TARGET ZERO®

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

REPORT **V1.0 DECEMBER 2010**

WWW.TARGETZERO.INFO

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

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

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

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

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

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

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

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

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

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

www.steel-sci.org

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1.0 INTRODUCTION

INTRODUCTION

Target Zero is a programme of work, funded by Tata Steel and the British Constructional Steelwork Association (BCSA)[1], to provide guidance on the design and construction of sustainable, low and zero carbon buildings in the UK. Five non-domestic building types have been analysed: a school, a distribution warehouse, an out-of-town supermarket, a 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 third of the five building types covered by Target Zero, the supermarket. 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 have been provided by ASDA and showcase recent examples of steel-framed supermarket buildings.

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 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.

ASDA, BOOTLE

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 SUPERMARKET BUILDINGS

In the competitive world of food retailing, sustainability is high on the agenda and supermarket chains face many emerging issues including carbon and climate change, car dependency, consumer labelling, fair trade and localism. These issues are recognised by responsible retailers as elements of a complex jigsaw that require a comprehensive sustainable development strategy.

Sustainable supermarket buildings must form part of any such strategy and leading UK supermarket chains are designing and building new stores which address many aspects of sustainable construction including:

- **improved operational energy efficiency**
- **use of sustainable construction materials**
- **introduction of new technologies such as LZC technologies and efficient refrigeration systems**
- **BREEAM assessment of new supermarket stores**
- **metering of energy and water consumption**
- **rainwater harvesting and sustainable urban drainage.**

To be sustainable, supermarket chains must remain profitable. In the context of their stores therefore, implementing sustainability measures should not detract from their customers' shopping experience. For example poor lighting, poor air quality and overheating are not acceptable in new supermarket stores.

While the economic downturn has heavily impacted most development in the UK, the performance of the major retailers continues to be strong. Supermarket chains procure large out-of-town stores, large distribution centres and are increasingly involved in the redevelopment of our town and city centres. There are also signs of retailers moving into housing and mixed-use (living and leisure) developments. Major retailers therefore have an important role in delivering sustainable and low carbon buildings and communities.

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 'basecase' building is defined (see Sections 5 and 5.1) that just meets the 2006 Part L requirements for operational carbon emissions and this basecase is used as a benchmark for the assessment. It is important to note that the basecase building differs from the actual building and that all operational carbon reductions are reported relative to the performance of the basecase building not 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 basecase 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[1] 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 E.

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, renewal 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. Appendix A summarises some of the limitations of the NCM with respect to supermarket buildings.

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.**

1 Project costing of the basecase supermarket building was based on UK mean values current at 4Q 2009.

5.0 THE STOCKTON-ON-TEES ASDA FOOD STORE

THE STOCKTON-ON-TEES ASDA FOOD STORE

The building on which the supermarket research was based, is the Asda food store in Stockton-on-Tees, Cleveland. This out-of-town supermarket, built adjacent to the site of a former Asda store, was completed in May 2008.

The building has a total floor area of 9,393m² arranged over two levels. The retail floor area, which includes a 1,910m² mezzanine level, is 5,731m². The remaining (back-of-house) accommodation includes offices, warehousing, cold storage, a bakery and a staff cafeteria.

The supermarket has a braced steel frame supported on CFA concrete piles and a suspended concrete ground floor slab. The roof is a monopitch, aluminium standing seam system and the external walls are clad with steel-faced composite panels. Windows and the main entrance elevation to the store comprise aluminium curtain walling with argon-filled double glazing units.

The retail area is based on a 12m x 12m structural grid. Back-of-house, the grid reduces to a 6m x 12m grid increasing to a 16m x 16m grid in the warehouse area, at the rear of the building.

The upper floor (back-of-house) comprises structural metal decking supporting in-situ concrete. The retail mezzanine floor comprises plywood boarding on cold-rolled steel joists.

The building is oriented with the glazed front façade and store entrance shown facing north west.

The main retail space is heated and cooled using an air system whilst the non-retail space is serviced using a variety of different systems. For example the warehouse is served by radiant heaters and warm air blowers; the WCs and food preparation areas have extract systems with limited supply and no heat recovery, heating is provided to these spaces via radiators. Dining areas, the pharmacy and the CCTV rooms have heating and cooling provided by local heat pumps and the first aid room has a local mechanical ventilation system. Hot water is provided to the whole via a gas-fired system.

