INSULATION TECHNOLOGIES AND STRATEGIES

Insulation types. Adding insulation is the simplest and most well known means of improving the thermal performance of a building. Figure 3.1 shows that, in cooler temperate climates such as Victoria, a significant amount of heat transfer occurs during hot and cold weather through the ceiling, walls and floor of a house without insulation, and with typical levels of air leakage. The main types of insulation are bulk, reflective, and foam. When choosing insulation for a building it is important to be mindful of local climate conditions and the construction method of the building, eg. wall type, ceiling type, etc.

FIGURE 3.2
Injection Foam Insulation. [R. Keech]

FIGURE 3.3
Spray Foam Insulation.

FIGURE 3.4
Bonded Bead Insulation
[Beattie Passive Build Systems Pty Ltd]

Bulk insulation. Bulk insulation contains still air pockets trapped within the insulating material structure. Bulk insulation includes materials such as polystyrene, polyester, natural wool, glass wool, rock wool (ie. mineral fibre), and cellulose fibre. It is available as batts, blankets and boards, or as loose fill which is pumped, blown or placed by hand into an area of your home. It is important not to compress bulk insulation because the trapped air pockets inside the insulation provide the material's insulating effect.

Reflective insulation. Reflective insulation when installed correctly resists transferring a large majority of radiant heat across an enclosed space due to its characteristics of being highly reflective and having low-emissivity. Emissivity refers to the capacity of a material to re-radiate heat. Reflective insulation is usually made from thin sheets of highly reflective aluminium foil laminate. It is available in sheets, concertina-type sections, and in rolls. Reflective foil's thermal resistance is influenced by the characteristics of adjacent air spaces, such as their orientation, thickness and temperature differences. For maximum effectiveness, reflective insulation requires an air layer of a minimum of 25mm next to the shiny surface.

Foam insulation. There are two main forms of foam used for insulation; spray foam, usually polyurethane, and injection foam made from phenolic or melamine formaldehyde resins. Spray foam insulation comes in either an open-cell or closed-cell form and involves a two component chemical reaction between Side A – a reactive chemical known as isocyanate that acts as a hardener and Side B – a polyol resin, often polyurethane, plus blowing agents and other chemicals including flame retardants. The two chemicals are sprayed onto a surface using a blowing agent, where they mix and undergo a chemical reaction to form a foam that hardens. The components of injection foam are a resin solution, catalyst, and a blowing agent that are mixed at the nozzle.

Unlike spray foam, injection foam is fully expanded as it leaves the hose making it suitable for filling existing cavities such uninsulated external walls. All current forms of injection foam insulation are open-cell [9, 10, 11, 12].

Open-cell foams contain cells with air pockets that have small holes in them. These initially contain CO_2which is replaced with air over time. These foams must be used internally as they can deteriorate in contact with water. Closed-cell foams have a closed cellular structure, which is impermeable to moisture and sets as a harder more-rigid surface that is better suited to external applications (eg under-floor). Most open-cell foams contain some organic component, either soy or castor oil and are blown with water, reducing its environmental impacts. Most closed-cell foams are blown with a hydrofluorocarbon (ozone-depleting and high-global warming potential). However products are available that use water and HFC 245 – a low-GWP option manufactured by Honeywell [13]. Foam insulation has the added benefit of being able to stop air infiltration by weather sealing, making it an ideal option for use under timber floors and cavity walls.

Bonded-bead insulation. Bonded-bead insulation combines the well-known properties of Styrofoam bulk insulation with the cavity-filling advantage of injection foam. Bonded-bead insulation is not only certified for the purpose of retrofit wall insulation in the UK and Ireland, it is one of the preferred materials for this application under the UK Green Deal energy grant scheme [14, 15].

The material is formed by pumping expandable polystyrene (EPS) beads into a cavity wall. A PVA based adhesive is used to hold the beads in place. The raw material of bonded bead insulation is called Expandable Polystyrene. EPS is formed from naphtha which is a by-product of crude oil. The benzene, the ethylene and the pentane are extracted from the naphtha. Styrene is produced from the chemical reaction between benzene and ethylene. With added pentane (as an expanding gas) and water, it is polymerized and gives the Expandable Polystyrene [16]. The grey beads shown in Figure 3.4 are white EPS bead with a graphite coating (Neopor) or they are coated using granite particles [17] (thermabead diamond).

