AUSTRALIAN MODERN BUILDING ALLIANCE
Safe and sustainable construction with polymers

Information Sheet 5:

Sustainability of buildings incorporating polyurethane (PUR) insulation

This information sheet explores the role of polyurethane insulation products in Australia's low-energy sustainable buildings and their implications for building design as we transition to a low-carbon economy.

Introduction

The Australian Modern Building Alliance (AMBA) fully supports initiatives to promote sustainable construction. As the building and construction industry moves towards sustainable design, this information sheet examines:

- Australia's transition towards net-zero energy buildings,
- how to assess a building product's sustainability,
- the implications for designing low-energy sustainable buildings, and
- the vital role of polyurethane (PUR), and the closely related polyisocyanurate (PIR) insulation in these buildings.

Green buildings have become synonymous with sustainable design,[1] and the term *green building* has been used interchangeably with *sustainable building*.

However, a sustainable building isn't constructed just by selecting from a list of so-called 'green' products – for this reason, it's better to think in terms of how to build a *low-energy sustainable building*. These buildings are energy efficient; saving the occupants money on heating and cooling costs, while simultaneously reducing carbon dioxide emissions.

Status of low-energy houses in Australia

There is no globally agreed definition of a low-energy house, and Australia does not currently have a target to achieve low-energy homes. However, the Australian Building Codes Board (ABCB) is looking at the adoption of a trajectory in the National Construction Code (NCC)[2] towards variations of a *net-zero energy building*.[3,4]

Net-zero energy homes generate as much electricity as they consume; they take from the power grid as needed or contribute to the power grid when possible.

Either of the net-zero energy buildings being investigated by the ABCB would serve Australia well, provided they are linked with the Energy Efficiency First principle as part of a transition to renewable energy. This principle avoids over-investment in renewable energy by increasing a building's insulation levels and decreasing the air leakage of the building envelope.

In California, a developed economy with a similar climate zone to Australia, all newly constructed homes must be net-zero energy ready as of 2020.[5]

Like Australia, it mostly uses lightweight timber frame construction[6] for residential homes. Unlike Australia, Californian net-zero homes use significant quantities of polyurethane insulation in all building elements.

A comparison of the external wall construction of a home in Melbourne (built to the Australian NCC 2019) to a home built in San Francisco (built to the California Title 24 2019 code) reveals that the thermal resistance of the Melbourne wall is only 54 per cent of the wall in the net-zero-ready San Francisco home (see Table 1).

Building Wall Components	**Australian NCC 2019**	**California Title 24 2019**
Location	Melbourne (climate zone 6)	San Francisco (climate zone 3)
NatHERS rating (design)	6-star	
Cladding	7.5mm fibre-cement	7.5mm fibre-cement
House wrap	0 m^{2}K/W	Not required
Timber studs	90mm x 45mm	4" x 2" (102 x 51mm)
Fiberglass batts (R-2.5) between studs	2.5 m^{2}K/W	2.3 m^{2}K/W
PIR board (38mm) external to frame	None	1.6 m^{2}K/W
Total wall R-value as calculated under NCC 2019 (Volume 2)	2.92 m^{2}K/W	
Total wall R-value (after adjustment for frame thermal bridging)	**1.87 m^{2}K/W**	**3.45 m^{2}K/W**
Air Leakage (required)	ACH@50 Pa ≤ 10	ACH@50 ≤ 3
Air Leakage (actual)	ACH@50 = 15	

Note: The U-factor (R=1/U) for a wall under CA Title 24 2019 includes the effects of framing, sheathing, cavity insulation, continuous insulation and interior and exterior finishes. So for comparison purposes, the total wall R-value (2.92) as calculated in the NCC 2019 was adjusted with a 25 per cent framing fraction.[7]

***Table 1:** Comparison of wall thermal resistance for a Melbourne and San Francisco house.*

This is compounded by a 2013-2014 finding that the 'as built' thermal performance of a 5-star building in Australia did not match the 'as designed' thermal performance[8] – with excessive air leakage identified by the CSIRO as the cause.[9] This is a significant problem, with air leakage (infiltration) responsible for between 15 to 25 per cent of heat loss in winter and 5 to 25 per cent of heat gain in summer.[10]

Because the energy demand of a building reduces proportionally with any reduction to the air infiltration rate,[11] there are significant energy savings to be made by reducing the target air leakage of Australian buildings to 5 ACH$_{50}$ in the NCC 2019.

