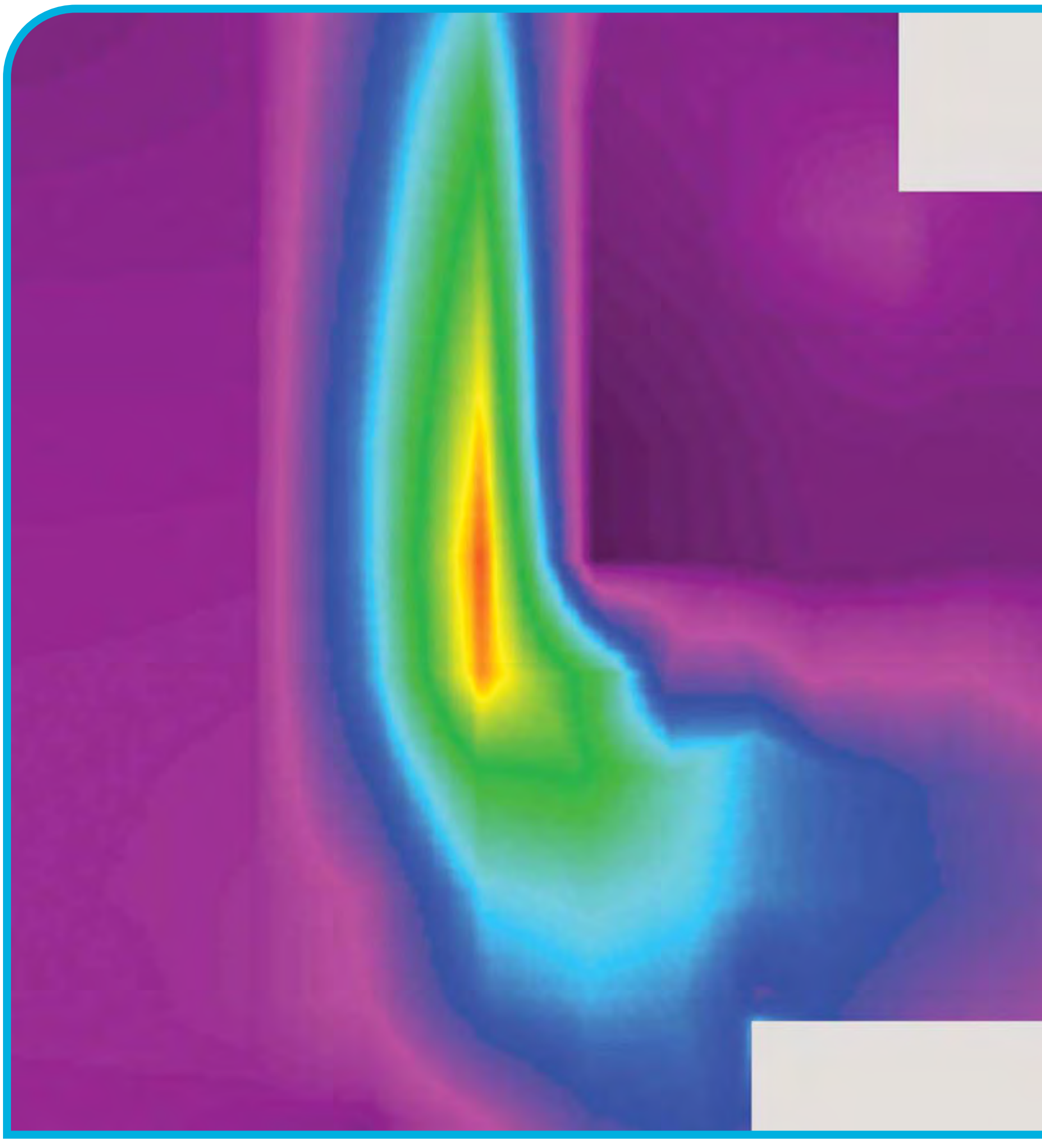
AECB CarbonLite Programme

Delivering buildings with excellent energy and CO_2 performance

AECB CarbonLite Design and Construction Guidance Part 2



AECB CarbonLite

CARBON LITERATE DESIGN AND CONSTRUCTION

Contents

Glossary of main terms

Heat Loss Parameter (HLP)
The building's specific heat loss (in units of W/K) divided by the building's floor area (measured internally – i.e. within the thermal envelope). Units W/K.m²

ψ – (psi) value
Linear thermal bridge heat loss coefficient, units W/mK

Note that the psi values in this document have all been calculated with respect to the inside to outside temperature difference, not the inside to ground temperature difference as recommended in the PHPP2007 manual. Consequently, these all need to be entered in PHPP 2007 in the Areas worksheet as 'Category 15 Thermal bridges to ambient'; not 'thermal bridges to ground/perimeter'.

λ – (lambda) value
Thermal conductivity of a material, units W/mK

K – (kay) value
Alternative symbol for thermal conductivity of a material, units W/mK

χ – (chi) value
Point thermal bridge heat loss coefficient, units W/K

R-value
Thermal resistance, units m²W/K

U-value
Thermal transmittance, units W/m²K

EPS
Expanded polystyrene

XPS
Extruded polystyrene

PU/PI foam
Polyurethane or polyisocyanurate foam

Contents (cont)

Glossary of main terms
(Cont)

CarbonLite
The AECB's Carbon Literate Design and Construction Programme

Silver Standard -
A low energy building standard used in CarbonLite Step 1.

Passivhaus Standard
A low energy building standard used in CarbonLite Step 2.

Gold Standard
A low energy building standard used in CarbonLite Step 3.

Passivhaus Institut (PHI)
A German research and consultancy establishment, the originator of the Passivhaus movement and of the Passivhaus Standard.

Passivhaus Planning Package (PHPP)
A modelling and accreditation software tool developed and updated by the Passivhaus Institut.

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1.0.0: Introduction

SECTION 1

To support ‘early adopters’ pioneering Passivhaus and the AECB Building Standard (previously called AECB Silver), the AECB produced this design guidance document (in two parts) in 2007: over the last 13 years more and more practitioners have changed the way they design and build - achieving better performing and more comfortable buildings. The details illustrated have been been successfully built, refined and varied to suit individual project challenges. This document remains a hugely useful guidance and learning resource for next stage adopters, the 'early majority'. The guidance concentrates on two of the areas where 'mainstream' UK practice most adversely affects building energy performance - thermal bridging and airtightness.

It is written in the context of constructional examples illustrating certain U values that might be commonly required for achieving the AECB Building Standard or the Passivhaus Standard, it can also more generally usefully inform design and construction aiming to reduce the performance gap and improve building occupants satisfaction levels. Please note that the AECB and Passivhaus Standards are performance based standards - so U values required will vary from project to project. The key design and construction principles illustrated in these guides are intended to be useful to skilled persons acting in a professional and commercial capacity who are attempting to design more thermally-efficient building envelopes.

Many of the examples used here have been used on “live” projects by various AECB members.

Please use these constructional examples to inform the detailed design of your own project’s building fabric. Applying the principles of reduced thermal bridging and increased airtightness to all fabric elements - walls, floors, roof, etc - and key junctions between elements will significantly reduce your building’s overall energy use and CO_2 emissions.

It is intended that these details be treated as constructional examples only, to illustrate the application of good thermal design principles. Do not treat them as “approved” or “accredited” details as they have not yet been through the necessary peer review process to gain this additional authority.

It is hoped that skilled persons acting in a professional or commercial capacity who are attempting to design more thermally-efficient building envelopes can utilise the constructional examples in their own work but the information contained in this document has not been prepared to meet any individual’s specific requirements or any particular given circumstances and you must exercise your own professional judgment and expertise to assess the suitability of the constructional examples for use or adaptation in your own designs and under your own particular circumstances.

Whilst reasonable care has been taken when compiling the information in this document and AECB believe it to be accurate it is provided without responsibility
and AECB shall not be liable for any loss, damage or expenses (including loss of profits, loss of contracts, business or goodwill howsoever arising.

U-values

The examples in this guidance are based on a number of construction methods and materials, namely load-bearing solid walls, concrete-frame and timber-frame.

All the constructions illustrated allow a degree of design modification to achieve the typical ranges of U-values required by Passivhaus and Gold Standard buildings.

Typical junctions between basic construction elements of the external building fabric – walls, roofs, floors – are illustrated.

- The exact U-value required for a specific element of a project's external fabric is determined by the maximum Heat Loss Parameter (HLP) set by the standard.
- The U-values listed in the standards are *upper* limits. A compact building with a low surface-to-volume ratio, such as a block of flats, may achieve the required HLP with near the maximum U-values, whereas a less compact building, such as a small detached house, would need lower U-values.[1]

In each Section, **U-values** are given for the 'plane elements'; e.g. masonry wall, timber wall, timber roof, etc, and ψ-values are given for junctions between these elements; e.g., masonry wall meets timber roof.

Real U-values

In some types of construction, especially timber, the impact of design standards and the reslting positioning and sizing of timber components has a significant impact on the U-value. For this reason the guidance quotes a range of U-values for some of the detailed constructions shown, based on 'good', 'typical' and 'poor' scenarios.

The underlying assumptions behind these U-values can be found in the appendices. They concern the proportion of each layer of the insulation zone which is taken up by solid timber, OSB or plywood instead of by thermal insulation. Small changes are enough to affect the space heating energy use of a low energy building by 5-10%.

ψ-values

The ψ-values are quoted both with reference to internal dimensions and with reference to external dimensions. The second convention is normally used in PHPP. If one is using the latter convention, then provided that no ψ-values are more than 0.01 W/mK the designer may consider the building to be 'thermal bridge-free'.

Please note that this rule does not apply if the designer is using internal dimensions. Using internal dimensions intrinsically tends to understate a building's heat loss. If a designer is measuring the areas of external walls, floors, roofs, etc with reference to internal dimensions, even small thermal bridges need to be included to avoid quoting an overoptimistic result.

Further development of the guidance

There will be further editions of this guidance over time, illustrating a greater range of construction types, methods and materials and critical building fabric details. Future details may for example include cavity masonry walls with sufficient insulation for the Passivhaus or Gold Standards, steel-frame construction and walls of aerated concrete blocks. Check the website for notification of dates of publication.

[1] Please refer to CLP Volume Two: Principles and methodologies for calculating and minimising heat loss and CO_2 emissions from buildings while using this document.

In the interim, some guidance on cavity walls can be found in the AECB's earlier Silver Standard Design Guidance. The government of Canada has issued much good guidance on high-rise steel-frame construction.[2] Also recent publications covering ecological and passive house construction and detailing can be referred to.

It is hoped that skilled persons acting in a professional capacity who are attempting to design more thermally-efficient building envelopes can utilise the constructional examples herein to inform their own work. However, the following information has not been prepared to meet any individual's specific requirements or any particular circumstances. You must exercise your own professional judgment and expertise to assess the suitability of the constructional examples for use or adaptation in your own designs and under your own particular circumstances.

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In this publication, materials and products are described in generic terms, except where specific examples of typical products are given in order to further illustrate the guidance. For instance, if an innovation is patented it can usually only be described by citing a brand or trade name. Mention of trade names is for information only and does not imply any support for one particular brand of a material instead of another.

In addition to applying the guidance in this document, readers are invited to participate in the AECB discussion forum to benefit from sharing low energy design and construction experiences, as well as sharing thinking on advanced construction detailing. This is a collaborative process based on open discussion and sharing of knowledge and experience, which will be facilitated by expert AECB technical input and moderators.

The three simple rules

In the following sections, the basic approaches to airtightness and insulation of each type of construction are discussed. Commentary on reducing the risk of interstitial condensation is also featured. The construction details herein show how building envelopes can be designed to be very highly-insulated, very airtight, and relatively free of thermal bridging.

This can in general be achieved by following three simple rules:

1. Continuous air barrier

Ensure that the structure has a designated air barrier; i.e., a layer in the structure which blocks air movement. If necessary, ensure that it also has a vapour barrier; i.e., a layer which reduces or blocks vapour diffusion. In masonry wall construction, the air barrier may be the internal plaster

[2] TBD

layer. In concrete walls, the material itself may be treated as the air barrier, since properly-vibrated concrete is airtight. In timber-frame construction, the air barrier may, for example, be a polyethylene membrane, protected as necessary from wind forces.[3]

For the demanding air permeability in the Passivhaus and Gold Standards to be reached, the air barrier must be continuous over the entire thermal envelope. No breaks are acceptable, except at services penetrations and at window and door openings. Even these junctions need careful sealing.

In general consideration should be given to the risk of interstitial condensation that may occur both during and after construction. In certain situations, the use of airtight membranes with variable vapour resistance, so-called intelligent membranes, may be appropriate.

Two of the constructions presented in this document are accompanied by prominent warnings of interstitial condensation risks, in one case with a strong recommendation not to use the construction illustrated. The other constructions herein are less prone to this problem, and no specific reference is made to the subject, but designers must always be mindful of the risk.

2. Continuous insulation

Make the thermal insulation layer continuous as far as possible, so that the insulation in one element connects seamlessly with the insulation in the adjacent element. This reduces or almost eliminates the associated non-repeating thermal bridges. Ensure that air-permeable insulation is contained within airtight layers, normally situated to both sides and in intimate contact with the insulation layer. This helps to ensure that cold air does not penetrate the insulation layer, carrying away heat. The protective layer on the outer face of the insulation is normally called a wind barrier.

3. Minimal thermal bridges

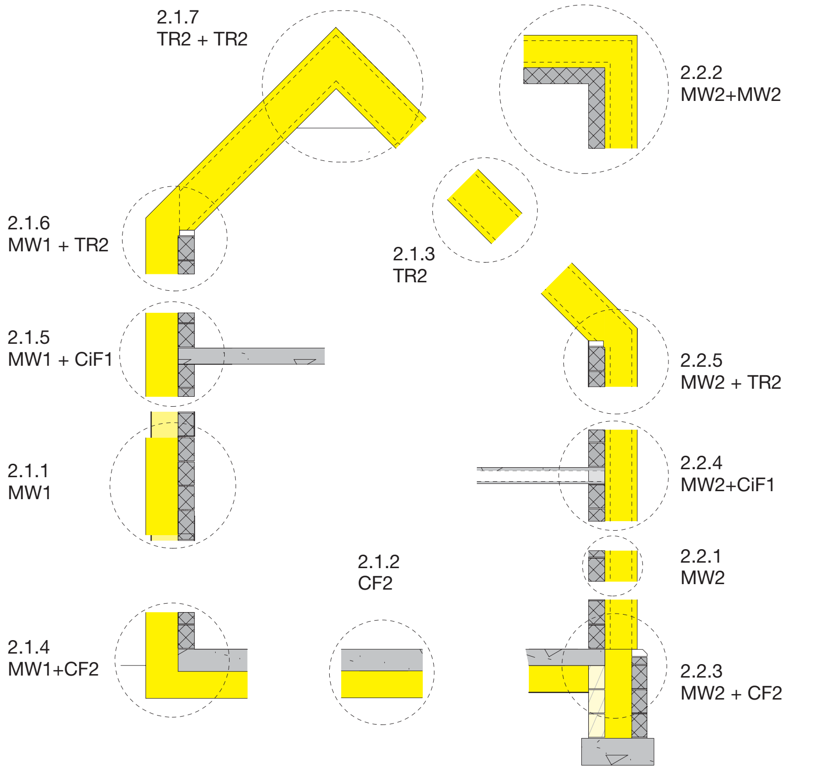
Minimise or avoid the use of mechanical fixings through the insulation. Metal fixings form a series of point thermal bridges. If fixings are unavoidable, try to use relatively non-conductive ones; e.g. plastic or hybrid fixings. If metal is unavoidable, try to select one of low thermal conductivity; e.g., stainless steel. Under current rules, mechanical fixings are required to be treated as point repeating thermal bridges and subsumed within the quoted U-value. For clarity, in part of this document the U-value is given for the insulated element alone and fixings are accounted for separately, multiplying the relevant χ-value by the number of fixings per unit area. In timber construction, minimise the timber fraction in each layer of the insulation zone. Such timbers form a set of repeating or non-repeating thermal bridges.

[3] The National Building Code of Canada defines an air barrier as a material with a maximum air permeance of 0.05 m^3/m^2hr @ 50 Pa. We have derived this, using a 2/3 power law; from the original quoted maximum which is 0.02 litres/sec.m^2 @ 75 Pa, tested to ASTM E 2178. Examples of materials which meet this definition include 0.15 and 0.25 mm thick polyethylene membranes, in situ concrete walls, plastered masonry walls and most practical thicknesses of foamed in situ polyisocyanurate foam. Variable-vapour-permeability polyethylene membranes of the above thicknesses usually comply with it too.

Some materials which may be thought of as impermeable to air are actually too permeable to meet the Canadian definition of an air barrier; e.g., typical breather membranes such as Nilvent, Monarperm, Tyvek and others. Using such materials as the air barrier could be risky if one is trying to reach the demanding air permeability set by the Passivhaus or Gold Standards. Also boards, at the thinner end of their product range, such as OSB and foam insulation such as EPS are not intrinsically airtight. Canada would not classify materials such as 9 mm OSB or 25 mm EPS as air barriers, even with joints between adjacent boards sealed. Sheet materials of an adequate vapour resistance and thickness, with permanently sealed joints between boards would be needed to substitute for a fully sealed airtight membrane.

2.0.0: Load-bearing masonry

SECTION 2



The diagram above represents a notional cross section through an externally-insulated load-bearing masonry building. It identifies areas of construction modeled in Section 2.

U-values are given for 'plane elements' (e.g. MW1, TR2 etc) and ψ-values are given for junctions (e.g. MW1 +TR2).

MW Masonry Wall
CF Concrete Floor
TR Timber Roof
CiF Concrete Intermediate Floor

SECTION 2

2.0.0: Load-bearing masonry – introduction

We have presented details for load-bearing solid masonry because of its ubiquity among our continental neighbours and the feasibility, as shown by the Low Energy and Passivhaus programs in Germany and the MINERGIE and MINERGIE P programs in Switzerland, of modifying this simple structural system to achieve very high energy efficiency standards. On the European landmass; i.e., all European countries except the UK, Ireland and Scandinavia, 90-95% of new low-rise buildings are constructed using this method.

In Germany, where the Passivhaus Standard was launched, it was reported at the 5th Passivhaus Conference in 2001 that approximately 65% of all Passivhaus dwellings constructed to date had been externally-insulated masonry, 20% concrete – mostly ICF – and 15% timber-frame. So although the Passivhaus Standard involved more use of 'non-standard' constructions, two-thirds of the dwellings were 'German standard' – external walls of solid masonry with external insulation, solid upper floors and timber roofs.

There may have been shifts in the proportions of masonry, timber-frame and concrete since then, towards more timber-frame. However, we have been unable to find written evidence on this matter.

Most of the principles which are set out below for a load-bearing masonry wall also apply to a load-bearing concrete wall. However, there are some differences.

Unlike discrete masonry units; e.g. concrete blocks, which leak air through the mortar joints unless the wall is wet-plastered, properly-vibrated concrete, normally with anti-crack mesh, is virtually airtight. Therefore the wall itself can act as the air barrier and need not be plastered to ensure a high level of airtightness. Also, unlike masonry, holes can be made or cast for electrical boxes anywhere on the inside of the wall and the back of these holes need not be parged beforehand.

This guidance is not intended to cover insulating concrete formwork (ICF) walls. Many suppliers of ICF systems have already published details which serve to meet the Passivhaus Standard and are equally suitable for the Gold Standard.

Two methods of construction for externally-insulated load-bearing masonry walls are illustrated in this guidance. The same approaches could be applied to an in situ concrete wall; a wall of large calcium silicate units, which are a common technique in the Netherlands and Germany; or a wall of precast concrete elements, which are sometimes used in the UK.

The first method described in 2.1 (based on plane element MW1) considers a typical type of proprietary 'insulated render' system where rigid insulation material; e.g., mineral fibre lamella, expanded polystyrene or sometimes phenolic foam is mechanically- or adhesive-fixed to the external face of the masonry or concrete. The adhesive fixing allows for fewer or no mechanical fixings and can potentially aid airtightness in some situations.

The insulation is then directly rendered by the same approved installers, using a proprietary render system. The insulation can also support finishes such as brick slips or brick or stone effect surfaces, and can be coloured and modelled if needed to create three-dimensional architectural surface detail.

The load-bearing masonry wall itself is plastered internally, if a full plaster finish is required. It usually is with masonry. Some concrete walls and most calcium silicate walls are smooth enough to be directly painted or skimmed with plaster, but the implications for airtightness of not fully plastering must always be checked beforehand.

The second method described in 2.2, based on plane element MW2, considers a different approach that allows for a wider range of cladding options, cheaper, fibrous insulation materials and more use of semi-skilled local or on-site labour.

Embodied energy

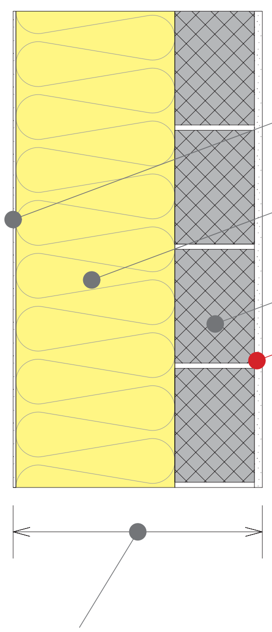
Over a lifecycle of 100 years, an analysis in the 1990s suggested that 8-10% of the primary energy use of a Passivhaus dwelling of typical German construction consists of the embodied energy and 90-92% consists of the energy consumed for space and water heating and cooking – assumed to be by gas – and electricity consumed by HVAC pumps and fans, lighting and appliances.

This conclusion was reached by PHI on the basis of the best available German data. This tends to emphasise the continuing importance of operational energy, even in very low-energy buildings. As better data emerges and buildings become even more energy-efficient, this conclusion may change slightly.

A point which is not included in conventional tables of embodied energy is the scope that different insulation materials offer for CO_2 sequestration, It appears that the use of wood-derived insulation materials could have a significant role in sequestering CO_2 from the atmosphere. Accordingly, it could be very beneficial to manufacture insulation materials from wood wherever possible, and not to burn it.

Plane element	Designated air barrier	Designated insulation zone(s)	Designated wind barrier
All elements and junctions	For the demanding air permeability in the Passivhaus or Gold Standards to be reached the air barrier must be continuous over the entire thermal envelope. No breaks are acceptable in the air barrier except at services penetrations and at window and door openings. Air barrier laps and junctions require careful sealing.	Make the thermal insulation layer continuous as far as possible so that the insulation in one element of the building connects seamlessly with the insulation in the adjacent element. This reduces or almost eliminates the associated non-repeating thermal bridges.	It is essential to stop wind from penetrating the thermal insulation layer. The material used in many elements of a building is mineral,cellulose or other natural fibre, all of which are very pervious to air. Expanded polystyrene is also pervious to air.
Wall MW1	In the masonry wall construction shown in this section, the air barrier is the internal plaster layer. In in situ concrete walls, the material itself may be classified as the air barrier.	The thermal insulation layer is continuous, except for the presence in some designs of plastic or metal mechanical fixings.	The rendered finish of the walls acts as a wind barrier on the outer face of the insulation.
Roof TR2	The air barrier is the polyethylene membrane.	The thermal insulation is continuous except for the webs and flanges of the I beam and timber noggins.	The sheathing membrane of the roof acts as a wind barrier on the outer face of the insulation.
Floor CF2	The air barrier is the reinforced concrete slab.	The thermal insulation layer is continuous except where it is intersected by incoming services.	This floor is in ground contact, and is not exposed to normal wind pressures. In any case the relatively dense insulant is quite air-impermeable, so a wind barrier is less applicable.

2.1.1: The basic construction - plane element MW1



MW1	U-value W/m²k
As shown Adhesive fixed only: assumes insulation is fixed to wall with adhesive and/or uses non-conductive mechanical fixings.	0.128
Typical range With mechanical fixings: The lower value is based on four fixings per m² for the insulation, each having a χ-value of 0.002 W/K. The render mesh is not mechanically fixed. The higher value is based on using four fixings per m² for the insulation slabs and the render mesh is mechanically fixed using two metal and plastic ‘thermodowels’ per m², each with a χ-value of 0.005 W/K.	0.136 – 0.158

Description

MW1 shows an externally-insulated dense masonry wall with 300 mm of lamella-type mineral fibre, adhesive-fixed only. The wall is plastered internally and rendered externally. This is the basic wall construction assumed in 2.1. The insulation thickness featured here, 300 mm of lamella-type mineral fibre, is typical of what might be needed in an average UK climate, such as Manchester or Derby, to meet the Passivhaus or Gold Standards. This is based on our experience of modelling buildings using PHPP.

On some projects; e.g., small detached houses, more insulation than 300 mm lamella mineral fibre may be needed. If this happens, under the prescriptive version of the CLP standards there is scope for tradeoffs between walls, roofs and floors, so long as the maximum HLP is not exceeded. Thus, if the HLP is too high when using 300 mm of wall insulation, and it is inconvenient to make the walls even thicker, the thickness of roof or floor insulation could be raised without raising the wall insulation thickness.

At present, 300 mm is the upper limit to insulation thickness using a single layer of mineral fibre but systems using expanded polystyrene (EPS) can go above 300 mm. This provides a single layer insulation system which should be suitable for low-energy buildings anywhere in the UK.

This simple wall construction avoids many of the pitfalls encountered in other masonry wall systems. It also avoids the difficulties with cavity walls; see *Silver Standard Design Guidance*. Unlike a cavity wall, this basic externally-insulated wall has no wall ties to deal with, usually no cavity trays, no cavity closers and only single lintels at openings.

One difficulty with cavity walls is that if both leaves are built at the same time, as is customary in the UK, the quality of the insulation cannot easily be inspected. It is soon covered up. With external insulation, though, the entire layer of insulation is all on display at once and the quality of the work can be quickly assessed by someone walking around the building.

The bulk of new buildings in Germany, Austria and Switzerland employ the principle of externally-insulated, directly-rendered masonry walls. Most of them, however, use masonry units other than dense concrete blocks. Calcium silicate blocks, with thin-joint glue, are probably the most common; fired clay blocks are also used. Cast in situ concrete walls are common on large blocks of flats. Some walls use storey-height ‘masonry’ units, usually of calcium silicate, craned into place. The principles are similar for all of them, but the large calcium silicate elements are usually the quickest to erect.

Variations

If a reduced wall thickness is important, one alternative to mineral fibre at these insulation thicknesses would be a product termed ‘Neopor’, which was developed by the German company BASF and is in turn sold as finished EPS by several companies under various tradenames. ‘Neopor’-

type EPS contains tiny graphite flakes and has a lower thermal conductivity than standard EPS of the same density.

Worked examples:

Using a 250mm thickness of 'Neopor'-type EPS insulation with a ψ-value of 0.030 W/mK in an adhesive only fixed version of MW1 with no conductive mechanical fixings, would result in a U-value of 0.113 W/m^{2}K,

Using a thinner 225 mm thickness of the same adhesive only fixed insulation would result in a U-value of 0.125 W/m^{2}K.

Introducing four typical 'thermodowel' fixings per square metre, with heads flush to external face of insulation and not recessed, would add 0.008 W/m^{2}K to the U-values above, giving 0.121 and 0.133 W/m^{2}K respectively.

Precedent

Across the European landmass, millions of new walls are now of this basic type, but there is limited precedent for the use of such walls in very exposed climates. The western shores of the UK are windier and wetter than the mainland countries where external render systems have been used for the last 50 years.

Proceed with caution in very exposed zones of the UK. In very exposed regions, forms of externally-insulated masonry which preserve an air gap between the cladding and the thermal insulation may be more appropriate.

Limiting Thermal Bridging

Wherever possible, we suggest utilising a system which is based upon purely adhesive-fixed slabs of insulation, or non-conductive plastic mechanical fixings, in conjunction with adhesive. This will give a thinner and more economical wall. Because of the advantages of adhesive over mechanical fixing, the bulk of German, Swiss and Austrian external insulation installations on new buildings appear to be of this type.

Adhesive fixing should aim to employ full coverage adhesive bonding of the insulation boards, rather than the more common 'ribbon' of adhesive, Then there is no risk of air movement behind the insulation boards.

Designers must be aware that even adhesive-fixed systems may use a reduced number of mechanical fixings through the insulation in order to hold the insulation in place whilst the adhesive sets; see below. So adhesive-fixed systems may not be entirely mechanical fixing-free although fixings could in some cases be temporary and could be removed after the adhesive has cured. On tall buildings, or for refurbishment projects with difficult substrates, it may be necessary to utilise a system which incorporates metal fixings.

Designers should ensure that the insulated render system installer is responsible for all of the insulation to the external wall around windows and other openings where joinery has been / is to be fitted. Good practice is to avoid inserting small amounts of perimeter insulation at the window frames and to cut the main wall insulation to fit around the window. This avoids the use of the thermally conductive adhesive to bond the small pieces of insulation to the larger pieces. Adhesive layers in these positions would compromise the thermal performance, as would a large number of locally placed conductive mechanical fixings.

Mechanically fixed insulation

Insulated render systems may include a series of mechanical fixings, which are normally of plastic and/or metal construction. Designers should be aware that all fixings that penetrate the insulation layer form a series of point repeating thermal bridges, directly analogous to the effect of metal cavity wall ties. See Silver Standard Guidance. Once accounted for, metal fixings raise the wall U-value significantly above the U-value for the adhesive-only fixed insulation shown in MW1. Plastic fixings have a much lesser effect.

Alternatively, insulation boards can be fixed to the wall on a series of tracks which slot into grooves cut into the edges of the insulation boards. Whilst this approach results in the mechanical fixings being behind the insulation, the tracks hold the insulation away from the wall surface by a few mm and this may result in air movement behind the insulation - leading to heat losses.

The upper range of U-values quoted above for the mechanically fixed version of MW1 is for plastic and metal ‘thermodowels’ with a ψ-value of 0.005W/K.

EN ISO 6946.1996 advises that where the thermal conductivity of a fixing or part of it is less than 1 W/mK the effect of the fixing can be disregarded in U-value calculations. However, for Passivhaus and Gold Standard buildings, the heat loss from mechanical fixings through the insulation to the substructure should be accounted for, using the ψ-value of each fixing multiplied by the number of fixings per unit area.

The system supplier may include the losses from mechanical fixings in their quoted U-values. Indeed, they are supposed to do so under current rules, as these are clearly repeating thermal bridges. But it is clear that many suppliers do not do this. They quote U-values which exclude the impact of any of the fixings.

Alternatively, the designer may wish to request the system supplier to quote separately the U-value for the insulated element alone and the further loss due to all the point thermal bridges. This enables him/her to investigate the benefit and the feasibility of using fewer, or less conductive, mechanical fixings, including the possibility of recessing initial fixing heads into the face of the wall insulation by approximately 25 mm and insulating over with plugs of insulation so that the losses through the fixings are reduced.

A smaller number of additional fixings may also be needed to hold the render reinforcement mesh onto the face of the insulation, or fix it into the substrate, before rendering. This is particularly true when applied to high-rise buildings and in relation to fire issues. These fixings cannot be countersunk with heads insulated over and may constitute further thermal bridges that should be accounted for. It is important to develop a clear and detailed specification with the system supplier for the approved installer to follow.

Higher-performance insulation fixings can be categorised into three bands, with c-values as follows: 0.000 W/K, less than 0.001 W/K and less than 0.002 W/K.

Designers must note the likely range in U-value of wall MW1 including the repeating point thermal bridges. Using a relatively large number of rather poor metal fixings, a wall with 300 mm of insulation could have a U-value of above 0.15 W/m^{2}K. This would not meet the Passivhaus or Gold Standards.

Airtightness

The material designated as the air barrier in this wall is the internal plaster layer. The render is also fairly resistant to air movement and provides a wind barrier. Overall, the wall offers little risk of wind penetration. In addition, if the insulation is adhesive-fixed and the adhesive is continuously applied, rather than applied in ‘ribbons’, then this layer also potentially becomes an air barrier. This could potentially be very useful in refurbishment projects. It might also offer an alternative method on new masonry buildings if plastering is to be avoided, or if a continuous plaster layer – see requirements below - is too difficult to achieve.

If the load-bearing wall is in situ concrete, the inner plaster finish is not needed for airtightness. Given a good enough finish on the concrete, and provision elsewhere for wiring routes, the walls could be directly painted.

If the load-bearing wall is precast concrete elements, these themselves are airtight. But the joints between them are not. Either an inner plaster finish is needed for airtightness or, if the walls are to be directly painted, all the elements must be sealed extremely tightly at seams; e.g., using expanding polyurethane foam.

On a masonry wall, the internal plaster must be continuous over the entire external wall area. This includes areas behind baths, stairs and skirtings, behind non-loadbearing stud partition walls, above suspended ceilings, and all other areas which are not normally plastered. ‘Hidden’ areas might possibly be plastered with a brush-applied parging, of the type used for acoustic insulation. But ensure that it is continuous; unplastered areas will leak.

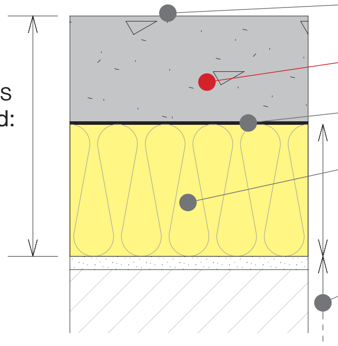
Structural Issues

150-200 mm thick in situ or precast concrete and calcium silicate elements usually give sufficient panel lengths and heights for most buildings without special strengthening. Some precast concrete walls can be only 100 mm thick. Walls of small masonry units can be reinforced either horizontally or vertically, using filled hollow cores, to achieve greater panel lengths or heights.