Benefits of insulation

The benefits of insulating the building fabric are significant. These include:

- Significant reduction of the amount of artificial heating and cooling required
- Opportunity to reduce the expense of heating and cooling in the home by about 50% ([17] pp101)
- Improvement of the comfort of building occupants
- Long life and low maintainence
- Near-elimination of condensation on the interior of walls and ceilings
- Reduction or elimination of air infiltration
- Quieter home environment due to good sound aborption.

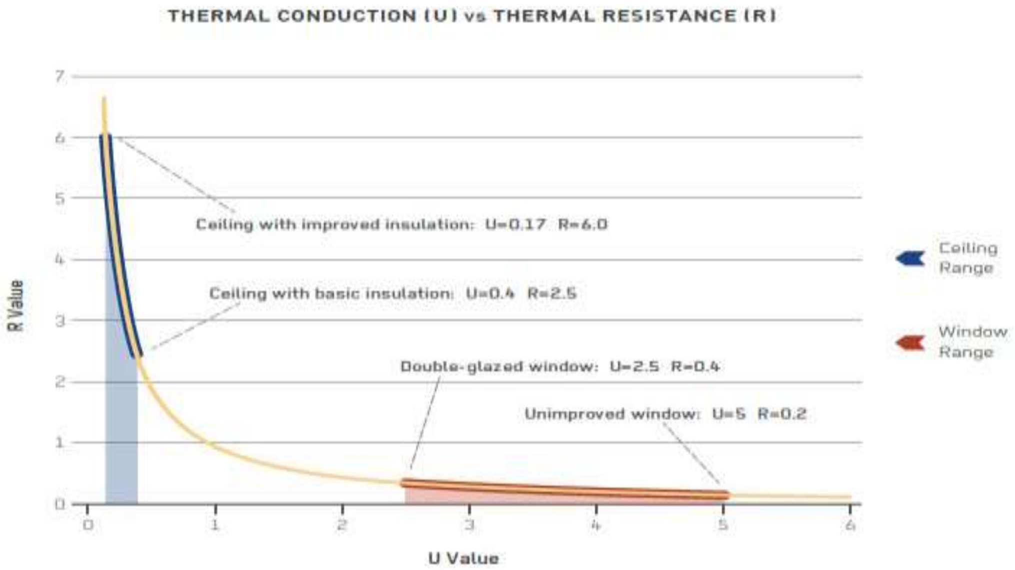


FIGURE 3.5

Thermal performance of insulation can be expressed as either thermal conduction (U) or thermal resistance (R)

Demand-Reduction Potential

Heat flow. The flow of heat into or out of a building (Q) is measured in Watts. When this is expressed per square meter of building surface, it is called heat flux [W/m^2]. The basic science tells us that the conduction of heat is directly proportional to the difference in temperature between inside and outside surfaces (the 'delta T', or ΔT). This is known as Fourier's law. Doubling the temperature difference will lead to a doubling of heat flow.

Measuring insulation performance. The thermal performance of insulation is expressed as thermal conduction (U value, W/m^2K) or more commonly, its arithmetic inverse, thermal resistance (R-value), ie **$U = 1/R$**.

The relationship between thermal conduction (U) and Thermal resistance (R) is illustrated in Figure 3.5. The performance of the insulating material, per meter of thickness is Lambda (λ) [W/mK], ie $\mathbf{U=\lambda/d}$, or $\mathbf{R=d/\lambda}$**,**where d is the thickness. As the R-value increases, the insulating performance improves. Conversely, the lower the U-value, the better the insulating performance. Commonly we use R-values for ceilings, walls and floors but use U-values for windows and glazed doors, although either can be used for any building element. The λ value can be thought of as the thickness giving an R value of 1, or as the U value of one meter of thickness.

