Design of Light Steel Infill Walls Using *Aqua Board* for Various Cladding Systems

Report To Lafarge Plasterboard Ltd

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FOREWORD

This SCI Report for Lafarge Plasterboard Ltd was prepared by Mark Lawson and Roland Chuter of the Steel Construction Institute.

The thermal analyses were carried out using the programs BISCO and TRISCO by *Physibel* and the 3D thermal models for brickwork cladding were performed by Chris Kendrick of Oxford Brookes University.

The Report supplements information on *Aqua Board* given in the SCI Assessed report on its use in combination with light steel framing.

Lafarge GTEC *Aqua Board* has been developed by the Lafarge Gypsum Division and is available in the following markets and with the following product names:

- UK (known as GTEC *Aqua Board,* GTEC *Aqua-R Board* or GTEC *Render Board.*
- Germany (known as *LaHydro*)
- France and Italy (known as *PregyWAB*)
- Poland and Romania (known as *Nida Wab*)
- Turkey (known as *Boardex*)
- Korea (known as *Aqualock)*
- North America (known as *Weather Defense)*

The Report has been reviewed by Claude Leclercq (Lafarge Gypsum Division, Technical Development Centre) and Julien Soulhat (Lafarge Plasterboard Ltd).

SUMMARY

This Report presents design information on the thermal and structural use of *Aqua Board* as a sheathing board attached to light steel infill walls, load-bearing light steel walls and in modular construction. It concentrates on the thermal performance of light steel walls with various types of insulation, wall build-ups and boundary conditions. The case of insulated render cladding directly fixed to *Aqua Board* and with a cavity using simple or double layers of *Aqua Board* are considered.

It is shown that a wall U value of 0.2 W/m^{2}K is obtained with 80 mm of closed cell insulation externally and 100 mm of mineral wool between the C sections. This takes account of thermal bridging through the C sections, which represents about 10% of the heat loss through the wall. This U value is insensitive to steel thickness, as changing from 1.2mm to 1.6mm steel only adds about 1% to the heat loss.

The analyses showed that the linear thermal bridging parameter or Psi-value is 0.05 W/mK at a steel edge beam or a concrete slab when supporting a light steel infill wall with *Aqua Board* as a sheathing board and insulated render cladding. This parameter adds about 7% to the total heat loss through the façade, which is relatively small. Conversely, the linear thermal bridging parameter for brickwork attached to a

steel edge beam by stainless steel brackets is 0.24 W/mK, which is much higher than for insulated render.

Similarly for a steel H column contained in a light steel infill wall, the linear thermal parameter is also 0.05 W/mK, which adds about 5% to the heat loss through the wall for columns at 6m spacing.

Contents

1 BACKGROUND

The use of light steel framing in load-bearing structures and infill walls within steel or concrete framed buildings is increasing rapidly in the UK. There is great potential to expand the use of this relatively new technology across Europe, based on modern practice and taking account of current and future Regulations for thermal performance.

Light steel walls may be used with many types of cladding, such as:

- Brickwork; either ground supported in load–bearing light steel structures, or supported at every floor in uses of primary structural frames with light steel infill walls
- Insulated render with sheathing board fixed directly to the light steel framing or to the infill wall within a structural frame
- Insulated render with an additional cavity, as often required in residential buildings
- Rain screen cladding, such as clay tiles, or various types of boards or panels, with a weather-tight sheathing board and insulated layer externally.

In all these cases, *Lafarge GTEC Aqua Board* may be used as a sheathing board to provide weather resistance and to act structurally to support the external cladding and to resist wind pressures applied to the wall.

This guide presents design information on the use of *Aqua Board* in light steel framing applications. It also illustrates the wall buildings for various applications, and presents information on the value benefits of *Aqua Board* relative to other sheathing materials.

In a separate Report RT1395, SCI has estimated that the market for *Aqua Board* could be of the order of 0.5 million m^2 per year in sheathing board applications.

1.1 *Aqua Board* as a product

Lafarge GTEC Aqua Board is a gypsum-silicon board that is orange-coloured and has taper-edges. It is shown in Figure 1.1. It is manufactured to BS EN 15283-1: 2008[1]. *Aqua Board* was developed by *Lafarge* to compete with products, such as cement boards, cement particle board, calcium silicate board, magnesium oxide board and specialist boards. It is designed to provide weather resistance in permanent and temporary conditions, but is much easier to use on site.

The boards are available with nominal dimensions of:

- Width - 1200 mm
- Length - 2400, 2700 or 3000 mm
- Thickness - 12.5 or 15 mm.

Figure 1.1 Lafarge GTEC *Aqua Board*

Aqua board is an extremely versatile product because it can be used both internally and externally to provide water-resisting and weather-resisting functions. It has the following attributes which make it attractive in external sheathing board applications:

- It is easily handled, cut and fixed in place, in comparison to cement particle board, for example.
- It is resistant to moisture, making it suitable for semi-exposed applications, such as 'rain screen' cladding.
- It is weather resistant during construction and can be used in prefabricated walls and in modular units, which are exposed during construction.
- It can be used to attach various lightweight cladding systems, such as insulated render, tiles, etc. either by direct fixing or by attachment of horizontal or vertical rails.
- It acts as a partial vapour barrier when placed internally to the insulation layer.
- It is durable over time and does not suffer from deterioration or mould growth.
- It is highly resistant to in-plane forces and can be used as part of the stability regime of the building ('racking' resistance).
- Pull-out resistance of fixings is good.
- Off-cuts of *Aqua board* can be recycled, as for other plasterboards.

1.2 Applications with light steel frames

The practical application of *Aqua Board* is in:

- Load-bearing light steel frames.
- Infill walling to steel or concrete frames.
- Modular construction.

An example of the use of light steel framing in a load-bearing structure is shown in Figure 1.2. In this case, the floor is gypsum-based screed, called *Gyvlon*. Examples of the use of light steel framing in infill walls are illustrated in Figures 0.4 and 0.5.

In all cases, *Aqua Board* is used as an external sheathing board, but may also be used internally in bathrooms and other wet areas etc. Modular construction is a special case of the use of load-bearing frames in which the side walls of the modules transfer forces vertically through the structure. In modular construction, the sheathing board acts as weather-resistant layer during transportation and installation, and also resists in-plane loads by diaphragm action to provide the stability of the group of modules.

The important functional requirements, which *Aqua Board* provides are:

- Resistance to negative and positive wind pressures and pull-out of fixings due to wind effects.
- Resistance to in-plane shear forces, where the sheathing board acts as a 'diaphragm' to provide stability.
- Weather resistance in the temporary condition when exposed during construction.
- Weather resistance in the permanent condition when combined with cladding, so that the *Aqua Board* is not subject to continuous moisture.
- Prevention of water absorption and mould growth.
- Fire resistance in terms of prevention of spread of fire externally and resistance to applied loads.
- Acoustic insulation to external noise such as traffic.

Figure 1.2 Load-bearing light steel wall using *Gyvlon* floor screed
(Courtesy of Metek Building Systems)

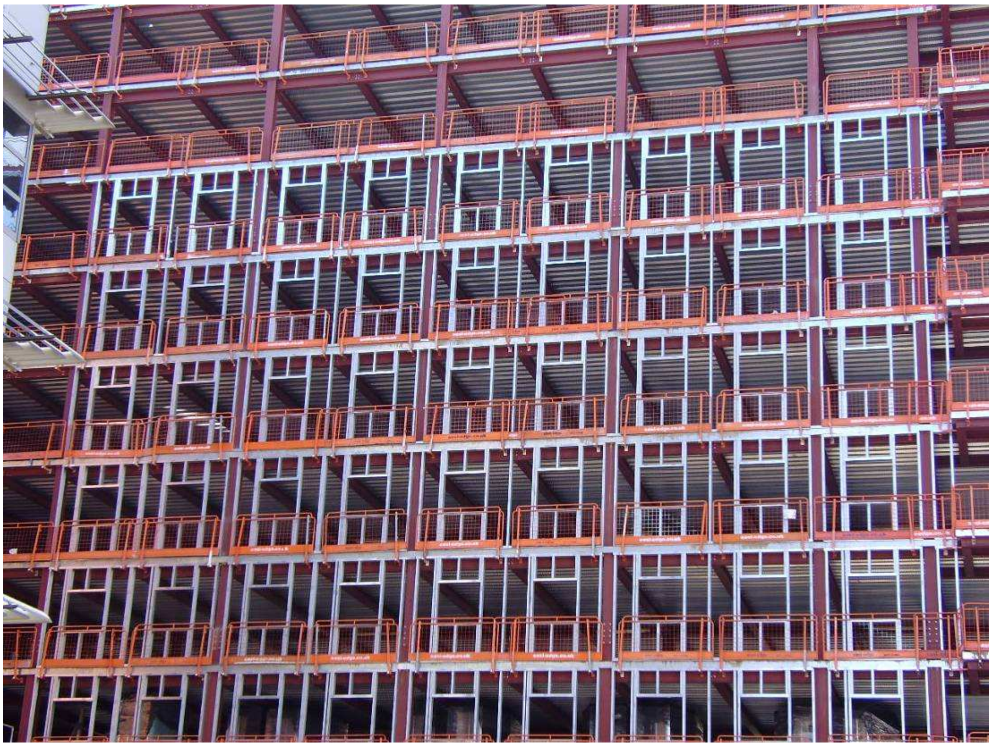


Figure 1.3 Light steel infill walls in a steel framed structure

Figure 1.4 Prefabricated light steel infill wall (by Kingspan)

1.3 Infill wall applications in steel frames

The two cases of light steel infill walls are presented in the following figures:

- Direct fix (or no cavity) system in which the external insulation is fixed to the *Aqua Board* as in Figure 1.5.
- Cavity system using one layer of *Aqua Board*, as in Figure 1.6. It is also possible to use two layers of *Aqua Board* in a cavity system but this less common.

The light steel infill walls (and mineral wool insulation) are discontinuous above and below the slab and edge beam, and so the primary steel or concrete structure acts as a partial thermal bridge. *Aqua Board* provides a continuous external sheathing board in both cases.

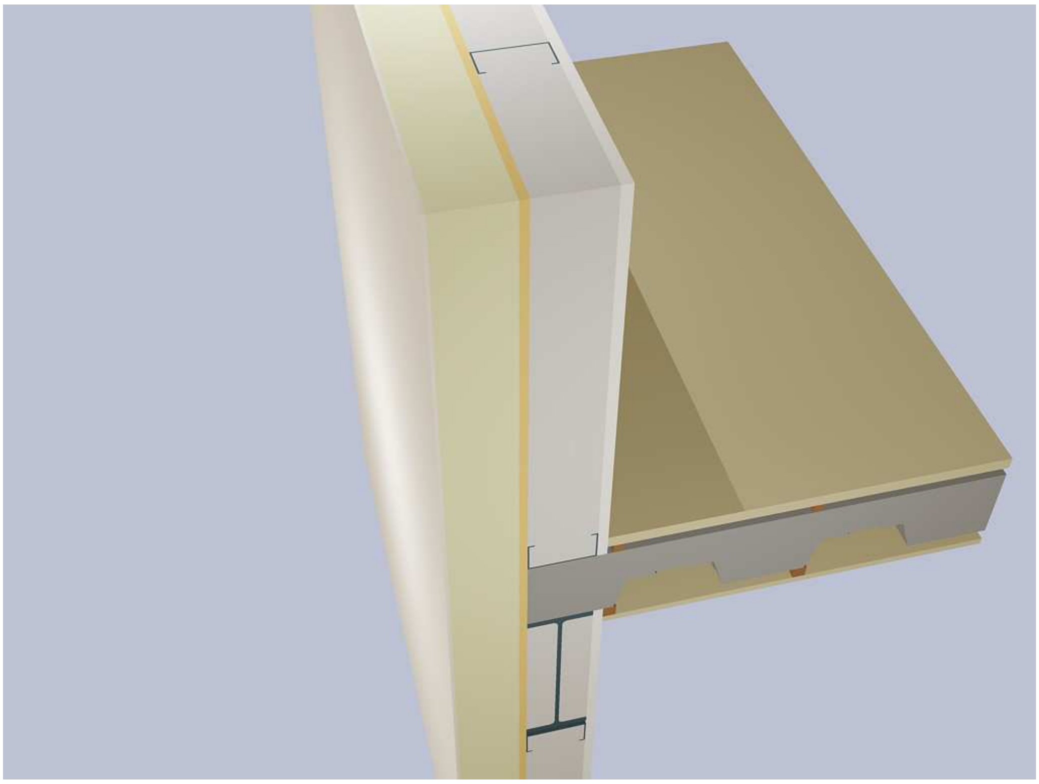


Figure 1.5 Direct fix of single layer of *Aqua Board* in an infill wall in a steel framed building

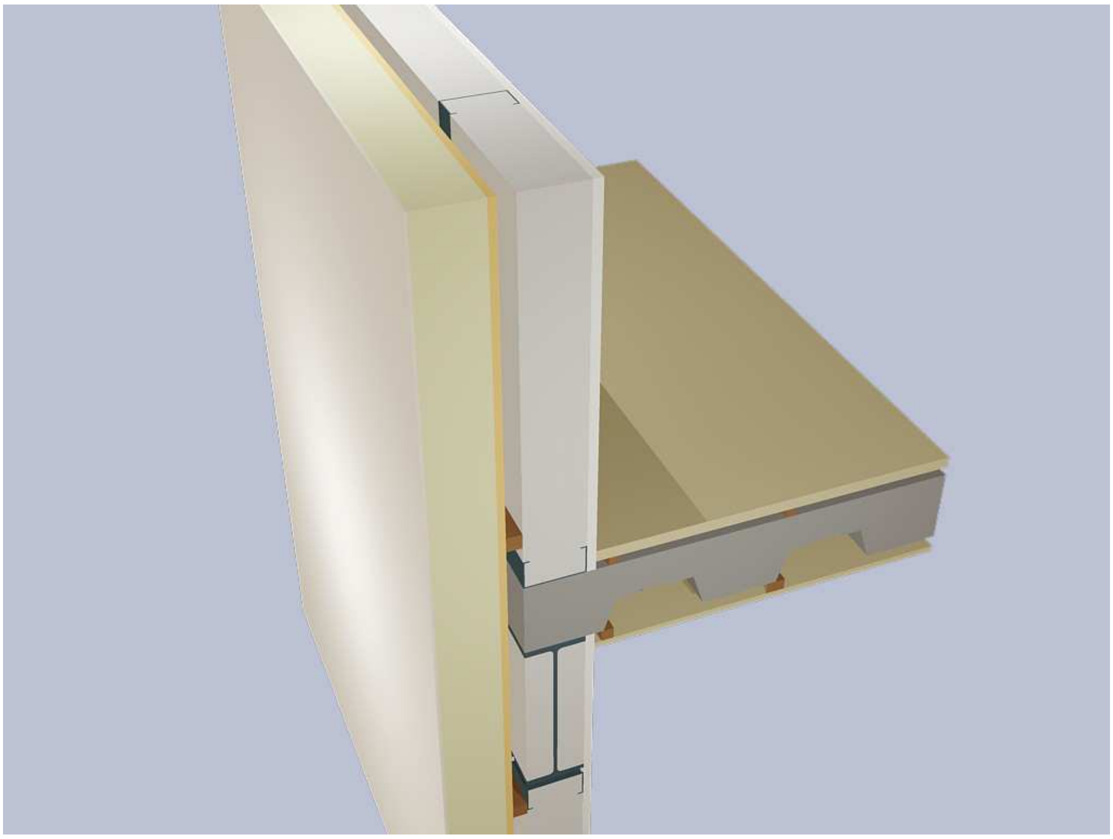


Figure 1.6 Cavity infill system using one layer of *Aqua Board* in a steel framed building

1.4 Cladding systems

Modern cladding systems may be defined generically by:

- Insulated render with or without a drained but non-ventilated cavity (see Figure 1.7 and Figure 1.8).
- Tile-supported systems with horizontal rails fixed through external insulation to the *Aqua Board*, e.g. '*Argiton*' system (see Figure 1.9).
- 'Rain-screen' system using metallic cladding or facia boards, e.g. *Trespa* or *Eternit* (see Figure 1.10).
- Brick segments, such as *Corium* supported by metallic sheets fixed through external insulation to *Aqua Board*.

In a 'rain-screen' system the sheathing board acts as the weather-resisting layer, as illustrated in Figure 1.11. In modular construction, a sheathing board is generally used on all sides of the module, independent of the type of cladding. The details in modular construction are illustrated in Figure 1.12.

