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From the cradle to the grave

by David Butler and Nigel Howard

Using results presented from an embodied energy and CO_2 audit of the BRE Low Energy Office, David Butler and Nigel Howard review the life cycle CO_2 emissions from office building services.

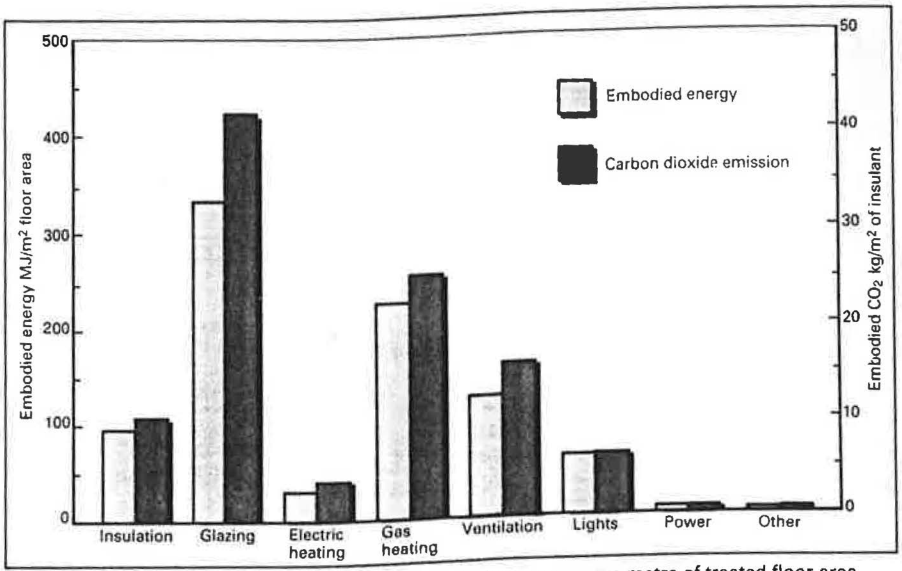


Figure 1: Embodied energy and associated CO_2 emissions per square metre of treated floor area for services at the BRE Low Energy Office.

The carbon dioxide (CO_2) emissions attributable to buildings result from both the embodied energy and the energy consumed in use over the building's life cycle.

Embodied energy is that used to produce building components from raw materials, deliver them to construction sites and build them into structures. Life cycle CO_2 emissions are the total emissions arising from embodied energy, in-use energy and the energy consumed in repair and maintenance work.

A major problem in estimating the energy embodied in building components is a lack of appropriate information. Embodied energy values quoted in technical literature are often expressed in terms of gigajoules per tonne of material rather than related to specific construction elements. Conversion to CO_2 emissions requires knowledge of the fuel mix used for each of the manufacturing processes.

Data relating to particular building elements is available from the US, but these do not correspond well to the UK situation, where the energy consumed in manufacture is significantly lower in most sectors.

The data available for wood relates specifically to use in its country of origin, and have to be adjusted to take account of transport in the UK. At present, some 95% of the timber used in the UK is imported.

In addition, a continuing problem is the age of the available data, much of which dates back to the mid-1970s.

On behalf of the BRE and as part of the DoE Construction Directorate's r&d strategy, Davis Langdon and Everest Consultancy Group has investigated the life cycle CO_2 emissions from offices.

The study took the form of an embodied energy and CO_2 audit of the BRE Low Energy Office (LEO). This was an ideal candidate for study because the building had been fitted with a wide variety of services as part of the BRE's other project work, and the changes were well documented.

At the time of the audit both electric and gas-fired central heating systems were in place, allowing direct comparison.

Figure 1 shows the embodied energy and consequential CO_2 emissions per square metre of treated floor area for each of the services investigated.

Heating system

In terms of CO_2 emissions, gas-fired heating systems are currently more environmentally friendly than oil, and oil-fired more environmentally friendly than electric.

Fuels with higher carbon contents also tend to have a high sulphur content and may contain other impurities, leading to greater release of acid and other toxic gases. Hence gas-fired plant is likely to be more environmentally friendly on these grounds as well.

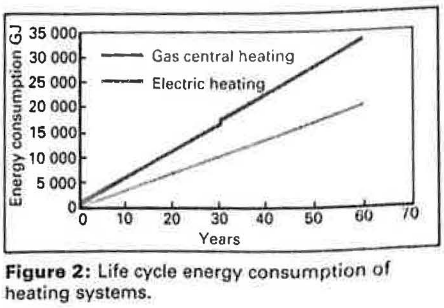


Figure 2: Life cycle energy consumption of heating systems.

