slab with added edge insulation and no insulation below the concrete slab, with a high-performance wall. SED allows the 140mm studs to overhang the slab edge, which permits lining up the edge insulation with the timber wall insulation.

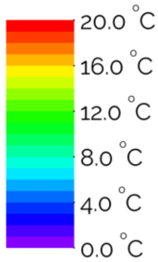
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		



$$\psi_{A\text{-}C\text{-}B,\,'} = \frac{39.073}{20.000} - 0.233 \cdot 1.099 - \frac{42.888}{20.000} = -0.447\ \mathrm{W/(m \cdot K)}$$

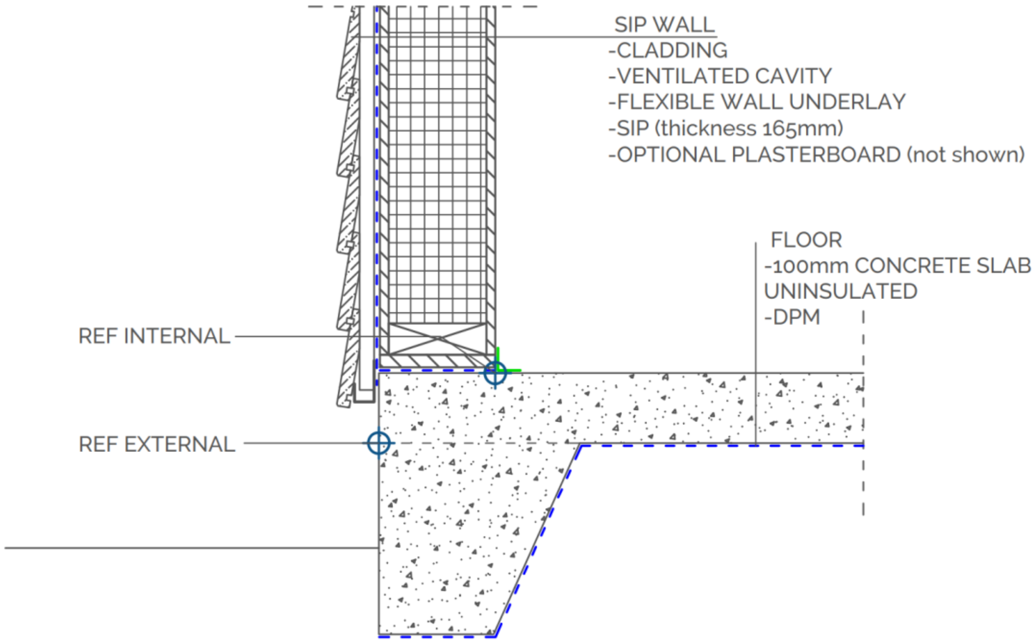
$$\psi_{D\text{-}G\text{-}F,\,'} = \frac{39.073}{20.000} - \frac{42.888}{20.000} - 0.233 \cdot 1.000 = -0.423\ \mathrm{W/(m \cdot K)}$$





Material	λ[W/(m·K)]
Concrete	2.100
Fibre Cement	0.250
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130
XPSInsul_L0.028	0.028

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

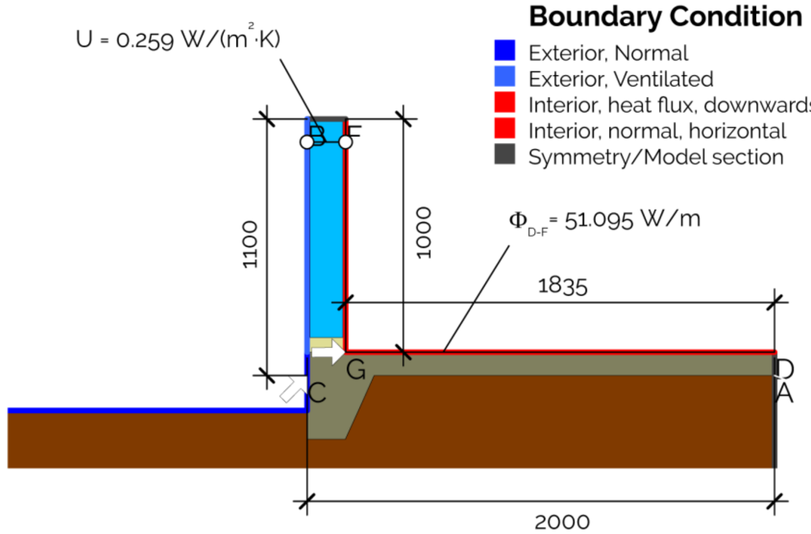


32 EWFS External Wall to Floor Slab - SIP wall current practice uninsulated raft slab no edge insulation

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.126 W/(mK)	0.152 W/(mK)
f_{RSI}	0.393	
Cost	$203 per linear metre	
Carbon	61 $kgCO_2eq/m$	
Carbon Storage	8 $kgCO_2eq/m$	

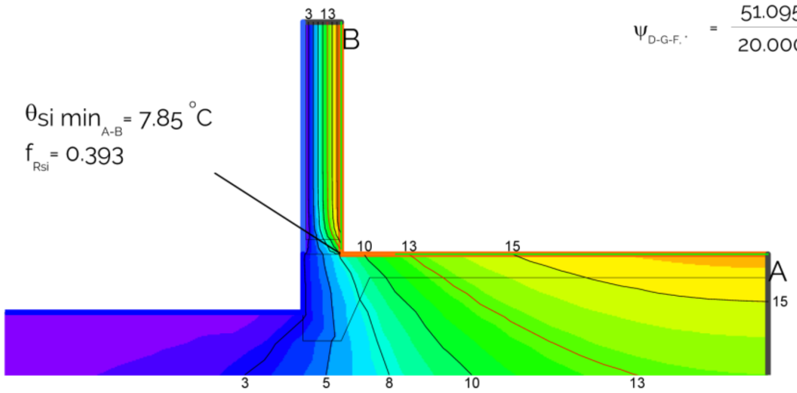
Current practice uninsulated slab with a SIP wall. This is a baseline for comparison with the following SIP floor edges with additional insulation.

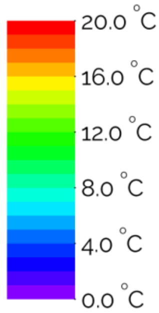


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

$$\Psi_{B\text{-}C\text{-}A,\cdot} = \frac{51.095}{20.000} - 0.259 \cdot 1.100 - \frac{42.888}{20.000} = 0.126 \text{ W/(m·K)}$$

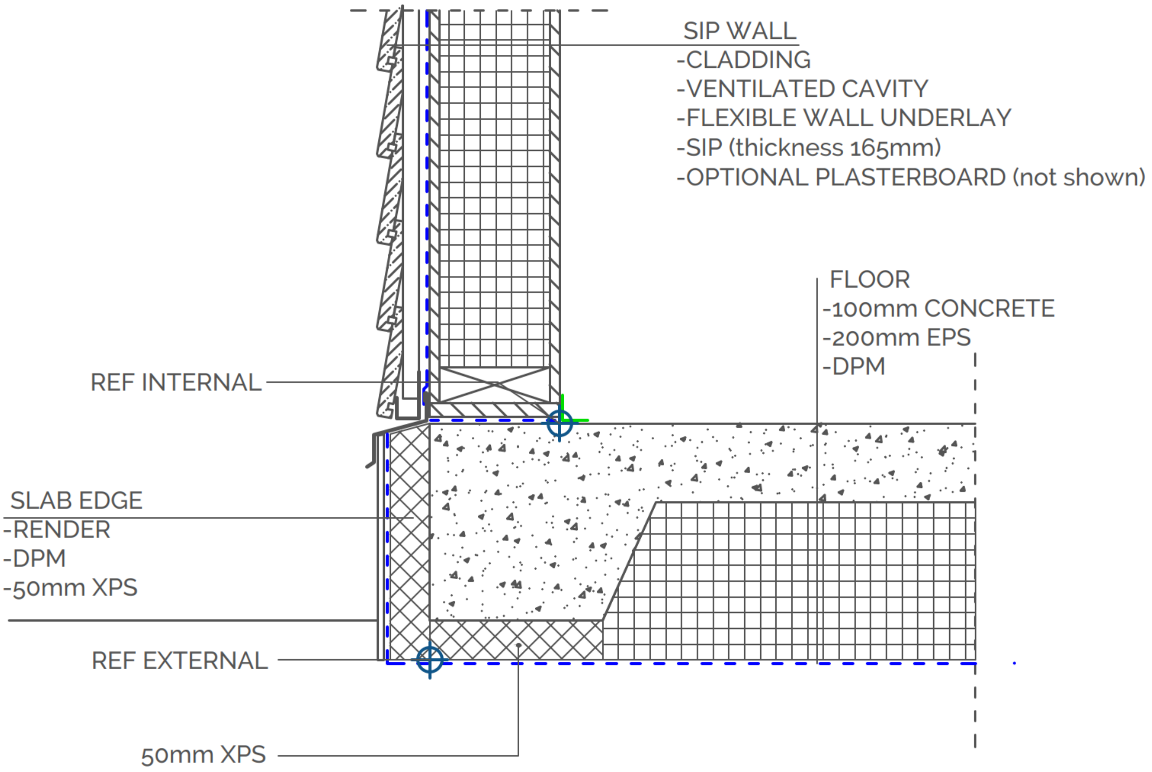
$$\Psi_{D\text{-}G\text{-}F,\cdot} = \frac{51.095}{20.000} - \frac{42.888}{20.000} - 0.259 \cdot 1.000 = 0.152 \text{ W/(m·K)}$$





Material	λ[W/(m·K)]
Concrete	2.100
Ground	2.000
SIPCore_L0.041	0.041
Timber (Softwood)	0.130

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

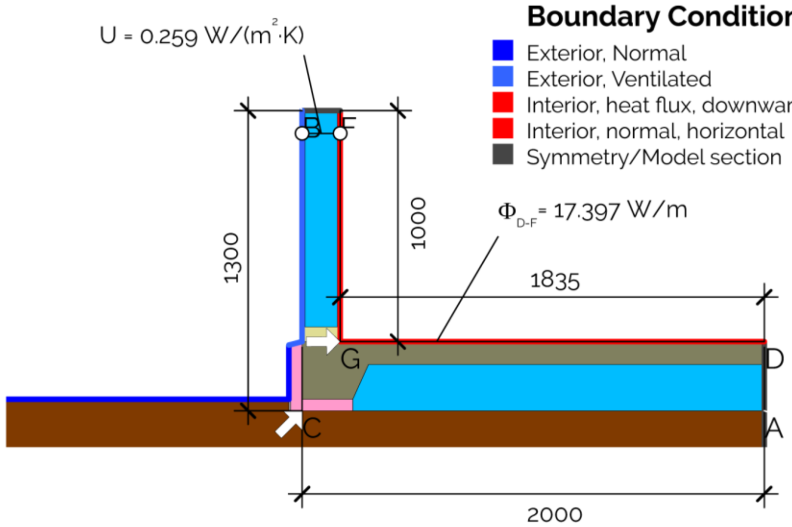


33 EWFS External Wall to Floor Slab SIP wall insulated raft slab edge insulation – no overhang

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.217 W/(mK)	0.295 W/(mK)
f_{RSI}	0.709	
Cost	Not calculated	
Carbon	Not calculated	

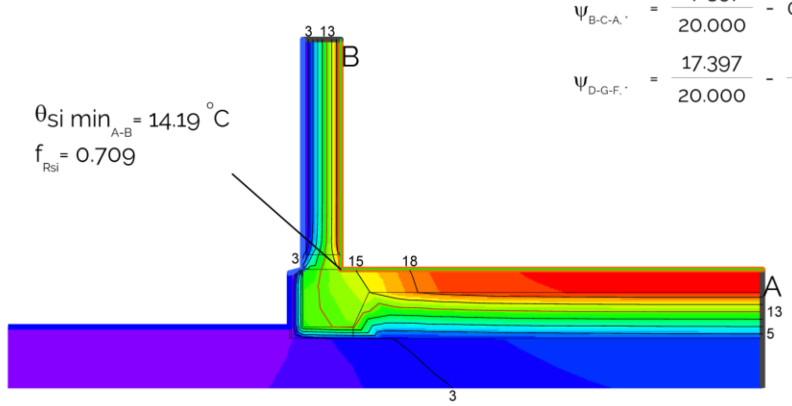
High-performance, very well insulated slab with a SIP wall and 50mm of edge insulation added to the outside face of the slab. The structural engineer sometimes does not allow overhang of the slab edge with the SIP. This can be directly compared to Junction 34.

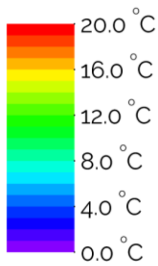


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

$$\Psi_{B\text{-}C\text{-}A,*} = \frac{17.397}{20.000} - 0.259 \cdot 1.300 - \frac{6.334}{20.000} = 0.217 \text{ W/(m·K)}$$

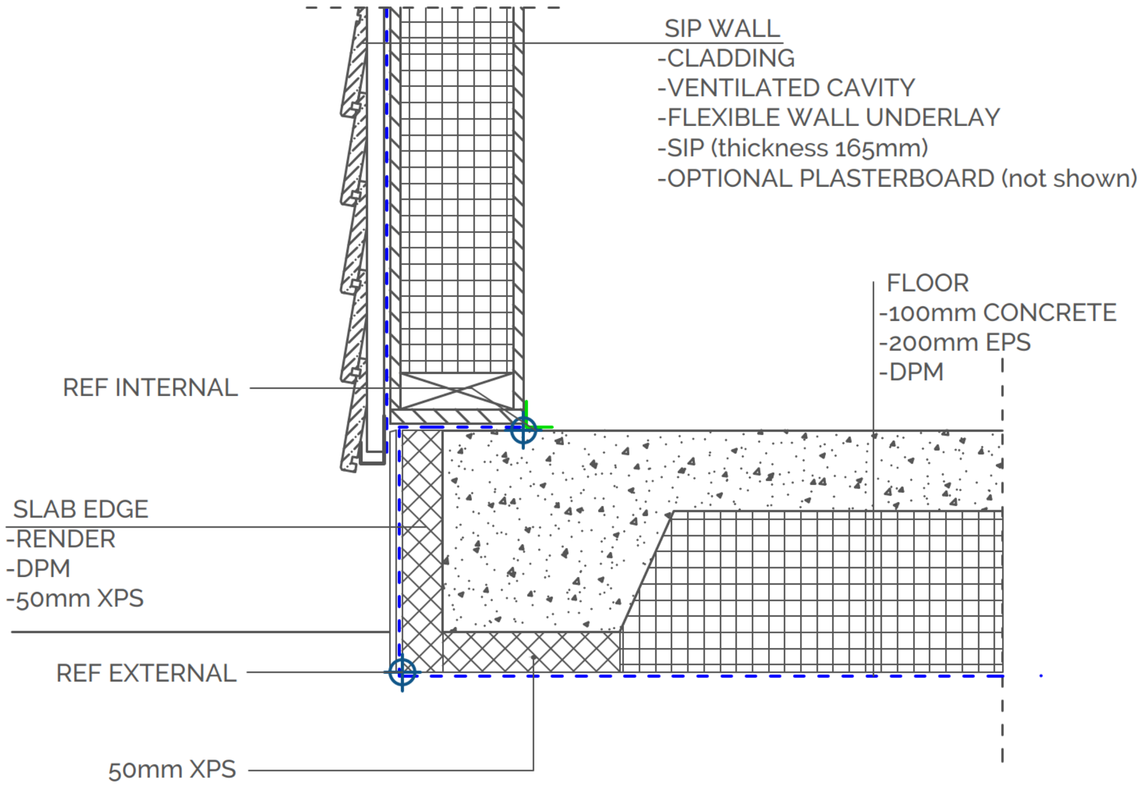
$$\Psi_{D\text{-}G\text{-}F,*} = \frac{17.397}{20.000} - \frac{6.334}{20.000} - 0.259 \cdot 1.000 = 0.295 \text{ W/(m·K)}$$





Material	λ[W/(m·K)]
Concrete	2.100
EPSInsul_L0.038	0.038
Fibre Cement	0.250
Ground	2.000
SIPCore_L0.041	0.041
Timber (Softwood)	0.130
XPSInsul_L0.028	0.028

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

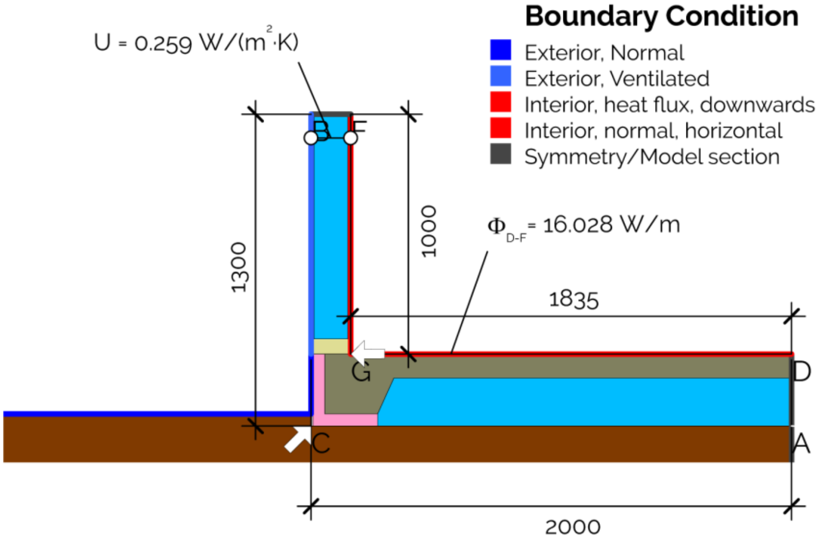


34 EWFS External Wall to Floor Slab - SIP wall insulated raft slab edge insulation 50mm overhang

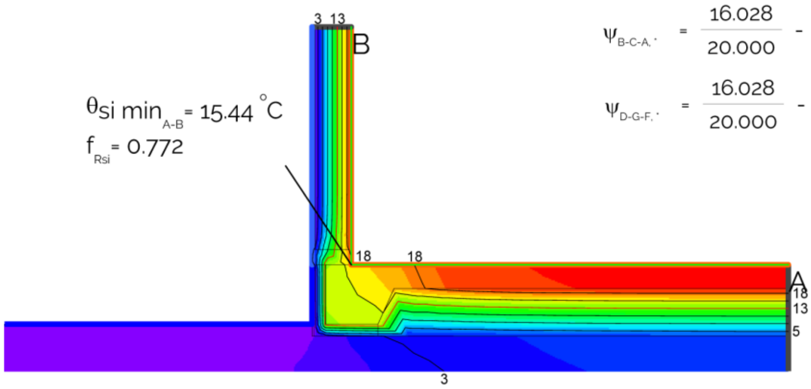
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.148 W/(mK)	0.226 W/(mK)
f_{RSI}	0.772	
Cost	$275 per linear metre	
Carbon	74 $kgCO_2eq/m$	
Carbon Storage	8 $kgCO_2eq/m$	

High-performance, very well insulation slab with a SIP wall and 50mm of edge insulation overhung. This has been consented in New Zealand and depends on the structural engineering. It can be directly compared to Junction 33.

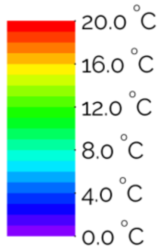


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		



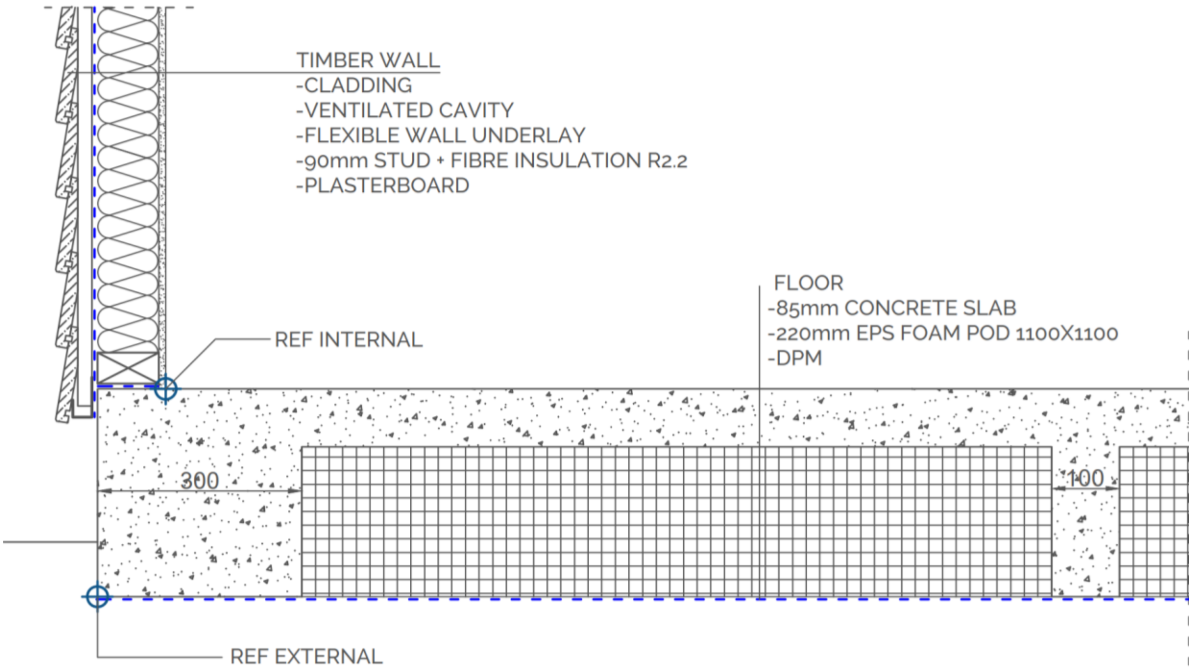
$$\psi_{B\text{-}C\text{-}A,'} = \frac{16.028}{20.000} - 0.259 \cdot 1.300 - \frac{6.334}{20.000} = 0.148\ \mathrm{W/(m \cdot K)}$$

$$\psi_{D\text{-}G\text{-}F,'} = \frac{16.028}{20.000} - \frac{6.334}{20.000} - 0.259 \cdot 1.000 = 0.226\ \mathrm{W/(m \cdot K)}$$



Material	λ[W/(m·K)]
Concrete	2.100
EPSInsul_L0.038	0.038
Fibre Cement	0.250
Ground	2.000
SIPCore_L0.041	0.041
Timber (Softwood)	0.130
XPSInsul_L0.028	0.028

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

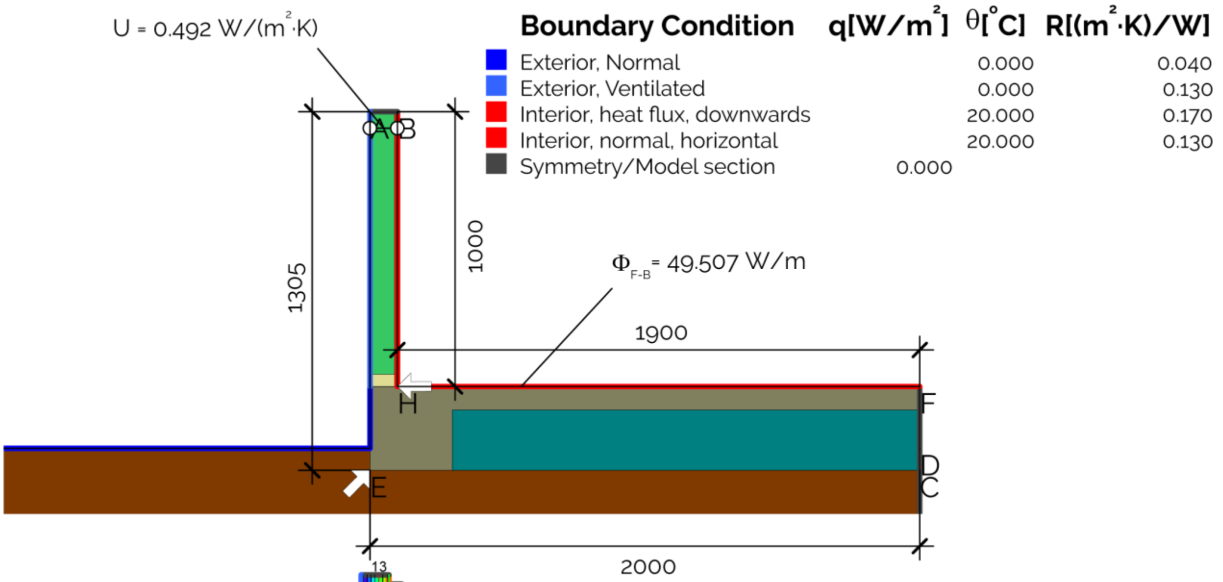


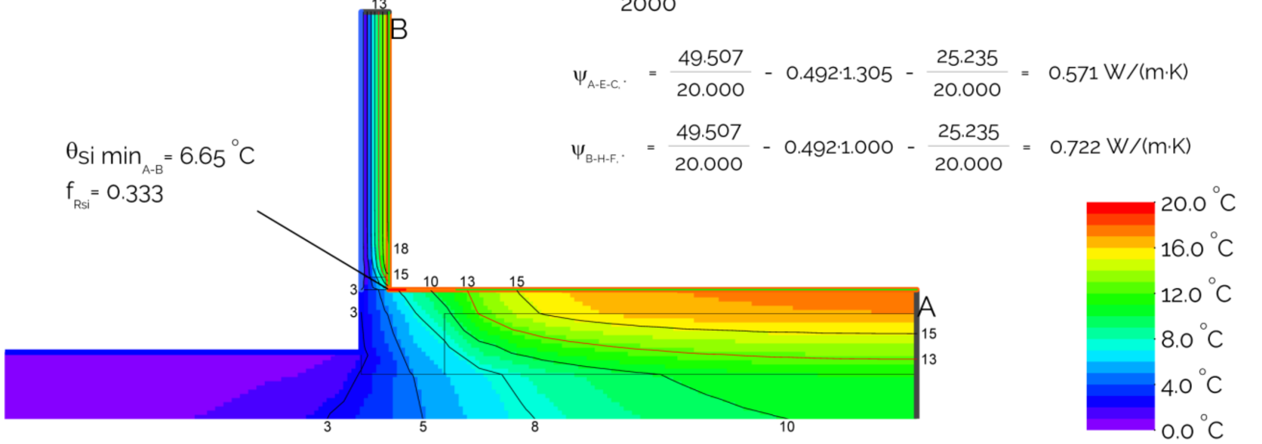
35 EWFS External Wall to Floor Slab - Stud wall 90mm stud current practice waffle pod slab no edge insulation

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.571 W/(mK)	0.722 W/(mK)
f_{RSI}	0.333	
Cost	$117 per linear metre	
Carbon	34 $kgCO_2eq/m$	
Carbon Storage	3 $kgCO_2eq/m$	

This detail represents a typical current practice waffle pod slab edge with no edge insulation and a no additional insulation below the concrete slab with a current practice 90mm timber stud wall. Excessive heat loss occurs due to the uninsulated edge and is primarily lost to the air.



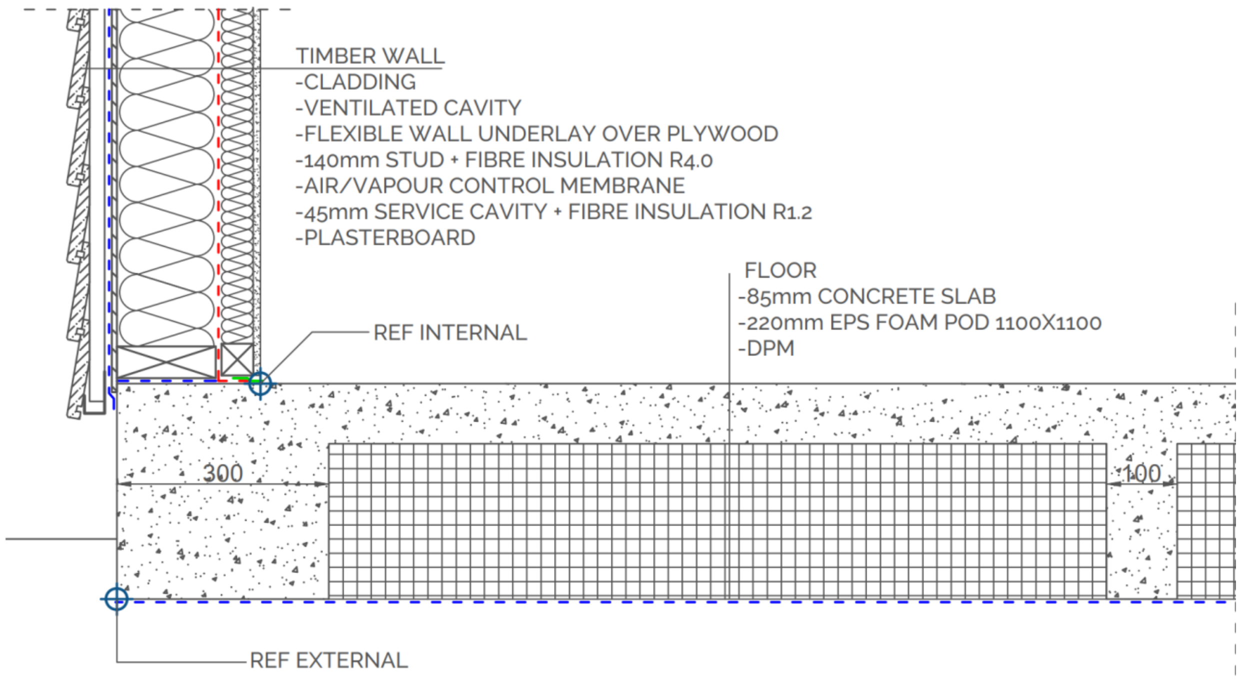


Material	λ[W/(m·K)]
220mmMouldedPodOnGround_EQ	0.380
Concrete	2.100
FibreInsulR2.2/90mm+12%Timber	0.052
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

In the2D thermal bridge calculation, the 220mm tall waffle pod EPS foam with air pockets and concrete ribs have been replaced with an equivalent thermal conductivity calculated with a 3D finite element model using ISO10211:2007. Note that 100mm concrete ribs at 1200mm centres in the field of the slab have been assumed. The 300mm wide concrete edge beam is modelled as concrete as shown.

In PHPP this should be entered with layers with the λ values and thicknesses shown above for the centre of the slab in the U-values sheet and the PSI value and perimeter on the Areas sheet.

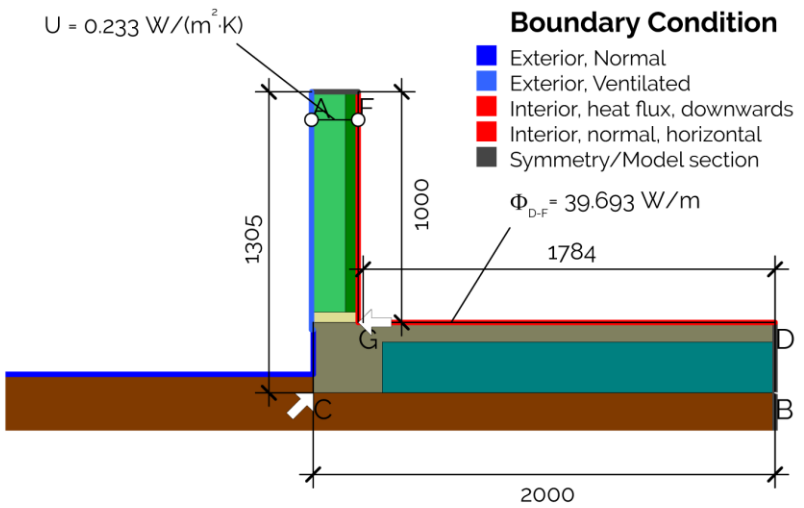


36 EWFS External Wall to Floor Slab - 140/45 stud wall waffle pod slab no edge insulation

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.419 W/(mK)	0.490 W/(mK)
f_{RSI}	0.405	
Cost	Not calculated	
Carbon	Not calculated	

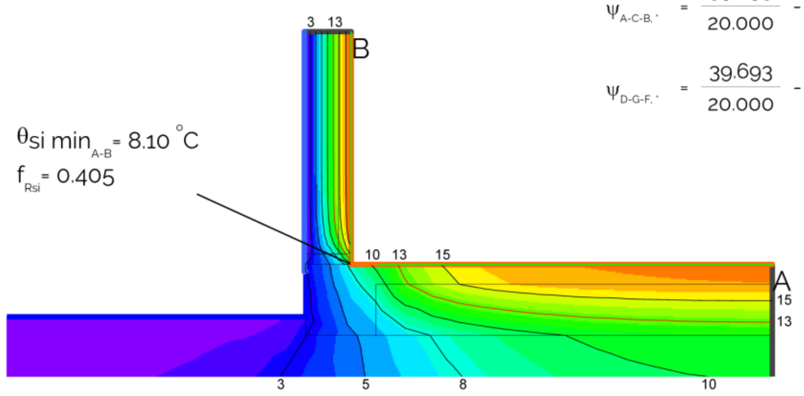
This detail represents a typical current practice waffle pod slab edge with no edge insulation and no additional insulation below the concrete slab with a high-performance wall. Excessive heat loss occurs due to the uninsulated edge and is primarily lost to the air.

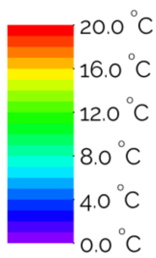


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

$$\psi_{A\text{-}C\text{-}B,\cdot} = \frac{39.693}{20.000} - 0.233 \cdot 1.305 - \frac{25.235}{20.000} = 0.419\ \mathrm{W/(m \cdot K)}$$

$$\psi_{D\text{-}G\text{-}F,\cdot} = \frac{39.693}{20.000} - \frac{25.235}{20.000} - 0.233 \cdot 1.000 = 0.490\ \mathrm{W/(m \cdot K)}$$



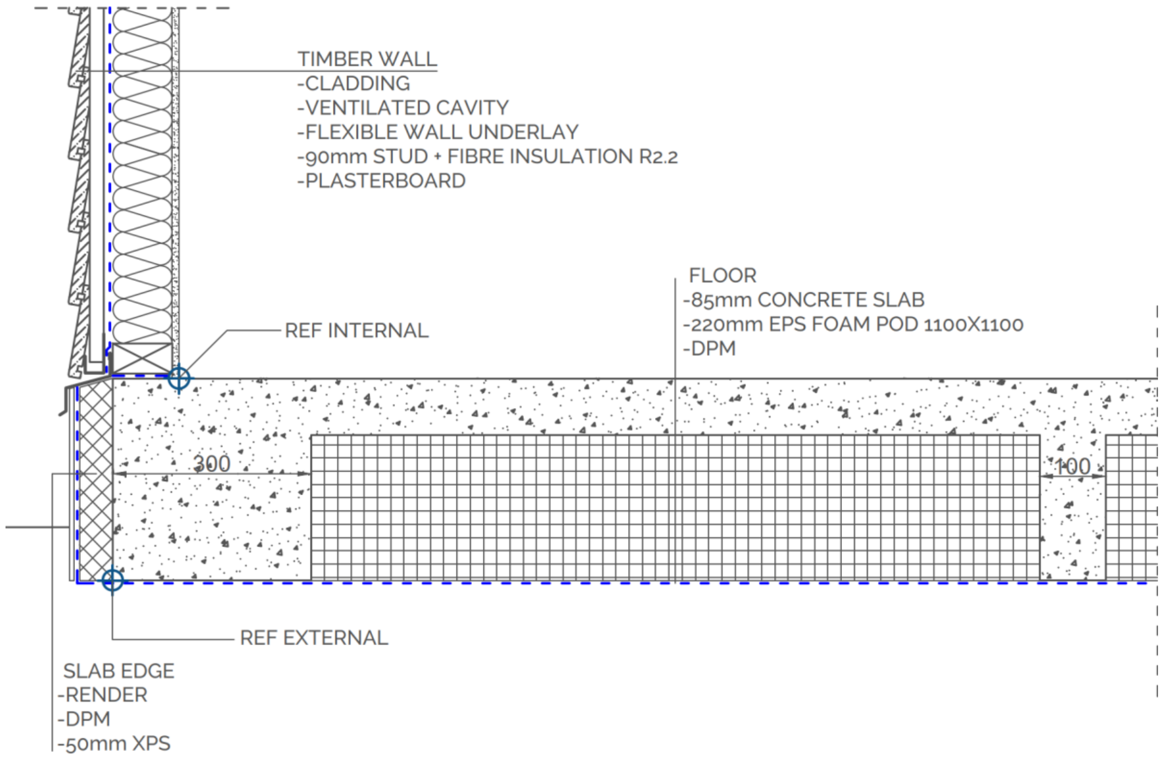


Material	λ[W/(m·K)]
220mmMouldedPodOnGround_EQ	0.380
Concrete	2.100
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

In the2D thermal bridge calculation, the 220mm tall waffle pod EPS foam with air pockets and concrete ribs have been replaced with an equivalent thermal conductivity calculated with a 3D finite element model using ISO10211:2007. Note that 100mm concrete ribs at 1200mm centres in the field of the slab have been assumed. The 300mm wide concrete edge beam is modelled as concrete as shown.

In PHPP this should be entered with layers with the λ values and thicknesses shown above for the centre of the slab in the U-values sheet and the PSI value and perimeter on the Areas sheet.

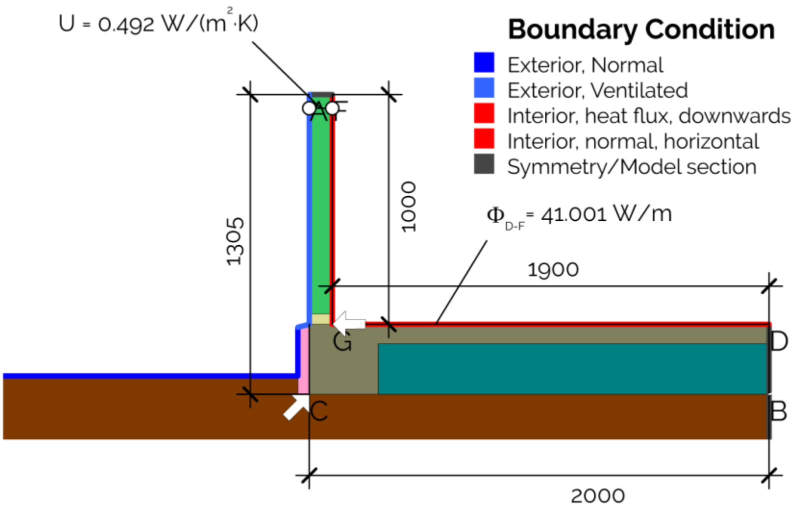


37 EWFS External Wall to Floor Slab - Stud wall 90mm stud current practice waffle pod slab edge insulation

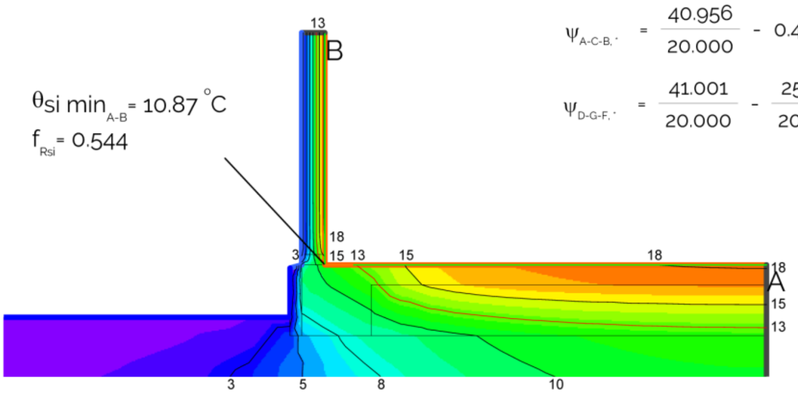
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.143 W/(mK)	0.296 W/(mK)
f_{RSI}	0.544	
Cost	$148 per linear metre	
Carbon	39 $kgCO_2eq/m$	
Carbon Storage	3 $kgCO_2eq/m$	

This detail represents a typical current practice waffle pod slab with added edge insulation and no insulation below the concrete slab, with a current practice 90mm timber stud wall. This edge only insulation significantly lowers the slab heat loss.

