TARGET
ZERO®

GUIDANCE ON THE DESIGN AND CONSTRUCTION OF SUSTAINABLE, LOW CARBON MIXED-USE BUILDINGS

REPORT **V2.0 JANUARY 2012**

WWW.TARGETZERO.INFO

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CONTENTS

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 (2008) 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 fifth of the five building types covered by Target Zero, the mixed-use building, which comprises office and hotel accommodation. 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 the MediaCityUK mixed-use development and have been supplied by kind permission of MediaCityUK, Peel Media and AECOM.

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[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 around 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.

Peel Media

MediaCityUK DEVELOPMENT, SALFORD QUAYS, MANCHESTER

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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.

SUSTAINABLE MIXED-USE BUILDINGS

In our overcrowded city centres, available land for building commercial, retail and housing space is at a premium. Often driven by political and social policy, mixed-use development is aimed at revitalising city centres, optimising land use and securing broader community benefits such as contributions to transport, infrastructure and affordable housing.

The term mixed-use development covers a diverse scale and range of different use classes. Depending on its size, a mixed-use building might incorporate offices, apartments, retail, restaurants, cinemas, health clubs, plazas, galleries, hotel accommodation and gardens.

In the UK, mixed-use development has predominantly taken the form of large-scale, scheme-based development in which the mix of uses has been separated out horizontally across a number of independent structures, rather than vertically within a single building. Many schemes are retail-led and, responding to demand for affordable housing, particularly in city centre locations, many schemes include an element of residential accommodation.

Successful design and construction of mixed-use schemes is focused primarily upon separating the two (or more) uses and managing the interfaces where they occur. From the point of view of Building Regulations compliance, mixed-use buildings do present some specific challenges. The requirement for separation of uses and complex servicing arrangements can add further pressure on developments with challenging cost targets. Key design issues in mixed-use schemes include:

- **Transfer structures to accommodate vertical changes of use, for example going from the rigid grid of an underground car park to column-free retail space, then to residential room layout**
- **Privacy; including noise, waste management and security**
- **Services distribution particularly ventilation from commercial uses and its impact on residential space planning**
- **Heating systems in residential-led schemes – Part L pressure requires a change from (dry) electric heating systems to more efficient but complex wet systems**
- **Car parking and delivery access.**

On larger mixed-use schemes, different design teams may be engaged to design the different elements of the building. The separation of, for example, residential and commercial expertise involved in the design and construction of such schemes can be problematic and mean that opportunities to add value and deliver holistic sustainable buildings can be missed. On the other hand, mixed-use schemes can allow developers to tailor the blend of elements in order to make buildings more economically viable; for example, on the ground floor, retail may provide a better return on investment than offices.

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.**

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

[2] Costing of the base case mixed-use building was based on UK mean values current at 4Q 2010.

5.0 MEDIACITYUK HOLIDAY INN TOWER

MediaCityUK HOLIDAY INN TOWER

The building on which the mixed-use research is based is the Holiday Inn tower located in MediaCityUK, Manchester.

MediaCityUK is a new media district in Salford Quays, Manchester; inspired by the success of other media clusters in cities such as Dubai and Singapore. Work on Phase 1 of MediaCityUK started in 2007 and is scheduled for completion in 2011. MediaCityUK will be the new home for parts of the BBC (relocated from London), ITV, Coronation Street and the University of Salford.

Phase 1 of MediaCityUK includes:

- **65,032m^2 of office space across five buildings**
- **a 23,225m^2 studio block**
- **7,432m^2 of retail space**
- **378 residential apartments (in two tower blocks)**
- **a 218 bed hotel (Holiday Inn, MediaCityUK)**
- **five-acre public realm area including a piazza for 4,000 people**
- **a tram terminus, extending the current Metrolink line**
- **a foot bridge across the Manchester Ship Canal, linking Salford Quays with Trafford Wharf**
- **a multi-storey car park with approximately 2,200 spaces.**

The 17-storey Holiday Inn tower is attached to the main studio building at ground, mezzanine and first floor levels. An atrium connects the office floors of the tower block to the studio block (floors 2 to 6) – see Figure 1.

The building accommodates 7,153m^2 of open-plan office space on five floors (floors 2 to 6) and 9,265m^2 of hotel space on eight floors (floors 8 to 15). The ground and mezzanine floors accommodate the hotel reception and a restaurant. Floor 7 houses plant for the office floors and Floor 16 houses plant serving the hotel. The first floor accommodates dressing rooms and make-up areas. The gross internal floor area of the building is 18,625m^2. The 67m high building is rectilinear with approximate dimensions of 74m x 15.3m.

The building has a steel frame structure with Slimdek[1] floors. The steel columns are located on a 6.35m/2.6m/6.35m grid spaced at 7.5m. Two concrete cores, one at each extremity of the building, provide the stability of the tower as well as housing the risers and lifts. The foundations are 750mm diameter CFA concrete piles.

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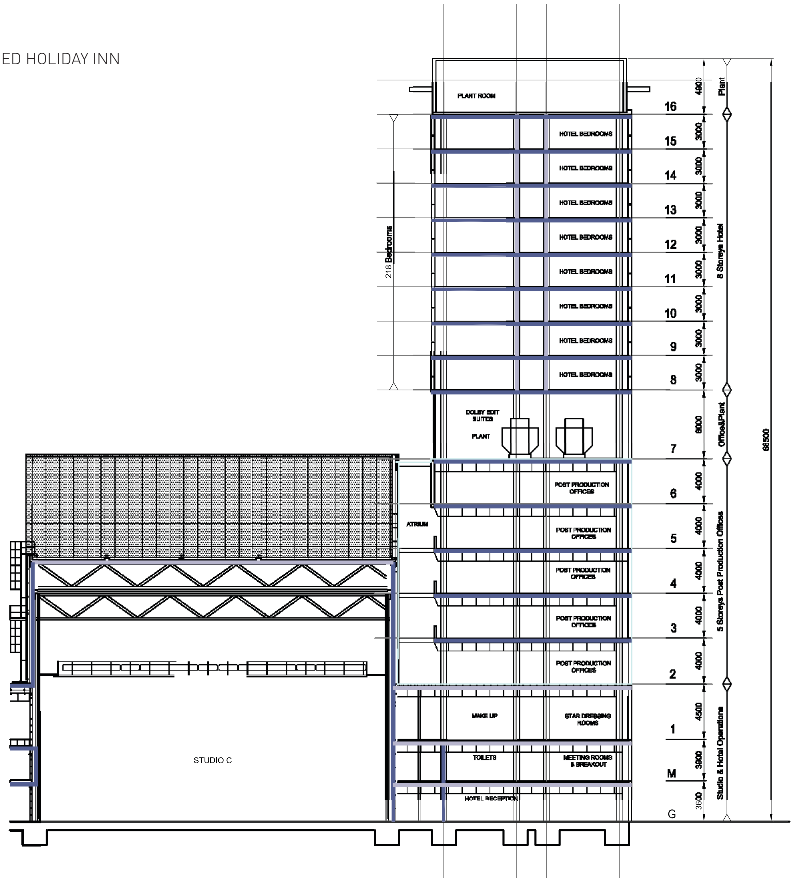
[1] Slimdek is an engineered flooring solution with deep steel decking spanning between Asymmetric Slimflor Beams (ASBs) and/or Rectangular Hollow Slimflor Beams (RHSFBs). For further information see www.tatasteelconstruction.com/en/design_guidance/slimdek/

5.0 MEDIACITYUK HOLIDAY INN TOWER

FIGURE 1
SECTION THROUGH MediaCityUK MAIN STUDIO BLOCK AND ATTACHED HOLIDAY INN TOWER BLOCK



The building is clad in a range of materials and systems including aluminium curtain-walling and rainscreen, ceramic granite cladding and external render.

This, and other MediaCityUK buildings, are served by a gas-fired, tri-generation system (combined cooling heat and power unit (CCHP)) providing heating, hot water, cooling and electricity. Heating and cooling is delivered to the building through fan coil units and a central mechanical ventilation system.

The glazing on most of the building is clear double glazing with a U-value of 2.2 and a G-value of 0.63. There is however solar control glass on the fully glazed 1st floor which has a U-value of 2.2 and a G-value of 0.3.

The building is oriented with the front elevation (shown right) facing north-east.

MediaCityUK HOLIDAY INN, SALFORD QUAYS, MANCHESTER

5.1 BASE CASE MIXED-USE BUILDING

For the purposes of the Target Zero mixed-use building study, a base case building was defined based on the MediaCityUK Holiday Inn tower, i.e. based on the same dimensions, specification, etc. as the actual building.

To make the building more representative of a typical mixed-use building, the tower was assumed to be isolated from the studio block and the atrium on the southwest façade was omitted. In addition, the make-up and dressing room accommodation on the first floor was assumed to be offices for operational carbon modelling purposes.

Changes were then made to the structure, fabric and services of the building to provide a base case mixed-use building that is representative of current practice and is no better than the minimum requirements under Part L (2006). These changes included:

- **the levels of thermal insulation were reduced until these were no better than Criterion 2 of Part L (2006)**
- **HVAC system efficiencies were altered to industry standards reflecting common commercial practice**
- **The tri-generation system (CCHP) was removed and replaced with conventional gas-fired boilers and electrically driven cooling systems**
- **the air leakage value was increased from 6 to 10m^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 and simplifying the energy efficiency of the lighting system. This was achieved by specifying lighting efficiencies of 2.5W/m^2 per 100lux in the office areas and 3.75W/m^2 per 100lux in the hotel areas.

More detail on the specification of the base case mixed-use building is given in Appendix A.

MediaCityUK HOLIDAY INN, SALFORD QUAYS, MANCHESTER

6.0 KEY FINDINGS

KEY FINDINGS

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

The base case building capital construction cost (4Q 2010) was estimated by independent cost consultants to be £36.7m (£1,970/m² GIFA). See Section 9.

The 2010 Part L compliance target of reducing operational carbon emissions by 25% (relative to the 2006 requirements) 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 31% reduction in regulated carbon emissions relative to the base case mixed-use building, at an increased capital cost of £475,000 (+1.3%) and yield a 25-year net present value[1] (NPV) saving of £620,225 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 36% and 41%. The first package of measures is 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 not, and in addition incurs a significant increase in capital cost (+4.6%). See Section 7.3.

Hot water and auxiliary energy (fans and pumps) were found to be the most significant regulated energy demands in the mixed-used building studied, accounting for 21% and 17% of the total operational carbon emissions respectively. Consequently energy efficiency measures relating to these demands are predicted to yield some of the largest carbon emission reductions. See Section 7.3.

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 commercial 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 building are very similar. Hence, energy efficiency measures which impact this heating/cooling balance of the building, e.g. glazing, 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 that is predicted to achieve true zero carbon, i.e. a regulated carbon emissions reduction of 165%[2] when used in conjunction with any of the energy efficiency packages. The greatest on-site reduction of 135% of regulated emissions was achieved using biogas-fired CCHP combined with a package of advanced energy efficiency measures (Package B – see Table 1). This solution is expensive however incurring a 9.25% capital cost increase but is nevertheless predicted to yield a 25-year net present value (NPV) saving of £202,160 relative to the base case building performance. See Section 7.5.

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[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 predicted base case building performance.

[2] 165% is the reduction required to achieve true zero carbon for the case study mixed-use building since unregulated small power demands contribute 40% of the total operational carbon emissions – see Figure 5. Therefore to achieve true zero carbon, a reduction in regulated emissions of 165% is required.

6.0 KEY FINDINGS

Forty-six on-site solutions (compatible combinations of energy efficiency measures and on-site LZC technologies) were identified for this building. None of these is predicted to achieve true zero carbon although 10 solutions are predicted to achieve a 100% reduction in regulated emissions relative to Part L 2006. See Section 7.5.

The greatest on-site carbon reduction (138% of regulated emissions) is achieved by a package of advanced energy efficiency measures (Package B – see Table 1), 290m² of photovoltaic panels mounted on the roof, a 6kW roof-mounted wind turbine and a biogas fuelled CCHP unit supplying heating, hot water, power and cooling.
The additional capital cost of this solution is £3,641,831 (9.9% of capital cost). This solution is also predicted to save money relative to the base case building performance, yielding a modest 25-year NPV saving of £127,430. See Section 7.5

Based on the assessment of this mixed-use building, the most cost-effective on-site routes to likely future low and zero operational carbon targets are as shown in Figure 2. 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 70% reduction in regulated carbon emissions (relative to 2006 Part L minimum requirements) using energy efficiency and on-site LZC technologies only. As such, reliance on offsite and Allowable Solutions (see Sections 7.6 to 7.8) will be required for large mixed-use commercial buildings to achieve very low and zero carbon targets.

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 mixed-use building was (see Section 8.1):

- **0.14% to achieve BREEAM 'Very Good'**
- **1.58% to achieve BREEAM 'Excellent'**
- **4.96% to achieve BREEAM 'Outstanding'.**

The impact of the structure on the operational carbon emissions of the base case mixed-use building was found to be small; the Building Emissions Rate (BER[1]) varying by just 1% between the steel and concrete-framed structures modelled. 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 0.7% between the steel and concrete-framed buildings modelled. See Section 9.1.

Both alternative structural options studied showed savings in terms of embodied carbon and capital cost compared to the base case building. This is because of the unusual constraints placed on the original building design. See Section 9.

Relative to the base case building, an equivalent flat slab concrete structure building (Option 1) had a lower (2.8%) embodied carbon impact but was 27% heavier. See Section 10.

Relative to the base case building, an equivalent steel-frame composite structure building (Option 2) had a lower (17.8%) embodied carbon impact. See Section 10.

MediaCityUK HOLIDAY INN, SALFORD QUAYS, MANCHESTER

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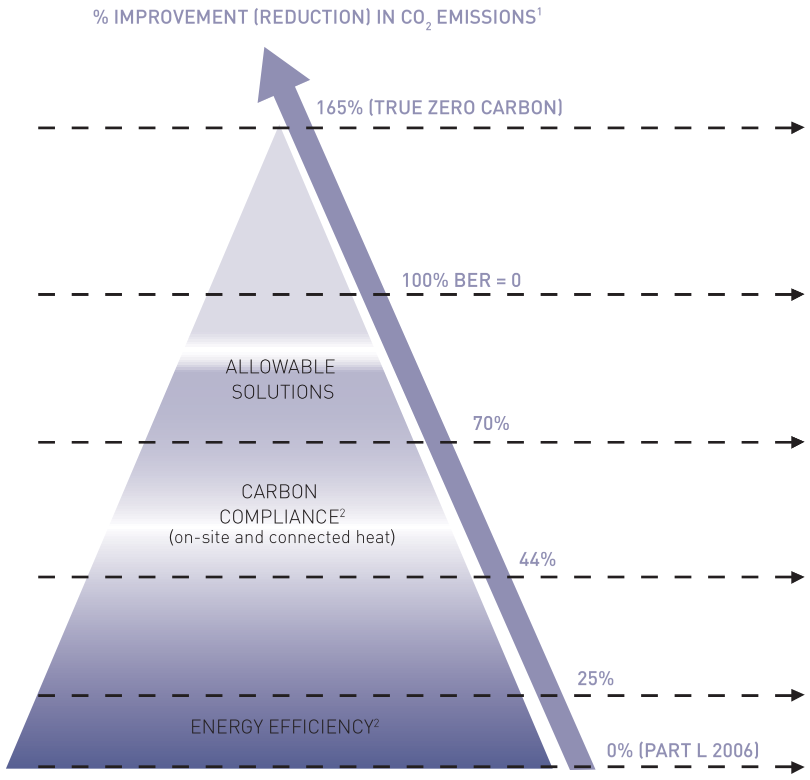
[1] The Building Emission Rate (BER) is defined by the National Calculation Methodology (NCM) as the amount of carbon dioxide emitted per square metre of floor area per year as the result of the provision of heating, cooling, hot water, ventilation and internal fixed lighting.

6.0 KEY FINDINGS

FIGURE 2
SUMMARY OF THE MOST COST-EFFECTIVE ENERGY EFFICIENCY AND LZC OPERATIONAL CARBON ROUTES FOR THE BASE CASE MIXED-USE BUILDING (FOR EXPLANATION OF ENERGY EFFICIENCY, CARBON COMPLIANCE AND ALLOWABLE SOLUTIONS, SEE SECTION 7.1)



ENERGY EFFICIENCY MEASURES	LZC TECHNOLOGIES	ADDITIONAL CAPITAL COST[3] (£)	25-YEAR NET PRESENT VALUE[3] (£)
No onsite routes identified			
Package A (see below)	Biomass-fired CCHP 290m² photovoltaics	1,700,761 [4.6%]	-871,855
Package A (see below)	Fuel cell CCHP 290m² photovoltaics	2,061,261 [5.6%]	-1,421,424
Package A (see below)	Natural gas CHP 290m² photovoltaics	1,525,661 [4.2%]	-1,519,221
Package A: Vertically reduced glazing by 2m; Specific fan power reduced by 20%; Improved boiler efficiency to 95%; Improved lighting efficiency to 2.0 W/m² per 100lux (office only); Improved hotel lighting efficiency to 2.2W/m² per 100lux (bedrooms) and 2.0W/m² per 100lux (bathrooms); Improved chiller efficiency SEER=6; Active chilled beams	-	475,000 [1.3%]	-620,225
Base case mixed-use building			

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 (3m) reduced by 2m

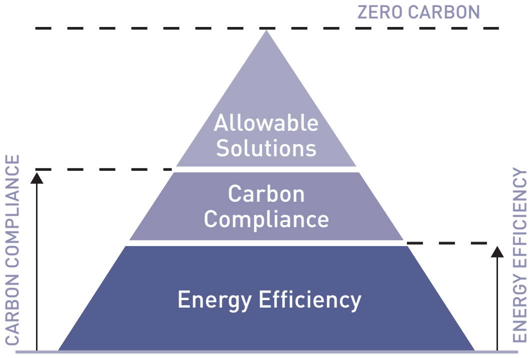
5 The biomass-fired CCHP unit modelled is the smallest commercially available and therefore although this solution meets the 100% reduction threshold, it was not possible to scale the CCHP unit down to just meet the 70% threshold at a reduced capital cost.

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 3
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 by 2019 and is consulting on the definition of 'zero carbon' for non-domestic 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/m^{2}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 and/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 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 city centre commercial 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% for offices and 25% for hotels. However, these targets are 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 planned for dwellings, i.e. an average or aggregate 44% improvement over 2006 requirements in 2013.

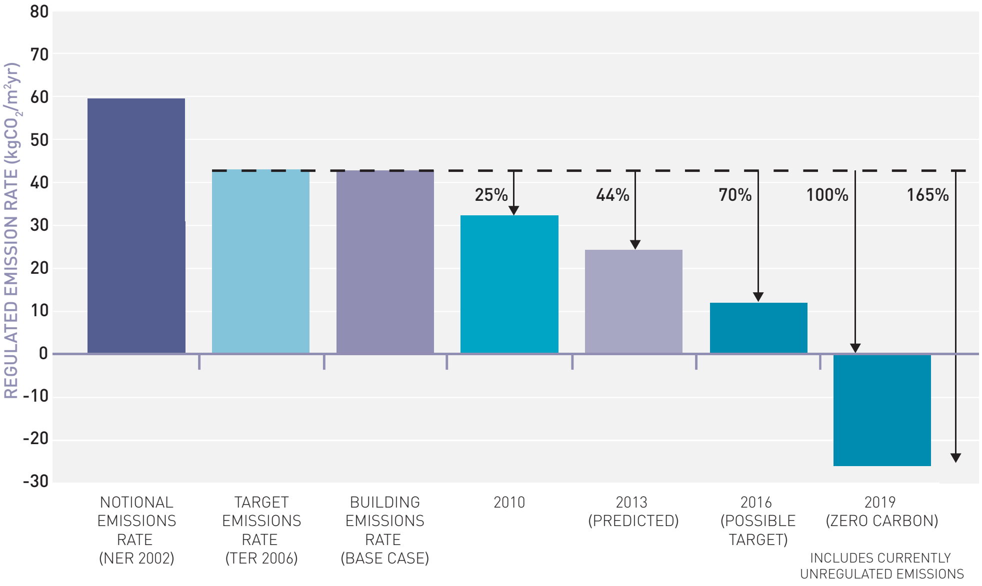
Figure 4 shows how the requirements of Part L have changed since 2002 and shows possible further reduction requirements on the trajectory to zero carbon non-domestic buildings. The emission rates shown relate to the base case mixed-use building.

Within Target Zero, the operational carbon emissions results for the mixed-use building analysed are presented with the 'flat' 25%, 44%, 70%, 100% (BER =0) and 165% (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 target. A reduction in regulated carbon emissions of 165% is required to achieve true zero carbon for the case study mixed-use 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 mixed-use building (see Section 5.1) were 1,186 tonnes CO_2 per year using the NCM within the IES dynamic thermal modelling software.

