ArupResearch+Development

MPBA (Modular and Portable Building Association)

CO2 emissions from use, scrapping and manufacture of modular buildings

Implications of proposals for the 2005 Building Regulation

ISSUE 2

ARUP

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EXECUTIVE SUMMARY

The MPBA (Modular & Portable Building Association) is currently in discussions with the ODPM (Office of the Deputy Prime Minister) regarding the proposed 2005 Building Regulation. These regulations require increases in the level of insulation in order to achieve a reduction in the CO_2 emissions resulting from their use.

Proposals by the ODPM, at the time of this report, are that modular and portable buildings older than 5 years, thus pre-dating 2000, when next moved must be brought up to the standard of Part L of the 2005 Building Regulation.

The Association is fully supportive of this principle but is seriously concerned that the proposals, as drafted, will have the opposite effect to that intended and will result in an increase in CO_2 emissions.

The Association has carried out its own analysis and commissioned Arup to validate that work and to provide further analysis on the environmental benefits of portable modular buildings. This analysis defines the embodied energy required to build a typical 10 module building and its energy in use and explores a number of scenarios of continued use and premature scrapping and replacement for the rental sector.

A 10-module building was taken as being typical for the industry. This was used to define two notional buildings, in line with the principles of the CECM calculation method, in which one was assigned minimum insulation levels according to the 1995 Building Regulation and the other values proposed for 2005 Building Regulations. The two notional buildings were then used to model emissions from use according to a variety of methods of heating and cooling.

To establish the embodied energy used in manufacture, emissions were derived from published data and the weights of component materials. Consideration was also given to emission reductions resulting from reuse of materials when the buildings are eventually scrapped.

The Association considers that upgrading pre-2000 buildings, constructed in accordance with the 1995 Building Regulation, to the new regulations will involve substantial work to their structure and will be impractical and uneconomic. As a result, they estimate that about 75% would be prematurely scrapped and need to be replaced, with an adverse impact on the environment.

This report identifies a number of positive attributes which are unique to portable modular buildings and summarises the implications for overall CO_2 emissions of prematurely scrapping these buildings and replacing with new build modules:

- The embodied energy required to manufacture modular buildings at 4.9GJ/m² is significantly less than that required to construct buildings traditionally (5.0 – 15.0GJ/m²).
- Modular buildings offer an alternative and sustainable solution to traditional buildings in that they can be relocated and the embodied energy in them is preserved.
- The ability to relocate modular buildings minimizes the need for landfill.
- This report shows that for the rental sector, based on the analysis of the notional buildings as described above and a scrapping rate of 75%, there would be an overall increase in emissions of about 49,000 tonnes CO_2 from scrapping 14,000 modules.

- If the actual thermal performance of existing buildings were to be measured and found to be much better than the 1995 Building Regulation, as the industry expect, the overall result could well be a greater increase in CO2 emissions.

The scrapping of an estimated 14,000 modules and the need to replace these would new build would have other negative implications:

- Disposal of old materials to land fill.
- A severe shortage of modules on the market because of insufficient production capacity, affecting the end user of which government is 60%.
- Increased cost of modular buildings as a result of the shortage of modules on the market.
- The benefit that modular buildings bring in contrast to permanent buildings of carrying their embodied energy with them when used in a new location would be lost.

1. OVERVIEW

The MPBA (Modular & Portable Building Association) is currently in negotiation with the ODPM (Office of the Deputy Prime Minister) over details of the proposed 2005 Building Regulations.

Proposals at the time of this report by the ODPM are that modular and portable buildings older than 5 years, thus pre-dating 2000, when next moved must be brought up to the standard of Part L of the Building Regulations 2005.

The industry has no problems complying with 2005 performance for new build. The issue is with existing buildings that have the unique ability to be moved but are then affected by the Part L regulations.

Given that a key objective of Part L is to achieve an overall reduction in CO2 emissions, this report describes an analysis of the implications for the modular and portable buildings of this requirement. In particular, a significant proportion of the buildings that would have to be brought up to the new standard will in fact have to be scrapped and replaced with new build. Thus this analysis considers emissions *reduction* intended by the new regulations set against emissions *increase* from new build.

The analysis here is in two parts:

- Method for estimating the emissions impact for any given circumstances of a module being prematurely scrapped and replaced by new build.
- Analysis of the market to derive an estimated number of modules that would be affected.

By combining this information, a total number of tonnes of CO2 emissions can be calculated in order to determine whether these will be an increase or reduction in emissions.

2. INTRODUCTION TO THE INDUSTRY

The modular and portable building industry is well established, providing important building solutions in a wide range of applications. About 60% are for government buildings with the rest for general use.

The industry is represented by the MPBA that has a membership of 65 companies involved in one or both the areas of manufacture and refurbishment for rental or resale.

2.1 Example products

The typical products of the industry are volumetric modular building produced in a factory or held in stock and transported to site for speedy erection and occupation.

The basic unit is a bay with typical dimensions of length 12.2 m, width 3.3 m and height 2.8 m. This size permits transport by truck and, with a mixture of end and middle types, can be configured into a wide variety of forms. A few of examples are shown in Figures 2.1 to 2.5.

Figure 2.1 Mixture of 5-module and single-module buildings.

Figure 2.2 7-module classroom.

Figure 2.3 7-module building (Swansea Docks).

Figure 2.4 Medical centre.

Figure 2.5 2-storey 13-bay and 9-bay buildings (Open University).

2.2 Size of the industry

The MPBA report that annual production of modules has been steady at about 10,000 per year. This is divided between the rental and sale sectors in the ratio 32.5% to 67.5%.

The typical rental periods in the rental sector are about 18 months and their useful life is in the range 12-15 years.

The sale sector is quite different in that most units are sold outright and remain in one place. Typical applications are for schools, the health sector, offices and other requirements for local government. A proportion of these is moved and enters the resale market. They would then be upgraded as for rental units that are moved between sites. The life of a unit in the sales sector is typically in the range 18-25 years.

2.3 Implications of the Building Regulations

This report is concerned with existing modules that are moved and are:

- more than 5 years old with respect to 2005, so modules built before 2000,
- compliant with the 1995 Building Regulations, so modules built since 1995.

Figure 2.6 gives an indication of the relative sizes of the overall industry with the modules of concern for this report shown by the shaded area.

The shaded area covers all the rental sector for the period 1995-2000 since these will all be moved eventually. The size of the resale part of the "sale & resale sector" is based on a refurbishment rate of 2500 modules per year. The total number of re-rental and resale modules affected over the 6-year period is estimated to be 34,500, corresponding to 1,380,000 m².

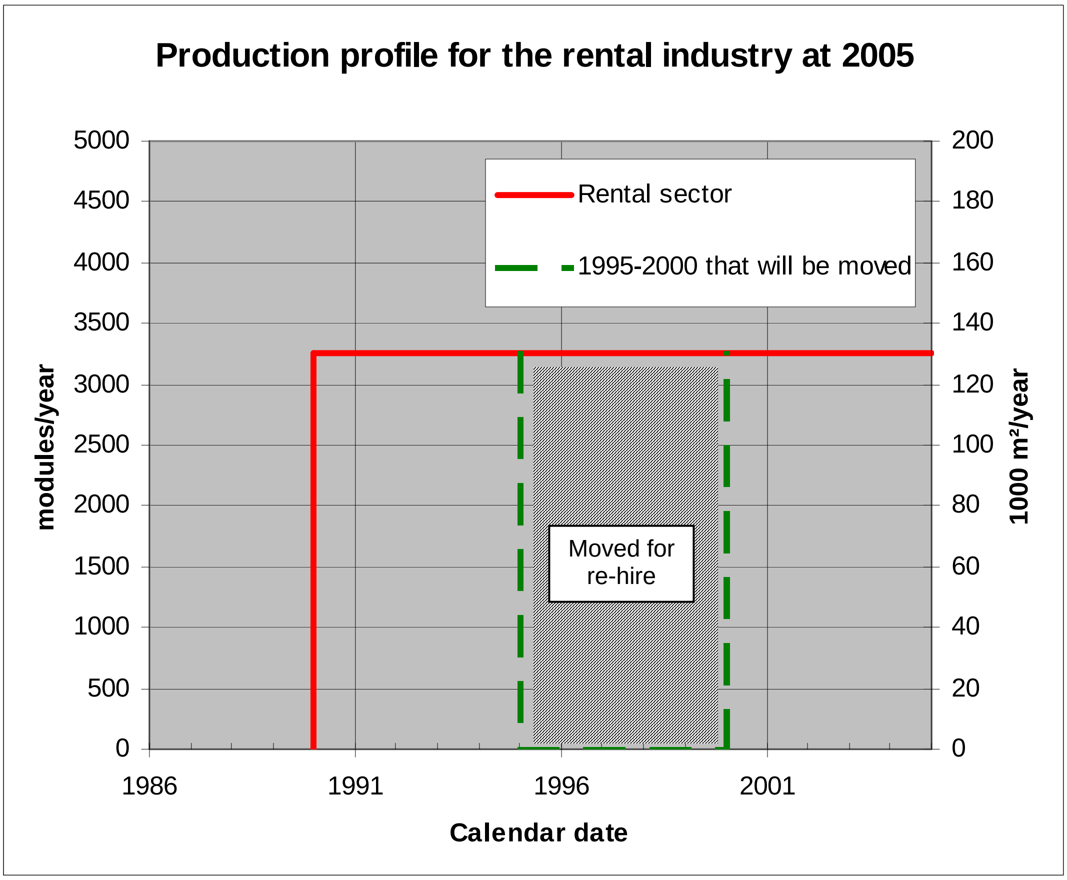

Figure 2.6 An indicative representation of production for the rental industry with a projection to the year 2005. The rental sector is shown from 1991 since their typical life is 15 years.

The shaded area represents those modules that are the subject of this analysis because they are: built to the 1995 Building Regulations, more than 5 years old (working back from 2005). This area corresponds to 16,250 modules (650,000 m²).

3. IMPACTS OF THE BUILDING REGULATIONS

It is important for this analysis to appreciate the nature of the industry for modular and portable buildings and the difference of impact of the 1995 and 2005 Building Regulations.

3.1 Original construction

The key point to note about manufacture is that large sheets are used which can be handled safely and effectively in the factory environment, see Figure 3.1. These elements are built up at bench height and the modules are worked on upside down when required. Floors are often chipboard and held down by many hundreds of screws but this assembly is efficiently managed in factory conditions, as shown in Figure 3.1.

Figure 3.1 Aspects of factory production: (left) an overhead crane and other equipment for handling large panels for the floor, walls and roof; (right) an automatic screw applicator for securing the flooring.

3.2 Steps to compliance with the 2005 Building Regulations

The process of upgrading to the full 2005 requirement can be broken down into two steps: upgrading to the 2002 requirements, then a further reduction of 25% in carbon emissions to meet the proposed 2005 requirements.

