Material change for a better environment

Information sheet for construction clients and designers

Cutting embodied carbon in construction projects

This guidance will help you identify basic cost-effective actions to reduce the carbon impact of the materials used in your construction projects.

What is good practice?

As Building Regulations reduce operational emissions towards zero, the "embodied" CO_2 emissions associated with supplying materials can be as much as 50% of total emissions over a building's lifetime.

If you reduce embodied carbon, you can benefit financially from:

- reductions in materials use and waste;
- less reliance on energy-intensive manufacturing routes; and
- a reputation for good environmental management.

From the client's perspective, a simple approach to cutting embodied carbon is to set the following requirement in the project specification and design team appointment:

> *"identify the [5-10] most significant cost-effective opportunities to reduce the embodied carbon emissions associated with the project (e.g. through leaner design, designing out waste, reusing materials, and selecting materials with lower embodied carbon over the project life-cycle), quantify the savings made through individual design changes, and report actions and outcomes as part of a Carbon Efficiency Plan"*

In response, the design team would focus on quantifying the savings associated with just a few changes for specific project elements/components. They can use existing assessment methods (and, in the future, methods compliant with the emerging European standard CEN TC350). They do not need to calculate a carbon footprint for the whole project – they would simply estimate with-without differences.

The following Table lists the types of action a design team should consider and the scale of savings achievable (which will vary from project to project). The examples mainly refer to buildings, although the principles apply to infrastructure projects as well.

Carbon saving action	Range of carbon savings
Using less materials	
1. More efficient building design (e.g. compact building form)	Varies by building type – typically, up to 5% (of a building's total embodied carbon)
2. Change the specification for building elements (e.g. lower-weight roof design)	Varies by element type and specification – typically, up to 20% for major structure and cladding elements is achievable – see also 6 below
3. Design for less waste on site (e.g. to cut wastage rates on the top 10 materials from baseline to good practice)	Varies depending on materials specified and extent of off-site construction – typically up to 10% is achievable
4. Design for off-site construction (e.g. to benefit from lower wastage and efficient fabrication)	Varies depending on the extent of off-site construction – up to 10% typically achievable
5. Design for reuse and deconstruction (e.g. increase reuse of materials from demolition and earthworks on the current site; design a building for deconstruction at the end of its life; design a building for easy reconfiguration during its life)	Significant savings on whole-life basis. Little impact on embodied carbon savings on 'cradle to gate' basis (see footnote 2)
Using alternative materials	
6. Select materials with lower carbon intensities (e.g. cement substitutes such as PFA or sustainably-sourced timber)	Varies by building type and specification – typically, up to 20% is achievable
7. Select reused or higher recycled content products and materials (e.g. reclaimed bricks, higher recycled content blocks, locally recycled aggregates) offering lower carbon intensities	Varies by extent of reusable materials available – typically up to 10% is achievable for some elements
8. Select materials with lower transport-related carbon emissions (e.g. locally-sourced aggregates)	Varies by transport volumes and modes – typically up to 2.5% is achievable, and more in infrastructure projects
9. Select materials with high levels of durability and low through-life maintenance (e.g. facades and fixing components which last as long as the building frame)	Significant savings on whole-life basis. Little impact on embodied carbon savings on 'cradle to gate' basis (see footnote 2)

What is embodied carbon?

The carbon dioxide emissions associated with making a building – as distinct from using it – are referred to as **embodied carbon**.

More precisely, embodied carbon covers greenhouse gas (GHG) emissions[1] that arise from the energy and industrial processes used in the processing, manufacture and delivery of the materials, products and components required to construct a building.

The emissions associated with maintaining, repairing, replacing and disposing of these materials and components over the lifetime of the building can also be calculated, although CEN TC350 is expected to treat these emissions separately[2].

Why is it important?

