Construction systems

The combinations of materials used to build the main elements of our homes — roof, walls and floor — are referred to as construction systems. They are many and varied, and each has advantages and disadvantages depending on climate, distance from source of supply, budget, maintenance requirements and desired style or appearance.

The environmental performance of a construction system is determined by life cycle or ‘cradle to grave’ analysis of the impact of the individual materials used in it. Preliminary decisions about construction systems are often made during the early design stages of a project whereas analysis of their environmental performance often occurs later during the detailed specification stage (see Before you begin). Making decisions in this order can limit the range of achievable and cost effective environmental outcomes.

Similar materials can have vastly different environmental impacts depending on where and how they are sourced. The source of the materials and the way they are processed ultimately determines their environmental impact. Give careful consideration to your choice of construction system early in the project, as changing systems late in the design or construction process can be costly, particularly if it requires structural alterations.

Most of Australia’s new housing stock is built to a common formula that varies only slightly, regardless of climate, geographic location and occupant lifestyle.

Choosing a construction system

Important factors influencing the selection of residential construction systems are:

- role in improving thermal performance
- durability compared to intended life span
- life cycle cost effectiveness
- life cycle energy consumption
- source and environmental impact of all component materials and processes
- availability of skills and materials
- maintenance requirements
- adaptability and reuse or recycling potential
- distances and transport modes required for components and system (road, rail or ship).

Decisions may also be guided by life cycle assessment, which is able to take into account a material’s environmental emissions and depletions from ‘cradle to grave’: source, extraction, manufacture, operating performance and end of life disposal or reuse.

There is no single best solution. Any combination of materials should be assessed in light of the above factors to arrive at the most appropriate compromise.
Every application is unique and should be individually evaluated. Exceptions are the norm — particularly in innovative design solutions.

Energy used for heating and cooling accounts for about 40% of home energy use (DEWHA 2008). Because the mass of materials influences thermal performance, embodied energy and many of the other factors listed above, it is a primary consideration from the earliest design stages.

Thermal performance of construction systems

An important point of differentiation between construction systems is their mass content. High and low mass materials make different thermal performance contributions depending on:

- the climate zone they are used in
- where they are used (internally or externally)
- availability or access to passive heating or cooling
- how they are designed to interact with or moderate the climate.

Mass can only contribute to thermal performance when it is exposed internally and insulated externally. When used this way as thermal mass, it can even out diurnal ranges by retaining or shedding heat. Diurnal variations greater than 6°C and access to passive heating and cooling are required for this. Where they are not accessible, low mass usually performs better.

When used externally, such as in brick veneer construction, high mass systems can have other advantages but do not contribute positively to thermal performance. Indeed, they can have a negative impact in poor designs. (see Thermal mass)

High mass systems

- generally have higher embodied energy
- can offset their embodied energy by reducing heating and cooling energy use over the life span of the home
- are most appropriate in climates with high diurnal (day–night) temperature ranges
- can be a liability in tropical climates where energy is used only for cooling
- require more substantial footing systems and cause greater site impact and disturbance
- are often quarried and processed with high environmental impact
- require careful cost–benefit analysis on remote sites where transport needs are significant.

Lightweight systems

- generally have lower embodied energy
- can yield lower total life cycle energy use, particularly where the diurnal range is low
- respond rapidly to external temperature changes or heating and cooling input
- can provide significant benefits in temperate and hot climates by cooling rapidly at night
- are often preferable on remote sites with high materials transport cost
- often require more heating and cooling energy in high diurnal range climates (where passive heating and cooling is available) due to their inability to moderate diurnal cycles
- can have thermal mass added through inclusion of water-filled containers or phase change materials (see Thermal mass)
- can have lower production impact if sustainably sourced.

Mixed mass systems

In most situations, a well-designed combination of low and high mass construction produces the best overall economic and environmental outcomes.

