AUSTRALIAN MODERN BUILDING ALLIANCE

Safe and sustainable construction with polymers

Information Sheet 9:

Spray polyurethane foam (SPF)

This information sheet examines spray polyurethane foam (SPF) and its credentials as an ideal insulation for both low-energy houses and commercial mass wall systems.

Spray polyurethane foam (SPF) is manufactured by mixing isocyanate and polyol resin. These react and expand over 30 times their original volume.

SPF self-adheres to most building materials and forms a continuous blanket of insulation that bridges gaps and cracks, without the need for fasteners which can act as thermal bridges.

Unlike fiberglass (FG) batts, SPF is durable, does not degrade over time, and can be used to insulate new buildings or to retrofit existing buildings.

Because SPF is applied by spraying, it will conform to the shape of the substrate, allowing large areas of complex shapes to be insulated quickly.

Due to its light weight, it has little design impact on existing structural elements, while structurally strengthening the substrate.

***Figure 1:** Application of SPF (photo courtesy of Huntsman Polyurethanes).*

Types of SPF

There are two basic types of SPF: closed cell spray polyurethane foam (ccSPF) and open celled spray polyurethane foam (ocSPF). Table 1 compares their typical physical properties against FG batts.

Closed cell spray polyurethane foam (ccSPF)

Both ccSPF and ocSPF are used in North America and Japan in the cavities of lightweight framed residential buildings (Figure 2).

ccSPF is commonly used in North America as continuous insulation (see AMBA Information Sheet 7) on commercial mass wall systems (Figure 3) as it provides insulation while acting as a rain barrier, air-barrier and vapour barrier.

ccSPF has better thermal resistance than FG batts and is 30 per cent thinner at equivalent performance, meaning it can provide a smaller building footprint or more usable internal space.

For example, using ccSPF in a lightweight frame construction gives the option of a 25mm cavity between the insulation and the drywall for easy installation of services such as electrical wiring or water pipes, or a reduction in the frame size to 70mm (Figure 4).

Figure 2: SPF applied in a timber frame house a) ocSPF in the USA, b) ccSPF sprayed between the wall studs in Melbourne Australia, c) ccSPF sprayed between the ceiling joists in the USA (photos courtesy of Huntsman Polyurethanes).

ccSPF is also water resistant under EN 12865:2001 up to the maximum test pressure of 1,800Pa (which is equivalent to a wind speed of 197 kilometres per hour),[2] and is an approved insulation for use in flood prone areas in the USA[3] and the UK.[4]

Unlike FG batts, ccSPF does not need to be replaced if subjected to a leak or flood.

ccSPF is also airtight; the National Research Council of Canada found an undetectable air leakage rate with ccSPF applied to a concrete block wall at a differential pressure of 75Pa (ASTM E 283). Further, performance of the system was unaffected by a 10-second wind load of up to 3000Pa.[5]

ccSPF applied to a concrete block wall at a nominal thickness of 25mm has low water vapour diffusion of 36 ng/Pa.s.m^2 under ASTM E 96 – well within the requirements of the Canadian National

Insulant	FG Batts	ocSPF	ccSPF
Density (kg/m^3) (ASTM D 1622)	10-14	8-10	32-38
Thermal conductivity (W/m.K) (AS 4859.1:2018)	0.038	0.038	0.026
R-value @ 25mm (m^{2}K/W)	0.66	0.66	0.96
Closed cell content (%) (ASTM D 2856)	✘	< 6	> 90
Air permeance (L/s.m^2 @ 75Pa) (ASTM E 283)	✘	0.001 @ 89mm*	< 0.02 @ 25mm*
Water vapour permeance (ng/Pa.s.m^2) (ASTM E 96)	✘	362 @ 89mm**	52.5 @ 25mm***
Water absorption (volume) (ASTM D 2842)	✘	✘	≤ 0.3%
Sound transmission class (STC)[1] (ASTM E413 and E90)	38	38	34
	Timber studs 89 x 38mm @ 406mm OC, 13mm gypsum board interior and 14mm OSB sheathing		
Noise reduction coefficient (NRC) (ASTM C423) @nominal 75mm	1.10 @ 24kg/m^3	0.75	0.10
Compressive strength (kPa) (ASTM D1621)	✘	4.8	214
Tensile strength (kPa) (ASTM D1623)	✘	8.6	303