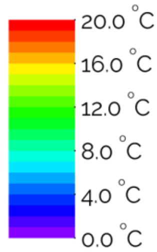


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		



$$\psi_{A\text{-}C\text{-}B,\cdot} = \frac{40.956}{20.000} - 0.492 \cdot 1.305 - \frac{25.235}{20.000} = 0.143 \text{ W/(m·K)}$$

$$\psi_{D\text{-}G\text{-}F,\cdot} = \frac{41.001}{20.000} - \frac{25.235}{20.000} - 0.492 \cdot 1.000 = 0.296 \text{ W/(m·K)}$$

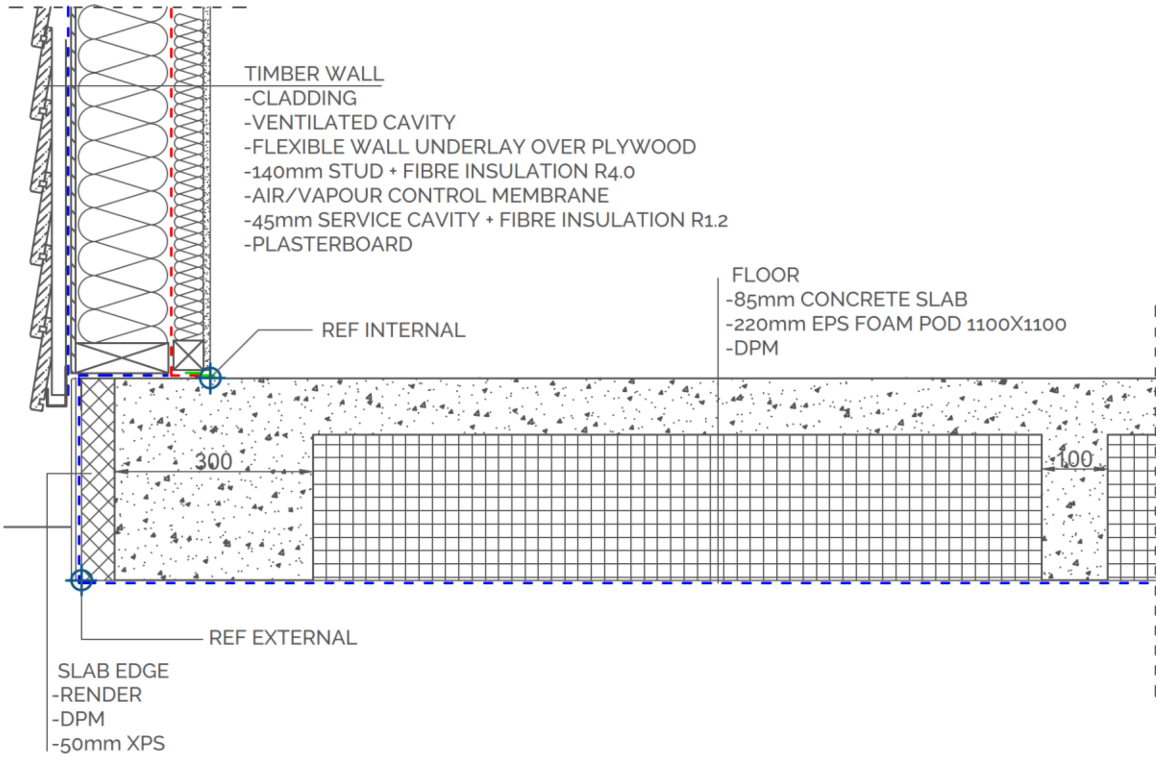


Material	λ[W/(m·K)]
220mmMouldedPodOnGround_EQ	0.380
Concrete	2.100
FibreInsulR2.2/90mm+12%Timber	0.052
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130
XPSInsul_L0.028	0.028

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

In the2D thermal bridge calculation, the 220mm tall waffle pod EPS foam with air pockets and concrete ribs have been replaced with an equivalent thermal conductivity calculated with a 3D finite element model using ISO10211:2007. Note that 100mm concrete ribs at 1200mm centres in the field of the slab have been assumed. The 300mm wide concrete edge beam is modelled as concrete as shown.

In PHPP this should be entered with layers with the λ values and thicknesses shown above for the centre of the slab in the U-values sheet and the PSI value and perimeter on the Areas sheet.

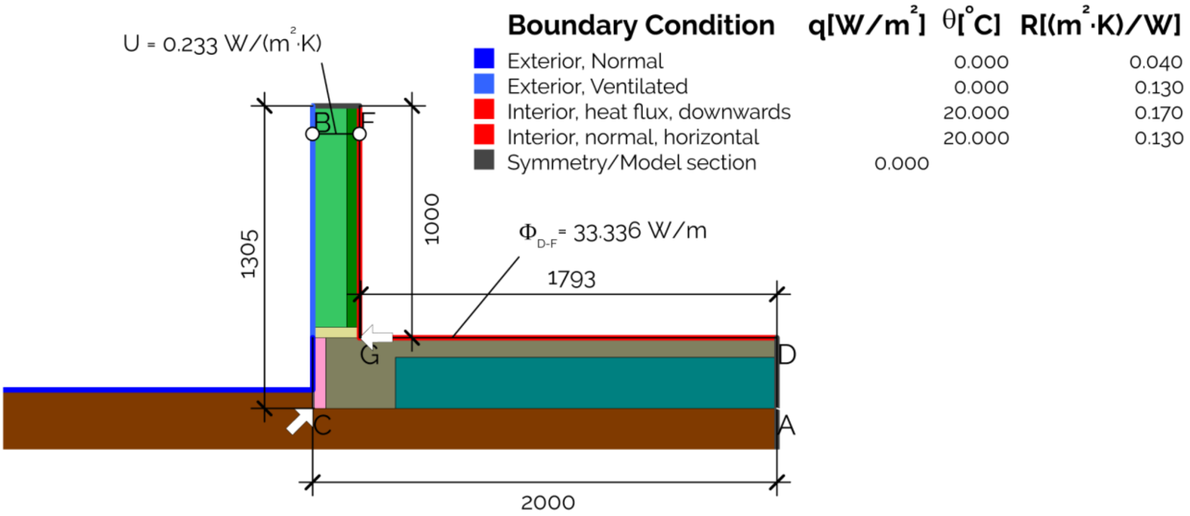


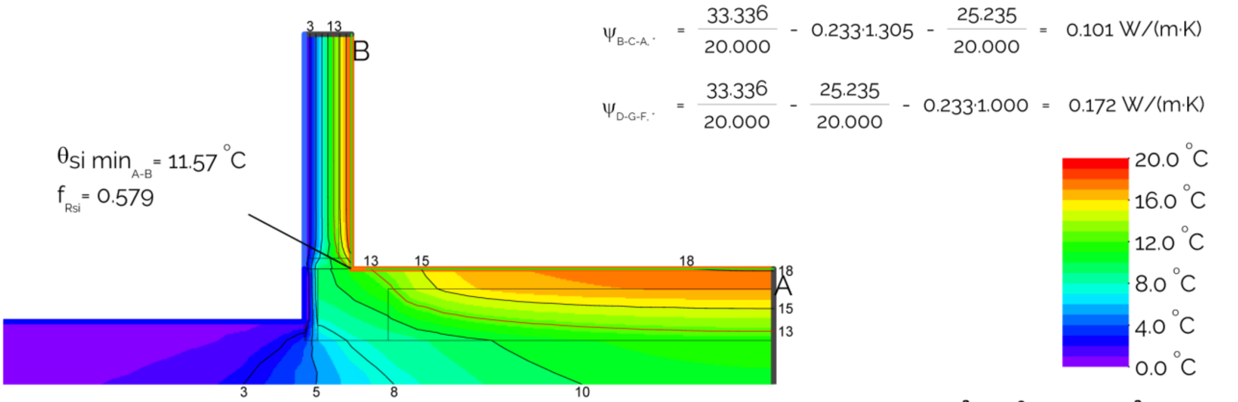
38 EWFS External Wall to Floor Slab - 140/45 stud wall waffle pod slab edge insulation

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.101W/(mK)	0.172 W/(mK)
f_{RSI}	0.579	
Cost	$146 per linear metre	
Carbon	40 $kgCO_2eq/m$	
Carbon Storage	3 $kgCO_2eq/m$	

This detail represents a typical current practice waffle pod slab with added edge insulation and no insulation below the concrete slab, with a high-performance wall. SED allows the 140mm studs to overhang the slab edge, which permits lining up the edge insulation with the timber wall insulation.



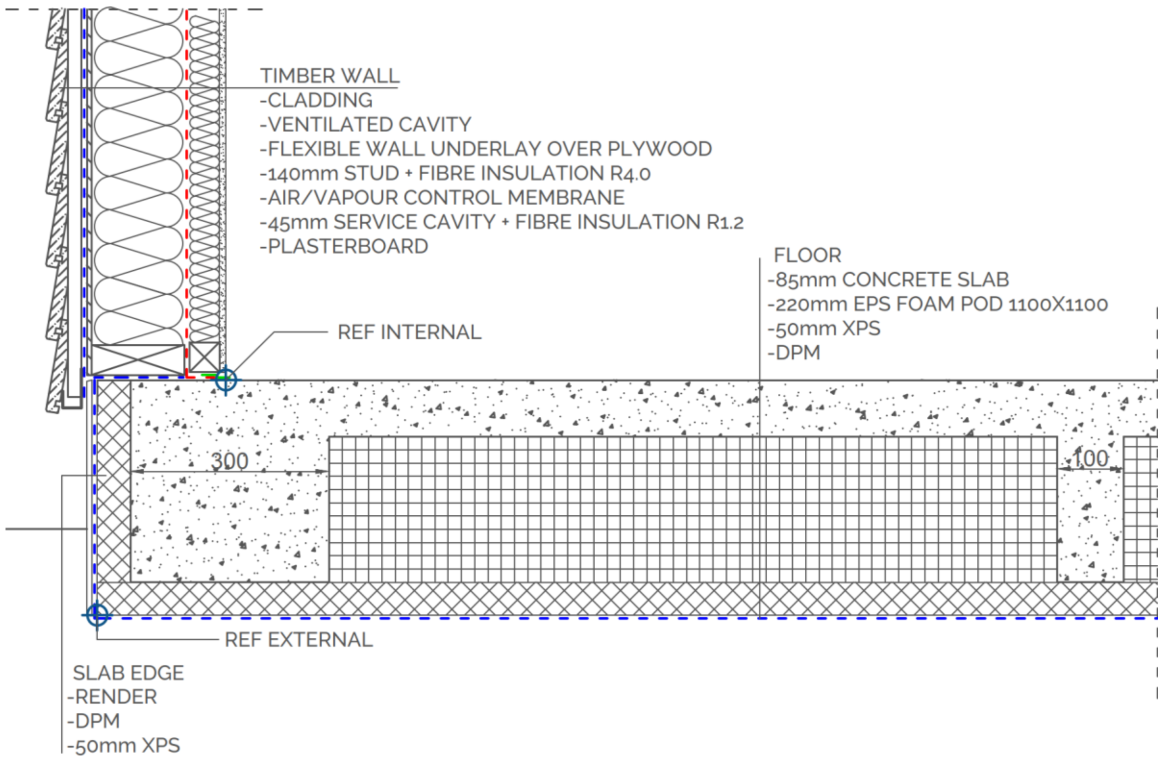


Material	λ[W/(m·K)]
220mmMouldedPodOnGround_EQ	0.380
Concrete	2.100
Fibre Cement	0.250
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130
XPSInsul_L0.028	0.028

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

In the2D thermal bridge calculation, the 220mm tall waffle pod EPS foam with air pockets and concrete ribs have been replaced with an equivalent thermal conductivity calculated with a 3D finite element model using ISO10211:2007. Note that 100mm concrete ribs at 1200mm centres in the field of the slab have been assumed. The 300mm wide concrete edge beam is modelled as concrete as shown.

In PHPP this should be entered with layers with the λ values and thicknesses shown above for the centre of the slab in the U-values sheet and the PSI value and perimeter on the Areas sheet.

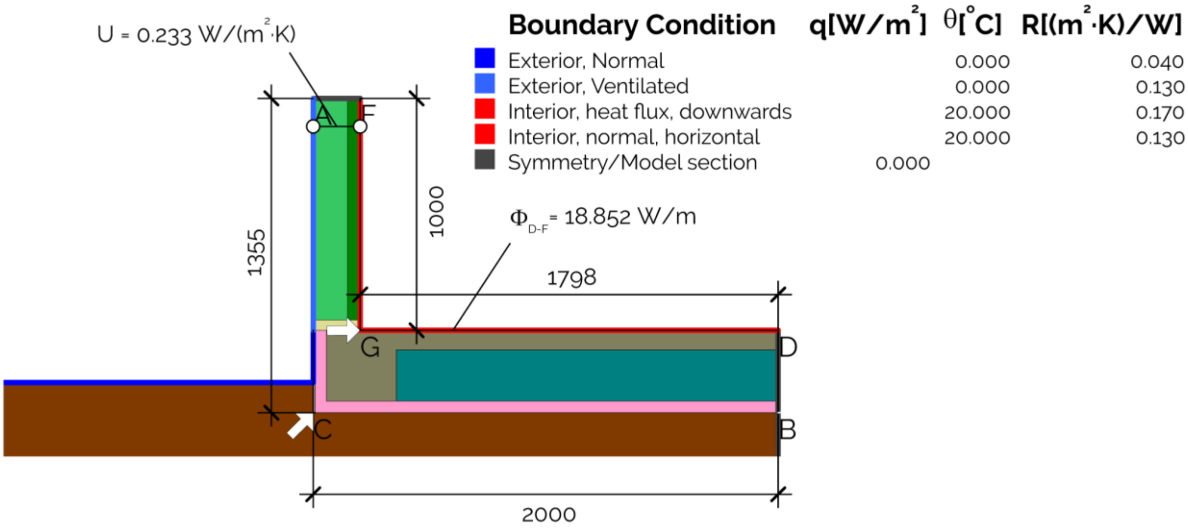


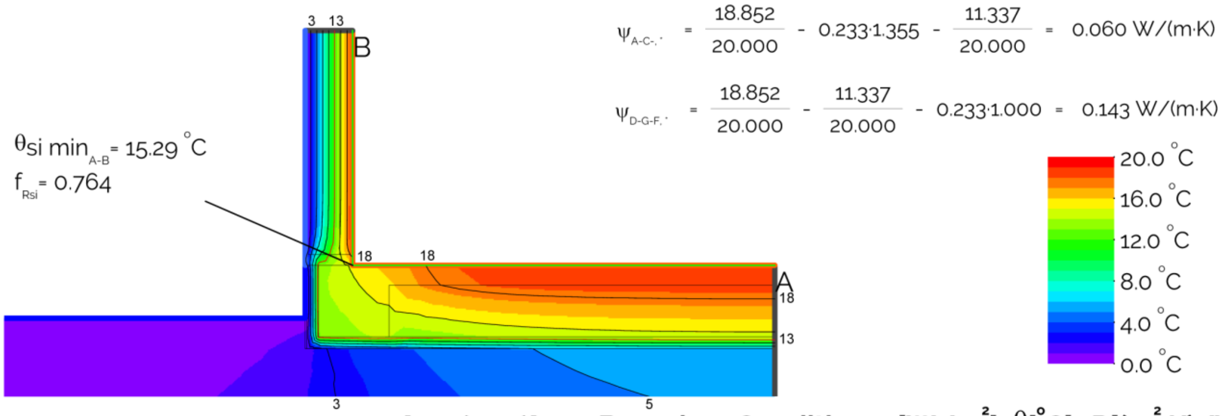
39 EWFS External Wall to Floor Slab 140/45 stud wall insulated waffle pod slab edge insulation and full insulation under ribs

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.060 W/(mK)	0.143 W/(mK)
f_{RSI}	0.764	
Cost	$153 per linear metre	
Carbon	41 $kgCO_2eq/m$	
Carbon Storage	3 $kgCO_2eq/m$	

This detail represents a waffle pod slab with added insulation under all of the slab concrete ribs and pods and edge insulation, with a high-performance wall. SED allows the 140mm studs to overhang the slab edge, which permits lining up the edge insulation with the timber wall insulation.





$$\Psi_{A\text{-}C\text{-},\cdot} = \frac{18.852}{20.000} - 0.233 \cdot 1.355 - \frac{11.337}{20.000} = 0.060\ \text{W/(m·K)}$$

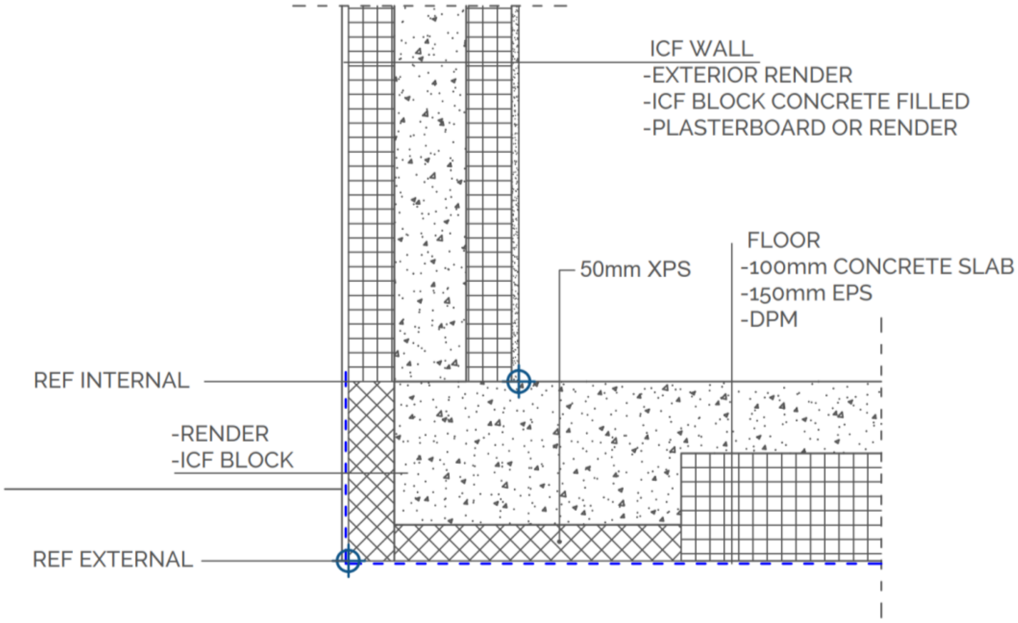
$$\Psi_{D\text{-}G\text{-}F,\cdot} = \frac{18.852}{20.000} - \frac{11.337}{20.000} - 0.233 \cdot 1.000 = 0.143\ \text{W/(m·K)}$$

Material	λ[W/(m·K)]
220mmMouldedPodOn50mmXPS_EQ	0.285
Concrete	2.100
Fibre Cement	0.250
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130
XPSInsul_L0.028	0.028

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

In the2D thermal bridge calculation, the 220mm tall waffle pod EPS foam with air pockets and concrete ribs have been replaced with an equivalent thermal conductivity calculated with a 3D finite element model using ISO10211:2007. Note that 100mm concrete ribs at 1200mm centres in the field of the slab have been assumed. The 300mm wide concrete edge beam is modelled as concrete as shown.

In PHPP this should be entered with layers with the λ values and thicknesses shown above for the centre of the slab in the U-values sheet and the PSI value and perimeter on the Areas sheet.

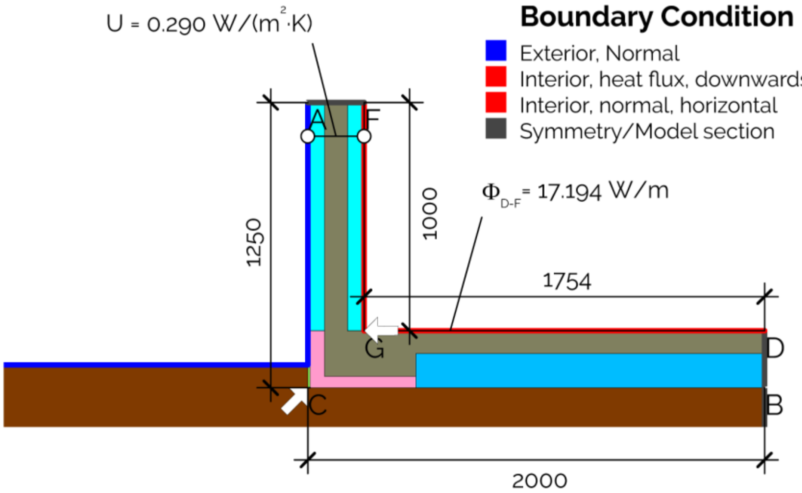


40 EWFS External Wall to Floor Slab - ICF slab edge to external wall

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.096 W/(mK)	0.169 W/(mK)
f_{RSI}	0.753	
Cost	Not calculated	
Carbon	Not calculated	

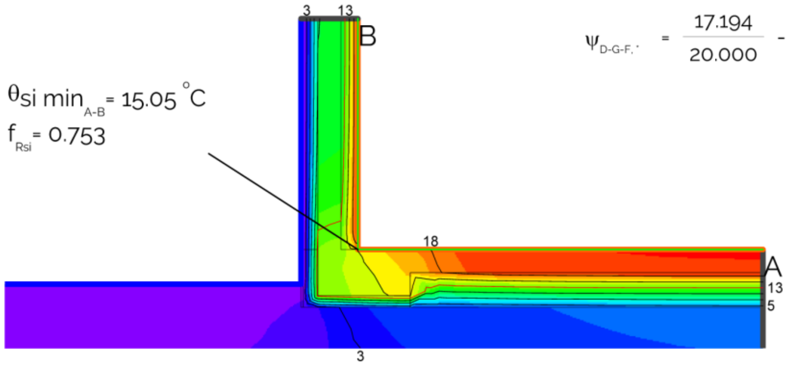
All the reviewed ICF walls connected to an insulated slab edge are similar to this detail. This was a common solution for high-performance buildings as the ICF wall blocks could be used to form the edge insulation. There was variation in the amount of insulation below the slab. The high level of insulation below the slab in this detail provide a conservative slab edge heat loss value.

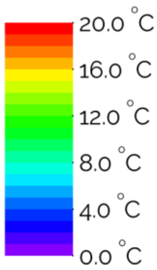


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

$$\psi_{A\text{-}C\text{-}B,\cdot} = \frac{17.194}{20.000} - 0.290 \cdot 1.250 - \frac{8.008}{20.000} = 0.096\ \mathrm{W/(m \cdot K)}$$

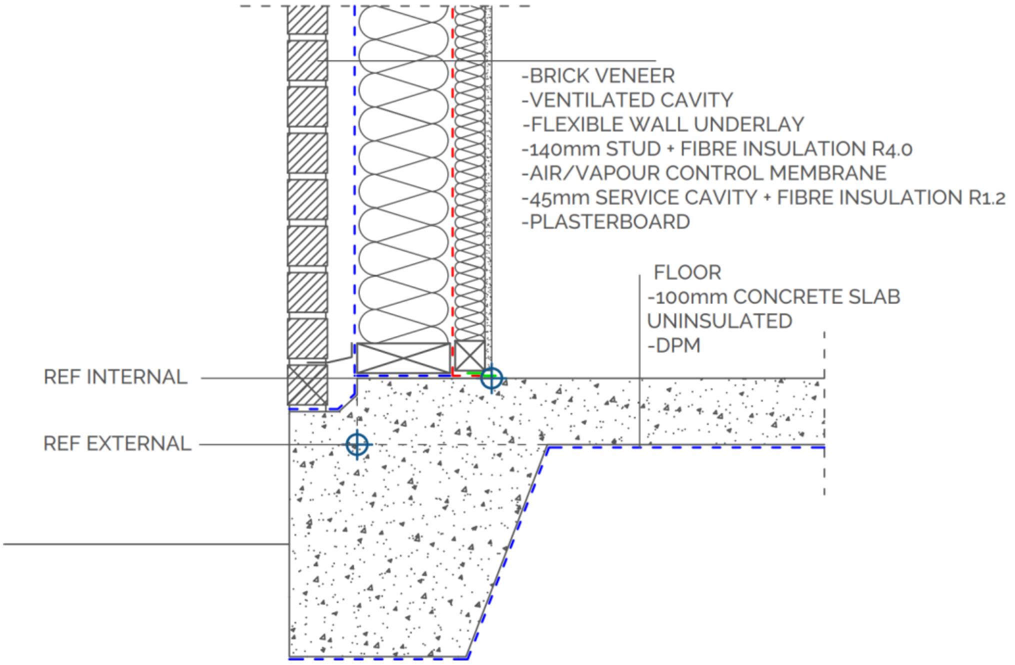
$$\psi_{D\text{-}G\text{-}F,\cdot} = \frac{17.194}{20.000} - \frac{8.008}{20.000} - 0.290 \cdot 1.000 = 0.169\ \mathrm{W/(m \cdot K)}$$





Material	λ[W/(m·K)]
Concrete	2.100
EPSInsul_L0.038	0.038
Ground	2.000
Plaster, lime, sand	0.800
Plasterboard	0.250
RigidInsulationL0.04	0.040
XPSInsul_L0.028	0.028

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

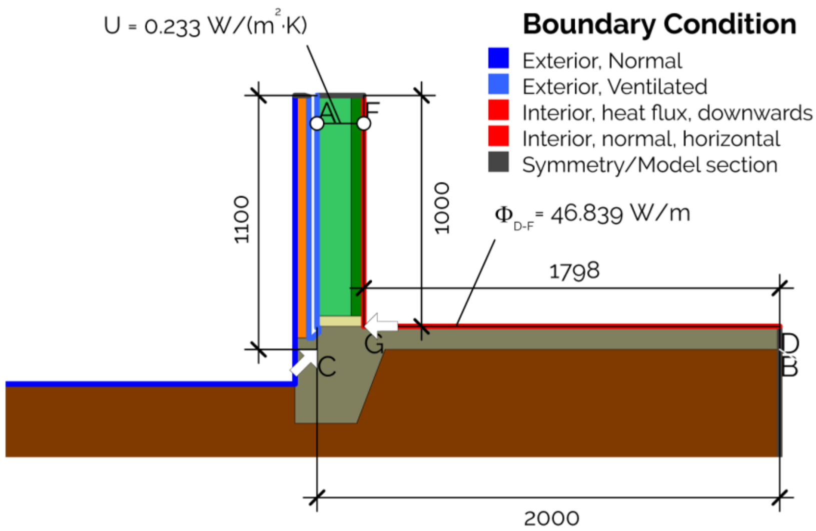


41 EWFS External Wall to Floor Slab - Brick veneer uninsulated slab on ground 140/45mm timber frame

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	-0.058 W/(mK)	-0.035 W/(mK)
f_{RSI}	0.461	
Cost	Not calculated	
Carbon	Not calculated	

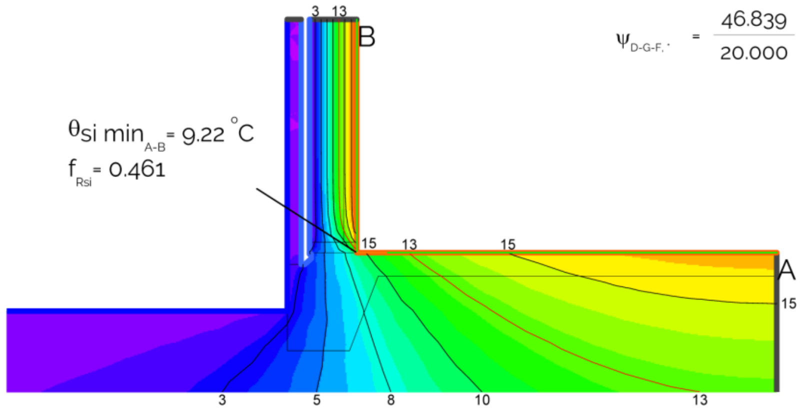
This detail represents a typical current practice slab edge with no edge insulation and no insulation below the concrete slab, with a high-performance brick veneer wall. The additional wall thickness lowers the heat loss through the slab edge but there is still significant heat lost through the slab edge.

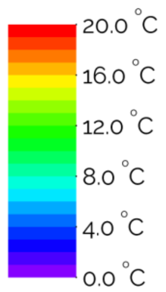


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

$$\psi_{A\text{-}C\text{-}B,\cdot} = \frac{46.839}{20.000} - 0.233\cdot1.100 - \frac{42.888}{20.000} = -0.058\ \mathrm{W/(m\cdot K)}$$

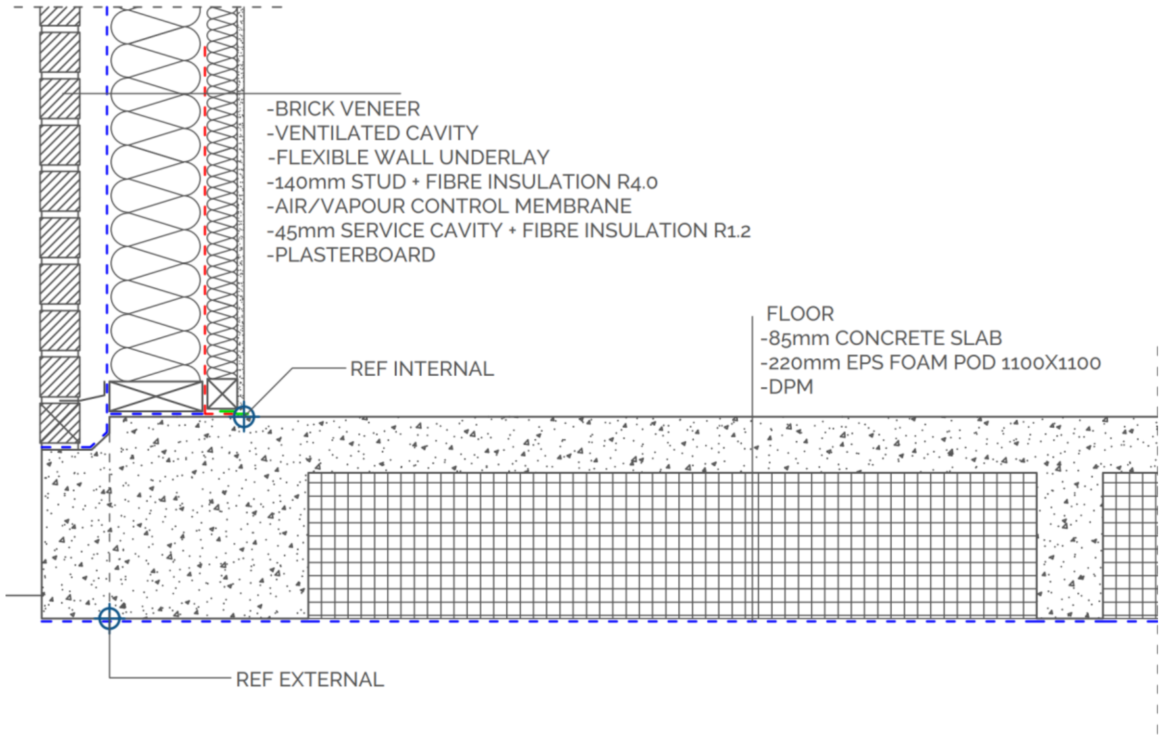
$$\psi_{D\text{-}G\text{-}F,\cdot} = \frac{46.839}{20.000} - \frac{42.888}{20.000} - 0.233\cdot1.000 = -0.035\ \mathrm{W/(m\cdot K)}$$





Material	λ[W/(m·K)]
Brick	1.200
Concrete	2.100
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



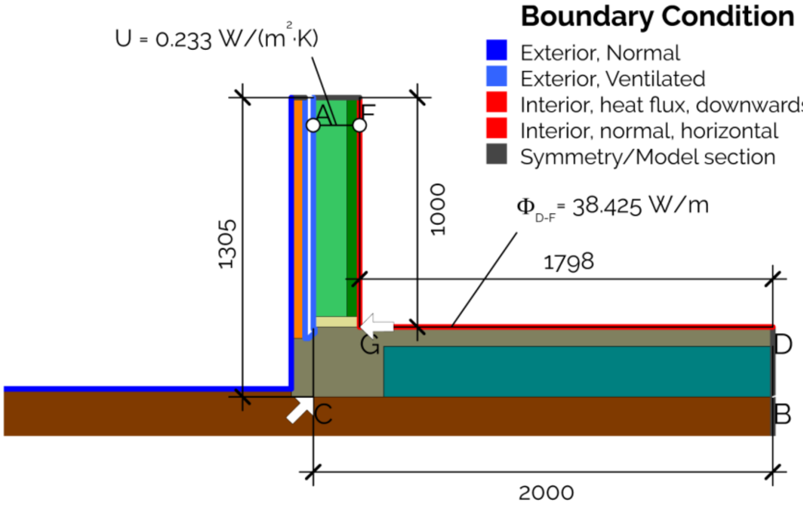
42 EWFS External Wall to Floor Slab - Brick veneer waffle pod slab on ground 140/45 timber frame

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.356 W/(mK)	0.427 W/(mK)
f_{RSI}	0.431	
Cost	Not calculated	
Carbon	Not calculated	

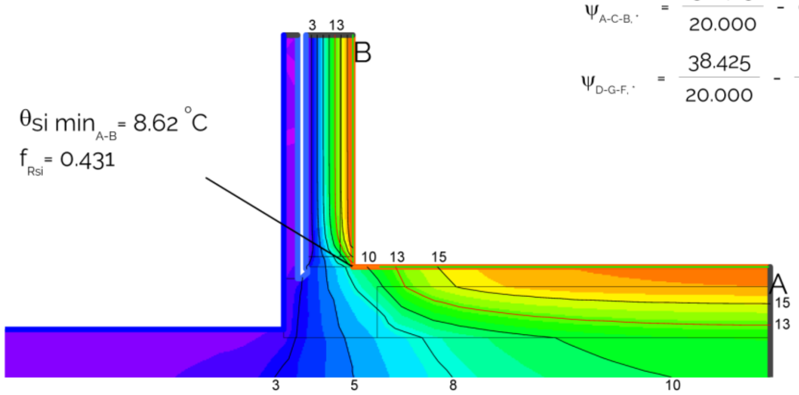
This detail represents a typical current practice waffle pod slab edge with no edge insulation and no insulation below the concrete slab, with a high-performance brick veneer wall. The additional wall thickness only slightly reduces the significant heat lost through the slab edge.

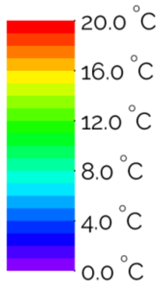
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		



$$\psi_{A-C-B,\cdot} = \frac{38.425}{20.000} - 0.233 \cdot 1.305 - \frac{25.235}{20.000} = 0.356\ W/(m\cdot K)$$

$$\psi_{D-G-F,\cdot} = \frac{38.425}{20.000} - \frac{25.235}{20.000} - 0.233 \cdot 1.000 = 0.427\ W/(m\cdot K)$$



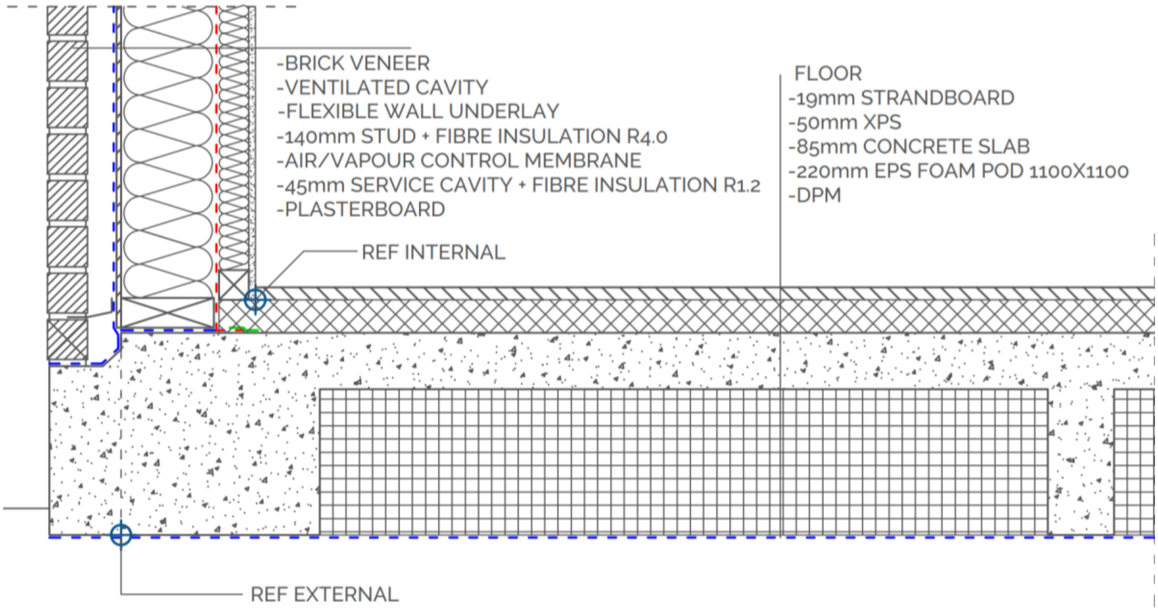


Material	λ[W/(m·K)]
220mmMouldedPodOnGround_EQ	0.380
Brick	1.200
Concrete	2.100
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

In the2D thermal bridge calculation, the 220mm tall waffle pod EPS foam with air pockets and concrete ribs have been replaced with an equivalent thermal conductivity calculated with a 3D finite element model using ISO10211:2007. Note that 100mm concrete ribs at 1200mm centres in the field of the slab have been assumed. The 300mm wide concrete edge beam is modelled as concrete as shown.