FIGURE 4

INDICATIVE GRAPH OF PAST AND POSSIBLE FUTURE PART L CHANGES



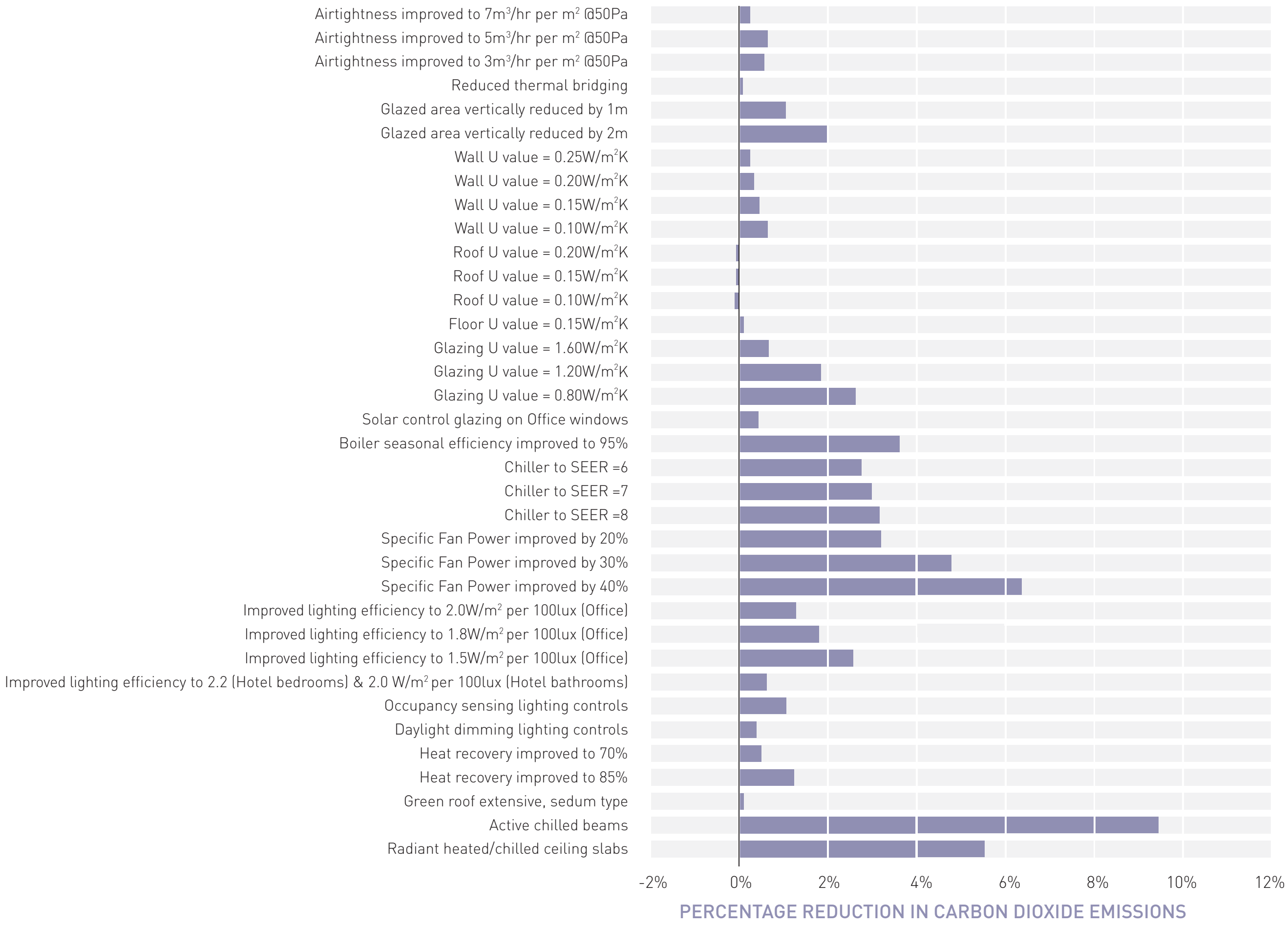
7.3 ENERGY EFFICIENCY

Figure 5 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 mixed-use building. The results show that the most effective measure is predicted to be the use of active chilled beams. Other measures predicted to achieve the largest reductions are those related to the provision of hot water (improved boiler efficiency) and fans and pumps (improved specific fan power). As shown in Figure 6, which gives the breakdown of carbon dioxide emissions by energy demand in the base case building, hot water (21%) and fans and pumps (17%) are the most significant sources of regulated carbon emissions in the base case building. Active chilled beams will also contribute to the reduction of the fan and pump energy demand significantly.

Most of the building fabric improvements modelled were found to yield only small reductions in carbon dioxide emissions.

FIGURE 5

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

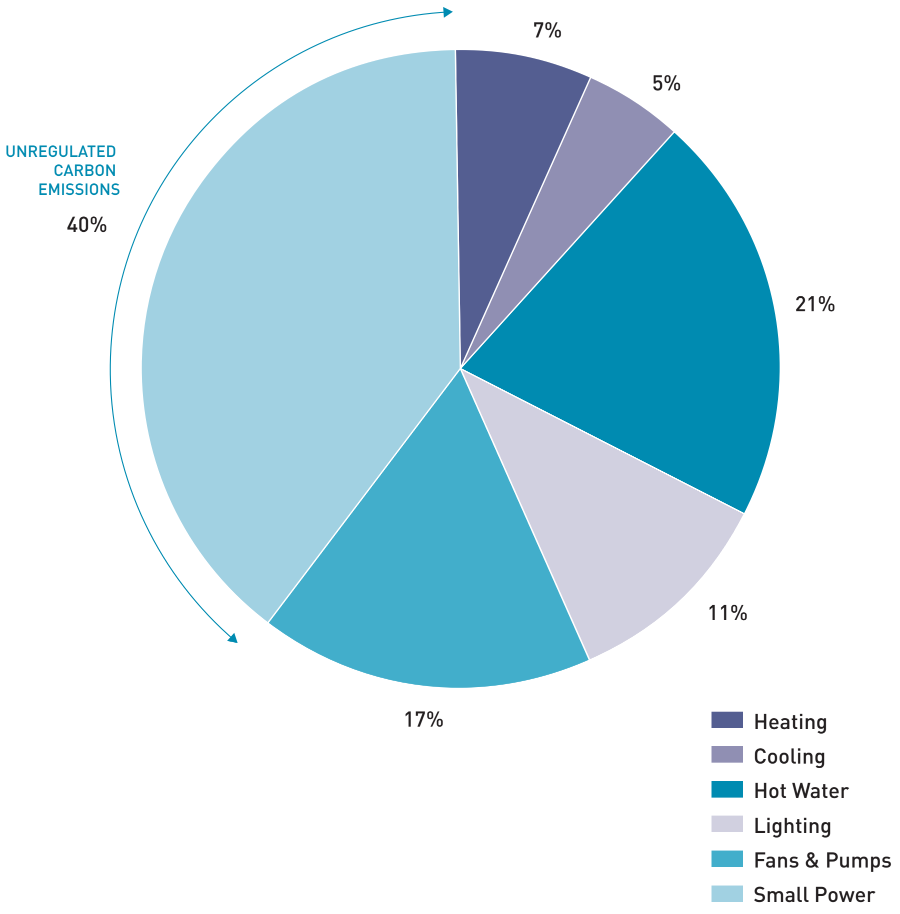


7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

The energy efficiency measures which affect the heating/cooling balance of the mixed-use building are difficult to optimise. This is because the proportion of annual carbon emissions from space heating (7%) and cooling (5%) are approximately equal - see Figure 6.

FIGURE 6

BREAKDOWN OF CARBON DIOXIDE EMISSIONS FOR THE BASE CASE MIXED-USE 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. Glazing is one such measure – see Section 7.4.

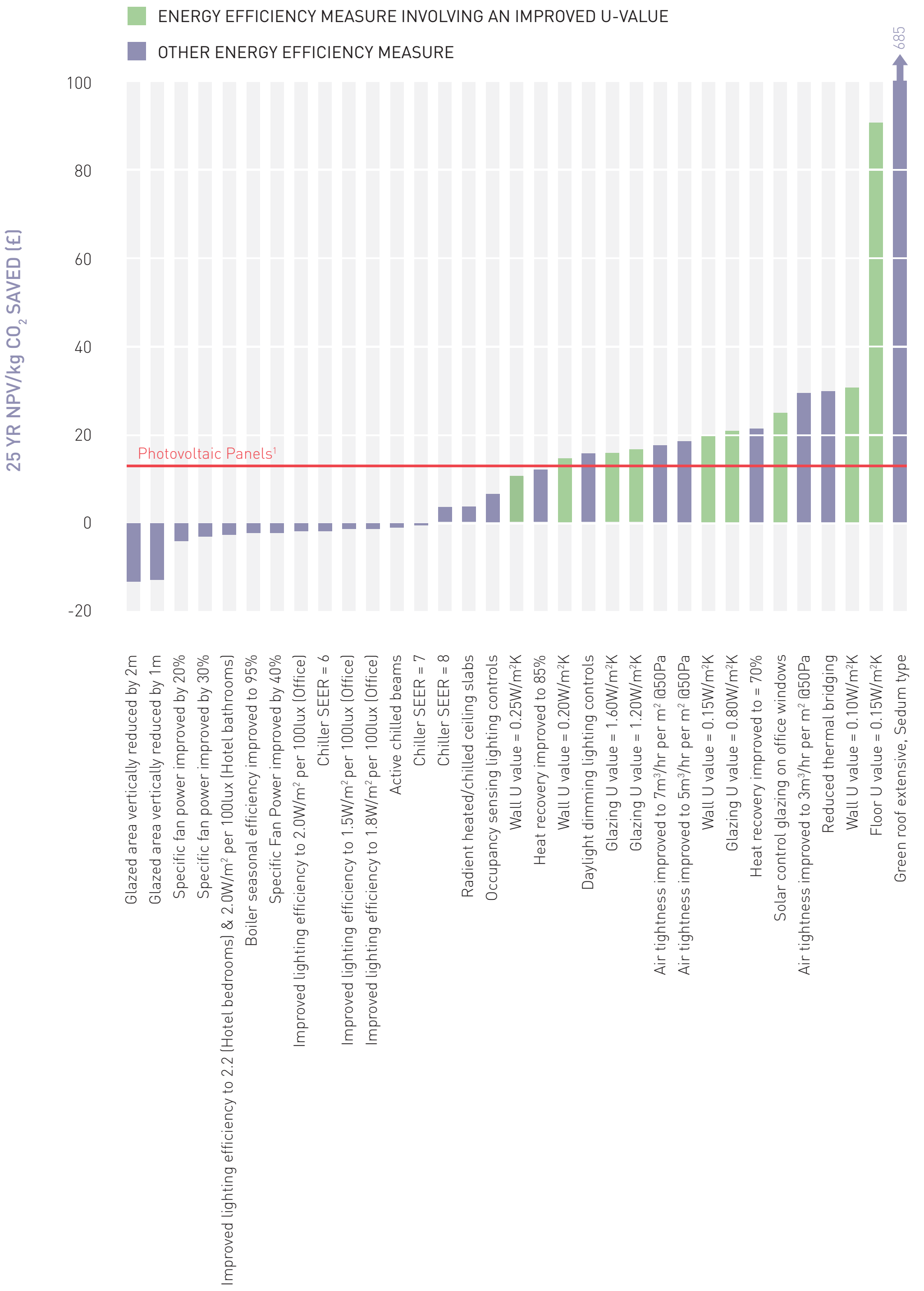
The results shown in Figure 5 take no account of cost and therefore the energy efficiency measures modelled have been ranked (see Figure 7) in terms of their cost effectiveness, i.e. 25-year NPV per kg of CO_2 saved per year relative to the base case building performance (see Appendix D).

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

Figure 7 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.

FIGURE 7

COMPARISON OF NPV COST EFFECTIVENESS OF MODELLED ENERGY EFFICIENCY MEASURES



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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

The ranked measures shown in Figure 7 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).

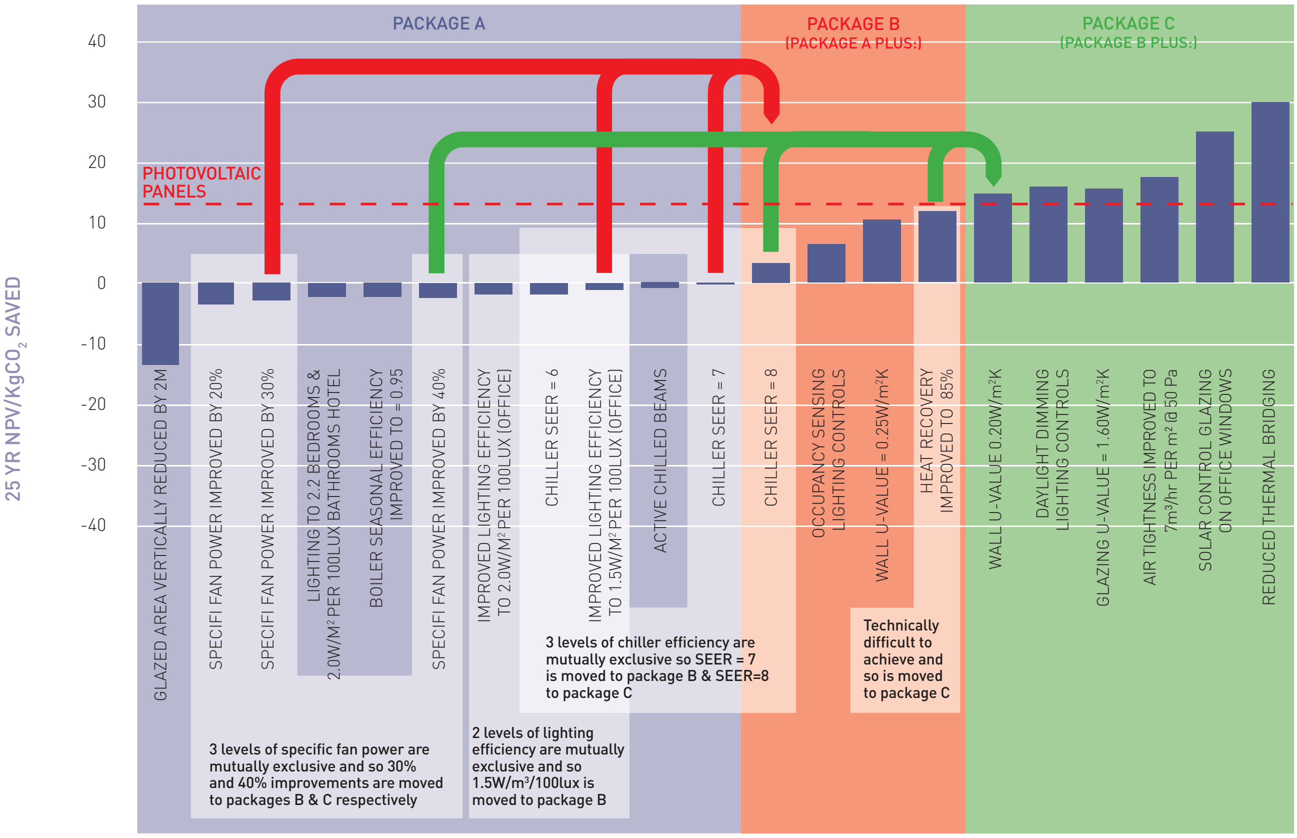
Packages were carefully checked to ensure that all of the energy efficiency measures were cost-effective[1] and compatible with each other. Some measures were 'stepped-up' between packages despite their cost effectiveness ranking – see Figure 8. For example Package A includes a 20% improvement to specific 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. specific fan power), supersedes them. Similarly, Package C contains (or supersedes) all the measures in Packages A and B.

Figure 8 shows the individual measures included within the three energy efficiency packages applied to the base case mixed-use building.

FIGURE 8

ENERGY EFFICIENCY MEASURE PACKAGES A, B AND C



3 levels of chiller efficiency are mutually exclusive so SEER = 7 is moved to package B & SEER=8 to package C

Technically difficult to achieve and so is moved to package C

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

2 levels of lighting efficiency are mutually exclusive and so 1.5W/m³/100lux is moved to package B

It is noted that the high efficiency lighting option was found to be less cost-effective than the very high efficiency lighting – see Figure 7- and so this measure was not included in any packages.

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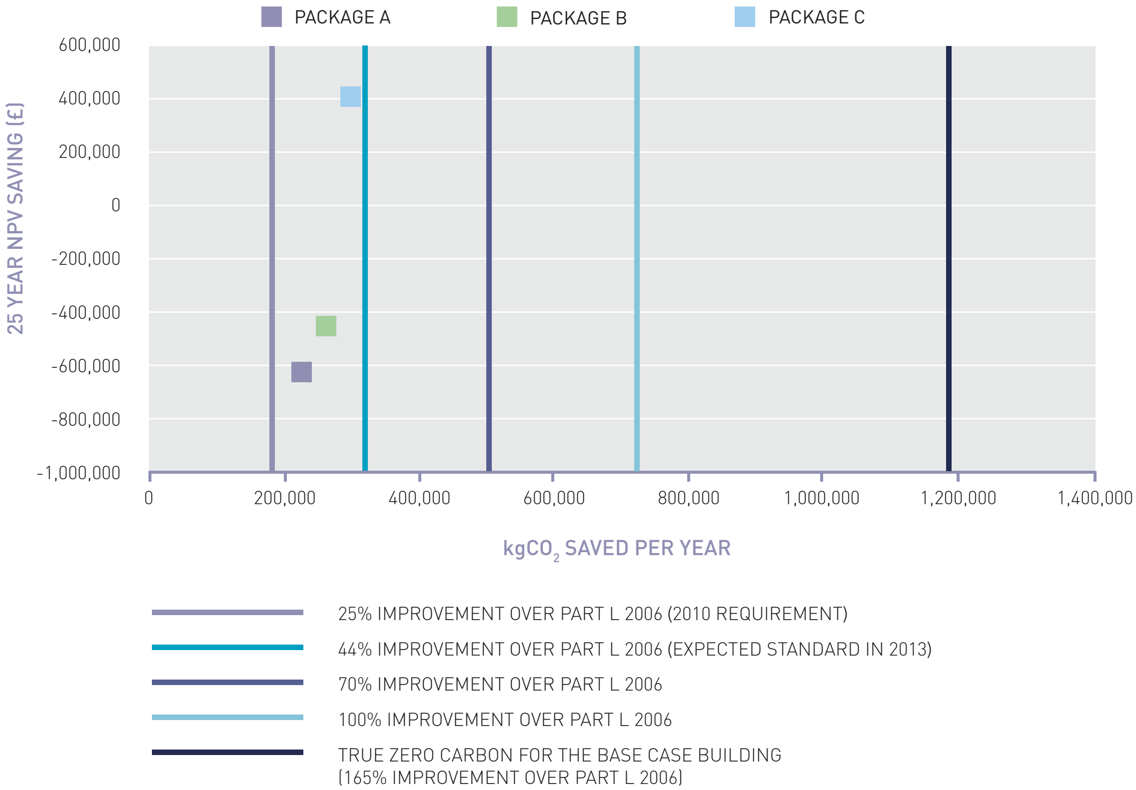
[1] For the purposes of this assessment, cost-effective was defined as less than £40 (25-year NPV) per kg of CO$_2$ saved per year.

Figure 9 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 performance) against 25-year NPV (relative to the base case building performance) and with reference to future likely Part L compliance targets.

FIGURE 9
RESULTS FOR ENERGY EFFICIENCY PACKAGES A, B AND C



The figure shows that the 25% reduction in regulated carbon dioxide emissions, which is required to comply with the 2010 regulations, can be achieved through the use of Package A energy efficiency measures alone. These measures achieve a 31% reduction in regulated emissions and incur an increase in capital cost of £475,000 relative to the base case building. See also Section 7.9 which discusses the impact of Part L 2010 on operational carbon emissions reduction targets.

The current expectation is that in 2013, Part L will require a reduction of 44% beyond the 2006 requirement; neither of the more advanced Energy Efficiency Packages (Packages B and C) is predicted to achieve this target.

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 performance) from their introduction into the base case mixed-use 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 BUILDING (£) [%]	CHANGE IN 25 YEAR NPV FROM BASE CASE BUILDING (£)
Base case building	Defined in Section 5.1 and Appendix A	1,186,131	-	-
Package A	Vertically reduced glazing by 2m Specific fan powers reduced by 20% Improved boiler efficiency to 95% Improved lighting efficiency to 2.0W/m^2 per 100lux (office only) Improved hotel lighting efficiency to 2.20W/m^2 per 100lux (bedrooms) and 2.0W/m^2 per100lux (bathrooms) Improved chiller efficiency SEER=6 Active chilled beams	966,197 [-19%] [-31%]	475,000 [1.3%]	-620,225
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 (office only) Improved chiller efficiency SEER = 7 Occupancy sensing lighting controls Improve wall insulation U-value to 0.25W/m^2K	928,051 [-22%] [-36%]	800,000 [2.2%]	-452,548
Package C	Package B plus (or superseded by): Specific fan powers reduced by 40% Improved chiller efficiency SEER = 8 Improved ventilation heat recovery (85% efficient) Improved wall insulation U-value to 0.2W/m^2K Daylight-dimming lighting controls Improved glazing U-value to 1.6W/m^2K Improved air tightness 7m^3/hr per m^2 @50Pa Solar control glass (office only) Reduced thermal bridging[1]	892,324 [-25%] [-41%]	1,670,000 [4.6%]	408,235

[1] Enhanced detailing to halve heat loss through thermal bridging

The reduction in carbon dioxide emissions resulting from implementing the energy efficiency packages ranges from 31% of regulated emissions (19% of total emissions) with an increased capital cost of 1.3% up to 41% of regulated emissions (25% of total emissions) with an additional capital cost of 4.6%. Packages A and B 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 package is not attractive, i.e. it incurs a greater capital cost than Package B and does not yield a whole life saving relative to the base case building performance. Therefore to reduce operational carbon emissions, beyond those achieved using Energy Efficiency Package B, LZC technologies should be used – see Section 7.5.

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RECOMMENDATION

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.

RECOMMENDATION

The targets for operational carbon reduction in mixed-use 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. For the base case building, the package of measures predicted to achieve the 2010, 25% reduction target most cost effectively is Energy Efficiency Package A – see Table 1.

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 Approved Document. Criterion 3 of 2006 Part L required that occupied rooms should not overheat; this meant that cooled rooms passed and that an overheating assessment should be carried out for rooms without cooling. The 2010 Part L2A Approved Document 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 had east-facing, 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 solar control glass and shading devices such as louvres, brise soleil and internal blinds.

The base case mixed-use building, like the MediaCityUK Holiday Inn building, has full height (floor to ceiling) 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. It should be noted that, in terms of good glazing design, the benefit of specifying glazing down to floor level is minimal. Daylight factors are measured on the working plane, i.e. at desk height, and so having glazing below this level is generally of little benefit.

The main advantage of 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 lets out more heat than opaque construction façades. Table 2 outlines the key effects of increasing the area of glazing.

The base case building was adapted from the actual building by isolating the office/hotel tower block from the attached studio block. This was effected by assuming that the case study building office floors are deep plan[2] with glazing on only one façade (north-east facing) 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; 65% of the floor area in the base case building is 6m or more from a window.

TABLE 2

EFFECTS OF INCREASING THE GLAZED AREA

EFFECT	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

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[1] Criterion 3 of Approved Document L2A (2010) 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.

The hours of operation of commercial buildings also have a significant impact on the usefulness of glazing. During the hours of darkness, glazing serves only to release heat therefore the more hours of darkness during which the building is used, the lower the optimal glazed area will be.

In order to address the complexity of optimising the glazed area, a series of simulations were run on a typical hotel floor[1]. Given the importance of the energy used by electric lighting in these analyses, it was decided that all the test simulations should include daylight dimming lighting controls and the lighting efficiencies described in Appendix A.

Two alternative[2] 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	■ G-value reduced from 0.63 to 0.40 ■ Light transmittance reduced from 0.76 to 0.60
Louvres	■ Horizontal projections 1m deep ■ Spaced at 1m vertical intervals
Overhang	Glazed height reduced by 1m ■ Horizontal projections 1.73m deep ■ Projecting from 1m above the window head height Glazed height reduced by 2m ■ Horizontal projections 0.87m deep ■ Projecting from 0.5m above the window head height

1 Overhangs not modelled on the base case building.

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[1] Reduced glazing was only modelled for the hotel floors; the office floors only have 40% glazing (on one façade) and therefore reducing this glazing ratio further was not considered viable.

[2] The full height glazing in the base case building is 3m 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 these, rather 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.

