ENVIRONMENT DESIGN GUIDE

BUILDING MATERIALS SELECTION – GREENHOUSE STRATEGIES

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SUMMARY OF

ACTIONS TOWARDS SUSTAINABLE OUTCOMES

Environmental Issues/Principal Impacts

- Buildings contribute substantially to greenhouse gas emissions through the energy used to operate them and produce building materials and components.
- Embodied energy represents 10 to 40 times the annual operational energy, depending mainly on efficiency.

Basic Strategies

In many design situations, boundaries and constraints limit the application of cutting EDGe actions. In these circumstances, designers should at least consider the following:

For residential buildings:

- use mass and insulation, located and sized according to the climate in which the building is located
- for high rise residential buildings, recognise and value the embodied energy of the structure.

For commercial buildings:

- structural and cladding systems should be designed to optimise embodied energy
- minimise redundant features and maximise usable space
- reduce the 'churn' rate of interior fitouts including furniture.

For all buildings:

- use long-life materials and components to optimise embodied energy
- design for a long building life and loose fit to allow for adaptation
- analyse the building as a system – do not make a decision based on embodied energy information alone.

Cutting EDGe Strategies

- Emphasise conservation of historic buildings and those that happen to have outlived their financial lives.
- Assess the energy payback period of any proposed strategy to ensure its life cycle environmental effect is positive.
- Use recycled materials and materials with high recycled content where possible.
- Undertake life cycle energy simulations and costing to assess building designs under consideration, to identify and rank scenarios in terms of financial and environmental improvement.
- Optimise the operational energy of building and, as a consequence, reduce plant size, also saving embodied energy.
- Be aware that reducing embodied energy also reduces embodied water (GEN 58) though there are exceptions.

Synergies and References

- BDP *Environment Design Guide*: GEN 58

NB It was found that recent updates to embodied energy figures have not changed the essence of the recommendations in the note.

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This Note considers the embodied energy of building materials in the context of greenhouse gas emissions mitigation strategies. Previous practice and research are highlighted where they have the potential to influence design decisions. Latest embodied energy figures are indicated, and the implications of applying these figures to whole buildings are discussed. Several practical examples are given to aid building designers in the selection of building materials for reduced overall life cycle greenhouse gas emissions.

1.0 INTRODUCTION

The selection of materials is one of several factors influencing the operational energy requirements of buildings, particularly heating and cooling energy. In addition, energy is used in the processing of raw materials and in the manufacture and installation of building materials and products. This is referred to as the embodied energy of a building. Greenhouse gases are emitted as a consequence of the operational and embodied energy associated with all buildings. The selection and use of materials and products influences both the operational energy and the energy embodied in the building. Over the lifetime of buildings, it is desirable that overall energy use and material consumption is minimised. In some cases, reductions in operational energy can require increased embodied energy. This indicates the need to calculate the energy pay back period and energy return on investment. In all cases, both embodied energy and operational energy should be optimised. This Note examines these issues for building materials and components. Through the use of examples in the context of whole buildings, this Note suggests strategies to assist designers optimise the life cycle greenhouse gas emissions associated with materials, systems, and energy saving features for buildings.

2.0 BACKGROUND

Embodied energy represents 20 to 50 times the annual operational energy of most Australian residential, commercial, institutional and educational buildings. This ratio depends on building design, fuel type, equipment type and operational efficiency, climate and the method of energy analysis used. Each year in Australia, the embodied energy used in construction is approximately equal to the annual operational energy of the built stock, and together they make up 30-40% of national energy use and greenhouse gas emissions. Material and product selection can influence heating and cooling energy, e.g. through insulation, mass and window design and specifications. Design changes to reduce operational energy can result in increased material usage, and hence embodied energy requirements. Therefore, rather than focusing on either operational energy or embodied energy, building designers should adopt an integrated design approach.

Methods for the embodied energy analysis of building materials comprise process analysis, input-output analysis and hybrid analysis. Process analysis, while accurate for particular processes, often ignores a large number of small to medium processes. Input-output analysis, despite its many inherent errors, is used because of its unique property of systemic completeness. Hybrid analysis methods attempt to reduce the errors inherent in each of the two previous methods. Errors for process analysis data are ±10% (Boustead and Hancock, 1979), for input-output data errors are approximately ±50% (Miller and Blair, 1986), and for the hybrid analysis method errors vary between these rates, depending upon the mix of process and input-output data. This methodological discussion might seem irrelevant to most outside the field of embodied energy analysis but they are crucial concepts for anyone wishing to use embodied energy figures in decision-making (as noted below).

