

THE CALCULATION OF EMBODIED ENERGY IN NEW BUILD UK HOUSING

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Reducing CO₂ emissions to mitigate the impacts of climate change is now an international imperative. The built environment is responsible for nearly half of all CO₂ emissions in the UK. Therefore, the reduction of carbon emissions from the products and processes involved in a building's lifecycle are of paramount importance in meeting national and global emissions reduction targets. The energy used and consequent carbon emissions associated with construction materials and processes are usually calculated using the concept of embodied energy, albeit with significant variations in methodology. In general, the embodied energy of a building is considered to account for less than one-fifth of its whole-life energy use. However, as energy efficiency for new-build improves towards the zero carbon target in 2016, the embodied energy will assume an increasingly greater proportion, approaching 100% of the lifetime energy use and emissions. The research reported here is aimed at achieving a better understanding of the aspects of embodied energy of new-build UK houses (in particular, the focus is on the accuracy of various calculation procedures) that are often simplified to a few building types via a generalised and frequently non-UK, representation of the construction process. The need for a more standardised calculation method for embodied energy and resulting CO₂ emissions is therefore discussed. Although considered in relation to the house building industry, this research is also applicable to the wider construction industry, as well as manufacturing.

Keywords: climate change, CO₂ emissions, embodied energy, new build housing

INTRODUCTION

The Government has set high targets for the reduction of emissions by the UK as a whole, with an 80% reduction below 1990 levels aimed for 2050 (Climate change Act 2008). To achieve this ambitious target *al.l* areas of life will have a role to play, including the construction industry. The construction of housing is of particular importance when the targets for achieving zero carbon homes by 2016, coupled with the Government's annual housing construction targets, are considered. However, it should be noted that to date there has been little consideration by legislators of the energy associated with the materials and construction processes, i.e. the embodied energy. This energy and its associated emissions may become a target for reductions in the near future as the industry is required to reduce its contribution to the overall emissions of the country.

Different aspects of embodied energy have been considered by a number of researchers over a considerable period; however, the methods of calculating it vary greatly.

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Embodied energy is considered to be the energy associated with a material or process as a result of all upstream activities relating to it. For example, the embodied energy of bricks would include that required to extract the clay from the ground, to transport it to the manufacturing site, to shape it and to fire it as well as other energy uses. To obtain a full evaluation of the embodied energy of a material Buchanan and Honey (1994) discuss the need to include energy used in the processes of making the machines that make the product and in generating the finance for the processes to occur.

There is currently a lack of incentive integrating the calculation of embodied energy in construction decision making. The primary reasons are the lack of appropriate legislation and a lack of interest in the impacts of embodied energy by the public and industry stakeholders. The time consuming nature of embodied energy calculation and the varying accuracy of the obtained results restrict its use in the decision making process. Hence, the exercise is carried out mostly in the academic contexts.

If, as predicted, embodied energy becomes a target for emissions reduction it will become necessary for companies to quantify the emissions associated with their projects. This may be necessary for a number of reasons; it would potentially allow the emissions of the sector as a whole to be calculated and allow a more accurate proportioning of responsibilities for the overall emissions of the country. If the emissions relating to a project are to be offset using approved offsetting schemes it is necessary to accurately know the value which must be offset; this avoids the possibility of companies paying out too much or too little in offsetting costs. Accurate values can also be used to identify those elements with the greatest emissions; both in terms of designs as a whole and if calculated on a material level in terms of which materials have the greatest impact on the overall emissions of a project. Once identified these elements can be considered for alteration or replacement with lower impact alternatives. Rerunning the embodied energy calculation with the alternative materials, processes or designs in place would clearly illustrate the effect of the changes. Pullen (2007) also considers the possibility of embodied energy databases being used to identify the potential for material recycling when a structure reaches the end of its life and even being used to predict what materials will become available in the near future as a result of demolitions, allowing the reuse of the material to be planned.

