Embodied energy analysis of fixtures, fittings and furniture in office buildings

Graham J. Treloar
Andrew McCoubrie
Peter E.D. Love and
Usha Iyer-Raniga

Introduction

The built environment uses a substantial amount of energy to procure construction facilities. This energy includes not only that energy used throughout the building’s life cycle but also that used to manufacture and assemble materials. The embodied energy in the manufacture and assembly of material and components has recently been found to be approximately equal to the operational energy of a typical office building in a temperate climate over the life of the building (Treloar, 1996).

The embodied energy of a building comprises indirect and direct energy. Indirect energy is used to create the inputs of goods and services to the construction process, whereas direct energy is purchased by the construction firm used on-site for construction (administration, transport, prefabrication etc.). Indirect energy can be divided into direct energy purchases by upstream manufacturers for each indirect stage of upstream processing. For example, energy is required to transport raw materials to refineries before their use in furniture manufacture, a process that is two transactions upstream from the furniture manufacture process.

Embodied energy research has typically focused on the general components of construction such as a building’s structure, its envelope and internal finishes (e.g. Pullen, 1995; Tucker et al., 1993; Lawson, 1992). Similarly, research conducted by Treloar (1996) developed estimates for the direct energy used to procure a building’s services such as electrical, plumbing and fire protection. However, there has been no research to date that has assessed the energy embodied in fixtures, fittings and furniture, which occupants use in their constructed facilities.

Fixtures, fittings and furniture are used in the initial construction and fit-out of a building and often are consumed several times over during the life of a building. The energy embodied in such products is known as recurrent embodied energy (Treloar, 1996). This includes that energy used in their manufacture and assembly. Treloar (1996) found from his research of an office building that the initial embodied energy of finishes to walls, floors and ceilings (i.e. the first application of paint), which tend to be replaced more regularly than other elements, was 12.5 percent of the total embodied energy for the...
whole building. It was further found that most of the embodied energy was contained in elements that are not replaced on a regular basis, if at all, throughout the building’s life cycle.

The concept of life cycle energy is an integral component of any constructed facility. Life cycle energy equals the initial and recurring embodied energy plus the operational energy and any energy required for decommissioning. Owing to typically high replacement cycles of office fixtures, fittings and furniture compared to other building elements, embodied energy is an important aspect of a building’s life cycle.

Thus, the aim of this paper is to demonstrate the importance of the energy embodied in the context of fixtures, fittings and furniture over an office building’s life cycle relative to other life cycle energy requirements. The paper will assist facility managers and businesses with their decision making with respect to their fixtures, fittings and furniture requirements, in the context of the building’s life cycle energy use and associated environmental impacts. Previous research has tended to ignore the embodied energy implications of the ongoing purchase of fixtures, fittings and furniture. Thus, this paper contributes to the study of embodied energy by identifying the importance of fixtures, fittings and furniture compared to other building elements.

**Background**

According to Bekker (1982) the life cycle of a building comprises the following stages:

- materials manufacture;
- construction, operation;
- maintenance, refurbishment; and
- demolition.

It is worth noting that there are also recycling streams at every stage.

The focus of building energy analysis and greenhouse mitigation initiatives has typically been operational energy. An aspect of energy analysis that is often overlooked is that of embodied energy. Embodied energy research has been ubiquitous, with respect to building types: for example, Stein *et al.* (1981), Baird and Chan (1983), and Treloar (1996). However, these studies have not accounted for the processes upstream in the supply chain that are used to manufacture goods and services consumed by construction organisations. Research undertaken by Treloar (1996) derived an embodied energy intensity of 8.76 gigajoules per square metre of gross floor area (GJ/m² GFA) for a 47,000m² GFA office building in Melbourne. According to Tucker *et al.* (1993) the Australian national average embodied energy for the “other construction”, or non-residential, sector in 1986-87 was 19m/m². This sector incorporates all non-residential construction of buildings and engineering structures and is susceptible to errors relating to input-output analysis (Pullen, 1996).

Stein *et al.* (1981) derived a figure of 18.6m/m² for US office buildings, which was also derived using input-output analysis. Input-output analysis uses national statistics, often economic, to sum the energy consumed at all upstream processes, aggregated at the sector level. This includes energy used in all sectors of the economy, for example, water supply and sewerage services, wherever they are used in the upstream supply chain of the sector under consideration. The value for the US study may be due to less efficient processes or errors attributable to the input-output method (Treloar, 1997). It is suggested that the discrepancy between the case study work of Treloar (1996) and the input-output work of Tucker *et al.* (1993) and Stein *et al.* (1981) may be due to:

- the systemic completeness of the input-output analysis system boundary; and
- issues of primary energy.