Embodied carbon can be as much as the carbon emissions that come from operating a building (i.e. from the energy used for heating, lighting, air conditioning, etc – often referred to as 'operational carbon') over its effective lifetime[3]. If the UK is to achieve its ambitious target of 80% reduction in carbon emissions by 2050, closer attention will need to be paid to embodied carbon in construction – by project teams as well as policy-makers.

Operational carbon emissions are being reduced via successive changes to the Building Regulations, and this often involves greater use of material resources (e.g. extra insulation, thermal mass, etc). As a result, the significance of embodied carbon is increasing.

Unpublished comparisons of office projects indicate that embodied carbon per m^2 of floor area varies by a factor of 2-10, with significant (10%+) savings available from individual design choices.

How to reduce it

Generally, buildings that are efficient in terms of the amount of materials used to construct them tend also to be efficient in terms of embodied carbon and construction cost.

Additionally, it is often possible to find a cost-effective alternative material that fulfils the required need but has lower embodied carbon.

As outlined above, a simple requirement in the client's procurement documents can catalyse the search for options as part of the design development and value engineering process. What's important is to focus effort on identifying and quantifying just a few significant savings (as illustrated below).

The design team would be expected to identify changes which are at least cost neutral (or cost saving when identified in the context of a value engineering process), and ensure approval by the structural engineer where appropriate.

Using less materials

Your design team can use **less materials** in construction by looking at:

- the overall efficiency of the building design (in terms of, for example, rationalising the building form; avoiding over-engineering the building structure, etc);
- ways of reducing waste – focusing attention on a few materials and opportunities for off-site construction[4]; and
- planning to maximise the reuse of materials already available on site (e.g. by reclaiming demolition and excavation materials), and designing for ease of reconfiguration and deconstruction of the new build.

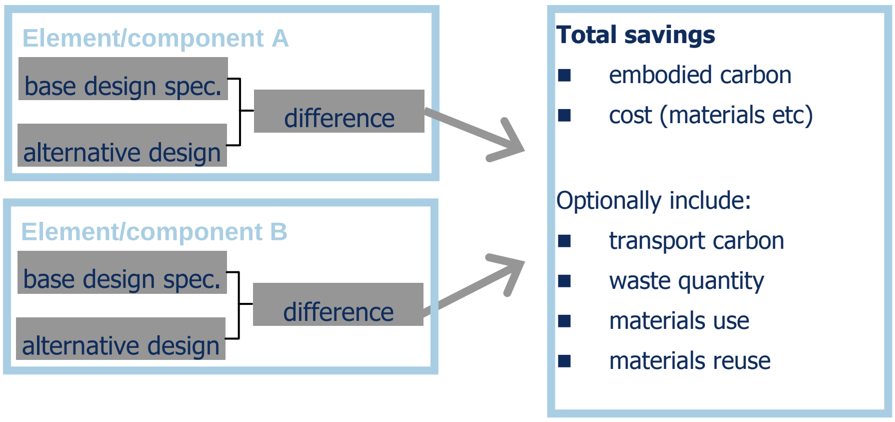
Overall building efficiency

Generally, efficient building forms use less materials because:

- the ratio of external walls to floors (wall/floor ratio) is minimised;
- the need for bracing to the structural frame (to manage wind loading) is reduced;
- compact forms can enable natural ventilation – i.e. by having spaces no further from the building perimeter than, say, 6-7 metres – whereas deep forms may require mechanical ventilation and/or air conditioning systems; and
- the need for vertical circulation (lifts/stairs) may be reduced with a more efficient building layout.

As well as reducing the embodied carbon from plant installation, natural ventilation is likely to save operational carbon by avoiding the use of mechanical ventilation and/or air conditioning.

Compactness and simplicity in terms of structural grid arrangements can save on carbon-intensive structural materials such as concrete and steel. Subject to site constraints, using structural spans of between 6 and 9 metres will tend to be resource-efficient. As beam spans increase beyond this range, beam depths increase with knock-on effects on storey heights and other vertical elements (e.g. external cladding, stairs, lift shafts, internal walls, and so on). These changes require more material resources. They can also add weight requiring additional material resources (and embodied carbon) in the building foundations.