Notes:

* Materials with an air permeance ≤ 0.2 L/s/m^2 @ 75Pa are considered air-barriers in Canada and the USA.
** Classified as Class 3 vapour permeable under AS/NZS 4200.1: 2017.
*** Classified as Class 2 vapour barrier under AS/NZS 4200.1: 2017.

Table 1: Typical physical properties of SPF compared with FG batts.

__Figure 3:__ ccSPF applied to a concrete block wall with a brick veneer cladding (photos courtesy of Huntsman Polyurethanes).

Buildings Code of 230 ng/Pa.s.m^2 for insulation installed in continuous contact with masonry or concrete walls without an additional vapour barrier.[5]

A hygrothermal simulation, using the climatic conditions of the Island of Montreal for a 52-week period on the spray foam/concrete block system concluded that the wall did not accumulate annual levels of moisture and the spray foam progressively became drier throughout the year.[5]

Air leakage is of particular importance in lightweight frame construction. The thermal performance (R-value) of an insulated wall will be significantly reduced due to air leakage around or through air permeable insulation compared to the nominal R-value of the insulation itself. SPF provides a ready solution.

As the air leakage increases the apparent R-value decreases. The Lawrence Berkeley National Laboratory Blower Door Test database [6,7] shows significant variability for FG batt insulated buildings ranging from 0.18

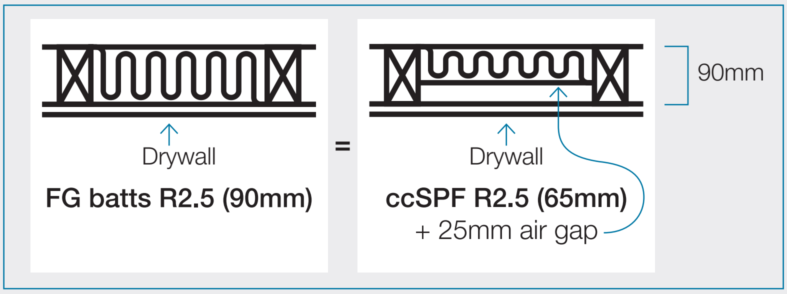


__Figure 4:__ ccSPF affords space for services or the option to reduce frame size.

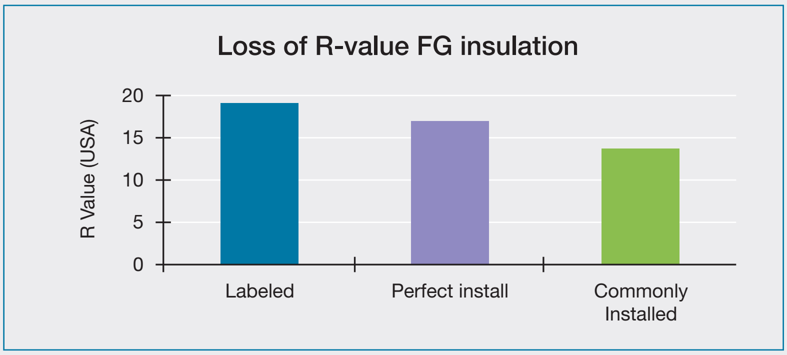


__Figure 5:__ Effect of air leakage on the installed R-value of FG batt insulation.

R-values in the United States of America are reported in imperial units, while Australian R-values are reported in metric units.

American R-values are measured on 25.4mm thick samples aged at 140°F (60°C) for 90 days, whereas Australian R-values are measured on 20mm samples aged at 70°C for 175 days.