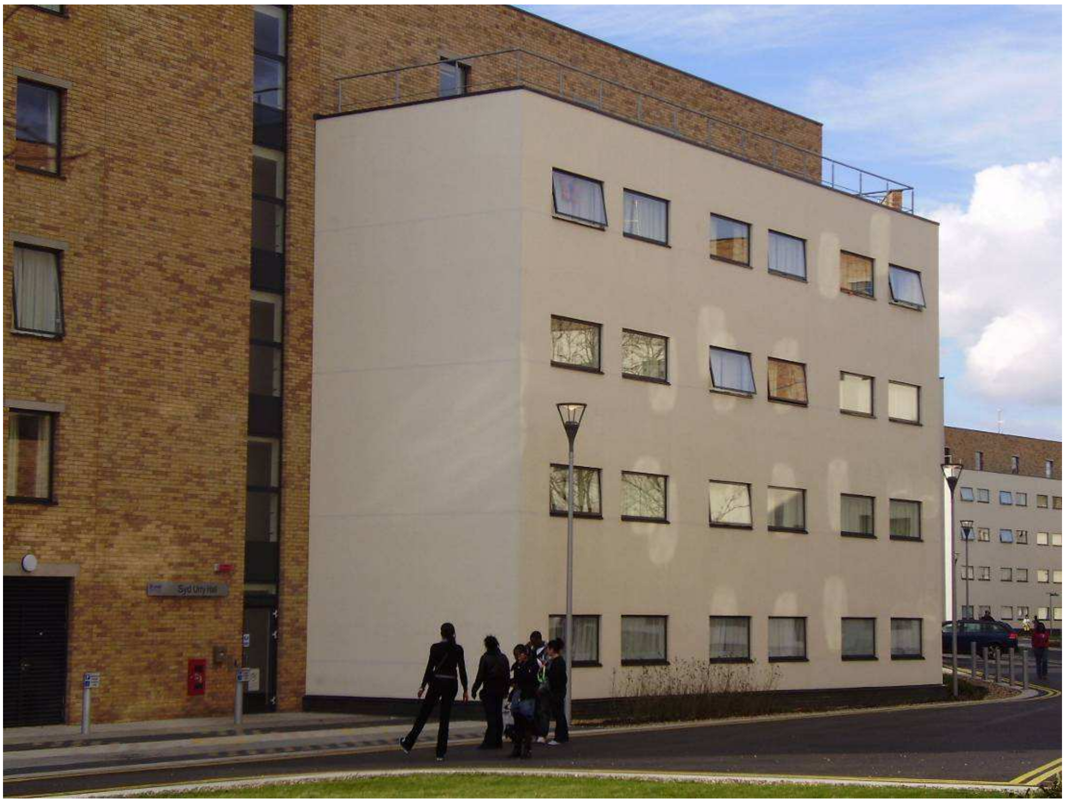


Figure 1.7 Insulated render used on light steel framing in a student residence in west London (Courtesy Metek Building Systems)

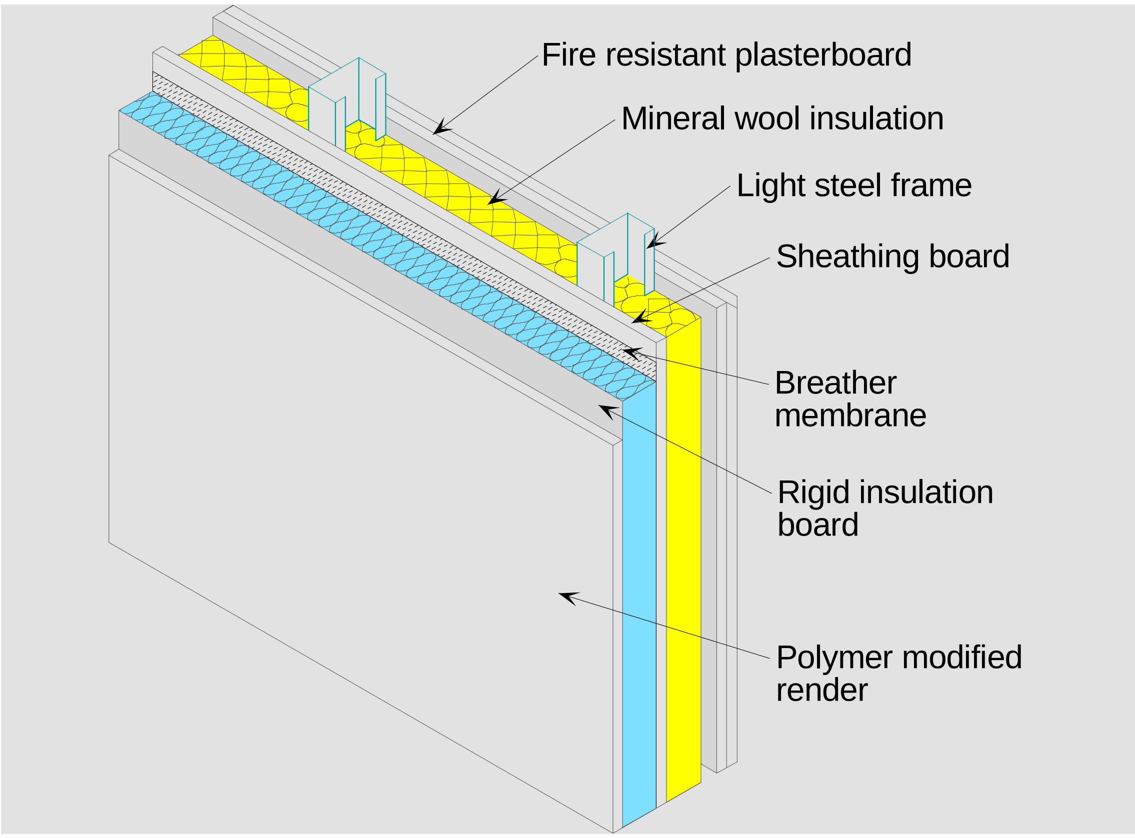


Figure 1.8 Build-up of layers in direct fix insulated render

Figure 1.9 Tile-hung rain-screen cladding system

Figure 1.10 Metallic cladding to a modular light steel building (Courtesy Corus)

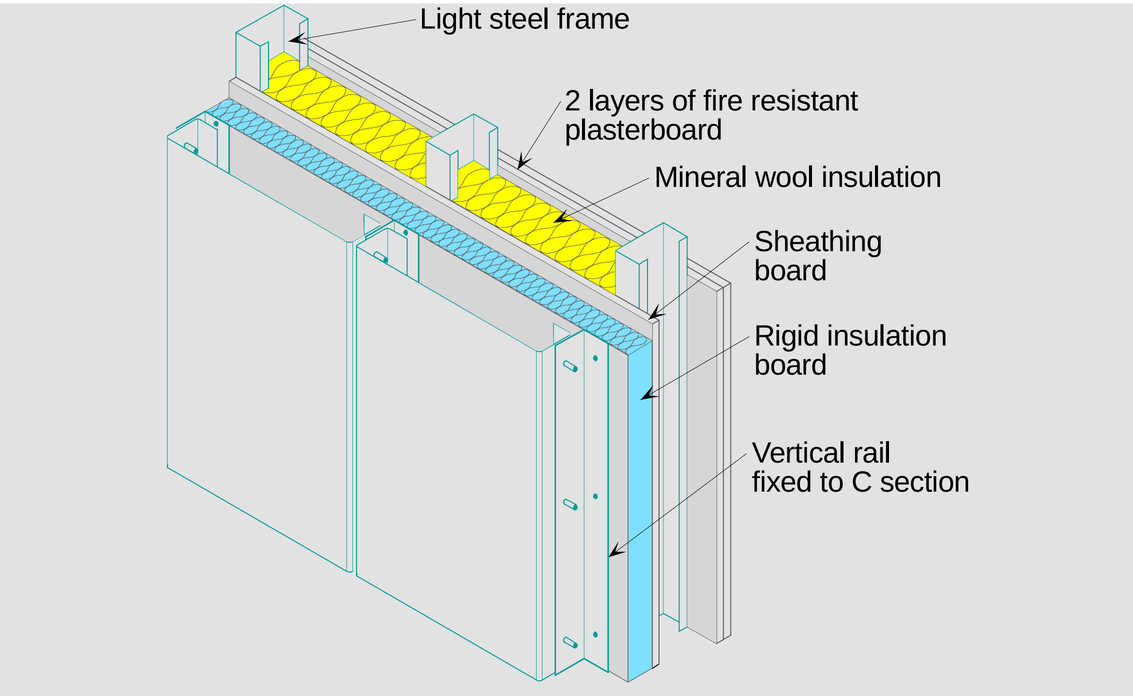


Figure 1.11 Build-up of layers in a metallic 'rain screen' cladding system

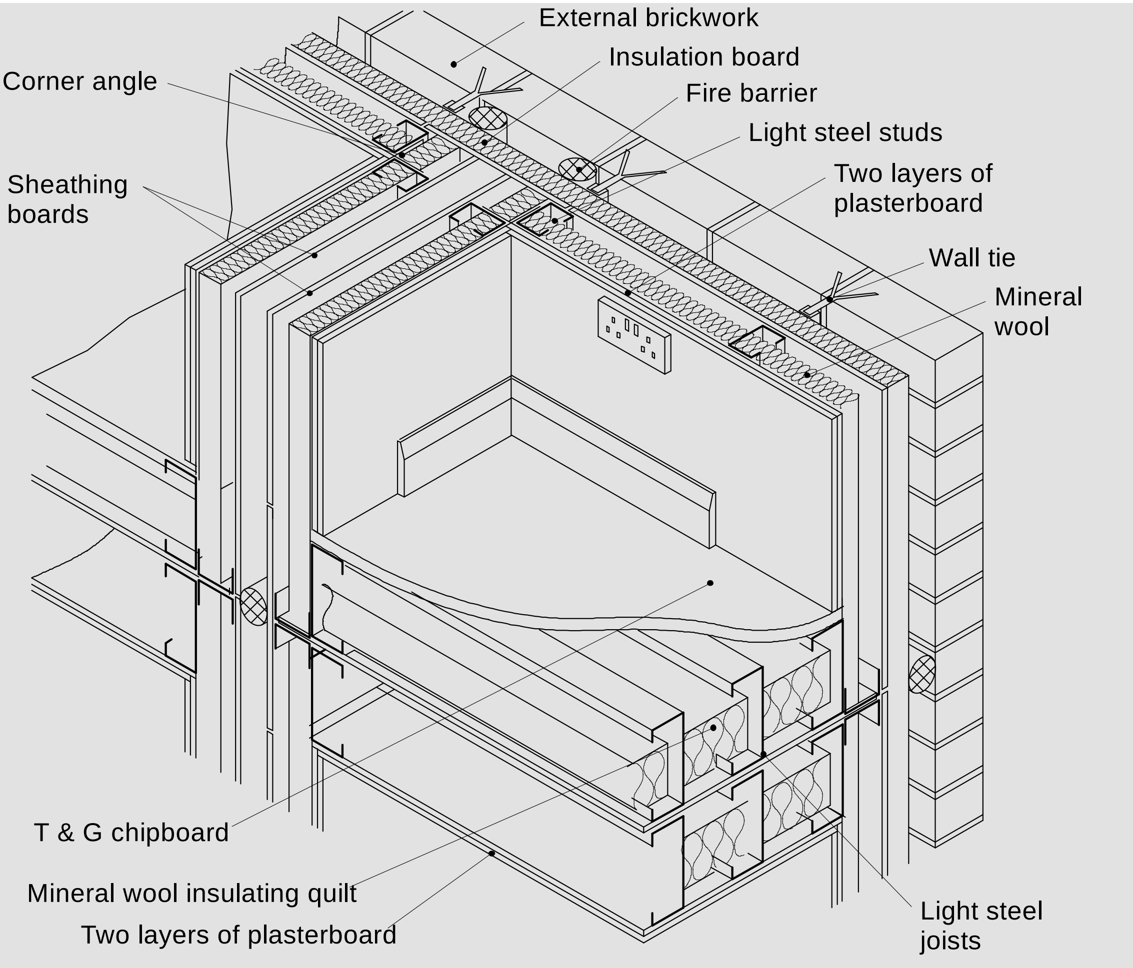


Figure 1.12 Use of sheathing boards in modular construction

2 DESIGN CASES FOR INFILL WALLS

The following design cases for the use of light steel walls with *Aqua Board* sheathing board may be considered:

- Direct-fix system
- Cavity system with a single layer of board
- Cavity system with two layers of boards

These forms of construction have some variants depending on the insulation thickness and type, and the size of the light steel C sections. Generally mineral wool is also used between the C sections to provide additional thermal and acoustic insulation.

2.1 Direct fix (non-cavity) systems

The direct fix system is illustrated in Figure 2.1. The *Aqua Board* sheathing board is fixed to the outer face of the light steel frame and provides the weather protection layer during construction, and acts as the secondary weather protection layer in the event of cracking of the external render. It also adds to the air-tightness of the wall. A breather membrane outside the *Aqua Board* is optional and is not normally required. It acts as a further weather protection layer, particularly at the joints in the *Aqua Board.*

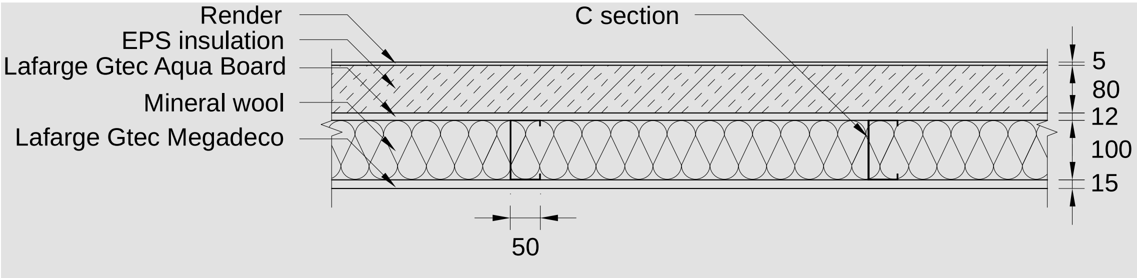


Figure 2.1 Wall build-up for direct fix system using insulated render on *Aqua Board*

This system is widely used in non-residential buildings.

2.2 Cavity systems

Cavity systems provide some back-up in the event of moisture penetrating the outer layers and may be required in housing and residential buildings. The simplest form of cavity system is illustrated in Figure 2.2. The *Aqua Board* sheathing board is fixed to a line of battens, which are fixed the outer face of the light steel frame. A cavity is created inside the *Aqua Board* layer, which allows for drainage of any small amount of water that in theory may penetrate the external layers. The minimum recommended cavity width is 15mm.

A breather membrane inside the *Aqua Board* is required so that the mineral wool placed between the C sections is not affected by the built up of any moisture in the cavity. The *Aqua Board* sheathing board also ensures that there is a rigid support to the external insulation layer. The cavity is not ventilated and therefore does not affect the insulating capacity of the external insulation.

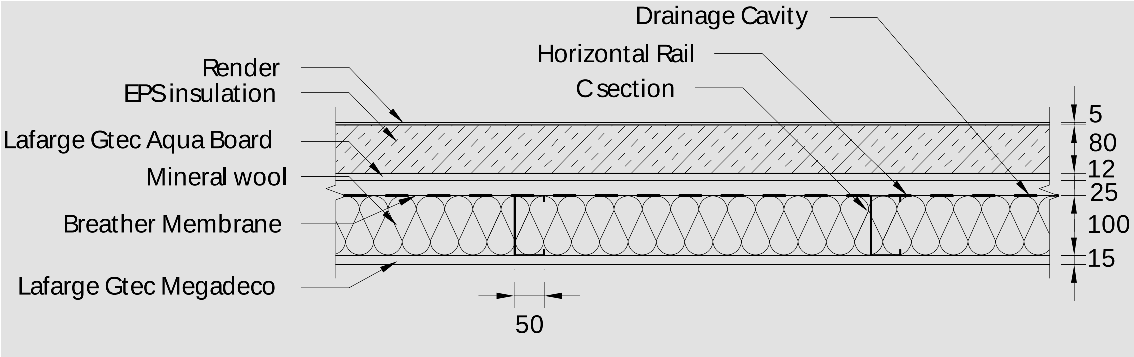


Figure 2.2 Wall build-up for a cavity system using insulated render - single layer of *Aqua Board*

A superior form of cavity system is illustrated in Figure 2.3 with two layers of *Aqua Board*, in which one layer as a sheathing board is fixed to the outer face of the light steel frame and a second layer is fixed to a line of battens. A cavity is created between the *Aqua Board* layers, which allows for drainage of any small amount of water that in theory may penetrate the external layers. A breather membrane is not required in this system. The two layers of *Aqua Board* sheathing board also ensures that excellent air-tightness is provided. Again, the cavity is not ventilated and therefore does not affect the insulating capacity of the external insulation.

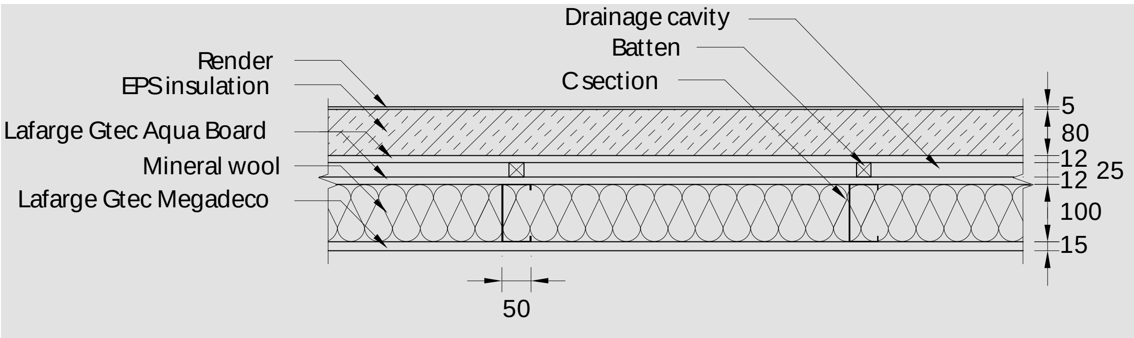


Figure 2.3 Wall build-up for cavity system- double layers of *Aqua Boards*

2.3 Infill walls in concrete framed buildings

Direct fix and cavity systems using *Aqua Board* can both be used in concrete framed buildings.

The use of a direct fix insulated render system in a concrete framed building is shown in Figure 2.4 with typical dimensions of the concrete structure. The concrete slab is typically 200 to 300mm deep. A built –up acoustic floor will generally be provided in a residential building but is not shown in this figure. The *Aqua Board* sheathing board passes outside the edge of the concrete slab and the insulation is fixed to it.

A 10 mm minimum gap is provided at the top of the light steel wall to allow for relative movement between the concrete structure and the infill wall.

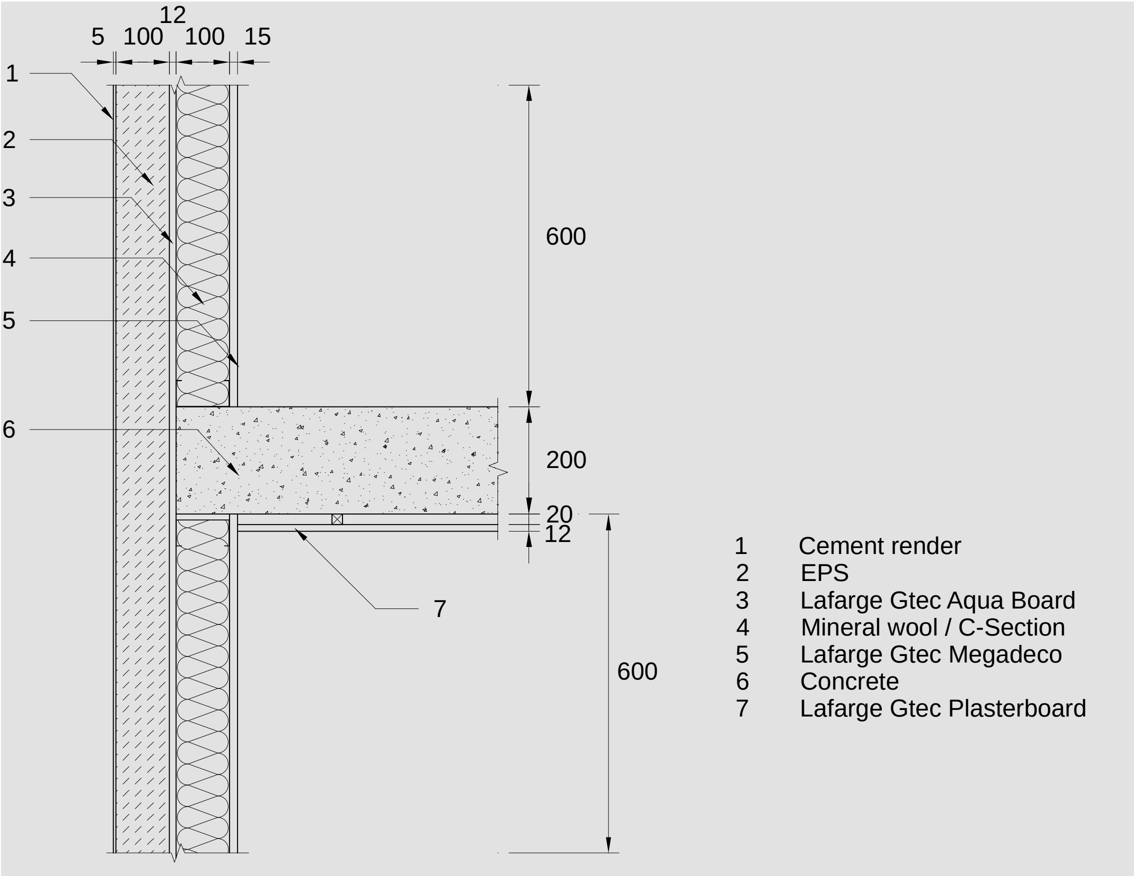


Figure 2.4 Insulated render (direct fix) applied to an infill wall in a concrete framed building

2.4 Infill walls in steel framed buildings

Infill walls may also be used in steel framed buildings in which the edge beam may be 200 mm to 450 mm deep. The composite slab is typically 130mm deep. Mineral wool may be provided around the I-beam to reduce thermal bridging. Direct fix and cavity systems using *Aqua Board* can both be used in steel framed buildings.