Calculate carbon savings as the with-without difference from changes in a few key project elements/components

Simplicity and repetition of structural grids can also lead to efficient layouts to heating, ventilation and air-conditioning pipe- and duct-work, and electrical installations. Additionally, the development of innovative, lightweight structural solutions – for elements such as long-span roofs, for example – can result in savings in embodied carbon not only in the element itself but in the associated structure as well.

How buildings are constructed

Some building elements can be assembled off-site and in a factory. These include precast concrete floors and pre-assembled external walls. They can also include more complete products, such as prepared bathroom pods, and pre-assembled rooms ready to make up a whole building. This approach has been used successfully for hospitals, hotels, student residences and houses, for example.

The advantages of off-site construction include waste reduction and improved waste management, as products are manufactured and assembled in a more controlled environment. On-site construction waste can account for up to 15% of the embodied carbon of a building; off-site construction can significantly reduce this, by well over half in most cases.

However, the energy used for factory heating and lighting must be considered in an embodied carbon assessment. Additionally, factory location may be a factor, especially if large pre-fabricated units are transported long distances by road, which will add significantly to embodied carbon emissions. If the pre-assembled products are transported in 'flat pack', then emissions per unit of product are reduced.

Good off-site construction would look to ensure that additional emissions for factory use and transport are not greater than the benefits of reduced waste. WRAP's Designing out Waste guides provide further guidance on designing for off-site construction.

Modular off-site construction.

Designing out waste

Designers have a critically important role in minimising waste in construction, principally by:

- designing buildings and infrastructure that can be constructed efficiently; and
- specifying work procedures and methods that avoid waste and allow use of waste arising (e.g. offcuts).

Designers can engage the supply chain in strategies to reduce waste by reviewing and agreeing methods of waste minimisation with suppliers, specialists and contractors. Areas to focus on include:

- packaging and damage to materials on site – suppliers can help minimise unnecessary packaging; contractors can provide adequate protection to fragile materials to minimise damage on site;
- wall lining systems/boarding (including plasterboard) – designs that accommodate standard products avoid the waste caused by excessive customisation and fitting on site; and
- formless materials – such as latex screeds – can avoid waste from cutting/fitting formed materials, such as vinyl tiles.

Contractors can also help reduce wastage allowances to good practice levels on major materials, by:

- requiring Just in Time (JIT) delivery;
- planning work sequences to minimise waste and re-work; and
- using 'take-back' schemes for material surpluses and offcuts.

WRAP's Designing out Waste guides provide further guidance on designing for waste-efficient procurement.

WRAP's Designing out Waste Guides for Buildings and Civil Engineering (www.wrap.org.uk/designingoutwaste)

Designing for reuse and deconstruction

Designers also need to consider future re-use and recyclability, which affects the embodied carbon of materials and products when assessed across their entire life-cycles. There are a number of factors to consider:

- deconstruction – that is, the ease with which buildings can be disassembled in future to enable key materials to be recovered for re-use and/or recycling;
- reconfiguration – the ease with which a building can be internally remodelled to meet changing needs; and
- reclamation and recycling – the extent to which material content can be reused, recycled into future materials/products, or 'downcycled' to lower-grade uses. This also applies to existing structures and materials arising from demolition, refurbishment and excavation.

In a 'cradle-to-gate' embodied carbon assessment (see footnote 2) the credit for potential savings on future projects through designing for reuse and deconstruction is not typically taken into account. Nonetheless, such an approach represents potentially significant savings in materials and embodied carbon when a longer term view is taken, and should not be ignored.

WRAP provides extensive guidance on options for materials reuse.

Using alternative materials

Using **alternative materials** that have intrinsically lower embodied carbon characteristics complements actions to use less materials. Care is needed to ensure that other factors such as technical performance, build cost and programme are not compromised.

