THERMAL INSULATION

How it works, why it is used and what products are available

This Building Technology Resource explains why thermal insulation is used in buildings and how it works. It also describes the most common types of thermal insulation commercially available in Australia and the applications where they are most suitable.

Thermal insulation reduces the flow of heat into and out of buildings. When used correctly, thermal insulation improves a building's energy efficiency, making it more comfortable to occupy and reducing the cost of heating and cooling. Regulations regarding the energy efficiency of Australian buildings mandate the use of some form of thermal insulation in most cases, in combination with other measures such as control of glazing area and ventilation. These requirements are part of Australia's National Construction Code, which is overseen by the Australian Building Codes Board (ABCB) and managed through state jurisdictions.

HOW THERMAL INSULATION WORKS

Insulating materials reduce the transfer of thermal energy by resisting the flow of heat. The measure of insulation performance is thermal resistance, or R value. The R value is calculated by dividing thickness by thermal conductivity and is expressed as square metre kelvin per watt ($m^2 \cdot K/W$). A higher R value indicates higher thermal resistance.

All building materials provide thermal resistance to some degree, but thermal insulation materials are designed specifically for this purpose. They are separated into two broad types: bulk and reflective. Bulk insulation is typically a low-density material such as a foam or fibrous blanket, which is composed largely of still air. The low thermal conductivity of this air provides an insulating effect. Heat conduction through the bulk material itself is low, because the material is present only at a low density. The presence of the bulk material also suppresses heat flow by convection (air movement) and by radiation. The best way to increase the thermal resistance of a particular bulk material is to make the material thicker (see Table 1).

Reflective insulation incorporates a shiny metallic surface (almost always aluminium), which reflects heat and thus prevents heat flow by radiation between facing surfaces – as well as blocking the radiation of their own heat energy. For reflective materials, thermal resistance is a property of the reflective airspace adjacent to the material rather than of the material itself. It is influenced by several factors, including the thickness and orientation of the airspace, and the temperature and reflectance of the materials on both sides of the airspace. This means that no single value of thermal resistance can be ascribed to a reflective insulation for all the ways in which it might be used. However, reflective airspaces typically have a thermal resistance similar to that of bulk insulation of the same thickness.

Only one surface or side of an airspace needs to be reflective in order to greatly reduce radiation heat transfer. However, unless a reflective airspace is evacuated (as in a vacuum flask), it is still subject to convective air movement. The amount of convection is affected by physical factors including orientation and temperature difference (larger gradients tend to drive stronger convective airflows and greater heat flows).

TABLE 1. TYPICAL THERMAL RESISTANCE VALUES FOR SELECTED MATERIALS.

Material (100 mm thickness)	Density (kg/m^3)	R value ($m^2 \cdot K/W$)
Airspace (vertical reflective)	–	0.6
Aluminium (solid metal)	2600	0.0005
Bricks	1800	0.15
Cellulose fibre (loose fill)	35	2.5
Glass fibre batt (low density)	8	2.0
Glass fibre batt (medium density)	16	2.6
Polyester fibre batt (low density)	8	1.6
Polyester fibre batt (medium density)	16	2.2
Polystyrene foam (EPS)	16	2.8
Polystyrene foam (XPS)	30	3.3
PUR, PIR & phenolic foams (new)	30	4.0
PUR, PIR & phenolic foams (aged)	30	3.7
Rockwool batt	40	2.8
Rockwool (loose fill)	40	2.7
Soil	1500	0.1
Timber (eucalypt)	750	0.6
Timber (pine)	500	1.0
Vacuum insulation panel	250	18.0
Wool batt (low density)	8	1.7
Wool batt (medium density)	16	2.2
Wool (loose fill, low density)	8	1.5
Wool (loose fill, medium density)	16	2.2

The total thermal resistance of a building element is the sum of the contributing parts if they are installed in series. If there is a more complicated arrangement of components, then the total R value may be difficult to determine. If different materials are installed in parallel, then those of low thermal resistance may act as a heat bridge – a path through or around the material that heat can travel along – drastically reducing the overall thermal resistance. This may occur, for example, when incomplete coverage of ceiling insulation leaves some air gaps between batts. Calculation of the total thermal resistance usually includes the air film resistance on each side of the building element, which measures the rate of heat transfer between a surface and the adjacent space.

