SUSTAINABLE STEEL FRAMED CONSTRUCTION

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1. ABSTRACT

This paper outlines the importance of immediate action to ensure sustainable development and explains why construction has such a major role to play. The broader issues are introduced but the focus is on those actions which the construction industry can take to make the biggest improvements, namely reducing energy use associated with both the building process and the operation of buildings throughout their life. It is also important that the useful life of the building is prolonged, opportunities are taken to reuse components and recycle materials when they are no longer needed, and that materials are sourced in such a way that impacts are minimised. The challenge of reducing demolition waste and making positive use of other waste products are also considered. These issues are discussed with particular reference to steel construction. The specific information and relative importance of different issues relate mainly to the UK, but the principles are universal.

1. INTRODUCTION

Sustainability is becoming an increasingly important consideration, but there is a good deal of confusion about what constitutes sustainable construction, and many sweeping claims for buildings, products, and even materials purporting to be 'sustainable'. In reality such things are neither sustainable nor unsustainable in themselves. However, used in an appropriate way they can contribute to a sustainable community, society, or way of life.

Sustainable construction can be considered as a subset of sustainable *development* in which economic growth and social progress for all is coupled with effective protection of the environment and prudent use of resources. It is becoming so important largely because of concerns about damage to our environment through climate change brought about by global warming, and a recognition that natural resources are finite. This is further accentuated by the rapid economic growth in a number of highly populated areas of the world, significantly increasing the potential environmental impacts. Pressure is therefore mounting on industry, including the building sector, from both legislation and public perception to change the way we operate.

Construction has been identified as being particularly important because of the significant environmental and social impacts which the built environment has on everyone's quality of life. It is estimated that, on average, we spend 90% of our lives in buildings. Whether at home, at work, in education or at leisure, everyone uses, and indeed relies on, the outputs from the construction industry. Furthermore people's performance and productivity can be enhanced by improving the quality of the buildings in which we live and work.

But the negative impacts are also significant. Construction is a major consumer of raw materials (including energy), and accounts for a high proportion of waste. Each year in the UK the construction sector consumes over 420 million tonnes of a wide range of raw materials, including aggregates, and generates about 94 million tonnes of waste – approximately 13 million tonnes of which is estimated to be due to over specification. The manufacture of cement alone accounts for over 2% of all carbon dioxide emissions in the UK [1]. There is accordingly a growing interest in using recycled materials and even reusing components, and steel construction is ideally suited to this.

Buildings are also major consumers of energy, accounting for approximately 50% of all energy used; energy efficient building design is therefore very important. Even in the UK, commercial buildings need cooling rather than heating for most of the year, and natural cooling systems are becoming more popular. These generally use exposed parts of the building's structure with significant implications for design and construction.

This paper discusses these issues with particular reference to how steel framed buildings can be designed and constructed to contribute to more sustainable construction.

2. GLOBAL WARMING AND CLIMATE CHANGE

The so-called 'greenhouse' gases, of which carbon dioxide is perhaps the most important, produce their warming effect by trapping solar heat in the earth's atmosphere, maintaining a remarkably consistent temperature regime. The possible consequences of changing the concentration of atmospheric carbon dioxide can be seen by looking at two other planets, Venus and Mercury. The atmosphere of Venus, which is twice as far from the sun as Mercury and receives only 25% of the solar irradiance, has a strong concentration of CO_2, raising the surface temperature to over 400 °C. In contrast, Mercury has no real atmosphere and consequently surface temperatures are very volatile, ranging from about −180°C to 430°C. In fact the atmosphere of Venus is thought to have been much more like Earth's than it is now, but evaporation of surface water generated a critical level of greenhouse gases leading to the present conditions.

A wide range of data sources give a consistent indication that, not only is the concentration of atmospheric carbon dioxide increasing, but that the rate of increase is accelerating alarmingly. The earliest direct measurements were started by Keeling [2] at Mauna Loa on Hawaii, and are summarised in Figure 1. Sceptics have pointed to the annual cycles which are apparent in this data as evidence of natural variations. In fact these regular changes are simply related to the seasonal growth and decay of plants. Since the proportion of land mass, and hence vegetation, is much greater in the Northern Hemisphere there is a net absorption of carbon dioxide between March and September and a net emission for the rest of the year.

