Information Sheet 7:

Continuous insulation for low-energy houses

This information sheet explores the continuous insulation concept for low-energy houses and its role in maximising the thermal resistance and energy efficiency of our buildings across their life cycle.

Introduction

Defined as "insulation that is continuous across all structural members without thermal bridges other than fasteners and service openings,"[1] continuous insulation can provide benefits for our built environment – and those that inhabit it – as Australia moves towards net-zero energy buildings.[2,3]

For example, use of continuous insulation in a building wall can:

- maximise wall thermal resistance by minimising thermal bridging and reducing air leakage – which reduces the condensation potential in the wall
- negate the need for separate thermal breaks, air-barriers and water-resistive barriers, and
- simplify the construction topologies to minimise waste, accelerate installation, reduce workmanship issues and seamlessly connect the thermal, air and moisture resistance barriers.

While this information sheet illustrates the use and benefits of the continuous insulation concept for residential timber frame wall construction, it is equally applicable to metal frame, brick veneer or mass wall systems, as well as roofs and foundations – and is applicable to any climate zone.

The role of polymer-based insulation

Polymer-based materials have an important role to play as part of continuous insulation. For example, polyisocyanurate (PIR) insulation board can be installed to the exterior of a timber frame wall as insulating sheathing (see Figure 1).

The insulating sheathing reduces thermal bridging and removes the need for a separate air-barrier and water-resistive barrier.

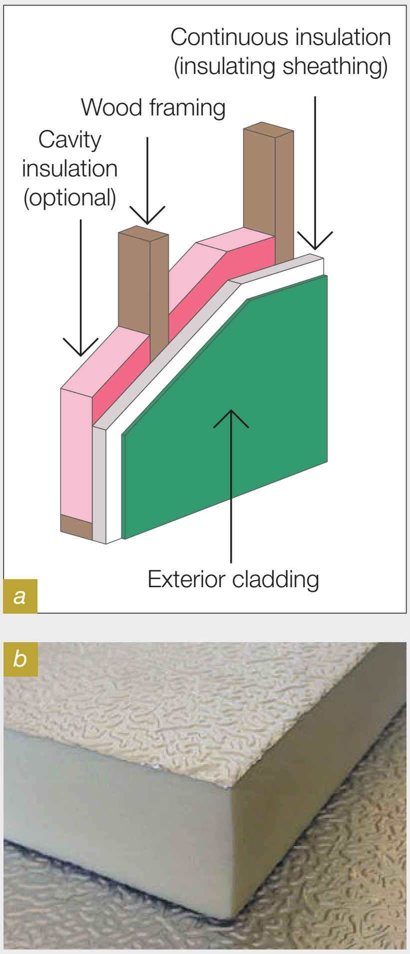


__Figure 1:__ a) Schematic illustration of the continuous insulation concept for a timber frame wall, b) PIR board insulation with foil facers (photo courtesy of Pirmax Pty Ltd).

This results in less materials on site, less waste, less workmanship issues and faster installation of the insulated wall element.

For these reasons, it complies with the Building Science Corporation's description of the perfect wall; it "has the rainwater control layer, the air control layer, the vapour control layer and the thermal control layer on the exterior of the building structure."[4]

PIR sheathing and thermal efficiency

Thermal bridging provides a ready route for heat loss/gain in a building and a cold surface for moisture condensation.

Up to 15 per cent of residential energy consumption in the USA is caused by thermal bridging, and Australian studies indicate that ignoring the effects of thermal bridging in timber frame houses (Figure 2) is equivalent to the loss of one star rating in the building's thermal performance.[5]

Under the deemed-to-satisfy (DTS) provisions of the National Construction Code (NCC) 2019 Volume 2 for residential buildings, an external timber frame wall with brick veneer in Australia requires a minimum weighted total R-value of 2.8 m^2.K/W (R-2.8) – which translates into R-2.5 of fiberglass (FG) insulation batts in a 90mm timber stud cavity.

However, the methodology used in NCC 2019 Volume 2 to calculate the R-values of wall assemblies for residential buildings does not allow for the thermal bridging of the timber frame. This means that the R-value of this standard wall assembly is overstated at R-3.09 (see Table 1).