2.1 Sourcing materials

The source of materials influences the embodied energy of buildings, including:

- transport distances (for example, savings from using an efficiently manufactured material may be reduced if materials are transported long distances)
- country of origin (for imported materials, fuel supply structures may differ from those of Australia)
- process type (for example, for the dry and wet processes for cement manufacture, the former is 50% more efficient than the latter, [ESDWG, 1991]); and
- raw material source and quality (for example, raw material moisture content can vary the energy required to fire bricks, as well as kiln type, process efficiency, climatic variations and brick type, [Sinclair, 1986]).

2.2 Comparing materials and components

Embodied energy should not be seen as the only selection parameter. Other issues include:

- non-energy greenhouse emissions and environmental impacts
- financial viability
- operational energy and performance

- building or component lifetime; and
- aesthetic, social and cultural issues.

Furthermore, where there is only a small difference between the embodied energy of materials, building systems or buildings being compared, the errors associated with the embodied energy analysis methods may lead to inappropriate decisions. There are many circumstances where error ranges are not significant, but few can be predicted before conducting any embodied energy calculations. The following principles are worth considering:

- use materials with high proportions of recycled content – reducing their overall embodied energy
- reuse products – saving large amounts of embodied energy compared to using new products
- reduce construction waste – producing a clear embodied energy saving
- select long life products or design for a long life – adding value to their initial embodied energy; and
- use financial life cycle costings as a rough guide, where net energy studies are not available.

With regard to units, if embodied energy and operational energy results are to be comparable, both must be in 'primary energy' terms (i.e., including the fossil fuels used to manufacture energy).

Table 1 lists the embodied energy of a number of materials, by mass or area. They were derived using hybrid analysis and are expressed in primary energy terms. These values are used throughout this Note (unless noted otherwise). The table highlights potential pitfalls when comparing materials in embodied energy terms. For example, aluminium and copper may be high in embodied energy per unit mass, but bricks and carpet are high in embodied energy per unit area. A 0.35mm sheet of aluminium has an embodied energy of approximately 0.22 GJ/m^2, which is comparable to 4mm glass or 100mm fibreglass insulation. Paint has one of the lowest embodied energy rates, but needs to be reapplied many times over a building's life. It is not possible to determine which material or product will be most important in the context of a whole building from such a list. Similarly, rules of thumb and past experience from financial cost planning will offer limited assistance to the designer, as embodied energy varies considerably with cost. Furthermore, embodied energy figures for basic materials are difficult to use in a decision making process, because materials are often used as part of a building system, rather than in isolation. A tile roof, for example, may require more framing material than a lightweight metal roof. Each item and process required for the system needs to be evaluated.

2.3 Materials with recycled content

The energy embodied in steel products is 80 to 115 GJ/t. Steel reinforcement with 100% recycled content has an embodied energy value of 20 to 50 GJ/t.

Material	Embodied energy (GJ/t)
Aluminium	200 – 260
Copper	95 – 175
Steel	80 – 115
Plastic	75 – 120
Cement	10 – 15
Concrete 30 MPa	3.2 – 4.5
Timber	2.5 – 4.3

Material	Embodied energy (GJ/m^2)
Brick	0.50 – 1.20
Carpet	0.25 – 1.23
Vinyl ooring 2mm	0.20 – 0.35
Clear oat glass 4mm	0.18 – 0.55
Fibreglass batts R2.5	0.10 – 0.25
Plasterboard 10mm	0.03 – 0.06
Paint	0.01 – 0.03

Table 1. Embodied energy of materials by mass and area, with error ranges
These values are not to be used for decision-making, as they were derived mainly using input-output data and have not been fully validated with industry data. Error ranges were based on estimates of known methodological errors. Variability between similar products (as outlined in section 2.1 above) has not been included explicitly in these error ranges.

While structural steel products with high recycled content are not generally available in Australia, steel reinforcement with 100% recycled content is available. Similarly, virgin aluminium has an embodied energy of 200 to 260 GJ/t, while the products with 100% recycled content would be 20 to 60 GJ/t. However, aluminium building products with high proportions of recycled content are not generally available in Australia. In concrete, ground granulated blast furnace slag (GGBS) and other recycled materials can be substituted for up to 90% of the cement (CCAA, 1994). The embodied energy of 30 MPa concrete, not including reinforcement, is 3.2 to 4.5 GJ/m^3. Assuming the energy to reclaim, transport and prepare the GGBS for use is minimal, the embodied energy of 30 MPa concrete with 90% GGBS would be 1 to 2 GJ/m^3.

Many other materials and components are able to be reused or recycled, such as bricks, timber, and roofing materials (Andrews, 1998, *BDP Environment Design Guide,* PRO 9). If the expected life was not reached in the first use of a material or product, some of the initial embodied energy could be attributed to the second use (perhaps discounted over time, as in financial life cycle costing).