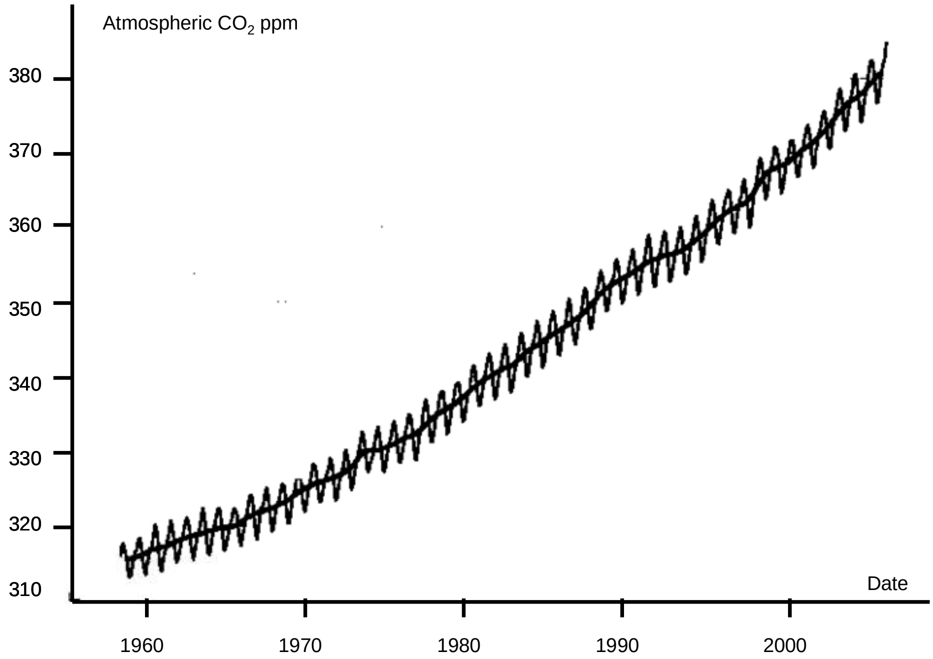

Figure 1. The record of atmospheric carbon dioxide at Mauna Loa – the Keeling curve (http://scrippsco2.ucsd.edu)

Much earlier levels of carbon dioxide can be determined from gas bubbles trapped in glacial ice. Figure 2 shows the results dating back more than 1000 years, but data now exists for almost one million years and shows a consistent pattern throughout with concentrations ranging from 220 to 300ppm; it is only recently – in the last 100 years or so – that concentrations have shown a dramatic increase.

