EMBODIED ENERGY OF DWELLINGS

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Abstract
The concept of sustainable development of human activities has highlighted the environmental impacts of buildings, particularly the use of energy for construction and operation and the resulting contributions to carbon dioxide (CO_2) in the atmosphere from the burning of fossil fuels for energy generation. A system to estimate energy used in creating buildings, and the resultant CO_2 emissions, direct from 3D CAD drawings has been developed using the materials quantities module from a commercial software package. The model calculates, direct from 3D CAD drawings, embodied energy, CO_2 emissions and mass for all materials in a building, and provides graphing and tabulation functions which call upon CAD information to provide a wide variety of breakdowns of energy and CO_2 by element category, material category, and individual materials. This paper discusses the uses and benefits of this type of embodied energy analysis.

INTRODUCTION

The concept of sustainable development of human activities has highlighted the environmental impacts of buildings, particularly the use of energy for construction and operation and the resulting contributions to carbon dioxide (CO_2) in the atmosphere from the burning of fossil fuels for energy generation. A system to evaluate energy used in creating buildings, known as embodied energy, and the resultant CO_2 emissions is needed in addition to the models used to estimate operating energy of buildings.

The CSIRO Division of Building, Construction and Engineering in partnership with Cedar Enterprises, RMIT University and Wilde and Woollard and with financial support from the Energy Research and Development Corporation (ERDC) set up a joint project:

- to create a procedure and its related database content, which together would estimate the amount of energy embodied in a building; and the resultant greenhouse gas emissions generated through energy consumed in these processes, and
- to develop software for the CAD package APDesign which would calculate the material quantities, embodied energy and greenhouse gas emissions directly from a 3D CAD model to provide quantitative values to determine the environmental impact of alternative design and building materials at the design stage of a building.

The aim of the software is a procedure which design professionals use to assess alternative designs in terms of the amount of energy required to construct a building and resultant CO_2 emissions from that energy generation (Tucker *et al.* 1996). The procedures developed have the potential to be integrated into APDesign as part of the existing commercial package which has thousands of current users world wide.

This paper outlines the approach used in the development of the techniques and discusses the operation, uses, limitations, benefits and future directions for this type of embodied energy analysis.

EMBODIED ENERGY

Embodied energy is defined as the quantity of energy required by all of the activities associated with a production process, including the relative proportions consumed in all activities upstream to the acquisition of natural resources and the share of energy used in making equipment and in other supporting functions. Buildings have a significant impact on the environment due to the energy embodied in construction materials.

Currently, the designers of buildings have very little guidance or quantitative information on the embodied energy impacts of individual materials or the total for the building. Building professionals such as architects, engineers and quantity surveyors who design or quantify materials and costs, require an efficient system to permit them to compare the effects of alternatives on the environment.

To be able to quantify the energy embodied in the construction of a building, the quantities of materials must first be estimated through a process of disaggregation and decomposition to a level of detail which allows for the separation of components into their principal materials. Energy intensities of each material from a database can then be multiplied by the quantities of individual materials and the products aggregated to obtain the total for each material, element or whole building.

Embodied energy intensities are derived from input-output tables and other national and international studies. Among the difficulties encountered in using a wide variety of sources to verify values is the need to clarify definitions of system boundaries or whether the values are in terms of primary energy or delivered energy. To obtain an accurate and reliable database of embodied energy but CO_2 intensities for all materials used in buildings is an enormous task in itself and is a necessity for detailed comparisons of materials.

Previous investigations have calculated the total embodied energy from individual houses (e.g. Lawson 1992, Pullen and Perkins 1995, Tucker and Treloar 1994). Pullen (1996) has formalised the process into a process which links a spreadsheet to a series of databases for embodied energy calculations for houses.

COMPUTER MODEL

The chosen approach to fast and practical estimates of embodied energy, CO_2 emissions and mass values directly from 3D CAD drawings requires both 3D CAD and accurate quantity functions to calculate embodied energy values from a database of embodied energy intensities. Existing software called APDesign was selected as a basis for development because it provided as many of the required functions as possible and was capable of extension. APDesign is a CAD package developed in Queensland and used extensively in Australia, Europe, Canada and the USA.