The introduction of the Carbon Emission Calculation Method (CECM) has helped the industry realise how thermally efficient their buildings are. If we consider the experience of one company that does a significant amount of refurbishment rather than new build, they find that the majority of the units they work on which were manufactured by one of the major manufacturers have been meeting the standards set in Part L of the 1995 Building Regulations since their introduction in 1987.

Where the industry has upgraded a 1995 compliant building to 2002 standards, they find this can be achieved by:

- replacing the single glazed windows with uPVC framed double glazed units using K glass (Figure 3.2),
- replacing external doors (Figure 3.3),
- replacing the luminaires with modern high frequency units (Figure 3.4).

Figure 3.2 Upgrade of old to new windows.

Figure 3.3 Upgrade of old to new doors.

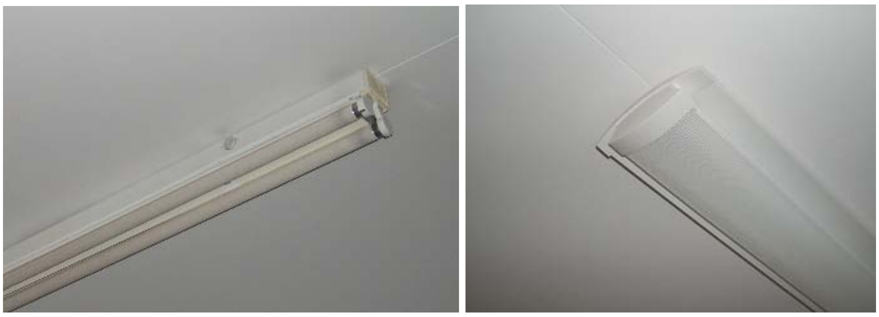

Figure 3.4 Upgrade of lighting fitting.

From the work done using the CECM, the view of the industry is that to achieve the further step change in performance required in 2005 of 25% will require work to the roof/ceiling and the floor deck to install additional insulation.

The industry has no problems complying with 2005 performance for new build. However, these are structural alterations, in contrast to fittings such as doors and windows, and have a major impact for refurbishment. All the internals of the building would need to be removed. The weight of the unit would increase affecting the fit out payload for safe lifting. Attempting this work in a completed building would be impractical, extremely costly and potentially dangerous as it would involve men working above their heads with heavy sheet materials and working under the buildings above their heads. (Other reactions from the industry are given in Appendix A3.)

3.3 Estimate of modules that could be scrapped

The industry estimate that of modules built during the period 1995-2000 and subsequently moved, only 25% will be worth refurbishment and upgrading to the 2005 Building Regulations.

Using the estimate in the previous section of 16,250 modules in the rental sector that will be moved, a scrap rate of 75% corresponds to about 14,625 modules or 585,000 m^2.

4. METHOD FOR ESTIMATING EMISSIONS IMPACT

This report analyses the implications of having to scrap buildings and replace with new.

The potential benefit of reduced CO2 emissions from operating to the 2005 requirement could be analysed by comparison to the measured performance of a sample stock of the modules that are expected to be scrapped, these modules being operated to the 1995 requirement or better.

However this is not a trivial exercise. Instead, the notional building defined in the 2002 Building Regulation is a convenient standard that enables a conservative estimate of the difference between Building Regulations to be considered. This approach is conservative since the MPBA point out that actual buildings have a better thermal performance due to their construction methods, such as air tightness.

A notional building is one which has the same basic geometry (floorplan, elevation, etc.) as the actual building but where materials, glazing areas, systems, etc., are replaced by basic ones that achieve the minimum acceptable elemental performance as stipulated in the Part L2 document.

4.1 Notional building

There is a wide range of different types of modular buildings, from toilet units to systems comprising many modules joined together to make large buildings (see Section 2). Classrooms are typically about 5 modules in size, but single storey buildings can be up to about 20 modules. A 10-module building is in the middle of this range so represents a typical building construction, see Figure 4.1. A 10-module size has been used for the notional building, as shown in Figure 4.2.

A single module is 12m deep, 3.3m wide and 2.8m high. A 10-module building would comprise two end modules and 8 central modules. The central modules do not have any 12m long walls and the end modules have one 12m wall and two 3.3m long walls. These are joined together to make the building. Thus the full dimensions are: length 33 m, width 12.2 m, height 2.8 m.

In the thermal analysis, the notional building is assigned insulation levels according to Building Regulations for 1995 and 2002. Typical values are used for each of occupancy, lighting, small power appliances and climate. The analysis is then run for all combinations electric or gas heating and cooling by air-conditioning (AC) or natural ventilation (NV).

For full details of the notional building, see Appendix A1 for thermal analysis and Appendix A2 for construction components.

Figure 4.1 An example 8-module building (with air-conditioning) which relates to a generic 10-module building used for the notional building.

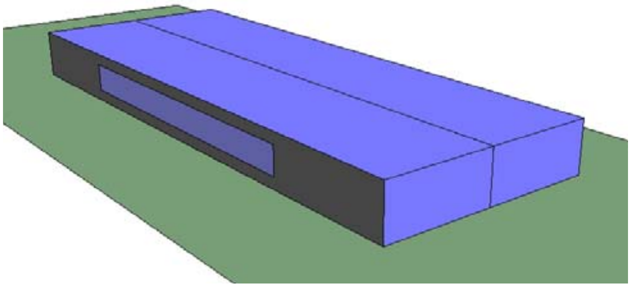

Figure 4.2 The model used in the thermal analysis program that represents the essential details of 10-module building.

Note that the windows are on two sides (only one of these sides is visible above) and the full window area is represented as a single rectangular area.

4.2 Use according to 1995 Building Regulations

For the method used to analyse overall emissions, first consider Figure 4.3 that shows emissions for use of a notional module from its year of build in mid 1997.

The line shows a drop in 2005 if this module has to be pre-maturely scrapped, the dip showing the emissions offset from the reuse of materials in the scrapping process. Otherwise the module would be used to end of its life, 13½ years in this example, at which point there is a drop in emissions from the reuse of materials followed immediately by a step increase in emissions representing the materials for the new built replacement.

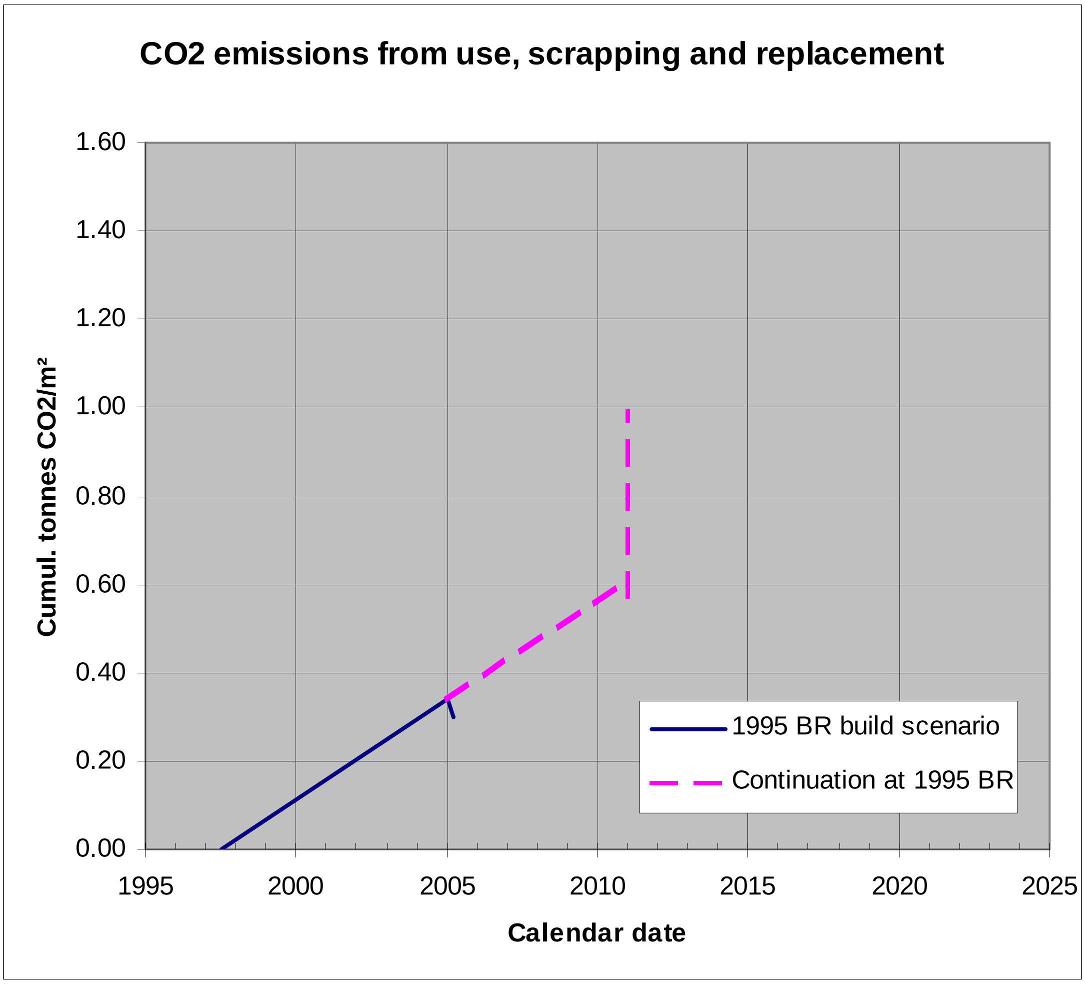

Figure 4.3 Use of module built in mid 1997 that is either scrapped in 2005 or continues to the end of its 13½-year life in 2011 when it is scrapped and must be replaced.

(Note that the original embodied energy from manufacture in mid 1997 is not shown.)

4.3 Replacement new-built module

Figure 4.4 now adds the new-build replacement module, as built in 2005. This module is compliant with the 2005 Regulation so has a lower gradient of emissions during use. The end of its life in 2018 after 13½ years would be the same situation as if the original module had been left in use. That is, emissions drop from scrapping followed by an emissions increase for the materials needed to build the replacement.

We need to establish whether this scenario results in an overall beneficial decrease in emissions or an undesirable increase. The problem is where to make the comparison between the two sloping lines. If the comparison in height is taken in 2011, then the replacement module represented by the upper line still has another 7 years of useful life that should really be taken into consideration in some way. The problem arises because of the new-for-old replacement in 2005.