Figure 2 shows the life cycle delivered energy consumption of the gas and electric heating systems in the LEO. The embodied energy of each system is very small compared with its in-use consumption, and produces small discontinuities in the lines at points of major overhaul and replacement.

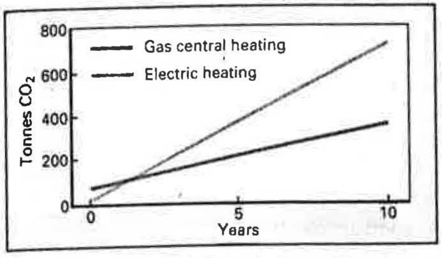


Figure 3: Life cycle CO_2 emissions of heating systems.

The electric heating system consumes less delivered energy in-use because it is notionally 100% efficient. Another contributory factor is that it also has a lower embodied energy.

The thermal efficiency of generating electricity from the present mix of fossil fuels and other sources, together with losses in distribution, results in a relatively high CO_2 emission overhead for delivered electricity. At present, one unit of delivered electricity results in about 3·6 times the CO_2 emissions of an equivalent unit of delivered gas, before taking account of boiler efficiency.

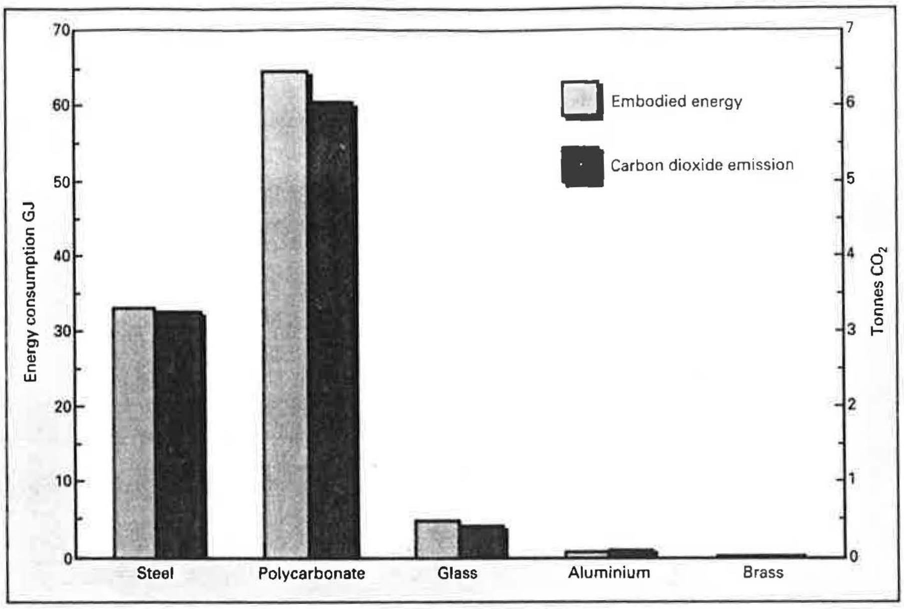


Figure 4: Embodied energy and CO_2 emissions for lighting components.

Figure 5: Embodied energy and CO_2 emissions of insulation materials.

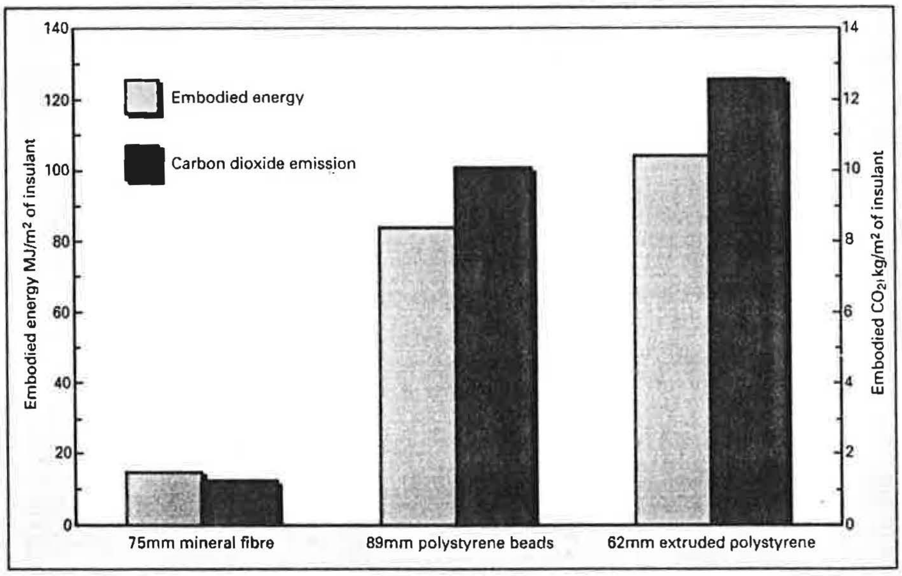


Figure 3 shows the CO_2 emissions over the first ten years of use. After approximately one year, the additional embodied CO_2 emission of the gas-fired installation is paid back from the reduced emissions in-use.