Key strategies (not ranked in order) include using materials with:

- inherently lower energy/carbon intensity in production than their conventional equivalents (e.g. organic materials in place of highly processed materials);
- lower transport-related carbon emissions (shorter transport distances or more efficient delivery strategies – e.g. flat-packing);
- higher recycled content (or reclaimed products)[5]; and
- high levels of durability and relatively low through-life maintenance.

Examples of strategies for reducing embodied carbon using alternative materials in key building types are illustrated in the table on the following pages, showing the kind of savings that are possible without increasing construction cost.

Using materials with lower carbon intensities

There are a number of low embodied carbon building materials/products that can be substituted for higher embodied carbon equivalents.

Cement requires relatively high amounts of energy (and associated carbon emissions) in its production. Additionally, the chemical processes involved also generate carbon emissions. It is possible to substitute cement with less carbon-intensive materials such as **Pulverised Fuel Ash** (**PFA** – a by-product of coal burned in power stations) and **Ground Granulated Blastfurnace Slag** (**GGBS** – a by-product of steel production). PFA can replace up to 40% of cement in typical construction and engineering applications; GGBS can replace up to 80%.

Savings in embodied carbon can be significant from using these substitutes, especially where a range of construction elements contain cement – such as building structure, flooring, cladding, blockwork, mortar, etc. While these cement substitutes are normally cost effective, they do result in longer curing (hardening) times for concrete and cannot always be accommodated in situations where speed of construction is critical.

Likely embodied carbon savings for key building types

The tables on the following pages provide a summary of key approaches to saving embodied carbon in construction, together with an assessment of the potential for embodied carbon savings on four key building types.

The carbon-saving approaches are structured around the broad strategy of using alternative materials. Savings from reducing on-site construction waste by up to 50% are included, as are potential savings from using materials and products with higher-than-normal recycled content, where applicable. No account is taken of savings from broader strategies such as improving overall building efficiency or adopting high levels of off-site construction.

The assessments cover the following:

- a medium rise office building in an urban area;
- a large office fit-out in an urban area;
- a predominantly single-storey primary school; and
- a semi-detached house (part of an 80-dwelling development).

Alternative materials and products are assessed against a typical specification for the building type in question. These alternatives have lower embodied carbon values than those in the project specification and, for the examples shown, generally cost no more (and in some cases may cost less). Additionally, these alternatives have been selected as being generally acceptable in the relevant market sector. The alternatives assessed are not exhaustive, but represent what typically can be achieved in each building type.

Saving embodied carbon in construction: Selected strategies and typical examples

This table summarises some of the more promising materials strategies for reducing embodied carbon and shows their potential impact on a range of different building types.

Key material strategies:

Building materials/products	Reduce waste[a]	Use high recycled content[b]	Use low embodied carbon materials	Further issues to consider
Concrete incl. concrete products (blocks etc.)	Typically some 4%of in-situ concrete goes to waste on construction sites. Adopting good practice can reduce this to 2%.		(Material waste reduction will achieve commensurate reductions in embodied carbon.)	Important to ensure that reclaimed/recycled product is not transported over long distances, as this can increase embodied carbon.
Aggregate		Up to 100% of aggregate may be recycled for building and engineering applications, though its use may be restricted in specific applications.	Recycled aggregate can have lower embodied carbon than virgin aggregate especially when transport distances are low.	
Cement			PFA can replace up to 40% of cement in many applications; GGBS can replace up to 80% of cement.	
Bricks	Typically up to 20% of bricks delivered to construction sites are not used due mainly to over-ordering and poor handling (resulting in damage). Adopting good practice can reduce wastage to 10%.	Existing bricks may be reclaimed and reused, provided bricks are generally sound and can be cleaned effectively (lime-based mortar is easier to remove than cement-based). Concrete blocks can contain up to 90% recycled content.	Use of reclaimed bricks will avoid the embodied carbon associated with new bricks.	Important to ensure that reclaimed/recycled product is not transported over long distances, as this can increase embodied carbon.
Metals	Metals used in construction vary considerably. Typically, some 10% of reinforcement steel, for example, goes to waste on construction sites. Good practice can reduce this to some 5%.	A good deal of steel used in construction has recycled content. Recovery rates from demolition sites in the UK have improved in recent years, and are 99% for structural steelwork and 94% for all steel construction products.		Anti-corrosion metals (aluminium, stainless steel) may have a high embodied carbon per kilogram but corrosion resistance means that carbon-intensive coatings (such as paint) may be avoided throughout the life of the product. Metals have a long lifetime, are durable and can easily be recovered for recycling.
Timber	Timber waste in construction varies considerably; typically, some 10% of sawn timber goes to waste. Adopting good practice can reduce this to 5%.	Timber and timber products (e.g. windows, doors) can sometimes be reclaimed and reused.	Use of reclaimed timber will avoid the embodied carbon associated with new timber. Timber can be a low embodied carbon alternative to: • steel and concrete in (low-rise) structures • steel and aluminium in framing and cladding (e.g. for windows & doors).	Important to ensure that reclaimed/recycled product is not transported over long distances, as this can increase embodied carbon.
Other bio-renewable materials			A range of organic and bio-renewable materials are available in construction having low embodied carbon compared to their more highly processed/synthetic equivalents, for example: • sheep's wool in place of mineral fibre or synthetic insulation • hemp-based blocks or in-situ Hemcrete in place of concrete blocks/bricks • bamboo in place of certain hardwoods, though transport-related emissions may increase embodied carbon • natural rubber in place of vinyl • straw bale construction in place of concrete blocks/bricks in some applications.	
Finishes, incl. paints etc.	A range of finishing materials are typically used in construction, and are subject to high wastage rates, including: • Plasterboard c 23%; good practice can reduce this to 15%	Plasterboard is available with a range of recycled content – from 45% to 95%.	Use of plasterboard with relatively high levels of recycled content will help reduce embodied carbon.	Important to ensure that reclaimed/recycled product is not transported over long distances, as this can increase embodied carbon.
	• Plaster c 5%; good practice can reduce this to 2.5%			
	• Carpet c.20%; good practice can reduce this to 10%.	Carpet is available with a range of recycled content – up to 25%.	Use of carpet with relatively high levels of recycled content will help reduce embodied carbon. Natural linoleum has lower embodied carbon than vinyl flooring.	

a Waste data derived from WRAP Net Waste Tool – see www.wrap.org.uk/nwtool

b Recycled content data derived from WRAP Net Waste Tool.