The current estimates of embodied energy in housing vary significantly. Ravetz (2008) gives construction carbon emissions as 27% of the lifetime emissions. The use of percentages has potential for misrepresentation as lifetime energy use and lifespan are both variable factors. In particular, as energy efficiency of appliances improves as a result of government targets (DEFRA 2007) the annual energy use may fall, giving a falsely low value of embodied energy. A more meaningful value would be an absolute figure for a particular building, or a value per unit of floor area.

EMBODIED ENERGY CALCULATION METHODS

Input-output analysis

This method uses data tables which show the units of output from each industry sector into each of the other sectors. This demonstrates product flows which can be converted into energy flows.

To use this method of calculation Input-Output data tables for the country concerned are required.

These tables usually take the form of a matrix which illustrates the financial input in GBP (for UK) from each sector (row) required to make one GBP worth of output (column). For example, based on the fictional input-output table in Figure 1, Industry C requires 0.3 units of input from A, 0.2 units of input from B and no input from C to make one unit of output.

	A	B	C
A	0.25	0.3	0.3
B	0.4	0.7	0.2
C	0.5	0.7	0

Figure 1- Sample input-output table

The direct input-output table as produced from industry data can be converted to the Leontief inverse Input-Output which is used to calculate the embodied energies by giving the total energy requirements in MJ/£. The Leontief inverse matrix for the UK is provided by the

Government (Office for National Statistics 2009) in addition to published direct input-output tables, alternatively the matrix inversion calculation is described by Leontief (1966).

The total energy requirement given by the inverse Input-Output matrix is the sum of direct and indirect energy requirements, therefore by subtracting the direct energy input per GBP of output the indirect energy inputs, i.e. the upstream energy inputs can be identified. The energy requirements, also referred to as energy intensities can be combined with material price data to produce a value for embodied energy. If this is summed for all the materials used in a project the embodied energy of the project can be found.

A simple to follow example of this method to calculate the embodied energy of housing is given by Suzuki *et al.* (1995) who use the method to analyse and compare housing in Japan.

The main disadvantage of this method is that it is time consuming if the Leontief matrix is not supplied. There are also identifiable sources of error. Pullen (2007) identifies varying energy and materials prices, as well as methods of data collection as sources of error for Input-Output calculations. The age of the data is also a potential source of error, for example the published 2008 input-output data for the UK is based on 2004-2006 data and published Leontief tables for the UK are based on 1995 data (Office for National Statistics 2009). As technology changes over time the use of older data may result in less than accurate values. Treloar *et al.* (2001) state that the Input-Output method is not suitable for use in calculating individual projects due to the potential for errors.

Process analysis

This method involves using the energy data from the factory manufacturing the material to determine the energy used in creating it. It is considered fairly straightforward and Treloar *et al.* (2001) state that this method can be the most accurate but Lave *et al.* (1995) note that values are likely to be incomplete due to higher levels of energy inputs being unaccounted for. This is further expanded by Pullen (2007) who identifies that the calculation process can become complicated when trying to evaluate higher levels of energy input, but that this is necessary to obtain an accurate value of embodied energy. Pullen (2007) also notes that the accuracy can be affected by different sources of data and their energy boundaries.

The speed and relative simplicity of this method make it preferable to Input-Output analysis as these would relate to lower costs in an industry setting. However, in the case of most materials this is achieved by a significant loss of detail and associated

accuracy where the energy inputs are not concentrated at the manufacturing stage. Process analysis also relies on the availability of data from manufacturers, who may not be willing to supply the information unless required by law.