It was necessary to extend the capabilities of APDesign to further levels of detail beyond the bills of quantities approach which was successfully implemented in the original software. Every item needed to be further disaggregated into its component materials and a generic approach developed to achieve such extra detail with minimal effort. The resulting software makes it a very simple and straightforward procedure for users to access and utilise the embodied energy analysis techniques.

The software is the first system which has attempted to design a framework for fast and useable estimations of embodied energy, CO_2 emissions and mass values directly from 3D CAD drawings at the design stage and the future possibility of simulating various design options for comparative purposes.

USES

The model has been developed as an evaluative tool for assessing the comparative embodied energy impacts of alternative materials to assist in determining the overall environmental impact (as measured by embodied energy or CO_2 emissions due to energy use) of alternative design and building materials at the design stage of a building. It provides a designer with a measure of the total environmental impact of a building or component from a perspective never before undertaken.

Designers and quantity surveyors are familiar with the elemental cost planning approach to building de-composition and, as it is an accepted analytical approach to building design, the same approach facilitates comparisons between embodied energy impacts and building costs of elements of building, not individual materials. Embodied energy calculations can be performed at any stage of the design development process, enabling designers to quickly see the likely impact of certain material options on the total for the building or element.

In using the software, the effect of "trade-offs" become apparent. For example, a particular insulating material may incur high embodied energy impacts in terms of product manufacture, but require little energy to install and maintain. Furthermore, in comparison to other insulating products, it may enable greater energy savings to be achieved in the operation of air cooling or heating systems. It may permit the installation of lower capacity heating and cooling systems - or even the omission of such systems altogether.

Embodied energy impacts are best studied at an early stage in the design process of buildings and should focus on the combinations of the main contributors to the totals for the building. The effect of using alternative materials, and alternative combinations of materials on the total embodied energy of a building, can most readily be investigated at this design stage, preferably before any major design decisions are taken.

This project has had several major achievements. The ability to perform any analysis work direct from CAD drawings is a relatively new concept and one that will probably be utilised more as systems are developed. This project has not only shown that such analysis work can be carried out, but that quite detailed studies are possible. The concept of embodied energy is relatively new and this program is one of the first to attempt to provide a simple and effective methodology for performing embodied energy calculations. The program is the first, as far as is known, to attempt to calculate quantities of every material in a building (rather than items which can be costed) and hence the first to estimate embodied energy direct from a 3D CAD drawing.

BENEFITS

The provision of fast environmental evaluations of nationally averaged embodied energy and CO_2 and accurate mass of whole buildings is the major benefit of the prototype software. It requires little additional effort by designers, architects and quantity surveyors when using APDesign, to perform embodied energy, CO_2 and mass calculations. Simple association of an appropriate embodied energy formula set with a component, through the database editor, is all that is required. This allows users to compare the embodied energy, CO_2 and mass for all or part of a building, for different design solutions.

The implemented approach identifies the main contributors of embodied energy and CO_2, by element and material categories so that designers can concentrate on the areas where gains are likely to be most easily achieved and provides detailed material breakdown of building elements for other environmental assessment procedures. The various multi-level analysis options provide users with a highly flexible method for obtaining the data required for analysis and decisions.

The final embodied energy total provides an energy value for the whole building on the same basis (delivered energy) as operating energy for life cycle energy assessments and provides a basis, in the form of CO_2 emissions, for comparing the impact of primary energy use. In addition, the contributions of materials in the whole building by mass are also calculated.

CASE STUDY

One of the first applications of the embodied energy model was estimating the embodied energy and resultant CO2 emissions of a typical dwelling. A detailed drawing typical of 3D CAD is illustrated in Figure 1.

The dwelling was a simple three bedroom brick veneer family home constructed on a concrete slab with internal stud walls lined with plasterboard and a timber framed roof with concrete tiles. Windows and doors were all timber framed and bathroom and kitchen fittings were all of a standard quality. The calculations included carpeting and painting, but drapes/blinds and furnishings were not included.