Because of these test differences, American aged thermal conductivities for ccSPF are often reported around 0.024 W/m.K, while Australian values are around 0.026 W/m.K.

to 9.1 ACH_{50} despite the use of OSB sheathing which provides an additional air-barrier layer.

FG batt insulation in timber framed construction has been studied by the Oak Ridge National Laboratory[8] who found that the observed R-value is 11 per cent and 28 per cent less than the labelled R-value due to air leakage caused by varying standards of insulation installation (Figure 5).

Movement of air into a wall through cracks and crevices from normal construction practices can reduce the R-value of FG batt insulation by up to 60 per cent (Figure 6a).[9]

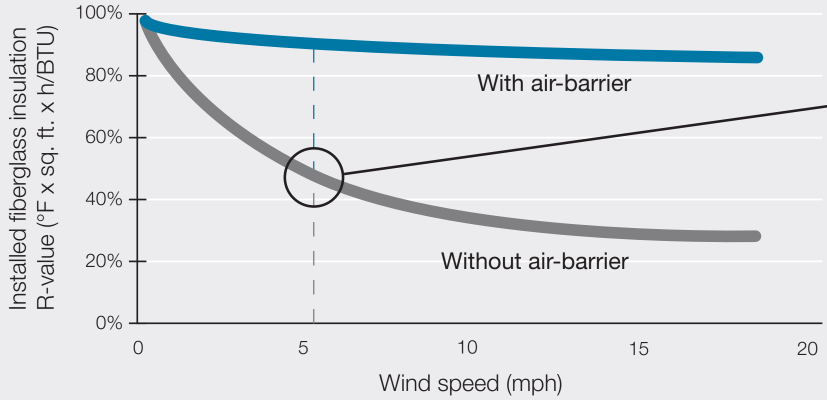
Further, air leakage in a wall through cracks can result in 100 times more water entering FG batt insulation than from water vapour diffusion (breathability) through a wall.[10]

This causes wet FG batt insulation that can lose up to 60 per cent of its R-value (Figure 6b).[11]

Simply substituting ccSPF[12] for FG batts reduces air leakage to between 0.1 and 0.2 ACH, which significantly reduces heating and cooling loads and improves comfort for inhabitants.

While the heating, ventilation, and air conditioning (HVAC) unit must be correctly specified to control ventilation and humidity, a building insulated with ccSPF can typically use an air conditioning unit half the size of the same building insulated with FG batts.[12]

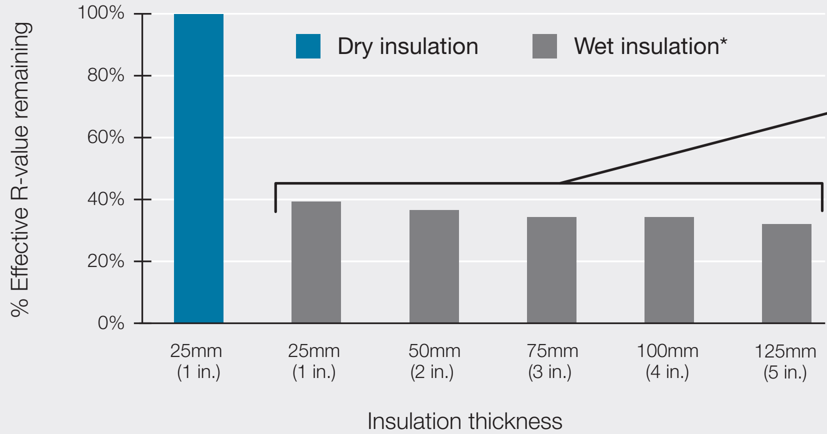
Reducing air flow through the wall and between transitions helps maintain thermal values (insulation R-value).



Even at wind speeds of 5 mph, a wall system without an air-barrier retains less than 40% of its original installed R-values.

Source: Impact of airflow on the thermal performance of various residential wall systems utilizing a calibrated hot box, David C. Jones – *Thermal Envelope VI/Heat Transfer in Walls II – Principles* (p. 247 – 260)

Effective R-value is reduced in wet insulation.