The interface details between light steel infill walls and steel edge beams are illustrated in Figure 2.5 for the case of insulated render (direct fix) cladding. The *Aqua Board* sheathing board passes outside the edge of the slab and steel edge beam and the insulation is fixed to it.

The case of brickwork cladding supported by the deg beams at every floor is shown in Figure 2.6. In this system, the brickwork cladding supported by a continuous stainless steel angle that fit in the mortar joint between the bricks. The angles are connected to stainless steel brackets that are placed at 400 to 900mm spacing along the edge beams, depending on the loads applied by the brickwork (normally one storey height).The brackets are bolted to 10 or 12mm thick steel plates that are welded to the flange tips of the beam.

Again, the *Aqua Board* sheathing board passes outside the edge of the slab and steel edge beam and the insulation is fixed to it. Spaces for the stainless steel brackets are cut out of the *Aqua Board* to allow the brackets to be bolted to the edge beam.

A 4m high brick wall can weigh up to 8 kN/m, whereas insulated render weighs less than 0.5 kN/m length of the wall.

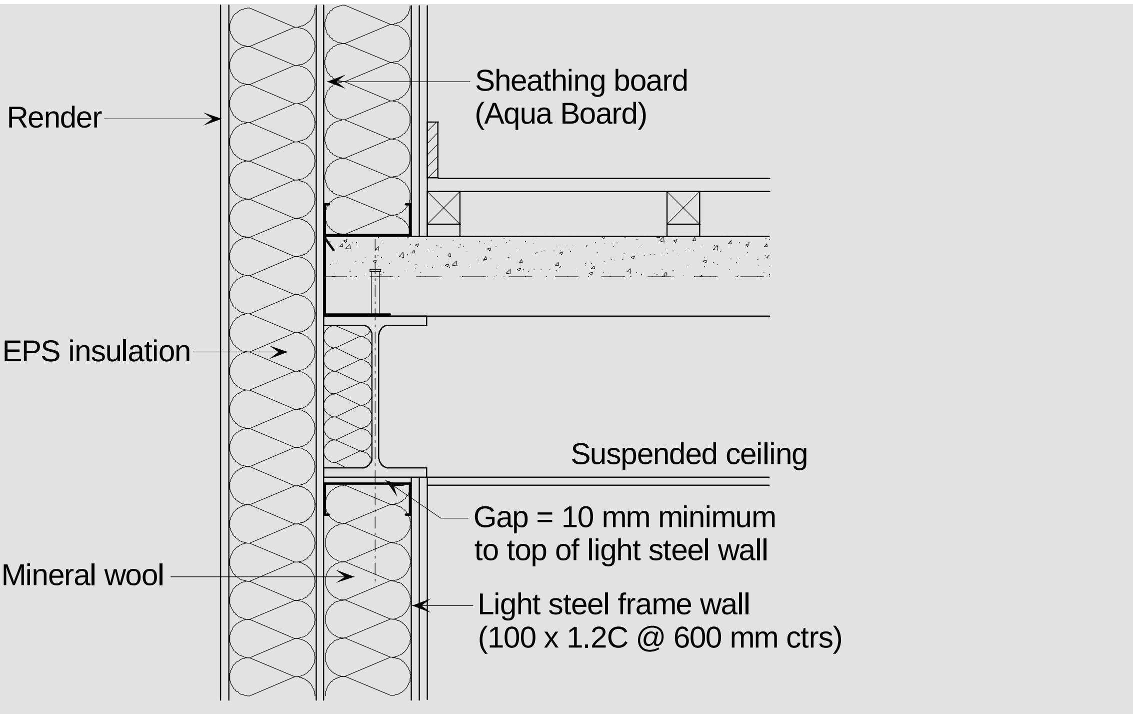


Figure 2.5 Insulated render (direct fix) applied to an infill wall in a steel framed building

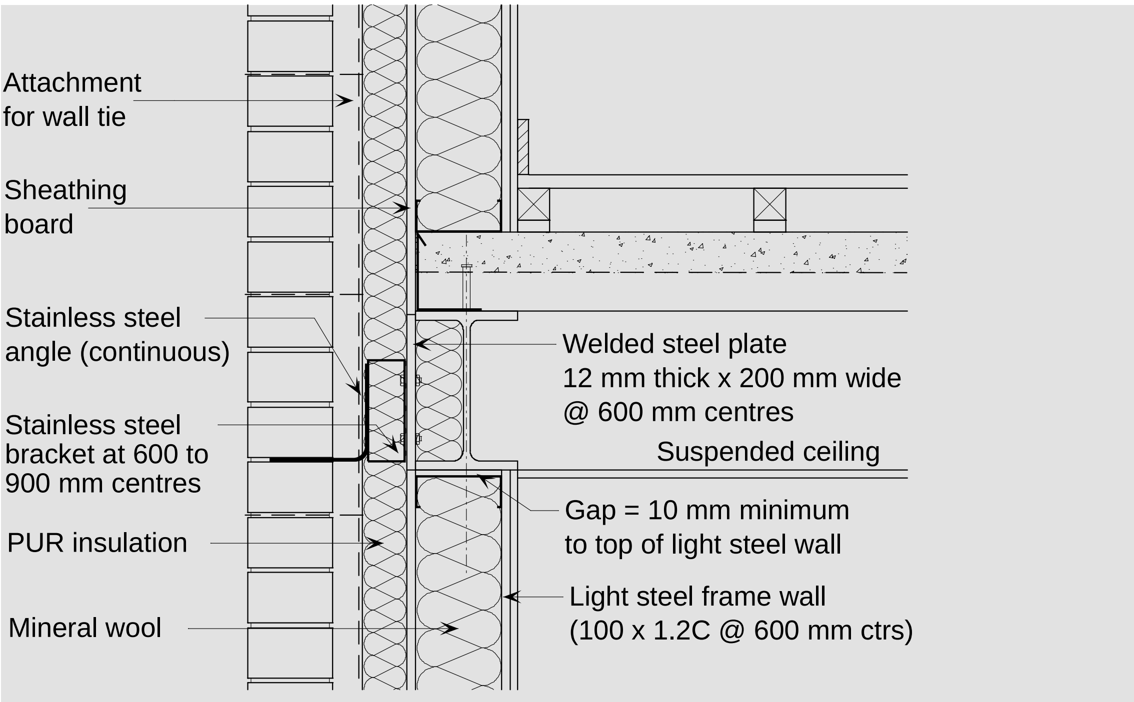


Figure 2.6 Brickwork supports using stainless steel brackets and angles at each floor in a steel framed building

3 *AQUA BOARD* PROPERTIES

3.1 General and mechanical properties

Table 3.1 presents a summary of the properties of *GTEC Aqua Board*, based on third party tests, and as presented in the SCI Assessed Report on *Aqua Board.* Lafarge also manufactures other similar boards with moisture resisting properties (see Foreword).

Table 3.1 Summary of *Aqua Board* properties

Topic	Description	Performance
General	Density	910.7 kg/m^3
	Weight of 12.5 mm board	10.9 kg/m^2
Structural	Flexural strength in longitudinal direction	6.98 N/mm^2
	Flexural strength in transverse direction	3.13 N/mm^2
	Elastic modulus in longitudinal direction	3220 N/m^2
	Elastic modulus in transverse direction	2950 N/m^2
	Impact resistance (at 20℃/65%RH)	13.4 mm/mm
Fire	Reaction to fire – Euro class	A2-s1,d0
Thermal	Thermal conductivity	0.25 W/mK
Permeability	Water vapour resistance (12.5 mm board)	0.69MNs/g
	Water vapour resistance factor	11
Moisture resistance	Water uptake (2 hrs immersion)	< 3 %
	Surface water absorption (2 hrs Cobb test)	< 100 g/m^2
	Dimensional change (20℃/30%-65%RH), longitudinal d irection	0.10 mm/m
	Dimensional change (20℃/65%-90%RH), longitudinal d irection	0.15 mm/m
	Dimensional change (20℃/30%-65%RH), transverse dir ection	0.13 mm/m
	Dimensional change (20℃/65%-90%RH), transverse dir ection	0.11 mm/m
Mould	Mould resistance	No mould growth
Aging	Ratio of aged strength to un-aged, longitudinal, 5 – 25 cycles	0.98 – 0.83
	Ratio of aged strength to un-aged, transverse, 5 – 25 cycles	0.91 – 0.79

3.2 Hygrothermal properties with render

The hygrothermal properties of two wall constructions using *Aqua Board* with insulated render were determined by testing in accordance with UEAtc (The European Union of Agrément) MOAT No. 22[2]. The wall systems tested are shown in Figure 3.1. Wall 1 is a direct render system where the render is applied to the sheathing board (for Direct Render Systems, the GTEC *Aqua Board* can be substituted by the GTEC *Aqua-R* board or the GTEC Render Board which have improved properties). Wall 2 is an External Insulated Façade System (EIFS) where a layer of rigid insulation is fixed to the sheathing board and then the render system is applied to the rigid insulation.

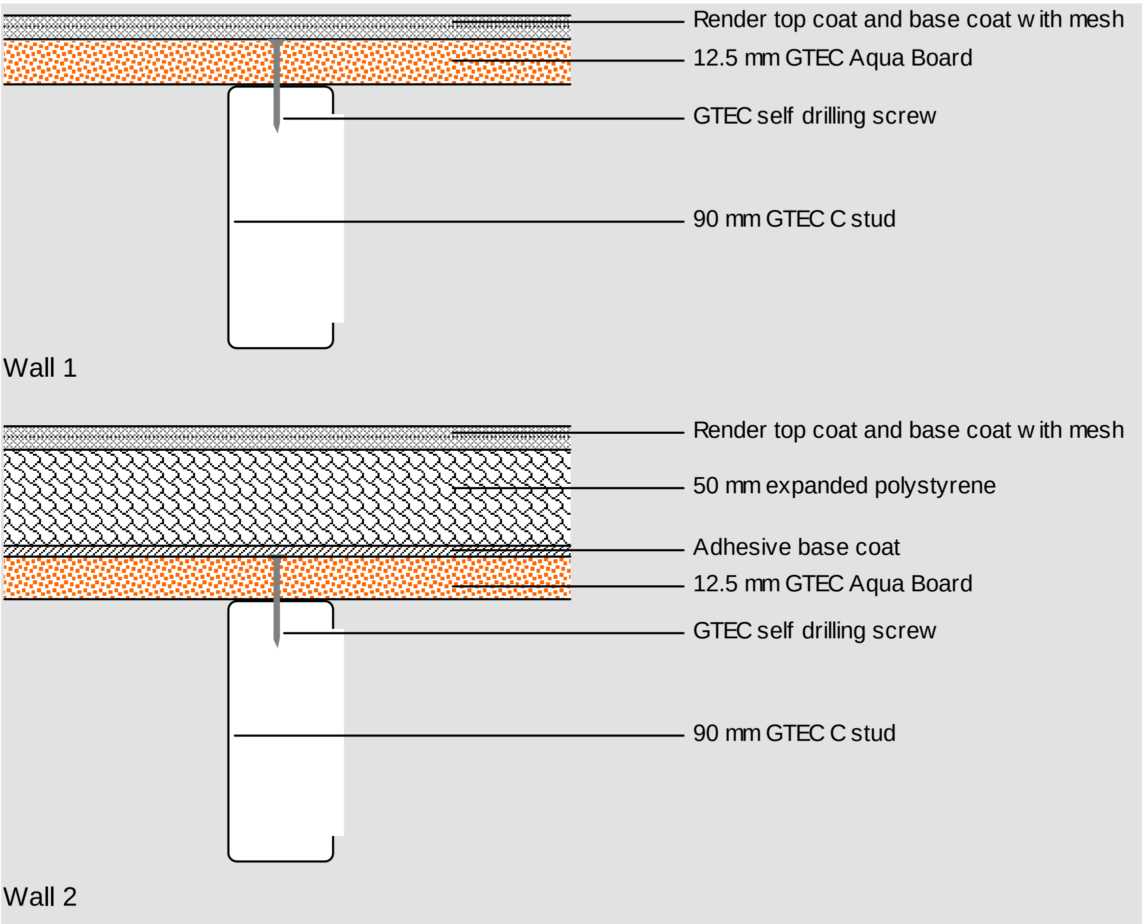


Figure 3.1 Wall systems with *Aqua Board* and render used in hygrothermal tests

The tests consist of heat / moisture cycles and freeze / thaw cycles and were carried out by BBA in 2009 [Ref.[3]]. The results for both tests were:

Heat / moisture: After 140 cycles no cracks or visible damage.

Freeze / thaw: After 20 cycles no visible damage.

3.3 Fire resistance

Internal load-bearing and partition walls incorporating *Aqua board* have been tested to determine their fire resistance. Four wall constructions have been tested.

Fire test 1 :Load bearing wall

The load bearing wall construction shown in Figure 3.2 was tested in accordance with BS 476[4] by Chiltern International Fire [Ref. [5]]. This case represented an internal fire on an external load-bearing wall. The results are given below.

Integrity = 44 minutes.
Insulation = 44 minutes.
Load-bearing = 44 minutes.

For a load-bearing external wall, the insulation criterion would not control as the heat transfer would be reduced by the cladding.

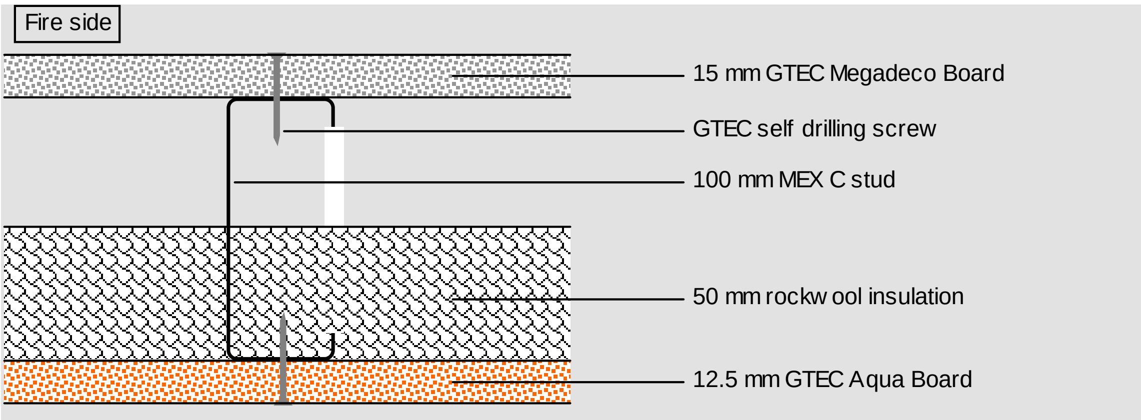


Figure 3.2 Load bearing wall for fire test (08020)

Fire test 2: Partition wall

The partition wall construction shown in Figure 3.3 was tested in accordance with BS 476 by Chiltern International Fire [Ref.[6]]. This also represents the case of an external infill wall. The results are given below.

Integrity = 59 minutes.
Insulation = 54 minutes.

For an external wall, these criteria would not be as critical as for partition because the heat transfer would be reduced by the cladding. It claimed that an external infill wall would achieve a fire resistance of at least 60 minutes.

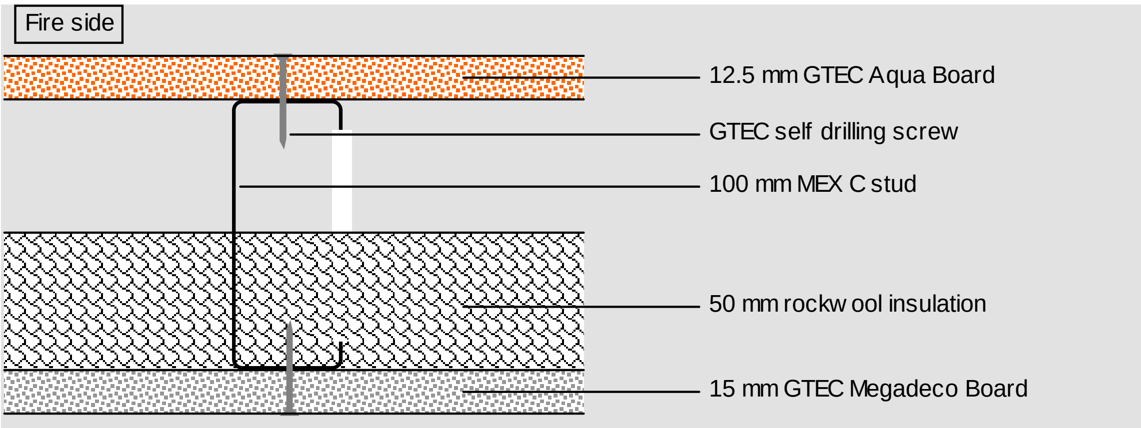


Figure 3.3 Partition wall for fire test (08041)

Fire test 3: Partition wall

The partition wall construction shown in Figure 3.4 was tested in accordance with BS EN 1364-1[7] by Chiltern International Fire [Ref. [8]]. The results are given below.

Integrity = 85 minutes.
Insulation = 74 minutes.

This test shows the superior performance of *Aqua Board* in fire conditions even without the internal mineral wool.