Designers should be aware that the thermal insulation layer provides 98% of the R-value of this basic wall. So any increases in the conductivity of the dense concrete blockwork, plaster or render, which combined provide only 2% of the wall's total R-value, have very little impact on the wall's overall heat loss. As any steel bars are embedded within the depth of the blockwork and occur relatively infrequently, their impact on the U-value is negligible.

2.1.2: The basic construction - plane element CF2

CONSTRUCTION THICKNESS
With materials illustrated: approx. 450mm above sub base



GENERAL CONSTRUCTION NOTES

Floor finish not shown

200mm reinforced concrete slab

Damp proof membrane

250mm expanded polystyrene insulation

Other construction membranes as required and sub base

CF2	U-value W/m²k
As shown U-value is for standard floor dimensions; B' =8m or P/A = 0.25, and assumes a slab in ground contact.	0.106

Description

This simple floor construction involves designing a shallow raft foundation, via which the entire building rests on rigid insulation. The concrete raft is sufficiently reinforced to spread all loads.

Precedent

The first use of such a detail, with zero thermal bridging, in modern low-energy buildings was possibly in the ten ultra-low-energy and zero-energy houses built at Wadenswil, Switzerland in 1989-90. Their basement floor rests on 120 mm extruded polystyrene (XPS). Altogether, the insulation supports a row of very heavy four-storey semi-detached houses which all have an in situ concrete basement, 350 mm thick concrete intermediate floors, concrete stairs, dense concrete block external walls and solid partitions.

There are now many thousands of precedents elsewhere in Europe and North America. The approach of a raft foundation has also been used to date on hundreds or more UK buildings, starting in the early 1990s. One of the earlier uses in the UK was a 2.5 storey house in Twyford, Berkshire built in 1995. It has ICF walls and a timber roof. Its concrete basement rests on 80 mm XPS.

Limiting Thermal Bridging

By using a shallow raft, which converts the usual ground-supported slab into the foundation for the building, the need for the perimeter foundation wall to interrupt the wall to floor insulation zone is avoided.

The raft shown is designed to take all loading from external and internal walls without increasing the thickness of the slab at the perimeter or below intermediate walls or load-bearing columns. Consequently, the insulation zone need not be penetrated or reduced in thickness at any point. Thermal bridging through this plane element due to structural elements is reduced to zero.

Airtightness

The material designated as the air barrier in this floor is the reinforced concrete.

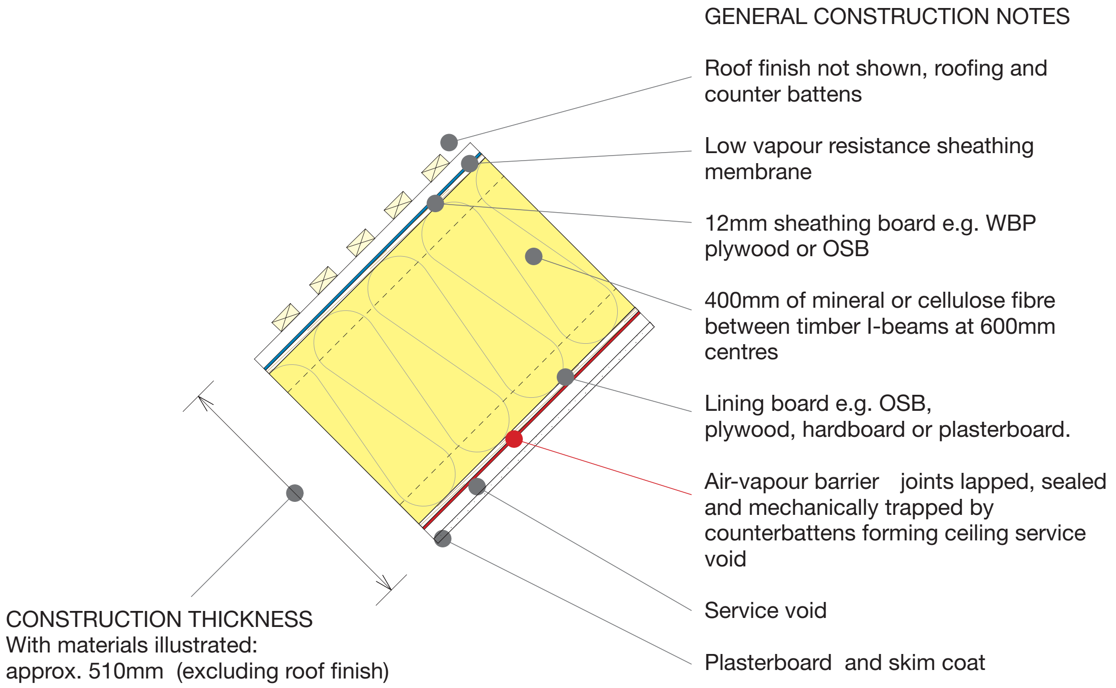
Structural Issues

The drawings here illustrate a raft of uniform 200 mm thickness. It is also possible to design a raft with a reduced slab thickness, such as 150 mm, and with discrete downstand beams below the external walls and any internal load-bearing walls. This uses less concrete, overall, but is more complicated to design and build, and more care needs to be taken with placing insulation around downstands in order to ensure minimal thermal bridging. Designing for a thinner concrete slab with downstands is considered later in this document.

The rafts here are typically satisfactory on the type of well-drained soil where strip footings of up to 750 mm deep were satisfactorily used in the past and where 900-1200 mm deep strip footings would normally be used today. The more difficult soils which were associated with rafts in the past may need considerably thicker rafts, placed deeper in the ground.

The insulation type must be suitable for this situation; i.e., compressive strength and durability. Expanded polystyrene insulation is widely available with typical compressive strengths up to 250 kPa. Insulation with a compressive strength of 70 kPa at 1% nominal strain is illustrated above.

2.1.3: The basic construction – plane element TR2



TR2	U-value W/m²k
Good	0.101
Typical	0.103
Poor	0.105

Description

TR2 above shows a roof suitable for meeting the Standards. The more conventional solid timber rafters are replaced by composite I beam rafters with a thin web of plywood, OSB, hardboard or similar boarding. A service void is provided, so that wiring can be installed in the ceiling without damaging the air barrier. The I beams are spaced 600 mm apart, which is conventional in the UK although not in Scandinavia.

Precedent

I beam rafters were probably first widely used in Sweden in the 1970s. 450 mm deep I beam rafters, on 1200 mm centres, were used in Denmark in several houses in the demonstration low-energy house project at Lyngby, in 1978.

The majority of new Swedish detached houses have I beam timber roofs, with the structural members on 1200 mm centres and a thick enough sheathing board to span this spacing. Most of the timber-frame homes also have I stud walls. In the UK, USA and Canada, I beams and studs are more commonly used on 600 mm centres. But where 1200 mm can be used, it gives rise to considerably less thermal bridging.

Limiting Thermal Bridging

This roof construction greatly reduces the thermal bridging which is found in a conventional roof of solid rafters. Indeed, it is impracticable to reach such a low roof U-value by using solid rafters alone, with insulation between. If one wishes to achieve a very good U-value in a timber roof, using a single layer of insulation material placed between the structural members, I beam rafters are a very good option.

Airtightness

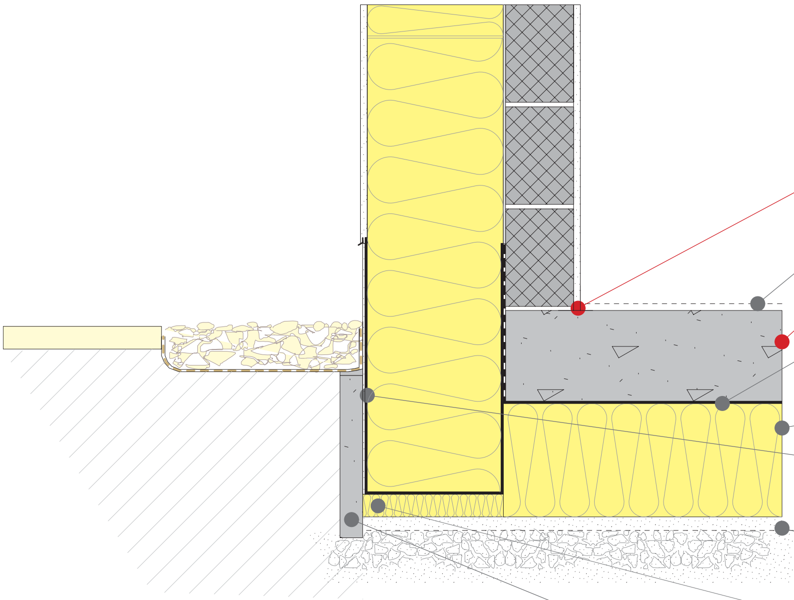
The material designated as the air-vapour barrier in this roof is the polyethylene membrane.

Structural Issues

TR2 above shows 400 mm deep timber I beam rafters on 600 mm centres with 47x47 mm softwood flanges and an 8 mm thick continuous plywood or OSB web.

A structural advantage can be gained when using a structural sheathing board as the ceiling lining, with further structural benefit from sheathing the roof externally. For example, rafter depths can be slightly reduced.

2.1.4: Wall to floor junction – MW1 + CF2



GENERAL CONSTRUCTION NOTES

Plaster or parging to blockwork taken down to slab to ensure airtightness

Floor finish not shown

Reinforced concrete slab

Damp proof membrane taken to edge of slab, joined to external waterproof tanking. Tanking taken up external face of slab and blockwork to required height above ground level

250mm expanded polystyrene insulation

External wall insulation incorporating applied layer of waterproof tanking prior to rendering external face of insulation below ground

Blinded surface on level sub-base, construction membranes as required

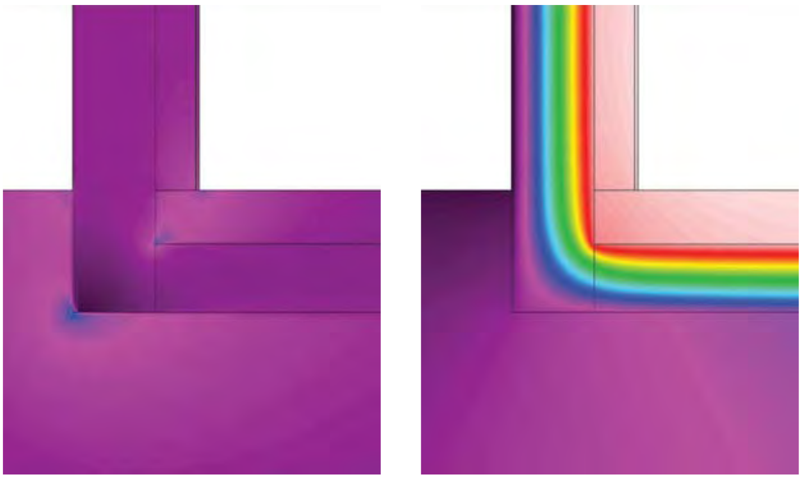
50 mm compressible insulation. NB: lean mix concrete replaces insulation strip at thresholds to provide bearing under wall insulation

Paving slab or similar to ensure continuity of insulation vermin barrier down to sub base

MW1 + CF2	ψ-value W/mk
ψ internal	0.061
ψ external	-0.047

Flux

Isotherms



THERM software image of heat flux and isotherms respectively, through MW1 + CF2

Description

MW1+CF2 above shows the junction of an externally-insulated mass wall and a shallow raft foundation. The external wall rests on the concrete slab, which transfers its load to the ground via the rigid insulation.

A shallow raft usually uses less concrete than trenchfill footings, although the concrete has to be of somewhat higher quality. It may use less material than traditional shallow strip footings on which a masonry wall is built up from footing to ground floor level.

To improve buildability, some companies in Germany make preformed moulds of EPS, which form the insulation both below and to the side of the raft foundation. After assembling these moulds, and the steel reinforcement, one pours the concrete raft and constructs a building on top of it. The wall external insulation begins where the foundation insulation ends.

External wall insulation below finished ground level will require a waterproof membrane over the faces to protect against water penetration. Manufacturers may have their own waterproof coating for this application.

Adequate care must be taken to reduce the risk of insulation damage from vermin. We now know from many authorities that this may be a more serious problem than insulation manufacturers have advised in the past. Insulation is a fragile material and must be carefully protected from the risk of attack below ground. Such materials as sheet metal, concrete paving slabs, concrete and similar have been used.

Precedent

As for plane element CF2.

Limiting Thermal Bridging

Thermal bridging is eliminated by using a raft foundation and turning the usual ground contact slab into the foundation of the building. There are no separate footings. The entire building rests on rigid insulation.

Airtightness

The plaster layer must join the concrete floor slab which, in this building, functions as the ground floor air barrier. It is essential to plaster all the way down to the floor slab and to ensure that there are no gaps. Even small ones will leak in a pressure test.

Any incoming services from below must be run in ducts; the gaps are then sealed with a non-hardening compound. In a solid building, it may be easier to run most of the services immediately above or below the intermediate floors in a raised floor or suspended ceiling, as these floors do not form part of the thermal envelope.

Structural Issues

The concept is acceptable to the vast majority of structural engineers. One can calculate the load imposed by a fairly tall concrete or masonry building on a slab of expanded polystyrene (EPS), assuming that the load is spread, and the loading is roughly as severe as that exerted on the ground by an adult standing in normal business shoes. This loading clearly does not cause undue distortion, even to a slab of low-density EPS.

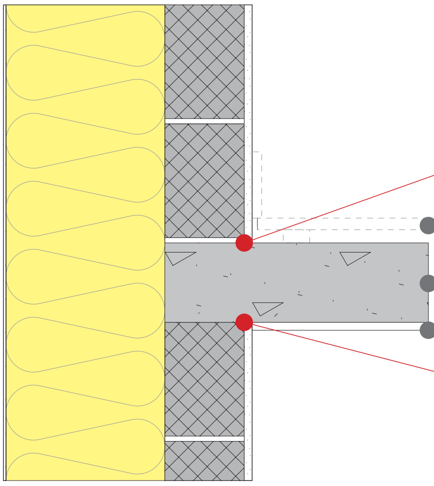
There are many different grades of expanded and extruded polystyrene, with differing abilities to bear such a load. Normally, as the load-bearing capability rises, so does the cost. Also, the thermal conductivity falls slowly with rising density, from almost 0.040 W/mK to 0.034 W/mK or lower.

The grade used can be chosen to suit the situation. Thus, a ten-storey concrete and masonry building resting on a basement raft would impose a much more severe load than a single-storey building resting on a ground floor raft.

At the junction of the wall base insulation with the under-slab insulation, obviously any minor building settlement is likely to disrupt the insulation at this point. It may be possible to minimise this by tapering the wall insulation in the zone below ground level or by using a separate thin layer of low-density EPS - as used by civil engineers to take up movement in shrinkable clay soils - under the bottom face of the wall insulation against the ground, to allow slight settlement without placing undue pressure on slabs of external wall insulation above. The insulation must be kept as continuous as possible to eliminate cold bridging. Also a vermin barrier must be provided in all cases to avoid long-term damage to the thermal insulation.

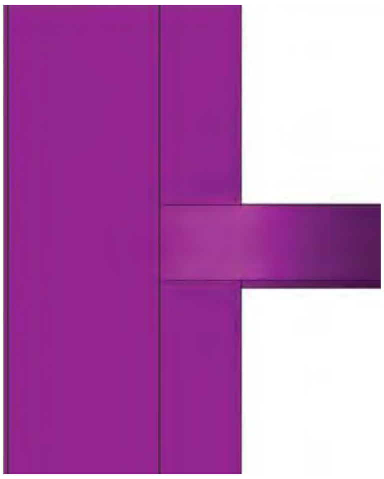
Care should be taken to ensure a reasonably crisp bottom edge to the perimeter of the concrete raft (where it is in contact with the edge of the top face of the underfloor insulation) by ensuring the DPM sits flat at all slab edges. There is a tendency for plastic membranes not to follow right angles unless carefully pleated at corners and changes in geometry.

2.1.5: Wall to intermediate floor junction – MW1 + CiF1

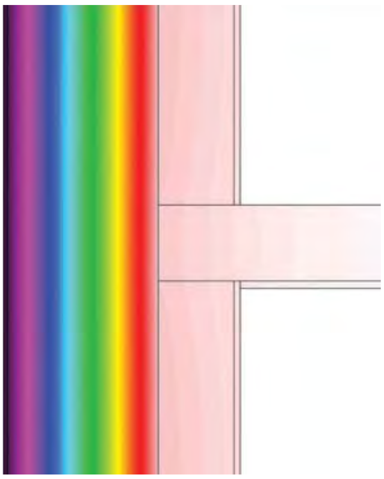


MW1 + CiF1	ψ-value W/mk
ψ internal	0.00
ψ external	0.00

Flux



Isotherms



THERM software image of heat flux and isotherms respectively, through MW1 + CiF1

Description

The junction of masonry walls and intermediate floors is one of the most problematic junctions in UK-type masonry buildings as regards airtightness. The basic problem with the orthodox UK approach is that at this point one is effectively attempting to join an example of 'wet' construction; i.e., a plastered masonry wall, to an example of 'dry' construction; i.e., a timber floor. The two do not meet at all happily and air leakage measurements show that most of the attempted solutions are unsatisfactory, although the better ones may suffice for meeting the Silver Standard.

Joist hangers, as often advocated, do not fully resolve the problem. The entire strip of blockwork wall at intermediate floor level still leaks air because it is unplastered. Attempts to parge this entire zone leave small unplastered areas around individual joist hangers, and these small areas still leak at 500 times the leakage rate through the same area of plastered wall. So leakage is reduced, but it is not eliminated.

A few fairly airtight UK buildings have been constructed using improved detailing at the junction with timber floors, and meeting the Silver Standard, but our impression is that they all benefited from very good workmanship. We are aware of no UK masonry buildings which have used timber intermediate floor(s) and have managed to meet the low air permeability required by the Passivhaus or Gold Standards.

In the above detail, the air leakage problem is overcome in arguably a more robust way, by adopting the practice of our continental European neighbours and increasingly the practice of new building projects in Ireland. The timber floor is replaced by a concrete floor, either an in situ reinforced slab or precast prestressed or reinforced planks.

Drawing MW1 + CiF1 shows an in situ reinforced floor. When it comes to precast floors, solid prestressed planks are available from some manufacturers. They appear to be preferable to hollow-core planks unless the designer intends to use the hollow cores for buried services.

Services can be routed through a raised timber floor and/or a suspended ceiling. However, an exposed concrete soffit is particularly effective for summer cooling, on projects where this is an issue. In situ concrete soffits can also be fitted with a plastered finish, if desired. Usually a skim coat suffices.

If one wishes, a building with in situ concrete walls – ICF or other – could use timber intermediate floors resting on joist hangers. In these buildings, the concrete wall fulfils the function of an effective and continuous air barrier extending from top to bottom of the building. So it no longer matters that there is an un-plastered area at intermediate floor levels, because the plaster does not constitute the air barrier.

A fire barrier may be required at intermediate floor level in external wall insulation systems for buildings over 2 storeys, where the insulation system employs insulation that is not of limited combustibility. With regard to fire breaks, refer to BR 135 ‘Fire performance of external thermal insulation for walls of multi-storey buildings’ and BS 8414 Parts 1 and 2.

Precedent

Almost all masonry building construction on the European mainland uses concrete intermediate floors, and it has done so for the last 50-100 years. In that sense, there are tens of millions of precedents for this construction technique.

UK blocks of masonry flats and non-domestic buildings normally use this technique too, albeit for fire protection and/or acoustic reasons, not for energy efficiency. It is less common on low-rise housing, where it is more often confined to specifically low-energy dwellings.

The six Salford Low-Energy Houses of 1978 were one of the first UK examples to utilise concrete intermediate floors specifically for energy reasons and also, in their unique situation, to reduce vandalism and wear and tear. The Vales’ Autonomous House of 1993 also used concrete floors.

Limiting Thermal Bridging

The full thickness of wall insulation continues past the intermediate floor, giving rise to no thermal bridging; note the zero ψ-values. However, the design of external balconies needs great care to avoid creating thermal bridges at the structural connection. Minimal or low thermal bridging can be achieved by designing such balconies as largely-freestanding wooden or steel structures, abutting the insulated external fabric, or by using thermally-broken structural connections for cantilevered concrete balconies.

Airtightness

Because in situ concrete itself is airtight, such a floor is capable of continuing the air barrier between floors, with no air leakage, assuming that the plaster layer meets the concrete at top and bottom. Unlike a timber floor, few or no special measures are needed to make a concrete floor airtight. Concrete floors do not move seasonally and do not tend to shrink away from the external wall as they dry out. As a consequence, the risk of air leakage at intermediate floor level is significantly reduced.

The in situ reinforced floor is the most straightforward. It gives little possibility of air leakage. A floor of precast planks needs more care. The planks are laid on a wet mortar joint. The joints between the ends of planks must be sealed. Usually the top of the planks is screeded. If one is using hollow-core planks, the ends of the cores must also be sealed to prevent air movement under wind pressure across the building, using mortar or preferably expanding polyurethane foam. The intermediate floor junction using hollow-core planks is illustrated in 2.2.4 MW2 + CiF1 and is modelled assuming that the fill material is mortar which extends 150 mm into the external wall.

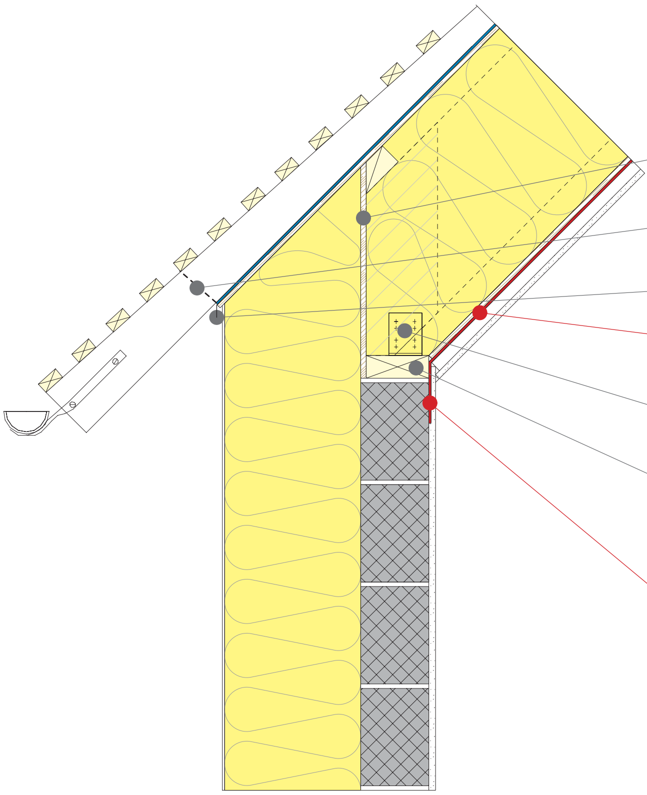
A third type of concrete floor has become common in the UK; i.e., inverted T beams with infill blocks or pots, known as beam-and-block or beam-and-pot respectively. It is not known whether buildings with plastered masonry walls and these intermediate floors can consistently met the Passivhaus or Gold Standard. To our knowledge, despite their widespread use in the UK no work has been done on such floors to test the wall-floor joint for air leakage. A few UK projects which utilised beam-and-block or -pot intermediate floors have met the Silver Standard. One house currently on site is attempting to meet the Passivhaus Standard.

With beam-and-block or -pot floors, in order to achieve airtightness a much greater number of points need to be sealed or filled than with prestressed or in situ concrete slabs. As a result, beam-and-block floors present greater practical difficulty in meeting the low air permeability required by the Gold Standard. Great caution is advised unless it is known that workmanship and attention to detail will be extremely good.

Structural Issues

Floor reinforcement is to follow structural engineer's recommendations. There is considerable scope to minimise steel usage through careful design.

2.1.6: Wall to roof junction – MW1 + TR2



GENERAL CONSTRUCTION NOTES

Plywood end stop fixed to rafter ends and wall plate

Insect mesh between 'false' rafers at eaves

Sheathing membrane / edge flashing to drain over render in 'telltale' design

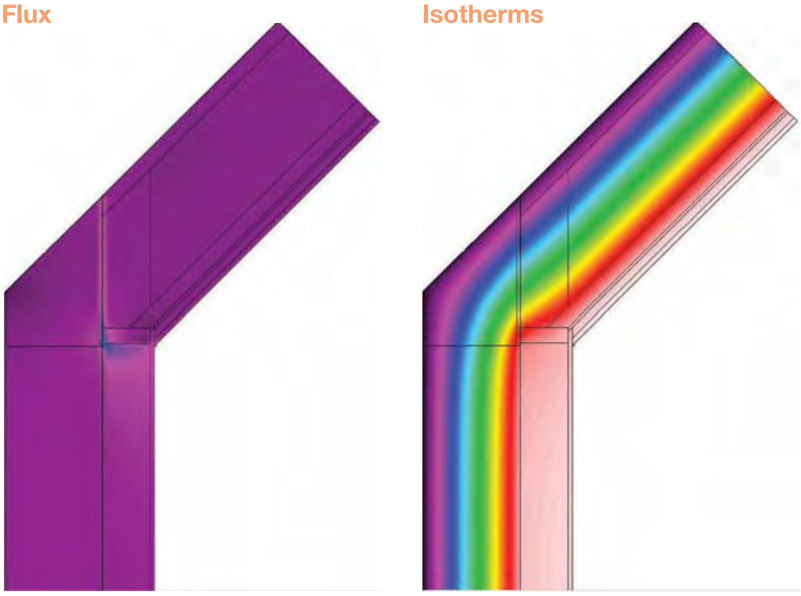
Air-vapour barrier

Rafter foot strengthened with 18 mm plywood 'squash board' fixed directly to rafter web

Timber wall plate fixed down with galvanised straps

Air-vapour barrier fixed against blockwork using expanded metal lathe and plastered over. Alternatively a proprietary air-vapour membrane incorporating a surface designed for direct plastering may be used.

MW1 + TR2	ψ-value W/mk
ψ internal	0.33
ψ external	-0.010



THERM software image of heat flux and isotherms respectively, through MW1 + TR2

Description

MW1 + TR2 above shows an I beam timber roof joined to a masonry wall with external insulation. The external insulation is carried up to roof level. Except for the false rafters, and the other timbers which support the tiles or slates, the roof structure finishes flush with the outside of the solid masonry wall.

Limiting Thermal Bridging

This detail reduces the problems found in the majority of new UK buildings. The ply end stop, and the ply blocking or ‘squash boards’ used to strengthen the lower end of each I beam - plywood placed between flanges of I beam and against the face of the I beam web – all form thermal bridges. But their extent is modest compared to normal UK buildings. Some types of additional strengthening required for the rafter foot and its connection to wall plate by the project engineer affect the ψ-value of the junction illustrated. Other measures may create extra point thermal bridges. If 'squash boards' are used, they must be designed not to make insulation placement difficult or create excessive thermal bridging.

Airtightness

With the influence of the wind barriers, there is minimal air movement within the roof or wall insulation. This reduces the risk that uncontrolled air movement could reduce the performance of the thermal insulation.

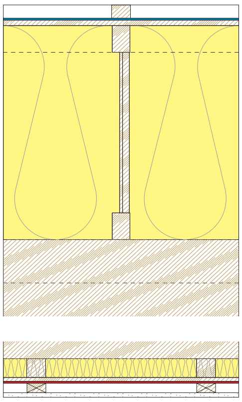
Where the wall plate is tied down using metal straps, care must be taken to ensure that these do not compromise the effective placement and continuity of the air-vapour barrier. It must be possible to trap the membrane cleanly and neatly to the top of the masonry with a continuous strip of expanded metal lath, and then to plaster over the lath, otherwise the junction will leak. It may be necessary to recess the straps into the face of the blockwork to achieve this.

Structural Issues

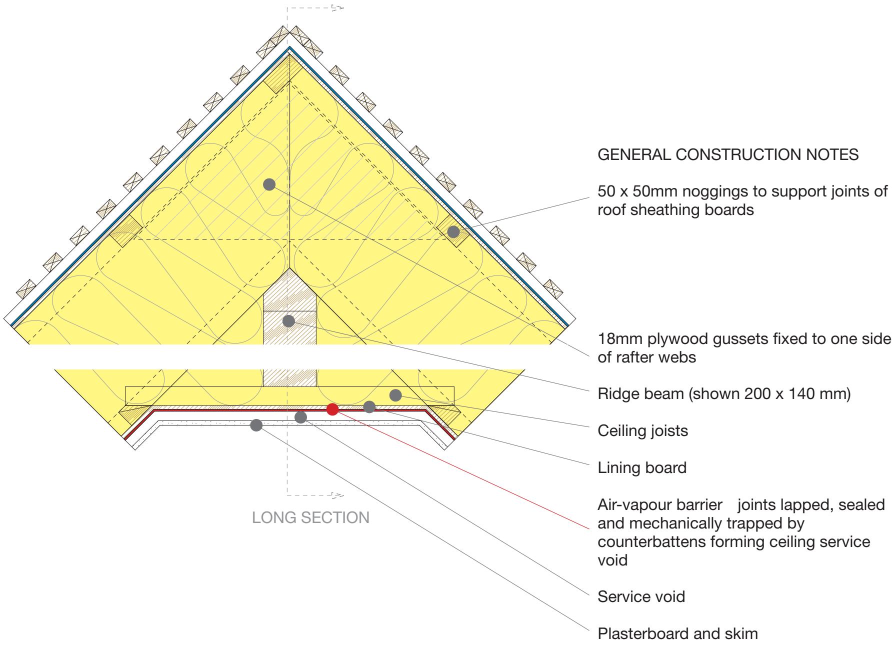
MW1 + TR2 above shows 18mm plywood ‘squash boards’ fixed both sides of rafter webs, between flanges. Follow engineer’s or manufacturer’s recommendations for local strengthening of I beams at critical points. Be careful not to compromise insulation placement or create unnecessary thermal bridging.

The overall stability of masonry panels should be taken into consideration, as should the contribution of lateral restraint from internal walls. Top floor masonry gable ends, in particular, may need reinforcement against wind loads.

2.1.7: Roof ridge junction – TR2 + TR2



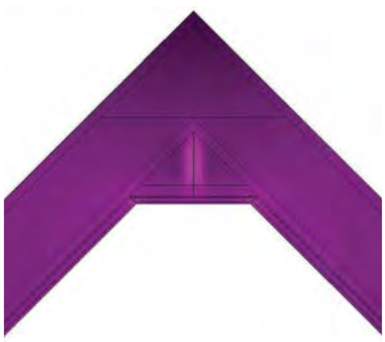
LONG SECTION



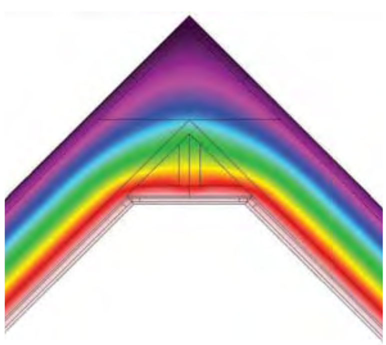
LONG SECTION

TR2 + TR2	ψ-value W/mk
ψ internal	0.002
ψ external	-0.089

Flux



Isotherms



THERM software image of heat flux and isotherms respectively, through TR2 + TR2

Description

TR2 + TR2 above shows a central ridge beam supporting pairs of opposing I beam rafters. The ridge beam is concealed within the insulation zone and the roof air barrier is routed along the flat ceiling formed below the ridge beam.

The ridge beam spans to masonry cross walls or, occasionally, to columns. Typically, a ridge beam may be able to span up to 5-7 m. So in small buildings, it may be able to span between external gable end walls without needing intermediate support(s). Deeper beams can be used where the situation demands it, in order to avoid or reduce the need for intermediate support(s).

Precedent

Used in a number of UK projects since the early 1990s, both domestic and small non-domestic buildings. Generally it has been very satisfactory and easy to build.

Limiting Thermal Bridging

The detail has very little thermal bridging, apart from that through the webs of the roof I beams and the extra plywood used to tie together the opposing I beams at the ridge.

In the version shown, the ridge beam is placed inside the insulation zone; i.e., inside the full thickness of the I beams. Even if the ridge beam is formed of solid timber, there is no excess heat loss to consider. In fact, because the zone around the ridge beam is usually insulated, there is a slight reduction in heat loss at this point in the roof and as one can see the ψ-values are quite favourable.

Any additional strengthening required for the ridge by the project engineer may affect the ψ-value of the junction illustrated - although greater ridge beam depth will lower the ψ-value. If 'squash boards' are used, care must be taken that they do not make placement of the insulation difficult or create excessive thermal bridging.

This guidance does not cover the situation where the ridge beam is left exposed to the building interior and the air-vapour barrier is routed outside the ridge beam. In that case, the ψ-values would be higher than shown here.

Airtightness

The air-vapour barrier is continuous over the entire roof area. The membrane which forms the air barrier is sealed to the wall plaster layer all around the building. There is no scope for air leakage if the work is done carefully. However, any electrical wiring must be confined to the service cavity and pipes to and from; e.g., solar panels on the roof must be sealed extremely carefully where they pass through the roof.