Regardless of thickness, wet insulation retains less than 40% of its effective R-value.

*Measured at 20°C temperature difference on FG batt insulation

Source: *Controlling the Transfer of Heat, Air & Moisture through the Building Envelope*, M.C. Swinton, W.C. Brown, G.A. Chown

***Figure 6:** a) Effect of air leakage on FG batt insulated walls, b) Effective R-value of wet FG batt insulation.*

Figure 7: *ocSPF applied between the wall studs to provide insulation and an air-barrier (photo curtesy of Huntsman Polyurethanes).*

Figure 8: *Application of ccSPF under a timber floor in Canberra (photo courtesy of Pacific Urethanes Pty Ltd).*

Figure 9: *Application of ocSPF between the roof rafters prior to trimming the foam back to stud level (photo courtesy of Huntsman Polyurethanes).*

Open celled spray polyurethane foam (ocSPF)

ocSPF has a similar thermal conductivity to FG batts. But, when applied between studs, it bridges all cracks and gaps (Figure 7) – providing a complete air-barrier that negates the need for a taped house wrap as required when using FG batts.

This improved airtightness translates directly into improved energy efficiency. To demonstrate this, Habitat for Humanity (Table 2) built two identical timber framed four-bedroom houses with the same orientation (northwest); one insulated with FG batts in the walls and over the ceiling, and one with ocSPF in the walls and between the roof rafters.

The study found that the ocSPF insulated house had 95 per cent less air leakage and only 32 per cent of the cost of running identical HVAC units located in the ceiling (Table 2).

Given that the thermal conductivity of FG and ocSPF are similar, this illustrates why air leakage is just as important as the thermal conductivity of individual building elements.

ccSPF in suspended timber floors

ccSPF is an ideal insulation material for ventilated timber framed floors (Figure 8) in new and existing buildings; it self-adheres to the timber flooring and floor joists, providing a complete air and vapour barrier[14] while providing superior insulation compared to FG batts. This application is currently being used in Melbourne and Canberra.

SPF in residential roofs and unvented attics

Australian ceilings (attics) are typically vented, meaning they're cold in winter and hot in summer because the insulation is usually placed between the ceiling joists.

However, if the insulation is placed between the roof rafters to create an unvented attic space, the temperature of the attic remains the same as the house.

Insulation	ocSPF	FG
Exterior wall	R = 2.29 m^2K/W	R = 2.29 m^2K/W
Roof deck	R = 3.70 m^2K/W	
Ceiling		R = 6.69 m^2K/W
Blower door leakage results	129 CFM @ 47.5Pa	1,884 CFM @ 49.9Pa
Monthly average cost to run HVAC unit	USD 36.87	USD 116.76

Table 2: *Habitat for Humanity test house results.*[13]

Location	Houston, TX		Richmond, VA		Minneapolis, MN	
Energy	Therms	kWh	Therms	kWh	Therms	kWh
Base Case	FG batts in wall cavities and at ceiling level					
Savings with ccSPF in wall cavities & at ceiling level	13%	1%	3%	0%	10%	0%
Savings with ccSPF in wall cavities & at roof deck level	19%	8%	12%	7%	19%	7%

Table 3: *Building energy simulation results for ccSPF compared with FG batts (both as cavity insulation).*

It also reduces energy costs by an average of 20 per cent for ducted HVAC systems installed in the ceiling. These savings can be as high as 28 per cent for cooling in hot climates.

ccSPF is one of the few technologies that enables builders to create unvented roofs.[15,16] This improves the building's structural and thermal performance and provides superior wind uplift protection.

ocSPF is also used for this application (Figure 9). Sealing soffits with SPF when creating an unvented attic can also help prevent entry of wind driven rain, reduce wind uplift pressurisation, and provide a back-up waterproofing layer to minimise potential water leakage.[17]

Comparative modelling of whole house energy savings[18] has shown that homes that use ccSPF insulation rather than FG batts in the timber frame wall cavities, and at the ceiling level (vented attic), have significantly lower energy consumption (Table 3).