After adjustment for thermal bridging the effective wall R-value is in fact only R-2.32 (see Table 1); 75 per cent of the nominal R-value of the FG insulation batts between the studs (see Table 1). This conclusion has been documented multiple times, both in Australia[5,6] and the USA.[7,8]

Building Element	**Wall R-value**[a]	**Effective Wall R-value**[b]	
		Scenario 1	**Scenario 2**
Outdoor air	0.04	0.04	0.04
110mm brick (2.75kg)	0.20	0.20	0.20
50mm cavity	0.17[c]	0.17[c]	0.85[d]
House wrap	0	0	None
20mm foil faced PIR board	None	None	0.95
FG batts (R-2.5) in cavity	2.50	1.73	None
70mm cavity in timber frame	None	None	0.80[d]
Plasterboard (10mm)	0.06	0.06	0.06
Indoor air	0.12	0.12	0.12
Total R-value	**3.09**	**2.32**	**3.02**
Wall Thickness (mm)	**260**	**260**	**260**

Scenario 1: Standard brick veneer with 90mm timber frame and R-2.5HD (90mm) FG batt cavity insulation.
Scenario 2: Brick veneer with 70mm timber frame and R-0.95 (20mm) foil faced PIR insulation board external to the frame.

[a] As calculated in the NCC 2019 Volume 2 for residential buildings.
[b] As calculated in AS/NZS 4859:2018 and NZS 4214:2006 using a 25 per cent framing fraction,[9] which is consistent with work by BRANZ.[10]
[c] Non-reflective airspace.
[d] Semi-reflective airspace.

***Table 1:** Effective thermal resistance of a brick veneer wall adjusted for thermal bridging by the timber frame. Calculations prepared by Anderson Energy Efficiency.[11]*

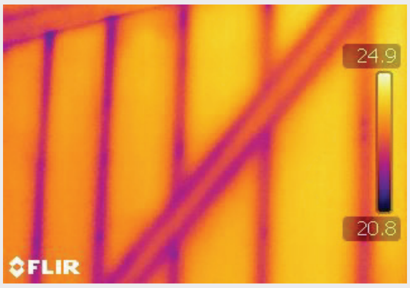


***Figure 2:** Thermal bridging with timber studs (photo courtesy of AUSCAN).*

However, removing the cavity insulation and using 20mm of PIR sheathing (R-0.95) alone with a thinner 70mm timber frame increases the effective wall R-value by 30 per cent to R-3.02 at an equivalent wall thickness of 260mm to the standard brick veneer wall (see Scenario 1, Table 1).

PIR sheathing and airtight walls

Air leakage is responsible for up to 25 per cent of heat loss/gain in Australian houses,[12] and the thermal performance of Australian houses – nominally 6 Star NatHERS rated at an average of 15 ACH @ 50 Pa[13] – is poorer than that required in houses in the USA (usually 3 or 5 ACH @ 50 Pa depending on climate zone).

The CSIRO identified excessive air leakage as the major problem causing the 'as built' thermal performance of a 5 Star NatHERS building in Australia to differ from its 'as designed' thermal performance.[14,15]

Making timber frame walls airtight with cavity insulation between the studs and an air barrier (wall wrap) external to the frame is difficult and reliant on multiple elements (Figure 3).

There may be workmanship issues such as installation of the wall wrap without sealing of the overlaps, windows and top and bottom plate, or other common installation problems including gaps, compression and sagging in the cavity insulation.

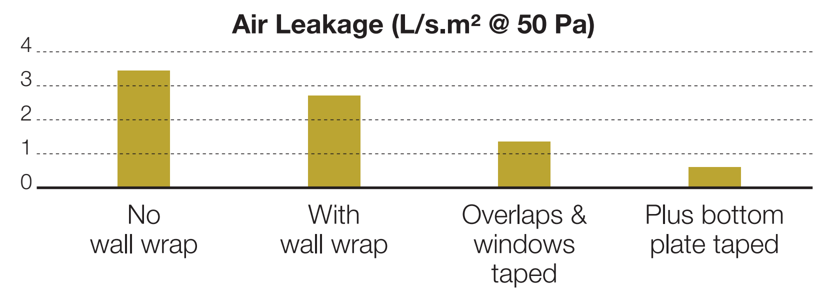
Because the wall wrap is not in close contact with the cavity insulation, there can be convective looping in the stud space, and gaps in the cavity insulation can lead to cold spots that could increase the risk of moisture condensation forming.