In temperate climates, the best overall outcome is most simply achieved with concrete slab-on-ground and lightweight walls. In hot humid climates, low mass construction is preferable. In cool climates, high mass is desirable. In cold and hot arid climates, careful positioning of low and high mass throughout the building is required to achieve the best outcomes. (see Design for climate)
Material Construction systems

Footings

Footings are the structures that transfer the weight of the home to the foundation material, most commonly soil. Footing systems must be designed to suit varying geotechnical (soil) conditions and provide adequate tie-down for the building structure under the site's wind classification. A good system meets these requirements while minimising both site disturbance and the quantities of materials with high embodied energy such as concrete and steel.

Lightweight framed systems have the lowest site impact and embodied energy. A broad range of lightweight steel footing systems is available including screw piles, adjustable steel piers on a simple concrete pad or bored columns, and pole and space frame systems.

Concrete slab integrated footings require substantial excavation on all but level sites, increasing impact. They can reduce construction costs where the slope is low and where the climate allows earth coupling to substantially offset additional embodied energy over the life cycle.

Waffle pod slabs are an effective structural solution where required for geotechnical reasons but should be used only on sites with moderate to reactive soils because the additional steel and concrete used wastes embodied energy on stable sites. Pods can be made from old car tyres filled with compacted fill. This maintains earth coupling whereas cardboard and expanded polystyrene (EPS) foam systems do not. EPS foam often contains highly detrimental greenhouse gases, with a higher embodied energy equivalent than carbon dioxide. This further increases the embodied energy level.

Detached strip footings combined with loadbearing brickwork to floor level can reduce excavation. However, brick dwarf walls with fill often increase the embodied energy of this system.

Engineered steel pile systems capable of supporting masonry walls are now available. They reduce excavation and site impact and make for faster construction. Cost varies with application but is generally more expensive than strip footings.

Floor systems

High mass floors

The most common high thermal mass floor system is concrete slab-on-ground. Earth coupled slabs are effective where deep (>3m) earth temperatures remain constantly between 16°C and 19°C. Where temperatures fall outside this range (e.g. Darwin or Tasmania), the underside should be insulated. (see Passive solar heating; Passive cooling; Concrete slab floors; Thermal mass)

Other systems include suspended slabs or precast concrete beams with lightweight infill and concrete topping. To contribute positively to thermal performance, the underside of suspended floors, including subfloor spaces, must be insulated if externally exposed (see Insulation).

Lightweight suspended concrete floor systems are competitive in cost with timber and steel framed floors, and can reduce site impacts where a slab floor is preferable to a lightweight floor. The slab underside must be insulated.

Compacted earth, flagstone or rock (e.g. Coober Pedy in central Australia) is used less commonly but is equally effective when properly designed and built for climate and site (see Thermal mass). Such systems have either low or no embodied energy and minimal transport impact. Generally low cost.

Low mass floors

The most common form of low mass flooring is lightweight timber or steel framing with particle board, timber, plywood or compressed fibre cement sheeting. When designed and built for deconstruction (e.g. screwed, not glued), this flooring has a high potential for reuse at the end of its life.

Lightweight steel framing has higher embodied energy than timber but is highly recyclable at the end of its life. Steel framing has greater durability in termite prone areas and often has lower transport costs than equivalent timber structures. It is subject to rust in corrosive environments; galvanising can eliminate this but does add to embodied energy. Usually more expensive than timber.

Lightweight timber framing using sustainably sourced plantation timber is a carbon sink effectively minimising embodied energy. Engineered timber bearers and joists allow for highly efficient use of materials but glues can have a detrimental effect on indoor air quality and human health. Timber is subject to termite attack and, while termite proofing reduces this risk, it often relies on chemical treatments that have other environmental implications. It is relatively low cost.
Engineered composite panel or structural insulated panel (SIP) systems are growing in popularity. Low mass insulation materials are bonded to lightweight steel or ply sheeting and usually achieve high levels of structural efficiency with inherently high insulation levels. Cost ranges from medium to high depending on the system.

Many of these low mass floor systems offer lower embodied energy, increased structural efficiency and reduced resource depletion when sustainably manufactured from environmentally preferred materials.