There is a view that if a material can be recycled, the initial embodied energy of the virgin product should be reduced. However, most materials and products used in buildings have a long life, and there is no certainty that they will be recycled. An alternative view is that the building in which the material or product is actually reused should be credited with any embodied energy saving (i.e., equalling the embodied energy of an equivalent new product, less any energy embodied in recovery, reprocessing, transport and reinstallation). For items with high 'churn' rates, such as furniture, coverings, finishes, and for items in short life buildings, recylability and design for deconstruction is essential (Lawson, 1996).

3.0 WHOLE BUILDING CONTEXT FOR MATERIALS SELECTION

In this section, embodied energy analyses of a residential and a commercial building are used to provide some contextual information for building designers in the selection of materials. The embodied energy values for the examples presented here differ from those in previous Notes, due to the use of recent, comprehensively derived embodied energy values.

3.1 Residential building case study

The two storey brick veneer suburban dwelling of 155 m^2 building area was designed for energy efficient operation. All living areas on the ground floor and bedrooms on the first floor face north and are glazed to provide solar gain in winter and shaded to restrict it in summer. East and west walls have smaller openings to reduce heat gain in summer and the south wall has small openings to reduce heat loss in winter. Total window area is equivalent to 19% of floor area. Service areas and circulation spaces are located to the south in accordance with accepted passive solar design principles. (For further information about the life cycle energy requirements of this dwelling, refer to Fay and Treloar, 1999, GEN 22. For a broader analysis of household energy requirements, refer to Treloar and Fay, 1999, GEN 20.)

Material quantities for the building were derived from architectural and engineering drawings and the architect's specifications. All elements were analysed, including substructure, walls, roof, finishes, fitments, services and external elements such as paving and pergolas. The quantities were manipulated into a form suitable for embodied energy analysis, e.g. window frames were converted into cubic metres of timber and glazing into square metres of 3mm or 6mm glass.

The initial embodied energy for the dwelling was found to be 11.1 GJ/m^2. Of this, 0.88 GJ/m^2 was energy used for the construction process. The life cycle embodied energy, over a 100 year period, was 23.9 GJ/m^2.

The error ranges are lower for materials for which more process analysis data has been derived. By assuming error rates for the process analysis data and input-output analysis, high and low values were derived for the materials and elements in the example building. The error rate assumed for the process analysis data was a flat rate of ±10% (based on Boustead and Hancock, 1979), while for the input-output analysis data a flat rate of ±50% was assumed (based on Bullard et al, 1978). This is a fairly crude assessment of reliability, but serves to give a measure of the comparative ranges of error for the mix of process analysis and input-output analysis data in a hybrid analysis.

Figure 1, showing error ranges, gives the embodied energy results for the residential building by *Material* and *Element* group, with error bars. The material groups are arranged in descending order of embodied energy. A logarithmic scale was used for the y-axis so that the smaller materials are visible. This tended to reduce the apparent absolute value of the error bars, but the relative comparisons between error ranges for adjacent material groups remain valid. The error bars for the first four material groups (ceramics, timber, concrete, steel) were sufficiently similar to indicate that, with expected variability and errors in the embodied energy data, the rankings of these four would be affected by potential errors. The development of strategies can now be prioritised but, as noted above, an elemental breakdown is perhaps a more appropriate basis.

The *Element* groups in Figure 1 are arranged in descending order of embodied energy. The distribution of embodied energy by element group is flatter than the distribution by material group, probably because each element comprised a range of materials, in various combinations. The first two elements, external walls and substructure, are sufficiently separated to

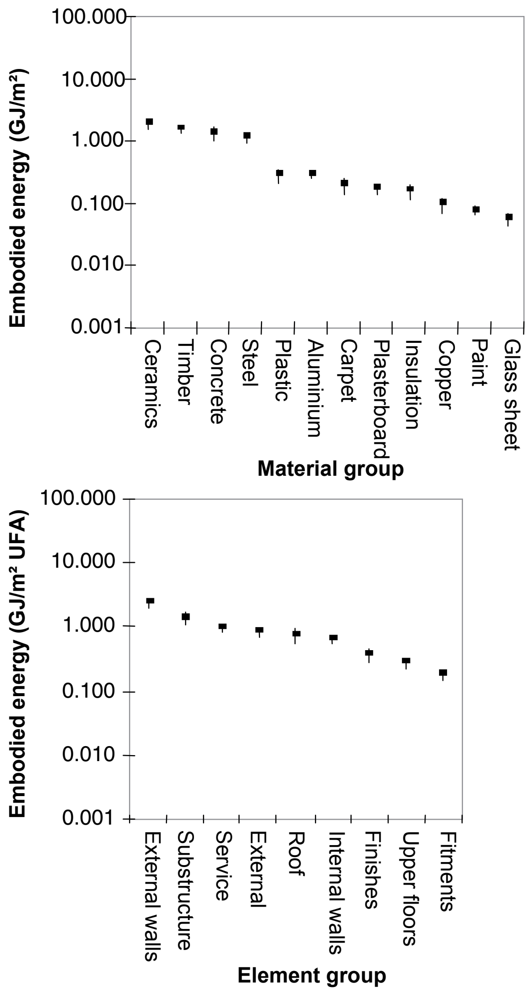

Figure 1. Initial embodied energy of residential building, by material group and element group