The store is open for 24 hours a day from Monday to Saturday. Sunday opening hours are 10am to 4pm.

ASDA FOOD STORE, STOCKTON-ON-TEES, CLEVELAND

5.1 BASECASE SUPERMARKET BUILDING

For the purposes of the Target Zero supermarket study, a basecase building was defined based on the Asda food store described in Section 5, i.e. based on the same dimensions, specification, etc. as the real building. Changes were then made to the fabric and services of the actual building to provide a basecase supermarket 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 required by criterion 2 of Part L (2006)**
- **HVAC system efficiencies were altered to industry standards**
- **the air leakage value was increased to 10m³/hr per m² @50Pa.**

The basecase building model was then fine-tuned to pass Part L2A (2006) to within 1% by altering the energy efficiency of the lighting system to 3.90 W/m² per 100lux.

More detail on the specification of the basecase supermarket is given in Appendix B.

MEZZANINE LEVEL - ASDA FOOD STORE, STOCKTON-ON-TEES, CLEVELAND

KEY FINDINGS

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

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 alone, i.e. without the need for LZC technologies. These measures are predicted to yield a 35% reduction in regulated carbon emissions relative to the basecase supermarket, save £56,345 in capital cost and yield a 25-year net present value[1] (NPV) saving of -£973,545 relative to the basecase building. See Section 7.3.

Two, more advanced, packages of energy efficiency measures were selected that are predicted to reduce regulated carbon emissions by 51% and 58%. Both packages are predicted to be cost-effective over a 25-year period, i.e. yield a negative NPV (relative to the basecase building) however the more advanced package is less attractive both in terms of capital and NPV cost. See Section 7.3.

Lighting was found to be the most significant energy demand in the supermarket building studied, accounting for around a half of the total operational carbon emissions. Consequently efficient lighting systems coupled with optimum rooflight design were found to be key in delivering operational carbon reductions. The complexity of the interaction between building orientation, rooflight design, lighting systems and daylight dimming lighting controls in supermarket buildings requires detailed dynamic thermal modelling in conjunction with good lighting design to develop an optimum lighting solution. See Sections 7.4 and 7.5.

The proportion of operational carbon emissions from heating and cooling of the supermarket building studied are very similar. Energy efficiency measures which impact this heating/cooling balance 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 Section 7.3.

Several of the assumptions in the National Calculation Methodology (NCM) were found to cause difficulties in developing optimal low and zero operational carbon solutions for the supermarket building. These are identified in subsequent sections of this report and summarised in Appendix A.

The research found no single, onsite LZC technology that is predicted to achieve true zero carbon, i.e. a regulated carbon emissions reduction of 127%[2]. The greatest onsite reduction of 94% of regulated emissions was achieved using biogas-fired CCHP combined with a package of advanced energy efficiency measures. This solution is expensive however incurring a 17% capital cost increase and is not expected to save money over a 25-year period. See Section 7.6 and 7.7.

Thirty three onsite solutions (compatible combinations of energy efficiency and LZC technologies) were identified. Two of these are predicted to achieve true zero carbon however they incur a minimum capital cost increase of 26.5%. Furthermore they both include a large 330kW wind turbine and biogas-fired CCHP. As such, they are unlikely to be viable on most supermarket sites. See Section 7.6 and 7.7.

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

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

- **0.24% to achieve BREEAM 'Very Good'**
- **1.76% to achieve BREEAM 'Excellent'**
- **10.1% to achieve BREEAM 'Outstanding'.**

The basecase building capital construction cost was estimated by independent cost consultants to be £15.8m (£1,682/m²) – 4Q 2009. See Section 9.

The impact of the structure on the operational carbon emissions of the basecase supermarket was found to be small; the Building Emission Rate (BER) varying by less than 1% between a steel portal-framed (basecase) and a glulam structure (Option 1). A steel portal frame with northlights (Option 2), was predicted have a 3.8% higher BER than the basecase supermarket. See Section 9.1.

