Embodied energy

Embodied energy is the energy consumed by all of the processes associated with the production of a building, from the mining and processing of natural resources to manufacturing, transport and product delivery. Embodied energy does not include the operation and disposal of the building material, which would be considered in a life cycle approach. Embodied energy is the 'upstream' or 'front-end' component of the life cycle impact of a home.

A complex combination of many processed materials determines a building's total embodied energy.

The single most important factor in reducing the impact of embodied energy is to design long life, durable and adaptable buildings.

Every building is a complex combination of many processed materials, each of which contributes to the building's total embodied energy. Renovation and maintenance also add to the embodied energy over a building's life.

Choices of materials and construction methods can significantly change the amount of energy embodied in the structure of a building, as embodied energy content varies enormously between products and materials. Assessing the embodied energy of a material, component or whole building is often a complex task.

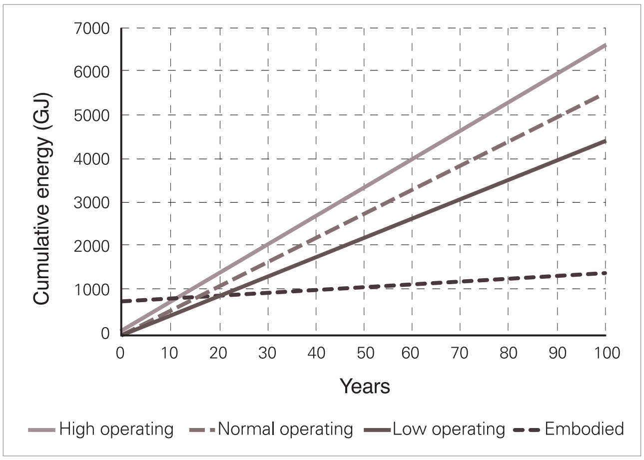
Embodied energy and operational energy

It was thought until recently that the embodied energy content of a building was small compared to the energy used in operating the building over its life. Therefore, most effort was put into reducing operating energy by improving the energy efficiency of the building envelope. Research has shown that this is not always the case.

Embodied energy can be the equivalent of many years of operational energy.

Operational energy consumption depends on the occupants. Embodied energy is not occupant dependent — the energy is built into the materials. Embodied energy content is incurred once (apart from maintenance and renovation) whereas operational energy accumulates over time and can be influenced throughout the life of the building.

Research by CSIRO has found that the average house contains about 1,000GJ of energy embodied in the materials used in its construction. This is equivalent to about 15 years of normal operational energy use. For a house that lasts 100 years this is over 10% of the energy used in its life.



Source: Adams, Connor and Ochsendorf 2006

Cumulative comparison of operating energy and embodied energy.

Embodied energy content varies greatly with different construction types. In many cases a higher embodied energy level can be justified if it contributes to lower operating energy. For example, large amounts of thermal mass, high in embodied energy, can significantly reduce heating and cooling needs in well designed and insulated passive solar houses. (see *Passive solar heating*; *Passive cooling*; *Insulation*; *Thermal mass*)

As the energy efficiency of houses and appliances increases, embodied energy will become increasingly important.

The embodied energy levels in materials will be reduced as the energy efficiency of the industries producing them is improved. However, a demonstrated demand for materials low in embodied energy is also needed.

Assessing embodied energy

Whereas the energy used in operating a building can be readily measured, the embodied energy contained in the structure is difficult to assess. This energy use is often hidden.

It also depends on where boundaries are drawn in the assessment process. For example, whether to include:

- the energy used to transport the materials and workers to the building site
- just the materials for the construction of the building shell or all materials used to complete the building such as bathroom and kitchen fittings, driveways and outdoor paving
- the upstream energy input in making the materials (such as factory/office lighting, the energy used in making and maintaining the machines that make the materials)
- the embodied energy of urban infrastructure (roads, drains, water and energy supply).

Gross energy requirement (GER) is a measure of the true embodied energy of a material, which would ideally include all of the above and more. In practice this is usually impractical to measure.

Process energy requirement (PER) is a measure of the energy directly related to the manufacture of the material. This is simpler to quantify. Consequently, most figures quoted for embodied energy are based on the PER. This would include the energy used in transporting the raw materials to the factory but not energy used to transport the final product to the building site.

In general, PER accounts for 50–80% of GER. Even within this narrower definition, arriving at a single figure for a material is impractical as it depends on:

- efficiency of the individual manufacturing process
- the fuels used in the manufacture of the materials
- the distances materials are transported
- the amount of recycled product used.

Each of these factors varies according to product, process, manufacturer and application. They also vary depending on how the embodied energy has been assessed.

Estimates of embodied energy can vary by a factor of up to ten. As a result, figures quoted for embodied energy are broad guidelines only and should not be taken as correct. Consider the relative relationships and try to use materials that have the lower embodied energy.