CHOOSING THERMAL INSULATION MATERIALS

When selecting the most appropriate materials for a particular application, it is useful to consider the following criteria:

- cost
- suitability for the application
- durability
- ease of installation
- thermal resistance
- fire resistance/performance
- sound absorption
- health and safety issues.

Several types of thermal insulation could be suitable depending on the building element, the particular application, and the contribution of other aspects of building design such as ventilation (Figure 1). Certain products might be suitable in some locations but not in others. And in some cases – such as in milder climate zones in Australia – thermal insulation may not be necessary at all. Within a building, insulation may be important in one area but less so in another where heat loss is lower.

The benefit of insulation may be undermined by the presence of ventilation or heat bridges, which can be prevented by ensuring a high standard of installation (Figure 2).

GLASS FIBRE AND ROCKWOOL

Glass fibre and rockwool – also known as glass wool, mineral wool or mineral fibre – are made using fine fibres that are spun from molten glass (recycled or virgin) or various combinations of blast-furnace slag and rock, such as basalt. Adding an adhesive binder enables the fibres to be shaped into rectangular batts (which are usually sized to fit the typical distance between studs or joists) or blankets (which are supplied in long rolls). If a binder is not added, the product is supplied as loose fill in bags. Batts and blankets can be pushed or laid in place, while loose fill is mechanically blown into ceiling cavities.

The diverse technologies and materials used to create these products result in significant differences in their density, thickness and insulation performance. They comprise one of the most versatile types of insulation materials, and are used in ceilings, walls and suspended floors, as well as in equipment insulation. Glass fibre can be made at a low density, resulting in lightweight,

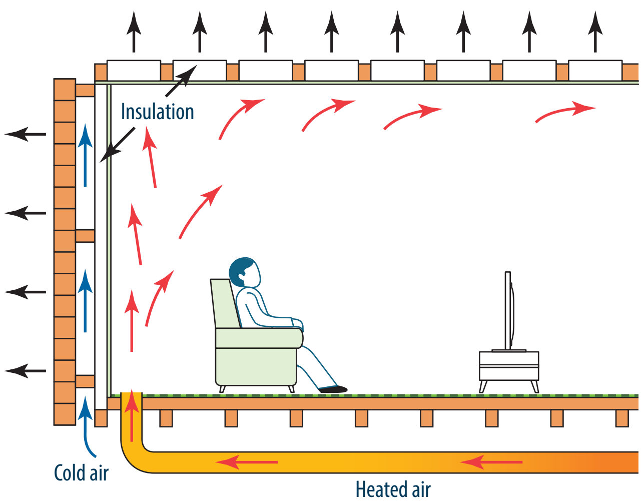

FIGURE 1 Insulation, ventilation and building design combine to determine overall thermal performance.

FIGURE 2 Thermal imaging reveals heat leaks in surprising places. (Ivan Smuk/Shutterstock.com)

economical batts and blankets. Rockwool is generally denser but otherwise similar in properties and use to glass fibre. Both have good fire resistance, as they contain only small amounts of combustible material. Because their fine, sharp fibres may cause temporary skin, nose and eye irritation, precautions should be taken when handling these materials (Figure 3).

CELLULOSE FIBRE

Cellulose fibre is made by combining pulverised paper with fire-retardant chemicals. It is used almost exclusively as a loose-fill ceiling insulation. Like other loose-fill materials, cellulose fibre insulation may settle over time, and allowance for this should be made during installation. It is easy to handle but may contain high levels of dust, so dust masks should be worn during installation.

POLYESTER FIBRE AND SHEEP'S WOOL

Products based on polyester fibre or sheep's wool are made using similar technologies and are often sold as mixtures or blends in batt and blanket form, with polyester 'melt' fibre typically used as a binder. This blended product is stronger, more uniform and more flexible than one made from wool alone. Polyester fibre, wool and blended insulation products are generally produced at low density for economic reasons and may need to be relatively thick to achieve target thermal performance (Figure 4). Sheep's wool is also sold as a loose fill that is blown into place as a ceiling insulation. Some grades may be self-supporting at extremely low density when first installed, but will perform poorly and settle greatly over time. Correct installation requires an appropriately high density, which depends on the product specification and should be stated by the installer. Batts of either material may be