Composite mass floors

Common examples of composite mass floors are:

- lightweight frames topped with concrete
- lightweight systems with water filled inserts to provide thermal mass
- autoclaved aerated concrete (AAC) floor systems (see Autoclaved aerated concrete)
- phase change materials embedded in low mass materials to produce lightweight flooring with high thermal storage capacity (see Thermal mass; Mud brick).

Wall systems

High mass walls

Common high thermal mass wall systems are masonry and include brick, concrete block and precast concrete. Other popular systems include rammed earth and mud brick.

Traditional masonry systems generally have high embodied energy while rammed earth and mud brick have significantly less. Rammed earth uses varying levels of cement depending on earth type and therefore has higher embodied energy than mud brick. (see Rammed earth; Mud brick)

All high mass wall systems must be externally insulated and internally exposed to improve thermal performance. Insulation levels depend on internal–external temperature differentials. The higher the temperature differential, the more insulation required. (see Insulation; Thermal mass; Passive design)

Thermal lag (i.e. the retention of heat or cold) in thick walls such as rammed earth or mud brick can reduce the insulation level required in mild climates but may not eliminate it. This is a common misconception about these systems. Significant external insulation is required in cold climates and their use should be avoided in hot, humid climates. Thermal performance modelling determines climate appropriateness and appropriate insulation levels. (see Thermal mass)

Double brick — High embodied energy, high thermal mass, requires cavity insulation. Highly durable on stable soil types. Low maintenance (if unpainted). Can be crushed and recycled as decorative gravel or road base but recycling and reuse rates are low. High cost. (see Brickwork and blockwork)

Reverse brick veneer — Moderate embodied energy with clay bricks, reduces to medium with concrete blocks. High thermal mass and high thermal performance. Simply insulated externally. Low internal maintenance; external maintenance dependent on the cladding system selected. Very durable. Range of environmentally preferred external cladding includes fibre cement,
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- plywood, sustainably sourced timber or corrugated steel sheets (e.g. Colorbond®). Cost varies from average to high depending on mass type and cladding.

**Insulated concrete** (tilt-up or precast) — High embodied energy, high thermal mass, high insulation values possible. Low maintenance internally and externally depending on construction method and cladding system selected. Extremely durable, and can be relocated and reused. Typical painted finishes require higher maintenance. Good acoustic performance. High cost. Reduced construction times. (see *Insulating concrete forms*).

- **Low mass walls**
  The most common form of low mass wall construction uses lightweight timber or steel framing as the structural support system for non-structural cladding and linings such as fibre cement, plywood and steel. Insulated lightweight walls reduce heat loss and can have minimal embodied energy, depending on the cladding material used.
  
  Fibre cement sheet, plywood and other sheet cladding systems have low embodied energy and generally low environmental impact. They are very durable — although maintenance is required for any painted surface. (see *Embodied energy*).

**Lightweight timber** — Low to medium embodied energy. Medium to high insulation values. High maintenance unless protected from weather and termites. Suited to off-site and on-site fabrication. Relatively low transport costs. (see *Lightweight framing*).

- **Earth bermed** — High embodied energy (assuming precast concrete or reinforced block walls are used). Highest thermal mass with additional earth coupling benefits. High site impact during construction. Insulation not required in locations where earth temperatures are favourable. Extremely durable. Significant operational energy savings. High cost.

- **Rammed earth (pisé)** — Low to medium embodied energy, depending on cement content. High thermal mass. Poor insulation (difficult to add unless lined externally, as shown in the image on the previous page of a rammed earth building being externally insulated and lined). Minimal transport energy when used on remote sites. Minimal manufacturing process impact. Very durable but requires some maintenance where used externally (reapplication of waterproofing). Average to high site impact, depending on footing system. High cost. (see *Rammed earth*).

