TARGET ZERO®

GUIDANCE ON THE DESIGN AND CONSTRUCTION OF SUSTAINABLE, LOW CARBON OFFICE BUILDINGS

REPORT **V2.0 JANUARY 2012**

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Tata Steel is one of the world's top ten steel producers. The combined group has an aggregate crude steel capacity of more than 28 million tonnes and approximately 80,000 employees across four continents.

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The British Constructional Steelwork Association Limited (BCSA) is the national organisation for the steel construction industry. Member companies undertake the design, fabrication and erection of steelwork for all forms of construction in buildings and civil engineering. Associate Members are those principal companies involved in the direct supply to all or some Members of components, materials or products.

The principal objectives of the association are to promote the use of structural steelwork, to assist specifiers and clients, to ensure that the capabilities and activities of the industry are widely understood and to provide members with professional services in technical, commercial, contractual, quality assurance and health & safety matters.

www.steelconstruction.org

AECOM, the global provider of professional technical and management support services to a broad range of markets; including transportation, facilities, environmental and energy, is project managing the Target Zero initiative.

It is leading on the structural, operational energy and BREEAM elements of the project. AECOM is investigating how operational energy use can be reduced through good design and specification of low and zero carbon technologies. It is also applying BREEAM to each of the solutions and advising how 'Very Good', 'Excellent', and 'Outstanding' BREEAM ratings can be achieved at the lowest cost.

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Cyril Sweett is an international construction and property consultancy offering expertise in quantity surveying, project management and management consultancy.

Our wide knowledge of the costs and benefits of sustainable design and construction, combined with expertise in strategic and practical delivery enables us to develop commercial robust solutions.

In Target Zero, Cyril Sweett is working closely with AECOM to provide fully costed solutions for all aspects of the project, and analysis of the optimum routes to BREEAM compliance.

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SCI
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SCI (The Steel Construction Institute) is the leading, independent provider of technical expertise and disseminator of best practice to the steel construction sector. We work in partnership with clients, members and industry peers to help build businesses and provide competitive advantage through the commercial application of our knowledge. We are committed to offering and promoting sustainable and environmentally responsible solutions.

The SCI is supporting AECOM with the operational energy and BREEAM work packages and is responsible for developing design guidance based on the research.

www.steel-sci.org

Development Securities PLC is a property development and investment company. Its principal objective is to carry out substantial, complex developments in a risk averse manner with a view to adding maximum value for its shareholders. The Company's major schemes under development have been forward funded, or the financial risk shared with a number of different institutional partners; such funding, quite apart from the significant reduction of downside risk to us, enables Development Securities to benefit in a material way from any strong improvement in specific letting markets.

Both the development and investment businesses are focused in the United Kingdom.

8.0 ROUTES TO BREEAM 'OUTSTANDING'

ROUTES TO BREEAM 'OUTSTANDING'

The objective of this aspect of the study was to determine the most cost-effective routes to achieving a 'Very Good', 'Excellent' and 'Outstanding' BREEAM Office (2008) rating for the base case building modelled on One Kingdom Street, Paddington, London.

To provide a benchmark for the BREEAM assessment, a base case building was defined as described in Section 5.1 and using the following four principles:

1. **If there is a regulatory requirement for building design that is relevant, then this was used for the base case, e.g. Building Regulations Part L 2006 provided a minimum requirement for the operational energy performance of the building.**
2. **If it is typical practice for an office building, then this was used for the base case, e.g. the average score under the Considerate Constructors scheme at the time of writing was 32, therefore, it was assumed that this is standard practice for contractors.**
3. **For design specific issues, such as materials choices, then the current specification for One Kingdom Street was applied as the base case.**
4. **Where a study is required to demonstrate that a credit is achieved, e.g. day lighting and thermal comfort for the office areas, and the required standards were achieved, then only the cost of the study has been included. Where a study determines that the required standard was not achieved, e.g. View Out, then a cost for achieving the credit has not been included as this would require a fundamental redesign of the building. The credits that are based on fundamental design decisions are identified in the guidance.**

Reflecting the influence of design and other factors on the achievable BREEAM score, three scenarios were modelled with different design assumptions as follows[1]:

- **two scenarios relating to early design decisions and contractor performance: poor approach and best approach – see Table 6**
- **one scenario related to the approach to achieving low operational carbon emissions, with (small) wind turbines being viable on the site.**

The key inputs for these three scenarios and the base case office building are set out in Table 6. Although several of the assumptions do not vary under the different scenarios considered, they are shown for consistency with the other Target Zero guides and also serve to illustrate the limitations posed on city centre commercial buildings, for example in terms of site ecological value, LZC technology viability, etc.

ONE KINGDOM STREET ENTRANCE

1 The number of BREEAM scenarios considered is less than for other building types considered under Target Zero and reflects the limitations concerning site selection and LZC technologies for large office buildings.

TABLE 6
KEY ASSUMPTIONS FOR THE THREE BREEAM ASSESSMENT SCENARIOS AND THE CASE STUDY BUILDING

ASSUMPTION	CASE STUDY	APPPROACH TO DESIGN		ZERO CARBON TARGET
		Best approach to design	Poor approach to design	Approach to zero carbon (wind viable)
Biomass feasible	No	No	No	No
Public transport links	Excellent	Excellent	Excellent	Excellent
Within 500m of shop, post box and cash machine?	Yes	Yes	Yes	Yes
Has ≥ 75% of the site been developed in the last 50 years?	Yes	Yes	Yes	Yes
Ecological value	Low	Low	Low	Low
Low/Zero carbon pursued?	No	No	No	Yes
Type of contractor	Best practice	Exemplar practice	Poor practice	Best practice
Potential for natural ventilation	Yes	Yes	No	Yes
Indoor air quality[1]	1	1	2	1
On-site wind viable?[2]	Yes	Yes	Yes	Yes
Design best practice followed?	Yes	Yes	No	Yes
Compliant recycled Aggregates to be used	Yes	Yes	Yes	Yes
Exemplar daylighting	No	Yes	No	No
Exemplar energy performance	No	Yes	No	No
Exemplar materials specification	No	Yes	No	No
Emerging technologies feasible	Yes	Yes	Yes	Yes

[1] 1= Natural ventilation opening ›10m from opening; 2 = Air intake/extracts ‹10m apart; [2] 6kW roof mounted turbine only

The case study scenario was based on the actual location, site conditions, etc. of the One Kingdom Street office building and is used as the basis for the comparison of the above three scenarios.

Each BREEAM credit was reviewed to determine the additional work that would be required to take the building design beyond the base case office building to achieve the targeted BREEAM ratings.
The costing exercise identified six different types of credits:

1. **Mandatory credits – see Tables 7 and 8**
2. **Credits that are achieved in the base case and so incur no additional cost. These credits should be achieved as part of legislative compliance or as part of 'typical practice'.**
3. **Credits that are entirely dependent on the site conditions, e.g. remediation of contaminated land, and so may or may not be achieved and, in some cases, may incur additional cost.**
4. **Credits that have to be designed in at the start of the project and therefore have no additional cost, e.g. Hea 1: Daylighting Levels and Hea 2: View Out. If they are not designed in at the start of the project, then these credits cannot be obtained later in the design process.**
5. **Credits that require a study or calculation to be undertaken which may incur an additional cost, but may not achieve the credit if the design does not comply, e.g. Hea 13 Acoustic performance.**
6. **Credits that only require a professional fee or incur an administrative fee to achieve, but do not then incur a capital cost on the project, e.g. Man 4 building user guide.**

All the credits that required additional work to achieve were assigned a capital cost with input from specialists and cost consultants with experience of office building projects. Credits were then assigned a 'weighted value' by dividing the capital cost of achieving the credit, by its credit weighting[1], and the credits ranked in order of descending cost effectiveness. These rankings were then used to define the most cost-effective routes to achieving 'Very Good', 'Excellent' and 'Outstanding' BREEAM ratings for each of the proposed scenarios.

1 Within BREEAM, credits in different sections of the assessment, e.g. energy, materials, etc. are given different weightings.

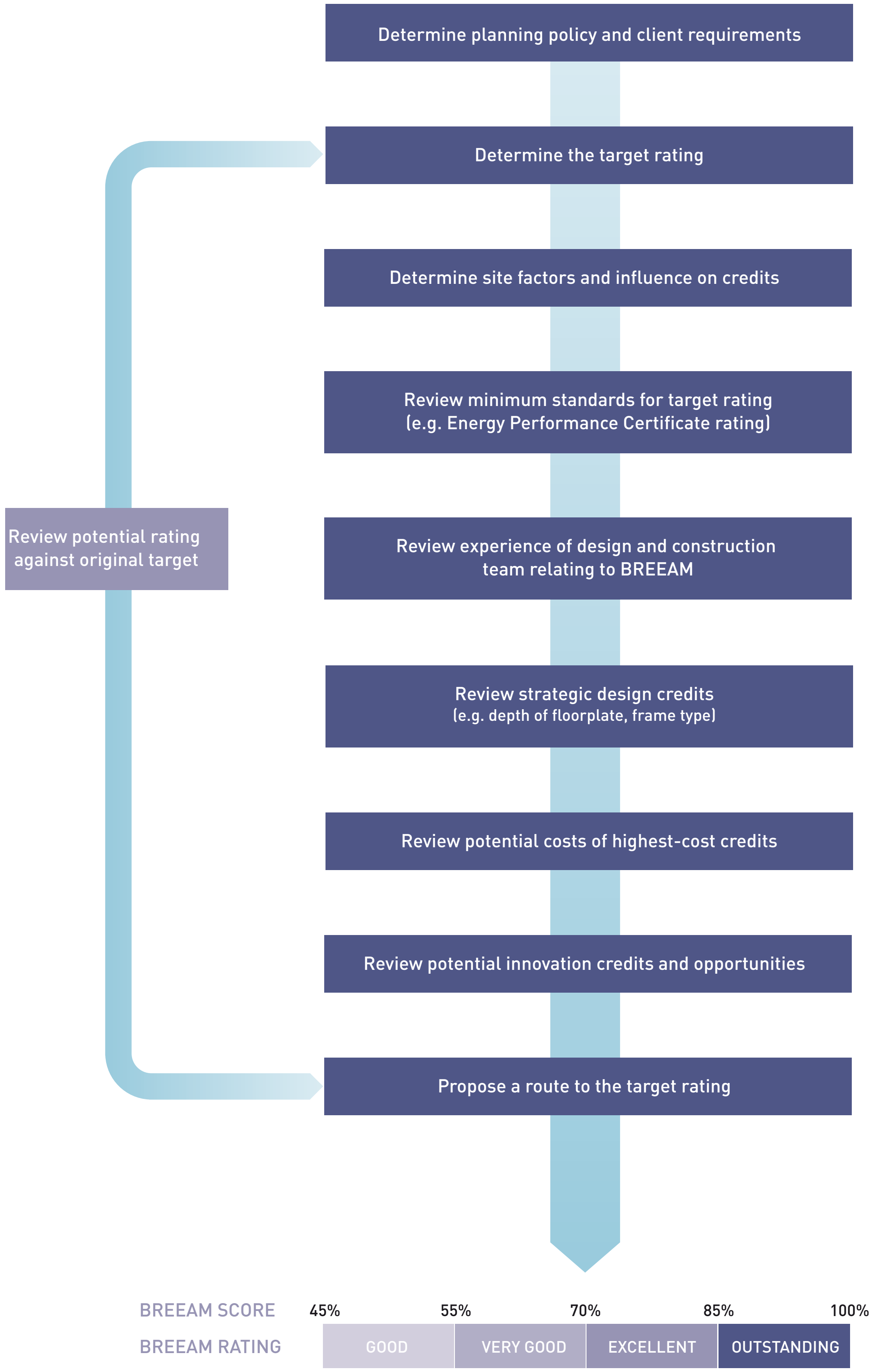
RECOMMENDATION

BREEAM is a useful assessment method to identify ways that the environmental performance of a building can be improved. It is also a useful benchmarking tool which allows comparison between different buildings. However, the overall purpose of a building is to meet the occupants' requirements. Therefore, project teams should aim to develop holistic solutions based on some of the principles of BREEAM rather than rigidly complying with the credit criteria. The benefits and consequences of the various solutions should be carefully considered to avoid counter-productive outcomes that can be driven by any simple assessment tool if applied too literally and without question.

8.1 RESULTS AND GUIDANCE

Figure 14 sets out a flowchart providing guidance on how to develop a cost-effective route to a target BREEAM rating. Guidance on the steps presented in the flowchart is given below.

FIGURE 14
BREEAM GUIDANCE FLOWCHART



THE TARGET RATING

The target BREEAM rating that is required for the project will depend on:

- **the requirements in the brief**
- **any targets set as a condition of funding**
- **the local planning policies, which sometimes include targets for BREEAM ratings.**

RECOMMENDATION

The project team should review the opportunities and constraints of the site against the BREEAM criteria as a prelude to setting out a route to the required target rating.

MINIMUM STANDARDS FOR BREEAM RATINGS

The minimum standards required to achieve BREEAM 'Very Good', 'Excellent' and 'Outstanding' ratings are shown in Table 7.

TABLE 7
MINIMUM BREEAM REQUIREMENTS

BREEAM CREDIT	MINIMUM STANDARDS FOR VERY GOOD	MINIMUM STANDARDS FOR EXCELLENT	MINIMUM STANDARDS FOR OUTSTANDING
Man 1 Commisioning	1	1	2
Man 2 Considerate Constructors	-	1	2
Man 4 Building user guide	-	1	1
Hea 4 High frequency lighting	1	1	1
Hea 12 Microbial contamination	1	1	1
Ene 1 Reduction in CO_2 emissions	-	6	10
Ene 2 Sub-metering of substantial energy uses	1	1	1
Ene 5 Low or zero carbon technologies	-	1	1
Wat 1 Water consumption	1	1	2
Wat 2 Water meter	1	1	1
Wst 3 Storage of recyclable waste	-	1	1
LE 4 Mitigating ecological impact	1	1	1

The majority of these 'mandatory credits' are relatively simple and cost-effective to achieve, with the exception of the Ene1 credits, which can be more costly and difficult to achieve for the 'Outstanding' rating, as shown in Table 8 which gives the estimated costs to achieve the mandatory credits shown in Table 7.

TABLE 8
COST OF ACHIEVING MINIMUM BREEAM REQUIREMENTS

BREEAM CREDIT	CAPITAL COSTS FOR VERY GOOD [£]	CAPITAL COSTS FOR EXCELLENT [£]	CAPITAL COSTS FOR OUTSTANDING [£]
Man 1 Commisioning	0	0	25,000
Man 2 Considerate Constructors	-	0	0
Man 4 Building user guide	-	5,000	5,000
Hea 4 High frequency lighting	0	0	0
Hea 12 Microbial contamination	0	0	0
Ene 1 Reduction in CO_2 emissions	-	£172,400[1]	£1,532,000[2]
Ene 2 Sub-metering of substantial energy uses	16,000	16,000	16,000
Ene 5 Low or zero carbon technologies	-	Costs included in Ene 1 above	Costs included in Ene 1 above
Wat 1 Water consumption	27,000	27,000	34,000
Wat 2 Water meter	0	0	0
Wst 3 Storage of recyclable waste	-	0	0
LE 4 Mitigating ecological impact	0	0	0

1 Based on Energy Efficiency Package A see Table 1.
2 Based on Energy Efficiency Package A plus a small fuel-cell CHP. Note that this package of measures achieves the minimum mandatory Ene 1 credits for an 'Outstanding' rating but is not sufficient to achieve the overall BREEAM score necessary for an 'Outstanding' rating.

CREDITS ASSOCIATED WITH THE EXPERIENCE OF THE DESIGN AND CONSTRUCTION TEAM

The experience of the design team in delivering BREEAM-rated buildings and their early involvement in the design process is important to achieve high BREEAM ratings cost effectively. By doing so, the requirements of many BREEAM credits can be integrated into the fundamental design of the building.

Design teams that have worked on other BREEAM projects are more likely to have specifications that are aligned with the credit requirements and will have template reports for the additional studies that are required under BREEAM, e.g. lift efficiency studies. Project managers who are experienced in delivering BREEAM targets are more likely to raise issues relating to additional expertise that may be required, such as input from ecologists. Equally, quantity surveyors will have previous cost data relating to achieving BREEAM credits.