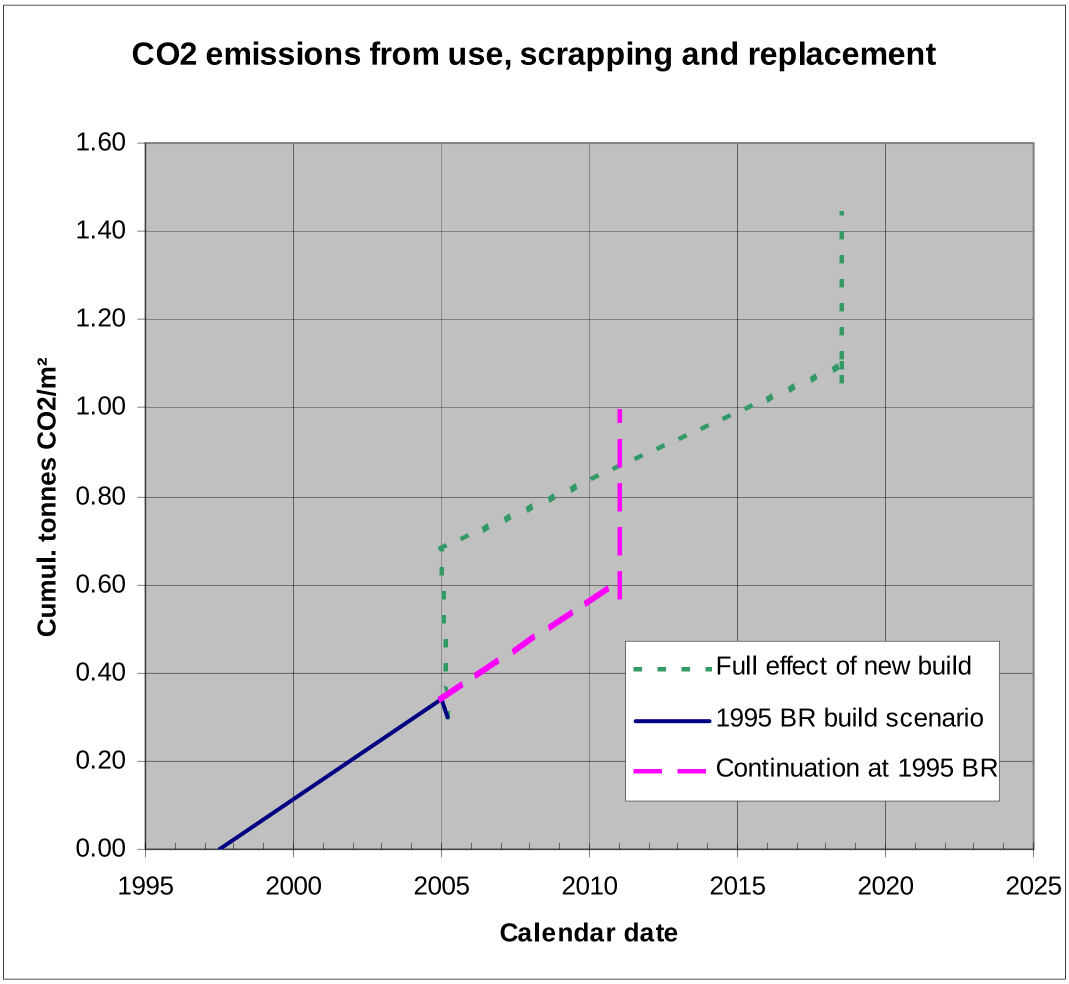

Figure 4.4 Compared to Figure 4.3, the additional dotted line is for a replacement module built in 2005 that would last for 13½ years before itself being scrapped and replaced.

4.4 Amortising new-build emissions

The difficulty shown in Figure 4.4 of determining whether this scenario results in an overall decrease or increase in emissions can be approached by borrowing a technique from accounting. That is to amortise the emissions from new build equally year-by-year over its useful life. This is shown in Figure 4.5 by the stepped line that arrives at the same end point in 2018.

The difference in height on the graph in 2011 between the stepped line and the dashed line for the replaced module (at its lowest point after scrapping) is 0.09 t-CO_2/m² (tonnes CO_2/m²). Thus this example shows a net increase in CO_2 emissions.

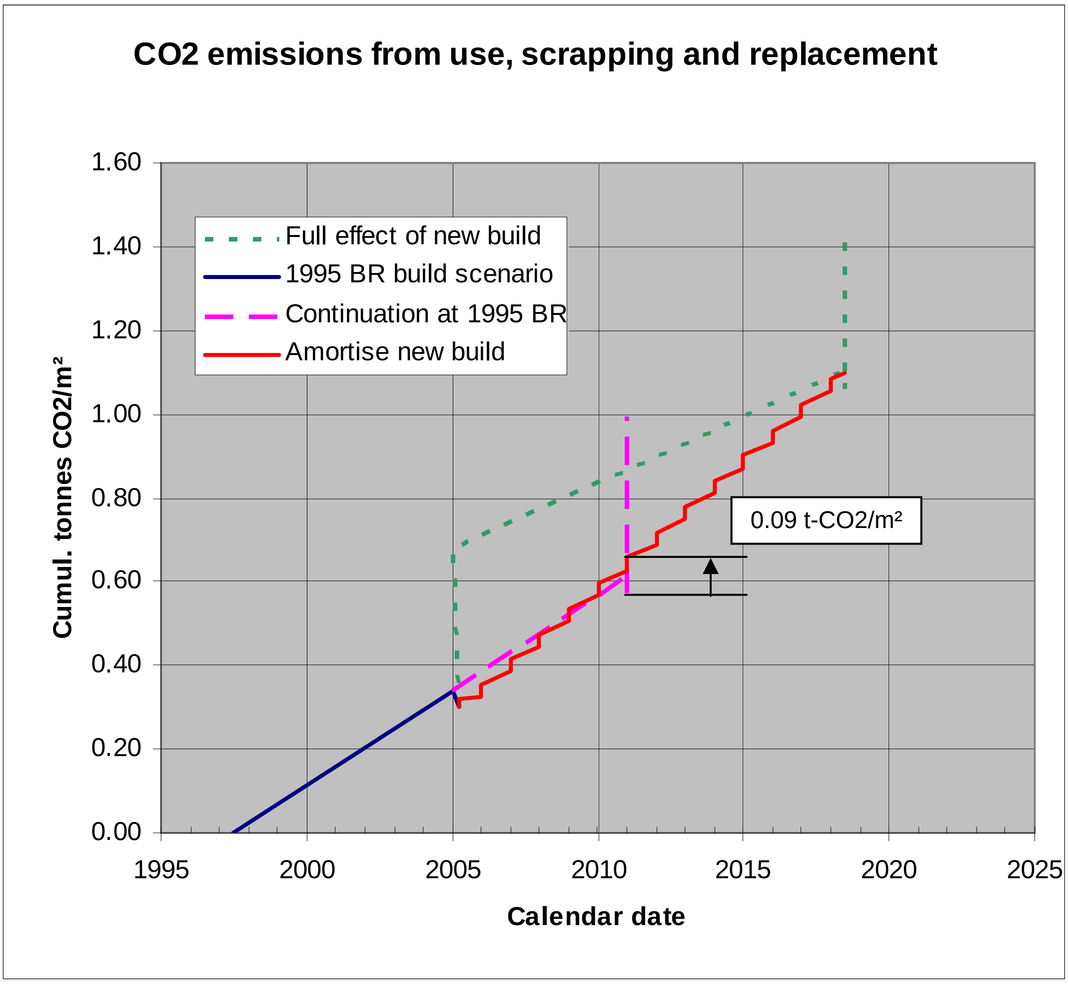

Figure 4.5 Compared to Figure 4.4, the replacement module built in 2005 has its emissions from build scaled spread out over its whole life rather than concentrated at the start.

The difference of the stepped line in 2011 and the dashed line (at its lowest point after scrapping) is 0.09 tonnes CO_2/m² in this example, an increase in overall emissions.

4.5 Corrected life of new-build module for whole-life considerations

The method used in this analysis is in fact to use a two-stage amortisation with the second stage starting at the natural end of life of the module being replaced, as shown in Figure 4.6.

This gives the same result as in Figure 4.5 but has the advantage of showing more clearly the lower emissions in use by the lower gradient of the sloping section (from 2005 to 2011).

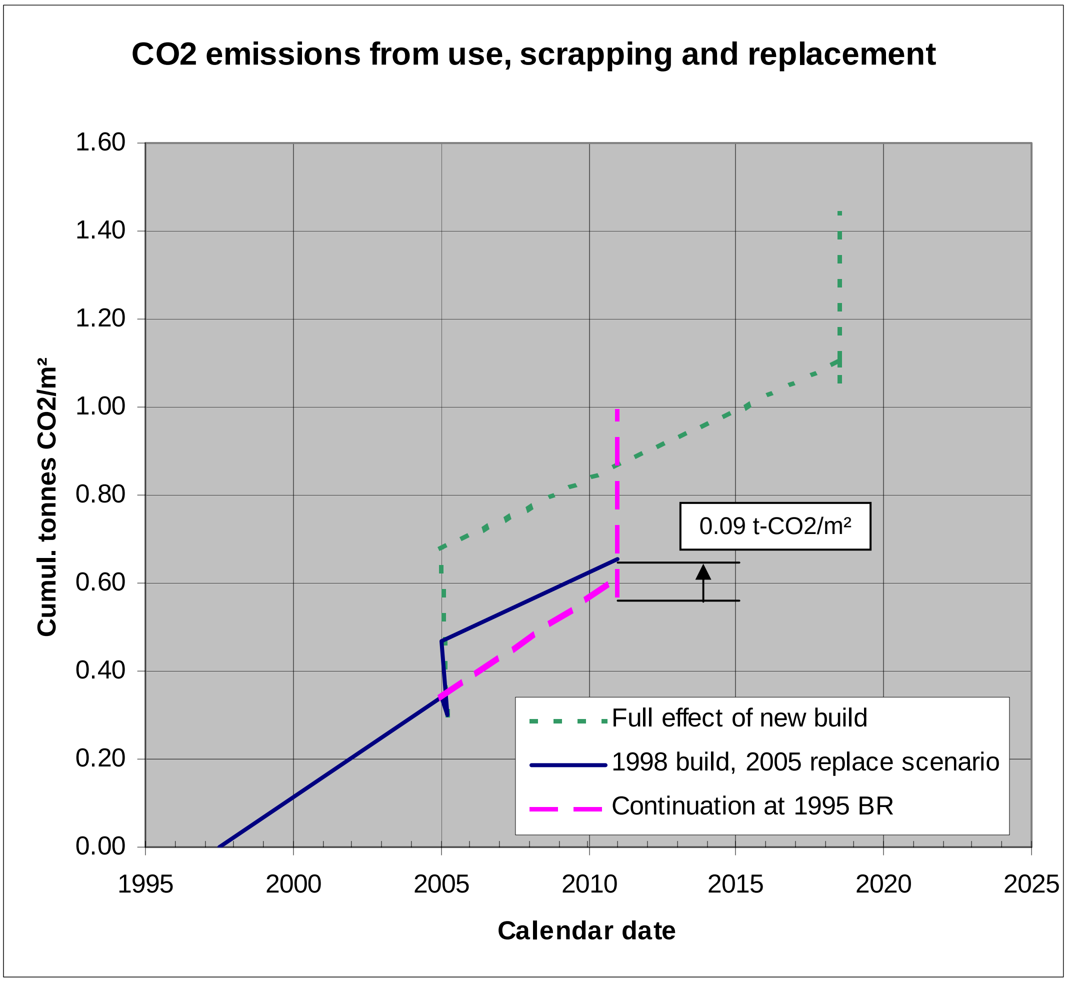

Figure 4.6 Compared to Figure 4.5, the replacement module built in 2005 has its emissions from build divided into just two stages in proportion to the remaining life of the module that has been scrapped, thus the full scenario is the solid line.