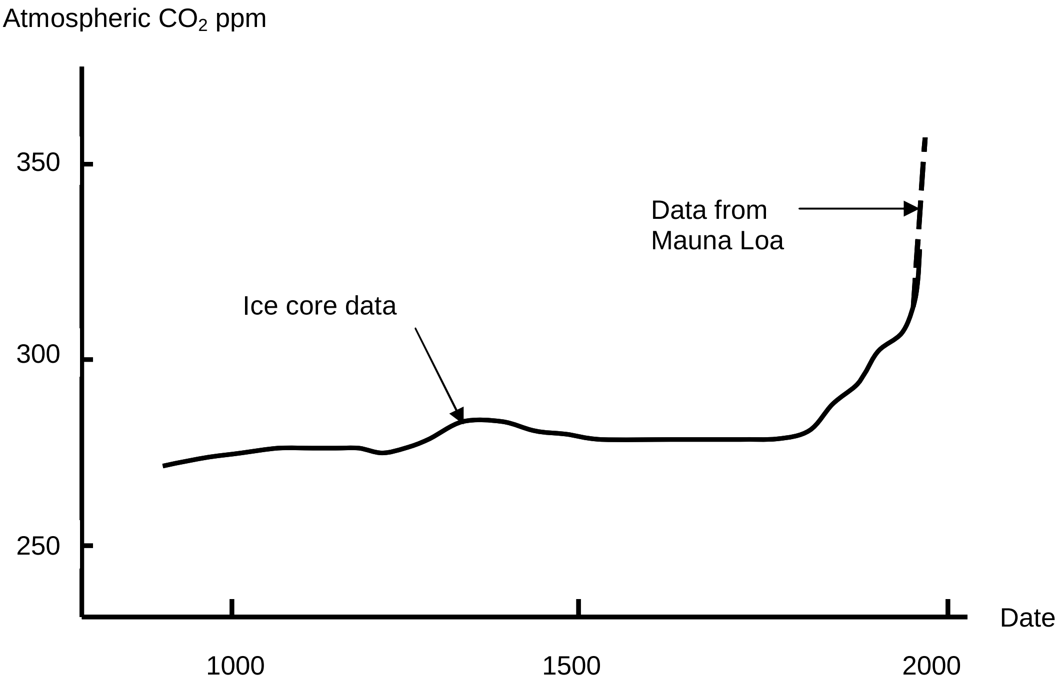

Figure 2. Data from ice cores and Mauna Loa observations

This provides convincing evidence that carbon dioxide levels remained very stable until the beginning of the industrial revolution since when there has been a rapid and accelerating increase. Current concentrations are about 30% higher than at any time before the 19th century, and they are still rising. The pattern closely follows that for fossil fuel emissions providing strong circumstantial evidence of a linkage between the two.

2.1 WHAT HAPPENS IF WE DO NOTHING?

If we continue on our present path it is almost certain that current trends will accelerate. Even if we stabilize emissions of carbon dioxide at existing levels the position will worsen rapidly, and this could trigger certain key events such as releasing methane gas currently trapped in the Siberian permafrost. Furthermore increasing pressure from developing countries will potentially add significantly to present emissions. The scale and rate of development in, for example, China and India is unsurpassed, but it would be totally unreasonable to expect those countries to limit their activities while the developed world carries on business as usual. This is a global problem, requiring a common approach, and developed countries have a particular responsibility. Figure 3 shows that the performance of the USA, the biggest contributor to carbon dioxide emissions, has worsened in recent years. Other developed countries have started to slow down but are still increasing, whilst the rapid expansion in the development of China has resulted in an inevitable acceleration.

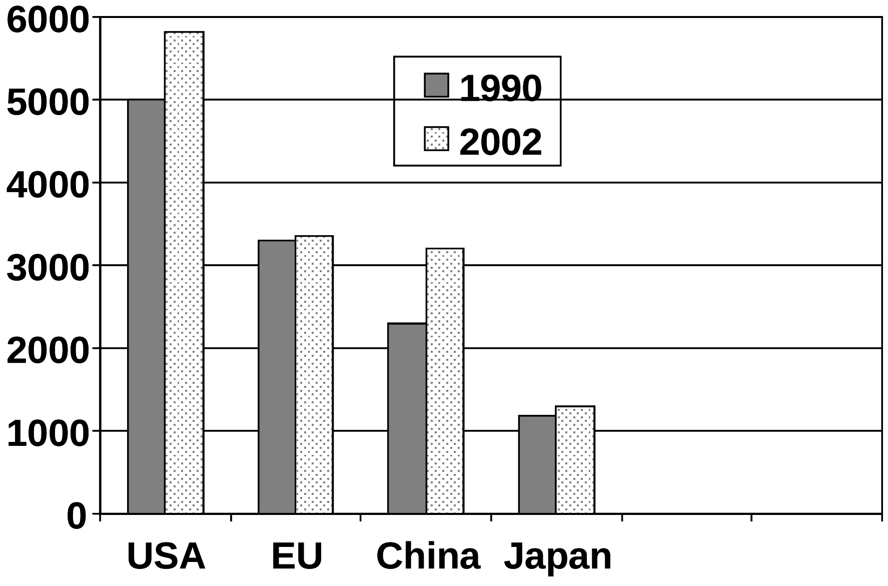

Figure 3. Carbon dioxide emissions (x1000 million tonnes) by state 1990 and 2002

We must therefore recognise the need for urgent action to address this threat, and the challenge is how to reduce carbon dioxide emissions in a way which allows continuing improvement in standards for all. This is the core of the sustainability challenge, although other issues such as caring for our physical and ecological environment also need to be considered.