Contractors who have delivered BREEAM Post-Construction Reviews will have set up the required systems and processes to do this efficiently. This will help to achieve the Construction Site Impact credits (Man 3) (monitoring energy, water and waste on-site) and the Responsible Sourcing credits (Mat 5), as well as being able to monitor the procurement of materials and equipment that complies with the credit requirements.

In this study, the credits related directly to the contractor's experience were costed, as shown in Table 9. It was assumed that an 'exemplar' contractor would be able to achieve all of these credits, which are all relatively low cost.

RECOMMENDATION

The project team's experience in delivering BREEAM ratings should be included in the criteria for selecting the design team and the consultants' briefs and contractor tender documents should include requirements to deliver the required rating.

TABLE 9

BREEAM CREDITS (AND COSTS) RELATING TO CONTRACTOR'S EXPERIENCE

BREEAM CREDIT	CREDIT NUMBER	CAPITAL COST (£)
Man 2 Considerate Constructors	First credit	0
	Second credit	0
Man 3 Construction Site Impacts	First credit	5,000
	Second credit	10,000
	Third credit	15,000
	Fourth credit	0
Wst 1 Construction Site Waste Management	First credit	0
	Second credit	0
	Third credit	0
	Fourth credit	0
Mat 5 Responsible Sourcing of Materials	First credit	0
	Second credit	0
	Third credit	0

CREDITS ASSOCIATED WITH STRATEGIC DESIGN

Early design decisions about the fabric and form of the building will have an impact on the following BREEAM credits:

- **Hea 1: Day lighting, in terms of depth of floor plate of the office and glazing area**
- **Hea 2: View Out, in terms of depth of floor plate of the office**
- **Hea 7: Potential for natural ventilation, in terms of the depth of floor plate and whether the occupied areas have been designed for natural ventilation. An occupied area is defined as a room or space in the building that is likely to be occupied for 30 minutes or more by a building user**
- **Hea 8: Indoor air quality, in terms of avoiding air pollutants entering the building**
- **Hea 13: Acoustic performance, which includes the performance of the façade**
- **Pol 5: Flood risk, assuming that the building has been designed to comply with Planning Policy Statement 25 and sustainable urban drainage systems (SUDS) have been included in the design.**

Figure 15 shows a comparison between the credits required under typical 'best practice' and 'poor' approaches to design. It illustrates the balance of credits required to achieve a BREEAM 'Outstanding' rating most cost effectively under the typical 'best' and 'poor' approaches assumed for the office building. It is noted that under the 'poor approach' scenario, it is not possible to achieve an 'Outstanding' rating for the case study building.

FIGURE 15
COMPARISON OF 'APPROACH TO DESIGN' SCENARIOS TO ACHIEVE A BREEAM OUTSTANDING RATING

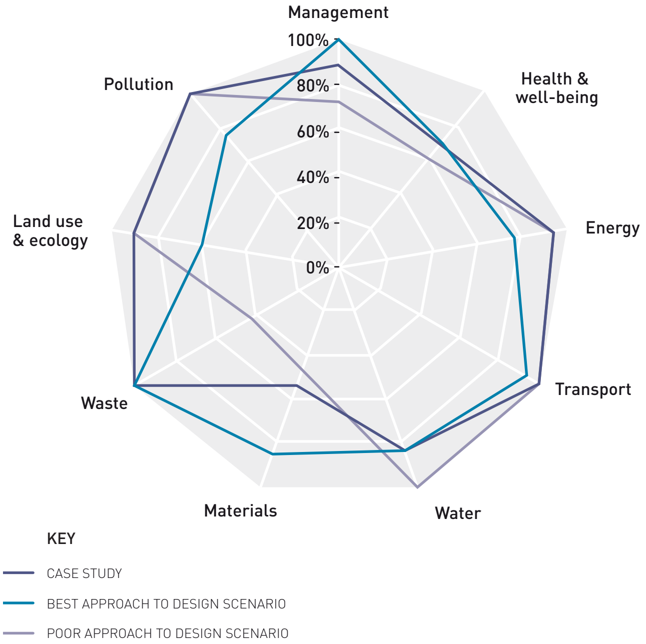
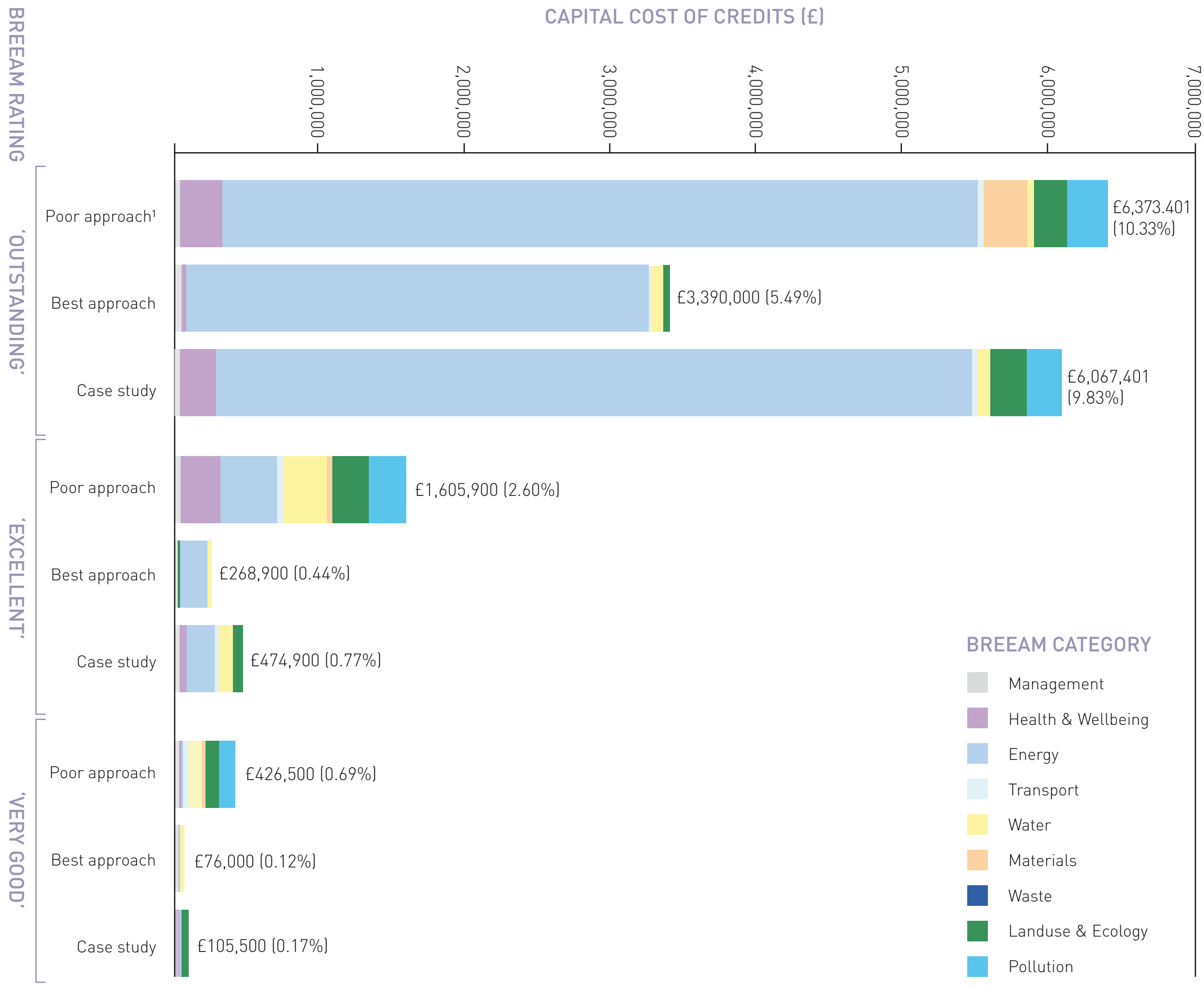


Figure 15 shows that a 'poor approach to design' implies that less credits are achievable in the Management, Health and Wellbeing, Materials and Waste sections and consequently that more credits have to be achieved in other sections: the Energy, Transport, Water, Land Use and Ecology and Pollution sections. Credits in these sections are more costly to achieve than those achieved through the 'best approach to design' scenario.

8.0 ROUTES TO BREEAM 'OUTSTANDING'

The total capital cost uplift of the two 'design approach' scenarios considered is shown in Figure 16.

FIGURE 16
COMPARISON OF COST UPLIFT FOR DIFFERENT APPROACHES TO DESIGN SCENARIOS



[1] Under the 'poor approach' to design scenario it is not possible to achieve an 'Outstanding' rating; this scenario only achieving a score of 78%

For the case study building analysed, the results show that to achieve an 'Excellent' rating there is a cost uplift of 2.6% for a poor approach to design compared to 0.4% for a building to which a best approach is applied. In terms of capital cost, this is a saving of £1,337,000.

To achieve an 'Outstanding' rating, a best practice design approach has to be taken. This incurs marginal capital cost of £3,390,000 (5.5%). Applying a poor approach to design, it was only possible to achieve a BREEAM score of 78%, falling short of the 85% threshold for achieving an 'Outstanding' rating, at a marginal capital cost of £6,373,401 (10.3%). Under this scenario, there are insufficient credits available due to the assumptions made based on site constraints and contractor performance and, in this case, the deficit could not be met by improving the operational energy performance.

Table 10 shows the credits that relate to the form and fabric of the building. These should be considered at an early stage in the project so that they can be cost effectively integrated into the design.

8.0 ROUTES TO BREEAM 'OUTSTANDING'

TABLE 10
BREEAM CREDITS RELATING TO THE FORM AND FABRIC OF THE BUILDING

CREDIT TITLE AND REFERENCE	COMMENTS ON POTENTIAL TO ACHIEVE CREDITS	CAPITAL COST (£)
Hea 1 Daylighting	Daylighting factors of at least 2% are easier to achieve with shallow floor office areas, this needs to be considered when deciding the depth and orientation of the office areas to ensure at least 80% of the floor area meets the criteria.	3,000 (to undertake daylighting study)
Hea 2 View Out	This credit needs desks in the office areas to be within 7m of a window which needs to be considered when deciding the depth of the floor plates	0
Hea 7 Potential for Natural Ventilation	Openable windows equivalent to at least 5% of the floor area in the office area or a ventilation strategy providing adequate cross flow of air for office areas.	2,050,000
Ene 1 Reduction of CO_2 emissions	Fabric performance in terms of: air tightness (3m³/hr per m² @ 50Pa); Vertically reduced glazing by 2m; Improved lighting efficiency to 1.5W/m² per 100lux with daylight dimming and occupancy sensing lighting controls; Improved wall insulation to 0.25W/m²K.	Cost varies depending on energy package: £172,400 for Excellent and £4,939,900.56 for Outstanding for case study scenario.

To achieve the Hea credits in Table 10, a narrow floor plate in the office areas would have to be used to allow desks to be less than 7m from a window and to allow cross-flow ventilation. The approach to ventilation and cooling would have to be integrated with the structural and building services design.

The trade-off between increasing glazing for more daylight and reducing glazing to improve energy performance is an important balance and needs to be investigated to ensure the most cost-effective route is taken.

Table 11 gives the credits that relate specifically to the space allocation, adjacencies and to the layout of the building and associated landscape:

TABLE 11
BREEAM CREDITS RELATING TO THE SPACE AND LAYOUT OF THE BUILDING AND ITS SITE

CREDIT TITLE AND REFERENCE	COMMENTS ON POTENTIAL TO ACHIEVE CREDITS	CAPITAL COST (£)
Wst 3 Storage space for recyclables	Central facilities for the storage of the building's recyclable waste streams will need to be provided in a dedicated space. This will need to store at least 6 waste streams and with good vehicular access to facilitate collections.	0
Tra 3 Cyclists facilities	Secure, covered cycle racks have to be provided for 10% of full time equivalent staff and the equivalent of 1 rack per 20 car parking spaces for customers. There also needs to be showers, changing facilities and lockers along with drying space for staff use.	1st credit 0 2nd credit 20,000
Tra 4 Pedestrians and cyclists Safety	Site layout has to be designed to ensure safe and adequate cycle access away from delivery routes and suitable lighting has to be provided.	10,000
LE 4 Mitigating ecological impact	Some ecological credits can be obtained through retaining and enhancing ecological features, which may have a spatial impact.	Low ecological value 0 for both credits Medium/high ecological value 1st credit 0 2nd credit 50,000
LE 5 Enhancing site ecology	Further enhancing the site ecological value may require additional space for ecological features such as wild flower planting or the creation of a pond.	Low ecological value 1st and 2nd credit 75,000 3rd credit 140,000 Medium/high ecological value 1st and 2nd credit 270,000 3rd credit 365,000

Plant room size will vary according to the LZC technologies that are to be used in the building. For example, the use of on-site technologies such as ground source heat pumps can result in larger plant rooms, if backup or supplementary heating or cooling plant is also required, conversely if back up plant is not required it can result in smaller plant rooms.

RECOMMENDATION

Consideration should be given to factors such as daylight calculations, external views and natural ventilation early in the design process. They can have a significant effect on certain credits which, in the right circumstances, can be easily achieved.

RECOMMENDATION

The use of dynamic thermal modelling can help to establish the optimal solutions with regard to the following architectural features:

- glazing and solar control strategy
- opening areas required for an effective natural ventilation strategy
- levels of insulation in the various envelope components.

CREDITS ASSOCIATED WITH STRATEGIC DESIGN

There may be an operational carbon emissions reduction target on a project, in which case, the necessary BREEAM energy credits (for a particular rating) may be gained by achieving that target.

If a low or 'zero carbon' target has been set for a project, then there is the potential to achieve an 'Outstanding' rating relatively easily and cost effectively. The Target Zero research explored the relationship between achieving maximum operational carbon reductions and BREEAM for the case study office building.

Figure 17 shows the capital and 25-year NPV costs of achieving the greatest operational carbon emissions reduction possible (using energy efficiency measures and on-site LZC technologies) for the case study office building i.e. acknowledging practical constraints relating to the size of the building and its location. This was achieved by using Energy Efficiency Package C (see Table 1) in conjunction with fuel-cell-fired CCHP, a 1,918m² array of photovoltaic panels and a small 6kW roof-mounted wind turbine. This package of measures is predicted to achieve a 78% reduction in regulated emissions; falling well short of the 146% reduction required for this building to be 'true zero' carbon[1].

The top bar in the figure represents the same scenario, but includes the NPV benefit of the energy efficiency measures and LZC technologies selected, i.e. accounting for the operational and maintenance costs of the LZC technologies, feed-in tariff income, the utility cost savings and the social cost of carbon reduction[2] over a 25-year period.

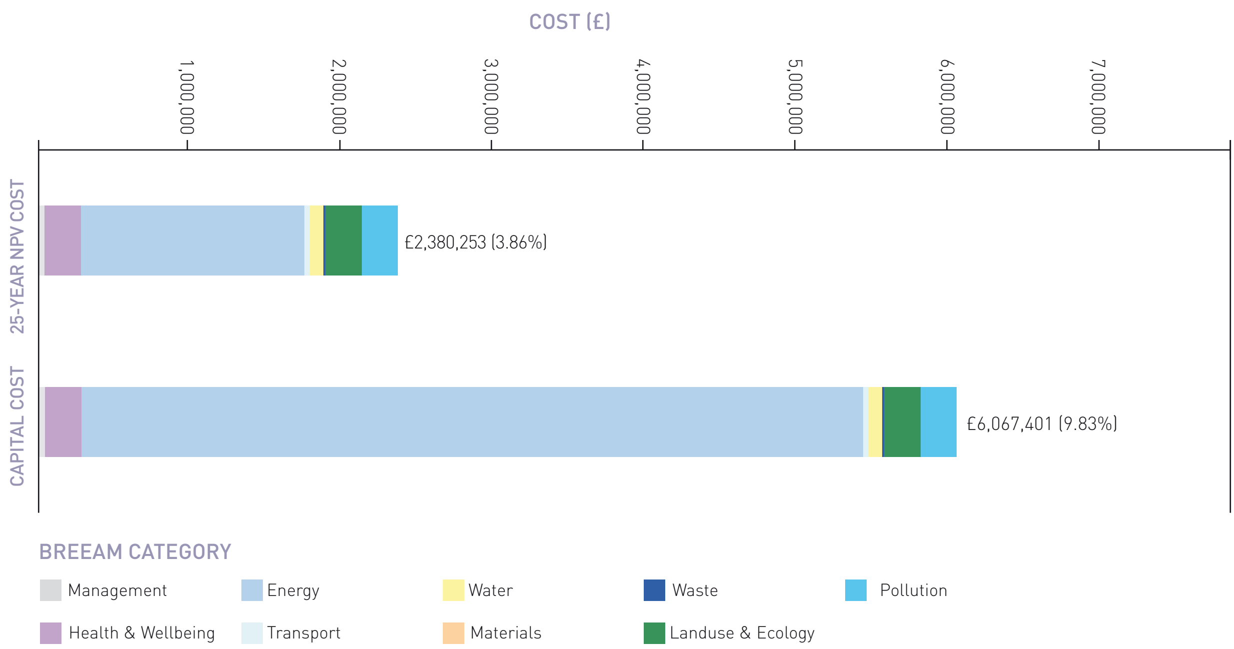
This graph focuses only on the 'Outstanding' rating as it is reasoned that if a zero carbon target was set for an office building, then it would be logical to also pursue an 'Outstanding' rating since, by far, the most significant costs associated with attaining of an 'Outstanding' BREEAM rating relate to the operational energy credits.