The y-axis scale is logarithmic, which causes error ranges to appear smaller than they are.

demonstrate that their ranking would not be effected by potential errors. This also applies to internal walls and finishes. Between other adjacent elements, the differences are not great enough to demonstrate that rankings are not affected by potential errors.

Nevertheless, the trend across the element groups highlights the importance of the first two element groups and the relatively small impact of finishes, upper floors and fitments.

As noted, the embodied energy values used are different to those used in previously published case studies, so these examples are worth presenting before discussing specific strategies. For example, a brick veneer wall typically comprises clay bricks, mortar, steel cavity ties, timber stud framing, galvanised steel cross bracing, reflective building paper, plasterboard internal wall lining, skirtings, cornices, architraves, fixings and paint. The total embodied energy of a square metre of such a system is approximately 1.5 GJ (derived using hybrid analysis, as described above). Lawson (1996) found a value for the same system of 0.56 GJ. The figures are probably significantly different because Lawson used mainly process analysis data (as discussed in Bullard et al, 1978) and end-use energy rather than primary energy.

The dwelling's operational energy was estimated to be 0.54 GJ/m^2 for non-space conditioning requirements, and 0.31 GJ/m^2 for space conditioning (heating and cooling) requirements. This results in a total operational energy requirement of 0.85 GJ/m^2 – all values are expressed in terms of primary energy. Thus, the initial embodied energy represented 13 years of operational energy, while the life cycle embodied energy represented 28 years of operational energy. Over the 100 year life cycle, the initial embodied energy was 10.2% of the total, while the total life cycle embodied energy was 21.9% and the operational energy was the remainder of 78.1%. However, over a 10 year life cycle, the initial embodied energy is 57% of the life cycle energy.

3.2 Commercial building case study

A typical 15 storey Melbourne commercial building, with a reinforced concrete substructure and frame, and a gross floor area (GFA) of 47,000 m^2, was analysed. The cladding is mostly granite veneer with aluminium framed windows. The building comprises offices, with some retail space, and several under- and above-ground car parking levels. Quantities for the various materials required for the construction of elements of the building were derived from a Bill of Quantities, comprising 2000 items. All elements of the building were analysed, including substructure, walls, roof, finishes, fitments, services, and external elements such as paving. In some cases, quantities had to be manipulated to allow correlation to the units of the embodied energy values. Most of the services elements were given in the Bill of Quantities as 'prime cost' items, and construction documents had to be consulted to enable product quantities for these elements to be derived.

The hybrid analysis result for the initial construction of the building was 17.4 GJ/m^2 GFA. In a previous study of the same building, the initial embodied energy was found to be 11.4 GJ/m^2 (Treloar et al, 1999), due to the use of older embodied energy values and techniques. The new result, having a more complete system boundary, is higher yet more accurate.

Figure 2, showing error ranges, gives the embodied energy results for the commercial building example, by *Material* group and *Element* group (in the same format as Figure 1). The error bars for the first four material groups (steel, concrete, aluminium and copper) were sufficiently separate to indicate that, with expected variability and errors in the embodied energy data, the rankings of these four were not affected by potential errors. Conversely, the fifth material group, carpet, overlapped the fourth, copper. Expected variations in embodied energy values could well have caused a change in ranking of these two particular material groups, possibly altering priorities for the development of design optimisation strategies for commercial buildings based on this information.

The *Element* groups are arranged in descending order of embodied energy. The distribution of embodied energy by element group is much flatter than the distribution by material group, probably because each element comprised a range of materials, in various combinations, as for the residential building example. Similarly, the error ranges in the elemental analysis are more consistent than the material analysis. The error bars in Figure 2 for the element groups highlight where pitfalls can occur when comparing elements of the building. For example, the error bars for the element groups Upper floors and Services did not overlap, indicating that there was a significant difference between these element groups. On the other hand, the error bars for the second and third element groups, Services and External walls, overlapped considerably. Thus, even though the initial value for Services was 11% higher than the initial value for External walls, this difference was not significant in terms of the likely error ranges.