Research by the National Research Council of Canada found that small gaps in FG batts installed in a wall can reduce the nominal R-value of the batts by up to 32 per cent.[16]

In contrast to a wall wrap, PIR insulation board taped at the joints or sealed with one component foam (OCF)[17] acts as an air, vapour and rain barrier because it has a closed cell structure, is hydrophobic and has a foil facing (Figure 4).

PIR insulated sheathing in a wall system:

- reduces thermal bridging
- can be used in conjunction with insulation between the studs to achieve a high total wall R-value
- simplifies meeting airtightness standards
- is durable (does not sag, shrink or settle, and is resistant to moisture ingress)
- is applicable to any climate by varying the thickness of the exterior PIR insulation board, and
- offers better productivity and less waste by using one product for four functions (insulation, thermal bridging control, air barrier and weather (rain) barrier.



- A typical timber framed wall insulated with FG batts between the studs has an air leakage rate of 3.4 L/s/m² @ 50 Pa.
- Installing a wall wrap only reduces this air leakage by 20 per cent.[18]
- Taping the wall wrap overlaps, window junctions and the bottom plate is required for the wall wrap to be truly effective.[19]
- Improving air tightness can reduce a building's energy use by up to 72 per cent.[20]

***Figure 3:** Air infiltration through a timber framed wall with FG batt insulation between the studs.*

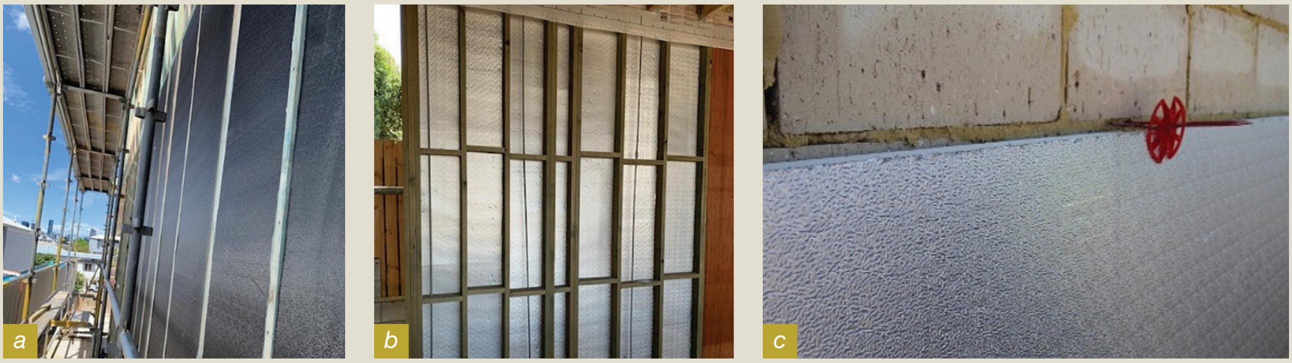


Figure 4: a) and b) Foil faced PIR insulation board installed external to the frame (continuous insulation) on a low-energy house in Brisbane prior to installing cladding (photos courtesy of Pirmax Pty Ltd), c) Foil faced PIR insulation board being installed in the cavity of a double brick construction (photo courtesy of Reflex Insulation Pty Ltd).

PIR sheathing reduces condensation risk

It was estimated in 2016 that 40 per cent of new and existing residential buildings in Australia were affected by condensation.[21]

Interstitial condensation of water vapour in a building can negatively impact its energy efficiency and durability, and the health of the occupants.[22]

Air leakage is a major factor in allowing moisture ingress into building elements – including walls – and is 100 times more important in allowing moisture ingress than the moisture permeability of individual building materials including vapour-permeable membranes.[23]

Because PIR sheathing makes it easier to control air leakage and virtually eliminates thermal bridging, it therefore also reduces the risk of moisture ingress and subsequent condensation.

Refer to AMBA Information Sheet 8 for more information about condensation control with continuous insulation.