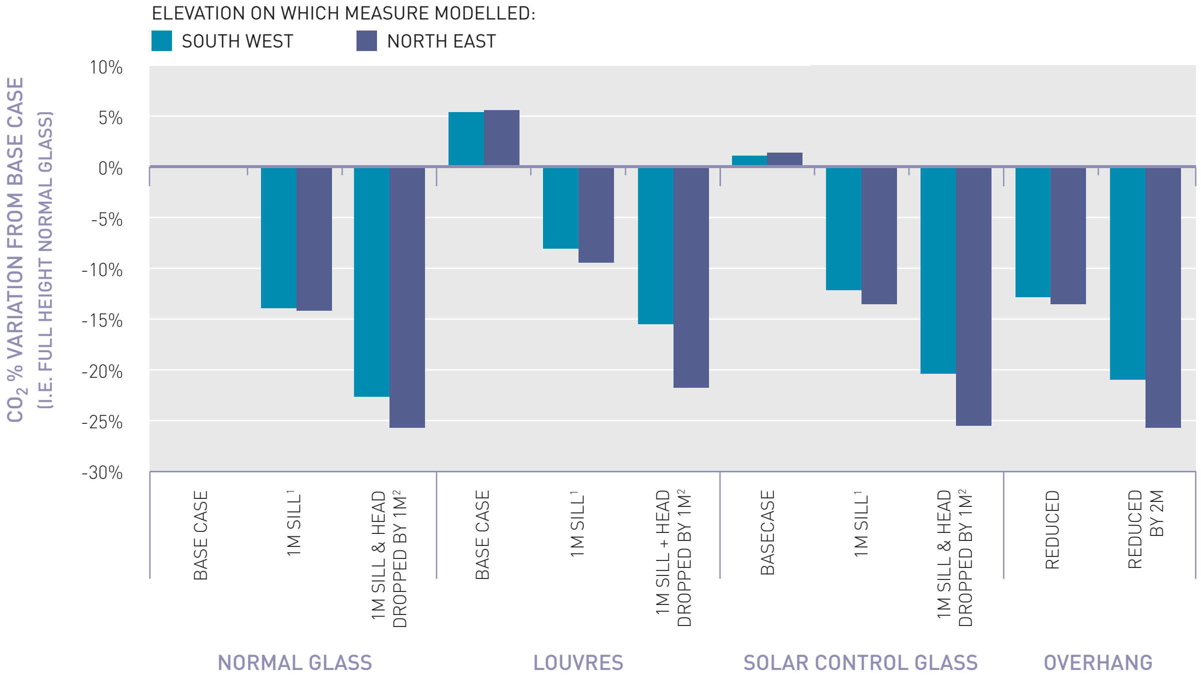
The geometry of the overhangs was determined in part by experience and in part through inspection of the sun path diagram for the building's location.

The results of this glazing analysis are shown in Figure 10 which gives the predicted change in carbon emissions for a typical hotel floor.

RECOMMENDATION

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

FIGURE 10
RESULTS OF THE GLAZING ANALYSIS



[1] A 1m reduction in glazing height.

[2] A 2m reduction in glazing height.

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 2m, i.e. having a 1m sill and dropping the head height by 1m.

Figure 10 also shows that the effect of reducing glazing height is greater on the Northeast façade than on the Southwest façade. The use of louvres with full height glazing, was found to increase the emissions of the hotel rooms on both façades whilst other solar control measures were found to have relatively minor effects. The greatest carbon dioxide reduction was achieved by using reduced height normal glass for both orientations.

7.5 ON-SITE LZC TECHNOLOGIES

Twenty nine 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 units. Both small and large units are capable of meeting the same base load. Although the smaller units will require back-up at times of peak demand, their utilization (and hence efficiency) is generally greater than the larger CHP units modelled.

Due to site constraints, the largest on-site wind turbine considered was a roof-mounted 6kW turbine (5.5m rotor diameter on a 9m tower). 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 165% reduction in regulated emissions. The greatest on-site reduction, using just one on-site LZC technology, is 135% of regulated emissions (82% of total carbon emissions) achieved by using biogas-fired CCHP combined with Energy Efficiency Package B. This solution will not however be practical on most sites as the space and feedstock required for anaerobic digestion will not be available on most city centre sites. Therefore, an 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, more difficult 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 heat rejection plant. 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 these 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.

Forty six on-site solutions (packages of compatible energy efficiency measures and on-site LZC technologies) were identified for the base case mixed-use building. None of these is predicted to achieve true zero carbon although 10 solutions are predicted to achieve a 100% improvement on 2006 Part L requirements.

The greatest on-site reduction in carbon emissions is predicted to be achieved using Energy Efficiency Package B coupled with 290m² of photovoltaic panels mounted on the roof, a 6kW roof-mounted wind turbine and a biogas-fuelled CCHP unit supplying heating, hot water, electricity and cooling.

This solution is predicted to achieve a reduction in regulated emissions of 138% (83% of total carbon emissions). The additional capital cost of this package of measures is estimated to be £3,641,831 (9.9%) and this solution is predicted to save money compared with the base case building performance over 25 years yielding a modest NPV saving of £127,430.

The selected packages of compatible on-site 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.

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)	ADDITIONAL CAPITAL COST (RELATIVE TO THE BASE CASE BUILDING) (£)	25-YEAR NPV COST (RELATIVE TO THE BASE CASE BUILDING) (£)
2010 revision to Part L requiring a 25% improvement over Part L 2006	Energy Efficiency Package A (see Table 1)	29.6	475,000 [+1.3%]	-620,225
Likely 2013 revision to Part L requiring a 44% improvement over Part L 2006	Solution A2 comprising: Energy Efficiency Package A (see Table 1) Natural gas CHP 290m² photovoltaics	17.57	1,525,661 [+4.2%]	-1,519,221
Possible on-site Carbon Compliance threshold: 70% improvement over Part L 2006	Solution A4 comprising: Energy Efficiency Package A (see Table 1) Fuel cell CCHP 290m² photovoltaics	3.63	2,061,261 [+5.6%]	-1,421,424
100% improvement over 2006 Part L (excludes unregulated emissions)	Solution A8 comprising: Energy Efficiency Package A (see Table 1) Biomass-fired CCHP 290m² photovoltaics	-1.29	1,700,761 [+4.6%]	-871,855
True zero carbon (expected standard for non-domestic buildings in 2019) i.e. 165% improvement on Part L 2006	No on-site routes identified			

[1] CCHP plant sized to supply space heating (excluding radiant systems), hot water, cooling and electricity to all areas.

[2] This compliance target was based on the domestic target and predates the Government's consultation on policy options for zero carbon new non-domestic buildings [3]. It was chosen as an appropriate target in the Target Zero methodology and is retained for consistency between the five building types considered.

The research found that a great reduction in carbon dioxide emissions can be achieved on-site; however the additional costs of doing this begin to become restrictive above certain levels. For example it is predicted to be possible to achieve improvements above 25% over the 2006 Part L minimum requirement at a capital cost rise of 1.3%; however to achieve a 70% improvement requires an additional capital investment of around 5%. Getting beyond the 100% (regulated) reduction threshold increases capital costs further and becomes technically very difficult.

It is noted in Table 4 that solution A4 has a higher capital cost than solution A8 but yields a greater NPV saving relative to the base case building performance. The CCHP unit modelled in Solution A8 is the smallest unit currently available and therefore although this solution meets the 100% reduction threshold, it is not possible to scale the CCHP unit down to just meet the 70% threshold at a reduced capital cost.

The government has stated its intention for all new non-domestic buildings to be 'zero carbon' from 2019 onwards – see Section 7.1. It is expected that this requirement will be achieved by a combination of on-site and near-site solutions and off-site 'allowable' solutions – see Section 7.8. It is clear that for most city centre, mixed-use buildings, allowable solutions will play a significant role in achieving low and zero carbon targets.

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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 offsite LZC installations tend to be more cost-effective than on-site solutions and so, if they are permitted as Allowable Solutions (see Sections 7.1 and 7.8), then these are likely to be more attractive than on-site solutions.

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 the investment would be for an appropriate share of a wind turbine. The share would be sufficient to offset the targeted carbon emissions reduction.

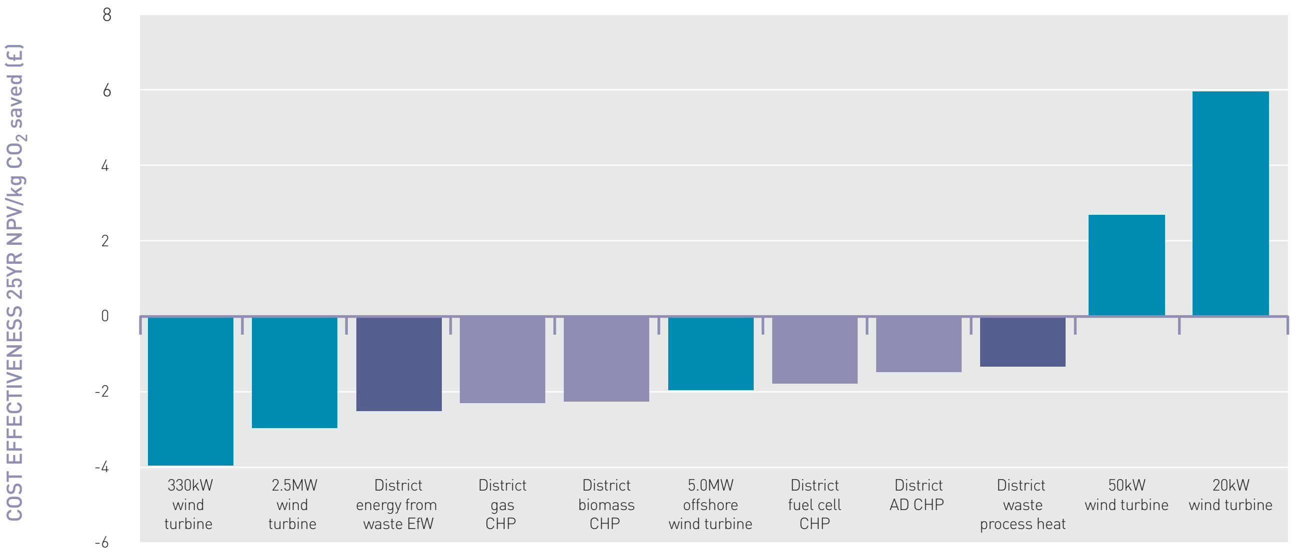
The only single offsite solutions able to achieve a 100% reduction in regulated carbon emissions and true 'zero carbon', are large wind turbines. It should be noted that the wind turbine has been modelled, in accordance with the NCM, as if it was erected on the same site as the case study building and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

District heating systems and district CHP systems also 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 11 shows the ranking of the cost effectiveness of all offsite technologies modelled. 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 11

COST EFFECTIVENESS OF OFFSITE TECHNOLOGIES MODELLED ON ENERGY EFFICIENCY PACKAGE A



7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

Table 5 shows the most cost-effective single offsite technologies which meet the likely future compliance targets. All technologies are applied in combination with Energy Efficiency Package A.

TABLE 5

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

TARGET	MOST COST-EFFECTIVE ROUTE	BER ($kgCO_2/m^2$ yr)	ADDITIONAL CAPITAL COST (RELATIVE TO THE BASE CASE BUILDING) (£)	25-YEAR NPV COST (RELATIVE TO THE BASE CASE BUILDING) (£)
2010 revision to Part L requiring a 25% improvement over Part L 2006	Energy Efficiency Package A (see Table 1)	29.6	475,000 [1.3%]	620,225
Likely 2013 revision to Part L requiring a 44% improvement over Part L 2006	Energy Efficiency Package A (see Table 1) 330kW wind turbine	16.95	1,247,500 [3.4%]	-1,373,654
The expected threshold for on-site Carbon Compliance: 70% improvement over Part L 2006	Energy Efficiency Package A (see Table 1) 13% share of a 2.5MW wind turbine	12.98	960,000 [2.6%]	-1,352,578
100% improvement over 2006 Part L (excludes unregulated emissions)	Energy Efficiency Package A (see Table 1) 23% share of a 2.5MW wind turbine	0	1,330,000 [3.6%]	-1,911,329
True zero carbon (expected standard for non-domestic buildings in 2019) i.e. 165% improvement on Part L 2006	Energy Efficiency Package A (see Table 1) 44% share of a 2.5MW wind turbine	-27.36	2,137,500 [5.8%]	-3,130,454

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-fired 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 most of the on-site technologies modelled 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 the most cost-effective although this technology does not achieve the greatest carbon emissions reductions – see Figure 11.

If large wind turbines cannot be used then a biomass district CHP system is predicted to be the most cost-effective route to achieving a 70% and a 100% reduction below the requirements of Part L 2006. The greatest reduction in carbon dioxide emissions achieved by a district heating system is 99.4% of total emissions achieved by anaerobic digestion CHP combined with Package B.

District heating schemes are most viable in dense urban areas where the heat demand is concentrated. The opportunities for connecting new commercial buildings to a district heating network are higher than for the connection of existing buildings.

Many existing buildings 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.

Most existing district CHP schemes are set up to supply public sector buildings with adjacent private customers being connected to the system once it has already been proved to be viable. District heating schemes are most viable when supplying buildings with a large and fairly constant thermal (heat and potentially cooling) 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 6 summarises the main offsite technologies that could provide directly-connected heat to the mixed-use building. The modelled results of savings in carbon emissions, capital costs and NPV values are presented. The results are based on the 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 this will be borne by the district heating network operators rather than by the owners/tenants of individual building connected to the network.

TABLE 6

DIRECTLY CONNECTED HEAT RESULTS – BASED ON ENERGY EFFICIENCY PACKAGE B

OFFSITE TECHNOLOGY	TOTAL OPERATIONAL CO2 EMISSIONS ($KGCO_2/M^2$ YR) [CHANGE FROM BASE CASE]	CHANGE IN CAPITAL COST FROM BASE CASE[1] (£) [%]	CHANGE IN 25-YEAR NPV[1] (£)
Biomass fired CHP	329,842 [-72%]	734,569 [2.0%]	-1,027,624
Fuel Cell fired CHP	170,103 [-86%]	734,569 [2.0%]	-1,027,624
Nat Gas fired CHP	249,563 [-79%]	734,569 [2.0%]	-1,026,368
Energy from waste	774,886 [-35%]	734,569 [2.0%]	-727,826
Waste process heat	654,631 [-45%]	734,569 [2.0%]	-727,826
Biogas fired anaerobic digestion CHP	1,171 [-99%]	734,569 [2.0%]	-1,026,369

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

7.8 ALLOWABLE SOLUTIONS

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

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.

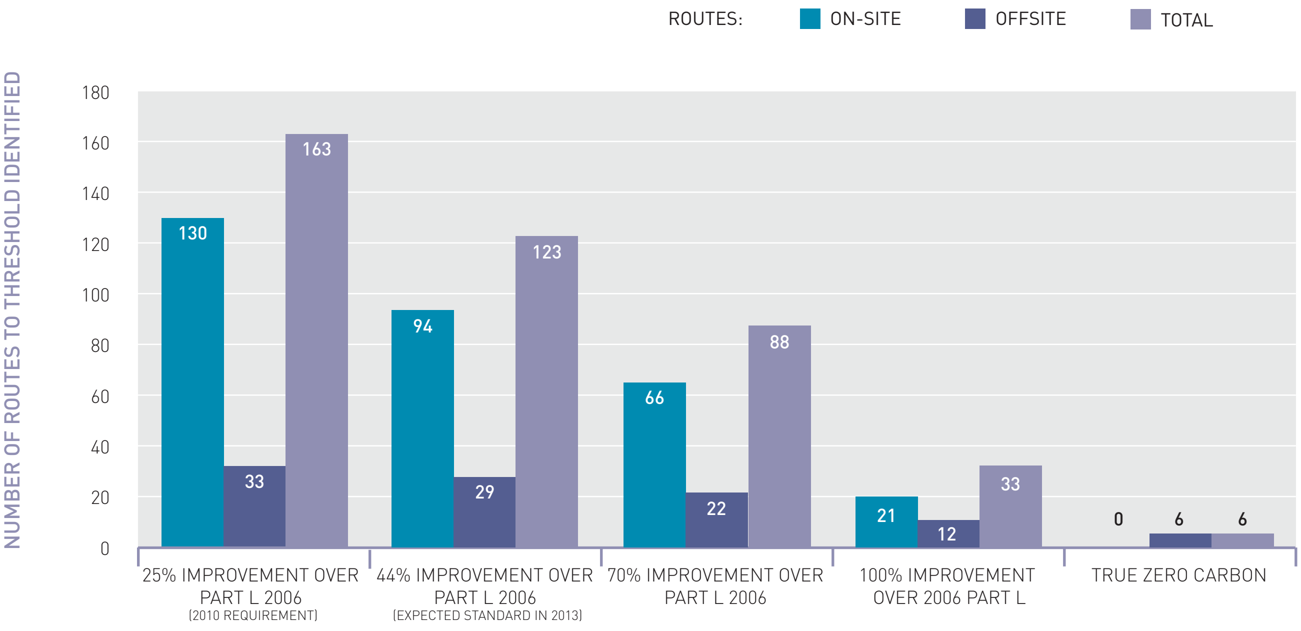
Figure 12 shows the number of routes (combinations of energy efficiency measures and LZC technologies) identified – based on the analysis of this mixed-use building - that are predicted to achieve compliance with the likely future Part L targets.
This reveals that there is a wide range of routes to reducing the carbon dioxide emissions on-site by up to 70% relative to Part L 2006. However, only 21 on-site routes to a 100% improvement over 2006 Part L requirements could be identified and no on-site solutions which achieve true zero carbon could be identified for this mixed-use building.

Most of the 94 on-site routes to the 44% reduction target are expected to be suitable for all city centre sites, however the proportion of options with special site requirements increases towards the 100% threshold, for example, 15 of the 21 on-site routes to 100% improvement require either biomass or biogas fired technologies.

Reduction in carbon dioxide emissions greater than 70% will only be technically and financially viable in areas where either energy can be sourced from large wind turbines, or where the local area is suitable for a district heating scheme.

FIGURE 12

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 (using energy efficiency measures and on-site LZC technologies) in industrial buildings than in hotels.

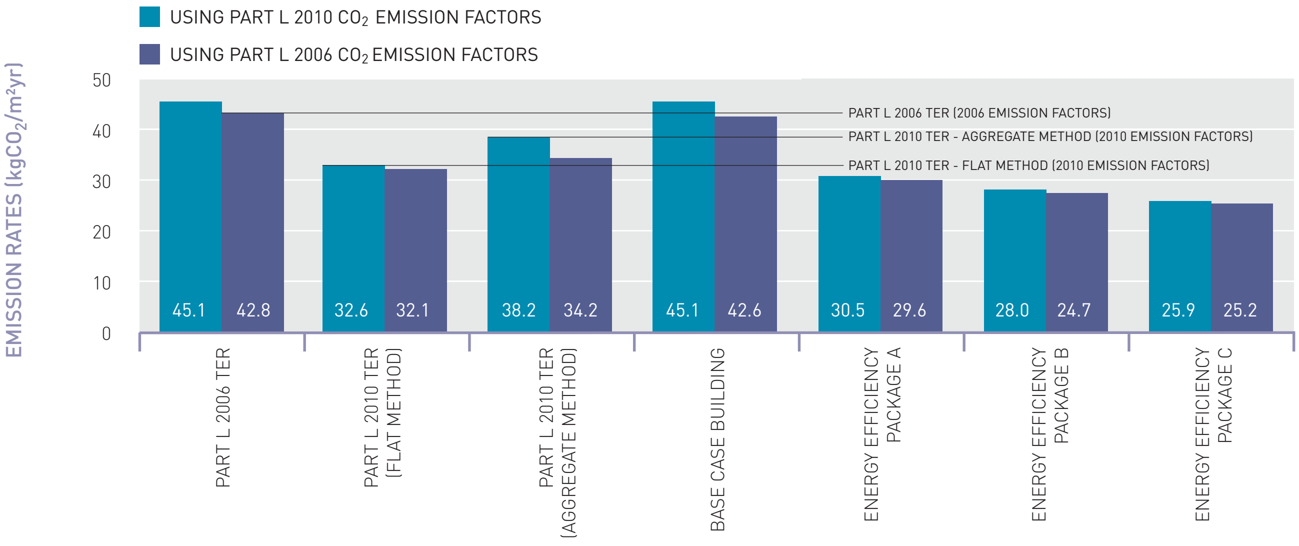
At the time of writing, the 2010 Part L requirements have not been implemented in the dynamic simulation models used for Part L compliance and therefore, under Target Zero, the proposed 2010 changes to the notional mixed-use building have been manually implemented in the IES model used for the operational carbon assessments. As such, these results should be considered as approximate. The impact of these changes on the mixed-use building operational carbon emissions results are illustrated in Figure 13.

Using Part L 2006, the Target Emission Rate (TER[1]) for the mixed-use building is 42.8kgCO$_2$/m^{2}yr. The base case building specification just meets this target, i.e. BER = 42.6kgCO$_2$/m^{2}yr. Using the new Part L 2010 carbon emission factors, the 2006 TER increases to 45.1kgCO$_2$/m^{2}yr and the BER of the base case building increases to 45.1kgCO$_2$/m^{2}yr.

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 32.1kgCO$_2$/m^{2}yr. Using the 2010 emissions factors gives a TER of 32.6kgCO$_2$/m^{2}yr. Applying the aggregate approach, the TER becomes 34.2kgCO$_2$/m^{2}yr with the 2006 emissions factors and 38.2kgCO$_2$/m^{2}yr 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 8% when assessed using the 2006 carbon emission factors. Applying the 2010 emissions factors, Energy Efficiency Package A passes by 7% using the flat method and by 20% using the aggregate approach.