RECOMMENDATION

If there is a requirement to achieve a BREEAM 'Excellent' or 'Outstanding' rating on a project and there is no corresponding carbon emissions reduction target, then it is recommended that the potential cost implications of the mandatory energy credits are established and budgeted for early in the design process since they are likely to be significant.

FIGURE 17

CAPITAL COST UPLIFT AND NPV OF ACHIEVING BREEAM OUTSTANDING AND TARGETING ZERO CARBON



1 A 79% reduction in regulated emissions is achievable more cost effectively using a different combination of technologies that includes biomass CCHP. However this technology was not considered viable because of the building's city centre location and associated fuel delivery and storage constraints.

2 Based on the Department for Environment Food and Rural Affairs (defra) Shallow Price of Carbon.

POTENTIAL COSTS OF BREEAM CREDITS

Figures 18 to 20 show the most cost-effective routes to achieve a BREEAM 'Very Good', 'Excellent' and 'Outstanding' respectively for the case study office building. They show the cumulative credits, and costs, required to achieve the target rating and taking into account mandatory and scenario-related credits, e.g. relating to location of the building. Credits are ranked in terms of their weighted cost (capital cost of the credit divided by the credit weighting) rather than total cost as shown in the figures.

The routes are based on the case study office building design with a set of assumptions that have been made to establish the capital cost of each credit – see Table 6. Therefore, these routes can be used as examples of the potential capital cost uplift and lowest cost routes to high BREEAM ratings, rather than as definitive guides that are applicable to all projects. As each situation varies, it is likely that the different opportunities and constraints on a project will influence and alter both the optimum route and the capital cost uplift

Working from the bottom up, the graphs identify (in red) the mandatory credit requirements. Above these the zero cost optional credits are listed (in black). These are not ranked in any particular order. Above these (in blue) are the non-zero cost optional credits. Collectively, these credits identify the most cost-effective route to achieving the required BREEAM target rating based on the case study office building.

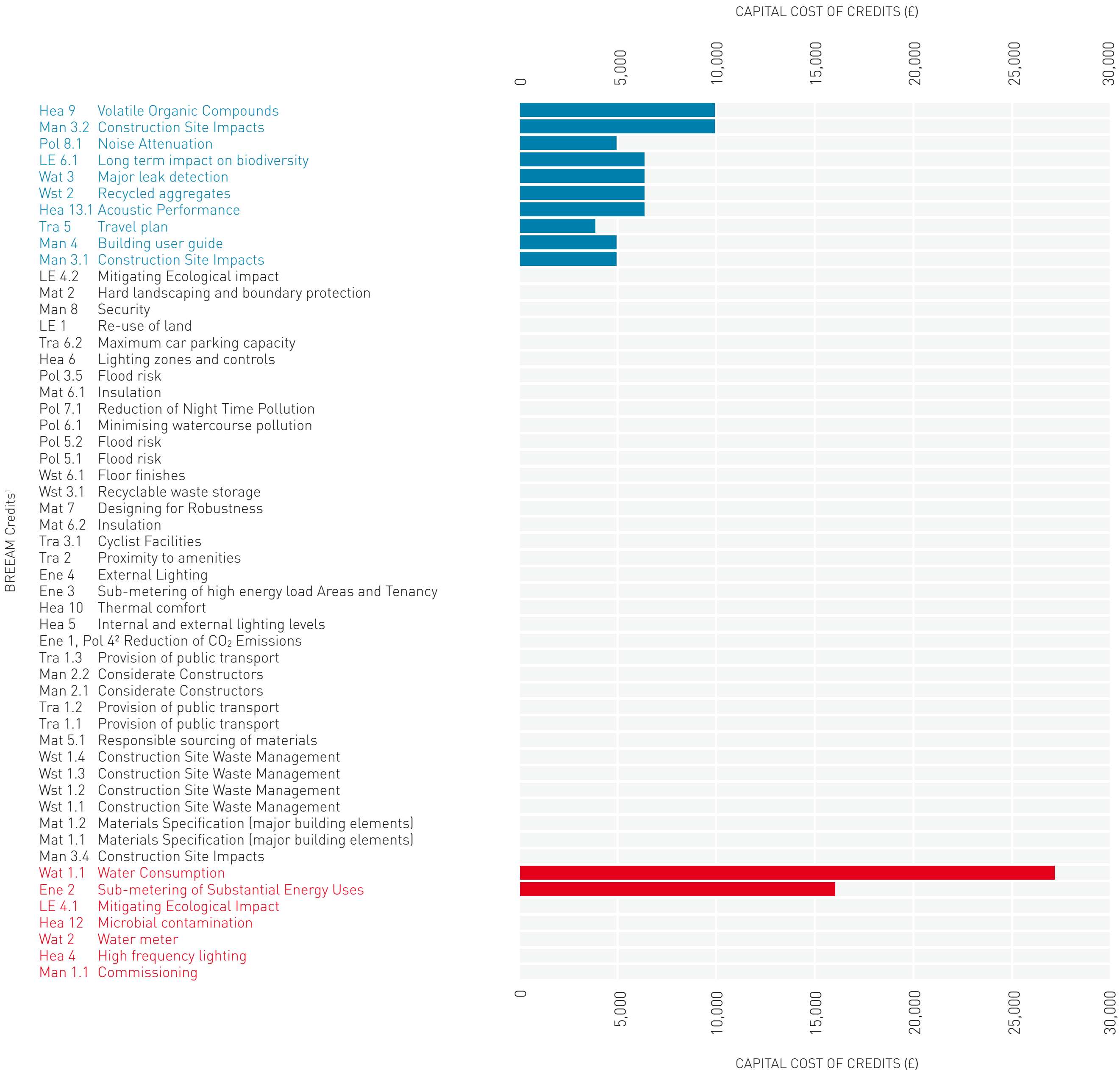
The graphs show that there are a number of credits that are considered zero cost for the case study office building. These credits will be low or zero cost on similar office buildings and can therefore be used as a guide to selecting the lowest cost credits on other projects. The graphs also identify the potentially high cost credits which need to be specifically costed for each project.

RECOMMENDATION

Low and high cost credits be established by working closely with an experienced BREEAM assessor and cost consultant and using this research to inform the assumptions that are made at early stages in the design process.

8.0 ROUTES TO BREEAM 'OUTSTANDING'

FIGURE 18
LOWEST COST ROUTE TO BREEAM "VERY GOOD" RATING

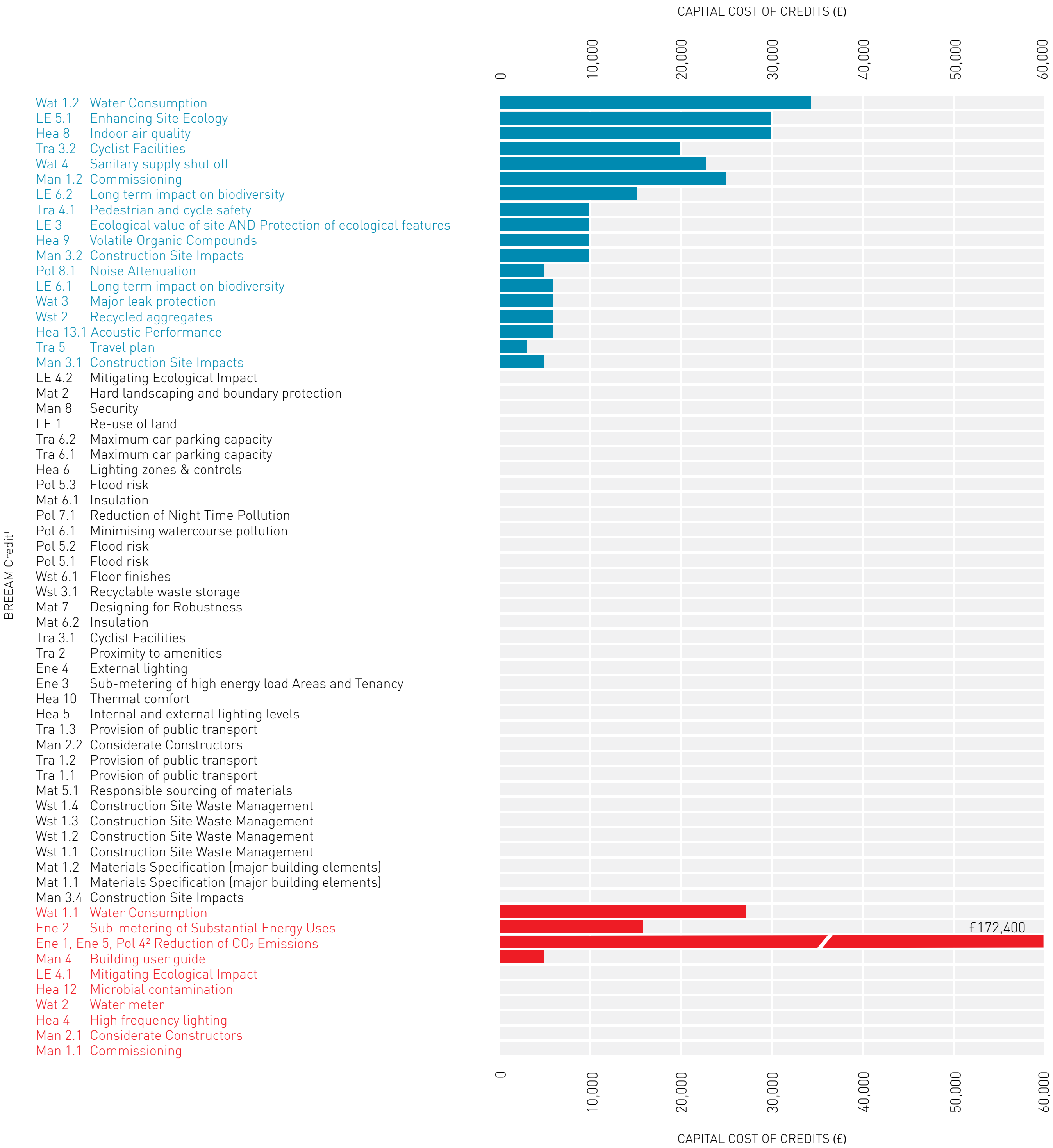


1 Ranking of credits is based on their weighted cost (capital cost of the credit divided by the credit weighting), whereas the values shown in the figures are the actual (non-weighted) cost of achieving the credit.

2 Because of the interrelationship between Ene 1 and Pol 4 credits, these credits have been grouped together in this table. Under this scenario, 1 Ene 1 and 3 Pol 4 credits are awarded.

8.0 ROUTES TO BREEAM 'OUTSTANDING'

FIGURE 19
LOWEST COST ROUTE TO BREEAM 'EXCELLENT' RATING

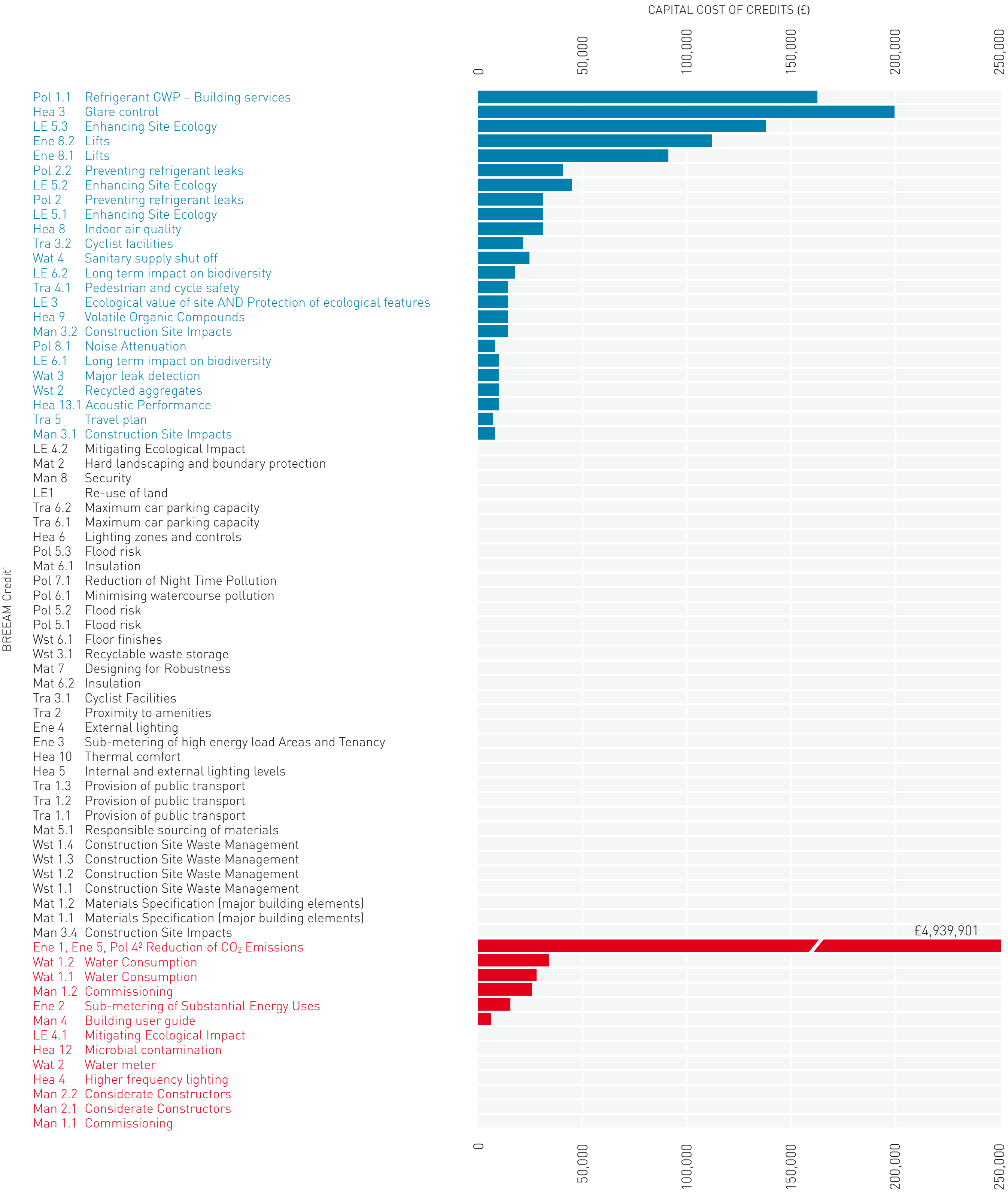


1 Ranking of credits is based on their weighted cost (capital cost of the credit divided by the credit weighting), whereas the values shown in the figures are the actual (non-weighted) cost of achieving the credit.

2 Because of the interrelationship between Ene 1, Ene 5 and Pol 4 credits, these credits have been grouped together in this table. Under this scenario, 7 Ene 1, 1 Ene 5 and 3 Pol 4 credits are awarded.

