Embodied energy

Embodied energy is the energy consumed by all of the processes associated with the production of a building, from the acquisition of natural resources to product delivery. This includes the mining and manufacturing of materials and equipment, the transport of the materials and the administrative functions. Embodied energy is a significant component of the lifecycle impact of a home.

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.

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. Most effort was therefore 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.

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

LIFE CYCLE ASSESSMENT

The materials we use to build our homes have many "unseen" adverse environmental impacts.

The importance of embodied energy and other environmental impacts does not become apparent until we examine the materials from a life cycle approach, usually known as Life Cycle Assessment (LCA).

LCA examines the total environmental impact of a material or product through every step of its life - from obtaining raw materials (for example, through mining or logging) all the way through manufacture, transport to a store, using it in the home and 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 fact sheet. An internationally agreed standard (ISO 14040) defines standard LCA methodologies and protocols.

THE IMPORTANCE OF EMBODIED ENERGY

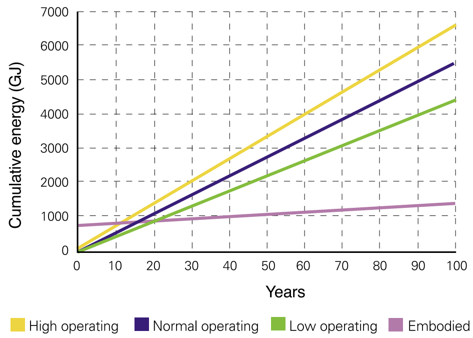
Choices of materials and construction methods can significantly change the amount of energy embodied in the structure of a building.

Embodied energy content varies enormously between products and materials.

True low energy building design will consider this important aspect and take a broader life cycle approach to energy assessment. Merely looking at the energy used to operate the building is not really acceptable.

Operational energy consumption is dependent 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 household contains about 1,000 GJ of energy embodied in the materials used in its construction. This is equivalent to about 15 years of operational energy use. For a house that lasts 100 years this is over 10 percent of the energy used in its life.



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: Thermal Mass; Passive Solar Heating; Passive Cooling; Insulation Overview]

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, there also needs to be a demonstrated demand for materials low in embodied energy.

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 and can only be fully quantified through a complete LCA.

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, outdoor paving, etc.

> 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, etc.).

> 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 to 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 manufacture of the materials.

> The distances materials are transported.

> The amount of recycled product used, etc.

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 10. As a result, figures quoted for embodied energy are broad guidelines only and should not be taken as 'correct'. What is important is to consider the relative relationships and try to use materials that have the lower embodied energy.

EMBODIED ENERGY OF COMMON MATERIALS

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

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	11.3
Plywood	10.4
Glue-laminated timber	11.0
Laminated veneer lumber	11.0
Plastics - general	90
PVC	80.0
Synthetic rubber	110.0
Acrylic paint	61.5
Stabilised earth	0.7
Imported dimension granite	13.9
Local dimension granite	5.9
Gypsum plaster	2.9
Plasterboard	4.4
Fibre cement	4.8*
Cement	5.6
Insitu Concrete	1.9
Precast steam-cured concrete	2.0
Precast tilt-up concrete	1.9
Clay bricks	2.5
Concrete blocks	1.5
AAC	3.6
Glass	12.7
Aluminium	170
Copper	100
Galvanised steel	38

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

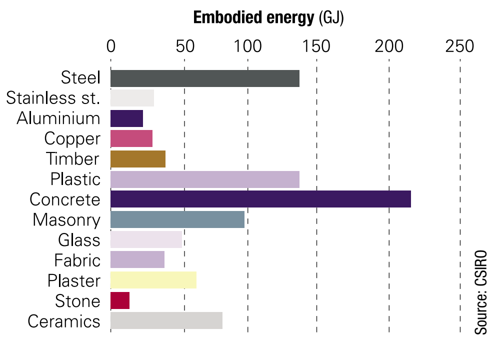
These figures should be used with caution because:

> The actual embodied energy of a material manufactured and used in Melbourne will be very different if the same material is transported by road to Darwin.

> Aluminium from a recycled source will contain less than 10 percent of the embodied energy of aluminium manufactured from raw materials.

> High monetary value, high embodied energy materials, such as stainless steel, will almost certainly be recycled many times, reducing their lifecycle impact.

CSIRO research has found that materials used in the average Australian house contain the following levels of embodied energy.



Materials with the lowest embodied energy intensities, 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 either from low embodied energy materials such as concrete, or high embodied energy materials such as steel.

ASSEMBLY	PER EMBODIED ENERGY MJ/m²
Walls	
Timber frame, timber weatherboard, plasterboard lining	188
Timber frame, clay brick veneer, plasterboard lining	561
Timber frame, aluminium weatherboard, plasterboard lining	403
Steel frame, clay brick veneer, plasterboard lining	604
Double clay brick, plasterboard lined	906
Cement stabilised rammed earth	376

Source: Lawson 1996

ASSEMBLY	PER EMBODIED ENERGY MJ/m²
Floors	
Elevated timber floor	293
110 mm concrete slab on ground	645
200 mm 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 will contain 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 above shows some typical figures that have been derived for a range of construction systems.

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, care should be exercised in making comparisons to figures produced by other manufacturers or in tables such as those above.

Different calculation methods produce vastly different results (by a factor of up to 10). 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.

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 lifecycle energy use (eg. hot, humid climates, sloping or shaded sites or 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.

Try to follow these 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. This will save materials.

> Modify or refurbish instead of demolishing or adding.

> Ensure materials from demolition of existing buildings, and construction wastes are re-used 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.

> Specify standard sizes, don't use energy-intensive materials as fillers.

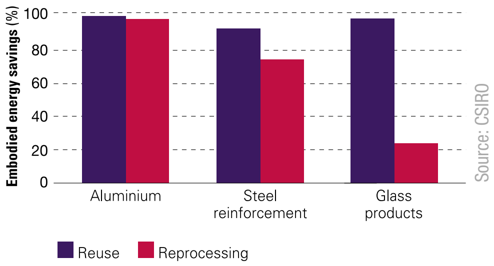
> Ensure off-cuts are recycled and avoid redundant structure, etc. Some very energy intensive finishes, such as paints, often have high wastage levels.

> Select materials that can be re-used or recycled easily at the end of their lives using existing recycling systems.

> Give preference to materials manufactured using renewable energy sources.

> Use efficient building envelope design and fittings to minimise materials (eg. an energy efficient building envelope can downsize or eliminate the need for heaters and coolers, water-efficient taps allow downsizing of water pipes, etc).

> Ask suppliers for information on their products and share this information.



REUSE AND RECYCLING OF MATERIALS TO REDUCE EMBODIED ENERGY

Some materials such as bricks and roof tiles suffer damage losses up to 30% in reuse.

Reuse of building materials commonly saves about 95% of embodied energy that would otherwise be wasted.

Savings from recycling of materials for reprocessing varies considerably with savings up to 95% for aluminium but only 20% for glass.

Some reprocessing may use more energy, particularly if long transport distances are involved.

ADDITIONAL KEY REFERENCES

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Treloar, G Fay, R 1998 *The embodied energy of living* EDG GEN 20 RAIA

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