In PHPP this should be entered with layers with the λ values and thicknesses shown above for the centre

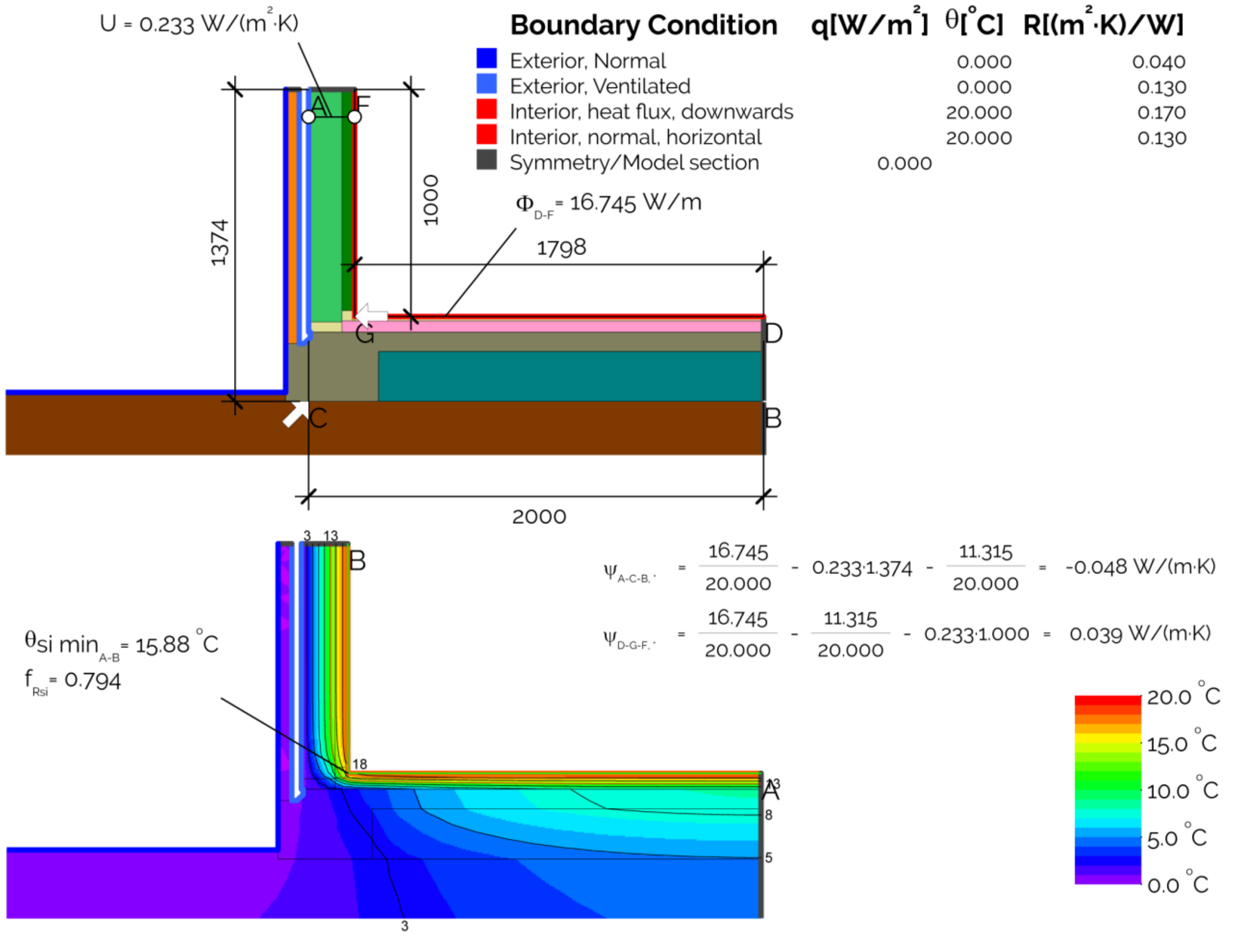


43 EWFS External Wall to Floor Slab - Brick veneer waffle pod slab on ground insulation above the slab 140/45 timber frame

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	-0.048 W/(mK)	0.039 W/(mK)
f_{RSI}	0.794	
Cost	Not calculated	
Carbon	Not calculated	

This detail represents a current practice waffle pod slab with brick veneer and high-performance wall that has a full internal insulation layer above the slab. This reduces the internal thermal mass but significantly reduces the heat loss at the slab edge to less than WORD? that of a fully insulated slab and edge.

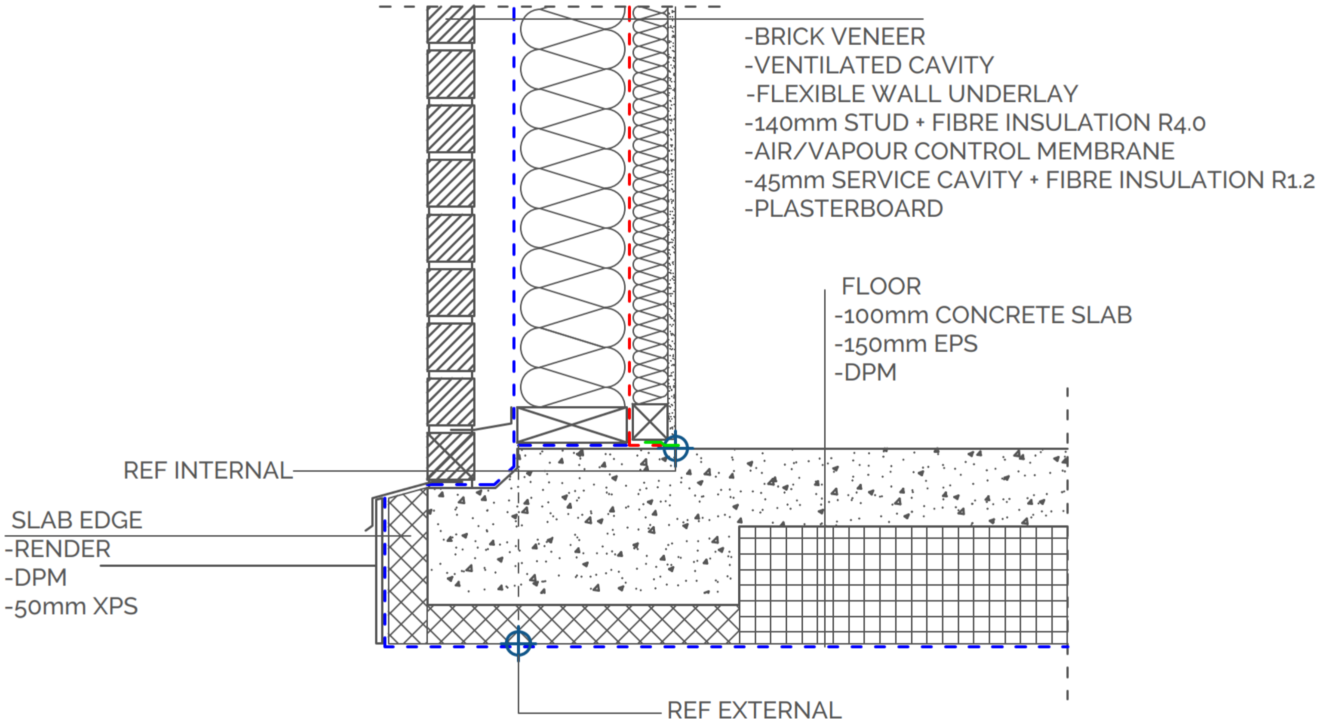


Material	λ[W/(m·K)]
220mmMouldedPodOnGround_EQ	0.380
Brick	1.200
Concrete	2.100
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130
XPSInsul_L0.028	0.028

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

In the2D thermal bridge calculation, the 220mm tall waffle pod EPS foam with air pockets and concrete ribs have been replaced with an equivalent thermal conductivity calculated with a 3D finite element model using ISO10211:2007. Note that 100mm concrete ribs at 1200mm centres in the field of the slab have been assumed. The 300mm wide concrete edge beam is modelled as concrete as shown.

In PHPP this should be entered with layers with the λ values and thicknesses shown above for the centre of the slab in the U-values sheet and the PSI value and perimeter on the Areas sheet..

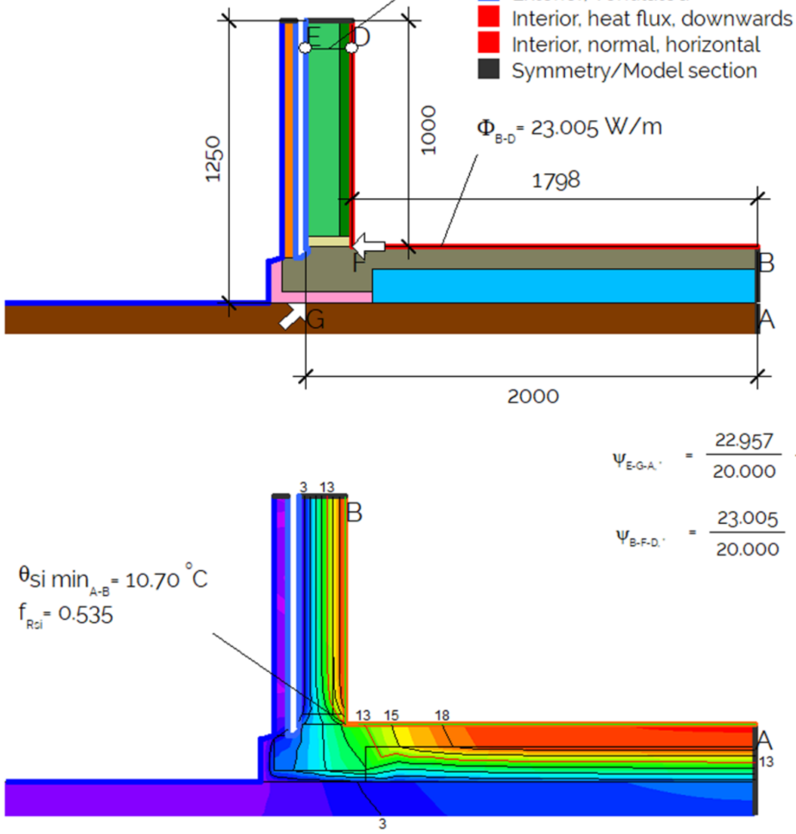


44 EWFS External Wall to Floor Slab - Brick veneer insulated slab on ground perimeter edge insulation 140/45mm timber frame

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.457 W/(mK)	0.517 W/(mK)
f_{RSI}	0.535	
Cost	Not calculated	
Carbon	Not calculated	

This detail represents several different variations of a high-performance brick veneer wall with a fully insulated slab and the largest amount of external slab insulation practical. The large thermal break produced by the brick veneer sitting on the slab edge can be seen in the results.



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

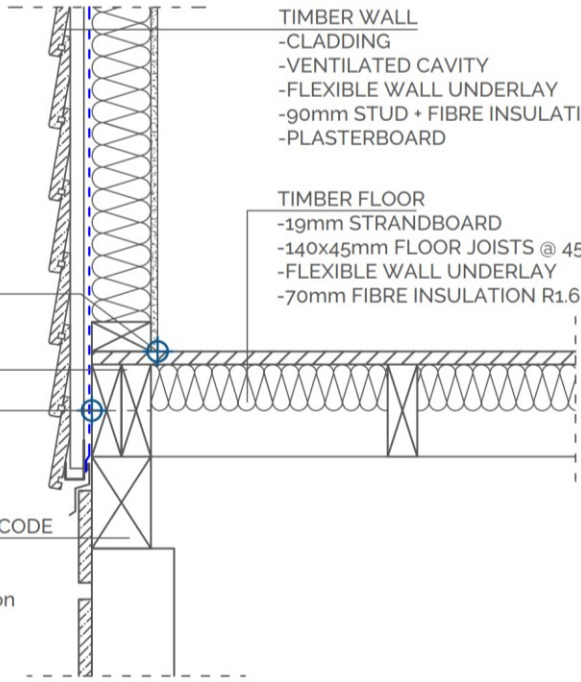
$$\Psi_{E\text{-}G\text{-}A} = \frac{22.957}{20.000} - 0.233 \cdot 1.250 - \frac{8.008}{20.000} = 0.457\ \text{W/(m·K)}$$

$$\Psi_{B\text{-}F\text{-}D} = \frac{23.005}{20.000} - \frac{8.008}{20.000} - 0.233 \cdot 1.000 = 0.517\ \text{W/(m·K)}$$

Material	λ[W/(m·K)]
Brick	1.200
Concrete	2.100
EPSInsul_L0.038	0.038
Fibre Cement	0.250
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130
XPSInsul_L0.028	0.028

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

Note revised 2022 to correct slab element error.

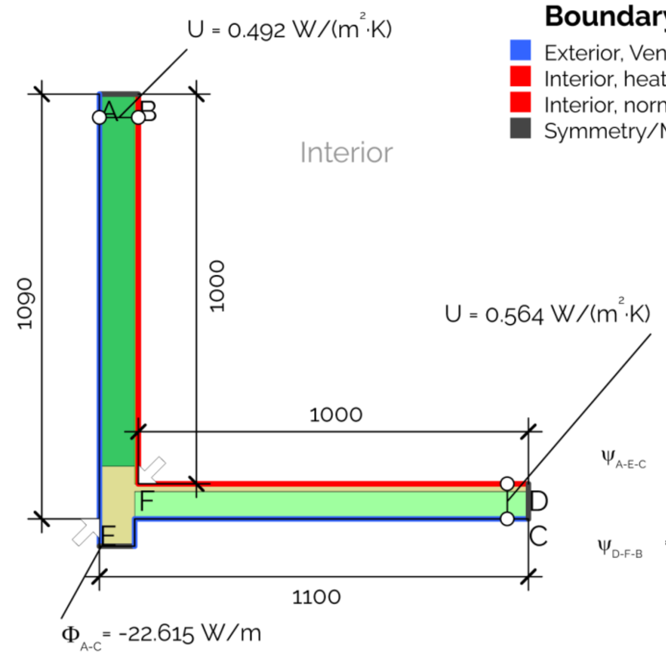


45 EWCS External Wall to suspended timber Floor Slab - 90mm stud wall current practice

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	-0.026 W/(mK)	0.075 W/(mK)
f_{RSI}	0.675	
Cost	$287 per linear metre	
Carbon	25 $kgCO_2eq/m$	
Carbon Storage	45 $kgCO_2eq/m$	

This current practice suspended timber floor slab edge has a small thermal bridge value. The value is similar to that of an External Wall External Corner thermal bridge as the timber content is similar.

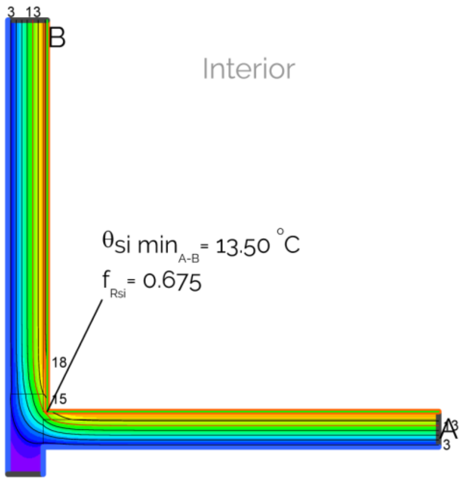


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

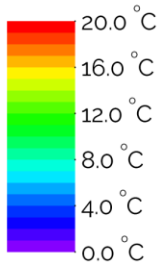
Material	λ[W/(m·K)]
FiberInsulR1.6/70mm+14%Timber	0.053
FibreInsulR2.2/90mm+12%Timber	0.052
Plasterboard	0.250
Timber (Softwood)	0.130

$$\Psi_{A\text{-}E\text{-}C} = \frac{22.615}{20.000} - 0.492 \cdot 1.090 - 0.564 \cdot 1.100 = -0.026\ \mathrm{W/(m \cdot K)}$$

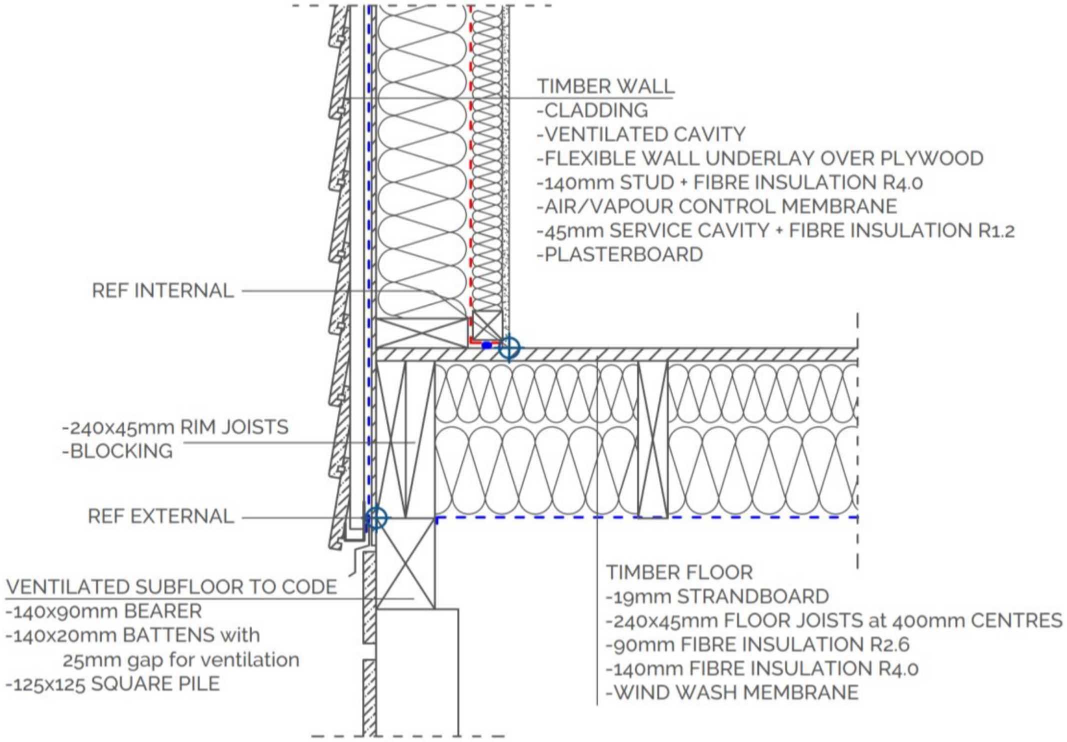
$$\Psi_{D\text{-}F\text{-}B} = \frac{22.615}{20.000} - 0.564 \cdot 1.000 - 0.492 \cdot 1.000 = 0.075\ \mathrm{W/(m \cdot K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



The boundary condition below the suspended timber floor would change depending on the subfloor void ventilation etc. The variation in the thermal bridge PSI value at the floor slab edge is small and the values provided here can be used for all cases while being only slightly conservative.

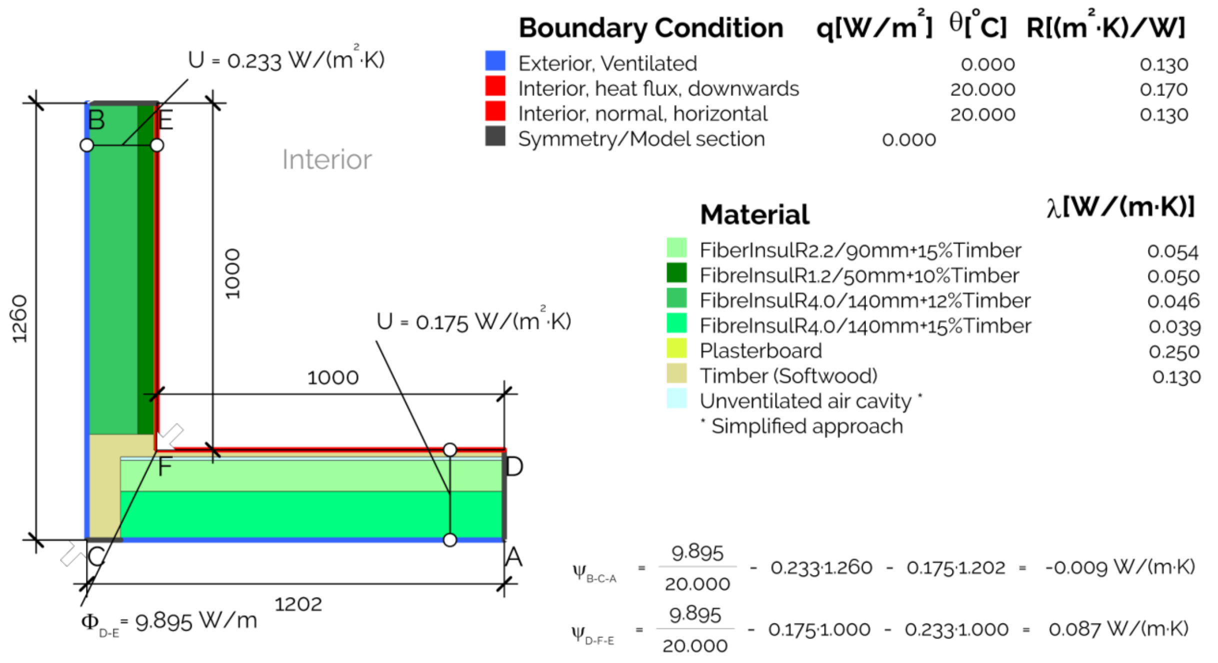


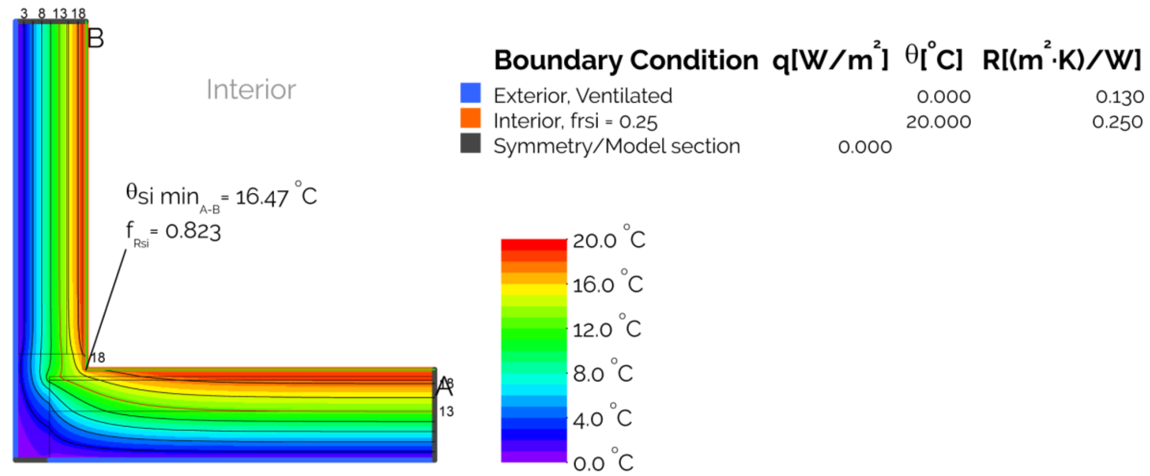
46 EWCS External Wall to suspended timber Floor Slab - 140/45 stud wall fully insulated timber floor

RESULTS TABLE

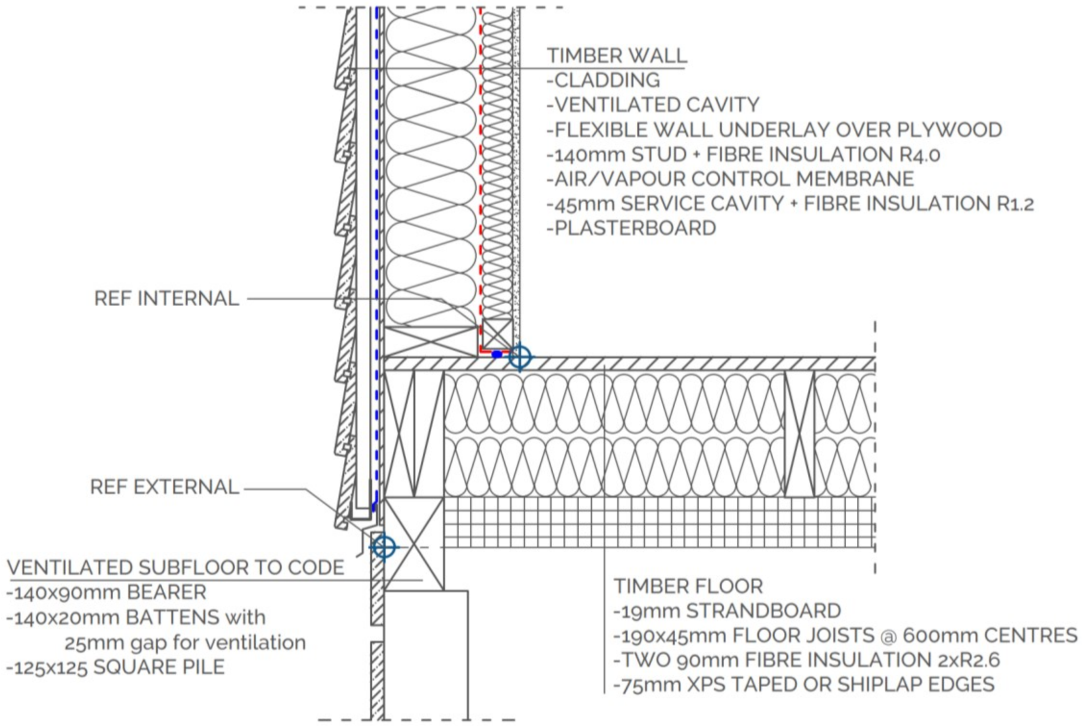
Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	-0.009 W/(mK)	0.087 W/(mK)
f_{RSI}	0.823	
Cost	$399 per linear metre	
Carbon	30 $kgCO_2eq/m$	
Carbon Storage	63 $kgCO_2eq/m$	

This high-performance timber stud wall to high-performance fully insulated timber floor has a small thermal bridge value. The value is similar to that of an External Wall External Corner thermal bridge as the timber content is similar.





The boundary condition below the suspended timber floor would change depending on the subfloor void ventilation etc. The variation in the thermal bridge PSI value at the floor slab edge is small and the values provided here can be used for all cases while being only slightly conservative.

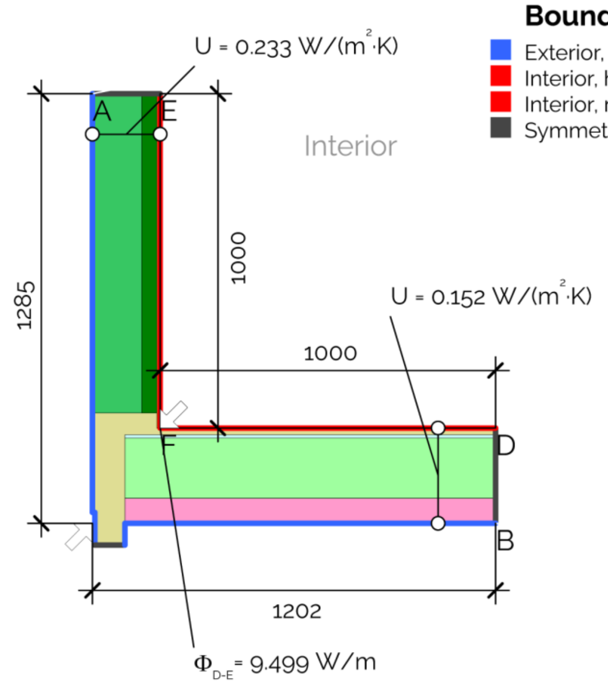


47 EWCS External Wall to Crawl Space 140/45 stud wall fully insulated timber floor plus rigid insulation below joists

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	-0.006 W/(mK)	0.091 W/(mK)
f_{RSI}	0.826	
Cost	$347 per linear metre	
Carbon	27 $kgCO_2eq/m$	
Carbon Storage	54 $kgCO_2eq/m$	

This high-performance timber stud wall to high-performance fully insulated timber floor with additional rigid insulation has a small thermal bridge value. The value is similar to that of an External Wall External Corner thermal bridge as the timber content is similar.



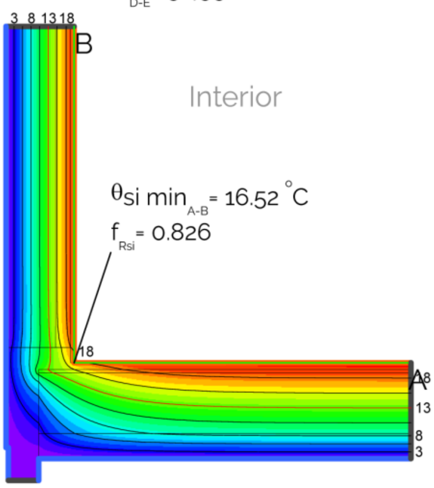
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR2.2/90mm+12%Timber	0.052
FibreInsulR4.0/140mm+12%Timber	0.046
Plasterboard	0.250
Timber (Softwood)	0.130
XPSInsul_L0.028	0.028
Unventilated air cavity *	

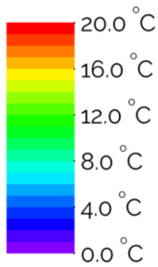
* Simplified approach

$$\Psi_{A\text{-}C\text{-}B} = \frac{9.499}{20.000} - 0.233 \cdot 1.285 - 0.152 \cdot 1.202 = -0.006\ W/(m \cdot K)$$

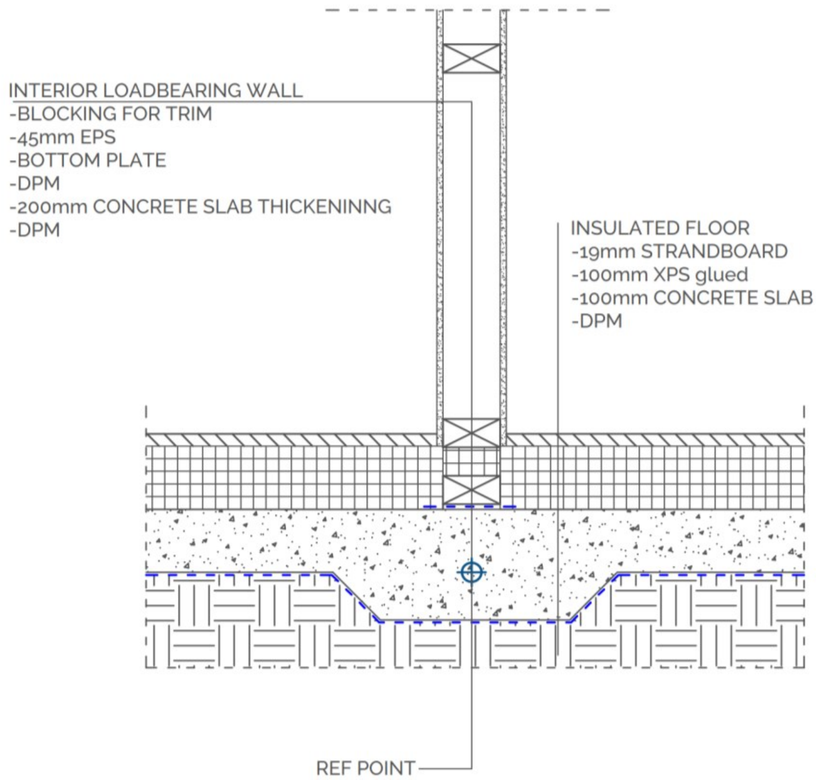
$$\Psi_{D\text{-}F\text{-}E} = \frac{9.499}{20.000} - 0.152 \cdot 1.000 - 0.233 \cdot 1.000 = 0.091\ W/(m \cdot K)$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



The boundary condition below the suspended timber floor would change depending on the subfloor void ventilation etc. The variation in the thermal bridge PSI value at the floor slab edge is small and the values provided here can be used for all cases while being only slightly conservative.



48 IWFS Internal Wall to Floor Slab - 90mm Stud wall to slab on ground slab insulated on top

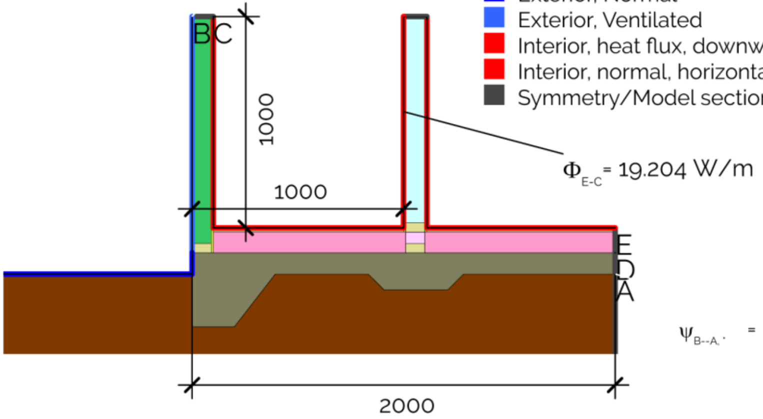
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.015 W/(mK)	0.015 W/(mK)
f_{RSI}	0.99	
Cost	Not calculated	
Carbon	Not calculated	

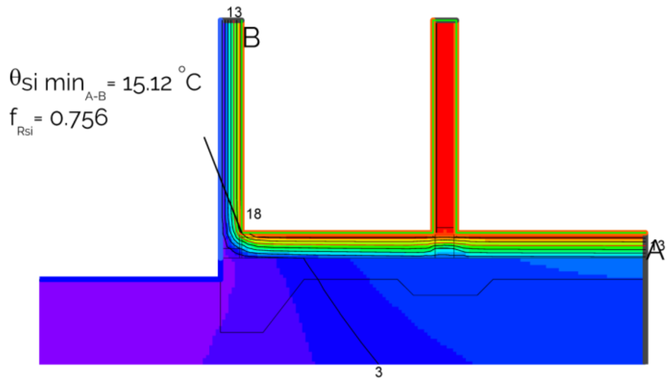
This high-performance top-insulated slab has a slab thickening and internal load bearing wall that causes a thermal bridge through the internal floor insulation. The resulting thermal bridge is a small impact.

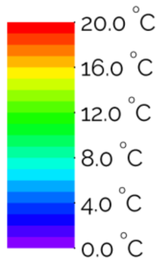
Note the fRSI near the slab thickening is high.

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		



$$\psi_{B\text{-}A} = \frac{19.204}{20.000} - \frac{18.903}{20.000} = 0.015 \text{ W/(m·K)}$$



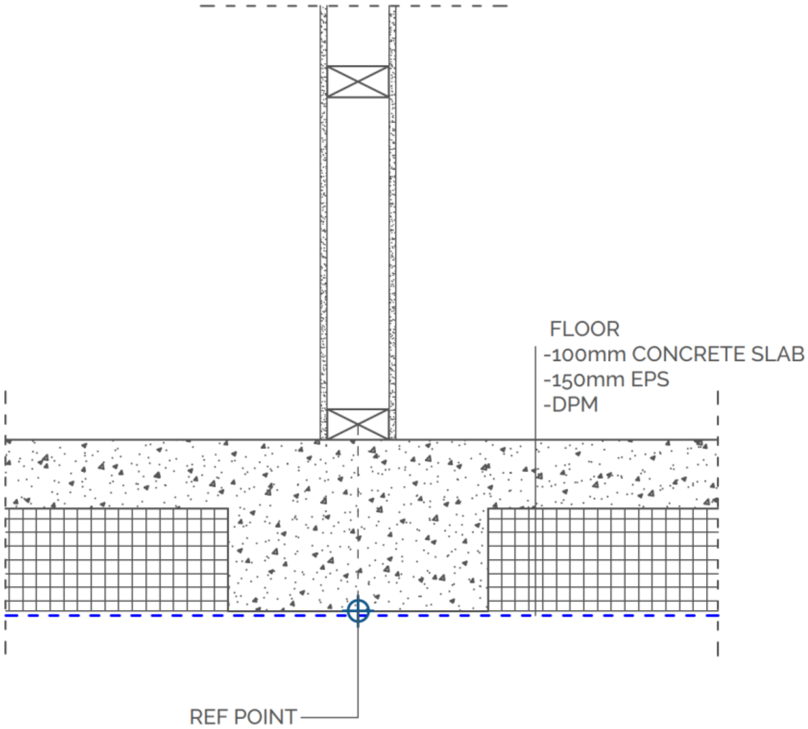


Material	λ[W/(m·K)]
Concrete	2.100
FibreInsulR2.2/90mm+12%Timber	0.052
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130
XPSInsul+7.5%Timber	0.036
XPSInsul_L0.028	0.028
Unventilated air cavity *	

* Simplified approach

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

Calculating the thermal bridge impacts of slab thickening or other reductions in floor insulation at interior load bearing walls is conservatively estimated by calculation of the floor slab edge with and without the thermal bridge and subtracting. PHI has determined that a distance of 1m from the slab edge for a 2D thermal calculation is sufficiently conservative and significantly reduces the complexity of a 3D calculation.



49 IWFS Internal Wall to Floor Slab - 90mm stud wall to slab on ground insulated underneath slab thickening

RESULTS TABLE

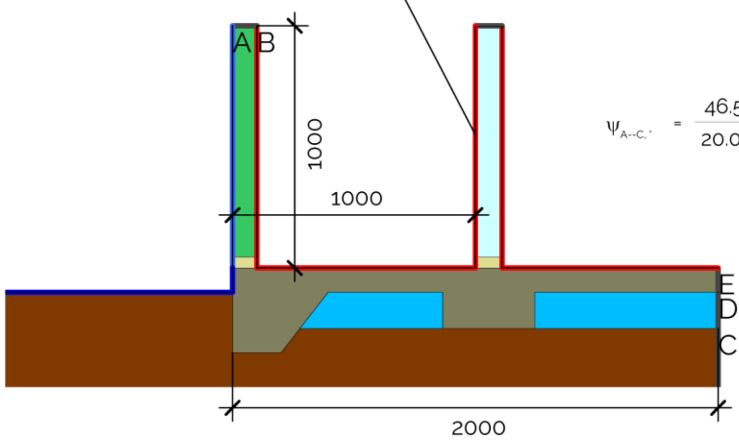
Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.414 W/(mK)	0.414 W/(mK)
f_{RSI}	0.75	
Cost	Not calculated	
Carbon	Not calculated	

This high-performance slab with insulation below the slab has a significant thermal bridge caused by the slab thickening bridging through all of the insulation below the slab.

Note the fRSI near the slab thickening is high.

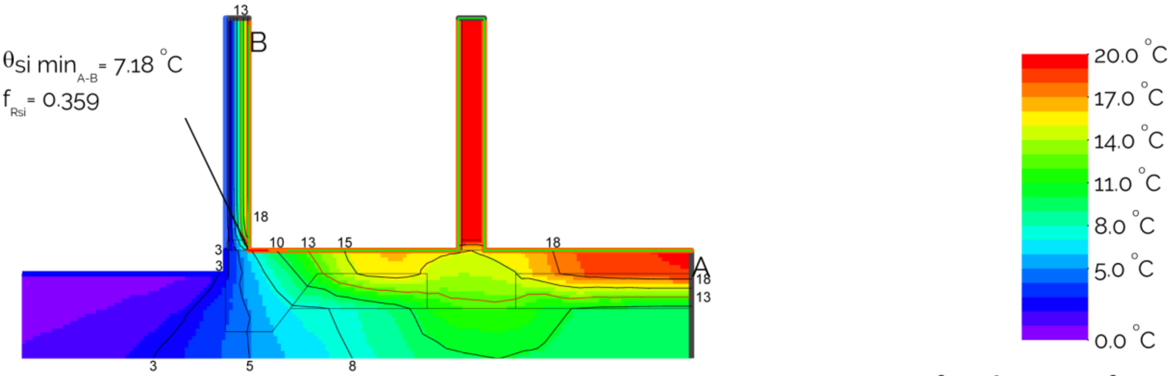
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

Φ_{E-B} = 46.512 W/m



$$\psi_{A-C} = \frac{46.512}{20.000} - \frac{38.230}{20.000} = 0.414\ \mathrm{W/(m{\cdot}K)}$$

$\theta_{si\ min_{A-B}}$ = 7.18 °C
f_{Rsi} = 0.359

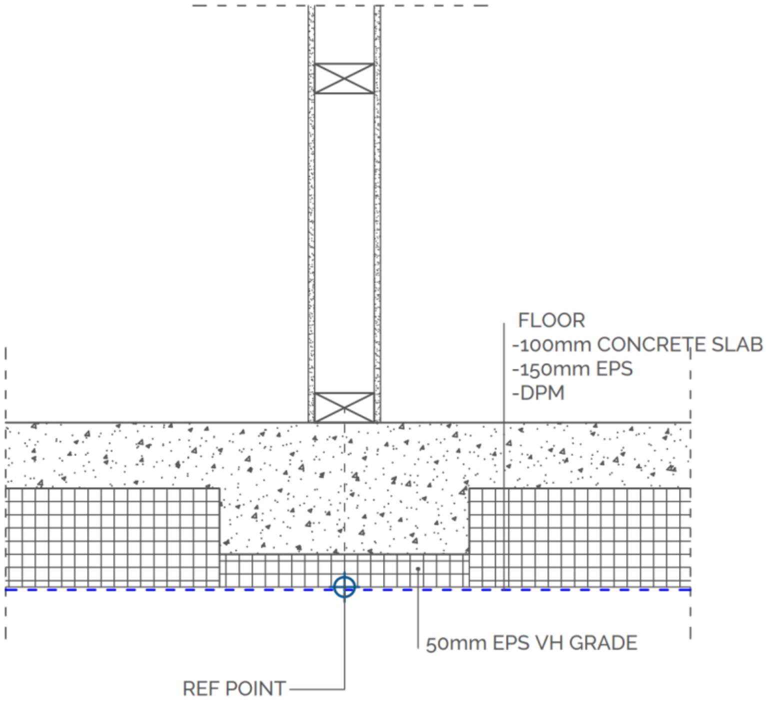


Material	λ[W/(m·K)]
Concrete	2.100
EPSInsul_L0.038	0.038
FibreInsulR2.2/90mm+12%Timber	0.052
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130
Unventilated air cavity *	

* Simplified approach

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

Calculating the thermal bridge impacts of slab thickening or other reductions in floor insulation at interior load bearing walls is conservatively estimated by calculation of the floor slab edge with and without the thermal bridge and subtracting. PHI has determined that a distance of 1m from the slab edge for a 2D thermal calculation is sufficiently conservative and significantly reduces the complexity of a 3D calculation.