A concurrent issue facing Australian buildings is condensation. In 2016, it was estimated approximately 40 per cent of new and existing buildings had a problem with condensation, which is also related to air leakage.[12]

Interstitial condensation of water vapour in a building can impact its energy efficiency, durability and the health of the occupants.[13]

For a detailed discussion about how PIR insulation board used as external continuous insulation makes it easier to control air leakage and condensation, see AMBA Information Sheet 7.

In response to the low level of thermal insulation in the walls of Australian homes (compared to Europe and the USA) at a time when domestic energy prices are significantly higher than the USA or Europe,[14] Australia is placing a large emphasis on the use of photovoltaic (PV) panels to offset the energy use of its buildings.

This product – which has an expected life of only 25 years – requires regular maintenance, is imported and comes with concerns regarding end-of-life disposal.[15] Instead, Australia should note the Energy Efficiency First principle as part of its transition to low-energy sustainable buildings.

Rather than over-investing in renewable energy, it can adopt this principle to increase the insulation levels and decrease the air leakage of its buildings. In contrast to PV panels, polyurethane insulation (such as PIR insulation board) is always manufactured locally, does not require any ongoing service maintenance, and can be recycled or reused at the end of the building's life.

Insulation	**Polyurethane**	**Straw Bale**
Embodied energy (MJ/kg)	95[17]	15[16]
Density (kg/m^3)	32	105[16]
Thermal Conductivity (W/m.K)	0.022	0.065[16]
Thickness at R-value 1 m^2.K/W.	22mm	65mm
Embodied energy (MJ/m^2 @ R-1)	67	102
Note: The embodied energy of straw bales is often quoted as less than 1 MJ/kg,[18] but when energy associated with baling with plastic twine is included it has been reported at 15 MJ/kg[16] based on data from suppliers in Italy.		

***Table 2:** Embodied energy of polyurethane insulation and straw bales using both MJ/kg and MJ/m²@R-1 as functional units of analysis.*

Insulation	**Stone Wool**	**Polyurethane**
Thickness to achieve 0.20 W/m.K	185-190mm	110-120mm (foil faced)
Density (kg/m^3)	150-180	32
Mass/m^2 (kg/m^3)	27.8-34.2	3.5-3.8
Embodied energy/kg (MJ/kg)	16.8	95
Embodied energy/m^2 (MJ/m^2)	466-575	332-361

***Table 3:** Embodied energy of stone wool and polyurethane on a steel deck flat roof.*[17]

Green building products aren't necessarily sustainable building products

A list of green building products doesn't always lead to a more sustainable building. For example, polyurethane insulation products can be more sustainable than other so-called 'green' products.

To demonstrate this, straw bales are considered to be a green product and environmentally friendly,[16] but when used as part of a wall system, have a total embodied energy 60 per cent higher than a polymer-based insulation like polyurethane – making them a less sustainable option (see Table 2).

Similarly, there is a misconception that traditional fibrous insulation – such as stone wool – is more sustainable than polyurethane insulation,[19] because the embodied energy in stone wool is lower than polyurethane on a per kilogram basis.

However, in the case of a warm steel deck flat roof, the larger quantity of stone wool that needs to be used for equivalent thermal insulation and the increased density required for equivalent load bearing capacity (walkability), means polyurethane insulation is the more sustainable material against these criteria (see Table 3).

Implications for building design

Firstly, building design must be holistic, using a 'system' rather than a 'component' approach.

One building component may have a knock-on effect on other components, which can adversely affect the building's overall environmental impact and life cycle cost (LCC). See the Evaluating building product sustainability section of this document for more information.

Secondly, embodied energy, which is a measure of a material's carbon footprint, is only one environmental impact factor and must be weighed against other factors when designing a building and selecting materials.