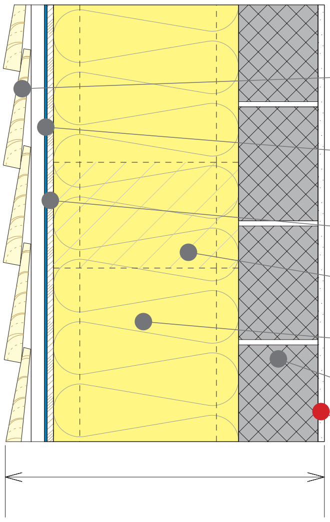
Structural Issues

TR2 + TR2 above shows 18mm triangular plywood ‘squash boards’ fixed both sides of rafter webs, between flanges. Follow engineer’s or manufacturer’s recommendations for local strengthening of I beams at critical points. Be careful not to compromise insulation placement or create unnecessary thermal bridging.

2.2.0: Insulated Larsen trusses - basic principles

Plane element	Designated air barrier	Designated insulation zone(s)	Designated wind barrier
All elements and junctions	See 2.1.0: BASIC PRINCIPLES	See 2.1.0: BASIC PRINCIPLES	See 2.1.0: BASIC PRINCIPLES
Wall MW2	In the masonry wall construction shown in this section, the air barrier is the internal plaster layer. With in situ concrete walls, the material itself may be classified as the air barrier.	The insulation is relatively continuous but is interrupted by timber flanges, webs and in some cases also by timber noggings.	The sheathing membrane in this wall forms a wind barrier outside the thermal insulation.

2.2.1: The basic construction – plane element MW2



GENERAL CONSTRUCTION NOTES

Timber cladding on vertical counter battens

Low vapour resistance sheathing membrane

Sheathing board e.g. WBP plywood or OSB

Plywood gussets

350 mm mineral or cellulose fibre between ladder studs

150 mm dense aggregate concrete block

12 mm plaster

CONSTRUCTION THICKNESS
With materials illustrated:
approx. 600 mm

MW2	U-value W/m²k
Good	0.129
Typical	0.132
Poor	0.133

Description

The externally-insulated dense masonry wall MW2 shown above is plastered internally and uses either timber cladding, render on mesh or metal cladding externally. The timber-clad version is shown. This is the basic wall construction assumed in section 2.2.

Based on experience of modelling buildings with PHPP, the insulation thickness featured here is typical of what might be needed in an average UK climate, such as Manchester or Derby, to meet the Passivhaus or Gold Standards. Under some circumstances, less or more insulation may be needed. There is also some scope for tradeoffs between insulation thicknesses in walls, roofs and floors.

Variations of MW2 can accommodate different cladding finishes e.g., vertical or horizontal timber claddings, metal cladding, rendered finishes of the sand-cement-lime or polymeric type.

If necessary, the U-value of MW2 could be reduced either by using wall insulation with a lower λ-value that that shown or by increasing the thickness of the external studwork and the insulation within it.

Using continuous vertical lengths of timber for the internal flange pieces has a very small impact on the wall U-value compared to separate discontinuous short flanges. Using continuous lengths gives flexibility to use the inner flanges as ‘straps’ to provide vertical restraint within wall elements, and simplifies the neat placement of insulation batts between the inner flange pieces.

Designers of some buildings whose solid wall is concrete, not dense aggregate blocks, have used a variation with very short inner flanges at each plywood gusset connection, on the basis that fixings to concrete are more secure than fixings to blockwork. This approach uses slightly less timber and gives a small improvement in the U-value, relative to using continuous inner flanges.

Precedent

There is limited UK precedent for this construction. It has mostly been used on one-off self-build houses in England and Wales, including cases in; e.g., S.W. London, the Essex/Suffolk border, Herefordshire and Worcestershire. It has also been used on developments by a small builder in Lancashire.

The original version of the ladder trusses on this wall was developed in Alberta, Canada by a builder called John Larsen, hence the common name for them there is ‘Larsen trusses’. In Canada, it has been used both on new construction and on retrofits. We refer to the external studwork in this document as ‘Larsen trusses’ or sometimes ‘ladder studs’.

In Canada, due to the prevalence of timber-frame construction, the inner part of such a wall is normally a load-bearing 90-140 mm thick timber frame, not as here 140-150 mm of load-bearing masonry or concrete. The UK buildings to date which have used Larsen trusses have all had mass walls.

The construction of this wall provides a vented air gap between the cladding and the vulnerable timber-based materials. Consequently, it is expected to be suited to use on relatively exposed sites. While UK government documents do not go into detail on specific methods needed to keep water out of buildings, for the last decade the Canadian Building Code has required the use of a pressure-equalised rainscreen in timber external walls, to help ensure that liquid water cannot penetrate the building. This follows a number of major building envelope failures in coastal British Columbia.

Limiting Thermal Bridging

This wall construction provides a moderately low level of thermal bridging. The only item which extends all the way through the insulation layer is the plywood gussets, which occur at infrequent intervals.

The outer timber flange and noggings combined provide a significant degree of thermal bridging, but this is confined to the outermost 47 mm of insulation. Continuous inner flanges provide a relatively lower degree of thermal bridging in the innermost 47 mm of insulation.

Whilst the overall level of thermal bridging in MW2 is low, it is by no means zero. Also, the λ-value of the fibrous insulation illustrated in MW2 is higher than that of EPS or similar rigid insulation materials. Consequently, depending on the exact λ-value of the insulation used in MW2, and on the timber fractions in different layers of the insulation zone, MW2 needs insulation up to 55% thicker than a wall of type MW1. Thermal bridging can also be reduced by extremely thorough attention to reducing the timber fractions and the cross-sectional areas of the plywood gussets to the structural minima, plus a necessary safety margin.

The noggings between adjacent sheathing boards could also be replaced by metal ‘H clips’, or ‘plywood clips’, which tie two sheets of rigid board such as plywood together where their edges meet so that they cannot move relative to each other. These devices are widely used in North America to tie together the adjacent edges of plywood or OSB sheathing boards, but they are rare or unknown in the UK. A few UK builders have imported them for use on projects here. They cost less than noggings and cause less thermal bridging.

Airtightness

The material designated as the air barrier in this wall is the internal plaster layer. The external sheathing membrane, which is sealed at seams, acts as a wind barrier and resists air movement into the insulation from outside. Overall, the wall gives very little risk of wind penetration or of air movement under pressure.

The internal plaster must be continuous over the entire external wall. This includes areas behind baths, skirtings, stairs, hollow partition walls, above suspended ceilings and other areas which are not normally plastered. ‘Hidden’ areas might possibly be plastered with a brush-applied parging[4], of the type used for acoustic insulation. Ensure that it is continuous.

[4] Parging: thin layer of plaster-type material, which does not need to be cosmetically perfect as it will be hidden from view in the finished building.

Structural Issues

As shown, 350 mm insulation between timber Larsen trusses spaced at 600 mm centres horizontally and with fixings at 1200 mm centres vertically.

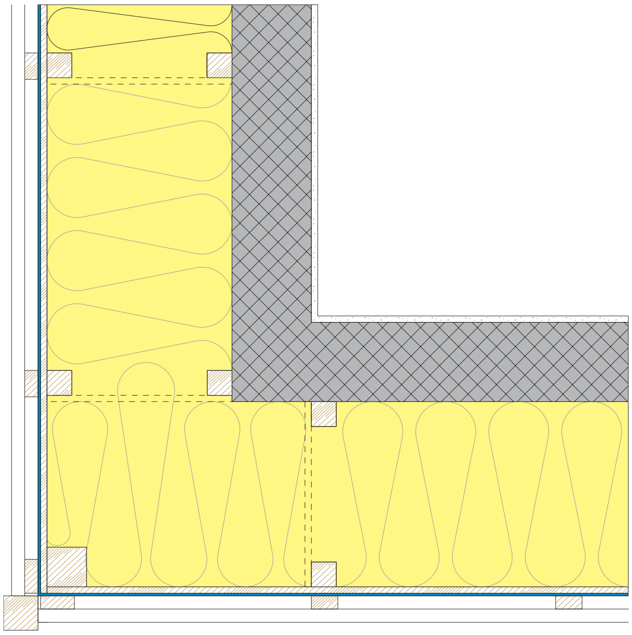
The masonry is the structural element. The Larsen trusses transfer wind loads back to the masonry wall, with the outer flanges being supported by an external plinth at ground level.

Alternatively, loads from the outer skin of the timber construction, including the external cladding, could be transferred to the masonry wall via the plywood gussets, avoiding the need for an external plinth. However, this needs a more robust Larsen truss, with more thermal bridging.

The arrangement using an external plinth is modeled here. Similar arrangements relating to a timber-frame wall using Larsen trusses and with no external plinth are modelled in Section 4 of this document.

Ladder studs shown have 47x47 mm softwood flanges, continuous external and internal flanges connected on 1200 mm vertical centres via 350 x 200 x 12 mm thick plywood gusset plates, glued and screwed or nailed to the flanges. Normally, gussets are alternately staggered either side of the flanges. Timber for the internal flanges must be very securely fixed to the mass wall. If short flange pieces are used, knots at critical areas must be avoided.

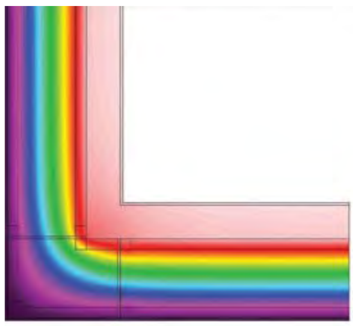
2.2.2: External corner – MW2 + MW2



MW2 + MW2	ψ-value W/mk
ψ internal	0.066
ψ external	-0.054

Flux

Isotherms



THERM software image of heat flux and isotherms respectively, through MW2 + MW2

Description

External corner - MW2 + MW2 shows an example of an external corner on a masonry wall with Larsen trusses. In this example, the corner is strengthened with a 72 x 72 mm timber, making the fixing of both sheets of plywood easier than it would be to a 47 x 47 mm timber. Some UK projects have been built using the same section timber as is used elsewhere in the wall.

In the detail shown above, one Larsen truss occurs very near the corner of the masonry and the other is displaced some distance away from the corner. The exact positioning of Larsen trusses will vary between projects.

Limiting Thermal Bridging

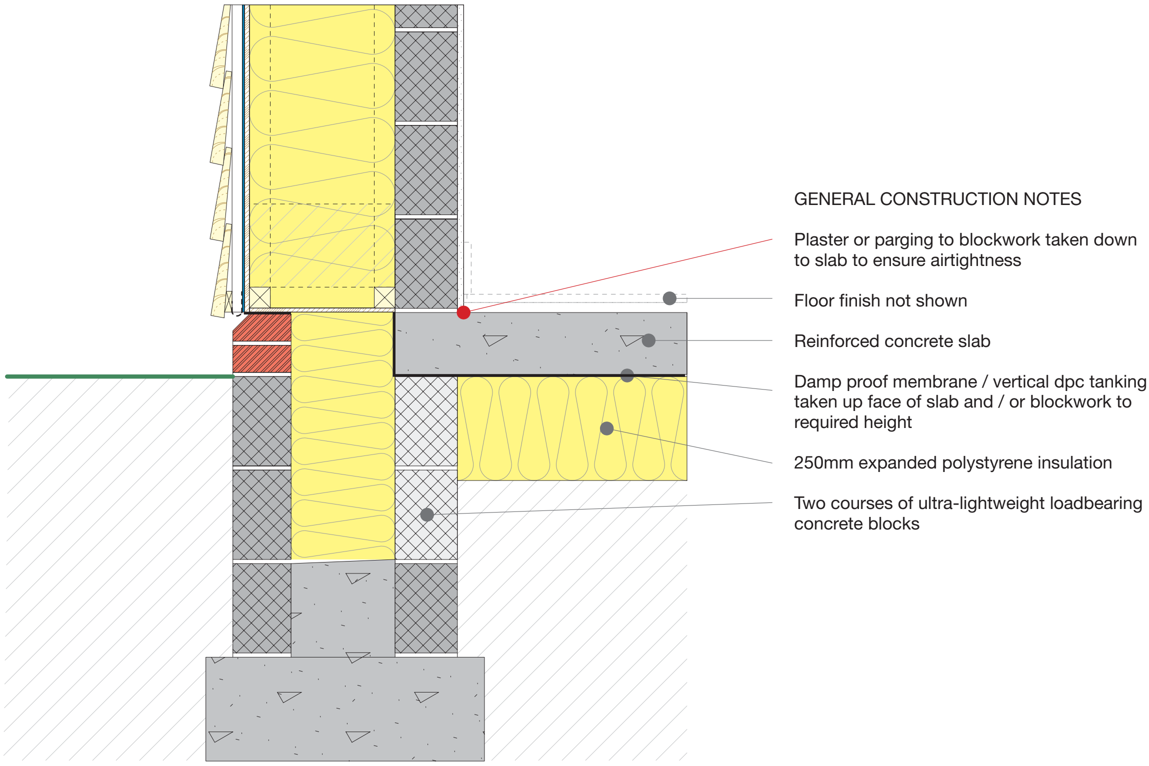
Thermal bridging is limited by using close to the minimum of timber at the corner. One possible improvement would be to use a slimmer timber flange at the corner; e.g., 50x50 mm. Greater care is then needed in fixing both plywood boards and other timber corner elements to adjacent faces of this timber.

Structural Issues

Structurally, this detail is braced in both directions once the sheathing board is fitted. The arrangement shown is broadly equivalent to the two-stud corner which is sometimes utilised in ordinary timber-frame buildings in the USA - this uses less timber, and provides better insulation, than the more common three-stud corner.

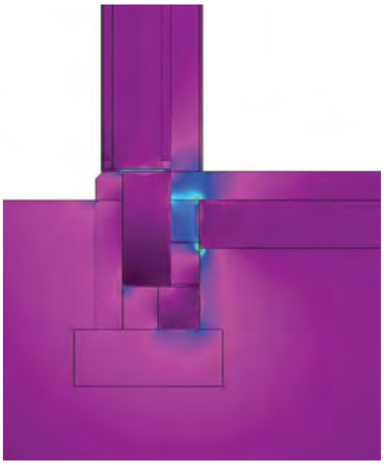
In MW2 + MW2 above, one Larsen truss occurs very close to the corner of the masonry. Care must be taken with fixing this truss, especially into dense concrete block, which is a more difficult substrate than concrete. An alternative in blockwork could be to move this truss away from the corner of the masonry and space it less than 600 mm away from the adjacent truss.

2.2.3: Wall to floor junction – MW2 + CF2

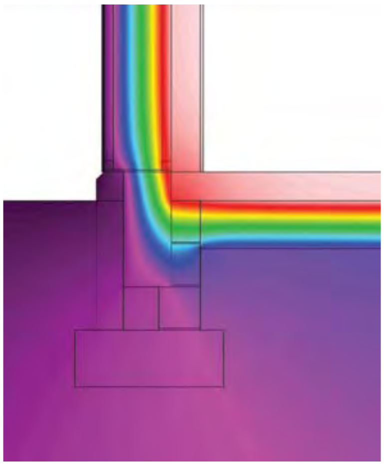


MW2 + CF2	ψ-value W/mk
ψ internal	0.108
ψ external	0.006

Flux

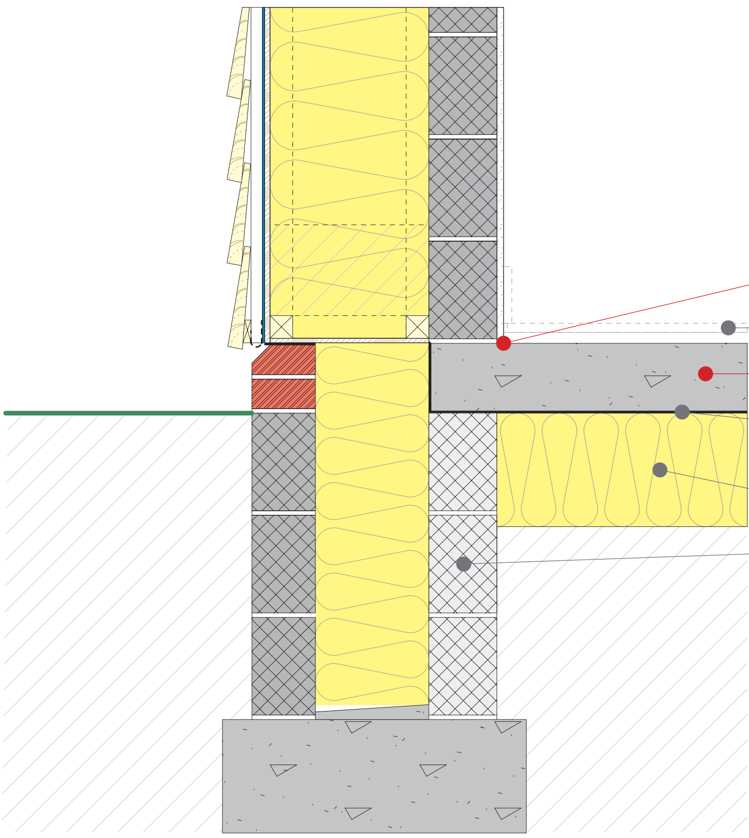


Isotherms



THERM software image of heat flux and isotherms respectively, through MW2 + CF2

2.2.3: Wall to floor junction – MW2 + CF2, *variation 1*



GENERAL CONSTRUCTION NOTES

Plaster or parging to blockwork taken down to slab to ensure airtightness

Floor finish not shown

Reinforced concrete slab

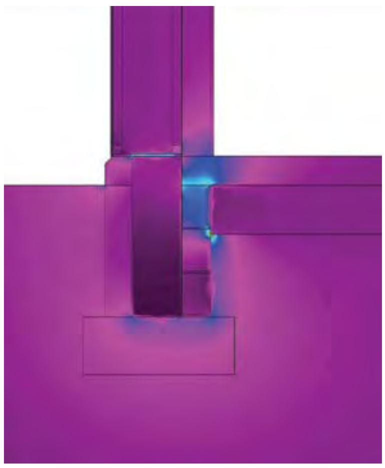
Damp proof membrane / vertical dpc tanking taken up face of slab and / or blockwork to required height

250mm expanded polystyrene insulation

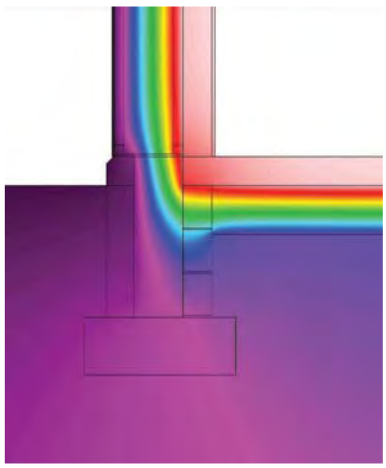
Three courses of ultra-lightweight loadbearing concrete block

MW2 + CF2 *variation 1*	ψ-value W/mk
ψ internal	0.106
ψ external	0.004

Flux



Isotherms



THERM software image of heat flux and isotherms respectively, through MW2 + CF2, variation 1

Description

MW2 + CF2 above shows the junction of the above external wall and an insulated ground floor. It assumes the use of conventional non-reinforced strip footings rather than a raft foundation. The load-bearing wall below ground contains two courses of aerated concrete blocks, in order to provide a thermal break at the point where the floor insulation meets the wall insulation. The wall insulation below ground level provides a degree of vertical perimeter insulation, which further reduces heat loss from the floor.

MW2 + CF2, *variation 1* shows the same detail but with deeper perimeter insulation and three courses of aerated concrete blocks.

Precedent

Some UK buildings have used one or more courses of lightweight concrete blocks as a thermal break in this way since the late 1980s. This also became relatively common in Germany at about the same time. It had happened in Denmark 10-15 years before that.

Limiting Thermal Bridging

Detail MW2 + CF2 greatly reduces the heat loss found when a dense masonry inner leaf continues down uninterrupted to the footing. Although there is some residual thermal bridging through the lightweight concrete block, it is drastically reduced compared to foundation designs which utilise concrete or dense concrete block at this point. The thermal conductivity is reduced by a factor of 6 to 11 before one takes account of thermal bridging by the mortar joints.

The ψ-value shows that the improved junction is thermal bridge-free using external dimensions, but the margin is small and care would be needed not to change anything for the worse.

In MW2 + CF2, variation 1, the use of three instead of two courses of lightweight block, and deeper vertical perimeter insulation, provides a small further reduction in the ψ-values.

Some other changes can reduce the extent of thermal bridging. The main one is to use thin-joint glue rather than conventional mortar. Another is to use even more lightweight aerated blocks, which should be practicable in very low-rise buildings.

Airtightness

Building the floor slab into the masonry wall greatly reduces the air leakage risk. During a pressure test in conventional masonry buildings, in which the concrete floor slab rests on the ground, one often observes air leakage at the junction of the external wall and the ground floor, just below the bottom of the plaster and through the slab of foam which is conventionally fitted at the edge of such slabs.

In this detail, the air barrier is plaster in the external wall and reinforced concrete in the ground floor. It is essential that these two materials meet, with no gaps at the junction.

Structural Issues

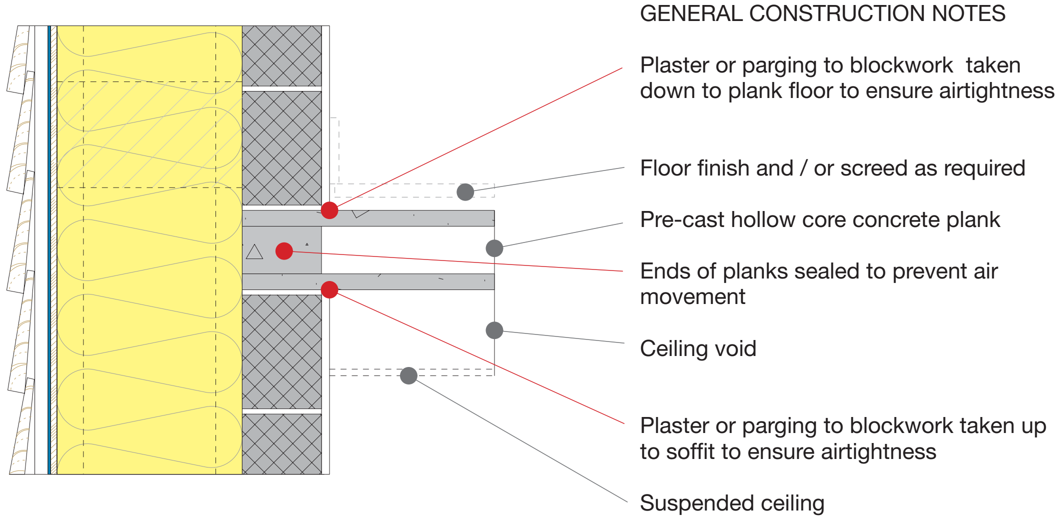
The drawing is based on a cavity plinth wall type arrangement. This allows a range of foundations for the building that do not affect the thermal performance of the basic junction shown.

Alternatives to the shallow unreinforced strip footings which are applicable to both MW2 + CF2 and MW2 + CF2 – variation 1 would be:

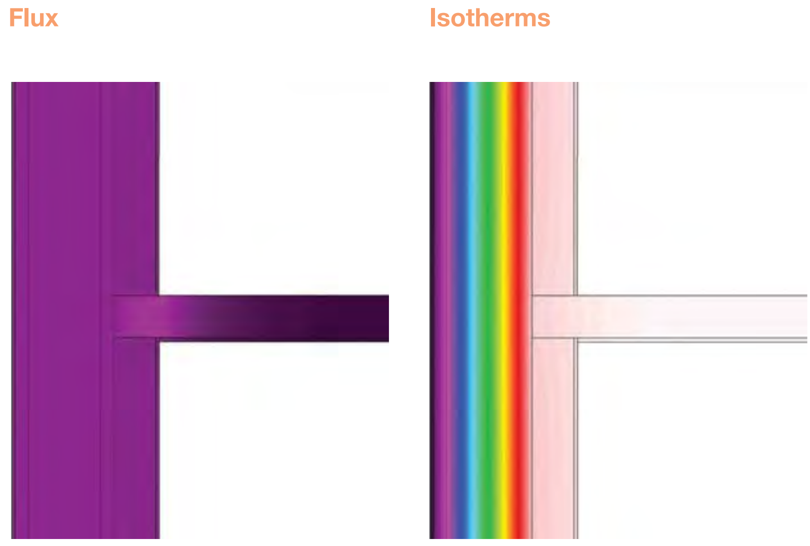
- Deeper footings, more closely resembling trenchfill;
- Reinforced shallow strip foundations,
- Ground beams over weak ground, or
- Ground beams combined with piles.

Check that the ultra-lightweight concrete blocks are suitable for use below ground. When using them for loadbearing purposes, design for robustness, illustrated here by using 150 mm wide blocks for a 450 mm high stretch of wall.

2.2.4: Wall to intermediate floor junction – MW2 + CiF1



MW2 + CiF2	ψ-value W/mk
ψ internal	0.000
ψ external	0.000



THERM software image of heat flux and isotherms respectively, through MW2 + CiF1

Description

The building shown in this drawing uses as its intermediate floor(s) precast concrete floor planks. These are often prestressed, but some manufacturers make reinforced planks. Prestressed planks 150-200 mm thick may be able to span 6-9 m without intermediate supports, a feature which may be very convenient to designers.

Such a floor does not move seasonally and does not shrink away from the external wall as wooden joists dry out. As a consequence, the risk of air leakage at intermediate floor level is significantly reduced, compared to a masonry building with timber floors.

The drawing shows a plasterboard-lined suspended ceiling beneath the floor soffit. This is fairly common in precast floors, because it provides space to run services in a solid building. Also, as opposed to reinforced floor units, some prestressed floor units may give rise to a differential camber and be unsuited to being plastered.

Precedent

The use of precast concrete floor slabs, craned into place, is common among our continental neighbours across the English Channel. It is also quite common now in Ireland, both the north and south.

Limiting Thermal Bridging

There are no major thermal bridging issues if such a floor is used in a dense masonry external wall. The result is similar to the junction of an in situ concrete floor and an externally-insulated masonry wall. Assuming that the wall has sufficient insulation outside the concrete block to meet the Passivhaus or Gold Standard, the magnitude of the resulting linear thermal bridge is very small. This is because, as noted earlier, only 2% of the R-value of this external wall is provided by the dense masonry and the plaster layer. Therefore, small adjustments to this 2% do not materially affect the overall result.

If dense concrete intermediate floors were used in a building whose external walls were constructed of lightweight blockwork - which would contribute significantly to the wall R-value - there would be a noticeable linear thermal bridge to take account of. Even if one used precast reinforced lightweight concrete floors in such a building, there would be a series of significant point and linear thermal bridges. This is due to the presence of mild steel reinforcement mesh or bars in the intermediate floor zone, but not in the lightweight masonry walls above or below.

Airtightness

This detail reduces considerably the air leakage problems normally found at intermediate floor level in masonry buildings. If it is built carefully, air leakage should be very low.

Ensure that planks are properly grouted at the junctions of adjacent planks for airtightness, and that, if the manufacturer recommends, a screed is poured to level the floor.

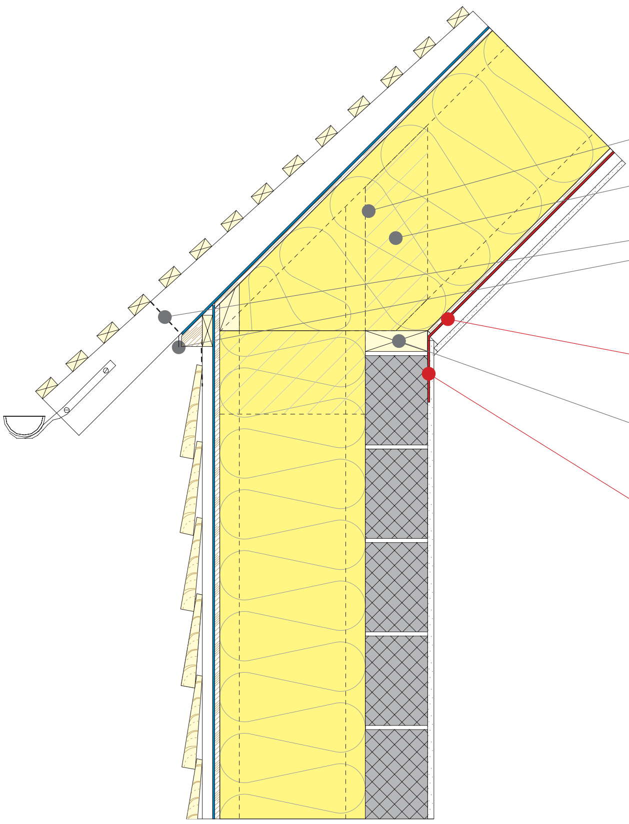
Ensure that the ends of hollow-core planks are filled, to ensure no unwanted air leakage and to prevent air movement through the hollow cores. If allowed, this air movement would create a convective bypass across the building.

Ensure that the vertical gaps between planks are filled at the ends, also to reduce risk of air leakage.

Structural Issues

None noted.

2.2.5: Wall to roof junction – MW2 + TR2



GENERAL CONSTRUCTION NOTES

Internal flange piece of wall ladder studs fixed directly to side of rafter web

18mm plywood 'squash boards' to side of rafter web.

Insect mesh between 'false' rafers at eaves

Sheathing membrane detailed to drain over cladding in 'telltale' design

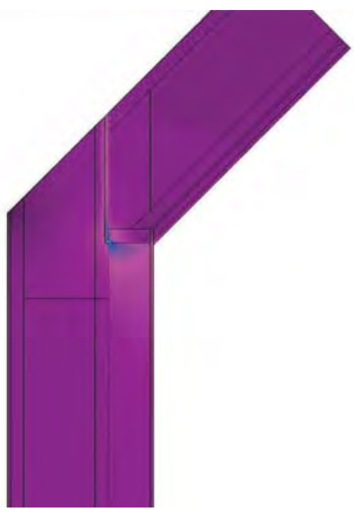
Air-vapour barrier, all joints lapped, sealed and mechanically trapped using service void battens

Timber wall plate and rafters tied down to blockwork using internal flange pieces of wall ladder studs

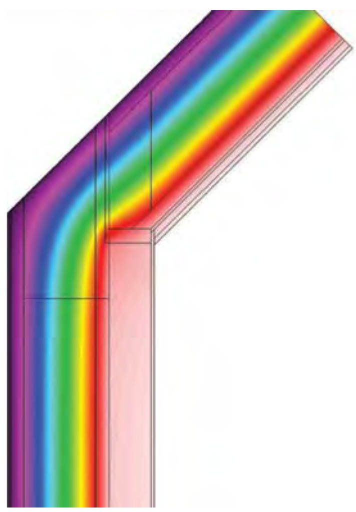
Air-vapour barrier fixed against blockwork using expanded metal lathe and plastered over. Alternatively a proprietary air-vapour membrane incorporating a surface designed for direct plastering may be used.

MW2 + TR2	ψ-value W/mk
ψ internal	0.037
ψ external	-0.006

Flux



Isotherms



THERM software image of heat flux and isotherms respectively, through MW2 + TR2

Description

The detail above shows an I beam timber roof joined to a masonry wall which has external insulation between Larsen trusses. The wall insulation support system is carried up to roof level and it replaces some other elements which are normally needed.

Precedent

Many energy-efficient UK buildings since the 1980s have utilised the basic technique of trapping the roof membrane to the wall with a strip of expanded metal lath and plastering over. It works extremely well. Care should be taken to cover this loose flap of membrane with sufficient mesh to form a good key for the plaster or render. The mesh forms an intermediate stage between the plaster and the membrane.

Limiting Thermal Bridging

This detail reduces the problems found at the eaves in conventional buildings, where the insulation thickness often reduces to almost zero. It is not clear that this feature of conventional construction is always taken into account in designers' calculations, but the absence of insulation at this point is often noted in practice. This improved detail has a low enough ψ-value to be classed as thermal bridge-free, using external dimensions.

Airtightness

Normal buildings have significant air leakage at the junction of the wall and roof at the eaves. This phenomenon may be undetectable except in a blower door test. It is usually driven by the stack effect, so it takes the form of air exfiltration at this point rather than air infiltration. Air exfiltration is normally undetectable to occupants.

This detail eliminates such problems. The seal resulting from clamping the membrane to the blockwork and plastering over it should be extremely airtight.