Hybrid analysis

This combines elements of both the input-output analysis in an attempt to achieve a more accurate value of embodied energy than that obtained by either of the methods individually. Examples of the use of hybrid methods can be found in Treloar *et al.* (2001) and Pullen (2007). Treloar *et al.* (2001) compared an input-output hybrid method with a standalone input-output calculation. The method uses data from input-output analysis of the sample building then modifies the values using process analysis to obtain a value containing 48% more embodied energy than the Input-Output analysis alone. They also discussed the use of process based hybrid analysis, noting that it is the more common method, but state that this method has a tendency to be incomplete as a result of excluded elements (Treloar *et al.* 2001). Pullen (2007) uses a hybrid method based on Input-Output data to determine the indirect embodied energy, combined with the results of process analysis to determine the direct embodied energy; these were combined to form an embodied energy coefficient for each material.

It can be seen that using a hybrid method can lead to greater accuracy, however, it involves a longer calculation process to obtain the final figure. Calculating the effect of changes in design would be a time consuming, and therefore costly, process. Many of the shortcomings noted for Input-output analysis can also impact hybrid analysis, such as the age and availability of data.

Embodied energy coefficients

Recent work by Hammond and Jones (2008) to create an updated list of embodied energy coefficients for a wide range of materials. This data provides values for the embodied energy per unit of material for the UK situation and can therefore be used in the calculation of embodied energy by combining the values with a bill of quantities. The creation of this database is discussed by Hammond and Jones (2008b), they state the importance of lifecycle assessments when considering embodied energy, however, the database largely covers materials on a cradle to factory gate basis meaning that the effects of transportation, construction and any end of life reuse or recycling should be considered separately to achieve a lifecycle assessment. The Inventory of Carbon and Energy (ICE) database (Hammond and Jones 2008) was compiled from a wide range of sources. To identify the suitability of the data it was considered in terms of the calculation method, systems boundaries, age of data, country of origin and the inclusion of an embodied carbon value. Although Hammond and Jones (2008b) detail the methodology used to identify the values given it is stated that for many of the materials included overseas data was used as values were not available for the UK.

The database only includes values for materials, site activities are not included. Some other existing tables for embodied energy and carbon, such as those given by Buchannan and Honey (1994) do include such data, however, it should be noted that these are based on New Zealand and some alteration would be required to make them fit the UK situation. In particular alteration of the fuel mix used to calculate the carbon emissions. The age of the data may also mean it requires some alteration.

Hammond and Jones (2008b) illustrate the accuracy of this method by evaluating a number of case studies and comparing them with other embodied energy values for

dwellings; although the values differed from previous results for the same buildings the overall comparison between buildings for embodied energy per metre square of floor area showed the values obtained were close to the mean.

The main advantages of this method are the speed and hence reduced costs achieved by use of existing data. It is also a relatively simple method to use, requiring little training and can be integrated with the existing design process with minimal effort. An example of such integration can be found in the Environment Agency's carbon calculator, which is used to calculate the embodied energy of civil engineering structures (The Environment Agency 2008).

CHALLENGES ASSOCIATED WITH THE DETAILED CALCULATION OF EMBODIED ENERGY

There are a number of issues associated with the calculation of embodied energy. The most important is that of achievable accuracy. To be truly representative of the embodied energy of a material or process the calculation needs to include all associated energy, regardless of quantity. However, it can be seen that to achieve this would require a large number of in depth calculations, many of which would only result in a tiny addition to the value of embodied energy. As discussed by Hammond and Jones (2008b) in order to limit the length of the calculations some of the upstream energy inputs are likely to be ignored; although they may only increase the embodied energy by a minor amount it is a potential entry point for inaccuracy. The use of data originating from other countries can also lead to significant inaccuracies. Varying energy mixes, processes and transport distances all alter the embodied energy and associated emissions of a material or process and these should be taken into account if it is necessary to source data from outside the UK. Even within the country embodied energy values may vary depending on processes at different factories and transportation distances. These may be considered unavoidable, but should be minimised to the greatest possible extent; for example, by averaging a range of values and considering the calculation of an exact value if a particular project has special circumstances, such as particularly long or short material transportation distances. Pullen (2007) also considers that inaccuracies in material prices, energy prices and data collection may lead to inaccuracies in the output values of embodied energy.