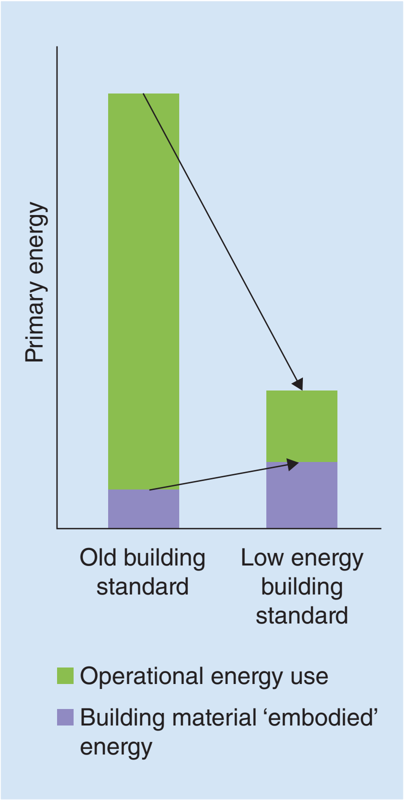


Figure 1: Operational energy versus embodied energy.

Finally, all buildings require the use of energy during their life cycle; directly during construction and operation (operating energy), refurbishment and demolition, and indirectly through the production of the materials used to construct the building (embodied energy).

Given that a building's operating energy represents 90 to 95 per cent of its total life cycle energy usage, it is much more important to control operating costs than to focus on embodied energy.[20]

By design, low-energy houses use more materials, such as insulation, and have higher embodied energy (see Figure 1) to reduce the operating energy.

However, the increase in embodied energy is insignificant compared to the overall net benefit in total life cycle energy demand that these materials enable.[20]

While energy efficiency should always be the main goal of a low-energy house design,[21] some guidance documents encourage avoiding the use of plastic building materials (such as PUR insulation), despite acknowledging that the choice of construction method and materials are best assessed by the life cycle assessment (LCA) methodology.[22]

Evaluating building product sustainability

There are three pillars of sustainable development that must be included when assessing a product's sustainability:[23] environmental performance, economic performance and social performance.

The entire life cycle of the product must be analysed to prevent burden shifts and must use the total building (or in some cases, building element) as the functional unit of analysis – as advocated by CEN/TC 350.

Life cycle assessment (LCA) is the preferred method of quantifying the environmental impacts of a product (or process). Typical standards, such as ISO 14044, cover the following five environmental impact categories:

- global warming potential (GWP)
- acidification potential (AP)
- eutrophication (surface water pollution) potential (EP)
- smog creation potential or photochemical ozone creation potential (POCP), and
- ozone depletion potential (ODP).

The environmental impact results are calculated from a range of environmental factors, such as primary energy demand (PED), resource depletion, water consumption and solid/hazardous waste.

For insulation products, many people focus on PED and GWP, because PED is a measure of embodied energy, while GWP is a measure of the carbon footprint.

However, the other impact categories should not be neglected when assessing sustainability.

Life cycle costing (LCC) is a discounted cash flow method of quantifying the total cost of ownership over the entire product life cycle. Typical standards include BS/ISO 15686-5 and EN 15643-4.

Figure 2: *a) PIR board insulation with foil facers (photo courtesy of Pirmax Pty Ltd), b) Installation of polyurethane spray foam to a wall (photo courtesy of Huntsman International LLC).*

Polyurethane insulation enables low-energy sustainable buildings

There are two broad classes of insulation products – traditional fibrous insulation, such as stone wool or glass wool (fiberglass batts), and polymer-based insulation, such as PUR spray foam (SPF) or PIR board insulation (see Figure 2).

Polyurethane insulation products play a significant role in enabling low-energy sustainable buildings.[24] They provide a higher level of thermal insulation at a given thickness (lower thermal conductivity or higher R-value) than traditional fibrous insulation and simultaneously, help to seal the building envelope to reduce air leakage and control condensation.

Their efficiency as a thermal insulant reduces the required thickness of both the insulation and building element – as in the case of a wall maximising the internal space and reducing associated building costs, such as larger foundations to support bigger walls.

PUR insulation products are also highly durable, save far more energy during their lifetime than is required for their manufacture, and there is an active market in North America for recycled polyisocyanurate insulation board for re-use in new buildings.[25]

Unlike traditional fibrous insulation, PUR insulation materials are resistant to the effect of moisture ingress, are unaffected by air infiltration and are not easily compacted (all factors that significantly degrade the performance of fibrous insulation products).

For further details about the benefits of PUR insulation in sealing a building envelope to control condensation and increase thermal efficiency, see AMBA Information Sheet 7.