There are aspects of incompleteness and unreliability within all of these embodied energy analysis studies. It has been estimated that the incompleteness in typical building embodied energy analyses is approximately 20 percent (Treloar, 1997).

**Embodied energy in fixtures, fittings and furniture**

The indirect energy relating to fixtures, fittings and furniture comprises numerous processes in the production and delivery of goods and services during the manufacturing process. Similarly, the direct energy is that energy consumed by the manufacturing firm in the assembly of the fixtures, fittings and furniture pieces and in ancillary functions such as administration, storage and transport. However, embodied energy studies of such items are rare.
A major issue in the life cycle energy analysis of fixtures, fittings and furniture is the “churn rate”; defined as the number of times an item is replaced over the life of a facility (note: not the number of times per year). If the item is never replaced, the churn rate is 0 percent. If the item is replaced once only in the building’s life, the churn rate is 100 percent.

According to Duffy et al. (1977) and Nuefert (1994), the life span of office fixtures, fittings and furniture is approximately five to seven years. Assuming a typical building life span of 40 years, the churn rate for fixtures, fittings and furniture would be approximately 560 percent. This value is high compared to other building elements. Fashion is the primary reason for such a high turnover rate. Up-to-date office fixtures, fittings and furniture are perceived as a status symbol and therefore gives a good impression to those outside the company.

Method

The embodied energy values for this study were derived from typical items used in an office. These values were then applied to the number of fixtures, fittings and furniture items in an office building layout in Melbourne. A case study approach was used to determine the significance of embodied energy of fixtures, fittings and furniture in the context of a building over a simulated life cycle.

Typical fixtures, fittings and furniture items

Ninety-one fixtures, fittings and furniture items were analysed in terms of their embodied energy. A variety of fixtures, fittings and furniture pieces were examined, including demountable partitions and “compactus” units (i.e. large volume document storage units on tracks), which were produced by seven different office fixtures, fittings and furniture manufacturers. Information regarding components, materials, masses, areas and volumes was obtained from technical officers of these companies, and through examination of product literature and the items themselves.

Embodied energy values for materials were derived from Treloar (1996). Approximately half were derived using input-output analysis and the other half obtained from the literature (e.g. Stein et al., 1981). The quantities of materials used in the fixtures, fittings and furniture components were multiplied by the appropriate embodied energy intensities in the most convenient units (e.g. tons for steel, m³ for timber, m² for 6mm glass). The direct energy of the manufacturing process for these items was not directly measured because the time taken to collect the data was not considered worthwhile, given the likely significant but small contribution of the total embodied energy of an item, based on initial investigations into the input-output data for the Australian furniture sector. Clearly, this represents a potentially significant area for future research.

The method of estimating the direct energy of the manufacturing process for fixtures, fittings, and furniture was determined using “assumed manufacturing coefficients”. This technique was devised by Treloar (1996) and is based on the “coefficient for further processing”. Input-output analysis suggests that the direct energy of fixtures, fittings and furniture manufacture is 15 percent of the total embodied energy of fixtures, fittings and furniture. The assumed manufacturing coefficients added much less than this amount to the total for all fixtures, fittings and furniture items, and can thus be considered conservative. They ranged in value, for example, from 1.1 for minor processing to 2.2 for steel wire (compared to basic steel products).

Figure 1 compares the average embodied energy calculated for the 91 fixtures, fittings and the other half obtained from the literature (e.g. Stein et al., 1981). The quantities of materials used in the fixtures, fittings and furniture components were multiplied by the appropriate embodied energy intensities in the most convenient units (e.g. tons for steel, m³ for timber, m² for 6mm glass). The direct energy of the manufacturing process for these items was not directly measured because the time taken to collect the data was not considered worthwhile, given the likely significant but small contribution of the total embodied energy of an item, based on initial investigations into the input-output data for the Australian furniture sector. Clearly, this represents a potentially significant area for future research.