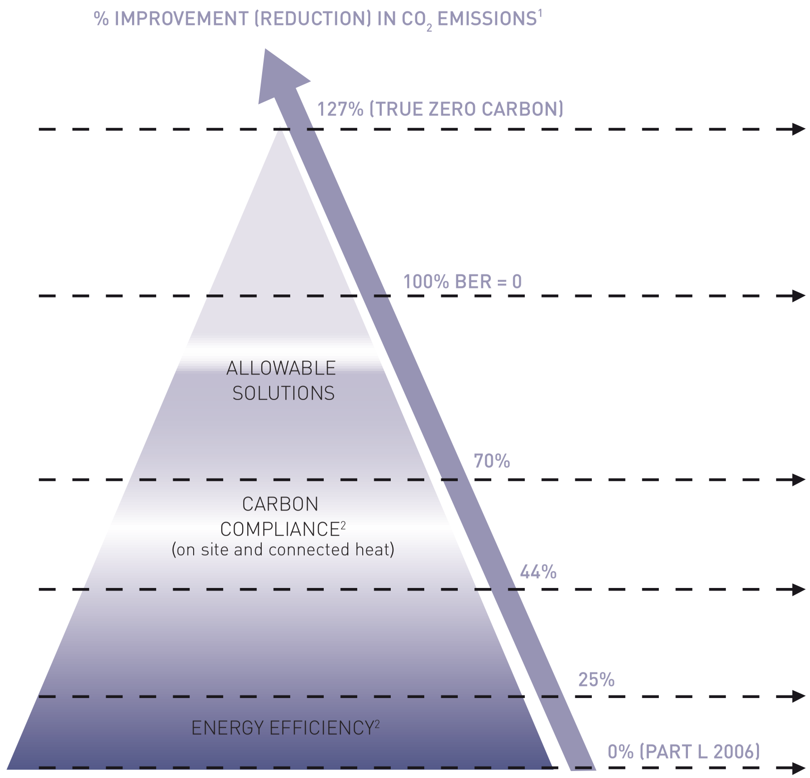
Relative to the steel portal frame basecase building, a glulam structure supermarket had a 2.4% higher embodied carbon impact and a steel portal frame with northlights had a 5% higher impact. See Sections 9.2 and 10.

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 basecase) that they yield over a 25-year period – see Appendix E. A negative NPV represents a saving over the 25-year period, relative to the basecase building.

2 127% is the reduction required to achieve true zero carbon for the case study supermarket building since unregulated small power demands contribute 21% of the total operational carbon emissions – see Figure 5. Therefore to achieve true zero carbon a reduction of in regulated emissions of 127% is required.

6.0 KEY FINDINGS

FIGURE 1
FIGURE 1 SUMMARY OF THE MOST COST-EFFECTIVE ENERGY EFFICIENCY AND LZC OPERATIONAL CARBON ROUTES FOR THE BASECASE SUPERMARKET 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] (£)
Package B (see below)	330kW wind turbine Biogas-fired CCHP 3,500m² array of photovoltaics	4,179,318 [26.5%]	-517,963
Package B (see below)	Reverse cycle air source heat pump 330kW wind turbine Refrigeration heat recovery 3,500m² array of photovoltaics	2,336,4963 [14.7%]	-2,367,946
Package A Composite internal floor[4] High efficiency lamps and luminaires[5] Specific fan powers reduced by 20% Motion sensing controls throughout Improved chiller efficiency SEER = 6 Improved boiler efficiency to 95% Building oriented so that glazed façade faces South	Reverse cycle air source heat pump 330kW wind turbine	652,141 [4.1%]	-2,496,463
Package B Very high efficiency lamps and luminaires[5] Specific fan powers reduced by 30% Rooflights 10% with daylight dimming Improved chiller efficiency SEER = 7 Ventilation heat recovery (60% efficient) Improved air tightness 7m³ per hr m² @50Pa	-	141,821 [0.90%]	-1,053,332
High efficiency lighting[5]	-	42,900 [0.27%]	-758,082
Basecase building – see Section 5.1			

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 basecase building

4 Replacing the lightweight mezzanine retail floor with composite metal decking and in-situ concrete

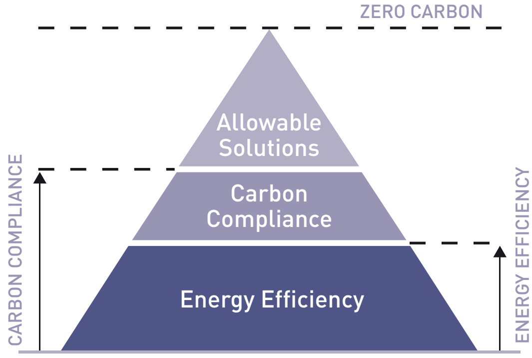
5 see Table C1 in Appendix C

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 proposed Part L compliance targets for 2010 and 2013. The approach taken to the assessment of low and zero operational carbon solutions is described in Appendix B.

