Measures of Sustainability

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Embodied Energy

Embodied energy in building materials has been studied for the past several decades by researchers interested in the relationship between building materials, construction processes, and their environmental impacts.

What is embodied energy?

There are two forms of embodied energy in buildings:

· ***Initial embodied energy;*** and
· ***Recurring embodied energy***

The ***initial embodied energy*** in buildings represents the non-renewable energy consumed in the acquisition of raw materials, their processing, manufacturing, transportation to site, and construction. This initial embodied energy has two components:

Direct energy the energy used to transport building products to the site, and then to construct the building; and

Indirect energy the energy used to acquire, process, and manufacture the building materials, including any transportation related to these activities.

The ***recurring embodied energy*** in buildings represents the non-renewable energy consumed to maintain, repair, restore, refurbish or replace materials, components or systems during the life of the building.

As buildings become more energy-efficient, the ratio of embodied energy to lifetime consumption increases. Clearly, for buildings claiming to be "zero-energy" or "autonomous", the energy used in construction and final disposal takes on a new significance.

	EMBODIED ENERGY	
MATERIAL	MJ/kg	MJ/m3
Aggregate	0.10	150
Straw bale	0.24	31
Soil-cement	0.42	819
Stone (local)	0.79	2030
Concrete block	0.94	2350
Concrete (30 Mpa)	1.3	3180
Concrete precast	2.0	2780
Lumber	2.5	1380
Brick	2.5	5170
Cellulose insulation	3.3	112
Gypsum wallboard	6.1	5890
Particle board	8.0	4400
Aluminum (recycled)	8.1	21870
Steel (recycled)	8.9	37210
Shingles (asphalt)	9.0	4930
Plywood	10.4	5720
Mineral wool insulation	14.6	139
Glass	15.9	37550
Fiberglass insulation	30.3	970
Steel	32.0	251200
Zinc	51.0	371280
Brass	62.0	519560
PVC	70.0	93620
Copper	70.6	631164
Paint	93.3	117500
Linoleum	116	150930
Polystyrene Insulation	117	3770
Carpet (synthetic)	148	84900
Aluminum	227	515700

NOTE: Embodied energy values based on several international sources - local values may vary.

How is it measured?

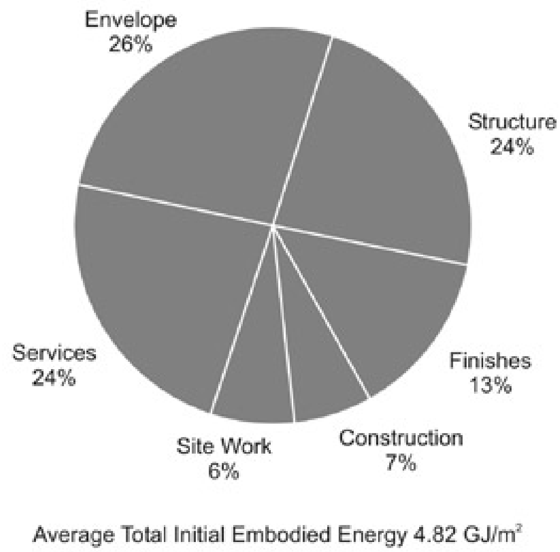
Typically, embodied energy is measured as a quantity of non-renewable energy per unit of building material, component or system. For example, it may be expressed as megaJoules (MJ) or gigaJoules (GJ) per unit of weight (kg or tonne) or area (square metre). The process of calculating embodied energy is complex and involves numerous sources of data. Refer to the Related Resources + References page for further information on embodied energy.

Implicit in the measure of embodied energy are the associated environmental implications of resource depletion, greenhouse gases, environmental degradation and reduction of biodiversity. As a rule of thumb, embodied energy is a reasonable indicator of the overall environmental impact of building materials, assemblies or systems. However, it must be carefully weighed against performance and durability since these may have a mitigating or compensatory effect on the initial environmental impacts associated with embodied energy.

How much embodied energy is typically found in buildings?

The amount of embodied energy in buildings varies considerably. Initial embodied energy consumption depends on the nature of the building, the materials used and the source of these materials (this is why data for a building material in one country may differ significantly from the same material manufactured in another country). The recurring embodied energy is related to the durability of the building materials, components and systems installed in the building, how well these are maintained, and the life of the building (the longer the building survives, the greater the expected recurring energy consumption).

Research carried out by Cole and Kernan(1) using a model based on Canadian construction of a generic 4 620 m2 (50,000 ft2) three-storey office building with underground parking, considered three different construction systems (wood, steel and concrete), and yielded the following results for average total initial embodied energy. (Note: Data were averaged for the three construction systems as the overall differences between the building types were not significant.