FIGURE 3 Protective equipment should be used when installing mineral fibre insulation. (Nagy-Bagoly Arpad/Shutterstock.com)

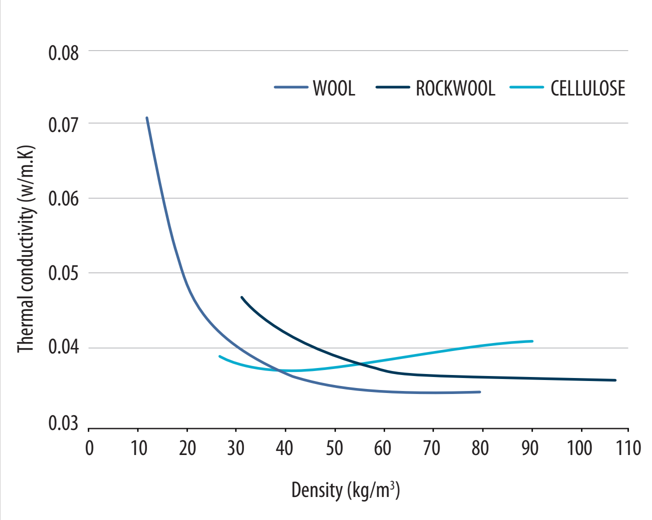

FIGURE 4 Density affects thermal performance.

handled easily with no special precautions. Although wool is one of the least combustible organic fibres, the fire performance of wool–polyester blends may not be good.

RIGID POLYSTYRENE FOAM

Although it may be better known as a packaging material, polystyrene is a good thermal insulator. Expanded polystyrene (EPS) is made from moulded beads that are steam-expanded before being fused into a shape. Extruded polystyrene (XPS) is made by extruding a foam as a uniform sheet. EPS is produced in a number of density grades, with higher densities providing better thermal and structural performance (albeit at a higher cost). XPS tends to be more expensive than EPS but has better thermal performance. XPS is useful for insulation under concrete slabs, as it is relatively tough and has very low water absorbance. EPS is suitable for many structural applications; for example, when laminated to steel facings, it is the mainstay of cool-room construction, where its lower cost and greater stability are valuable. Both EPS and XPS are widely used in other building applications, especially in walls that use exterior insulation and finish systems (EIFS).

One disadvantage of these products is that polystyrene softens at temperatures above 80°C and after exposure to many common organic solvents. Polystyrene is also combustible, although flame-retardant grades are available.

POLYISOCYANURATE AND POLYURETHANE FOAMS

Polyisocyanurate (PIR) and polyurethane (PUR) foams are produced as rigid sheets that trap bubbles of gas. These gases, which are better insulators than air, may diffuse out over time, diminishing the foams' thermal performance. Adding impermeable facings to composite foam panels may slow this ageing process.

PUR and PIR foams offer some of the highest thermal performances of readily available materials. PIR foam has slightly higher thermal resistance than PUR foam and a slightly higher maximum service temperature – the highest temperature at which the material can be used continuously without any loss in performance. The foams are most suitable for situations in which maximum thermal resistance is required in small spaces, such as in the walls of refrigerators. As the foams may be sprayed into place on site, they are suitable for other applications with space constraints – although care must be taken, because they can generate significant pressure as they expand and harden, which may cause damage. PUR and PIR foams are often sprayed onto the interior or exterior surfaces of industrial and agricultural buildings, because they are a quick and relatively easy retrofit and can be applied around fittings and odd shapes. As the foams are fragile and easily broken, they should be protected from impact and from the sun. Flame-retardant grades are available for applications where compliance with fire-performance regulations is required.

PHENOLIC FOAM

Phenolic foam has similar appearance and thermal resistance to PIR foam but a different composition. Like PIR foam, it is used in situations requiring maximum thermal performance in a constrained space. Phenolic foam has inherently good fire resistance, but it is relatively expensive. It may be mixed with EPS to make composite panels that combine the fire resistance of the former with the lower cost and good structural properties of the latter.

VERMICULITE AND PERLITE

Vermiculite is a steam-expanded (exfoliated) form of mica, and perlite is a porous volcanic material. These two minerals have horticultural uses but are also used as insulation, either as loose fills or as additives to improve the thermal properties of low-density cementitious or plaster products. They are granulated and available in various grades. They are also non-combustible and have a high maximum service temperature.