The operational energy of the commercial building was estimated to be 0.4 GJ/m^2 GFA per annum, in primary energy terms (based on BOMA targets, which represent relatively efficient buildings). Thus, the time taken for the operational energy to become equivalent to the initial embodied energy was 40 years. However, for a less energy efficient building or a more severe climate, this period would be shorter. If the building lifetime were 20 years, the embodied energy would be more than twice that of the operational energy. Conversely, if the building were operated half as efficiently as assumed, the embodied energy would represent only one quarter of the operational energy. If the building used more energy for operation, the embodied energy would be less important. Thus, as buildings become more energy efficient, in operational terms, their embodied energy becomes more significant – especially since embodied energy savings occur immediately, but the wait for operational energy savings, may be decades before buildings pay back their initial embodied energy.

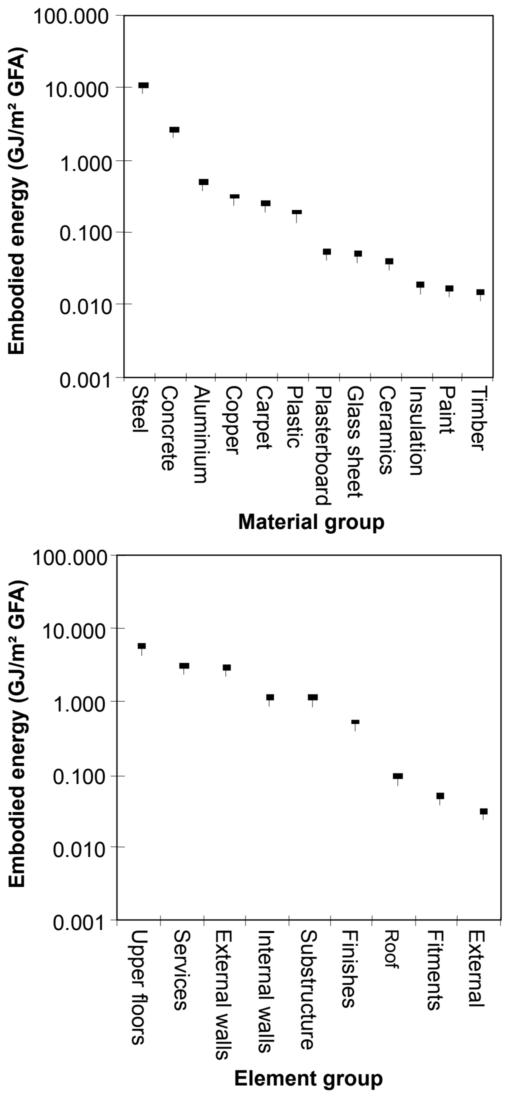

Figure 2. Initial embodied energy of commercial building, by material group and element group

The y-axis scale is logarithmic, which causes error ranges to appear smaller than they are.

Upon demolition, more than half the building's mass could be recycled through existing programs. However, the embodied energy saved through doing so would be much less than this, due to the energy embodied in the recycling processes and the likelihood of down-graded uses for the recycled materials. For example, 30 MPa concrete has an embodied energy of around 3 GJ/m^3 when in place (not including reinforcement), yet when demolished, crushed and recycled displaces only new aggregate at around 0.3 GJ/m^3 (i.e., only a 10% saving, assuming no significant mass loss). Furthermore, the energy embodied in the transportation and crushing processes embodies around the same as the amount saved (Salomonsson and Ambrose, 1998). Consequently, the saving may be of natural resources rather than of primary energy and greenhouse gas emissions.

The energy embodied in maintenance and refurbishment activities was found to be 3.13 GJ/m^2 GFA over a simulated 40 year building life cycle (Treloar et al, 1999). Though this figure was produced with older data, it shows that maintenance and refurbishment represents less than 30% of the initial embodied energy of that building. This indicates that conserving buildings requires less embodied energy than new construction. If the refurbishment includes energy efficient strategies and features that lower operational energy, this can further reduce the life cycle energy of the building.

The life cycle energy embodied in furniture and fitout items was found to be 1.5 GJ/m^2 GFA, representing approximately 13% of the initial embodied energy. However, it represents a much larger proportion of the life cycle embodied energy of the building, at 9.9 GJ/m^2 GFA, over the 40 year period (Treloar et al, 1999). This is due to the high 'churn' (replacement) rate of furniture in office buildings.

The initial embodied energy of this commercial building was compared to the operational energy, the energy embodied in refurbishment and the energy embodied in furniture in Figure 3. Only the energy embodied in the initial construction was updated from the Treloar et al (1999) results using the data outlined above. Items requiring embodied energy analysis (i.e., all but the operational energy) comprised 71% of the total life cycle energy of the building over a 40 year period.