Operational carbon is the term used to describe the emissions of carbon dioxide during the in-use 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 2006 Building Regulations, and other, currently 'unregulated' emissions, including appliance use and small power plug loads such as IT. The latter are not currently regulated because building designers generally have no control over their specification and use and they are also likely to be changed every few years.

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



7.1 WHAT IS ZERO CARBON?

The Government has announced its aspiration for new non-domestic buildings to be zero carbon 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 per 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 onsite LZC measures or directly connected heat or coolth. Possible carbon compliance targets for non-domestic buildings have been modelled as part of the Government's consultation [3] using onsite and offsite (technology) rich scenarios and an 'aggregate' approach under which different carbon compliance targets are set for different building types**
- **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.**

The Government also proposes [3] that the zero carbon target for non-domestic buildings will include both regulated and unregulated energy use. There is a proposal that a flat rate allowance for the unregulated energy use in a building could be set as an additional 10 or 20% improvement over the regulated energy use.

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

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.

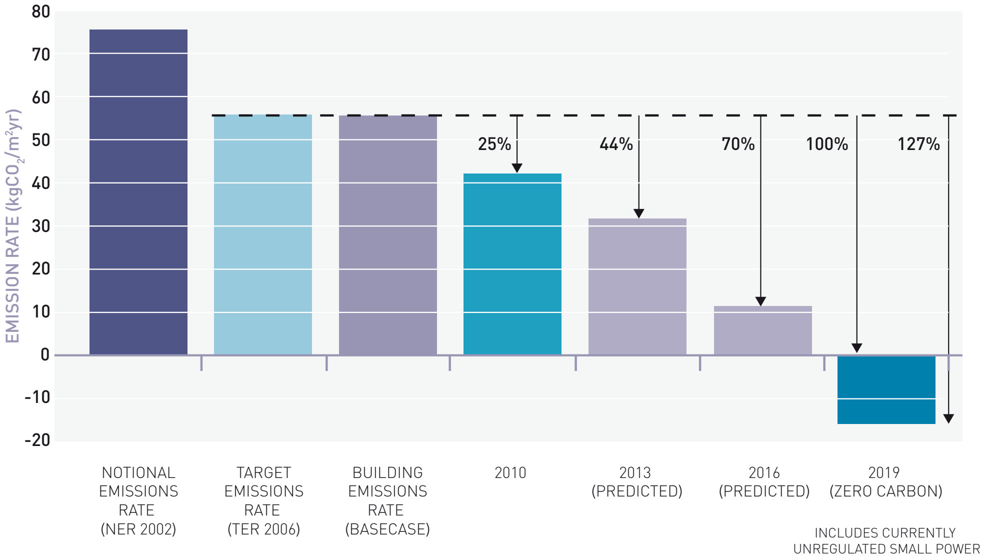
The 2006 revisions to Part L required a 23.5% saving over the 2002 standards for fully naturally ventilated spaces and a 28% saving for mechanically ventilated and cooled spaces. Revisions to Part L in 2010 suggest that a further 25% average reduction in regulated carbon emissions over the 2006 requirements will be required for non-domestic buildings. In recognition of the variation in energy demand profiles in different non-domestic building types and hence the cost-effectiveness of achieving carbon emission reductions in different building types, Part L (2010) adopts an 'aggregate' approach for non-domestic buildings. Under this approach, it is expected that large supermarkets will be required to contribute slightly greater operational carbon emission reductions than the 'average' 25%; results of recent modelling [10] suggest a possible target reduction of 26%[1]. However, this target is indicative only as it depends upon many variables and therefore the actual reduction required will be building specific. Section 7.10 shows the likely impact of the 2010 Part L Regulations on the Target Zero results.

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

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

FIGURE 3

INDICATIVE GRAPH OF PAST AND POSSIBLE FUTURE PART L CHANGES



1 Modelling of the 2010 reduction targets as part of the Part L [5] and Zero carbon [3] consultations suggested an 11-13% reduction (over Part L 2006) for large supermarkets under the 'aggregate' approach. Subsequently revised modelling assumptions changed this target. For supermarkets, the SBEM assumption of general sales retail area has been changed to chilled sales retail area and this has resulted in the indicative 2010 reduction target for large supermarkets being increased to 26% [10].