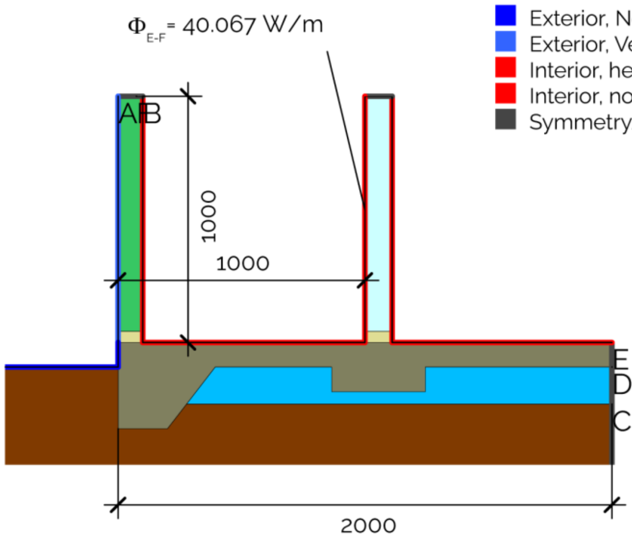
50 IWFS Internal Wall to Floor Slab - 90mm stud wall to slab on ground insulated underneath slab thickening insulated

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.092 W/(mK)	0.092 W/(mK)
f_{RSI}	0.90	
Cost	Not calculated	
Carbon	Not calculated	

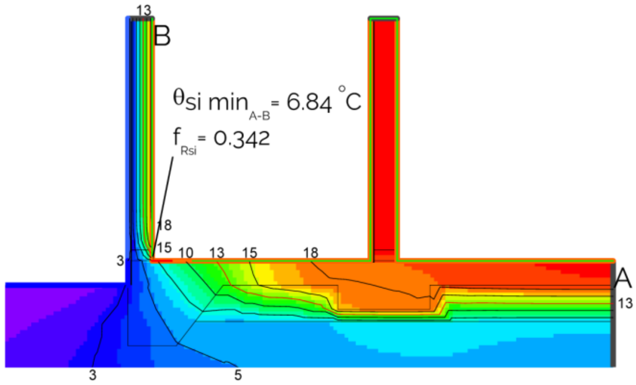
This high-performance slab with insulation below the slab has a much smaller thermal bridge compared to Junction 49, as the slab thickening has a third of the below slab insulation below the thickening.

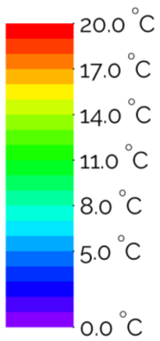
Note the fRSI near the slab thickening is high.



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

$$\Psi_{A\text{--}C,^{\cdot}} = \frac{40.067}{20.000} - \frac{38.230}{20.000} = 0.092\ \mathrm{W/(m{\cdot}K)}$$



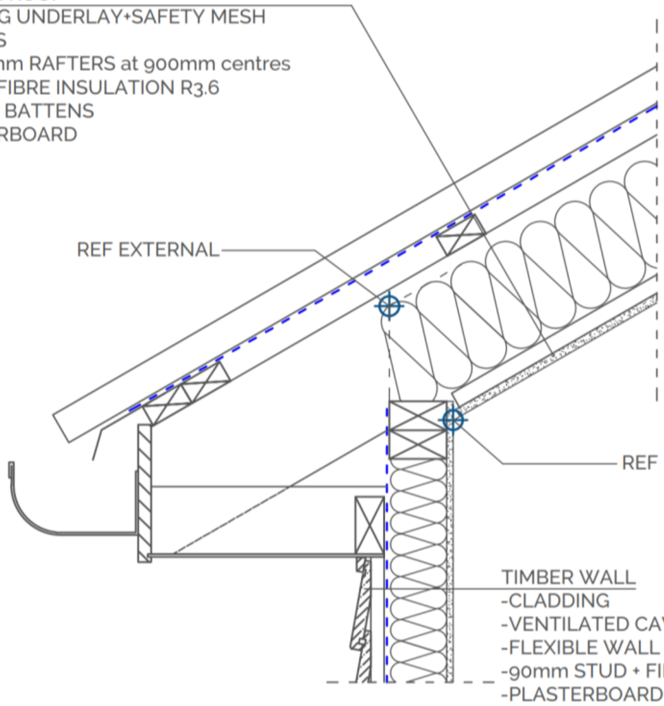


Material	λ[W/(m·K)]
Concrete	2.100
EPSInsul_L0.038	0.038
FibreInsulR2.2/90mm+12%Timber	0.052
Ground	2.000
Plasterboard	0.250
Timber (Softwood)	0.130
Unventilated air cavity *	

* Simplified approach

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

Calculating the thermal bridge impacts of slab thickening or other reductions in floor insulation at interior load bearing walls is conservatively estimated by calculation of the floor slab edge with and without the thermal bridge and subtracting. PHI has determined that a distance of 1m from the slab edge for a 2D thermal calculation is sufficiently conservative and significantly reduces the complexity of a 3D calculation.



51 ROEA Eaves - Current good practice skillion roof to 90mm timber wall

RESULTS TABLE

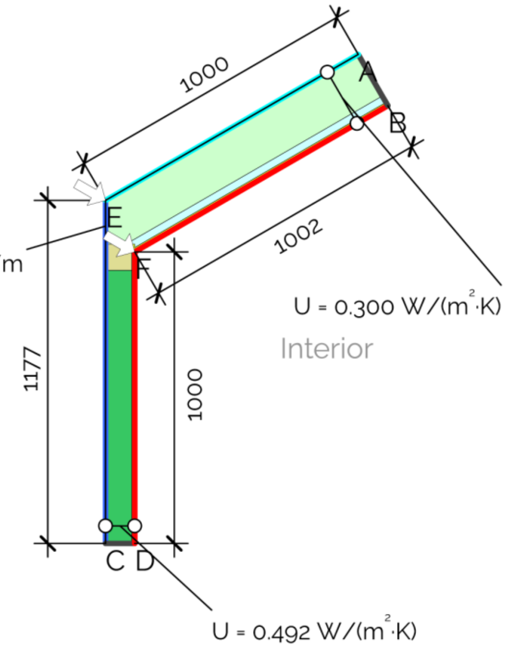
Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.001 W/(mK)	0.088 W/(mK)
f_{RSI}	0.789	
Cost	$273 per linear metre	
Carbon	47 $kgCO_2eq/m$	
Carbon Storage	25 $kgCO_2eq/m$	

This detail is current good practice for a skillion roof eave where the insulation thickness is maintained over the exterior wall.

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Roof Ventilated		0.000	0.100
Exterior, Ventilated		0.000	0.130
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
FibreInsulR2.2/90mm+12%Timber	0.052
FibreInsulR3.6/165mm+10%Timber	0.054
Plasterboard	0.250
Timber (Softwood)	0.130
Unventilated air cavity *	

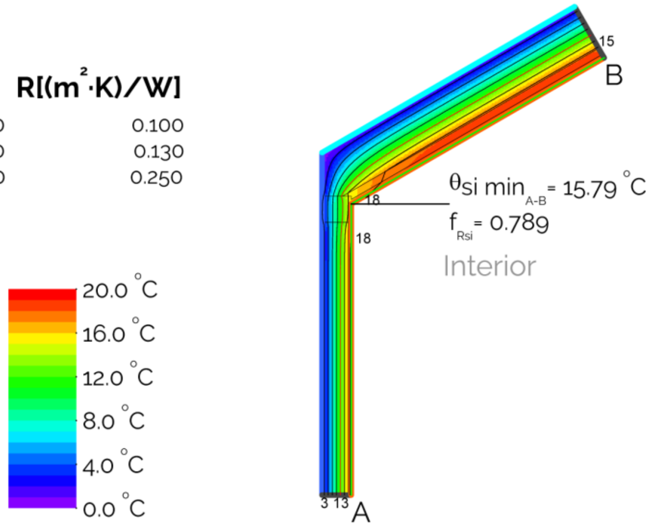
* Simplified approach

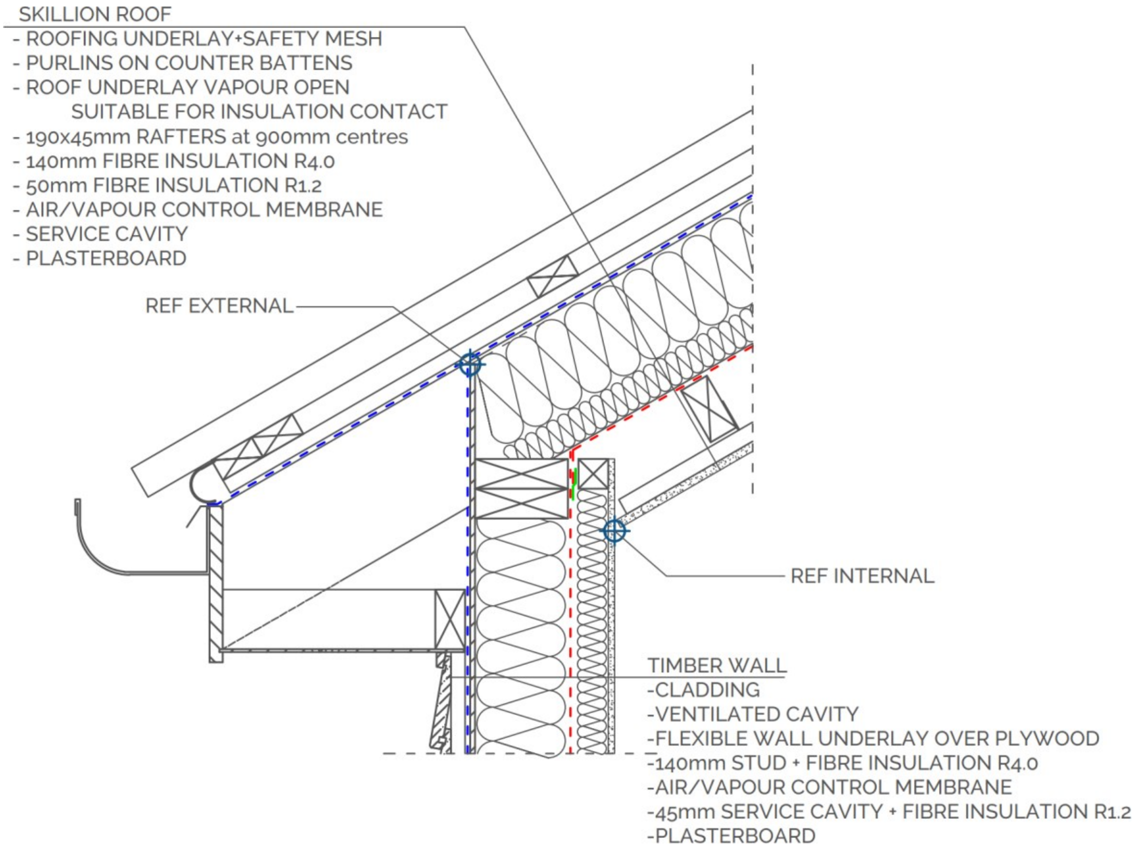


$$\psi_{A-E-C} = \frac{17.607}{20.000} - 0.300 \cdot 1.000 - 0.492 \cdot 1.177 = 0.001 \text{ W/(m·K)}$$

$$\psi_{D-F-B} = \frac{17.607}{20.000} - 0.492 \cdot 1.000 - 0.300 \cdot 1.002 = 0.088 \text{ W/(m·K)}$$

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Roof Ventilated		0.000	0.100
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		





52 ROEA Eaves - Skillion to 140/45 timber stud wall – flash to gutter – cross-batten roof

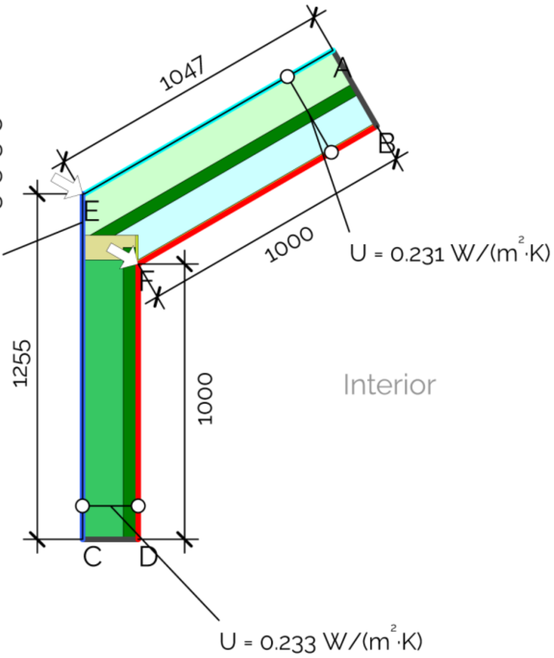
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.006 W/(mK)	0.076 W/(mK)
f_{RSI}	0.902	
Cost	$317 per linear metre	
Carbon	44 $kgCO_2eq/m$	
Carbon Storage	31 $kgCO_2eq/m$	

This detail is for a high-performance wall to high-performance skillion roof. Note the counter battens under the roofing and the vapour open roof underlay allow the full rafter depth to be filled with insulation: the moisture vents through the underlay and is ventilated out of the roof assembly via the counter battens.

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Roof Ventilated		0.000	0.100
Exterior, Ventilated		0.000	0.130
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

Φ_{A-C} = -10.801 W/m



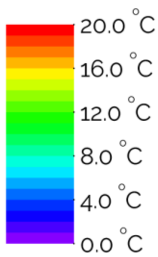
Material	λ[W/(m·K)]
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+10%Timber	0.045
FibreInsulR4.0/140mm+12%Timber (1)	0.046
Plasterboard	0.250
Timber (Softwood)	0.130
Unventilated air cavity *	

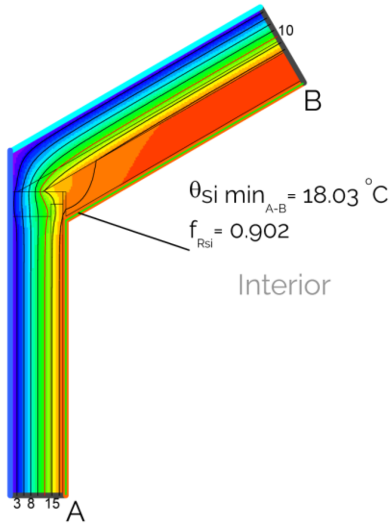
* Simplified approach

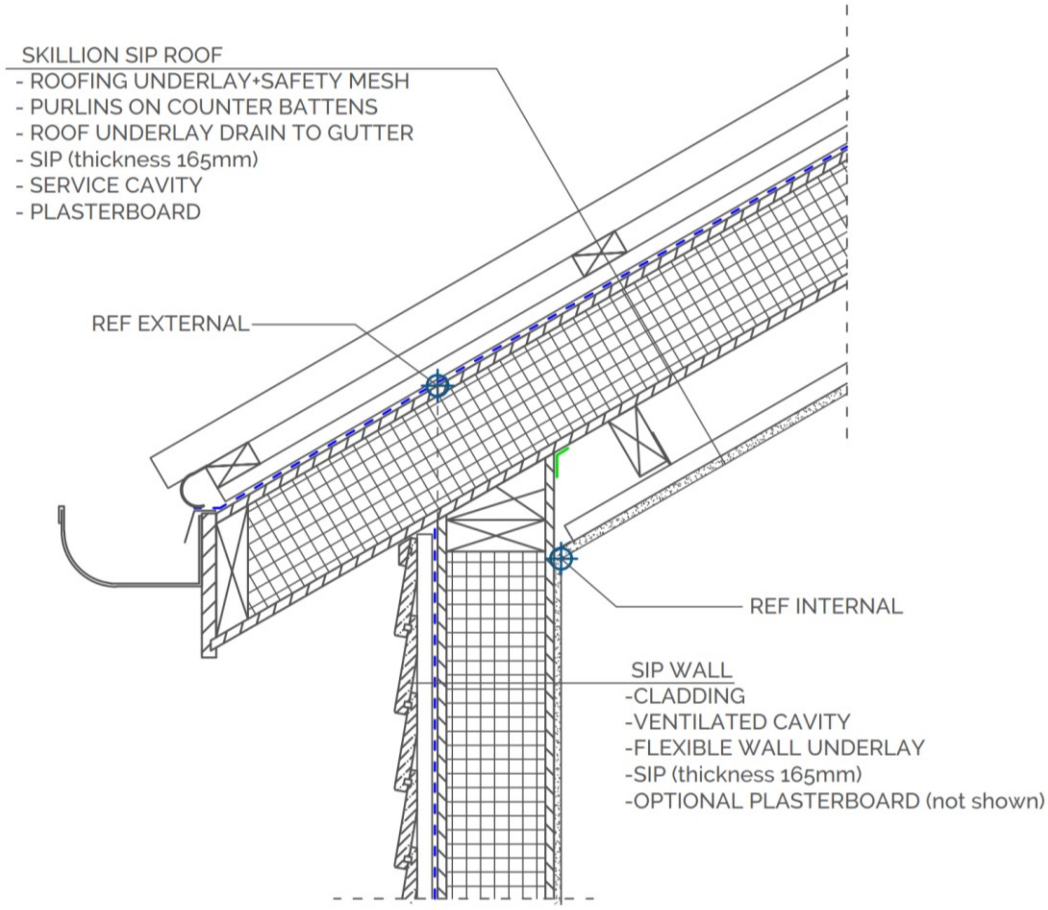
$$\Psi_{A-E-C} = \frac{10.801}{20.000} - 0.231 \cdot 1.047 - 0.233 \cdot 1.255 = 0.006 \text{ W/(m·K)}$$

$$\Psi_{D-F-B} = \frac{10.801}{20.000} - 0.233 \cdot 1.000 - 0.231 \cdot 1.000 = 0.076 \text{ W/(m·K)}$$

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Roof Ventilated		0.000	0.100
Exterior, ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		







53 ROEA Eaves - SIP roof to SIP wall

RESULTS TABLE

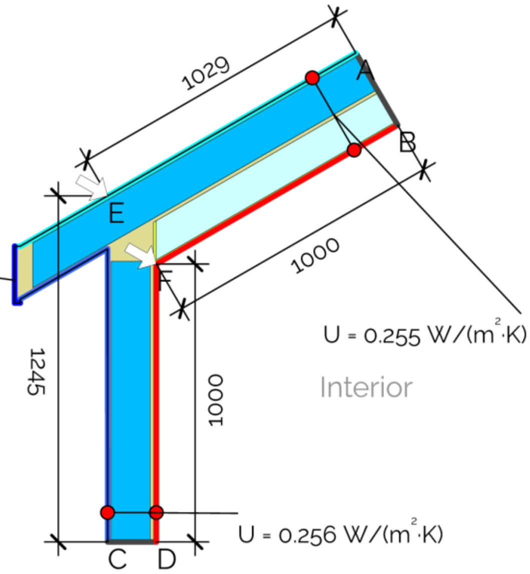
Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	-0.004 W/(mK)	0.067 W/(mK)
f_{RSI}	0.892	
Cost	$387 per linear metre	
Carbon	44 $kgCO_2eq/m$	
Carbon Storage	36 $kgCO_2eq/m$	

This is a typical SIP roof to SIP wall with timber angle cut to provide solid support.

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Roof Ventilated		0.000	0.100
Exterior, Ventilated		0.000	0.130
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
Plasterboard	0.250
SIPCore_L0.041	0.041
Timber (Softwood)	0.130
Unventilated air cavity *	

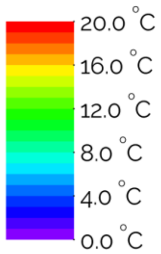
* Simplified approach

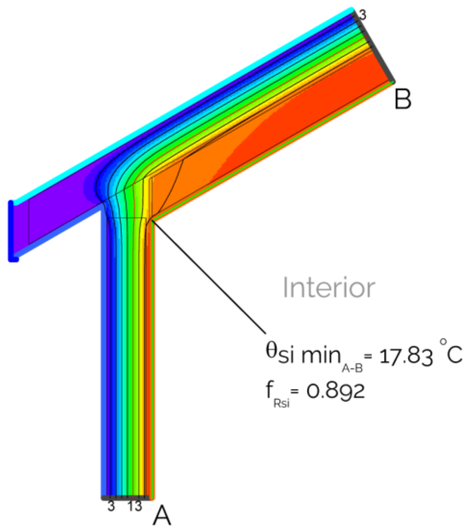


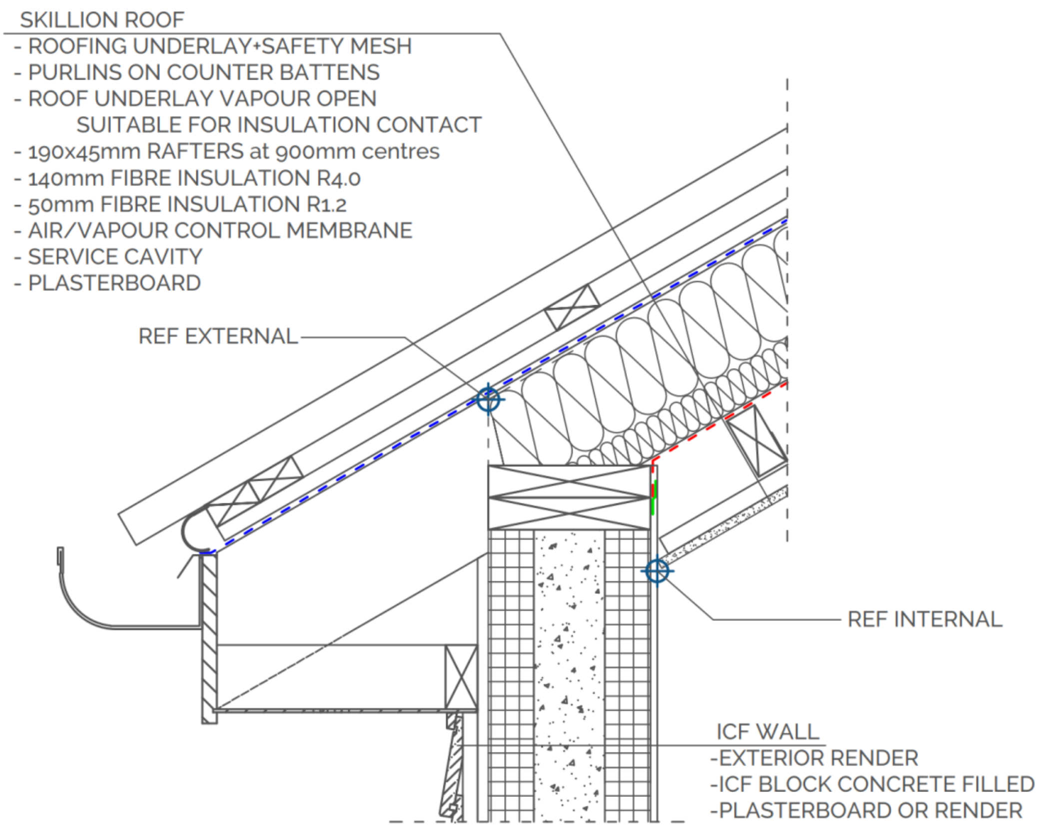
$$\psi_{A-E-C} = \frac{11.544}{20.000} - 0.255 \cdot 1.029 - 0.256 \cdot 1.245 = -0.004\ W/(m \cdot K)$$

$$\psi_{D-F-B} = \frac{11.544}{20.000} - 0.256 \cdot 1.000 - 0.255 \cdot 1.000 = 0.067\ W/(m \cdot K)$$

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Roof Ventilated		0.000	0.100
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		







54 ROEA Eaves - Skillion to ICF wall

RESULTS TABLE

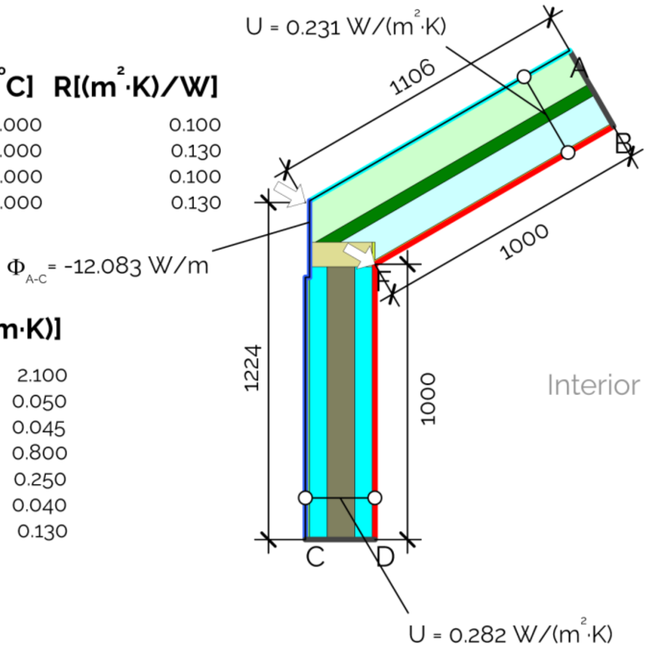
Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.003 W/(mK)	0.091 W/(mK)
f_{RSI}	0.880	
Cost	Not calculated	
Carbon	Not calculated	

This detail is for an ICF wall to high-performance skillion roof. Note the counter battens under the roofing and the vapour open roof underlay allow the full rafter depth to be filled with insulation: the moisture vents through the underlay and is ventilated out of the roof assembly via the counter battens.

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Roof Ventilated		0.000	0.100
Exterior, Ventilated		0.000	0.130
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
Concrete	2.100
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+10%Timber	0.045
Plaster, lime, sand	0.800
Plasterboard	0.250
RigidInsulationL0.04	0.040
Timber (Softwood)	0.130
Unventilated air cavity *	

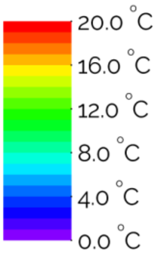
* Simplified approach

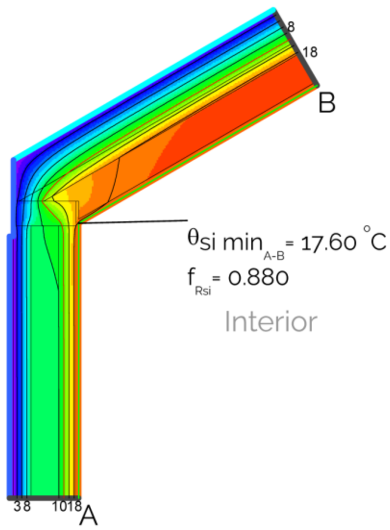


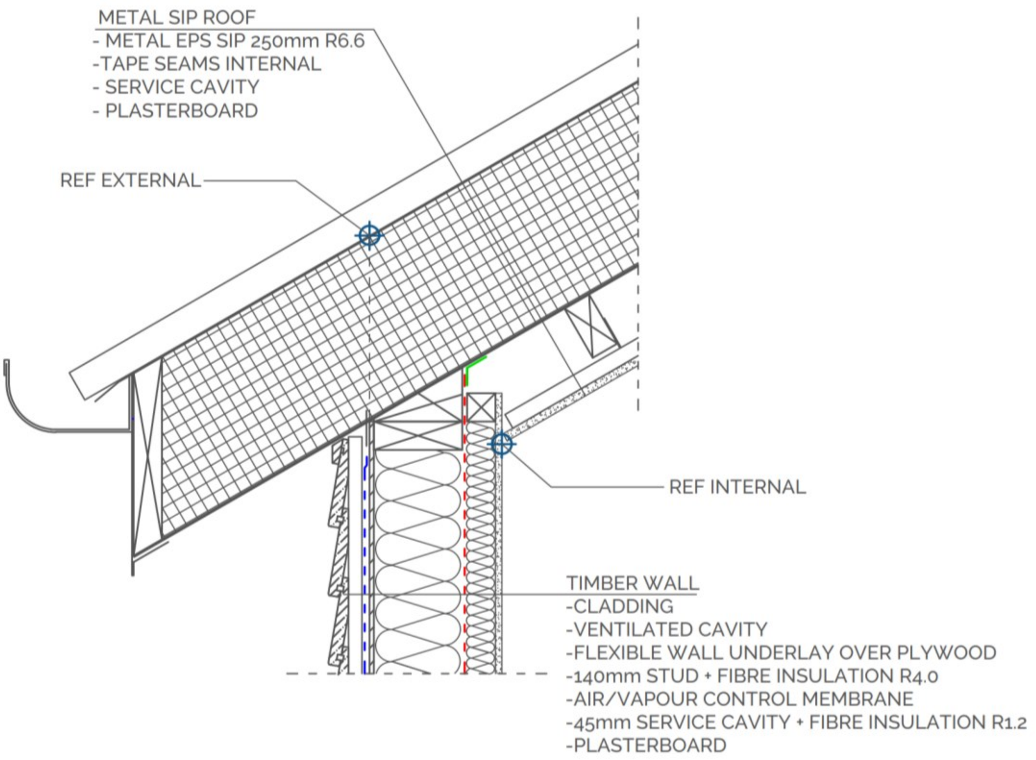
$$\psi_{A-E-C} = \frac{12.083}{20.000} - 0.231 \cdot 1.106 - 0.282 \cdot 1.224 = 0.003\ W/(m \cdot K)$$

$$\psi_{D-F-B} = \frac{12.083}{20.000} - 0.282 \cdot 1.000 - 0.231 \cdot 1.000 = 0.091\ W/(m \cdot K)$$

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Roof Ventilated		0.000	0.100
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		







55 ROEA Eaves - Metal SIP panel roof to 140/45 stud wall

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.245 W/(mK)	0.327 W/(mK)
f_{RSI}	0.818	
Cost	Not calculated	
Carbon	Not calculated	

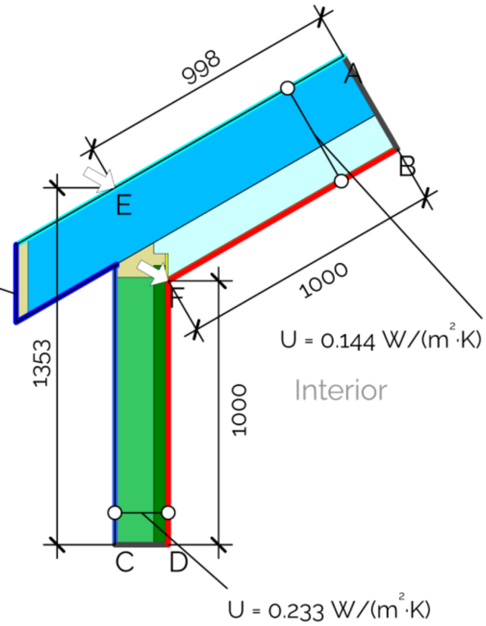
This detail is for a metal SIP to a high-performance wall. Note the high thermal bridge value is due to the metal SIP skin running from outside the soffit into the inside of the thermal envelope. This can be seen in the isotherms in the thermal calculations. A small gap in the steel over the external wall can significantly lower the thermal bridge in this location.

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Roof Ventilated		0.000	0.100
Exterior, ventilated		0.000	0.130
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

$\Phi_{A\text{-}C}$ = -14.072 W/m

Material	λ[W/(m·K)]
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
MetalEPS_SIPR6.6/250mm	0.038
Plasterboard	0.250
Steel	50.000
Timber (Softwood)	0.130
Unventilated air cavity *	

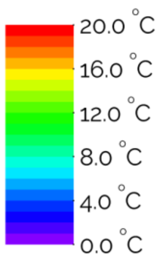
* Simplified approach

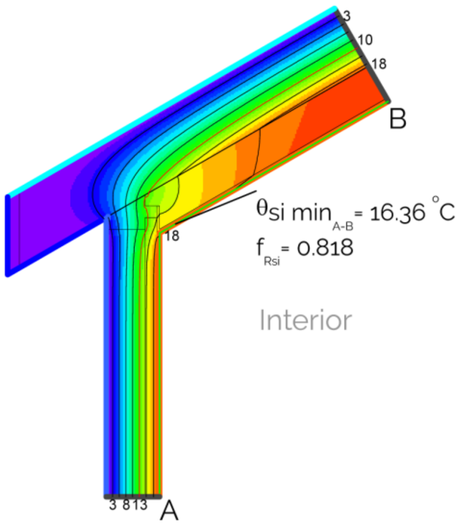


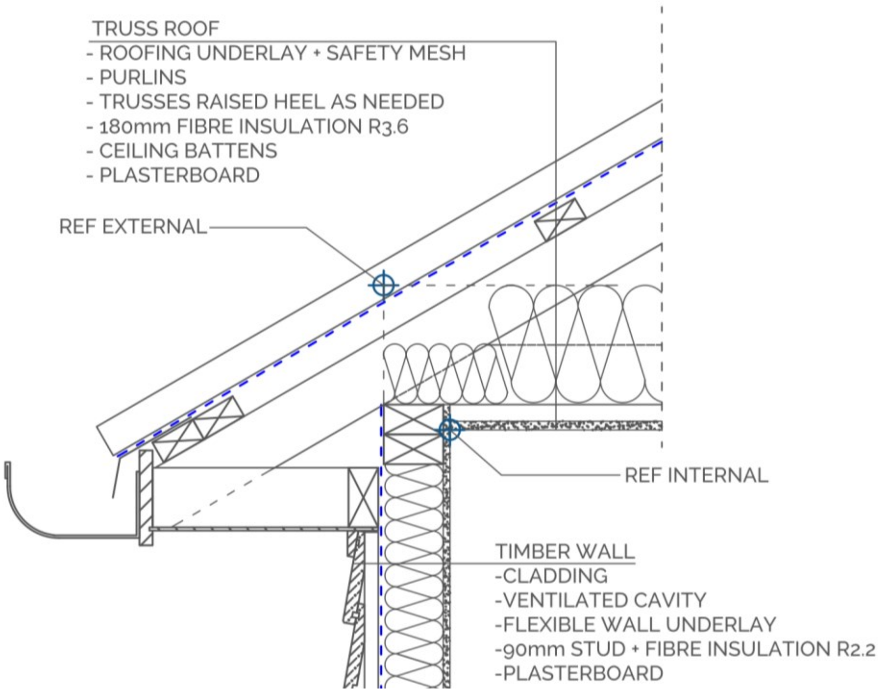
$$\psi_{A\text{-}E\text{-}C} = \frac{14.072}{20.000} - 0.144 \cdot 0.998 - 0.233 \cdot 1.353 = 0.245 \text{ W/(m·K)}$$

$$\psi_{D\text{-}F\text{-}B} = \frac{14.072}{20.000} - 0.233 \cdot 1.000 - 0.144 \cdot 1.000 = 0.327 \text{ W/(m·K)}$$

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Roof Ventilated		0.000	0.100
Exterior, ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		





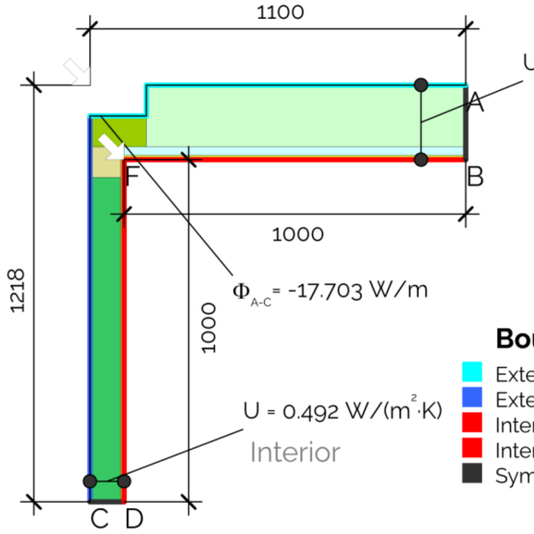


56 TCEA Truss Ceiling Roof Eaves - Truss roof current good practice

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	-0.042 W/(mK)	0.095 W/(mK)
f_{RSI}	0.787	
Cost	$274 per linear metre	
Carbon	45 $kgCO_2eq/m$	
Carbon Storage	18 $kgCO_2eq/m$	

This detail shows a good practice solution where there is insufficient height for the truss roof insulation to maintain full thickness over the external wall. A smaller thickness of insulation (90mm in this case) is added to the perimeter so that a gap is not left. Note that a gap would have a significant impact on the thermal bridge.