3.3 Construction systems in mid–size to large commercial buildings

Aye et al (1999) examined differences in embodied energy for framing systems for medium sized commercial buildings, based on changes in the number of floors and the aspect ratio. They found that "the number of floors has a substantial effect upon embodied energy as the number of floors is increased from one to three but that there is very little difference once the number of floors exceeds three" (Aye et al, p.222). They also found that increases in aspect ratio (i.e., ratio of plan width to depth) had little effect for low-rise buildings but was more significant for medium-rise buildings.

However, the embodied energy values used in Aye et al, (1999) were sourced from older less reliable sources and these values tend to be 2-4 times lower than those used here. This may affect their conclusion that "design features employed to minimise energy use should concentrate on measures to reduce operating energy at the potential expense of embodied energy" (Aye et al, 1999, p.223), because they appeared to have under-estimated the embodied energy.

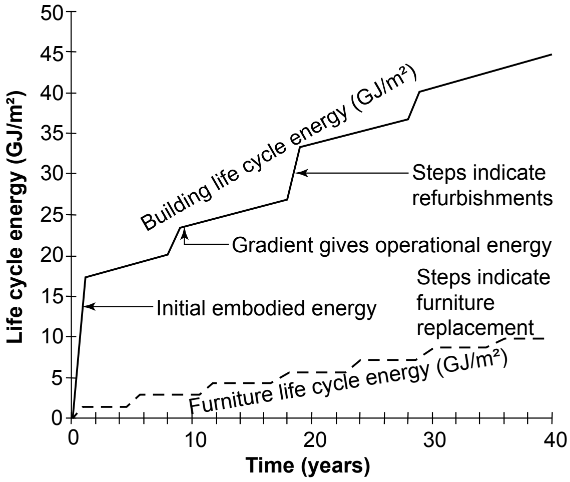

Figure 3. Life cycle energy time series for the commercial building and furniture, 40 years

4.0 STRATEGIES FOR GREENHOUSE REDUCTIONS

In this section, a number of practical strategies for reducing greenhouse gas emissions through materials selection are discussed, within a life cycle context. Issues addressed include: comparing materials and components, construction systems and products, energy saving features and devices, and finally, industry strategies applicable to various building life cycle phases. Embodied energy and life cycle energy were used as a basis for comparison. However, there are other issues involved with the selection of construction systems and products that may require consideration, such as those discussed earlier in this Note.

4.1 Construction systems and products

The external wall element group was the most important in the example residential building (Figure 1), and comprised opaque and transparent items (i.e., including windows). In this section, various construction systems and products for this element group are briefly evaluated in net embodied energy and life cycle energy terms, including rammed earth and double glazing.

4.1.1 Comparison of rammed earth versus brick veneer

Rammed earth is frequently cited as an ecologically sustainable construction system. This is based on its use of local, unprocessed soil, which is low in embodied energy. However, the cement used to stabilise the soil can be highly energy intensive (refer to Table 1). Generally, the cement content is approximately 8% of the soil by mass. For a detached dwelling, the net saving in embodied energy using rammed earth compared to brick veneer is less than 10% of the total for the building, including the net effect of increased footing requirements for the heavier rammed earth, compared to the brick veneer case. Furthermore, in certain climates, building designs and operating conditions, rammed earth wall construction may lead to increased heating and/or cooling requirements, compared to insulated brick veneer construction (i.e., due to its low thermal resistance).

Opportunities for reducing the embodied energy in the cement required for rammed earth wall construction include:

- alternative stabilisation compounds (for example, natural fibres)
- use of cement with lower embodied energy (for example, manufactured using the 'dry' process); and
- displacement of some cement content with recycled materials such as fly ash and slag (Owen et al, 1999).

Opportunities for reducing the embodied energy of brick veneer construction include:

- the reuse of bricks from the demolition of existing buildings (where possible)
- the use of bricks from local, energy efficient kilns; and
- the use of low embodied energy internal wall linings and finishes.

4.1.2 Comparison of steel and timber domestic wall framing

For timber and steel domestic wall framing studs, the embodied energy comparisons are interesting. Steel products have an embodied energy value of 75 to 115 GJ/t. Australian softwood framing has an embodied energy of 2.6 to 4.2 GJ/m^3. The values need to be multiplied by the quantities of materials in comparative sized members. For a 90 x 45mm timber stud, the embodied energy is 0.011 to 0.017 GJ/m of stud. The embodied energy of an equivalent steel domestic wall stud, having a mass of 2.3 kg/m of stud, is 0.18 to 0.26 GJ/m. However, if steel studs are made with 100% recycled content, this value could be lowered considerably. Similarly, the use of recycled timber could further reduce the embodied energy of timber studs. Timber studs, though, have reduced thermal bridging problems.