Heat flow and insulation. Combining heat flow and insulation performance, we can calculate the conductive heat loss or gain as $\mathbf{Q=U.A.\Delta T}$, or $\mathbf{Q=A.\Delta T/R}$, where A is the area. For example with a wall, where temperature difference is 10°C, and thermal resistance is 0.5, and area is 20m^2, then heat flow through the wall will be 10 x 20/0.5 = 400W

The total R-value of a building element takes into account not only any insulation materials but also the construction materials (linings, cladding, timber, masonry), any internal air spaces, thermal bridging, and air films adjacent to all surfaces. So, uninsulated building elements have modest R-values: uninsulated walls typically in the range R0.5 (weatherboard, brick veneer, cavity brick) to R0.3 (concrete, 100mm thick); uninsulated timber floors around R0.4. Adding R2.5 batts into a weatherboard wall results in a total R-value for the wall of about R3.0.

Thermal bridging. Structures should avoid having any points where conductive heat can flow through very easily. Such points, which act as *thermal bridges,* can seriously compromise the overall thermal performance as shown in Figure 3.6, below. Ceiling joists and wall frames are examples of thermal bridges. The decreased R-value of a ceiling due to thermal bridging can be demonstrated by beginning with a bulk insulation material R-value of 2.5. When this is placed between timber joists it the resultant R-value for the whole ceiling is only R2.2 [18]. This can be further reduced if a material with a lower thermal resistance such as metal framing is used. This means that higher levels of insulation are required to compensate for this reduction in R-value.

Direction of heat flow. A particular ceiling, roof or floor has different R-values depending on whether the heat flow is up or down, relating to different performance in summer and winter. This effect is more marked where reflective insulation is used.

Combining multiple elements

R values add in series. A benefit of expressing insulation performance as an R value is that the cumulative effect of combining layers of different type is that the resultant R value is the simple sum of the thermal resistance of the layers.

Conduction adds in parallel. Calculating the net R value of side-by-side surfaces is not simply the arithmetic average of the R values.

For example, one square meter of window $R_1=0.2$ alongside one square meter of wall $R_2=2$ is not as simple as the layered case because U.A values add in parallel. So in this example, $A_1=1$, $U_1=5$ and $A_2=1$ $U_2=0.5$, therefore the $U.A_{total}=5.5$, i.e. $U_{average}=2.75$, so $R_{average}=0.36$.

Net insulation performance. The fact that U.A values add in parallel means that the net insulative performance of an entire house can be calculated as the sum of the U.A values of all the external faces. This becomes convenient for calculation since units of U.A become [W/K]. So the net thermal conduction in Watts is the net U.A value multiplied by the ΔT. Note U.A is the same as A/R. This method is applied in the example below.

The effect of gaps in insulation

In some situations ceiling insulation has gaps in it, such as where downlights are installed, or where fitting has been done incorrectly. The effect of this can be disproportionate to the area uninsulated because of the arithmetic consequences of conduction adding in parallel. The more insulation is installed, the greater the effect of gaps, as the graph below shows. For example, the insulation effectiveness of R6 insulation degrades by 50% if a mere 4% of the area is left uninsulated.

Figure 3.7 gives the typical thickness of various products to achieve an R value of 1. Rigid foam products require less thickness than the fibre products; for this reason they are favoured where space is limited, such as in cavity walls.

Implementation Recommendations

The insulation that can be installed in a particular building depends on the type of construction. For instance the type of insulation recommended for a home built on a concrete slab would differ from a home that has a suspended timber floor. The proposed treatments generally can be implemented without any permanent alteration of the building fabric (refer to Table 3.3).

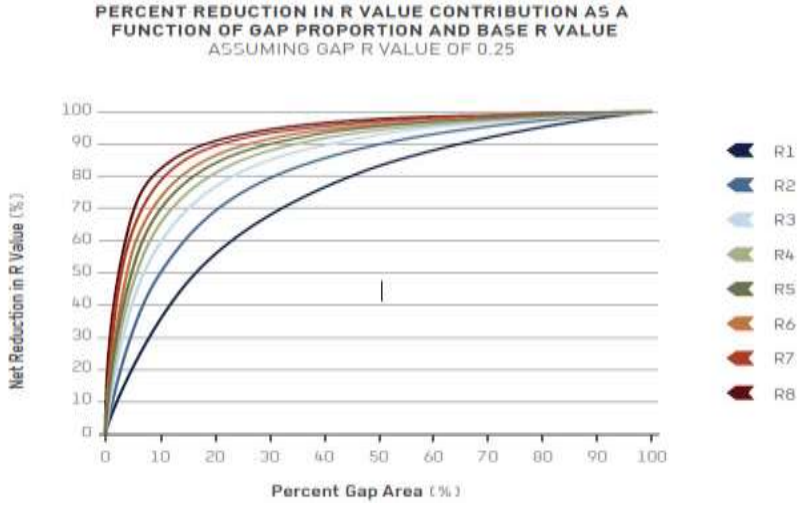


FIGURE 3.6

Insulation effectiveness degrades quickly with the size of gaps, especially for high R values