The time consuming nature of embodied energy calculations is one of its major problems as processes involving a great deal of time result in considerable expense for the company carrying it out. The current lack of incentives to carry out embodied energy calculation, coupled with this cost, result in minimal occurrences of calculation, largely restricted to research projects. If the incentives increase, for example, by a requirement to accurately offset emissions from projects, then the industry will require a method of calculation which produces the best possible accuracy for the minimal outlay in terms of time and money.

Once the embodied energy of the materials used in the construction are evaluated the effects of transportation and site activities must be considered in order to obtain a true value for the embodied energy and emissions associated with a project. Work done by Cole (1999) to evaluate the effect of transportation and construction activities on energy and emissions totals gave values of 2-25% of the material embodied energy depending on the type of structure; with worker transportation considered to be of particular impact.

Calculating the energy used by transport during the project covers two areas, the first being material transportation, the second being worker transportation. In order to successfully and accurately evaluate these detailed records need to be kept during the construction process. The distances travelled by all materials and workers, as well as the type of transport should be recorded. This can then be combined with emissions data to determine the value for the embodied energy which must be assigned to the project for transportation. The main drawback of this is the significant time and financial commitment required to record and process the data. An alternative could be to make generalisations about the distances travelled, in particular by the workforce. For example, an average commuting distance could be established, this can then be multiplied by the number of man days to give a value for the project. However, it should be noted that this will result in a loss of accuracy and may be affected by factors such as size of firm- some members of larger firms may have longer travelling distances.

Calculating the effect on embodied energy of transportation associated with materials is simpler as the energy associated with the trip need only be calculated once, then multiplied by the number of trips. For more complicated material transportation, involving imported materials and several methods of transportation the data may be available from the supplier or else would require calculation if it cannot be located from elsewhere.

The lack of available data regarding site activities is also considered to be a challenge. Site activities can account for a considerable proportion of the energy associated with the construction of a building and hence to obtain an accurate total value for a project must not be ignored. In addition while the site manager cannot control the embodied energy and associated emissions of the materials the site activities are under their control. Monitoring the impact of different activities on the total embodied energy and emissions for the building can lead to reductions. The use of available figures for emissions and energy relating to activities, such as those given by Buchannan and Honey (1994) could be examined to determine the applicability to the UK situation. The age and differing country of origin of the data may result in significant inaccuracies. If this is the case figures should be altered to provide values more representative for the UK case, however, it would be better to include activities with some inaccuracy than to ignore their effect on the totals for embodied energy and emissions of the project. Once energy and emissions coefficients for site activities are known they can be multiplied by the number of hours to obtain a total figure.

The use of plant onsite is likely to be the main contributor to energy use and emissions associated with site activities. It should also be remembered the plant is transported to site from either the rental depot or the contractor's storage site, this must also be included and can be calculated as for materials transportation.

PROPOSED CALCULATION METHOD

It is considered that the use of existing embodied energy coefficients to calculate embodied energy of a building is likely to be the most effective way for evaluating new build housing. Although this is not a new method, being based on that demonstrated by Hammond and Jones (2008b), it is proposed that the method is expanded to incorporate emissions from a wider range of sources than just materials. The use of existing data makes the process much more rapid than attempting to evaluate each project from scratch, this in turn would result in lower costs.

When using this method it is important to ensure that the values used for embodied energy coefficients are the most accurate possible as this will affect the accuracy of the overall calculation. Regular updates would be required and in some cases a small number of coefficients may have to be generated from scratch, for example, if a unique element is used. The quality of the construction data used is also important and relies on effective collection and recording.

The accuracy of this method is considered acceptable for the proposed use based on the examples in the Hammond and Jones paper (2008b). A potentially beneficial characteristic of the method is that it is simple to alter the level of detail as specified by the client. For example, it may be that only the top ten materials by quantity are considered, alternatively every element included in the structure and construction processes may be evaluated. The use of pre-existing coefficients makes the change between these a much faster step than if every material had to be evaluated.