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

Within Target Zero, the operational carbon emissions results for the supermarket analysed are presented with the 'flat' 25%, 44%, 70%, 100% (BER =0) and 127% (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 127% is required to achieve true zero carbon for the case study supermarket, i.e. one in which the annual net carbon emissions from **both** regulated and unregulated energy consumption are zero or less.

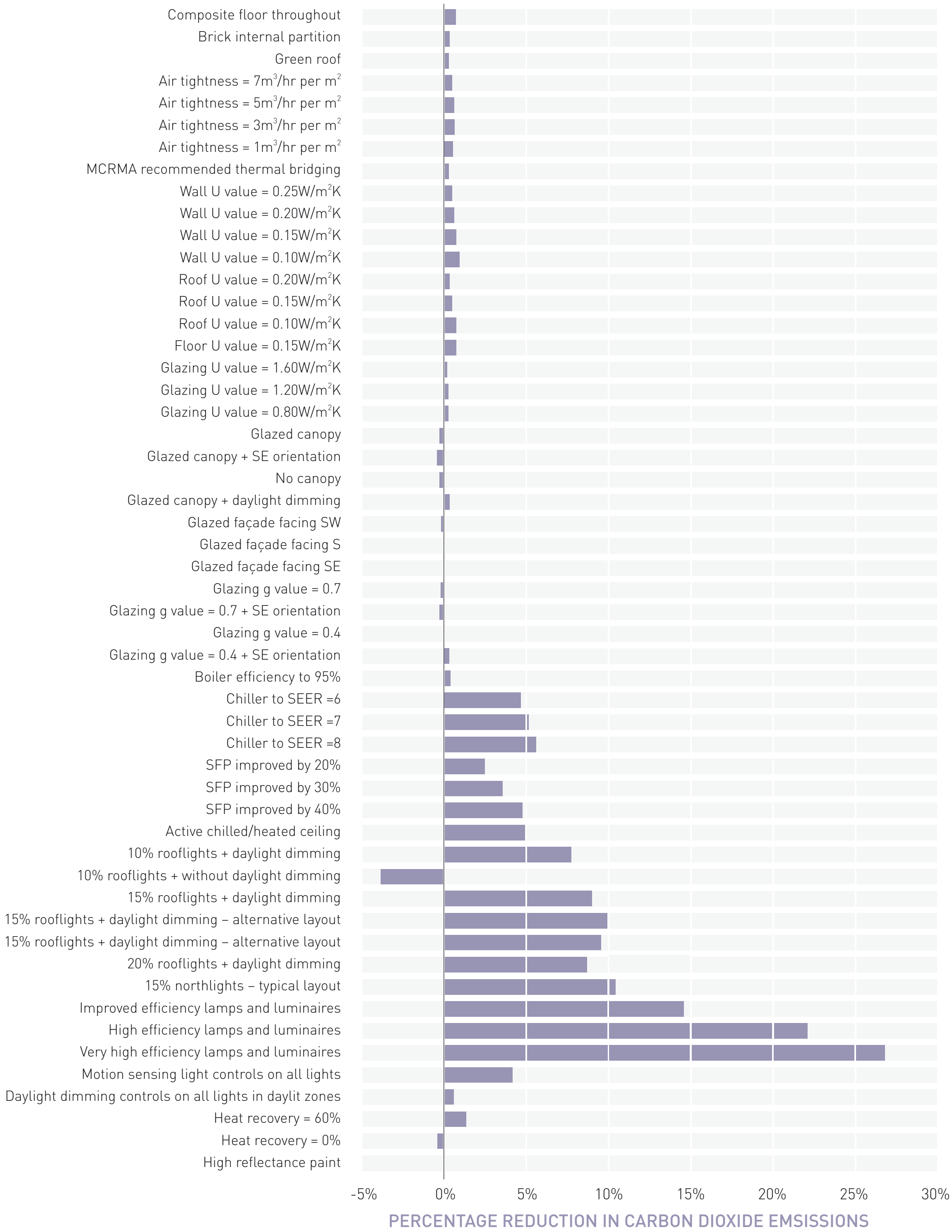
The 2010 Part L requirements stipulate that a prescriptive methodology, known as the National Calculation Methodology (NCM), should be used to assess the operational carbon emissions from buildings. The aim of Target Zero is to assess the technical and financial impacts of meeting future Building Regulation Part L requirements, and therefore the NCM has been used as the basis of this research – see Appendix A. The assessed total operational carbon emissions for the basecase supermarket building were 699 tonnes CO_2 per year using the NCM.