Try to use materials that have lower embodied energy.

Precautions when comparing embodied energy analysis results

The same caution about variability in the figures applies to assemblies as much as to individual materials. For example, it may be possible to construct a concrete slab with lower embodied energy than a timber floor if best practice is followed.

Where figures from a specific manufacturer are available, compare them with care to figures produced by other manufacturers or in the tables below.

Different calculation methods produce vastly different results (by a factor of up to ten). For best results, compare figures produced by a single source using consistent methodology and base data.

Given this variability it is important not to focus too much on the ‘right’ numbers but to follow general guidelines. Precise figures are not essential to decide which building materials to use to lower the embodied energy in a structure.

Embodied energy of common materials

Typical figures for some Australian materials are given in the tables that follow. Generally, the more highly processed a material is the higher its embodied energy.

Embodied energy for common building materials

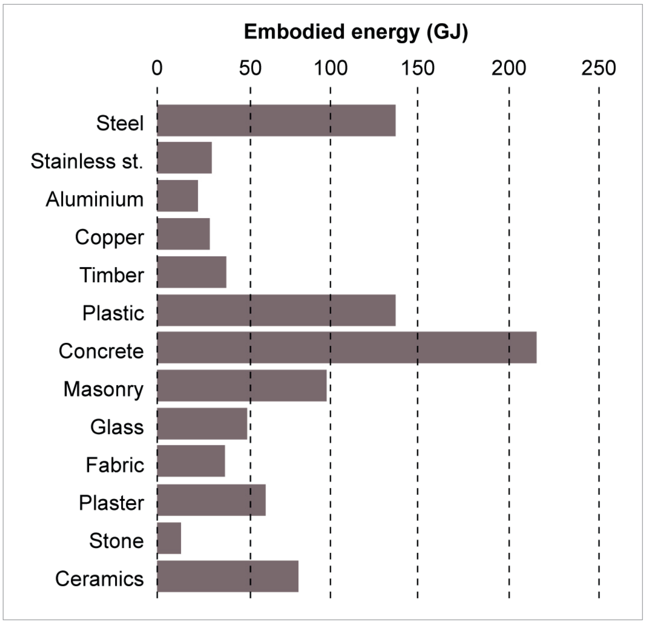
Material	PER embodied energy MJ/kg
Kiln dried sawn softwood	3.4
Kiln dried sawn hardwood	2.0
Air dried sawn hardwood	0.5
Hardboard	24.2
Particleboard	8.0
MDF (medium density fibreboard)	11.3
Plywood	10.4
Glue-laminated timber	11.0
Laminated veneer lumber	11.0
Plastics — general	90.0
PVC (polyvinyl chloride)	80.0
Synthetic rubber	110.0
Acrylic paint	61.5
Stabilised earth	0.7
Imported dimensioned granite	13.9
Local dimensioned granite	5.9
Gypsum plaster	2.9
Plasterboard	4.4
Fibre cement	4.8*
Cement	5.6
In situ concrete	1.9
Precast steam-cured concrete	2.0
Precast tilt-up concrete	1.9
Clay bricks	2.5
Concrete blocks	1.5
Autoclaved aerated concrete (AAC)	3.6
Glass	12.7
Aluminium	170.0
Copper	100.0
Galvanised steel	38.0

* Fibre cement figure updated from earlier version and endorsed by Dr Lawson.
Source: Lawson 1996

These figures should be used with caution because:

- the actual embodied energy of a material manufactured and used in one location, e.g. Melbourne, is very different from the same material transported by road to Darwin
- aluminium from a recycled source contains less than 10% of the embodied energy of aluminium manufactured from raw materials
- materials of high monetary and high embodied energy value, such as stainless steel, are almost certain to have been recycled many times, reducing their life cycle impact.

The graph below, based on CSIRO research, shows levels of embodied energy for materials used in the average Australian house.



Source: CSIRO

Levels of embodied energy for materials used in the average Australian house.

Materials with the lowest embodied energy, such as concrete, bricks and timber, are usually consumed in large quantities. Materials with high energy content such as stainless steel are often used in much smaller amounts. As a result, the greatest amount of embodied energy in a building can be from either low embodied energy materials such as concrete or high embodied energy materials such as steel.

Materials
Embodied energy

Embodied energy for assembled floors and roofs

Assembly	PER embodied energy MJ/m^2
Floors	
Elevated timber floor	293
110mm concrete slab-on-ground	645
200mm precast concrete, T beam/infill	644
Roofs	
Timber frame, concrete tile, plasterboard ceiling	251
Timber frame, terracotta tile, plasterboard ceiling	271
Timber frame, steel sheet, plasterboard ceiling	330

Source: Lawson 1996

For most people it is more useful to think in terms of building components and assemblies rather than individual materials. For example, a brick veneer wall contains bricks, mortar, ties, timber, plasterboard and insulation.