The method of estimating the direct energy of the manufacturing process for fixtures, fittings, and furniture was determined using “assumed manufacturing coefficients”. This technique was devised by Treloar (1996) and is based on the “coefficient for further processing”. Input-output analysis suggests that the direct energy of fixtures, fittings and furniture manufacture is 15 percent of the total embodied energy of fixtures, fittings and furniture. The assumed manufacturing coefficients added much less than this amount to the total for all fixtures, fittings and furniture items, and can thus be considered conservative. They ranged in value, for example, from 1.1 for minor processing to 2.2 for steel wire (compared to basic steel products).

Figure 1 compares the average embodied energy calculated for the 91 fixtures, fittings and furniture items.
and furniture items classified into 13 fixtures, fittings and furniture types. Aside from “compactus” units, which are rather large, the work-surfaces tend to have the highest embodied energy per unit. It must be stressed that the functional unit here is the item itself. A more reasonable functional unit for comparison between fixtures, fittings and furniture items of the same type may be square metres of worksurface area or volume of storage area.

**Case study building**

An office fit-out plan was obtained for a typical high rise office building level and the numbers of each fixture, fitting and furniture item type collated. In Table I a summary of fixtures, fittings and furniture type quantities derived for this typical office layout can be seen. The embodied energy values for the 91 fixtures, fittings and furniture items (in MJ/item) were then multiplied by the quantities of each of the items, giving a total embodied energy value for fixtures, fittings and furniture for the typical office building level. For the assumed office fit-out it was thus determined that the 1,834m$^2$ of gross floor area (GFA) contained 2,730GJ of energy embodied in office fixtures, fittings and furniture, giving a typical embodied energy intensity for initial quantities of fixtures, fittings and furniture of 1.5GJ/m$^2$ of GFA.

The non-furniture embodied energy for a similar building was obtained from Treloar (1996). Essentially, Treloar (1996) analysed the life-cycle energy requirements of a 15-storey inner city Melbourne office building (as noted earlier). Initial embodied energy was compared to an estimate for operational energy and the energy embodied in materials used for periodic maintenance and refurbishment. Furniture was not included in the 1996 study. A value for fixtures, fittings and furniture can be compared to the other elements in a typical medium rise office building. The initial non-furniture embodied energy was 8.62GJ/m$^2$ (Treloar, 1996), which excluded the direct energy of construction.

Tucker et al. (1993) suggested that the direct energy of the construction process adds a further 10 percent (Tucker et al., 1993), or 0.862GJ/m$^2$. Some processes directly and indirectly involved with construction were also inevitably excluded (Treloar, 1997). A factor of 20 percent was allowed for the incompleteness of the initial embodied energy figure, an addition of 1.72GJ/m$^2$.

Table II gives the churn rates assumed for various elements in the building. It was arbitrarily assumed that 10 percent of the cladding was replaced over the 40-year period due to glass breakage, minor alterations, cleaning and maintenance (i.e. a churn rate of 10 percent). A churn rate of 560 percent was assumed for fixtures, fittings and furniture, as noted above. Typically, 20 percent of “services” and “other” elements were assumed to be replaced during the building’s life cycle (i.e. mainly plant improvements rather than a complete reticulation re-fit, a churn rate of 20 percent). Churn rates of between 100 percent and 400 percent were assumed for the wall, floor and ceiling finishes elements.

### Table I Summary of quantities of fixtures, fittings and furniture items in a typical office level

<table>
<thead>
<tr>
<th>Item</th>
<th>Number</th>
<th>Item Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pull-up chairs</td>
<td>51</td>
<td>&quot;Compactus&quot;, six-unit 900mm wide 1</td>
</tr>
<tr>
<td>Desk chairs</td>
<td>119</td>
<td>&quot;Compactus&quot;, eight-unit 900mm wide 1</td>
</tr>
<tr>
<td>Workstations</td>
<td>78</td>
<td>&quot;Compactus&quot;, four-unit 1,200mm wide 2</td>
</tr>
<tr>
<td>Two-drawer filing cabinets</td>
<td>136</td>
<td>Storage cupboards 2</td>
</tr>
<tr>
<td>File/drawer pedestals</td>
<td>157</td>
<td>Shelving 20</td>
</tr>
<tr>
<td>Conference tables</td>
<td>4</td>
<td>Desks/tables (1,200 m$^2 \times 735$) 33</td>
</tr>
<tr>
<td>Credenzas</td>
<td>4</td>
<td>Desks/tables (1,800 m$^2 \times 735$) 10</td>
</tr>
<tr>
<td>Wall units</td>
<td>24</td>
<td>Partitions (m$^2$) 508</td>
</tr>
<tr>
<td>Reception hutches</td>
<td>2</td>
<td>–</td>
</tr>
</tbody>
</table>