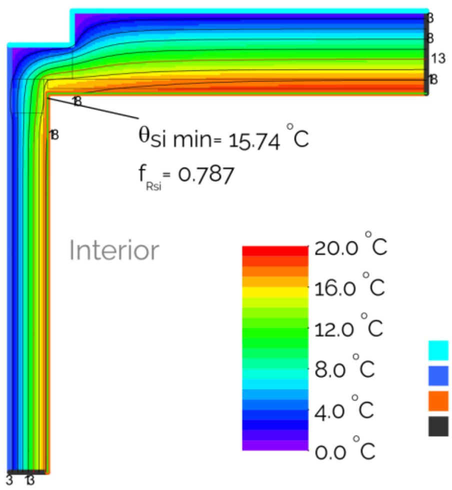
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Roof Ventilated		0.000	0.100
Exterior, Ventilated		0.000	0.130
Interior, heat f ux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

$$\Psi_{A\text{-}E\text{-}C} = \frac{17.703}{20.000} - 0.297 \cdot 1.100 - 0.492 \cdot 1.218 = -0.042 \text{ W/(m·K)}$$

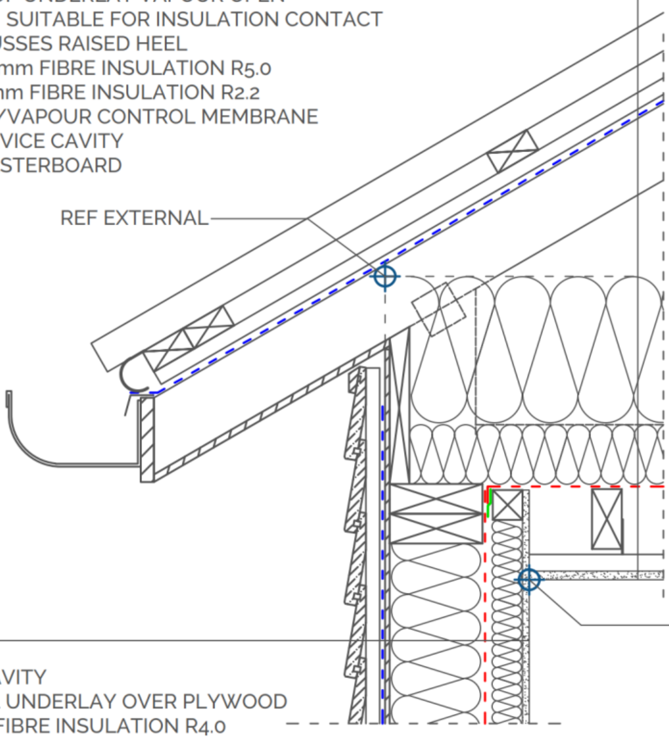
$$\Psi_{D\text{-}F\text{-}B} = \frac{17.703}{20.000} - 0.492 \cdot 1.000 - 0.297 \cdot 1.000 = 0.095 \text{ W/(m·K)}$$

Material	λ[W/(m·K)]
FibreInsulR2.2/90mm+10%Timber	0.050
FibreInsulR2.2/90mm+12%Timber	0.052
FibreInsulR3.6/180mm+10%Timber	0.058
Plasterboard	0.250
Timber (Softwood)	0.130
Unventilated air cavity *	

* Simplif ed approach



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Roof Ventilated		0.000	0.100
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

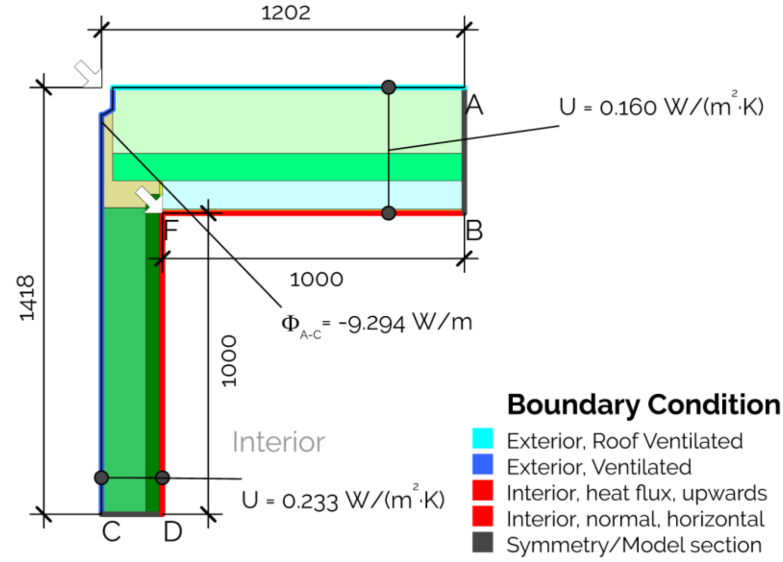


57 TCEA Truss Ceiling Roof Eaves - Truss roof raised heel to maintain insulation thickness

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	-0.057 W/(mK)	0.072 W/(mK)
f_{RSI}	0.911	
Cost	$442 per linear metre	
Carbon	51 $kgCO_2eq/m$	
Carbon Storage	31 $kgCO_2eq/m$	

This detail is for a high-performance wall to high-performance truss roof with an AVCL and raised heel (energy truss) to allow full insulation over the exterior wall. Note the counter battens under the roofing and the vapour open roof underlay the moisture vents through the underlay and is ventilated out of the roof assembly via the counter battens.



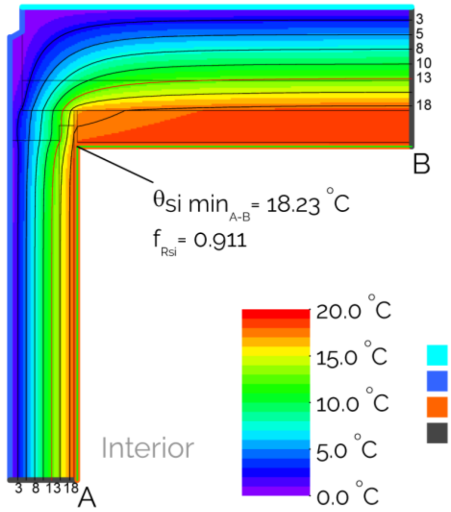
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Roof Ventilated		0.000	0.100
Exterior, Ventilated		0.000	0.130
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

$$\psi_{A-E-C} = \frac{9.294}{20.000} - 0.160 \cdot 1.202 - 0.233 \cdot 1.418 = -0.057 \text{ W/(m·K)}$$

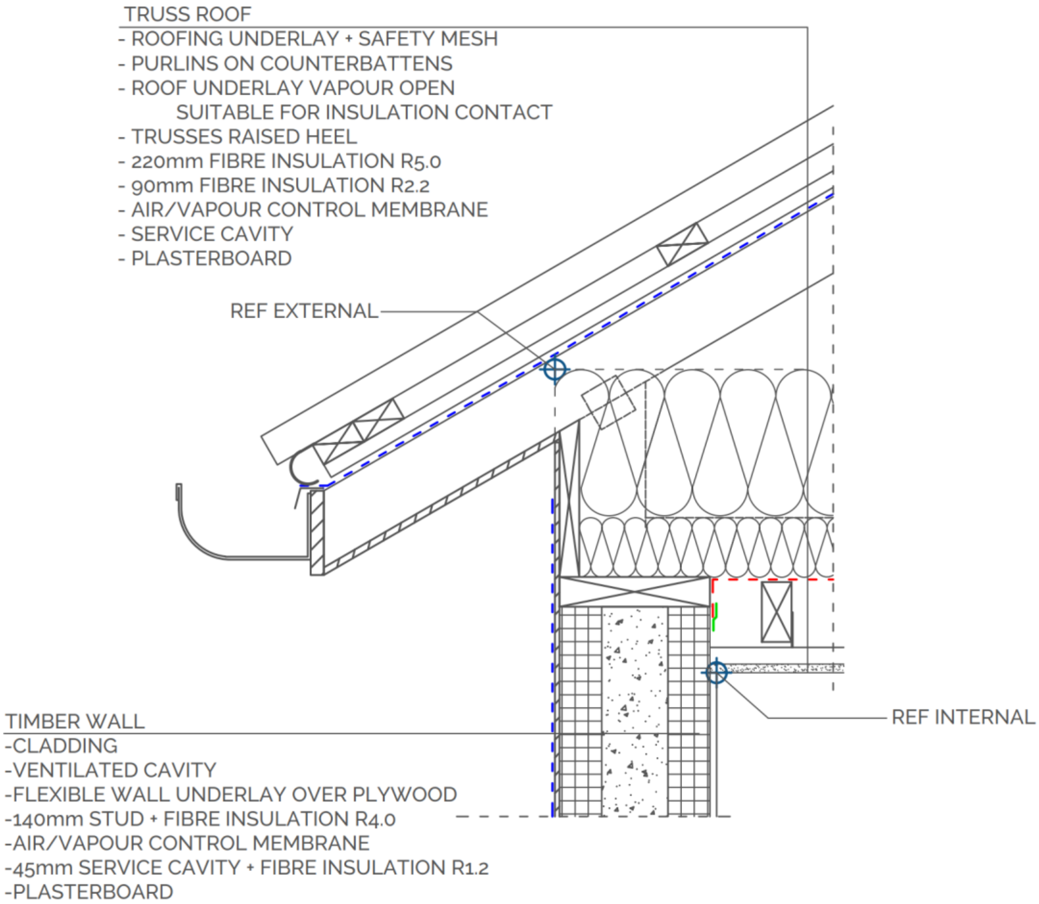
$$\psi_{D-F-B} = \frac{9.294}{20.000} - 0.233 \cdot 1.000 - 0.160 \cdot 1.000 = 0.072 \text{ W/(m·K)}$$

Material	λ[W/(m·K)]
FiberInsulR2.2/90mm+10%Timber	0.049
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
FibreInsulR5.0/220mm+10%Timber	0.053
Plasterboard	0.250
Timber (Softwood)	0.130
Unventilated air cavity *	

* Simplified approach



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Roof Ventilated		0.000	0.100
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

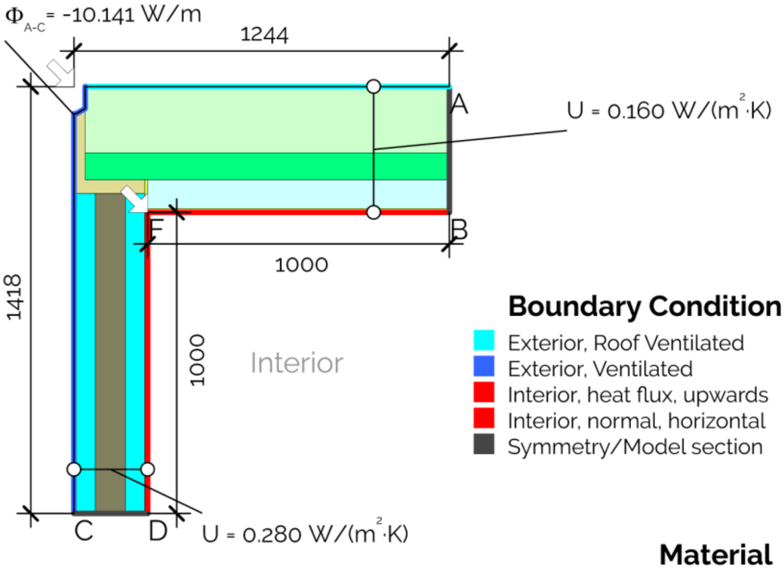


58 TCEA Truss Ceiling Roof Eaves Truss roof to ICF wall

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	-0.088 W/(mK)	0.068 W/(mK)
f_{RSI}	0.915	
Cost	Not calculated	
Carbon	Not calculated	

This detail is for an ICF wall to high-performance truss roof with an AVCL and raised heel (energy truss) to allow full insulation over the exterior wall. Note the counter battens under the roofing and the vapour open roof underlay the moisture vents through the underlay and is ventilated out of the roof assembly via the counter battens.



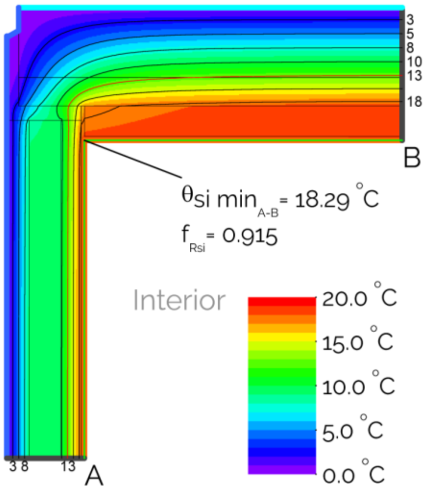
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Roof Ventilated		0.000	0.100
Exterior, Ventilated		0.000	0.130
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
Concrete	2.100
FiberInsulR2.2/90mm+10%Timber	0.049
FibreInsulR5.0/220mm+10%Timber	0.053
Plasterboard	0.250
RigidInsulationL0.04	0.040
Timber (Softwood)	0.130
Unventilated air cavity *	

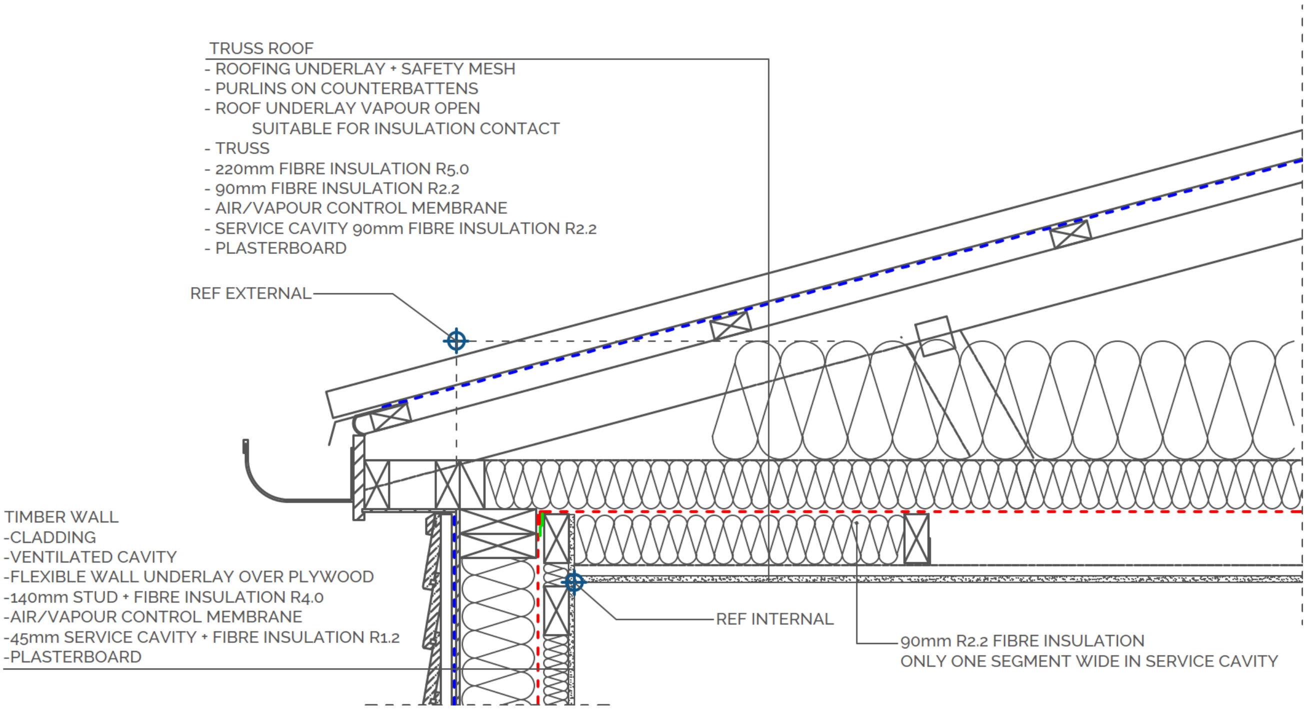
* Simplified approach

$$\psi_{A\text{-}E\text{-}C} = \frac{10.141}{20.000} - 0.160 \cdot 1.244 - 0.280 \cdot 1.418 = -0.088\ \mathrm{W/(m \cdot K)}$$

$$\psi_{D\text{-}F\text{-}B} = \frac{10.141}{20.000} - 0.280 \cdot 1.000 - 0.160 \cdot 1.000 = 0.068\ \mathrm{W/(m \cdot K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Roof Ventilated		0.000	0.100
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

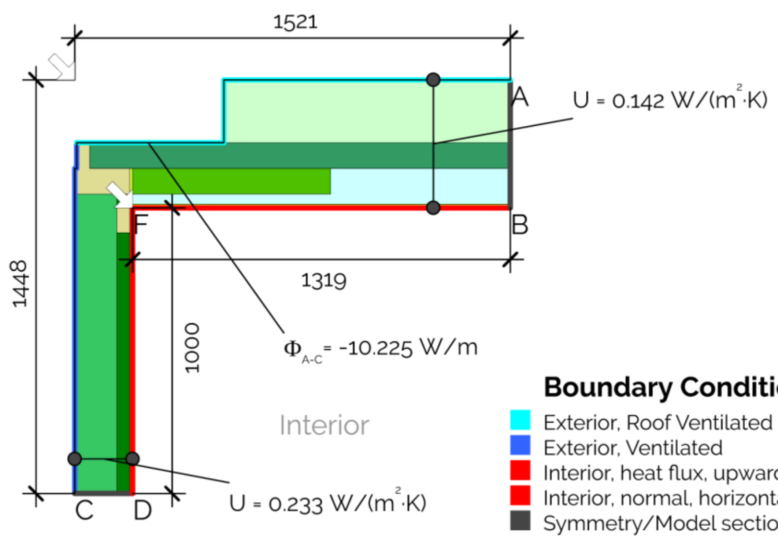


59 TCEA Truss Ceiling Roof Eaves - Truss roof edge insulation offset to maintain ventilation gap service cavity insulated

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	-0.041 W/(mK)	0.092 W/(mK)
f_{RSI}	0.889	
Cost	$351 per linear metre	
Carbon	36 $kgCO_2eq/m$	
Carbon Storage	27 $kgCO_2eq/m$	

This detail shows a good practice solution where there is insufficient height for the truss roof insulation to maintain full thickness over the external wall. A smaller thickness of insulation (90mm in this case) is added to the perimeter to prevent a gap remaining and additional insulation is added to the perimeter of the ceiling service cavity.



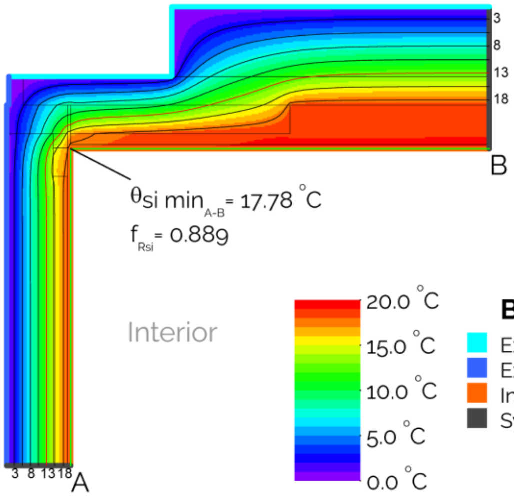
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Roof Ventilated		0.000	0.100
Exterior, Ventilated		0.000	0.130
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
FiberInsulR2.2/90mm+5%Timber	0.045
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR2.2/90mm	0.041
FibreInsulR4.0/140mm+12%Timber (1)	0.046
FibreInsulR5.0/220mm+2%Timber	0.046
Plasterboard	0.250
Timber (Softwood)	0.130
Unventilated air cavity *	

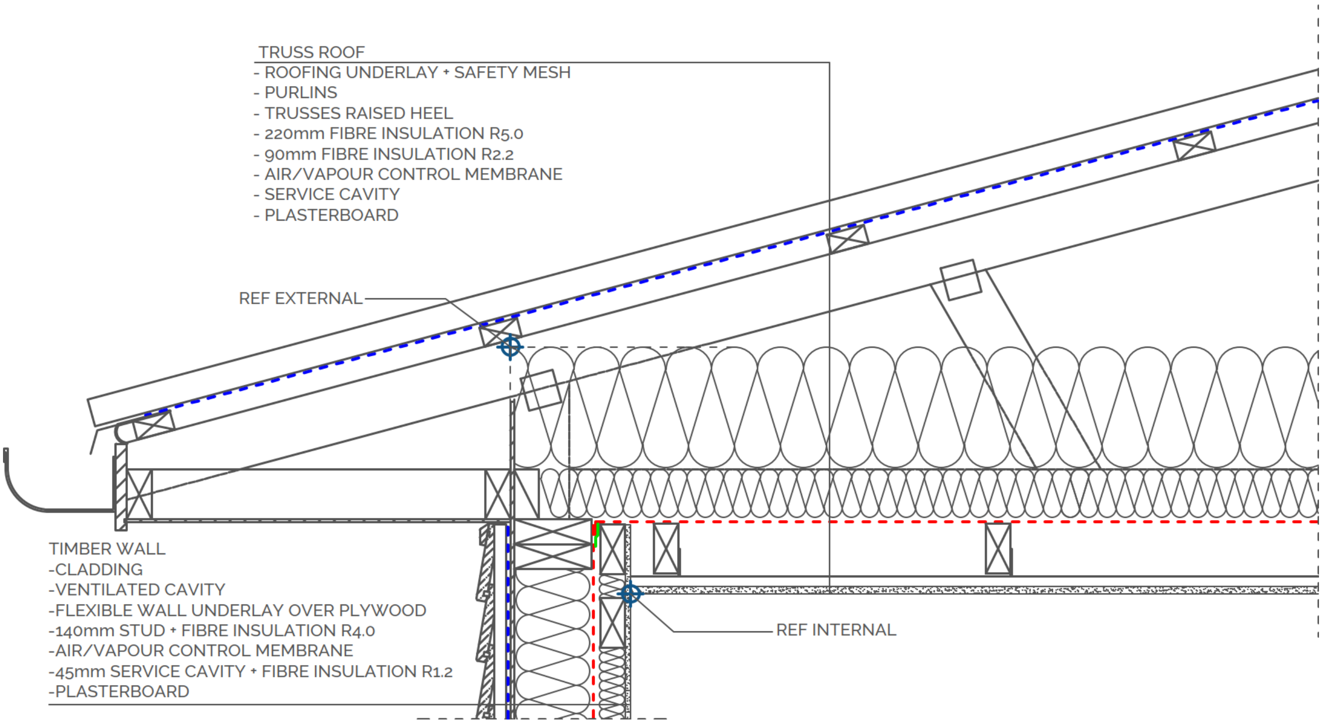
* Simplified approach

$$\Psi_{A\text{-}E\text{-}C} = \frac{10.225}{20.000} - 0.142 \cdot 1.521 - 0.233 \cdot 1.448 = -0.041 \text{ W/(m·K)}$$

$$\Psi_{D\text{-}F\text{-}B} = \frac{10.225}{20.000} - 0.233 \cdot 1.000 - 0.142 \cdot 1.319 = 0.092 \text{ W/(m·K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Roof Ventilated		0.000	0.100
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

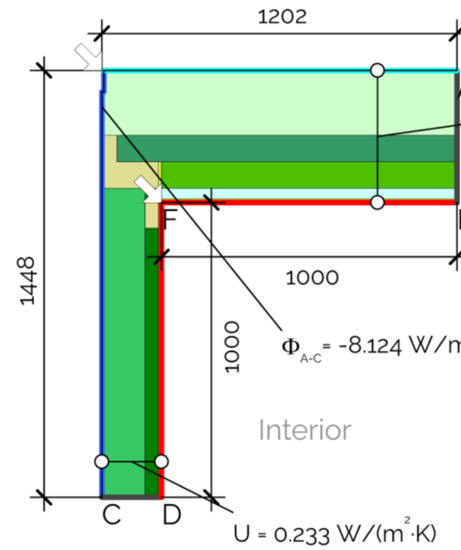


60 TCEA Truss Ceiling Roof Eaves - Truss roof raised heel to maintain insulation thickness

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	-0.061 W/(mK)	0.065 W/(mK)
f_{RSI}	0.906	
Cost	$408 per linear metre	
Carbon	56 $kgCO_2eq/m$	
Carbon Storage	34 $kgCO_2eq/m$	

This detail shows a good practice solution when there is insufficient height for the truss roof insulation to maintain full thickness over the external wall. The raised heel (energy truss) increases the space and allows the full thickness.



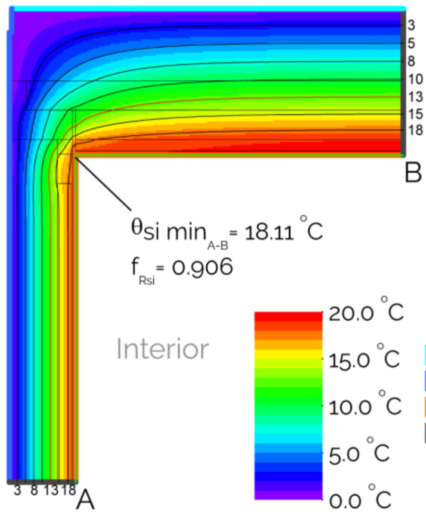
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Roof Ventilated		0.000	0.100
Exterior, Ventilated		0.000	0.130
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

$$\psi_{A\text{-}E\text{-}C} = \frac{8.124}{20.000} - 0.108 \cdot 1.202 - 0.233 \cdot 1.448 = -0.061\ \mathrm{W/(m \cdot K)}$$

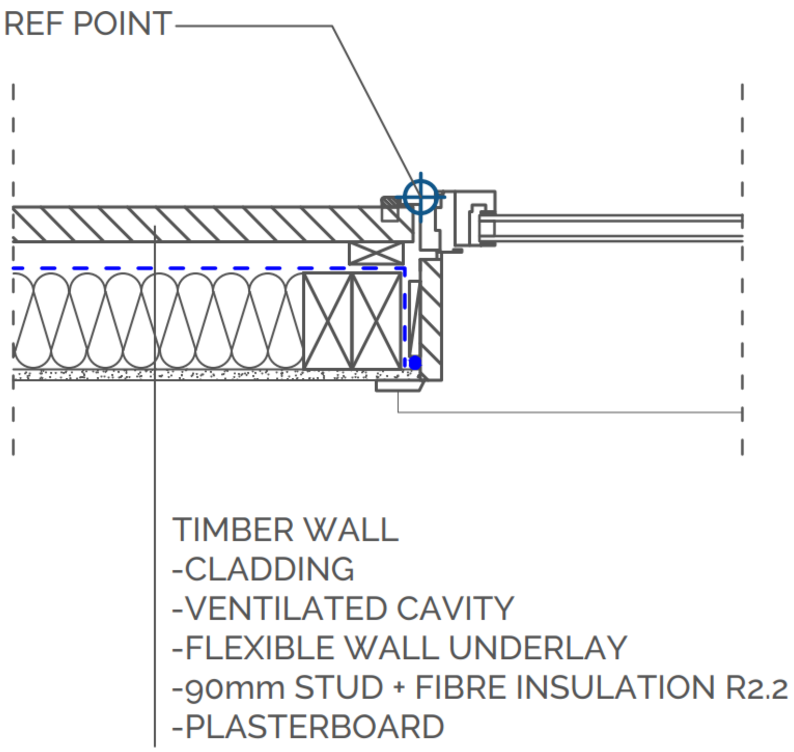
$$\psi_{D\text{-}F\text{-}B} = \frac{8.124}{20.000} - 0.233 \cdot 1.000 - 0.108 \cdot 1.000 = 0.065\ \mathrm{W/(m \cdot K)}$$

Material	λ[W/(m·K)]
FiberInsulR2.2/90mm+5%Timber	0.045
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR2.2/90mm	0.041
FibreInsulR4.0/140mm+12%Timber	0.046
FibreInsulR5.0/220mm+2%Timber	0.046
Plasterboard	0.250
Timber (Softwood)	0.130
Unventilated air cavity *	

* Simplified approach



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Roof Ventilated		0.000	0.100
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

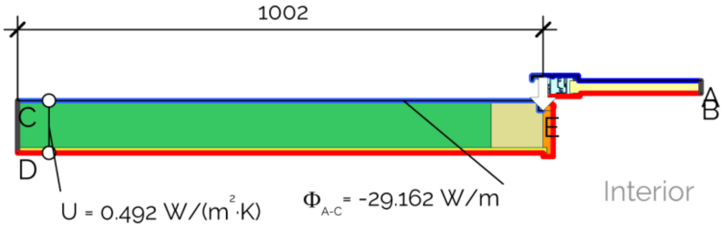


61 WISI Window Side (Jamb) - Solid aluminium current practice install frame face flush with cladding

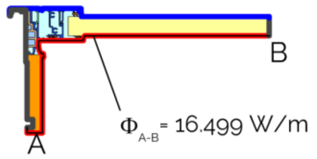
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.140 W/(mK)	0.140 W/(mK)
f_{RSI}	0.120	
Cost	Not calculated	
Carbon	Not calculated	

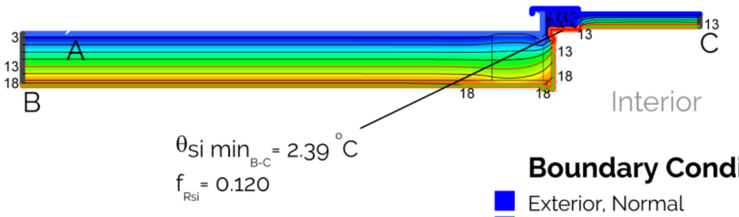
Current practice install of a Code-minimum solid aluminium-framed window jamb without a thermal break on a ventilated cavity, where the face of the window is flush with the cladding. This is the most common install but it creates a significant thermal bridge and a very low fRSI value.



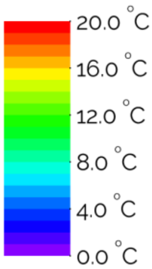
$$\psi_{A\text{-}E\text{-}C,\cdot} = \frac{29.162}{20.000} - \frac{16.499}{20.000} - 0.492 \cdot 1.002 = 0.140 \text{ W/(m·K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

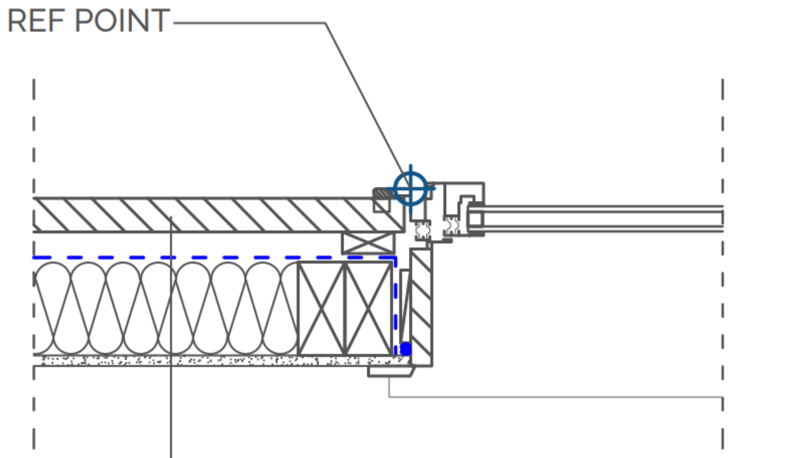


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR2.2/90mm+12%Timber	0.052
PVC-U (polyvinylchloride), rigid	0.170
Panel	0.035
Plasterboard	0.250
Polyethylene HD, high density	0.500
Timber (Softwood)	0.130
Window Liner	0.120
Slightly ventilated air cavity *	
Unventilated air cavity *	

* Simplified approach

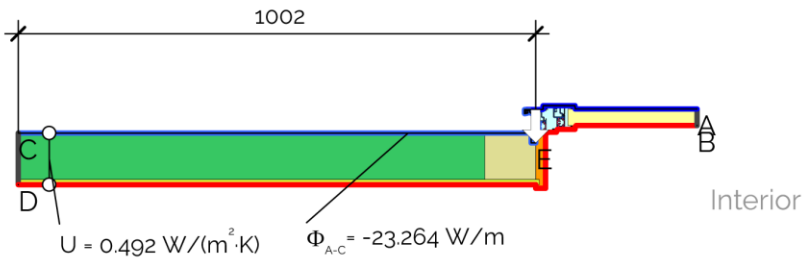


62 WISI Window Side (Jamb) - Thermally broken aluminium current practice install frame face flush with cladding

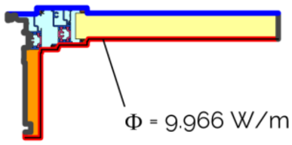
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.172 W/(mK)	0.172 W/(mK)
f_{RSI}	0.307	
Cost	Not calculated	
Carbon	Not calculated	

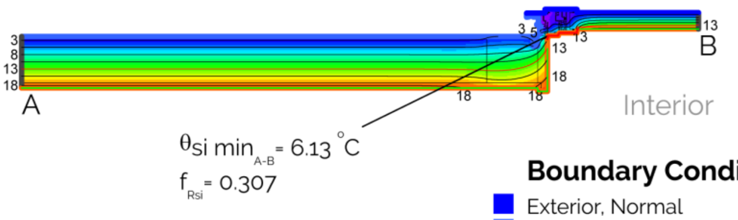
Current practice install of a thermally-broken aluminium-framed window jamb on a ventilated cavity, where the face of the window is flush with the cladding. This is the most common install but it creates a significant thermal bridge and a very low fRSI value.

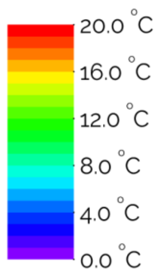


$$\psi_{A\text{-}E\text{-}C,\cdot} = \frac{23.264}{20.000} - \frac{9.966}{20.000} - 0.492 \cdot 1.002 = 0.172 \text{ W/(m·K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

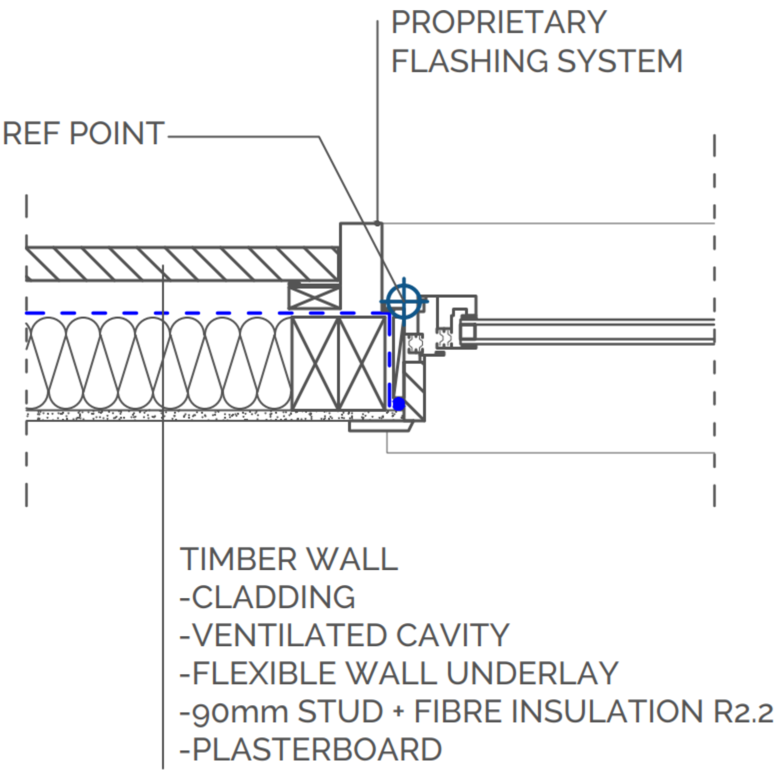




Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR2.2/90mm+12%Timber	0.052
Panel	0.035
Plasterboard	0.250
Polyamid (nylon)	0.250
Timber (Softwood)	0.130
Window Liner	0.120
Unventilated air cavity *	

* Simplified approach

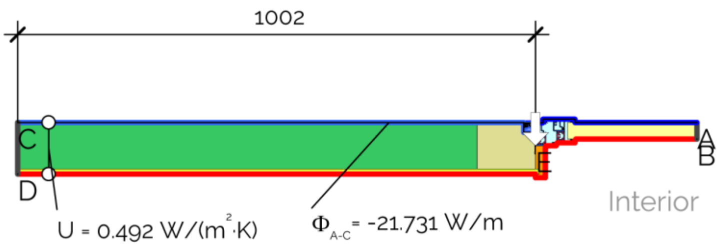


63 WISI Window Side (Jamb) - Thermally broken aluminium recessed frame face flush with thermal envelope exterior

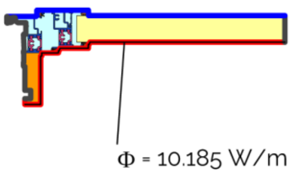
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.084 W/(mK)	0.084 W/(mK)
f_{RSI}	0.420	
Cost	Not calculated	
Carbon	Not calculated	

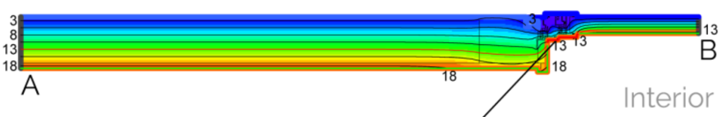
Recessed install of a thermally-broken aluminium-framed window jamb on a ventilated cavity, where the face of the window is even with the outside of the thermal envelope. This is a significant improvement over fixing flush with the cladding but due to the small thermal break still yields a low fRSI value.



$$\psi_{A\text{-}E\text{-}C,'} = \frac{21.731}{20.000} - \frac{10.185}{20.000} - 0.492 \cdot 1.002 = 0.084\ W/(m \cdot K)$$

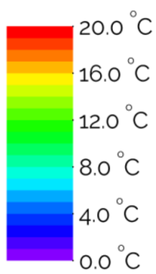


Boundary Condition	$q[W/m^2]$	$\theta[°C]$	$R[(m^2 \cdot K)/W]$
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		



$\theta si\ min_{A\text{-}B} = 8.40\ °C$

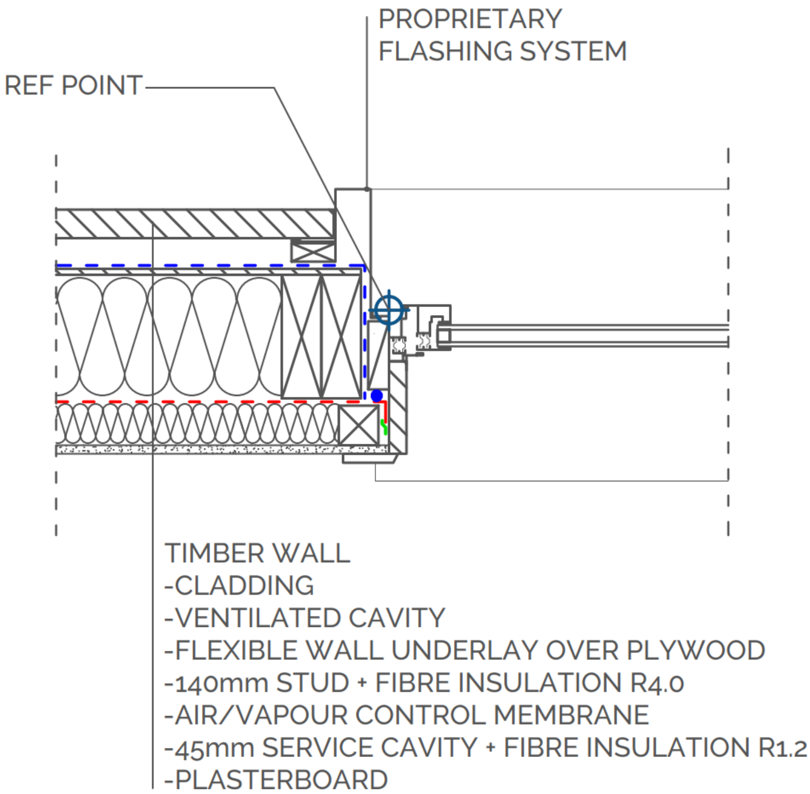
$f_{Rsi} = 0.420$



Boundary Condition	$q[W/m^2]$	$\theta[°C]$	$R[(m^2 \cdot K)/W]$
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

Material	$\lambda[W/(m \cdot K)]$
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR2.2/90mm+12%Timber	0.052
Panel	0.035
Plasterboard	0.250
Polyamid (nylon)	0.250
Timber (Softwood)	0.130
Window Liner	0.120
Unventilated air cavity *	

* Simplified approach

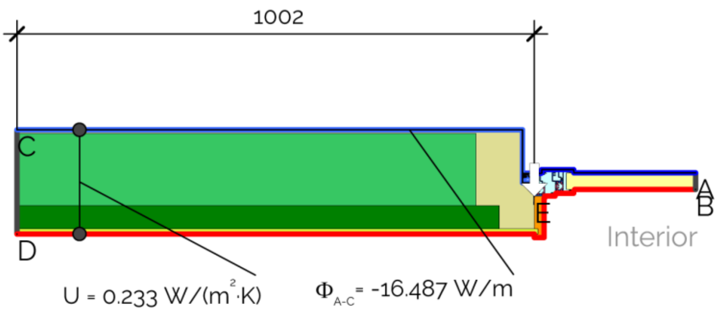


64 WISI Window Side (Jamb) - Thermally broken aluminium recessed frame to middle of 140/45 wall

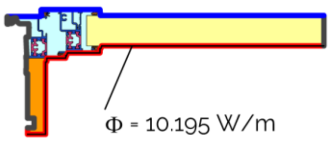
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.081 W/(mK)	0.081 W/(mK)
f_{RSI}	0.419	
Cost	Not calculated	
Carbon	Not calculated	

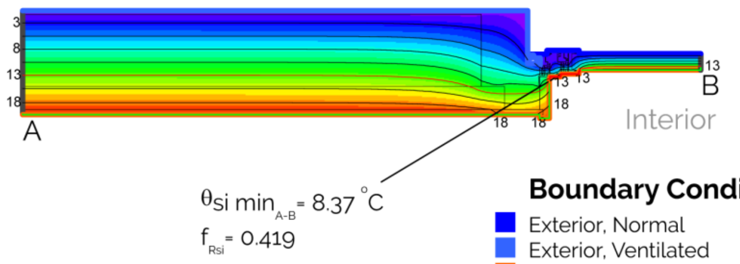
Recessed install of a thermally-broken aluminium-framed window jamb on a ventilated cavity with the window centred in the thermal envelope thickness. This is only a slight improvement over fixing flush with the outside of the thermal envelope. The small thermal break produces a low fRSI value.