VACUUM-INSULATING PANELS

Vacuum-insulating panels are produced by encasing a core of low-conductivity porous material (such as perlite or glass fibre) in a gas-tight wrapping and extracting the air. As with vacuum-packing foods, this process produces a rigid shape, generally a thin panel. Well-made panels can achieve outstandingly high thermal resistance. However, the panels are susceptible to deterioration through the slow entry of air and must be handled carefully to avoid punctures, which would dramatically affect their performance. As vacuum-insulating panels must be made to size, there is the potential for significant heat leaks at their edges due to fitting imperfections. Heat may also be lost by conduction through the wrapping. These products are used in industrial and equipment applications where space is limited, and they are making inroads in other applications such as wall insulation.

REFLECTIVE INSULATION

The most widely used form of reflective insulation is a laminate consisting of a core layer of fibre-reinforced kraft paper with facings of aluminium foil, usually on both sides. Variations may use plastic film instead of a paper core or evaporated aluminium films instead of thin foil. This product is supplied in roll form and generally referred to as reflective foil insulation (RFI) or laminate (RFL). In addition to its use in thermal insulation, reflective insulation is commonly used as sarking to control liquid water and as a vapour barrier to control water vapour.

As previously explained, the thermal performance of reflective insulation depends on the characteristics of the airspace and the infrared reflectance of the foil (products may quote the 'emittance' value, which is related to the reflectance). Bright aluminium foil can reach a reflectance of 0.95 (i.e. 95%) or better, and most reflective foil insulations achieve a similar value. To reduce the glare hazard during construction, the foil surface is often sprayed with an anti-glare coating, which slightly reduces the infrared reflectance and thus the thermal performance.

Some insulation products incorporate several stacked reflective surfaces or combine reflective and bulk materials. Many such composite products are relatively thin, and the thermal resistance is attributable largely to their reflective properties rather than their bulk-insulation properties. Examples include thin foil-faced EPS boards and reflective plastic bubble materials. These products may have useful applications in floor, wall, ceiling and roofing insulation and also in vapour control.

OTHER MATERIALS

Although they are not technically a form of thermal insulation, solar reflective paints can help to keep buildings cool in summer by reflecting the radiant energy of the sun. Instead of thermal resistance, these paints are characterised by their solar reflectance, which should be as high as possible. Because ~45% of the sun's energy is in the visible spectrum and white materials reflect visible light, paints that have high solar reflectance are invariably close to pure white in colour (and all white paints have high solar reflectance). Some specialist coatings may be visibly off-white without too much loss in solar reflectance, because they maintain more reflectance in the solar infrared spectrum. However, solar reflective paints provide no insulation inside a building and only work outside when the sun is shining.

There may be alternative and innovative solutions for thermal insulation, including organic materials such as straw, straw bale and seaweed, and materials with high thermal mass such as rammed earth, mud bricks and earth. However, their suitability for a particular application should be assessed using established criteria, particularly R value.

CSIRO offers a National Association of Testing Authorities (NATA) accredited service for measuring thermal insulating properties.

Note: The references to fire resistance and fire performance of materials in this BTR are for general information purposes only. Specific advice on regulatory compliance should be sought in all cases.

MORE INFORMATION

Additional information can be found in the following resources. Please check your local authorities for specific legislation, codes and guidelines, as they can vary between states and territories.

Australian Building Codes Board (2016) Energy efficiency provisions. NCC volume two. Canberra: Australian Building Codes Board

Australian Building Codes Board (2016) National construction code. Canberra: Australian Building Codes Board

Australian Standard AS 3999:2015 Bulk thermal insulation – Installation

Australian Standard AS/NZS 4859.1:2018 Thermal insulation materials for buildings, Part 1: General criteria and technical provisions

Building Research Association of New Zealand (2012) Building basics: Insulation. Porirua: BRANZ Limited.

Insulation Council of Australia and New Zealand (2016) Insulation handbook. Part 1: Thermal performance. Version 3. Melbourne: Insulation Council of Australia and New Zealand

Insulation Council of Australia and New Zealand (2016) Insulation handbook. Part 2: Professional installation guide. Version 4. Melbourne: Insulation Council of Australia and New Zealand