The difference in height of the end of the solid line and the dashed line (at its lowest point after scrapping) is 0.09 tonnes CO_2/m^2 in this example, an increase in overall emissions.

5. EMISSIONS RESULTS

5.1 Emissions from use

The following conditions have been examined within the thermal analysis (see Appendix A1):

- Gas heating in winter.
- Electric heating in winter.
- Natural ventilation (NV) for summer cooling in which windows are opened by occupants when the internal temperature is high, while the required minimum ventilation in winter is achieved by window ventilation grilles.
- Air conditioning (AC) for summer cooling.

These conditions were analysed for Building Regulations of 1995 and 2002. Emissions results for the latter were then reduced by a blanket 25%, as proposed for the 2005 Building Regulations. The full results are summarised in Table 5.1.

Table 5.1 Emissions of CO2 during use (kgCO2/m²) according to different methods of heating and cooling and for the notional building according to Building Regulations of 1995 and as proposed for 2005.

Heating fuel	Cooling method	1995	2005
Gas	AC	48.6	35.8
Electric	AC	53.0	38.0
Gas	NV	40.7	28.7
Electric	NV	45.4	31.4

The Building Regulations require that the building does not overheat due to solar gains. This is both to ensure occupant comfort but, more importantly, to ensure that an excessive cooling capacity is not required. Compliance in the elemental method is shown if the solar gain to a perimeter zone 6 m deep from a window is less than 25 W/m². In order to meet this, an external louvre was defined and added to the model.

5.2 Embodied emissions

Table A2.1 in Appendix A2 shows the composition of a ten module building, broken into its constituent materials. The total weight of a ten module building is almost 43 tonnes.

Table 5.2 summarises the embodied results for a ten module building. The embodied energy of 4.9 GJ/m² is lower than permanent buildings, which for an internal Arup study were found to range from 5-15 GJ/m² (embodied CO2 the values ranged from 0.4 to 1.1 tonnes CO2/m²).

Table 5.2 Summary of embodied emissions results

Total embodied energy	1,950	GJ/10-module building
Total embodied CO2	149	tonnes CO2/10-module building
Total embodied energy/m²	4.9	GJ/ m²
Total embodied CO2/m²	0.38	tonnes CO2/m2

Figure A2.1 and A2.2 are pie charts which highlight how the embodied impacts are distributed between the materials. The steel and insulation are by far the most significant elements, with timber, miscellaneous elements and transport each contributing only a few percent.

The internal partitions, wiring, windows, internal paint, vinyl flooring all contributed less than 1% each to the total.

A total of 14,046 kg of steel is typically reclaimed from a scrapped ten module building, being the sections which are not buried within composite panel construction. The amount of energy and CO_2 saved as a result of recycling of this amount of steel is 599 MJ/m2 and 42 kg CO_2/m2 respectively. This is about 12% of the initial total impact of construction of the building.

It is possible that the amount of steel recycled could be increased by stripping off the steel skins from the wall and roof panels but this would have only a small impact as far as this analysis is concerned.

5.3 Life

According to ranges of module life provided by the MPBA as typical for the industry, the following value has been used for the rental sector.

- Average module life of 13.5 years for the rental sector, as derived from the industry range of 12-15 years.

5.4 Consideration of build date

Since the period in question ranges from 1995 (year of major change to the Building Regulations) to 2000 (for 5 years older than the 2005 Building Regulations), we need to check by how much the year of original manufacture affects the outcome.

For a given scenario, Figures 5.1 and 5.2 show the extreme build years of 1995 and 2000. Both graphs show very similar outcomes (increases in emissions) which differ little: emissions increases of 0.050 and 0.120 t-CO_2/m², respectively. Thus it appears reasonable to use one year in the middle of this period: mid 1997.

Figure 5.4 shows the same scenario for mid 1997 and an emissions increase of 0.085 t-CO_2/m², an average of the 1995 and 2000 values above.

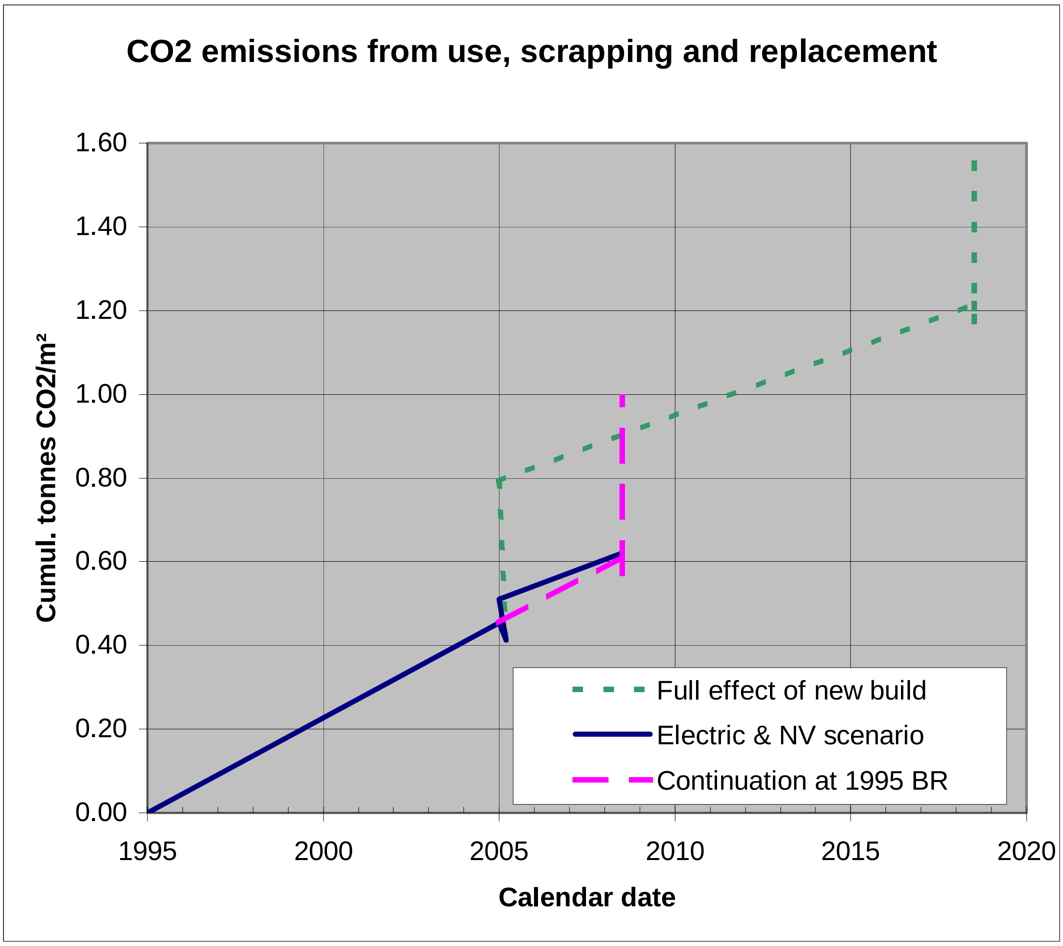

Figure 5.1 Rental (13.5 life) built 1995 with electric heating and NV cooling: +0.050 t-CO_2/m².

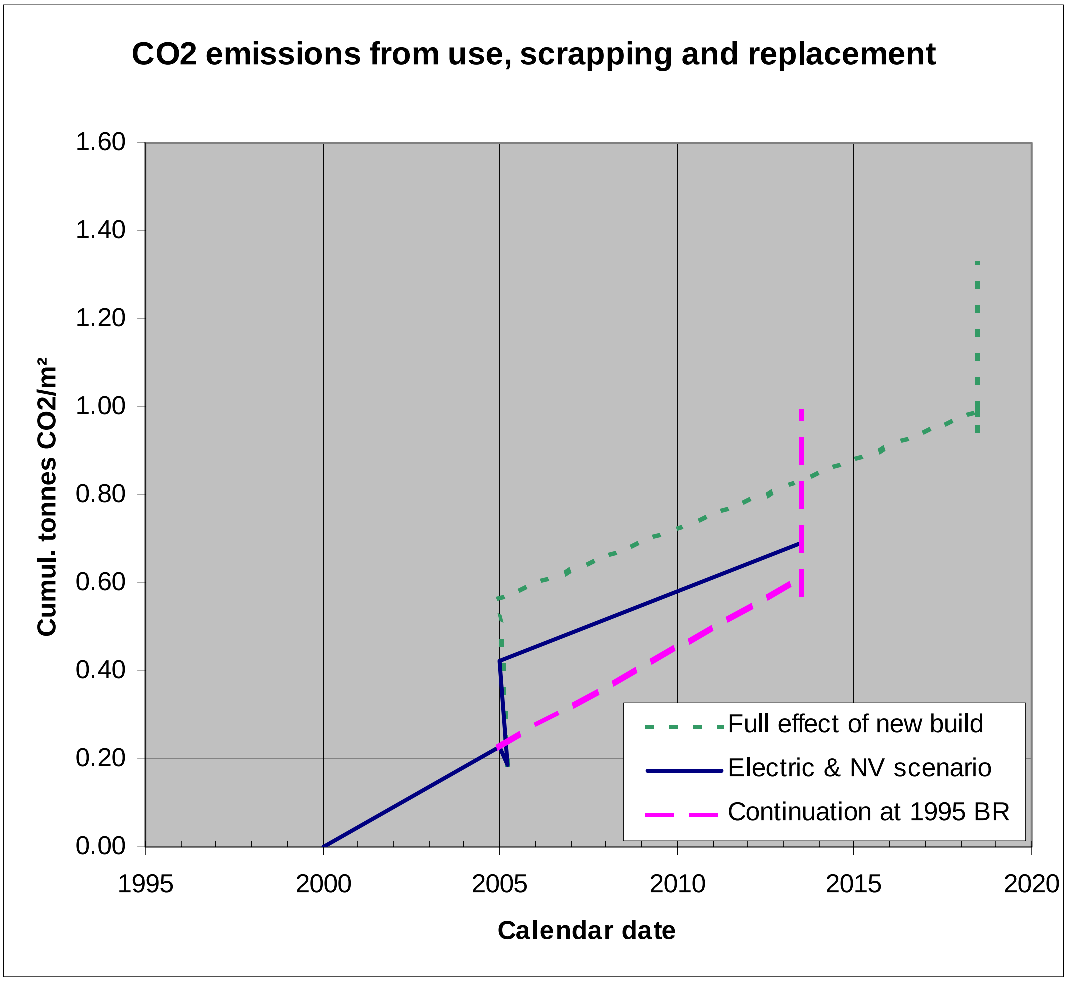

Figure 5.2 Rental (13.5 life) built 2000 with electric heating and AC cooling: +0.120 t-CO_2/m².