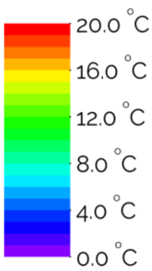


$$\psi_{A\text{-}E\text{-}C,*} = \frac{16.487}{20.000} - \frac{10.195}{20.000} - 0.233 \cdot 1.002 = 0.081\ W/(m \cdot K)$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

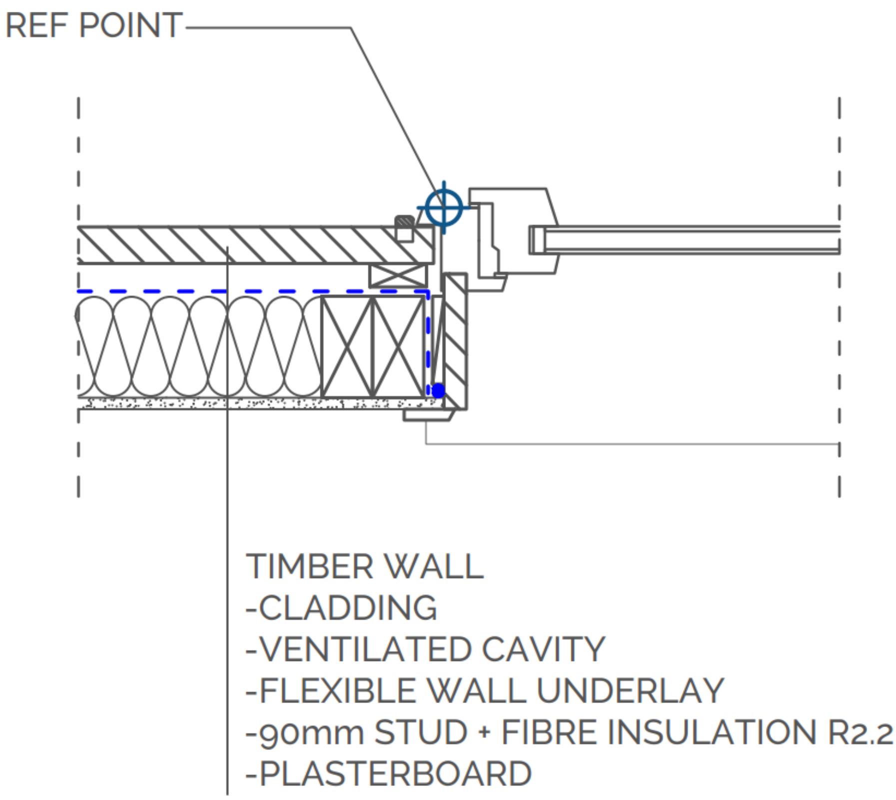




Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
Panel	0.035
Plasterboard	0.250
Polyamid (nylon)	0.250
Timber (Softwood)	0.130
Window Liner	0.120
Unventilated air cavity *	

* Simplified approach

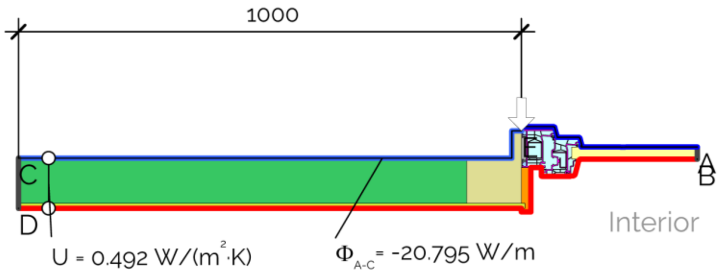


65 WISI Window Side (Jamb) - uPVC current practice install frame face flush with cladding

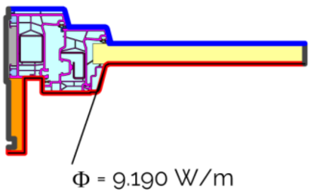
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.088 W/(mK)	0.088 W/(mK)
f_{RSI}	0.607	
Cost	Not calculated	
Carbon	Not calculated	

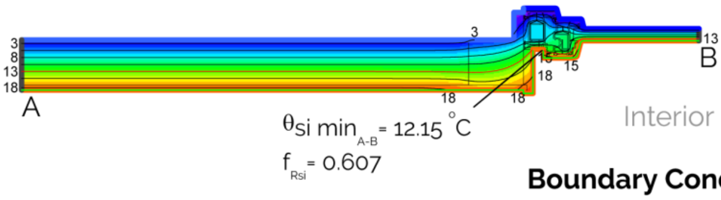
This detail represents a typical current practice install of a uPVC window flush with the ventilated cladding. Excessive heat loss occurs due to the uPVC frame leaking heat to the ventilated cavity.



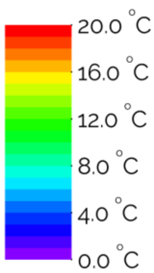
$$\psi_{A\text{-}E\text{-}C} = \frac{20.795}{20.000} - \frac{9.190}{20.000} - 0.492 \cdot 1.000 = 0.088\ W/(m \cdot K)$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

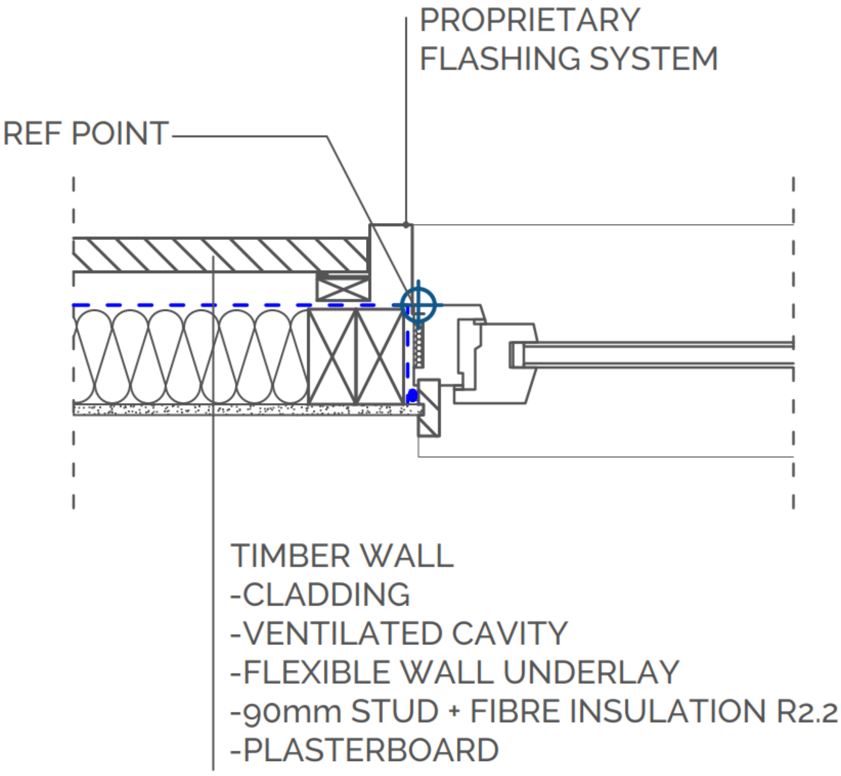


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR2.2/90mm+12%Timber	0.052
PU Foam	0.040
PVC (polyvinylchloride), rigid	0.170
Panel	0.035
Plasterboard	0.250
Steel	50.000
Timber (Softwood)	0.130
Window Liner	0.120
Slightly ventilated air cavity *	
Unventilated air cavity *	

* Simplified approach

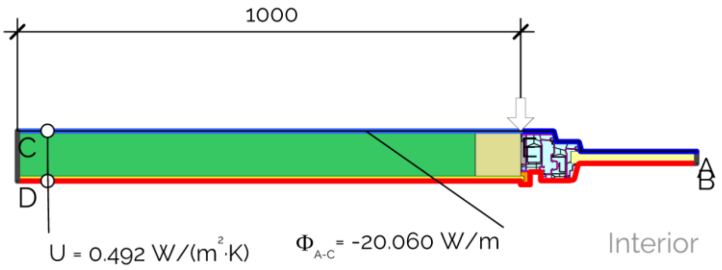


66 WISI Window Side (Jamb) - uPVC recessed frame face flush with thermal envelope exterior

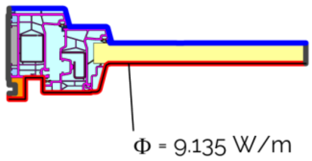
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.054 W/(mK)	0.054 W/(mK)
f_{RSI}	0.649	
Cost	Not calculated	
Carbon	Not calculated	

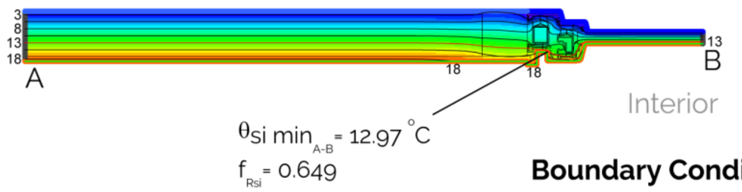
Recessed install of a uPVC-framed window jamb on a ventilated cavity with the face of the window flush with the outside of the thermal envelope. This is a significant improvement over fixing flush with the cladding.

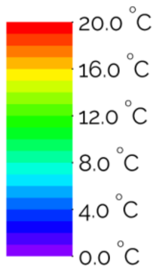


$$\psi_{A\text{-}E\text{-}C} = \frac{20.060}{20.000} - \frac{9.135}{20.000} - 0.492 \cdot 1.000 = 0.054\ W/(m \cdot K)$$



Boundary Condition	$q[W/m^2]$	$\theta[^\circ C]$	$R[(m^2 \cdot K)/W]$
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

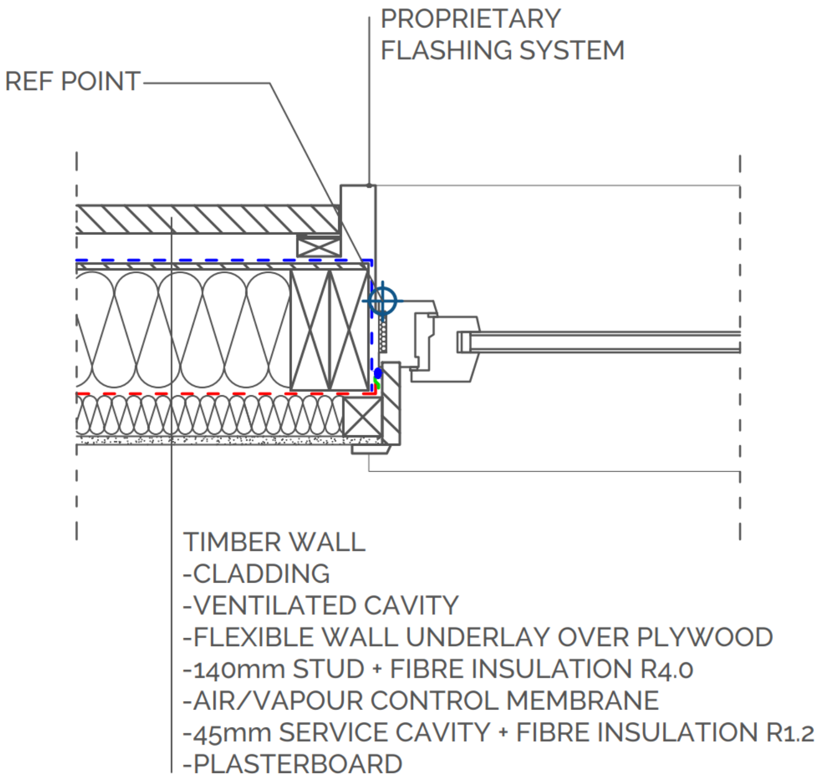




Boundary Condition	$q[W/m^2]$	$\theta[^\circ C]$	$R[(m^2 \cdot K)/W]$
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

Material	$\lambda[W/(m \cdot K)]$
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR2.2/90mm+12%Timber	0.052
PU Foam	0.040
PVC (polyvinylchloride), rigid	0.170
Panel	0.035
Plasterboard	0.250
Steel	50.000
Timber (Softwood)	0.130
Window Liner	0.120
Slightly ventilated air cavity *	
Unventilated air cavity *	

* Simplified approach

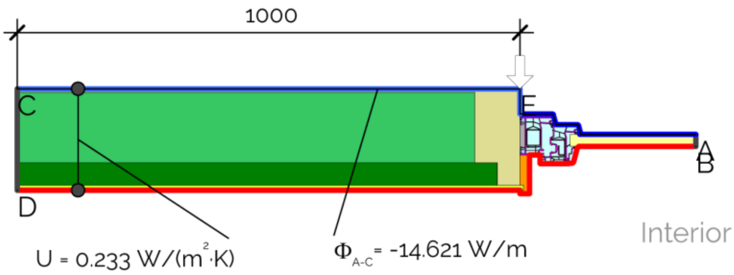


67 WISI Window Side (Jamb) - uPVC recessed frame to middle of 140/45 wall

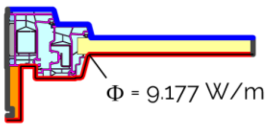
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.040 W/(mK)	0.040 W/(mK)
f_{RSI}	0.640	
Cost	Not calculated	
Carbon	Not calculated	

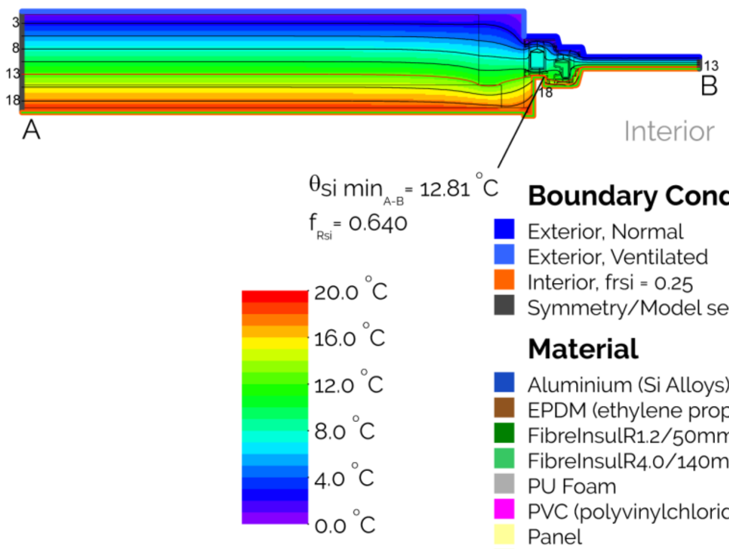
Recessed install of a uPVC-framed window jamb on a ventilated cavity with the window centred in the thermal envelope thickness. This is only a slight improvement over fixing flush with the outside of the thermal envelope.



$$\psi_{A\text{-}E\text{-}C,\cdot} = \frac{14.621}{20.000} - \frac{9.177}{20.000} - 0.233 \cdot 1.000 = 0.040\ \text{W/(m·K)}$$



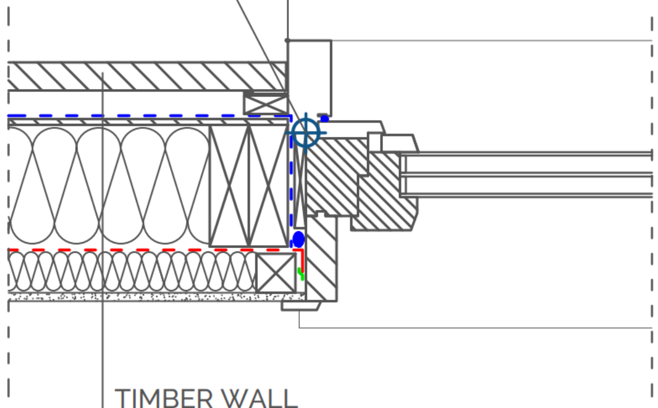
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
PU Foam	0.040
PVC (polyvinylchloride), rigid	0.170
Panel	0.035
Plasterboard	0.250
Steel	50.000
Timber (Softwood)	0.130
Window Liner	0.120
Slightly ventilated air cavity *	
Unventilated air cavity *	

* Simplified approach

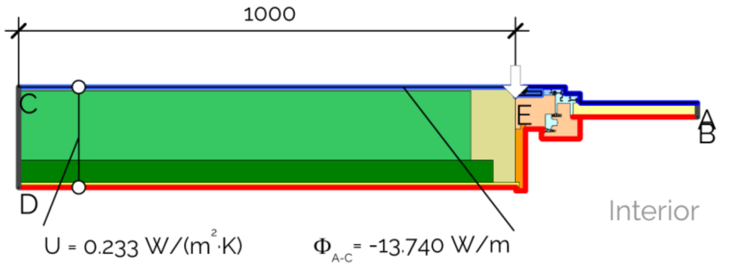


68 WISI Window Side (Jamb) - Timber window recessed frame timber reveal face flush with thermal envelope exterior

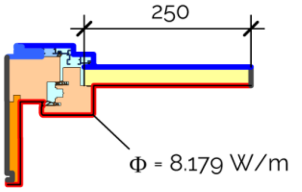
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.045 W/(mK)	0.045 W/(mK)
f_{RSI}	0.692	
Cost	Not calculated	
Carbon	Not calculated	

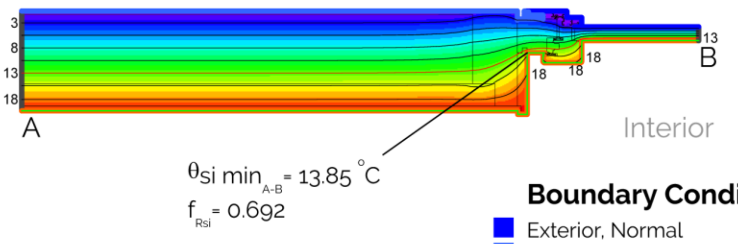
Recessed install of an aluminium-clad timber-framed window jamb on a ventilated cavity with the face of the window flush with the outside of the thermal envelope.

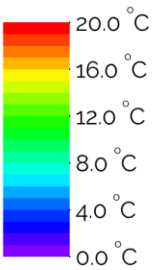


$$\psi_{A\text{-}E\text{-}C} = \frac{13.740}{20.000} - \frac{8.179}{20.000} - 0.233 \cdot 1.000 = 0.045\ W/(m \cdot K)$$



Boundary Condition	$q[W/m^2]$	$\theta[°C]$	$R[(m^2 \cdot K)/W]$
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

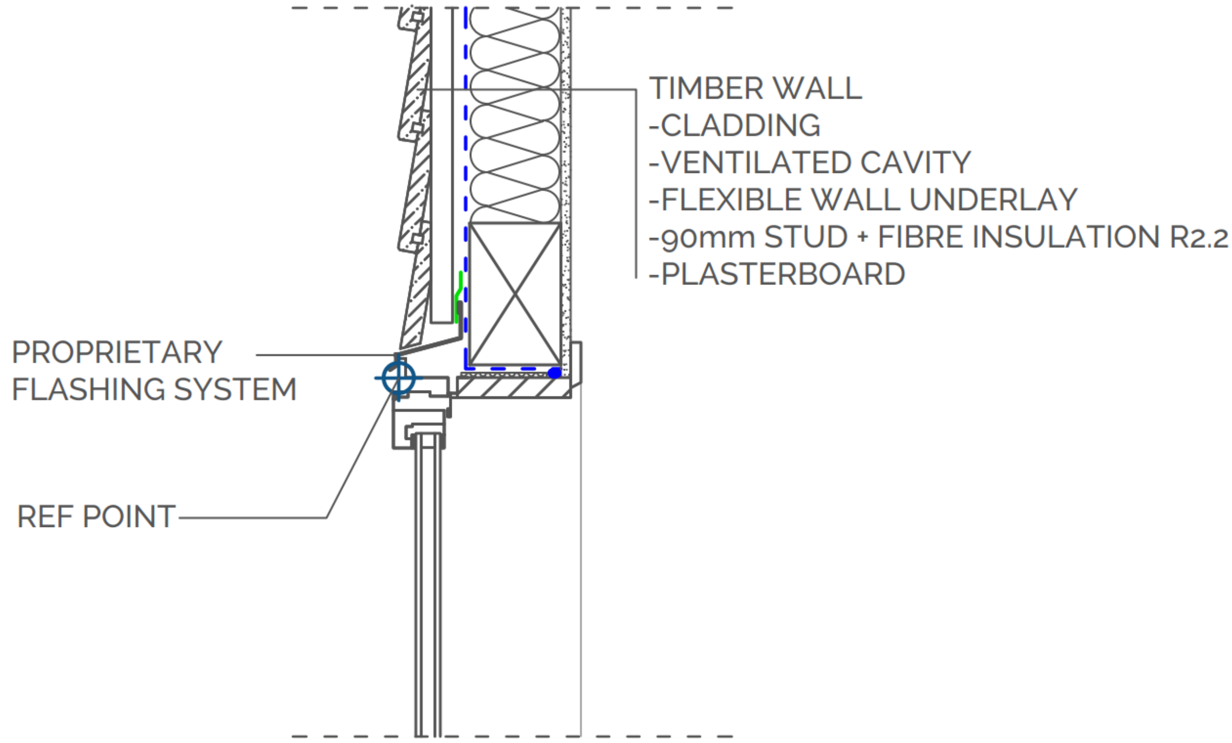




Boundary Condition	$q[W/m^2]$	$\theta[°C]$	$R[(m^2 \cdot K)/W]$
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

Material	$\lambda[W/(m \cdot K)]$
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
Larch	0.110
Panel	0.035
Plasterboard	0.250
Timber (Softwood)	0.130
Window Liner	0.120
Slightly ventilated air cavity *	
Unventilated air cavity *	

* Simplified approach

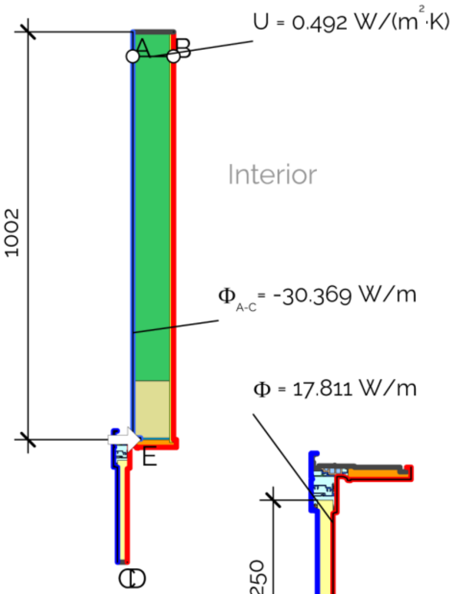


69 WITO Window Top (Head) - Solid aluminium current practice install frame face flush with cladding

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.135 W/(mK)	0.135 W/(mK)
f_{RSI}	0.118	
Cost	Not calculated	
Carbon	Not calculated	

Current practice install of a Code-minimum aluminium framed window head without a thermal break (solid aluminium) on a ventilated cavity with the face of the window flush with the cladding. This is the most common install but it creates a significant thermal bridge and a very low fRSI value.

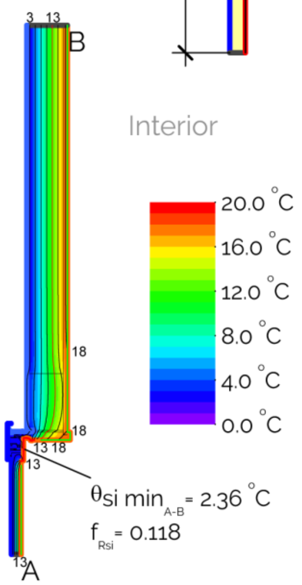


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

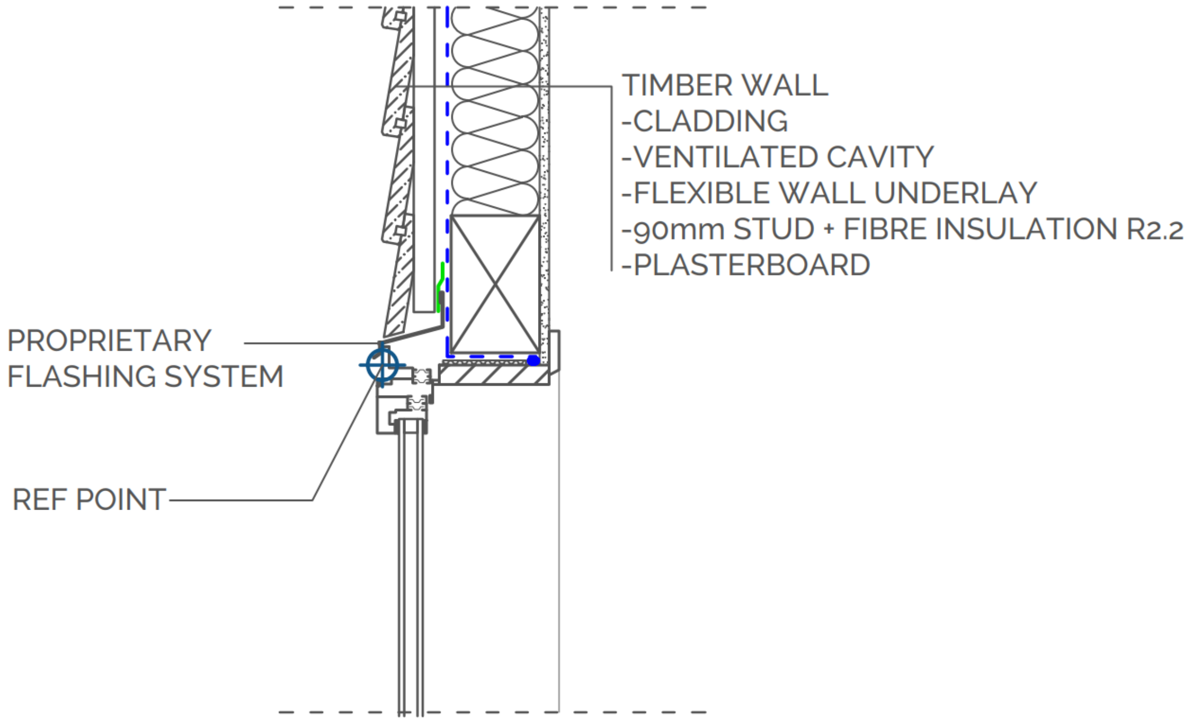
Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR2.2/90mm+12%Timber	0.052
PUGunFoam	0.032
PVC-U (polyvinylchloride), rigid	0.170
Panel	0.035
Plasterboard	0.250
Polyethylene HD, high density	0.500
Timber (Softwood)	0.130
Window Liner	0.120
Slightly ventilated air cavity *	
Unventilated air cavity *	

* Simplified approach

$$\Psi_{A\text{-}E\text{-}C,\cdot} = \frac{30.369}{20.000} - 0.492 \cdot 1.002 - \frac{17.811}{20.000} = 0.135 \text{ W/(m·K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

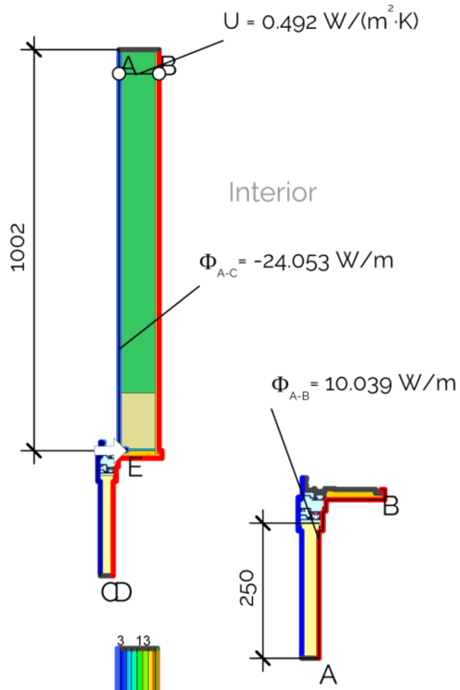


70 WITO Window Top (Head) Thermally broken aluminium current practice install frame face flush with cladding

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.208 W/(mK)	0.208 W/(mK)
f_{RSI}	0.302	
Cost	Not calculated	
Carbon	Not calculated	

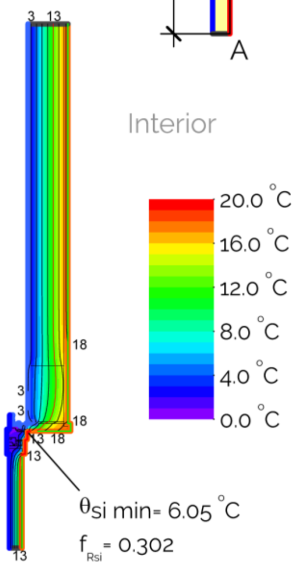
Current practice install of a thermally broken aluminium-framed window head on a ventilated cavity with the face of the window installed flush with the cladding. This is the most common install but it creates a significant thermal bridge and a very low fRSI value.



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

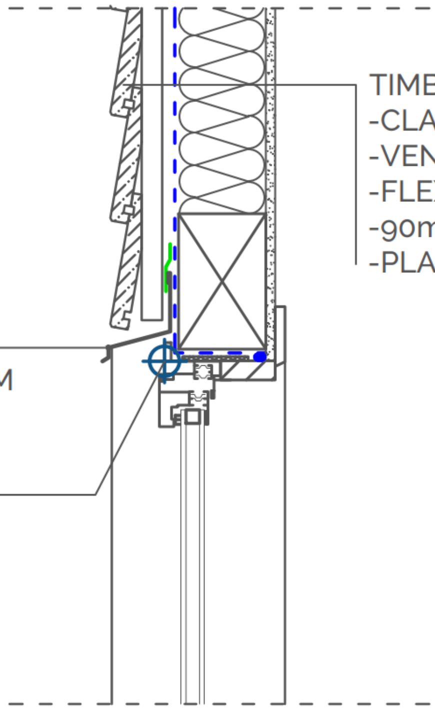
Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR2.2/90mm+12%Timber	0.052
PUGunFoam	0.032
Panel	0.035
Plasterboard	0.250
Polyamid (nylon)	0.250
Timber (Softwood)	0.130
Window Liner	0.120
Slightly ventilated air cavity *	
Unventilated air cavity *	

* Simplified approach



$$\psi_{A\text{-}E\text{-}C,'} = \frac{24.053}{20.000} - 0.492 \cdot 1.002 - \frac{10.039}{20.000} = 0.208\ \text{W/(m·K)}$$

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

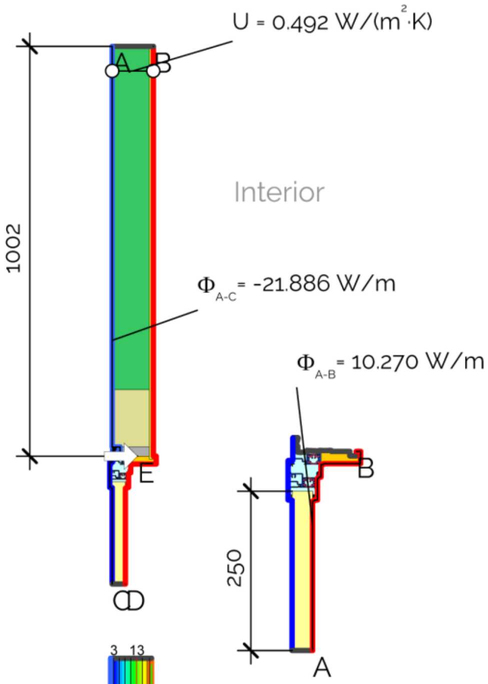


71 WITO Window Top (Head) - Thermally broken alum recessed frame face flush with thermal envelope exterior

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.088 W/(mK)	0.088 W/(mK)
f_{RSI}	0.422	
Cost	Not calculated	
Carbon	Not calculated	

Recessed install of a thermally broken aluminum framed window head on a ventilated cavity with the face of the window even with the outside of the thermal envelope. This is a significant improvement over fixing even with the cladding but due to the small thermal break still yields a low fRSI value.

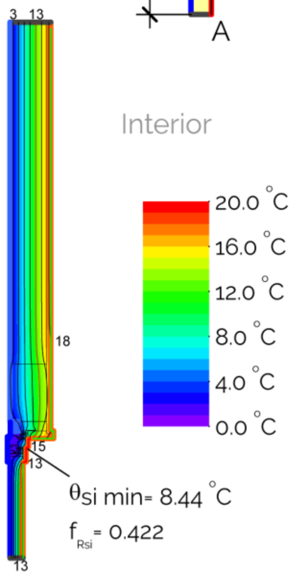


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

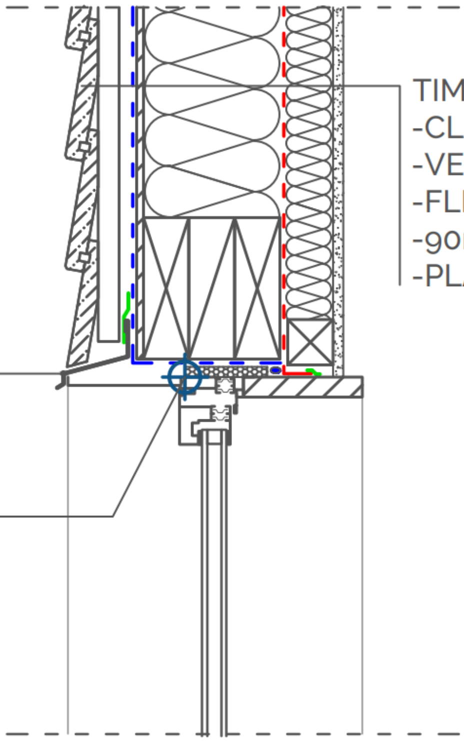
Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR2.2/90mm+12%Timber	0.052
PU Foam	0.040
Panel	0.035
Plasterboard	0.250
Polyamid (nylon)	0.250
Timber (Softwood)	0.130
Window Liner	0.120
Unventilated air cavity *	

* Simplified approach

$$\psi_{A\text{-}E\text{-}C,\cdot} = \frac{21.886}{20.000} - 0.492 \cdot 1.002 - \frac{10.270}{20.000} = 0.088\ \mathrm{W/(m \cdot K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

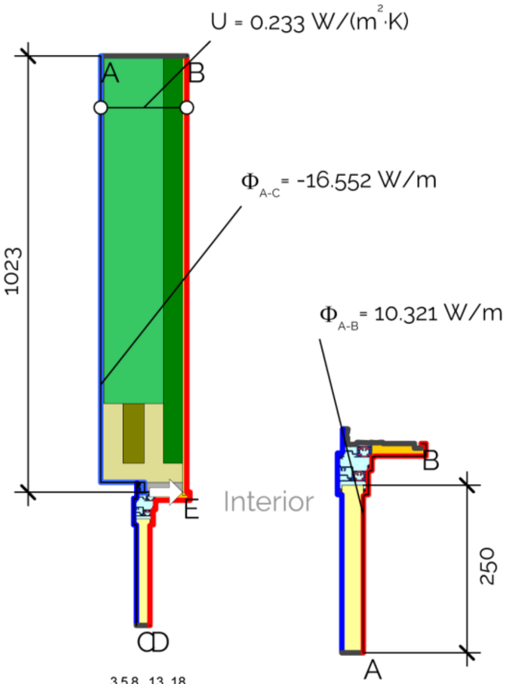


72 WITO Window Top (Head) - Thermally broken aluminium recessed frame to middle of 140/45 wall

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.074 W/(mK)	0.074 W/(mK)
f_{RSI}	0.421	
Cost	Not calculated	
Carbon	Not calculated	

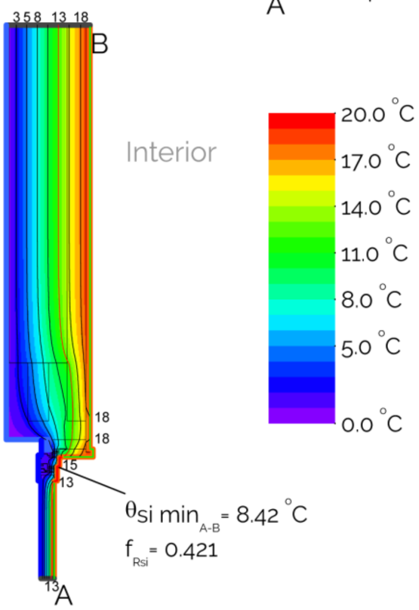
Recessed install of a thermally-broken aluminium-framed window head on a ventilated cavity with the window centred in the thermal envelope thickness. This is only a slight improvement over fixing flush with the outside of the thermal envelope. Due to the small thermal break, it still yields a low fRSI value.



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

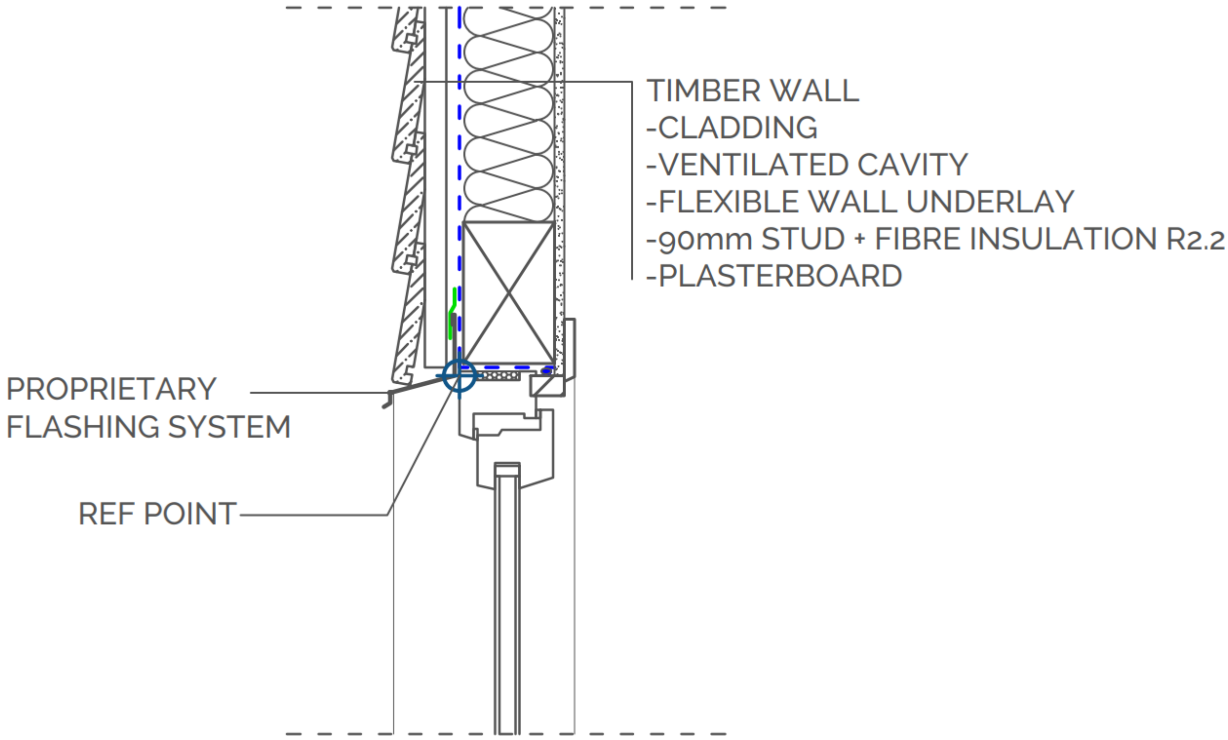
Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR1.2/50mm+50%Timber	0.086
FibreInsulR4.0/140mm+12%Timber	0.046
PU Foam	0.040
Panel	0.035
Plasterboard	0.250
Polyamid (nylon)	0.250
Timber (Softwood)	0.130
Window Liner	0.120
Unventilated air cavity *	

* Simplified approach



$$\psi_{A\text{-}E\text{-}C,\,\text{-}} = \frac{16.552}{20.000} - 0.233 \cdot 1.023 - \frac{10.321}{20.000} = 0.074\ \text{W/(m·K)}$$

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

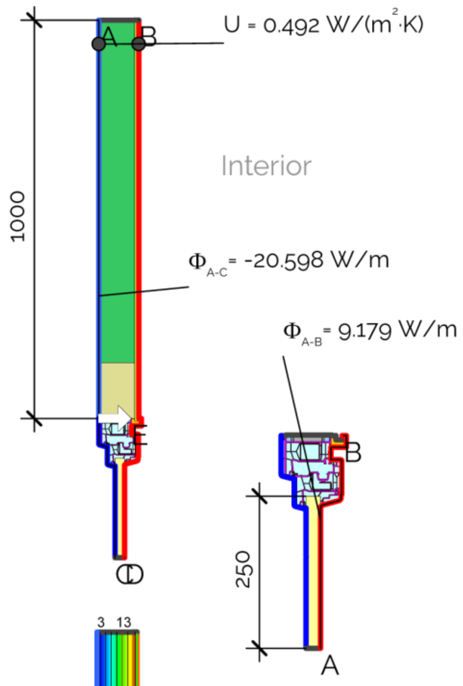


73 WITO Window Top (Head) - uPVC recessed frame face flush with thermal envelope exterior

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.079 W/(mK)	0.079 W/(mK)
f_{RSI}	0.648	
Cost	Not calculated	
Carbon	Not calculated	

Recessed install of a uPVC-framed window head on a ventilated cavity, with the face of the window installed flush with the outside of the thermal envelope.