Structural Issues

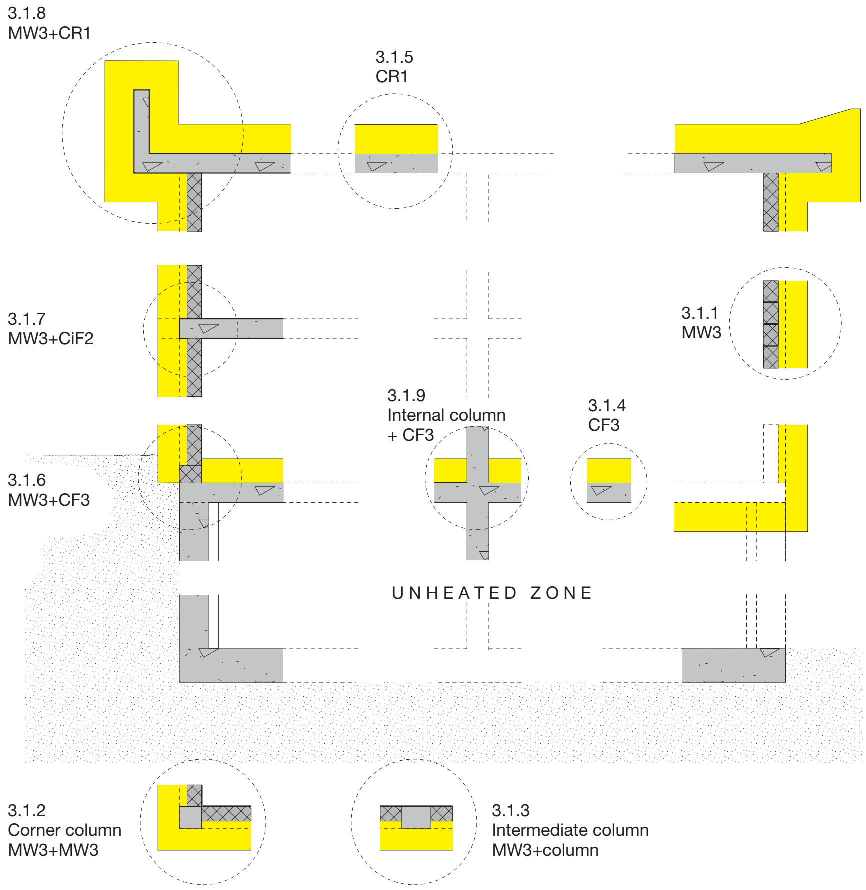
The wall plate and rafters are fixed down to blockwork using the softwood internal flange pieces of the wall's Larsen trusses. This arrangement avoids the need for galvanised metal straps and also potentially avoids the need for a metal angle bracket or other metal fixing securing the rafter foot to the wall plate. All flange pieces should be knot-free timber.

Should this arrangement not be adopted, then the conventional approach of galvanised straps could be used without compromising the ψ-value. But if metal straps are used, as noted before care must be taken not to compromise the seal of the air-vapour barrier and the plaster finish.

Any additional strengthening required for the rafter foot and its connection to wall plate required by the project engineer may affect the ψ-value of the junction illustrated. If 'squash boards' are used, take care that they do not make insulation placement difficult or cause excessive thermal bridging. Detail above shows 18 mm plywood ‘squash boards’ fixed both sides of rafter webs, between flanges.

The overall stability of masonry panels should be taken into consideration, including the contribution of lateral restraint from internal walls.

3.0.0: Concrete frame with masonry infill



The diagram above represents a notional cross section through an externally insulated concrete frame building with masonry infill panels. The diagram identifies construction junctions modeled in Section 3.

In this section U-values are given for the circled 'plane elements' (e.g. MW3) and ψ-values are given for circled junctions (e.g. MW3 +MiF2).

MW	Masonry Wall
CR	Concrete Roof
CiF	Concrete intermediate Floor

Introduction

A reinforced in situ concrete frame is commonly used to construct offices, hospitals, schools, etc. It is also utilised in many new blocks of flats.

Steel-frame is also used for many non-residential buildings and its UK market share has risen to around 80%, a higher fraction than in other European countries. But steel-frame buildings can be problematic in terms of air leakage. Given their shape, the frame members themselves provide a network of hollow air channels through which air can leak into and out of the building, unless the building envelope is detailed extremely carefully to block all such air movement.

We do not know of any steel-frame non-domestic buildings which have yet set airtightness standards on a par with the requirement of the Silver, Passivhaus or Gold Standards. However, we do know that conventional steel frames can be greatly improved.

Where practicable, concrete-frame construction is recommended as an alternative to steel-frame. The techniques to make it airtight are relatively straightforward and should inspire confidence that they can be constructed in practice, given the constraints of normal building sites.

Concrete-frame buildings tend to have a higher thermal capacity than steel-frame buildings. This feature may have beneficial implications for summer comfort in the future.

The example which we consider in Section 3 is a concrete-frame building above a basement car park. The building is insulated outside the thermally-massive wall and roof elements, but its ground floor is insulated above; i.e., on the inside of, the floor slab. The concrete columns are flush with the outer face of the floor slabs. Except at window and door openings, the walls are infilled with dense concrete blockwork between the concrete columns. The ground and intermediate floors are in situ flat concrete slabs, without downstand beams. The building has a flat in situ concrete roof, with a parapet.

The building's reinforced concrete columns extend all the way down to the basement floor, passing through the ground floor insulation. They provide an example of a thermal bridge which cannot practicably be designed out, given the assumed need for an underground car park. One must allow for the additional heat loss resulting from the presence of these columns, which form a series of repeating point thermal bridges.

One method for externally-insulating concrete-frame walls has been illustrated in this guidance. A similar, indeed simpler, approach could be applied to an in situ concrete wall or to a wall of precast concrete wall panels, which are sometimes used in the UK, or to a wall of tilt-up concrete.

The guidance illustrated in this document for creating thermal bridge-free details in a concrete-frame building assumes a scenario of buildings usually at least five storeys high and typical column spacings, floor to ceiling heights and section sizes for columns and floor slabs. It assumes an engineering design approach that aims to avoid the use of steel wind bracing in the external walls, due to the ensuing implications for thermal bridging and airtightness. If designers wish to incorporate steel wind posts into external wall constructions similar to those described here, they must ensure that they do not compromise the insulation or the air barrier.

The concrete frame illustrated is based on a notional building of up to 26 storeys, with columns set out on a 5 m plan grid. Columns between floor slabs and in line with external walls have been illustrated as 225x300 mm in section and 225x225 mm at building corners. Internal columns have been shown as square, 300x300 mm in section.

In section 3, an engineering approach has been adopted of dealing with lateral structural stability by using internal elements; e.g., solid partition or separating walls. This simplifies the design of the external thermal fabric and may allow solutions which give better thermal performance. However, attention must be paid to the impact of these elements on ground floor heat loss.

It is implicitly assumed in this document that the stairwells, and lifts if applicable, are provided in structures which are external to the main building, albeit often tied to it. The purpose of this is to avoid the extreme thermal bridging and air leakage issues which arise if a complete concrete lift shaft, or stairwell, extends from an unheated basement up into a heated building, passing through the floor insulation. These potential heat loss problems are very serious, probably insurmountable. They should be carefully designed out at an early stage, not left to develop in the vain hope that suitable details can be devised later.

The method described in 3.1, based on plane element MW3, considers a typical type of proprietary ‘insulated render’ system, using two layers of a lightweight rigid insulation material; e.g., EPS or sometimes phenolic foam, which is both mechanically- and adhesive-fixed to the external face of the masonry infill panels or concrete frame members. The insulation is then directly rendered by the same approved installers, using a proprietary render system.

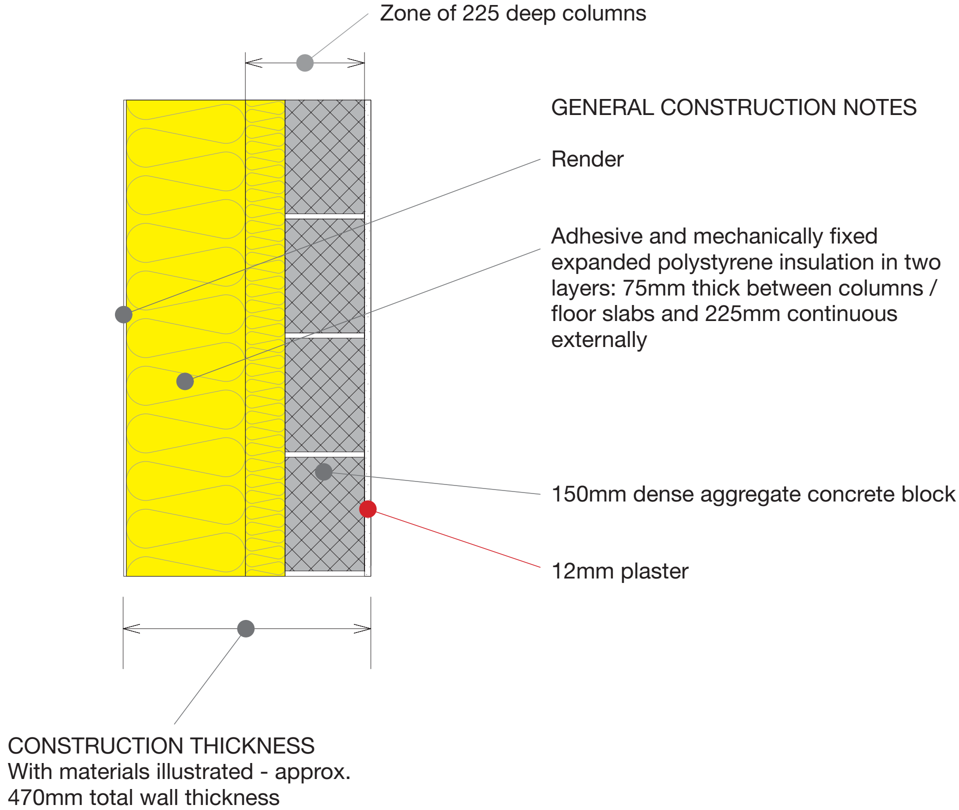
A wide variety of insulant materials are used both on tall and low-rise buildings. The examples chosen here are purely illustrative and are not intended to imply that they are more common than any others. In fact, the most common external insulation systems in the UK at present tend to involve the use of plastic foam insulants on low-rise buildings and mineral fibre on tall buildings.

Masonry infill panels in the external walls can be reinforced either horizontally or vertically to achieve greater panel lengths or heights. However, as any steel bar is embedded within the depth of the blockwork, and occurs relatively infrequently, the impact on the wall’s U-value is negligible.

3.1.0: Insulated wet render systems – basic principles

Element	Designated air barrier	Designated insulation zone(s)	Designated wind barrier
All elements	See 2.1.0	See 2.1.0	See 2.1.0
Wall MW3	In the concrete frame construction shown, the air barrier is the internal plaster layer. In wholly in situ concrete walls, the material itself may be classified as the air barrier, because properly-vibrated concrete is airtight.	The outer layer of wall insulation is uninterrupted. The inner layer is thermally-bridged at intervals by the vertical concrete columns and by the horizontal edges of the floor slabs.	The rendered finish of the walls acts as a wind barrier on the outer face of the insulation.
Roof CR1	The reinforced concrete roof slab acts as the air barrier.	The roof insulation is uninterrupted, except at the parapet-type junction of the roof and the external wall.	The waterproofing membrane of the roof acts as a wind barrier on the outer face of the insulation.
Floor CF3	The reinforced concrete floor slab acts as the air barrier.	The floor insulation is uninterrupted, except by the concrete columns which support the building and pass straight through the insulation and by the concrete block infill.	The reinforced concrete slab outside the insulation acts as a wind barrier on the outer face of the insulation.

3.1.1: The basic construction – plane element MW3



MW3	U-value W/m²k
As shown Insulation adhesive-fixed only, assuming insulation either fixed to wall with adhesive only or uses non-conductive mechanical fixings.	0.122
Typical Including impact of point repeating thermal bridges - typical. See worked example below for details of fixing type and number.	0.137
Typical range Including impact of both point and linear repeating thermal bridges - typical range. See worked example below for details.	0.142-0.146

Description

This shows a section through the external wall. It is made up of the thermal insulation zone; the dense blockwork infill, which is flush with the inner face of the concrete frame; and a layer which is mostly thermal insulation but is thermally bridged by the outer 75 mm of the concrete columns and floor slabs.

Precedent

Many buildings with such insulation systems have now been constructed in the UK, albeit generally with less insulation than Passivhaus levels. Two energy-efficient buildings at the University of East Anglia, in the 2000s, used external insulation systems on a concrete frame and reached wall U-values of around 0.20 W/m^{2}K. Concrete-frame blocks of flats with external insulation are regularly seen under construction in major UK cities.

On continental Europe, such developments are widespread, and a growing number meet the Passivhaus Standard. On much of the continent, however, in situ concrete buildings are more common than concrete frames with masonry infill. They are quicker to build and they give a thinner wall for the same U-value, because the insulation is not in part thermally bridged by concrete frame members.

Limiting Thermal Bridging

The areas where the concrete frame projects into the insulation zone form a series of linear repeating thermal bridges as follows:

1. Up and down the building on 5 m centres; and

2. Around the building every storey; i.e., typically on 3 m centres.

This type of thermal bridge is almost inevitable if designers wish to avoid the frame members projecting into the room itself. This is because concrete columns are thicker than the 140 or 150 mm of dense blockwork which is commonly used as infill to the frame.

However, the majority of the frame can be located in the same plane as the blockwork infill. Only 75 mm of the total 300 mm of insulation in this wall is thermally-bridged by concrete frame members.

The thermal insulation in this wall is also thermally-bridged by various mechanical fixings which are used to hold the insulation in place.

Currently EN ISO 6946.1996 advises that where the thermal conductivity of a fixing or part of it is less than 1 W/mK the effect of the fixing can be disregarded in U-value calculations. However, for Passivhaus and Gold Standard buildings, the heat loss from mechanical fixings through the insulation to the substructure should be accounted for, using the χ-value of each fixing multiplied by the number of fixings per unit area.

The system supplier may include the losses from mechanical fixings in their quoted U-values. Indeed, they are supposed to do so under current rules, as these are repeating thermal bridges. But it is clear that many suppliers do not do this. They quote U-values which exclude the impact of any of the fixings.

Alternatively, the designer may wish to request the system supplier to quote separately the U-value for the insulated element alone and the further χ-value due to all the point thermal bridges. This enables him/her to investigate the benefit and the feasibility of using fewer, or less conductive, mechanical fixings.

A smaller number of additional fixings may also be needed to hold the render reinforcement mesh onto the face of the insulation before rendering. This is particularly true when applied to high-rise buildings and in relation to fire issues. These fixings cannot be countersunk with heads insulated over and may constitute further thermal bridges that should be accounted for. It is important to develop a clear and detailed specification with the system supplier for the approved installer to follow.

FIRE: Using EPS, Neopor or otherwise on high-rise or multi-storey buildings, there may be a requirement under the Building Regulations to limit the spread of fire on external walls, as well as to reduce the risk of disproportionate collapse in the event of a fire. BR 135 provides guidance on the requirements to reduce these risks. This might require the introduction of non-combustible fire breaks horizontally at each floor level above second floor and vertically at dividing walls between units.

Alternatively, if a proposed system without fire breaks is tested in accordance with the relevant BS (BS 8414 Part 1 – masonry walls, or BS 8414 Part 2 – steel frame walls) and is assessed in accordance with BR 135, then it is deemed to comply with the requirements.

On mechanical fixing, BR 135 states: ‘Use no fewer than one stainless steel fixing - in addition to those of plastics - per square metre of insulation. The fixings should be sized and fitted to resist the increased duty that may be required under fire conditions’.

Generally, therefore, for an EPS insulated render system on a multi-storey building, the insulation boards would be adhesively bonded and mechanically fixed, usually referred to as initial fixings. In addition, after the render and reinforcement have been applied over the EPS, further mechanical fixings would be inserted in stainless steel at a minimum rate of 1 no. fixing per square metre of wall area. Typical stainless fasteners would have a cross-sectional area of ca. 13 mm^2.

The number of initial fixings is dependent on the wind suction forces acting on the building and the dead weight of the system. Where insulation is being applied in two layers, there is the added complication of the fact that at each stage of the installation, the applied insulation boards should be secure and able to withstand the wind suction forces acting on them. Therefore, for the scenario in considered in Section 3 of this guidance document both layers of insulation boards would require ‘initial’ fixing with a similar number of ‘initial’ fixings.

Using 4-5 initial fixings per insulation board would be considered typical. The first layer of insulation boards need not be fixed using the recessed head type fixings, since these heads will be trapped behind the second layer of insulation. The second layer can either be recessed head fixings, which tend to have a metal pin running down the centre and are therefore more heat-conductive, or plastic fixings, with reinforced plastic pins running down the core, having a lower χ-value than the recessed head types.

Where mineral fibre fire breaks are used, these are usually fully adhesively bonded and mechanically fixed, with additional fixings through the render reinforcement mesh so that, in the event of the EPS insulation melting away in a fire, the reinforced render system, which will be very heavy on a multistorey building, is still mechanically secured to the load-bearing substrate.

The analysis below is based on horizontal fire breaks at each floor level.

Worked example

In calculating the likely range of overall wall U-values shown above the following worked example indicates the impact of both the point repeating thermal bridges from the mechanical fixings and the three types of linear repeating thermal bridges associated with the concrete frame elements.

In calculating a possible range of overall wall U-values, including the impact of the point thermal bridges, we have assumed that:

1. One fixing per m^2 is provided to attach the render mesh to the masonry or concrete substrate, with a χ-value of 0.005 W/K.
2. Five fixings per m^2 are provided to attach the outer layer of insulation through the inner layer of insulation into the masonry or concrete substrate and also to hold the adhesive while it is setting, each having a χ-value of 0.002 W/K.
3. Five fixings per m^2 are provided to attach the inner layer of insulation temporarily to the masonry or concrete substrate, while the adhesive sets. These fixings are all-plastic, with a χ-value of 0.000 W/K, and so are omitted from the calculation.

In calculating the overall wall U-value, we first calculate the typical impact of the point thermal bridges. This is assumed to be the same for buildings of different height.

Wall elemental U-value
= 0.122 + (5x0.002) + (1X0.005)
= 0.137 W/m^2K.

We next calculate the typical impact of the linear repeating thermal bridges. There are three different ones to consider:

1. The floor slabs all around the building each storey height, also featuring a fire break formed by an insulant with a higher l-value, with an overall ψ-value of 0.014 W/mK.
2. The columns up and down the walls of the building on 5 m centres, with a ψ-value of 0.013 W/mK.
3. The columns up and down the corners of the building, with a ψ-value using external dimensions of -0.023 W/mK.

First, we take a building which is 3 storeys high excluding the basement, 10 x 15 m in plan and has a floor-to-floor height of 3.33 m; i.e. 10 m high.

Wall overall elemental U-value
= 0.137 + ((4X0.014X50)+(6X0.013X10)+(4X-0.023X10))/(10X50)
= 0.137 + (2.8+0.78-0.92)/500
= 0.142 W/m^2K.

Second, we take a building which is 25 storeys high excluding the basement, 15 x 50 m in plan and has a floor-to-floor height of 2.8 m.

Wall overall elemental U-value
= 0.137 + ((26X0.014X130)+(20X0.013X70)+(4X-0.023X70))/(70X130)
= 0.137 + ((47.3+44.2-6.4)/9100)
= 0.146 W/m^2K.

summarised in MW3's U-value table above. As one can see, the final U-value approaches the upper limit permitted by the Passivhaus or Gold Standards and is 20% greater than the calculated U-value based on insulation thickness alone.

This reinforces the need to take extreme care in heat loss calculations. On this building, an insulation thickness which may initially have appeared more than sufficient proves to be only marginally acceptable. On some projects, the impact of thermal bridging would be even more severe than this, making this insulation thickness insufficient.

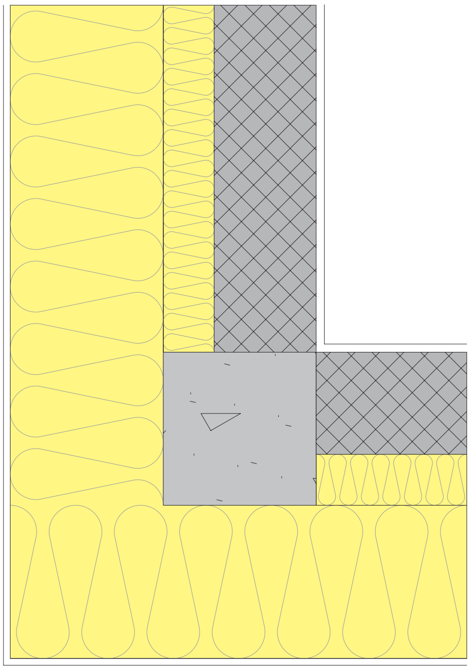
Airtightness

The key, as with load-bearing masonry, is to ensure that the plaster layer on the masonry is absolutely continuous. Since the adjacent concrete is airtight, designers may choose to stop the plaster at the concrete or, more often, to plaster over the entire wall area.

Structural Issues

None noted.

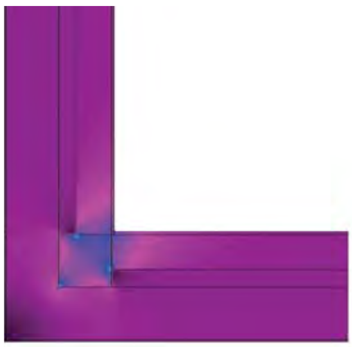
3.1.2: Corner column: MW3 + MW3



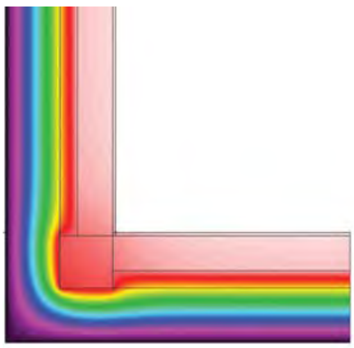
HORIZONTAL SECTION AT CORNER

Corner column: MW3 + MW3	ψ-value W/mk
ψ internal	0.091
ψ external	-0.023

Flux



Isotherms



THERM software images of heat flux and isotherms respectively through corner column: MW3 + MW3

Description

MW3 + MW3 above shows the external corner of the concrete-framed building, viewed in plan. The reinforced concrete column protrudes 75 mm outwards into the insulation zone, in both directions.

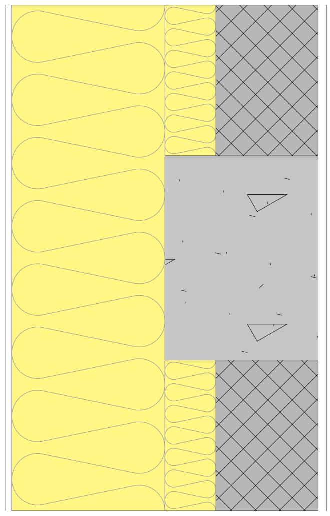
Limiting Thermal Bridging

See earlier comments. Based upon external dimensions, this detail has a low enough ψ-value to be treated as thermal bridge-free.

Structural Issues

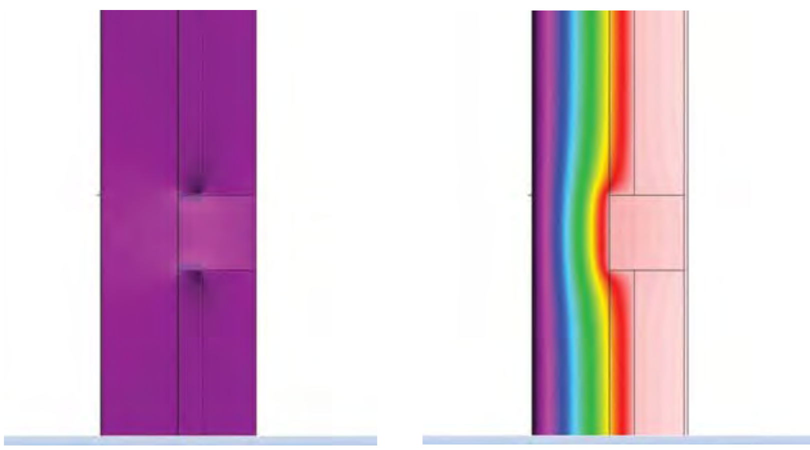
None noted.

3.1.3 Intermediate column: MW3 + column



HORIZONTAL SECTION AT COLUMN

Intermediate column: MW3 + MW3	ψ-value W/mk
ψ internal	0.013
ψ external	0.013



THERM software images of heat flux and isotherms respectively through intermediate column: MW3 + MW3

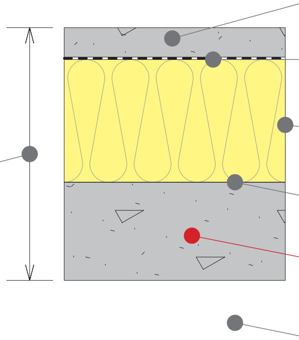
Description

This vertical linear thermal bridge in the external wall is formed where the vertical columns of the concrete frame protrude into the thermal insulation zone.

Structural Issues

None noted.

3.1.4: The basic construction – plane element CF3



CF3	U-value W/m²k
As shown Insulation only and excluding impact of point repeating thermal bridges	0.111
Typical range Including impact of point thermal bridges due to internal concrete columns: typical range. See worked example below.	0.134-0.142

Description

The floor construction in this concrete-frame building is insulated on the inside. A cautionary note is needed; we have examined this case not because it is recommended, but because it is relatively common.

Limiting Thermal Bridging

The U-value calculated for the insulated floor alone has to be corrected for the point repeating thermal bridges caused by the structural columns that penetrate the ground floor slab insulation. *See 3.1.9.*

Structurally, the columns cannot be avoided, unlike many potential thermal bridges in a building which can be designed out. So it is important to know by how much they increase the floor heat loss.

Section 3 uses the example of a concrete frame based on a 5.0 m plan grid for column spacing. The associated worked example shows the likely impacts on the floor U-value for CF3, with the resulting range in corrected U-values being shown above.

The χ-value of the point thermal bridge where each column within the external wall meets the ground floor in MW3+CF3 has not been calculated in this draft of the guidance. However, it is reasonable to account for the additional heat loss associated with these particular columns by using the same χ-value that arises in Section 3.1.9 for free-standing internal reinforced concrete columns passing through the centre of the ground floor slab insulation.

Our calculation may slightly overestimate point thermal bridge heat loss when it is applied to columns in the external walls since, in the frame modelled, the peripheral columns are smaller in cross section. However, the difference is very small and it is much safer to marginally overestimate a building's heat loss than it is to underestimate it.

Worked example

In calculating the likely range of overall floor U-values shown above, the following worked example indicates the impact of the concrete columns which penetrate the ground floor insulation.

We first consider a building which is 10 m deep and 10 m long. It is three columns deep in both directions.

Floor elemental U-value = 0.111 + (9x0.392)/100
= 0.111 + 0.035
= 0.146 W/m^{2}K.

We next take a building considerably larger in plan, which is 15 m deep and 50 m long. It is four columns deep and 11 columns long.

Floor elemental U-value = 0.111 + (44x0.392)/750= 0.111 + 0.023 = 0.134 W/m^{2}K.

As shown in the example above, these thermal bridges are very significant, giving in the two different cases an increased heat loss in the range 21-31%. However, they are manageable provided that they are considered for at design stage, when the floor insulation level can be increased to allow for the thermal bridging.

Any other structural penetrations of the ground floor insulation must also be allowed for. Solid partition walls which are too heavy to be supported on the floor screed, or which are designed to act structurally as lateral bracing, could come into this category.

With the floor insulation placed above the concrete slab, thermal bridging is likely to be at a maximum. In similar buildings where the floor insulation is placed under the slab; i.e., on the basement ceiling, heavyweight partition walls would not cause thermal bridging and there would be the possibility of insulating around the top portion of the concrete columns, as well as below the basement slab.

Even insulating around the top portion of the columns would not totally eliminate the thermal bridge; it would only reduce it. But if the basement is used as a car park, any insulation on its ceiling and/or over the top of its columns would clearly have to be non-flammable.

Airtightness

The material which is treated as the air barrier in this element is the concrete floor slab below the insulation. It also acts as an extremely thorough wind barrier, preventing any risk of air movement into the insulation from the ventilated airspace below.

Interstitial Condensation

With the insulation placed inside the floor slab, a vapour barrier has conventionally been advised on the inside face of the floor insulation. The purpose of this barrier is to limit vapour diffusion into the structure from the interior and to reduce the risk of interstitial condensation.

There has, however, been much discussion of this topic over the years. More recent published advice reverses this orthodox position. It recommends not installing a vapour-impermeable layer on the inside of the insulation zone.

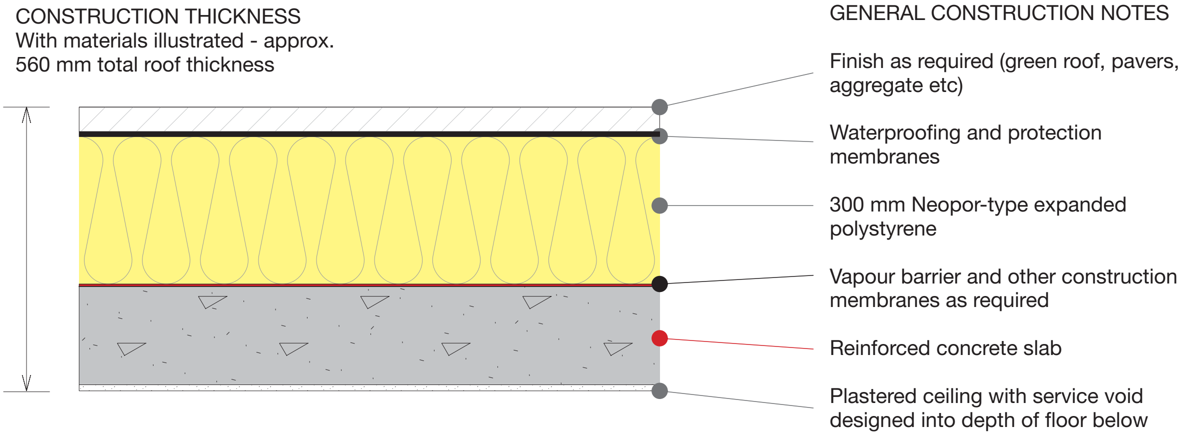
Overall, we offer readers a note of caution. Construction elements which feature internal insulation are very problematic from a ‘building physics’ viewpoint and the above disagreement hints at this. Yet internal insulation is very common in the UK, possibly due to a lack of awareness of the risks which it gives rise to. Designers should make themselves aware of the significant advantages of always placing the insulation externally. This does not give rise to the same problems.

Structural Issues

On concrete-frame buildings, the column dimensions and steel reinforcement are calculated by the structural engineer on a project-specific basis. The details here, including the column spacing, are believed to represent a typical to worst-case basis in thermal terms. Some low-rise concrete-frame buildings may be able to utilise greater column spacings than 5 m, using these same column dimensions, although the floor slabs would become thicker.

The insulation type must be suitable for this situation; i.e., in terms of compressive strength and durability. EPS insulation is widely available with typical compressive strengths up to 250 kPa. Insulation with a compressive strength of 70 kPa at 1% nominal strain is illustrated above.

3.1.5: The basic construction - plane element CR1



CR1	U-value W/m²k
As shown	0.104

Description
This is fairly typical of the type of roof which might be encountered on concrete-framed offices, schools, hospitals and blocks of flats. There is a parapet at the junction of roof and external wall which directs rainwater onto the flat roof. Guttering and downpipe details are not shown. The parapet provides access for maintenance purposes.

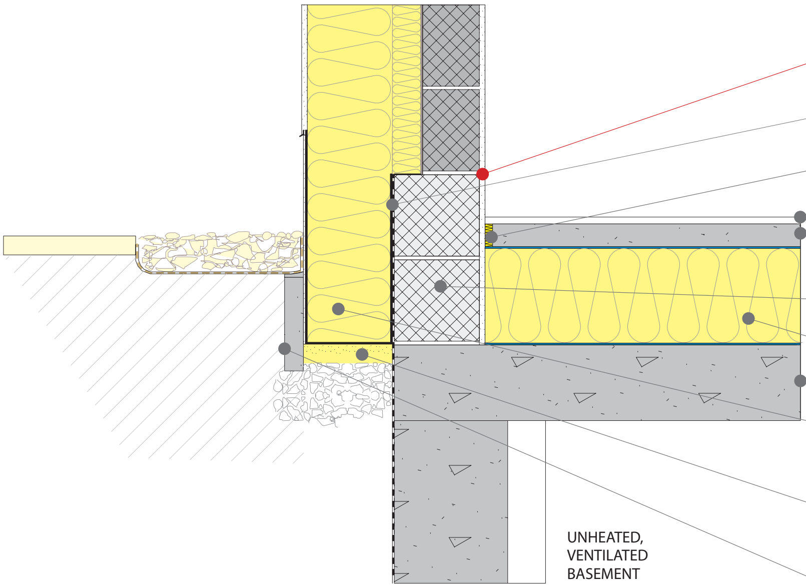
Limiting Thermal Bridging
This roof has no significant thermal bridging, except around the edges. The full thickness of insulation is continuous from side to side of the building.

Airtightness
The roof material is in situ reinforced concrete, which is an effective air barrier.

Structural Issues
The insulation type must be suitable for this situation; i.e., appropriate compressive strength and durability.