An additional benefit of this method is that it is simple to substitute an alternative material into the calculation and see the effect of the change on the total embodied energy. If used at the design stage this could enable the selection of materials which have low embodied energy in preference to higher embodied energy alternatives and hence produce the lowest impact building possible.

The energy and emissions associated with materials transport should be evaluated by the use of records of distance from factory to site, number of loads and method of transport. Although this requires a financial and time commitment to achieve it should not be too great as it makes use of repeated calculations.

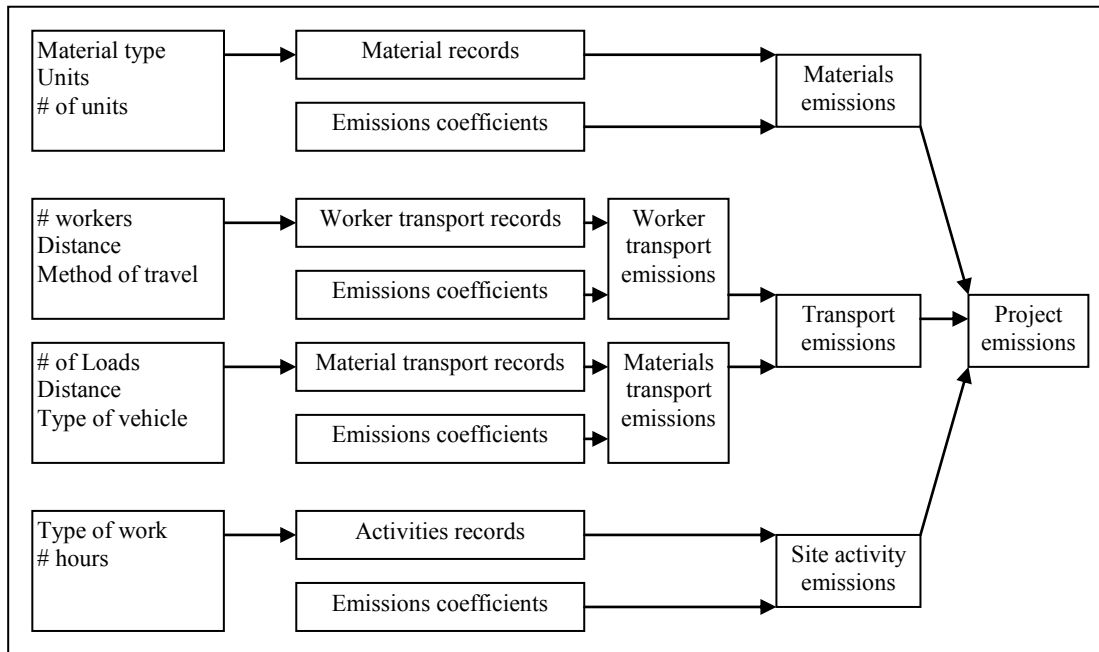
In order to determine the effect of worker transportation it is suggested that some generalisations are used to minimise the time and financial requirements of the calculations. A site specific value should be obtained for average commuting distance, this could be by use of questionnaires during the site induction process or by requesting information from subcontractors who will be used. The averaged value for commuting distance can then be combined with workforce data to determine the value to be assigned to the project. It should be noted that the average value used should be reviewed at appropriate intervals (depending on project size) as the nature of construction projects mean the workforce changes over time, which may impact commuting distances. If there is an individual case which is expected to have a significant additional impact this should be dealt with separately, for example, specialist workers flown in from abroad to install a particular element. The use of this method limits the cost to the calculator while still producing accurate results.