FIGURE 13
THE IMPACT OF CHANGES TO PART L 2010



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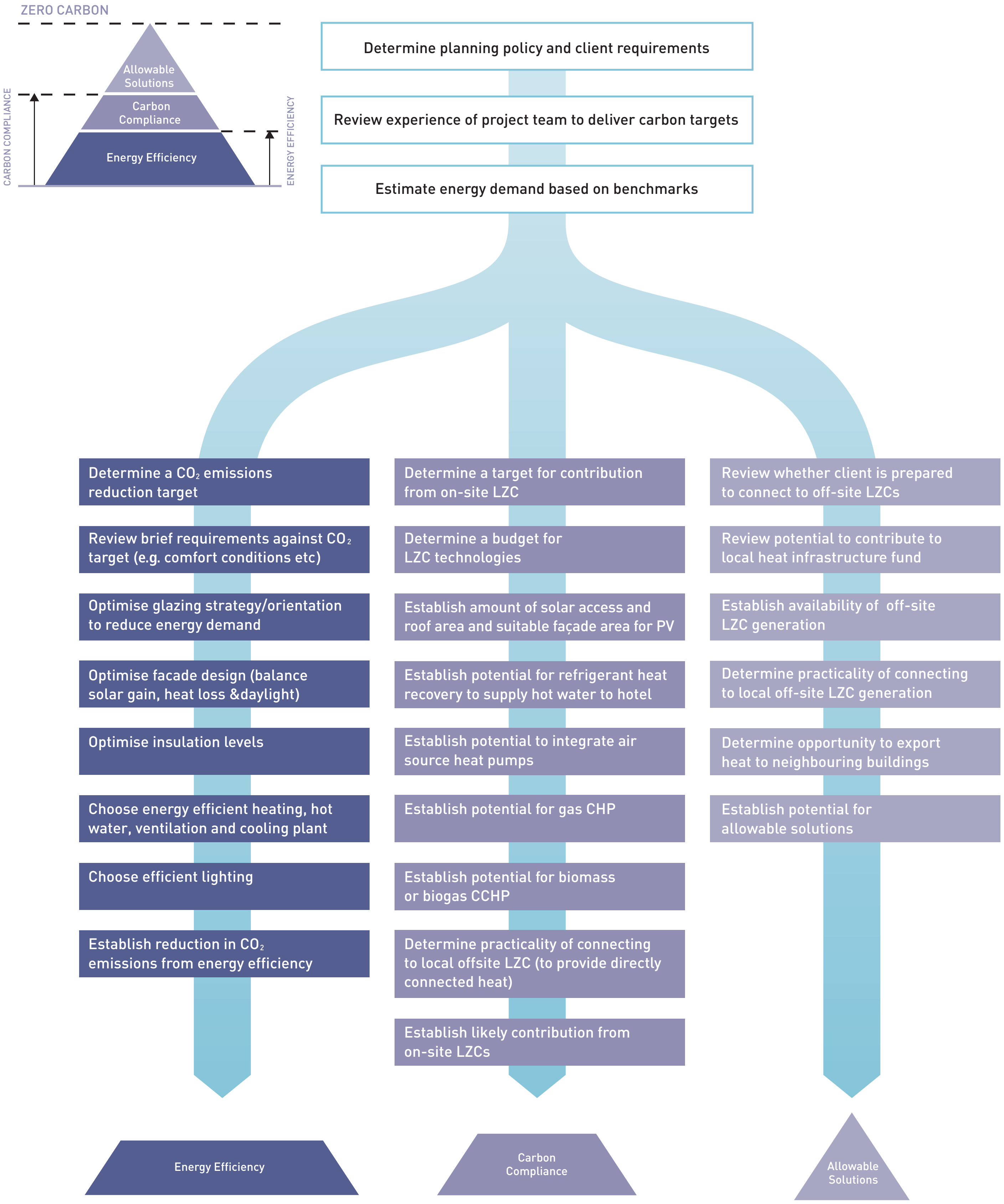
[1] The Target Emission Rate (TER) is defined by the National Calculation Methodology (NCM). The TER is based on the amount of carbon dioxide emitted per square metre of floor area per year by a notional building as the result of the provision of heating, cooling, hot water, ventilation and internal 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.

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

FIGURE 14

GUIDANCE FLOWCHART FOR DELIVERING LOW AND ZERO OPERATIONAL CARBON MIXED-USE BUILDINGS



Determine planning policy and client requirements

Review experience of project team to deliver carbon targets

Estimate energy demand based on benchmarks

- Determine a CO_2 emissions reduction target
- Review brief requirements against CO_2 target (e.g. comfort conditions etc)
- Optimise glazing strategy/orientation to reduce energy demand
- Optimise facade design (balance solar gain, heat loss &daylight)
- Optimise insulation levels
- Choose energy efficient heating, hot water, ventilation and cooling plant
- Choose efficient lighting
- Establish reduction in CO_2 emissions from energy efficiency

Energy Efficiency

- Determine a target for contribution from on-site LZC
- Determine a budget for LZC technologies
- Establish amount of solar access and roof area and suitable façade area for PV
- Establish potential for refrigerant heat recovery to supply hot water to hotel
- Establish potential to integrate air source heat pumps
- Establish potential for gas CHP
- Establish potential for biomass or biogas CCHP
- Determine practicality of connecting to local offsite LZC (to provide directly connected heat)
- Establish likely contribution from on-site LZCs

Carbon Compliance

- Review whether client is prepared to connect to off-site LZCs
- Review potential to contribute to local heat infrastructure fund
- Establish availability of off-site LZC generation
- Determine practicality of connecting to local off-site LZC generation
- Determine opportunity to export heat to neighbouring buildings
- Establish potential for allowable solutions

Allowable Solutions

7.10 OPERATIONAL CARBON GUIDANCE

Figure 14 sets out a flowchart providing guidance on how to develop a cost-effective route to low or zero operational carbon mixed-use 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 mixed-use 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 mixed-use buildings – see Figure 2.

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 accounted for**
- **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.**

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 - see Figure 1.

Many commercial buildings are built speculatively and it is likely therefore that, in some cases, capital construction cost will be a key factor when investing in energy efficiency measures and on-site 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 the capital cost of introducing those measures into the base case building. The analysis found:

- **the lowest capital cost on-site route to a 25% improvement over Part L 2006 is achieved through the use of Energy Efficiency Package A (see Table 1) at a capital cost of £475k (+1.3%)**
- **the lowest capital cost on-site route to a 44% improvement over Part L 2006 comprises Energy Efficiency Package A with a reverse cycle air source heat pump, refrigeration heat recovery and 290m² of roof-mounted photovoltaics at a capital cost of £599k (+1.6%)**
- **the lowest capital cost on-site route to a 70% and a 100% improvement over Part L 2006 comprises Energy Efficiency Package A with a biomass-fuelled CCHP unit and 290m² of roof-mounted photovoltaics at a capital cost of £1,701k (+4.6%). The majority of the carbon reduction is achieved through the use of a biomass-fuelled CCHP unit. The unit modelled is the smallest commercially available and so although this solution exceeds the 70% and the 100% threshold, it is not possible to scale-back the solution to just meet the 70% threshold at a reduced capital cost.**

RECOMMENDATION

The client brief for a low carbon mixed-use 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.

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 mixed-use building, hot water and fans and pumps for ventilation are the dominant contributors and, as shown in Figure 6, improvements in boiler efficiency and fan efficiencies provide some of the largest 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 hotel or large commercial office building operating 24 hours a day, e.g. an office building with trading floors/rooms, 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 schedules. 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.

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 calculated effectiveness of combined heat and power units is artificially reduced.

The hours of operation of the commercial buildings 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 building operates, the lower the optimal glazed area will be.

Site factors

Site constraints, including building orientation, can have a major effect on a building's operational energy requirements and on the viability of delivering LZC buildings and therefore site selection is a key issue. The site constraints for large city centre commercial buildings are far more onerous than for other building types studied under Target Zero.

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 and zero carbon commercial buildings and therefore should be given due consideration early in the design process.

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 LZC technologies and other buildings and networks.

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.

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.

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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.

Building form and fabric

This research has established that the glazing design in both offices and in hotels is an important factor if low carbon mixed-use building design is to be achieved. Optimising of the location and area of glazing involves a detailed understanding of the sun's interaction with the heating, cooling and lighting energy requirements of the 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 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 mixed-use 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 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. Offices are ideally suited with suitable shading (it should be noted that blinds will be 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 the design of mixed-use buildings, careful consideration of the aspect of each room can yield significant carbon savings. Spaces with high internal gains should be orientated so as to avoid high solar heat gains. Conversely rooms with low internal heat gains should be orientated to make best use of solar gain. Solar control measures should be incorporated to minimise summer overheating.

For the case study building, it would generally be most appropriate to locate densely occupied office spaces on the Northeast façade whilst hotel rooms could be placed on the Southwest façade with the addition of solar control measures. Rooms with minimal glazing or with high ventilation rates, such as toilets or kitchens can be placed on the East and West facing façades where the solar heat gain is more difficult to control. It is recognised that generally, as for the case study building, mixed-use buildings are separated horizontally and that vertical segregation (by use) to reduce carbon emissions, can incur practical issues such as access, acoustics, security and views out.

In addition to the glazing design, it is important to optimise the solar control strategy. Table 7 provides preliminary advice on this.

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

TABLE 7
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

RECOMMENDATION

Glazing design in large commercial buildings is critical to achieve low operational carbon emissions. Optimising the area of glazing to balance the sun's interaction with the heating, cooling and lighting energy requirements of the building is a complex process which should be done, on a project-specific basis, using dynamic thermal modelling.

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 however, server rooms should be positioned so that they need a minimum of mechanical cooling by avoiding high solar gains. 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 more 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

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 luminaire output ratios (LOR). Controls should also be carefully designed in order to facilitate efficient use of the lighting 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 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 of this measure 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 four-way interaction becomes complex and therefore dynamic thermal modelling should be carried out.

MediaCityUK MAIN STUDIO BLOCK WITH THE ATTACHED HOLIDAY INN TOWER BLOCK

Heating, cooling and ventilation

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

- **providing heat recovery to supply 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 used by ventilation systems (fans and pumps) was found to account for 17% of the base case building. This can be reduced through the use of low energy ventilation systems; the architect can have a large impact on the successful design of efficient ventilation systems. For example the positioning and size of plant rooms can have a dramatic effect on the energy used by ventilation systems. The amount of energy used by fans increases as ductwork becomes longer, narrower and includes more bends.

The use of large diameter ventilation ductwork and air handling units is a highly effective way of reducing carbon emissions; however it may require increased depth of ceiling void and a larger plant room.

The choice of delivery system for heating and cooling can have a dramatic effect on the 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 they are linked together.

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 pipe work into the floors, a similar performance to chilled beams can be achieved without the visual intrusion.

The new version of Part L (2010) has tightened up the requirements for energy efficient ventilation systems, in particular the specific fan power limits have been reduced below those previously required. In order to achieve these requirements it is likely that the cross sectional area of both ductwork and air handling units will need to increase. Therefore it is essential that the building service engineer should liaise with the architect at an early stage to ensure that voids, risers and plant rooms are appropriately sized to accommodate this.

Hot Water and heat exchangers

The requirement for hot water in the case study building is larger than that of most other building types; hotels use a large amount of hot water primarily for showers and baths. This provides a year-round base load requirement for heat which is ideally suited to low carbon technologies such as combined heat and power (CHP). A year-round requirement for hot water allows an appropriately sized CHP system to run efficiently throughout the year yielding good carbon savings.

Mixed-use buildings often offer the possibility of sharing energy between building uses. In the case of the case study building the large cooling requirement of the office provides the opportunity to use the heat rejected from cooling the offices to provide some of the large quantity of hot water required by the hotel. This can be done by connecting a heat exchanger to the rejection side of the office cooling system. This technology is well established and has been offered by manufacturers for over a decade, but it is seldom used.

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:

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

Overheating

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

The base case building is not designed to allow natural ventilation; the office floors only have openings on one side of the building and have a floor depth of 16m, far greater than the 7m limit recommended for natural ventilation in these circumstances. The hotel bedrooms are a little over 7m deep and therefore might be expected to have greater promise for natural ventilation. Therefore simulations were run to test the viability of using a mixed-mode ventilation system without mechanical cooling.

This analysis found that around 40% of the rooms in the building overheated, with similar proportions of overheating predicted in both the hotel and office parts of the building.

The analysis was repeated with the reduced height glazing measures described in Section 7.4, and overheating was still predicted to occur in many areas of the building. Note that reducing the window size reduces the solar gain but also reduced the area available for openings.

Coupled with the likely problems caused by traffic noise and pollution in city centre locations, the overall conclusion was that a natural or mixed-mode ventilation strategy was not viable for this building.

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 8 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 8

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**
Reverse cycle air source heat pump	✓		Space heating and cooling
Gas CHP large	✓		Space heating, hot water and electricity
Medium 330kW wind turbine		✓	**Enercon** 50m tower height. Could be on-site in some cases
Large 2.5MW wind turbine on-shore		✓	**Nordex** 100m tower height. 99.8m rotor diameter
Gas CCHP large	✓		Space heating, hot water, cooling and electricity
Fuel cell CCHP small	✓		Space heating, hot water, cooling and electricity
Refrigeration heat recovery	✓		Recovering heat from space cooling to supply hot water
Energy from waste district heating		✓	Space heating and hot water
Fuel cell CHP small	✓		Space heating, hot water and electricity
Large 5.0MW wind turbine off-shore		✓	**Repower** 117m tower height (Largest commercially available)
Waste process heat district heating		✓	Space heating and hot water
Biomass district CHP		✓	Space heating, hot water and electricity
Gas district CHP		✓	Space heating, hot water and electricity
Fuel cell district CHP		✓	Space heating, hot water and electricity
Biomass CCHP small	✓		Space heating, hot water, cooling and electricity
Biogas district CHP		✓	Space heating, hot water and electricity
Single cycle air source heat pump	✓		Space heating
Biomass CHP small	✓		Space heating, hot water and electricity
Biogas CCHP large	✓		Space heating, hot water, cooling and electricity
Single cycle closed loop ground source heat pump	✓		Space heating
Medium 50kW wind turbine		✓	**Entegrity** 36.5m tower height
Biomass CCHP large	✓		Space heating, hot water, cooling and electricity
Biogas CHP large	✓		Space heating, hot water and electricity
Biomass CHP large	✓		Space heating, hot water and electricity
Biomass boiler	✓		Space heating and hot water
Small 20kW wind turbine		✓	**Westwind** 30m tower height
Photovoltaics	✓		Roof-mounted monocrystalline PV 291m^2
Energy Efficiency Package B			**See Table 1**
Biogas CCHP small	✓		Space heating, hot water, cooling and electricity
Gas CCHP small	✓		Space heating, hot water, cooling and electricity
Small 6kW wind turbine on-site	✓		**Proven** roof mounted 9m tower height on 43.6m building = 52.6m total height
Solar Thermal Hot Water	✓		291m^2, ie. 30% of roof area
Fuel cell CHP large	✓		Space heating, hot water and electricity
Photovoltaics	✓		291m^2 roof mounted monocrystalline and 181m^2 as overhangs above windows on the South facing staircore
Energy Efficiency Package C			**See Table 1**
Reverse cycle closed loop ground source heat pump	✓		Space heating and cooling
Fuel cell CCHP large	✓		Space heating, hot water, cooling and electricity
Gas CHP small	✓		Space heating, hot water and electricity
Single cycle open loop ground source heat pump	✓		Space heating
Small 1kW wind turbine	✓		**Futurenergy** 6.2m tower
Reverse cycle open loop ground source heat pump	✓		Space heating and cooling
Biogas CHP small	✓		Space heating, hot water and electricity

1 The ranking is based on the cost effectiveness of the technology when combined with Energy Efficiency Package A. The ranking of technologies varies slightly when the technologies are used in conjunction with more advanced energy efficiency measures, i.e. Packages B and C, however the generic ranking of cost effectiveness of technologies remains the same.

From the rankings in Table 32, it is clear that near-site and offsite solutions may, in many cases, lead to the most cost-effective route to low and zero carbon targets and therefore should be investigated. Building services engineers should look beyond the site boundary for opportunities to reduce carbon emissions.

The orientation of photovoltaic panels is important as it can have a dramatic effect on their output performance. 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 or increasing their spacing. Analyses and experience has found that the best compromise in this situation is to install the panels at a pitch of 10° to 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 and some require access for fuel delivery and storage. Once LZC technologies have been selected their effect on the building design should be considered at the earliest opportunity to enable efficient integration 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 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 commercial city centre buildings.

The cost effectiveness of LZC technologies which provide heat rely on there being a sufficient heat demand. Therefore the cost 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 Energy Efficiency Package B than with Package C.

The focus of this guide is large city centre mixed-use buildings. 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 any obstruction. Clearly this is not a viable approach for city centre locations. In such locations therefore, the most appropriate use of on-site wind turbines is roof-mounted units; generally these cannot be much larger than 6kW.

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 at the early design stage.

RECOMMENDATION

Local obstructions are critical factors in determining the wind resource at the precise location that the wind turbine is to be installed. Therefore on-site wind monitoring and Computational Fluid Dynamic (CFD) modelling should be undertaken to assess the viability of wind turbines at specific locations.

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 space requirements**
- **programming implications: both on-site and supply, CHP systems, for example, may 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 back up or supplementary heating or cooling plant is required.

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. For example, a dynamic thermal simulation model not constrained by the NCM or technology specific design software.

7.11 IMPACTS OF CLIMATE CHANGE

Modelling the effects of climate change on the case study mixed-use building, using CIBSE weather tapes based on UKCIP climate predictions for the UK , showed that the heating requirements of the building will progressively reduce over time while the cooling requirements are predicted to increase. Analysis of the case study building showed that heating loads are expected to decrease by 9-10% between 2005 and 2020 and by 25-26% between 2005 and 2050. Conversely cooling loads increase by 19-21% between 2005 and 2020 and by 56-57% from 2005 to 2050.

The effect on carbon dioxide emissions from these changes in heating/cooling demand is to reduce total building emissions marginally (0.03% to 0.14%) by 2020 and by 0.37-0.45% 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**
- **use of an efficient lighting system.**

The rise in temperature caused by climate change will also reduce the heating requirements of many commercial buildings 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 'Other buildings'[1] (2008) rating for the MediaCityUK, Holiday Inn base case building in Salford Quays, Manchester. This building is a mix of office (lower floors) and hotel accommodation – see Section 5.

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 is used for the base case, e.g. Building Regulations Part L provides a requirement for the operational energy performance of the building.**
2. **If it is typical practice for a commercial building, then this is 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 specification for the MediaCityUK Inn tower is applied as the base case.**
4. **Where a study is required to demonstrate a credit is achieved, e.g. day lighting and thermal comfort for the office areas, and the required standards are achieved, then only the cost of the study has been included. Where a study determines that the required standard is 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. Instead, the credits that are based on fundamental design decisions are identified in the guidance.**
5. **For site related issues, e.g. reuse of previously developed land, urban and rural (greenfield) scenarios are proposed and tested to determine the likely best and worst case situations – see below.**

Reflecting the influence of location and other factors on the achievable BREEAM score, five scenarios were modelled with different site conditions and different design assumptions as follows:

- **two site-related scenarios: urban and rural (greenfield). These scenarios represent best and worst cases in terms of the likely site conditions**
- **two scenarios relating to early design decisions and contractor performance: poor approach and best approach**
- **one scenario related to the approach to zero carbon, without wind turbines being viable on the site – on-site wind turbines bigger than 6kW (roof-mounted) were not considered viable for this site.**

The key inputs for these five scenarios and the base case mixed-use building are set out in Table 9. 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 they also serve to illustrate the limitations associated with many city centre commercial buildings, for example in terms of site ecological value, LZC technology viability, etc.

The case study scenario was based on the actual location, site conditions, etc. of the MediaCityUK Holiday Inn building and is used as the basis for comparison with the above five scenarios.

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[1] BREEAM 'Other Buildings' is a family of schemes and methods that provide a number of different options for assessing non-domestic buildings that fall outside the scope of the current standard UK BREEAM schemes.

Under the 'Tailored criteria' option, a set of drawings and information on the base case building was submitted to the BRE who developed a set of project-specific criteria based on the different uses in the building and the areas associated with each use.

TABLE 9
KEY ASSUMPTIONS FOR THE FIVE BREEAM ASSESSMENT SCENARIOS AND THE CASE STUDY BUILDING

ASSUMPTION	CASE STUDY BUILDING	SITE CONDITIONS		APPPROACH TO DESIGN		ZERO CARBON TARGET
		Urban	Greenfield	Best approach to design	Poor approach to design	Approach to zero carbon (wind not viable)
Biomass feasible	Yes	No	Yes	Yes	Yes	Yes
Public transport links	Good	Excellent	Poor	Good	Good	Good
Within 500m of shop, post box and cash machine?	Yes	Yes	Yes	Yes	No	Yes
Has ≥ 75% of the site been developed in the last 50 years?	Yes	Yes	No	Yes	Yes	Yes
Ecological value	High	Low	High	High	High	High
Zero carbon pursued?	No	No	No	No	No	Yes
Emerging technologies feasible?	No	No	No	No	No	Yes
Type of contractor	Best practice	Best practice	Best practice	Exemplar practice	Poor practice	Best practice
Potential for natural ventilation	Yes	Yes	Yes	Yes	No	Yes
Indoor air quality[1]	1	1	1	1	4	1
On-site wind viable?	No	No	No	No	No	No
Design best practice followed?	Yes	Yes	Yes	Yes	No	Yes
Compliant Recycled Aggregates to be used	Yes	Yes	Yes	Yes	No	Yes
Exemplar Daylighting	No	No	No	Yes	No	No
Exemplar energy performance	No	No	No	Yes	No	No
Exemplar materials specification	No	No	No	Yes	No	No
Has the land been contaminated?	No	Yes	No	No	No	No

[1] 1= Natural ventilation opening >10m from opening; 2 = Air intake/extracts <10m apart ; 3 = intakes/extracts >10m apart; 4= intakes/extracts <10m apart

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

1. **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'.**
2. **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.**
3. **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.**
4. **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.**
5. **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 and hotel 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.

