TARGET ZERO®

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

REPORT **V2.0 JANUARY 2012**

WWW.TARGETZERO.INFO

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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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1.0 INTRODUCTION

INTRODUCTION

Target Zero is a programme of work, funded by Tata Steel and the British Constructional Steelwork Association (BCSA)[1], to provide guidance on the design and construction of sustainable, low and zero carbon buildings in the UK. Five non-domestic building types have been analysed: a school, a distribution warehouse, a supermarket, a medium to high-rise office and a mixed-use building.

Using recently constructed, typical buildings as benchmarks, Target Zero has investigated three specific, priority areas of sustainable construction:

- **Operational carbon - how operational energy use and associated carbon emissions can be reduced by incorporating appropriate and cost-effective energy efficiency measures and low and zero carbon (LZC) technologies**
- **BREEAM[2] assessments - how 'Very Good', 'Excellent' and 'Outstanding' BREEAM ratings can be achieved at lowest cost**
- **Embodied carbon - quantification of the embodied carbon of buildings particularly focussing on different structural forms.**

The work has been undertaken by a consortium of leading organisations in the field of sustainable construction including AECOM and Cyril Sweett with steel construction expertise provided by Tata Steel RD&T and the Steel Construction Institute (SCI).

This document presents guidance for the fourth of the five building types covered by Target Zero, the office building. The information will be useful to construction clients and their professional advisers in designing and constructing more sustainable buildings. More results, information and guidance from Target Zero are available at **www.targetzero.info**

The images in this guide showcase One Kingdom Street, London, the actual building on which the base case building was modelled.

[1] The BCSA is the representative organisation for steelwork contractors in the UK and Ireland.

[2] BREEAM (BRE Environmental Assessment Method) is the leading and most widely used environmental assessment method for buildings. It has become the de facto measure of the environmental performance of UK buildings [1].

2.0 BACKGROUND

BACKGROUND

The UK Government has set an ambitious and legally binding target [2] to reduce national greenhouse gas emissions[1] by at least 80% by 2050 with an intermediate target of a 34% reduction by 2020 (against a 1990 baseline). The operation of buildings currently accounts for nearly half of the UK's greenhouse gas emissions and therefore significant improvement in new and existing building performance is required if these targets are to be met.

The Government has announced its aspiration for new non-domestic buildings to be zero carbon in operation by 2019 and is currently consulting on the definition of 'zero carbon' for non-domestic buildings.

Although the definition is still to be resolved, the direction of travel is clear and, via Part L of the Building Regulations, a roadmap of likely targets is in place to provide guidance to the construction industry to enable it to develop solutions to meet future low and zero carbon targets. See Section 7.2.

It is against this background that the UK steel construction sector is supporting Government and the construction industry by funding research and providing guidance in this important and challenging area through the Target Zero programme.

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1 These include carbon dioxide and emissions of other targeted greenhouse gases. In the context of embodied impacts, GHG emissions are correctly expressed in terms of carbon dioxide equivalents (CO_2e). In the context of operational impacts, emissions are generally expressed in terms of carbon dioxide. In this report, the terms operational carbon and operational carbon dioxide emissions have the same meaning.

3.0 SUSTAINABLE OFFICE BUILDINGS

SUSTAINABLE OFFICE BUILDINGS

Office buildings come in many forms and sizes; from low-rise, out-of-town business park offices to high-rise, inner city, prestige office buildings. This guide focuses on the larger end of this spectrum, i.e. medium to high rise office buildings which are most commonly constructed in city centres.

In common with all new buildings, commercial office buildings are increasingly required to be more sustainable. Although subject to the same regulations as other types of non-domestic buildings, e.g. Part L2 of the Building Regulations, the commercial office buildings sector has arguably lagged behind some other sectors such as schools, universities and hospitals. This is changing because tenants are demanding sustainable office buildings that align with their brand and Corporate Social Responsibility (CSR) values. Hence, large speculative office developers are now constructing sustainable office buildings that go far beyond regulatory compliance.

High-rise, Grade A city centre office buildings face several challenges with respect to future low and zero operational carbon emissions targets. These include limited opportunities:

- to include some low and zero carbon technologies, for example limited roof area for solar technologies, shading by neighbouring buildings affecting the viability of both solar and wind technologies and restricted access for biomass deliveries, etc.
- to naturally ventilate the building, mainly due to security, acoustic and air quality issues associated with inner city locations
- to optimise orientation due to tighter site constraints than less restricted suburban and rural sites.

Conversely, because of their location and high-rise nature, such buildings can score relatively well in other areas of sustainable construction; such as their proximity to public transport and other amenities.

There is clearly an ongoing need to construct high quality, city centre office buildings that attract and retain businesses in our towns and cities. By designing buildings that are aesthetically appealing and user-friendly and ensuring that they are robust, flexible and adaptable to change, i.e. future-proofed, city centre office buildings are more likely to last longer enabling greater value to be extracted from the finance and resources invested in them.

4.0 TARGET ZERO METHODOLOGY

TARGET ZERO METHODOLOGY

The Target Zero methodology is based on recently constructed buildings that are typical of current UK practice. For each building type considered, a 'base case' building is defined (see Sections 5 and 5.1) that just meets the 2006 Part L requirements for operational carbon emissions and this base case is used as a benchmark for the assessment[1]. It is important to note that the base case building differs from the actual building and that all operational carbon reductions are reported relative to the predicted base case building performance and not that of the actual building.

This approach was chosen in preference to fundamentally redesigning buildings from first principles for the following reasons:

- **fundamental redesign would introduce significant uncertainties concerning accurate construction costing into the analyses**
- **construction clients are, in general, reluctant to adopt untried and untested solutions that deviate from current practice**
- **solutions that meet reduced operational carbon emissions targets are required now and in the near future, i.e. 2013; the Target Zero findings suggest that these likely targets are relatively easily and cost effectively achievable using current, typical construction practice and proven low and zero carbon technologies.**

The base case building is then modelled using the following tools, to assess the impacts and costs of introducing a range of specific sustainability measures:

- **Operational Carbon – Integrated Environmental Solutions (IES) Part L compliant software (version 5.9)**
- **BREEAM 2008**
- **Embodied carbon – CLEAR Life Cycle Assessment model developed by Tata Steel RD&T.**

The complexities of sustainable construction assessment inevitably mean that there is overlap between these measures. Where relevant, impacts have been assessed consistently under Target Zero. For example, the operational carbon assessment is consistent with this aspect of BREEAM. Guidance is provided where a low and zero carbon target and a BREEAM rating are jointly or individually pursued on a project.

The results of the modelling and associated costing[2] are then used to develop the most cost-effective ways of achieving low and zero operational carbon buildings and buildings with 'Very Good', 'Excellent' and 'Outstanding' BREEAM ratings. See Appendix D.

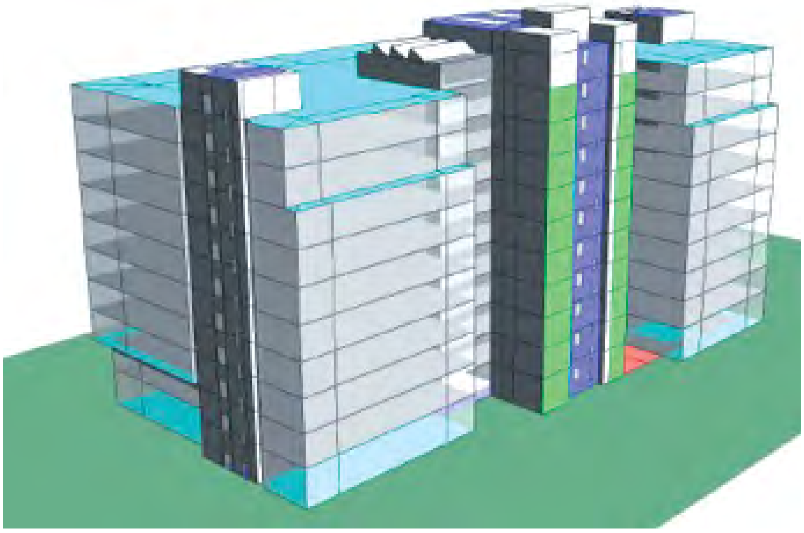
Sustainable construction is a rapidly evolving science. In the UK, designers face a plethora of new and changing initiatives that impact on their decision-making. These include Part L revisions, the definition of 'zero carbon', LZC technology development, BREEAM updates, feed-in tariffs, renewable heat incentive, etc. The Target Zero methodology was developed in 2009 and, as such, is based on the state-of-the art and on regulations in place at that time. Where appropriate and practical, the methodology has been adapted over the programme of research; for example this guide includes the impacts of the feed-in tariffs introduced in April 2010.

It is important to differentiate between operational carbon **compliance** and operational carbon **design** modelling. Part L compliance is based on the National Calculation Methodology (NCM) which includes certain assumptions that can give rise to discrepancies between the predicted and actual operational carbon emissions. Actual operational carbon emissions may be more accurately assessed and reduced using good thermal design software that is not constrained by the NCM.

The aim of Target Zero is to assess the most cost-effective ways of meeting future Building Regulation Part L requirements, and therefore the NCM has been used as the basis of the operational carbon assessments assisted, where appropriate, by further design modelling.

Alternative structural designs for each building were also developed to:

- **investigate the influence of structural form on operational energy performance**
- **provide the material quantities for the embodied carbon assessment**
- **compare capital construction costs.**



ONE KINGDOM STREET, DYNAMIC THERMAL SIMULATION MODEL

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[1] The Target Zero methodology was developed in 2009 and the office building operational carbon assessment was undertaken before the 2010 Part L requirements were established and the 2010 Part L compliance software became available.

[2] Costing of the base case office building was based on UK mean values current at 2Q 2010.

5.0 ONE KINGDOM STREET

ONE KINGDOM STREET

The building on which the office research is based is One Kingdom Street, located in the Waterside regeneration area near Paddington railway station in Central London. This Grade A office building was completed in 2008.

The building accommodates 24,490 m² of open-plan office space on ten floors and, on the eastern half of the building, two basement levels providing car parking and storage. The gross internal floor area is 33,018 m². The 40m high building is rectilinear with approximate dimensions of 81m x 45m. The front façade faces north and comprises a reverse ellipse along the length of the building plan on the podium and first floor levels.

One Kingdom Street has three cores and is designed around two central atria on its southern elevation, which house six scenic wall chamber lifts. The western half of the building is partly constructed on a podium transfer structure enclosing future works access for Crossrail.

The building was designed to achieve the maximum floor plate depth consistent with British Council for Offices (BCO) guidance. A typical office floor plate provides approximately 2,500m² of highly flexible space on a 1.5m planning grid.

One Kingdom Street has a steel frame, on a typical 12m x 10.5m grid, comprising fabricated cellular steel beams supporting a lightweight concrete slab on a profiled steel deck. The larger span is dictated by the location of beams within the Crossrail podium deck on which they are supported. The steel beams are designed to act compositely with the concrete floor slabs through the use of welded shear studs. The cellular floor system enables the services to be integrated within the structural zone, i.e. within web openings in the beams. The clear floor to ceiling height in the office areas is 2.8m.

Upper floors support a 175mm raised floor and a perforated metal tile suspended ceiling incorporating acoustic insulation.

The foundations comprise 750mm diameter bored-piled foundations with insitu concrete pilecaps. Ground beams provide lateral restraint to the pilecaps. The piles are the same size as those used to support the existing Crossrail podium in order to reduce potential differential settlement arising from the use of different pile diameters.

The office areas are clad with an anodised aluminium curtain walling system consisting of storey height double-glazed windows units on a 1.5m module. Vertical fins at 3m centres support the external aluminium louvres for solar shading on the southern elevation and part of the east and west elevations.

A ground source heat pump (GSHP) is the primary source of space heating and cooling to the building. Conventional heating and cooling plant provides for peak loads and backup in the event of a failure or scheduled maintenance of the GSHP. The ground source collector coils are integrated within the foundation piles.

Cooling is delivered to office spaces by fan-coil units with inverter-driven motors. The conventional (backup) cooling system comprises two air-cooled chillers mounted on the roof.

Heating is delivered to the office areas by the same fan-coil units used to deliver cooling. Heating is provided to other areas by central air handling units. The backup conventional heat source comprises three gas-fired condensing boilers which are also located at roof level. The building also has 116m² of roof-mounted solar panels providing hot water.

Ventilation is supplied to the office areas by the same fan-coil units which are supplied by the central air handling units. The air handling units include heat recovery in the form of thermal wheels. The WCs and changing rooms have dedicated extract only systems with the make-up air being provided by adjacent spaces. The atrium is provided with high level extract fans.

The office lighting is provided by T5 linear fluorescent tubes with manual switched controls. These are positioned to achieve a minimum illuminance level of 200lux at floor level.

ONE KINGDOM STREET, LONDON

5.1 BASE CASE OFFICE BUILDING

For the purposes of the Target Zero office building study, a base case building was defined based on One Kingdom Street, i.e. based on the same dimensions, specification, etc. as the actual building. Changes were then made to the fabric and services of the building to provide a base case office building that is no better than the minimum requirements under Part L (2006). These changes included:

- **the levels of insulation were reduced until these were no better than Criterion 2 of Part L (2006)**
- **HVAC system efficiencies were altered to industry standards, this included removing the ground source heat pump used to provide heating and cooling to the original building and removing the solar water heating system**
- **solar shading was removed and solar control glazing replaced with standard clear glazing. This change had the effect of causing the south stair core to overheat and so the level of glazing in this area was reduced to prevent this**
- **the air leakage value was increased from 8.9 to 9.0m^3/hr per m^2 @ 50Pa.**

The base case building model was then fine-tuned to pass Criterion 1 of Part L2A (2006) to within 1% by altering the energy efficiency of the lighting system to 2.5W/m^2 per 100lux.

In addition, the foundations were redesigned disregarding the abnormal constraints associated with the Crossrail works beneath the building. This was done to provide a more typical and representative base case.

More detail on the specification of the base case office building is given in Appendix A.

6.0 KEY FINDINGS

KEY FINDINGS

This section provides key findings from the Target Zero office building study and directs readers to relevant sections of the report.

The 2010 Part L compliance target of reducing operational carbon emissions by 25% is achievable by using a package of compatible, cost-effective energy efficiency measures, i.e. without the need for LZC technologies. These measures are predicted to yield a 42% reduction in regulated carbon emissions relative to the base case office building, at an increased capital cost of £172,400 and yield a 25-year net present value[1] (NPV) saving of £1,853,479 relative to the base case building performance. See Section 7.3.

Two, more advanced, packages of energy efficiency measures were selected that are predicted to reduce regulated carbon emissions by 52% and 55%. Both packages are predicted to be cost-effective over a 25-year period, i.e. yield a negative NPV (relative to the base case building), however the more advanced package is less attractive both in terms of capital and NPV cost. See Section 7.3.

Lighting was found to be the most significant regulated energy demand in the office building studied, accounting for around a quarter of the total operational carbon emissions. Consequently efficient lighting systems coupled with optimum glazing and solar shading design were found to be key in delivering operational carbon reductions. The complexity of the interaction between the glazing, lighting, heating and cooling in large office buildings requires detailed dynamic thermal modelling to develop an optimum low carbon solution. See Sections 7.4.

The proportion of operational carbon emissions from heating and cooling of the office building studied are very similar. Therefore, energy efficiency measures which impact this heating/cooling balance of the building are difficult to optimise. Measures to reduce heat loss or increase solar gains, reduce emissions from space heating but increase those from cooling. Similarly measures that increase heat loss or reduce solar gains, increase emissions from space heating and reduce those from cooling. See Sections 7.3 and 7.4.

The research found no single, on-site LZC technology, in conjunction with the most advanced energy efficiency package, which is predicted to achieve true zero carbon, i.e. a regulated carbon emissions reduction of 146%[2]. The greatest on-site reduction was 75% of regulated emissions which was achieved using fuel cell fired CCHP combined with a package of advanced energy efficiency measures (Package B – see Table 1). This solution is expensive however incurring a 10% capital cost increase and is not expected to save money, compared to the base case building, over a 25-year period. See Section 7.5.

Sixteen potential on-site solutions (compatible combinations of energy efficiency measures and LZC technologies) were identified. None of these is predicted to achieve true zero carbon. It is noted that the number of viable solutions identified is much lower than for other non-domestic buildings studied under Target Zero. This reflects the difficulty of integrating many low and zero carbon technologies into large, inner city office buildings.

[1] The NPVs of energy efficiency measures and LZC technologies combine the capital, maintenance and operational costs of measures and the net operational energy savings (relative to the base case building performance) that they yield over a 25-year period – see Appendix D. A negative NPV represents a saving over the 25-year period relative to the base case building.

[2] 146% is the reduction required to achieve true zero carbon for the case study office building since unregulated small power demands contribute 32% of the total operational carbon emissions – see Figure 5. Therefore to achieve true zero carbon a reduction equivalent to 146% of regulated emissions is required.

6.0 KEY FINDINGS

The greatest carbon reduction (79% of regulated emissions) is achieved by a package of advanced energy efficiency measures (Package C – see Table 1), 1,918m² of photovoltaic panels mounted on the roof and on the southern façade, a 6kW roof-mounted wind turbine and a biomass-fuelled CCHP unit supplying heating, hot water, power and cooling. The additional capital cost of this solution is £4,594,851 (7.4% of capital cost) and does not save money, relative to the base case building, over 25 years. See Section 7.5

Based on the assessment of this office building, the most cost-effective on-site routes to likely future low and zero operational carbon targets are as shown in Figure 1. Likely future targets are discussed in Sections 7.1 and 7.2.

The analysis has demonstrated that it is technically challenging and costly to achieve greater than a 44% reduction in regulated carbon emissions (relative to 2006 Part L minimum requirements) using energy efficiency and on-site LZC technologies. As such, greater reliance on offsite and Allowable Solutions will be required for large city centre office buildings compared to other commercial building types. See Sections 7.6 to 7.8.

BREEAM [1] is the leading and most widely used environmental assessment method for buildings in the UK. The estimated capital cost uplift of the base case office building was (see Section 8.1):

- **0.17% to achieve BREEAM 'Very Good'**
- **0.77% to achieve BREEAM 'Excellent'**
- **9.83% to achieve BREEAM 'Outstanding'.**

The base case building capital construction cost (2Q 2010) was estimated by independent cost consultants to be £61.7m (£1,869/m²). See Section 9.

The impact of the structure on the operational carbon emissions of the base case office building was found to be small; the Building Emissions Rate (BER)[1] varying by just 0.05% between a steel-frame composite (base case) and a post-tensioned concrete structure (Option 1). See Section 9.1.

The effect of exposing the thermal mass in the upper floors on operational carbon emissions was assessed by removing the suspended ceilings. The difference in BER was predicted to be 0.9% between a steel-frame composite (base case) and a post-tensioned concrete structure (Option 1). See Section 9.1.

Relative to the base case building, an equivalent post-tensioned concrete structure office building (Option 1) had a higher (11.9%) embodied carbon impact and is 72% heavier. See Section 10.

ONE KINGDOM STREET, LONDON

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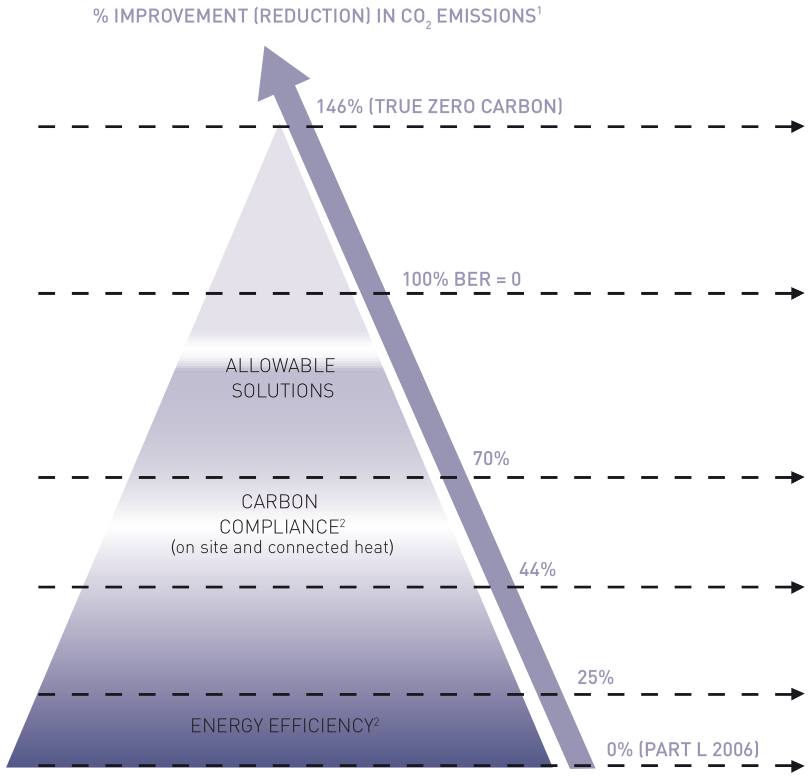
[1] The Building Emission Rate (BER) is defined by the National Calculation Methodology (NCM) as the amount of carbon dioxide emitted per square metre of floor area per year as the result of the provision of heating, cooling, hot water, ventilation and internal fixed lighting.