8.0 ROUTES TO BREEAM 'OUTSTANDING'

FIGURE 20
LOWEST COST ROUTE TO BREEAM 'OUTSTANDING' RATING



1 Ranking of credits is based on their weighted cost (capital cost of the credit divided by the credit weighting), whereas the values shown in the figures are the actual (non-weighted) cost of achieving the credit.

2 Because of the interrelationship between Ene 1, Ene 5 and Pol 4 credits, these credits have been grouped together in this table. Under this scenario, 13 Ene 1, 4 (including 1 exemplar credit) Ene 5 and 3 Pol 4 credits are awarded.

EXEMPLAR PERFORMANCE AND INNOVATION CREDITS

There are three ways in which a building can achieve an Innovation credit:

- **by meeting 'exemplary performance criteria' for an existing BREEAM issue for example, increasing the daylight factors from 2% to 3%;**
- **where the client/design team sets a specific BREEAM performance targets/ objectives and appoints a BREEAM Accredited Professional (AP) throughout the key project work stages to help deliver a building that meets the performance objectives and target BREEAM**
- **where an application is made to BRE Global to have a particular building feature, system or process recognised as innovating in the field of sustainable performance, above and beyond the level that is currently recognised and rewarded by standard BREEAM credits.**

The maximum number of innovation credits that can be awarded on any one building is 10.

It may be cost-effective to propose an innovation credit instead of one of the more costly credits to achieve the 'Excellent' or 'Outstanding' ratings. If an innovation credit can be proposed that has a lower capital cost than credits close to the 'Excellent' and 'Outstanding' threshold score, then they should be pursued. These credits can be defined by ranking the weighted cost of credits and identifying the credits that take the cumulative score over a threshold.

For the case study scenario considered, the capital cost of the credit next to the 'Excellent' threshold is £34,000, so an innovation measure that is cheaper than this would achieve the 'Excellent' rating at a lower cost. Similarly, for the 'Outstanding' rating, the capital cost of the credit next to the threshold is £195,600[1].

RECOMMENDATION

Design teams should explore opportunities to gain innovation credits. By ranking credits in terms of cost, the thresholds between achieving an 'Excellent' and 'Outstanding' rating can be identified to help decide whether the proposed innovation credit is cost-effective compared to other credits.

GUIDANCE ON MATERIALS SELECTION

The research showed that there is an inherent weighting within the tool used to calculate the score under credit Mat 1 in the materials section of BREEAM. This inherent weighting is used in addition to weighting each element by area. The inherent weightings are shown in Table 12.

TABLE 12
ELEMENT WEIGHTINGS WITHIN THE BREEAM MATERIALS ASSESSMENT TOOL

ELEMENT	EXTERNAL WALLS	WINDOWS	ROOF	UPPER FLOORS
Weighting	1.00	0.30	0.74	0.23

The table shows that external walls and roofs are highly weighted.
An assessment of alternative materials specifications showed that:

- **the external walls achieve an A rating in the Green Guide using coated aluminium rainscreen cladding. There is an opportunity to achieve an A+ rating by using Autoclaved fibre cement rainscreen cladding**
- **the aluminium curtain walling only achieves a C rating and requires a different solution including a medium dense blockwork section instead of a spandrel panel to achieve a higher rating of B**
- **the roof construction only achieves a D rating and could achieve an C rating by using rounded pebbles instead of concrete pavers**
- **the upper floor slab achieves an A+ rating for the case study building.**

For the case study building, the first two (of four) Mat 1 credits were achieved using the base case building specification. To achieve the third credit the rainscreen cladding would need to be upgraded to the autoclaved cement sheet cladding.

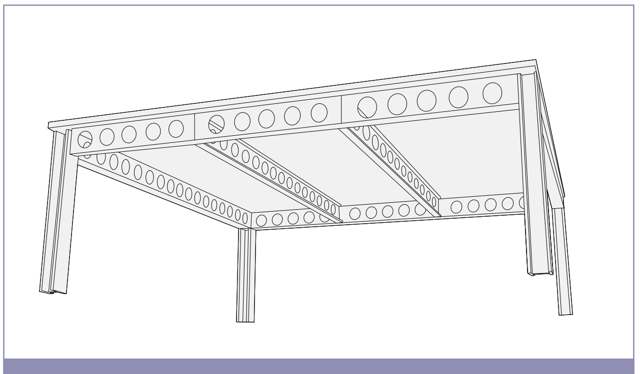
1 Exemplar performance and innovation credits are achievable at all BREEAM rating levels. Target Zero methodology is focussed on achieving the highest BREEAM ratings and has therefore only assessed the cost of viable measures at the 'Excellent' and 'Outstanding' levels. In practice, such credits are unlikely to be sought or to be cost-effective at the lower BREEAM levels, i.e. 'Pass' and 'Good'.

9.0 STRUCTURAL DESIGN

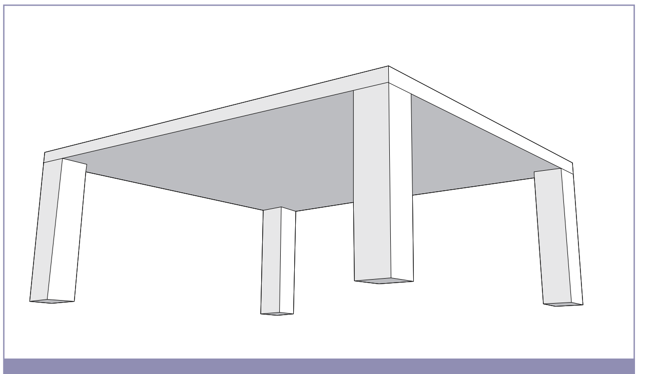
STRUCTURAL DESIGN

Two structural options for the office building were assessed as shown in Figure 21.

FIGURE 21
ALTERNATIVE STRUCTURAL OPTIONS



BASE CASE: CELLULAR STEEL BEAMS SUPPORTING LIGHTWEIGHT CONCRETE SLAB ON PROFILED STEEL DECKING



STRUCTURAL OPTION 1 : POST-TENSIONED CONCRETE FLAT SLAB

Full building cost plans for each structural option were produced by independent cost consultants using mean values, current at 2Q 2010. The costs, which include prelims, overheads and profit and a contingency, are summarised in Table 13.

TABLE 13
COMPARATIVE COSTS OF ALTERNATIVE STRUCTURAL DESIGNS

STRUCTURAL OPTION	DESCRIPTION	STRUCTURE UNIT COST[1] (£/m² of GIFA)	TOTAL BUILDING COST (£)	TOTAL BUILDING UNIT COST (£/m² of GIFA)	DIFFERENCE RELATIVE TO BASE CASE BUILDING (%)
Base case building	Cellular steel beams supporting lightweight concrete slab on profiled steel decking	316	61,700,000	1,869	-
Option 1	350mm thick post-tensioned concrete flat slab	377 (+19.2%)	64,100,000	1,941	+3.90

[1] Frame and upper floors

The build rate for city centre offices can vary depending upon a range of factors:

- **the overall size and specification of the principal elements, i.e. substructures, frame, cladding, lighting**
- **the quality and scope of the fit-out**
- **the efficiency ratios such as wall: floor or net: gross ratios.**

With reference to external published cost analyses, such as the RICS Building Cost Information Service (BCIS), the typical benchmark cost range for large scale office developments of this nature is expected to be in the order of £1,780/m² to £2,500/m²; albeit that developments at the high quality end of the range, such as those procured for financial institutions in central London could exceed this typical range. The base case building cost model is positioned broadly in the middle of this range.

A notional allowance of £500,000 was included in the costs for external works.

9.1 IMPACT OF STRUCTURE ON OPERATIONAL CARBON EMISSIONS

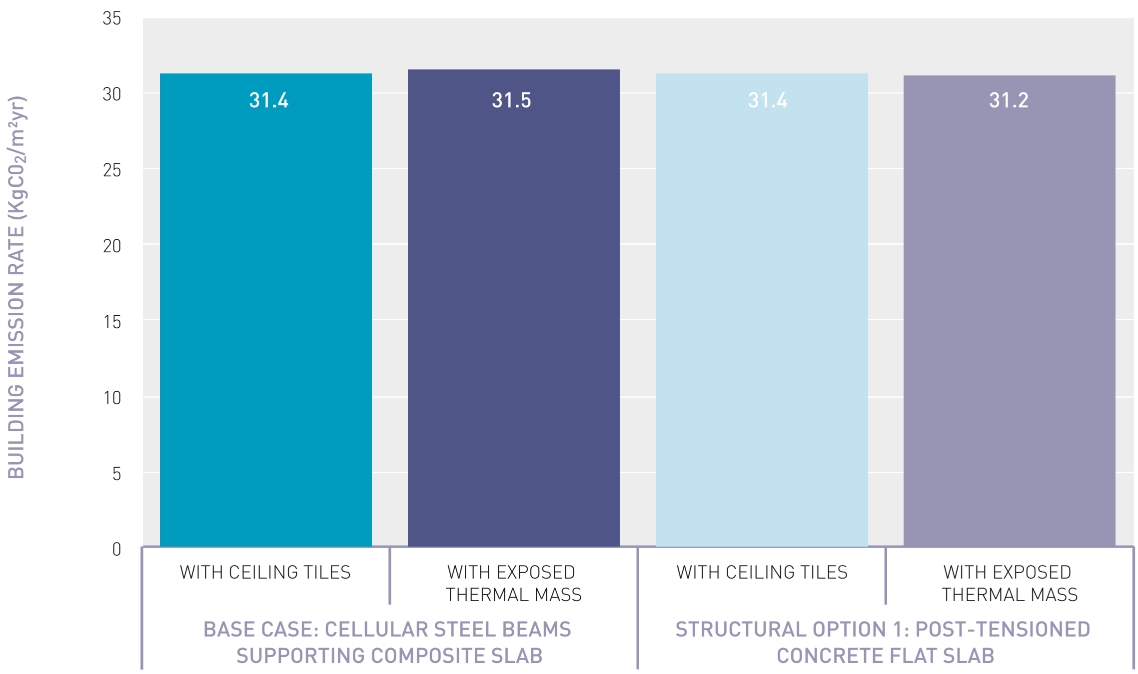
Buildings with the two structural options shown in Figure 21 were modelled both with and without suspended ceilings to establish the impact of the structural form on operational carbon emissions. The omission of ceiling tiles exposes the upper floor soffits to the occupied spaces allowing the thermal mass to be mobilised.

Exposing thermal mass is generally thought to be helpful in moderating the rate of change of temperature in the building and reducing the amount of cooling energy required over the year. However, it can also have the effect of increasing the energy required for space heating if, by exposing the floor soffits, the volume requiring heating is increased. The interaction of these impacts is complex and depends on the balance of heating and cooling in the building in question.

As shown in Figure 5, cooling contributes 8% of the total operational carbon emissions of the base case building while space heating contributes 10% and therefore the net effect on total carbon emissions is predicted to be small – see Figure 22. The Building Emission Rates (BERs) were found to vary by only 0.3 kg CO_2/m^2 yr (less than 1%) across both structural forms with and without suspended ceilings. Figure 24 gives the breakdown of carbon emissions by energy load for the two structural options modelled.

The conclusion is that mobilising thermal mass provides minimal advantage in terms of regulated carbon emissions within Grade A, city centre office buildings. It may also have detrimental impacts on aesthetics and acoustics, which are not considered in this guidance.

FIGURE 22
BUILDING EMISSION RATES FOR THE DIFFERENT STRUCTURAL OPTIONS



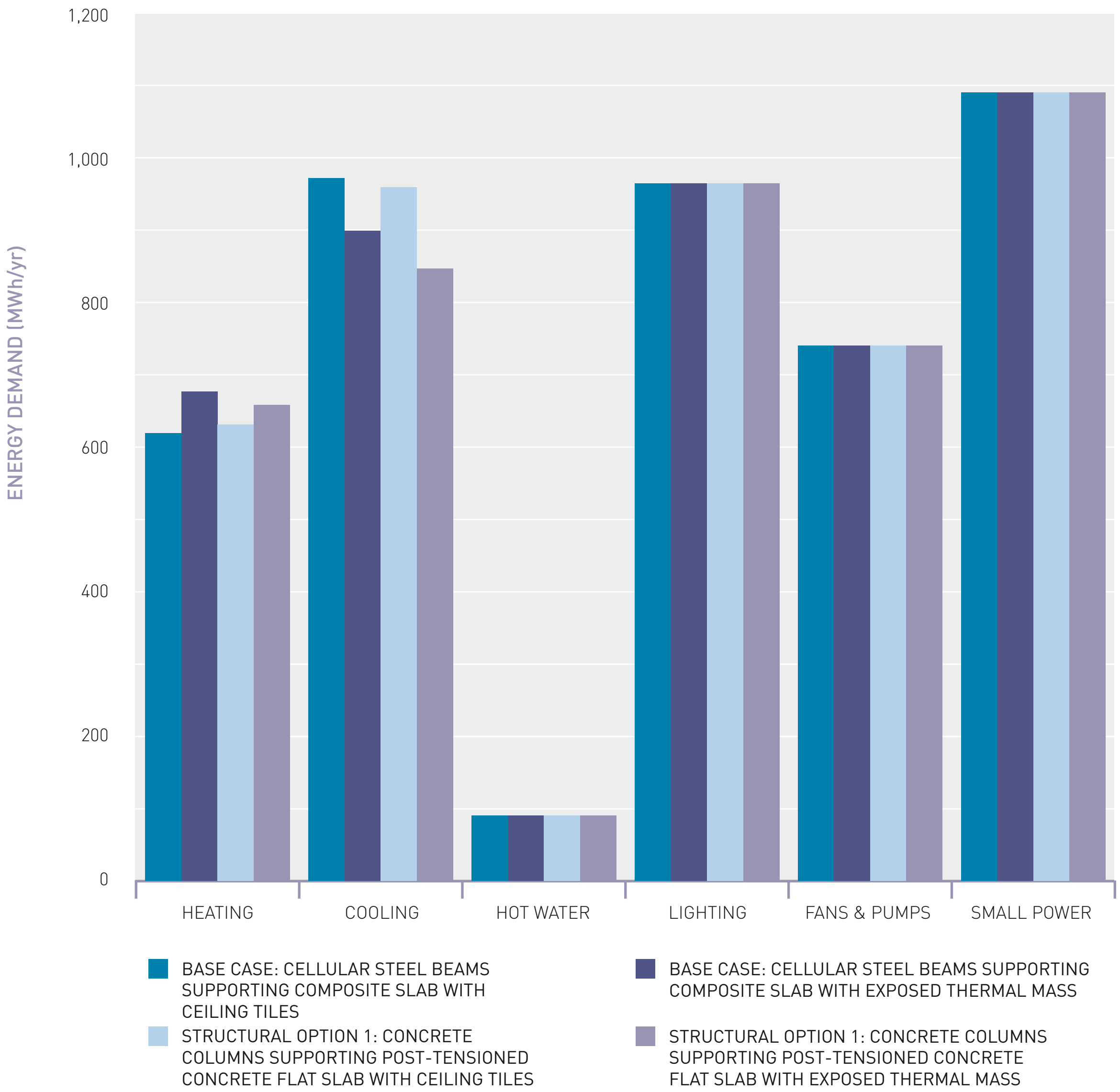
Structural Option 1 has a greater structural depth than the base case building; the typical floor height being 7% greater[1]. Increased storey heights result in greater heat losses and therefore higher heating but lower cooling requirements - see Figure 23 which gives the variation in energy demand by energy load for the two structural options modelled.

The interaction of these impacts is complex and so their net effect on the total building carbon dioxide emissions is sometimes surprising. For example the net effect of exposing upper floor soffits is to marginally increase emissions in the base case building, but slightly reduce emissions for the alternative structural option.

1 It should be noted that, for the purposes of the thermal modelling, when the ceiling height was raised, the area of glazing was not increased; rather a strip of unglazed wall was introduced along the top of the window.

The choice of structural option often affects the envelope area of the building. Buildings with a greater surface area will experience a larger amount of heat loss; this will increase the heating energy requirement in winter, but may also reduce the cooling load in summer.

FIGURE 23
VARIATION IN OPERATIONAL ENERGY DEMAND



EMBODIED CARBON

As the operational energy efficiency of new buildings is improved, the relative significance of the embodied impacts of construction materials and processes increases. In recognition of this, one objective of Target Zero was to understand and quantify the embodied carbon emissions of office buildings, focussing particularly on different structural forms.