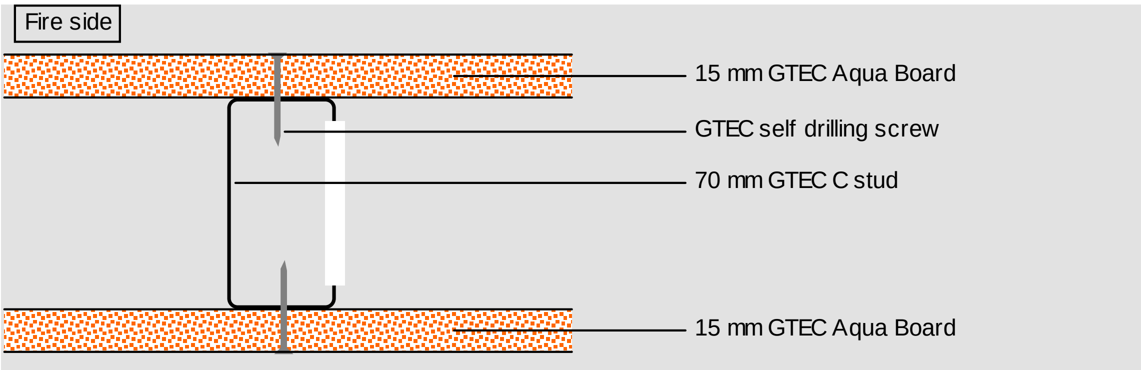


Figure 3.4 Partition wall for fire test (09075)

3.4 Shear resistance of walls

The in-plane shear resistances of 2.4 m square wall panels with 12.5 mm *Aqua Board* directly fixed to the light steel wall frames were tested by BRE in 2007 [Ref. [9]]. The tests were carried out according to BS EN 594[10]. Fixings were placed at 150 mm spacing at the edges of the boards. The tests were carried out for no vertical load , which is the most conservative case for uplift at the base of the wall. The results of the tests in terms of characteristic shear resistance and mean stiffness are:

Ultimate shear resistance	F_{max}	=12.3 kN (= 5.1 kN/m length of wall)
Mean in-plane shear stiffness	R	= 835 M/ mm

The design shear resistance is obtained by dividing by a partial factor of safety of 1.5 to take account of the variability of the test results. For design at the ultimate limit state, the design shear resistance of the *Aqua Board* is therefore 3.4 kN/m length of the wall, which is comparable with other sheathing materials. For design at working loads, the shear resistance is further divided by a load factor of 1.5, making a global factor of safety of 2.25 based on the characteristic shear resistance from the test results.

3.5 Wind load resistance

The wind load resistance of the wall system shown in Figure 3.5 was tested in accordance with ETAG 004[.and were carried out by BBA [Ref.[11]]. The maximum negative wind pressure resisted by the board and render system was 4.0 kN/m^2. The failure mode was pull out of the fixings to the *Aqua board* around its fixings.

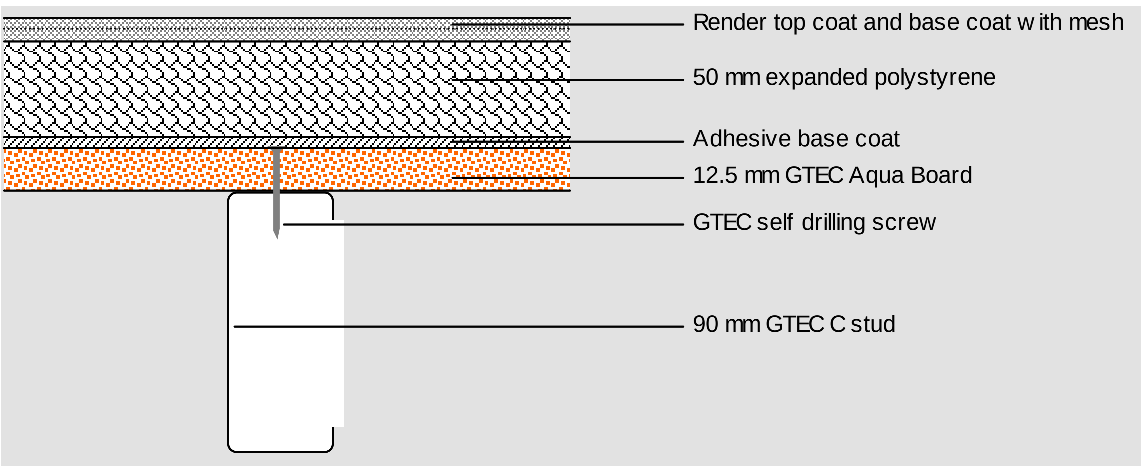


Figure 3.5 Panel cross section for wind suction tests

Design wind pressures /suctions depend upon many factors including building geometry, location, altitude, surrounding physical features etc. Typical values would be expected within the range of 0.6 kN/m^2 to 2.0 kN/m^2. This load is more than a factor of 2 higher than the wind load experienced at the corners of a high-rise building. This test shows that the wind resistance of the system is acceptable.

3.6 Sound insulation

The sound insulation of various external wall systems including *Aqua Board* were tested in accordance with BS EN ISO 140-3: 1995[12]. The tests were carried out by University of Salford (Acoustic Test Laboratory) in 2009 [Ref. 13], and are described as follows . The normal specification for acoustic performance of external wall systems is 35 dB including the low frequency correction factor, C_{tr}.

Sound test 1

The external wall construction using insulated render is shown in Figure 3.6 was tested for sound insulation. The results are given below showing the basic sound reduction index (50 dB) and the low frequency correction factor (-6 dB) in this case). The sound reduction including this factor is 44 dB. This shows that the acoustic performance of an external wall is acceptable.

R_w (C, C_{tr}) = 50 (-1, -6) dB.

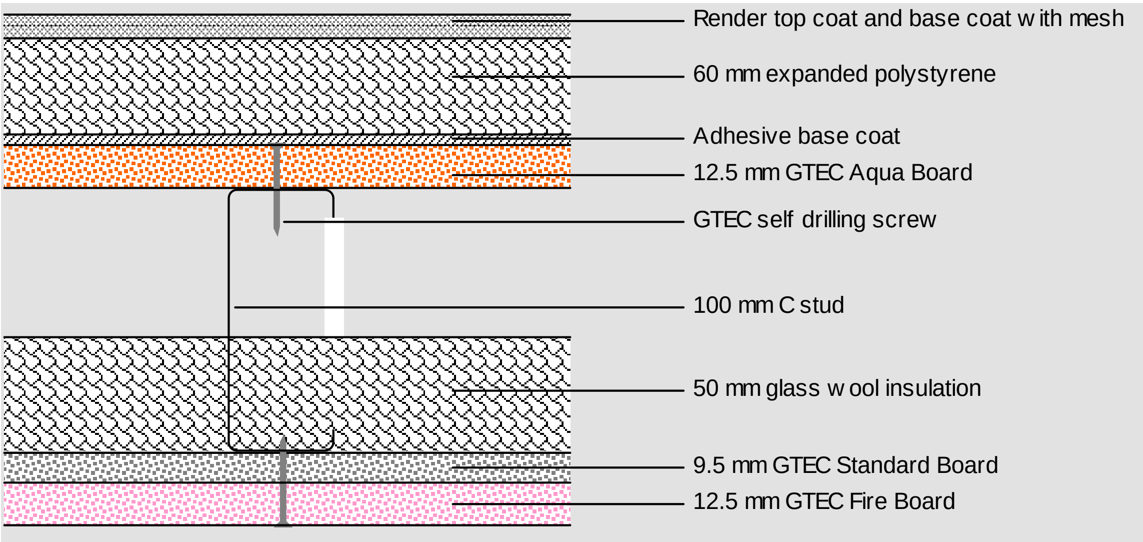


Figure 3.6 Wall for sound test 1

Sound test 2

The external wall construction shown in Figure 3.7 was tested for sound insulation . the difference with respect to the previous test was in the single layer of GTEC *Megadeco* board internally. The results are given below.

R_w (C, C_{tr}) = 48 (-2, -8) dB.

The sound reduction including the low frequency correction factor is 40 dB.

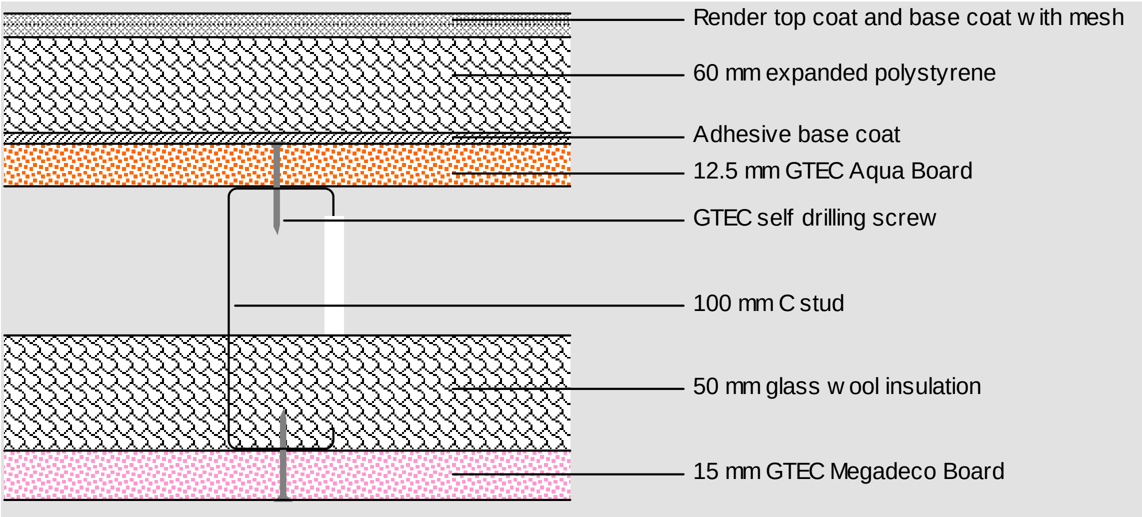


Figure 3.7 Wall for sound test 2

Sound test 3

The external wall construction shown in Figure 3.8 was tested for sound insulation. The difference with respect to the previous test was in the single layer of GTEC *Megadeco* board but with resilient bars to fix to the C section internally. The results are given below.

R_w (C, C_{tr}) = 53 (-4, -11) dB.

This shows that the resilient bars make a significant difference to the basic sound reduction but do not significantly affect the value including the low frequency correction factor (42 dB in this test)

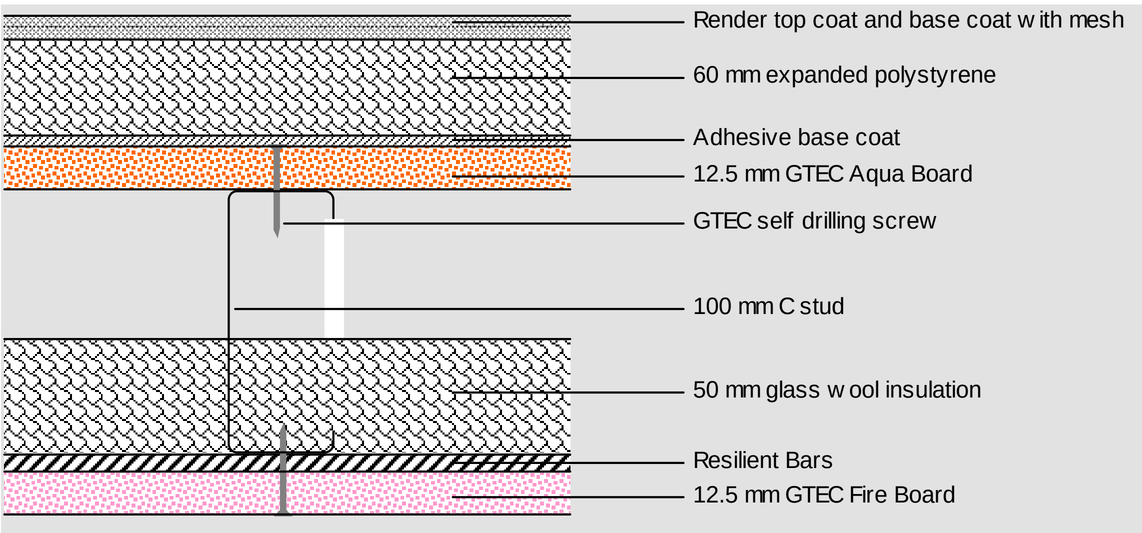
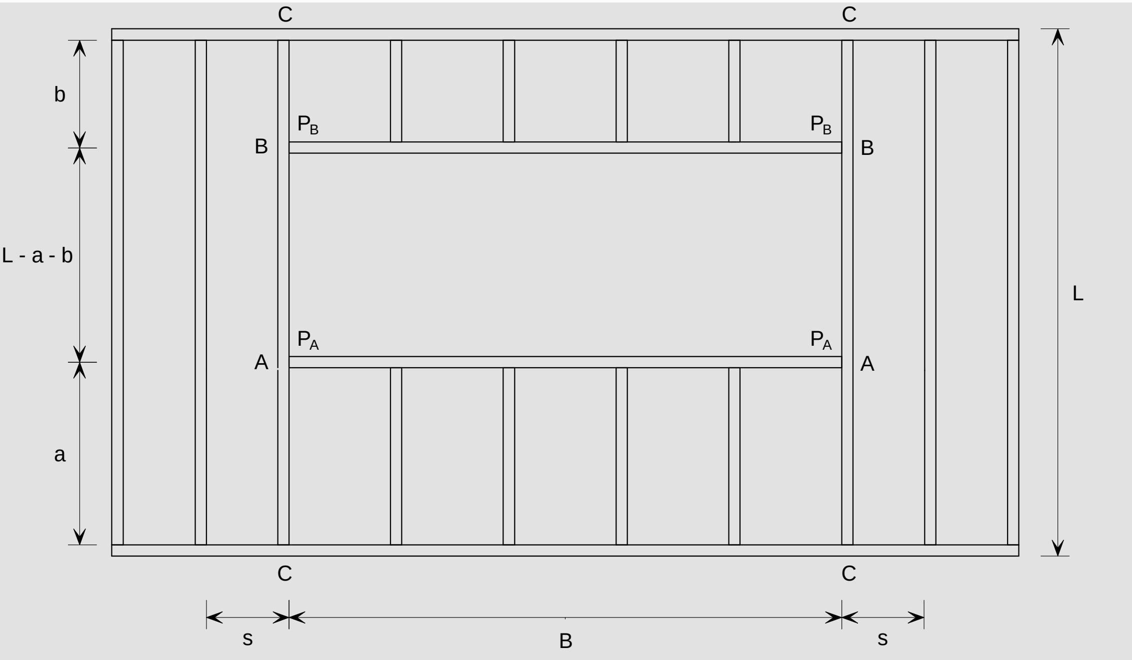


Figure 3.8 Wall for sound test 3

4 STRUCTURAL DESIGN OF LIGHT STEEL INFILL WALLS WITH WINDOW OPENINGS

The following design equations may be used to determine the bending moments and deflections of the supporting horizontal and vertical members around large openings in light steel walls, illustrated in Figure 4.1, as below: For the plain part of the wall remote from the opening, the proposed deflection limit for lightweight cladding is wall height/250, but not exceeding a maximum of 15mm, which may control for taller walls. These limits apply for wind pressures in the normal range of 0.6 to 1.2 kN/m^2.



(a) Illustration of dimensions and forces around window opening

Figure 4.1 Definition of the key members A-A , B-B and C-C around an opening

4.1 Horizontal members above/below openings

The bending moments in the members around large openings are:

Bending moment (A-A), $M_{Ed} = \gamma_f q\ (L\text{-}b)\ B^2/(16 n_h)$

Bending moment (B-B), $M_{Ed} = \gamma_f q\ (L\text{-}a)\ B^2/(16 n_h)$

The notation is presented on the following page. For adequate bending resistance, verify that $M_{Ed} \leq M_{Rd}$, depending on number and size of horizontal members.

The deflection of the members around large openings are:

Deflection (A-A) $\delta_{A-A} = \dfrac{5q(L-b)B^4}{768 EI_{yy}.n_h}$

Deflection (B-B) $\delta_{\mathrm{B-B}} = \dfrac{5q(L-a)B^4}{768EI_{\mathrm{yy}}.n_{\mathrm{h}}}$

For lightweight cladding, it is proposed to adopt deflection limits of; $\delta \leq$ B/250 but not exceeding an absolute value ≤ 15 mm above or below the openings.

4.2 Vertical members next to openings

For the vertical member C-C next to the opening, the bending moment is determined using the conditions at the top or bottom of the opening.

The larger of the bending moments at points A or B will control, as follows:

$$M_{\mathrm{Ed,A}} = P_{\mathrm{A}}(L-a)a/L + P_{\mathrm{B}}ab/L + \gamma_{\mathrm{f}}qsL^2/16$$

$$M_{\mathrm{Ed,B}} = P_{\mathrm{B}}(L-b)b/L + P_{\mathrm{A}}ab/L + \gamma_{\mathrm{f}}qsL^2/16$$

where:

P_{A} $= \gamma_{\mathrm{f}}\, q(L-b)\, B/4$

P_{B} $= \gamma_{\mathrm{f}}\, q(L-a)\, B/4$

For bending resistance, verify that $M_{\mathrm{Ed,\,A}}$ and $M_{\mathrm{Ed,\,B}} \leq M_{\mathrm{Rd}}$, depending on the number and size of vertical members next to the openings.

Deflection at point A on member C-C:

$$\delta_A = \frac{q(L-b)(L-a)^2a^2B}{12LEI_{yy}.n_v} + \frac{q(L-a)(L^2-a^2-b^2)abB}{24LEI_{yy}.n_v} + \frac{5qsL^4}{768EI_{yy}.n_v}$$

Deflection at point B on member C-C :

$$\delta_B = \frac{q(L-a)(L-b)^2b^2B}{12LEI_{yy}.n_v} + \frac{q(L-b)(L^2-a^2-b^2)abB}{24LEI_{yy}.n_v} + \frac{5qsL^4}{768EI_{yy}.n_v}$$

For lightweight cladding, it is proposed to adopt a deflection limit of the larger of δ_{A} or δ_{B} ≤L/250, depending on the number and size of vertical members.

It is also proposed to adopt an absolute deflection limit of the larger of $\delta_{\mathrm{A\text{-}A}} + \delta_{\mathrm{A}}$ or $\delta_{\mathrm{B\text{-}B}} + \delta_{\mathrm{B}} <$ 20 mm, which will control for long windows.

Notation:

L	= wall height
B	= width of window opening
a	= distance of underside of window from bottom of wall
b	= distance of top of window from top of wall
s	= spacing of vertical C sections (300 to 600 mm)
q	= design wind pressure on face of wall
γ_{f}	= partial factor for wind (= 1.5 to EN 1991-1-4)
E	= elastic modulus of steel (= 210 kN/mm^2)
I_{yy}	= second moment of area of C section in major axis direction
n_{h}	= number of horizontal members above or below the opening
n_{v}	= number of vertical members next to the opening
M_{Ed}	= bending moment on horizontal member next to opening
$M_{\mathrm{A,Ed}}$	= bending moment on vertical member at point A next to opening

$M_{B,Ed}$ = bending moment on vertical member at point B next to opening
M_{Rd} = bending resistance of C section (kNm)
δ = maximum deflection of member at point A or B.