6.0 KEY FINDINGS

FIGURE 1
SUMMARY OF THE MOST COST-EFFECTIVE ENERGY EFFICIENCY AND LZC OPERATIONAL CARBON ROUTES FOR THE BASE CASE OFFICE BUILDING
(FOR EXPLANATION OF ENERGY EFFICIENCY, CARBON COMPLIANCE AND ALLOWABLE SOLUTIONS, SEE SECTION 7.1)



ENERGY EFFICIENCY MEASURES	LZC TECHNOLOGIES	ADDITIONAL CAPITAL COSTS[3] (£)	25 YEAR NET PRESENT VALUE[3] (£)
No on-site routes identified			
No on-site routes identified			
PACKAGE C: Reduced glazing[4] Daylight dimming lighting controls Improved boiler efficiency to 95% Improve wall insulation to 0.25 W/m²K Very high efficiency lighting to 1.5 W/m² per 100lux Improved chiller efficiency SEER = 8 Occupancy sensing lighting controls Improved ventilation heat recovery (85% efficient) Radiant heated/chilled ceiling Improved glazing U-value to 1.6W/m²K Specific fan powers reduced by 40% Ultra air tightness 3m³/hr per m² @50Pa Louvres/Overhangs on South facade Reduced thermal bridging Solar control glass on the South, East and West facades	Refrigeration heat recovery 1,918m² photovoltaics[5] 6kW roof-mounted wind turbine Single cycle air source heat pump	3,930,058 [+6.4%]	-83,067
PACKAGE A: Reduced glazing[4] Specific fan powers reduced by 20% Daylight dimming lighting controls Improved chiller efficiency SEER = 6 Improved boiler efficiency to 95% Improved lighting efficiency to 2.0 W/m² per 100lux Improve wall insulation to 0.25 W/m²K Active chilled beams		1,013,569 [+1.6%]	-1,699,663
Package A (see above) but excluding active chilled beams		-863,400 [-1.4%]	-2,658,056
Base case building			

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1 The trajectory to zero carbon for non-domestic buildings is subject to further consultation. Figure is not to scale

2 The Energy Efficiency and Carbon Compliance standards for non-domestic buildings are subject to further consultation

3 Relative to the base case building

4 Full height glazing (3.9m) reduced by 2m

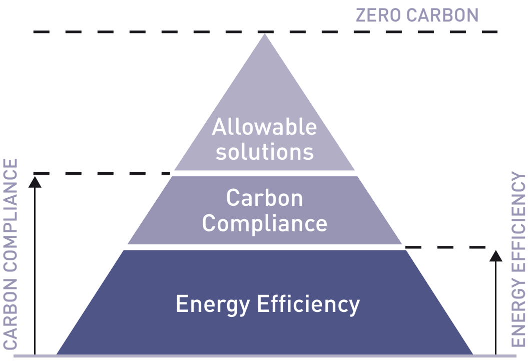
5 1026m² roof mounted; 892m² façade mounted

ROUTES TO LOW AND ZERO OPERATIONAL CARBON

The objective of this aspect of the work was to develop cost-effective, low and zero operational carbon solutions that meet the Government's aspirations for 'zero carbon' non-domestic buildings and the projected compliance targets on the roadmap to 'zero carbon', i.e. the 2010 and the proposed 2013 Part L compliance targets. The approach taken to the assessment of low and zero operational carbon solutions is described in Appendix A.

Operational carbon is the term used to describe the emissions of greenhouse gases during the operational phase of a building. Emissions arise from energy consuming activities including heating, cooling, ventilation and lighting of the building, so called 'regulated' emissions under the Building Regulations Part L, and other, currently 'unregulated' emissions, including appliance use and small power plug loads such as IT. These appliances are not currently regulated because building designers generally have no control over their specification and use and they are likely to be changed every few years.

FIGURE 2
THE GOVERNMENT'S HIERARCHY FOR MEETING A ZERO CARBON BUILDINGS STANDARD



7.1 WHAT IS ZERO CARBON?

The Government has announced its aspiration for new non-domestic buildings to be zero carbon in operation by 2019 and is consulting on the definition of 'zero carbon' buildings.

The Government supports a hierarchical approach to meeting a zero carbon standard for buildings, as shown in Figure 2. The approach prioritises, in turn:

- **Energy Efficiency measures - to ensure that buildings are constructed to very high standards of fabric energy efficiency and use efficient heating, cooling, ventilation and lighting systems. The current proposal [3], following the precedent set for domestic buildings[1], is to set a standard for energy efficiency based on the delivered energy required to provide space heating and cooling (kWh/m²/yr). The level for this standard has currently not been set for non-domestic buildings.**
- **Carbon Compliance on or near site. This is the minimum level of carbon abatement required using energy efficiency measures plus on-site LZC measures or directly connected heat or coolth.**
- **Allowable Solutions – a range of additional beneficial measures to offset 'residual emissions', for example exporting low carbon or renewable heat to neighbouring developments or investing in LZC community heating.**

As a minimum, Government has stated [3] that 'the zero-carbon destination for non-domestic buildings will cover 100% of regulated emissions', i.e. a Building Emissions Rate (BER) of zero.

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[1] The standards set for dwellings are likely to be fully implemented in 2016 with an interim step introduced in 2013 [4].

7.2 BUILDING REGULATIONS PART L

Part L of the Building Regulations is the mechanism by which operational carbon emissions are regulated in UK buildings and it has a key role to play in defining suitable intermediate steps on the trajectory towards zero carbon buildings.

The 2006 revisions to Part L required a 23.5% saving over the 2002 standards for fully naturally ventilated spaces and 28% savings for mechanically ventilated and cooled spaces. Revisions to Part L in 2010 require a further 25% (average) reduction in regulated carbon emissions over the 2006 requirements for non-domestic buildings. In recognition of the variation in energy demand profiles in different non-domestic building types and hence the cost effectiveness of achieving carbon emission reductions in different building types, Part L (2010) adopts an 'aggregate' approach for non-domestic buildings. Under this approach, it is expected that large city centre office buildings will be required to achieve smaller operational carbon emission reductions than the 'average' 25%; results of recent modelling [10] suggest a possible target reduction of 19%. However, this target is indicative only as it depends upon many variables and therefore the actual reduction required will be building specific. Section 7.9 shows the likely impact of the 2010 Part L Regulations on the Target Zero results.

Changes in 2013 and beyond for non-domestic buildings will be the subject of consultation but it is expected that further thresholds will be set similar to those for dwellings. These are expected to include an average 44% improvement over 2006 requirements in 2013.

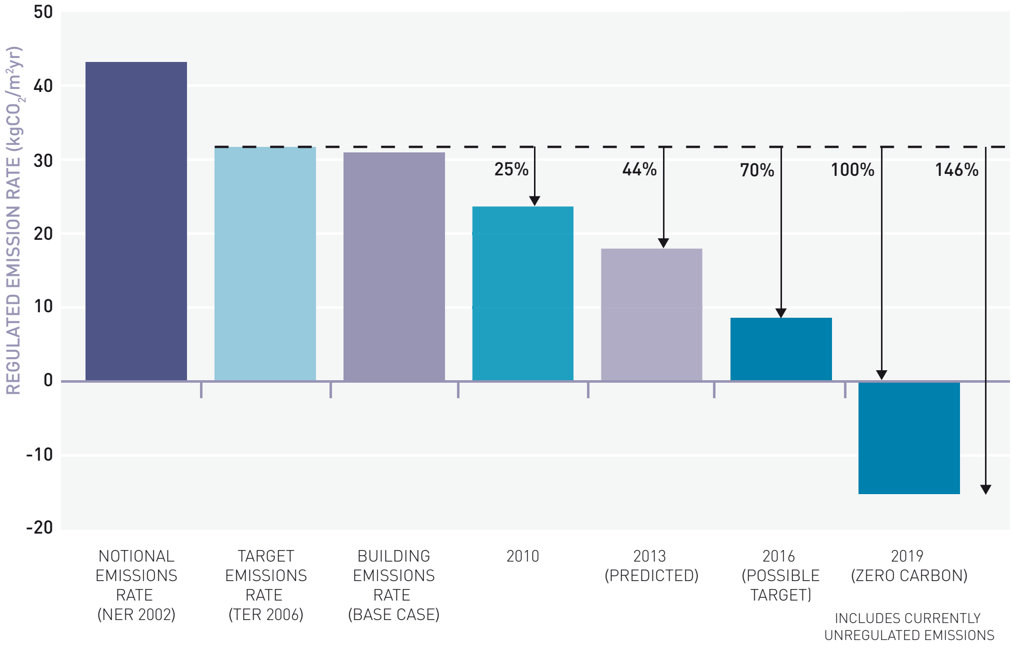
Figure 3 shows how the requirements of Part L have changed since 2002 and shows possible further reduction requirements on the trajectory to zero carbon non-domestic buildings. The emission rates shown relate to the base case office building.

Within Target Zero, the operational carbon emissions results for the office building analysed are presented with the 'flat' 25%, 44%, 70%, 100% (BER =0) and 146% (true zero carbon) reduction requirements in mind. Setting of these reduction targets predates the Government's consultation on policy options for new non-domestic buildings [3] published in November 2009. The 70% reduction target was based on the domestic building carbon compliance target. A reduction in regulated carbon emissions of 146% is required to achieve true zero carbon for the case study office building, i.e. one in which the annual net carbon emissions from **both** regulated and unregulated energy consumption are zero or less.

The 2010 Part L requirements stipulate that a prescriptive methodology, known as the National Calculation Methodology (NCM), should be used to assess the operational carbon emissions from buildings. The aim of Target Zero is to assess the technical and financial impacts of meeting future Building Regulation Part L requirements, and therefore the NCM has been used as the basis of this research. The assessed total operational carbon emissions for the base case office building (see Section 5.1) were 1,455 tonnes CO_2 per year using the NCM within the IES dynamic thermal modelling software.

FIGURE 3

INDICATIVE GRAPH OF PAST AND POSSIBLE FUTURE PART L CHANGES

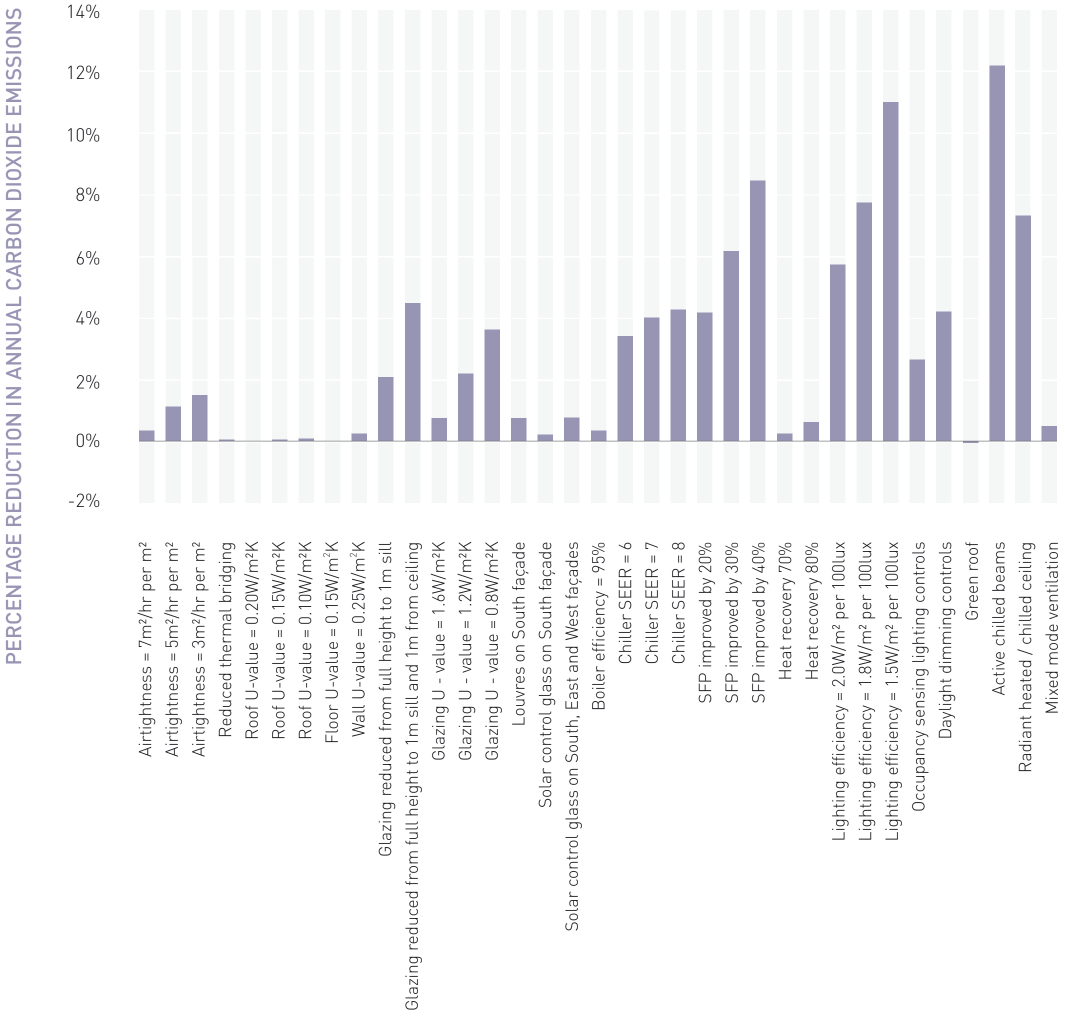


7.3 ENERGY EFFICIENCY

Figure 4 shows the modelled reductions in operational carbon dioxide emissions achieved by introducing the individual energy efficiency measures defined in Appendix B into the base case office building. The results show that the measures with the greatest predicted impact are those related to space cooling and fan and lighting efficiencies. Most of the building fabric improvements modelled were found to yield only small reductions in carbon dioxide emissions. The introduction of a green roof was predicted to yield a very small increase in emissions.

FIGURE 4

REDUCTION IN ANNUAL CARBON DIOXIDE EMISSIONS ACHIEVED BY INTRODUCING ENERGY EFFICIENCY MEASURES (RELATIVE TO THE BASE CASE BUILDING)



7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

The energy efficiency measures which affect the heating/cooling balance of the office building are difficult to optimise. This is because the proportion of annual carbon emissions from space heating and cooling are approximately equal - see Figure 5 which gives the breakdown of carbon dioxide emissions by energy demand in the base case building.

As a consequence, energy efficiency measures which tend to reduce fabric heat losses or increase solar gains will reduce the emissions from space heating, but also increase those from cooling. Similarly measures which increase heat loss or reduce solar gain will increase the emissions from space heating but reduce those from cooling.

The results shown in Figure 4 take no account of cost and therefore the energy efficiency measures have been ranked (see Figure 6) in terms of their cost effectiveness, i.e. 25-year NPV per kg of CO_2 saved per year relative to the base case building performance (see Appendix D).

FIGURE 5

BREAKDOWN OF CARBON DIOXIDE EMISSIONS FOR THE BASE CASE OFFICE BUILDING

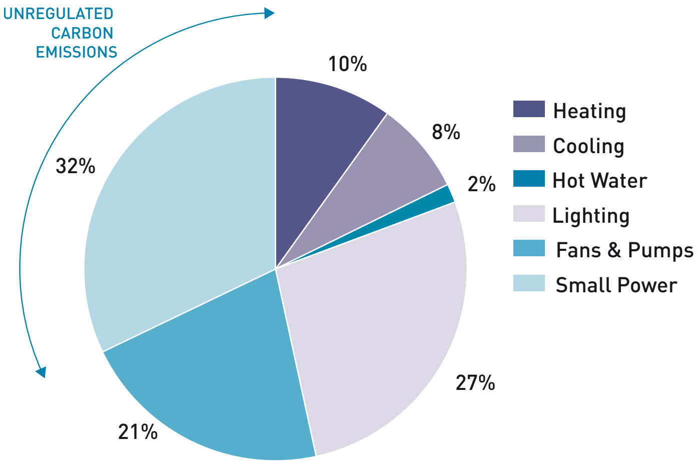
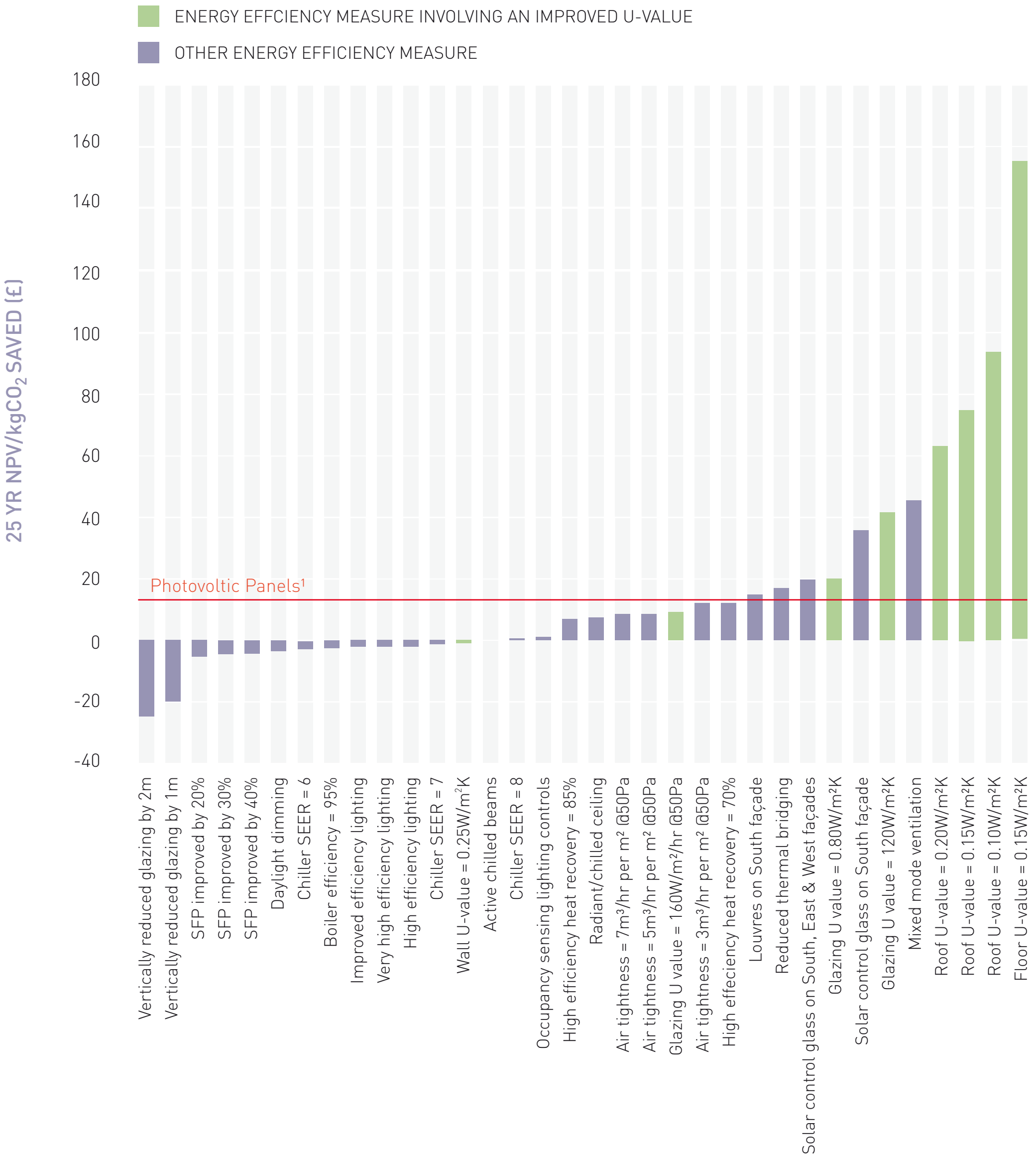


FIGURE 6

COMPARISON OF NPV COST EFFECTIVENESS OF MODELLED ENERGY EFFICIENCY MEASURE



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[1] This line represents the cost effectiveness of photovoltaic panels excluding the effect of the Feed-in tariffs.

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

Figure 6 shows that the energy efficiency measures involving an improvement to the fabric thermal insulation performance of building elements (green bars in the figure) are generally not very cost-effective, i.e. they have a high NPV cost per kgCO$_2$ saved. This is largely because the addition of thermal insulation increases the cooling load in summer as well as reducing the heating load in winter. Therefore the net carbon saving from such measures is relatively small and their cost effectiveness is relatively low.

The ranked measures shown in Figure 6 were then grouped into three energy efficiency packages, each one representing a different level of additional capital investment; low, medium and high (see Appendix B).

Packages were carefully checked to ensure that all of the energy efficiency measures were cost-effective and compatible with each other. Some measures were 'stepped-up' between packages despite their cost effectiveness ranking – see Figure 7. For example, Package A includes a 20% improvement to specific fan power, whereas this measure is 'stepped up' in Packages B and C to improvements of 30% and 40% respectively. A similar approach was adopted for the lamps and luminaires and for airtightness.