The term 'embodied carbon' refers to the lifecycle greenhouse gas emissions (expressed as carbon dioxide equivalent or CO_2e) that occur during the:

- **manufacture and transport of the construction materials**
- **construction process**
- **demolition and disposal of the building materials at the end-of-life.**

RECOMMENDATION

It is important that all lifecycle stages are accounted for in embodied carbon assessments. For example the relative benefits of recycling metals compared to the methane emissions from timber disposed of in a landfill site are ignored if end-of-life impacts are ignored. This is a common failing of many embodied carbon datasets and analyses that only assess 'cradle-to-gate' carbon emissions i.e. studies that finish at the factory gate.

ONE KINGDOM STREET, LONDON – ATRIUM

10.0 EMBODIED CARBON

The embodied and operational carbon emissions from the building together make up the complete lifecycle carbon footprint of the building.

The embodied carbon impact of the two structural options considered (see Section 9) was measured using the Life Cycle Assessment (LCA) model CLEAR - See Appendix E.

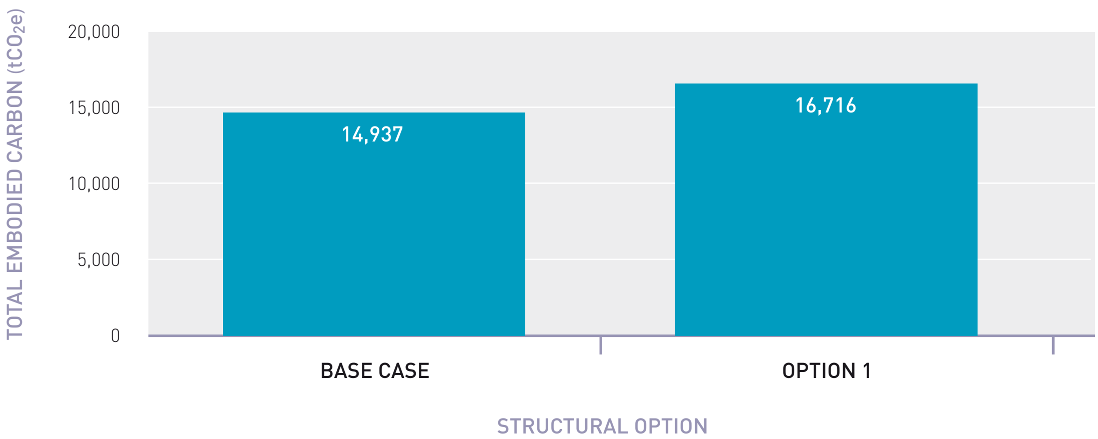
The CLEAR model has successfully undergone a third party critical review to the relevant ISO standards on Life Cycle Assessment by Arup. This review concluded that the CLEAR methodology and its representation in the GaBi software has been undertaken in accordance with the requirements of ISO 14040 (2006) and ISO 14044 (2006). Furthermore Arup are also confident that the data quality rules used to select the material lifecycle inventory data in the CLEAR GaBi model are also consistent to these standards and goals of the methodology.

Each building was assumed to have the same drainage and therefore the embodied carbon of this element was identical. The same façade and glazing specifications were assumed for both buildings with adjustments to areas to take account of the different storey heights. Items excluded from the analysis were access ladders and gantries, internal doors, internal fit-out lifts, wall, floor and ceiling finishes and building services such as water, heating and cooling systems. Maintenance issues were excluded from the analysis as there is sparse data on this and any impacts are likely to be similar between the different building options assessed.

Figure 24 shows the total embodied carbon impact of the base case office building and the alternative structural option studied. Relative to the base case, the concrete structure (Option 1) has an 11.9% higher embodied carbon impact.

Normalising the data to the total floor area (gross internal floor area) of the building, yields embodied carbon emissions of 452 and 506kg CO_2e per m² for the base case and structural Option 1 respectively.

FIGURE 24
TOTAL EMBODIED CARBON EMISSIONS OF THE BASE CASE BUILDING AND STRUCTURAL OPTION 1



10.0 EMBODIED CARBON

Figures 25 and 26 show the mass of materials used to construct each of the two office building alternatives, broken down by element and material respectively. The total mass of materials used to construct the office building was estimated to vary between 32.3mt (base case) and 55.4mt (Option 1); a 72% difference.

The figures show that most of the materials are used in the foundations (22% to 36%), bearing structure (22% to 23%) and particularly the upper floors (31% to 50%).

Concrete is by far the most abundant material used to construct the office building representing between 68% (base case) and 86% (Option 1) of all materials by weight. Compared to the base case building, the post-tensioned concrete building (Option 1) requires an additional 25,692kt of concrete. Because of the dominance of concrete, the mass of the other materials used to construct the building is shown separately in Figure 27.

FIGURE 25

MASS OF MATERIALS - BREAKDOWN BY ELEMENT

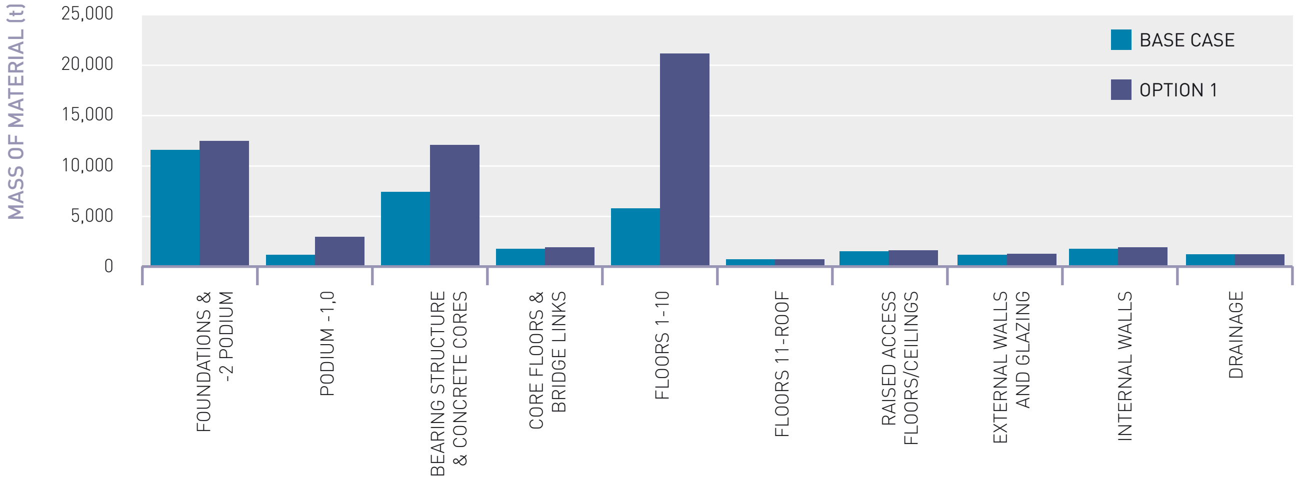
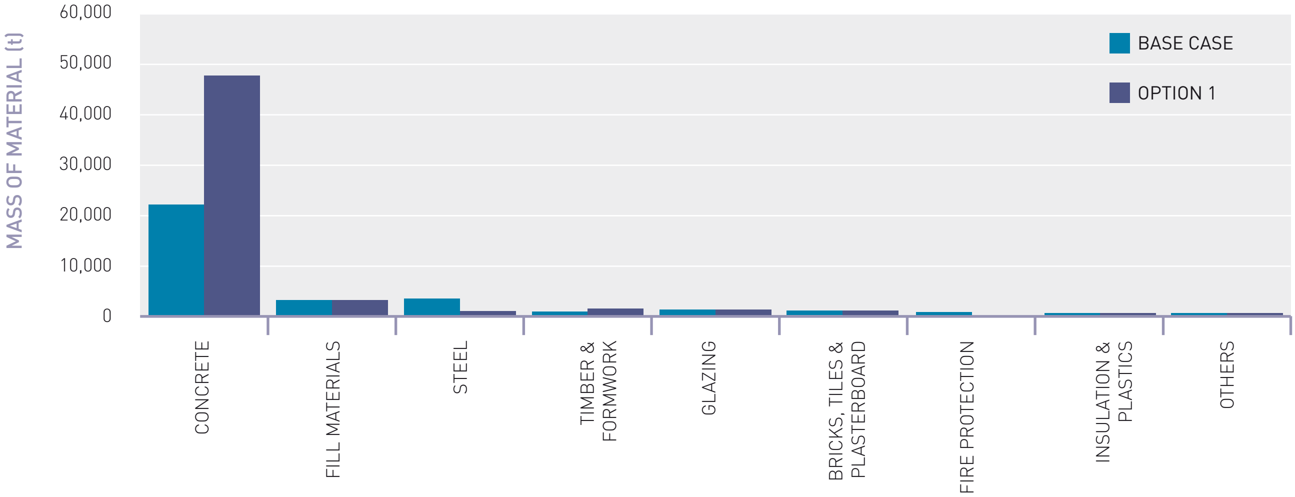


FIGURE 26

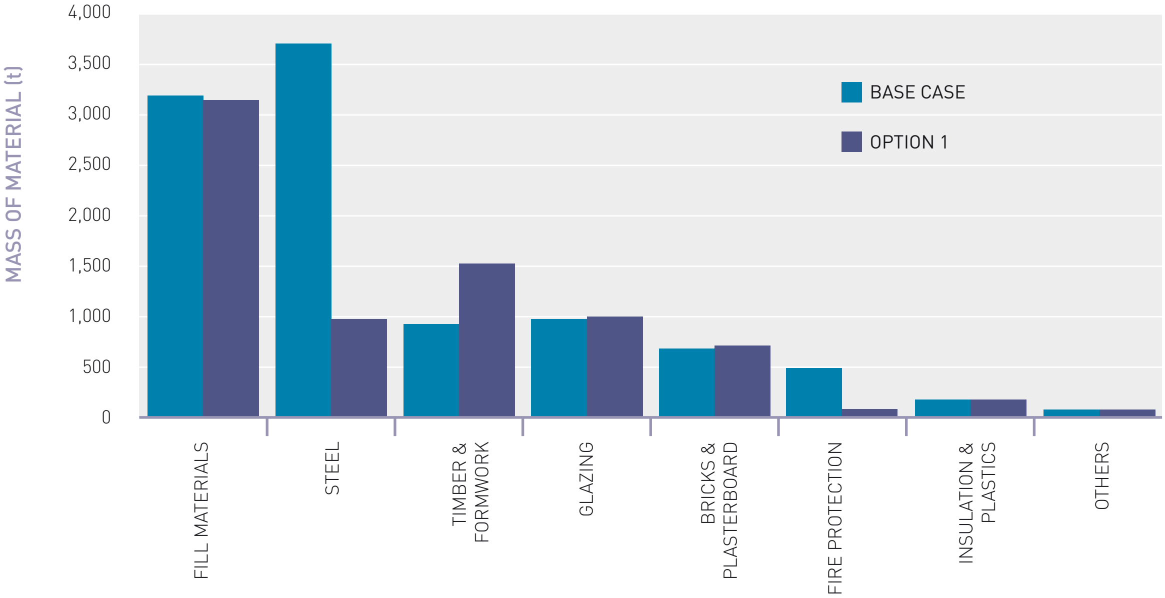
MASS OF MATERIALS - BREAKDOWN BY MATERIAL



10.0 EMBODIED CARBON

FIGURE 27

MASS OF MATERIALS (EXCLUDING CONCRETE) - BREAKDOWN BY MATERIAL



Figures 28 and 29 show the breakdown of embodied carbon in the two buildings by material and building element respectively. The following points are noted from the figures:

- **the largest contribution in both structural options comes from concrete, most of which is used in the foundations and floor slabs. Even though on a per tonne basis, concrete is relatively low in embodied carbon, the weight of concrete used in the building makes its contribution very significant.**
- **the impact of substituting the steel frame in the base case with a post-tensioned concrete structure (Option 1) is evident in both figures, i.e. an increased concrete and reduced steel impact**
- **despite its large volume, the embodied carbon contribution from fill (included within Others in Figure 29) materials is small**
- **transport related emissions from Option 1 (715 tCO_2e) were 32% greater than for the base case building. As a proportion of the total embodied carbon impact, transport represents 3.6% and 4.3% for the base case and Option 1 buildings respectively**
- **the estimate of embodied carbon from general on-site construction activity is significant at around 13-14% of the total impact. Insufficient on-site data were available to differentiate between the two structural options considered although the speed of erection, lower weight and offsite nature of the base case steel structure is likely to incur lower impacts than Option 1.**

On-site energy use during the construction of One Kingdom Street was recorded by the main contractor, Skanska as part of their environmental management procedure. As such, these data are relevant to the base case building. No data were available for the concrete structure (Option 1) and therefore the same data have been used for Option 1. In reality, the longer programme for concrete structures (relative to steel) is likely to mean that on-site impacts for Option 1 are higher than shown.

10.0 EMBODIED CARBON

FIGURE 28

BREAKDOWN OF EMBODIED CARBON BY MATERIAL

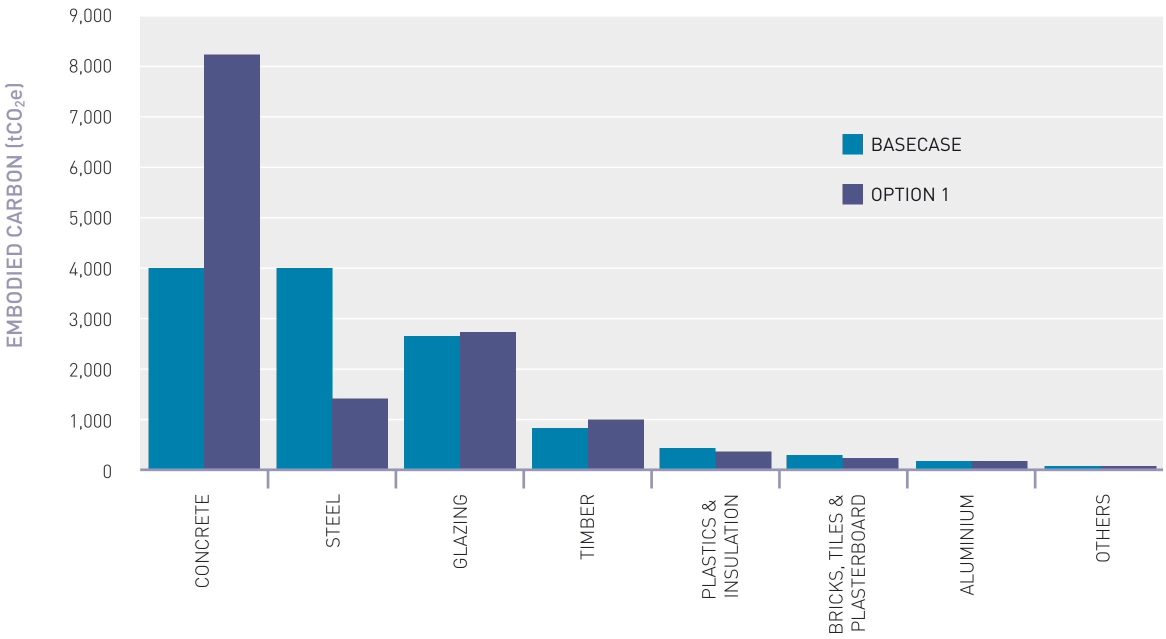
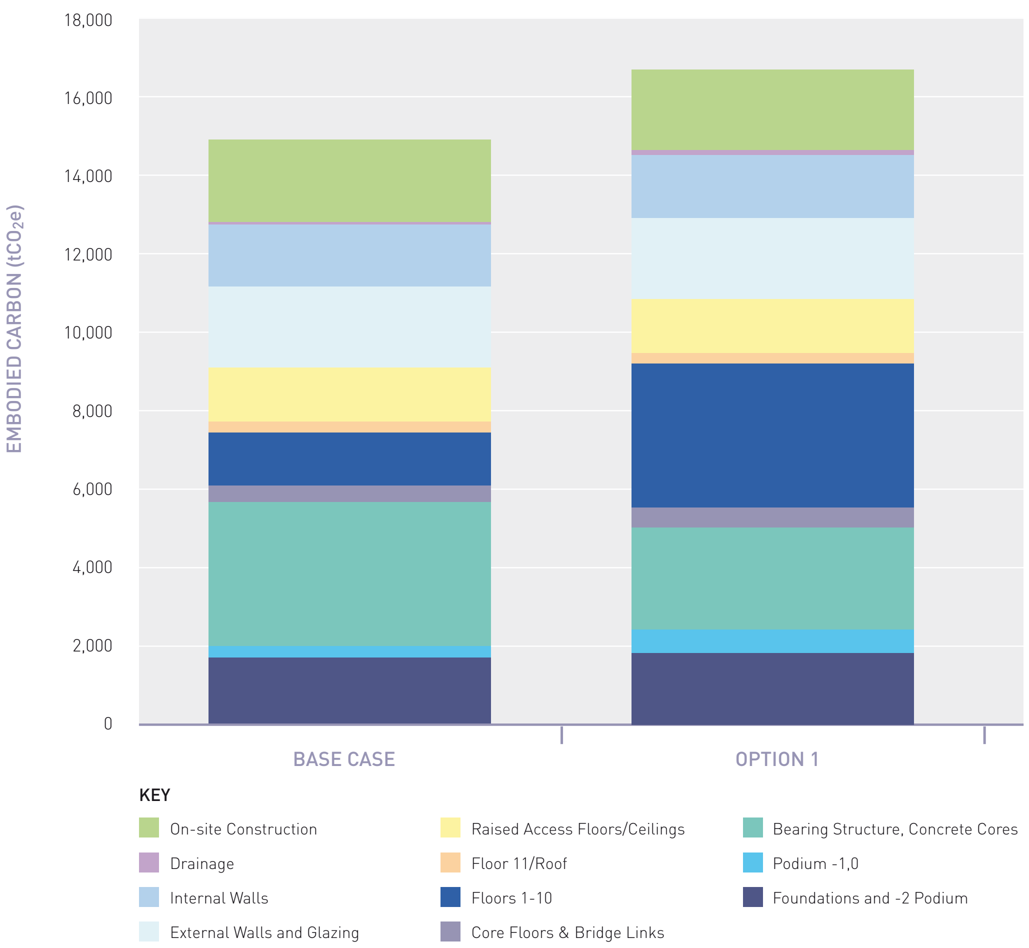