- **Structural insulated panels** — SIPs consist of an insulating layer of rigid insulation material sandwiched between two structural skins of sheet metal, plywood, fibre cement or engineered timber. These systems usually achieve high levels of structural efficiency with high insulation levels. Many now use environmentally preferred materials. One Australian SIP system, for example, uses panels made from forestry waste through a carbon zero manufacturing process. While already an environmentally preferred product, its sustainability performance could be further improved through use of recycled cellulose (paper) insulation as a substitute for the rigid foam insulation material.

  The range of SIP products is growing rapidly. These systems can be particularly effective because they position the mass where it is most useful and can use environmentally preferred materials to provide insulation and structural integrity.
Log walls — Low mass systems include log wall construction. While a broad range of systems is used, they generally achieve good insulation and have low environmental impact when logs are sustainably sourced. Construction detailing and timber stability are critical to retain airtightness and thermal performance. (see box ‘Log walls’)  

Cladding — Insulated lightweight walls reduce heat loss and can have minimal embodied energy, depending on the cladding material used. Fibre cement sheet, plywood and other sheet cladding systems have low embodied energy and generally low environmental impact. They are very durable, although maintenance is required for any painted surface. (see Embodied energy)  

Composite (mixed) mass walls  
These systems fit between high and low mass with either moderate density, such as AAC where high mass concrete is used to trap tiny (no mass) air bubbles, or a combination of high and low mass, like straw bale where straw is low mass and the render finish is high mass.  

AAC block — Medium to low embodied energy, fair thermal mass, fair insulation, average durability (depending on finishes). Maintenance required depends on finish but these blocks are prone to impact damage. They have low processing impacts and moderate transport requirements. (see Autoclaved aerated concrete)  

Concrete block — Block walls have lower embodied energy than concrete or brick because they are hollow and contain less concrete per square metre. However, when filled with concrete they can equal or exceed the embodied energy of brick. Fly ash blocks further reduce embodied energy. They have good thermal mass when filled with concrete, but low insulation values (which is difficult to add unless lined externally). Not easily recycled because they have insufficient strength for reuse as aggregate for concrete. Can be crushed as gravel or fill. Average cost.  

Mud brick (adobe) — Lowest embodied energy (if sourced locally), high thermal mass, poor insulation (difficult to add unless lined externally), suited to remote sites. High labour content. No manufacturing impact. Low site impact. Low cost if labour is not included (owner built). Requires regular waterproofing in exposed locations. (see Mud brick)  

Straw bale — Low embodied energy (some additional embodied energy and materials in extra width footings and slabs). Low–medium thermal mass (depending on render thickness). Extremely high insulation, excellent thermal performance, and high level renewable material content. Long term durability is unproven in Australia and maintenance levels are variable. Bales must be compressed well to minimise settlement and movement. Cost varies from average to high. (see Straw bale)  

Panel systems — Sandwich panels have varying embodied energy depending on surface materials and insulation. Other lightweight panel systems such as straw board and recycled paper products have low thermal mass, high insulation levels and very low embodied energy. They respond rapidly to heating and cooling and are ideally used with a high mass concrete slab floor. The recycled content of many commonly available systems is high. Reuse potential is good, waste rates are low and transport costs are low. Construction cost varies from high to average.
Log walls

Log wall construction — a low mass system — is one of the oldest methods of building, dating back to prehistoric times. It developed as a natural consequence of having a plentiful supply of tall, straight timber that could be relatively easily cut and worked and turned into building components. It is historically associated with countries and regions with tall pines and similarly straight-trunked trees. It appears to have first developed in northern Europe and spread with European colonisation, notably to North America where the indigenous pine forests provided plentiful timber suited to the method.

Australian log homes use solid timber logs. At least one supplier uses imported Scots pine and Norway spruce, laminated when wider logs are needed; others use Australian white cypress or Monterey pine (Pinus radiata), which is native to the central coast of California but widely grown in Australia as a plantation tree. Systems of log wall construction that use composite ‘logs’, each made of a timber plank sandwiching a layer of rigid insulation behind an outer face or veneer of natural log, have yet to enter the Australian market. A variant on the log facing technique is used on ‘log veneer’ houses in which logs are cut lengthwise to create cladding on insulated stud frames with timber panelled interior faces.