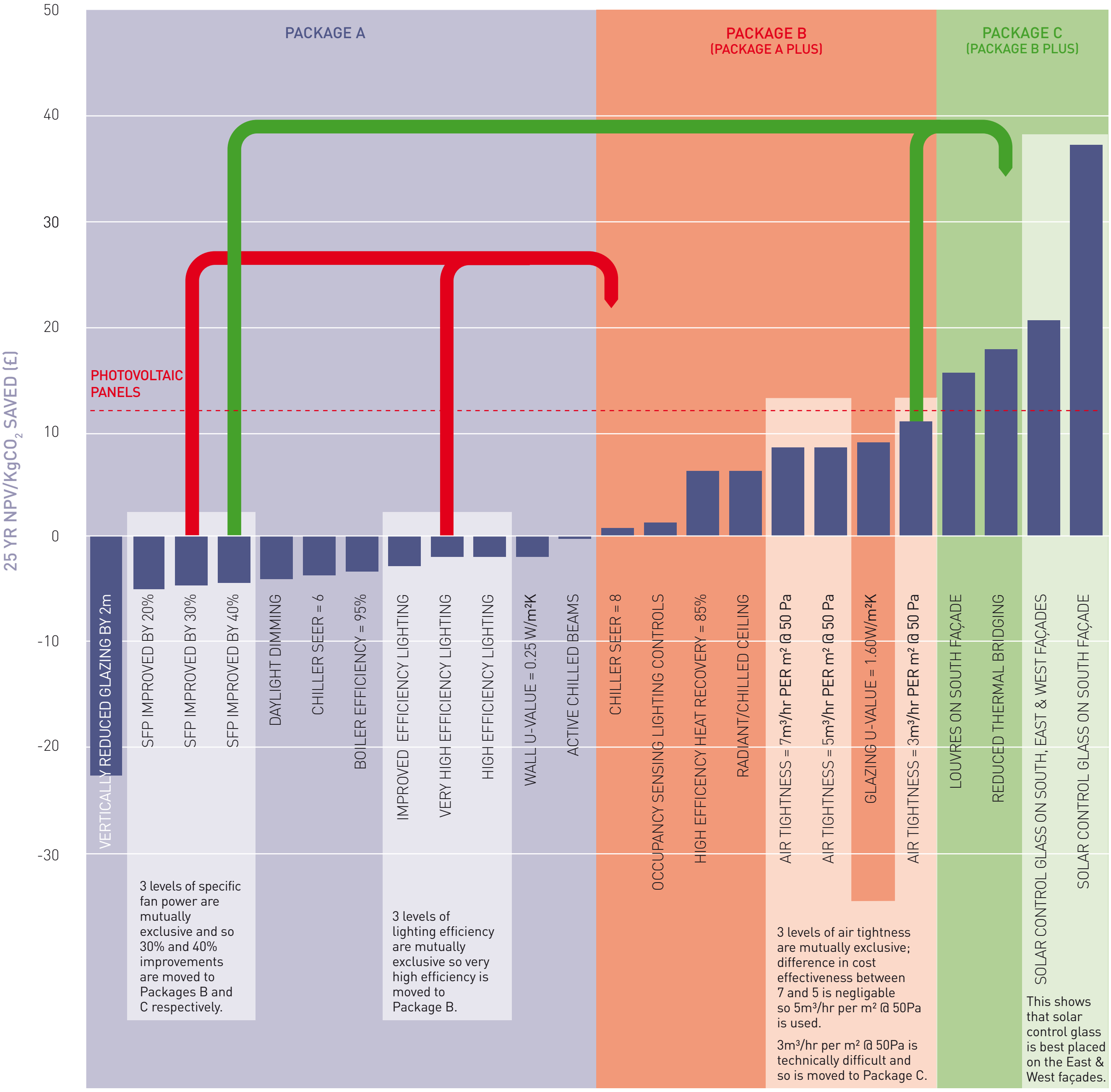
Note: Package B includes all the measures in Package A or, where relevant (e.g. lighting efficiency), supersedes them. Similarly, Package C contains (or supersedes) all the measures in Packages A and B.

Figure 7 shows the individual measures included within the three energy efficiency packages applied to the base case office building.

It should be noted that the high efficiency lighting option was found to be less cost-effective than the very high efficiency lighting and so this measure was not included in any packages.

FIGURE 7

ENERGY EFFICIENCY MEASURE PACKAGES A, B AND C



3 levels of specific fan power are mutually exclusive and so 30% and 40% improvements are moved to Packages B and C respectively.

3 levels of lighting efficiency are mutually exclusive so very high efficiency is moved to Package B.

3 levels of air tightness are mutually exclusive; difference in cost effectiveness between 7 and 5 is negligable so 5m³/hr per m² @ 50Pa is used.

3m³/hr per m² @ 50Pa is technically difficult and so is moved to Package C.

This shows that solar control glass is best placed on the East & West façades.

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

FIGURE 8
RESULTS FOR ENERGY EFFICIENCY PACKAGES A, B AND C

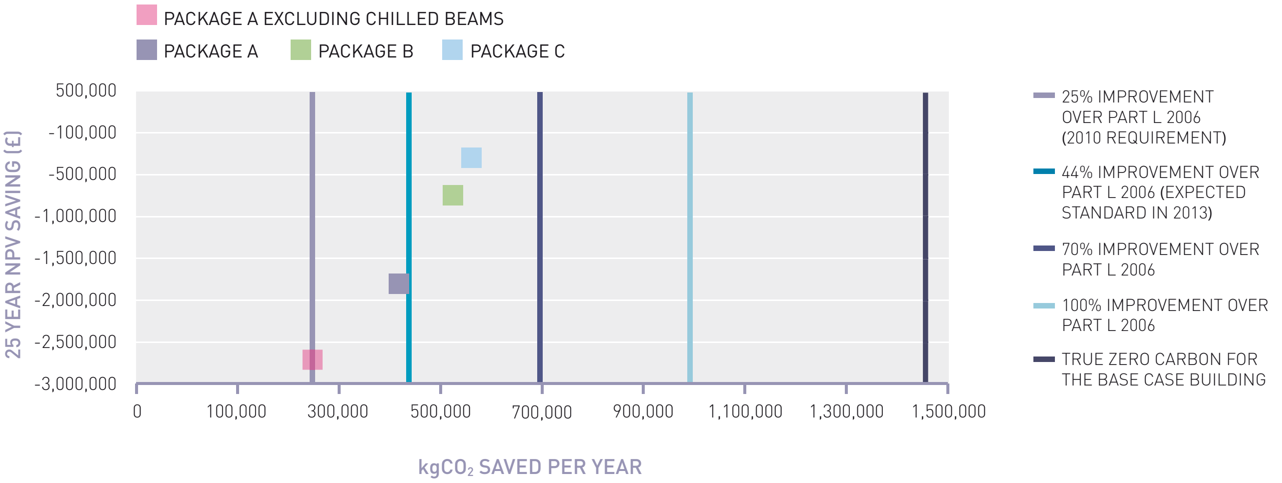


Figure 8 shows the predicted performance of Energy Efficiency Packages A, B and C plotted on axis representing carbon emissions saved per year (relative to the base case building) against 25-year NPV (relative to the base case building performance) and with reference to future likely Part L compliance targets.

The figure shows that the 25% (average) reduction in regulated carbon dioxide emissions, which is required to comply with the 2010 regulations, can be surpassed through the use of Package A energy efficiency measures alone. In fact the 25% reduction target can be achieved by applying a subset of Package A, i.e. all Package A measures but excluding the active chilled beams. These measures achieve a 25.1% reduction in regulated emissions and save £863k in capital cost relative to the base case building[1]. See also Section 7.9 which discusses the impact of the Part L 2010 NCM on operational carbon emissions reduction targets.

The current expectation is that in 2013, the Part L target will be a reduction of 44% relative to the 2006 requirement; energy efficiency Packages B and C also achieve this target. However, this target can be achieved more cost effectively using LZC technologies combined with Package A, where site conditions allow – see Section 7.5.

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[1] The capital cost of the Package A energy efficiency measures (relative to the base case building) is dominated by a saving of £1,290.6k for the reduced glazing and a cost of £1,035.8k for the introduction of active chilled beams.

The three energy efficiency packages are fully defined in Table 1 along with the modelled operational carbon emissions savings (relative to the base case building) from their introduction into the base case office building. The table also gives the capital cost and 25-year NPV of the three packages of measures relative to the base case building performance.

TABLE 1

OPERATIONAL CARBON EMISSIONS AND COST (CAPITAL AND NPV) FOR ENERGY EFFICIENCY PACKAGES A, B AND C

OPTION	ENERGY EFFICIENCY MEASURES	TOTAL OPERATIONAL CO_2 EMISSIONS ($kgCO_2$/ YR) [CHANGE FROM BASE CASE TOTAL EMISSIONS] [CHANGE FROM BASE CASE REGULATED EMISSIONS]	CHANGE IN CAPITAL COST FROM BASE CASE (£) [%]	CHANGE IN 25 YEAR NPV FROM BASE CASE (£)
Base case building	Defined in Section 5.1 and Appendix A	1,455,047	-	-
Package A	Vertically reduced glazing by 2m Specific fan powers reduced by 20% Daylight dimming lighting controls Improved chiller efficiency SEER = 6 Improved boiler efficiency to 95% Improved lighting efficiency to 2.0W/m^2 per 100lux Improve wall insulation to 0.25W/m^2K Active chilled beams	1,037,072 [-29%] [-42%]	172,400 [0.28%]	-1,853,479
Package A-	As above but excluding active chilled beams	1,206,256 [-17%] [-25%]	-863,400 [-1.4%]	-2,658,056
Package B	Package A plus (or superseded by): Specific fan powers reduced by 30% Very high efficiency lighting to 1.5W/m^2 per 100lux Improved chiller efficiency SEER = 8 Occupancy sensing lighting controls Improved ventilation heat recovery (85% efficient) Radiant heated/chilled ceiling Improved glazing U-value to 1.6W/m^2K Very high air tightness 5m^3/hr per m^2 @ 50Pa	938,463 [-36%] [-52%]	1,789,900 [2.90%]	-690,416
Package C	Package B plus (or superseded by): Specific fan powers reduced by 40% Ultra air tightness 3m^3/hr per m^2 @ 50Pa Louvres/Overhangs on South façade Reduced thermal bridging Solar control glass on South, East and West façades	908,873 [-38%] [-55%]	2,191,000 [3.55%]	-376,051

The reduction in carbon dioxide emissions resulting from implementing the energy efficiency packages ranges from 42% of regulated emissions (29% of total emissions) with an increased capital cost of 0.28% up to 55% of regulated emissions (38% of total emissions) with an additional capital cost of 3.55%. All three packages are predicted to save money (relative to the base case building) over a 25-year period, i.e. they have a negative NPV.

Despite the greater reduction in operational carbon emissions afforded by Package C, the economic performance of this is not attractive, i.e. it incurs a greater capital cost and yields a lower whole life saving than Package B. Therefore to reduce operational carbon emissions, beyond those achieved using energy efficiency Package B, LZC technologies can be shown to be more cost-effective than implementing Package C measures – see Section 7.5.

RECOMMENDATION

The targets for operational carbon reduction in office buildings required from 2010 as a result of changes to Part L can be achieved by using energy efficiency measures only, i.e. without LZC technologies. The package of measures predicted to achieve the 2010, 25% reduction target most cost effectively is energy efficiency Package A excluding active chilled beams – see Table 1.

Clients and their professional advisers, need to assess (and balance) both the capital and whole life costs of potential energy efficiency measures. Packages of relatively low capital cost energy efficiency measures can yield significant long-term savings, particularly those that are low maintenance.

7.4 GLAZING AND SOLAR CONTROL

The effect of glazing design on a building is complex; it impacts the heating, cooling and lighting requirements in different ways at different times of day and year.

The 2010 revision to Part L of the Building Regulations includes a significant change to Criterion 3[1] of the regulation. Criterion 3 of the 2006 Part L required that occupied rooms should not overheat; this meant that cooled rooms passed (automatically) and that an overheating assessment needed to be carried out only for rooms without cooling. The 2010 version of Part L sets a limit on the amount of solar gain which enters the building from April to September. The precise requirement is that the solar gain in a side lit room should be less than, or equal to, the gain that would be experienced if that room was east-facing with 1m high glazing across its width with a G-value of 0.68 and a 10% frame factor. This is intended to discourage highly glazed façades or, where they are used, encourage the use of shading devices such as louvres, brise soleil and blinds.

The base case office building, like One Kingdom Street, has full height glazing but does not have any external solar shading. Consequently it could fail Criterion 3 of Part L 2010, although the use of internal blinds might still allow the building to pass this criterion.

The main advantage to increasing the glazed area is to reduce the energy used for lighting. However, for each building there is a point where this improvement will be cancelled out by the increased requirement for space heating as glazing releases more heat than opaque constructions. Table 2 outlines the key effects of increasing the area of glazing.

TABLE 2
EFFECTS OF INCREASING THE GLAZED AREA

EFFECTS	POSITIVE EFFECTS	NEGATIVE EFFECTS	NOTES
Solar heat gain increases	Space heating requirement reduces during daylight hours	Cooling load increases	Reducing the G-value will reduce the solar gain
Fabric heat loss through glazing increases	Cooling load reduces	Space heating requirement increases	Reducing the U-value will reduce the fabric heat loss
Natural light level increases	If daylight dimming is used then the energy used for lighting will decrease	Reduced use of electric lighting will increase the requirements for space heating	Improving the efficiency of the lighting will also reduce the heat gain from lighting

In terms of good glazing design the benefit of specifying glazing down to floor level is minimal. Daylight factors are measures on the working plane, i.e. at desk height, and so having glazing below this level is of little benefit.

The case study office building is deep plan[2] and so the effect of glazing is less dominant than it would be in a shallow plan building. For example the effect of daylight dimming lighting controls is of little benefit more than around 6m from the perimeter of the building; 55% of the office floor area in the base case building is 6m or more from a window.

The hours of operation of office buildings also have a significant impact on the usefulness of glazing. During the hours of darkness, glazing serves only to release heat, releasing more heat through conduction than opaque envelope elements. Whereas, during daylight, glazing provides both light and some benefit from solar heat gains which may help to reduce heating loads. Therefore the more hours of darkness during which the building is used, the lower the optimal glazed area will be. The NCM defines that offices should be assessed with occupancy from 7am to 7pm Monday to Friday. Therefore, offices with longer hours of operation, may not be accurately assessed under the NCM. During unoccupied hours the NCM defines that the heating set point reduces to 12°C (from the occupied set point of 22°C). In practice, the night time temperature rarely falls to 12°C and so the effect of night time heat losses on the heating load is reduced.

Two alternative[3] glazing strategies were modelled as part of this study:

- **glazing with a 1m sill height, i.e. 1m above finished floor level**
- **glazing with a 1m sill height and the head height dropped by 1m.**

In addition, the solar control measures shown in Table 3 were modelled.

TABLE 3
MODELLED SOLAR CONTROL MEASURES

SOLAR CONTROL MEASURE	DESCRIPTION
Solar control glass on the south façade only and on the south, east and west façades	G-value reduced from 0.64 to 0.40 Light transmittance reduced from 0.76 to 0.60
Louvres on the south façade	Horizontal projections 1m deep Spaced at 1m vertical intervals
Overhangs on the south façade	Horizontal projection 1.65m deep Projecting from 0.95m above the window head height

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[1] Criterion 3 of Approved Document L2A concerns limiting the effects of solar gain in summer.

[2] There is no formal definition of what constitutes a deep or shallow plan office building. BREEAM uses a threshold of 7m, i.e. if no part of the floor is more than 7m from an external wall then the building is deemed to be shallow plan otherwise it is deemed to be deep plan. For example, a double-sided office may be 14m wide before it is considered to be deep plan.

[3] The full height glazing in the base case building is 3.9m high.

In addition to louvres, shading provided by overhangs was also modelled. Overhangs have the advantage that it is far easier to mount standard size photovoltaic panels onto overhangs than on louvres. By providing both solar shading and support for photovoltaic panels, this measure can be very cost-effective. It was only possible to model this measure in scenarios where the glazing height was reduced.

The geometry of the overhangs was determined in part by experience and in part through inspection of the sun path diagram for the building's location. The sun path diagram reveals that the sun angle in midsummer exceeds 60° for a few weeks and so the shading is positioned to fully shade the glazing when the sun is above this angle. The optimal geometry for the solar shading was calculated to be a projection of 1.65m located 0.95m above the window head.

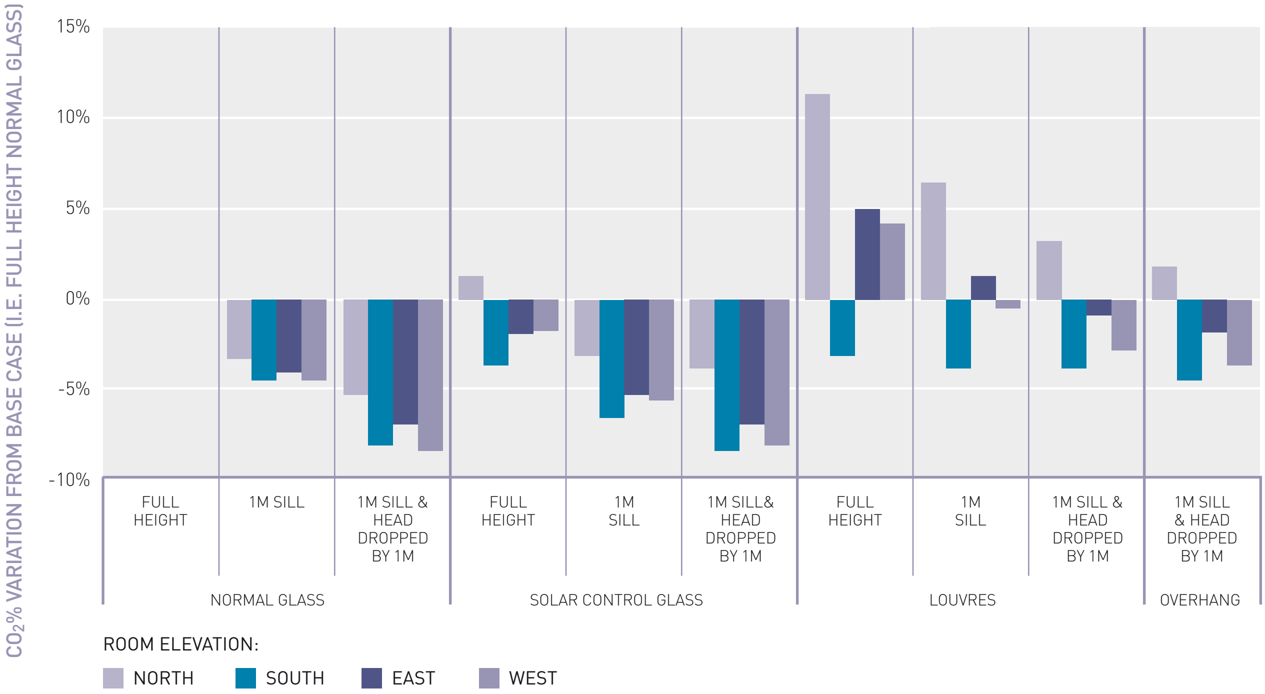
A series of dynamic thermal simulations were run on a sample office space based on an 8.2m deep dummy room. Daylight dimming lighting controls were included in all cases. The results of this glazing analysis are shown in Figure 9.

RECOMMENDATION

Good design of glazing and solar control measures is very important to achieve low operational carbon office buildings and as such, dynamic thermal modelling should be used to produce an optimum solution on a project specific basis.

FIGURE 9

RESULTS OF THE GLAZING ANALYSIS



The analysis found that, when the effect of daylight dimming controls is taken into account, the greatest saving could be achieved by reducing the glazed area by having a 1m sill and dropping the head height by 1m.

Figure 9 also shows that the use of solar control measures on the north façade is always less effective than their use on other facades, in many cases using solar control on the North façade was found to increase carbon dioxide emissions. Other observations from the analyses include:

- **solar control glass was found to reduce emissions slightly more than using normal clear glass and much more than louvres**
- **louvres and overhangs are best placed on the southern façade**
- **although louvres were found to save less carbon than solar control glass, they were found to be more cost-effective, see Figure 6.**

7.5 ON-SITE LZC TECHNOLOGIES

Twenty four on-site LZC technologies were individually modelled on each of the three energy efficiency packages defined in Section 7.3 – see Table C1 in Appendix C. Some technologies were modelled as both large and small-scale installations, for example CHP systems were modelled as large-scale to supply space heating and hot water to the whole building and as small-scale, sized to supply hot water only. The methodology used to assess and compare LZC technologies and different combinations of technologies, is described in Appendices C and D.

The research found that no single, on-site LZC technology (in conjunction with appropriate energy efficiency measures) is predicted to achieve true zero carbon, i.e. a 146% reduction in regulated emissions. The greatest on-site reduction, using just one on-site technology, is 75% of regulated emissions (51% of total carbon emissions) achieved by using fuel-cell-fired CCHP combined with Energy Efficiency Package B[1]. Therefore, assessment of a range of viable combinations of LZC technologies was undertaken to identify the most cost-effective packages of compatible measures to achieve the likely future Part L compliance targets. Further information and guidance on the cost effectiveness of individual on-site LZC technologies is given in Section 7.10.

