Energy Implications of the Transportation of Building Materials

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Abstract

The embodied energy is a significant factor in the whole life energy consumption of a building. Its proportion of the total energy consumption attributable to a building throughout its life is increasing as improvements in thermal performance and energy efficiency of systems reduce the energy consumption during the occupied phase of the building life.

The embodied energy can include all energy attributed to a building material from its original source through to construction on site. This paper considers the component of embodied energy that is attributable to the transportation of the materials. It is based on a case study undertaken of a single construction site, determining the energy consumed in transporting the construction materials to site. The results of this study are based on the energy consumed in delivery only, the fuel consumed for a one way delivery journey.

Literature search identified that common assumptions made by different researchers when evaluating transportation by road vary between 1.18 – 4.5 MJ/tonne/km. However these figures are assumed to include allowances for other aspects of the energy consumed that can be attributed to transportation such as return journeys and. the manufacture and maintenance of vehicles and roads.

The paper shows that for a particular study of a site in Brighton 1.5% of the total embodied energy was attributed to the energy consumed in the delivery of the materials.
Part load delivery and packing ratio are identified as factors affecting the energy consumed in transportation of materials and these issues are discussed with reference to the Brighton case study.
Keywords: Embodied Energy, Transportation

1.0 Introduction

The life cycle of a building commences with the winning of the raw materials that are usedto produce building materials and components and ends with the final disposal of those materials after demolition of the building and the re-use or recycling of suitable products. It includes all of the stages of construction, operation and demolition as depicted in fig. 1.