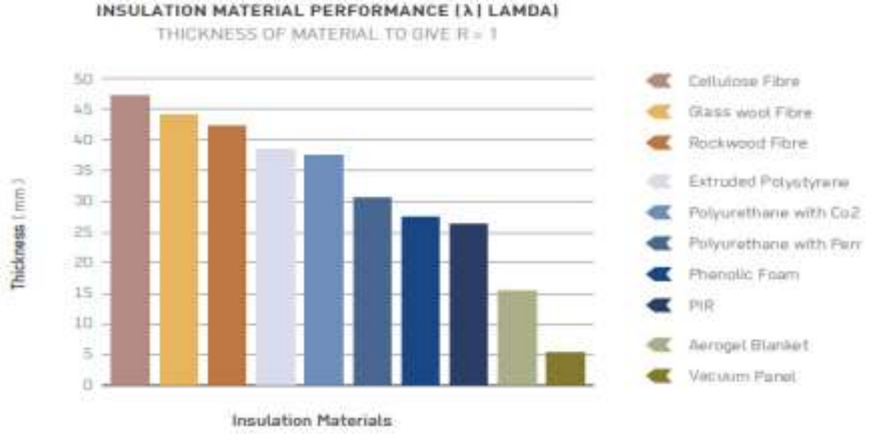


FIGURE 3.7

Insulation Performance values for a number of insulating materials

Example of Thermal Improvement

So what difference does insulation actually make in a house?

As a simple illustrative example, consider a modest-sized, rectangular weatherboard or brick veneer house 8m by 12m with 2.7m high walls and suspended timber floors. It is winter and the outdoor temperature is 10°C while inside it is 23°C.

TABLE 3.1

Element	**Uninsulated R values**	**Insulated R values**
Ceiling	0.5	6.0
Floor, Walls	0.5	2.5
Doors, Windows	0.17	0.4

The following calculations apply the methodology described above (net insulation performance) and ignore influences such as thermal mass, air leakage, and radiation gain/loss, mainly through windows.

Wall + glazed area = perimeter x wall height

$= 2(8 + 12) \times 2.7 = 108\text{m}^2$

The heat, measured in watts, lost through the ceilings, walls and floors is given by the formula: $\mathbf{Q = \Delta T.A/R}$, which is the same as: $\mathbf{Q = \Delta T.A.U}$, where A is area in m^2 and ΔT is temperature difference in °C.

TABLE 3.2

Element	Area	A/R uninsulated	A/R insulated
Ceiling	8 x 12m2 = 96m2	192 W/K	16 W/K
Wall	80% of 108m2 = 86.4m2	172 W/K	34.5 W/K
Floor	8 x 12m2 = 96m2	192 W/K	38.4 W/K
Glazing	20% of 108m2 = 21.6m2	127.9 W/K	54 W/K
Total Heat Loss Factor		683.9 W/K	142.9 W/K
Total heat loss with ΔT=13C		8890 W	1858 W

This means that to maintain the inside temperature at 23°C we would need to continuously run a heater at 8.9 kW in the uninsulated house but at only 1.9 kW in the insulated house, representing a reduction of 7.0 kW or 79%.

Doing the sums for the same house but where the ceilings had previously been insulated to R2.5, the results become 6.9 kW and 1.9 kW, representing a reduction of 5.0 kW or 73%.

The insulation levels proposed for residential buildings are higher than required for minimum compliance under the current National Construction Code (NCC). For non-residential buildings the added insulation levels are roughly in line with the NCC requirements.