5.5 Analysis

The rental sector uses virtually no gas heating so only electric heating is considered here.

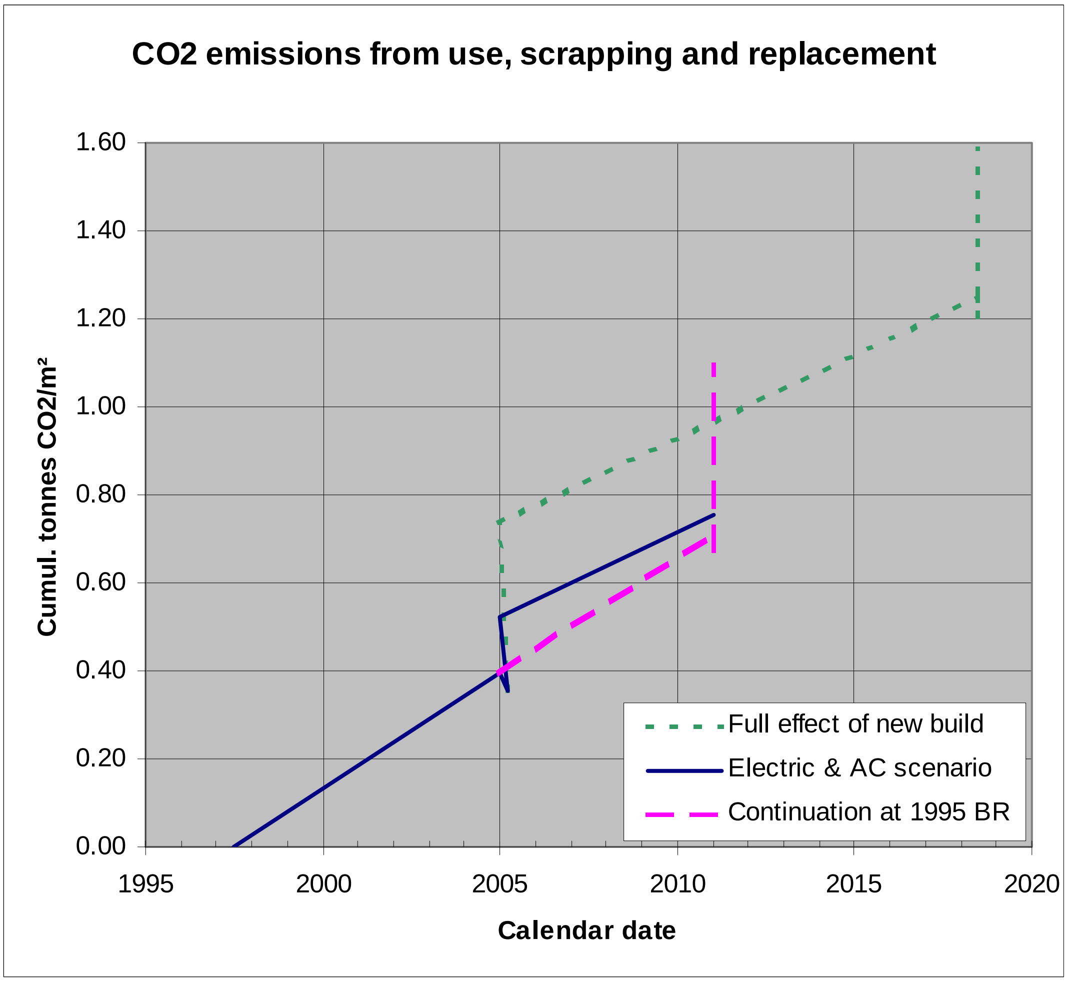

Figure 5.3 Rental (13.5 life) with electric heating and AC cooling: +0.079 t-CO_2/m².

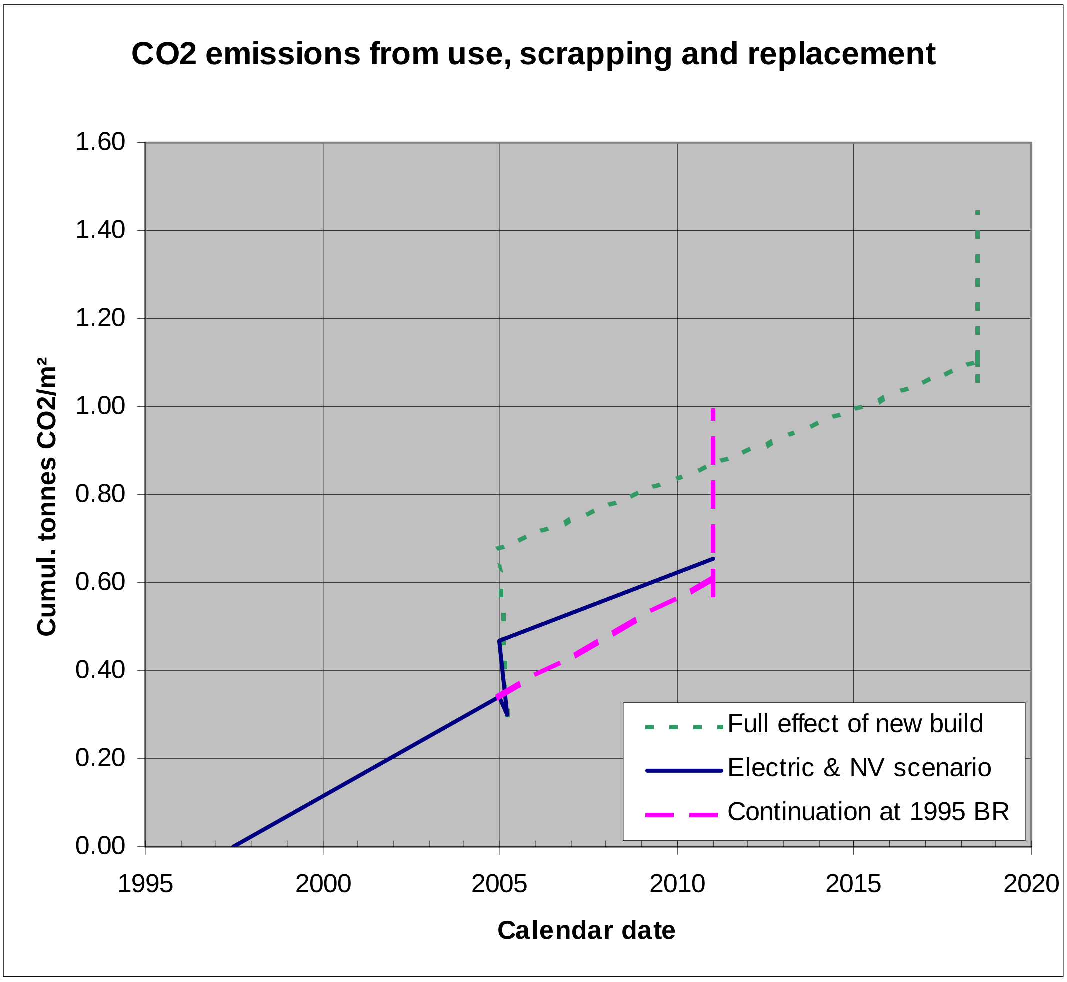

Figure 5.4 Rental (13.5 life) with electric heating and NV cooling: +0.085 t-CO_2/m².

For rental sector, both scenarios for cooling show a small overall increase in emissions:

- Electric heating with AC scenario: 0.079 t-CO_2/m²
- Electric heating with NV scenario: 0.085 t-CO_2/m²

The total impact from this sector is computed as follows:

- 40 m²/module
- Manufacture rate of 3,250 modules/year
- 6 year period (1995-2000) of original manufacture
- Scrap rate of 75%
- Proportion air conditioned estimated at 10%

Thus:

- 4,622 t-CO_2 for AC scenario
- 44,753 t-CO_2 for the NV scenario

The result is a total increase of CO_2 emissions of about 49,000 tonnes from the scrapping and replacement of 14,625 modules (585,000 m²).

6. CONCLUSION

The analysis for the rental sector, assuming 75% would be scrapped and replaced, shows an increase in CO2 emissions of about 14,000 tonnes, not the reduction which is the intentional of the revised Building Regulations.

Note that the basis of this analysis was conservative and that the overall effect in reality could be worse.

For the reference emissions through continued use of modules built before 2000, a notional building has been used according to the minimum specification in the 1995 Building Regulation. The industry believes that the thermal performance of these modules is in fact much better due to the nature of construction (low air leakage, etc.). This statement would need to be verified by actual testing of a sample of such modules, but any degree of reduction in use of energy will reduce of slope of the reference consumption line (as in Figure 4.3). A reduced slope would increase the CO2 emissions further.

The emissions from new build have been amortised only over the period that the scrapped module would otherwise have been used, but it must not be forgotten that all the emissions from building replacement modules really occur at the start. All the emissions from building replacement modules occur when they are built so the longer modular buildings can be kept in use the better. Modular buildings offer an alternative sustainable solution to traditional structures in that by moving them, the embodied energy within them is preserved. Once there are impediments to movement, this benefit is lost.

The basis of this analysis is purely in terms of CO2 emissions in order to end up with a single value and to see whether it is positive or negative. There are other impacts from the scrapping a large number of modules.

The scrapping a large number of modules will result in a significant increase in landfill. Limited re-cycling of the main steel members is possible but all other material will be consigned to landfill, with the consequent loss of embodied energy, at a time when Government is attempting to reduce both carbon emissions and landfill use. Furthermore, much bio-material in landfill is starved of oxygen so producing methane from decomposition. When this methane eventually escapes from ground into the atmosphere, it has a greater climate change impact than CO2 by a factor of 20.

In reality, the cost implications of scrapping and the limited capacity within the industry to increase production, over the short term, will mean that there will be both a shortage of suitable buildings and a steep rise in the price of supplying modular buildings. A reduced supply and higher cost will have undesirable knock-on effects to the end users for these buildings of which Government is a major user.