Calculating the effect of site activities is essential to obtaining a representative value for associated emissions and energy of the project. It is recommended that the hours of each activity are logged and then combined with a value per hour for energy and emissions, as with the energy of materials. Although this requires some time to ensure accurate records are kept the process is less time consuming, and therefore less expensive than performing a full calculation for each activity. The availability of coefficients for site activities is limited as discussed previously, however, it is considered more important that site activities are included rather than ignored, even if some inaccuracies are introduced by the coefficients used. As more accurate coefficients become available in the future, these should be used.

The effect of plant use on the emissions and embodied energy should be calculated by recording hours of use and combining with coefficients. The transportation of plant to site should be included by calculating as if for materials transportation.

Figure 2 shows the proposed method in the form of a flow diagram.

Figure 2- Diagrammatic representation of proposed method



The use of a database driven application for each section would greatly aid the calculation process. The tables could be pre-populated with the embodied energy coefficients. The data from records such as hours of use, distances travelled etc could then be inputted and the spreadsheet set to automatically calculate the total values for each section and overall project values, see Figure 3. This is similar in nature to the Environment Agency’s carbon calculator (The Environment Agency 2008), however with a much wider range of inputs, resulting in a more accurate total value. The time saving which could be achieved by this would represent a considerable financial saving, reducing the effort required to data recording and entry and minimising the need for specialist training.

Figure 3- A sample of the proposed calculation spreadsheet, values from Hammond and Jones 2008a

Material	Unit	Units used (#)	Embodied energy (MJ/kg)	Embodied carbon (kgCO2/kg)	Total Embodied energy (MJ)	Total embodied carbon (kg CO2)
Fibreglass insulation	kg	28	1.35			
Plasterboard	kg	6.75	0.38			
Concrete block 10MPA compressive strength	kg	0.67	0.074			

FUTURE WORK

Evaluation of embodied energy associated with transportation of materials from factory to site to create emissions coefficients for incorporation in the spreadsheet.

Calculation of embodied energy and emissions coefficients for site activities for incorporation in the spreadsheet.

Creation of a spreadsheet capable of processing all inputs into a project (materials, transportation, site activities) to produce an accurate energy and emissions value.

CONCLUSIONS

It is considered highly likely that the calculation of embodied energy will soon move from the domain of academic research into construction practices. Being able to accurately predict values of embodied energy will enable companies to offset the effects of their construction and highlight areas in need of improvement to achieve overall reductions in embodied energy and the associated emissions.

In order to become acceptable in mainstream business the method used must be cost effective, balancing time to complete and cost with achieving an acceptable level of accuracy. Because of this it is recommended that the method used involves the use of a spreadsheet pre-programmed with values of embodied energy and carbon emissions coefficients such as those produced by Hammond and Jones (2008) for materials. The values used should be as applicable to the individual case as possible, for example calculated for the UK situation, rather than abroad. It is also important that the figures used are the most updated versions possible. These values can then be combined with either a preconstruction bill of quantities or an accurate post construction list of materials as well as records of site activities and transportation to calculate the embodied energy of the project.

When attempting to minimise the environmental impact of a design it is important to compare changes to obtain a realistic assessment of their impact. The availability of a simple and rapid calculation of embodied energy would aid this process, making it easier to see if a design change perceived as sustainable has a positive or negative effect on the embodied energy of the project.

This method would produce a value for embodied energy and emissions up to the point of building completion. To extend this value to a lifecycle assessment it would be necessary to consider all maintenance, energy use and emissions associated with the building during its life as well as the demolition and end of life use of the materials. It may be possible to extend the calculation spreadsheet to accommodate this depth of calculation. This would allow a more accurate comparison of changes perceived as environmental as it would show if the change has resulted in higher or lower energy use over the life of the building. However, it would add a significant cost and time requirement to the calculation. It may also be possible to obtain a reliable estimate of the effect of material changes without performing a full lifecycle assessment by considering and comparing other available data such as U-values, maintenance requirements and disposal options.

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