There are a number of technologies which are not compatible with each other; these are all LZC technologies which supply heat. If surplus electricity is generated on-site then this can be sold to the national grid for use in other buildings. The infrastructure for doing this with heat is more complex, expensive, harder to manage and relies on having a close neighbour with an appropriate heat requirement. The normal approach is to either size or operate the system so that surplus heat will not be produced, or to 'dump' any surplus heat using a heat rejection plant.

Sixteen on-site solutions (packages of compatible energy efficiency and on-site LZC technologies) were identified for the base case office building. None of these is predicted to achieve zero carbon.

The greatest on-site reduction in carbon emissions is predicted to be achieved using Energy Efficiency Package C coupled with 1,918m^2 of photovoltaics mounted on the roof and as shading devices on the southern façade, a 6kW roof-mounted wind turbine and biomass-fired CCHP. This solution is predicted to achieve a reduction in regulated emissions of 79% (54% of total carbon emissions). The additional capital cost of this package of measures is estimated to be £4,594,851 (7.4% of the base case building capital cost) and is predicted, over 25 years, to add to the cost of the base case building with a change in NPV of +£932,661. It is however unlikely that biomass-based technologies would be viable or acceptable in city centre office buildings.

RECOMMENDATION

The use of multiple LZCs which provide heat increases the risk of surplus heat being produced and therefore reduces the whole life cost effectiveness of the technologies. Therefore when combining LZCs to create on-site solutions, care must be taken to avoid the selection of LZCs which are less cost-effective than viable energy efficiency measures as well as avoiding the selection of incompatible LZCs.

TABLE 4

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

TARGET	MOST COST-EFFECTIVE ROUTE	BER (KGCO$_2$/M^2 YR)	CHANGE IN CAPITAL COST (£)	25-YEAR NPV COST (£)
Base case building	-	31.5	-	-
2010 revision to Part L requiring a 25% improvement over Part L 2006	Energy Efficiency Package A excluding active chilled beams/slabs (see Table 1)	23.6	-863,400[1] [-1.4%]	-2,658,056
Likely 2013 revision to Part L requiring a 44% improvement over Part L 2006	Solution A5 comprising: Energy Efficiency Package A (see Table 1) Refrigeration heat recovery 1,026m2 photovoltaics	15.12	1,013,569 [+1.6%]	-1,699,663
Possible on-site Carbon Compliance threshold: 70% improvement over Part L 2006	Solution C1 comprising: Energy Efficiency Package C (see Table 1) Refrigeration heat recovery 1,918m^2 photovoltaics[2] 6kW roof-mounted wind turbine Single cycle air source heat pump	8.83	3,930,058 [+6.4%]	83,067
100% improvement over 2006 Part L (excludes unregulated emissions)	No on-site routes identified			
True zero carbon (expected standard for non-domestic buildings in 2019) i.e. 146% improvement on Part L 2006	No on-site routes identified			

[1] This large reduction in capital cost, relative to the base case, is achieved by reducing the full height glazing by 2m on each floor.

[2] This additional area of photovoltaics is possible because of the availability of overhangs on the southern elevation when Package C is specified.

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1 The greatest on-site emissions reduction is achieved using Package B rather than Package C. This is because the space heating and cooling loads using Package C are less than those of Package B and therefore the running time of the CCHP unit (and hence the carbon saving) is reduced when used with Package C.

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

The selected packages of compatible measures which meet the likely future compliance targets most cost effectively are graphically illustrated in Figure C1 in Appendix C and fully defined in Table 4.

The research found that a great reduction in carbon dioxide emission can be achieved on-site; however the costs of doing this begin to become restrictive as the carbon savings increase. For example it is predicted to be possible to achieve a 44% improvement over the 2006 Part L minimum requirement at a capital cost rise of 1.6%, however to improve this to a 70% improvement requires an additional capital investment of around 6%. Getting beyond the 70% reduction threshold increases capital costs further and becomes technically very difficult.

RECOMMENDATION

Offsite and Allowable Solutions and directly connected heat will play a significant role in achieving low and zero carbon targets for city centre office buildings – see Sections 7.6 to 7.8.

ONE KINGDOM STREET LOBBY

7.6 OFFSITE LZC TECHNOLOGIES

Offsite LZC technologies are those which are either too large to fit on the site, or those which are sized to supply multiple buildings, for example district heating schemes. Larger LZC installations tend to be more cost-effective than on-site solutions and so, if offsite LZCs are permitted as Allowable Solutions (see Sections 7.1 and 7.8), then these are likely to be more attractive than on-site solutions. In addition, some technologies such as district heating, may be included within Carbon Compliance targets – see Section 7.7.

The offsite technologies modelled are shown in Table C1 in Appendix C. For the large offsite wind turbines (5.0MW (offshore) and 2.5MW (onshore)) it was assumed that an investment in an appropriate share of the turbine would be made. The share would be sufficient to offset all of the modelled carbon emissions.

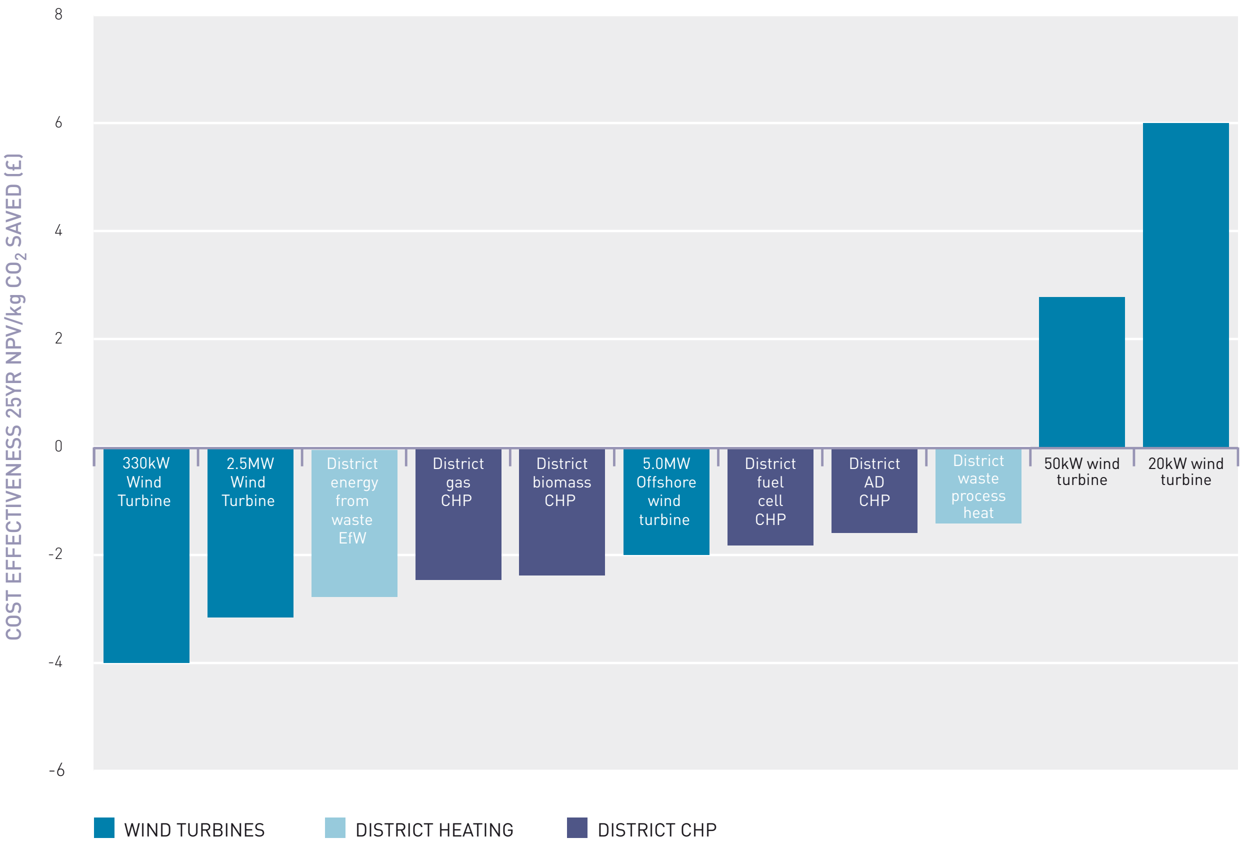
The only offsite solutions theoretically able to achieve a 100% reduction in regulated carbon emissions and true 'zero carbon', are large wind turbines. It should be noted that the wind turbine has been modelled, in accordance with the NCM, as if it was erected on the same site as the office building and in reality its output would probably be higher than estimated using this method.

District heating systems and district CHP systems proved to be more cost-effective than all on-site technologies investigated. The cost effectiveness of all the district heating system schemes modelled are broadly similar, with energy from waste predicted to be marginally the most cost-effective.

Figure 10 shows the ranking of the cost effectiveness (in terms of 25-year per kg of CO_2 saved relative to the base case building) of all offsite technologies modelled. A negative NPV represent a whole-life cost saving relative to the base case building. The results shown are based on the technology modelled in conjunction with Energy Efficiency Package A. A 330kW turbine is predicted to be more cost-effective than larger turbines; this is due to the banding of the Feed-in tariffs – see Appendix D.

FIGURE 10

COST EFFECTIVENESS OF OFFSITE TECHNOLOGIES MODELLED ON ENERGY EFFICIENCY PACKAGE A



7.7 DIRECTLY CONNECTED HEAT

The Carbon Compliance target discussed in the consultation on policy options for zero carbon non-domestic buildings [3] allows for 'directly-connected heat' as well as on-site generation. This can be provided by LZC technologies such as district CHP heating networks or heat networks from Energy from Waste (EfW) plants.

The Target Zero research found that the most cost-effective route to providing directly-connected heat is district heating. The following types of district heating plant were modelled:

- **fuel cell CHP**
- **natural gas fired CHP**
- **biomass-fired CHP**
- **biogas-fired CHP fed by an anaerobic digester**
- **district heating fuelled by energy from waste**
- **district heating fuelled by waste heat.**

District heating systems and district CHP systems proved to be more cost-effective than all on-site technologies in terms of NPV saving relative to the base case building performance. The cost effectiveness of the district heating systems considered is broadly similar. Energy from waste proved to be marginally the most cost-effective although this technology does not achieve the greatest carbon emissions reductions.

None of these systems on their own is predicted to achieve true zero carbon. The greatest modelled reduction in regulated carbon dioxide emissions is 78% using anaerobic digestion CHP combined with Energy Efficiency Package A[1].

The most cost-effective route to achieving a 70% reduction below the requirements of Part L 2006 is predicted to be a fuel-cell fired district CHP system in conjunction with energy efficiency Package A.

District heating schemes are most viable in dense urban areas where the heat demand is concentrated. The opportunities for connecting new office buildings to a district heating network are higher than for the connection of existing offices. Many existing offices have heating plant mounted on their roof and so heating pipes would have to be run from street level to roof top in order to integrate into the existing building services.

District heating schemes are most viable when supplying buildings with a large and fairly constant thermal demand; buildings which fall into this category include:

- **industrial sites (requiring heat for industrial processes)**
- **swimming pools/leisure centres**
- **hospitals**
- **universities**
- **hotels**
- **apartment buildings.**

Table 5 summarises the main offsite technologies that could provide directly-connected heat to the office building. The modelled results of savings in carbon emissions, capital costs and NPV values are presented. The results are based on the individual technology in conjunction with Energy Efficiency Package B (see Table 1).

The change in capital cost for each of these technologies is the same because they all involve the replacement of conventional boilers with heat exchangers connected to a district heating system. The cost of the main plant of the different types of district heating system will vary, however these will be borne by the district heating network operators rather than by the owners/tenants of individual building connected to the network.

TABLE 5
DIRECTLY CONNECTED HEAT RESULTS

OFFSITE TECHNOLOGY	TOTAL OPERATIONAL CO_2 EMISSIONS ($KGCO_2$/YR) [CHANGE FROM BASE CASE]	CHANGE IN CAPITAL COST FROM BASE CASE[1] (£) [%]	CHANGE IN 25-YEAR NPV[1] (£)
Biomass fired CHP	768,747 [-47%]	-55,914 [-0.1%]	-524,790
Fuel Cell fired CHP	723,060 [-50%]	-55,914 [-0.1%]	-524,790
Nat Gas fired CHP	771,378 [-47%]	-55,914 [-0.1%]	-524,790
Energy from waste	895,380 [-38%]	-55,914 [-0.1%]	-131,051
Waste process heat	862,143 [-41%]	-55,914 [-0.1%]	-131,051
Biogas fired anaerobic digestion CHP	699,205 [-52%]	-55,914 [-0.1%]	-498,737

[1] These costs exclude the capital cost and NPV of Energy Efficiency Package B measures, i.e. they relate to the LZC technology only.

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[1] The greatest on-site emissions reduction is achieved using Package B rather than Package C. This is because the space heating and cooling loads using Package C are less than those of Package B and therefore the running time of the CHP unit (and hence the carbon saving) is reduced when used with Package C. This also applies to CCHP technologies.

7.8 ALLOWABLE SOLUTIONS

The consultation on policy options for zero carbon non-domestic buildings [3] proposes the following Allowable Solutions:

- **further carbon reductions on-site beyond the regulatory standard (increased Carbon Compliance) to abate residual emissions, to account for circumstances where going further on Carbon Compliance is more cost-effective than other Allowable Solutions**
- **energy efficient appliances meeting a high standard. This could incentivise IT focused businesses towards using low-energy hardware**
- **advanced building control systems which reduce the level of energy use**
- **exports of low carbon or renewable heat from the development to other developments (renewable heat imported from near the development would be included as part of the Carbon Compliance calculation)**
- **investments in low and zero carbon community heat infrastructure.**

Other options also remain under consideration.

The potential for cost-effective Allowable Solutions needs to be considered alongside the Energy Efficiency and Carbon Compliance solutions. For instance, it would be expected that large-scale offsite Allowable Solutions would be more efficient than smaller-scale, on-site LZCs. The choice may be limited, however, by the need to meet some of the carbon reduction target by on-site LZCs as Carbon Compliance measures. In addition, the NPV for offsite wind (and other offsite LZCs) is dictated by the costs/values assumed for current and future energy imported/exported across the site boundary, and these energy import/export costs/values for use in evaluating Allowable Solutions may be established by regulation.

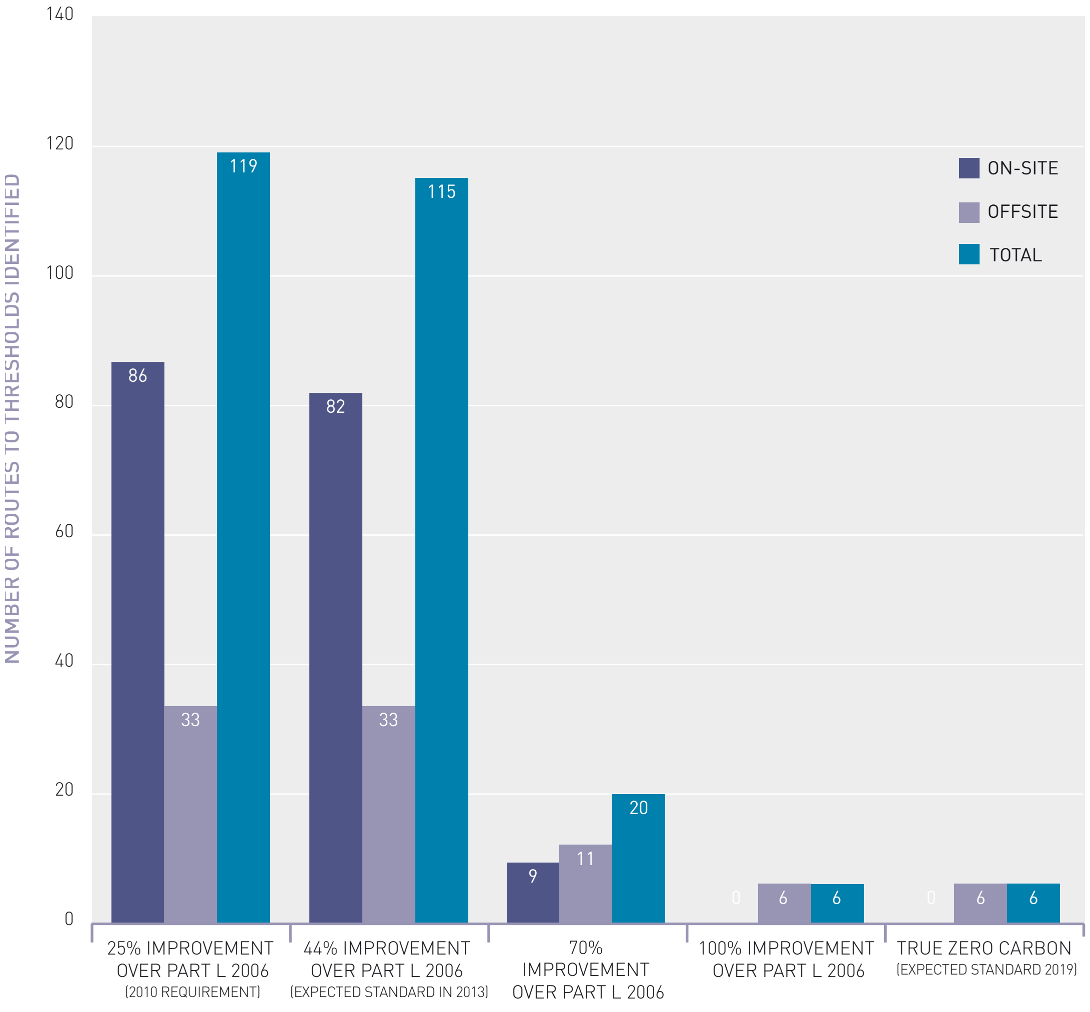
The analysis has demonstrated that the use of on-site LZC technologies and energy efficiency measures alone cannot achieve zero carbon and that it will therefore be necessary to make use of Allowable Solutions for large, city centre office buildings to achieve net zero carbon emissions.

Figure 11 shows the number of routes (combinations of compatible energy efficiency measures and LZC technologies) identified – based on the analysis of this office building - that are predicted to achieve compliance with the likely future Part L compliance targets. This reveals that there is a wide range of routes to reducing the carbon dioxide emissions on-site by up to 44% relative to Part L 2006.

Only nine on-site routes to a 70% improvement over 2006 Part L requirements could be identified and no on-site solutions which achieve a 100% improvement or true zero carbon could be identified for this office building.

Most of the 82 on-site routes to the 44% reduction target are expected to be suitable for all city centre office sites. However to reduce carbon dioxide emissions beyond 70% will only be technically and financially viable in areas where either large wind turbines can be erected, or where the local area is suitable for a district heating scheme.

FIGURE 11
NUMBER OF ROUTES TO ACHIEVING LIKELY FUTURE PART L TARGETS



7.9 THE IMPACT OF PART L 2010

Part L 2010 has an overarching objective of reducing total regulated operational carbon dioxide emissions from all new buildings by 25% compared to the 2006 Part L regulations. To achieve this target in the most cost-effective way, an 'aggregate' approach has been developed to reflect the likely number/floor area of non-domestic building types expected to be constructed over the next few years and the cost effectiveness with which carbon reductions can be made within each building type. For example, it is considered [5] that it is more cost-effective to reduce operational carbon emissions (via energy efficiency measures and on-site LZC technologies) in industrial buildings than in hotels.

At the time of writing, the 2010 Part L requirements have not been implemented in the dynamic simulation models used for Part L compliance and therefore, under Target Zero, the proposed 2010 changes to the notional office building have been manually implemented in the IES model used for the operational carbon assessments. As such, these results should be considered as approximate. The impact of these changes on the office building operational carbon emissions results are illustrated in Figure 12.

Using Part L 2006, the TER[1] for the office building is 31.7$kgCO_2/m^2yr$. The base case building specification just meets this target, i.e. BER = 31.5$kgCO_2/m^2yr$. Using the new Part L 2010 carbon emission factors[2], the 2006 TER increases to 34$kgCO_2/m^2yr$ and the BER of the base case building increases to 35.7$kgCO_2/m^2yr$.

The flat 25% improvement on Part L 2006 using the 2006 emissions factors (the 2010 target used in the Target Zero analysis) yields a TER of 23.8$kgCO_2/m^2yr$. Using the 2010 emissions factors gives a TER of 25.5$kgCO_2/m^2yr$. Applying the aggregate approach, the TER becomes 22.2$kgCO_2/m^2yr$ with the 2006 emissions factors and 26.5$kgCO_2/m^2yr$ with the 2010 emissions factors, i.e. less challenging than the flat 25% target.

Energy Efficiency Package A (see Table 1) was expected to pass Part L 2010 by 24% when assessed using the 2006 carbon emission factors. Applying the 2010 emissions factors, Energy Efficiency Package A passes by 20% using the flat method and by 23% using the aggregate approach.