A1. CECM (CARBON EMISSIONS CALCULATION METHOD)

This appendix details a study to obtain predicted carbon emission figures from a notional (in the Building Regulations Part L2 context) Portable/Modular building for both 1995 and 2002 building regulation insulation standards. The building models used was defined according to the Carbon Emissions Calculation Method (CECM). The information on the method was drawn from the 2002 Part L2 document[1] itself as well as CIBSE Technical Memorandum TM32[2] – Guide for the use of the carbon emissions calculation method 2003.

A1.1 The notional building

A notional building is one which has the same basic geometry (floorplan, elevation etc.) as the actual building but where materials, glazing areas, systems etc. are replaced by basic ones of minimum acceptable performance as stipulated in the Part L2 document directions for the elemental method.

The elemental method is one in which the various features of the building are considered separately and have to at least match the specifications stipulated by the Building Regulations. In the CECM the whole building is considered with the performance of the actual building design being compared to that of a notional building, compliance being achieved if the actual building performs as well or better in emission terms than the notional one.

A1.2 Methodology

A1.2.1 Overview

The stages of the analysis were as follows.

1) The model geometry consisted of a configuration of 10 bays (seen as a typical installation). The building is 33m x 12.2m x 2.8m. Figure A1.1 is a graphical representation of the model. This represents a typical configuration.
2) The model was run in a dynamic thermal simulation using the CIBSE London TRY climate data. The building was heated but not cooled. The results were examined for any overheating. The model was run for both North South and East West orientation.
3) The model was then be run as in 2) but was heated and cooled. Again the model was run for both North South and East West orientation.
4) The heating and cooling demands calculated in the simulation then had a coefficient of system performance (COSP) applied to them. This takes into account boiler, chiller and distribution efficiencies.
5) The results from 4) were then converted to a carbon emission quantity. Both electrical and gas heating were considered.

[1] The Building Regulations 2000 – Conservation of fuel and power in buildings other than dwellings – L2. 2002 edition.
[2] Guide for the use of the carbon emissions calculation method – CIBSE TM32: 2003

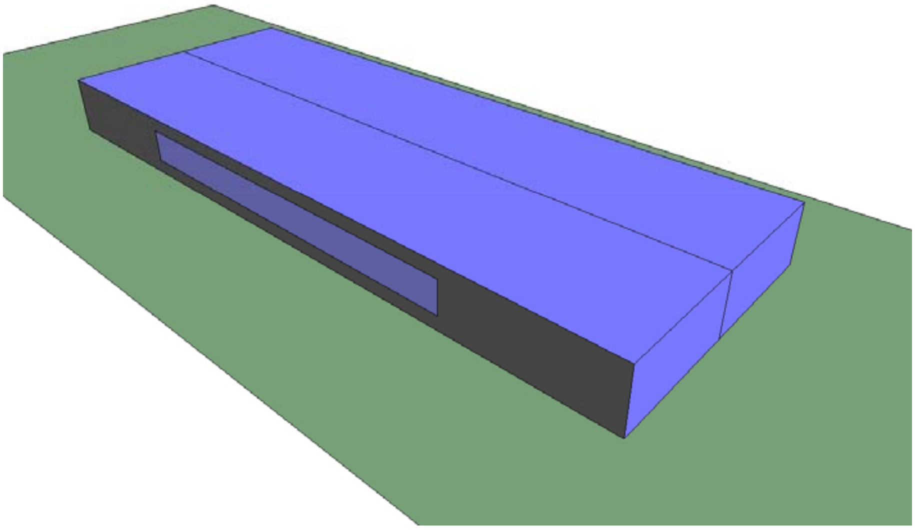

Figure A1.1 Graphical representation of the model.

A1.2.2 Openings

The Building Regulations Part L (both the 1995 and 2002 L2) Elemental method prescribes the maximum percentage area of a wall that should be glazed. Table A1.1 gives the areas.

Table A1.1 Opening areas

Type of building	1995 Regs	2002 Regs
Offices	40%	40%
Industrial	15%	15%
Rooflights	20%	20%

The CECM is normally used to determine the performance target that the actual building must better and so a glazing area of 40% would be used. However, for this exercise it was intended to maintain a link between the actual 10 bay building and the notional model. It was observed from details of existing buildings that the glazing area is typically 17 to 33% of the wall area. For the notional model an area of 30% was chosen to be conservative.

The building regulations allow an offset of 50% of the allowable rooflight area against the glazing area in the walls in the CECM. This was not done in the model because the notional building would have had a far greater glazing area than an actual building (which is not being considered here) and so an increased area of glazing would have been unrepresentative.

A1.2.3 Materials

Part L Elemental method defines the maximum U-value of the constructions of a building. The materials in the dynamic thermal model will be defined from actual material layers in order to match the stipulated U-values. Table A12 gives the required U-values.

Table A1.2 Material specifications

Surface Type	1995 Regs	2002 Regs
Flat roofs	0.25 W/m^2K	0.25 W/m^2K
Pitched roofs	0.25 W/m^2K	0.16-0.2 W/m^2K
Exposed walls	0.45 W/m^2K	0.35 W/m^2K
Exposed Floors	0.45 W/m^2K	0.25 W/m^2K
Semi exposed walls and floors	0.6 W/m^2K	-
Windows	3.3 W/m^2K	2.2 W/m^2K
Garage doors	0.7 W/m^2K	0.7 W/m^2K

A1.2.3.1 Modelling materials – Opaque surfaces

The surface types present in the model were flat roof, exposed wall, exposed floor and windows. In the model the fabric types had to be defined as a number of layers of construction materials. In general this took the form of a steel outer skin, insulation and a fibreboard internal surface. The insulation thickness was then altered to meet the required U-value.

A1.2.3.2 Modelling materials – Transparent surfaces

The glazing in the model was defined as a simple double glazed system. The cavity resistance between the two panes was then altered to meet the required U-value

A1.2.4 Occupancy, lighting and small power

For the CECM the internal gains into the space should be the same for both the actual and notional buildings. Energy Consumption Guide 19[3] (ECON 19) gives benchmark figures for four types of office building.

1) Naturally ventilated cellular
2) Naturally ventilated open plan
3) Air conditioned standard
4) Air conditioned prestige

The values given in ECON 19 for types 1, 2 and 3 are given.

For the model the values for small power and occupancy were taken from CIBSE TM32 as typical values and the lighting taken as the good practise level from ECON 19.

A1.2.4.1 Occupancy gains

For the purposes of this analysis occupancy of 1 person per 12m^2 will be assumed. These occupants will be seated at rest and therefore will have a standard CIBSE[4] heat output.

[3] Energy efficiency best practise program – Energy consumption guide 19 – Energy use in offices, 2000
[4] CIBSE Design Guide A – Environmental Design

A1.2.4.2 Occupancy Hours

Occupancy will be as follows

Monday to Friday – 08:00 to 18:00

Saturday – 08:00 to 12:00

Sunday – No occupancy

A1.2.4.3 Lighting

TM32 indicates that the lighting should be on all the time when available for use. For this study it would appear to indicate that the load should apply during occupied hours.

Table A1.3 Lighting loads from ECON 19

	Type 1		Type 2		Type 3	
	Good practice	Typical	Good practice	Typical	Good practice	Typical
Load	12 W/m^2	15 W/m^2	12 W/m^2	18 W/m^2	12 W/m^2	20 W/m^2

The selected value of 12 W/m2 represents a good practise level of energy consumption but is also typical of modern lighting installations.

A1.2.4.4 Small power

TM32 gives 15 W/m^2 as a typical figure and this is what has been applied to the model. The small power loads were applied during occupancy hours.

Table A1.4 Small power loads from ECON 19

	Type 1		Type 2		Type 3	
	Good practice	Typical	Good practice	Typical	Good practice	Typical
Load	10 W/m^2	12 W/m^2	12 W/m^2	14 W/m^2	14 W/m^2	16 W/m^2

A1.2.5 Heating and cooling systems

A1.2.5.1 Environmental criteria

CIBSE Guide A Table A1.1.1 gives the following criteria

- Winter temperature – 21 to 23 ºC
- Summer temperature – 22 to 24 ºC
- Air supply rate – 8 l/s/person

Therefore the heating setpoint will be 21ºC and the cooling setpoint 24ºC.

Overheating is assumed to be above 27ºC

A1.2.5.2 Setpoints outside of occupied hours

Outside occupied hours a setpoint of 10ºC will be used for heating and the cooling will be turned off.

A1.2.5.3 Heating

The heating energy demand will be calculated based on a heat emitter where 70% of the heating is convective and 30% radiant for gas and 90% convective for electricity. For a gas heating system the boiler and distribution efficiencies must first be factored in. This will be done using the COSP's defined in CIBSE TM32.

A1.2.5.4 Cooling

The cooling load output from the thermal analysis will need to be factored by the coefficient of performance of the chiller and the distribution efficiency. This will be done using the COSP's defined in CIBSE TM32. It will also be assumed that the air conditioning is via a fan coil unit and therefore the fan energy consumption must be added. TM32 states that a figure of 20W/kW cooling may be used.

A1.2.5.5 Natural ventilation

The natural ventilation system was based on a control strategy that meant the windows in the building would begin to be opened at 24ºC internal temperature and be fully open at 27ºC.

A1.2.6 Solar overheating

The Building Regulations requires that the building does not overheat due to solar gains. This is both to ensure occupant comfort but more importantly to ensure that an excessive cooling capacity is not required. Compliance in the elemental method is shown if the solar gain to a perimeter zone 6m deep from a window is less than 25 W/m². In order to meet this, an external louvre was defined and added to the model.

A1.2.7 Climate data

TM32 states that the climate file used must be the CIBSE TRY data for the nearest location to the actual site of the building. For this analysis the London TRY was used.

A1.2.8 Carbon emission factors

In order to convert from the annual heating, cooling and lighting demands which are in kWh (kilowatt hours) to carbon emissions in kgC (kg of carbon) or $kgCO_2$ (kg of carbon dioxide) conversion factors are required. The following are given in Part L2.

Table A1.5 Carbon emission factors

Delivered fuel	Carbon emission factor (kgC/kWh)	Carbon emission factor ($kgCO_2$/kWh)
Natural gas	0.053	0.194
Electricity	0.113	0.414

A1.2.9 Coefficient of system performance

The coefficients of system performance (COSP) for the heating and cooling systems allow energy consumption to be predicted without the need to accurately model the whole system. These COSP's are given in CIBSE TM32.

Table A1.6 Coefficients of system performance (COSP) factors.

System	COSP
Heating (gas)	0.73
Heating (electricity)	1
Cooling (electricity)	1.96

In order to calculate the energy consumption from the heating demand the demand is divided by the COSP.

Similarly CIBSE TM32 gives equations for evaluating pump and fan energy consumption for the systems.