For oil-fired central heating, the embodied energy components would be similar, but with a lower efficiency and more carbon rich fuel, the annual CO_2 emissions would be higher. As a result, this would give an intermediate performance between the results for both gas and electric heating.

This result proved to be insensitive to changes in insulation and glazing standards, with the gas system always giving lower net CO_2 emissions within the first year. In the study, the embodied CO_2 emissions for the boiler house itself were added to those for the gas system in order to give a fair comparison with the electric system, which in itself has no requirement to house central plant.

Sensitivity to alternative plan configurations and internal arrangements was also evaluated to test whether the result could be applied reliably to all office types. As it transpired, the result proved insensitive to a wide range of floor-to-wall area ratios, plan forms, storey heights and internal arrangements.

The planned introduction of combined cycle gas-fired power stations, and an increase in the proportion of electricity produced from renewable sources, would reduce the future CO_2 emission of electric heating overhead.

Lighting systems

Overall, the embodied energy and CO_2 emissions associated with the lighting system were small compared to the consumption of the system in-use. Only 14 months of use equates to the embodied energy component.

From the point of view of the building services designer or building manager/operator, installing high efficiency lighting gear and controls is thus well justified on environmental grounds.

There are also opportunities to reduce the embodied energy and CO_2 emissions of lighting installations by adopting alternative diffusers that have a reduced plastics content. About 84% of the embodied energy of the lighting system is accounted for by the luminaires themselves.

Figure 4 shows a breakdown of the embodied energy and CO_2 emissions for these components. Over 60% is accounted for by the polycarbonate diffuser. In general, plastic components have high embodied energies arising from their multistage, energy intensive processing, mainly from crude oil feedstocks.

Mechanical ventilation

The mechanical ventilation system in the LEO is comparitively simple, but represents a substantial proportion of the total services embodied energy and consequential CO_2 emissions. The steel ductwork contributes the largest part to the embodied energy, followed by the foamed plastic – extruded polystyrene – insulation.

The mechanical ventilation system in the LEO is not particularly representative, however, and it is probable that further work will be needed to examine a wider range of mechanical ventilation and air conditioning systems.

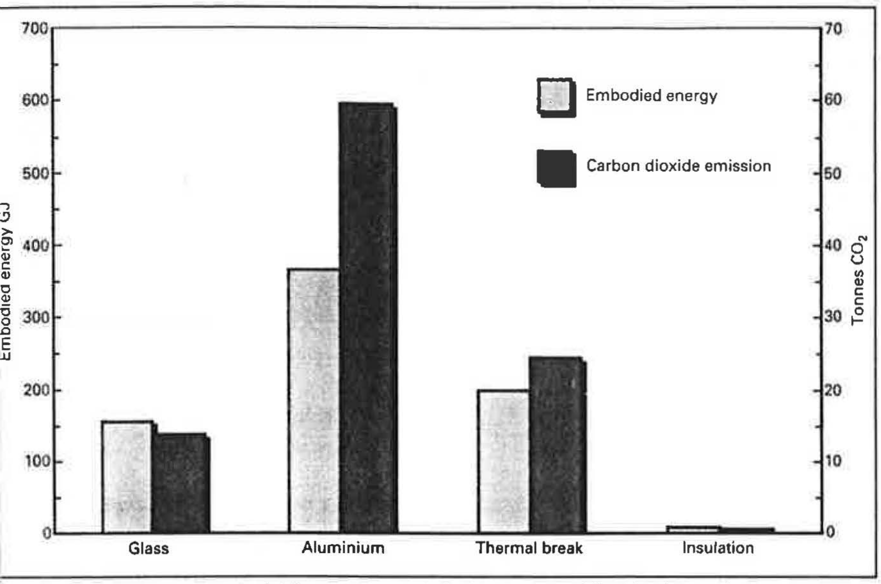
Insulation

The embodied CO_2 for insulation products is low compared to the reduction in CO_2 emissions that result from their building use. Accordingly, substantial thicknesses of insulation might be justified to minimise CO_2 emissions.

However, beyond approximately 100-200 mm thickness, proportionally more heat would escape from buildings due to ventilation or transmission through windows, and other measures may provide more cost effective approaches to reducing CO_2 emissions.