3.1.6: Wall to floor junction – MW3 + CF3

SECTION 3



GENERAL CONSTRUCTION NOTES

Plaster / parging to blockwork taken down to reinforced concrete ground floor slab to ensure airtightness

Vertical DPC tanking applied to external face of blockwork and columns to required height

Acoustic decoupling -if required

Floor finish not shown

Reinforced concrete slab / screed sealed to walls to prevent liquid water ingress into floor construction

Two courses of ultra-lightweight block

250mm expanded polystyrene insulation

Reinforced concrete ground floor slab

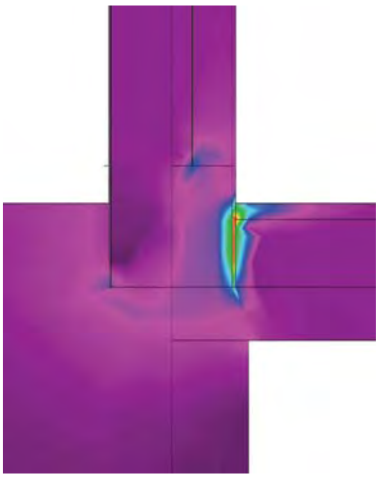
External wall insulation below ground incorporating applied layer of waterproof tanking prior to rendering external face of insulation

50 mm compressible insulation. NB: lean mix concrete replaces insulation strip at thresholds to provide bearing under wall insulation

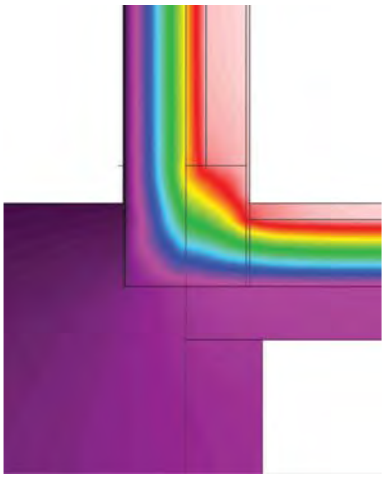
Paving slab or similar down to compacted base or lean mix concrete below wall insulation - to ensure continuity of insulation vermin barrier

MW3 + CF3	ψ-value W/mk
ψ internal	0.0113
ψ external	-0.005

Flux



Isotherms



THERM software image of heat flux and isotherms respectively, through MW3 + CF3

Description

This drawing shows a ring of aerated lightweight concrete blocks all around the building, placed between the concrete columns, providing a partial thermal break where the wall insulation meets the floor insulation. We have analysed a case using 215 mm blocks; i.e., the blocks are virtually the full thickness of the concrete frame and are thicker than the dense blockwork wall above them.

The ψ-value quoted includes the impact of these blocks and their mortar joints, but it excludes the impact of the reinforced concrete columns. These form a series of point thermal bridges in the ground floor and are accounted for separately.

Limiting Thermal Bridging

Using lightweight blocks reduces thermal bridging where the wall insulation meets the floor insulation. Depending on block and mortar details, the heat loss through these blocks is 5-8 times lower than if dense aggregate blocks were used from top to bottom of the wall.

Airtightness

The plaster on the wall remains the air barrier. It continues down to the top of the concrete floor slab. It is essential to seal the reinforced screed and membrane to the external wall. This screed forms a barrier to any liquid water which is spilt internally.

It is especially important when plastering lightweight concrete blocks, in this case aerated autoclaved blocks, to take care to avoid problems with cracking or failing plaster. If the plaster were to fail, it would affect the airtightness of the wall. There are more requirements to be observed with walls of lightweight concrete blocks than there are with dense block walls.

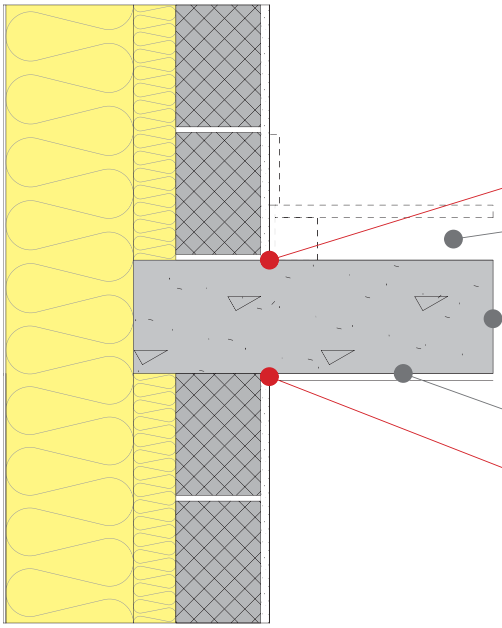
The choice of plaster and its application should be made with regard to guidance given in BS EN 13914-2 and BS 5628-3 and the NFPC/AACPA Advisory Note 1 ‘The Application of Plaster to Aircrete Block Walls’. The NHBC’s 2008 Standards recommend referring to block manufacturers’ recommendations, which are specific to the particular block. Other relevant standards include BS 1191 ‘Specification for Gypsum Building Plasters’ and BS 5492 ‘Code of Practice for Internal Plastering’.

Structural Issues

The loading on these aerated blocks is very low, compared to cases elsewhere in this guidance where one or two courses of such blocks support a complete masonry and concrete building. In this building, the frame takes most of the load and blockwork infill panels are usually only assessed for their ability to withstand wind forces or to contribute to the wall’s racking strength.

On the basis of floor-to-ceiling heights of 2.4 to 3.0 m, these aerated blocks are likely to be supporting a dense block wall 2.0 to 2.8 m high above them. Subject to the engineer’s recommendations, it should be possible to use very low-density blocks, with reduced thermal bridging as a result. However, our thermal modelling has been based on typical aerated concrete blocks.

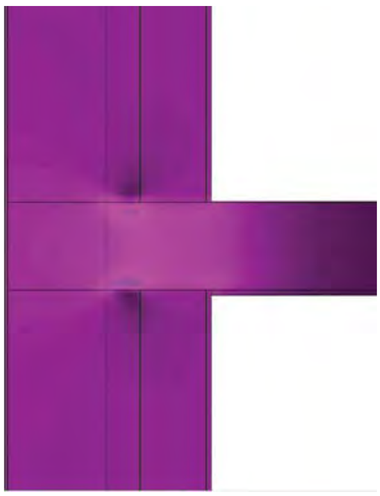
3.1.7: Wall to intermediate floor junction – MW3 + CiF2



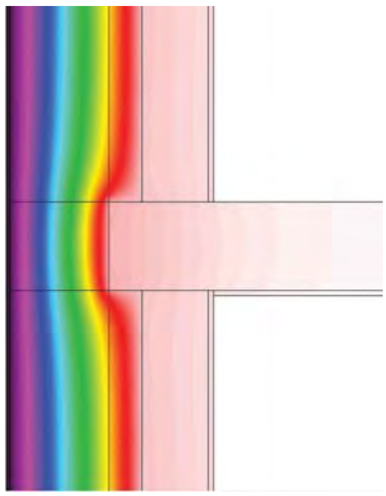
MW3 + CiF2	ψ-value W/mk
ψ internal	0.013
ψ external	0.013

As shown: no fire breaks

Flux

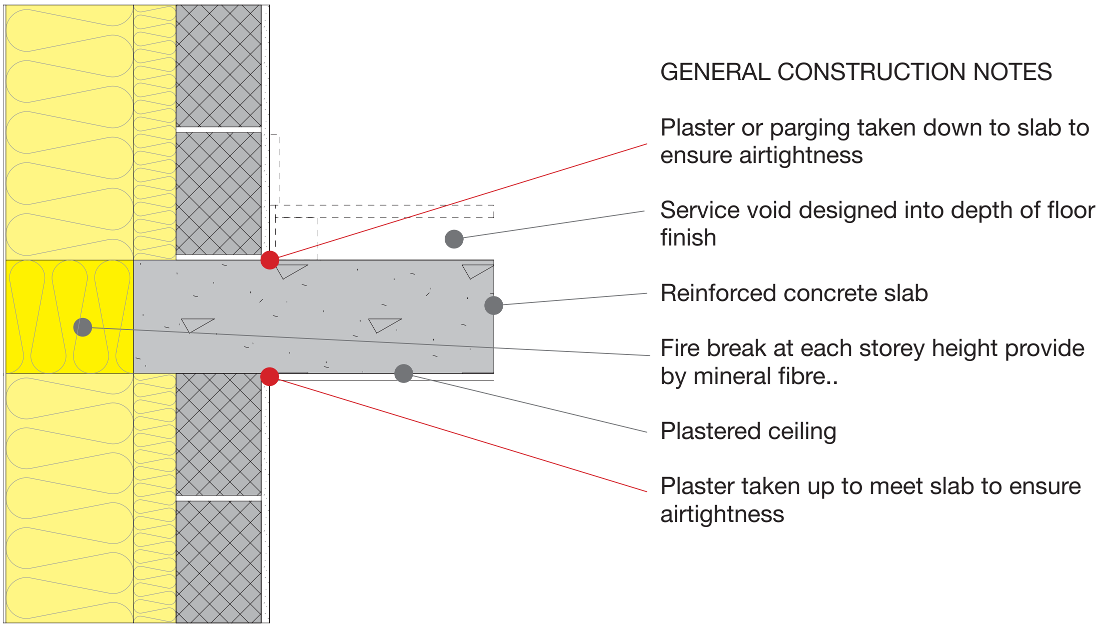


Isotherms



THERM software image of heat flux and isotherms respectively, through MW3 + CiF2

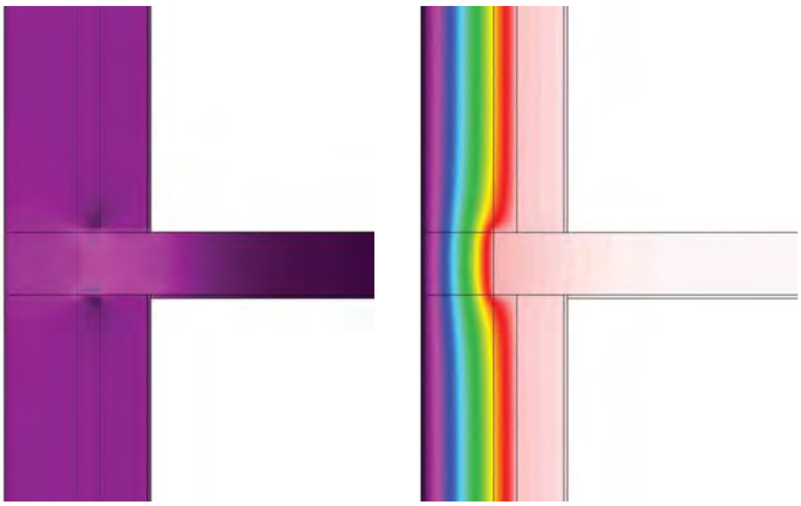
3.1.7: Wall to intermediate floor junction: MW3 + CiF2, *variation 1*



MW3 + CiF2 variation 1	ψ-value W/mk
ψ internal	0.014
ψ external	0.014

As shown: fire break of lamella mineral fibre at intermediate floor level

Flux **Isotherms**



THERM software image of heat flux and isotherms respectively, through MW3 + CiF2 variation 1

Description

MW3 + CiF2 above shows the situation in this building at intermediate floor level. The bulk wall insulation is assumed to be EPS.

The inclusion of fire breaks of mineral fibre at all intermediate floors has been modelled in MW3 + CiF2, *variation 1*, for situations where fire breaks are needed.

The fire break should be to the full depth of the insulation system. So if, for example, you are using a 250 mm EPS insulation system, the non-combustible firebreak; i.e., in mineral fibre or similar, should also be the full 250 mm thickness. This is the arrangement modelled above.

Owing to the potential complexity of changing insulant to create the fire breaks, it is more common on tall buildings to use mineral fibre alone. This is particularly so in Scotland, where the Building Regulations set stricter requirements for fire resistance than in England and Wales. Mineral fibre is virtually fireproof, whereas plastic foams are not.

On the other hand, there are some potential advantages in using EPS on tall buildings. It is some seven times lighter than dense mineral fibre, giving advantages in manual handling at height. Owing to its lower λ-value, it gives a thinner wall than a wall with lamella-type mineral fibre. For these reasons, we have illustrated the use of EPS in this example.

Limiting Thermal Bridging

One needs to allow for the varying thickness of thermal insulation in this wall. The thickness of insulation covering the structure varies from 225 mm outside the concrete frame members to 300 mm outside the masonry infill. It is assumed that the designer chooses to place the concrete columns and beams flush with the inside of the external wall. This makes a variation in insulation thickness inevitable.

The ψ-values indicate that this junction is not thermal bridge-free relative to external dimensions, as defined by PHI. Technically, it forms a repeating linear thermal bridge and its impact should be subsumed into the overall wall U-value. However, we also quote its value separately, to illustrate to designers the magnitude of its impact.

Variations: If a designer wished to develop a concrete-frame wall to become ‘thermal bridge-free’, to help simplify the thermal modelling using PHPP software, then the outermost layer of insulation would need to become thicker over the whole building and the thickness of the inner layer would need to be reduced. It seems doubtful whether this would be feasible in a concrete-frame structure unless the external face of the blockwork infill panels could be aligned with the external face of the concrete columns, allowing an uninterrupted layer of insulation to cover all slab / column junctions. However, unless the dense blocks are thickened to say, 215 mm, this comes at the cost of columns protruding into the internal spaces of the building and other consequential spatial issues.

Alternatively, and more promisingly, replacing in situ concrete columns and masonry infill by in situ concrete walls could overcome the problems of variable insulation thickness. The structural wall is then likely to be a uniform 150 to 180 mm thick and the insulation is of uniform thickness, probably 250 mm.

Such a wall need not be plastered for airtightness, only for cosmetic purposes. The reinforcement needed in the RC columns may be distributed over the area of the wall, subject to sufficient bracing at right angles to the wall. The reinforcement also serves double duty as anti-crack mesh. Overall, such a wall could be 25-50 mm thinner for the same U-value. As we noted earlier, this approach is very common on the continent, although less so in the UK.

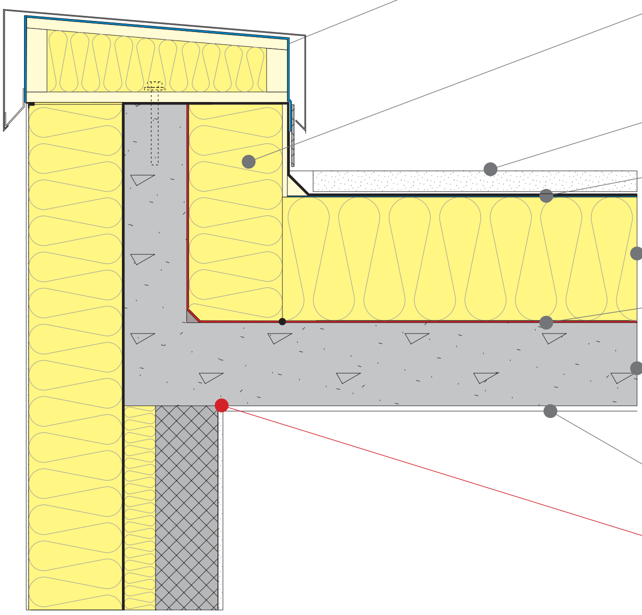
Airtightness

There are no airtightness problems with the concrete-frame wall, as long as the plaster on the masonry infill extends down to floor level and up to the soffit of the floor above.

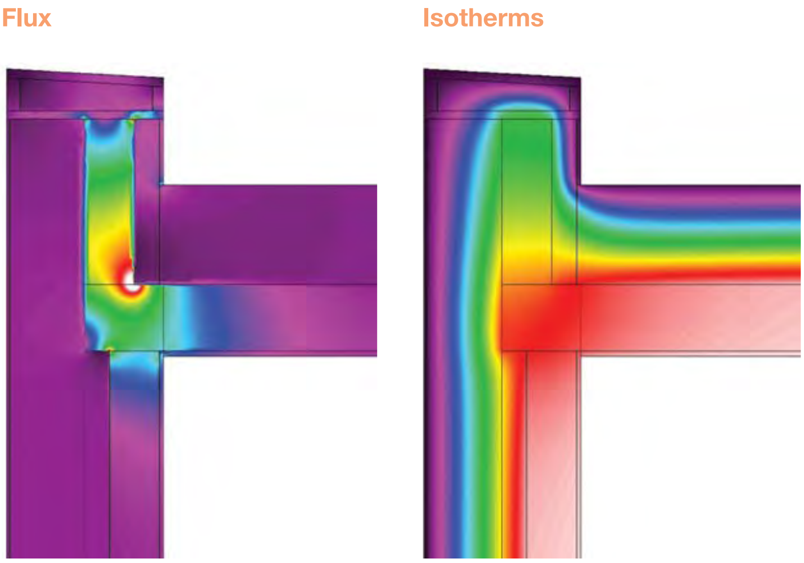
Structural Issues

The concrete frame shown in this building employs flat slabs and rectangular columns. There are no downstand beams. This type of frame is cheaper to build than one which contains downstand beams, because the shuttering is very much simpler. However, it uses slightly more concrete. On the other hand, if summer cooling is an issue, a building with a greater volume of concrete, and so a higher thermal capacity, could actually be favoured.

3.1.8: Wall to roof junction: MW3 + CR1

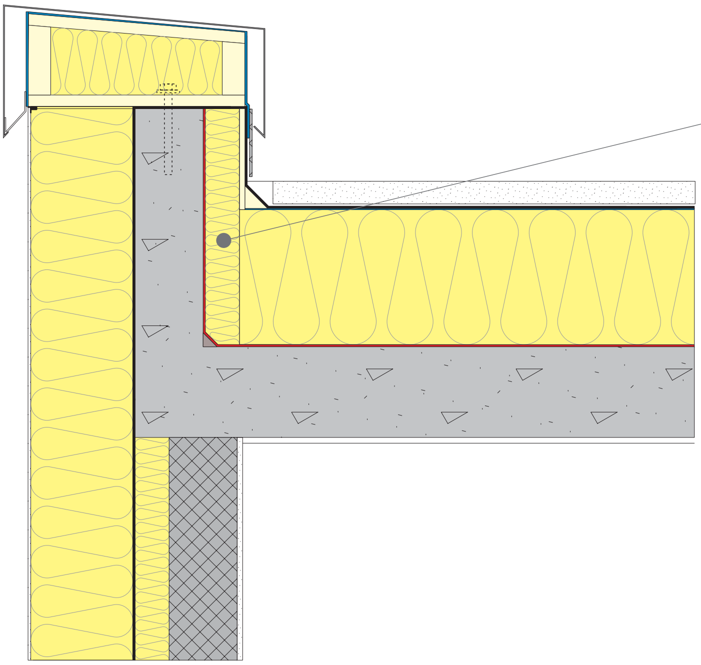


MW3 + CF1	ψ-value W/mk
ψ internal	0.190
ψ external	0.081



THERM software image of heat flux and isotherms respectively, through MW3 + CR1

3.1.8: Wall to roof junction: MW3 + CR1, *variation 1*

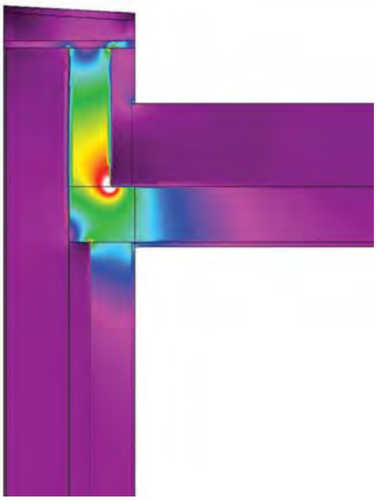


GENERAL CONSTRUCTION NOTES

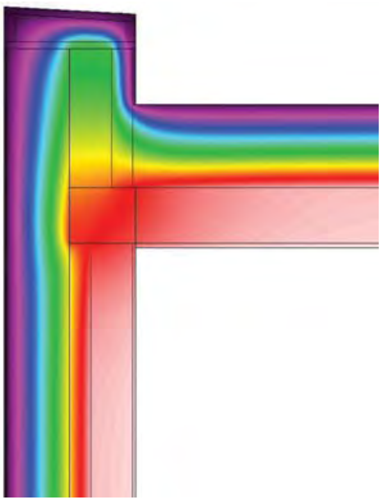
75 mm Neopor-type expanded polystyrene insulation fixed to face of concrete parapet sub-structure.

MW3 + CR1 *variation 1*	ψ-value W/mk
ψ internal	0.245
ψ external	0.135

Flux

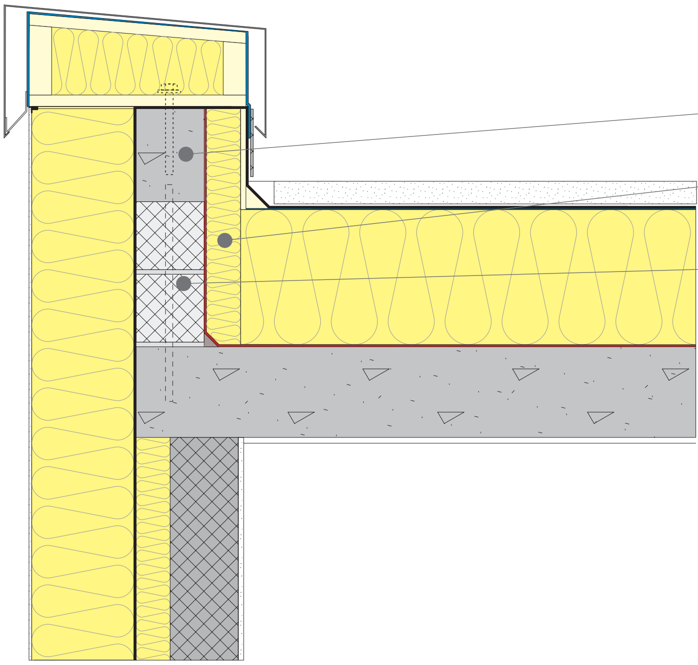


Isotherms



THERM software image of heat flux and isotherms respectively, through MW3 + CiF2 variation 1

3.1.8: Wall to roof junction: MW3 + CR1, *variation 2*



GENERAL CONSTRUCTION NOTES

Insitu cast concrete ring beam on top of concrete blockwork

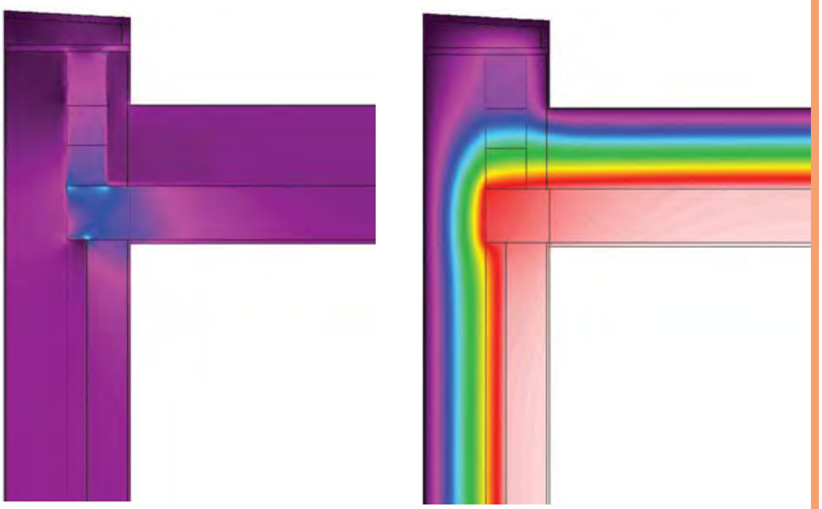
75 mm Neopor-type expanded polystyrene insulation fixed to face of concrete parapet sub-structure

Two courses of 150 x 150 mm wide aerated autoclaved concrete blocks with stainless steel reinforcement

MW3 + CR1 *variation 2*	ψ-value W/mk
ψ internal	0.120
ψ external	0.010

Flux

Isotherms



THERM software image of heat flux and isotherms respectively, through MW3 + CR1 variation 2

Description

A basic reinforced concrete parapet is ubiquitous, but a redesigned detail giving low or minimal thermal bridging is extremely uncommon. The leading-edge details considered here have probably only been used on buildings which aimed at the Passivhaus or MINERGIE-P Standards.

MW3 + CR1 shows close to the best ψ-value likely to be achieved for this junction if the designer wishes to use a simple in situ concrete upstand to form a low parapet. The construction incorporates Neopor-type EPS roof insulation on the inner side of the parapet to improve performance and reduce thickness.The upstand height is typically sufficient for weathertightness and emergency maintenance access, but not for guarding.

Good as it may be versus an uninsulated concrete parapet, even this much-improved detail is not thermal bridge-free with reference to external dimensions. The resulting heat losses must be accounted for.

The arrangement shown in MW3 + CR1, variation 1 is most unlikely to be workable in buildings aiming at the Passivhaus or Gold Standard. It demonstrates the much higher heat loss associated with a thinner layer of insulation on the inside face of the parapet, even though the concrete may still appear to be 'surrounded by insulation'.

The arrangement shown in MW3 + CR1, variation 2 demonstrates a method which is more complicated to build but is likely to approach or achieve a thermal bridge-free detail. The parapet structure incorporates a row of 150 mm thick aerated concrete blocks of λ = 0.15 W/mK; the value quoted is the composite conductivity of blocks and associated mortar joints. Neopor-type EPS is used inside the parapet and for the main roof insulation.

Limiting Thermal Bridging

A normal exposed concrete parapet could be regarded as a cooling fin fitted all around a building. With reinforced concrete having 50-100 times the thermal conductivity of common thermal insulation materials, this parapet very effectively transfers heat by conduction from the warm building interior to the cold exterior. The wind and rain incident on an exposed UK roof only serve to augment the rate of heat dissipation.

Parapet details for concrete-framed buildings are hard to detail as thermal bridge-free without radically redesigning the parapet sub-structure. Where the parapet must be high enough to provide guarding, the challenge to limit heat loss from this junction increases further.

In the detail MW3 + CR1 featured here, the concrete parapet is surrounded on both sides by full-thickness insulation, which dramatically cuts thermal bridging. On top, a timber and plywood box profile is constructed and a metal flashing is in turn fitted over this.

Another way to significantly limit heat loss from low parapets, as shown in MW3 + CR1, variation 2, is to introduce a thermal break in line with the concrete upstand forming the parapet or guarding substructure. This needs robust insulating blocks; e.g., aerated autoclaved concrete could be ordered in the height and width to suit the building dimensions. It also needs steel reinforcing bars through these blocks, and a concrete topping, to form a stiff parapet structure atop the concrete roof.

Stainless steel is more appropriate here as it has a much lower λ-value than mild steel reinforcement. Such steel rods act as a series of point thermal bridges and a composite λ-value has been used for the lightweight blocks.

Another approach to form a low parapet could be to create a raised and angled edge - an integral part of the roof insulation itself - sloping back in towards the building's roof to drain. The external vertical face of this edge block would provide a vertical face to attach the external wall insulation, albeit bridged by a thickness of adhesive. This block would need to be tied down to the substructure without significantly compromising the thermal performance of the detail, using stainless steel bars, for the same reason as above, and also while providing a sound surface for the attachment of the roofing membrane, metal copings and other anchor points as needed. This approach has not yet been modelled but may form the basis for the development of a more cost-effective solution.

There is a further possibility for reducing thermal bridging at cantilevered parapets or balconies. This is to use a proprietary German system which substitutes a thin layer of stainless steel and EPS or XPS for concrete in the balcony or parapet, forming a partial thermal break. At the time of writing, we had been unable to obtain details of the heat loss associated with this system.

There is a small point thermal bridge where the column in the external wall meets the concrete roof slab, which has not been modelled. However, applying the ψ-value for the wall/roof junction, together with the ψ-values from Section 3.1.7 or Section 3.1.8, as appropriate, will adequately account for total heat losses from the building. These junctions have been treated in this document as linear repeating thermal bridges, whose impact should be subsumed into the quoted wall U-value on a particular building.

A typical range of overall wall U-values for this building is given in the above table. Although the 'raw' U-value is well below the Passivhaus and Gold Standards' upper limit of 0.15 W/m^{2}K, the U-value after accounting for repeating thermal bridges is considerably higher. Care is needed in unfavourable cases to ensure that it does not actually exceed the upper limit.

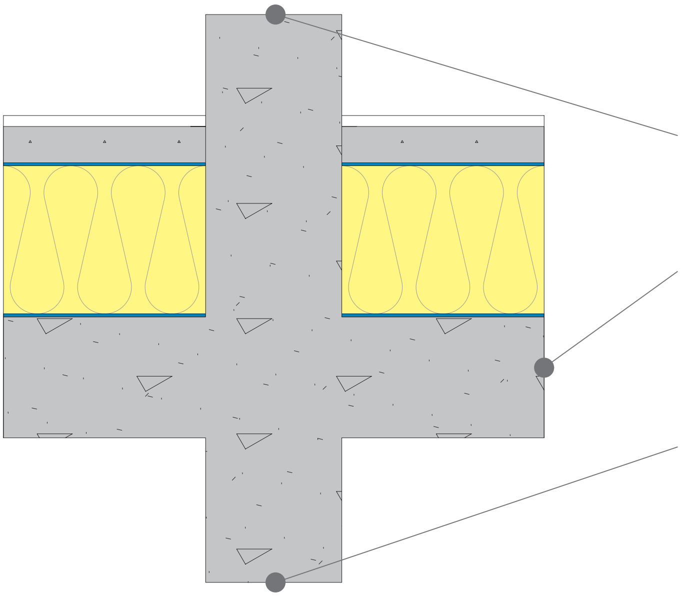
Airtightness

There are no airtightness implications with these details, as they are external to the concrete structure.

Structural Issues

None noted.

3.1.9: Internal column + CF3



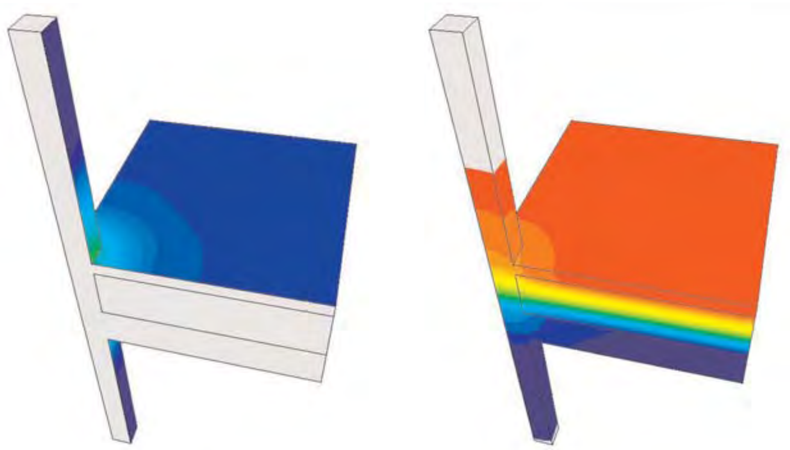
GENERAL CONSTRUCTION NOTES

Loadbearing internal concrete column

Reinforced concrete ground floor slab spanning over unheated basement

Loadbearing concrete column in unheated basement

Internal column + CF3	χ-value W/K
As shown: for each 300 x 300 mm concrete column	0.392



Images of heat flux and isotherms respectively produced using KOBRA, KOBRU86, TRISCO – Thermal analysis program. Cut-away quarter 3-D views of junction of column with CF3.

Description

This is the point where the internal reinforced concrete columns of the building pass through the ground floor en route into the basement. Some thermal bridging is inevitable.

Limiting Thermal Bridging

A moderate degree of thermal bridging occurs, assuming that the concrete columns form the only thermal bridge interrupting the ground floor insulation. This is unavoidable in this type of building, which provides one or more levels of car parking below the building to make more efficient use of the available site area.

The heat loss from a given type of point thermal bridge rises non-linearly with the cross-sectional area of the material. More concrete columns, each with a smaller cross-sectional area, give rise to a higher heat loss than fewer, larger columns even though the total cross-sectional area of reinforced concrete in the columns is assumed to be the same in both cases.

Solid partition walls between internal columns will also lead to heat losses if these partitions have to be built off the concrete slab, interrupting the floor insulation. This junction has not been modelled in this draft of the guidance.

An alternative version of this ground floor, with the floor insulation placed below the concrete slab, would tend to reduce thermal bridging and resolve other issues such as condensation. We have modelled the internally-insulated case in this guidance, as it tends to be more common, but we hope that this document adequately points out the very significant advantages of the less common practice of insulating below the slab. It has both thermal and ‘building physics’ advantages.

Airtightness

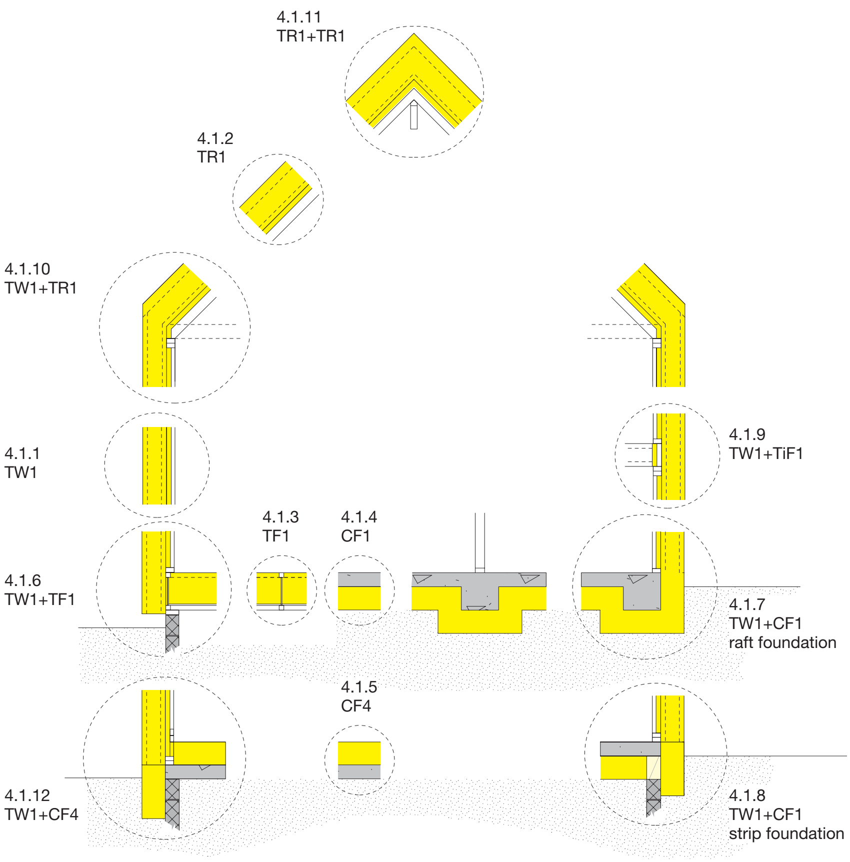
There are no major issues to overcome. As before, the screed and membrane below it should be sealed to the intersecting columns to control air movement and vapour transport by convection.