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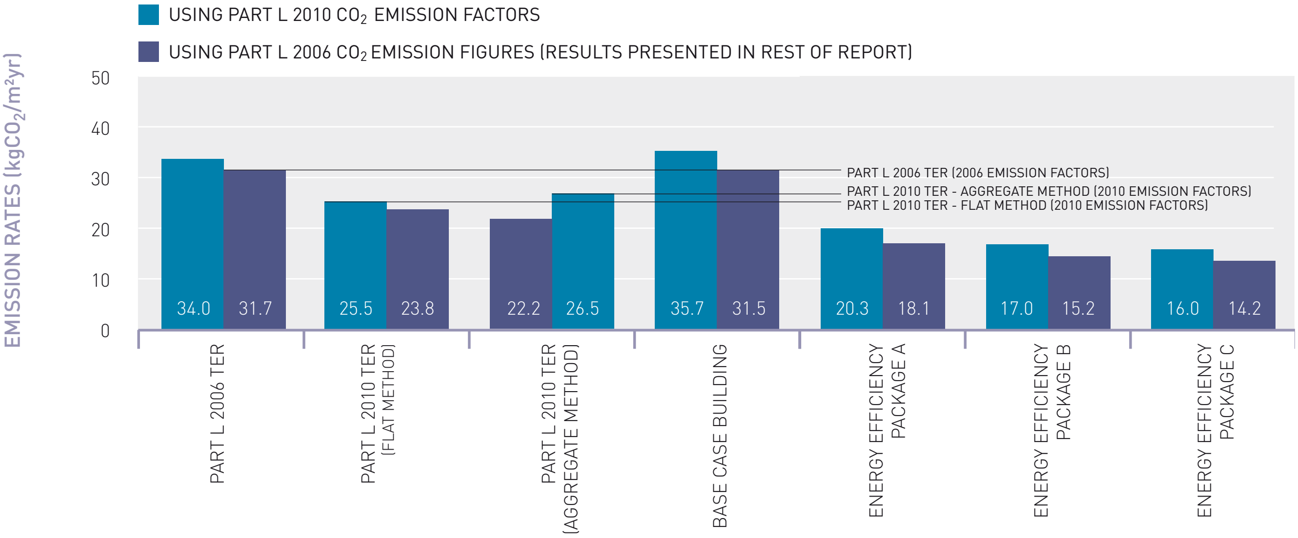
FIGURE 12
THE IMPACT OF CHANGES TO PART L 2010



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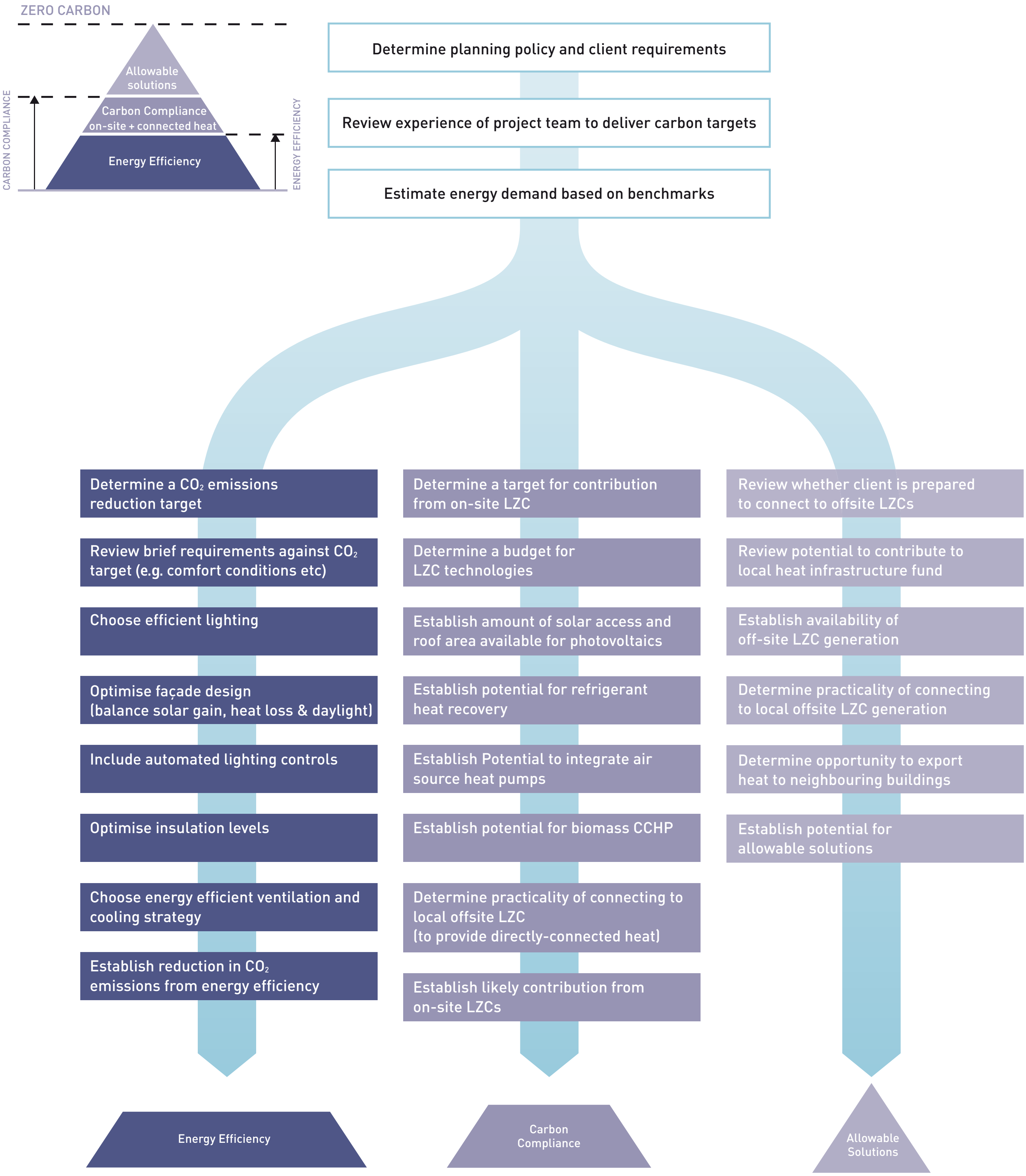
[1] The Target Emission Rate (TER) is defined by the National Calculation Methodology (NCM). The TER is based on the amount of carbon dioxide emitted per square metre of floor area per year by a notional building as the result of the provision of heating, cooling, hot water, ventilation and internal fixed lighting.The notional building has the same geometry, orientation and usage, etc., as the evaluated building. The TER is calculated by applying improvement and LZC factors to the notional building emissions. The check for compliance with the CO_2 performance requirements is that BER ≤ TER.

[2] Carbon emission factors are used in Part L to convert the amount of power used for heating, hot water, lighting and general appliances, etc. into kilograms of carbon dioxide. Most of the Part L 2010 carbon emission factors have increased since 2006. The emissions factor for grid-displaced electricity has decreased.

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

FIGURE 13

GUIDANCE FLOWCHART FOR DELIVERING LOW AND ZERO OPERATIONAL CARBON OFFICE BUILDINGS



7.10 OPERATIONAL CARBON GUIDANCE

Figure 13 sets out a flowchart providing guidance on how to develop a cost-effective route to low or zero operational carbon office buildings. Guidance on the steps presented in the flowchart is given below.

Client and brief

Client commitment to achieving sustainable and low and zero carbon targets should be captured in terms of a clear brief and target(s), for example, a 70% improvement in regulated carbon emissions or an Energy Performance Certificate (EPC) A rating.

The brief, and any operational carbon targets, should specify the contribution to be made from on-site LZC technologies and whether the client is prepared to connect to offsite technologies. This should also take account of any funding or local planning requirements, such as a policy requiring that a minimum proportion of a building's energy needs to be met using renewable energy.

Undertaking the relevant analyses and integration of design early on a project is key to ensuring that the design is maximising its potential for low carbon emissions at minimum cost.

Cost

The provision of easy-to-understand, accurate cost advice early in the design process is key to developing the most cost-effective low and zero carbon solution for any new-build office building.

It is essential to set aside a budget to reduce operational carbon emissions. The Target Zero research results can be used to provide an indication of likely capital cost uplift for a range of carbon reduction targets for large, city centre office buildings - see Figure 1.

When looking at the costs of energy efficiency measures and low and zero carbon technologies it is important that:

- **lifecycle costs are investigated**
- **benefits from energy cost savings are taken into account**
- **benefits from sales of renewable obligation certificates (ROCs) and renewable heat obligation certificates and feed-in tariffs (see Appendix D) are considered**
- **potential savings from grants are considered and the potential costs of Allowable Solutions taken into account**
- **the cost implications to the building structure/fabric are considered. For example, a PV array installed on a flat roof requires additional supporting structures whereas PV laminate on a low-pitch roof does not.**

RECOMMENDATION

The client brief for a low carbon office building must set out clearly the targets and the contributions to be made from energy efficiency, LZC technologies (on and offsite) and Allowable Solutions. Integration of low carbon technologies must be considered from the start of the design process.

RECOMMENDATION

The Target Zero approach to ranking energy efficiency and LZC measures is based on lifecycle costs (25-year NPV per $kgCO_2$ saved relative to the base case building). It is recommended that the same or similar approach is adopted to demonstrate the economic feasibility of energy efficiency and LZC measures and help design teams to prioritise the most appropriate and cost-effective measures.

Many commercial office buildings are built speculatively and it is likely therefore that, in many cases, capital construction cost will be a key factor when investing in energy efficiency measures and LZC technologies. Therefore the operational carbon analyses (see Sections 7.3 to 7.5) were repeated and the most cost-effective package of measures selected based on their capital cost rather than their whole-life cost. The analysis found:

- **the lowest cost on-site route to a 25% improvement over Part L 2006 is achieved through the use of Energy Efficiency Package A excluding active chilled beams/slabs (see Table 1) at a capital cost (saving) of -£863.4k (-1.4%) compared with the base case building capital cost**
- **the lowest cost on-site route to a 44% improvement over Part L 2006 comprises Energy Efficiency Package A with a roof-mounted 6kW wind turbine, a reverse cycle air source heat pump and solar thermal water heating at a capital cost of £588k (+1.0%)**
- **the lowest cost on-site route to a 70% improvement over Part L 2006 comprises energy efficiency Package B with 1,026m^2 of roof-mounted photovoltaics, a roof-mounted 6kW wind turbine and a biomass-fuelled CCHP unit at a capital cost of £3,637k (+5.9%).**

Design team

All members of the design team should understand the operational carbon targets set for a project and their role in achieving them. Targets should be included in their briefs/contracts with a requirement to undertake their part of the work necessary to achieve the target. It can be useful to appoint a 'carbon champion' on the project who would be responsible for delivering the target. This is often the role taken by either the building services engineer or the BREEAM assessor.

It is important to understand the breakdown of energy use within the building so that measures can be targeted where the greatest reductions are achievable. For example, in the base case office building, lighting and fans and pumps for ventilation are the dominant contributors and, as shown in Figure 4, improvements in lighting and fan efficiencies provide some of the greatest and most cost-effective reductions in carbon dioxide emissions.

The likely occupancy pattern of the building should also be considered early on in the design process since this will affect the energy demand profile of the building. For example, a large commercial office building operating 24 hours a day will have a far higher lighting and heating demand than an office building only operating during normal business hours. The National Calculation Method (NCM) applies a standard activity schedule to different building types[1] and therefore cannot take into account different occupancy patterns. This is a limitation of the NCM and is an example where operational carbon compliance modelling is not able to accurately model/predict actual emissions. In addition, many modern, city centre office buildings are more densely occupied than the NCM assumption of 9m² per person.

The viability of technologies such as CCHP is largely dependent on the number of hours for which there is a sufficient heat demand. In the case of buildings which operate for 24 hours a day, the constancy of the heat load is increased relative to normal office hours. However because the NCM does not allow users to model an office as if it operates in this way, the modelled effectiveness of combined heat and power units is artificially reduced.

The hours of operation of the office building will also have a significant impact on the usefulness of glazing. During the hours of darkness glazing serves only to release heat. Glazing releases more heat through conduction than the opaque building element. Therefore the more hours of darkness during which the office operates, the lower the optimal glazed area will be.

RECOMMENDATION

Where the occupancy schedule of the building is known, this should be taken into account in any thermal simulation modelling rather than relying on the Part L compliance software alone. This is particularly relevant to the optimisation of glazed areas, see Section 7.4.

RECOMMENDATION

On all projects where a carbon reduction target is set, a 'carbon champion' should be appointed to oversee the process.

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[1] The NCM defines that offices should be assessed with occupancy from 7am to 7pm Monday to Friday excluding bank holidays.

Site factors

Site constraints, including building orientation, can have a major effect on a building's operational energy requirements and on the viability of integrating LZC technologies. Site selection can therefore be a key issue. Most site constraints for large city centre office buildings are far more onerous than for other non-domestic building types studied under Target Zero as these are more typically located outside city centres.

The design team must therefore be fully aware of the viability of available LZC technologies and the constraints imposed by the site. They will also need to look beyond the site boundary for opportunities to integrate with other offsite LZC technologies and other buildings and networks.

The ability to integrate into (or initiate) a low-carbon district heating system, for example, may have a large positive impact on the cost effectiveness of constructing low carbon, city centre office building and therefore should be given due consideration early in the design process.

Building form and fabric

Although all energy efficiency measures may be important, the glazing and solar shading strategy was found to be most effective in delivering cost-effective carbon savings in the base case office building.

The glazing strategy will have a significant impact on the cooling load, the requirement for artificial lighting and the energy required for space heating. East and West facing glazing should be minimised with an emphasis on North and South facing glazing. Glazing with a sill height less than around 1m does not generally provide much useful daylight, but does increase the cooling load in summer and heating requirements in winter. South facing glazing should have external solar control measures to block high-angle sunlight in summer whilst allowing the useful low-angle sunlight to enter the building in winter.

Although the form and layout of the case study office building has not been varied as part of this study, where site constraints allow, consideration should also be given to:

- **reducing the plan depth to maximise daylight and the potential for natural ventilation**
- **optimising the building orientation for minimum energy use should be investigated where possible.**

The following generic guidance is based on the analysis undertaken for this research – see Section 7.4:

- **North facing rooms have low solar heat gain without the need for shading. This is suitable for rooms requiring cooling which will benefit from reduced energy usage (such as rooms with high IT loads and server rooms). Rooms which can be kept cool without the need for mechanical cooling would also benefit from being located on a north elevation.**
- **South facing rooms have high useful winter solar heat gain and, when shaded, low solar heat gain in summer. With suitable shading, offices are ideally suited on south facing façades; blinds are generally required to block glare from low angle sun in winter.**
- **East/West facing rooms have high solar heat gain when not fitted with solar control glazing or adjustable shading to block out low angle sun. Rooms without large levels of external glazing are ideally suited here (such as toilets, risers, lifts, etc).**

In addition to the glazing design, it is important to optimise the solar control strategy. Table 6 provides preliminary advice on this.

RECOMMENDATION

The availability of offsite LZC technologies and renewable sources of energy should be investigated. These are often the most cost-effective means of reducing carbon emissions when integrated with appropriate energy efficiency measures.

A benefit of overhangs rather than louvres is that they can more easily accommodate photovoltaic panels. Photovoltaic panels may be integrated into wide louvres or overhangs, however very few standard size panels are narrow enough to fit on louvres and therefore bespoke and hence expensive systems are often required. Overhangs are generally much wider than louvres so can be designed to fit standard size photovoltaic panels more easily.

TABLE 6

ADVANTAGES AND DISADVANTAGES OF DIFFERENT SOLAR CONTROL STRATEGIES

SOLAR CONTROL METHOD	ADVANTAGES	DISADVANTAGES
Solar tinted glass	Unobtrusive.	Reduces solar gain indiscriminately. Internal light quality and colour can be affected.
Overhangs	Reduces solar gain in summer, but not in winter. Cost-effective. Photovoltaic panels can be easily integrated.	Requires careful design. Can be aesthetically challenging if not well integrated into façade.
Louvres	Reduces solar gain in summer, but not in winter. Can be actuated Photovoltaic panels can be integrated.	Expensive. Obscures the view out. Requires careful design.

Computing systems

Addressing computer energy use at the building design stage is a real challenge as the computer system is generally not in the design team's remit. Also IT systems are typically replaced every three to four years, potentially making any initial design optimisation obsolete.

Where possible, server rooms should be positioned to avoid high solar gains so that they need a minimum of mechanical cooling. In many cases it may be appropriate to avoid insulating a server room so that it can passively emit heat to the outside in cool weather. Alternatively it may be possible to recover this waste heat and use it to heat other parts of the building in winter or to provide some of the building's hot water requirements throughout the year. Thin client computer systems are generally most efficient, but can restrict functionality for high computing power demand users. IT managers can make a huge difference to the amount of energy used by their systems by specifying efficient machines and integrating energy saving software which shuts down unused computers. Surprisingly, most desktop computers use energy even when shut down; this can be mitigated by either encouraging users to unplug unused computers or by having a master switch which cuts power to computers when out of use. Laptop chargers and docking stations also use energy when their associated machines are shut down and therefore should be treated in the same way.

Lighting

Improving lighting efficiency was found to be very important in delivering cost-effective carbon savings. Lighting contributes over a quarter of the carbon dioxide emissions of the base case office building. Optimising the lighting design in conjunction with the glazing strategy can reduce energy use significantly without major capital cost implication and achieve very good payback periods for the office. For advice on glazing strategies see Section 7.4.

Lighting energy use can be dramatically reduced through good design involving efficient lighting layout and use of low energy lamps and luminaires with high light output ratios (LOR). Lighting controls should also be carefully designed in order to facilitate efficient use of the system. Well placed user controls combined with automatic controls including daylight dimming and occupancy sensing lighting controls can have a dramatic impact on lighting energy use particularly when combined with a well-designed glazing strategy. It is important however that these systems are designed to suit the building users otherwise there is a tendency to override automatic controls, leading to greater energy consumption.

The research found that daylight dimming controls on lighting is a cost-effective measure. The effect is to introduce an interaction between glazing strategy and the amount of energy which is consumed by artificial lighting. Generally as the glazing area is increased, the amount of energy consumed by lighting will reduce; this also has 'knock-on' effects. For example lighting systems give off heat into the room as well as light; this heat gain reduces the heat load which the heating systems needs to provide in winter, but also increases the cooling load in summer. This interaction becomes complex and therefore dynamic thermal modelling should be carried out.

RECOMMENDATION

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

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

Heating, cooling and ventilation

Heating, cooling and ventilation system energy demands can be reduced by:

- **providing heat recovery to provide fresh air whilst minimising heating loads**
- **providing large diameter air handling units to minimise fan energy**
- **using waste heat from space cooling to provide hot water.**

The energy required by the ventilation systems in the base case building was found to be high (21%) – see Figure 5. This can be reduced through the use of low energy fans and pumps. The architect can also have a large impact on the design of efficient ventilation systems, for example the positioning and size of plant rooms can have a dramatic effect on the energy used.

The amount of energy used by fans increases as ductwork becomes longer, narrower and includes more bends and therefore structural and M&E engineers have a role to play in designing more efficient ventilation systems.

The choice of delivery system for heating and cooling can have a dramatic effect on the energy performance of a building. Chilled beams lend themselves to the thermal characteristics of heat pumps allowing the two technologies to offer a greater overall efficiency when linked together than when used separately.

An alternative to chilled beams is to integrate the heating/cooling system into the structure of the building, so called water-cooled/heated slabs. By embedding the pipework into the floors, a similar performance to chilled beams can be achieved without the visual intrusion.

Analyses were carried out in order to assess the potential for avoiding the use of mechanical cooling in this office building. This identified that, given the deep-plan nature of this building, mechanical cooling was necessary in order to maintain thermal comfort.

Climate change is predicted to raise temperatures and so the risk of overheating is likely to rise in future. Testing of a number of different approaches found that the cooling load in the base case office building could be significantly reduced by a number of measures including:

- **careful optimisation of the area of glazing**
- **inclusion of solar shading such as louvres or overhangs**
- **use of an efficient lighting system.**

The predicted rise in temperature caused by climate change will also reduce the heating requirements of the office building in winter. This may have the effect of reducing the benefits of many low and zero carbon technologies which supply heat.

Low and zero carbon (LZC) technologies

Once energy demands have been reduced and efficient baseline HVAC systems selected, the introduction of LZC technologies should be considered. Table 7 ranks the Energy Efficiency Packages and LZC technologies based on the assessment of the office building (most cost-effective at the top in terms of 25-yrNPV/kgCO_2 saved).

The cost effectiveness of LZC technologies is based on their use in conjunction with Energy Efficiency Package A. Although each office building will be different and the precise ranking of LZC technologies will vary, the table provides the generic ranking of cost effectiveness of technologies applicable to a building of this type and size.