Possible carbon savings in key buildings/project types

Building element	Office			Office fit-out			School			House		
	Embodied carbon (kgs CO_2e/m^2)	Carbon reduction action	% saving on total building	Embodied carbon (kgs CO_2e/m^2)	Carbon reduction action	% saving on total building	Embodied carbon (kgs CO_2e/m^2)	Carbon reduction action	% saving on total building	Embodied carbon (kgs CO_2e/m^2)	Carbon reduction action	% saving on total building
Foundations	**202**	PFA increased from norm of 20% to 40% rather than Ordinary Portland Cement (in insitu concrete only) in foundations. Blockwork instead of brickwork in foundations	**c.1%**				**120**	PFA increased from norm to 20% to 40% rather than Ordinary Portland Cement (in insitu concrete only)	**<1%**	**135**	Use 40%PFA in insitu concrete	**4%**
Frames	**227**	PFA rather than 20% Ordinary Portland Cement in core walls	**c.1%**				**56**	Timber frame rather than steel frame	**5%**			
Upper floors	**87**	PFA rather than 20% of Ordinary Portland Cement in concrete floors	**<1%**	50						**10**	Use PFA in preset	**<1%**
Roof	**21**						**80**	Flat green roof (26% sedum) instead of clay title pitched roof Concrete tile roof instead of clay tiled pitched roof Alternative: composite steel panel system instead of clay roof tiles Alternative: aluminium standing seam roof system instead of clay tiled pitched roof	**1%** **2%** **-1%** **-6%**	**40**	Use concrete roof tiles in place of clay	**3%**
Ext walls	**285**	Rainscreen cladding with terracotta facing rather than aluminium framed curtain walling (Alternative: use of recycled opaque stone effect glass)	**8%** **4%**				**215**	Timber laminated walls rather than masonry construction Alternative: timber laminated walls rather than masonry construction using recycled bricks	**6%** **1%**	**135**	Reclaimed brick in external walls; use PFA in blocks Increase PFA in blocks	**12%** **1%**
Windows and ext doors	Incl. in ext walls	Aluminium-clad timber windows rather than aluminium framed double glazing curtain walling	**8%**				**80**			**43**	Aluminium-clad timber windows rather than uPVC framed double glazed	**1%**
Internal walls	**20**	Use timber framework instead of steel framework in stud partitions Use of natural wool instead of mineral wool in 10% of all stud partitions	**<1%** **<1%**	**7**	Use timber framework instead of steel framework in stud partitions Use of natural wool instead of mineral wool in insulated (8% of) partitions	**1%** **C1%**	**60**	Cross-laminated timber load-bearing walls, rather than 215mm blockwork walls, with emulsion paint	**5%**	**13**		
Internal doors	**3**			3			**3**			**4**		
Internal finishes	**95**	Linoleum flooring instead of vinyl Ceiling with substantial recycled content (>50% of all stud partitions) (provisional assessment)	**<1%** **<1%**	**45**	Linoleum flooring instead of vinyl Ceiling with substantial recycled content (>50%) (provisional assessment)	**<1%** **1%**	**110**	Natural rubber flooring rather than vinyl Wool acoustic insulation rather than mineral wool	**<1%** **<1%**	**55**		
M&E services	**132**			**40**			**76**			**40**		
Fittings & furnishings				**45**			**10**					
Ext works	**32**	PFA rather than 20% Ordinary Portland Cement	**2%**							**125**	Use 50% Recycled Asphalt Planing instead of a 100% virgin asphalt road	**<1%**
Waste		Carbon savings from a 50% reduction in materials wastage on site. Top 5 materials/products: ■ raised floors ■ ceilings ■ framework to partitions and other plasterboard finishes ■ free pour concrete in foundations ■ plasterboard	**2%**		Carbon savings from a 50% reduction in materials wastage on site	**1%**		Carbon savings from a 50% reduction in materials wastage on site. Top 5 materials/products: ■ plasterboard ■ concrete blocks ■ flat felt roof ■ electrical goods ■ carpet	2%		Carbon savings from a 50% reduction in materials wastage on site. Top 5 materials/products: ■ bricks ■ concrete blocks ■ free pour concrete ■ insulation ■ softwood timber	**6%**
Notes					Reuse of materials in the fit-out of an existing office could account for up to 10% of total embodied carbon	**C10%**						
Totals	**1104**		**22%**	**190**		**6%**	**810**		**20%**	**600**		**25%**

Timber is a highly versatile organic material with relatively low embodied carbon (provided it is sustainably sourced[6]). It can be used in a range of structural and non-structural applications in construction. It can be a viable structural alternative to steel and/or concrete in low-rise buildings, with significantly lower embodied carbon than these alternatives.

Glulam timber beams

The use of **timber** in other applications (for example, as an alternative to aluminium or PVC-U in window framing) can also have significantly lower embodied carbon than these materials. Other significant applications for timber resulting in embodied carbon savings compared to more conventional materials include:

- external cladding, as a finishing material – for example, cedar boarding – in place of steel, aluminium or glass cladding, for example;
- internal partitions, as a framing material, in place of steel; and
- internal doors (wood-finished), in place of melamine-faced doors, for example.

Generally, timber-finished products – particularly used externally such as cladding, windows and external doors – require more regular maintenance in terms of treatment/painting than metal, glass or plastic alternatives. Hybrid products are available – such as aluminium covered timber framed windows, for example – that provide some of the embodied carbon benefits of timber with some of the durability and low-maintenance characteristics of some metals.