3. THE ISSUES

Neither buildings, nor products, nor materials can be described as 'sustainable' – but how we build, manufacture, source and use buildings are significant factors in contributing to sustainable development. In construction the important issues concern:

- planning (what to build, where to build, whether to build) - these issues are very important but they are generic and are independent of the form of construction and material
- design (ensuring that buildings make a positive contribution to occupants and others, that their consumption of resources through their expected life is minimised, that the potential life of the building is as long as possible, and that there is maximum opportunity for reuse or recycling at the end of life) - these issues are influenced principally by the form of construction
- construction (minimising material consumption, particularly of critical resources, and reducing disturbance during the building process itself) - these issues are influenced by both the form of construction and material
- suppliers (ensuring that manufacturing processes, including transportation, are as energy efficient as possible, and raw materials are sourced with minimum impact)

Many government bodies across the world have published high level policies, often with associated strategies and targets, but the biggest issue is how to realize these. This presents real difficulties because the interactions between the various issues can be complex, and an holistic approach is needed. However we can still usefully discuss the major aspects separately.

3.1. ENERGY USE

Buildings account for a significant proportion of total energy consumption, partly through the process of construction – so called embodied energy, which represents the energy used in manufacturing materials and products, and the energy for transportation and site work – and operational energy, which is that used to service buildings (heat, ventilation, light, power). Figure 4 compares the relative contributions to embodied energy from the structure with other non-structural components (walls, carpets, etc) and operational energy for heating, ventilation and lighting over a 60 year cycle for a typical commercial office, including an allowance for refitting certain non-structural components and finishes. Clearly the structure contributes relatively little, so arguably it is more important to design structures which facilitate replacement of these other components than it is to minimize the embodied energy of the structure.

3.1.1. EMBODIED ENERGY

Embodied energy is relatively small compared with operational energy but as buildings become more efficient in use this balance will change and embodied energy will become more important. In the UK 10% of all energy is accounted for by this embodied energy for buildings, compared with 50% to operate them and 26% for transportation generally.

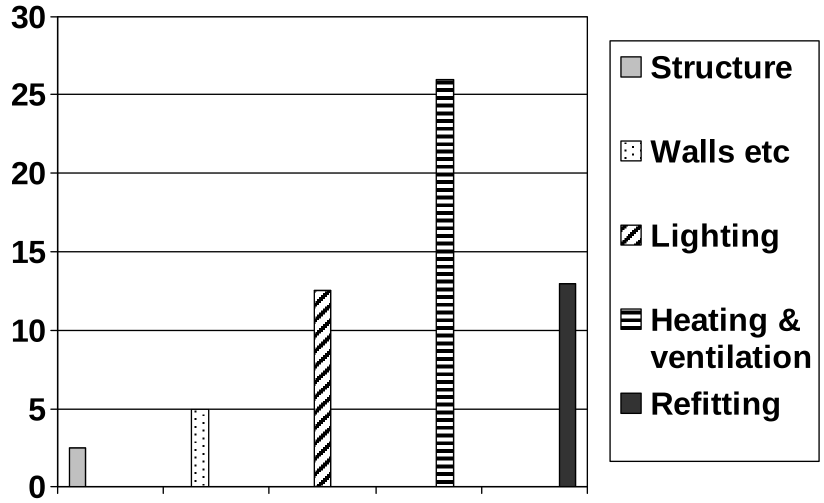

Figure 4. Embodied and operational energy consumption (GJ/m^2) for a typical commercial office over a 60 year cycle [3]

Embodied energy depends largely on the materials used and the associated production process. It can therefore be used to compare the environmental impact of different materials favouring those which use least energy in manufacture, delivery etc, and therefore have the lowest Global Warming Potential (GWP). Table 1 compares the embodied energy for different materials. These values have been extracted from an independent database compiled in the UK by Hammond and Jones [4] on the basis of an extensive survey, and show a wide range of values for all materials. In some cases the database only includes average values because of dependency on particular circumstances, location or supplier. For example, the embodied energy of steel depends on the process and proportion of scrap in the feedstock; for cement, clinker content, the use of additions such as fly ash or slag, and the method of manufacture are critical. The survey also considered embodied carbon which is perhaps a more appropriate measure when considering global warming. Generally the comparisons follow a similar pattern to those for embodied energy, but with some distortions, notably for cement.

Material	**Embodied Energy (MJ/kg)**	**Carbon kg CO_2/kg**
Aggregates	0.15 (av)	0.008
Cement	2.8-6.8	0.82
Concrete	1.0 (av)	0.134
Steel	15-25	1.8
Timber	6-11 (+2-3 for Glulam)	0.5

Table 1. Embodied energy and carbon footprint for different construction materials

Comparisons of embodied impacts at a material level are generally by weight or volume. Notwithstanding the wide range of data for nominally the same material as shown in Table 1, there is clearly a wide variation in embodied energy and carbon for different construction materials. However realistic comparison should be made on the basis of component or function, such as a beam or column for a given set of data. In fact the comparisons are ideally made at the level of an assembly such as a complete floor. When this is done the differences are much smaller, and a number of studies have shown that for complete buildings the uncertainties in embodied energy data are greater than the differences between different systems designed to the same performance requirements. The key issue is therefore 'lean design' rather than selecting one material over another.