FIGURE 29

BREAKDOWN OF TOTAL EMBODIED CARBON BY ELEMENT

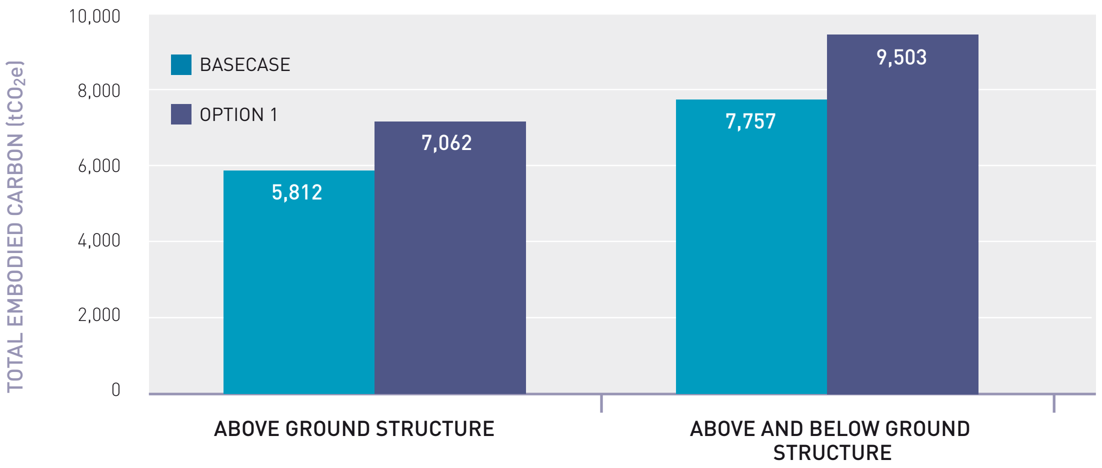


10.0 EMBODIED CARBON

Figure 30 shows the embodied carbon associated with the structures of both buildings analysed. The 'above ground structure' comprises all structural elements including the cores, upper floors and roof. In addition, the 'above and below ground structure' includes the below ground podium levels and the foundations.

The above ground post-tensioned concrete structure (Option 1) has 21.5% more embodied carbon than the base case building steel structure. Including the below ground floors and foundations, increases this differential to 22.5%.

FIGURE 30
TOTAL EMBODIED CARBON OF THE BASE CASE BUILDING



10.1 EMBODIED CARBON GUIDANCE

The quality and consistency of embodied carbon emissions factors are key to undertaking robust, comparative whole building studies. It is important that the assessor fully understands the scope and pedigree of the data being used and uses consistent data.

Many embodied carbon datasets are 'cradle-to-gate' values, i.e. they exclude all impacts associated with that product after it has left the factory gate, e.g. transport, erection, site waste, maintenance, demolition and end-of-life impacts including reuse, recycling and landfill. Such impacts can be significant and therefore it is important that all lifecycle stages are accounted for in a thorough assessment.

Accounting for the end-of-life impacts of construction products is important in embodied carbon assessments, for example the end-of-life assumptions relating to the disposal and treatment of timber products can significantly influence their whole lifecycle impacts. Similarly the benefits of highly recyclable products such as metals, needs to be understood and quantified. The assessor needs to understand these issues and account for them accurately and fairly in comparative assessments.

A summary of the main embodied carbon emissions factors used in the office building assessment are given in Appendix E.

Although carbon is a current priority, it is important to remember that there are many other environmental impacts associated with the manufacture and use of construction materials. It is good practice therefore to undertake a more thorough Life Cycle Assessment (LCA) study that includes other environmental impacts such as water use, resource depletion, ecotoxicity, eutrophication, ozone depletion, acidification, etc. in addition to embodied carbon.

RECOMMENDATION

Embodied carbon assessments can be very sensitive to the assumptions made and methods used for data sourcing and analysis. When undertaking embodied carbon assessments therefore transparency is crucial so that all assumptions are clearly set out alongside the results. It is good practice to undertake sensitivity analyses on key assumptions and methodological decisions used in the embodied carbon assessments.

Embodied carbon assessments can be very sensitive to the assumptions made, for example in the areas described above. When undertaking embodied carbon assessments therefore transparency is crucial so that all assumptions are clearly set out alongside the results.

It is good practice to undertake sensitivity analyses on key assumptions and methodological decisions used in the embodied carbon assessments.

APPENDIX A

METHODOLOGY USED TO ASSESS LOW AND ZERO OPERATIONAL CARBON SOLUTIONS

The approach taken to develop low and zero operational carbon solutions was as follows:

1. The One Kingdom Street office building was amended as follows:
   - the levels of thermal insulation were reduced until these were no better than required by Criterion 2 of Part L 2006
   - HVAC system efficiencies were altered to industry standards;
   - the ground source heat pump and solar water heating system were removed
   - solar shading was removed and solar control glazing was replaced with standard clear glazing
   - the air leakage value was increased to 9m³/hr per m² @ 50Pa.
2. A dynamic thermal model of the building was then developed using the IES software suite. This Part L approved software is capable of modelling the annual operational energy/carbon performance of the building. For consistency, all buildings studied in Target Zero are assessed using Manchester 2005 weather tapes.
3. The model was then fine-tuned to just pass Part L2A 2006 by altering the energy efficiency of the lighting system. This was done to ensure that the base case was no better than the current minimum regulatory requirements, i.e. within 1% of the Target Emission Rate (TER). The base case building was defined in terms of elemental U-values, air-tightness, etc. shown in Table A1.
4. This base case building was then modified to have an alternative structure to investigate the influence of the structural form on the operational carbon emissions.
5. 34 energy efficiency measures were then introduced individually into the base case model. The results of the operational carbon analysis, combined with the cost data, were then used to derive three energy efficiency packages that utilise different combinations of compatible energy efficiency measures which were found to be cost-effective (see Appendix B).
6. 34 low and zero carbon technologies were then individually incorporated into each of the three energy efficiency packages (see Appendix C). The results from these models, together with the associated cost data, were then used to derive a number of low and zero carbon office building solutions. This approach has been devised to reflect the carbon hierarchy shown in Figure 2 and the likely future regulatory targets (see Figure 3).

TABLE A1

BASE CASE BUILDING FABRIC PERFORMANCE PARAMETERS

ELEMENT	U-VALUE (W/m²K)
External wall	0.35
Ground floor	0.25
Intermediate floors	2.28
Concrete partitions	0.19
Roof	0.25
External glazing	2.0
Building air tightness	9 m³/hr per m² @50Pa
Thermal bridging	0.035W/m²K

APPENDIX B

ENERGY EFFICIENCY ASSESSMENT METHODOLOGY

For the purposes of this research, energy efficiency measures are defined as changes to the building which will reduce the demand for operational energy and, in so doing, reduce carbon emissions. The 34 energy efficiency measures modelled on the base case building are shown in Table B1.

Dynamic thermal modelling, using IES software, was used to predict the operational energy requirements of the office building for each energy efficiency measure and the predicted energy costs coupled with the capital and maintenance costs to derive a net present value (NPV) for each measure over a 25-year period. This period was selected to represent the maximum likely timescale after which full asset replacement would have to be considered for the LZC technologies analysed.

These NPVs were expressed as a deviation from that of the base case office building, thus some energy efficiency measures have negative NPVs as they were found to save money over the 25-year period considered.

The cost data and the energy modelling results were then combined to provide each energy efficiency measure with a cost effectiveness measure in terms of 25 YR NPV/kgCO_2 (£) saved relative to the base case. The 34 measures were then ranked in terms of this cost effectiveness measure. At this point, some energy efficiency measures were rejected on one or more of the following bases:

- **the measure was found to increase carbon emissions**
- **the measure was incompatible with more cost-effective measures**
- **the measure was found to be highly expensive for very little carbon saving.**

Three energy efficiency packages were then selected from the remaining measures by identifying two key thresholds:

- **Package A where the measure was found to save money over the 25-year period being considered, i.e. it has a negative NPV**
- **Package C where the measure is less cost-effective than photovoltaic panels. This was chosen since PV is generally considered to be one of the more capital intensive low or zero carbon technologies which can be easily installed on almost any building.**

Package B contains measures which fall between these two thresholds. Package B also includes or supersedes Package A measures and Package C includes (or supersedes) all Package A and all Package B measures.

In some cases an energy efficiency measure was not compatible with a more cost-effective measure in the same package. Where similar, mutually exclusive, cost-effective energy efficiency measures were available, the most cost-effective was chosen for that package and the others moved into the next package for consideration. An example of this is the chiller efficiency.

The results obtained for this assessment are shown in Figure 6 in the main body of the guide.

The methodology used to cost the energy efficiency measures considered is described in Appendix D.

TABLE B1
ENERGY EFFICIENCY MEASURES CONSIDERED

ENERGY EFFICIENCY AREA	DESCRIPTION OF MEASURE
Air tightness	Improved to 7 m³/hr per m² @50Pa
	Improved to 5 m³/hr per m² @50Pa
	Improved to 3 m³/hr per m² @50Pa
Thermal bridging	Enhanced thermal bridging details (0.018W/m²K)
External wall insulation	Improved to 0.25W/m²K
Roof insulation & green roof	Improved to 0.20W/m²K
	Improved to 0.15W/m²K
	Improved to 0.10W/m²K
	Green Roof extensive, sedum type (2,491m²)
Ground floor insulation	Improved to 0.15W/m²K
Improved external glazing	Improved to 1.60W/m²K
	Improved to 1.20W/m²K
	Improved to 0.80W/m²K
Glazed area, Solar shading & Solar control glazing	Glazing reduced from full height to 1m sill
	Glazing reduced from full height to 1m sill and 1m from ceiling
	Louvres on South façade
	Solar control glass on South, East and West façades
Heating, Cooling & Ventilation	Improved boiler seasonal efficiency to 95%
	Improve cooling efficiency to SEER = 6
	Improve cooling efficiency to SEER = 7
	Improve cooling efficiency to SEER = 8
	Improved Specific Fan Power by 20%
	Improved Specific Fan Power by 30%
	Improved Specific Fan Power by 40%
	Heat recovery improved to 70%
	Heat recovery improved to 85%
	Active chilled beams
	Radiant heated/chilled ceiling
	Mixed mode ventilation
Lighting	Daylight dimming lighting controls
	Occupancy sensing lighting controls
	Improved lighting efficiency to 2.0W/m² per 100lux throughout
	Improved lighting efficiency to 1.8W/m² per 100lux throughout
	Improved lighting efficiency to 1.5W/m² per 100lux throughout

APPENDIX C

LOW AND ZERO CARBON (LZC) TECHNOLOGY ASSESSMENT

For the purposes of this research LZC technologies have been broadly defined as technologies which meet building energy demands with either no carbon emissions, or carbon emissions significantly lower than those of conventional methods.

Thirty four LZC technologies were modelled (see Table C1) on each of the three energy efficiency packages. Each of the LZCs was applied to each energy efficiency package (see Appendix B) individually and, where relevant, was modelled as both a large and a small-scale installation, for example the ground source heat pumps were modelled as a large case sized to supply space heating and cooling to the whole building and as a small case sized to supply space heating only.

As for the energy efficiency measures, a 25-year NPV was established for each LZC technology, taking account of the capital cost of the technology and the operational energy savings that result from its use.

Initial results of the LZC modelling revealed no single, on-site technologies that were able to achieve zero carbon when used in conjunction with any energy efficiency package and therefore further modelling was undertaken to combine a number of on-site technologies. This was done using graphs similar to that shown in Figure C1.

Figure C1 shows the relationship between carbon dioxide emissions saved per year (relative to the base case) on the horizontal axis, against the change in 25-year NPV (relative to the base case) on the vertical axis. The figure shows just a subset of the many combinations of energy efficiency measures and LZC technologies assessed. Figure C1 shows the on-site LZC solutions defined in Table 4 in Section 7.5.

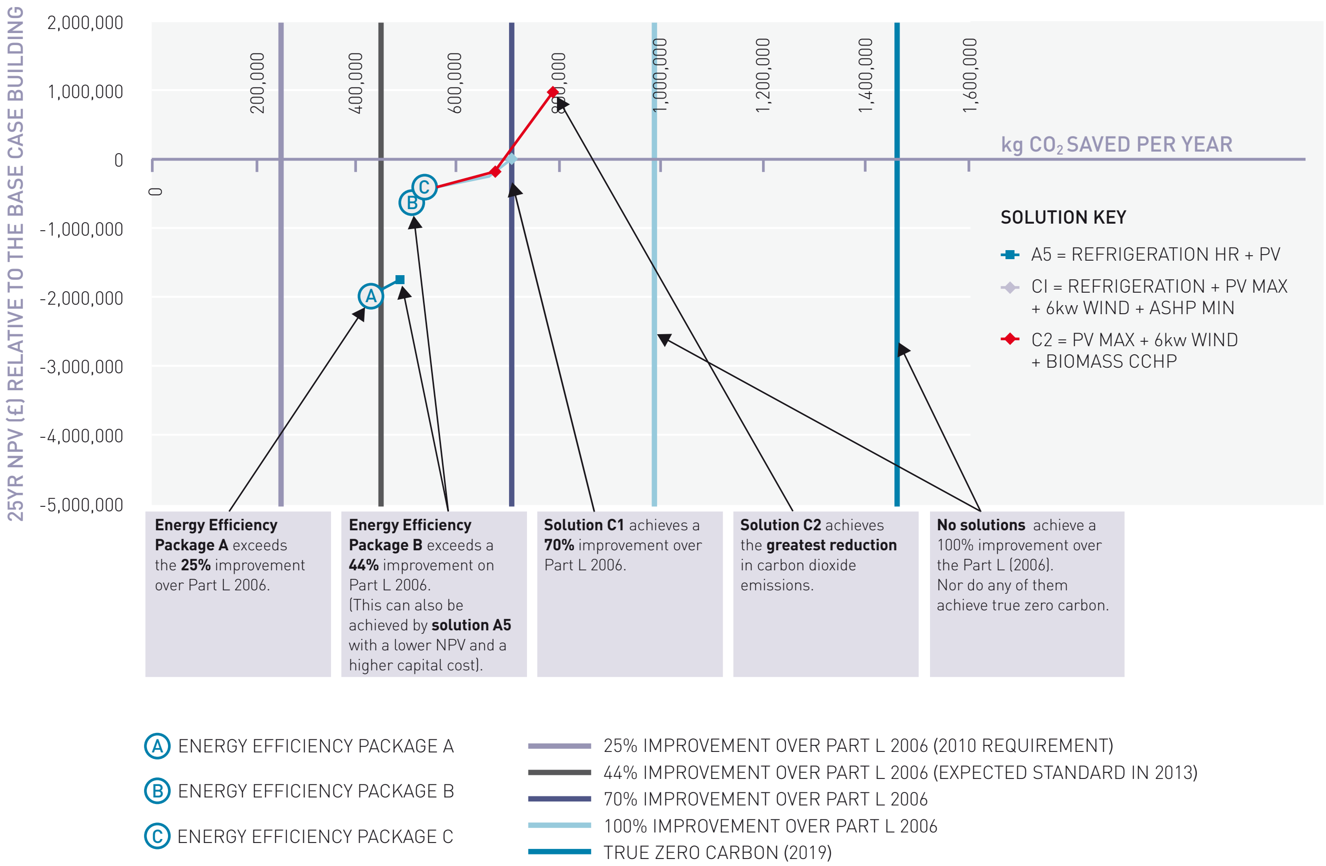
Figure C1 shows three coloured circles representing the three energy efficiency packages described in Appendix C. Straight lines emanating from these circles represent an LZC technology. The gradient of each line represents the cost effectiveness of each measure. Having decided the carbon reduction target, as represented by the dashed vertical lines in the graph, the most cost-effective technology package will be the lowest intercept with the selected target.