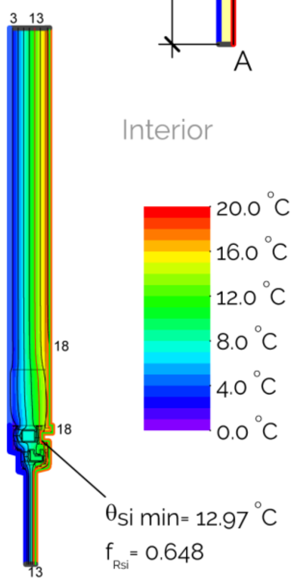


Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

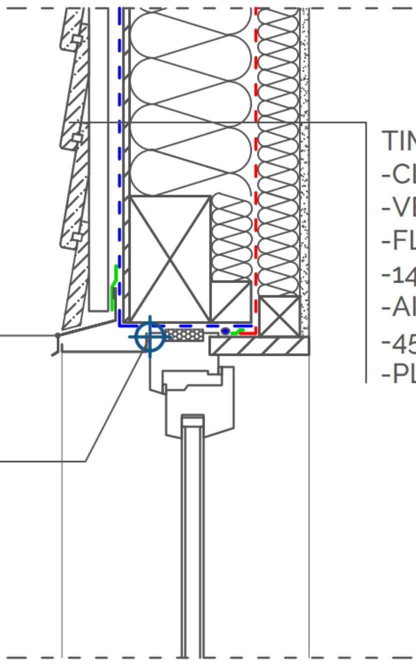
Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR2.2/90mm+12%Timber	0.052
PU Foam	0.040
PVC (polyvinylchloride), rigid	0.170
Panel	0.035
Plasterboard	0.250
Steel	50.000
Timber (Softwood)	0.130
Window Liner	0.120
Slightly ventilated air cavity *	
Unventilated air cavity *	

* Simplified approach

$$\Psi_{A\text{-}E\text{-}C,} = \frac{20.598}{20.000} - 0.492 \cdot 1.000 - \frac{9.179}{20.000} = 0.079\ \mathrm{W/(m \cdot K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

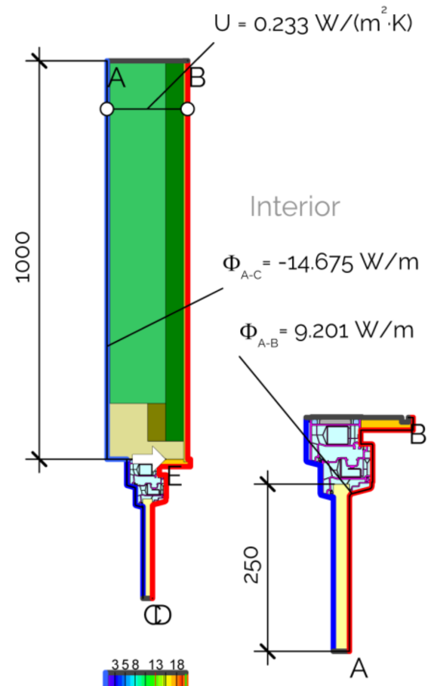


74 WITO Window Top (Head) - uPVC recessed frame to middle of 140/45 wall

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.041 W/(mK)	0.041 W/(mK)
f_{RSI}	0.639	
Cost	Not calculated	
Carbon	Not calculated	

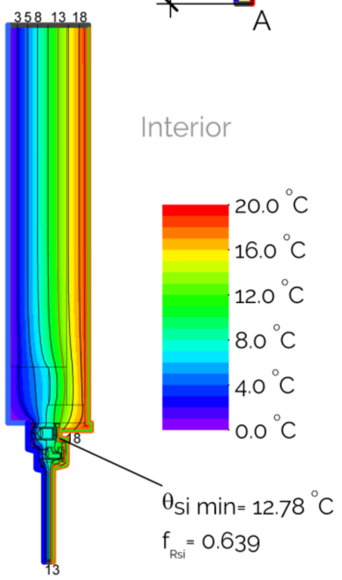
Recessed install of a uPVC-framed window head on a ventilated cavity with the window centred in the thermal envelope thickness. Note that this is only a slight improvement over fixing flush with the outside of the thermal envelope .



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

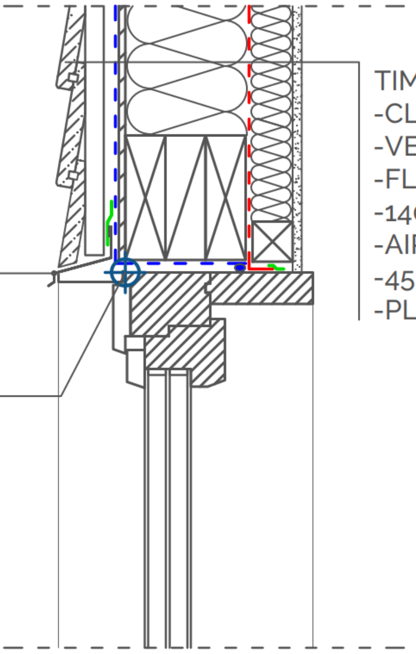
Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR1.2/50mm	0.048
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
PU Foam	0.040
PVC (polyvinylchloride), rigid	0.170
Panel	0.035
Plasterboard	0.250
Steel	50.000
Timber (Softwood)	0.130
Window Liner	0.120
Slightly ventilated air cavity *	
Unventilated air cavity *	

* Simplified approach



$$\Psi_{A\text{-}E\text{-}C'} = \frac{14.675}{20.000} - 0.233 \cdot 1.000 - \frac{9.201}{20.000} = 0.041\ W/(m \cdot K)$$

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

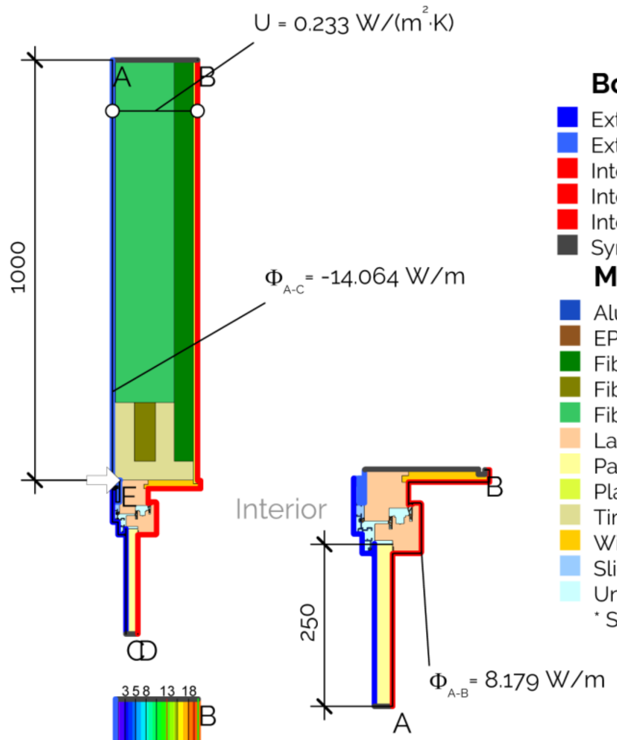


75 WITO Window Top (Head) - Timber window recessed frame aluminium flashing face flush with thermal envelope exterior

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.062 W/(mK)	0.062 W/(mK)
f_{RSI}	0.687	
Cost	Not calculated	
Carbon	Not calculated	

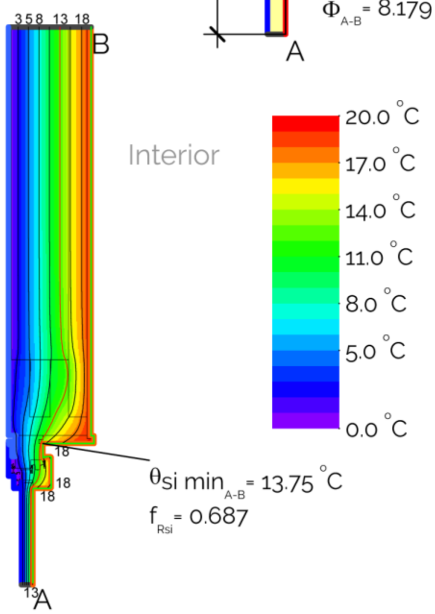
Recessed install of an aluminium-clad timber-framed window head on a ventilated cavity, with the face of the window flush with the outside of the thermal envelope.



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

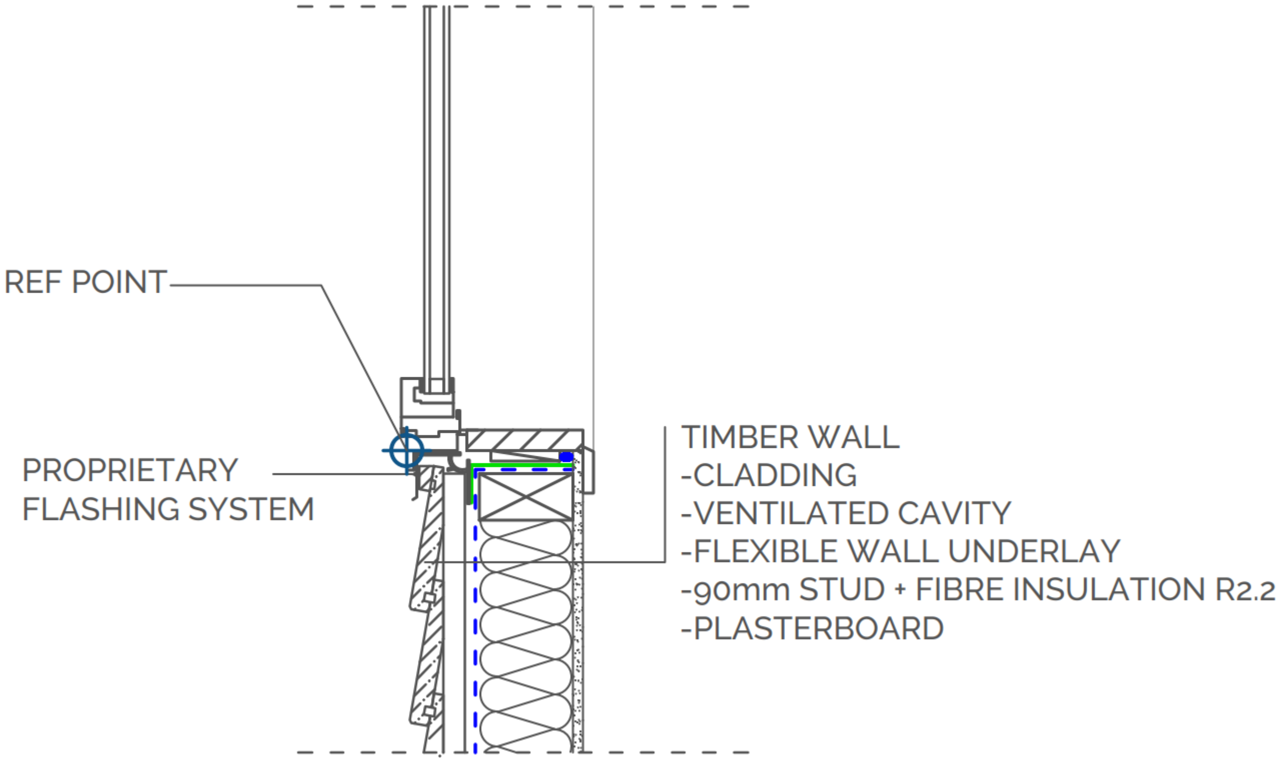
Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR1.2/50mm+50%Timber	0.086
FibreInsulR4.0/140mm+12%Timber	0.046
Larch	0.110
Panel	0.035
Plasterboard	0.250
Timber (Softwood)	0.130
Window Liner	0.120
Slightly ventilated air cavity *	
Unventilated air cavity *	

* Simplified approach



$$\psi_{A\text{-}E\text{-}C,} = \frac{14.064}{20.000} - 0.233 \cdot 1.000 - \frac{8.179}{20.000} = 0.062 \text{ W/(m·K)}$$

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

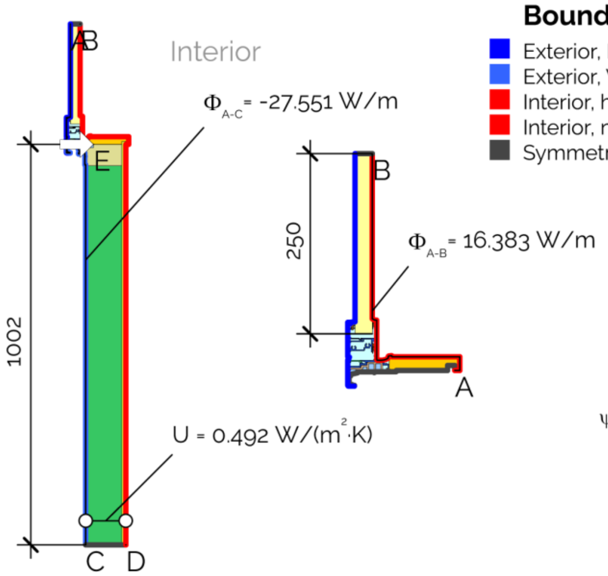


76 WIBO Window Bottom (Sill) - Solid aluminium current practice install frame face flush with cladding

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.065 W/(mK)	0.065 W/(mK)
f_{RSI}	0.127	
Cost	Not calculated	
Carbon	Not calculated	

Current practice install of a Code-minimum solid aluminium-framed window sill without a thermal break) on a ventilated cavity, with the face of the window even with the cladding. This is the most common install but it creates a significant thermal bridge and a very low fRSI value.



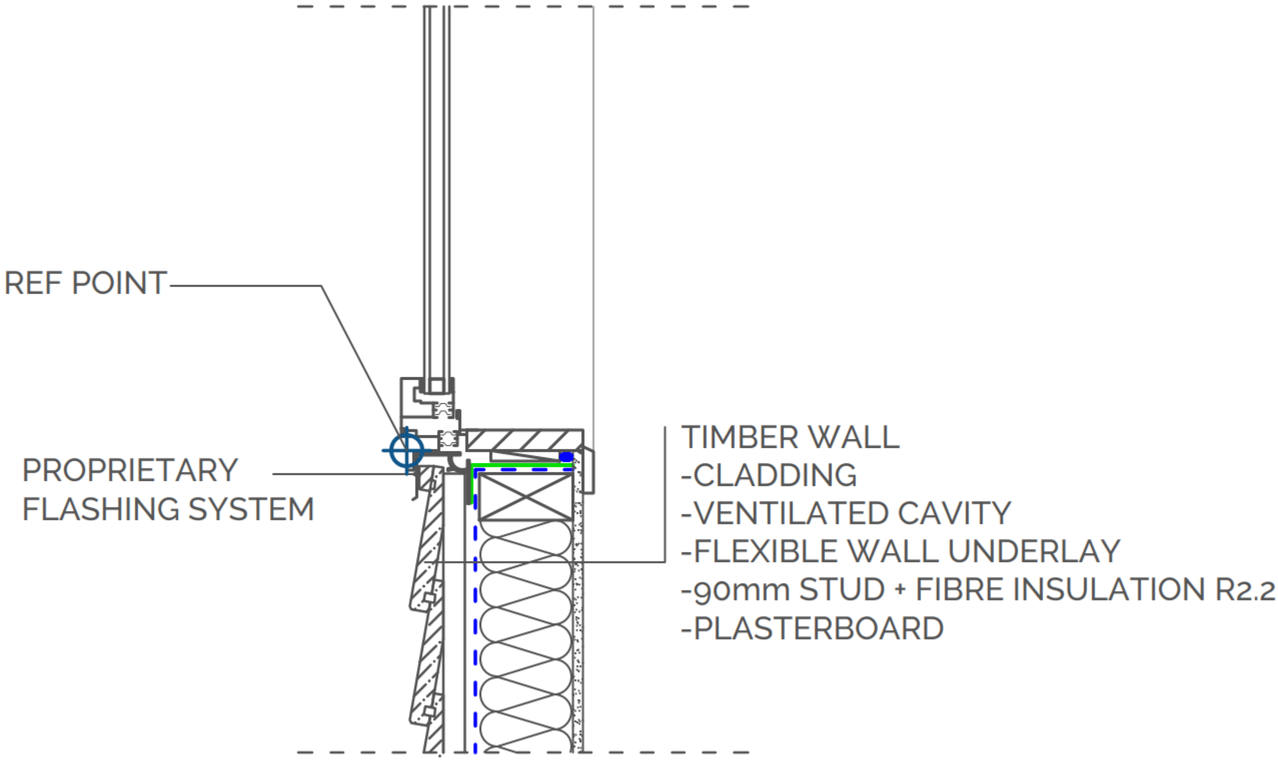
Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

$$\psi_{A\text{-}E\text{-}C,\cdot} = \frac{27.551}{20.000} - \frac{16.383}{20.000} - 0.492 \cdot 1.002 = 0.065 \text{ W/(m·K)}$$

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR2.2/90mm+12%Timber	0.052
PVC-U (polyvinylchloride), rigid	0.170
Panel	0.035
Plasterboard	0.250
Polyethylene HD, high density	0.500
Timber (Softwood)	0.130
Window Liner	0.120
Slightly ventilated air cavity *	
Unventilated air cavity *	

* Simplified approach

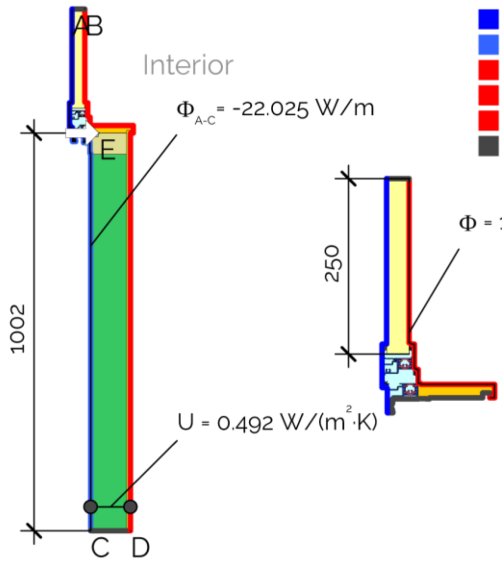


77 WIBO Window Bottom (Sill) - Thermally broken aluminium current practice install frame face even with cladding

RESULTS TABLE

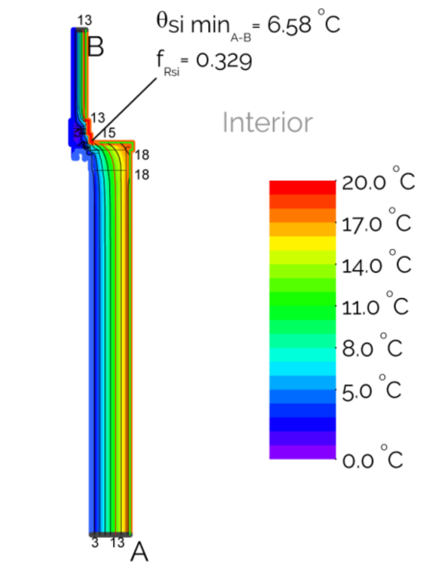
Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.106 W/(mK)	0.106 W/(mK)
f_{RSI}	0.329	
Cost	Not calculated	
Carbon	Not calculated	

Current practice install of a thermally-broken aluminium-framed window sill on a ventilated cavity with the face of the window installed flush with the cladding. This is the most common install but it creates a significant thermal bridge and a very low fRSI value.



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

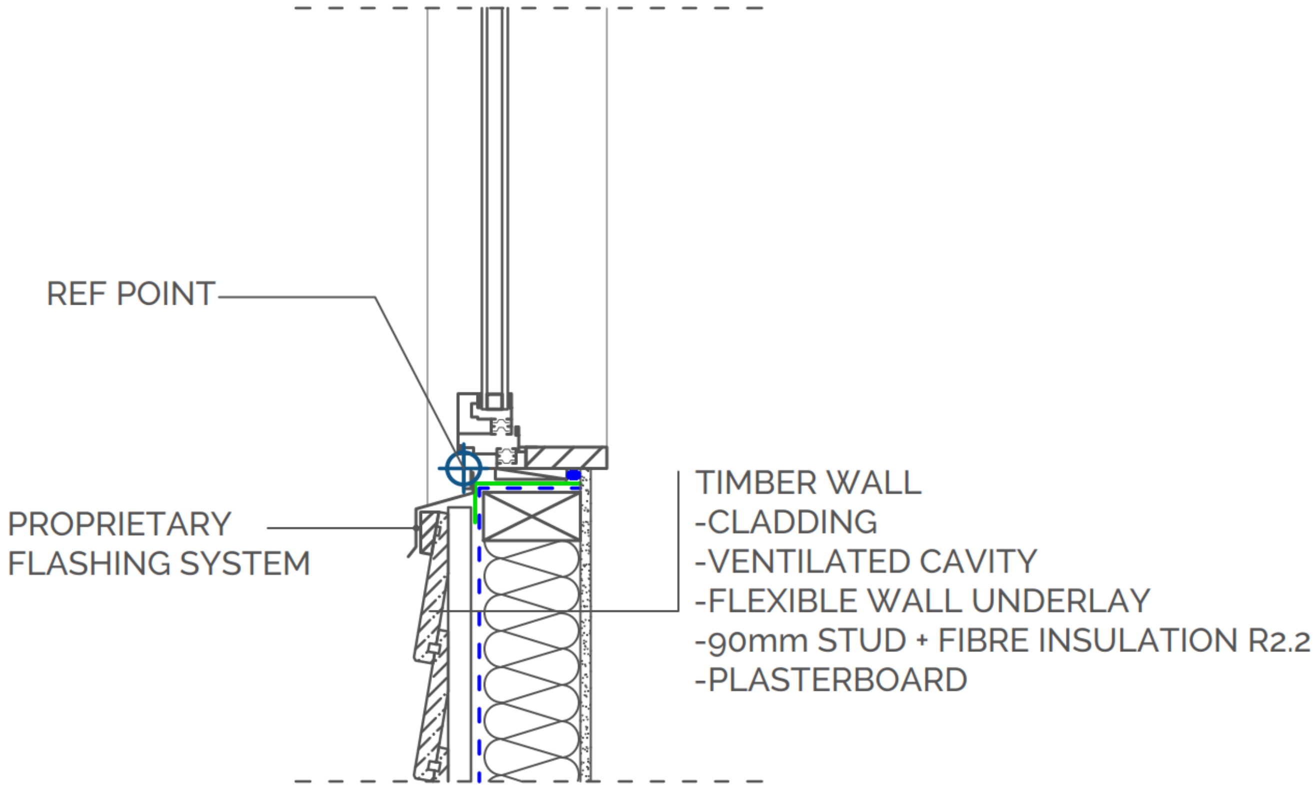
$$\Psi_{A\text{-}E\text{-}C} = \frac{22.025}{20.000} - \frac{10.034}{20.000} - 0.492 \cdot 1.002 = 0.106 \text{ W/(m·K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR2.2/90mm+12%Timber	0.052
Panel	0.035
Plasterboard	0.250
Polyamid (nylon)	0.250
Timber (Softwood)	0.130
Window Liner	0.120
Slightly ventilated air cavity *	
Unventilated air cavity *	

* Simplified approach

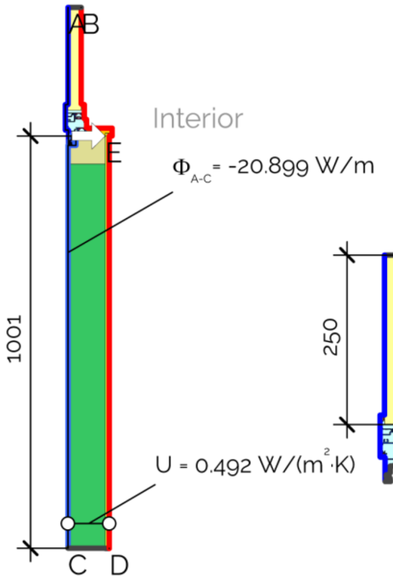


78 WIBO Window Bottom (Sill) - Thermally broken aluminium recessed frame face flush with thermal envelope exterior

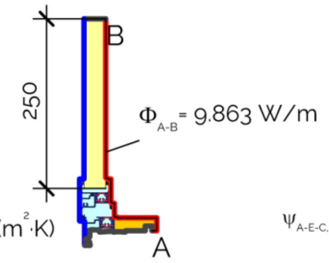
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.059 W/(mK)	0.059 W/(mK)
f_{RSI}	0.421	
Cost	Not calculated	
Carbon	Not calculated	

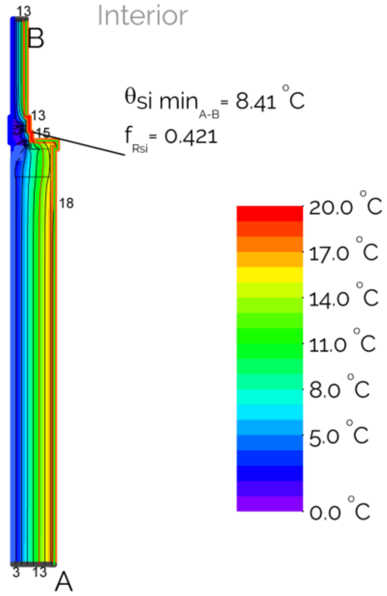
Recessed install of a thermally-broken aluminium-framed window sill on a ventilated cavity, with the face of the window installed flush with the outside of the thermal envelope. This is a significant improvement over fixing flush with the cladding but due to the small thermal break, it still produces a low fRSI value.



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		



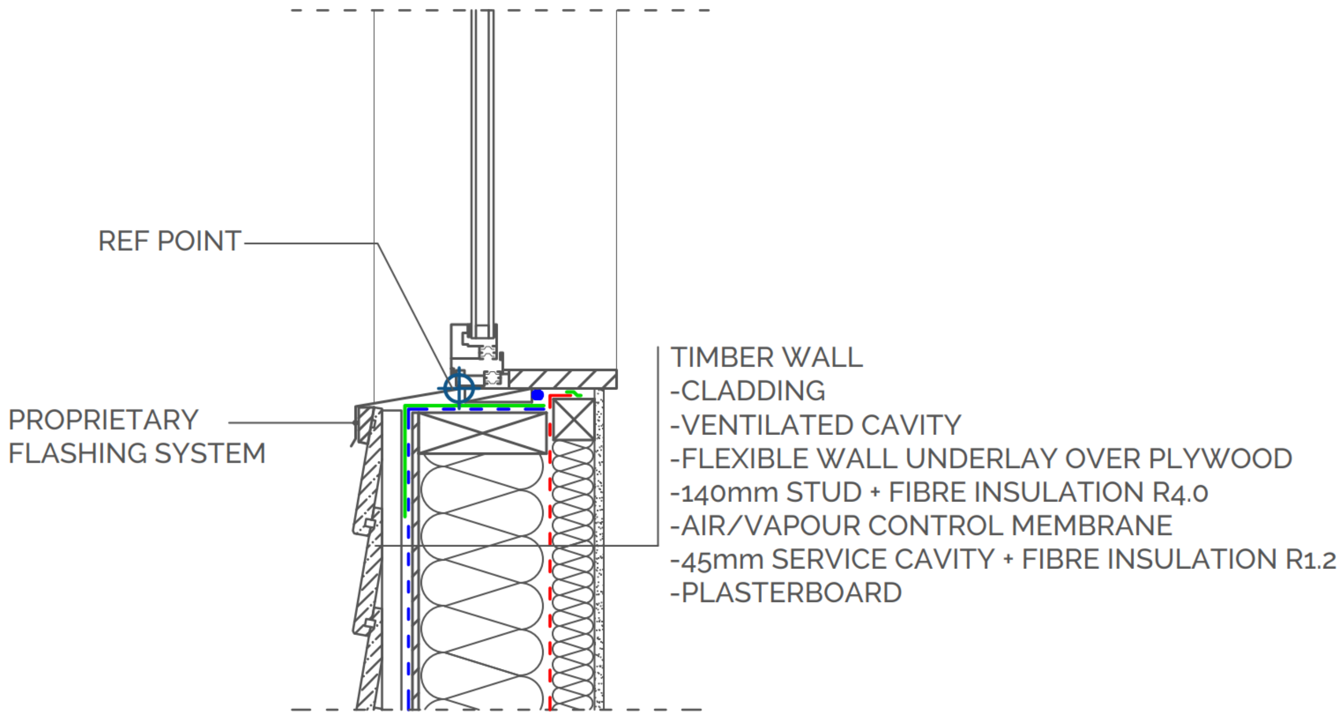
$$\psi_{A-E-C,\cdot} = \frac{20.899}{20.000} - \frac{9.863}{20.000} - 0.492 \cdot 1.001 = 0.059\ \text{W/(m·K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR2.2/90mm+12%Timber	0.052
Panel	0.035
Plasterboard	0.250
Polyamid (nylon)	0.250
Timber (Softwood)	0.130
Winow Liner	0.120
Unventilated air cavity *	

* Simplified approach

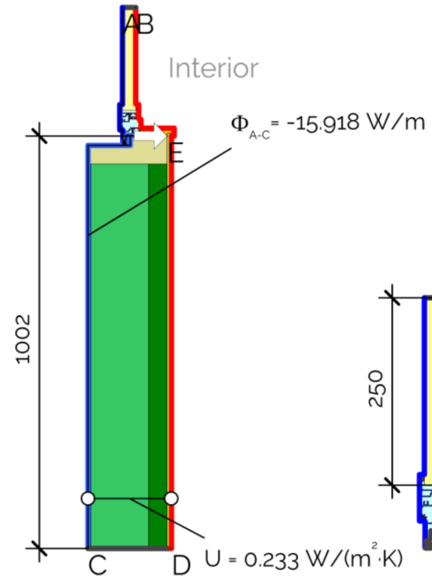


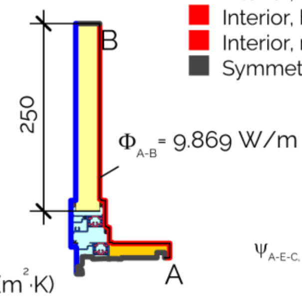
79 WIBO Window Bottom (Sill) - Thermally broken aluminium recessed frame to middle of 140/45 wall

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.069 W/(mK)	0.069 W/(mK)
f_{RSI}	0.419	
Cost	Not calculated	
Carbon	Not calculated	

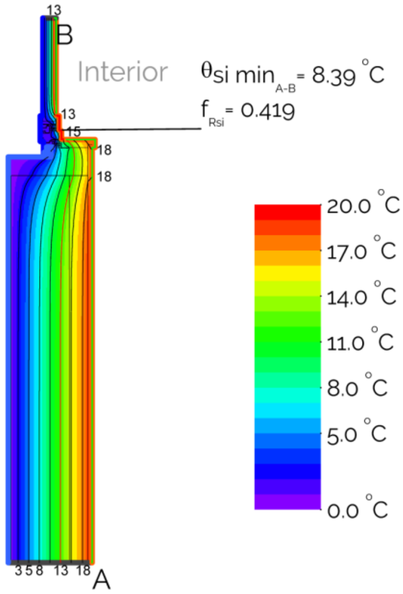
Recessed install of a thermally-broken aluminium-framed window sill on a ventilated cavity with the window centred in the thermal envelope thickness. This is only a slight improvement over fixing flush with the outside of the thermal envelope. Due to the small thermal break, it still produces a low fRSI value.





Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

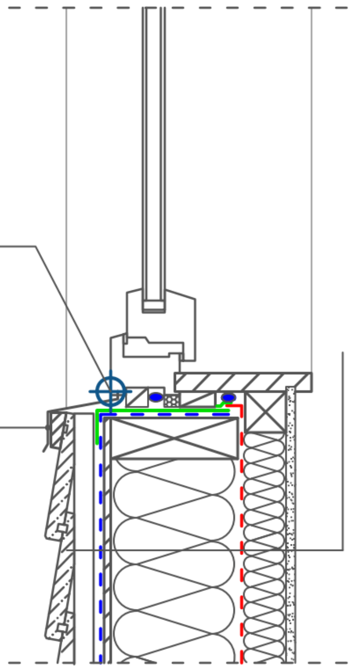
$$\psi_{A-E-C'} = \frac{15.918}{20.000} - \frac{9.869}{20.000} - 0.233 \cdot 1.002 = 0.069\ W/(m \cdot K)$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
Panel	0.035
Plasterboard	0.250
Polyamid (nylon)	0.250
Timber (Softwood)	0.130
Window Liner	0.120
Unventilated air cavity *	

* Simplified approach

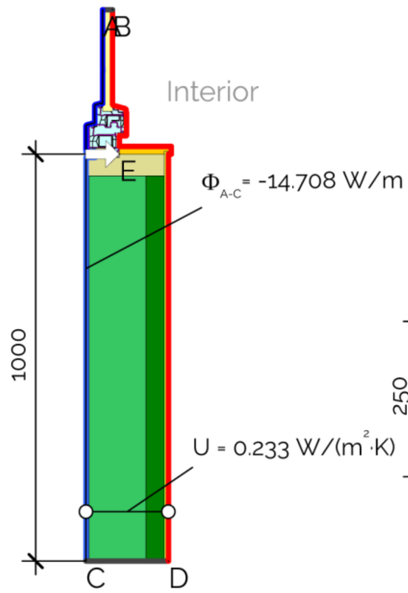


80 WIBO Window Bottom (Sill) - uPVC recessed frame face flush with thermal envelope exterior

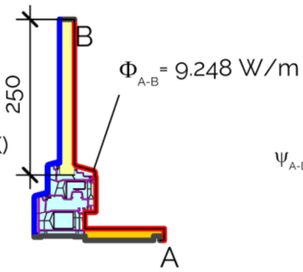
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.040 W/(mK)	0.040 W/(mK)
f_{RSI}	0.624	
Cost	Not calculated	
Carbon	Not calculated	

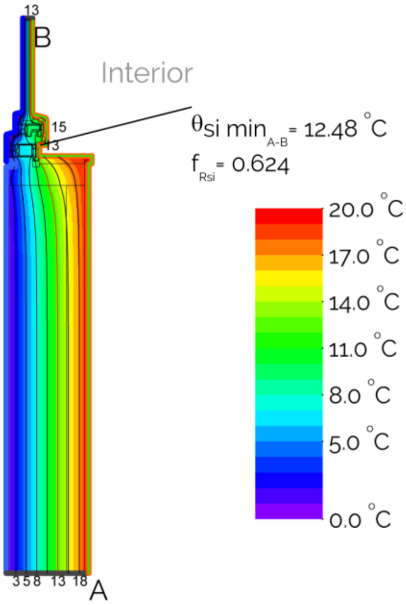
Recessed install of a uPVC-framed window head on a ventilated cavity with the face of the window installed flush with the outside of the thermal envelope to improve performance.



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		



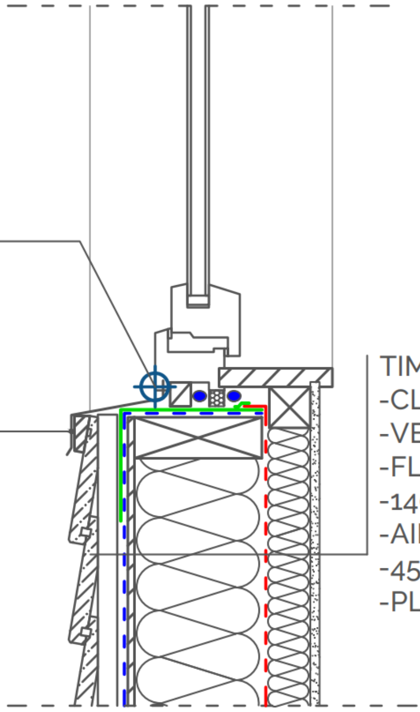
$$\Psi_{A\text{-}E\text{-}C,^*} = \frac{14.708}{20.000} - \frac{9.248}{20.000} - 0.233 \cdot 1.000 = 0.040\ \mathrm{W/(m\cdot K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
PU Foam	0.040
PVC (polyvinylchloride), rigid	0.170
Panel	0.035
Plasterboard	0.250
Steel	50.000
Timber (Softwood)	0.130
Window Liner	0.120
Slightly ventilated air cavity *	
Unventilated air cavity *	

* Simplified approach

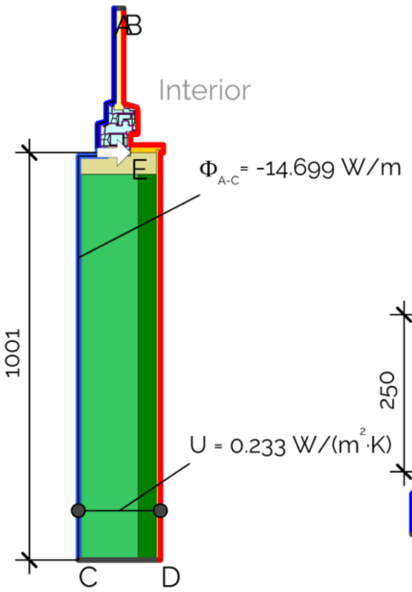


81 WIBO Window Bottom (Sill) - uPVC recessed frame to middle of 140/45 wall

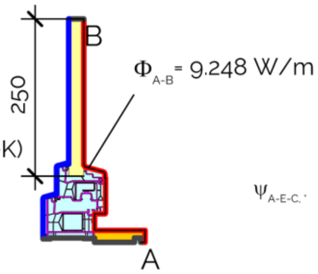
RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.040 W/(mK)	0.040 W/(mK)
f_{RSI}	0.631	
Cost	Not calculated	
Carbon	Not calculated	

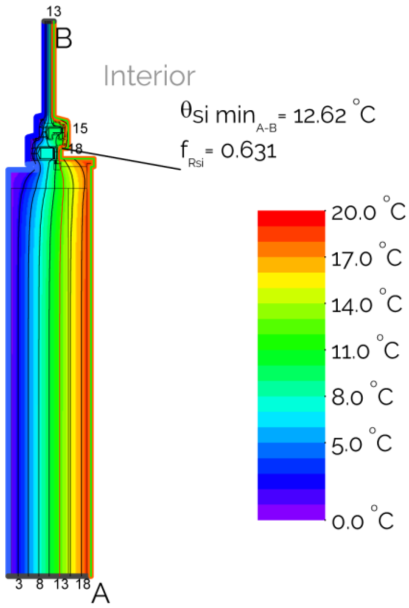
Recessed install of a uPVC-framed window sill on a ventilated cavity with the window centred in the thermal envelope thickness. This is only a slight improvement over fixing flush with the outside of the thermal envelope.