Sustainability of PIR sheathing

The sustainability of insulation must be assessed at the triple bottom line (environmental, economic and social impacts) over the life cycle of the product in a specific end-use application.[24]

Given that a building's operating energy represents 90-95 per cent of its total life cycle energy consumption, including embodied energy in the materials,[25] it is most important to minimise the building energy usage by specifying high levels of insulation, and choosing a form of insulation which will help prevent air leakage and is durable (does not sag, shrink or settle) over the lifetime of the building.

Studies by the Building Research Establishment[26] in the UK have shown that there is negligible difference in environmental impact between common insulation materials when measured at the total building level.

However, polyurethane-based insulation usually has the lowest life cycle cost due to its lower thermal conductivity (see AMBA Information Sheet 6 – Comparison of polyurethane insulation with other insulants).

For more information about the sustainability of polymer-based insulation, see AMBA Information Sheet 1 – The benefits of polymers for Australia's built environment and AMBA Information Sheet 5 – Sustainability of buildings incorporating polyurethane (PUR) insulation.

Fire properties of foil faced PIR board

Foil faced PIR board is a thermoset polymer, which means it chars and burns similar to timber.

Tests undertaken by Exova Warrington Fire (UK)[27] showed that there was a slight improvement in the fire resistance performance of a timber frame wall incorporating PIR board, compared to a timber frame wall incorporating FG insulation when tested to EN 1365-1.

Similarly, tests undertaken by Exova Warrington Fire Gent (Belgium)[28] using a furnished room scenario under ISO 9705 showed that there was no significant difference in the flashover time, heat release rate or carbon monoxide and carbon dioxide concentrations when PIR board or mineral wool insulation were used in the wall assembly.

Further, the insulation materials' contribution to human toxicity – which largely occurred after flashover – was insignificant compared to the contribution to human toxicity from the room furnishings.

For more information about fire safety, see AMBA Information Sheet 3 – Grenfell Tower, Neo 200, Lacrosse and the fire safety of facades.

Installation of insulating sheathing

Insulating sheathing is first fastened to the studs[29] with broad-head nails, wide plastic washers and/or adhesive, and all board joints are sealed with construction tape.

In 2012 the Building Science Corporation[30] noted that field inspection of taped insulating sheathing showed no performance issues after 16 years of service.

However, insulating sheathing alone is not structural and should not be expected to provide racking resistance to wind or seismic loads. Instead, the following can be used:

- inset plywood installed at the corners
- metal cross bracing, or
- tensioning rods in the studs for severe conditions.[29]

If insulating sheathing is to function both as an air-barrier and weather-resistive barrier (drainage plane) all seams must be taped and penetrations, such as windows, must be flashed and sealed.[29, 31]

Building Element	Effective Wall R-value		
	Scenario 1	Scenario 2	Scenario 3
Outdoor air film	0.04	0.04	0.04
Light weight cladding (7.5mm)	0.02	0.02	0.02
Batten air gap (35-40mm)	0.17[a]	0.17[a]	0.85[b]
External vapour permeable membrane	0.00	0.00	None
20mm foil faced PIR board	None	None	0.95
Fibreglass batts (R-2.5) in cavity	1.73	1.73	None
Internal vapour permeable membrane	0.00	None	None
Wall cavity (50mm)	0.17	None	None
Stud air gap (70mm)	None	None	0.80[b]
Brick (110mm)	0.20	None	None
Plasterboard (10mm)	0.06	0.06	0.06
Indoor air	0.12	0.12	0.12
Total R-value	**2.51**	**2.14**	**2.84**
Wall Thickness (mm)	**308**	**143**	**143**

Effective Wall R-value as calculated in AS/NZS 4859:2018 and NZS 4214:2006 using a 25 per cent framing fraction[9] which is consistent with work by BRANZ.[10]

Scenario 1: Reverse brick veneer with 90mm timber frame and R-2.5HD (90mm) FG batt cavity insulation.
Scenario 2: Light weight fibre cement board cladding with 90mm timber frame and R-2.5HD (90mm) FG batt cavity insulation.
Scenario 3: Light weight fibre cement board cladding with 70mm timber frame and R-0.95 (20mm) foil faced PIR insulation board external to the frame.

[a] Non-reflective airspace.
[b] Semi-reflective airspace.