Where a technology was found to be less cost-effective than moving to the next energy efficiency package then it was discounted. Similarly if a technology could not be combined with one of those already selected then it was also discounted. An example of incompatible technologies would be biomass boilers and CHP; both of these provide heat to the building and so would be competing for the same energy load. This process identified 16 different combinations of compatible on-site technologies (based on the three energy efficiency packages).

The methodology used to cost the LZC technologies considered is described in Appendix D.

FIGURE C1

MOST COST-EFFECTIVE ON-SITE SOLUTIONS TO MEET FUTURE LIKELY PART L COMPLIANCE TARGETS



APPENDICES

TABLE C1
LZC TECHNOLOGIES MODELLED

LZC TECHNOLOGY	ON-SITE	OFFSITE	NOTES
Wind			
Large 5.0MW wind turbine		✓	**Repower** 117m tower height. 126m rotor diameter (Largest commercially available)
Large 2.5MW wind turbine		✓	**Nordex** 100m tower height. 99.8m rotor diameter
Medium 330kW wind turbine		✓	**Enercon** 50m tower. 33.4m rotor diameter
Medium 50kW wind turbine		✓	**Entegrity** 36.5m tower height. 15m rotor diameter
Small 20kW wind turbine		✓	**Westwind** 30m tower height. 10m rotor diameter
Small 6kW wind turbine	✓		Roof mounted; **Proven**; 9m tower height on 43.6m building giving total height of 52.6m; 5.5m rotor diameter
Small 1kW wind turbine	✓		Roof mounted; **Futurenergy**; 6.2m tower height on 43.6m building giving total height of 49.8m; 1.8m rotor diameter
Solar			
Solar Thermal Hot Water (STHW)	✓		116m² sized the same as system put on real building
Photovoltaics	✓		Roof mounted monocrystalline, plus PV used in place of solar shading where present on package C:
Heat Pumps			
Open-loop Ground Source Heat Pump Single Cycle	✓		Space heating
Open-loop Ground Source Heat Pump Reverse Cycle	✓		Space heating and cooling
Closed-loop Ground Source Heat Pump Single Cycle	✓		Space heating
Closed-loop Ground Source Heat Pump Reverse Cycle	✓		Space heating and cooling
Air Source Heat Pump Single Cycle	✓		Space heating
Air Source Heat Pump Reverse Cycle	✓		Space heating and cooling
Biomass Boilers			
Biomass Heating	✓		Space heating and hot water
Combined Heat & Power CHP			
Biomas CHP	✓	✓	Space heating, hot water and electricity
Small fuel cell CHP	✓		Hot water and electricity
Large fuel cell CHP	✓	✓	Space heating, hot water and electricity
Small gas-fired CHP	✓		Hot water and electricity
Large gas-fired CHP	✓	✓	Space heating, hot water and electricity
Small anaerobic digestion CHP	✓		Hot water and electricity
Large anaerobic digestion CHP	✓	✓	Space heating, hot water and electricity
Combined Cooling Heat & Power CCHP			
Biomass CCHP	✓		Space heating, cooling, hot water and electricity
Large fuel cell CCHP	✓		Space heating, cooling, hot water and electricity
Small fuel cell CCHP	✓		Space heating, cooling, hot water and electricity
Gas-fired CCHP	✓		Space heating, cooling, hot water and electricity
Anaerobic digestion CCHP	✓		Space heating, cooling, hot water and electricity
Waste			
Energy from waste		✓	Space heating and hot water
Waste process heat		✓	Space heating and hot water
Miscellaneous			
Refrigeration heat recovery system	✓		Recovering heat from space cooling to supply hot water

APPENDIX D

ENERGY EFFICIENCY AND LZC TECHNOLOGY COSTING

The objectives of the energy efficiency and LZC technology costings were:

- **to provide the net capital cost differential of each proposed energy efficiency measure and LZC technology option considered; the costs being presented as net adjustments to the base case building cost plan;**
- **to provide an estimate of the through-life cost of the each proposed energy efficiency measure and LZC technology option considered; these through-life costs being presented net of the equivalent base case cost.**

Capital costs

The base case office building cost plan was developed by Cyril Sweett using their cost database. UK mean values current at 2Q 2010 were used.

The capital costs for each energy efficiency and LZC technology option considered were calculated on an add/omit basis in relation to the base case cost plan. The methodology and basis of the pricing is as used for the construction costing. Where possible, costs have been based on quotations received from contractors and suppliers.

It should be noted that capital costs for certain LZC technologies may vary considerably depending on the size of the installation. It has not been possible to fully scale applicable technologies within the limitations of the study.

Through-life costs

The through-life costs were assessed using a simple net present value (NPV) calculation. The NPVs were calculated based upon the expected maintenance, operational, i.e. servicing, requirements and component replacement over a 25-year period; this period being selected to represent the maximum likely timescale after which full asset replacement would have to be considered for the LZC technologies analysed.

Fabric energy efficiency measures would generally all be expected to have a service life in excess of 25 years.

All ongoing costs are discounted back to their current present value. A discount rate of 3.5% has been used, in line with HM Treasury Green Book guidance.

The benefits of each technology option were considered in terms of net savings in energy costs in comparison to current domestic tariffs. For the purposes of this study, the following domestic tariffs were used:

- **gas: £0.03 per kWh**
- **grid-supplied power: £0.12 per kWh**
- **district supplied power: £0.108 per kWh**
- **district supplied cooling: £0.036 per kWh**
- **biomass: £0.025 per kWh**
- **district supplied heat: £0.027 per kWh.**

The prices used for gas and grid-supplied electricity were based on data published by Department for Energy and Climate Change (DECC).

Pricing assumptions for district supplies and biomass were derived from benchmark figures provided by suppliers and externally published data.

Where applicable, tariffs were adjusted to account for income from Renewable Obligation Certificates (ROCs), the Climate Change Levy and Feed-in tariffs (see below).

Feed-in tariffs

In April 2010, the Government introduced a system of feed-in tariffs (FITs) to incentivise small scale, low carbon electricity generation by providing 'clean energy cashback' for householders, communities and businesses.

These FITs work alongside the Renewables Obligation, which will remain the primary mechanism to incentivise deployment of large-scale renewable electricity generation, and the Renewable Heat Incentive (RHI) which will incentivise generation of heat from renewable sources at all scales. The RHI is expected to be launched in July 2011.

The FITs consist of two elements of payment, made to generators, and paid for, by licensed electricity suppliers:

1. A **generation tariff** that differs by technology type and scale, and is paid for every kilowatt hour (kWh) of electricity generated and metered by a generator. This generation tariff is paid regardless of whether the electricity is used on-site or exported to the local electricity network.
2. An **export tariff** which is either metered and paid as a guaranteed amount that generators are eligible for, or is, in the case of very small generation, assumed to be a proportion of the generation in any period without the requirement of additional metering.

The scheme currently supports new anaerobic digestion, hydro, solar photovoltaic (PV) and wind projects up to a 5MW limit, with differing generation tariffs for different scales of each of those technologies. The current feed-in tariffs for low and zero carbon electricity are shown in Table D1.

All generation and export tariffs are linked to the Retail Price Index (RPI), and FITs income for domestic properties generating electricity mainly for their own use are not taxable income for the purposes of income tax.

Tariffs are set through consideration of technology costs and electricity generation expectations at different scales, and are set to deliver an approximate rate of return of 5 to 8% for well sited installations. Accordingly, the tariffs that are available for some new installations will 'degress' each year, where they reduce to reflect predicted technology cost reductions to ensure that new installations receive the same approximate rates of return as installations already supported through FITs. Once an installation has been allocated a generation tariff, that tariff remains fixed (though will alter with inflation as above) for the life of that installation or the life of the tariff, whichever is the shorter.

TABLE D1

FEED-IN TARIFFS FOR LOW AND ZERO CARBON ELECTRICITY (DECC)

TECHNOLOGY	SCALE	TARIFF LEVEL FOR NEW INSTALLATIONS IN PERIOD (p/kWh) [NB: TARIFFS WILL BE INFLATED ANNUALLY]			TARIFF LIFETIME (YEARS)
		YEAR 1: 1/4/10-31/3/11	YEAR 2: 1/4/11-31/3/12	YEAR 3: 1/4/12-31/3/13	
Anaerobic digestion	≤500kW	11.5	11.5	11.5	20
Anaerobic digestion	>500kW	9.0	9.0	9.0	20
Hydro	≤15kW	19.9	19.9	19.9	20
Hydro	>15-100kW	17.8	17.8	17.8	20
Hydro	>100kW-2MW	11.0	11.0	11.0	20
Hydro	>2MW-5MW	4.5	4.5	4.5	20
MicroCHP pilot*	<2kW	10*	10*	10*	10*
PV	≤4kW (new build)	36.1	36.1	33.0	25
PV	≤4kW (retro fit)	41.3	41.3	37.8	25
PV	>4-10kW	36.1	36.1	33.0	25
PV	>10-100kW	31.4	31.4	28.7	25
PV	>100kW-5MW	29.3	29.3	26.8	25
PV	Stand alone system	29.3	29.3	26.8	25
Wind	≤1.5kW	34.5	34.5	32.6	20
Wind	>1.5-15kW	26.7	26.7	25.5	20
Wind	>15-100kW	24.1	24.1	23.0	20
Wind	>100-500kW	18.8	18.8	18.8	20
Wind	>500kW-1.5MW	9.4	9.4	9.4	20
Wind	>1.5MW-5MW	4.5	4.5	4.5	20
Existing microgenerators transferred from the RO		9.0	9.0	9.0	to 2027

* This tariff is available only for 30,000 micro-CHP installations, subject to a review when 12,000 units have been installed.

APPENDIX E

CLEAR LIFE CYCLE ASSESSMENT MODEL

The CLEAR model is a generic LCA tool that enables the user to assess the environmental impacts of a building over its full lifecycle. The user defines key parameters in terms of building materials, building lifetime, maintenance requirements, operational energy use and end-of-life scenarios. The tool can be used to gain an understanding of how building design and materials selection affects environmental performance of buildings and to compare the environmental impacts of different construction options for the same functional building. The model was built by Tata Steel Research Development & Technology using both construction and LCA expertise, and follows the ISO 14040 and 14044 standards.

CLEAR allows 'cradle-to-grave' LCAs of buildings to be generated. It allows all of the stages of a building's existence to be analysed in terms of their environmental impact: from the extraction of earth's resources, through manufacture, construction and the maintenance and energy requirements in the building-use phase, to end-of-life, reuse, recycling and disposal as waste.

The CLEAR model has successfully undergone a third party critical review to the relevant ISO standards on Life Cycle Assessment by Arup This review concluded that the CLEAR methodology and its representation in the GaBi software has been undertaken in accordance with the requirements of ISO 14040 (2006) and ISO 14044 (2006). Furthermore, Arup are also confident that the data quality rules used to select the material lifecycle inventory data in the CLEAR GaBi model are also consistent to these standards and goals of the methodology.

In addition to material quantities, data on the following activities were input to the CLEAR model for each building product:

- **materials transport distances to site**
- **waste transport distances from site**
- **construction waste rates including excavation material and waste from materials brought onto the construction-site**
- **construction-site energy use – diesel and electricity consumption**
- **end-of-life recovery rates.**

LCA data sources

There are several sources of lifecycle inventory (LCI) data available that allow the calculation of embodied carbon (CO_2e) per unit mass of material. In this project, GaBi software was found to be the most appropriate. Most of the data was sourced from PE International's 'Professional' and 'Construction Materials' databases. PE international are leading experts in LCA and have access to comprehensive materials LCI databases.

The most appropriate steel data were provided by the World Steel Association (worldsteel) which are based on 2000 average production data. The worldsteel LCA study is one of the largest and most comprehensive LCA studies undertaken and has been independently reviewed to ISO standards 14040 and 14044.

Table E1 gives the embodied carbon coefficients for the principle materials used in the office building assessment.

TABLE E1

THE EMBODIED CARBON COEFFICIENTS FOR THE PRINCIPLE MATERIALS USED IN THE OFFICE ASSESSMENT

MATERIAL	DATE SOURCE	END-OF-LIFE ASSUMPTION	SOURCE	TOTAL LIFECYCLE CO_2 EMISSIONS (tCO_2e/t)
Fabricated Steel sections	Worldsteel (2002)	99% closed loop recycling, 1% landfill	MFA of the UK steel construction sector[1]	1.009
Steel purlins	Worldsteel (2002)	99% closed loop recycling, 1% landfill	MFA of the UK steel construction sector[1]	1.317
Organic Coated Steel	Worldsteel (2002)	94% closed loop recycling, 6% landfill	MFA of the UK steel construction sector[1]	1.693
Steel Reinforcement	Worldsteel (2002)	92% recycling, 8% landfill	MFA of the UK steel construction sector[1]	0.820
Concrete (C25)	GaBi LCI database 2006 – PE International	77% open loop recycling, 23% landfill	Department for Communities and Local Government[2]	0.132
Concrete (C30/37)	GaBi LCI database 2006 – PE International	77% open loop recycling, 23% landfill	Department for Communities and Local Government[2]	0.139
Concrete (C40)	GaBi LCI database 2006 – PE International	77% open loop recycling, 23% landfill	Department for Communities and Local Government[2]	0.153
Glulam[5]	GaBi LCI database 2006 – PE International	16% recycling, 4% incineration, 80% landfill	TRADA[3]	1.10
Plywood[5]	GaBi LCI database 2006 – PE International	16% recycling, 4% incineration, 80% landfill	TRADA[3]	1.05
Plasterboard	GaBi LCI database 2006 – PE International	20% recycling, 80% landfill	WRAP[4]	0.145
Aggregate	GaBi LCI database 2006 – PE International	50% recycling, 50% landfill	Department for Communities and Local Government[2(a)]	0.005
Tarmac	GaBi LCI database 2006 – PE International	77% recycling, 23% landfill	Department for Communities and Local Government[2]	0.020

1 Material flow analysis of the UK steel construction sector, J. Ley, 2001.

2 Survey of Arisings and Use of Alternatives to Primary Aggregates in England, 2005 Construction, Demolition and Excavation Waste, www.communities.gov.uk/publications/planningandbuilding/surveyconstruction2005