TABLE 7

LZC TECHNOLOGIES MODELLED – IN DESCENDING ORDER OF COST EFFECTIVENESS (25 YEAR NPV/KG CO_2 SAVED (£))

LZC TECHNOLOGY	ON-SITE	OFFSITE	NOTES
Energy Efficiency Package A			**See Table 1**
Medium 330kW wind turbine		✓	**Enercon** 50m tower 33.4m rotor diameter.
Large 2.5MW wind turbine on-shore		✓	**Nordex** 100m tower height. 99.8m rotor diameter
Energy from waste district heating		✓	Space heating and hot water
Gas district CHP		✓	Space heating, hot water and electricity
Biomass district CHP		✓	Space heating, hot water and electricity
Large 5.0MW wind turbine offshore		✓	**Repower** 117m tower height. 126m rotor diameter (Largest commercially available)
Refrigeration heat recovery large	✓		Recovering heat from space cooling to supply hot water
Fuel cell district CHP		✓	Space heating, hot water and electricity
Biogas district CHP		✓	Space heating, hot water and electricity
Waste process heat district heating		✓	Space heating and hot water
Gas CHP large	✓		Space heating, hot water and electricity
Medium 50kW wind turbine		✓	**Entegrity** 36.5m tower height. 15m rotor diameter
Photovoltaics	✓		Roof-mounted monocrystalline PV 1,026m²
Reverse cycle air source heat pump	✓		Space heating and cooling
Biomass CCHP	✓		Space heating, hot water, cooling and electricity
Small 20kW wind turbine		✓	**Westwind** 30m tower height. 10m rotor diameter
Small 6kW wind turbine on-site	✓		**Proven** roof mounted 9m tower height on 43.6m building = 52.6m total height 5.5m rotor diameter
Biomass CHP	✓		Space heating, hot water and electricity
Single cycle air source heat pump	✓		Space heating
Biomass boiler	✓		Space heating and hot water
Fuel cell CCHP small	✓		Space heating, hot water, cooling and electricity
Biogas CCHP	✓		Space heating, hot water, cooling and electricity
Gas CCHP	✓		Space heating, hot water, cooling and electricity
Fuel cell CHP small	✓		Space heating, hot water and electricity
Energy Efficiency Package C[1]			**See Table 1**
Energy Efficiency Package B[1]			**See Table 1**
Biogas CHP large	✓		Space heating, hot water and electricity
Gas CHP small	✓		Space heating, hot water and electricity
Small 1kW wind turbine	✓		**Futurenergy** 6.2m tower. 1.8m rotor diameter
Solar Water Heating	✓		116m² sized the same as system put on real building. Providing some hot water
Fuel cell CCHP large	✓		Space heating, hot water, cooling and electricity
Biogas CHP small	✓		Space heating, hot water and electricity
Single cycle open loop ground source heat pump	✓		Space heating
Reverse cycle open loop ground source heat pump	✓		Space heating and cooling
Fuel cell CHP large	✓		Space heating, hot water and electricity
Single cycle closed loop ground source heat pump	✓		Space heating
Reverse cycle closed loop ground source heat pump	✓		Space heating and cooling

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[1] It is marginally more cost-effective (in terms of 25-yrNPV/kgCO_2 saved) to move from Energy Efficiency Package A to Package C than it is to move from Package A to B.

The orientation of photovoltaic panels is important as it can have a dramatic effect on their efficiency. In the UK, maximum efficiency is achieved when panels are south facing with a pitch of around 30° above the horizontal. However, this is not optimum when several rows of panels are to be fitted on a flat roof. In this situation each row is partially shaded by the adjacent row on its southern side; this self-shading effect can be reduced by lowering the pitch of the panels. Analyses and experience has found that the best compromise in this situation is to pitch the roof in a saw-tooth shape with the south-facing side at between 10° and 15° above the horizontal. In this arrangement, the total area of photovoltaic panels can be around one third of the area of the flat roof once space for roof access and maintenance has been included.

A number of the low and zero carbon technologies that were found to be most cost-effective will require larger plant space (than conventional heating and cooling systems) and some require access for fuel delivery and storage. Once LZC technologies have been selected, they should be integrated into the design at the earliest opportunity to optimise the design and reduce capital expenditure. If the building is to be connected to a district heating system then the capital cost can be reduced if plant rooms for the heating systems are kept close to street level. If biomass fuel is to be delivered to site then delivery access will be important and should be considered very early in the design process. In reality, biomass based technologies are unlikely to be viable for large city centre office buildings.

The cost effectiveness of LZC technologies which provide heat rely on there being a sufficient heat demand. Therefore the effectiveness of low carbon heating technologies is reduced when they are used on highly insulated buildings. For example, in the analysis of the base case building, CCHP was more cost-effective when used with Energy Efficiency Package B than with Package C.

The size of wind turbines that can be installed on-site will be restricted by site and other, e.g. planning, constraints. As a general rule however, the most cost-effective approach will be to install the largest possible turbine.

The focus of this guide is large city centre offices. This building type and location is generally unsuitable for wind turbines as buildings create large areas of turbulence and wind-shadows develop down-wind of obstructions. Both of these phenomena will reduce the performance of wind turbines. Generally this can be avoided if the turbine is situated at a distance of at least 20 times the height of the obstruction. Clearly this is not a viable approach for city centre locations.

Given these site constraints, the most appropriate use of on-site wind turbines is roof-mounted units; generally these cannot be much larger than 6kW.

For a city centre, commercial building of the scale of the base case building, one 6kW turbine roof-mounted centrally and as high as possible is likely to be optimal. Two 6kW turbines, mounted at either end of the building, may be viable but more than two is unlikely to be of any real benefit.

Roof-mounted turbines are not always appropriate and normally have lower outputs than turbines located away from buildings, however if the building is taller than its neighbours then the technology may be cost-effective. Care should be taken to ensure that the structural implications of roof-mounted turbines are taken into account from early design stage.

RECOMMENDATION

Photovoltaics proved to be cost-effective when mounted on the southern façade as a tilted shading device. By combining measures, in this case energy generation and solar shading, capital cost savings can be achieved and it is recommended that synergy between energy efficiency measures and LZC technologies should be explored on all projects.

RECOMMENDATION

Local obstructions are important factors in determining the viability of wind technologies on a particular site. Therefore on-site wind monitoring and Computational Fluid Dynamic (CFD) modelling should be undertaken to assess the viability of wind turbines at specific locations.

RECOMMENDATION

To counteract inaccuracies in the manner in which the National Calculation Methodology calculates the impact of some LZC and offsite low carbon technologies, it is recommended that their performance should be assessed using a suitable dynamic thermal model.

Structural design considerations

It is important to consider the impacts of introducing LZC technologies and certain energy efficiency measures on the building design. Examples include:

- **changes to the roof or cladding elements, such as increases in insulation or the introduction of a green roof may require enhancement to the building foundations or structure**
- **the impact on space planning. For example, variation in plant location and space requirements**
- **programming implications: both on-site and supply. CHP systems, for example, might have a long lead-in time.**

Plant room size will vary according to the LZC technologies that are to be used in the building. For example, biomass boilers will require additional storage space for wood chip fuel and for ash as well as access for fuel deliveries and waste collections. For buildings connected into district heating schemes, plant room size could be much smaller than required for traditional plant particularly if no backup plant is required. Similarly, the use of on-site technologies such as ground source heat pumps can result in smaller plant rooms, if no backup or supplementary heating or cooling plant is required.

The influence of the structure on the operational carbon emissions of the office building was found to be small, less than 1% - see Section 9.1.

7.11 IMPACTS OF CLIMATE CHANGE

Modelling the effects of climate change on the case study office building, using CIBSE weather tapes based on UKCIP climate predictions for the UK[1], showed that the heating requirements of the office building will progressively reduce over time while the cooling requirements are predicted to increase. Analysis of the case study office building showed that heating loads are expected to decrease by 10% between 2005 and 2020 and by 26% between 2005 and 2050. Conversely cooling loads increase by 11% between 2005 and 2020 and by between 34% and 39% from 2005 to 2050.

The effect on carbon dioxide emissions from these changes in heating/cooling demand is to reduce total building emissions marginally (0.01% to 0.025%) by 2020 and increase total emissions by 0.3% between 2005 and 2050.

Climate change is predicted to raise temperatures and so the risk of overheating is also likely to rise in future. Testing of a number of different approaches found that the risk of overheating in the office building could be reduced by a number of relatively simple measures including:

- **careful optimisation of the glazed area**
- **inclusion of solar control measures such as louvres or overhangs**
- **use of an efficient lighting system.**

The rise in temperature caused by climate change will also reduce the heating requirements of the office building in winter. This will have the effect of reducing the benefits of many LZC technologies which supply heat.

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[1] In light of new global greenhouse gas evidence, since the development of the CIBSE/UKCIP weather tapes, the 'high' scenario has been modelled.

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

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[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.

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.

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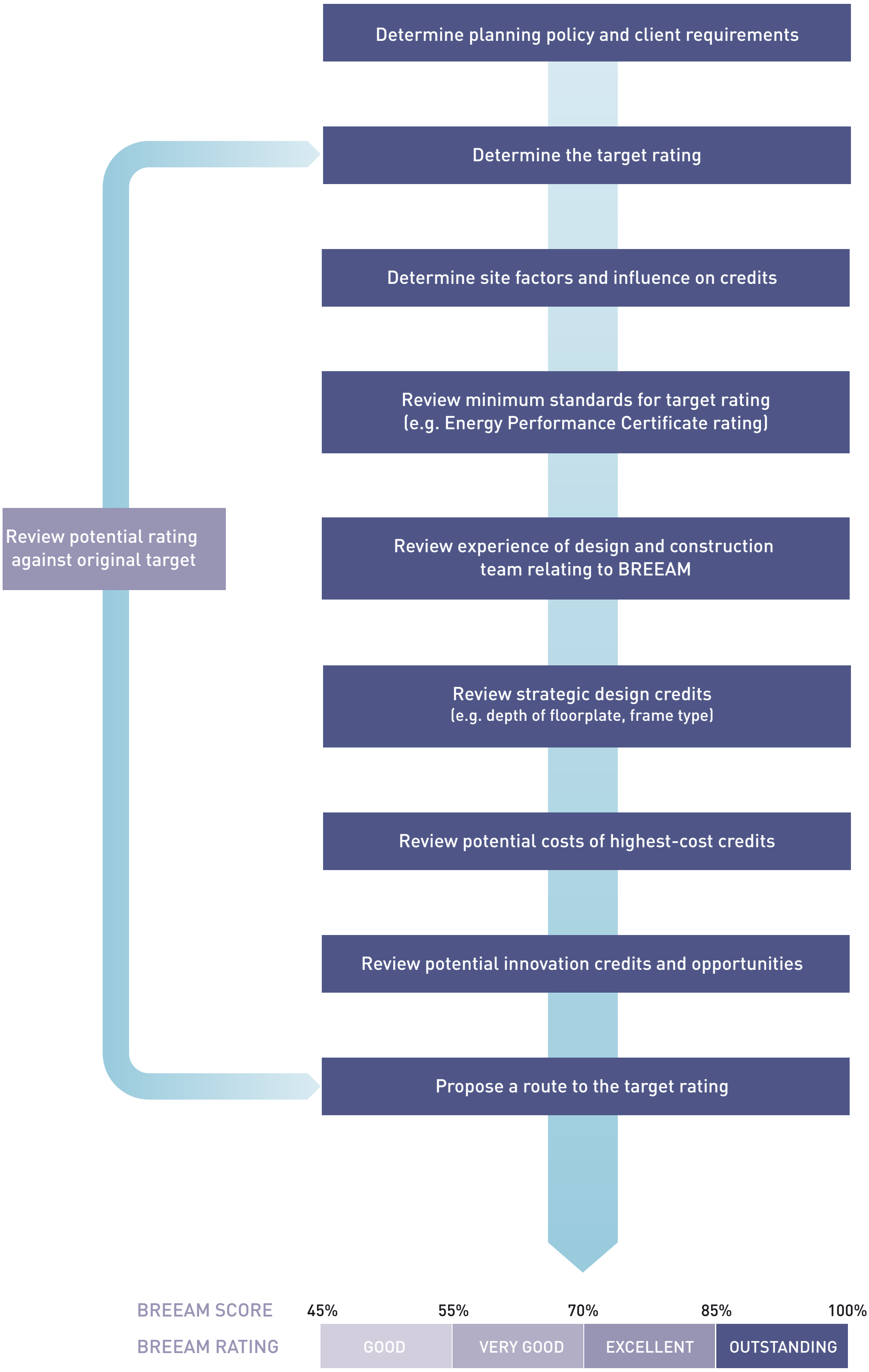
[1] Within BREEAM, credits in different sections of the assessment, e.g. energy, materials, etc. are given different weightings.

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



8.0 ROUTES TO BREEAM 'OUTSTANDING'

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

8.0 ROUTES TO BREEAM 'OUTSTANDING'

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

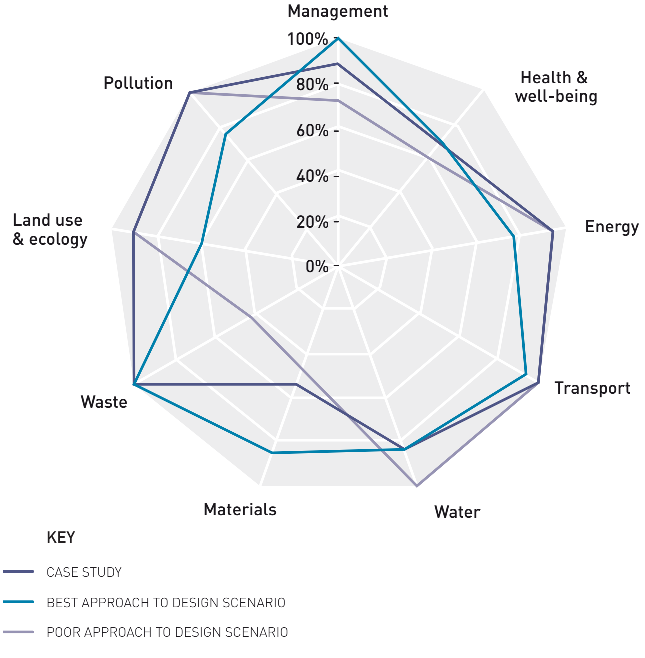
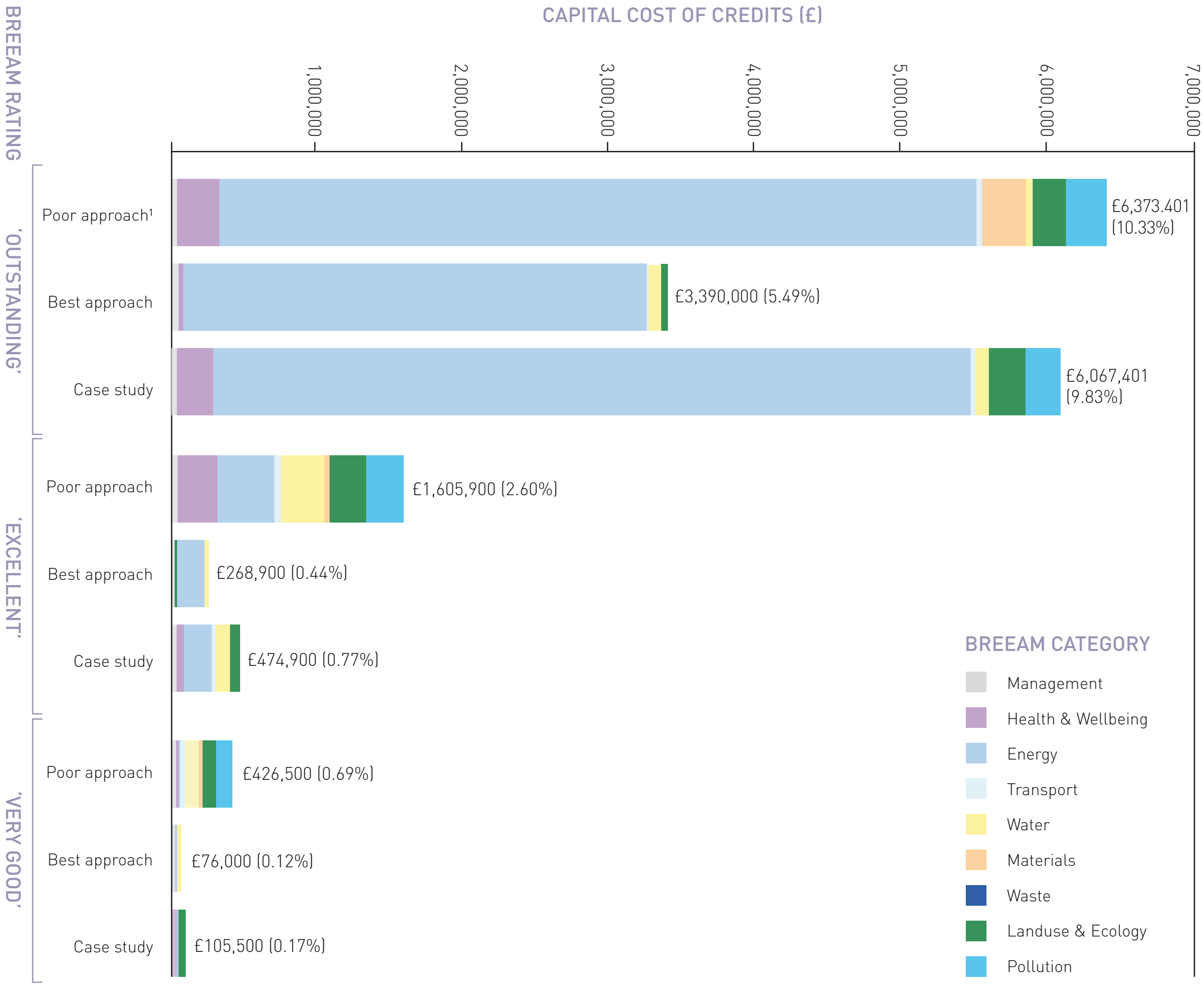


Figure 15 shows that a 'poor approach to design' implies that less credits are achievable in the Management, Health and Wellbeing, Materials and Waste sections and consequently that more credits have to be achieved in other sections: the Energy, Transport, Water, Land Use and Ecology and Pollution sections.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

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 (3m^3/hr per m^2 @ 50Pa); Vertically reduced glazing by 2m; Improved lighting efficiency to 1.5W/m^2 per 100lux with daylight dimming and occupancy sensing lighting controls; Improved wall insulation to 0.25W/m^2K.	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:

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.

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.

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.

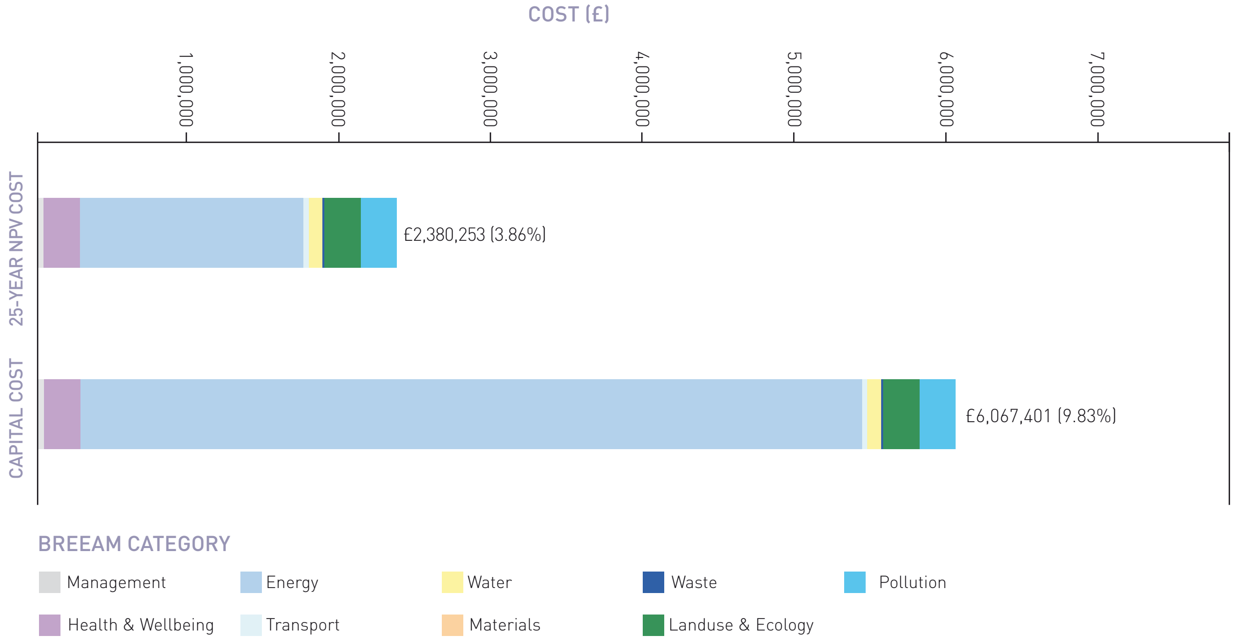
This graph focuses only on the 'Outstanding' rating as it is reasoned that if a zero carbon target was set for an office building, then it would be logical to also pursue an 'Outstanding' rating since, by far, the most significant costs associated with attaining of an 'Outstanding' BREEAM rating relate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



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[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.