4.3 Example of use of these formulae

Data: L = 2.8 m; a = 1 m; b = 0.6 m; B = 3 m
q = 1 kN/m^2; γ_f = 1.5; M_{Rd} = 3.5 kNm; I_{yy} = 530 × 10^3 mm^4

For horizontal member A-A:

M = 1.5 × 1.0 × 2.2 × 3.0^2/ 16 = 1.86 kNm < 3.5 kNm

$$\delta_{A-A} = \frac{5 \times 1.0 \times 2.2 \times 3.0^4 \times 10^9}{768 \times 210 \times 530 \times 10^3} = 10.4\text{mm} \quad (= L/288) < B/250 \text{ OK}$$

For vertical member C-C:

M = 1.5 × 1.0 × 2.2 × (3.0/4) × 2.0 × 1.0 /2.8
+ 1.5 × 1.8 × (3.0/2) × 1.0 × 0.6/2.8 + 1.5 × 0.6 × 2.8^2/ 16
= 1.8 + 0.9 + 0.4 = 3.1 kNm < 3.5 kNm

Deflections at points A and B on member C-C :

$$\delta_A = \frac{1.0 \times 2.2 \times 1.8^2 \times 1.0^2 \times 3.0 \times 10^6}{12 \times 2.8 \times 210 \times 530 \times 10^3} + \frac{1.0 \times 1.8 \times (2.8^2 - 1.0^2 - 0.6^2) \times 1.0 \times 0.6 \times 3.0 \times 10^6}{24 \times 2.8 \times 210 \times 530 \times 10^3} + \frac{5 \times 1.0 \times 0.6 \times 2.8^4 \times 10^9}{768 \times 210 \times 530 \times 10^3}$$

Total deflection of vertical member C-C:

$\delta_A = 5.7 + 2.8 + 2.2 = 10.7\text{mm} \quad (= L/260) < L/250$ - just acceptable

$$\delta_B = \frac{1.0 \times 1.8 \times 2.2^2 \times 0.6^2 \times 3.0 \times 10^6}{12 \times 2.8 \times 210 \times 530 \times 10^3} + \frac{1.0 \times 2.2 \times (2.8^2 - 1.0^2 - 0.6^2) \times 1.0 \times 0.6 \times 3.0 \times 10^6}{24 \times 2.8 \times 210 \times 530 \times 10^3} + \frac{5 \times 1.0 \times 0.6 \times 2.8^4 \times 10^9}{768 \times 210 \times 530 \times 10^3}$$

$\delta_B = 2.5 + 3.4 + 2.2 = 8.1\text{mm} \quad (= L/345) < L/250$

Absolute deflection = 10.7 + 10.4 = 21.1 mm > 20 mm – not acceptable
Therefore use double C sections next to the wall:
Absolute deflection = 0.5 × 10.7 + 10.4 = 16.1 mm < 20 mm – acceptable

Conclusion:

For openings up to 2.8 m wide in a 2.8 m high wall, use single C sections horizontally and vertically around the opening.
For wider openings, use double C sections horizontally and vertically.

4.4 Simplified design table for infill walls

The following design tables may be used for infill walls using 100 mm and 150 mm deep C sections with lightweight cladding systems. The wind load of q = 1 kN/m^2 is unfactored, and is typical of wind loads on medium-rise buildings in England.

Table 4.1 Design table for 100 × 50 × 1.6C as an infill wall with opening of 1.5 m height for wind pressure, q = 1 kN/m^2

Wall Height, *L*	Window Opening Width, *B*				
	1.5 m	2 m	2.5 m	3 m	3.5 m
2.4 m	IV/IH	IV/IH	IV/IH	IV/IH	2V/2H
2.7 m	IV/IH	IV/IH	IV/IH	2V/IH	2V/2H
3.0 m	IV/IH	IV/IH	2V/IH	2V/2H	2V/2H
3.3 m	IV/IH	2V/IH	2V/IH	2V/2H	3V/2H
3.6 m	2V/IH	2V/IH	2V/2H	3V/2H	3V/2H

IV means single 100 × 1.6C next to opening
2V means a pair of 100 × 1.6C next to opening
IH means 100 × 1.6 C above/below opening

Table 4.2 Design table for 150 × 50 × 1.6C as an infill wall with opening of 1.5 m height for wind pressure, *q* = 1 kN/m^2

Wall Height, *L*	Window Opening Width, *B*				
	2.5 m	3 m	3.5 m	4 m	4.5 m
3.0 m	IV/IH	IV/IH	IV/IH	IV/IH	IV/IH
3.5 m	IV/IH	IV/IH	IV/IH	IV/IH	IV/2H
4.0 m	IV/IH	IV/IH	IV/IH	2V/1H	2V/2H
4.5 m	IV/IH	2V/IH	2V/IH	2V/2H	2V/2H
5.0 m	2V/IH	2V/IH	3V/1H	3V/2H	3V/2H

IV means single 150 × 1.6C next to opening
2V means a pair of 150 × 1.6C next to opening
IH means 150 × 1.6 C above/below opening

5 THERMAL ANALYSES OF LIGHT STEEL WALLS USING *AQUA BOARD*

Two light steel wall configurations using insulated render cladding and Lafarge *Aqua Board* were considered in order to establish the basic thermal transmission (U-value) of the wall. These are:

- Direct fix system: Insulated render bonded to the *Aqua Board* as a sheathing board that is directly fixed to the light steel wall.
- Cavity system: Insulated render bonded to a single layer of *Aqua Board* sheathing board with an internal cavity to the light steel wall.
- Cavity system: Insulated render bonded to the *Aqua Board* sheathing board with an internal cavity and a second *Aqua Board* layer directly fixed to the light steel wall.

The direct fix system is illustrated in Figure 0.6. A cavity system may be preferred in residential buildings in order to satisfy NHBC insurance requirements in the UK. In both cases, the C sections are 100 mm × 50 mm × 1.2 mm thick and are placed at 600 mm spacing. Mineral wool is placed between the C sections. A single layer of 12.5 mm *Aqua Board* sheathing board is used externally together and a 15 mm *Megadeco* board is used internally.

Two types of insulation board in various thicknesses were used externally, plus a thin render layer.

5.1 Results of thermal analyses of walls with insulated render

Thermal analyses of light steel walls with insulated render cladding were carried out using the 2-D thermal model BISCO. The temperature difference across the wall was 20℃ ie 0℃ externally and 20℃ internally. The hea t loss is directly proportional to the temperature difference across the wall in these static thermal models. The thermal properties of the materials are presented in Table 5.1. The thermal conductivity of mineral wool and Polyurethane (PUR) or Polyisocyanurate (PIR) are taken from manufacturers' data, but the 0.035 W/m^{2}K for Expanded Polystyrene (EPS) is taken conservatively as for the lightest density of EPS. It may be possible to justify a lower value (e.g. 0.03 W/m^{2}K) depending on the material used in practice.

The C sections are assumed to be 1.2 m thick initially, which is typical of residential buildings and infill walls of up to 2.8 m height. The thermal analyses will be repeated for 1.6 mm thick steel to assess the sensitivity of the results to thermal bridging through C sections.

The thermal analyses were carried out for external insulation in EPS or foil-backed PUR/PIR of 60 mm to 110 mm thickness. Various configurations of *Aqua Board* were considered in single and double sheathing board layers- see Figures 5.1 and 5.2.

The 25 mm air gap in the cavity system has been assumed to have a thermal resistance of 0.18 m^{2}KW^{-1}, which is in line with BRE 446:2006 (Conventions for U-value Calculations). This assumes a normal, or high emissivity of the inner surface of the cavity. If this is changed to a low emissivity surface for example by applying a foil backing to the *Aqua Board*, a higher value of 0.44 m^2KW^{-1} can be used. In the BISCO analyses, this thermal resistance was modelled by considering the air space as a solid material and adjusting its thermal conductivity to give the required thermal resistance.

Table 5.1 Thermal properties of materials

Material	Thermal conductivity λ-value ($Wm^{-1}K^{-1}$)	Thermal resistance (m^2KW^{-1})
Steel	50	
Lafarge *Megadeco*	0.25	
Lafarge *Aqua Board*	0.25	
Render	1.0	
Extruded/Expanded Polystyrene	0.032	
Mineral Wool	0.037	
PUR/PIR	0.025	
Wood	0.17	
Concrete	2.6	
Air gap (high emissivity)		0.18
Air gap (low emissivity)		0.44
External surface resistance		0.04
Internal Surface resistance		0.13

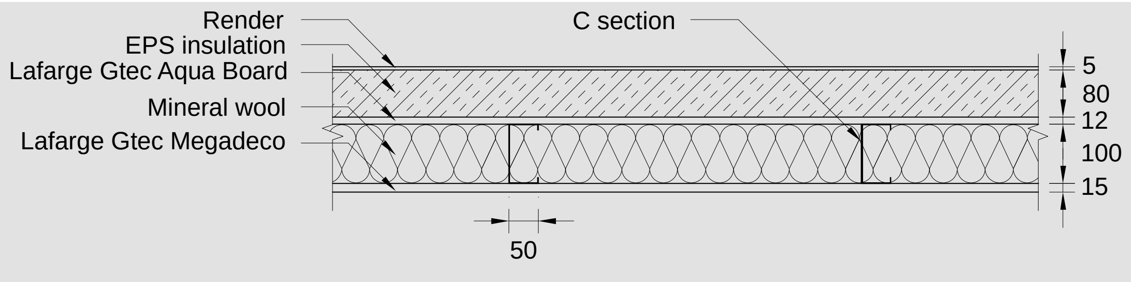


Figure 5.1 Direct fix insulated render system

For each wall build-up, the U-value was calculated for Expanded Polystyrene (EPS) and Polyisocyanurate/Polyurethane (PIR/PUR); taking into account the thermal bridging through the C section. The results for the direct fix case are presented in Table 5.2 and for the cavity case are presented in Table 5.3. The thermal conductivity of the insulation material is presented. The figures in brackets give the U-value of the wall ignoring the C section. Table 5.4 gives the U-values calculated for the cavity construction assuming that the inner surface of the *Aqua Board* has low emissivity.

Table 5.2 U-values (W/m^2K) for insulated render with direct fix (no cavity) *Aqua Board*

Insulation	No Cavity Case		
Thickness (mm)	**EPS (λ = 0.035)**	**EPS (λ = 0.032)**	**PIR/PUR (λ = 0.025)**
60	0.271 (0.213)	0.259 (0.206)	0.227 (0.186)
80	0.234 (0.190)	0.222 (0.182)	0.192 (0.162)
100	0.206 (0.171)	0.195 (0.164)	0.166 (0.143)
120	0.184 (0.156)	0.174 (0.148)	0.146 (0.128)

The figures in brackets refer to the U-value without the C sections

Table 5.3 U-values (W/m^{2}K) for insulated render with a cavity using one layer of *Aqua Board*

Insulation	Cavity Case		
Thickness (mm)	**EPS (λ = 0.035)**	**EPS (λ = 0.032)**	**PIR/PUR (λ = 0.025)**
60	0.262 (0.205)	0.250 (0.198)	0.220 (0.180)
80	0.227 (0.183)	0.216 (0.177)	0.187 (0.157)
100	0.200 (0.166)	0.190 (0.159)	0.163 (0.140)
120	0.180 (0.152)	0.170 (0.145)	0.144 (0.126)

The figures in brackets refer to the U-value without the C sections

Table 5.4 U-values (W/m^{2}K) for insulated render with a cavity using two layers of *Aqua Board* with reflective backing

Insulation	Cavity (Reflective Backing)	
Thickness (mm)	**EPS (λ = 0.035)**	**PIR/PUR (λ = 0.025)**
60	0.246 (0.193)	0.210 (0.170)
80	0.215 (0.174)	0.179 (0.150)
100	0.191 (0.158)	0.157 (0.134)
110	0.181 (0.151)	0.147 (0.127)

The figures in brackets refer to the U-value without the C sections

The thermal profile through the wall with directly fixed external insulation is shown in Figure 5. . The results show that thermal bridging through the light steel C sections adds 15 to 25% to the heat transmission through the walls, depending on the type and thickness of insulation. For the direct fix (no cavity case), a 'target' U-value of 0.2 W/m^{2}K is achieved for an insulated render system with 100 mm of EPS or 80 mm of PIR/PUR externally.

The f_{si} values for the direct fix and the cavity cases are presented in Table 5.5 and Table 5.6. It is apparent that f_{si} always exceeds 0.9, which is excellent and is insensitive to the presence of a cavity.

Table 5.5 f_{si}-values for the direct fix (no cavity) case

Insulation	No Cavity Case		
Thickness (mm)	**EPS (λ = 0.035)**	**EPS (λ = 0.032)**	**PIR/PUR (λ = 0.025)**
60	0.905	0.909	0.922
80	0.919	0.923	0.935
100	0.929	0.933	0.944
110	0.937	0.941	0.951

The figures in brackets refer to the U-value without the C sections

Table 5.6 f_{si}-values for the cavity case (for one layer of *Aqua Board*)

Insulation	Cavity Case		
Thickness (mm)	EPS (λ = 0.035)	EPS (λ = 0.032)	PIR/PUR (λ = 0.025)
60	0.906	0.910	0.921
80	0.919	0.923	0.933
100	0.928	0.932	0.942
120	0.936	0.940	0.949

The figures in brackets refer to the U-value without the C sections

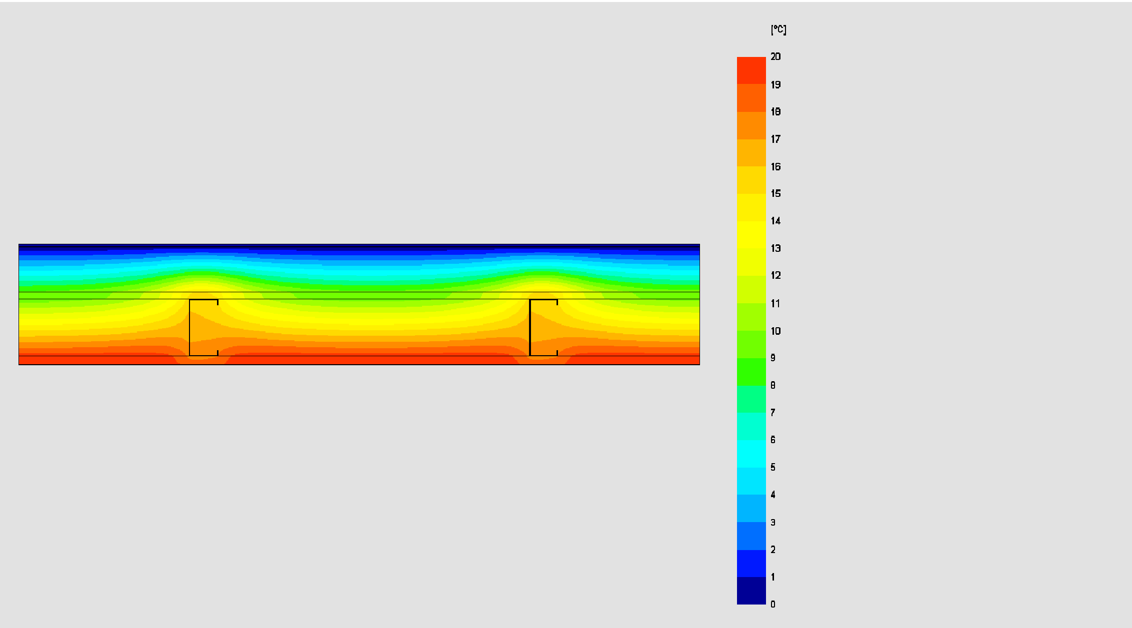


Figure 5.2 Thermal profile in directly fixed insulated render system (80 mm PIR insulation thickness in this case)

The thermal profile through the wall with a cavity system is shown in Figure 5.3 . For the cavity case, this U-value is achieved by 100 mm of EPS or 70 mm of PIR/PUR externally. For *Aqua Board* with a reflective backing, this U-value is achieved by 90 mm or EPS or 65 mm of PIR/PUR externally.

Examples of the output files from a typical direct fix case using EPS is presented in the Appendix. For this case, the surface temperature of the internal plasterboard is 18.3℃ (compared to 20℃) on the rest of the wall, which e quates to a f_{Rsi} = 0.915. This is acceptable in terms of controlling condensation and 'ghosting' on the surface.

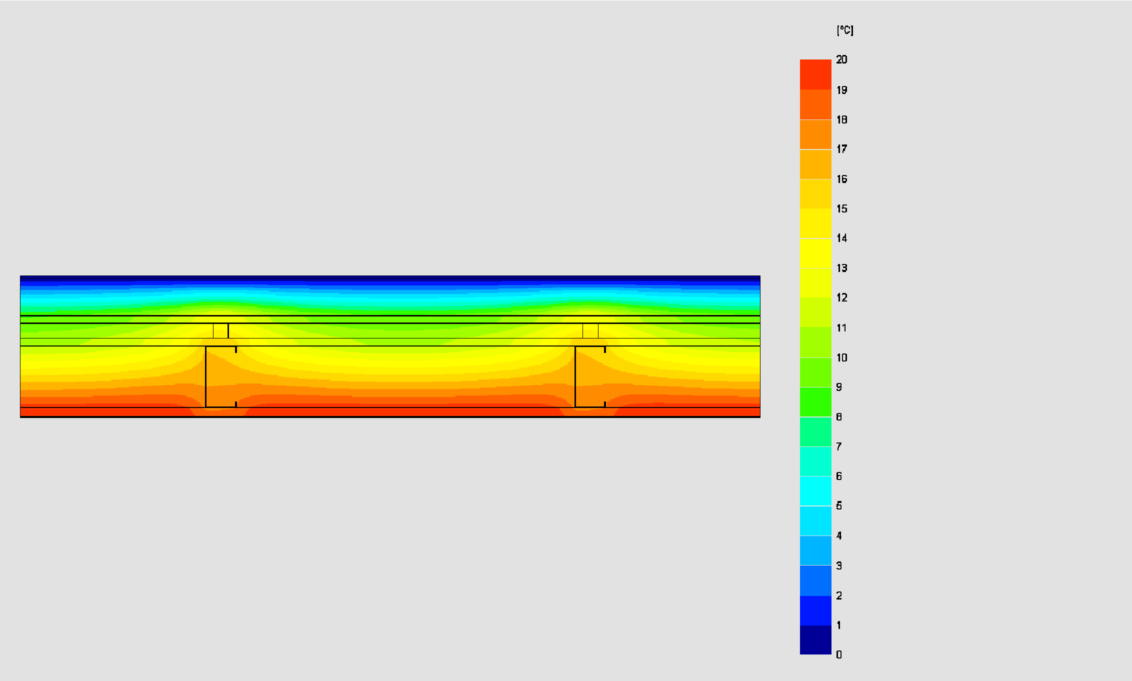


Figure 5.3 Thermal profile in an insulated render system with a cavity (with 80 mm PIR insulation)

5.2 Effect of C-section thickness

In the examples above, the thickness of steel used for the C-sections will vary depending on the application, and usually between 1.2 and 1.6 mm. All the above results are for 1.2 mm thick steel, and it is shown that the repeated thermal bridges through the C sections add 14 to 22% to the heat loss of the basic wall, depending on the insulation thickness.