A1.2.10 Simulation program

The analysis tool used to predict the energy consumption of the notional buildings was IES[5] ApacheSim. This program is a dynamic thermal analysis tool capable of modelling solar gains, airflow including infiltration and plant. Originally developed by Oscar Faber Consulting Engineers it is now developed by IES and is commercially available.

A1.3 Results

A1.3.1 1995 Building regulations insulation standards – air conditioned

Table A1.7 gives the carbon emissions for the air conditioned 1995 standard notional building

Table A1.7 Results for 1995 regulations air conditioned case.

Item	Emissions (kgC/m^2 floor)	Emissions (kgCO_2/m^2 floor)
Heating (gas)	2.3	8.6
Heating (electricity)	3.5	13.0
Cooling	2.3	8.5
Lighting	3.8	14.0
Small power	4.8	17.5

A1.3.2 2002 Building regulations insulation standards – air conditioned

Table A1.8 gives the carbon emissions for the air conditioned 2002 standard notional building

[5] Integrated Environmental Systems – http://www.ies4d.com, 0141 552 8368

Table A1.8 Results for 2002 regulations air conditioned case.

Item	Emissions (kgC/m^2 floor)	Emissions (kgCO_2/m² floor)
Heating (gas)	1.6	5.9
Heating (electricity)	2.4	8.9
Cooling	2.8	10.3
Lighting	3.8	14.0
Small power	4.8	17.5

A1.3.3 1995 Building regulations insulation standards – naturally ventilated

Table A1.9 gives the carbon emissions for the naturally ventilated 1995 standard notional building

Table A1.9 Results for 1995 regulations naturally ventilated case

Item	Emissions (kgC/m^2 floor)	Emissions (kgCO_2/m² floor)
Heating (gas)	2.5	9.1
Heating (electricity)	3.8	13.8
Cooling	0	0
Lighting	3.8	3.8
Small power	4.8	4.8

A1.3.4 2002 Building regulations insulation standards – naturally ventilated

Table A1.10 gives the carbon emissions for the naturally ventilated 2002 standard notional building

Table A1.10 Results for 2002 regulations naturally ventilated case

Item	Emissions (kgC/m^2 floor)	Emissions (kgCO_2/m² floor)
Heating (gas)	1.9	6.8
Heating (electricity)	2.8	10.3
Cooling	0	0
Lighting	3.8	3.8
Small power	4.8	4.8

A1.3.5 Summary of results

A1.3.5.1 Not including small power

Case		Total emissions (kgCO_2/m² floor)
1995 Air conditioned	Gas	31.1
	Electricity	35.5
2002 Air conditioned	Gas	30.2
	Electricity	33.2
1995 Naturally ventilated	Gas	23.2
	Electricity	27.9
2002 Naturally ventilated	Gas	20.1
	Electricity	24.3

A1.3.5.2 Including small power

Case		Total emissions (kgCO_2/m² floor)
1995 Air conditioned	Gas	48.6
	Electricity	53.0
2002 Air conditioned	Gas	47.7
	Electricity	50.7
1995 Naturally ventilated	Gas	40.7
	Electricity	45.4
2002 Naturally ventilated	Gas	38.3
	Electricity	41.8

A2. EMBODIED EMISSIONS OF MATERIALS

A2.1 Construction of a typical building

Classrooms are typically about 5 modules in size, but single storey buildings can be up to about 20 modules. A ten module building is in the middle of this range so represents a typical building construction.

The construction of the floor, walls and roof are the same for a single module building and for multiple-module units. This construction is the same for about 80% of the market.

A single module is 12m deep, 3.3m wide and 2.8m high. A ten-module building will comprise two end modules and 8 central modules. The central modules do not have any 12m long walls and the end modules have one 12m wall and two 3.3m long walls. These are joined together to make the building.

The spreadsheet supplied by the MPBA containing the elemental break-down of a 10 module building was used as the basis for this calculation. It is summarised in here. The construction of the basic elements which, according to MPBA, are used in a large proportion of all modular units, are as follows:

Walls

70% of the market uses in-situ foam insulation. This has the benefit of bonding the outer and inner facings of the panel together to make a single element. Of the buildings not using such composite panels, 15% uses polystyrene slab and 15% uses mineral fibre slab. Whilst the majority of manufacturers use timber for the top and bottom studs, one manufacturer uses a recycled plastic. The use of plastic may represent the worst case in terms of energy content, so has been included in this analysis.

The panel with in-situ foam has been taken as the most widely used construction:

- Plastisol-coated steel outer face
- Vertical timber stud
- Recycled plastic horizontal top and bottom rails
- PVC-faced plasterboard inner
- In-situ foamed polyurethane insulation
- The panels are bolted to square section steel columns located outside the envelope.

For in-situ blown foam panels the holes for windows are cut from completed panels. The section of panel is then cut out and discarded, or may be used in the floor construction of some types of module. Therefore, the area of the wall panels has not been reduced by the total area of windows and doors because they do not result in any material savings.

Floor

The typical floor construction comprises:

- Pre-galvanised steel sections welded or bolted together
- Steel sheet underfaring
- Steel joists at 1200 centres
- Chipboard deck fixed to joists

- MMMF/ foam insulation board between joists
- Floor finish may be vinyl sheet or carpet tiles

Most units are finished with carpet tiles, and a small proportion will have vinyl tiles. For this model, 95% of the floor is finished with carpet and 5% with vinyl.

Roof

The roofing construction is either a built-up or composite panel. 60% of manufacturers use a composite sandwich panel and 40% use a built-up roof. The following composite sandwich panel is use in this analysis, as it represents the most common type of construction:

- Plastisol coated steel facing panels
- Timber edges
- Steel joists at 1200 centres

Windows

Windows are either one large window [2.2m X 1.2m] in each short wall, or two smaller ones [0.9m X 1.1m]. The frame may be PVC or aluminium. The advantage of the two smaller windows is that they are the same width as a door, so the panel could easily be converted from having two windows to two windows and a door. Windows are single glazed in pre 2000 construction and double glazed in post 2000 build. For this analysis two double glazed small windows was used.

Doors

Doors were not included in this analysis as their contribution to the overall impact of the modules is likely to be small.

Internal partitions

The amount of internal partitions will depend on the client's requirements and can vary widely. A ten module building could typically be arranged to be mostly open plan with toilets and a couple of offices. This would require about 30m of partitioning, ie. 3m per module. Partitioning typically comprises two plasterboard panels and supporting timber studs.

Services

All heating and lighting services are electrical and use PVC-coated copper wire. 180m has been included for power and 150m for lighting.

Table A2.1 Composition of 10 unit module by weight of materials, kg

	Weights of single modules		Weights of modules needed for 10 module building		**Total weight of 10 module unit, kg**
	Single end module, kg	Single middle module, kg	Ends - 2	Middles - 8	
Main elements			5824	20128	25952
Steel components.	2912	2516	1484	5504	6988
Timber components.	742	688	872	2664	3536
Insulation.	436	333	64	96	160
Bottom rails (styrene).	32	12	1154	1576	2730
Wallboards.	577	197	68	408	476
Misc. (Fixings, transport sheets etc).	34	51			
Secondary elements					
Windows - uPVC double glazed glass					617
Paint exterior gloss/undercoat					444
Paint interior ceiling emulsion					92.4
Internal partitions plasterboard					1814.4
Internal partitions studding in timber					271
M & E systems plastic					5
M & E systems copper wire					18
Vinyl flooring					13.6
Polypropylene carpet					344
Total weight of modules, kg	**4733**	**3797**	**9466**	**30376**	**42844.4**

A2.2 Embodied energy and CO_2 calculations

The data used for the embodied CO_2 calculation is for UK construction materials and can be found in SCI Publication P-182, 'A comparative environmental life cycle assessment of modern office buildings.' Appendix D, 1998. K J Eaton & A Amato. The values used in this analysis are presented in Table A2.2. They are based on the UK power generation mix and the efficiency of materials production processes and includes all fuels used at all stages, including import of raw materials or products and an allowance for transport of materials to a typical UK site. There is no allowance for the energy used and CO2 generated in the construction process but since this is considered to be a small proportion it is not significant.

The total embodied energy and CO_2 for the ten module building is calculated by multiplying the materials totals for the per kg data for the respective materials.

The value for sheet steel (34.4MJ/kg) has been used for the steel since these lightweight elements are made from sheet which is then formed into sections.

A number of miscellaneous items have been grouped together. These include fixings and flexible sheeting used during transportation. They have been assumed to be 50% steel and 50% plastic.

For some materials, there is not an exact match between the data available and the materials used in the modular building. For example, there is no value for polyurethane foam insulation, so the nearest value for resin has been used. Similarly, there is no data for recycled plastic, so the resin value has been used again. A value does not exist for polypropylene carpet, so one for nylon has been used instead.

A nominal transport distance of a complete module of 300km has been included in the analysis. A transport energy of 4300kJ/tkm has been used from the Swiss ESU-ETH database. Fuel consumption includes empty return of the lorry. To convert this into CO2 emissions, a CO2 production rate of 76.7gCO2/MJ has been taken from BRE's Environmental Profiles report.

Table A2.2 Embodied energy and CO2 values for the materials used

Material	**Embodied energy**	**Embodied CO_2**
	MJ/kg	**$kgCO_2$/tonne**
Steel	34.2	2702
Timber	13	1638
Insulation	200	13800
Recycled plastic	200	13800
Plasterboard.	2.7	181
Misc. (Fixings, transport sheets etc).	117.1	8251
Glass	14.7	1132
Paint	13	3300
PVC	110	7590
Copper	110	7260
Carpet	190	13300

Table A2.3 Embodied energy and CO2 for 10 module unit

	Building Embodied Energy	**Building Embodied CO2,**
	MJ	**kg**
Steel components.	887,558	70,122
Timber components.	90,844	11,446
Insulation.	707,200	48,797
Bottom rails (styrene).	32,000	2,208
Wallboards.	7,371	494
Misc. (Fixings, transport sheets etc).	55,740	3,927
Windows - uPVC double glazed glass	9,070	698
Paint exterior gloss/undercoat	22,200	1,465
Paint interior ceiling emulsion	4,620	305
Internal partitions plasterboard	4,899	328
Internal partitions studding in timber	3,523	444
M & E systems plastic	550	38
M & E systems copper wire	1,980	131
Vinyl flooring	1,632	113
Polypropylene carpet	65,360	4,575
Lorry transport for 300km one way	55,269	4,239
Total	**1,949,816**	**149,330**

Table A2.4 Summary of normalised results for 10 module building

Total embodied energy	MJ	1,949,816
Total embodied CO2	Kg CO2	149,330
Total embodied energy	GJ	1,950
Total embodied CO2	Tonnes CO2	149
Total embodied energy/m2	MJ/m2	4,923.78
Total embodied CO2/m2	Kg CO2/m2	377.10
Total embodied energy/m2	GJ/m2	4.9
Total embodied CO2/m2	Tonnes CO2/m2	0.38