4.1.3 Comparison of single glazing versus double glazing

Energy saving features and devices such as double glazing need to be analysed, not only in terms of operational energy savings, but also in terms of additional embodied energy requirements, if any. Net energy analysis provides methods based on financial life cycle costing, including:

- energy pay back period (i.e., the time taken for the annual energy savings to equal the embodied energy); and
- energy return on investment (i.e., the life cycle operational energy savings, less the embodied energy, expressed in terms of the embodied energy—this parameter is expressed as a dimensionless ratio, or 'factor').

It is useful to identify energy saving features and devices that not only reduce operational energy, but also pay back their initial embodied energy within a reasonable period. For competing options that all have short pay back periods, the energy return on investment factor can be used to identify the lowest life cycle energy option. There are factors that may lead to wide variations in net energy analysis results. They include climate, material or system specifications, fuel type/mix, transport distances, building type or form, user conditions and site constraints. However, several strategies together may be required to reduce the load on an energy supply system (such as a remote area power supply), thus potentially saving more energy embodied indirectly.

Double glazing, and other complex glazing systems and products, may improve the thermal performance of the building envelope – depending on the building usage, design and climate. If double glazing is to be a feasible option in net energy terms for temperate climates, such as Melbourne, it would need to pay back its initial net embodied energy, compared to single glazing, within a reasonable period of time. This might be the warranty period on the seal (which is often less than 10 years). The dwelling discussed earlier was analysed to assess the energy pay back period and the energy return on investment.

Double glazed windows resulted in annual heating and cooling energy savings of 5.5 GJ/annum over the single glazed version, according to the NatHERS computer simulation (including adjustment for appliance conversion efficiency). The embodied energy of the single glazed version of the dwelling was found to be 1803 GJ, while that for the double glazed version was 1814 GJ – a difference of 11 GJ. Consequently, the energy pay back period is 2 years (i.e.11/5.5). The average energy return on investment factor, over 100 years, is 49 (i.e. [100x5.5-11]/11).

These results speak in favour of installing double glazing in residential buildings in Melbourne, at least in terms of net primary energy savings. Double glazing appears to be a sound strategy for lowering life cycle energy use and associated greenhouse emissions well within a 10 year period for a wide range of occupant behaviour possibilities. Financial pay back periods for double glazing relative to single glazing may be longer in many cases.

4.1.4 Comparison of light timber versus cavity brick construction

The brick veneer residential building analysed above was modelled as a light timber frame construction (including a suspended timber floor for ground and first floor) and then as a cavity brick construction with concrete ground floor slab and suspended timber framed floor. In both cases, the buildings were assumed to be lightly insulated (i.e., in accordance with Victoria's building regulations). The space heating and cooling requirements for the timber version was 43.4 GJ/annum while for the cavity brick version it was 32.8 GJ/annum—a difference of 10.6 GJ/annum. The embodied energy of the timber version was 1427 GJ and of the brick version 2063 GJ—a difference of 636 GJ. The energy pay back period for the extra mass therefore is 60 years (i.e., 636/10.6). This suggests that mass is not an effective energy strategy for this dwelling design. However, in combination with other features and strategies, and taking its other properties into account, mass may be considered more desirable.

4.2 Industry strategies

In this section, strategies are suggested for various members of the construction supply chain, including building material and product manufacturers, construction managers and professionals, building designers and engineers, building owners and managers, as well as academics and government.

In the future, the wide adoption of open loop recycling may reduce the average total energy intensities of building materials. This has occurred, for example, in glass manufacture. Items with advertised recycled content may have it because of commercial or technological advantage (for example, up to 50% of ingredients for glass manufacture routinely comprise recycled 'cullet', to reduce melting points). Some producers may not advertise recycled content, due to fears it will be perceived as 'second rate' quality (typical specifications require 'new' materials only).

However, for industry to realise its full potential, education, lobbying, research and development, regulation and government and private sector funding will be required. More efficient processes at all stages of production, local plants to reduce transportation energy, the use of process ('waste') energy where possible, reduced packaging, efficient warehousing and retailing, will all contribute to embodied energy reductions.

Manufacturers of energy efficiency equipment and products should consider using renewable energy and energy efficient equipment, to lower the embodied energy and reduce the energy pay back periods of these items.

Currently, there is recognition that building operational energy must be reduced if greenhouse gas reductions are to be achieved. Consequently, space and water heating and appliance efficiency have been targeted. Appliances (nationally) and dwellings (currently compulsory only in the ACT) are now star rated to show their potential for low operational energy requirements. However, strategies to reduce the life cycle energy of buildings have not been addressed.