7.3 ENERGY EFFICIENCY

Figure 4 shows the modelled reductions in operational carbon dioxide emissions achieved by introducing the individual energy efficiency measures defined in Appendix C into the basecase supermarket building. The results show that the measures with the greatest predicted impact are those related to the greatest energy demand in the supermarket, i.e. lighting (see Figure 5). Most of the glazing, shading and building orientation combinations of measures modelled were found to yield only small reductions in carbon dioxide emissions with some predicted to cause an increase relative to the basecase.

FIGURE 4

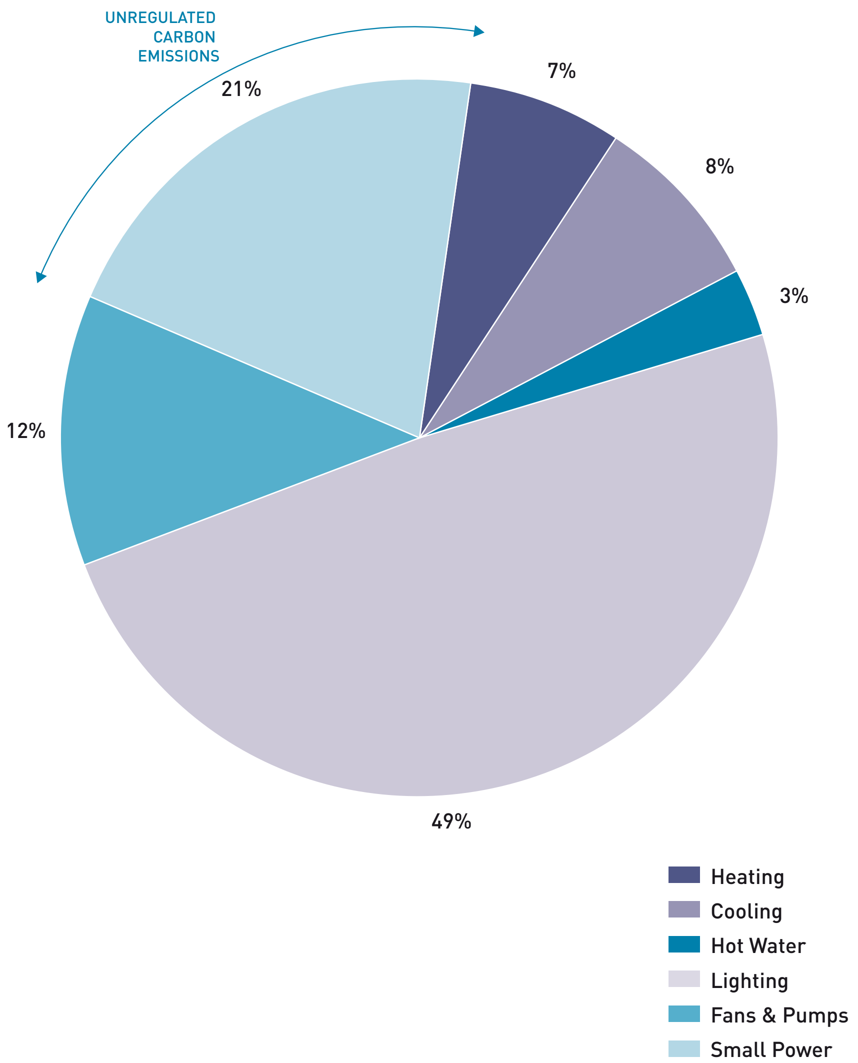
REDUCTION IN CARBON DIOXIDE EMISSIONS ACHIEVED BY INTRODUCING ENERGY EFFICIENCY MEASURES (RELATIVE TO THE BASECASE)