**Note:** The functional units are the items, unless otherwise noted.

### Table II Churn rates for building elements

<table>
<thead>
<tr>
<th>Building element</th>
<th>Churn rates (%)</th>
<th>Building element</th>
<th>Churn rates (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper floors</td>
<td>0</td>
<td>Columns</td>
<td>0</td>
</tr>
<tr>
<td>External walls</td>
<td>10</td>
<td>Wall finishes</td>
<td>400</td>
</tr>
<tr>
<td>Substructure</td>
<td>0</td>
<td>Fire protection</td>
<td>20</td>
</tr>
<tr>
<td>Electrical</td>
<td>20</td>
<td>Plumbing</td>
<td>20</td>
</tr>
<tr>
<td>Floor finishes</td>
<td>200</td>
<td>Ceiling finishes</td>
<td>100</td>
</tr>
<tr>
<td>Internal walls</td>
<td>10</td>
<td>Other</td>
<td>20</td>
</tr>
<tr>
<td>Air-conditioning</td>
<td>20</td>
<td>Fixtures, fittings and furniture</td>
<td>560</td>
</tr>
</tbody>
</table>

**Note:** A churn rate of 0 percent indicates that the element is not replaced during the building’s life, while a churn rate of 100 percent means the element is completely replaced once during the building’s life, and so forth.
Many fixtures, fittings and furniture are sold second-hand, and actually have a much longer useful life. Filing cabinets, for example, are often refurbished and re-sold. Office fixtures, fittings and furniture are often “handed down” through the hierarchy, and are often sold at auctions to other businesses or private buyers. However, modeling the energy implications of the demand for new fixtures, fittings and furniture will give a better indication of the environmental loadings attributable to the manufacture of new fixtures, fittings and furniture to satisfy demand. Thus, the recycling of office fixtures, fittings and furniture is ignored in this method.

Major refurbishments and demolition were excluded, and a 40-year life was assumed. For office buildings in Melbourne the operational energies required for heating, cooling, lighting, etc. range between 0.15GJ/m² of Net Lettable Area (NLA) and 0.33GJ/m² NLA per annum (Building Owners and Managers Association (BOMA), 1986). For this study, a value of 0.25GJ/m² NLA was assumed (see Treloar, 1996). Assuming an efficiency ratio of 80 percent (which is high, but allows for operational energy in non-rentable areas of the building), this becomes 0.2GJ/m² GFA. Over 40 years, this represents 8.0GJ/m² GFA. It is worth noting that the above value is in delivered energy terms and, since much of it is likely to be electricity, this would be approximately 16GJ/m² GFA in primary energy terms.

**Results**

Figure 2 presents each component of the building’s life-cycle, including:

- operational energy;
- fixtures, fittings and furniture;
- a factor for incompleteness in the embodied energy estimates;
- the direct energy of the construction process; and
- the energy embodied initially in other building elements.

The initial non-furniture embodied energy was 8.62m² (Treloar, 1996). The fixtures, fittings and furniture was assumed to add 1.5m² initially and the operational energy to add 8.0m² over 40 years. The replaced elements that were not fixtures, fittings and furniture added 3.13m²/m² and the replaced fixtures, fittings and furniture added 8.4m²/m², giving a sub-total of 29.65m²/m².

The initial embodied energy of the case study medium rise office building, including the direct energy and the assumed incompleteness, but not including fixtures, fittings and furniture, was found to be 11.2m²/m². The operational energy was assumed to be 8.0m²/m². The energy embodied in fixtures, fittings and furniture was estimated to be 1.5m²/m² and the energy embodied in recurrent non-furniture elements was assumed to be 3.13m²/m². The largest single element in the simulated life-cycle energy analysis was the replaced fixtures, fittings and furniture at 8.4m²/m² which, when added to the initial fixtures, fittings and furniture embodied energy, comprised 31 percent of the total life-cycle delivered energy (Figure 3). Even with an assumed life which is twice as long, it remains one of the top few contributors to life-cycle energy. The ratio found between the building initial and recurring embodied energy, the furniture initial recurring embodied energy and the building operational energy was 1.79: 1.24: 1.00.