In order to investigate the difference in U-value due to these thicknesses, a 1.6 mm thick C-section has also been modelled. Additionally, the model was compared to the case for 1.2 mm thick steel where the thermal conductivity (or λ value) of the steel is increased in proportion to its thickness.

In Table 5.6 , the U-values results are given for the original C-section thickness of 1.2 mm, for 1.6 mm steel thickness and for 1.2 mm steel thickness with proportionally increased λ value (up to 66.7 from 50 W/mK).

It is clear that the increase in C-section thickness from 1.2 mm to 1.6 mm leads to only a small increase in U-value (less than 1%), which can be accurately modelled by increasing the thermal conductivity of the steel rather than its thickness. Therefore, it is concluded that the U-value of the light steel wall is not sensitive to the steel thickness.

It follows that for steel thicknesses less than 1.2mm, the U values of the wall may be taken as given in this Report for a steel thickness of 1.2mm.

Table 5.7 U values (W/m^{2}K) for the direct fix (no cavity) case with differing steel thickness

Insulation	*t* =	*t* =	*t* =
Thickness (mm)	**1.2 mm**	**1.6 mm**	**1.2 mm with modified λ value**
60	0.259 (0.206)	0.262 (0.206)	0.262 (0.206)
80	0.222 (0.182)	0.225 (0.182)	0.225 (0.182)
100	0.195 (0.164)	0.196 (0.164)	0.196 (0.164)

(Values in brackets are the U values of the wall without the C section)

5.3 Effect of C-section depth

For insulated render cladding, the depth of the C section was increased to 150mm, also with 150mm thickness of mineral wool between the C sections. This depth of C section is often used in educational and commercial buildings. The thermal analyses used 1.2mm thick steel and 60 to 120mm of external insulation. The U values for this case are presented in Table 5.8.

It is apparent that the 50mm increase in mineral wool depth leads to a 0.05 W/m^{2}K decrease in wall U-value. A U value of 0.2 W/m^{2}K is obtained for 80mm of external EPS insulation or 60mm of PIR/PUR insulation. The overall wall depth is nevertheless 30mm wider than for a 100 mm deep C section for the same U value.

Table 5.8 U-values (W/m^{2}K) for insulated render with direct fix (no cavity) *Aqua Board* and using 150mm deep C sections

Insulation	No Cavity Case	
Thickness (mm)	**EPS (λ = 0.032)**	**PIR/PUR (λ = 0.025)**
60	0.224 (0.161)	0.199 (0.149)
80	0.197 (0.146)	0.172 (0.133)
100	0.175 (0.134)	0.151 (0.120)
120	0.157 (0.124)	0.134 (0.109)

The figures in brackets refer to the U-value without the C sections

5.4 Thermal bridging of concrete slab and steel edge beams using insulated render cladding

The thermal bridging at the intermediate slab or beam when supporting a light steel infill wall of the previous forms was investigated. The cases considered are:

- Concrete slab of 200 mm depth with 80 or 100 mm of EPS insulation and 12.5 mm *Aqua Board* externally
- Steel edge beam of 300 mm depth with 80 or 100 mm of EPS insulation and 12.5 mm *Aqua Board* externally.

For each configuration, two cases were considered:

- Direct fix
- Cavity case.

The various layers and materials used in the thermal models are presented in Figures 0.5 and 5.5 for the cases of a concrete slab and a steel edge beam. The steel beam and cavity case with double layers of *Aqua Board* is illustrated in Figure 5.6.

The Psi-value is calculated by modelling the heat loss through the floor-wall junction and subtracting the heat loss that is due to the planar wall construction by itself. It is expressed as the heat loss per unit length of the beam or floor slab and is therefore a linear thermal bridging parameter.

In order to take account of the repeating thermal bridging due to light-steel C-sections, the same U value as in the 2-D model is replicated by increasing the thermal conductivity of the mineral wool from 0.037 to 0.059 W/mK.

The results are presented for the ‘direct fix’ case with EPS insulation in the form of thermal profiles in Figure 5. and Figure 5. . The linear thermal bridging Psi- value due to the concrete slab or edge beam is dependent on the build-up and U value of the infill wall. The same analyses were repeated for the case of PIR/PUR insulation.

In all cases, the f_{si} values are well above 0.9, which indicates that there is no risk of local condensation or mould growth when using these details.

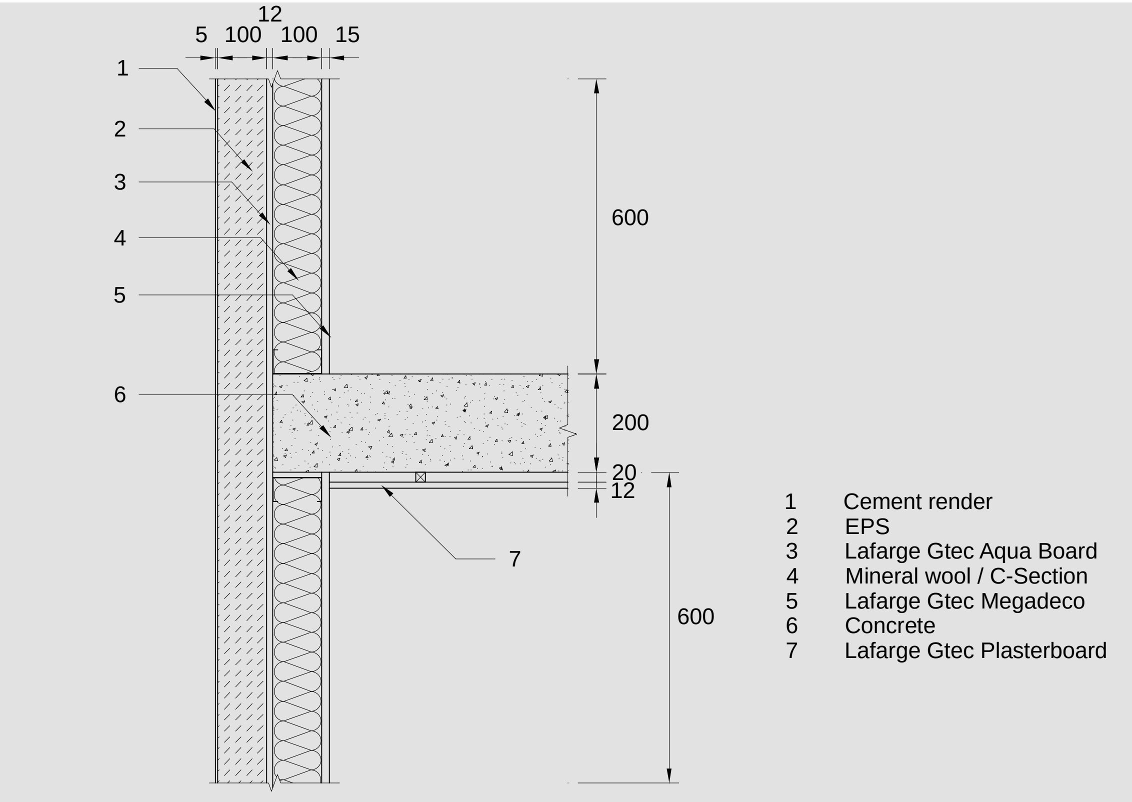


Figure 5.4 Light steel infill wall in a concrete framed building- no cavity system

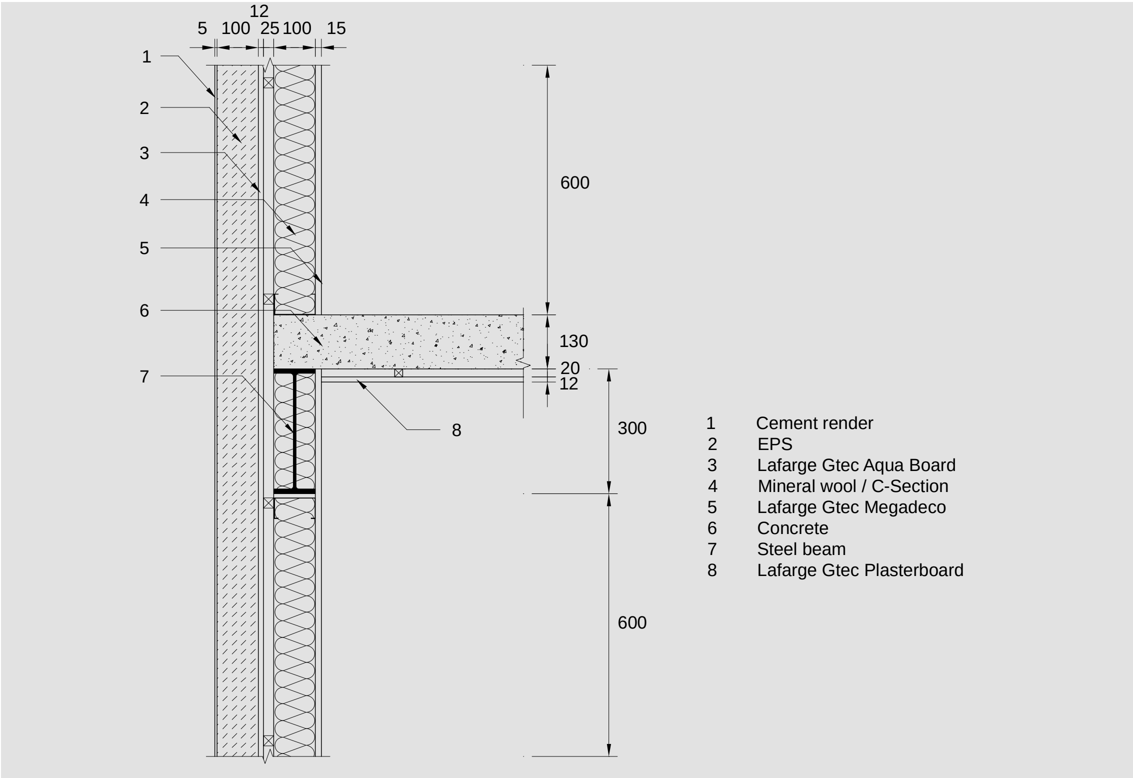


Figure 5.5 Light steel infill wall in a steel framed building – cavity system with single layer of board is shown

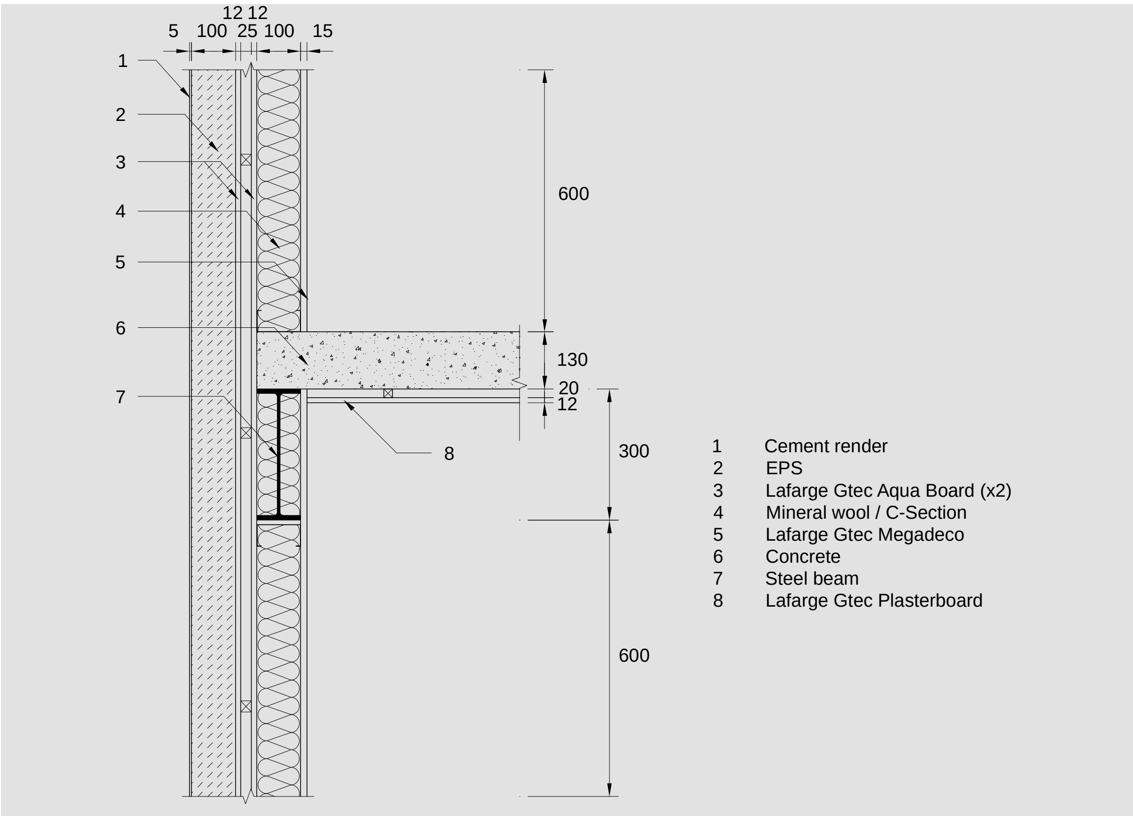


Figure 5.6 Light steel infill wall in a steel framed building –cavity system with double layers of boards is shown

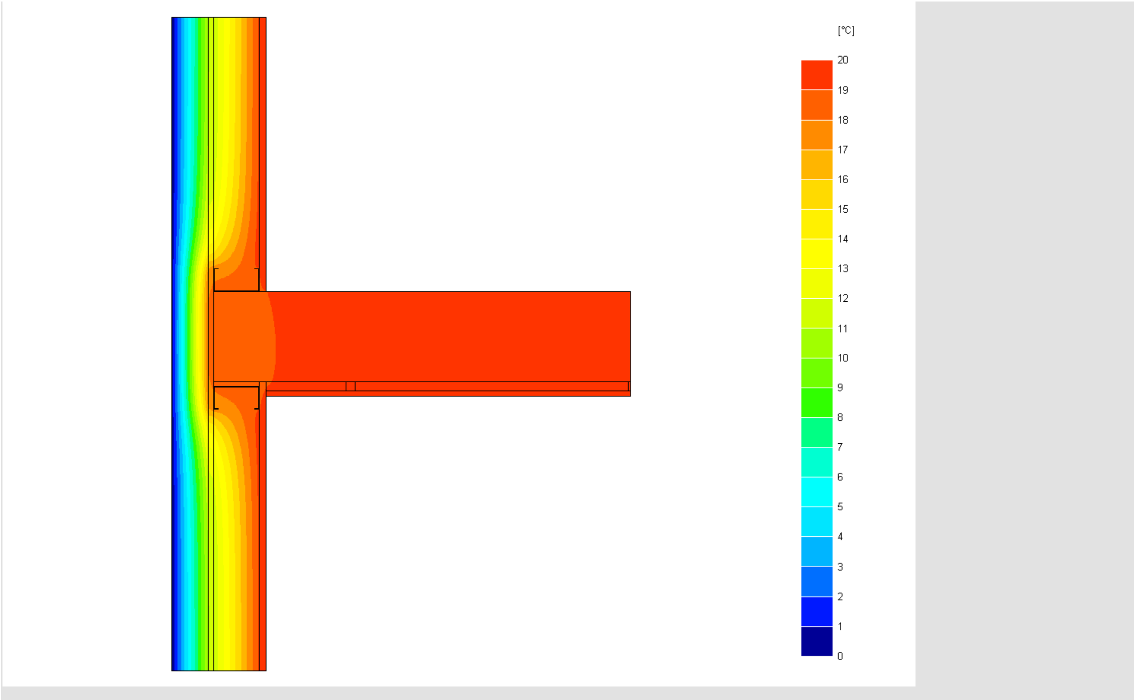


Figure 5.7 Thermal profile of a light steel infill wall in a concrete flat slab construction

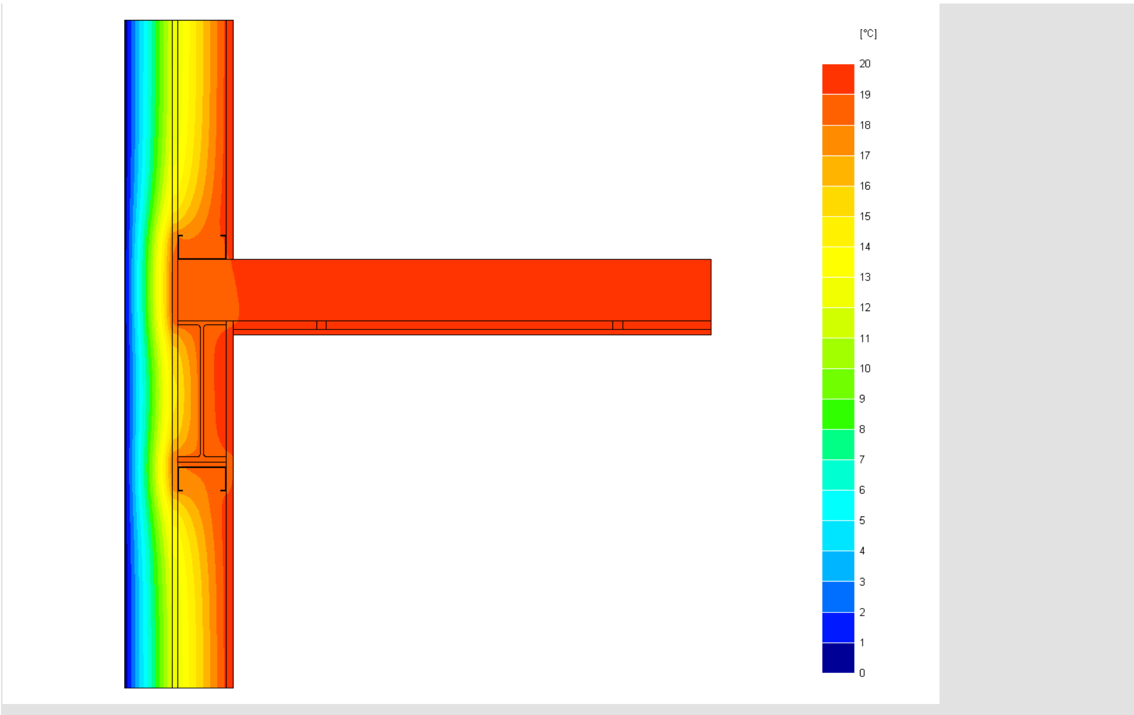


Figure 5.8 Thermal profile of a light steel infill wall in a steel and composite slab construction

The Psi-values for the two cases of a concrete slab with EPS or PIR/PUR insulation are presented in Table 5.5 and Table 5.6 together with the basic U value of the wall (without the effect of the slab or beam). In both cases, the Psi-value is relatively low.