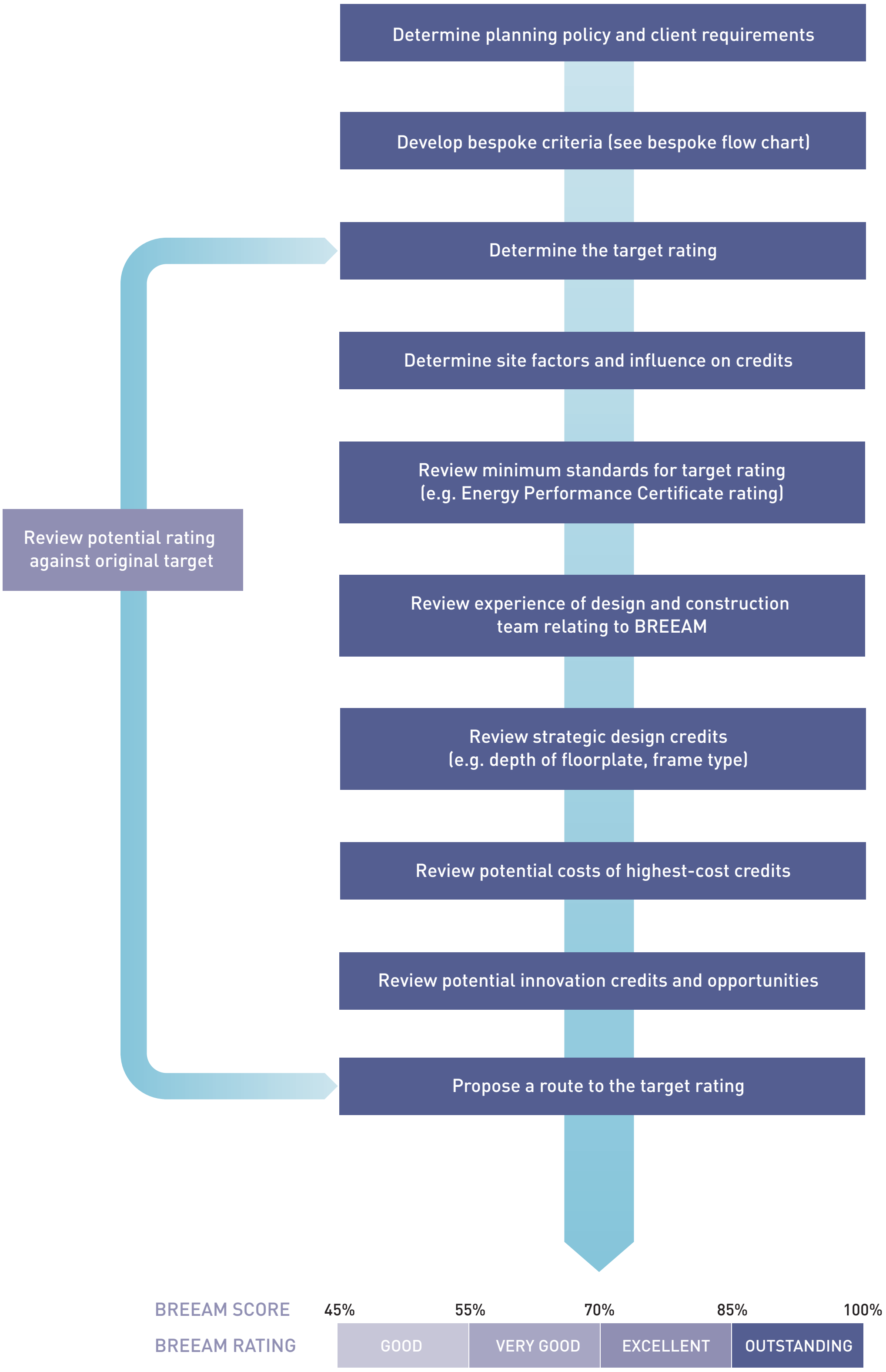
8.0 ROUTES TO BREEAM 'OUTSTANDING'

8.1 BREEAM RESULTS AND GUIDANCE

Figure 15 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 15

BREEAM GUIDANCE FLOWCHART



8.0 ROUTES TO BREEAM 'OUTSTANDING'

The case study building is mixed-use and so falls under BREEAM 'Other Buildings' assessment scheme. Designers need to establish, early on in a project, whether the proposed building can be assessed under one of the standard BREEAM schemes or the 'Other buildings' scheme. For example, an office building with a public gymnasium could not be assessed under the 'Offices' scheme and would fall under the 'Other Buildings' scheme.

Mixed-use buildings can be assessed in two different ways:

- **the whole building can be assessed under the 'Other Buildings' scheme – this can be useful when there is one intended occupier requiring one BREEAM certificate**
- **it may be possible to assess parts of the building using standard BREEAM schemes if the different building uses are clearly defined – this approach can be useful when the building is to be occupied by different owners/tenants who require separate BREEAM certificates.**

If the building falls under the 'Other Buildings' scheme, then the BRE will develop a set of tailored criteria that more closer reflect the uses and spaces in the proposed development. The process, shown in Figure 16, does incur an additional cost (approximately £2,250 at the time of writing) and can take up to 7 weeks.

RECOMMENDATION

It is recommended that designers submit drawings to the BRE if there is any doubt about whether the development falls under a standard BREEAM scheme. BRE will then be able to advise whether a bespoke scheme needs to be developed.

FIGURE 16
BRE PROCESS FOR SETTING CRITERIA FOR BREEAM 'OTHER BUILDINGS'

Figure 16 shows that there is an opportunity for project teams to influence the draft criteria that will be used to assess the project. The 'Other Buildings' scheme is more complex than the standard BREEAM schemes as some of the credits are only applicable to certain areas of the building and are awarded on an area weighted basis, for example day lighting credits.

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 10.

TABLE 10

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. The exception is the Ene1 credits, which are generally far more costly and difficult to achieve for the 'Excellent' and 'Outstanding' ratings, as shown in Table 11 which gives the estimated costs to achieve the mandatory credits shown in Table 10 for the case study building.

TABLE 11

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	-	£337,000[1]	£999,785[2]
Ene 2 Sub-metering of substantial energy uses	£5,000	£5,000	£5,000
Ene 5 Low or zero carbon technologies	-	Costs included in Ene 1 above	Costs included in Ene 1 above
Wat 1 Water consumption	0	0	£52,000
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 and a reverse cycle ASHP. This cost is less than that of Energy Efficiency Package A on its own since there is a net saving achieved by substituting the conventional heating plant with an ASHP.

[2] Based on Energy Efficiency Package A with a biomass boiler.

CREDITS ASSOCIATED WITH SITE FACTORS

The location of the building has the most impact on:

- **Transport credits in terms of connections to public transport and amenities;**
- **Land Use and Ecology credits including whether the site is re-used, and whether it is of low or high ecological value.**

Figure 17 shows the balance of credits required to achieve a BREEAM Outstanding rating. The radial axis represents the proportion of available credits achieved under each section of BREEAM for each site scenario using the case study mixed-use building. It shows the most cost-effective routes under the urban, rural (Greenfield) and case study scenarios to achieve BREEAM Outstanding.

FIGURE 17

COMPARISON OF URBAN AND GREENFIELD SITE SCENARIOS TO ACHIEVE A BREEAM 'OUTSTANDING' RATING

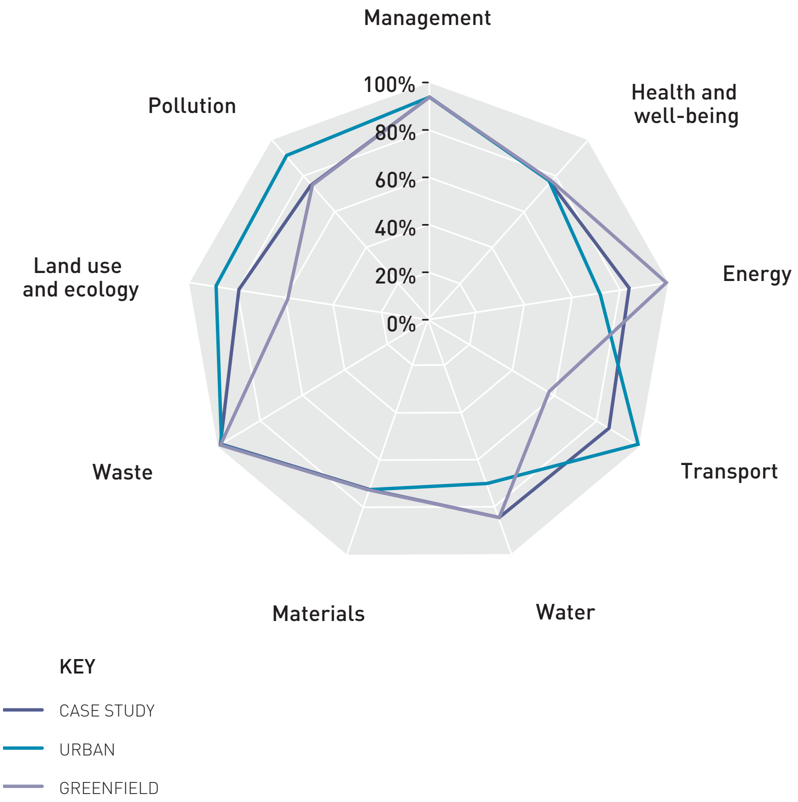


Figure 17 shows that under the rural (Greenfield) site scenario, Transport (Tra) and Land Use and Ecology (LE) credits are lost relative to the other scenarios, requiring credits to be obtained in other BREEAM sections. In this case, the most cost-effective credits are in the Energy and Water sections.

An 'urban' site is more likely to achieve the following credits:

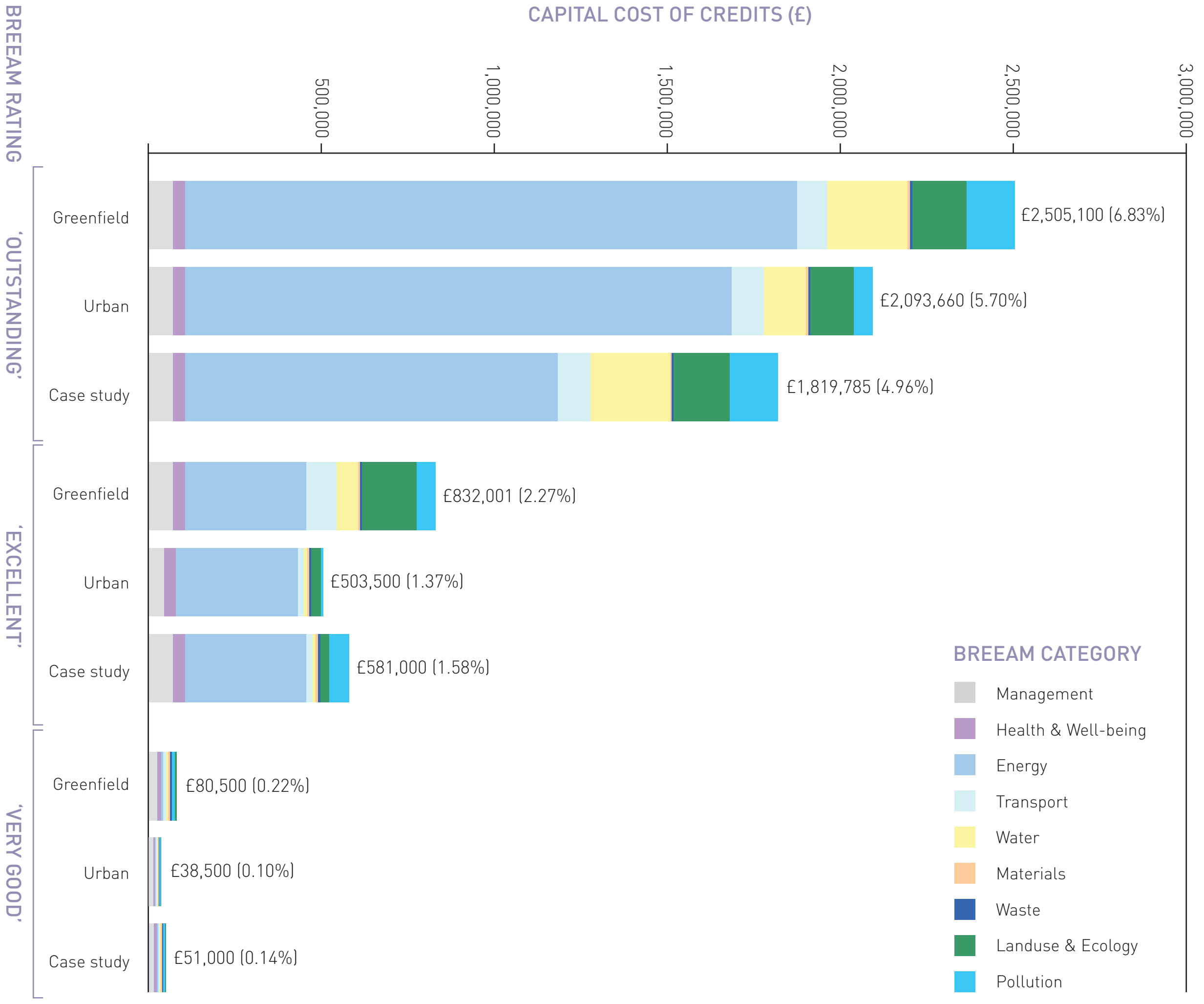
- **LE1 - Re-use of land**
- **LE3 - Ecological value of site and protection of ecological features**
- **Tra1 - Provision of public transport**
- **Tra2 - Proximity to amenities**

All of these credits are zero cost as they are based on the location of the development.

The total capital cost uplift for the two location scenarios considered and the case study building is shown in Figure 18.

FIGURE 18

COMPARISON OF COST UPLIFT FOR URBAN AND GREENFIELD SITE SCENARIOS



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.

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.

8.0 ROUTES TO BREEAM 'OUTSTANDING'

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 12. It was assumed that an 'exemplar' contractor would be able to achieve all of these credits, which are all relatively low cost.

TABLE 12
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[1]
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

[1] It is assumed that the practice of responsibly sourcing timber is implemented through careful supply chain management and therefore will not incur a cost uplift.

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 to be naturally ventilated. 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 have been included in the design.**

Figure 19 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 mixed-use building.

FIGURE 19
COMPARISON OF 'APPROACH TO DESIGN' SCENARIOS TO ACHIEVE A BREEAM 'OUTSTANDING' RATING

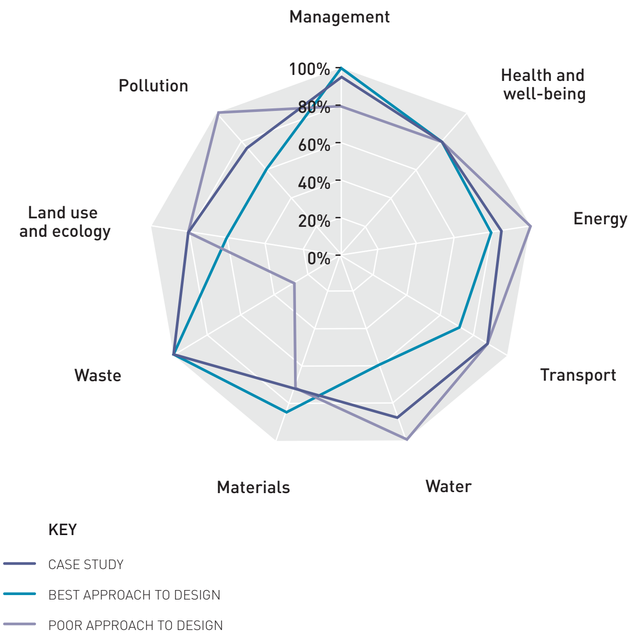
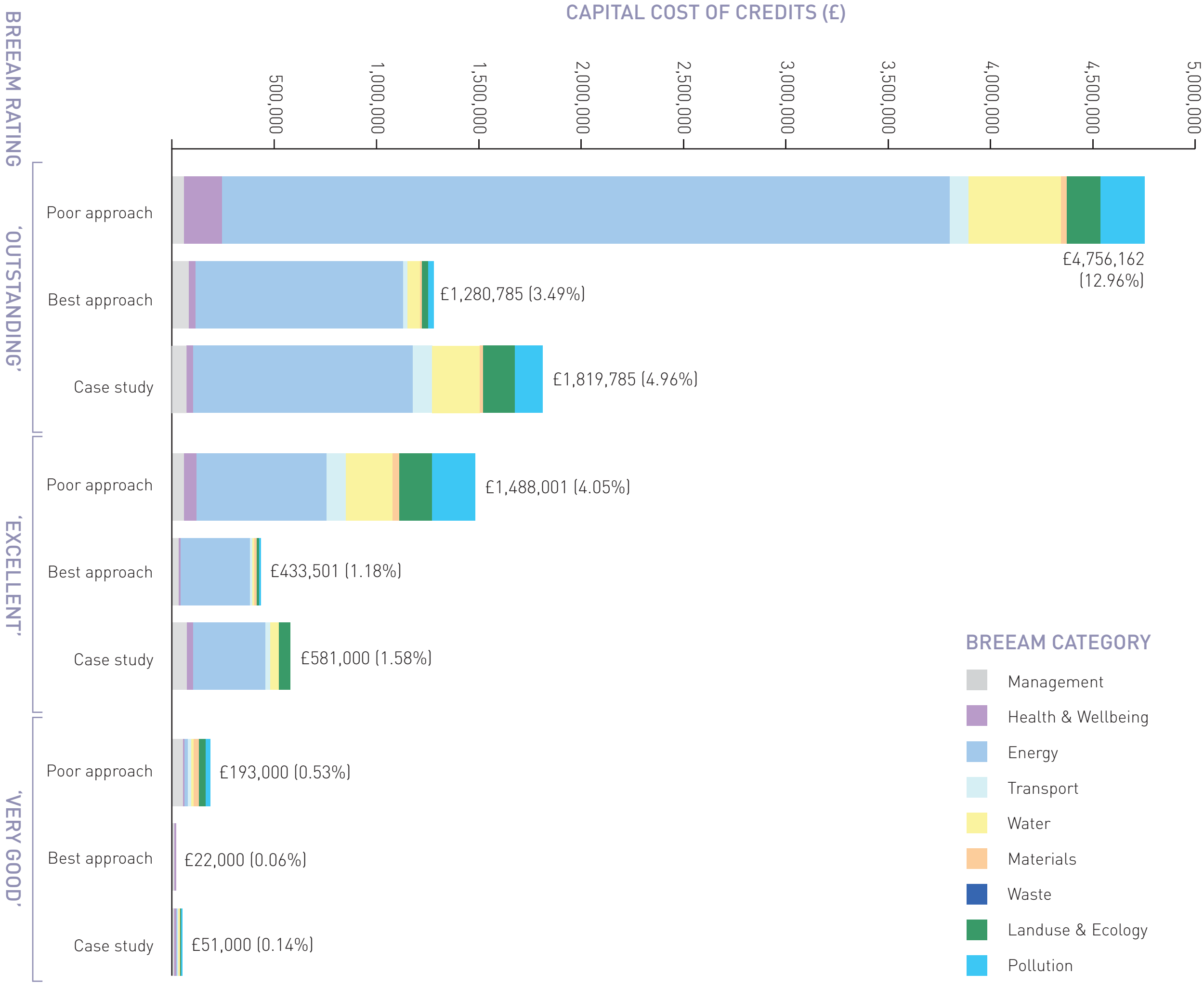


Figure 19 shows that a 'poor approach to design' implies that less credits are achievable in the Management, Health and Wellbeing, Materials and Waste sections and consequently that more credits have to be achieved in other sections: the Energy, Transport, Water, Land Use and Ecology and Pollution sections. Credits in these sections are more costly to achieve than those achieved through the 'best approach to design' scenario.

The total capital cost uplift of the two 'design approach' scenarios considered are shown in Figure 20.

FIGURE 20
COMPARISON OF COST UPLIFT FOR DIFFERENT APPROACHES TO DESIGN SCENARIOS



For the case study building analysed, the results show that to achieve an 'Excellent' rating there is a cost uplift of 4% for a poor approach to design compared to 1.1% for a building to which a best approach is applied. In terms of capital cost, this is a saving of £1,054,500.

To achieve an Outstanding rating there is a capital cost uplift of 13% for poor approach to design compared to 3.5% for a building that applies a best practice approach to design. In terms of capital cost, this is a difference (saving) of £3,475,377 to achieve an Outstanding rating.

8.0 ROUTES TO BREEAM ‘OUTSTANDING’

Table 13 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 13

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 day lighting 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.	500,000
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: £337,000 for Excellent and £999,785 for Outstanding for case study scenario.

To achieve these credits, 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 natural 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 to improve 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 – see Section 7.4.

RECOMMENDATION

Consideration should be given to factors such as daylight calculations, use of rooflights 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 strategy for office floors
- solar shading for office windows
- window opening areas required for an effective ventilation strategy
- levels of insulation in the various envelope components.

Table 14 gives the credits that relate specifically to the space allocation, adjacencies and to the layout of the building and associated landscape.

TABLE 14
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
Wst 5 Composting	Space will need to be allocated for a vessel on-site for composting food waste and adequate storage for such waste generated by the building's users and operation.	0
Tra 3 Cyclists facilities	Secure, covered cycle racks have to be provided for 10% of building users. There also needs to be showers, changing facilities and lockers along with drying space for staff use.	First credit = 37,500 Second credit = 37,500
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
Tra 8 Deliveries and manoeuvring	Parking and turning areas should be designed to avoid the need for repeated shunting.	0
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 First credit = 0 Second credit = 10,000
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 First credit = 45,000 Second credit = 50,000 Third credit = 85,000 Medium/high ecological value First credit = 65,000 Second credit = 65,000 Third credit = 155,000

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 require 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 OPERATIONAL CARBON REDUCTION

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

As low or 'zero carbon' targets increasingly become mandated for projects, then there will be the potential to achieve an 'Outstanding' rating relatively more easily and cost effectively. The Target Zero research explored the relationship between achieving maximum operational carbon reductions and BREEAM for the case study mixed-use building.

Figure 21 shows the capital and 25-year NPV costs of achieving BREEAM 'Outstanding' and the greatest operational carbon emissions reduction possible (using energy efficiency measures and on-site LZC technologies) for the case study mixed-use building i.e. acknowledging practical constraints relating to the size of the building and its location. This was achieved by using Energy Efficiency Package A (see Table 1) in conjunction with biomass-fired CCHP and a 290m² array of photovoltaic panels. This package of measures is predicted to achieve a 103% reduction in regulated emissions; falling well short of the 165% reduction required for this building to be 'true zero' carbon[1].

The bottom bar in the figure shows capital cost and highlights the high cost of achieving the energy credits. The top bar 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.

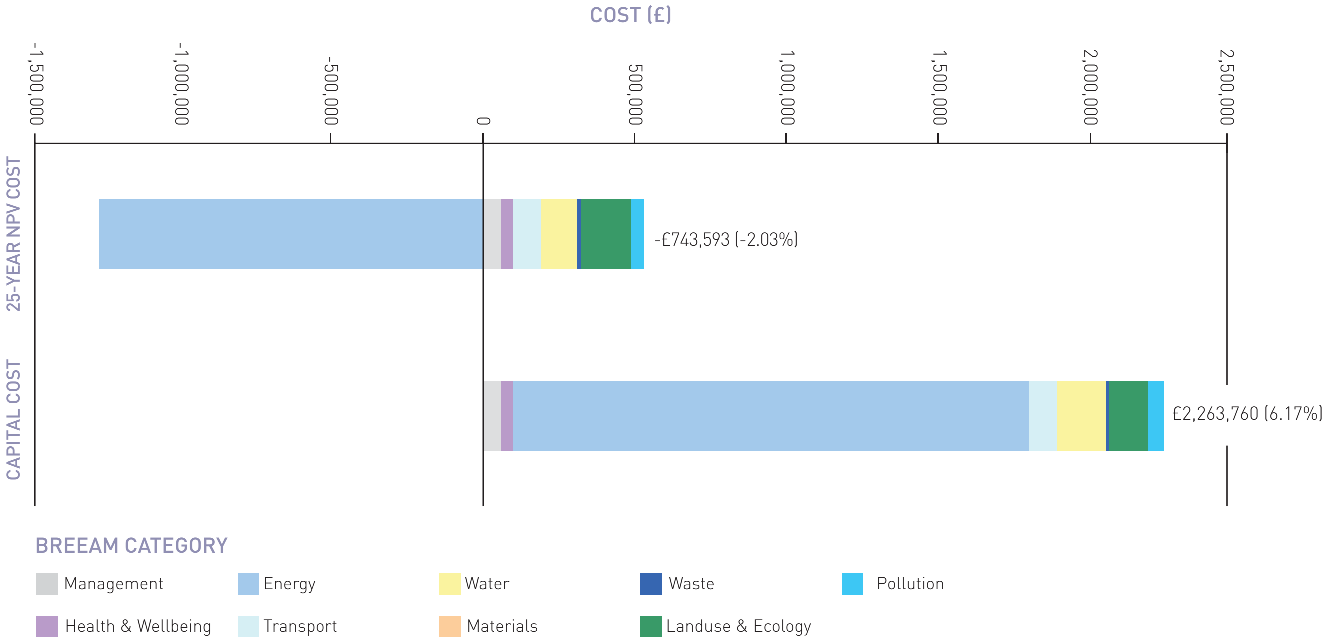
This graph focuses only on the 'Outstanding' rating as it is reasoned that if a zero carbon target was set for an office building, then it would be logical to also pursue an 'Outstanding' rating since, by far, the most significant costs associated with attaining of an 'Outstanding' BREEAM rating relate 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 21

CAPITAL COST UPLIFT OF ACHIEVING BREEAM OUTSTANDING AND TARGETING ZERO CARBON



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[1] A greater (137%) reduction in regulated emissions is achievable using a different combination of technologies that includes biogas 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 Department for Environment Food and Rural Affairs (Defra) Shadow Price of Carbon.