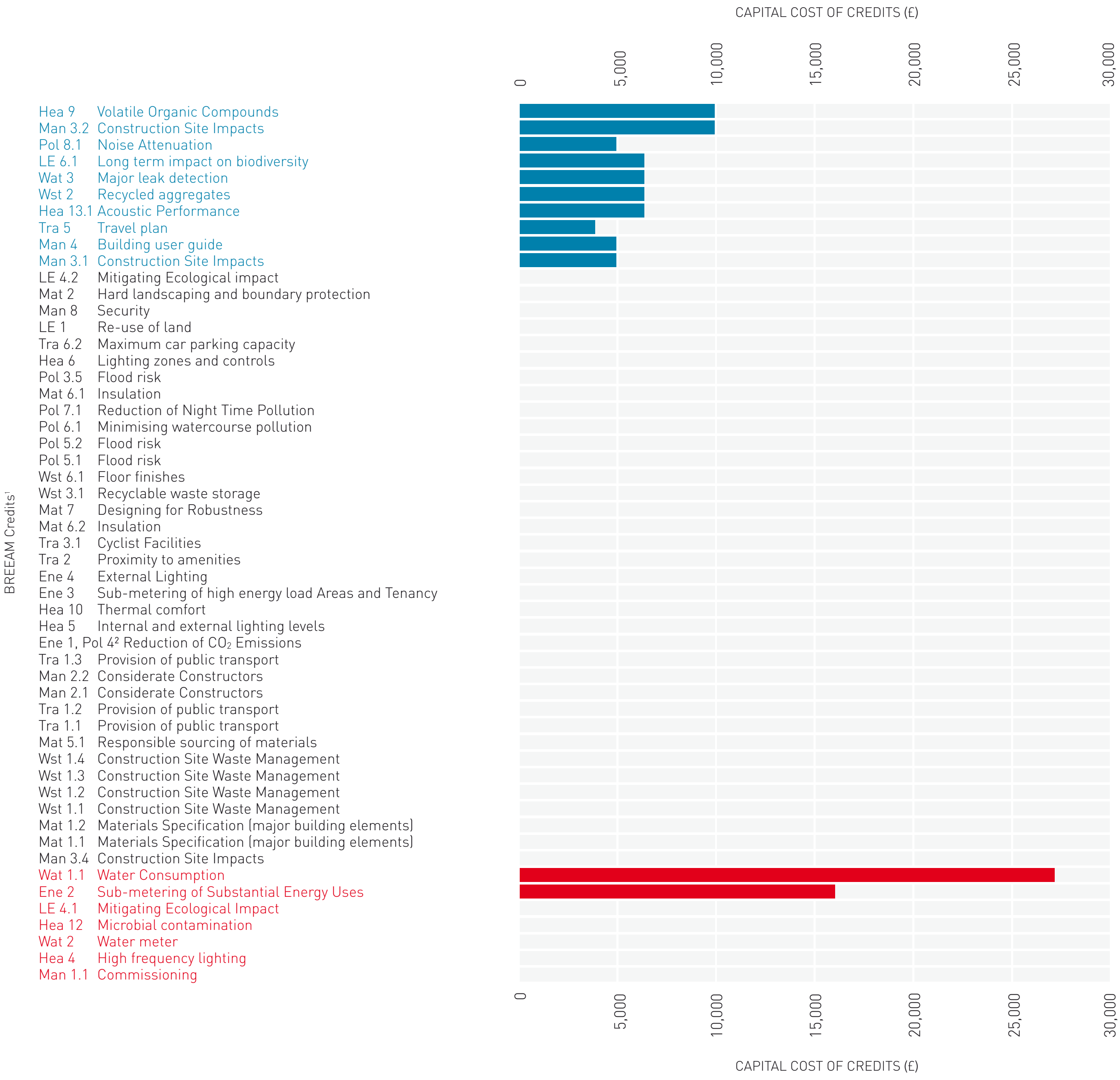
RECOMMENDATION

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



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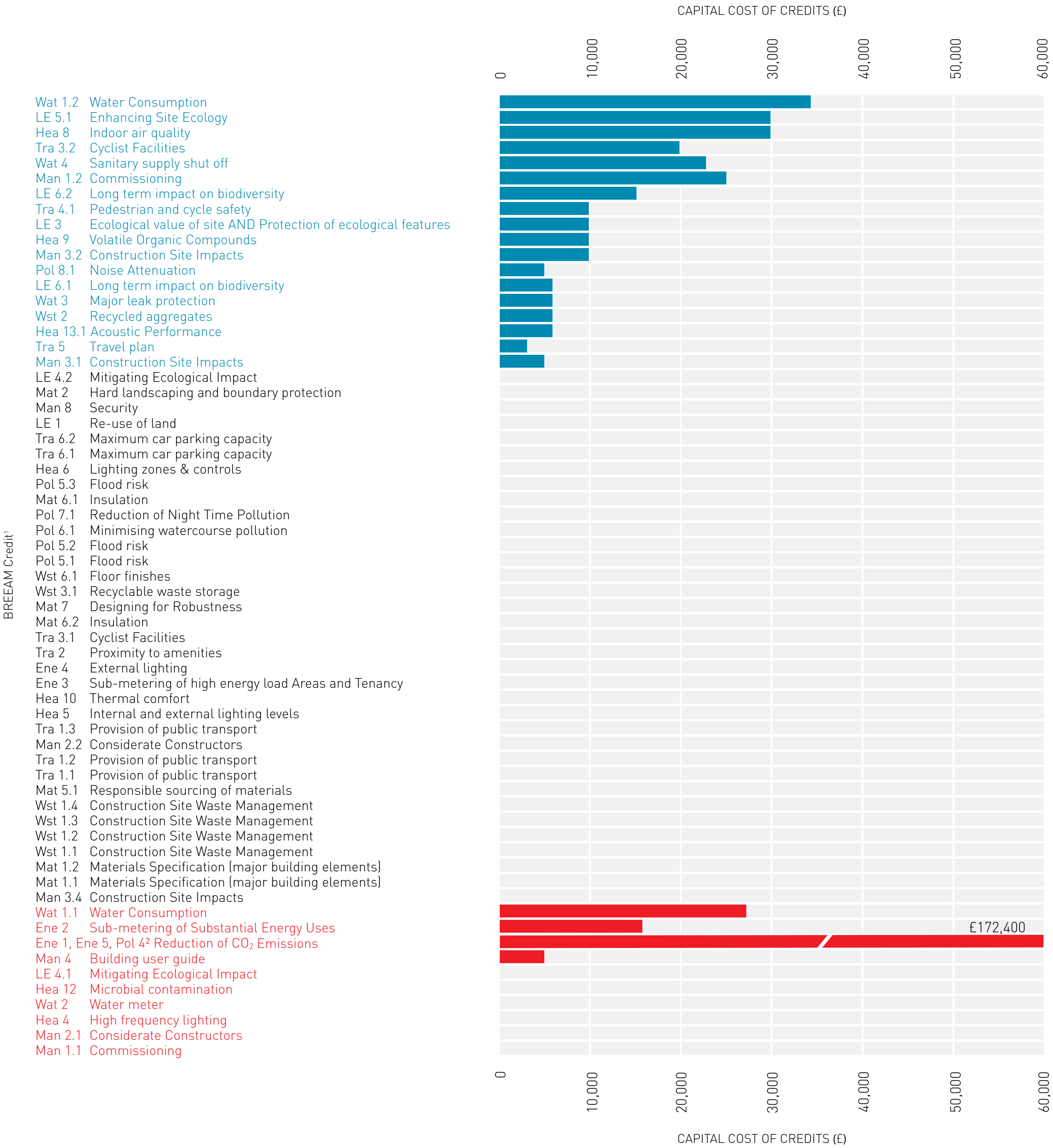
1 Ranking of credits is based on their weighted cost (capital cost of the credit divided by the credit weighting), whereas the values shown in the figures are the actual (non-weighted) cost of achieving the credit.

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



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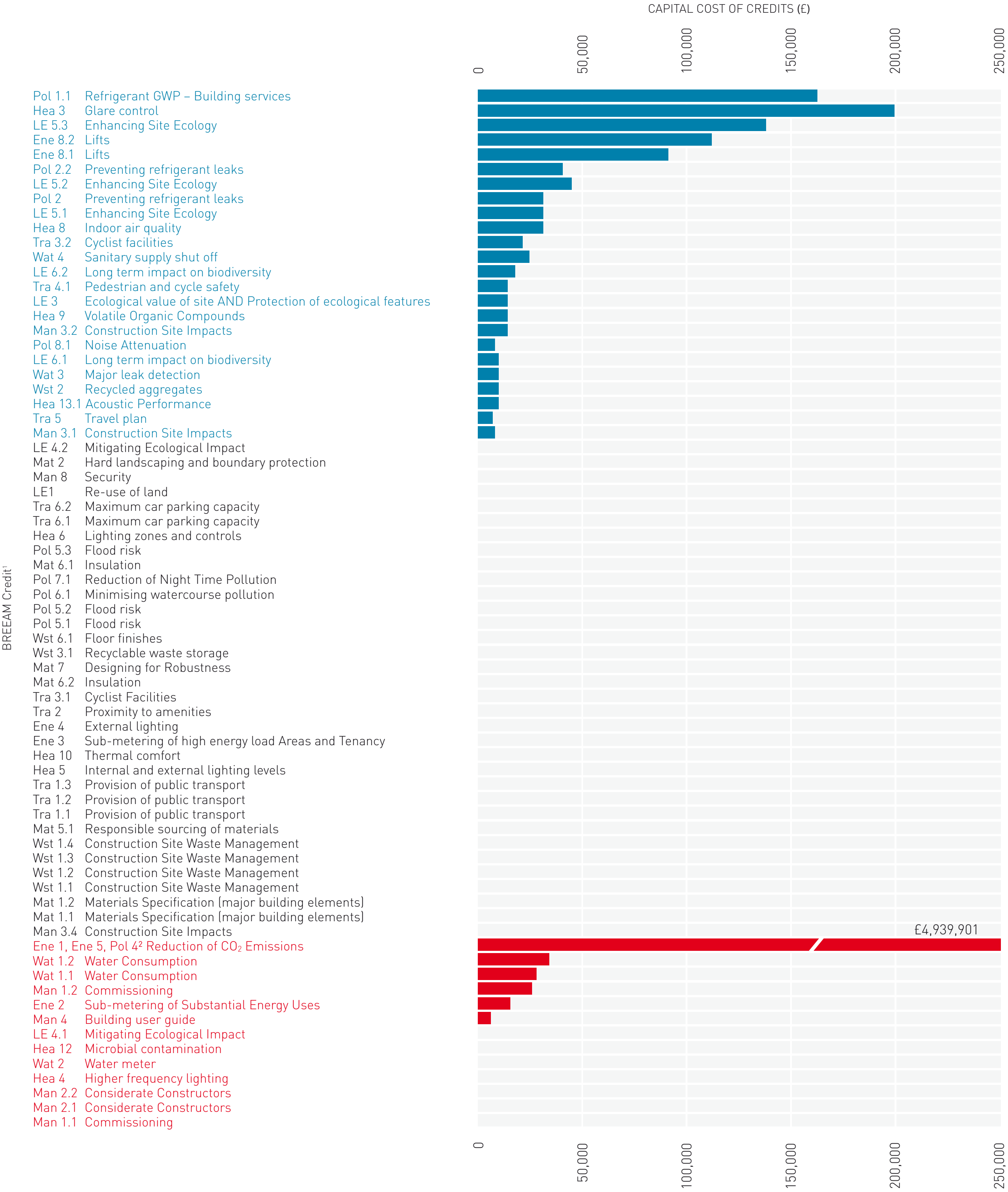
1 Ranking of credits is based on their weighted cost (capital cost of the credit divided by the credit weighting), whereas the values shown in the figures are the actual (non-weighted) cost of achieving the credit.

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



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[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.

---

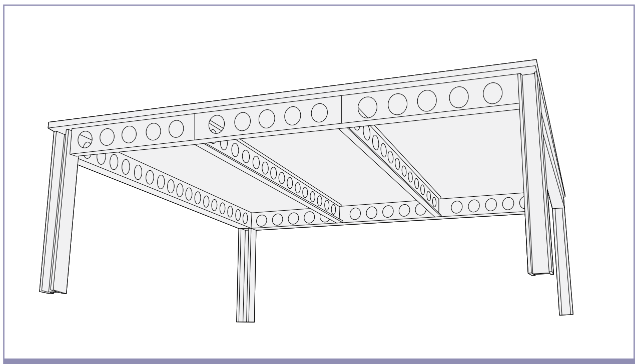
[1] Exemplar performance and innovation credits are achievable at all BREEAM rating levels. Target Zero methodology is focussed on achieving the highest BREEAM ratings and has therefore only assessed the cost of viable measures at the 'Excellent' and 'Outstanding' levels. In practice, such credits are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

STRUCTURAL DESIGN

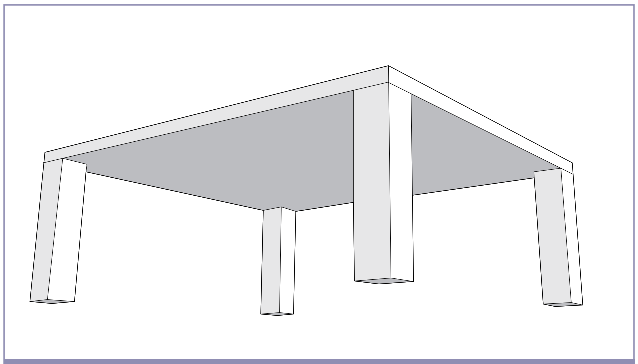
Two structural options for the office building were assessed as shown in Figure 21.

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

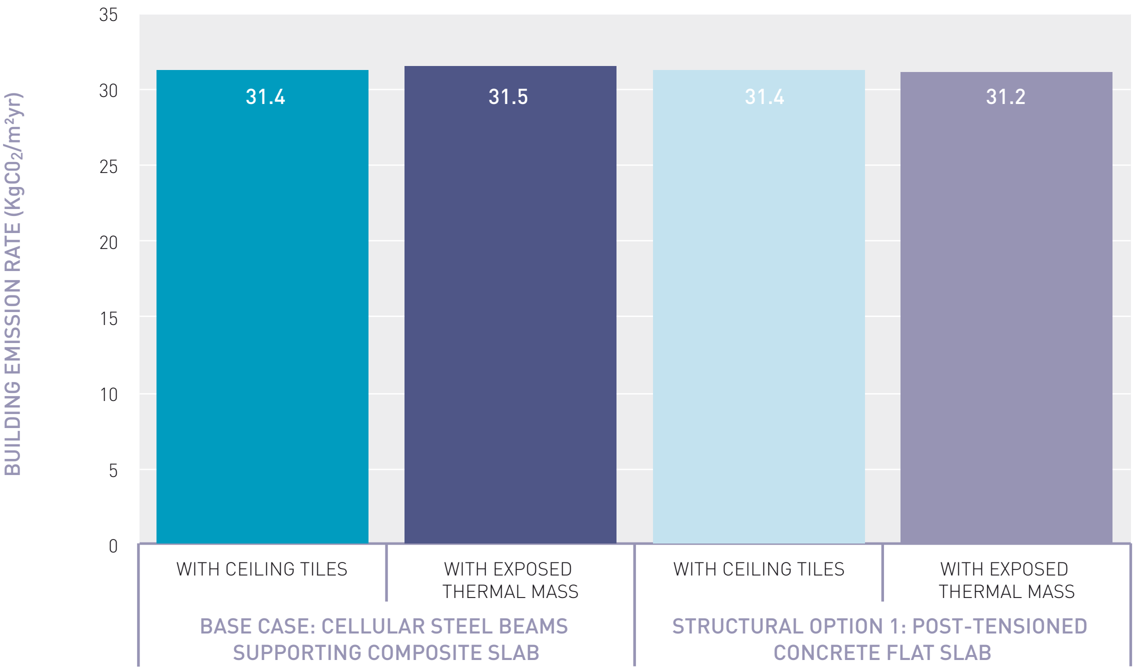
Buildings with the two structural options shown in Figure 21 were modelled both with and without suspended ceilings to establish the impact of the structural form on operational carbon emissions. The omission of ceiling tiles exposes the upper floor soffits to the occupied spaces allowing the thermal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



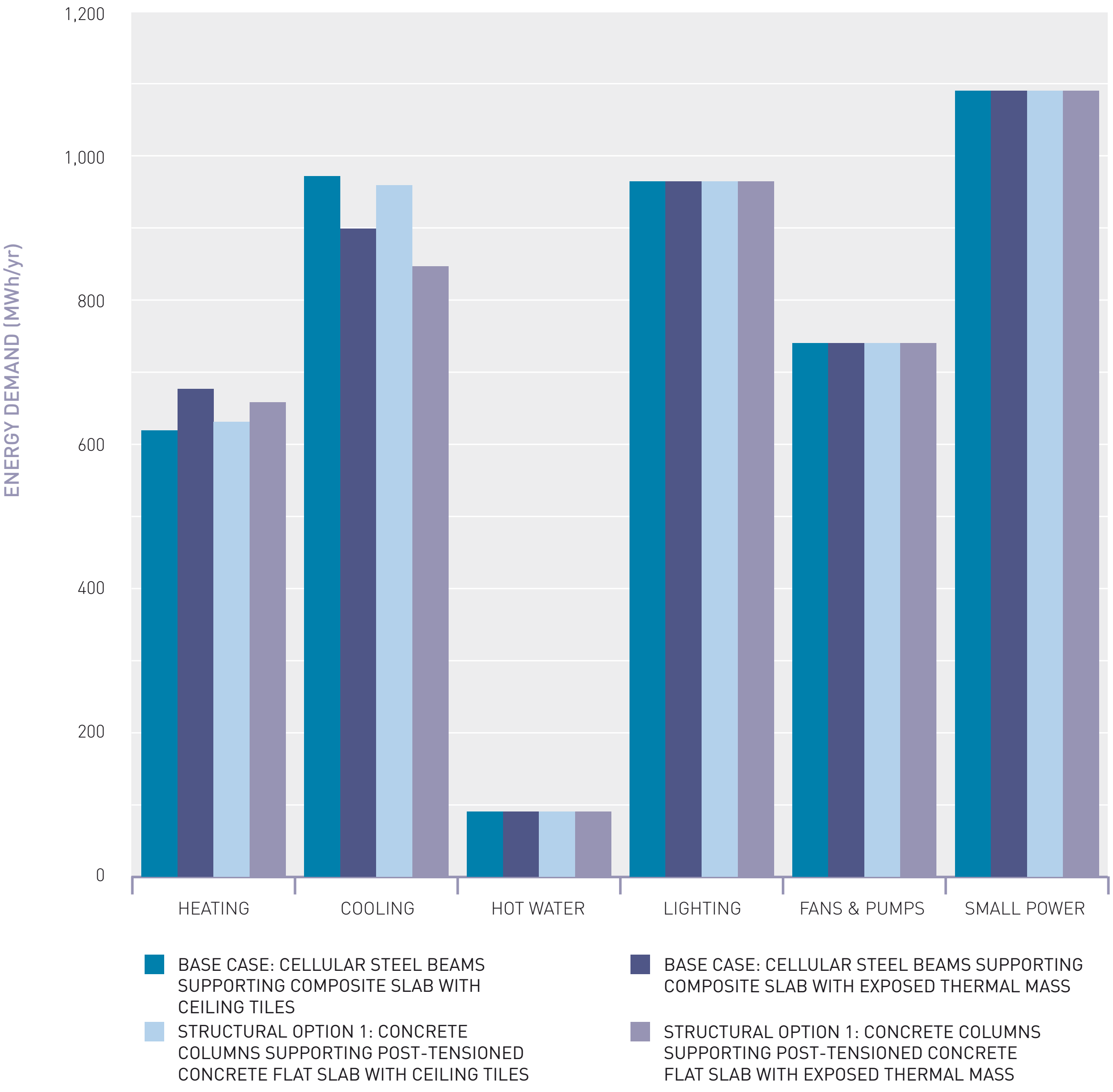
Structural Option 1 has a greater structural depth than the base case building; the typical floor height being 7% greater[1]. Increased storey heights result in greater heat losses and therefore higher heating but lower cooling requirements - see Figure 23 which gives the variation in energy demand by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



10.0 EMBODIED CARBON

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.