Insulation	**Polyurethane**		**Stone Wool**		**Glass Wool**	
Application	Cavity Wall	Pitched Roof	Cavity Wall	Pitched Roof	Cavity Wall	Pitched Roof
Thickness (mm)	180	90 (BR) & 100 (OR)	270	220 (BR) & 90 (OR)	270	300 (BR)
Density (kg/m^3)	32	32	39	45 (BR) & 145 (OR)	17	17
Weight (kg/m^2)	5.76	5.76	10.53	22.95	4.59	4.59
Lambda (W/mK)	0.022	0.023	0.037	0.038	0.032	0.037
U-value (W/m^{2}K)	0.15	0.13	0.15	0.13	0.15	0.13

Abbreviations & Notes: BR = between rafters, OR = over rafters.
The ground floor was insulated in all three cases with polyurethane at a constant U-value of 0.18 W/m^{2}K.

Table 4: *Design details for the BRE model house.*[26]

Comparative LCA/LCC of insulation at the total building level on low-energy houses

A 2010 study by the Building Research Establishment (BRE) in the UK supports the role of PU insulation in low-energy sustainable buildings.[26]

It undertook a comparative LCA/ LCC study of the impact of insulation choice on a new low-energy, three-bedroom double storey detached house, in three climatic zones (see Table 4 for findings).

The findings demonstrated negligible difference in environmental impact between polyurethane, stone wool or glass wool insulation materials when measured at the total building level (Figure 3).

In addition, the study found that the embodied GWP of the insulation accounted for only four per cent of the total GWP of the building. That is, the insulation had limited effect on the total environmental impact of the building (Figure 3).

Of those materials tested, the polyurethane insulation was found to have the lowest life cycle costing (LCC) (Figure 3), with significant savings of four per cent and 20 per cent in the walls and roof respectively.

The BRE also assessed the LCC of these insulation materials when replacing the pitched roof in the same house with a warm deck flat roof. It found that polyurethane insulation had:

- the lowest LCC
- a 26 per cent lower GWP than stone wool, and
- a 57 per cent lower acidification potential (AP) than stone wool.

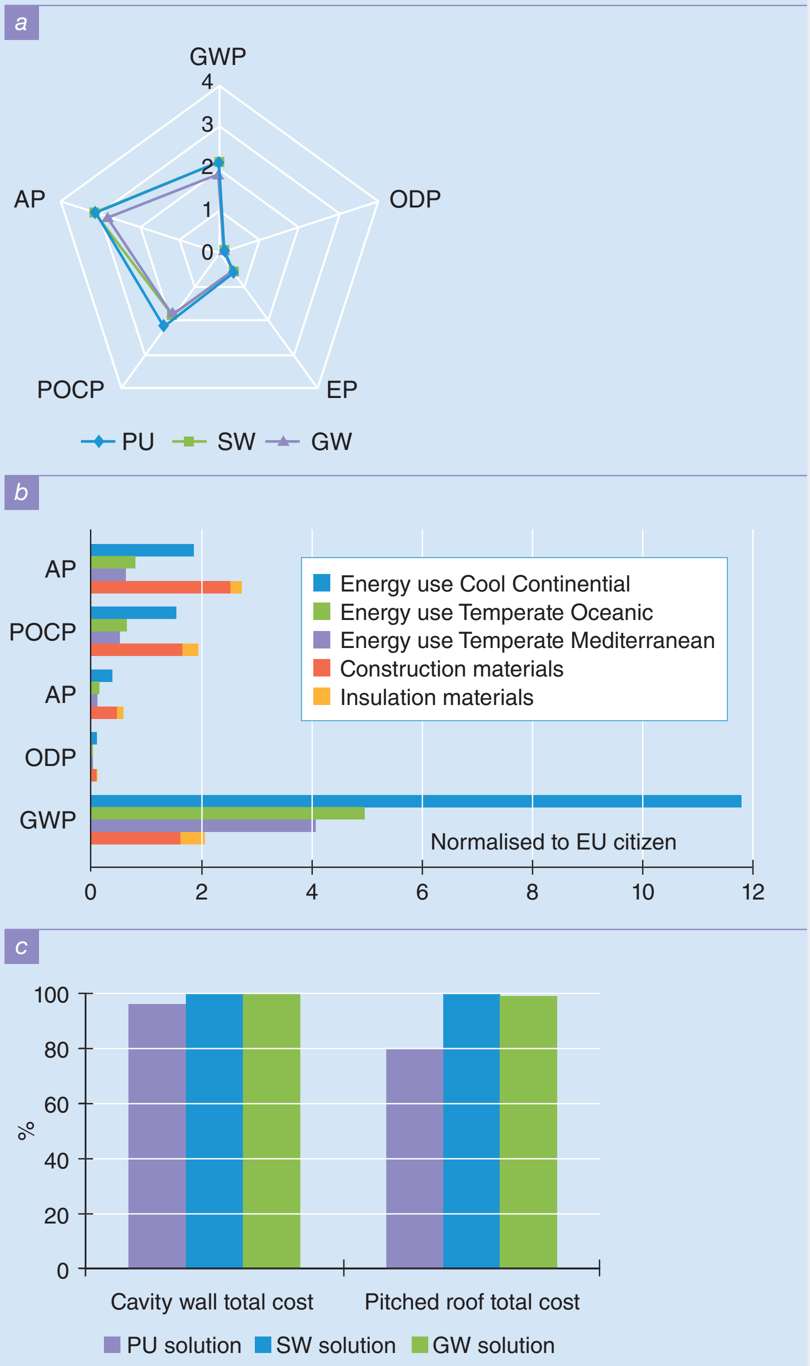
Due to its high strength to weight ratio (material intensity), less polyurethane insulation was used on the roof; in total, 307kg of polyurethane insulation was used, versus 422kg for EPS and 2,121kg for stone wool.