POTENTIAL COSTS OF BREEAM CREDITS

Figures 22 to 24 show the most cost-effective routes to achieve a BREEAM 'Very Good', 'Excellent' and 'Outstanding' respectively for the case study mixed-use 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 mixed-use building design with a set of assumptions that have been made to establish the capital cost of each credit – see Table 9. 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 mixed-use case study building.

The graphs show that there are a number of credits that are considered to be zero cost for the case study mixed-use building. These credits will be low or zero cost on similar mixed-use 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 should be established by working closely with an experienced BREEAM assessor and using this research to inform the assumptions that are made at early stages in the design process.


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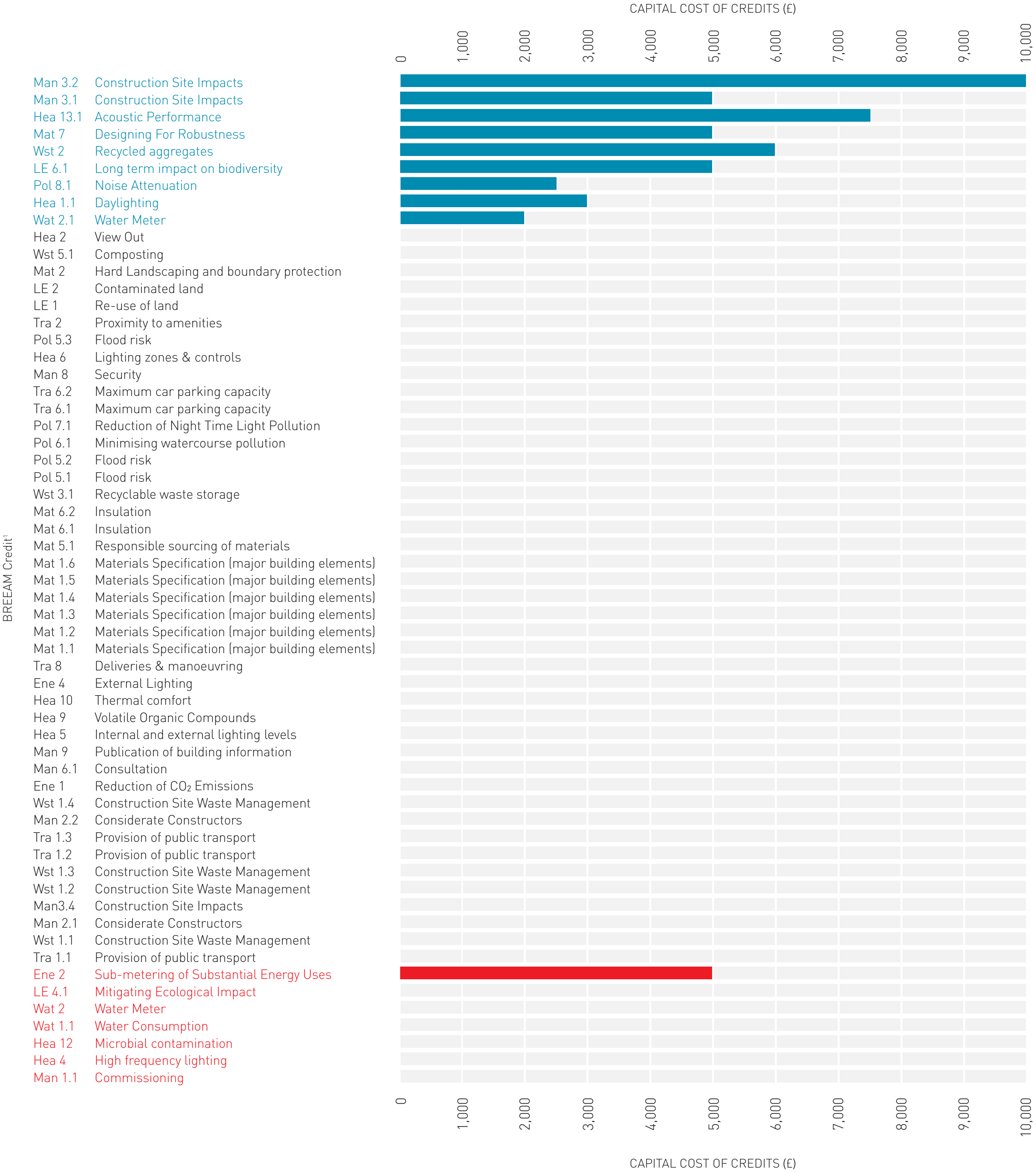
FIGURE 22

LOWEST COST ROUTE TO BREEAM 'VERY GOOD' RATING



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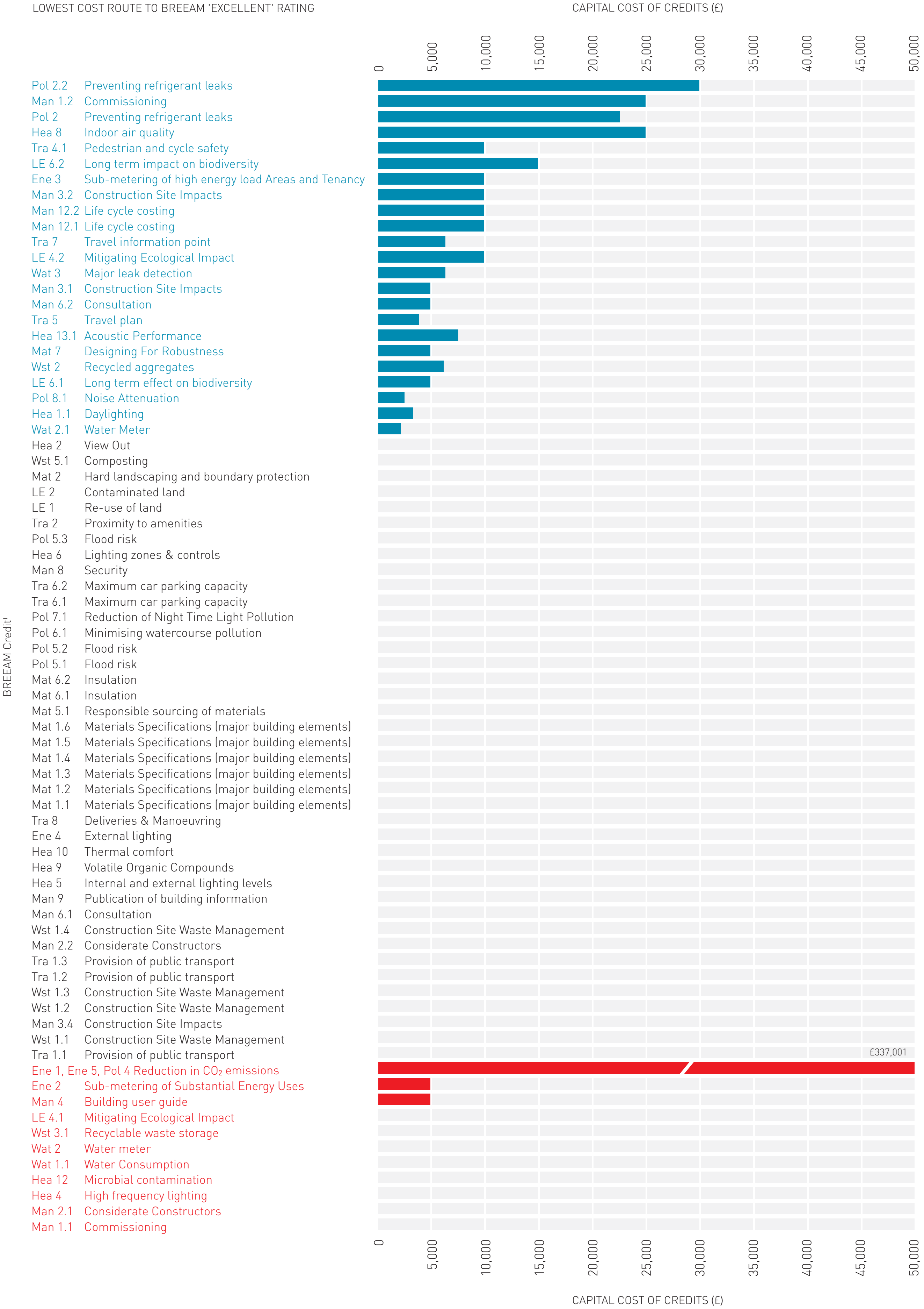
1 Ranking of credits is based on their weighted cost (capital cost of the credit divided by the credit weighting), whereas the values shown in the figures are the actual (non-weighted) cost of achieving the credit.

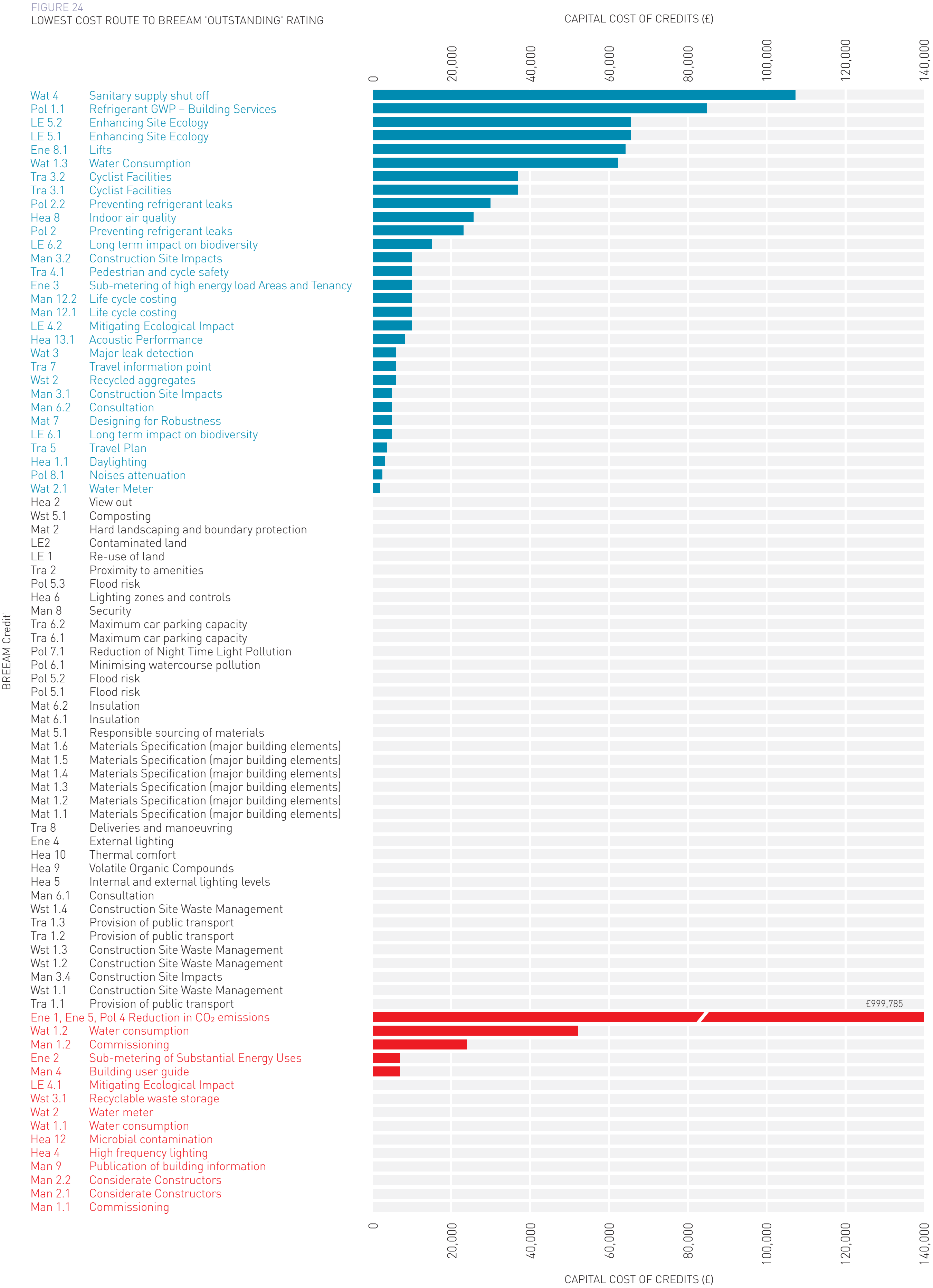
FIGURE 23
LOWEST COST ROUTE TO BREEAM 'EXCELLENT' RATING



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

8.0 ROUTES TO BREEAM 'OUTSTANDING'

FIGURE 24
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. (non-weighted) cost of achieving the credit.

EXEMPLAR PERFORMANCE AND INNOVATION CREDITS

BREEAM 2008 includes 'innovation credits' which recognise innovation in building design and procurement. Innovation credits are in addition to the mandatory credits and other BREEAM credits and are awardable at any BREEAM rating level.

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

- **by meeting 'exemplary performance criteria' for an existing BREEAM issue such as increasing the daylight factors from 2% to 3%. Not all assessment issues have exemplary performance criteria;**
- **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**
- **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 £36,000, 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 £126,000.

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

For the case study building, all five of the Mat 1 credits were achieved. Although not all materials were 'A rated' (according to the Green Guide to Specification), the area-weighting of highly rated specifications was sufficient to achieve the full Mat 1 credits.

Assessment of the base case building materials showed:

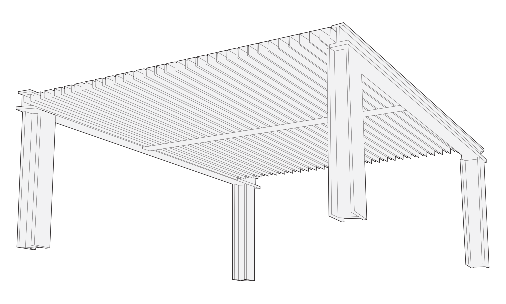
- **the External Walls achieve an A rating for the rainscreen cladding and an A+ rating for the external render. If the rainscreen cladding was replaced with the render system an A+ could be achieved overall.**
- **the aluminium double glazing only achieves a C rating and requires a different glazing solution to achieve higher ratings: for example Powder coated aluminium double glazing achieves an A rating.**
- **the roof construction achieves a D rating and could achieve a C rating by rounded pebbles rather than paving slabs.**
- **the upper floor slab achieves an A+ rating for the case study building.**

Although these upgrades could be made to the various elements of the building, they would not have resulted in any additional material credits.

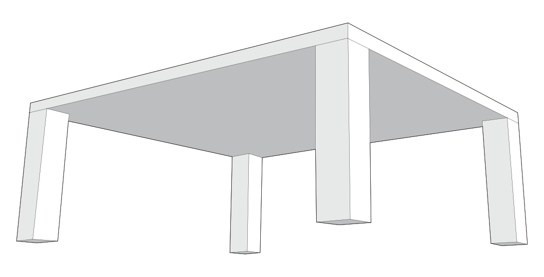
STRUCTURAL DESIGN

Three structural options for the mixed-use building were assessed as shown in Figure 25.

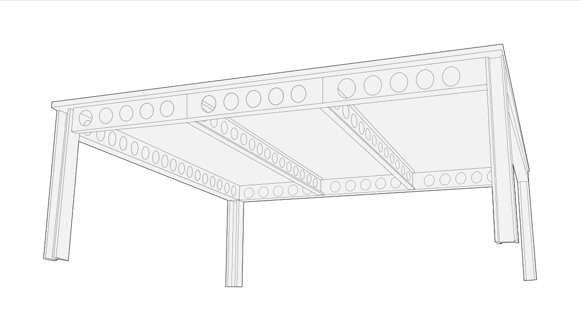
FIGURE 25
STRUCTURAL OPTIONS CONSIDERED



BASE CASE: SLIMDEK[1]



STRUCTURAL OPTION 1: CONCRETE FLAT SLAB



STRUCTURAL OPTION 2: COMPOSITE DECK ON CELLULAR BEAMS (OFFICE) AND UKCs USED AS BEAMS (HOTEL)[2]

Full building cost plans for each structural option were produced by independent cost consultants using mean values, current at 4Q 2010. The costs, which include prelims, overheads and profit and a contingency, are summarised in Table 15.

TABLE 15
COMPARATIVE COSTS OF ALTERNATIVE STRUCTURAL DESIGNS

STRUCTURAL OPTION	DESCRIPTION	STRUCTURE UNIT COST[3] (£/m^2 of GIFA)	TOTAL BUILDING COST (£)	TOTAL BUILDING UNIT COST (£/m^2 of GIFA)	DIFFERENCE RELATIVE TO BASE CASE BUILDING (%)
Base case building	Slimdek[1]	411	36,700,000	1,970	-
Option 1	Concrete flat slab: 260mm thick slab in office floors 250mm thick slab in hotel floors	355 (-13.6%)	35,300,000	1,895	-4
Option 2	Cellular steel beams supporting lightweight concrete slab on profiled steel decking[2]	318 (-22.6%)	34,800,000	1,868	-5

1 Slimdek is an engineered flooring solution with deep steel decking spanning between Asymmetric Slimflor Beams (ASBs) and/or Rectangular Hollow Slimflor Beams (RHSFBs). For further information see www.tatasteelconstruction.com/en/design_guidance/slimdek/

2 The office floors comprise composite metal deck with lightweight concrete supported by deep cellular steel beams. The hotel floors are formed of a composite metal deck supported by shallow UKC beams. The change in structure is achieved by the inclusion of a transfer floor at the plant level (level 7), which results in the removal of one set of columns below level 7.

3 Foundations, frame and upper floors.

9.0 STRUCTURAL DESIGN

The build rate for commercial city centre buildings can vary depending upon a range of factors including:

- **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.**

For mixed-use buildings the overall cost is strongly influenced by the functional mix.

With reference to external published cost analyses, such as the RICS Building Cost Information Service (BCIS), and data compiled by Cyril Sweett, the typical benchmark cost range for a mixed-use building of this type is expected to be of the order of £1,780/m² to £2,500/m². The base case cost model is positioned broadly in the lower quartile of this range.

Hotel costs can vary considerably dependent upon classification. In this instance the base case cost plan has been constructed on the basis of a hotel of mid range 3–4 star standard.

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

With respect to the total building costs shown in Table 16, it is important to note some project specific factors influencing the decision to use a Slimdek solution for the actual, and hence the base case, building structure. As shown in Figure 1, the Holiday Inn tower building is connected to the adjacent studio block between floors 1 to 7.

The long-span requirements for the studio could only be achieved using steel and therefore it was preferable to use a steel structure for the tower block to facilitate the integration of the two structures. Speed of construction was also important for the tower block and this integration gave programme benefits relative to concrete solutions.

The mixed-use tower block was originally designed with the lower floors as residential accommodation. Key design considerations for the hotel/residential tower block were floor depth and acoustic performance and hence a Slimdek design was chosen. It was not possible to achieve the required floor depths using a cellular steel beam solution with downstands. The decision to change the residential accommodation to office floors was only taken at a very late stage of the project; this coupled with the time constraints for the project, precluded redesign of the tower block and hence the original Slimdek design was constructed.

The base case building structure is therefore a relatively unusual solution reflecting the constraints imposed by the wider MediaCityUK development and Options 1 and 2 are arguably more typical solutions for a building of this type.

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9.1 IMPACT OF STRUCTURE ON OPERATIONAL CARBON EMISSIONS

Buildings with the three structural options shown in Figure 25 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 6, cooling contributes 5% of the total operational carbon emissions of the base case building while space heating contributes 7% and therefore the net effect of heating and cooling on total carbon emissions is predicted to be small – see Figure 26. The Building Emission Rates (BERs) were found to vary by only 0.5 $kgCO_2/m^2yr$ (less than 1.2%) with and without suspended ceilings and across all three structural forms.