Other **natural materials** having relatively low embodied carbon compared with their conventional alternatives include:

- natural wool for use as an insulant, compared with mineral fibre and synthetic foam products;
- bamboo, in place of certain hardwoods (e.g. for flooring systems);
- water-based paint providing a lower embodied carbon alternative to solvent-based paint for some applications; and
- hemp and straw-based products, in place of conventional concrete blocks in some applications.

Using materials with lower transport-related carbon emissions

The contribution of transport activities to the embodied carbon of materials and products vary widely. For manufactured products and materials with relatively high embodied carbon per kilogram (metals and bricks, for example), a relatively small proportion is due to transport. Bulk materials with relatively low embodied carbon per kilogram (for example, sand and aggregate) can have a high proportion due to transport.

Reducing transport distance alone is not always enough to reduce embodied carbon. The mode of transport is important. Transport by road is far more carbon intensive than transport by rail. Transport by rail is more carbon intensive than transport by sea.

Carbon emissions for different modes of transport

Mode	Indexed to Bulk Shipping = 1
Air - Short-haul international	466
Road - Average of all HGVs	37
Rail	9
Shipping - Container	5
Shipping - Bulk carrier	1

Source: DEFRA

Using products with higher recycled content and reclaimed products

Products with a higher recycled content tend generally to have lower embodied carbon than their equivalents with low (or zero) recycled content. In many cases these products cost no more – and can cost less – than what is typically supplied.

For many projects it is relatively easy to exceed 15-20% average recycled content. An even higher proportion is achievable for infrastructure projects.

Key materials/products for which readily available alternatives exist having higher than typical levels of recycled content include:

- concrete;
- bricks and blocks;
- plasterboard;
- floor coverings;
- aggregate;
- asphalt;
- pavers;
- roof tiles;
- thermal insulation; and
- wood-based boards.

Many important materials and products reclaimed from the stripping-out and/or demolition of existing buildings can be re-used. As reclamation processes are generally considerably less carbon-intensive than manufacturing processes, the use of reclaimed products can represent significant embodied carbon savings. Reclaimed materials/products can include:

- bricks and blocks;
- floor coverings;
- timber and timber products (e.g. windows and doors);
- pavers;
- roof tiles; and
- some finishes (e.g. suspended ceiling grids and tiles).

Using materials with high levels of durability and low through-life maintenance

Conventional measures of embodied carbon in construction typically adopt a 'cradle-to-gate' (or cradle-to-site) approach. However, this ignores the impact of material/product maintenance and replacement throughout the life of the building (or asset). Durable, long-life materials requiring low maintenance – even those having relatively high initial embodied carbon – can have lower embodied carbon over the whole life-cycle than less durable alternatives.

It is important, therefore, to consider the through-life embodied carbon of materials and products, taking account of emissions associated with maintenance and replacement over time as well as their initial production and delivery. Situations where this is important include, for example, buildings where the expected life is particularly long, as well as building elements where access for future maintenance and replacement will be particularly difficult and costly (e.g. high-rise buildings).

Examples of durable, relatively low-maintenance building materials/products include:

- aluminium facades – note that harsh environments such as coastal areas can cause deterioration of powder coating;
- glass block walls;
- ceramic or stone floor finishes;
- stainless steel ironmongery;
- bricks; and
- clay or concrete roof tiles.

Alternative materials with lower embodied carbon, especially natural materials such as timber, may require regular maintenance, repainting and so on and this will increase embodied carbon (though will also prolong the product life).

Outline process for reducing embodied carbon in construction

Using less material in construction and using alternative materials with low embodied carbon can be combined into an effective design strategy for carbon reduction. Clients, designers and contractors need to consider this from the earliest stages. The main actions required at key design stages are shown below.