When divided by the wall height of 3.6 m, the case of a 200 mm deep concrete slab leads to a 6 to 8% increase in heat loss depending on the insulation thickness. For the case of a 300 mm deep edge beam and a 130 mm deep composite slab, linear thermal bridging leads to a 7 to 9% increase in heat loss depending on the insulation thickness.

The corresponding Psi-values for a steel edge beam are presented in Table 5.11 and in Table 5.12 for EPS and PIR/PUR insulation.

The equivalent results for a 3D thermal model (TRISCO) are presented in Table 5.13, which shows similar results to the 2D models in Tables 5.11 and 5.12..

The results for the case of a concrete slab with insulated render cavity cladding system are presented in

Table **5.**14 and Table 5.15 for the two insulation materials. This case shows similar results to the non-cavity case.

Table 5.9 Linear thermal bridging for the direct fix (no- cavity) Case with EPS – Concrete slab

External Insulation thickness (EPS)	U-value of wall (W/m^2K)	Psi-value (W/mK)
60 mm	0.259	0.085
80 mm	0.222	0.059
100 mm	0.195	0.048
120 mm	0.174	0.033

Table 5.10 Linear thermal bridging for the direct fix (non- cavity) case with PUR/PIR – Concrete slab

External Insulation thickness (EPS)	U-value of wall (W/m^2K)	Psi-value (W/mK)
60 mm	0.227	0.062
80 mm	0.193	0.040
100 mm	0.167	0.029
120 mm	0.147	0.022

Table 5.11 Linear thermal bridging for the direct fix (non-cavity) case with EPS and an I-beam support

External Insulation thickness (EPS)	U-value of wall (W/m^2K)	Psi-value (W/mK)
60 mm	0.259	0.094
80 mm	0.222	0.067
100 mm	0.195	0.049
120 mm	0.174	0.037

Table 5.12 Linear thermal bridging for the direct fix (non-cavity) case with PUR/PIR and an I-beam support

External Insulation thickness (PUR/PIR)	U-value of wall (W/m^2K)	Psi-value (W/mK)
60 mm	0.228	0.068
80 mm	0.193	0.046
100 mm	0.167	0.033
120 mm	0.147	0.026

Table 5.13 3D TRISCO analysis of linear thermal bridging for the direct fix (non-cavity) case with EPS – I-beam support

External Insulation thickness (EPS)	U-value of wall (W/m^2K)	Psi-value (W/mK)	f_{Rsi}
60 mm	0.259	0.096	0.913
80 mm	0.222	0.067	0.927
100 mm	0.195	0.049	0.936
120 mm	0.174	0.038	0.944

Table 5.14 Linear thermal bridging for the cavity case with EPS – Concrete slab

External Insulation thickness (EPS)	U-value of wall (W/m^2K)	Psi-value (W/mK)
60 mm	0.250	0.078
80 mm	0.216	0.055
100 mm	0.190	0.041
120 mm	0.170	0.032

Table 5.15 Linear thermal bridging for the cavity case with PUR/PIR – Concrete slab

External Insulation thickness (PUR/PIR)	U-value of wall (W/m^2K)	Psi-value (W/mK)
60 mm	0.221	0.057
80 mm	0.188	0.038
100 mm	0.163	0.029
120 mm	0.144	0.022

5.5 Thermal analysis of steel column in a wall

Consider the case of a steel 203 x 203 x 60 kg/m steel UKC column located within a light steel infill wall and with insulated render cladding. The thermal model was carried out for two cases of 80 mm and 100 mm of external PIR/PUR insulation with an *Aqua Board* sheathing board external to the steel column. Mineral wool was contained between the 100 x 1.2 mm C sections in the wall and also between the flanges of the steel column. The steel column is encased in a single layer of plasterboard for 30 minutes fire resistance. The thermal profile is shown in Figure 5. .

The same analysis was repeated without mineral wool between the flanges of the column and the results are presented in Figure 5.10. The influence of the mineral wool between the flanges of the beam is shown to be small.

The heat flux associated with the steel column and the light steel C sections next to the column was obtained by subtracting the heat flux through the same form of a continuous wall with C sections at 600 mm centres. The linear thermal bridging Psi – values for the two cases are presented in Table 5.16 with EPS insulation. The Psi – value is 0.055 W/mK for a wall U value of 0.2 W/m^{2}K, which is relatively small and is similar to the case of an edge beam.

The results are repeated for the same case but using PUR/PIR insulation in Table 5.17. The Psi values are reduced in this case relative to the use of EPS insulation. The heat loss through steel columns at 6m spacing will add about 5% to the heat loss through the infill wall.

Table 5.16 Linear thermal bridging for a 203UKC column in a wall with EPS insulation externally

External Insulation thickness (EPS)	Mineral wool between the flanges of the UKC	U-value of wall (W/m^{2}K)	Psi-value (W/m K)	f_{Rsi}
60mm	With mineral wool	0.259	0.098	0.936
80mm		0.222	0.070	0.948
100mm		0.195	0.053	0.956
120mm		0.174	0.042	0.962
60mm	No mineral wool	0.259	0.103	0.932
80mm		0.222	0.074	0.946
100mm		0.195	0.055	0.954
120mm		0.174	0.044	0.961

Data for EPS insulation with thermal conductivity of 0.032 W/m^{2}K

Table 5.17 Linear thermal bridging for a 203UKC column in a wall with PUR/PIR insulation externally

External Insulation thickness (PUR/PIR)	Mineral wool between the flanges of the UKC	U-value of wall (W/m^{2}K)	Psi-value (W/mK)	f_{Rsi}
60mm	With mineral wool	0.227	0.073	0.947
80mm		0.192	0.051	0.957
100mm		0.166	0.038	0.964
120mm		0.146	0.029	0.969
60mm	No mineral wool	0.227	0.077	0.944
80mm		0.192	0.053	0.955
100mm		0.166	0.039	0.963
120mm		0.146	0.030	0.968

Data for PUR/PIR insulation with thermal conductivity of 0.025 W/mK

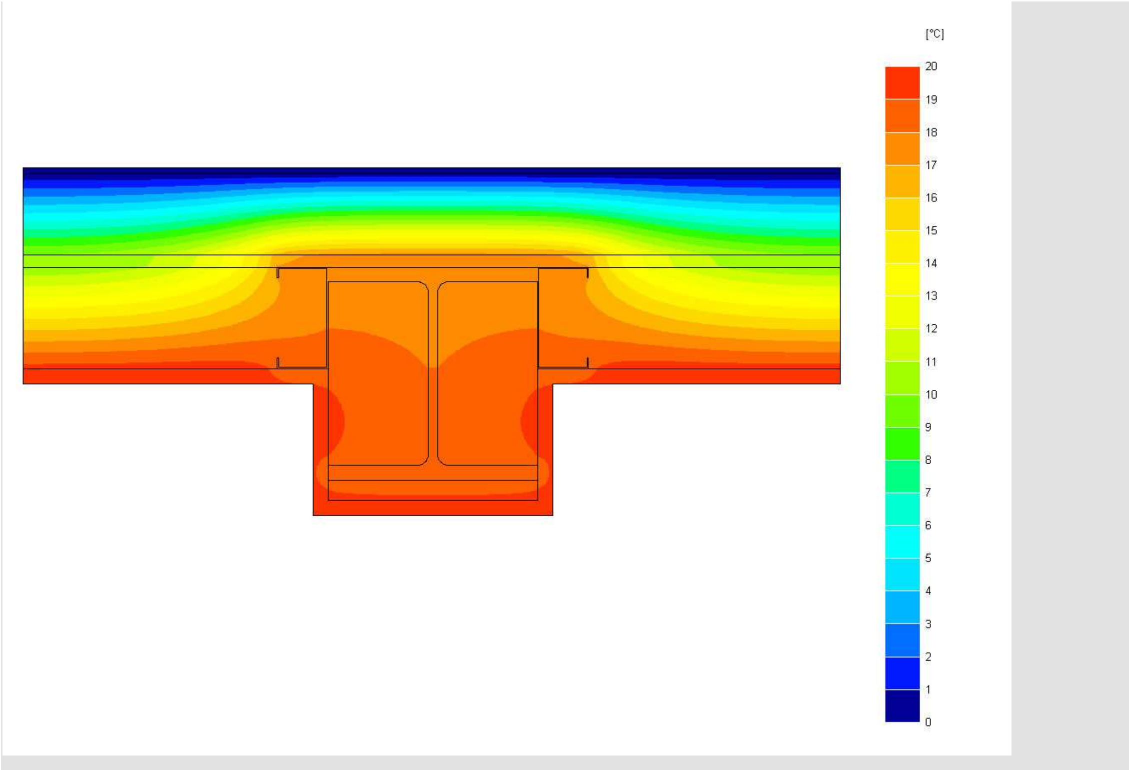


Figure 5.9 Thermal profile of steel column in a light steel infill wall with mineral wool between the flanges

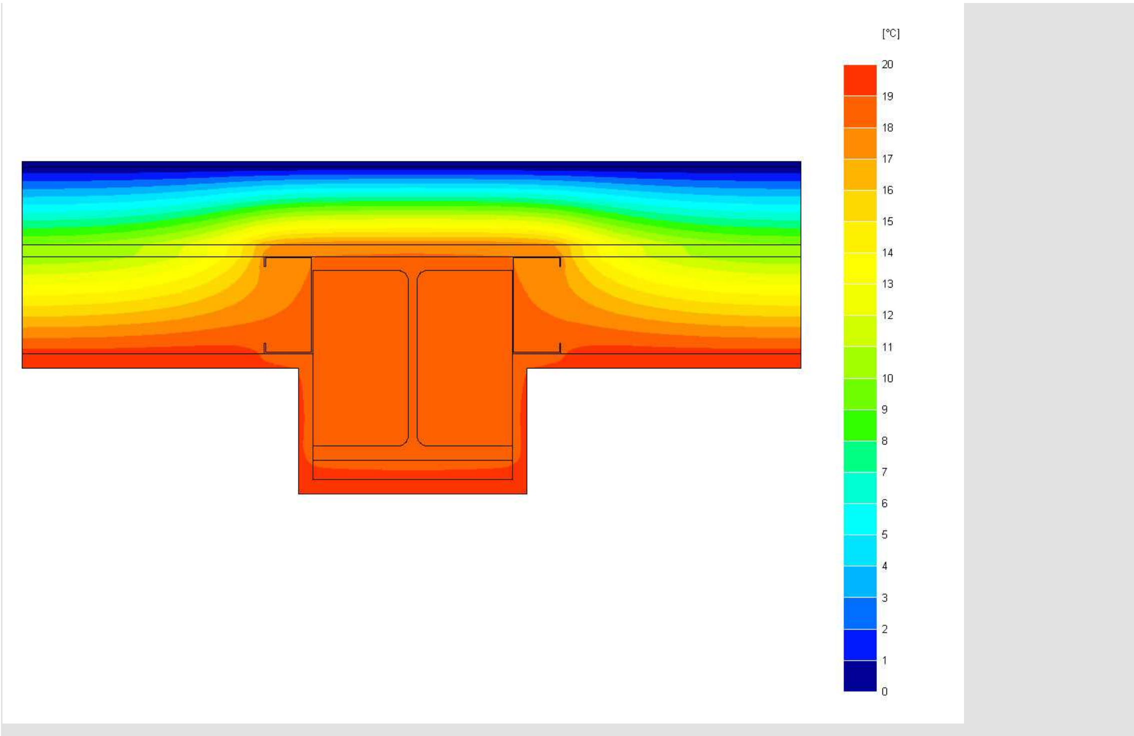


Figure 5.2 Thermal profile of steel column in a light steel infill wall without mineral wool between the flanges

5.6 3D Thermal model of brickwork support to steel edge beam with *Aqua Board*

5.6.1 Details of construction

The use of stainless steel angles to support brickwork in steel framed buildings leads to thermal bridging at the connection points to the steel edge beams. In this model, stainless steel brackets are attached at 900 mm centres to a 10 mm thick steel plate that is welded to the tips of the flange of the UB or IPE edge beam. The stainless steel angle supports one storey height (typically 3 to 3.6 m) of brickwork.

The light steel infill wall is supported by the slab and by the underside of the beam, and mineral wool is placed between the C sections. Closed cell thermal insulation and Lafarge *Aqua Board* are placed externally to the light steel infill wall, the slab edge and edge beam. The target U-value is 0.2 W/m^2K by calculation, which is representative of thermally efficient construction. The build-up from the inside of the wall is:

- 12 mm plasterboard.
- 100 mm deep C sections × 1.2 mm thick placed at 600 mm centres.
- 100 mm mineral wool between the C sections.
- 12 mm *Aqua Board.*
- 50 mm PIR closed cell insulation.
- 40 mm cavity.
- 102 mm brickwork.

The welded steel plates are considered to be 200 mm square × 10 mm thick and are welded to the flange tips at 900 mm spacing along the edge beam. The stainless steel brackets are also installed at 900 mm centres long the beam and are bolted to the plate. The stainless steel angle that supports the brickwork is 120 mm × 120 mm × 10 mm thick and is attached rigidly to the brackets. The *Aqua Board* is cut around the steel plates so that the brackets can be attached to the plates. The insulation board passes around the brackets.

The 200 mm deep steel edge beam is clad in plasterboard internally, which provides fire resistance. Mineral wool was placed between the flanges of the beam, which would be considered to be good practice to reduce thermal bridging. No acoustic layer or other covering is applied to the floor slab, which is conservative in terms of thermal bridging.

5.6.2 Thermal model of junction with edge beam

The physical model is illustrated in Figure 5.3. It is 900 mm wide and approximately 800 mm high so that the local heat loss through the beam is dissipated vertically and horizontally. This model is based on the build-up of materials as defined above. The stainless steel brackets and angle are shown and the brickwork and insulation are omitted for clarity. The relevant thermal conductivities of the materials are used as shown in Table 5.18 . The brickwork thermal model includes a surface resistance of R_{si} = 0.13 $m^2/K/W$, which is conventionally used in these models. Other cavity resistances are as specified in CEN models.

Table 5.18 Thermal conductivities of materials used in thermal analyses

Material	Thermal conductivity W/mK
Brickwork	0.770
Closed Cell PUR/PIR Insulation	0.025
Mineral Wool	0.037
Plasterboard and *Aqua Board*	0.25
Concrete	1.5
Steel Section	50
Stainless Steel	14.7

The thermal model was analysed using the 3D thermal analysis program TRISCO for 0°C external temperature and 20°C internal temperature.

The thermal model was also run for the basic wall building (not including the steel beam and stainless steel bracket). The excess heat that is lost is therefore due to linear thermal transmission at the line of the beam.

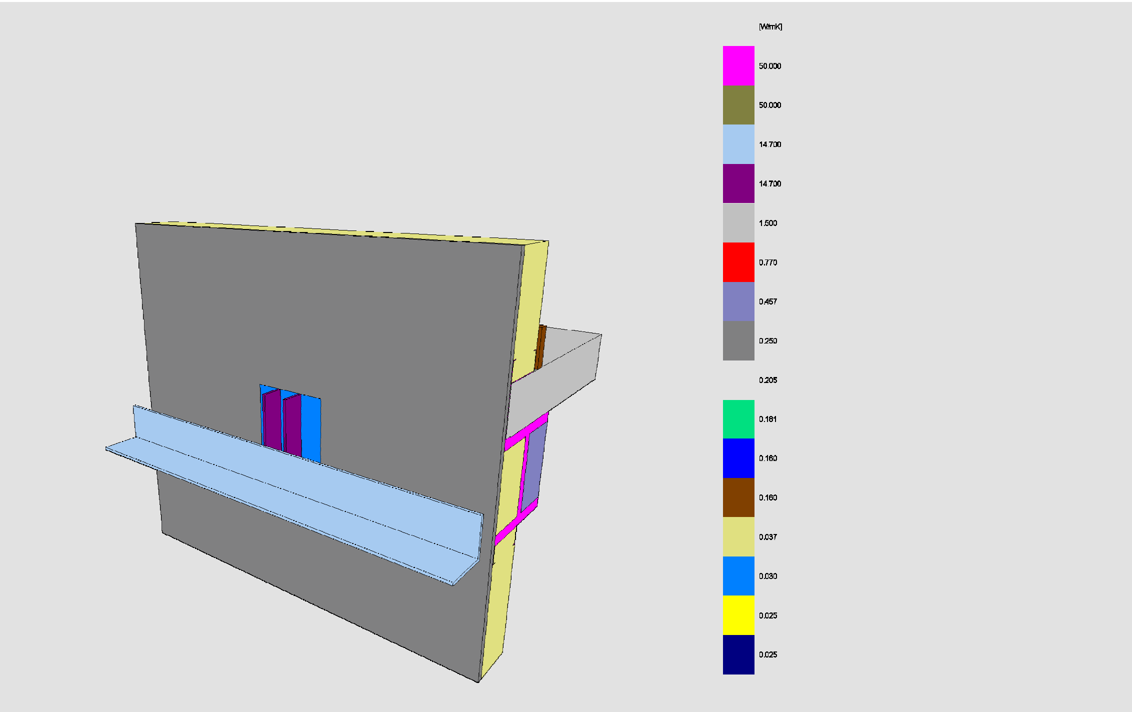


Figure 5.3 Physical model of brickwork attachment to a steel edge beam (external insulation and brickwork not shown for clarity)

5.6.3 Results of 3D Thermal Model

The temperature distribution through the wall, edge beam and slab as viewed from the inside of the building is shown in Figure 5.4. The main source of heat loss is through the stainless steel brackets, as shown by the external view in Figure 5.5.

The equivalent linear thermal bridging through the edge beam probably represents about 30% of the heat loss, the rest being due to the stainless steel brackets. It is not clear how this could be improved without introducing a thermal break, which might affect the integrity of the brickwork support system.