Appearance

Log walls that retain the natural shape of the original timbers can have a quite rustic appearance but those made with machine finished logs can present a very smooth, much more formal appearance. It is usual to finish the timbers with oils or coatings that allow the warm natural colour of the wood to show through.

Structural capability

In true log wall construction the horizontally laid logs are load bearing and the roof is constructed from substantial, solid timber members, often using traditional joints and details. Other variants include using large diameter logs to build post and beam frames that are filled with lighter stud-framed construction. In the least authentic (and most economical) form, the logs are an applied veneer and the structure is timber frame with the roof being made from lighter, smaller section timbers in a similar manner to conventional brick veneer houses. Machined and laminated ‘logs’ can be as narrow as 75mm, but solid natural logs can be 350–450mm in diameter. There are two main ways of joining solid timber logs horizontally: scribing the logs lengthwise to fit snugly onto each other, often incorporating grooves to improve weather sealing; and fitting the logs on top of one another and sealing the air gaps with caulking or foam backing rods.

The ends of the logs are ‘saddle notched’ to fit onto each other. Log walls may be finished with or without the logs extending past the corners, creating a stronger and more resilient structure if they do as this exploits the structural benefits of the interlocking joints.

Log walls can be built on almost any foundation, including stumps, pads and slabs.

Thermal mass and insulation

Log walls have moderate to good thermal insulation with thermal mass characteristics that become more significant as the wall thickness increases. Although some manufacturers’ information may indicate that solid log walls of 300mm diameter logs are on a par with straw bale construction, they are likely to be around R2 as the insulating value of straw bale is approximately three times that of timber per unit of thickness. However, log walls do possess a similar acoustic insulation capability to straw bale.

Fire resistance

In the same way that a large log takes a considerable time to burn through in a wood stove, so large diameter logs used in solid log wall construction do not burn easily and, depending on overall wall thickness (and whether the construction is scribed and interlocked or sealed with caulking), overall fire resistance can satisfy bushfire requirements.
Roof systems

High mass roof systems

Roof systems are unable to improve thermal performance in thermal mass terms unless they can be exposed internally and insulated externally. Because ceiling level insulation is critical, exposed roof mass is unusual except in multi-level homes or apartments.

Earth covered construction — A high mass roof system capable of delivering highest thermal performance. The thermal lag provided by the depth of earth cover or garden provides an adequate barrier to heat loss allowing the mass to be exposed internally. When carefully designed, these systems can provide sufficient thermal lag to moderate seasonal cycles so that summer earth temperatures reach the exposed ceiling mass in winter and vice versa. Maintenance free and very durable when waterproofed correctly. High site disturbance during construction, minimal on completion. High embodied energy and high cost. Rainwater collection is limited to out-buildings.

Durability, moisture and vermin resistance

Log walls are subject to the same vermin and hazards as other timber building systems and are protected in the same way with appropriate mechanical or chemical barriers.

Toxicity and environmental impacts

Log timber is non-toxic. Oils, stains, varnishes, rot protection and other finishes should be checked for toxicity before specification for application to the timber. Most log wall manufacturers claim to use plantation timbers. As log walls use timber that has had minimal processing, the overall environmental impacts have the potential to be significantly less than for conventional construction.

Buildability, availability and cost

Construction approaches range from fully handcrafted houses, with each log individually notched and fitted to the next, to machine finished ‘milled’ logs that are more regular in shape and require less labour on site. Log wall companies in Tasmania and the south-east of Australia are able to deliver projects anywhere in the country. The cost varies considerably according to location and the kind of log wall adopted, with fully scribed and notched solid log walls being the most expensive. It is not unusual for firms to preassemble log houses to test their buildability before site delivery.