***Table 2:** Effective thermal resistance of a wall adjusted for thermal bridging by the timber frame.*

While the level of taping required may seem onerous, many house wrap installations in Australia fail to follow manufacturers' recommended taping instructions, and the required level of taping for compliant installation of PIR sheathing is on par with that of wall wrap used with cavity insulation.[32]

Continuous insulation case study – California

California has a net-zero energy building requirement as of 2020[33] and a similar climate to Australia and has used the continuous insulation concept for timber frame construction in residential houses since 2012.

The 2019 California Title 24 Energy Code's DTS provisions[34] require above grade timber framed walls to not exceed a U-value of either 0.290 or 0.369 W/m²K (significantly better thermal resistance values than Australia) depending on climate zones.

Under California's DTS provisions, weatherproofing (airtightness) of building envelope penetrations by caulking or sealant is mandatory. The use of a separate air barrier[35] is only required if FG batt insulation is used alone between the studs.

A wall wrap is not required if taped foil faced PIR board is used as insulating sheathing or if PUR spray foam is used between the studs. Finally, no vapour retarders[36] are required in the wall assembly of Californian residential homes if the R-value of the insulating sheathing exceeds 0.70 m².K/W.

NCC 2022 recommendations

In addition to the recommendations outlined in AMBA Information Sheet 4, AMBA proposes a number of recommended changes to the NCC 2022 incorporating continuous insulation that will help Australia move towards net-zero energy buildings.

Firstly, the addition of continuous insulation as a DTS solution in the NCC 2022 would help in closing the current gap between the as-built and as-designed thermal performance of buildings.

Secondly, the methodology used in NCC 2019 Volume 2 to calculate the R-values of wall assemblies for residential buildings does not allow for the thermal bridging of the timber frame.

To remedy this, AMBA recommends that the NCC 2022 Volume 2 for residential buildings adopt the same methodology for the calculation of building element thermal resistance values as in the NCC 2019 Volume 1 for commercial buildings; AS/NZS 4859.2:2018 (which references NZS 4214:2006).

Build better with continuous insulation

The Australian Building Codes Board is considering increasing the residential buildings NatHERS rating to 7-stars in the NCC 2022.[3] Government published plans for 7 Star NatHERS compliant houses[37] could be considerably improved by the adoption of the continuous insulation concept.

For example, the Melbourne house uses two different wall construction topologies: reverse brick veneer for external walls (Scenario 1 in Table 2) facing east, south and west, and a conventional fibre-cement cladding with cavity insulation (Scenario 2 in Table 2).

Use of fibre-cement cladding with foil faced PIR board as insulating sheathing in conjunction with a reduction in the frame size to 70mm (Scenario 3 in Table 2) instead:

- improves the wall thermal resistance by 13 per cent at only 46 per cent of the thickness of a reverse brick veneer wall (which reduces the knock-on costs of the thicker walls and provides increased living space for the same footprint),
- improves the wall thermal resistance by 33 per cent at the same thickness compared to a fibre-cement clad wall with cavity insulation, and
- reduces the number of construction topologies used on site; minimising waste, accelerating installation and reducing workmanship issues by seamlessly connecting the thermal, air and moisture resistance barriers.

Conclusion

- Exterior insulated sheathing (continuous insulation) for walls is significantly more thermally efficient than cavity insulation. It minimises the thermal bridging of the frame, simplifies the task of making the wall airtight, enhances the thermal efficiency of the wall and minimises the risk of interstitial condensation.

- While the use of exterior insulated sheathing (continuous insulation) has been illustrated in this document for a timber framed wall system, it is equally applicable to metal frames, brick veneer or mass wall systems (Figure 4c), roofs and foundations.
- When measured at the total building or building element level there is negligible difference in the environmental impact between common insulation materials, but polyurethane-based insulation usually has the lowest life cycle cost because of its lower thermal conductivity.
- Continuous insulation is robust, applicable to any climate, readily installed, increases the effectiveness of any FG batt insulation in the stud cavities due to increased airtightness of the wall, and negates the need for separate thermal breaks, air-barriers and water-resistive barriers.
- Use of exterior insulated sheathing does not significantly affect the overall fire resistance of a timber frame building compared with using FG batts as cavity insulation.

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