The potential for errors and variation in the inputs to this model has not been tested. Nevertheless, it has been demonstrated that the energy embodied in fixtures, fittings and furniture is one of the most important items in the life-cycle of a building, closely followed by the operational energy and then the embodied energy of the other elements. If latest BOMA figures are used, operational energy becomes the most significant single item in the life-cycle energy, and more so if primary energy values are used and the operational energy mix is primarily electricity. However, over time as buildings become more efficient or renewable energy is used, the embodied energy components will become relatively more important. Fixtures, fittings and furniture thus appears to be a key item for the future environmental assessment of buildings.

**Conclusion**

The energy embodied in furniture, fixtures and fit-out was found to be one of the most important elements of the life cycle of a building, in energy terms. This information is useful for facilities managers, because previously the energy implications of the
replacement of fixtures, fittings and furniture in office buildings were unknown. Greater weight should now be given to the optimisation of fixtures, fittings and furniture use in terms of environmental performance, relative to the time spent particularly optimising the operational environmental performance of buildings.

Implementation strategies for the optimisation of life cycle requirements for fixtures, fittings and furniture need to be developed, and may include:

- manufacturing low embodied energy materials, materials with recycled content, materials manufactured with renewable energy, minimised wastage;
- design furniture which can be easily refurbished, demounted or recycled; and
- facilities management re-use of existing fixtures, fittings and furniture in the same building, utilisation of second-hand fixtures, fittings and furniture, extension of life of sound existing fixtures, fittings and furniture.

Further research into more accurate quantification techniques for energy and other goods and services inputs to fixtures, fittings and furniture manufacture is justified. The flows of second-hand fixtures, fittings and furniture also need to be investigated, though the demand for new fixtures, fittings and furniture was the focus of this work. The material energy intensities also need to be updated and validated as national, technological and regional averages for Australian and imported products. Further aspects of this problem also need to be considered, such as the environmental impacts of the energy embodied in fixtures, fittings and furniture.

We recommend research into furniture embodied energy focuses first on the energy required to process and assemble items, even though the input-output data suggest the indirect energy embodied in materials used and other goods and services required by manufacturers will be more important in total. Manufacturers should make themselves more aware of the energy implications of their designs and operations, taking account of waste minimisation and recycling activities, for example, that may save relatively large amounts of indirect energy use and associated greenhouse gas emissions. By considering also the life cycle implications of furniture,

![Figure 2 Life-cycle delivered energy of case study building, 40 years](image1)

![Figure 3 Life-cycle energy time series for building and furniture, 40 years](image2)
allowing for long-life or loose-fit or low environmental impact, furniture manufacturers may be able to add value in environmental terms to their products. Ultimately, it will be up to designers and consumers (mainly facility managers) to support items and practices designed to minimise overall building energy use, maximise life cycle utility and ultimately to involve less resource depletion and thus less strain on the global environment.

References


(Graham J. Treloar recently completed his PhD, titled “A comprehensive embodied energy analysis framework” (Deakin University). He has worked as a researcher for the Division of Building, Construction and Engineering at the Commonwealth Scientific and Industrial Research Organisation, Melbourne, Australia, and has published several journal and conference papers, and research reports. He is a steering committee member for an Australian Greenhouse Office project, titled “Study of Greenhouse Gas Emissions from the Australian Residential Building Sector to 2010”. He is the project leader for the Australian Agile Construction Initiative program on Life Cycle Assessment and has written over 50 papers and reports.

Andrew McCoubrie is a Bachelor of Architecture degree graduate. His honours research thesis, titled “Embodied energy in office furniture and fit-out”, earned the Vice Chancellor’s Prize across the University in 1996. He is currently working on a Master of Architecture degree (Deakin University).

Peter E.D. Love is an active researcher, and is recognized internationally for his work in the areas of quality management and business process management. He has authored/co-authored over 100 refereed research papers.

Usha Iyer-Raniga recently completed her PhD from Melbourne University focusing on the improvement of suburban environments using concepts from management, group and social theory. Over the last four years, she has worked as a research consultant for the Sustainable Human Habitat Consultants, the winners of the National Ideas Competition for the Sustainable Development of Jerrabomberra held by the ACT government in 1994).