Interstitial Condensation

This detail, like all floor constructions which use internal insulation, is potentially problematic and is included to illustrate the risk. Risks should be carefully assessed on a project by project basis and the alternative approach of external insulation should be considered and adopted wherever possible. See discussion of risks in Sections 3.1.4 and 4.1.12.

4.0.0: Timber frame

SECTION 4



Above: Keyed notional section diagram showing areas of construction modeled for externally insulated studwork and rafters built off a traditional timber platform frame. U-values are given for 'plane elements' (e.g. TW1) and ψ-values are given for junctions (e.g. TW1 + TR1).

TW Timber wall
TR Timber roo
TiF Timber intermediate floor
TF Timber floor (suspended)

SECTION 4

4.0.0: Timber-frame – introduction

Platform-framed timber buildings are thought to make up approximately 10% of new dwelling starts in England, Wales and Ireland and more in Scotland. Some non-domestic buildings are also constructed of a timber frame.

The frame can be entirely site-built, the basic wall and floor elements can be prefabricated off-site, an entire wall/roof section can be factory-built or, very occasionally, an entire small building can be factory-built. In the UK, a timber-frame building most often arrives at site in the form of factory-built panels.

By contrast, in the USA and Canada, most timber-frame buildings are site-built by skilled carpenters. In other words, a lorryload of loose, small-section timber is delivered to site, giving rise to the phrase 'stick-built' for this method of building. In Sweden, many wooden houses are completely built in the factory. Or large wall and roof panels, containing the thermal insulation and even the windows, may be craned into place and stitched together on site.

In timber-frame buildings of the UK and North American type, the stud wall is externally sheathed with plywood or OSB for racking strength. After insulating between studs, an air-vapour barrier of polyethylene is fixed on the inside of the walls, before plasterboarding.

This positioning of the air barrier gives rise to major air leakage problems when services are installed. A membrane in this position usually gets shredded by electricians who are fitting electrical boxes or sometimes by plumbers who are seeking to bury piping in the wall.

The wall section here is based upon experience in Canada with new construction and retrofits to extremely high energy standards. What happens is that an ordinary timber-frame building is constructed with 90 mm stud walls and a roof of equally normal solid timber rafters. However, instead of following the normal sequence from then on, the air-vapour barrier is fitted outside the frame. Subsequently, the roof and walls are wrapped in a non-structural timber framework which is filled with the thickness of insulation needed.

In these wall and roof sections, so much insulation is placed outside the 90 mm studwork, within the non-structural trusses, that the air-vapour barrier can safely be placed entirely outside the timber frame. With approximately four to six times as much thermal resistance outside as inside the air-vapour barrier, the temperature of the membrane is kept above the dewpoint and there is no risk of interstitial condensation at the range of internal and external temperatures expected in the UK.

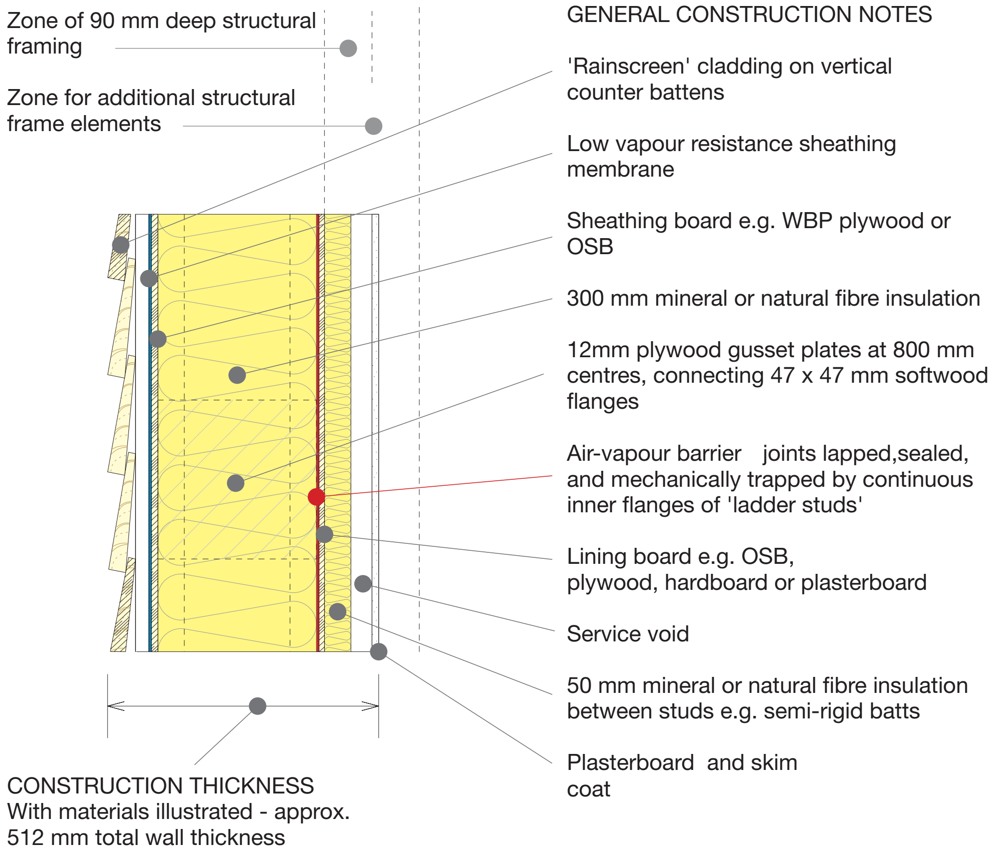
This construction sequence also allows the installation of services to proceed more rapidly. As soon as the membrane is fitted securely outside the frame, the building is virtually watertight from above and from the sides. Ensure plenty of ventilation inside the building at this stage, though, or temporary internal condensation could occur on the inside of the membrane before insulation is fitted outside it.

If there is a risk that temporary interstitial condensation on the internal face of the air-vapour barrier might have undesirable consequences on adjacent materials; i.e., before the external insulation is put in place), then care should be taken to allow adequate ventilation of the membrane, appropriate vapour resistance; e.g., use of a variable permeability membrane, or prompt placement of the insulation between the Larsen trusses.

4.1.0: Larsen trusses - basic principles

Plane element	Designated air barrier	Designated insulation zone(s)	Designated wind barrier
All elements and junctions	Provide the construction with a designated air barrier, a material that blocks air movement; and if necessary a vapour barrier, to control vapour diffusion. In a timber-frame structure, the air and vapour barrier may often be a polyethylene membrane. For the demanding air permeability in the Passivhaus or Gold Standards to be reached, the air barrier must be continuous over the entire thermal envelope. No breaks are acceptable in the air barrier, except at services penetrations and at window and door openings which must also be sealed. Air barrier laps and junctions need careful sealing.	Make the thermal insulation layer continuous as far as possible, so that the insulation in one element connects seamlessly with the insulation in the adjacent element. This reduces or almost eliminates the associated non-repeating thermal bridges.	It is essential to stop wind from penetrating the thermal insulation layer. Ensure that the insulation is contained within airtight layers, ideally to both sides. This will ensure that cold outside air does not find its way to the warm side of the insulation.
Wall TW1	In the timber-frame wall construction shown in this section, the air barrier is a polyethylene membrane.	The main insulation zone is very low in timber. The secondary insulation zone contains more timber, but this zone contributes very little to the overall wall R-value.	The sheathing membrane in the walls performs the role of a wind barrier on the outer face of the insulation.
Roof TR1	In the timber roof construction shown, the air barrier is a polyethylene membrane	The main insulation zone has a very low timber fraction.The secondary insulation zone, inside the air-vapour barrier, contains more timber, but this zone contributes very little to the overall roof R-value.	The sheathing membrane in the roof performs the role of a wind barrier on the outer face of the insulation.
Floor TF2, (CF1, CF4 - See 3.1.0)	In the timber floor construction shown, the air barrier is a polyethylene membrane.	The insulation is thermally-bridged only by the upper flanges of the I beams and noggings between, and by the I beam webs.	The timber retaining boards between I beam joists perform the function of a wind barrier.

4.1.1 The basic construction: plane element TW1



MW3	U-value W/m²k
Good	0.118
Typical	0.120
Poor	0.121

Description

The drawing above shows the conventional timber-frame wall, externally clad with extra insulation, contained within the site-built Larsen truss.

MW3 shows 300 mm deep, timber Larsen trusses on 600 mm horizontal centres fixed to the externally-sheathed, timber platform frame building shell. The platform frame shown uses 89x38 mm solid timber studs on 600 mm centres.

The external and internal timber flanges for each truss are shown as continuous pieces of 47x47 mm softwood with 12x300x300 mm plywood gusset plates fixed to flanges at 800 mm centres. Gussets are alternately staggered either side of flanges.

Precedent

MW2 illustrated the track record of this construction in UK projects where Larsen trusses are attached to the outside of a mass wall. The main precedent for its use on a timber frame is its original record of use in western and central Canada in the early 1980s onwards. It was developed privately, soon after the federal government had developed the 'double wall', which was another way to construct timber-frame buildings with very thick insulation.

Limiting Thermal Bridging

The major thermal bridges associated with timber-frame construction are formed by the solid timber itself. There has been much UK discussion of what fraction of a wall is made up of solid timber, rather than insulation. The UK uses 15% timber as a default to cover the repeating thermal bridges, in cases where 38 mm wide members are spaced on 600 mm centres.

Over and above the UK's 15% figure for repeating thermal bridges, designers are supposed to make a further allowance to cover the non-repeating thermal bridges. It is not known to what extent they do. It is suspected that often some or all of the non-repeating thermal bridges are forgotten and the associated heat loss is unaccounted for during the design stage.

Timber fractions of over 35%, i.e. including all repeating and non-repeating thermal bridges combined, were reported by researchers who examined standard timber-frame houses erected by a major developer in the UK in 2001. Earlier investigations of site-built homes in the USA showed similar figures, on average 30% but also quite variable.

Work in the north-west USA in the early 1990s showed that in site-built houses and flats, in which the frame is designed by an independent structural engineer, this timber fraction could usually be reduced by care in design to no more than 25%. In favourable cases, usually on one- and two-storey buildings, it could be reduced as low as 17%. Accordingly, the Washington State Building Code lists the wall U-values for a wide range of timber fractions.

Clearly the U-value of a timber-frame wall is very sensitive to the overall timber fraction. 35% is the fraction we have assumed for the platform frame itself in this document; i.e., including repeating and non-repeating thermal bridges. Making this assumption is relatively conservative and eases the burden on the designer and builder. At present, because of their limited influence on suppliers, they may have difficulty in obtaining a kit from a UK prefabricated frame supplier which goes as low as a timber fraction of 25%, still less 17%.

This construction uses a standard 38x90 mm deep timber stud wall which is externally-sheathed. An air-vapour barrier and site-built Larsen trusses are then added to its external face. Most of the wall insulation goes between the Larsen trusses; the space between the 90 mm studs is left partly or wholly free as a service void. Placing most insulation outside the frame significantly reduces the impact of the thermal bridges within the timber framework.

Airtightness

The basic airtightness of the wall TW1 is maintained by the air-vapour barrier. It is fixed over the external face of the platform frame's sheathing board, with joints lapped, stapled on 50 mm centres with stainless steel staples, sealed with a suitable material and clamped between solid materials. In TW1, the membrane joints could be clamped between the platform frame sheathing board and the inner flanges of the Larsen trusses. Basic services such as wiring or plumbing can be run in the service void behind the plasterboard and pictures, shelves, etc can be hung on the wall without damaging its airtightness. Also, if the plasterboard finish cracks, this does not affect the airtightness of the structure.

Wiring and services work within the timber frame can be carried out without compromising the integrity of the air-vapour barrier, except where incoming mains services pass through the wall. Unlike a normal timber-frame wall, electrical sockets in this building will not leak air, because all the wiring runs inside the air barrier.

It is possible that on some projects the designer or builder would choose to fit the membrane to the external face of the structural frame before fixing the sheathing board. In this arrangement, one way to clamp the air-vapour barrier joints would be to use thin battens over the joints to form the service cavity.

The approach of separating the air barrier from the structure makes an airtight building very easy to achieve. Similar techniques were used on a pioneering housing development by Flair Homes Ltd. in Winnipeg, Canada in 1981. Those detached houses are reported to have reached individual air permeabilities within the range of 0.12-0.20 m^3/m^2hr @ 50 Pa, averaging about 0.15 m/h @ 50 Pa.

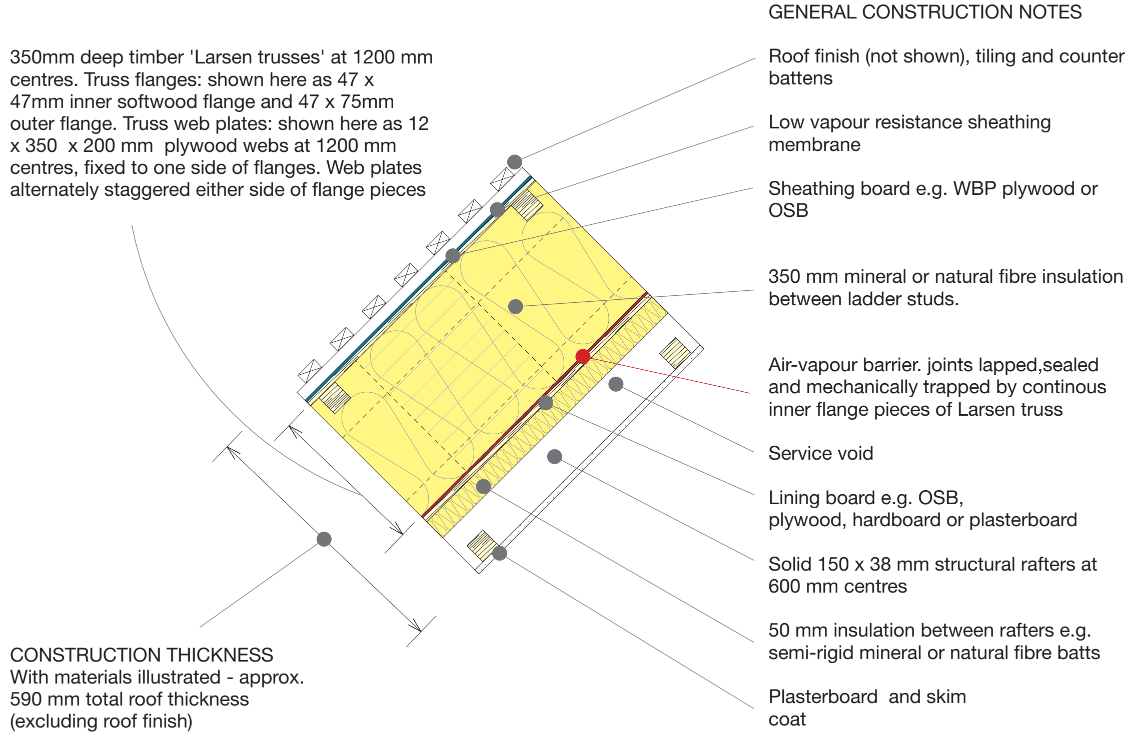
Structural Issues

Because the load-bearing element of this building is a normal platform frame, no more structural issues are raised than with an 'industry standard' timber-frame building, which in the UK tends to be factory-built, not site-built. The Larsen trusses transfer wind loadings to the main wall and bear the weight of 300 mm insulation and of the outer cladding, whether this be render on mesh, timber cladding or metal.

Additional internal timber posts, internal decorative trusses and the like may be accommodated within this system to meet the designer's requirements, without greatly affecting the thermal insulation and without any impact on airtightness.

It is important to consider section strength of Larsen trusses for vertical and horizontal loads for each project. This is particularly where there is no plinth wall and/or where the trusses are very widely-spaced; e.g., on 1200 mm horizontal centres.

4.1.2: The basic construction: plane element TR1



TR1	U-value W/m²k
Good	0.102
Typical	0.104
Poor	0.105

Description

The drawing above shows a conventional roof of solid 150x38 mm timber rafters, insulated on the outside with Larsen trusses. As with the walls, the air-vapour barrier is placed outside the solid timber and adjacent to the main insulation zone.

Precedent

There is relatively limited experience of this technique in the UK. It was used to construct the timber roof of one self-build house which aims at the AECB Gold Standard. The walls of that house are load-bearing concrete, not timber-frame. The structural roof consists of 50x100 mm rafters on 600 mm centres and the Larsen trusses outside the roof sheathing are 400 mm deep and are fitted on 1200 mm centres. This reduces thermal bridging more effectively than using them on 600 mm centres, as is shown in this document, but needs thicker sheathing. 19 mm Finnish spruce plywood sheathing was used, along with small amounts of diagonal bracing.

Limiting Thermal Bridging

Thermal bridging is restricted by minimising the timber cross-sectional areas within the insulation zone. Since this layer of the roof is not load-bearing, timber dimensions are considerably less than they would be in a conventional timber roof, especially if crucial pieces of timber are knot-free. The Larsen trusses transfer tile, snow and wind loadings back to the main roof structure, but do not themselves hold up the roof.

Noggings between top flanges of Larsen trusses, supporting the junctions of the external sheathing board, are shown here as 47x47 mm on 1200 mm centres. This, combined with the dimensions of the top flange, results in a significant level of thermal bridging. Reducing the amount of timber in these areas is well worth pursuing, in order to reduce the overall thickness of the roof construction whilst maintaining the same U-value. As before, the noggings shown could be replaced by 'H clips'.

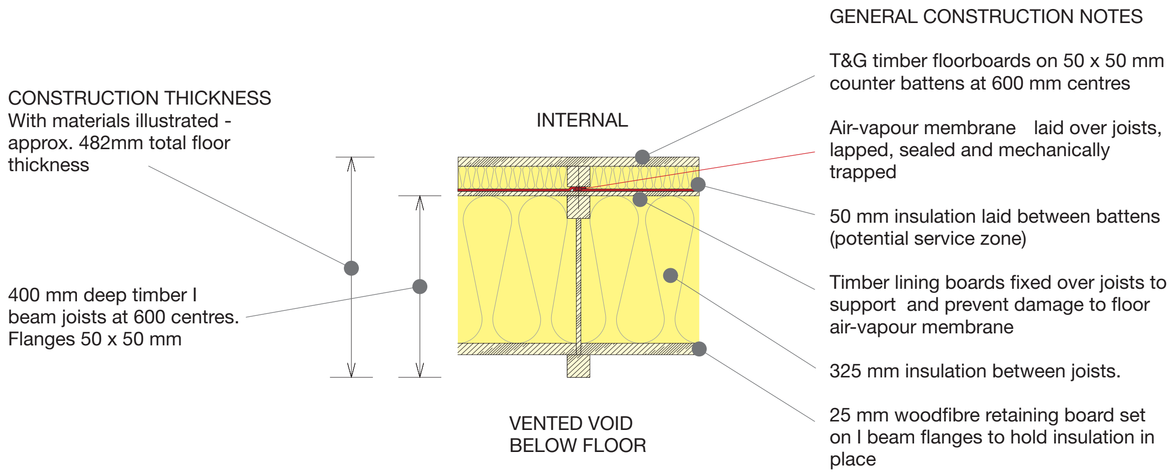
Airtightness

In this roof construction, the air barrier is the polyethylene membrane, which is located outside the conventional rafters and inside the Larsen trusses.

Structural Issues

The conventional rafters, the inner flange of the Larsen trusses and the plywood or OSB sheathing between them act as a composite structure, with considerable strength. If these members are appropriately fixed together in crucial places, one can reduce the rafter dimensions significantly compared to what they would be using rafters alone; i.e., without the sheathing and without the inner flange of the trusses. So the load-bearing ability of the roof illustrated may be at least as good as a roof of solid 50x200 mm rafters. The project engineer should be prepared to take this into account on a case-by-case basis.

4.1.3: The basic construction: plane element TF1



TF1	U-value W/m²k
As shown	0.089

Description

The drawing above shows a suspended timber ground floor formed of deep I beams. The insulation is all fitted from above after the retaining boarding is in place. This is followed by a layer of sheathing or lining board and later by placement of the membrane, counter battens, wiring or cabling, a further layer of insulation between counter battens and finished floorboards.

Precedent

None are known in the UK to this depth, although shallower I beam floors have been installed.

Limiting Thermal Bridging

Thermal bridging is limited in this detail by replacing solid timber joists by I beams. It is further reduced by arranging for the lower flange of the I beam to lie below the insulation zone. As a result, the insulation is only thermally-bridged by the web of the I beams and by their upper flange and noggings. The lower flange of the I beams supports the boarding, which in turn supports the insulation batts.

Airtightness

The air barrier in this floor is the polyethylene membrane. As in other timber constructions, it is lapped, stapled, sealed and clamped at joints. It must also be sealed to the membrane on the walls.

One option is to fix the air barrier directly over the floor joists - after insulation has been placed - and to protect it during subsequent works with the first layer of boarding; e.g., OSB. The second option adopted in TF1 and illustrated above is to use the first boarding layer as safe access during works and fix the air barrier later on top of this layer.

As the wall air barrier may be in place before the floor barrier is laid, enough wall membrane should be left at wall to floor junctions to form an adequate lap with the floor membrane. This over-length material should be carefully protected from subsequent works to prevent damage in the period before being sealed to the floor membrane.

TF1 also incorporates a service void created above the air barrier by fixing 50x50 mm counter battens above the I beams. Lapped and sealed joints in the air barrier should be mechanically clamped for long-term performance and this could be done using the floor counter battens. Alternatively thin strips of batten over the air barrier joints and screwed through to the OSB board could be used for any lapped joints occurring between counter batten spacings.

A final layer of floor insulation can be placed between counter battens, helping to reduce the overall thickness of the floor construction.The final timber flooring is only fitted relatively late in the construction process; it could be damaged if fitted earlier.

The air-vapour barrier is reasonably protected from damage over its lifespan; e.g., from uninformed DIY work, by being placed approximately

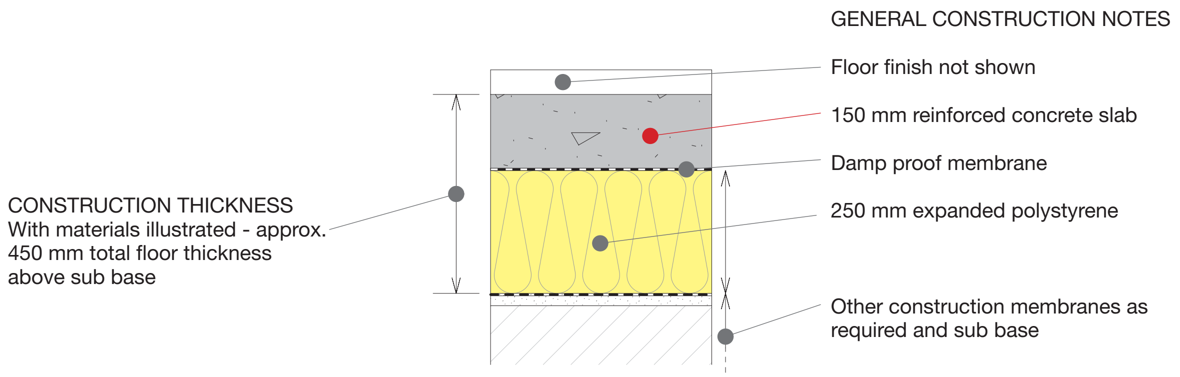
70 mm below finished floor level. This assumes that 20 mm thick floorboards are used.

A clear strategy for fixing cables and other services in the floor void should be developed, to avoid damage to the floor membrane. As the membrane is visible and accessible at this stage, any damage can be immediately seen and repaired with patches or tape.

Structural Issues

Even at this beam depth, the floor may be unable to span across some buildings without intermediate supports. Care must be taken that any intermediate support walls which are introduced do not contribute to thermal bridging or disrupt the wind barrier.

4.1.4: The basic construction: plane element CF1



CF1	U-value W/m²k
As shown	0.106

Description

The drawing above shows a raft foundation supporting a timber-frame building. Unlike the previous raft discussed with reference to a load-bearing masonry building, which had a uniform thickness of 200 mm, this raft is 50 mm thinner but features downstands below external walls and below any structural internal walls.

Being structurally more efficient, this raft is likely to use less concrete and steel than a flat raft. However, it is also significantly more difficult to construct and to insulate. These factors may in practice outweigh the savings on concrete and steel.

Precedent

Several UK timber-frame buildings have been supported on raft foundations which rest on rigid insulation. One of the earliest was a small non-domestic building constructed in Birmingham in 1991. Experience has generally been satisfactory. Some had rafts with downstands; more recently, most were flat rafts which made insulation placement easier.

Limiting Thermal Bridging

This floor construction has minimal thermal bridging, as long as the downstands are modest, e.g. 225-250 mm of extra depth of concrete versus the main 150 mm slab. If deeper downstands are used, thermal bridging starts to be more significant and the amount of insulation consumed also rises.

Airtightness

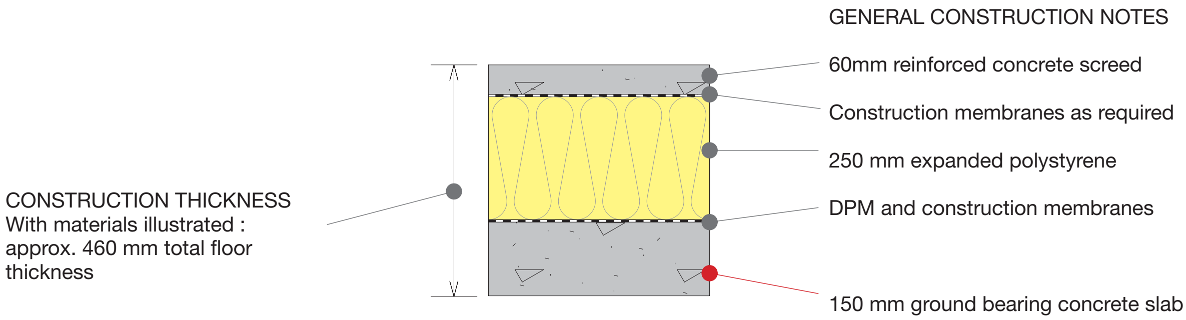
The material which acts as the air barrier in this floor is the reinforced concrete slab.

Structural Issues

The rafts illustrated here are typically used on the type of well-drained soil where foundations of up to 750 mm deep were satisfactorily used in the past, and where 900-1200 mm deep strip footings would normally be used today. Difficult soils may need much thicker rafts, placed deeper in the ground.

The insulation type must be suitable for this situation; i.e., its compressive strength and durability.

4.1.5: The basic construction: plane element CF4



CF4	U-value W/m²k
As shown	0.106

Description

This drawing shows an internally-insulated concrete ground floor, used in conjunction with a timber-frame building.

Limiting Thermal Bridging

The floor construction shown has a low level of thermal bridging, because the insulation layer is continuous. However, internal load-bearing walls or any other heavy internal structures which cannot rest on the screed alone and have to rest on the slab would constitute linear thermal bridges. Consequently, the U-value shown may be optimistic in some situations.

Airtightness

The air barrier is the main reinforced concrete floor slab.

Structural Issues

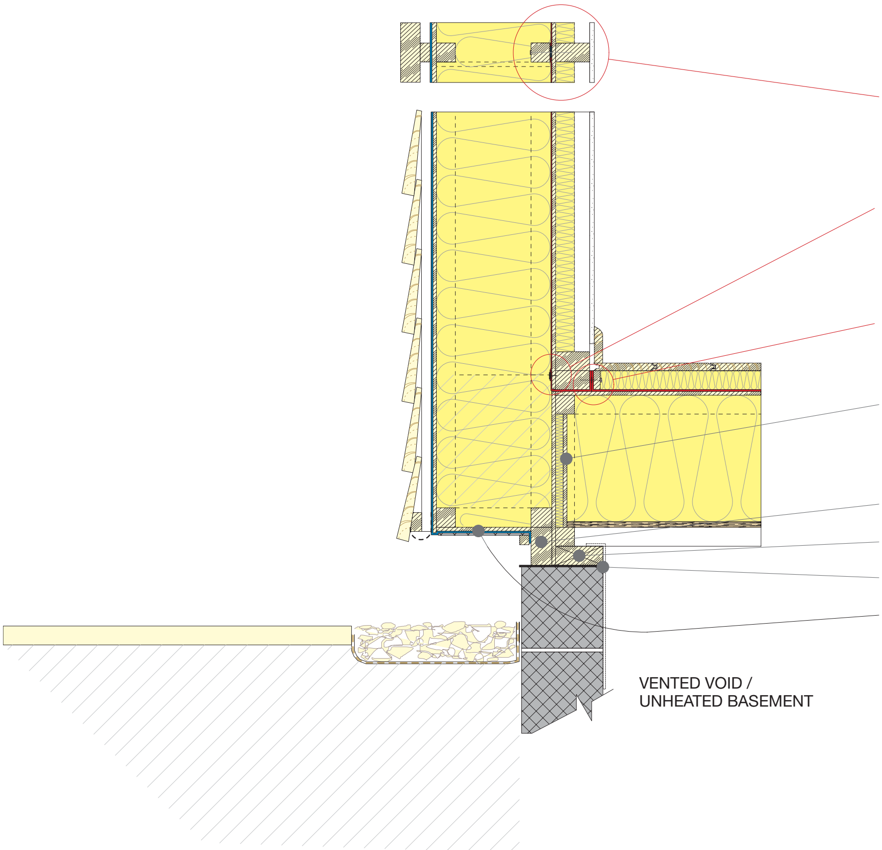
Apart from the need for high standards of precision in the foundation, there is relatively minimal interaction between the process of constructing the groundworks and the subsequent installation of the timber-frame structure on top of them. But see below.

Interstitial Condensation

The use of a floor construction which is in effect internally-insulated; i.e., with the insulation zone inside the structural zone, gives rise to ‘building physics-related problems’. For example, there is a possible risk of interstitial condensation occurring at the junction of CF4 with the timber-frame external wall TF1. This junction is modeled in Section 4.1.12 in order to give the reader an example of a thermally-efficient detail which is not recommended.

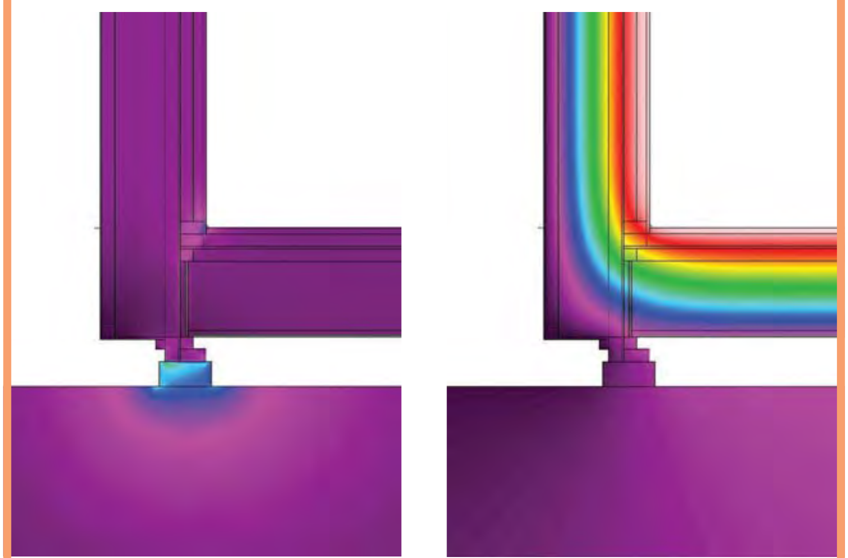
We strongly advise designers to utilise ground floors and other elements which have external, rather than internal insulation. See earlier discussion of risks in Section 3.1.4.

4.1.6: Wall to floor junction: TW1 + TF1



ψ-value	W/mk
ψ internal	0.039
ψ external	-0.049

Flux **Isotherms**



THERM software image of heat flux and isotherms respectively, through TW1 + TF1

Description

This shows a construction suited to a timber-frame building which is situated above an unheated masonry cellar or basement. It could equally well be applied to an unheated cellar of concrete construction.

The whole of the building thermal envelope, including the suspended ground floor, is of timber-frame construction. In principle, this structure could be built in a factory and transported to site in large elements which are subsequently sealed together and which all rest on the prepared foundation. The transition from timber-frame to masonry or concrete all occurs at DPC level.

Limiting Thermal Bridging

Thermal bridging is reduced to a low level; the junction is thermal bridge free. The main thermal bridge is the perimeter I beam.