There are also huge variations in embodied energy calculations depending on specific sources and methodologies, so comparisons can be very misleading. This is not helped by the 'black box' approach adopted in some software tools, and much greater transparency and flexibility is needed. This will enable designers to make much more informed and precise decisions with respect to material specification and suppliers, and also encourage producers to further improve performance.

3.1.2. OPERATIONAL ENERGY

The building designer is largely responsible for operational energy. They, and more importantly their clients, are recognizing this and incorporating means to reduce energy for lighting, air conditioning and heating, partly by specifying energy efficient equipment, and partly by considering this as an integral part of the design.

Artificial lighting consumes a surprisingly large amount of energy and good levels of natural light can clearly help. Shading and careful location of glazing is important to avoid glare and solar gain, and reflected light, for example from exposed concrete surfaces, can be particularly helpful in allowing deeper penetration into the interior of buildings.

Cooling is now needed in most commercial buildings, even in the UK, because of heat emissions from equipment and occupants, and solar gain. Air conditioning is very energy intensive, and much attention has been given to using natural ventilation as an alternative. This typically uses the thermal mass of the building fabric as an inverted radiator and the concrete floor slab is the most convenient element for this, absorbing heat during the day and releasing it to the atmosphere during the cooler night. The model for this was the cool interior of massive building such as cathedrals. However, the concept of 'heavy' construction is oversimplified as in most circumstances only a relatively thin layer of the concrete – approximately 100mm - can effectively be utilized; thicker floor construction therefore offers very little added benefit as shown in Figure 5.

The degree to which natural ventilation can reduce peak internal temperatures is limited – for 'passive' systems 3°C may be all that can be achieved with a slightly bigger reduction if some form of forced air flow is introduced. In hotter climates this may be insufficient to dispense with air conditioning entirely, and hybrid systems in which natural cooling is supplemented when necessary by mechanical systems are a more realistic option.

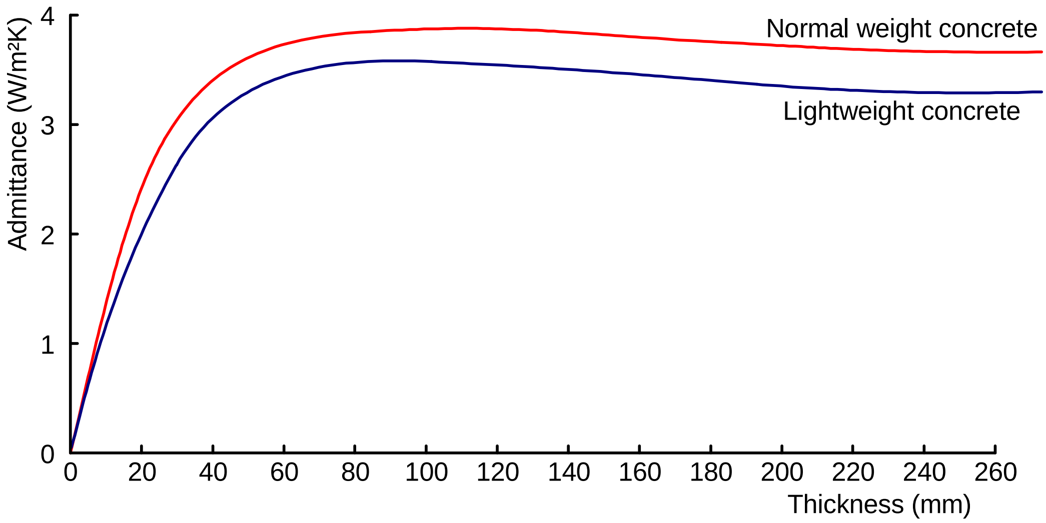

Figure 5. The effect of increasing floor slab thickness on the cooling effect for a daily cycle of heating and cooling

For residential construction the concern is generally to retain heat during the winter months. The issues here are therefore a well sealed and insulated envelope. As housing accounts for a very high proportion of all energy use in buildings, enormous savings are therefore possible. Using steel construction it is relatively easy to incorporate very high levels of insulation and minimize air leaks, thereby achieving a very efficient envelope. In the UK there has been a resistance to using non-traditional construction methods for housing, but this is beginning to change – steel framed housing is still relatively unusual but is growing rapidly as the benefits it offers for reducing operational energy are recognised.