RIBA Design Stage

Consider efficiency of overall building form; compactness helps reduce embodied carbon.

Consider simple repetitive structural solutions; consider low-embodied carbon materials; consider potential for off-site construction.

Consider designing-out waste strategies; investigate alternative materials; model impact on embodied carbon.

Specify low embodied carbon materials; ensure plans in place for effective site waste management and waste reduction.

Monitor/evaluate on-site construction to ensure material efficiency and effective waste management.

Reducing embodied carbon is a viable and worthwhile carbon-reduction strategy, and significant savings are achievable at no additional capital cost and with little additional design effort. It should be borne in mind, however, that major design decisions (such as the choice of structural frame) can be driven by a complex range of statutory, user and commercial factors and will not be determined primarily by embodied carbon considerations.

Further information

Methodology and data sources

In simple terms, assessing the embodied carbon of construction materials and products requires two key pieces of data:

- the mass of the material (or for composite products such as reinforced concrete, the mass of each constituent material – cement, sand, aggregate, water and reinforcing steel); and
- the embodied carbon per kg of the material (i.e. the emissions associated with raw material extraction, transportation, processing/manufacture, construction and, if appropriate, maintenance, replacement and disposal [see footnote 2]).

Carbon savings from individual design changes are calculated by multiplying a change in materials quantity by a carbon emissions factor, or multiplying a materials quantity by a change in carbon emissions factors. Emission factors can be taken from published or commercially available datasets, and material quantities can be derived from cost plan data or a bill of quantities. Figures should be reported in kg CO_2e if possible, in line with international reporting standards, but where this is not possible, reporting may be in kg CO_2.

Embodied carbon values for the data quoted in this guide were taken from the latest Inventory of Carbon and Energy (ICE)[7].

Interpretation

Embodied carbon factors commonly express values in terms of unit of mass (i.e. $kgCO_2e$ per kg of material). It is not always helpful to compare different materials (say steel and timber) directly in these terms, as the mass of each material required to perform a given function varies considerably. It is more helpful to compare the embodied carbon of different building materials/products in terms of the functions they perform – as in the main tables in this guide which show the embodied carbon of different building elements (e.g. floors, roofs) which perform a particular function.

This guide was written by John Connaughton and David Weight of Davis Langdon, Craig Jones of Sustain and David Moon of WRAP.

Footnotes and references

[1] In this guide, 'carbon' refers to the impact of all major GHG emissions expressed as carbon dioxide equivalent (CO_2e)

[2] The carbon emissions presented in this guide are calculated on a 'Cradle to Gate' basis (i.e. from raw material extraction through to leaving the factory 'gate'). Emissions arising due to transport to site, assembly as well as subsequent maintenance, replacement and disposal are not included, but are discussed in this guide.

[3] See for example the RICS report *Redefining zero* (May 2010).

[4] Guides on designing out waste in building and infrastructure projects are available at www.wrap.org.uk/construction. Waste estimation tools include the Designing out Waste Tools and the Net Waste Tool.

[5] WRAP's Net Waste Tool provides data on recycled content for a range of building materials/products and helps identify approaches to waste reduction – www.wrap.org.uk/nwtool

[6] Estimates of the embodied CO_2e of timber in this guide assume that timber comes from sustainably managed forests in line with the Central Point of Expertise on Timber (CPET - see http://www.proforest.net/cpet) guidelines. This means that timber can be attributed with the benefit of CO_2 sequestration. CPET includes the Forestry Stewardship Council (FSC) as an approved scheme.

[7] Hammond, G and Jones, C (2011*) Embodied Carbon: The Inventory of Carbon and Energy (ICE).* A BSRIA Guide, BSRIA, Bracknell.

Waste & Resources Action Programme

The Old Academy
21 Horse Fair
Banbury, Oxon
OX16 0AH

Tel: 01295 819 900
Fax: 01295 819 911
E-mail: info@wrap.org.uk

Helpline freephone
0808 100 2040

www.wrap.org.uk/construction

recycle