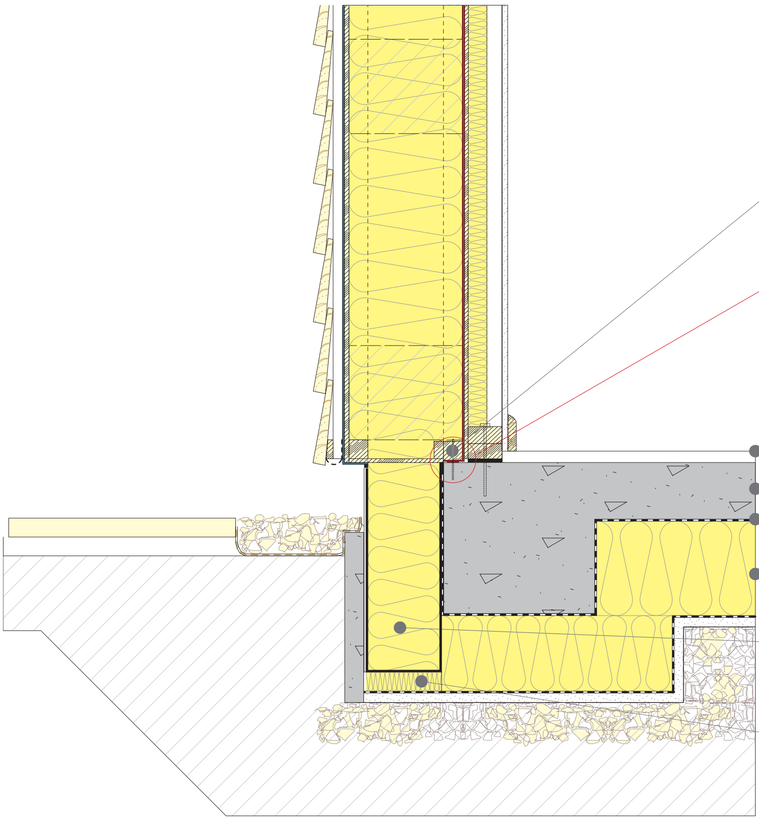
Airtightness

This depends on the continuity of the air-vapour barrier at the junction of wall and floor. If the work is done correctly, no air leakage should be observed in a pressure test.

Structural Issues

None noted.

4.1.7: Wall to floor junction: TW1 + CF1, raft foundation



GENERAL CONSTRUCTION NOTES

50 mm x 50 mm timber bearing plate to support inner flange peices of ladder studs fixed to concrete slab. Shown here also acting as clamping batten forjoint between air-vapour barrier and concrete slab.

Wall air-vapour barrier sealed or taped to concrete slab. Sealed joints mechanically trapped by suitably robust clamping strip or by 50 x 50 mm bearing plate. If taped direct to slab the concrete surface must be clean and dust free and primed to ensure longterm airtight bond between air-vapour barrier tape and slab. Where DPM acts as a radon barrier, designers will need to ensure continuity between air-vapour barrier and DPM/radon barrier

Floor finish not shown

Reinforced concrete raft

DPM

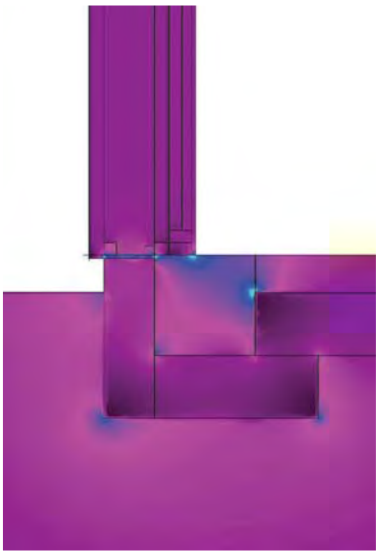
250 mm expanded polystyrene insulation below raft.

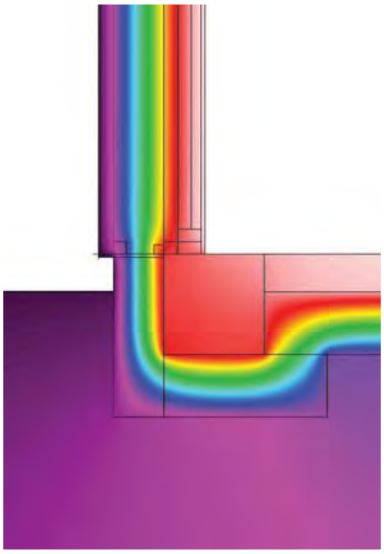
200 mm expanded polystyrene insulation to raft edges

50 mm compressible insulation. NB: lean mix concrete replaces insulation strip at thresholds to provide bearing under wall insulation

ψ-value	W/mk
ψ internal	0.099
ψ external	0.007

Flux **Isotherms**





THERM software image of heat flux and isotherms respectively, through TW1 + CF1, raft foundation.

Description

This shows a timber-frame building, with the same wall construction as before, resting on a 150 mm reinforced concrete slab, with thicker downstands at the perimeter, forming a raft foundation. The total thickness of the concrete downstand illustrated is 400 mm. The outer face of the structural timber-frame wall is placed 50 mm in from the edge of the raft, allowing the inner flange of the Larsen truss to rest on the raft.

Variations

It would be necessary to model ψ-values for each project if the depth of the concrete raft downstand increases beyond the levels shown here.

Precedent

Many timber-frame buildings have been supported before on a shallow raft. Rafts both with and without downstands have been used.

Limiting Thermal Bridging

As the ψ-values show, the junction can just be considered thermal bridge-free, using external measurements. This reflects the slight thinning of the thermal insulation at this point from 250 to 200 mm.

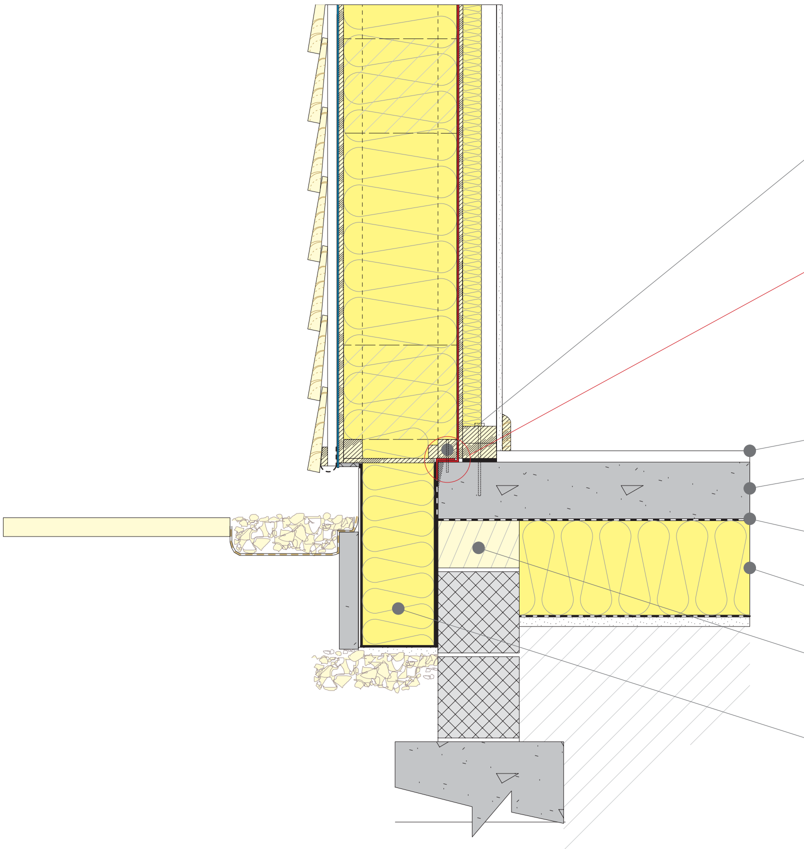
Airtightness

The airtightness of this junction depends largely on the quality of the seal between the two air barrier materials, which are reinforced concrete in the floor and polyethylene in the wall. It is essential that this work is done well.

Structural Issues

The bottom of the timber frame is fixed to the raft to resist uplift forces. This may be done using a number of methods. One is the use of hooked threaded rods which are inserted in the concrete downstand soon after it has been poured and subsequently fixed through the sole plate.

4.1.8: Wall to floor junction: TW1 + CF1, strip foundation



GENERAL CONSTRUCTION NOTES

50 mm x 50 mm timber bearing plate to support inner flange peices of ladder studs fixed to concrete slab. Shown here also acting as clamping batten for joint between air-vapour barrier and concrete slab.

Wall air-vapour barrier sealed or taped to concrete slab. If air-vapour barrier is sealed directly to concrete slab using a tape, concrete surface must be clean and dust free and primed to ensure long-term airtight bond between tape and slab. If measures are required for radon, then In addition to sealing the barrier directly to the concrete slab for airtightness, designers must ensure that the radon barrier/DPM is continous with the air vapour barrier

Floor finish not shown

Reinforced concrete slab

DPM. Other construction membranes below insulation as required

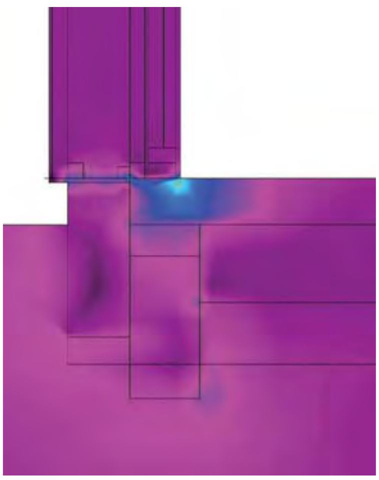
250 mm expanded polystyrene insulation below slab

One course of cellular glass blocks. (NB: variation in psi-value noted below is based on two courses of 215 mm ultra-lightweight loadbearing block only, directly below slab)

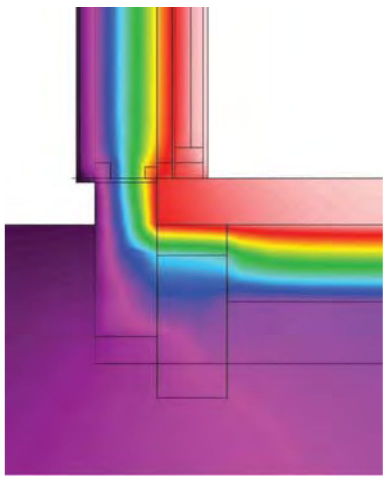
200 mm expanded polystyrene insulation

TW1 + CF1, strip foundation	ψ-value W/mk
As shown: one course of cellular glass blocks immediately below slab	
ψ internal	0.094
ψ external	0.001
Aerated concrete blocks only below slab	
ψ internal	0.141
ψ external	0.048

Flux



Isotherms



THERM software image of heat flux and isotherms respectively, through TW1 + CF1, strip foundation.

Description

This drawing shows a timber-frame building resting upon a concrete and masonry foundation. The timber-frame wall is recessed relative to the edge of the concrete slab. This may be done in order to centre the load better on the masonry foundation wall. It also provides a degree of support for the inner flange pieces of the Larsen trusses, thereby reducing the degree to which the Larsen trusses are cantilevered; this building has no plinth wall. This detail illustrates one possible way to support a prefabricated timber-frame structure on a prepared foundation.

Variations: The table above illustrates the ψ-value when using two courses of 215 mm wide aerated blocks only, directly below the slab, omitting the course of cellular glass blocks.

Precedent

At least one UK house, albeit of in situ concrete not timber, has utilised a similar foundation to this. A row of 150x600x600 mm aerated blocks, fixed with thin-joint glue, support its ground floor slab and superstructure. The aerated blocks rest on a concrete strip footing which extends to 900 mm below ground.

We are not aware of any UK projects using cellular glass but the material appears to have a suitable compressive strength to be used for this purpose on low-rise buildings. On the other hand, cellular glass costs more than aerated concrete, so the cost should be assessed carefully and set against the reduction in heat loss.

Limiting Thermal Bridging

Thermal bridging in this detail is reduced by using a combination of cellular glass blocks and aerated concrete blocks in the foundation wall. If the aerated blocks are fitted using conventional mortar joints, they give a thermal conductivity which is about a factor of five lower than that of dense aggregate concrete blocks. If thin-joint glue rather than conventional sand-cement-lime mortar is used in the wall, heat losses might be reduced by a factor of seven or more. We recommend such measures, which can make considerable economies in heat loss for low cost.

The drawing shows a foundation wall of 215 mm wide aerated blocks. This width represents a significant degree of overdesign which aims to cater for poor site practice, some non-uniform loading from the frame and a risk of some damage to the edges of the relatively fragile and brittle aerated blocks by careless handling. On building sites with tight supervision, where careful handling is expected, designers should be able to specify narrower blocks to support the slab and superstructure, reducing thermal bridging.

Some designers may prefer to order a row of custom-sized blocks; large blocks of aerated concrete in the factory can be cut into any size which customers desire.

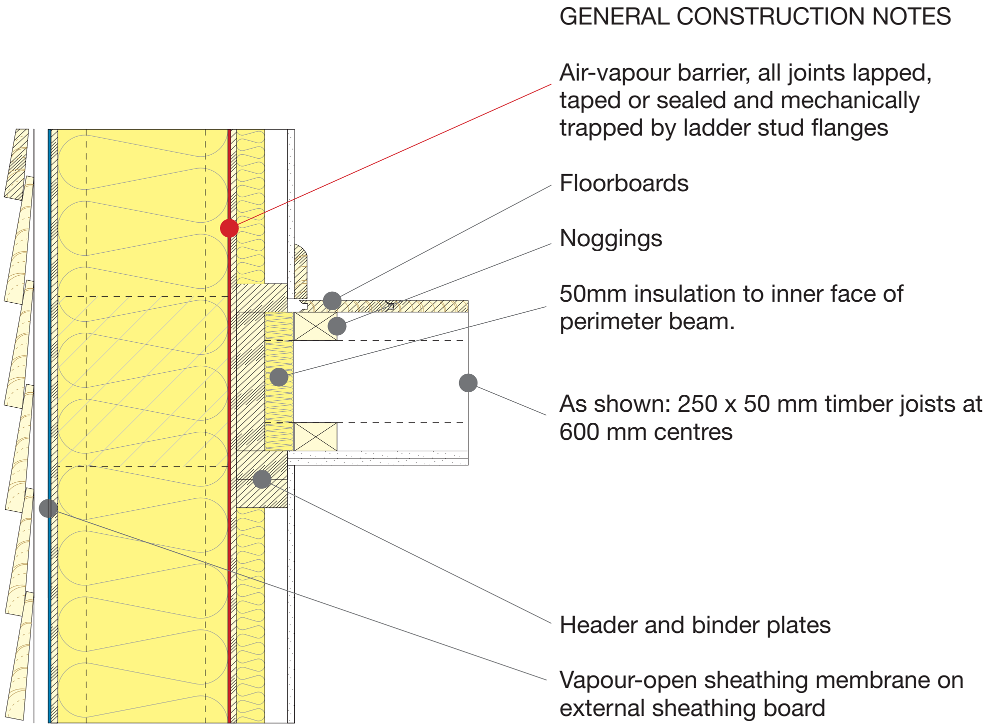
Airtightness

The airtightness of this detail depends largely on the quality of the seal which is formed between the two air barriers, which are the polyethylene membrane in the wall and the reinforced concrete in the floor slab. This work must be carried out extremely carefully. Even small residual gaps will leak in a pressure test. Such leaks could prejudice the achievement of the air permeability required by the Passivhaus or Gold Standards.

Structural Issues

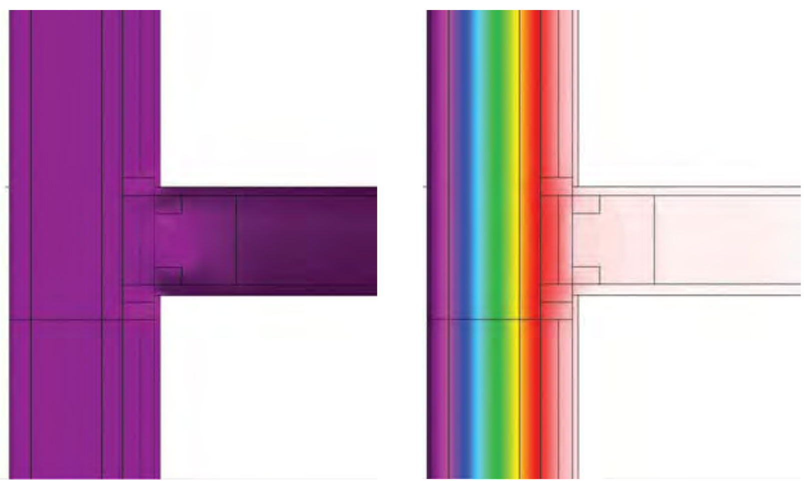
See discussion in Thermal Bridging, above.

4.1.9: Wall to intermediate floor junction: TW1 + TiF1



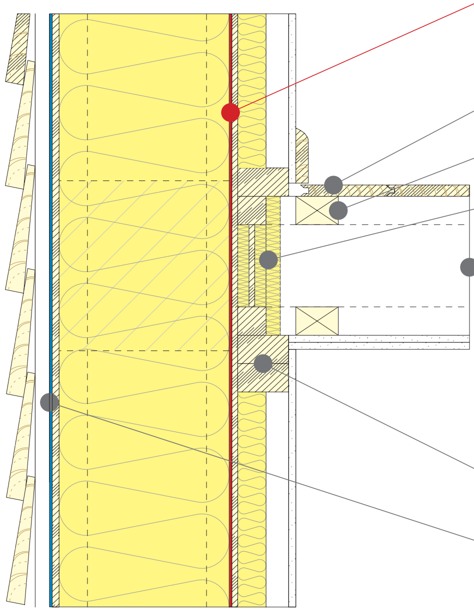
TW1 + TiF1	ψ-value W/mk
As shown	
ψ internal	0.000
ψ external	0.000
Omitting the 50 mm insulation to inner face of perimeter floor beam	
ψ internal	0.003
ψ external	0.003

Flux **Isotherms**



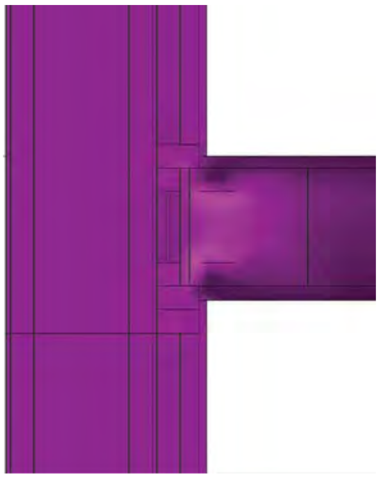
THERM software image of heat flux and isotherms respectively, through TW1 + TiF1.

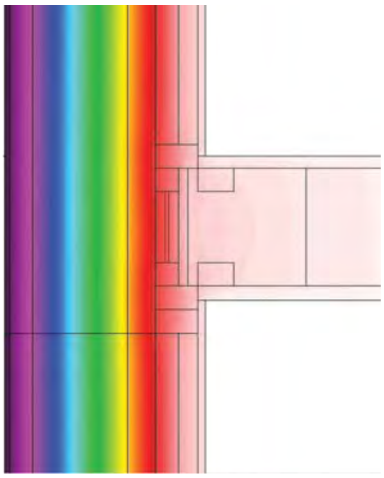
4.1.9: Wall to intermediate floor junction: TW1 + TiF1 – *Variation 1*



ψ-value	W/mk
As shown: with external flange insulation inserted at intermediate floor level	
ψ internal	0.000
ψ external	0.000

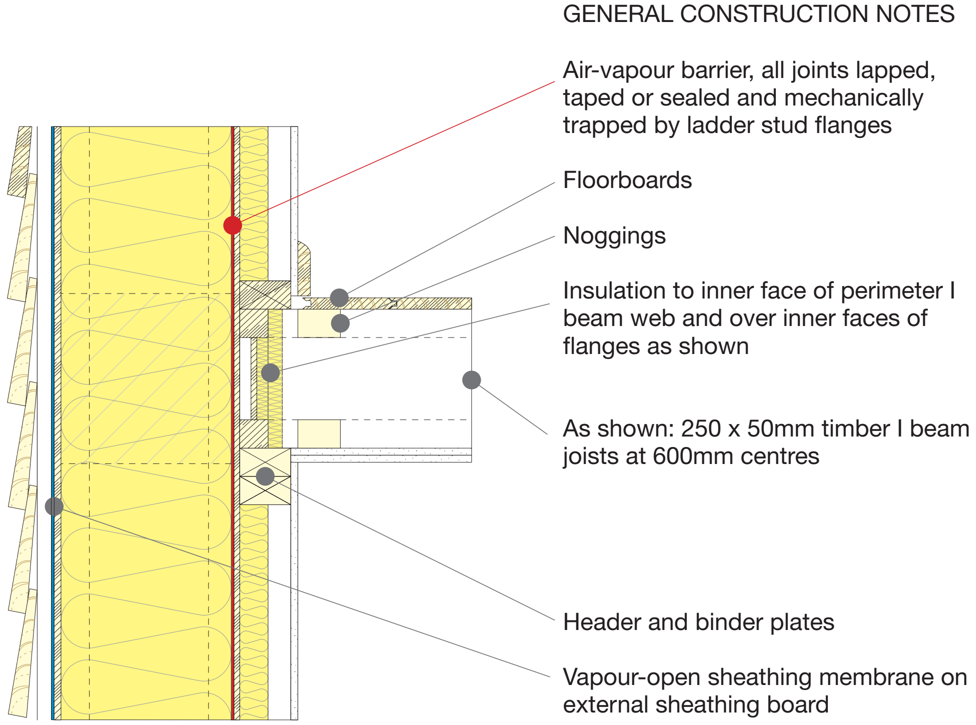
Flux **Isotherms**





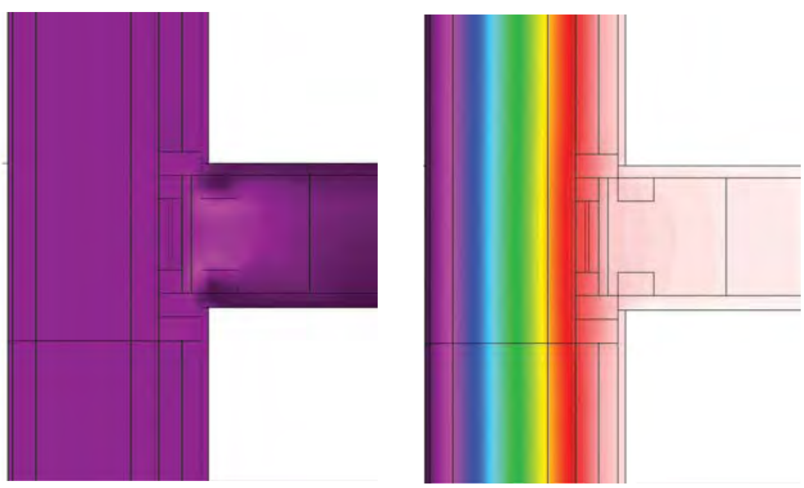
THERM software image of heat flux and isotherms respectively, through TW1 + TiF1 Variation 1.

4.1.9: Wall to intermediate floor junction: TW1 + TiF1 – *Variation 2*



TW1 + TiF1 *Variation 2*	ψ-value W/mk
As above: with external flange insulation omitted at intermediate floor level	
ψ internal	0.003
ψ external	0.003

Flux **Isotherms**



THERM software image of heat flux and isotherms respectively, through TW1 + TiF1 Variation 2.

Description

This shows an intermediate floor junction in a timber-frame building which uses Larsen trusses to provide a thick layer of external insulation to the frame.

In TW1 + TiF1 above the intermediate floor is constructed with solid 38 x 200 mm timber joists. Careful placement of strips of insulation over the exposed faces of the perimeter joist and perimeter noggings ensures that the junction is thermal bridge free.

Both TW1 + TiF1, variations 1 and 2 illustrate the same junction but with the intermediate floor constructed using I beams. It might be thought that using I beams at this junctions might result in a more thermally efficient detail. However, the effective placement of insulation around I beams can be more problematic and the resulting detail less thermally effective, as discussed below.

Limiting Thermal Bridging

In TW1 + TiF1, the internal faces of the solid perimeter joists or, on adjacent walls, the perimeter timber noggings between joists, are covered by a layer of fibrous insulation. The insulation is easily placed and can be readily checked on site before the ceiling linings are fitted. Any wiring or cables running through the wall service void and into the intermediate floor void will have to pass through, or compress, this strip of insulation. In TW1 + TiF1, variation 1 (using I beams for the intermediate floor), the ψ-value of this junction remains at zero- if the piece of insulation on the 'cold' side of the web of the floor's perimeter joist is fitted correctly. If this insulation is omitted the heat loss rises as shown in variation 2, above.

Realistically, with variation 2 we must admit that there is a risk of this insulation being omitted on all but the most careful building sites. This is not an easy detail to get totally right. Also, cutting this insulation to fill the available spaces between the I beam joists, without leaving gaps, can be an awkward job. Where insulation is omitted and leaves voids, air movement between the warmer and colder sides of the construction can arise, and by bypassing the remaining insulation this air movement may reduce even further the performance of the junction.

So overall, if using I beams to construct this intermediate floor, it would probably be more prudent to assume that the insulation is not fitted and to design such buildings to achieve an acceptable heat loss despite having a small thermal bridge at intermediate floor level.

Airtightness

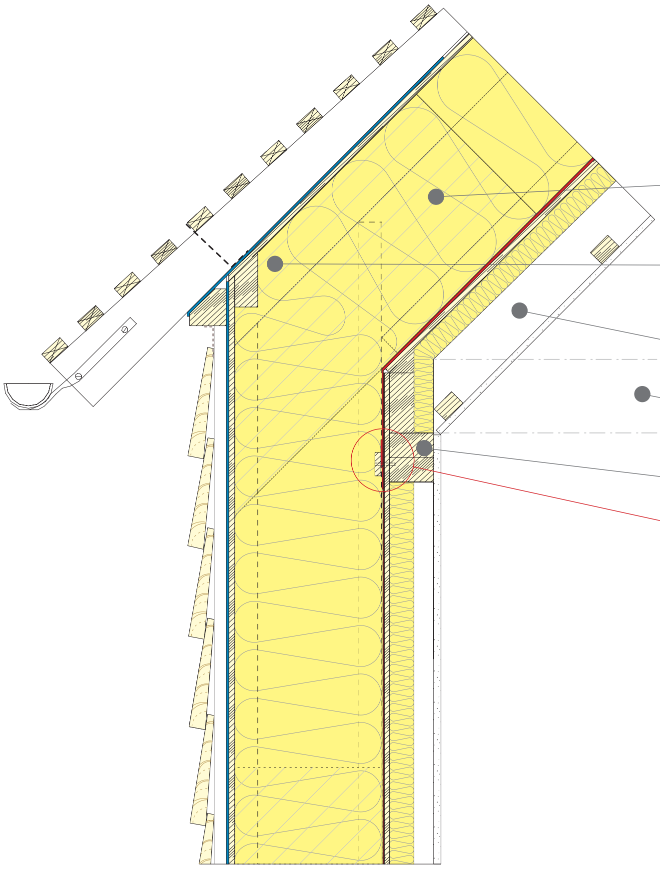
TW1 + TiF1 resolves the problems which one encounters at intermediate floor level in a conventional timber-frame building. Usually, the air barrier is located on the inside of the solid timber stud wall and comes to a total halt at intermediate floors. Continuing the air barrier through the intermediate floors of buildings is rarely done in conventional site practice. It can be done in energy-efficient buildings but this takes special measures, which may disrupt the construction flow. See, for instance, *Silver Standard Design Guidance*.

In this building, the air barrier continues totally uninterrupted past this point. A continuous air barrier becomes extremely easy to achieve.

Structural Issues

These are no different from a conventional timber-frame building.

4.1.10: Wall to roof junction: TW1 +TR1



GENERAL CONSTRUCTION NOTES

Shaped 12 mm plywood web piece fixed to one side of inner and outer roof beam flanges and inner and outer ladder stud flanges

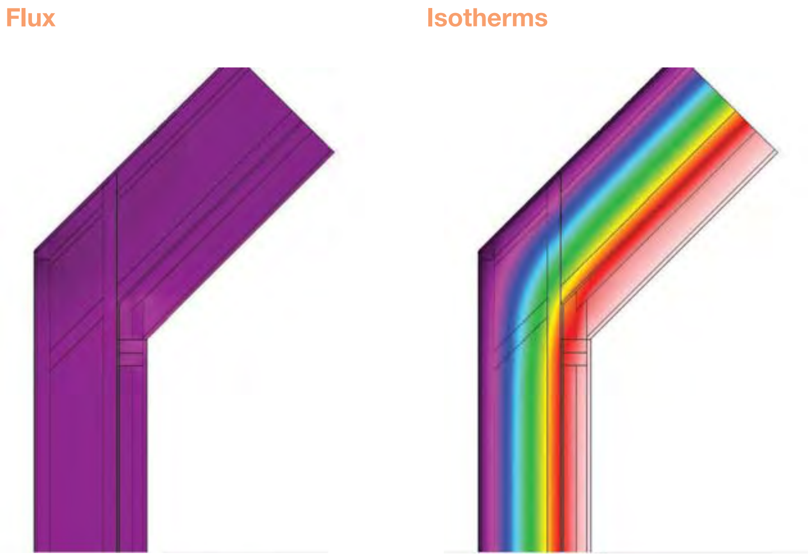
Noggings between top flanges of Larsen trusses to support external sheathing boards

Solid rafters spanning from wall plates to purlin / ridge beams
or
connected at plate level with timber or metal ties / ceiling / floor joists

Timber header / binder plates

Air-vapour barrier horizontal joints lapped, sealed and mechanically trapped with a durable fixing strip

TW1 + TR1	ψ-value W/mk
ψ internal	0.044
ψ external	-0.064



THERM software image of heat flux and isotherms respectively, through TW1 + TR1.

Description

This is a junction of a roof and wall which both employ Larsen trusses to contain most of the roof and wall insulation. This junction is fairly conventional, because all the crucial ingredients; i.e., the air barrier and the main insulation zone, are placed outside the structural frame.

Precedent

We are not aware of direct precedents in the UK. However, this technique is more widely-used in central and western Canada, mostly in Alberta and Manitoba provinces. Many people there were pioneering highly-insulated timber-frame buildings, starting in the late 1970s and early 1980s. This was one of the more successful of the approaches that incorporated very high insulation thicknesses.

Limiting Thermal Bridging

Thermal bridging is limited to low levels. The only extra materials present at the junction are a little plywood and the inner flange of the Larsen truss extending through the insulation.

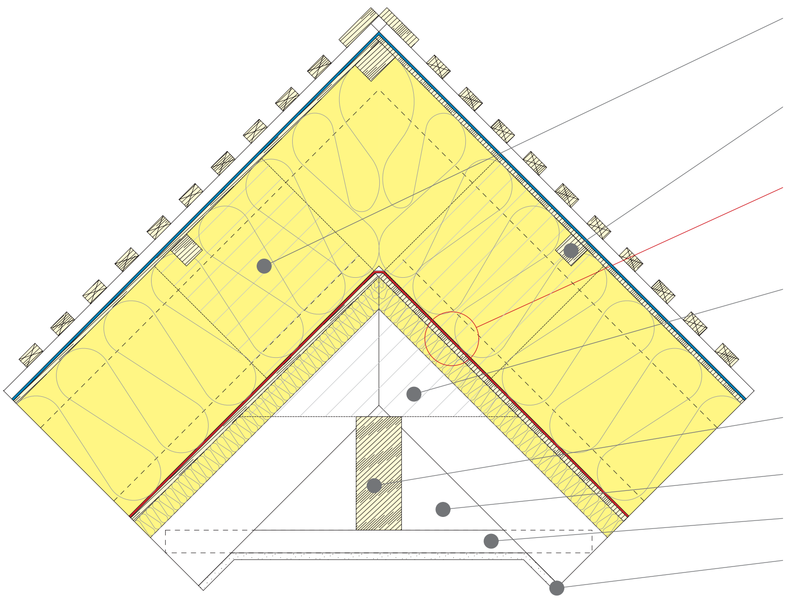
Airtightness

The membrane which acts as the air-vapour barrier is continuous. In principle, it is easily-sealed, because there are no obstructions. Very good results are attainable if such buildings are carefully-built, possibly as good as the projects in the USA, Canada and Denmark 25-30 years ago, some of which reached air permeabilities of 0.15-0.25 m/h @ 50 Pa.

Structural Issues

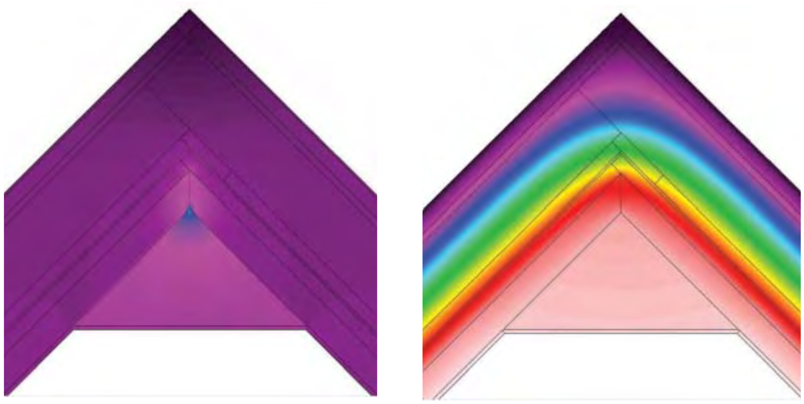
These are the same as in a conventional timber frame.