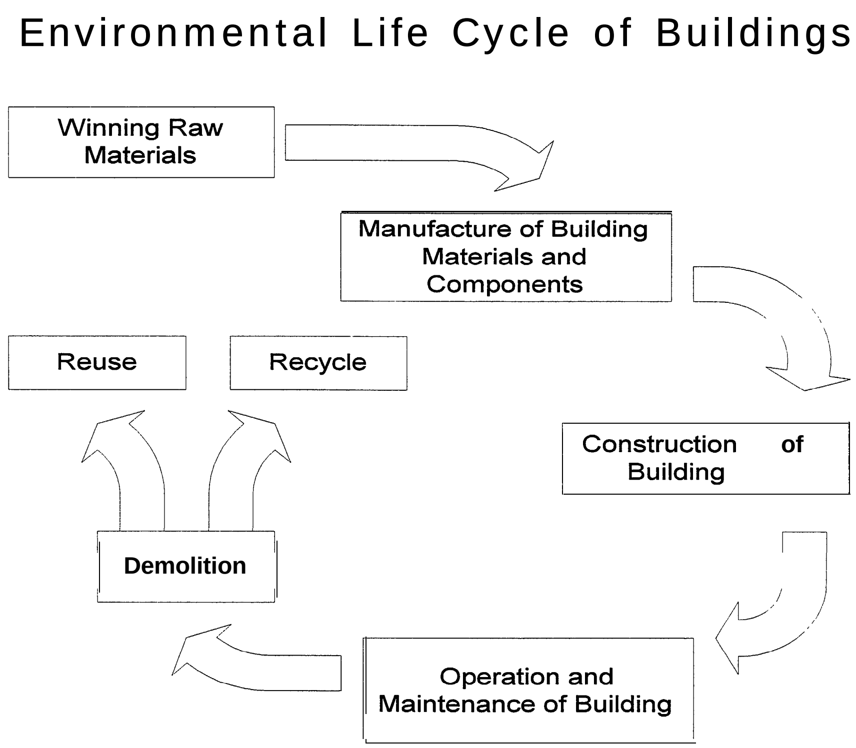


Fig. 1 Environmental Lifecycle of Buildings

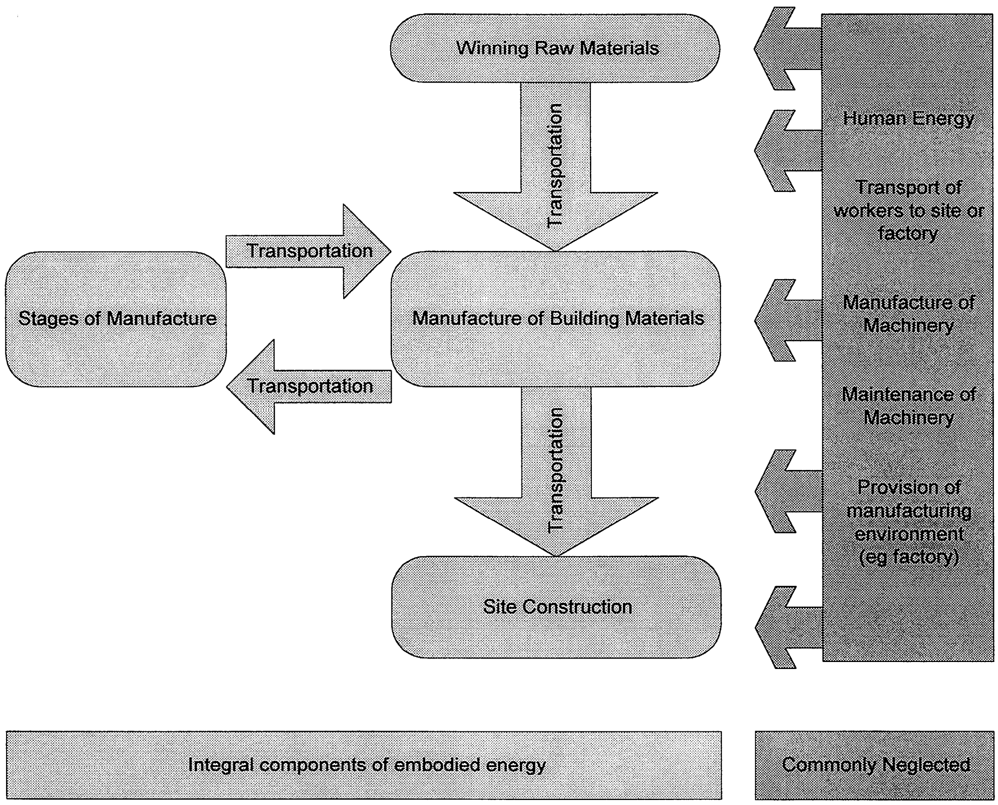
Throughout its life cycle a building will consume energy, generally in the form of fossil fuels. The consumption of fossil fuels results in the depletion of natural resources and in the production of pollution with its subsequent problems such as global warming and acid rain. It is estimated that more than 50% of UK energy consumption can be attributed to buildings and a similar proportion of the carbon dioxide emissions.

Much research has been aimed at understanding the energy consumption of occupied buildings and at reducing that consumption. However it is estimated that the delivered energy embodied in the constituent building materials and components is 350 PJ per annum (equivalent to 20% of the annual energy consumption in the UK domestic sector) and is responsible for 8% of the national carbon dioxide emissions. (1)

This paper is based on research undertaken at the University of Brighton aimed at improving our knowledge of the total embodied energy of building materials. In particular it studies the component of the embodied energy that is attributable to the transportation of those materials. The research project was sponsored by the Engineering and Physical Sciences Research Council.

2.0 Embodied Energy

The embodied energy of a building material or component is the total energy consumed in winning the raw materials, manufacturing the components and constructing the building on site. It includes the energy consumed for transportation within and between each of the stages leading to the completed building as shown in fig.2.



.Fig. 2 Components of Embodied Energy of a Building

2.1 Boundaries

A full audit of the embodied energy of any item can be very complex and there are diminishing returns with respect to the accuracy of the calculation the further removed the analysis becomes from the item under consideration. As a result the evaluation is often simplified and Fig.2 presents a commonly accepted definition of the embodied energy of a building.

Calculated in this way embodied energy figures are clearly site specific. They are related to the specific materials, suppliers and efficiency of distribution and delivery route. There is however generally no need for such a precise figure to be determined in order to provide useful data for building designers.

Published embodied energy figures for common building materials vary enormously and there is often little indication of what has been included in the analysis or how they have been obtained. Common exclusions are shown down the right hand side of Fig.2 but the transportation component is also often omitted or considered using gross simplifications.

3.0 Transportation Energy

This paper focuses on the energy consumed in transporting building materials from their origin to the building site and highlights a wide variation for different materials.

It is appreciated that the transportation component of embodied energy is often small compared to the total embodied energy of a material, but investigations have shown that in general, oversimplifications are made when estimating this component.

It is common practice to estimate transportation energy embodied in building materials through the use of a standard consumption in MJ/tonne/km.

Estimations of energy consumed in the transportation of building materials vary considerably and table 1, based on an original by Lawson (2), presents published figures for estimates used in Canada, Denmark, the UK and the USA. There is however no indication of the basis on which these figures were determined and comparisons are therefore dangerous.

Road Vehicles		
Country	MJ/tonne/km	Reference
Canada	1.18	(3)
Denmark	1.44	(4)
UK	4.50	(1)
USA	2.13	(5)

Table 1. Published figures for vehicle transportation energy

The research undertaken at Brighton has focussed on the delivery of materials to a single building site situated on the Brighton seafront and full details of the measurements have been published elsewhere (6). Vehicle fuel consumptions were calculated based the consumption of diesel with a calorific value of 35.7 MJ / 1 and vehicle efficiencies were based on the miles per gallon figures published in Philips (7).

A summary of the results of this study is given in table 2. The energy consumption figures are an order of magnitude lower than the estimates shown in table 1, however they represent only the energy consumed in the process of delivery and not the total amount of energy that can be attributed to the transportation of the materials.