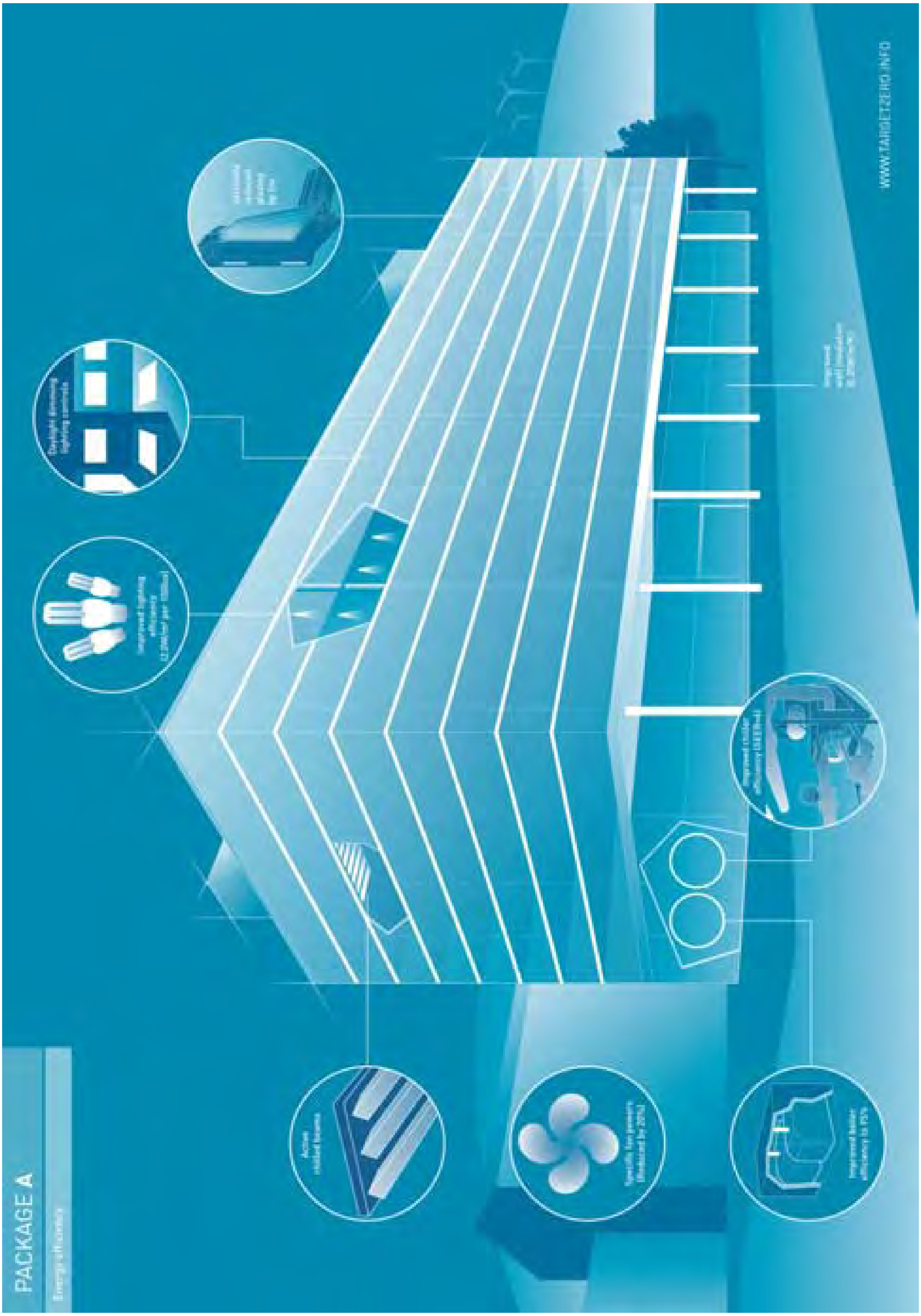
(a) Adjusted for material left in ground at end-of-life.

3 TRADA Technology wood information sheet 2/3 Sheet 59 ' Recovering and minimising wood waste', revised June 2008.

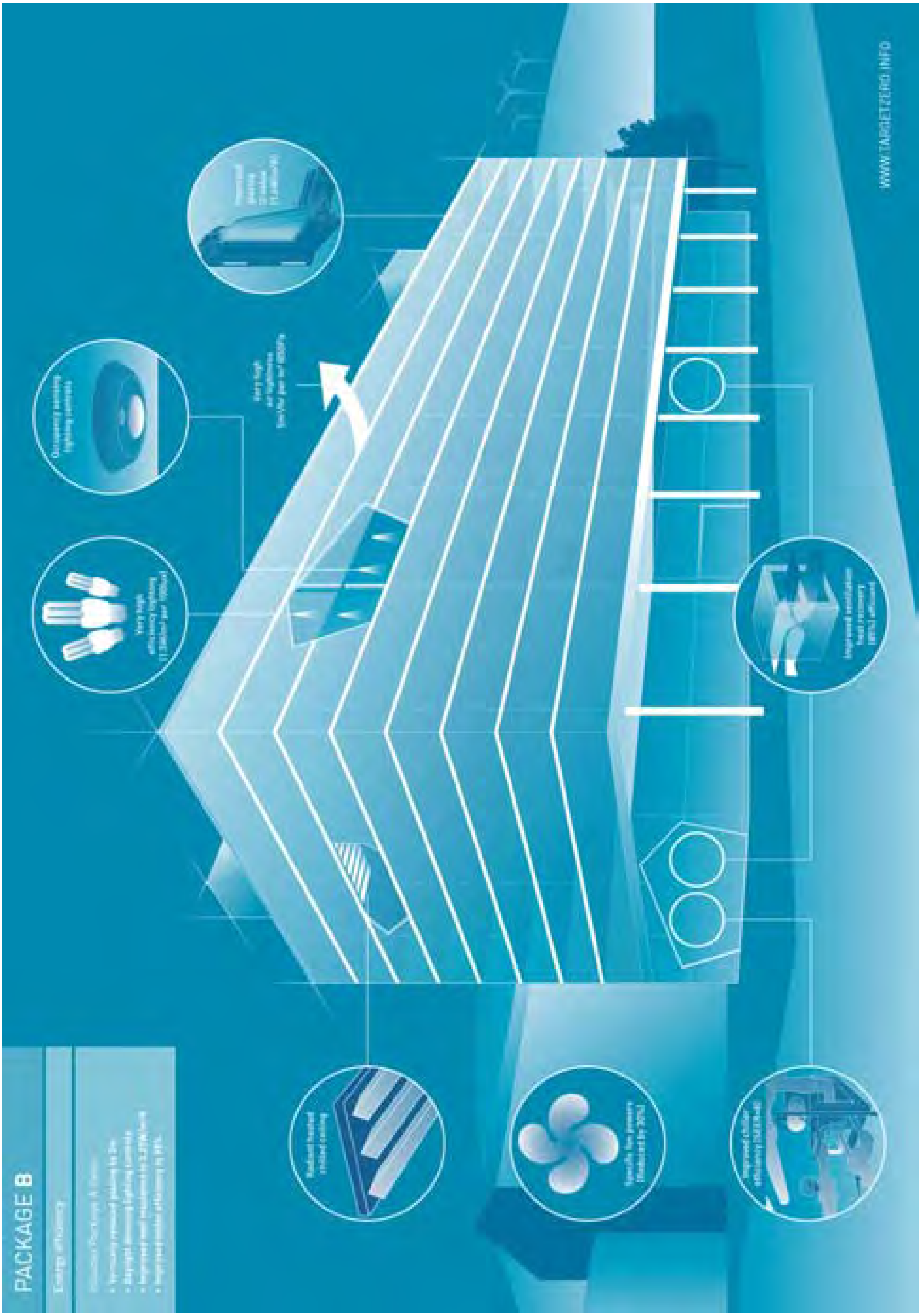
4 WRAP Net Waste Tool Reference Guide v 1.0, 2008 (good practice rates).

5 Data excludes CO_2 uptake or CO_2 emissions from biomass.

ENERGY EFFICIENCY PACKAGES



ENERGY EFFICIENCY PACKAGES



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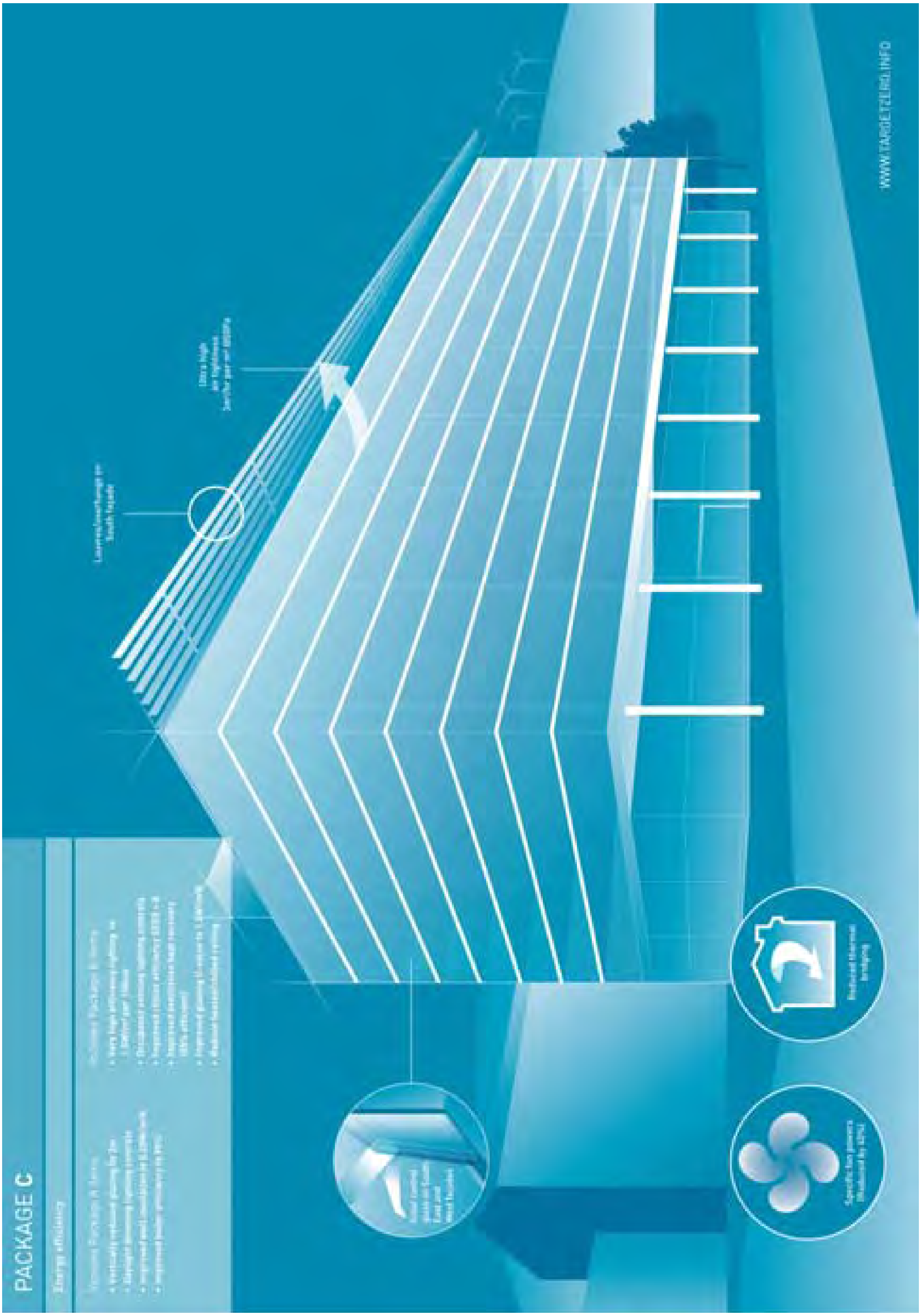

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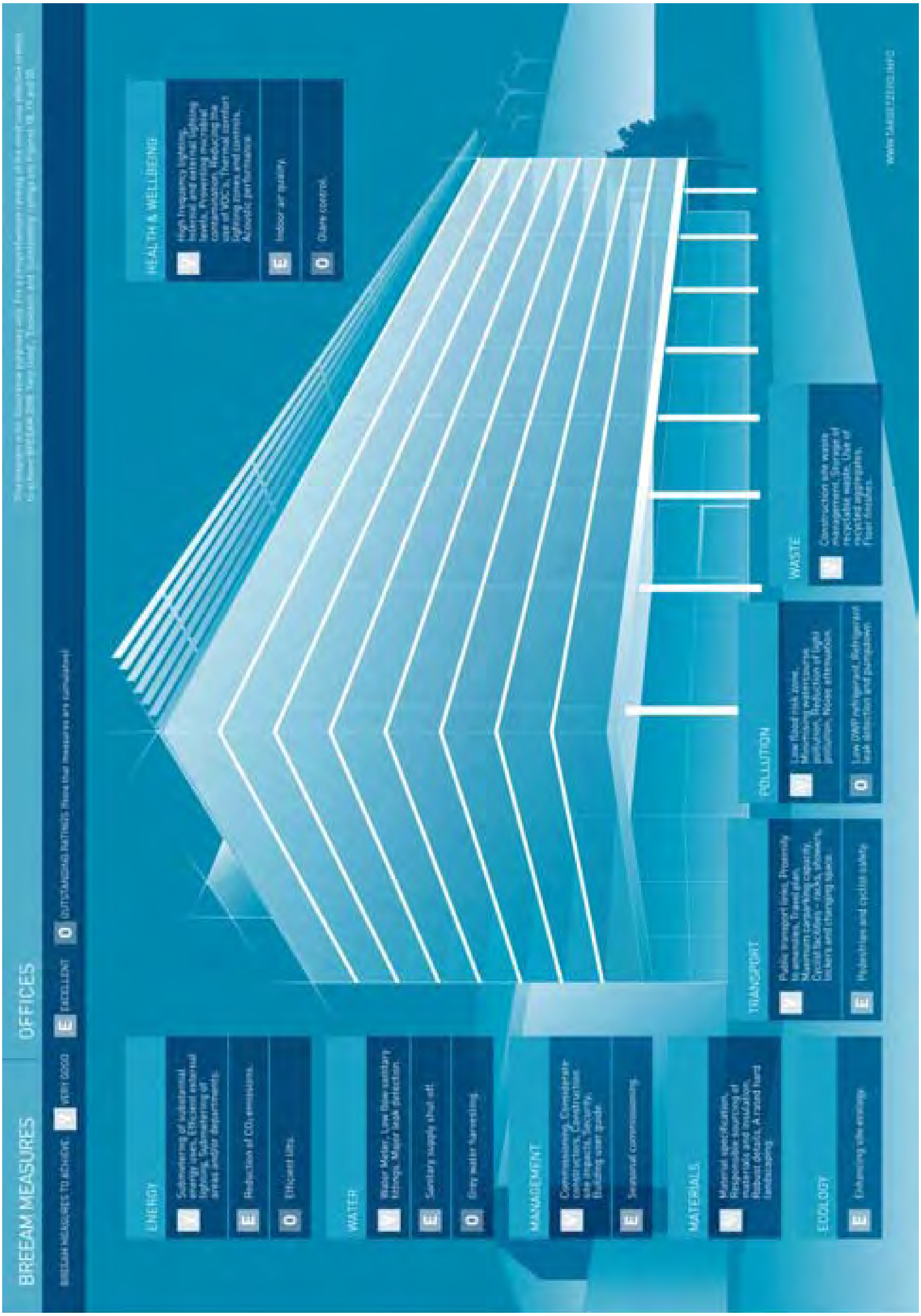

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2 Climate Change Act, 2008

3 Zero carbon for new non-domestic buildings; Consultation on policy options. Department for Communities and Local Government

4 Defining a fabric energy efficiency standard for zero carbon homes. Zero Carbon Hub, November 2009

5 Proposals for amending Part L and Part F of the Building Regulations – Consultation. Volume 2: Proposed technical guidance for Part L. Department for Communities and Local Government, June 2009

6 Target Zero guidance on the design and construction of sustainable, low carbon distribution warehouse www.targetzero.info

7 Planning Policy Statement 22: Renewable energy. Office of the Deputy Prime Minister

8 CIBSE Guide A – Environmental design (2006)

9 www.bre.co.uk/greenguide

10 Implementation Stage Impact Assessment of Revisions to Parts F and L of the Building Regulations from 2010. Department for Communities and Local Government, March 2010.

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