General. The minimum requirements proposed for insulation installation include:

- Bulk insulation should not be compressed – it reduces its effectiveness
- No thermal bridges – such as metal ties that link the internal wall to the external wall
- No gaps in the insulation
- Allow clearance around fittings and appliances
- Protection from moisture/vapour or creation of a moisture barrier for prevention of condensation[18]

Roofs. The best approach for conventional residential roofs is to install R2.5 batts between ceiling joists then lay R3.5 at right angles to reduce the thermal bridging effect of the joists. For ceilings which already have some insulation, batts should be added at right angles to ceiling joists to bring the total R-value to R6.0. Obviously if the existing insulation has been poorly laid then this should be rectified before the top layer is added. If in-roof access is unavailable, then in regions where cooling load dominates, an alternative to bulk insulation is to use a cool-roof coating (see Cool Roofs).

Walls. Adding insulation to walls is currently much less common than adding it to roofs. However in structures with timber stud frames, and with cavity brick, it will often be possible to add bonded-bead or foam insulation through holes drilled in the surface.

As per the table above, the recommended method is to use bonded-bead injection. This is not yet widely available in Australia. A suitable alternative is injected foam which is currently more widely available.

Under-floor. Where under-floor access is available, floors should be insulated. If the recommended spray foam method is not possible, then a suitable alternative would be to use insulation batts in conjunction with sheets of Aircell which are non-conductively fastened between floor joists (Aircell is an insulating sheet material which looks like heavy-duty bubble wrap which is metalised on both sides. Electrical precautions apply).

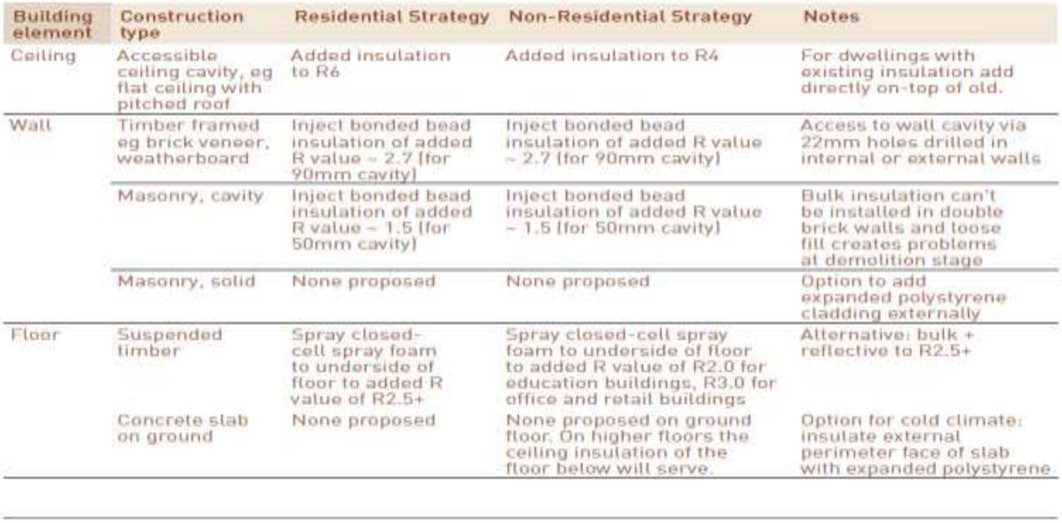
Product Issues and Development

Foil insulation. Reflective foil insulation is generally electrically conductive. The fixing of this insulation using metal staples has been associated with electrical risk. This type of insulation has limited application and is not generally recommended in the Buildings Plan. Where foil insulation is employed, it should be installed with due care and fixed in place using non-conductive means.

Insulation and electrical wiring. Installation of bulk insulation needs to take into account the requirements of electrical wiring standard AS/NZS 3008.1. In general this means a) insulation needs to be kept clear of light fittings (see Section 4.1.1), and b) the maximum-current rating of any wiring needs to be considered if it is covered by insulation.

Embodied chemicals. Historically there have been various issues with the manufacture of insulation. Some of these manufacturing issues have been of risk to the environment, or human health. The most significant environmental issue associated with insulation manufacture has been the use of chlorofluorocarbons (CFCs). CFCs were once used extensively as blowing agents. Almost all CFCs were phased out from insulation manufacturing by 1993 [19]. They were replaced in most products by Hydro chlorofluorocarbons (HCFCs). Whilst HCFCs contribute to global warming and some ozone depletion they have significantly less impact than CFCs. HCFC foam insulation materials are scheduled to be almost entirely eliminated by the year 2020 according to the Montreal Protocol on Substances That Deplete the Ozone Layer [20]. Whilst HCFCs are less damaging to the environment than CFCs they should be avoided where possible and spray foams that rely on water based blowing agents are recommended.