4.1.11: Roof ridge junction: TR1 + TR1



TR1 + TR1	ψ-value W/mk
ψ internal	0.041
ψ external	-0.067

Flux **Isotherms**



THERM software image of heat flux and isotherms respectively, through TR1 + TR1.

Description

This drawing shows an externally-insulated roof at the ridge where the Larsen trusses meet. The ridge beam shown is just one method to support the roof. If used, it would span to cross walls or external walls. Another method would be to triangulate the roof further down the roof slope and to span as normal from external wall to opposite external wall. Another method would be to replace the solid rafters by scissors trusses, again spanning from external wall to opposite wall.

As opposed to the situation in a conventional building, none of these structural modifications seriously interfere with airtightness or insulation. This is because in this building, the insulation and air-vapour barrier are wholly separated from the structure.

Limiting Thermal Bridging

Thermal bridging is minimal. The full thickness of insulation extends up to and over the ridge, with little need to strengthen the roof at the apex. Thermal bridging of the insulation is largely reduced to the line of timber noggings along the ridge. The materials which are introduced to support or strengthen the roof at this point are largely located inside the air-vapour barrier.

As a result of this lack of thermal bridging, the ψ-values are extremely good. The ψ-value with reference to external areas is more than just thermal bridge-free; it is quite strongly negative.

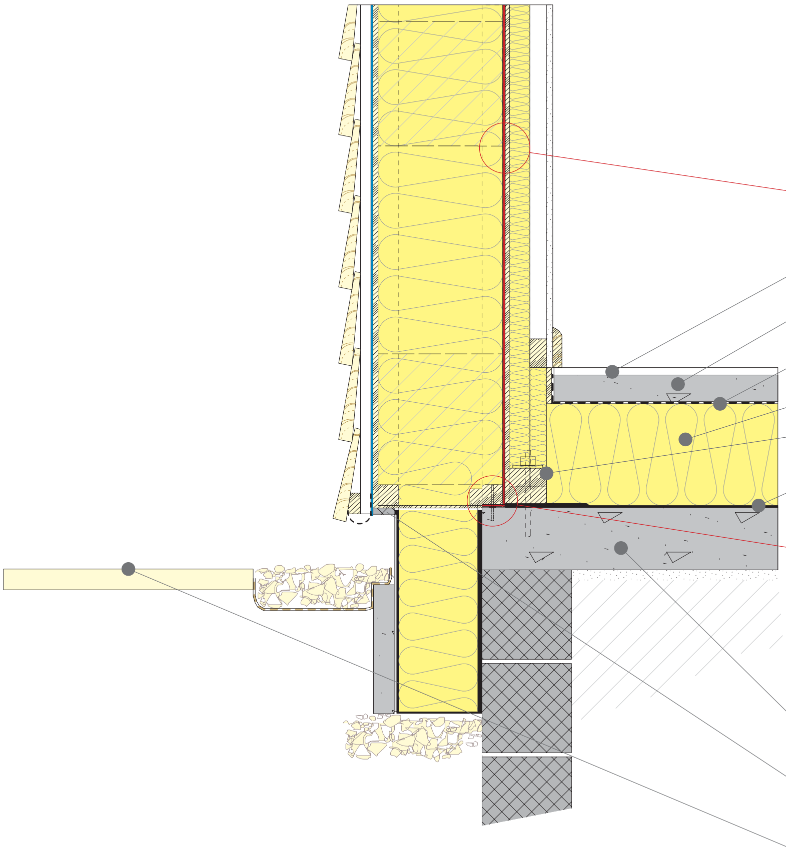
Airtightness

The air-vapour barrier extends right over the roof ridge, with no interruptions. Obviously, any pipes or wires to or from roof-mounted solar panels must be sealed where they pass through the air-vapour barrier.

Structural Issues

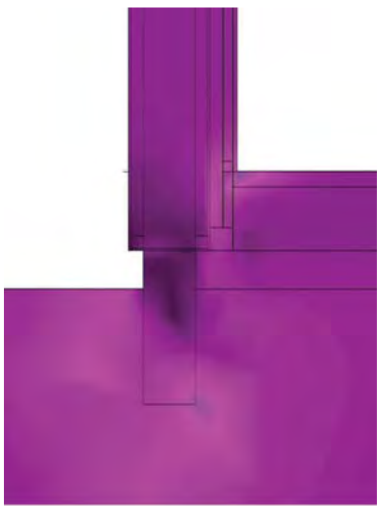
Because the insulation is separated from the structure, the structural issues are much the same as for a conventional ridge.

4.1.12: Wall to floor junction: TW1 + CF4

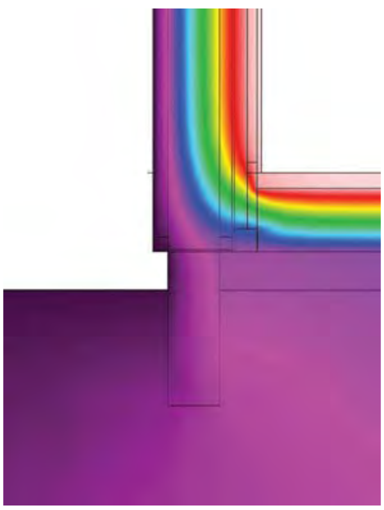


TW1 + CF4	ψ-value W/mk
As shown, with slab of EPS	
ψ internal	0.040
ψ external	-0.042

Flux

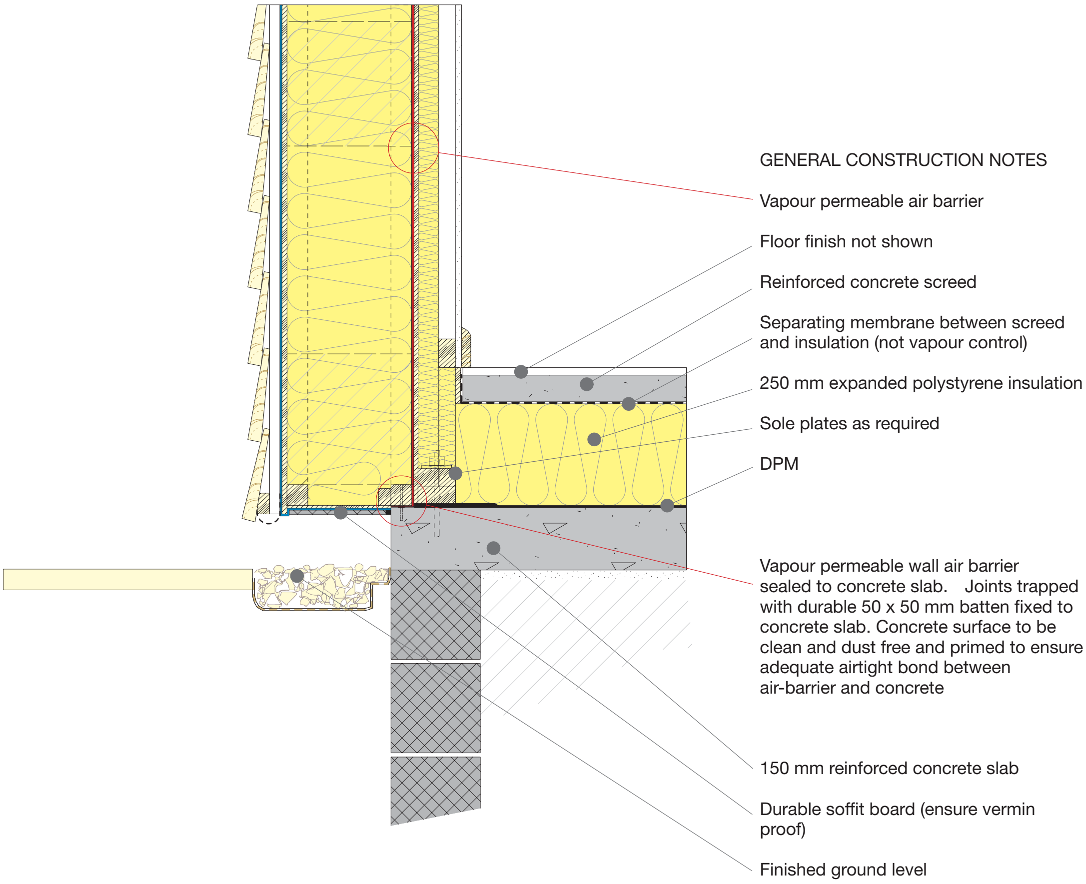


Isotherms



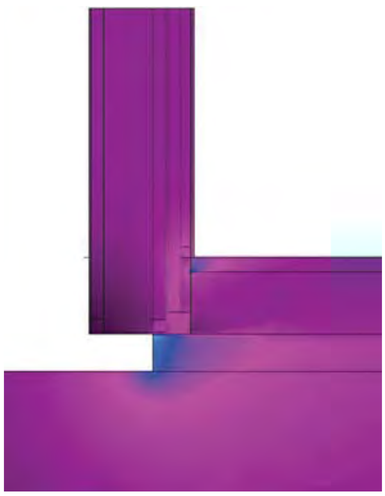
THERM software image of heat flux and isotherms respectively, through TW1 + CF4.

4.1.12: Wall to floor junction: TW1 + CF4 – *Variation 1*

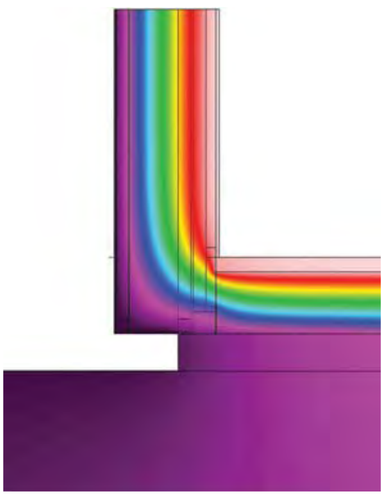


TW1 + CF4 *Variation 1*	ψ-value W/mk
Without insulation to external face concrete slab edge	
ψ internal	0.065
ψ external	-0.017

Flux



Isotherms



THERM software image of heat flux and isotherms respectively, through TW1 + CF4, variation 1.

Description

TW1 + CF4 shows a timber-frame building resting upon a concrete and masonry foundation. The timber-frame wall is recessed relative to the edge of the concrete slab. This centres the load on the masonry foundation wall. Another benefit is that it provides a degree of support for the inner flanges of the Larsen trusses; they are no longer fully cantilevered and could be somewhat less substantial.

Crucially, the detail incorporates a 600x80 mm EPS slab placed over the face of the concrete masonry which supports the floor slab. This slab of insulation extends below ground level. This has the benefit of increasing the slab temperature under the sole plate under CEN design conditions from 1°C to 3°C, reducing the risks of interstitial condensation at this point. It also of course improves the ψ-value.

TW1 + CF4, variation 1 illustrates the detail built without the EPS insulation placed over the concrete slab edge.

Limiting Thermal Bridging

These ψ-values are similar to those of other details covered elsewhere in this document, and give no cause for concern.

Airtightness

In principle, airtightness could easily be ensured by sealing the membrane in the wall to the floor DPM, which is routed over the top of the concrete slab. At certain critical points, a vapour-permeable but airtight membrane would have to be used, particularly in the zone below finished floor level where the timber sole plate rests on the concrete slab.

Interstitial Condensation

Reading the foregoing two sections, the junction TW1 + CF4 may appear to offer a practicable and thermal bridge-free construction. It certainly qualifies as a radically improved detail from the viewpoint of airtightness and thermal bridging.

However, these are not the only two issues. In this detail, there is a very serious risk of interstitial condensation forming at the point where the timber sole plate rests on the concrete slab. The predicted temperature here in the heating season is far below the dewpoint. It is also open to question whether internal floor insulation concealing pieces of structural timber is adequately robust with respect to such risks as flooding, plumbing leaks and 'over-enthusiastic' cleaning with water-based materials.

It is not practicable in this particular detail to prevent interstitial condensation by using a vapour barrier on or near the warm side of the floor insulation and sealing this to the wall air-vapour barrier. Because the membrane which serves as the air-vapour barrier in this wall is routed outside the frame for long-term protection, it is inaccessible for this purpose. Even if a vapour-tight junction could be created between wall and floor on the warm side of the insulation, then this would have to allow vapour transfer from cold to warm side to allow drying out due to construction moisture or accidental water ingress i.e., it would need the junction to be modelled using a variable permeablity membrane.

If the detail is built without a slab of EPS placed over the concrete slab edge, as illustrated in TW1 + CF4, variation 1, a poorer ψ-value results. The colder slab at the point where the timber frame rests on it then gives rise to even greater insterstitial condensation risks.

For this reason, although a lot of people in the UK may like to insulate internally, and although this detail may appear to create a fairly neat division of responsibilities between the masonry and concrete groundworks and foundations and the insulated timber superstructure, we cannot recommend its use. Unlike most details in this document, we illustrate it not so much to show the possibilities for designers to apply it in their own work, as to highlight some of the serious problems which can arise.

Here is a summary of currently recommended practice:

- Don't insulate internally unless you have to, not even with ground contact slabs.
- On new buildings, always try to insulate externally; i.e., with the insulation zone outside the structural zone.
- While heated basements are not covered in this document, internally-insulated basement walls are particularly troublesome. This is because the external tanking and an internal vapour barrier can cause conflict and a risk of interstitial moisture build-up. Try to insulate them externally.

SECTION 5

5.0.0: Glazed openings and opaque doors in the external fabric – overview

Introduction

In the current version of this document, we have not been able to model window- or door-in-wall junctions to give a range of ψ-values. This is due to resource limitations.

These junctions are very significant in relation to a building's heat loss and it is important to use details designed for low thermal bridging. The worked example below illustrates the order of magnitude of heat losses due to the junctions between doors and windows and the building's walls.

Worked example

Consider a small building of 100 m^2 floor area, such as a detached house, which has 22 m^2 of windows, 5 m^2 of external doors and a total of 110 m of window - or door-wall junction, with a ψ-value of 0.04 W/mK, as typical of reasonably-careful detailing. The extra heat loss via these linear thermal bridges is 4.4 W/K, or 0.044 W/K.m^2. If the building aims at the Passivhaus Standard, which sets an upper limit to the heat loss parameter of some 0.6 W/K.m^2, this extra heat loss from window-to-wall linear thermal bridges is of the order of 7% of the building's entire allowable heat loss.

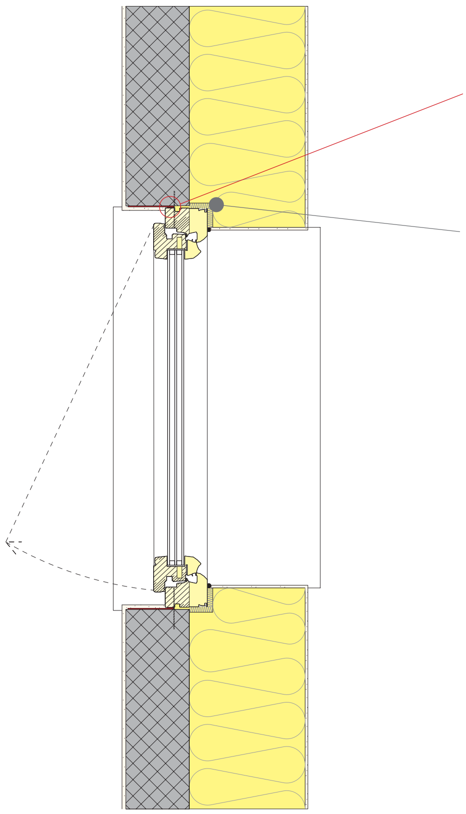
Until we have expanded this guidance to include the ψ-values for a range of as-installed windows and doors, we suggest that designers adopt the following basic principles and work closely with the manufacturers or importers of Passivhaus-certified or 'Passivhaus-suitable' windows and doors, to assess likely heat losses from these junctions. Where in doubt, you may wish to follow the useful guidance in the PHPP Manual and use the accompanying default ψ-values.

Meanwhile, due to the importance of good detailing practice for these junctions, we have included in this guidance several drawings illustrating the possibilities for positioning inward-opening windows and doors in wall construction types MW1 and MW2. If followed carefully, the arrangements illustrated are likely to achieve the low ψ-values needed in Passivhaus and Gold Standard builidngs.

5.1.0: Inward opening doors and windows

We have illustrated constructional arrangements showing inward opening windows and doors as currently inward opening Passivhaus level products are more widely available in the UK. The triple-glazed window in the constructional examples below incorporates metal-clad thermal insulation on the outer face of the timber window.

5.1.1: Window in MW1: jamb



GENERAL CONSTRUCTION NOTES

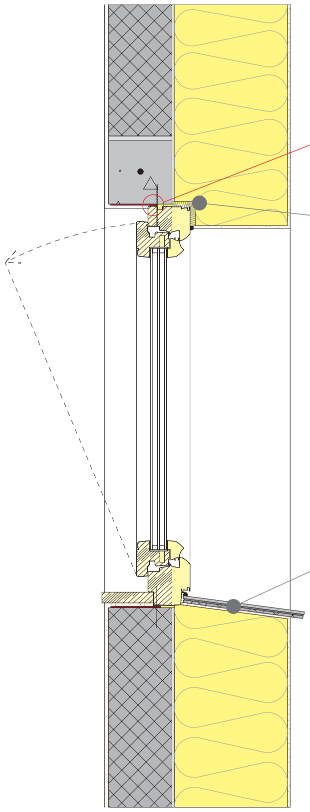
Air barrier sealed to window before installation and incorporated into wall plaster to achieve an airtight joint

Tolerance gap between window frame and wall insulation - designed to allow full fill insulation giving good thermal integrity to joint, in order to reduce risks of interstitial condensation at this point.

Airtight but vapour permeable membranes should be considered to further reduce risks of interstitial condensation, potentially caused by site defects in the thermal integrity of this joint

JAMB

5.1.1: Window in MW1: head and cill



GENERAL CONSTRUCTION NOTES

Air barrier sealed to window before installation and incorporated into wall plaster to achieve an airtight joint

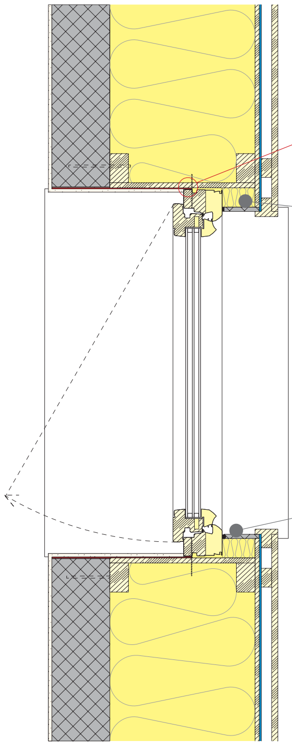
Tolerance gap between window frame and wall insulation - designed to allow full fill insulation giving good thermal integrity to joint, in order to reduce risks of interstitial condensation at this point.

Airtight but vapour permeable membranes should be considered to further reduce risks of interstitial condensation, potentially caused by site defects in the thermal integrity of this joint

Proprietary or site made cill piece weathered to window frame and wall jambs

HEAD & CILL

5.1.2: Window in MW2: jamb



GENERAL CONSTRUCTION NOTES

Air barrier sealed to window before installation and incorporated into wall plaster to achieve an airtight joint

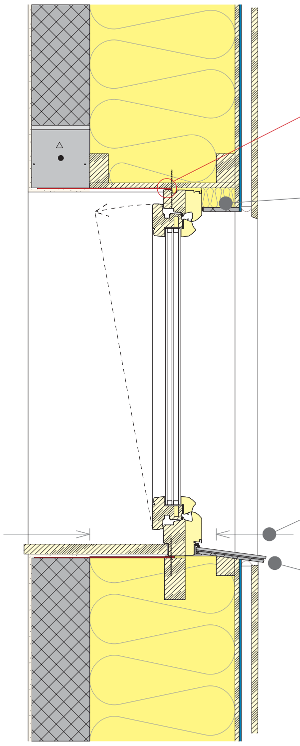
Additional frame insulation carefully fitted to timber frame to cover window frame jambs and head - designed to provide good thermal integrity between window frame and wall, in order to reduce risks of interstitial condensation at this point

Airtight but vapour permeable membranes should be considered to further reduce risks of interstitial condensation, potentially caused by site defects in the thermal integrity of this joint

Weatherproof window reveal boards, sealed to window frame to prevent water ingress

JAMB

5.1.2: Window in MW2: head and cill



GENERAL CONSTRUCTION NOTES

Air barrier sealed to window before installation and incorporated into wall plaster to achieve an airtight joint

Additional insulation carefully fitted to timber wall reveal to cover window frame jambs and head - designed to provide good thermal integrity between window frame and wall, in order to reduce risks of interstitial condensation at this point

Airtight but vapour permeable membranes should be considered to further reduce risks of interstitial condensation, potentially caused by site defects in the thermal integrity of this joint

Typical limits for window placement

Proprietary or site made cill piece weathered to window frame and wall jambs

HEAD & CILL

5.1.3: Door in MW1 & MW2: threshold

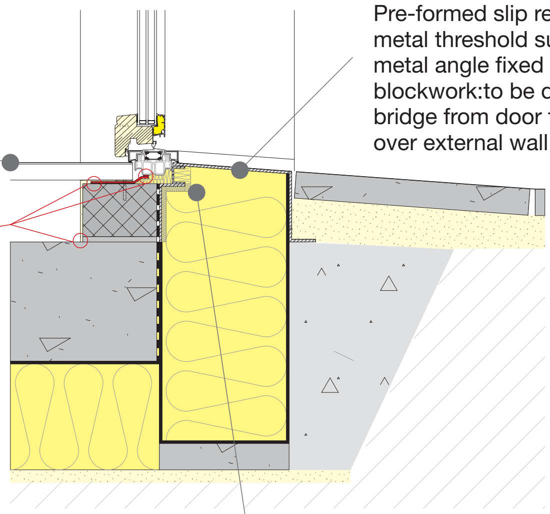
GENERAL CONSTRUCTION NOTES

Typical finished floor level

Raised access floor panel

Where the threshold is not fixed directly to the concrete slab, e.g. where a raised access floor is used (as illustrated here) careful and robust measures are needed to ensure the air barrier is sealed to the blockwork plaster (or parging coat) and that the plaster or parging coat is taken down to the concrete slab, thereby ensuring an airtight seal between the door threshold and the concrete slab

Airtight but vapour permeable membranes should be considered to further reduce risks of interstitial condensation, potentially caused by site defects in the thermal integrity of this joint



Pre-formed slip resistant metal threshold supported off metal angle fixed to blockwork:to be designed to bridge from door threshold over external wall insulation

Tolerance gap between door frame and wall insulation - designed to allow full fill insulation giving good thermal integrity to joint, in order to reduce risks of interstitial condensation at this point.

Detailing junctions of windows and doors with the thermal fabric - rules of thumb and basic principles

- Choose windows based on requirements in the CLP Energy Standards
- Refer to *Principles and Methodology* to understand the impact of non-repeating linear thermal bridging caused by windows and external doors;
- Take great care with rooflights and roof windows; i.e. sloping glazing. You may be unable to reach the Passivhaus or Gold Standards or maintain satisfactory levels of thermal comfort adjacent to larger areas of sloping glazing if using off-the-shelf products at present.
- With inward-opening windows and doors, adopt the detailing principle of additional external insulation over the frame, as per the PHPP Manual.
- With outward-opening windows, adopt the principle of using very slimline frames and casements, as seen in elevation.
- The CLP Energy Standards also allow ‘PH-suitable’ windows to be used where appropriate. Exercise caution as outlined below.

Fixing Methods

Different windows need different fixing methods. The inward opening sash illustrated in 5.1.1 – 5.1.3 is timber with external thermal insulation. The wooden portion of the frame is screwed directly to the masonry for wall type MW1 and to the sides of the Larsen truss plywood gussets in the case of wall type MW2. Alternatively, metal straps or angles can be used. Ensure that fixings do not damage the air-vapour barrier ‘skirt’ around the window or door, nor compromise the integrity of wall insulation adjacent to the window frames.

Some high-performance window frames are a laminated cork and timber sandwich. Others are solid timber with the centre hollowed-out and filled with injected PU/PI foam insulation. Others are hollow GRP or PVC profiles, filled with insulation, either foamed-in-place or containing pieces manually inserted during manufacture. In case of doubt, refer to the manufacturer.

Reduced Thermal Bridging

General

The thermal bridging which is caused in cavity walls by masonry returns and steel lintels does not arise in single-leaf solid masonry construction. In fact, windows in solid externally-insulated walls give rise to few thermal bridging problems so long as one important point is observed. The window must be sited fully in the plane of the thermal insulation, or it must overlap with the insulation in other ways.

Inward-Opening Windows

Inward-opening tilt-and-turn windows prevail in central Europe, where the Passivhaus Standard originated. With these windows, the external insulation can be wrapped around the outside of the window frame, reducing the area of exposed frame and reducing the ψ-value of the window-wall junction. This approach works especially well with windows which have a wooden frame bonded to external rigid insulation, since the wood can be installed wholly in the plane of the masonry and the rigid insulation on the frame is in the plane of the wall external insulation.

With windows installed in this way it is important to be aware of the effect on daylighting and solar gain of the specified thickness of the building's external insulation. If, for example this is 250 mm thick, the window frame could typically be recessed by about 150 – 200 mm, relative to the outside of the rendered wall insulation. Visually this is a fairly deep reveal, but not unreasonable.

Very deep reveals protect the window from the weather and from the summer sun, but they have an adverse effect on winter solar gains; i.e., they partly shade the glass from incoming solar radiation. They increase the need for space heating and lighting energy; they reduce the need, if any, for space cooling energy.

Depending on the external wall insulation method adopted, it is possible to have more scope to vary the window position within the thickness of the wall construction. The two wall constructions shown in Section 5 illustrate this.

Take care in buildings where large numbers of inward-opening windows are coupled side-to-side or top-to-bottom. These junctions cannot easily be wrapped with insulation.

Outward-Opening Windows

In the UK, Scandinavia and North America, outward-opening are more common than inward-opening windows. Outward-opening windows make the above strategy less practicable or impossible, because extending the external insulation over the outside of the window frame would soon start to interfere with the opening mechanism.

With outward-opening windows, the best way forward is to adopt the principle of very slimline frames and casements. Some windows, especially from Canada which had a government research program on super-windows, have deliberately been designed with very low-profile insulated frames and sashes as seen in elevation. Yet they are relatively deep in the direction of heat loss. This profile both reduces the problem of blocking solar gains and reduces the potential benefit of covering the outside of the frame with thermal insulation.

With outward-opening windows, bear in mind also that individual top-hung opening lights can usually be larger than side-hung lights from the same manufacturer, perhaps 1200-1600 mm wide instead of 750-900 mm wide. Usually, by adopting top-hung opening lights, a designer can devise windows which overall utilise fewer mullions and transoms. This gives rise to lower heat losses, because the centre-of-glass of a modern window has a much lower U-value than either the edge-of-glass or the glazing bar.

Rooflights

To our knowledge, no commercially-available products yet meet the requirements of the PH or Gold Standards.

Also, a single rooflight, installed in a deep roof structure in a weathertight manner; i.e., with the rooflight kerb protruding just above the roof covering, gives rise to a severe linear thermal bridge. Almost by definition, a rooflight which is designed to resist the weather and to keep water out of the building is not located within the plane of the roof insulation.

The very few UK projects to aim at the Passivhaus or Gold Standard and having a significant area of roof window(s) incorporate custom-built glazing systems along the lines of; e.g., the 3+1 rooflight used in the 1st Canadian Advanced House in Brampton in 1989. This reduces the linear thermal bridge losses considerably.

Note also that SE-, S-, SW- and W-facing sloping glazing is subject to very high solar gains in midsummer, because the plane of the glazing is almost perpendicular to the incoming sun's rays. This can contribute to severe overheating. This contrasts with the same rooflight's lack of solar gains and high heat losses in winter. By contrast, vertical south-facing windows gain solar heat in winter and can be more easily and affordably shaded to consistently control solar gains in summer.

Passivhaus-Certified and 'Suitable' Windows

A given building in the southern UK needs slightly less space heating energy than in the average German city. Also, except for inland areas such as the Midlands, mid Wales, central Scotland and the Pennines, our design temperatures are somewhat more moderate than Germany's. Consequently, the CLP Energy Standards also allow 'PH-suitable' windows to be used where appropriate as well as PH-certified windows.

The upper limits to U-values set in the CLP Standards must be observed. Exercise caution when specifying 'PH-Suitable' windows, because a building in an average UK location needs virtually as much space heating energy as one in an average German location. Increases in window U-value above the Passivhaus figure to the upper limit of 0.95 in the CLP Standards will usually have to be partly or fully compensated by improvements elsewhere in the building fabric; e.g., by thicker floor, wall and roof insulation and designers must ensure that thermal comfort will be adequate next to large areas of glazing in cold weather.

This is particularly critical if the building is heated via the ventilation air. Even in the UK, windows must remain free of downdraughts down to quite low ambient temperatures.

Appendix 1

The following information is available as a separate downloadable spreadsheet from the CLP website.

Note the information on the spreadsheet is broken down into sheets 1-5 as follows;

- Materials (1) – covers all individual materials used, with their associated conductivity, references etc.
- Materials (2) – show in which constructions the materials are used.
- Materials (3, 4 & 5) – developments of 2 above.

Appendix 2

APPENDICES

Assumptions for calculation of ‘theoretical’, ‘typical’ and ‘poor’ U-values.

			case (1) theoretical		case (2) typical		case (3) poor		bridge	
Detail	section	Layer	assumptions	resulting % & U value	assumptions	resulting % & U value	assumptions	resulting % & U value	material assumptions	Conductivity W/m2K
TR2	2	Flanges	47mm flange every 600mm plus 1% for noggins	8.8%	47mm flange every 600mm plus 20% AND 47/1200 plus 10% for noggins	13.7%	47mm flange every 600mm plus 50% AND 47/1200 plus 20% for noggins	16.5%	Softwood	0.130
TR2	2	Web	8mm web every 600mm	1.3%	8mm flange every 600mm plus 20%	1.6%	8mm web every 600mm plus 50%	2.0%	Ply/OSB	0.22
TR2	2	Service void batten	38mm every 600mm	6.3%	38mm every 600mm plus 20%	7.6%	38mm every 600mm plus 50%	9.5%	Softwood	0.13
Resulting		U-value		0.101		0.103		0.105		
MW2	2	outer flange	47mm flange every 600mm	7.8%	47mm flange every 600mm plus 20% + 47/1200 plus10% for noggins	13.7%	47mm flange every 600mm plus 50% + 47/1200 plus20% for noggins	16.5%	Softwood	0.130
MW2	2	Web	12mm web every 600mm, 200 every 1200 deep	0.3%	12mm flange every 600mm, 200mm deep every 1200mm, plus 20%	0.4%	12mm flange every 600mm, 200mm deep every 1200mm, plus 50%	0.5%	Ply/OSB	0.22
MW2	2	Inner flange	as outer less noggins	7.8%	as outer less noggins	9.4%	as outer less noggins	11.8%	Softwood	0.13
Resulting		U-value		0.129		0.132		0.133		
TW1	4	outer flange	47mm flange every 600mm	7.8%	47mm flange every 600mm plus 20% + 47/1200 plus10% for noggins	13.7%	47mm flange every 600mm plus 50% + 47/1200 plus20% for noggins	16.5%	Softwood	0.130
TW1	4	Web	12mm web every 600mm, 300 every 800 deep	0.75%	12mm web every 600mm, 300 every 800 deep, plus 10%	0.83%	12mm web every 600mm, 300 every 800 deep, plus 12%	0.90%	Ply/OSB	0.22
TW1	4	Inner flange	as outer less noggins	7.8%	as outer less noggins	9.4%	as outer less noggins	11.8%	Softwood	0.13
TW1	4	Service void batten	worst case fixed (whole point of design)	35%	worst case fixed (whole point of design)	35%	worst case fixed (whole point of design)	35%	Softwood	0.13
Resulting		U-value		0.118		0.120		0.121		
TR1	4	outer 50mm of outer flange	47mm flange every 600mm, 47 noggin every 1200	7.8%	47mm flange every 600mm plus 20% + 47/1200 plus10% for noggins	13.7%	47mm flange every 600mm plus 50% + 47/1200 plus20% for noggins	16.5%	Softwood	0.130
TR1	4	inner 25mm of outer flange	47mm flange every 600mm	7.8%	47mm flange every 600mm plus 20% no noggins	9.4%	47mm flange every 600mm plus 50% no noggins	11.8%	Softwood	0.130
TR1	4	Web	12mm web every 600mm, 200 every 1200 deep	0.3%	12mm flange every 600mm, 200mm deep every 1200mm, plus 20%	0.4%	12mm flange every 600mm, 200mm deep every 1200mm, plus 50%	0.5%	Ply/OSB	0.22
TR1	4	Inner flange	as outer less noggins	7.8%	as outer less noggins	9.4%	as outer less noggins	11.8%	Softwood	0.13
TR1	4	Service void batten	worst case fixed (whole point of design)	30%	worst case fixed (whole point of design)	30%	worst case fixed (whole point of design)	30%	Softwood	0.13
Resulting		U-value		0.102		0.104		0.105		

Appendix 3

APPENDICES

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