Comparing the energy content per square metre of construction is easier for designers than looking at the energy content of all the individual materials used. The table below shows some typical figures derived for a range of construction systems.

Embodied energy for assembled walls

Assembly	PER embodied energy MJ/m^2
Single skin AAC block wall	440
Single skin AAC block wall gyprock lining	448
Single skin stabilised (rammed) earth wall (5% cement)	405
Steel frame, compressed fibre cement clad wall	385
Timber frame, reconstituted timber weatherboard wall	377
Timber frame, fibre cement weatherboard wall	169
Cavity clay brick wall	860
Cavity clay brick wall with plasterboard internal lining and acrylic paint finish	906
Cavity concrete block wall	465

Source: Lawson 1996

Guidelines for reducing embodied energy

Lightweight building construction such as timber frame is usually lower in embodied energy than heavyweight construction. This is not necessarily the case if large amounts of light but high energy materials such as steel or aluminium are used.

There are many situations where a lightweight building is the most appropriate and may result in the lowest life cycle energy use (e.g. hot, humid climates; sloping or shaded sites; sensitive landscapes).

In climates with greater heating and cooling requirements and significant day–night temperature variations, embodied energy in a high level of well-insulated thermal mass can significantly offset the energy used for heating and cooling.

There is little benefit in building a house with high embodied energy in the thermal mass or other elements of the envelope in areas where heating and cooling requirements are minimal or where other passive design principles are not applied.

Each design should select the best combination for its application based on climate, transport distances, availability of materials and budget, balanced against known embodied energy content.

The guidelines

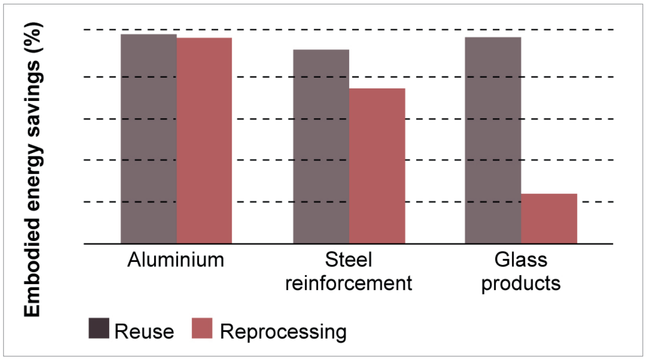
- Design for long life and adaptability, using durable low maintenance materials.
- Ensure materials can be easily separated.
- Avoid building a bigger house than you need — and save materials.
- Modify or refurbish instead of demolishing or adding.
- Ensure construction wastes and materials from demolition of existing buildings are reused or recycled.
- Use locally sourced materials (including materials salvaged on site) to reduce transport.
- Select low embodied energy materials (which may include materials with a high recycled content), preferably based on supplier-specific data.
- Avoid wasteful material use. For example, specify standard sizes wherever possible (windows, door, panels) to avoid using additional materials as fillers. Some energy intensive finishes, such as paints, often have high wastage levels so try to buy only as much as you need.
- Ensure offcuts are recycled and use only sufficient structural materials to ensure stability and meet construction standards.

- Select materials that can be reused or recycled easily at the end of their lives using existing recycling systems.
- Give preference to materials that have been manufactured using renewable energy sources.
- Use efficient building envelope design and fittings to minimise materials (e.g. an energy efficient building envelope can downsize or eliminate the need for heaters and coolers, water-efficient taps can allow downsizing of water pipes).
- Ask suppliers for information on their products and share this information.

Reuse and recycling

Reuse of building materials commonly saves about 95% of embodied energy that would otherwise be wasted. However, some materials such as bricks and roof tiles may be damaged when reused.

Savings from recycling of materials for reprocessing varies considerably, with savings up to 95% for aluminium but only 20% for glass. Also, some reprocessing may use more energy, particularly if long transport distances are involved. (see *Waste minimisation*)



Source: CSIRO

Comparative savings associated with recycling and reprocessing.

Life cycle assessment

Life cycle assessment (LCA) examines the total environmental impact of a material or product through every step of its life — from obtaining raw materials (e.g. through mining or logging) all the way through manufacture, transport to a store, and using it in the home, to disposal or recycling.

LCA can consider a range of environmental impacts such as resource depletion, energy and water use, greenhouse emissions, waste generation and so on.

LCA can be applied to a whole product (a house or unit) or to an individual element or process included in that product. It is necessarily complex and the details are beyond the scope of this article. An internationally agreed standard (ISO 14040:2006, Environmental management — life cycle assessment — principles and framework) defines standard LCA methodologies and protocols.

References and additional reading

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Author

Principal author: Geoff Milne

Contributing author: Chris Reardon

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