Green roofs — An entirely different system to earth covered roofs. Growing medium is usually lightweight manufactured material. Insulation is medium to high and provided by conventional insulation rather than the covering. Medium to high embodied energy, depending on support structures. Thermal mass is generally inaccessible due to structure and insulation. Other environmental benefits include food production, reduction of heat island over built-up areas, air quality improvement and on-site stormwater detention. Medium to low maintenance for intensive roofs to high maintenance for most green wall systems. (see Green roofs and walls)

Low mass roof systems

The performance of lightweight timber or steel framed roof systems is similar to walls and frames. Variations in embodied energy arise from cladding systems that do not contribute to thermal performance.

Tiles — Concrete tiles have slightly lower embodied energy than terracotta. They require more structural support than lightweight materials and can add to heat gain (because they are external, uninsulated thermal mass) unless well insulated. While recycling and reuse rates are improving, they are still lower than other materials. Some manufacturers claim up to 40% recycled content in concrete tiles. High transport costs make them inappropriate for remote sites.

Metal sheeting — High embodied energy; very durable; ideal for transport to remote sites; available in light colours and reflective finishes to reduce heat gain in summer. Recycled content of up to 40% is common and end of life recycling or reuse rates are high.
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Other construction system considerations
A host of other considerations must be taken into account for construction systems. Many are beyond the scope of environmental performance addressed in Your Home and require expert advice from geotechnical and structural engineers.

For other considerations with environmental performance implications see the relevant articles including:

- specific site requirements such as slope, stormwater, sediment control, biodiversity impact, noise control and fire resistance (Choosing a site; Challenging sites)
- regulatory and planning issues (The liveable and adaptable house; Transport; the appendices Streetscape, Safety and security;)
- exposure to destructive forces of nature such as fire, termites, rain, UV and humidity (Challenging sites).

In most situations, a carefully designed combination of lightweight and heavyweight systems produces the best overall economic and environmental outcomes.

Rule-of-thumb checklist for choosing a construction system

Thermal mass
- Combine high and low mass construction within the building to maximise the benefits of each. (see Thermal mass; Passive design)
- Use heavyweight systems internally and lightweight systems externally for lowest lifetime energy use.
- Higher embodied energy content in heavyweight construction can outweigh operational energy savings, particularly in climates where heating and cooling energy requirements are low. (see Embodied energy)
- Where solar access is unachievable or undesirable (e.g. steep south facing sites, overshadowed sites or tropical locations), insulated lightweight construction is often more efficient as it responds rapidly to mechanical heating or cooling.

Maintenance
- Unpainted external brick cladding (brick veneer) has minimal maintenance requirements when compared to many alternative painted claddings.
- The durability of well-maintained lightweight systems is equivalent to heavyweight systems.
- Poor maintenance can reduce life span by up to 50%, negating embodied energy savings and doubling materials consumption.
- Reliable maintenance regimes for the whole life cycle are a critical consideration when selecting external cladding systems.

Source and use of materials
Choose materials that are:
- life cycle certified by an accredited scheme (e.g. GECA, Green Tick, EcoSpecifier)
- renewable in preference to those from finite resources
- low in embodied energy unless that embodied energy content can be amortised over life span through operating energy savings
- certified as not threatening to biodiversity
- low toxicity in both production and operation
- high in renewable or recycled content provided durability and performance are appropriate for life span (e.g. fibre cement cladding, sustainably managed forest timber frames or recycled plastic/sawdust decking).

Design for:
- deconstruction, recycling and reuse to amortise the life cycle impact of materials high in embodied energy or non-renewable resources (where these materials are the best option)
- structural efficiency to minimise overall materials use, waste, transport and processing
- materials with similar and appropriate life spans (e.g. use fixings, flashings or sealants with a similar life span to the material being fixed)
- construction systems with known low wastage rates and environmentally sound production processes (see Waste minimisation).

Transportation
- Avoid systems with a high on-site labour component in remote projects to reduce travelling.
- Use locally made products where possible to reduce transportation.
## References and additional reading

Contact your state or territory or local government for further information on building sustainability and energy efficiency: www.gov.au

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