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		



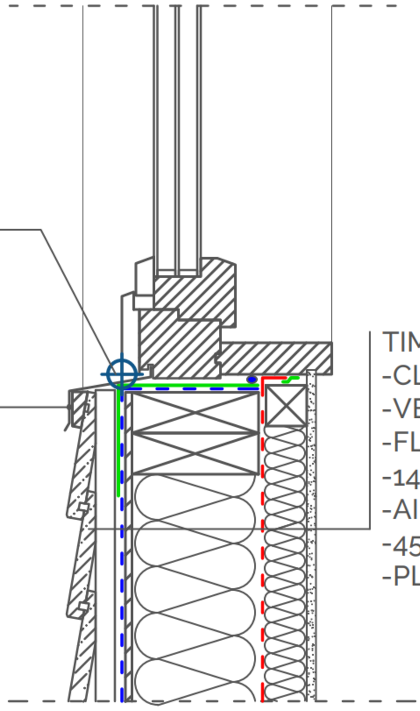
$$\Psi_{A\text{-}E\text{-}C'} = \frac{14.699}{20.000} - \frac{9.248}{20.000} - 0.233 \cdot 1.001 = 0.040\ W/(m \cdot K)$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
PU Foam	0.040
PVC (polyvinylchloride), rigid	0.170
Panel	0.035
Plasterboard	0.250
Steel	50.000
Timber (Softwood)	0.130
Window Liner	0.120
Slightly ventilated air cavity *	
Unventilated air cavity *	

* Simplified approach

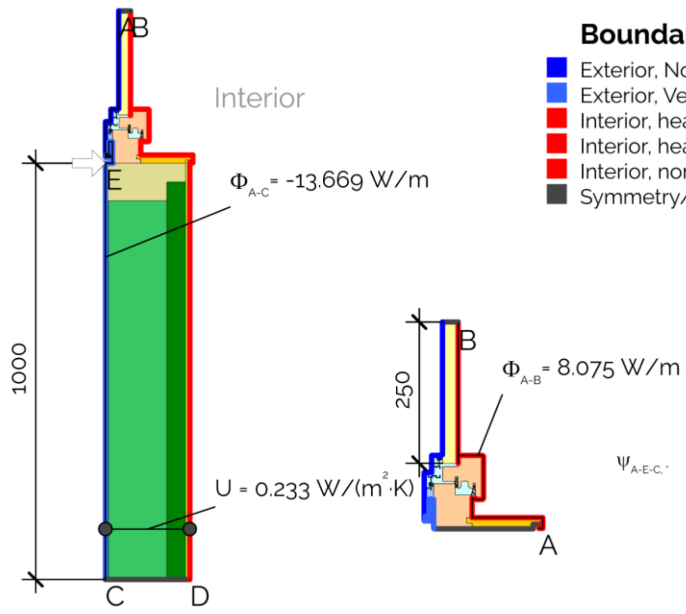


82 WIBO Window Bottom (Sill) - Timber window recessed frame aluminum flashing face even with thermal envelope exterior

RESULTS TABLE

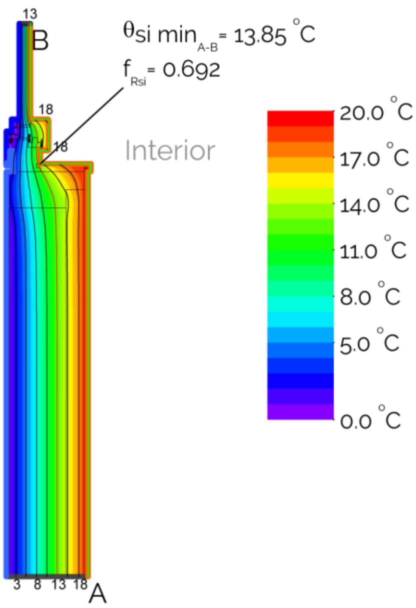
Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.047 W/(mK)	0.047 W/(mK)
f_{RSI}	0.692	
Cost	Not calculated	
Carbon	Not calculated	

Recessed install of an aluminium-clad timber-framed window sill on a ventilated cavity with the face of the window installed flush with the outside of the thermal envelope.



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, heat flux, upwards		20.000	0.100
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		

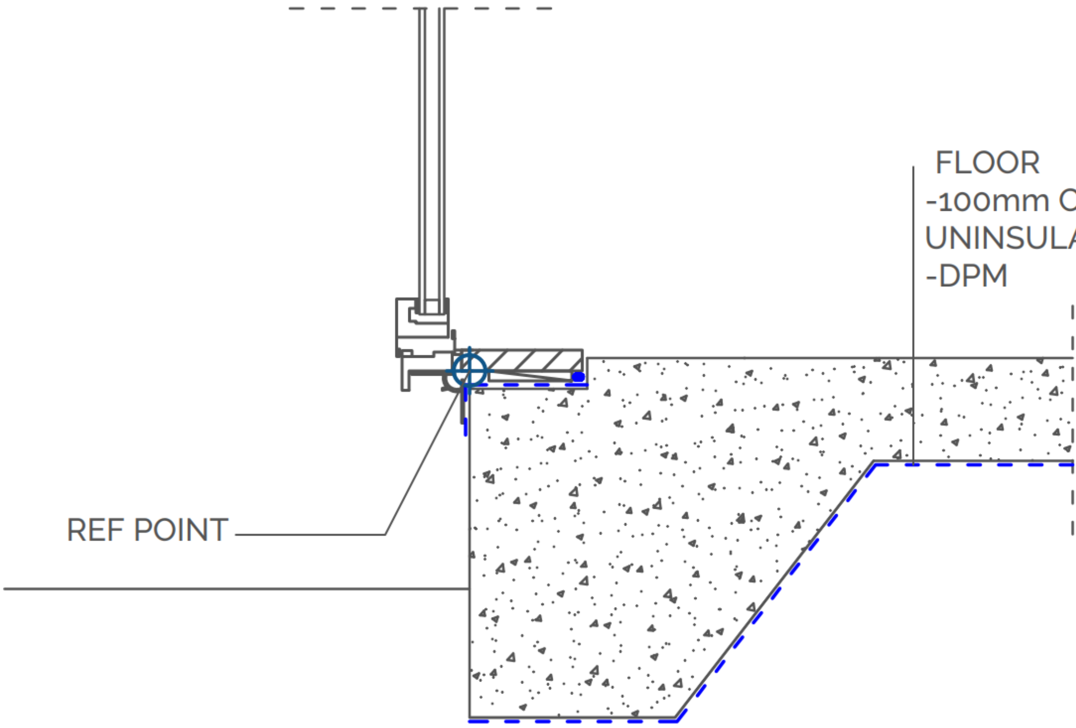
$$\psi_{A-E-C} = \frac{13.669}{20.000} - \frac{8.075}{20.000} - 0.233 \cdot 1.000 = 0.047 \text{ W/(m·K)}$$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		

Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
EPDM (ethylene propylene diene monomer)	0.250
FibreInsulR1.2/50mm+10%Timber	0.050
FibreInsulR4.0/140mm+12%Timber	0.046
Larch	0.110
Panel	0.035
Plasterboard	0.250
Timber (Softwood)	0.130
Window Liner	0.120
Slightly ventilated air cavity *	
Unventilated air cavity *	

* Simplified approach



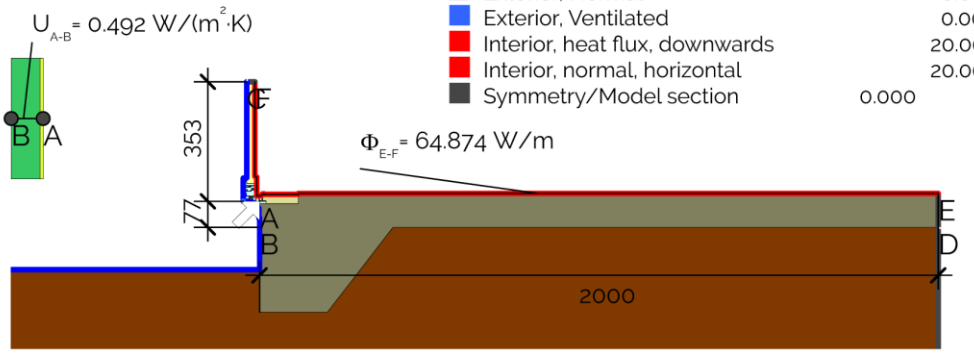
83 WITH Window Threshold or Door Threshold - Solid aluminium current practice install frame face flush with cladding

RESULTS TABLE

Ψ	EXTERIOR REFERENCE AREA (PH)	INTERNAL REFERENCE AREA
	0.225 W/(mK)	0.225 W/(mK)
f_{RSI}	0.139	
Cost	Not calculated	
Carbon	Not calculated	

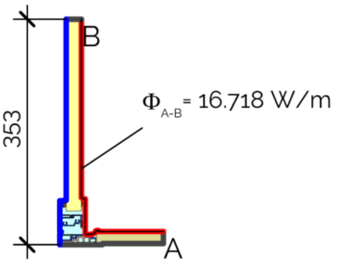
Current practice installation of a Code-minimum aluminium-framed window or door sill overhanging the concrete slab edge on an solid aluminium support bar without a thermal break. This is the most common install but causes a very low fRSI value.

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, heat flux, downwards		20.000	0.170
Interior, normal, horizontal		20.000	0.130
Symmetry/Model section	0.000		



$$\psi_{C\text{-}A\text{-}D,\,*} = \frac{64.874}{20.000} - \frac{16.718}{20.000} - 0.492 \cdot 0.077 - \frac{42.888}{20.000} = 0.225\ \mathrm{W/(m \cdot K)}$$

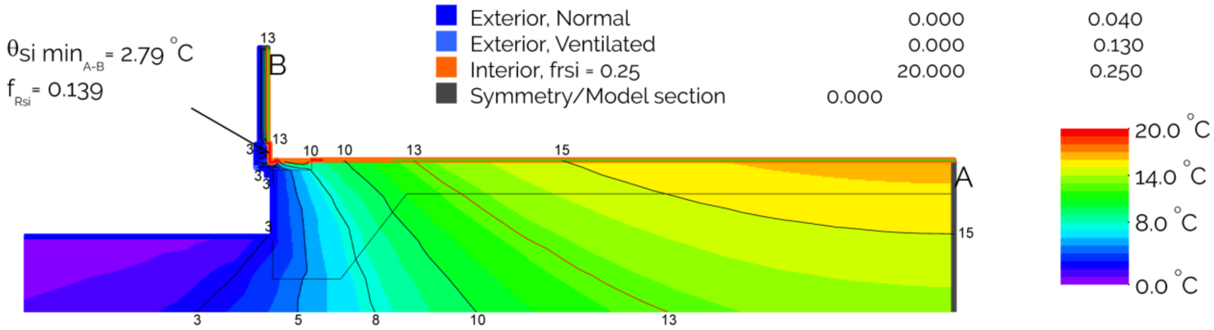
Ψ WITH= 0.225W/(mK)-0.223W/(mK)= +0.002W/(mK)



Material	λ[W/(m·K)]
Aluminium (Si Alloys)	160.000
Concrete	2.100
EPDM (ethylene propylene diene monomer)	0.250
Ground	2.000
PVC-U (polyvinylchloride), rigid	0.170
Panel	0.035
Polyethylene HD, high density	0.500
Timber (Softwood)	0.130
Slightly ventilated air cavity *	
Unventilated air cavity *	

* Simplified approach

Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, Normal		0.000	0.040
Exterior, Ventilated		0.000	0.130
Interior, frsi = 0.25		20.000	0.250
Symmetry/Model section	0.000		



Methodology notes

The thermal bridge calculations are using ISO10211:2007 and/or 10077-2:2012 using ISO6946:2007. Mixed materials are calculated using ISO6946:2007 as well as ventilated cavities.

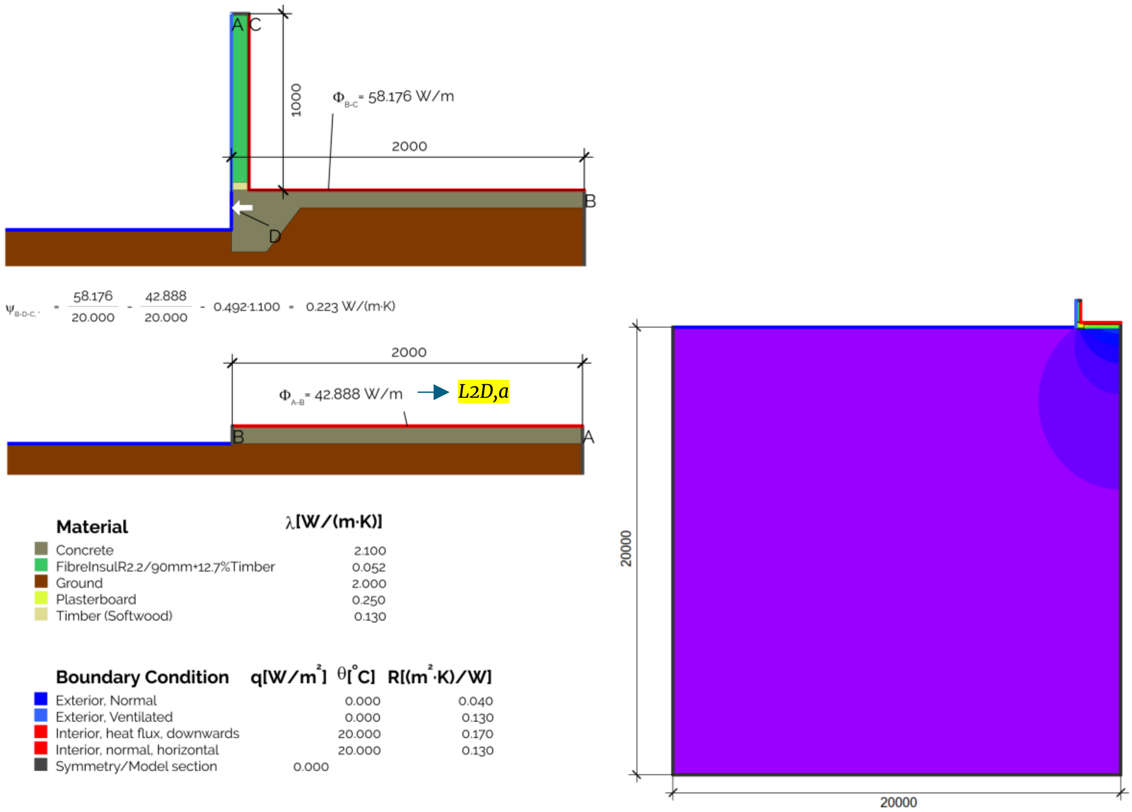
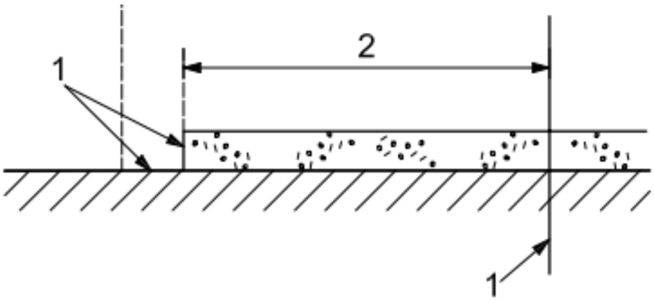


Figure 17: In the interest of space in the details the full model with ground elements are not shown. This figure shows how the ground element was taken as 20m by 20m in all cases. Also note that the slab A/P=B'/2=2m in all Junctions modelled.

Slab edges are calculated using the PHI practice which differs slightly from the ISO10211:2007 as there are some differences in the interpretation of the way to model the base of the wall. Note in ISO10211:2017 the methodology was changed to more accurately account for the slab height above or below ground. The PHI practice is to calculate the *L2D,a* as a surface film with an equivalent R-value to the slab construction (neglecting the effects of the ground) or as a slab construction layers on top of the ground with and adiabatic edge as shown in Figure 17 above. The practice in ISO10211:2007 would be to remove the slab construction under the wall width and apply an adiabatic boundary condition to the edge and width as shown in the Figure 18 below.



Key

1 adiabatic boundary

2 0,5 × *B′* or 4 m

Figure 18: Slab edge detail used in ISO10211:2007 to calculate the *L2D,a*. Note the adiabatic edge (vertical on the slab edge and below where the wall was removed. This is Figure 16 from ISO10211:2007.

Contact resistances are neglected in the application of ISO10211:2007 / ISO6946:2007. As these typically are negligible except in steel-to-steel connections.

Fixing bolts and discontinuous hardware, such as bottom plate hold-down bolts, window hinges and window latches, are not considered except where stated otherwise.

Suspended floors calculated using ISO13370:2007 Section 9.2 Suspended Floors. Using U-value crawl space floor U_{crawl}=5.9 W/(m^{2}K), height of crawl space wall 0.6m, U-value of crawl space wall U_w=3.5 W/(m^{2}K). Wind velocity at 10m height v=4.0 m/s, wind shield factor f_w=0.02, 0.05, and 0.1 for Sheltered, Average and Exposed building sites. Note wall thickness was varied but the results are nearly identical and only the 100mm thick wall is shown.

Software used for thermal modelling included PHPP, Flixo, UcanPSI and Mold3D

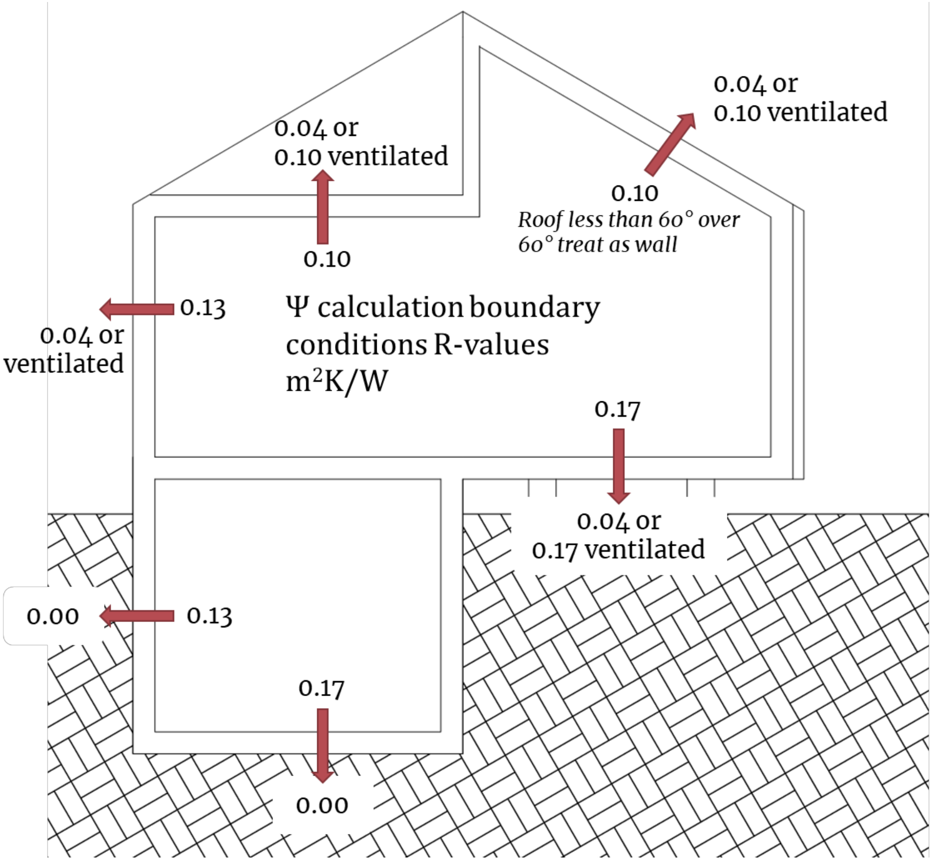


Figure 19: Air film surface resistances using ISO6946:2007. These were used for all Elements and Junctions. They differ only slightly from the NZS standard values.

References

NZS 4214:2006, *Methods of determining the total thermal resistance of parts of buildings*

Provides methods of determining the thermal resistance of building components and elements consisting of thermally homogeneous layers, in steady-state environmental conditions.

NZS 4218:2009, *Thermal insulation – Housing and small buildings*

Specifies the thermal insulation requirements for housing and small buildings. It provides three methods for demonstrating compliance with the New Zealand Building Code: Schedule, Calculation and Modelling methods.

ISO 6946:2007 (withdrawn), *Building components and building elements – Thermal resistance and thermal transmittance – Calculation method*

ISO 10077-1:2006 (withdrawn), *Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part1: General*

Author's Note: This adds up the areas for the different parts of window/doors. The calculations performed in PHPP are per this standard.

ISO 10077-2:2012 (withdrawn), *Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 2: Numerical method for frames*

Author's Note: This is for details of Uf and PSI glazing edge calculations

ISO 10211:2007 (withdrawn), *Thermal bridges in building construction – Heat flows and surface temperatures – Detailed calculations*

Abstract (abridged)

ISO 10211:2007 sets out the specifications for a three-dimensional and a two-dimensional geometrical model of a thermal bridge for the numerical calculation of:

- heat flows, in order to assess the overall heat loss from a building or part of it;
- minimum surface temperatures, in order to assess the risk of surface condensation.

These specifications include the geometrical boundaries and subdivisions of the model, the thermal boundary conditions, and the thermal values and relationships to be used.

ISO 10211:2017, *Thermal bridges in building construction – Heat flows and surface temperatures – Detailed calculations*

ISO 13370:2007 (withdrawn), *Thermal performance of buildings – Heat transfer via the ground – Calculation methods*

Abstract (abridged)

Provides methods of calculation of heat transfer coefficients and heat flow rates for building elements in thermal contact with the ground, including slab-on-ground floors, suspended floors and basements. It applies to building elements, or parts of them, below a horizontal plane in the bounding walls of the building situated

- for slab-on-ground floors, suspended floors and unheated basements, at the level of the inside floor surface;

Includes calculation of the steady-state part of the heat transfer (the annual average rate of heat flow) and the part due to annual periodic variations in temperature (the seasonal variations of the heat flow rate about the annual average). These seasonal variations are obtained on a monthly basis and, except for the application to dynamic simulation programmes in Annex D, does not apply to shorter periods of time.

Author's Note: This is the methodology used (revised and enhanced through Passive House Institute's own research) for the ground sheet in PHPP.

ISO 13370:2017 *Thermal performance of buildings – Heat transfer via the ground – Calculation methods*

Abstract As for ISO 13370:2007 but with the addition of:

NOTE 1 In some cases, external dimension systems define the boundary at the lower surface of the floor slab.

Author's Note: This is the methodology (not the PHPP methodology) that was used with, in some cases additional simplifications, to calculate the slab and suspended floor element R-values.

ISO 13789:1999 (withdrawn), *Thermal performance of buildings — Transmission heat loss coefficient — Calculation method*

Abstract (abridged)

Specifies a method and provides conventions for the calculation of the transmission heat loss coefficient of buildings and parts of buildings. Heat loss by ventilation is not within the scope of this standard. However, in order to evaluate transmission heat loss through unheated spaces, this standard gives conventional values of air change rates of such spaces.

Author's Note: This is the methodology used by PHPP (revised and enhanced through Passive House Institute's own research).

ISO 13789:2007, *Thermal performance of buildings — Transmission heat loss coefficient — Calculation method*

Abstract (abridged)

Specifies a method and provides conventions for the calculation of the steady-state transmission and ventilation heat transfer coefficients of whole buildings and parts of buildings. It is applicable both to heat loss (internal temperature higher than external temperature) and to heat gain (internal temperature lower than external temperature).

ISO 14683:2017, *Thermal bridges in building construction – Linear thermal transmittance – Simplified methods and default values*

Annotated bibliography

Building Envelope Thermal Bridging (BETB) Guide prepared by Morrison Hershfield et al. (2016).

Note: this document uses the term "clear field assemblies" for Elements and "interface details" for Junctions. Version 1.0 has more background and cost/benefits while the latest (version 1.1 (2016)) contains more details. Internal dimensions were used to define the thermal bridge coefficients.

Morrison Hershfield Limited. (2011). ASHRAE 1365-RP Thermal Performance of Building Envelope Construction Details for Mid- and High-Rise Buildings. Atlanta, GA: American Society of Heating, Refrigerations and Air-Conditioning Engineers Inc.

Note: as above.

Siddall, Mark, (2009). "Thermal Bypass – The impact of natural and forces convection upon building performance," Green Building Magazine. http://www.leap4it.co.uk/uploads/2/5/0/9/25096989/2009_impact_of_thermal_bypass_green_building_magazine.pdf

Excellent article on practical considerations of thermal bypass – especially good notes on party wall issues.

Bernhardt, Rob, (2020/10/15). "Policy Series #5 – The Reference Building Approach", https://www.passivehousecanada.com/downloads/policy-series-5-reference-building-approach.pdf

Berggren, Bjorn and Wall, Maria, (2018/11/09). "State of Knowledge of Thermal Bridges—A Follow up in Sweden and a Review of Recent Research," *Buildings* **2018**, *8*(11), 154, https://doi.org/10.3390/buildings8110154

Urge-Vorsatz, et al. (2020/9/1). Advances Toward a Net-Zero Global Building Sector p.242, https://www.annualreviews.org/doi/abs/10.1146/annurev-environ-012420-045843

Rosemeier, Kara, (2020/03/11). "Ventilation and airtightness: chicken and egg?", https://www.airah.org.au/Content_Files/EcoLibrium/2020/03-20-Eco-technical-paper.pdf

Ryan, V., Penny, G., Cuming, J., Baker, G and Mayes, I. (2019). Measuring the Extent of Thermal Bridging in External Timber-Framed Walls in New Zealand. Final Report – Building Levy Project LR11092. Report Wall/3 from Beacon Pathway Inc. BRANZ ER53(2020).

Glossary

Accredited Passive House certifier	An individual who has been accredited by PHI in Darmstadt, Germany to carry out building certification reviews and award the PHI certification certificate (and plaque of course).
Adiabatic	Surface across which no heat flows.
Air leakage	A measure of building quality. Measured via a blower door test done toward the end of construction, which verifies that the building will perform as modelled.
ANSI/ASHRAE Standard 160-2016	Criteria for Moisture-Control Design Analysis in Buildings; Hygrothermal modelling standard.
AVCL	Air/vapour control layer. This is a layer designed to control the air and vapour flow through a building assembly. Examples include specialist membranes and taped plywood or OSB.
Breathable	The ability of a material or building assembly to allow water vapour through it by diffusion. It assumes the material itself is airtight. This term should be avoided as it causes confusion.
Building envelope	The surface that separates the inside of the building from the outside. This term can be used to be inclusive or exclusive of the unconditioned spaces (ie garage).
Certified Passive House designer or consultant	An individual who has passed the PHI Darmstadt, Germany exam. (Alternatively, it is possible to become a certified Passive House designer by doing the Passive House design for a certified Passive House or PHI Low Energy Building and having a case study approved by PHI).
CHI value χ	Represents the rate at which heat passes through a Junction per Kelvin temperature difference [W/K]. Similar to PSI value, this represents the rate at which heat passes through a Junction at a location: for example, a metal beam, used to support a balcony, that passes through an external wall. The number of instances of the Junction (ie number of steel beams) is multiplied by the CHI value to calculate the heat loss. Expressed in units of W/K (watts per kelvin). The calculation of the CHI value typically requires a three-dimensional thermal bridge calculation.

Construction R-value (m2K/W)	Overall R-value for a building element including regularly repeating elements (such as timber studs/dwangs). Like the tables in the BRANZ House Insulation Guide, this includes both interior and exterior surface resistances.
Element	Refers to roof/ceiling, walls, floors, windows, doors and skylights: the areas that make up the bulk of the thermal envelope. The Element performance is calculated using ISO6946:2007, which is a one-dimensional calculation like NZS4214:2006.
EnerPHit	The Passive House Institute's energy performance standard for retrofits. It allows a maximum annual space heat demand higher than that of Passive House Classic and an upper airtightness limit of 1.0 n50. There is also a component method. Note the moisture criteria of the full Passive House Certification must still be met.
Form factor	The ratio of total external surface area of the thermal envelope (including the floor slab area) to the treated floor area. Typically, a large building will have a lower form factor than a smaller one. A simpler shape will also have a lower form factor than a more complex shape. The lower the number, the less insulation needed in the same climate (everything else being equal).
Frequency of overheating	A certified Passive House must not overheat (defined as 25º C or above) more than 10% of the time. Note this can assume night and window ventilation, so if the building is modelled with more ventilation than used in practice it may overheat more than predicted.
Glass edge spacer	The dividing strip along the edge of a double- or triple-glazed unit that separates each pane. Warm-edge spacers are made from material or materials with a lower thermal conductivity. The thermal performance of a spacer is measured by its psi-value.
Glazing or Glazing element	Window *including* frame, glass and spacer. This publication avoids these terms, as it is easy to confuse with the glass alone.
Glazing ratio	Equivalent to the window-to-wall ratio and not used in this guide. It is easily confused with a ratio of glass (excluding frame) to total wall area.
Glazing R-value	Thermal performance of the entire windows assembly, including frame, glass, spacer and installation. This publication avoids the term, as it is easy to confuse with the R-value for the glass alone. "Overall Window R-value" is used instead.
g-value	Fraction of solar energy that enters a building compared to that which hits the outside of the window glass unit. Roughly equivalent to SHGC.
Heat flow (W)	Rate of energy transfer, J/s.
Heat flux (W/m^2)	Heat flow per unit area

Heat loss coefficient (W/K) or (W/°C)	Rate of heat flow under a temperature difference of 1K. This can be attributed to junctions, elements or even whole buildings given knowledge of the materials and geometries. Sometimes referred to as the H-value or weighted H-value.
Heat transfer coefficient (W/K)	Rate of Heat flow per degree of temperature difference. Synonymous with Heat Loss, the term preferred in this publication.
Indoor air quality (IAQ)	A term referring to the quality of air within buildings, with respect to both health and comfort. Indoor air often contains a complex mixture of contaminants and common pollutants, including smoke, volatile organic compounds (VOCs) and moulds. The level of carbon dioxide (CO) in indoor air also relates to IAQ and is an accepted marker for the wider mix of potential indoor air pollutants. ASHRAE issues guidelines on acceptable IAQ.
Internal heat gains	The heat gains in a building from its occupants and the use of appliances within the thermal envelope.
Isotherm	Contours of constant temperature when looking at a cross section of a thermal analysis.
Junction	Intersection of multiple elements such as floor-to-wall or interruptions in the regular Element performance (eg steel penetration of a wall). These can be two-dimensional, such as along a wall-to-wall corner or three-dimensional, such as a beam penetrating through a wall. These are calculated using ISO10211:2007.
kWh	Kilowatt hour, a unit of energy. A typical portable heater available in New Zealand used for one hour would use 2kWh (2000Wh) of energy. 1kWh = 3.6MJ (megajoules).
kWh/(m2a) or kWh/(m2year) or kWh/m2/year	Kilowatt hours per m^2 per year. A metric to enable the contribution of different facets of a building to the specific space heating demand. Aspects such as solar gain, conductive losses etc are able to be converted to this metric. All are referenced to the usable or treated floor area (TFA).
Lambda value	A commonly used way to refer to the thermal conductivity of a material. Sometimes referred to as the lambda or k value. (W/(mK)).

low-e coatings	Low emissivity coating, most commonly on glass surfaces between double or triple panes. Low emissivity coatings reduce heat transfer by lowering the level of infrared radiation transmission. They achieve this by reflecting IR radiation and work best if there is both a physical gap and the coating is not covered with dirt or condensation (which is why they are commonly used in the sealed environment between glass panes). There are many types of low-e coatings and the thermal performance can vary significantly between them.
Mechanical ventilation with heat recovery (MVHR)	Also known as heat recovery ventilation (HRV) or comfort ventilation. A whole-house ventilation system that exchanges heat between the exhaust air and the supply air. Fresh air is typically delivered to living areas (eg living room and bedrooms) and extracted from kitchens and bathrooms. MVHR units do not necessarily supply additional heat into the supplied air. However, a supply duct radiator or electric coil can be used to add heat to the new air after it leaves the MVHR unit. The functional definition of a Passive House is a building where the peak heating loads can be met by simply heating the ventilation air required for the building.
n50	A measurement of the rate of air leakage through the thermal envelope at a pressure difference of 50Pa between indoors and outdoors, referenced to the volume enclosed by the building. This is used as a means to compare buildings at a pressure difference high enough to reduce errors due to wind pressure when undertaking the test. As it is dependent on the building volume—and air leakage is typically a function of surface area—it is easier to achieve an air tightness target of n50 for larger buildings given the same envelope permeability.
Pa	Pascal, unit of pressure [N/m^2]. Building leakage is measured for Passive House at 50Pa pressure difference. 1Pa is 1 newton per m^2.
Passive House Institute (PHI)	The independent foundation established in Darmstadt, Germany in 1996 to develop, promote and protect the Passive House standard. passivehouse.com
Passive House Planning Package (PHPP)	The Excel software tool used to build an energy model of buildings and determine if they meet the Passive House Institute's building standards: Passive House, PHI Low Energy Buildings and EnerPHit

Predictive thermal modelling	Building thermal modelling that is intended to predict the actual energy consumption or heating/cooling loads. This is often significantly different to Building Code *assumed* performance, which is not intended to be predictive of building performance. An example of this is assuming that an uninsulated slab on grade is R1.3 – this has little relation to how that building Element will perform in a particular building and is a legislative assumption designed to make Building Code compliance easier.
PSI value ψ	Represents the rate at which heat passes through a Junction per metre per Kelvin temperature difference [W/m/K]: for example, the Junction between two walls forming an external corner. The length of the Junction (ie height of the corner) is multiplied by the PSI value to calculate the heat loss coefficient for that corner. This is similar to CHI value but per unit length rather than per number of occurrences.
Relative humidity (RH)	The ratio of the vapour pressure of a parcel of air to the saturation pressure of air at the same temperature.
Roof area	Roof area excluding skylights and/or roof hatches.
Rse	Surface Resistance Coefficient on the exterior surface.
Rsi	Surface Resistance Coefficient on the interior surface.
R-value (m^2K/W)	This document uses SI units with R-values in m^2K/W. Each metric R-value unit is equal to 5.678 imperial R-value units. For example, a USA wall of R(imperial)30 is only R5.3 m2K/W. U-value or thermal transmittance ($W/(m^2K)$), which is typically used in association with windows, is the inverse of R-value. U-value is also used in the place of R-value in the UK and much of Europe.
Service cavity	A service cavity is a secondary insulation layer usually to the inside of the structural Elements and the AVCL. It contains the wiring, plumbing etc to keep penetrations of the AVCL to a minimum. The service cavity is usually but not necessarily insulated. Commonly, the AVCL is tested for air leakage before insulating the service cavity or installing the interior finish. Service cavities on all exterior walls and ceilings that form the thermal envelope are common on high-performance buildings in New Zealand.
SHGC	Solar Heat Gain Coefficient, the ratio of solar energy that enters a building compared to that which reaches the outside of the window glass unit. Similar to g-value.
Specific space heating demand (kWh/m2/year)	This is the amount of heat required to keep the home within the acceptable, comfortable temperature range, expressed as the amount of kilowatt hours per square metre per year.

Specific space heating load (W/m2)	The power used by a heater of sufficient size to maintain the comfortable temperature on the coldest days. A 200m² Passive House can typically rely on a single portable 2kW heater.
Specific heat capacity	The amount of heat required to change the temperature of a unit mass of a material by a unit temperature. (In standard metric units, it is the number of joules required to raise 1 kilogram of the material by 1 Kelvin.) Specific heat capacity is a measure of a material's thermal mass.
Thermal break	A lower conductivity material that reduces conductive heat flow. For example, a plastic thermal break in a thermally-broken aluminium window.
Thermal bridge	A location in the thermal envelope where the uniform thermal resistance is changed by higher conductivity materials or geometry change. This increases (or sometimes decreases) the heat flow at that location.
Thermal bypass	A type of thermal bridge caused by air movement in the insulation layer or around it (like a road bypass).
Thermal conductivity	A material's ability to transmit heat is measured by the thermal conductivity (or lambda value). Unlike R-value, the thermal conductivity of a material remains the same irrespective of the thickness of the material. Thermal conductivity can vary with temperature but is usually treated as constant. For example, ISO10211 holds air conductivity constant as function of the cavity dimension and bounding materials while ISO10077-2 varies the air conductivity with bounding temperatures as well.
Thermal envelope	The surfaces that enclose the building's conditioned spaces. This includes the floor area to the exterior. For Passive House tools such as PHPP, external dimensions are used. This means from the bottom of the insulation below the concrete slab to the top of the insulation in the ceiling. Using external dimensions can simplify the number of PSI value calculations needed to conservatively estimate the heat loss of a building.
Thermal mass	The ability of a body of material to absorb, store and subsequently release heat (due to its specific heat capacity and its mass).
Total roof area	Roof area including the area of any openings such as skylights or roof hatches.
Total wall area	Wall area including the area of the joinery (windows and doors).
Treated floor area (TFA)	Treated floor area is a measure of the useful floor area inside the conditioned area of the home. It excludes stairways and wall thickness (both exterior and interior).

U-value ($W/(m^2K)$)	Thermal conductance, the inverse of thermal resistance. Describes the heat flow per m^2 of an assembly per Kelvin. (U-value is the inverse of R-value.)
Vapour barrier	Also called vapour closed. A material that is nearly impermeable to water vapour, eg aluminium foil.
Vapour permeability	The degree to which a material allows the passage of water vapour due to a vapour pressure difference across it. Permeability is usually expressed as $g/m^2/d$. The inverse of permeability (Vapour Resistance) is usually used in calculations. Typically quoted by four different values: 1. vapour resistivity (R-value, units: MNs/gm – meganewton seconds per gram metre); 2. vapour resistance (G-value, units: MNs/g - meganewton seconds per gram) 3. water vapour resistance factor (u-value, no units) and 4. equivalent air layer thickness (Sd-value, units: m - metres).
Vapour-open	A material that is permeable to water vapour, eg a 'breathable' or 'breather' membrane (these are both airtight and liquid-moisture-tight but vapour-open).
W	Watt, a unit of power (ie energy per unit time.) For example, a typical LED light might be 10W and a hair dryer 3kW (kilowatts, ie 1,000W). 1W = 1 joule per second.
W/K	Watts per Kelvin. Heat loss per Kelvin temperature is the difference between inside and outside.
W/m^2	Heating or cooling load (power) divided by the TFA of the building.
Wall area	Wall area excluding the doors and windows (note using NZS4218:2009, the door area is sometimes included for NZBC compliance, but it is always excluded here.)
Window area	Area of the window measured to the outside of the timber reveal liner using BRANZ SR306. This is the smallest opening into which the window could be fitted into the wall and does not include the area of the flange that overlaps the rough opening and wall.
Window schedule	A list of all the windows in a building, with their dimensions.

Window-to-wall ratio	Area of all the windows (and glazed doors) divided by the total wall area (which includes the windows and doors). The area of the windows specifically includes the frames but not the rough openings. Ranges from 0 to 100%. Same as glazing ratio and is the preferred term.
WRB	Water Resistive Barrier. This is typically the flexible wall underlay but this can be the top layer of a rigid air barrier product used under the ventilated rainscreen cladding. Used to designate the control layer in the building assembly that is intended to stop rain/water.