Finally, the study tested the performance of these insulants in a renovated external wall of the same model house. Due to its lower thermal conductivity, the polyurethane insulation has a LCC eight per cent lower than the EPS insulation and 11 per cent lower than the stone wool or glass wool insulation.

Overall, the study highlights that while insulation is a key contributor to sustainable construction, the selection of the insulation material cannot be disconnected from the overall design of the building to ensure there are no adverse knock-on effects on the performance of other components.

Because insulation materials show a very similar environmental performance when assessed at the total building level over the whole life cycle, the choice of insulation material should be based on:

- their ability to provide the highest energy performance at the total building level
- their ability to maintain their performance levels over their whole life cycle (e.g. resistance to moisture, settlement or air leakage), and
- their ease of installation (e.g. lightweight).



Environmental Indicators: GWP = global warming potential (kg CO_2 eq), ODP = ozone depletion potential (kg CFC11 eq), EP = eutrophication potential (kg PO_4), AP = acidification potential (kg SO_2 eq) and POCP = photochemical ozone creation potential (kg ethene eq).

***Figure 3:** New residential building for a temperate oceanic climate. a) LCA: whole building normalised environmental impact by category, b) Normalised data for energy use, construction materials and insulation,[26] c) LCC: 50 years cumulative costs at 3.5 per cent discount rate.*

The social impacts of polyurethane insulation

Polyurethane insulation is key to making low-energy buildings sustainable and affordable.

In addition to making our living and work environments more comfortable, it supports a wider supply chain and the economy.

Unlike traditional fibrous insulation (stone wool and glass wool), polyurethane insulation is typically manufactured close to the end market, with products generally transported less than 1,000 kilometres from the point of manufacture.

While the polyurethane insulation industry in Australia is underdeveloped due to the nation's slow move towards low-energy buildings, it has been estimated that if Australia adopted leading international practices in building energy efficiency it would:

- slash the energy bills of households and businesses by \$7.7 billion a year,
- create 120,000 extra jobs, and
- meet over half of Australia's commitment to reduce emissions by 26 to 28 per cent by 2030.[27]

By way of example, the PU industry in the United States of America generates more than 550,000 jobs across manufacture distribution and installation – some \$33 billion in payroll that supports families and local communities, as well as income for local, state and federal tax revenues.[28]

Conclusion

As Australia hastens its move towards the adoption of low-energy sustainable buildings, it must focus on the Energy Efficiency First principle.

Polyurethane insulation materials have an important role to play in these buildings; they are efficient, durable and sustainable, saving significantly more energy during their lifetime than is required for their manufacture.

Their energy efficiency and environmental benefits far outweigh their embodied energy and environmental impacts, and their use as external continuous insulation on lightweight timber or metal residential buildings will help address the issues of air leakage and condensation currently prevalent in Australian homes.

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