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

FIGURE 26
BUILDING EMISSIONS RATES FOR THE DIFFERENT STRUCTURAL OPTIONS

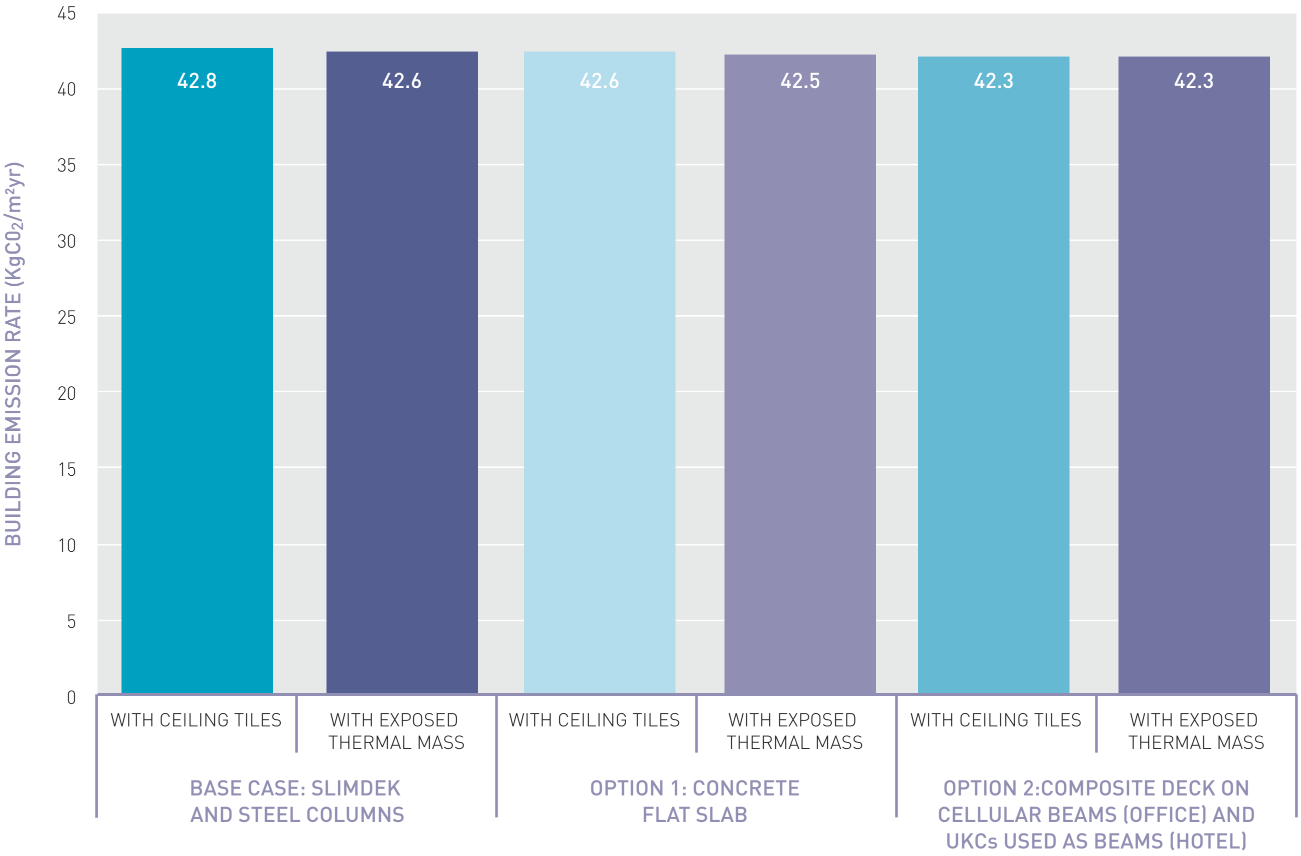


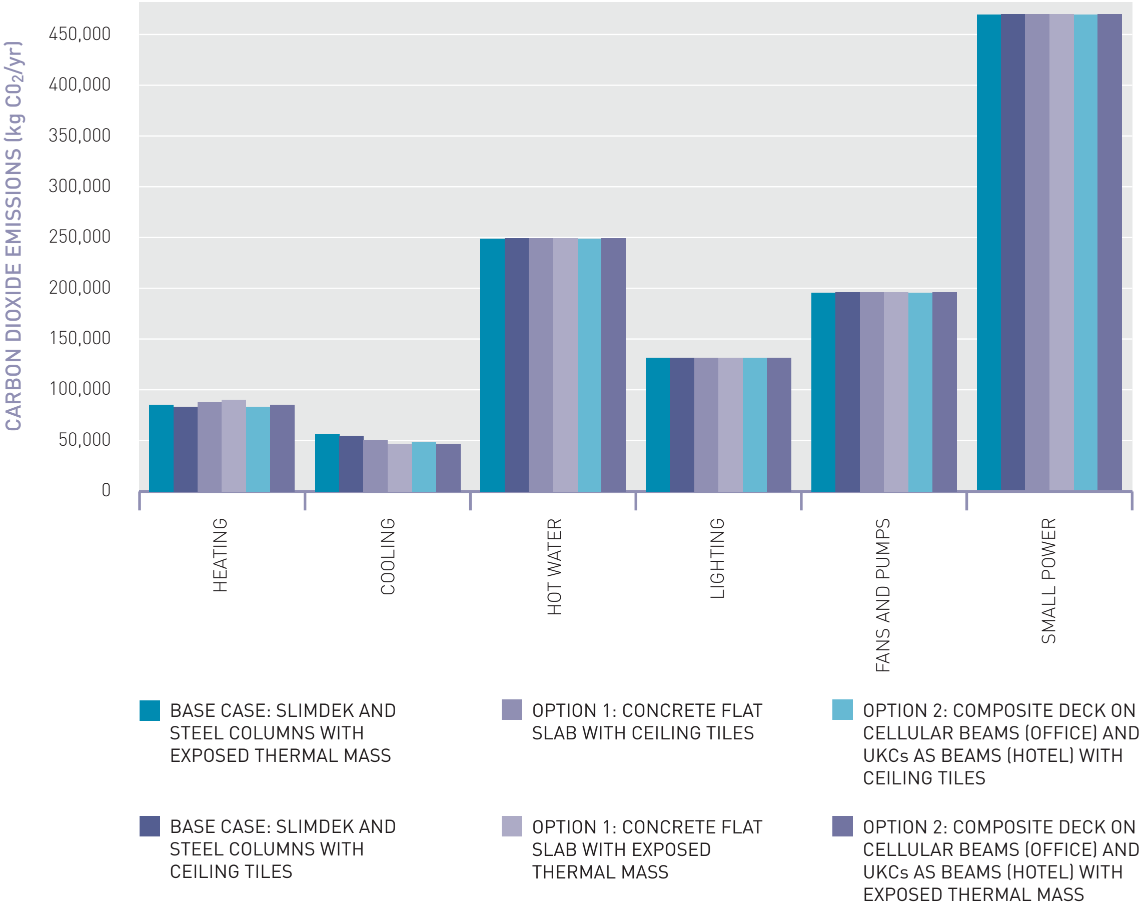
Figure 27 gives the breakdown of carbon emissions by energy load for the three structural options modelled and shows the impact of the structure on the heating and cooling demand of the building.

The effect of exposing the thermal mass, for all three structural options, is to reduce the annual cooling requirement whereas the effect on heating demand is to reduce the requirement in the base case building and to increase it for structural options 1 and 2. These changes are relatively small however and the net effect on predicted total carbon emissions is small, as shown in Figure 26.

The choice of structural option can often affect 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. In this case, for all three structural options modelled the envelope area is similar.

FIGURE 27

BREAKDOWN IN CARBON EMISSIONS FOR BUILDINGS WITH ALTERNATIVE STRUCTURAL OPTIONS



9.2 FOUNDATION DESIGN

To explore the influence of the substructure on the cost and embodied carbon of the MediaCityUK Holiday Inn building, the foundations for the alternative building options were redesigned. The base case building has CFA concrete piled foundations. The weight of the superstructure in building Option 1 is 47% greater than the base case building, however this extra load did not require additional foundations and therefore the same foundation design was used for Option 1. The foundation solution for the lighter Option 2 was redesigned using steel H-piles. Table 16 defines the different foundation solutions assessed.

TABLE 16
FOUNDATIONS ASSESSED IN EACH BUILDING OPTION

BUILDING	FOUNDATION TYPE AND NUMBER
Base case	CFA concrete piles (275 Nr 8m x 750mm nominal diameter)
Option 1	CFA concrete piles (275 Nr 8m x 750mm nominal diameter)
Option 2	Steel H-piles (205 Nr of various sizes)

The comparative costs for these different foundation options are shown in Table 17 and represent an estimate of the cost for a piling subcontractor to carry out the works, including materials supply and installation, sub-contractor's preliminaries, overheads and profit. The piling costs include the pile materials, installation and testing. Notional allowances have been made for contamination, site obstructions etc.

TABLE 17
BREAKDOWN BY COST OF THE DIFFERENT FOUNDATION SOLUTIONS

	BASE CASE AND OPTION 1 CFA PILES		OPTION 2 H-PILES	
	COST (£)	COST (£/m² GIFA)	COST (£)	COST (£/m² GIFA)
Piling	838,510	45	457,000	25
Pile caps and ground beams	384,730	21	205,770	11
Ground floor slab	146,900	8	146,900	8
Total	**1,370,140**	**74**	**809,670**	**43**

The reduced number of piles and pile caps in the H-pile solution leads to a significant cost saving; the overall sub-structure cost of the H-pile solution is estimated to be 41% less than for the base case (and Option 1) CFA solution.

The embodied carbon of the different substructure options was assessed using the CLEAR model (see Section 10 and Appendix E). Table 18 summarises the amounts of materials used for the piles, pile caps, edge beams and ground floor slab and the total embodied carbon for each option. These results have been included in the whole building embodied carbon assessments described in Section 10.

TABLE 18
EMBODIED CARBON RESULTS AND BREAKDOWN OF MASS OF MATERIALS FOR EACH SUBSTRUCTURE OPTION

BUILDING	NUMBER AND TYPE OF PILES	MASS OF MATERIALS (tonnes)	EMBODIED CARBON (tCO_2e)
Base case and Option 1	275 CFA concrete piles	8,583	1,394
Option 2	205 steel H-piles	4,426	787

EMBODIED CARBON

The embodied carbon of the substructure (piles, pile caps, edge beams and ground floor slab) represents between 11% and 16% of the total embodied carbon footprint of the mixed-use building. The base case and Option 1 buildings have the heavier substructure with a larger embodied carbon footprint. Relative to the H-pile solution (Option 2), the base case and Option 1 substructure is 94% heavier and has a 77% greater embodied carbon footprint.

Steel piles have the major advantage that they can be easily retracted and reused leaving the site uncontaminated for redevelopment. This important benefit is generally not factored into the appraisal of foundation solutions.

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10.0 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 mixed-use 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.**

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 not considered 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.

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 three 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 glazing and drainage and therefore the embodied carbon of these elements was identical. The specification of the façades was identical for each building but the area was varied due to the different structural depths for the three building options. 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 28 shows the total embodied carbon impact of the base case mixed-use building and the alternative structural options studied. Relative to the base case, the concrete structure (Option 1) has a 2.8% lower embodied carbon impact and the steel composite structure (Option 2) has a 17.8% lower impact.

As described in Section 9, it is noted that the decision to use the Slimdek solution was dictated by other project constraints and therefore the base case building is a relatively unusual solution they may not be optimal where such constraints are not present.

Normalising the data to the total floor area (gross internal floor area) of the building, yields embodied carbon emissions of 480, 467 and 395kgCO_2e/m^2 for the base case building and structural Options 1 and 2 respectively.

FIGURE 28

TOTAL EMBODIED CARBON EMISSIONS OF THE BASE CASE BUILDING AND STRUCTURAL OPTIONS 1 AND 2

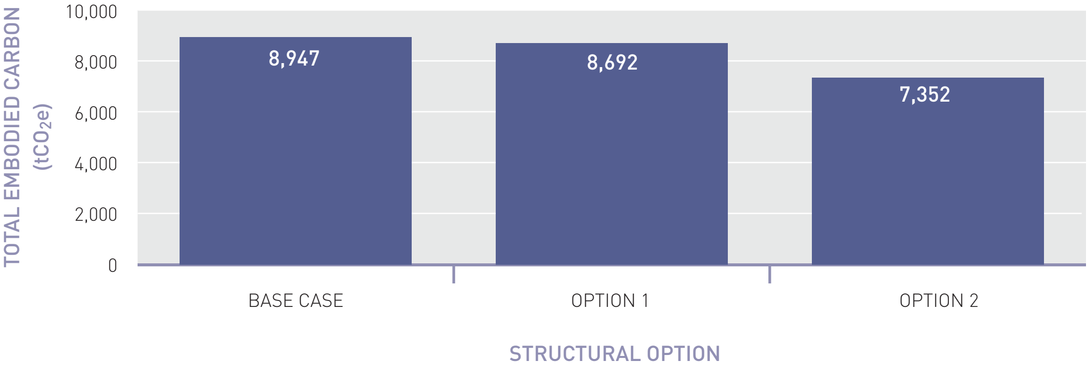
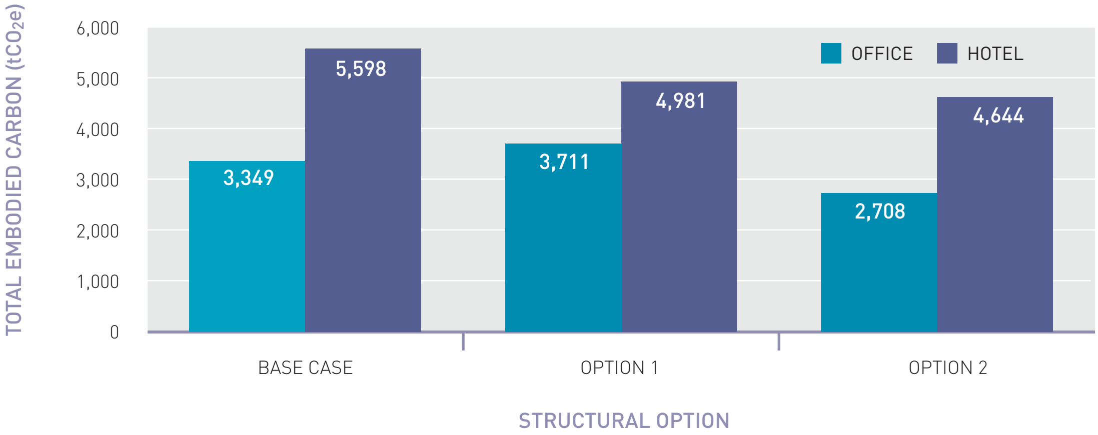


Figure 29 shows the breakdown of embodied carbon emissions between the office and hotel areas of the mixed-use building. Parts of the building which serve both the hotel and office accommodation such as the foundations, roof and drainage, were allocated on the basis of the relative areas of the two parts of the building.

FIGURE 29
BREAKDOWN OF EMBODIED CARBON EMISSIONS

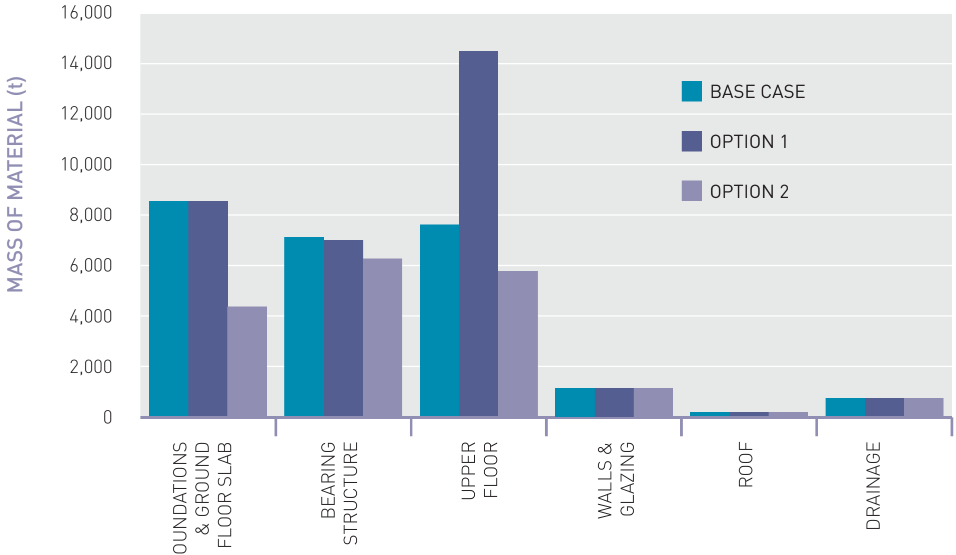


Figures 30 and 31 show the mass of materials used to construct each of the three mixed-use building alternatives, broken down by element and material respectively. The total mass of materials used to construct the mixed-use building was estimated to be 25.4mt (base case), 32.3mt (Option 1) and 18.6mt (Option 2); Option 1 is 27% heavier than the base case and 74% heavier than Option 2.

The figures show that most of the materials are used in the foundations (24% to 34%), bearing structure (22% to 34%) and the upper floors (30% to 45%).

Concrete is by far the most abundant material used to construct the mixed-use building representing between 77% (base case), 87% (Option 1) and 72% (Option 2) of all materials. Compared to the heavy weight concrete building (Option 1), the base case building requires 8,543kt less concrete and Option 2 requires 14,907kt less. Because of the dominance of concrete, the mass of the other materials used to construct the building is shown separately in Figure 32.

FIGURE 30
MASS OF MATERIALS - BREAKDOWN BY ELEMENT



10.0 EMBODIED CARBON

FIGURE 31
MASS OF MATERIALS - BREAKDOWN BY MATERIAL

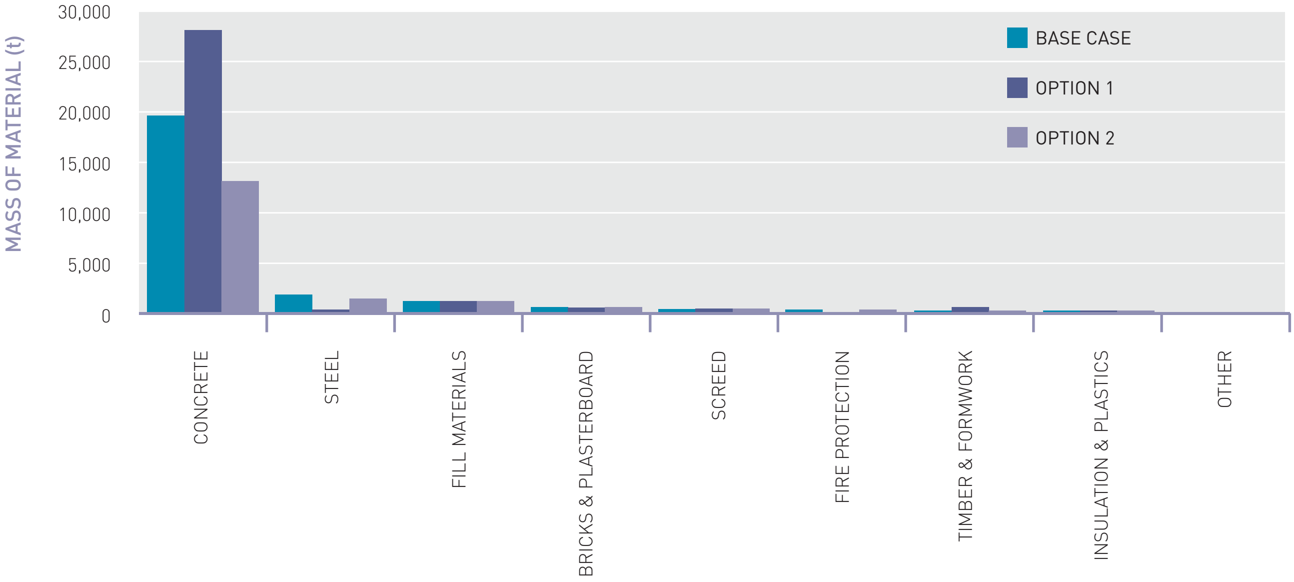
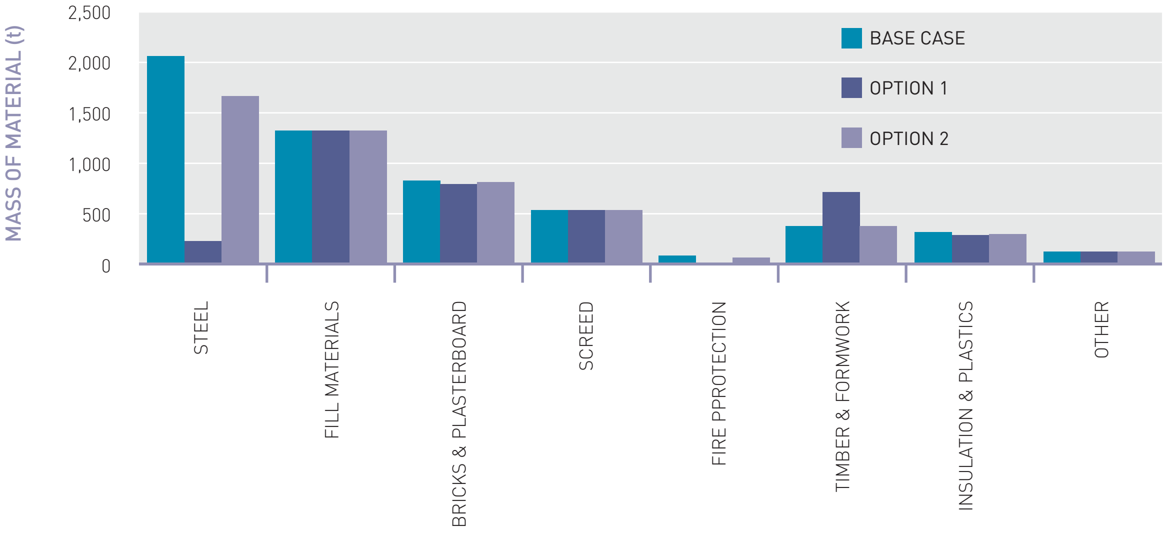


FIGURE 32
MASS OF MATERIALS - BREAKDOWN BY MATERIAL



10.0 EMBODIED CARBON

Figures 33 and 34 show the breakdown of embodied carbon in the three buildings by material and building element respectively. The following points are noted from the figures:

- **the largest contribution in all three structural options comes from concrete, most of which is used in the bearing structure and upper floors. Even though on a per tonne basis concrete is relatively low in embodied carbon, the volume of concrete used in the building makes its contribution significant**
- **the impact of substituting the steel frame in the base case with a flat slab 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 33) materials is small**
- **there is little variation in the transport impact between the two options considered. The impact varying between 3.6% for Option 2 to 4.2% for Option 1**
- **although based on less robust data, the estimate of embodied carbon from on-site construction activity is significant at around 14% of the total impact.**