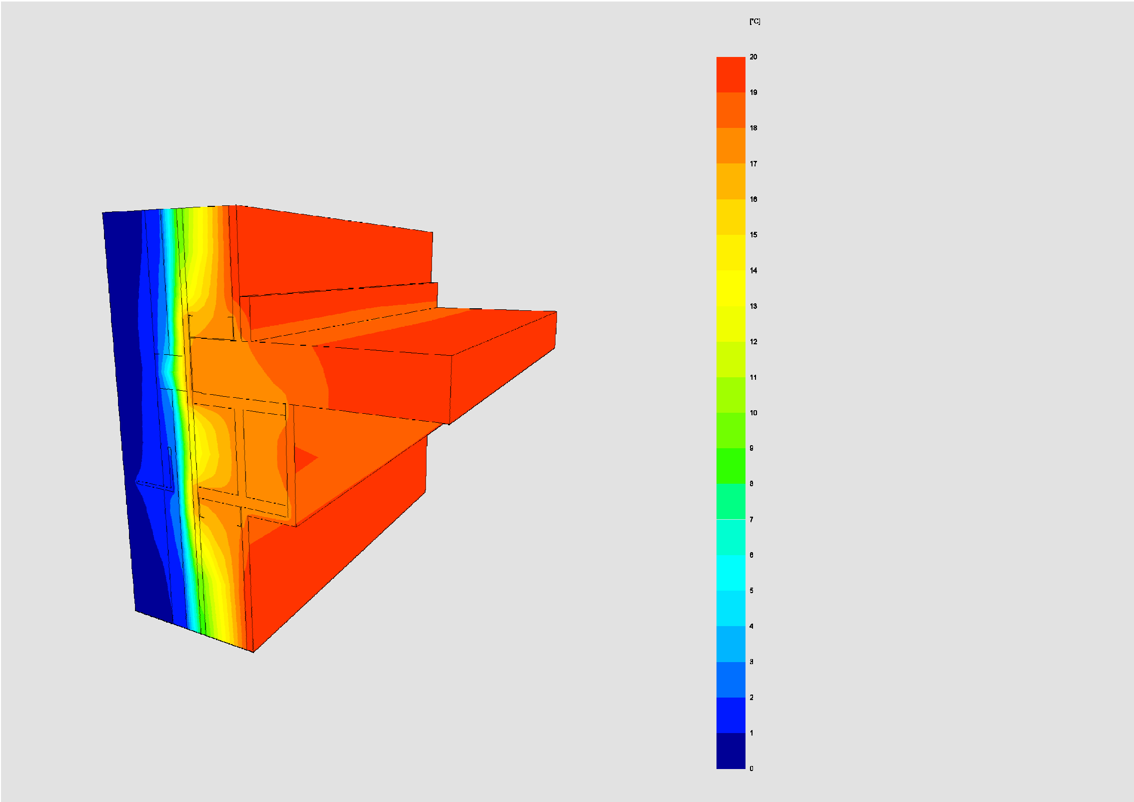


Figure 5.4 Temperature distribution through the edge beam viewed from the inside

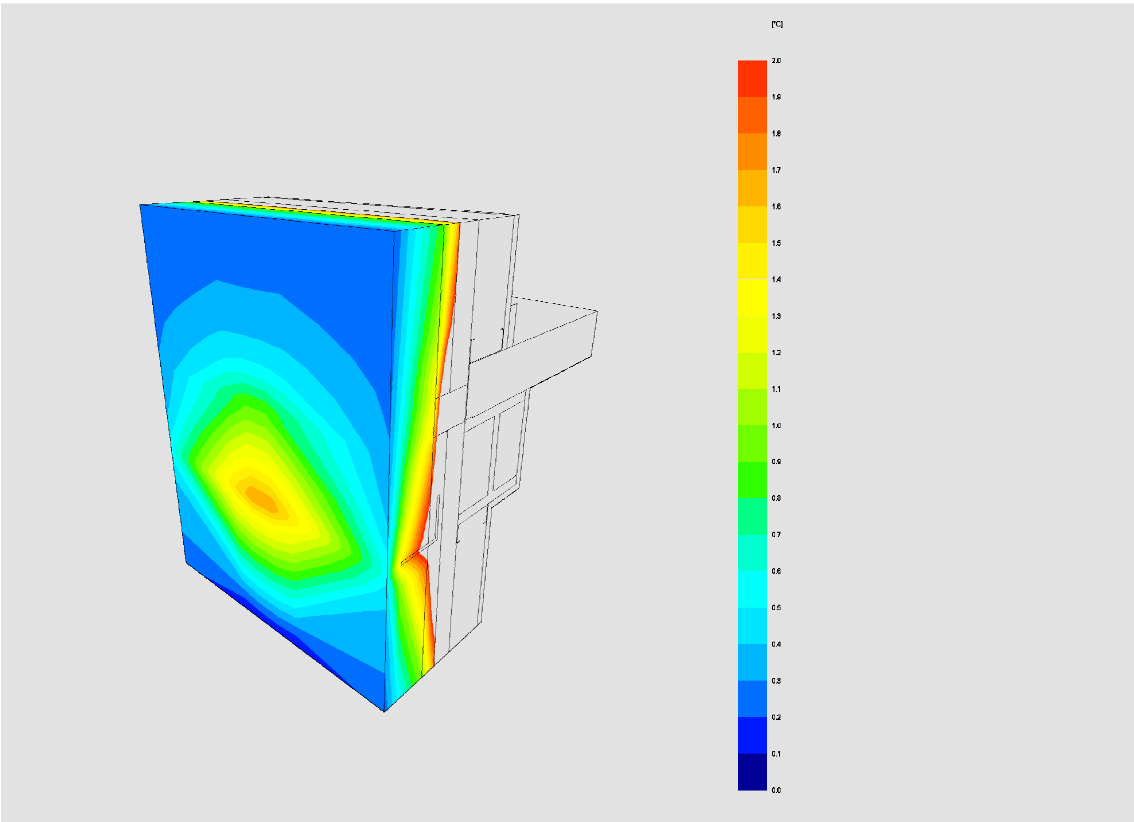


Figure 5.5 Temperature distribution through the edge beam viewed from the outside and showing the 'hot spots' at the stainless steel brackets

The U-value of the basic wall build-up using *Aqua Board* and 50 mm of closed cell insulation is 0.195 W/m^{2}K. This U-value ignores the presence of the beam and the stainless steel brackets. From the thermal analysis (see data below), the additional thermal transmittance due to the edge beam and the brackets is 0.22 W/K, which is divided by the length of the model (in this case 0.9 m). The linear thermal bridge is therefore 0.244 W/m/K, for stainless steel brackets placed at 900 mm centres.

The results are presented in Table 5.19 in terms of the heat loss through linear thermal bridging parameter, Psi- value (or Ψ). Also, shown is the same case without *Aqua Board* sheathing board but with the same thickness of insulation. It is apparent that the *Aqua Board* reduces thermal bridging by about 7% in this case, although thermal bridging is dominated by the direct stainless steel-welded steel plate attachment. The effect of *Aqua Board* would be greater in other cladding systems without such high thermal bridging locally.

The minimum surface temperature on the wall (relative to a room temperature of 20ºC) is defined by the parameter, f_{RSi} , which is given by:

$$f_{si} = \frac{\theta_{min} - \theta_{ext}}{\theta_{int} - \theta_{ext}}$$

where:

θ_{min} is the minimum internal temperature on the wall

θ_{ext} is the external temperature (0ºC in this analysis)

θ_{int} is the internal temperature (20ºC in this analysis)

A maximum temperature variation of 3ºC is considered acceptable to avoid 'ghosting' on the surface and both cases satisfy this limit. The influence of the additional *Aqua Board* sheathing board makes only 0.1ºC increase to the surface temperature.

Table 5.19 Results of thermal analyses of I beam supporting brickwork by stainless steel brackets

Case	Linear bridging Ψ	Min surface temp	F_{RSi}
With *Aqua Board* sheathing board	0.244 W/m/K	18.1ºC	0.906
No sheathing board	0.262 W/m/K	18.0ºC	0.901

Data for stainless steel brackets at 900 mm spacing
Basic U-value of the wall is 0.195 W/m^{2}K.

The linear thermal bridge occurs at each floor at approximately 3.6 m vertical spacing. Dividing the Ψ value by 3.6 m shows that the average heat loss through thermal bridging is equivalent to an additional U-value of 0.07 W/m^{2}ºC in comparison to the basic U-value of 0.195 W/m^{2}ºC for the brickwork façade with its light steel infill wall. Therefore linear thermal bridging represents a 35% additional heat loss for brickwork supports at 900 mm centres.

5.6.4 Thermal bridging –slim floor beams

Consider the case where a slim floor edge beam is integrated in the slab depth. As for a downstand I-beam, the slim floor edge beam supports brickwork by stainless steel brackets and the wall construction is a light steel infill wall with 50 mm of closed cell insulation and *Aqua Board* sheathing board external to the wall. The construction details are shown in Figure 5.14. A steel asymmetric beam, ASB, and a slab depth of 300 mm are used in this analysis.

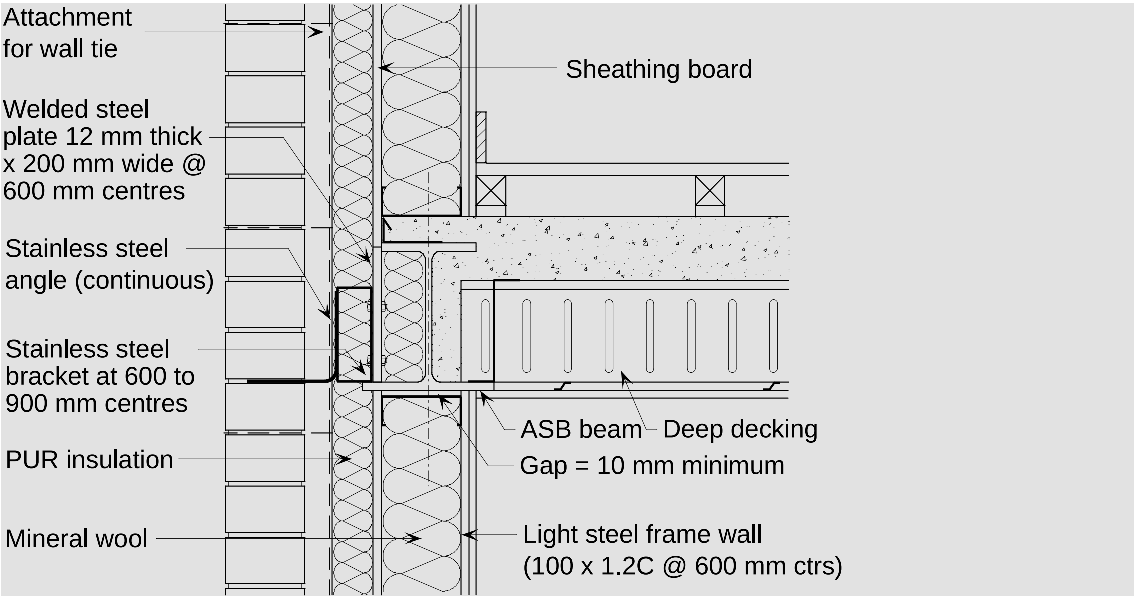


Figure 5.14 Slim floor edge beam supporting brickwork

5.6.5 Conclusion from thermal bridging analyses

Where a steel edge beam or concrete slab supports a light steel infill wall with insulated render cladding and *Aqua Board* sheathing board, the linear thermal bridging parameter Psi-value (Ψ) may be taken as 0.055 W/mK for a wall U value of 0.2 W/m^{2}K, which is an average of the preceding calculations. This U value is achieved by 80mm of external PIR/PUR insulation or 100mm of Expanded Polystyrene (EPS) insulation with mineral wool between the C sections.

For brickwork supported by stainless steel brackets and a light steel infill wall, the basic U-value of the wall of 0.2 W/m^{2}K is achieved with 50 mm of PIR/PUR insulation and *Aqua Board* sheathing board. The Psi-value (Ψ) at the line of the edge beam is primarily due to the brackets that support the brickwork and is not due significantly to the edge beam itself. The Ψ value for brickwork supports at 900 mm centres is 0.24 W/mK, which is over 4 times higher than for insulated render with *Aqua Board* sheathing board.

For other spacings of brickwork support brackets, the Psi-value may be assumed to be proportional to the number of the brackets per unit length, or:

$$\Psi = 0.24 \times (900/ s) \text{ W/m/K}$$

Where *s* is the horizontal spacing of the brackets in mm.

For the case of a steel column in an infill wall with insulated render, the Psi-value may be taken as 0.05 W/mK for a wall U value of 0.2 W/m^{2}K.

6 CASE STUDY

6.1 Residential Development, Farnborough, Surrey

Aqua Board was used successfully as an external sheathing board to a load-bearing light steel structure on a mixed residential and commercial project in Farnborough, Surrey in 2009 (see Figure 6.1).

Figure 6.1 Residential Development, Farnborough, Surrey

A 3 storey residential building in light steel framing was built over a Sainsbury's supermarket in Farnborough, Surrey. The residential part consists of 72 apartments for private and social housing which were constructed in load bearing light steel framing. The upper floors are supported on a composite steel-concrete podium and one of the design criteria was for a lightweight, robust super-structure that minimised the load on the podium level. The load-bearing facade system uses *Thruwall*, which consists of 100 mm deep × 1.6 mm thick steel C sections (by Advanced Cold Formed Steel Sections), which supported the *Aqua Board*, external insulation and render. Balconies were also introduced, which are supported by square hollow section posts integrated into the facade walls.

The internal structure uses light steel cross-walls using 100 × 1.6 C sections which support 300 mm deep C section floor joists that span up to 6 m. The cross-walls were braced to resist wind loads (see Figure 6.2).

A novel 50 mm deep composite floor system using Lafarge's *Gyvlon* floor screed was placed on shallow steel decking and achieved the stiffness, acoustic insulation and fire resistance requirements, whilst still using a lightweight construction technology. The light steel framing was installed at rate of one floor every 2 weeks.

The *Aqua Board* provided a weather tight building envelope early in the construction process. The *Gyvlon* floor screed was then placed in dry internal conditions off the critical path. No movement joints in the facade were required and a high degree of surface accuracy was achieved. It was completed in early 2010. A view of the residential building over the roof of the extended podium is shown in Figure 6.3.

Figure 6.2 Internal light steel bracing and external walls sheathed with *Aqua Board*

Figure 6.3 Residential building viewed over the roof of the extended podium

7 CONCLUSIONS ON THERMAL MODELLING

The following conclusions may be drawn from the thermal analyses of light steel infill walls to steel and concrete framed buildings using *Aqua Board* as a sheathing board:

- For 100 mm deep C sections at 600 mm centres, a U value of 0.2 W/m^{2}K is obtained for insulated render cladding with 80 mm of PUR/PIR and 100 mm of EPS external insulation, supplemented by 100 mm of mineral wool between the C sections. This takes account of thermal bridging due to the C sections in the wall.
- The effect of changing steel thickness from 1.2 mm to 1.6 mm makes less than 1% difference in the U value of the wall. Therefore, the U values presented for the infill walls with a steel thickness of 1.2mm may be used conservatively for thinner steel, and with reasonable accuracy for steel up to 1.6mm thick.
- A U value of 0.15 W/m^{2}K can be obtained for 120 mm of PUR/PIR insulation externally. This is close to *Passive House* standards.
- The effect of a cavity rather than direct fix insulated render makes a 5% reduction in U value.
- The effect of a foil backed reflective sheathing board in a cavity system makes a further 5% reduction in U value.
- The effect of a 200 mm thick concrete slab used to support a light steel infill wall is to create a linear thermal bridge of approximately 0.04 W/mK for a wall U value of 0.2 W/m^{2}K. This adds about 8% to the heat loss through the wall.
- The effect of a 300 mm deep steel edge beam is to create a linear thermal bridge of approximately 0.045 W/mK for a wall U value of 0.2 W/m^{2}K, which is similar but slightly higher than the case of a 200mm deep concrete slab.
- The effect of a 254 mm deep steel H-section column in a wall with insulated render is to create a linear thermal bridge of approximately 0.05 W/mK for a wall U value of 0.2 W/m^{2}K, which adds about 5% to the heat loss through the wall.
- In all cases with insulated render and *Aqua Board*, the f_{si} values are well above 0.9, which indicates that there is no risk of local condensation or mould growth when using these details.
- For the case of brickwork cladding supported by stainless steel brackets attached to a steel edge beam, linear thermal bridging increases to 0.24 W/mK with *Aqua Board* sheathing board, which is 7% less than for the case without sheathing board. The stainless steel brackets add about 40% to the heat loss through the wall. The f_{si} values are approximately 0.9, which indicates that there is no risk of local condensation or mould growth when using these details.

APPENDIX A TYPICAL RESULTS OF THERMAL MODEL

Temperature factor (EN ISO 10211-2), f_{Rsi} = 0.906
R_{si} = 0.13 m^2 .K/W- surface resistance of brickwork
Equivalent thermal transmittance:
U_{eq} = Q/((ti-te)*(A1) = 0.508 W/(m^2.K)
Q = 7.161 W- quantity of heat passing through the wall area A1
t_i = 20.00°C- internal temperature
t_e = 0.00°C-external temperature
U1 = 0.195 W/(m^2.K)- thermal transmittance of the basic wall build up without the thermal bridge
A1 = 0.705052 m^2, which is the external wall surface area - 0.9m width x 0.783m.
Equivalent thermal transmittance of the linear thermal bridge:
dL = Q/(ti-te) – U1*A1 =7.161 /20 - 0.195 × 0.705 = 0.358 – 0.137 = 0.22 W/K
where the heat loss through the basic wall build-up = 0.195 × 0.705 W/K = 0.137 W/K
Heat loss by thermal bridging = 0.22/0.9 = 0.244 W/m/K

Table A.1 Detailed data file of output

Col.	Type	Name	tmin (°C)	X	Y	Z	tmax (°C)	X	Y	Z
4	MATERIAL		1.10	7	0	33	17.24	18	0	32
5	MATERIAL		9.02	12	18	13	16.94	19	18	29
7	MATERIAL		16.99	25	15	32	19.84	64	0	38
8	MATERIAL	*Aqua Board*	9.68	18	0	0	17.64	21	0	27
9	MATERIAL		0.97	5	0	12	11.96	12	10	21
10	EQUIMAT		15.64	18	11	12	17.11	19	4	28
20	MATERIAL		17.90	50	15	36	19.77	52	0	46
100	MATERIAL		15.98	19	10	12	17.16	23	4	30
103	BC_SIMPL		18.12	50	15	8	19.84	64	0	38
184	EQUIMAT		0.91	7	0	48	4.27	11	16	34
191	MATERIAL		9.87	21	0	0	19.40	46	4	1
228	EQUIMAT		17.25	48	15	16	18.51	60	0	21
249	MATERIAL		0.20	3	0	0	6.72	7	15	14
251	MATERIAL		1.60	11	0	12	17.23	18	0	30
252	MATERIAL		17.21	46	15	12	19.69	50	15	1
253	MATERIAL		16.03	21	16	4	18.02	44	0	44
254	BC_SIMPL		0.20	3	0	0	1.49	3	15	14
255	EQUIMAT		0.86	7	0	0	13.57	11	17	26

Col.	Type	Name	ta (°C)	Flow in (W)	Flow out (W)
10^{-3}	BC_SIMPL			7.16	0.00
254	BC_SIMPL			0.00	7.16

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