Tables and graphs enable users to quickly see the relativities of different building items and materials with regard to their embodied energy, CO_2 and mass values and also enable comparisons of different construction techniques and materials.

Most of the embodied energy is in the substructure and external walls (Figure 2) with other significant contributions from the staircase, roof, windows, floor finishes, plumbing and electric light and power. The material group which produces the most CO_2 is concrete followed by plastic, steel, masonry and ceramics (Figure 3). The individual materials which contribute most to the resultant CO_2 emissions was headed by cement and brickwork (Figure 4).

Thus it was the materials with the lowest embodied energy intensities which headed the list of materials producing the most CO_2 in the dwelling. The conclusion is that it is the **total** of embodied energy consumed or CO_2 generated by the dwelling, or part thereof, which should be focussed on as a potential target for CO_2 reductions not a material itself.

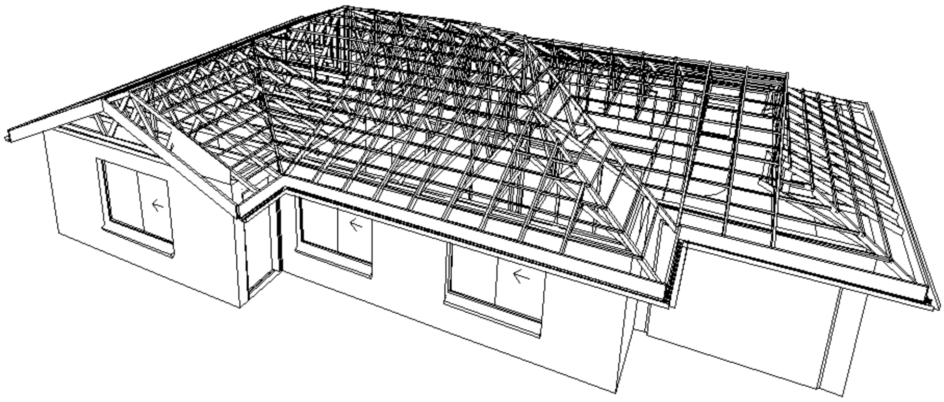

Figure 1 3D CAD drawing of a dwelling

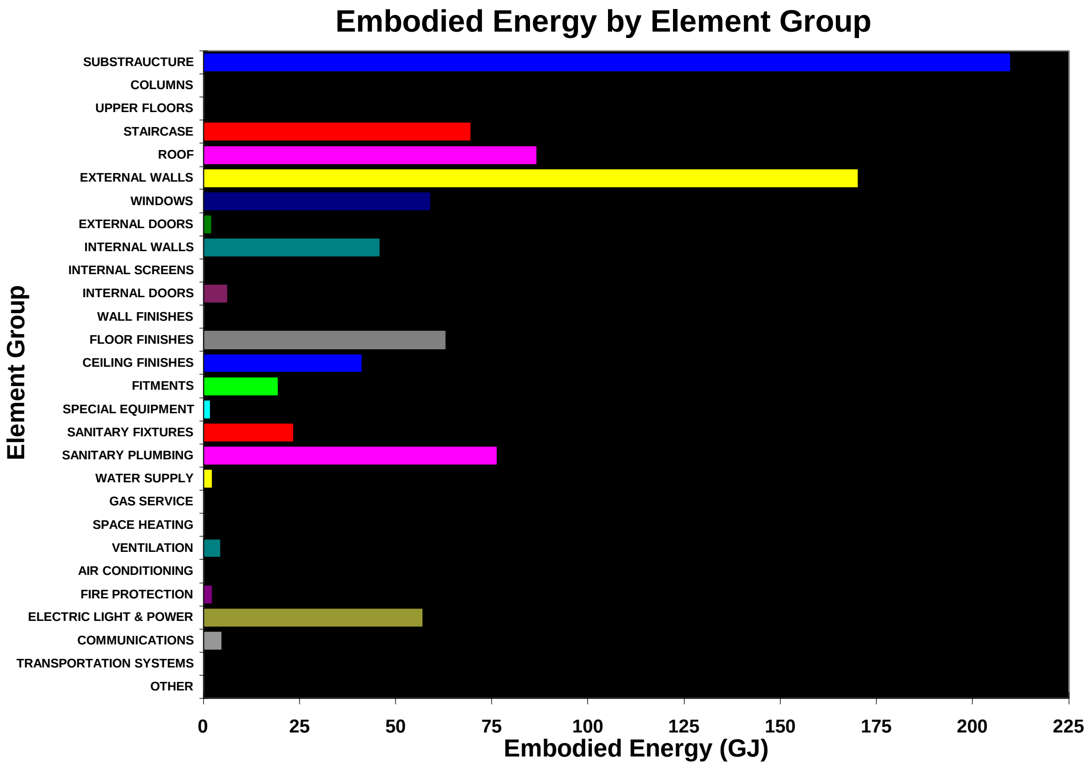

Figure 2 Graph of embodied energy by element category

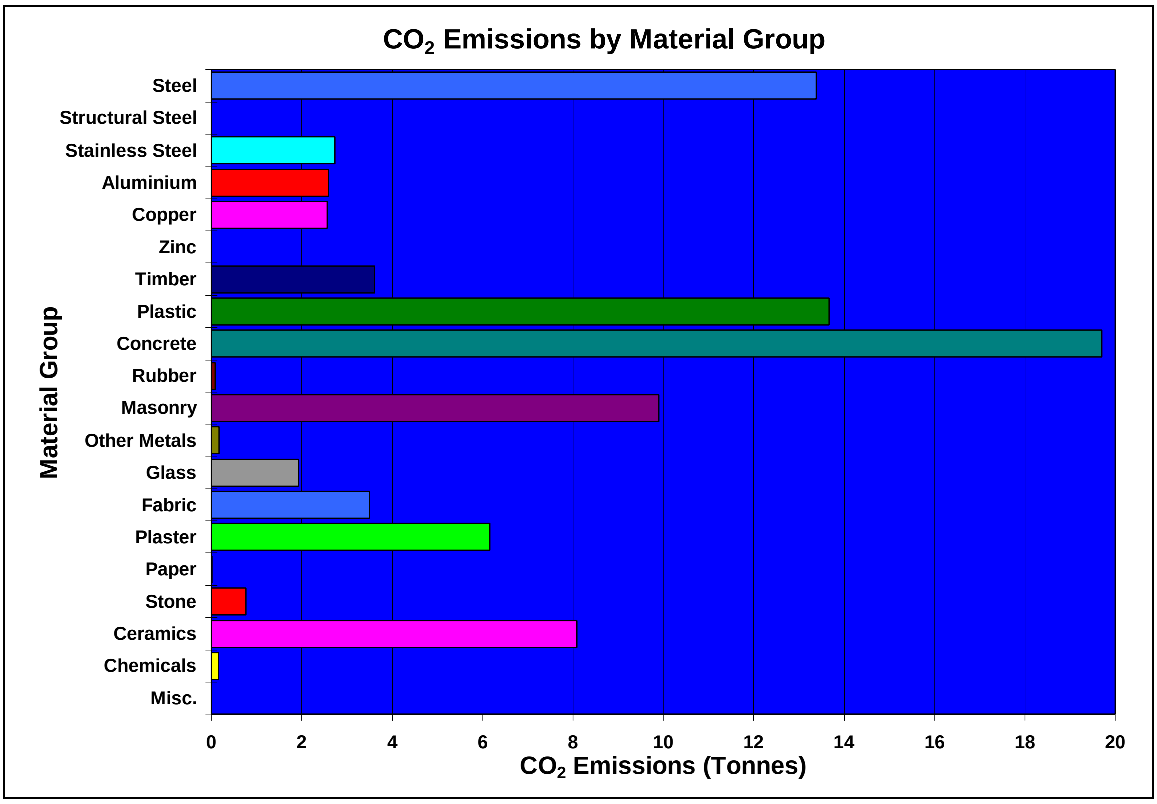

Figure 3 Graph of CO_2 emissions by material category

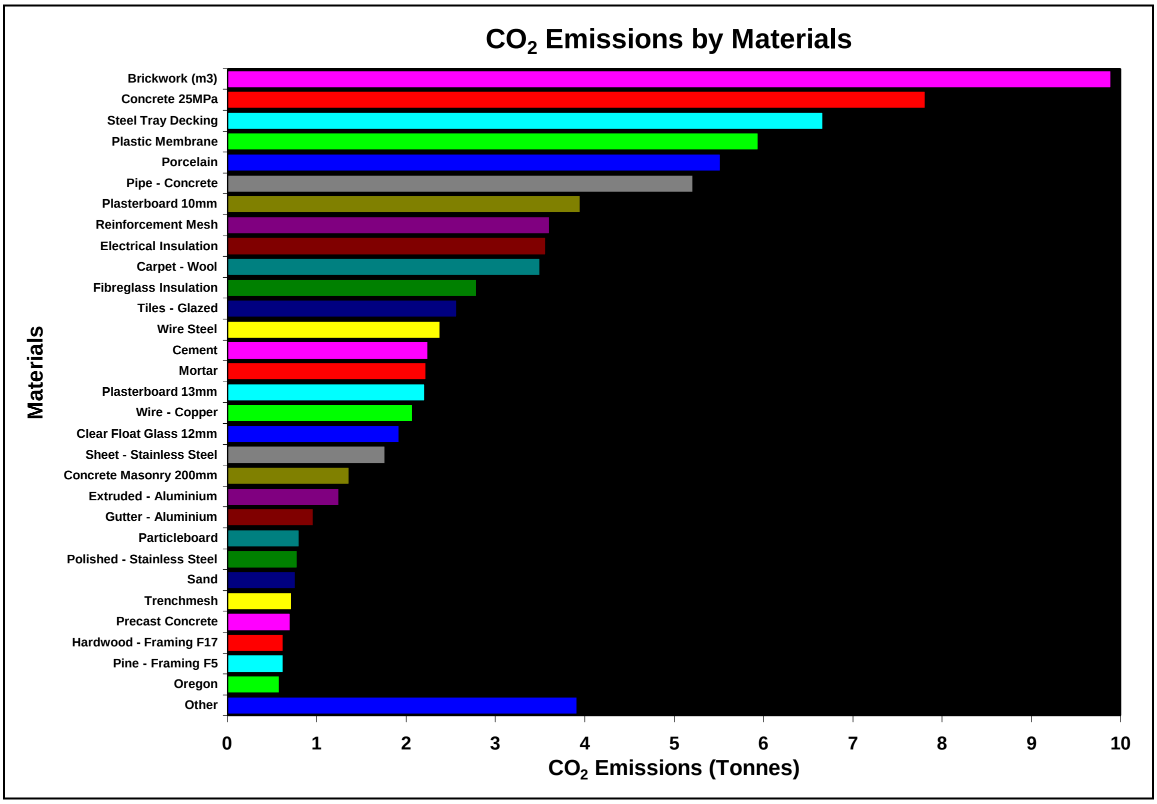

Figure 4 Graph of CO_2 emissions for top 30 materials

CONCLUSION

Embodied energy and CO_2 emissions are becoming important factors in the built environment and with the possibility of legislative requirements and standards, the ability to perform accurate calculations is essential. The software is the first example of a simple, yet effective CAD based tool to perform these calculations directly from quantities of individual components of a building. It allows designers to undertake a sophisticated analysis on their designs and compare alternative design solutions, quickly and effectively. The **total** of embodied energy consumed or CO_2 generated by the dwelling, or part thereof, is what should be focussed on as a potential target for CO_2 reductions not an individual material itself. Although the software is still in its prototype form, it demonstrates the enormous potential for using 3D CAD based tools for analysis work, not only for embodied energy, but for a range of environmental areas.

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