Manufacturers should be encouraged to make available information on their energy use and greenhouse gas emissions, perhaps through a product labelling scheme. In practical terms, this may be even more useful and practical than energy labelling for equipment, because the energy has already been used and metered. In some cases, annual average figures may be used for embodied energy labelling (where processes are consistent). However, in others cases, a piece by piece method for energy labelling may be required (such as in machine grading of plantation timber, which is already common in Australia), where processes are inconsistent from product to product.

Due to the complexity of construction, designers and clients will need to be educated to interpret and use this information, but the precedents and techniques exist in financial management and quantity surveying.

Governments should develop policies on embodied energy, and foster labelling schemes or the development of standard tools, methods and databases (as they are for LCA tools, through Environment Australia). The impact of energy and greenhouse efficiency schemes such as carbon credits should be evaluated in embodied energy terms, to confirm that savings are being achieved. It is not sufficient to focus either on the supply side of the economy, or on the direct consumers of fossil fuels and emitters of greenhouse gas emissions. Supply-side management must also extend to the consumers of goods and services, not only to energy and fuels.

Consumers at various stages of industrial processing and marketing (i.e., building designers), as well as final demand consumers such as householders, have opportunities to buy more energy efficient devices, purchase low embodied energy products, or choose to extend the life of their existing products. Many of these opportunities may need to be identified and encouraged, or legislated in some instances, if we are to achieve short, medium and long term energy, greenhouse goals (such as meeting the Kyoto Protocol).

5.0 CONCLUSION

Building materials selection has demonstrable and significant energy and greenhouse gas emission consequences. The appropriate choice of materials and building systems can reduce the life cycle energy of buildings. This includes the energy embodied in the construction of buildings, initially and as they are maintained and modified.

Since this Note has focused on energy and greenhouse gas emission aspects of materials selection, other important environmental issues have not been addressed. It is acknowledged that they too deserve attention. Nonetheless, the need to reduce Australia's anthropogenic greenhouse gas emissions has been recognised as being of critical importance if global warming is to be arrested and eventually reversed.

A number of strategies which designers may use to reduce the life cycle energy of buildings may now be summarised.

Specify materials and products which:

- are local, in preference to those transported over long distances
- have a high recycled content or which have been used previously
- have a long life or are replaced less often
- are low in embodied energy, if they do not increase life cycle energy over the planned building life; and
- are high in embodied energy, if they result in a net decrease in life cycle energy over the planned building life.

This Note suggests that intuition, while powerful in design, sheds limited light on the energetics of buildings. Materials thought to be low in embodied energy may be similar to conventional manufactured products; recycling of materials does not always result in reduced embodied energy; and other materials, while initially energy intensive in their production, may reduce the life time energy of buildings. However, for the moment, energy analysis tools that building designers find easy to use, and which are applicable at the various stages of design, are not available.

Finally, the responsibility for reducing the life cycle energy does not rest entirely with building designers. Building users, through their patterns of building usage, also significantly influence life cycle energy. However, in relation to materials selection, industry has the capacity to further reduce the initial embodied energy of their products, to facilitate their reuse or recycling and to ensure they are designed or manufactured to provide a long life. Government may also assist by providing incentives for industry, by promoting an embodied energy labelling system for materials and products and by adopting life cycle energy in preference to operational energy as the measure of building energy efficiency.

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GLOSSARY

Embodied energy: Embodied energy is the energy required directly and indirectly to produce a product (which may be a physical entity or a service).

Energy units: Energy has been expressed in GJ (Gigajoules). One GJ is 1000 MJ, the amount of energy contained in approximately 30 litres of petrol. In all instances, energy is quote in primary terms, i.e., including the enthalpy of fossil fuels used in generation and delivery.

Process analysis: A method for determining the energy requirements for a particular process, such as might be metered at the boundary of a brickworks, and a limited number of upstream processes.

Input-output analysis: A statistical method, using a national economic table (in the form of a matrix) produced by the Australian Bureau of Statistics which shows financial flows (inputs and outputs) between all sectors of the economy. The financial flows are converted to energy flows and the table is inverted (a mathematical method developed by Leontief). From the inverted matrix, upstream energy requirements from all sectors to any one sector are summed. Consequently, this method, unlike process analysis, is systemically complete. However, it is subject to assumptions and errors, and is a 'black box'.

Hybrid analysis: An energy analysis method which combines the benefits of process analysis (accuracy for particular processes) with those of input-output analysis (systemic completeness).

Life cycle energy: The energy attributable, in the case of a building, to the energy used in operation over its lifetime, together with the initial embodied energy and the added embodied energy as the building is maintained and refurbished or altered, over its lifetime.

Net energy analysis: A method of evaluating the life cycle performance of energy efficiency features and devices, comprising: the 'energy pay back period' and the 'energy return on investment'.

Operational energy: The energy used for space conditioning (heating and cooling), cooking, refrigeration, lighting and appliances and other equipment.

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