FIGURE 33
BREAKDOWN OF EMBODIED CARBON BY MATERIAL

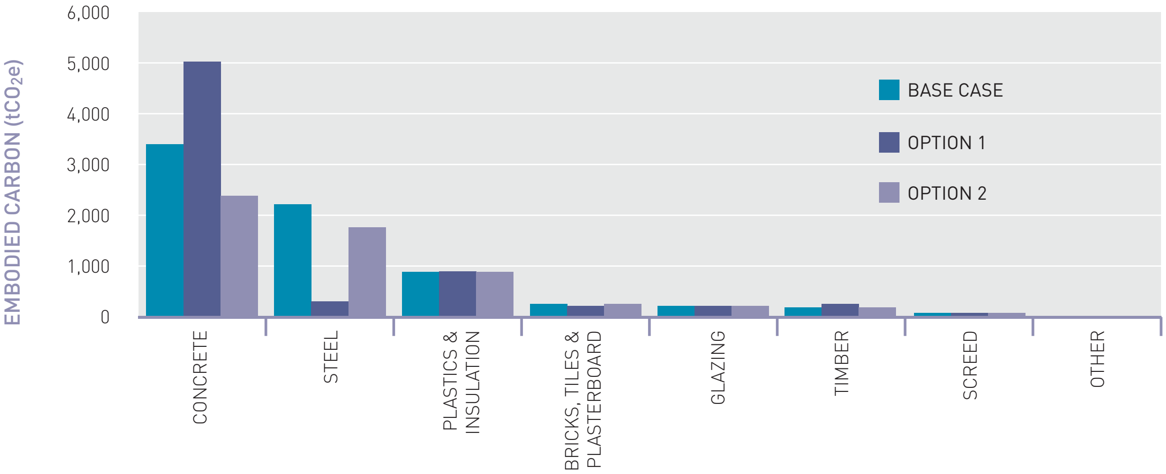
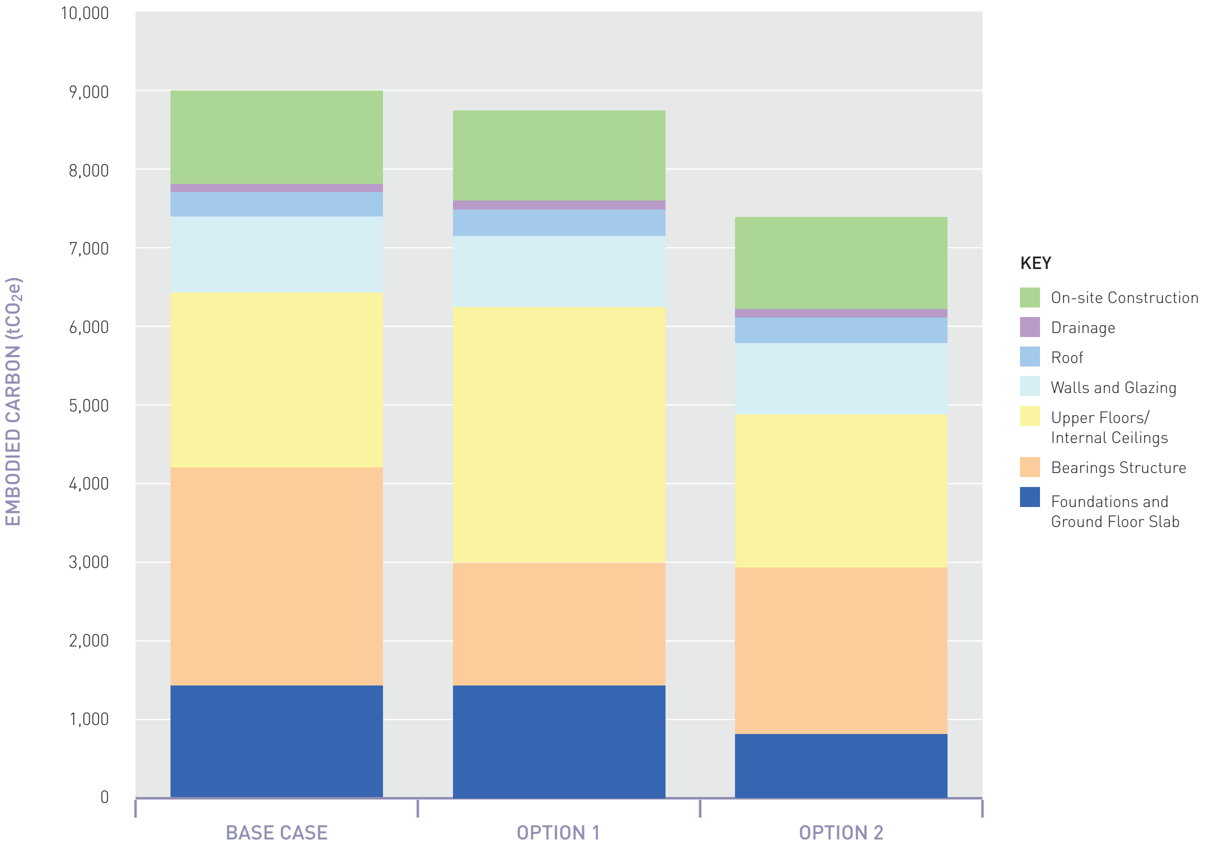


FIGURE 34
BREAKDOWN OF EMBODIED CARBON BY ELEMENT



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 have 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 lifecycle 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.

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.

RECOMMENDATION

All carbon foot-printing exercises should ensure that they encompass demolition and end of life recovery/disposal. This is where significant impacts and/or credits can often accrue.

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.

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. **In order to produce a building which is more typical of current practice, the MediaCityUK Holiday Inn mixed-use 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 tri-generation system (CCHP) was removed and replaced with conventional gas-fired boilers and electrically driven cooling systems**
- **solar shading was removed and solar control glazing was replaced with standard clear glazing**
- **the air leakage value was increased to 10m³/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 modelling the annual operational energy/carbon performance of the building. For consistency, all buildings studied in Target Zero were 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). This was achieved by setting the lighting efficiency as 2.50W/m² per 100lux in the office areas and to 3.75W/m² per 100lux in the hotel floors.**

The base case building was defined in terms of elemental U-values, air-tightness, etc. shown in Table A1.

TABLE A1
BASE CASE BUILDING FABRIC PERFORMANCE PARAMETERS

ELEMENT	U-VALUE (W/m²K)
External wall	0.35
Ground floor	0.25
Intermediate floors	0.9
Concrete partitions	2.11
Lightweight partitions	0.28
Heavyweight internal partition	2.11
Roof	0.25
External glazing	2.2 (G-value = 0.72)
Building air tightness	10 m³/hr per m² @50Pa
Thermal bridging	0.035W/m²K

4. **This base case building was then modified to have alternative structures to investigate the influence of the structural form on the operational carbon emissions.**
5. **36 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. **36 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 mixed-use building solutions. This approach has been devised to reflect the carbon hierarchy shown in Figure 3 and the likely future regulatory targets (see Figure 4).**

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 36 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 mixed-use 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-yrNPV/ $kgCO_2$ saved relative to the base case. The 36 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, excluding the effect of feed-in tariffs.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 7 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 7m³/hr per m² @50Pa
	Improved to 5m³/hr per m² @50Pa
	Improved to 3m³/hr per m² @50Pa
Thermal bridging	Enhanced detailing to half heat loss through thermal bridging
Glazed area	Glazing reduced from full height to 1m sill
	Glazing reduced from full height to 1m sill and 1m down from ceiling
External wall insulation	Improved to 0.25 W/m²K
	Improved to 0.20 W/m²K
	Improved to 0.15 W/m²K
	Improved to 0.10 W/m²K
Roof insulation	Improved to 0.20 W/m²K
	Improved to 0.15 W/m²K
	Improved to 0.10 W/m²K
Ground floor insulation	Improved to 0.15 W/m²K
Improved external glazing	Improved to 1.60 W/m²K
	Improved to 1.20 W/m²K (G-value = 0.71, light transmittance = 0.55)
	Improved to 0.80 W/m²K (G-value = 0.68, light transmittance = 0.47)
Solar control glazing	Solar control glass on office windows
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%
Lighting	Improved lighting efficiency to 2.0W/m² per 100lux (office)
	Improved lighting efficiency to 1.8W/m² per 100lux (office)
	Improved lighting efficiency to 1.5W/m² per 100lux (office)
	Improved lighting efficiency to 2.2W/m² per 100lux (hotel bedrooms) & to 2.0W/m² per 100lux (hotel bathrooms)
	Occupancy sensing lighting controls
	Daylight dimming lighting controls
Heat recovery	Heat recovery improved to 70%
	Heat recovery improved to 85%
Green Roof	Green Roof extensive, sedum type
Alternative systems	Active chilled beams
	Radiant heated/chilled ceiling slabs

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.

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

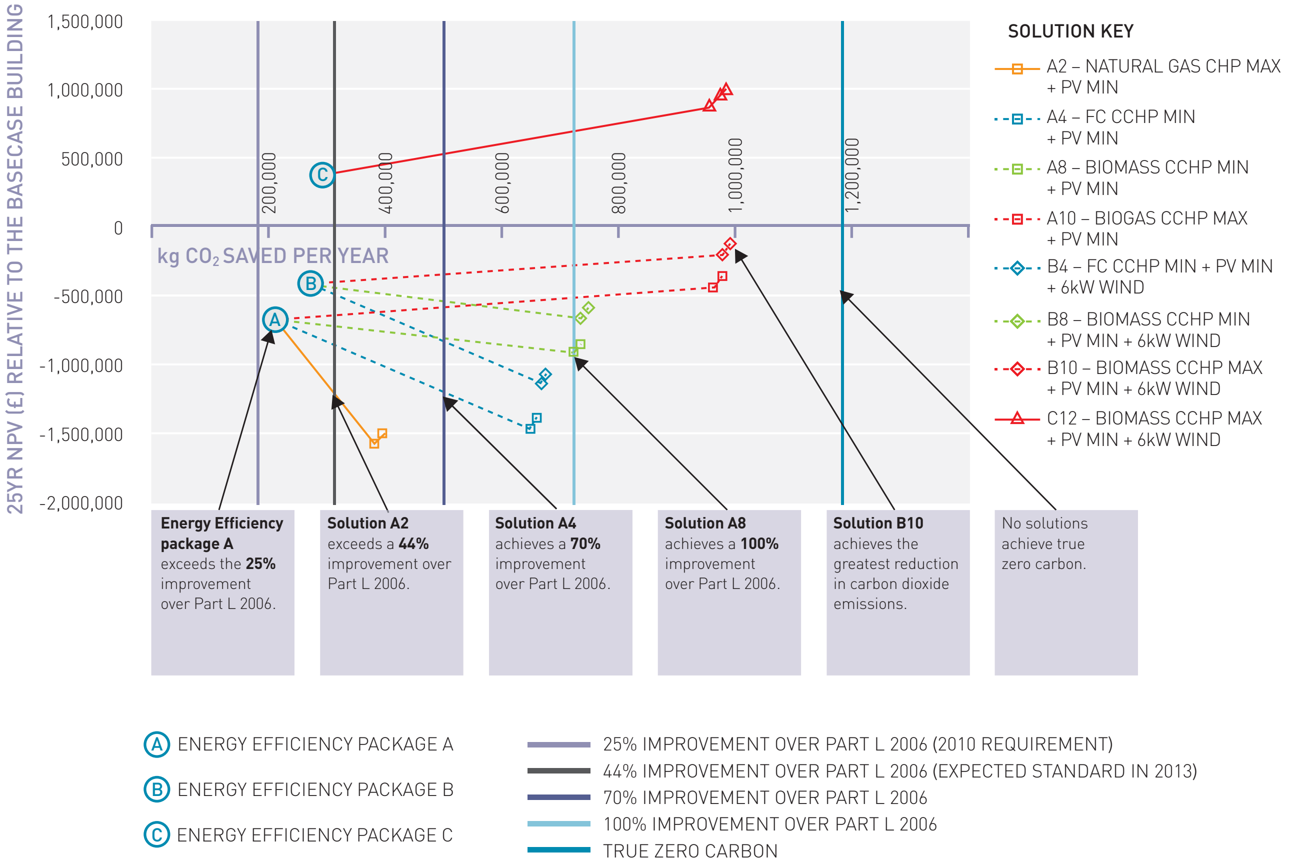
Figure C1 shows three coloured circles representing the three energy efficiency packages described in Appendix C. Straight lines emanating from these circles represent an LZC technology. The gradient of each line represents the cost effectiveness of each measure. Having decided the carbon reduction target,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

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

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

FIGURE C1

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



APPENDICES

TABLE C1
LZC TECHNOLOGIES MODELLED

LZC TECHNOLOGY	ON-SITE	OFFSITE	NOTES
Wind			
Large 5.0MW wind turbine		✓	**Repower** 117m tower height. 126m rotor diameter (Largest commercially available)
Large 2.5MW wind turbine		✓	**Nordex** 100m tower height. 99.8m rotor diameter
Medium 330kW wind turbine		✓	**Enercon** 50m tower. 33.4m rotor diameter
Medium 50kW wind turbine		✓	**Entegrity** 36.5m tower height. 15m rotor diameter
Small 20kW wind turbine		✓	**Westwind** 30m tower height. 10m rotor diameter
Small 6kW wind turbine	✓		Roof mounted; **Proven**; 9m tower height on 43.6m building giving total height of 52.6m; 5.5m rotor diameter
Small 1kW wind turbine	✓		Roof mounted; **Futurenergy**; 6.2m tower height on 43.6m building giving total height of 49.8m; 1.8m rotor diameter
Solar			
Solar Thermal Hot Water (STHW)	✓		291m² (i.e. 30% of roof area)
Photovoltaics on roof	✓		291m² roof mounted monocrystalline (i.e. 30% of roof area), mounted at 30° pitch on frame on roof
Photovoltaics on roof and Southern façade	✓		291m² roof mounted monocrystalline (i.e. 30% of roof area), mounted at 30° pitch on frame on roof, and 181m² as overhangs above windows on the South facing staircore
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			
Small fuel cell CHP	✓		Space heating, hot water and electricity
Large fuel cell CHP	✓	✓	Space heating, hot water and electricity
Small Biomass CHP	✓		Space heating, hot water and electricity
Large Biomass CHP	✓	✓	Space heating, hot water and electricity
Small gas-fired CHP	✓		Space heating, hot water and electricity
Large gas-fired CHP	✓	✓	Space heating, hot water and electricity
Small anaerobic digestion CHP	✓		Space heating, hot water and electricity
Large anaerobic digestion CHP	✓	✓	Space heating, hot water and electricity
Combined Cooling Heat & Power CCHP			
Fuel cell CCHP (large and small)	✓		Space heating, cooling, hot water and electricity
Gas-fired CCHP (large and small)	✓		Space heating, cooling, hot water and electricity
Biomass CCHP (large and small)	✓		Space heating, cooling, hot water and electricity
Anaerobic digestion CCHP (large and small)	✓		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 mixed-use building cost plan was developed by Cyril Sweett using their cost database. UK mean values current at 4Q 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 building 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 derived from 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 for 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 (April 2011) for low and zero carbon electricity are shown in Table D1. These data and the Target Zero operational carbon analyses, predate the FIT Amendment Order 2011, which came into effect on 30th May 2011.

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

* The microCHP pilot will support up to 30,000 installations with a review to start when the 12,000th installation has occurred.

[1] These data and the Target Zero operational carbon analyses, predate the FIT Amendment Order 2011, which came into effect on 30th May 2011.

APPENDIX E

CLEAR LIFE CYCLE ASSESSMENT MODEL

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

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

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

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

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

LCA data sources

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

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

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

TABLE E1

THE EMBODIED CARBON COEFFICIENTS FOR THE PRINCIPLE MATERIALS USED IN THE MIXED USE BUILDING ASSESSMENT.

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

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

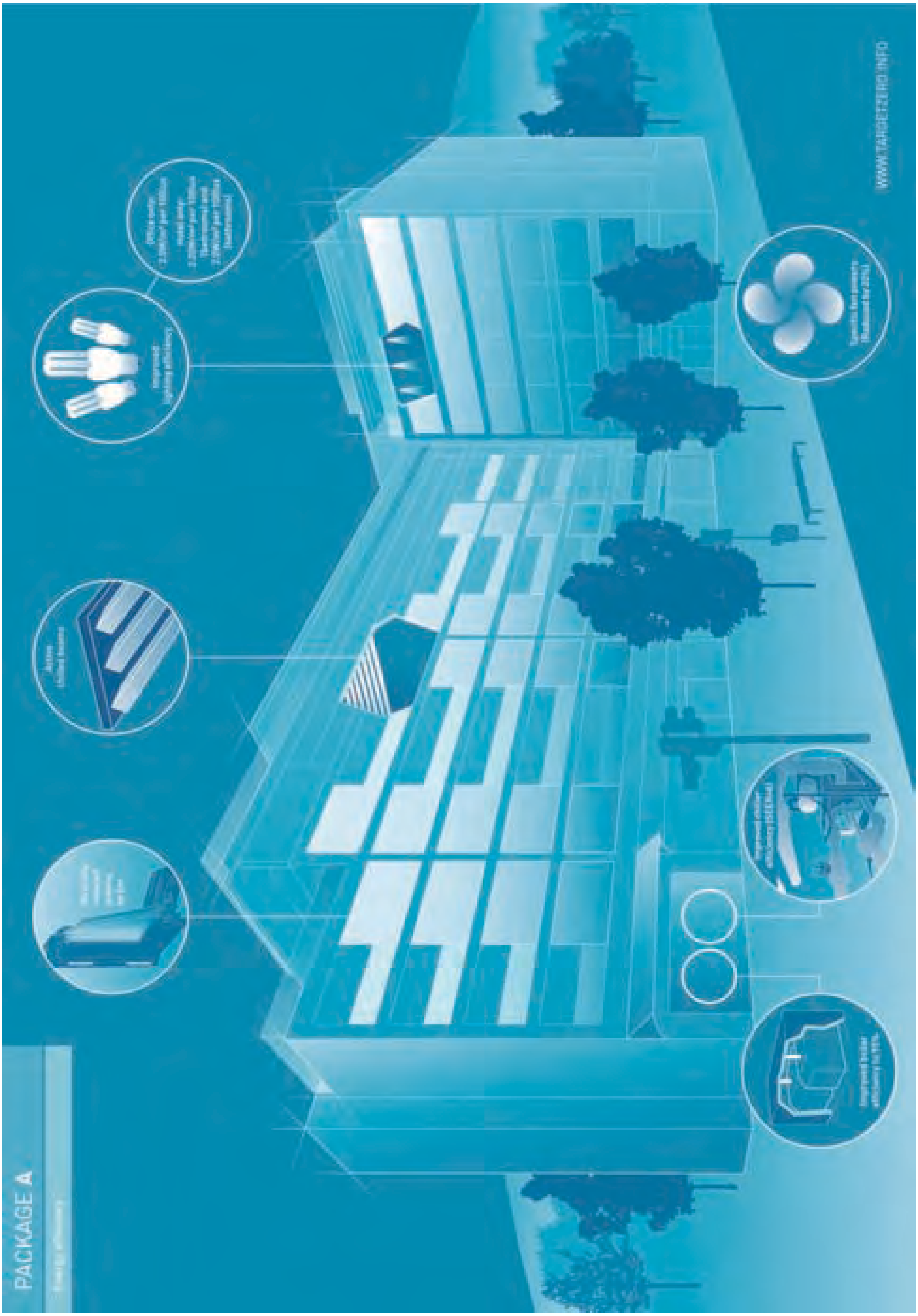
2 Survey of Arisings and Use of Alternatives to Primary Aggregates in England, 2005 Construction, Demolition and Excavation Waste, www.communities.gov.uk/publications/planningandbuilding/surveyconstruction2005.

(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.


PACKAGE A
Energy efficiency
Active chilled beams
Improved lighting efficiency
Office only: 2.0W/m² per 100lux
Hotel only: 2.20W/m² per 100lux (bedrooms) and 2.0W/m² per 100lux (bathrooms)
Improved boiler efficiency to 95%
Improved chiller efficiency (SEER=6)
Specific fan power (Reduced by 20%)
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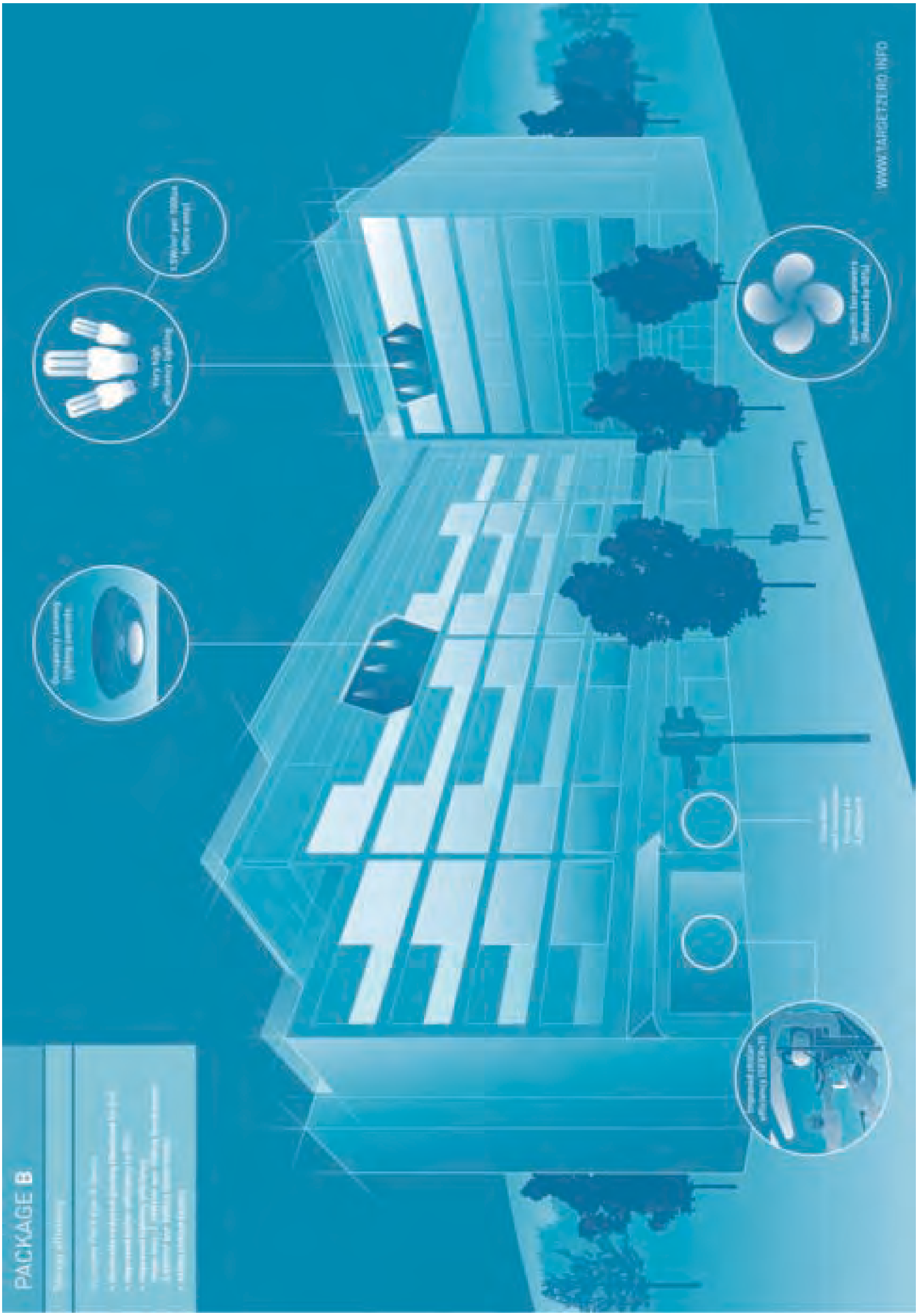
ENERGY EFFICIENCY PACKAGES



ENERGY EFFICIENCY PACKAGES

BREEAM MEASURES — MIXED USE

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. Reduction of CO2 emissions.
- E Sub-metering of areas and/or departments.
- O Efficient lifts. Building fabric performance

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

MANAGEMENT
- V Commissioning. Considerate constructors. Construction site impacts. Security. Publication of building information. Consultation. Building user guide.
- E Seasonal commissioning. Lifecycle costing.

WASTE
- V Construction site waste management. Storage of recyclable waste. Use of recycled aggregates. Composting.

ECOLOGY
- V Enhancing site ecology.

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

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. View out. Daylighting.
- E Indoor air quality.

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

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

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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 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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