The solutions are not necessarily sophisticated or requiring advanced technology or large investment. Indeed the huge stock of old, inefficient housing represents one of the biggest obstacles to reaching agreed reduction targets, and if all existing UK housing simply achieved the performance levels set out in current regulations for new construction, the savings in energy and carbon dioxide emissions would be very significant. If these were bettered by raising them to the standard of current best practice, the benefits would be even more dramatic. Yet all of this could be done using existing cost-effective, proven methods such as higher standards of thermal insulation in walls and roofs.

Buildings which are more energy efficient in operation may be more demanding in construction, for example consuming more materials or simply costing more. In many cases, however, even capital costs can be reduced since greater operational efficiency means a reduced requirement for building services.

3.2 DESIGNING FOR LONG BUILDING LIFE

Extending the useful life of a building is almost certainly better than replacing it with another. It is therefore important that the design provides for not only operational efficiency but also flexibility and adaptability so that changes in patterns of use can be easily accommodated. Long span floors, creating column free spaces, will facilitate this. In contrast non-structural components of a building such as finishes and services are likely to need replacing at relatively frequent intervals (Table 2), in which case it is important that the structural form and detail, and the interfaces between the different components will facilitate this. Steel offers the potential for very long, column-free spans – column spacings of 15m or more in multi-storey construction are increasingly common, and very long roof spans have been a characteristic of steel framed single storey buildings for many years.

Component	Replacement cycle	% value
Communications	2-5 years	5-15%
Main Services	5-10 years	20-35%
Internal finishes	5-15 years	5-15%
Cladding	20-40 years	20-40%
Structure	50-100 years	10-15%
Foundations	100+	3-10%

Table 2. Comparison of replacement cycles and relative value of different building components

Materials should also be sufficiently durable to avoid the need for replacement during the life of the building

3.3 DESIGNING FOR END OF LIFE

End of life issues are becoming increasingly important as a design consideration. Traditionally the building has been demolished, creating vast quantities of waste. In the UK this creates approximately 70 million tonnes of waste each year, the majority of which has traditionally been disposed of as landfill.

There are a few examples of complete buildings being dismantled and reused at a different location, but it is more realistic to expect that, once a building has reached the end of its life, components will be reused or materials recycled. At present the reclaiming of structural components, such as beams and columns, for further use is very limited, regardless of the material. This is partly because of the difficulties of dismantling and separating the structural components, but it is clear that a dry form of construction is much easier to deal with. In principle, steel construction lends itself to dismantling, but clearly this depends on suitable connection details, both between steel components and with other materials. Bolted connections which are readily accessible are therefore preferred over welded details. Separating composite deck floors from the supporting beams is more difficult, and schemes which have deliberately set out to facilitate dismantling have generally used precast floor units with a non-composite frame.

There are also concerns about the provenance of elements recovered from a demolition site. At present there are major problems in identifying components and their history – essential to determine their structural capabilities – and in these circumstances most clients and designers are understandably very cautious. In reality the practical difficulties of reuse and the attitude of most clients and designers is likely to make reuse a minority activity for the foreseeable future.

It is therefore more realistic to expect that the current practice of reclaiming materials for recycling will continue and increase. Traditionally large quantities of demolition materials such as masonry and concrete were sent to landfill. However, they are being increasingly reused in other construction projects as recycled aggregate, and currently about 75-80% of such waste is used in this way. This is principally as low quality materials for sub-base and fill, for example in road building and airfield pavements, so the benefits are more associated with waste reduction than reducing demand for virgin materials. In contrast, steel is easily recycled through its production route, with no reduction in quality, and there is a well developed infrastructure for handling scrap steel. As a result, a very high proportion of steel is recycled, reducing waste and minimizing demand for iron ore extraction. However, although some steel is manufactured entirely from scrap, there is insufficient to satisfy demand, and some steel has to be produced from newly mined ore.