Unventilated attics with air impermeable insulation under the roof deck minimise ceiling energy loss and protect the HVAC ducting by placing it inside the building envelope.

Finally, SPF under the roof deck also provides a secondary water barrier and triples the roof deck wind uplift.

ccSPF improves wind resistance and cyclone resilience

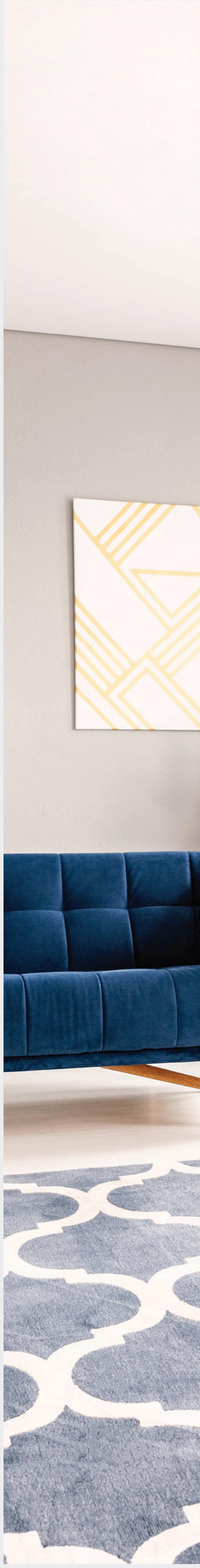
ccSPF is an ideal insulation to use in resilient construction for cyclonic and flood prone areas; it is unaffected by immersion in water and structurally strengthens the building elements.

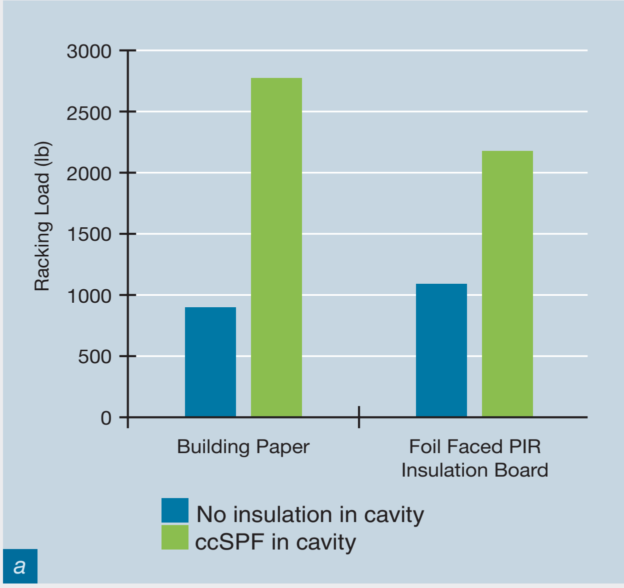
In a report by the Federal Emergency Management Agency (FEMA), ccSPF was the only cavity insulation material approved as resistant to floodwater damage.[3]

Other studies have shown that ccSPF can improve the racking strength of residential walls two to three times.[19,20,21,22,25]

For example, a 2.4m by 2.4m test panel using a 50mm by 100mm frame at 405mm centres (Figure 10a) finished with internal plasterboard (13mm) and building paper (asphalt impregnated felt) external to the frame tripled the racking strength with ccSPF in the cavity.

ccSPF can increase roof deck uplift resistance by a factor of two to three times[17,23,24,25] by placing it on the underside of the roof deck (Figure 10b).