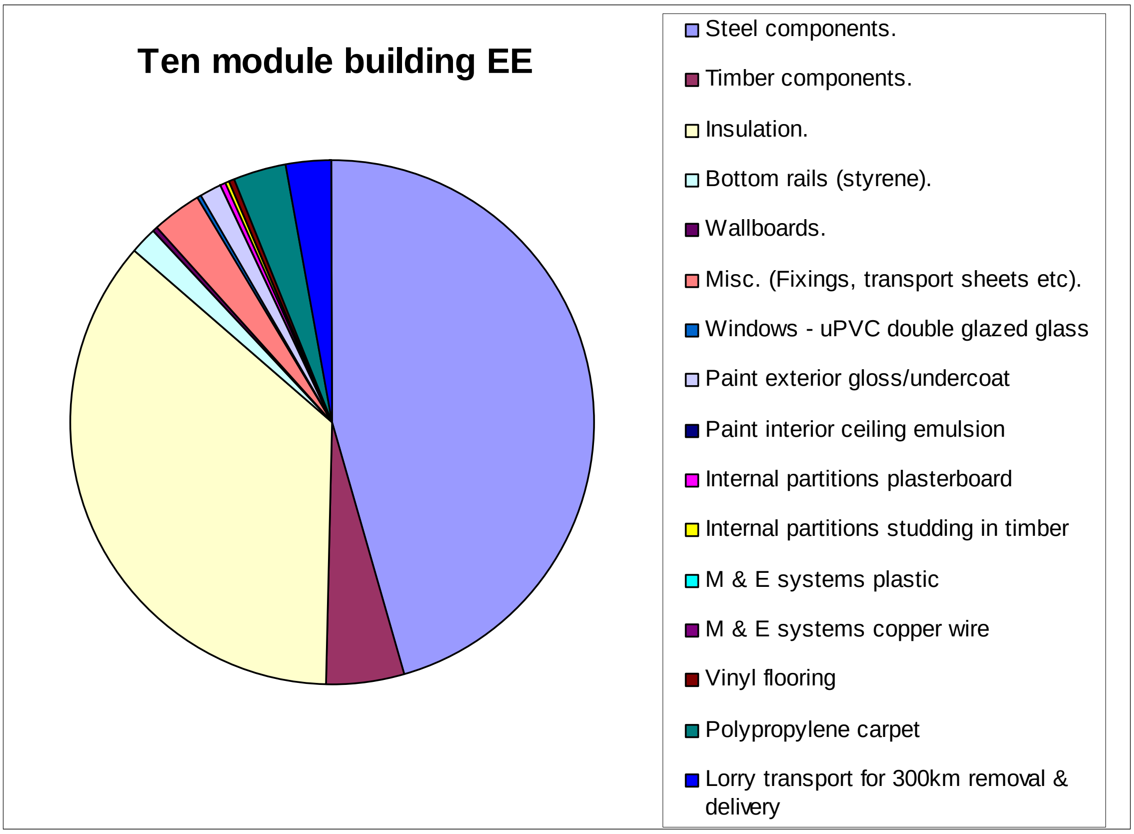

Figure A2.1 Embodied energy distribution between materials

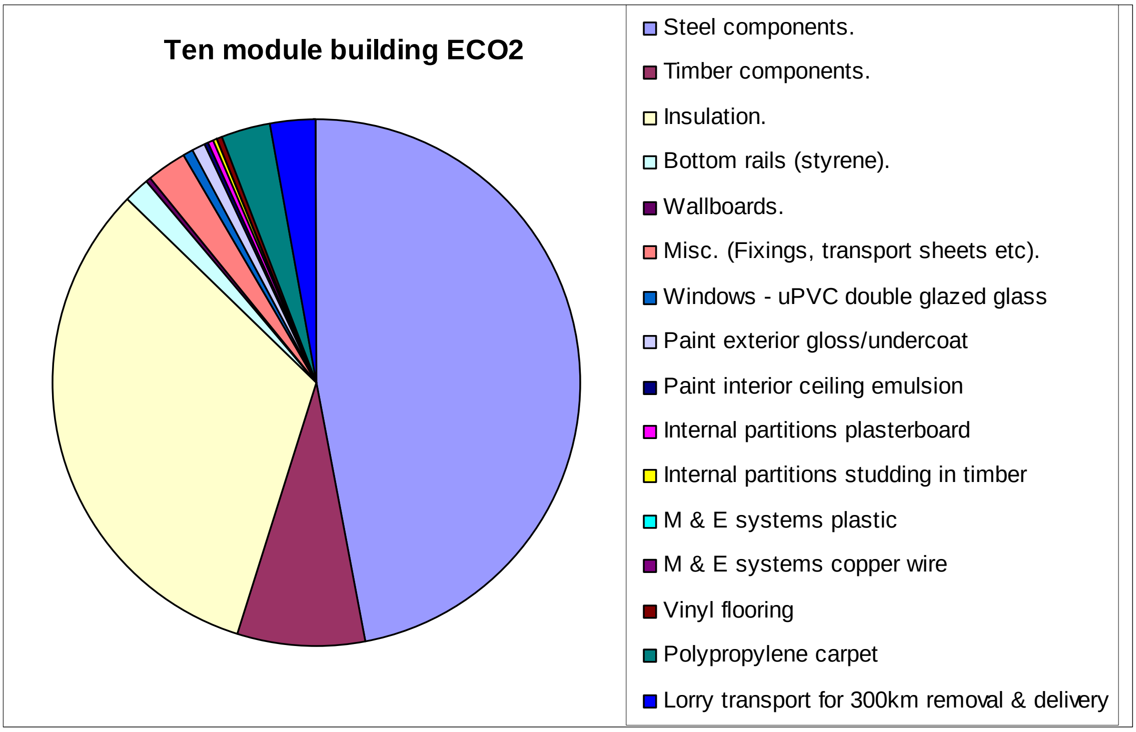

Figure A2.2 CO2 distribution between materials

Table A2.5 % Embodied Energy and CO2

Material	Embodied Energy, %	Embodied CO2, %
Steel	46	47
Insulation	36	33
Timber	5	8
Miscellaneous	3	3
Polypropylene carpet	3	3
Transport	3	3
Bottom rails (styrene)	2	1
Exterior paint	1	1

A2.3 Recycling and end-of-life options

When a module is returned after a period of rental, it is refurbished according to its condition. The best case scenario is that it only requires washing and painting before being rerentald. The internal partitions may be repositioned if required. The electrics are replaced if necessary.

For a major refurbishment, the panels are replaced if the inner PVC layer is damaged, windows are replaced and upgraded from single to double glazing. Partitions are removed and replaced. The vinyl flooring may be covered with carpet tiles.

At the end of life of the unit, the external steel elements and those in the floor are removed for recycling by disassembling the building. The composite panels are sent to landfill because it is impractical to separate them from the foam plastic core. Whilst the external steel skin could be stripped off for recycling, this is not done in practice. Any element that has a useable level of residual life is removed for deployment in another module.

The elements which are recycled are presented in Appendix A2 table 2.6.

In order to calculate the benefit from recycling a proportion of the steel structure, the amount of energy and CO2 saved is equal to the energy used/ CO2 produced for the same quantity of virgin steel, less the energy used /CO2 produced in the recycling process.

Table A2.6 Impacts saved by recycling steel structure of 10 module unit

Recyclable steel elements	**Weight, kg**
Floor beams & column connection unit	4576
Long wall corner & intermediate columns	322
Short walls columns	2212
Roof beams & spacer tubes	6936
Total	**14046**
Embodied energy of this mass of virgin steel, MJ	480373
Embodied CO2 of this mass of steel, kg CO2	37952
Energy to recycle this steel, MJ	242996
CO2 produced in recycling of this steel, kg CO2	16767
Embodied energy saving, MJ	237377
Embodied CO2 saving, kg CO2	16573
Embodied energy saving/ m2 floor area, MJ/m2	599
Embodied CO2 saving / m2 floor area, kg CO2/m2	42

A3. CONSULTATION WITH MEMBERSHIP OF THE MPBA

A3.1 Reaction to need to upgrade from MPBA members

A number of rental companies were asked:

What would it mean to your business if the 2005 Part L2 Building Regulations became law as written at present? (That is, any unit built prior to 2000 would need to be brought up to 2005 regulations.)

The responses were:-

Company A

A considerable amount of money. We are perhaps fortunate as we have designed our modules with removable wall panels. We would have to scrap, wall ceilings and floors and rebuild around our existing framework. Achievable but at a cost of 75 – 80% of original. Rental business would suffer considerably.

Company B

Our Building Services division has already placed an embargo on the purchase of any pre 2002 buildings as the cost of upgrading to 2002 specification is generally too expensive. This has meant a considerable down turn in business in that sector.

Company C

We are currently doing the exercise but it would have a significant impact on our rental fleet. We are awaiting the computer programme to evaluate fully the implications of CO2 emissions.

Not a scrap situation as originally envisaged but probably a major re-build programme. Would most certainly cause major supply problems.

Company D

Would put a big hole in our rental fleet. Generally, because of the cost of upgrading or buying new, we have stuck with the 1995 specification. We wait to see if the proposals are implemented as written.

We foresee a major problem with many rental fleets as the cost of upgrading to the 2002 specification is considered to be excessive. It could result in a serious shortage of supplies and possible employment losses in the rental market.

Company E

Devastating – it would cripple our rental business as the majority of our units are over 5 years old.

We are replacing units, but we expect to get 12 – 15 year life from units already built. A major refurbishment programme would result in a shortfall of availability.

Company F

Would cause a major supply problem as capacity to refurbish units is limited. From an initial look at the costings they are well in excess of a years projected profit for the business, and we only have a small amount of modules compared with a number of other companies.

A3.2 Overview of MPBA membership

Comments supplied by R Ford, Secretary to the MPBA

The cost of upgrading does depend upon the design of the building and the installation values built into that design, types of windows etc.

We know that for some companies the upgrading from 1995 specification to 2002 specification has already been done at acceptable cost. Other companies have held off of upgrading because of unacceptable cost.

The refurbishment market will have serious problems unless we obtain dispensations. The changes from the 2002 regulations to 2005 regulations are most significant and it is foreseen that anything already constructed to 1995 or 2002 regulations will need to be scrapped or major rebuilds. Some buildings built to 1995 specification will be worth upgrading to 2002 specification but supply may be limited by the quality of buildings becoming available. Any upgrading would need to be carried out prior to the new regulations coming into force.

There is a definite projection of serious disruption to the rental market and the point should be made that, Government Agencies, are customers for over 50% of that market.

For the sales market the manufacturing companies will comply with the ultimate requirements of the revisions to Part L2.