3.4. MATERIALS FOR CONSTRUCTION

The principal concern for product and material suppliers is energy efficiency in manufacture and transportation, but safeguarding natural resources, protecting habitats, reducing waste and minimising landfill are also important. The main issues are therefore to:

- Reduce energy and carbon dioxide emissions in production
- Increase use of recycled and waste materials (this also makes a positive contribution by diverting material from the waste stream)
- Use water efficiently

Traditionally the raw materials for steel production – iron ore, coal and limestone – are quarried as virgin material. However this is minimized by the use of scrap in the steelmaking feedstock. Some designers have tried to specify that the steel used in their projects is manufactured entirely from scrap. However, this would do nothing to improve sustainability overall as there is not sufficient scrap available to produce all the new steel needed. Thus while it is generally important to check that individual suppliers of materials and components are themselves operating in accordance with best practice – minimizing energy use, waste and pollution – the proportion of scrap used by any individual supplier is not relevant.

Resource efficient design however is important, and the off-site preparation of steel structures minimises waste at the building site and reduces other impacts, such as noise and dust. Modular systems allow complete units to be manufactured off-site, extending this principle even further.

4. CONCLUSIONS

Sustainability is becoming increasingly important for society and the threats of global warming and climate change are now generally accepted as very real and requiring immediate and urgent action. Because construction has such major implications for energy consumption and resource use, it has to have a central role in any plans for sustainable development. Unfortunately there are no magic answers, no prescriptive methods and no single solution. Rather it is a very broad topic best addressed through an holistic approach considering the whole life cycle from planning and material supply through construction and service, to dismantling or demolition.

Unfortunately the construction industry is characterised by long supply chains, making it difficult to achieve such a long term holistic approach. Certainly this is very unlikely to happen unless the client is committed to sustainable construction. Even then it is important that all organizations, companies, suppliers etc are engaged. This can mean, for example, selecting responsible contractors who have embraced sustainable development principles, rather than simply accepting the lowest price. Nevertheless there are actions which individuals and companies can take which will help. Indeed sustainable construction depends on the contributions, however small, from all parties involved in a project. At present this may seem an altruistic position to adopt, but because of the growing swell of opinion that we must develop in a sustainable way, it will increasingly become a commercial imperative that companies can demonstrate their credentials, and show that they are acting responsibly. Furthermore, there is a growing realization that such actions do not run counter to sound commercial and financial strategies, but are more often directly aligned.

The specific issues and alleviating measures associated with sustainable construction will depend on individual circumstances – location, design brief, availability of materials, energy sources – in particular electricity generation – climate, etc. However there are some general points of good practice which are likely to be almost universally applicable. The structural steelwork industry clearly has a central position in construction, and therefore has a crucial role in this context. High standards of design and quality of construction need to be maintained to ensure buildings (and other works) make a positive contribution and are sufficiently durable and flexible to do so for at least the intended design life. For buildings, the most important issue is to ensure minimum energy use throughout the whole life cycle. This is related to broad design issues and is little inflenced by the structural system adopted. However, steel does offer some particular benefits in other respects, notably the ability to span long distances to create spaces which can be adapted to changing use, the relative easewith which steel framed structures can be modified or extended, and the facility for reusing and recycling at the end of life.

There is no doubt that the sustainability challenge can be addressed in a satisfactory way, and there is a moral obligation to do so. Even if the standard of all construction projects were lifted, so that what is currently regarded as best practice becomes the norm – ie using approaches which are not revolutionary but which have been tried and tested in practice – the improvements would be very significant. For example newly built homes in the UK currently use more than three times as much energy in use than those in some other European countries. So simply by adopting their standards and practices we would see a marked reduction in UK emissions of carbon dioxide. And there is room for improvements even on that. We do however face the continuing problem of a large, inefficient stock of existing buildings. In this respect those countries which are developing rapidly at present are much better placed to create an infrastructure which will support sustainable development.

We all need to contribute – many small changes can add up to big differences and stop global warming. It will take time because there is a natural and considerable inertia in the system, but the time for action is now. This is a threat which we ignore at our peril – government legislation, fiscal measures, and societal pressures are all increasing, and any organization which keeps its head in the sand will not survive commercially. And globally, if we ignore the threat, the consequences are unthinkable – perhaps not for us, but for our children and grandchildren.

5. REFERENCES

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