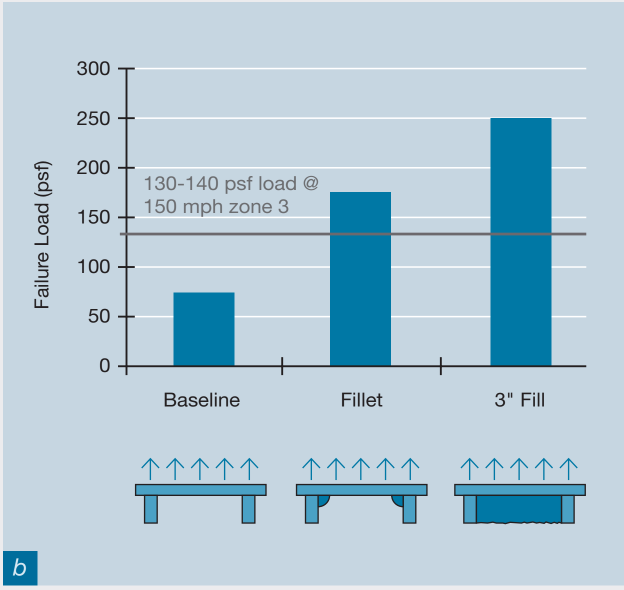


Figure 10: *a) Racking strength.[25] b) Wind uplift.[17]*

Further, ccSPF has negligible water permeability, minimal water absorption and excellent adhesion (it seals joints and cracks) – allowing it to act as a secondary rainwater barrier to limit damage when a primary rain barrier is breached.

Wind uplift of the roof structure is second only to broken windows as the most prevalent mode of hurricane damage – water penetration is responsible for loss of property and contents more than 80 per cent of the time and can lead to losses more than half of the structure's insured value. For this reason, structures need to be designed to get wet and then dry.[3]

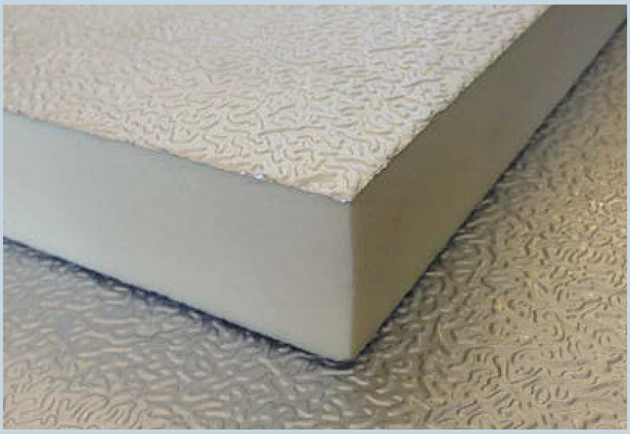
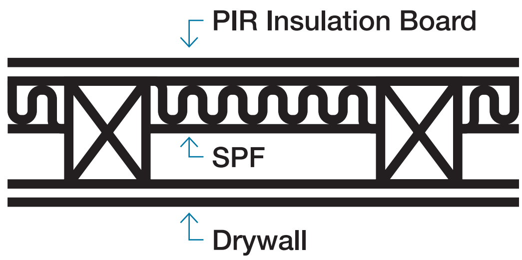


Figure 11: PIR board insulation with foil facers (photo courtesy of Pirmax Pty Ltd).



A system with internal gypsum board – (10mm), 35mm of ccSPF (R-value = 1.4 m^2K/W) and 25mm PIR insulation board (R-value = 1.14 m^2K/W) – with seam tape does not require a separate wall wrap (air-barrier) or weather resistive barrier and can be covered with cladding once erected on site.

Figure 12: Schematic illustration of a prefabricated wall panel for a low-energy building.

Prefabricated houses

With a combination of polyisocyanurate (PIR) insulation board (Figure 11) and ccSPF, it is possible to manufacture either complete modular or panelised houses in a factory.

Figure 12 depicts one possible wall panel system which would allow a prefabricated housing manufacturer to offer low-energy buildings without the need to increase the frame thickness.

The external PIR insulation board minimises thermal bridging of the timber frame and the ccSPF in the frame cavity provides additional insulation, a complete air seal, and structural strength.