Material	MJ/tonne/km	Material	MJ/tonne/km
RMC Concrete	0.10	Chipboard Flooring	0.29
RMC Mortars	0.05	Plasterboard	0.24
Dense Concrete Blocks	0.02	External Plaster	0.62
High Density Blocks	0.09	Internal Plaster	0.48
Thermal Blocks	0.05	Windows	0.33
Concrete lintels	0.72	Roof Slates	2.55
Structural Steel Beams	0.08	Celtex Insulation	7.92
Steel Shuttering	0.16	Angle Ties	49.24
Concrete Reinforcement	0.36	Zinc phosphate paint	1.34
Roofing timber	0.15		

Figures estimating the total energy consumed in transportation would include:

- fuel consumption in the delivery of materials
- fuel consumption in the return journey of the delivery vehicle
- attributable proportion of the energy consumed in the manufacture and maintenance of the vehicles

- attributable proportion of the energy consumed in the construction and maintenance of the roads

The components found to consume the most energy in transportation in the Brighton study were the steel beams, accounting for 18% of the total energy consumed in transportation. The steel shuttering and the ready mixed concrete were the other major proportions of the transportation energy, each representing approximately 11% of the total. It has been shown that these figures, based on consumption for delivery only, represent approximately 1.5% of the total embodied energy of the materials, when related to an average of published embodied energy figures.

4.0 Identification of Key Issues

Analysis of the results identifies that the delivered quantity of materials and the relationship to the maximum payload of the delivery vehicles are important factors in determining the energy consumed in transportation.

Vehicles may not be carrying their full payload capacity for a number of reasons and these are considered further under the headings of part load and packing ratio.

Part Load

A construction site may have received part load deliveries because:-

- The total site requirements are for less than a full load and the manufacturer or haulage company cannot schedule a full load.

An example of this can be seen in the delivery of angle ties of which only 0.1 tonnes were required on the site. These were delivered as a single load in a 4.5 tonne truck over a distance of 369 km.

There are of course a number of reasons why some deliveries need to be made in this way, but the relative energy cost is high. Careful planning of ordering schedules from the site and delivery schedules from the supplier would reduce this component.

- The restrictions on site storage are such that the total requirements for a material cannot be ordered at one time resulting in part load orders.

This problem was experienced in the delivery of thermal blocks where the 3 14 tonnes required were delivered in 22 separate deliveries. On this occasion it was not caused by part loading individual vehicles as smaller vehicles were used, but naturally the overall distance travelled was far greater than it needed to be.

- Security on the site is such that sub-contractors are unwilling to order the full requirements for fear of theft.

Loose materials are generally the responsibility of the sub-contractor until built into the building. Valuable materials that can easily be removed from site are therefore often delivered in small quantities.

On this site the plaster for the building was delivered in 14 separate journeys, once again increasing the distance travelled. However in this case the fmal leg of the deliveries, from supplier to site, were also at only 65% of the possible payload.

These issues will be affected by the material's distribution network, the management of the transportation system and the site management. The ability to organise full load distribution will be affected by whether the transportation is being undertaken by a manufacturers supplying their own products or by a specialist haulage contractors who might have the opportunity to plan a more efficient schedule for individual vehicles.

Packing Ratio
The nature of the building materials or components being transported dictate the type of vehicle being used which may result in the maximum load not being carried.

- The physical shape of the materials or components may make it impossible to load the vehicle to its maximum load.

The steel shuttering was a typical example of this effect as for each section of the journey the vehicles were only carrying approximately 25% of their payload capacity.

- The density of the material may be so low that it occupies a large volume.

The rigid insulation materials used on the site weighed a total of 1.1 tonnes but for the two legs of the journey travelled in a 25 tonne and 18 tonne vehicles.

These results do not identify inefficiencies in delivery but highlight limitations of the existing transportation system.

5.0 Conclusion

This project has resulted in the determination of transportation energy consumption figures for the full range of construction materials to a specific building site in Brighton. These figures are site specific and depend upon the specific set of circumstances relating to the building and its construction programme. The calculated transportation energy figures should therefore not be taken as transferable to any other construction site.

However the key factors raised by this study are widely applicable and their sensitivity need to be considered whenever embodied energy figures are evaluated.

The transportation energy calculated in this project, based on fuel consumption for delivery only, represents approximately 1.5% of the total embodied energy when published embodied energy figures are used. This figure will naturally increase when return journeys, vehicle manufacture and maintenance and the road network infrastructure are considered. Further, it relates to published embodied energy figures, which themselves vary by more than 100% in some instances. Nevertheless it serves as an indicator as to the significance of the transportation component for individual materials.

The key factors of part load and packing ratio have been analysed identifying common occurrences that make it impossible to optimise the efficiency of delivery. The more obvious factors of vehicle used, distance travelled and route taken, have also been considered and extenuating circumstances identified.

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