Figure 5 shows the embodied energy of the three types of insulant used in the BRE LEO. Non-standard thicknesses have been used for the assessment in order to compare the materials on the basis of comparable thermal conductivity. The rockwool insulant embodies less energy than the foamed plastic (polymeric) insulants.

There appear to be large discrepancies in the literature between embodied energy factors for similar materials. These could



gure 6: Embodied energy and CO_2 emissions of glazing systems. The aluminium frame counts for a large proportion of the total.

ise from differences in methods and ssumptions among the sources of data, or om the different manufacturing processes used to produce insulants of differg densities. There is therefore a need for reful consideration of the source, validy and application of published data.

In general, mineral fibre insulants emdy substantially less energy and CO_2 nissions than polymeric ones for an quivalent thermal performance.

There may be occasions where resistnce to water absorption is required, or here a dimensional constraint forces an sulant to be used in thin section, for stance in the prevention of thermal bridng. In these circumstances, the enanced properties of a high performance lymeric insulant may be justified.

lazing system

here appears to be significant potential r new designs of window frame to reduce e energy and CO_2 emissions embodied in indows, and to improve the performance the thermal break.

The BRE LEO owes part of its low ergy performance to its high performce glazing system, comprising argon lled sealed double-glazed units with a w-emissivity coating on the external ane. These are mounted in aluminium ames with an unusually substantial theral break to prevent thermal bridging.

Overall, the windows embody surprisgly high energy and CO_2 emissions, exeding the embodied energy of the gas ntral heating system, for example.

Figure 6 shows the embodied energy d CO_2 emissions attributable to the window components. As expected, the aluminium frame accounts for a large proportion of the total. What was not expected was the high contribution of the thermal break.

It is essential that the embodied components be compared with the in-use energy and CO_2 emissions associated with the fuel used to replace the heat lost through the windows.

Figures 7 and 8 compare the net energy consumption and CO_2 emission respectively for three alternative glazing options in the BRE LEO. The comparison assumes 2000 degree days of gas-fired heating requirement at 80% efficiency.

No account is taken of the energy implications of changes in window design on natural lighting levels. The comparison is made over a life cycle replacement interval of 30 years.

Reduced energy in use as a result of the high performance glazing system recovers the additional embodied energy of manufacture, compared with more common glazing systems, typically within a period of 5 to 18 years, this timescale depending on frame details.

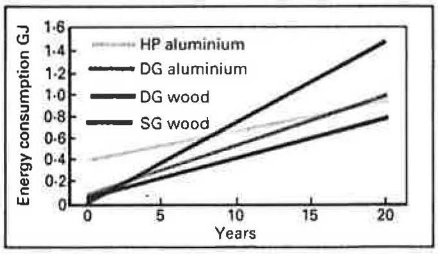


Figure 7: Life cycle energy consumption of glazing systems.

However, it takes about 25 years for the reduced energy in-use to recover the additional embodied CO_2 emissions of manufacture compared to conventional double glazing, and even 12 years when compared with single glazing.

Wooden frames appear to offer significant advantages for reducing embodied energy and CO_2, but need additional maintenance. Some further work is necessary to investigate the energy and CO_2 emissions embodied in paints and preservatives.

Published embodied energy documents are in urgent need of updating, most having been compiled in the mid-1970s. Further appraisals are needed to examine the life-cycle performance of more typical mechanical ventilation and air conditioning systems.

Nevertheless, a number of broad conclusions can be drawn from the study:

☐ gas-fired heating plant currently results in substantially lower net CO_2 emissions than other heating systems for most configurations of office;

☐ although priority should generally be given to reducing energy consumption, there are immediate environmental benefits to be realised by reducing the plastics content of lighting diffusers;

☐ in general, mineral fibre products embody less energy and CO_2 emissions than polymeric insulants;

☐ aluminium-framed high performance glazing systems are probably not of net environmental benefit from the viewpoint of reducing net CO_2 emissions;

☐ at present, conventional double glazing appears to give the best compromise between embodied and in-use performance, especially if it is wooden framed. Further development could, however, significantly change this result.

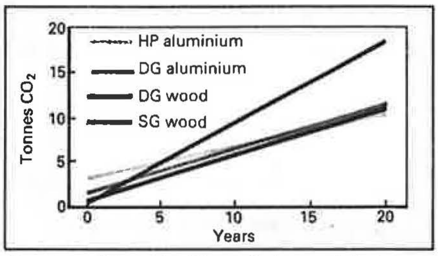


Figure 8: Life cycle CO_2 emissions of glazing systems.

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