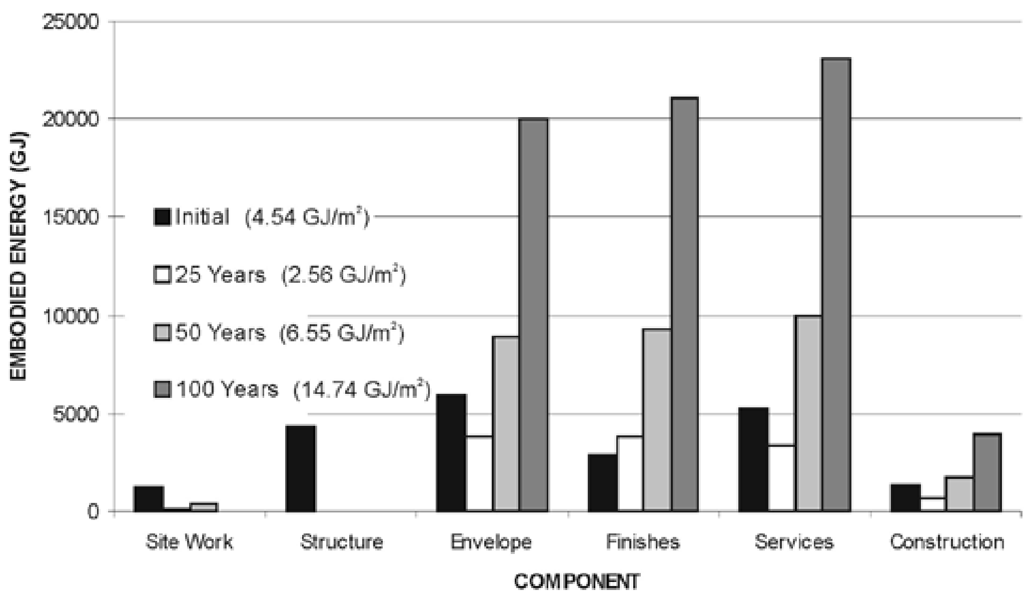


Breakdown of Initial Embodied Energy by Typical Office Building Components Averaged Over Wood, Steel and Concrete Structures [Cole and Kernan, 1996].

The building envelope, structure and services contribute fairly equally and account for about three-quarters of total initial embodied energy. The finishes, which represent only 13% of the embodied energy initially, typically account for the highest increase in recurring embodied energy. Embodied energy may not be significantly different between building systems (e.g., wood versus steel versus concrete), however, the environmental impacts associated with one material versus another can be dramatically different.(2)

It is interesting to consider the relationship between site work (6% of initial embodied energy) and services (24%). The reallocation of embodied energy, and hence project budget, from conventional services to the site management of stormwater, for example, may have a negligible effect on initial embodied energy, but the impact on recurring embodied energy may prove significant. Additional benefits downstream of the building at the community infrastructure level should also be considered. This points to one of the shortcomings of embodied energy analysis, which typically ends at the property line and is somewhat unwieldy in dealing with a broader context.

When recurring embodied energy in buildings is considered, yet more interesting relationships are revealed from the work of Cole and Kernan. First, to the credit of civil engineers, the structures of buildings normally do not expend recurring embodied energy, lasting the life of the building. By year 25, however, a typical office building will see an increase of almost 57% of its initial embodied energy due mostly to envelope, finishes and services. By year 50, recurring embodied energy will represent about 144% of the initial embodied energy, and it was projected that by year 100, this proportion would rise to almost 325%. This relationship is a direct result of what is referred to as ***differential durability***, where the service lives of the various materials, components, and systems comprising the building differ dramatically. The current preoccupation with lower first costs in buildings reveals its disregard for sustainability when viewed from a building life cycle perspective.



Comparison of Initial to Recurring Embodied Energy for Wood Structure Building Over a 100-Year Lifespan [Cole and Kernan, 1996].

Is embodied energy a useful measure?

Embodied energy can be a very useful measure provided it is not viewed in absolute terms. The initial embodied energy of various materials, components and systems can vary between projects, depending on suppliers, construction methods, site location and the seasonality of the work (e.g., winter heating). The recurring embodied energy is difficult to estimate over the long term since the non-renewable energy contents of replacement materials, components or systems are difficult to predict. For example, how energy intensive will glass be 100 years from now? However, as buildings become more energy efficient and the amount of operating energy decreases, embodied energy becomes a more important consideration. There also exist strong correlations between embodied energy and environmental impacts. But it is widely acknowledged today that embodied energy represents one of many measures and should not be used as the sole basis of material, component or system selection.

FOOTNOTES:
1.Cole, R.J. and Kernan, P.C. (1996), Life-Cycle Energy Use in Office Buildings, Building and Environment, Vol. 31, No. 4, pp. 307-317.

2.Comparing the Environmental Effects of Building Systems, Wood the Renewable Resource Case Study No.4, Canadian Wood Council, Ottawa, 1997.

The next section deals with Operating Energy as a measure of sustainability.

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