TABLE 3.3
Insulation recommendations



Building element	Construction type	Residential Strategy	Non-Residential Strategy	Notes
Ceiling	Accessible ceiling cavity, eg flat ceiling with pitched roof	Added insulation to R6	Added insulation to R4	For dwellings with existing insulation add directly on-top of old.
Wall	Timber framed eg brick veneer, weatherboard	Inject bonded bead insulation of added R value ~ 2.7 (for 90mm cavity)	Inject bonded bead insulation of added R value ~ 2.7 (for 90mm cavity)	Access to wall cavity via 22mm holes drilled in internal or external walls
	Masonry, cavity	Inject bonded bead insulation of added R value ~ 1.5 (for 50mm cavity)	Inject bonded bead insulation of added R value ~ 1.5 (for 50mm cavity)	Bulk insulation can't be installed in double brick walls and loose fill creates problems at demolition stage
	Masonry, solid	None proposed	None proposed	Option to add expanded polystyrene cladding externally
Floor	Suspended timber	Spray closed-cell spray foam to underside of floor to added R value of R2.5+	Spray closed-cell spray foam to underside of floor to added R value of R2.0 for education buildings, R3.0 for office and retail buildings	Alternative: bulk + reflective to R2.5+
	Concrete slab on ground	None proposed	None proposed on ground floor. On higher floors the ceiling insulation of the floor below will serve.	Option for cold climate: insulate external perimeter face of slab with expanded polystyrene

TABLE 3.4
Insulation material cost

Location	**Insulation Type and R Value**	**Material cost** ($/m^2)	**Cost** ($/household, including installation)
Ceiling	High-performance ceiling batts to R6.0	5 (for top-up from R2.5 to R6)	960 (for top-up from R2.5 to R6), 2,200 (for new R6)
Wall	Bonded-bead insulation to R2.5 (90mm cavity) or R1.5 (50mm cavity)	8	1,700
Floor	Closed-cell spray foam R2	20	3,900

Another issue with spray foams is the potential health hazards from exposure to the chemicals used during installation. The US EPA proposes that installers use protective equipment including respirators, eye protection, and chemical resistant clothing. This is due to concern about exposure to isocyanates, for which the US EPA says "if sensitized to isocyanates, even low concentrations of isocyanates can trigger a severe asthma attack or other lung effects, or a potentially fatal reaction" [9]. For the same reason it is recommended that re-entry to the building not occur before 24-72 hours have passed. While spray foams have initial risk they generally have low VOCs once fully set.

A great deal of controversy surrounds potential human health concerns regarding contact with synthetic mineral fibers, including fiberglass and mineral wool.

Extensive monitoring and research by the Insulation Council of Australia and New Zealand (ICANZ) has identified that 'no serious health effects have ever occurred in those manufacturing, using or otherwise exposed to glasswool or rockwool insulation [21]'. The handling of glasswool and rockwool may result in skin irritation and sensible work practices, and appropriate clothing are recommended [21].

In the past, concerns have been raised at the presence of formaldehyde as a binding agent in mineral wool. Formaldehyde is known to off-gas as a volatile compound that can affect health, particularly for asthma sufferers. Urea-formaldehyde is no longer used as a binding agent, and other formaldehyde-free products are now on the market. In addition a number of studies have shown that once properly installed the mineral wool batts are very stable and minimal off-gassing occurs [21, 18].

Other Service Upgrade Options

Brick and concrete walls can be insulated with external expanded polystyrene sheets. This is appropriate for temperate/heating-dominated climates as it would allow for the insulation of thermal mass, which could be utilised in conjunction with a passive solar heating strategy. Nonetheless this option is not proposed in the Buildings Plan due to diminishing returns if undertaken in conjunction with insulated cavities. Also, the proportion of the building stock that is single brick/concrete (i.e. without cavity) in temperate climates is relatively small (between 1% and 4% outside QLD & NT [22]).

Source: http://decarboni.se/publications/zero-carbon-australia-buildings-plan/2-improving-thermal-performance-building-envelope