Panelised prefabricated houses are easier to ship to site than modular houses and have additional benefits including:

- Reduced construction time (60 per cent less hours to erect a house), and
- 25 per cent less wood and 30 per cent less job site waste than conventional framed construction with FG batts.[26,27]

Fire tests

While there is a clear difference in the fire hazard properties of SPF and FG batts (Table 4), SPF compares well against the values for the timber frame. When installed in the frame cavity it is always covered by plasterboard as a fire barrier on the internal face of the wall.

Finally, SPF as part of a complete wall assembly can pass intermediate scale fire tests such as NFPA 285[28] and achieve fire resistance ratings of 1, 2 or 3 hours under ASTM E119.[29] Fire-retardant SPF can also achieve a Group 2 rating under AS 5637.1: 2015 and AS 3837: 1998.

SPF can be used in a Bush Fire Attack Level (BAL) rated home under AS 3959-2009 up to BAL-40 using conventional wall cladding and roofing materials. For BAL-FZ, the wall and roofing assembly (including the SPF) must be tested and comply with AS 1530.8.1. For more detailed information consult AMBA Information Sheet 10.

AS 1530.3: 1999	FG batts	ccSPF	ocSPF	Timber (softwood)
Ignitability	0	13-16	0	16
Flame Spread	0	0	0	9
Heat Release	0	1-2	0	7
Smoke Release	0-1	5	4-6	3

Table 4: *Typical comparative material fire hazard properties (AS 1530.3).*

SPF and volatile organic compounds (VOC)

While spraying SPF, applicators should wear the appropriate personal protective equipment (PPE).[30]

Global safety science organisation UL recommends a 24-hour re-occupancy time and two-hour ventilation period before PPE is no longer required.[31]

Installed SPF can pass standardised VOC tests like GreenGuard and CA 01350 in the USA or ULC S774 in Canada.[31,32]

Environmental impact, sustainability, and disposal of SPF Waste

Environmental product declarations to ISO standards are available for SPF.[33]

SPF is manufactured with zero ozone depletion potential (ODP) and low global warming potential (GWP) blowing agents. In addition, SPF products can contain up to 19 per cent and six per cent of recycled and renewable content respectively.

Choosing the most sustainable insulation material relies on more than selecting a material from a 'green list' or by considering only one factor like embodied energy on a per kilogram basis. While insulation is a key contributor to sustainable construction, the selection of the insulation material must be connected to the overall design of the building to ensure there are no adverse effects on the performance of other components.

Because insulation materials show a very similar environmental performance when assessed at the total building level,[34] the choice of insulation material should be based on its:

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

Based on these criteria, SPF and polyurethane insulation should be at the top of the selection list. For more information consult AMBA Information Sheet 5.

SPF waste can be sent to landfill or burned together with other household waste in incineration plants with heat recovery systems.

The latter process presents a dual energy saving; during the product's life it saves up to 100 times the energy used in its manufacture, then it is burned at an incineration plant in place of other new energy sources such as oil or gas.

Conclusion

- SPF is an ideal insulation for low-energy houses;[35] it has low thermal conductivity and seals cracks and gaps during installation. This minimises the thickness and air leakage of building elements and reduces the risk of interstitial condensation.
- ccSPF is an ideal insulation for commercial mass wall systems; when used on the exterior of a building it virtually eliminates thermal bridging while providing insulation, an air-barrier, and a water resistive barrier. See AMBA Information Sheet 7 for more information about continuous insulation.
- SPF is superior to traditional FG batts when used as cavity insulation in lightweight frame construction of residential houses because it seals gaps and cracks – in turn reducing air leakage in building elements like walls.
- SPF is one of the few technologies that enables builders to create unvented roofs – which provides significant energy savings with HVAC units located in the ceiling.
- ccSPF is an ideal insulation to use in resilient construction for cyclonic and flood prone areas – it is unaffected by immersion in water and structurally strengthens the building elements.

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