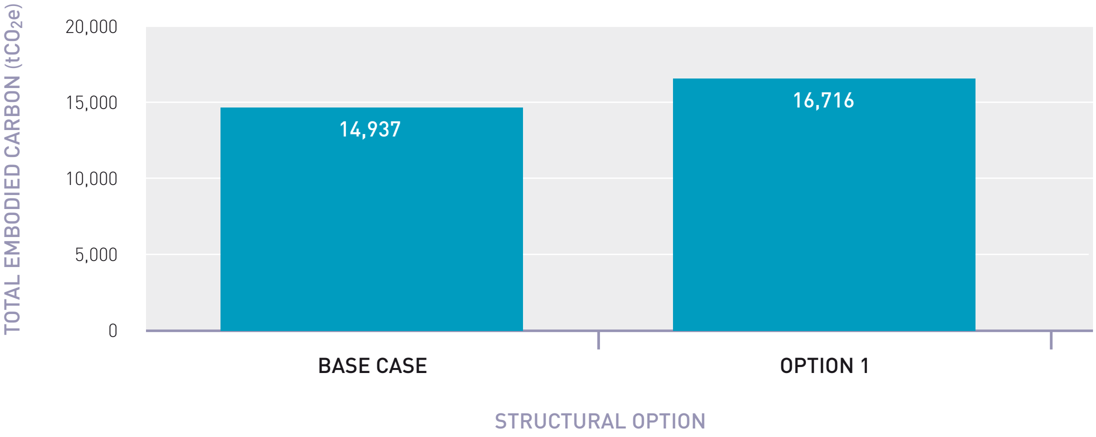
The CLEAR model has successfully undergone a third party critical review to the relevant ISO standards on Life Cycle Assessment by Arup. This review concluded that the CLEAR methodology and its representation in the GaBi software has been undertaken in accordance with the requirements of ISO 14040 (2006) 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



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

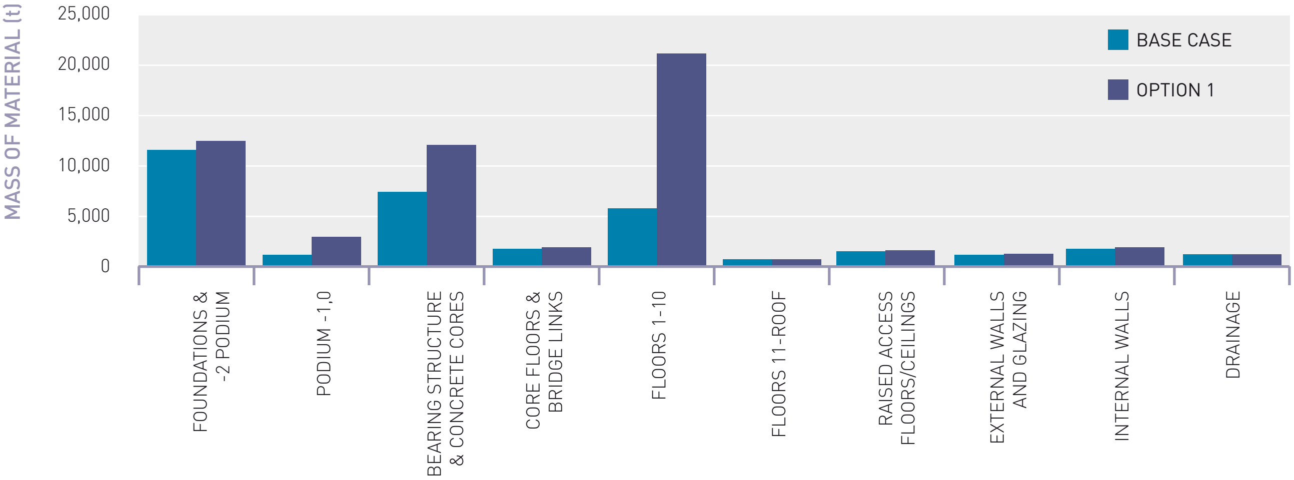
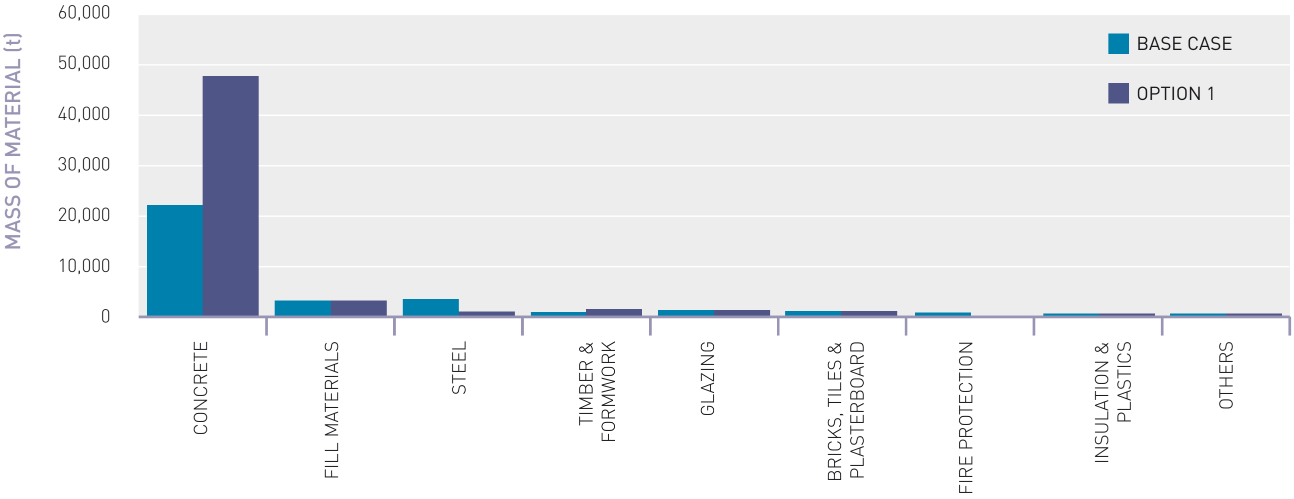


FIGURE 26

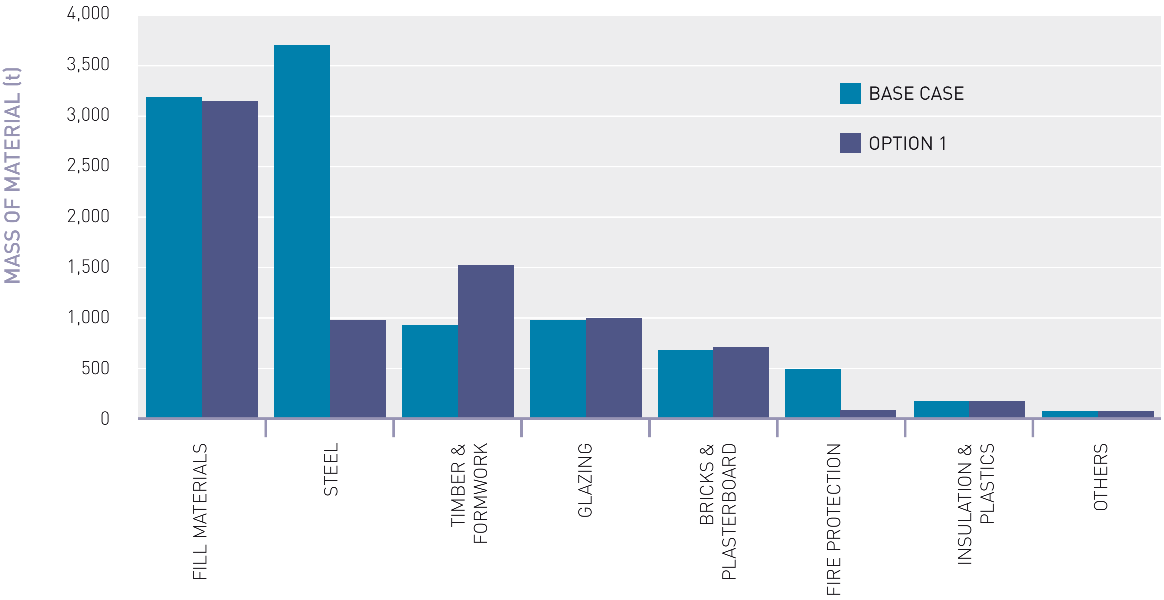
MASS OF MATERIALS - BREAKDOWN BY MATERIAL



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

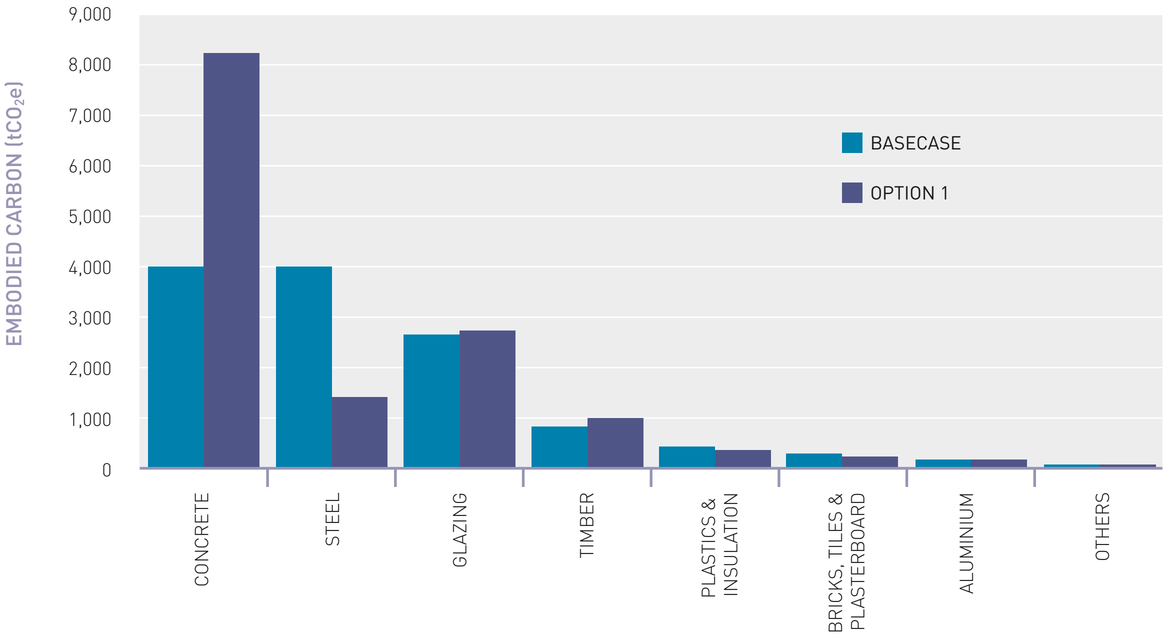


FIGURE 29

BREAKDOWN OF TOTAL EMBODIED CARBON BY ELEMENT

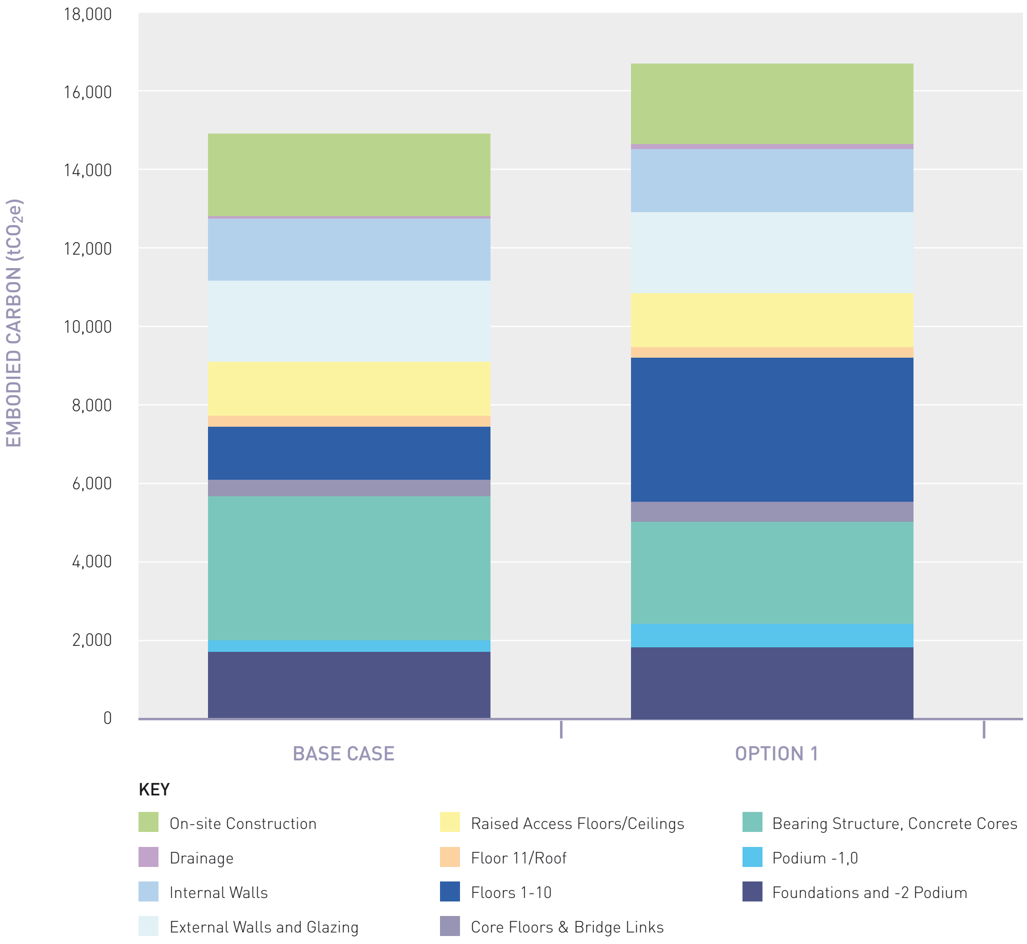
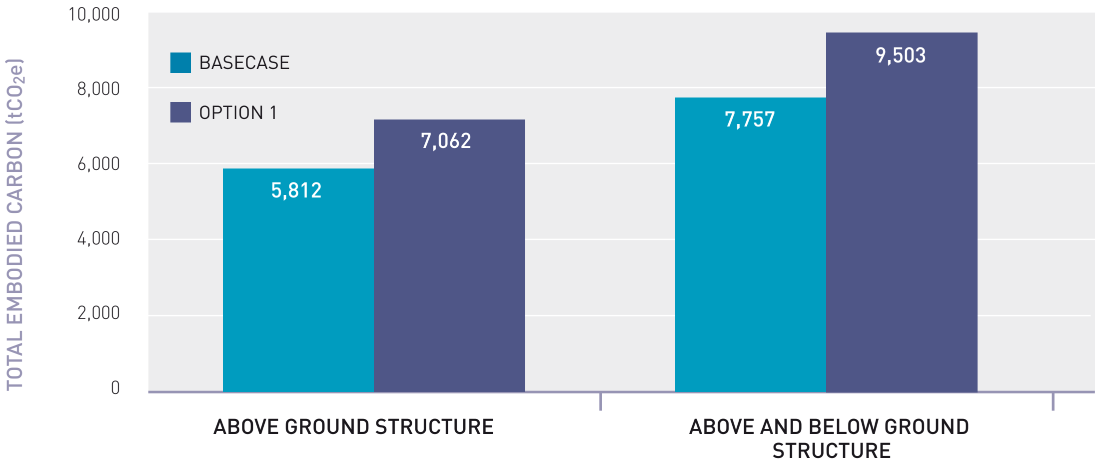


Figure 30 shows the embodied carbon associated with the structures of both buildings analysed. The 'above ground structure' comprises all structural elements including the cores, upper floors and roof. In addition, the 'above and below ground structure' includes the below ground podium levels and the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

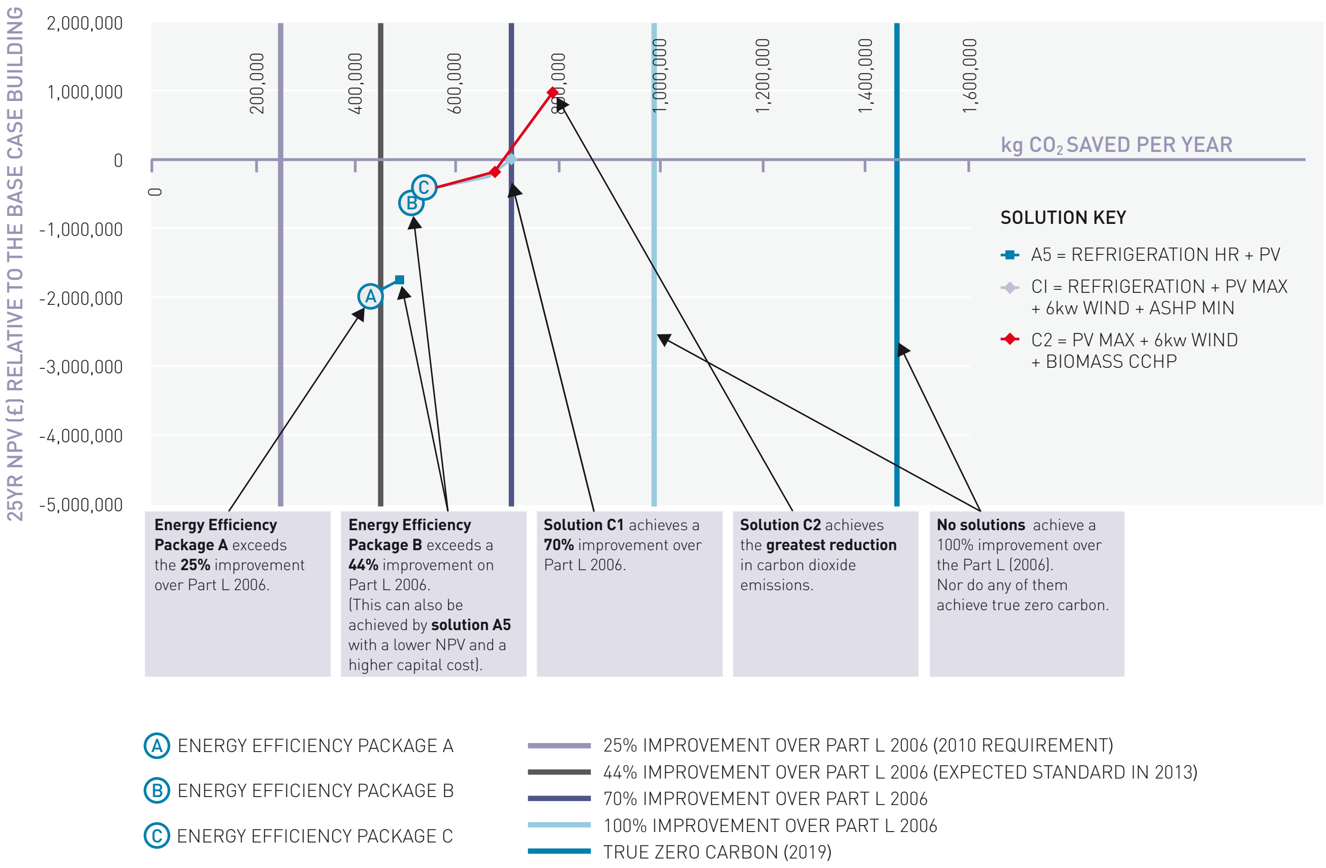


TABLE C1
LZC TECHNOLOGIES MODELLED

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$_2$e) 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$_2$e/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


PACKAGE **C**
Energy efficiency
Removes Package A items
• Vertically reduced glazing by 2m
• Daylight dimming lighting controls
• Improved wall insulation to 0.20W/m²K
• Improved boiler efficiency to 95%
Includes Package B items
• Very high efficiency lighting, ie 1.5W/m² per 100lux
• Occupancy sensing lighting controls
• Improved chiller efficiency EER = 8
• Improved ventilation heat recovery (85% efficient)
• Improved glazing U-value to 1.0W/m²K
• Radiant heated/chilled ceiling
Louvres/overhangs on South façade
Ultra high air tightness 1m³/hr per m² @50Pa
Solar control glass on South East and West facades
Specific fan powers (Reduced by 40%)
Reduced thermal bridging
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BREEAM MEASURES

BREEAM MEASURES | OFFICES

BREEAM MEASURES TO ACHIEVE: **V** VERY GOOD **E** EXCELLENT **O** OUTSTANDING RATINGS (Note that measures are cumulative)

ENERGY

- **V** Submetering of substantial energy uses. Efficient external lighting. Submetering of areas and/or departments.
- **E** Reduction of CO_2 emissions.
- **O** Efficient lifts.

WATER

- **V** Water Meter. Low flow sanitary fittings. Major leak detection.
- **E** Sanitary supply shut off.
- **O** Grey water harvesting.

MANAGEMENT

- **V** Commissioning. Considerate constructors. Construction site impacts. Security. Building user guide.
- **E** Seasonal commissioning.

MATERIALS

- **V** Material specification. Responsible sourcing of materials and insulation. Robust details. A rated hard landscaping.

ECOLOGY

- **E** Enhancing site ecology.

TRANSPORT

- **V** Public transport links. Proximity to amenities. Travel plan. Maximum carparking capacity. Cyclist facilities – racks, showers, lockers and changing space.
- **E** Pedestrian and cyclist safety.

POLLUTION

- **V** Low flood risk zone. Minimising watercourse pollution. Reduction of light pollution. Noise attenuation.
- **O** Low GWP refrigerant. Refrigerant leak detection and pumpdown.

WASTE

- **V** Construction site waste management. Storage of recyclable waste. Use of recycled aggregates. Floor finishes.

HEALTH & WELLBEING

- **V** High frequency lighting. Internal and external lighting levels. Preventing microbial contamination. Reducing the use of VOC's. Thermal comfort. Lighting zones and controls. Acoustic performance.
- **E** Indoor air quality.
- **O** Glare control.

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REFERENCES

1 www.breeam.org

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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