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

FIGURE 5

BREAKDOWN OF CARBON DIOXIDE EMISSIONS FOR THE BASECASE SUPERMARKET BUILDING

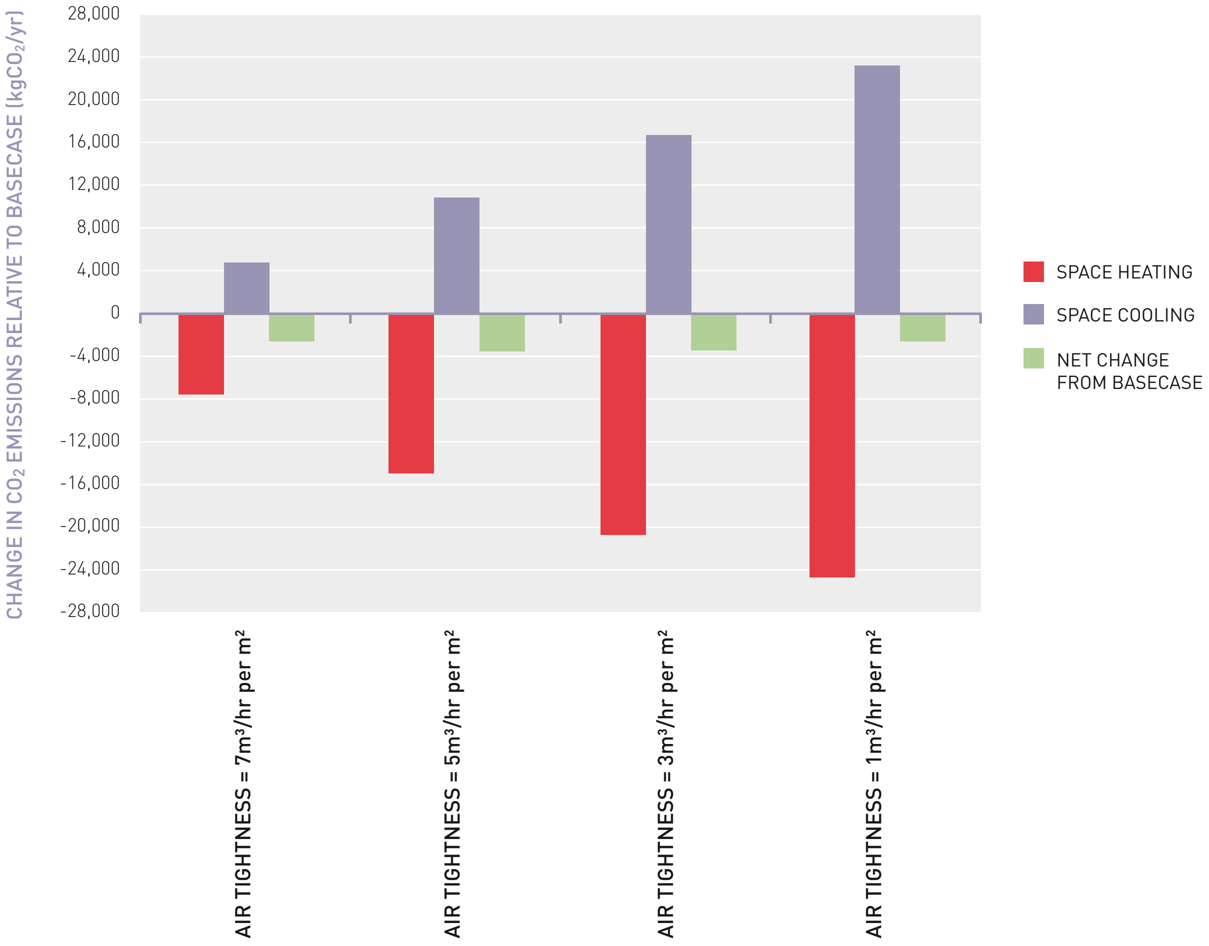


7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

Similarly measures which increase heat loss or reduce solar gain will increase the emissions from space heating but reduce those from cooling. This effect is illustrated in Figure 6 which shows the impact of increasing the air-tightness of the building on annual space heating and cooling carbon dioxide emissions. The figure shows that predicted net savings in annual carbon dioxide emissions (relative to the basecase) do not vary substantially as the air-tightness of the building is improved.

FIGURE 6

EFFECT OF CHANGING AIR TIGHTNESS ON CARBON DIOXIDE EMISSIONS FROM SPACE HEATING AND COOLING



7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

Based on the NCM, the predicted unregulated carbon emissions in the basecase supermarket represent 21% of total carbon emissions. The principal use of unregulated energy in supermarkets is chilled/frozen food display units. In practice, the unregulated carbon emissions in many supermarkets is likely to be much higher than this. Surveys have estimated that chilled food displays can account for up to 50% of the buildings total carbon emissions.

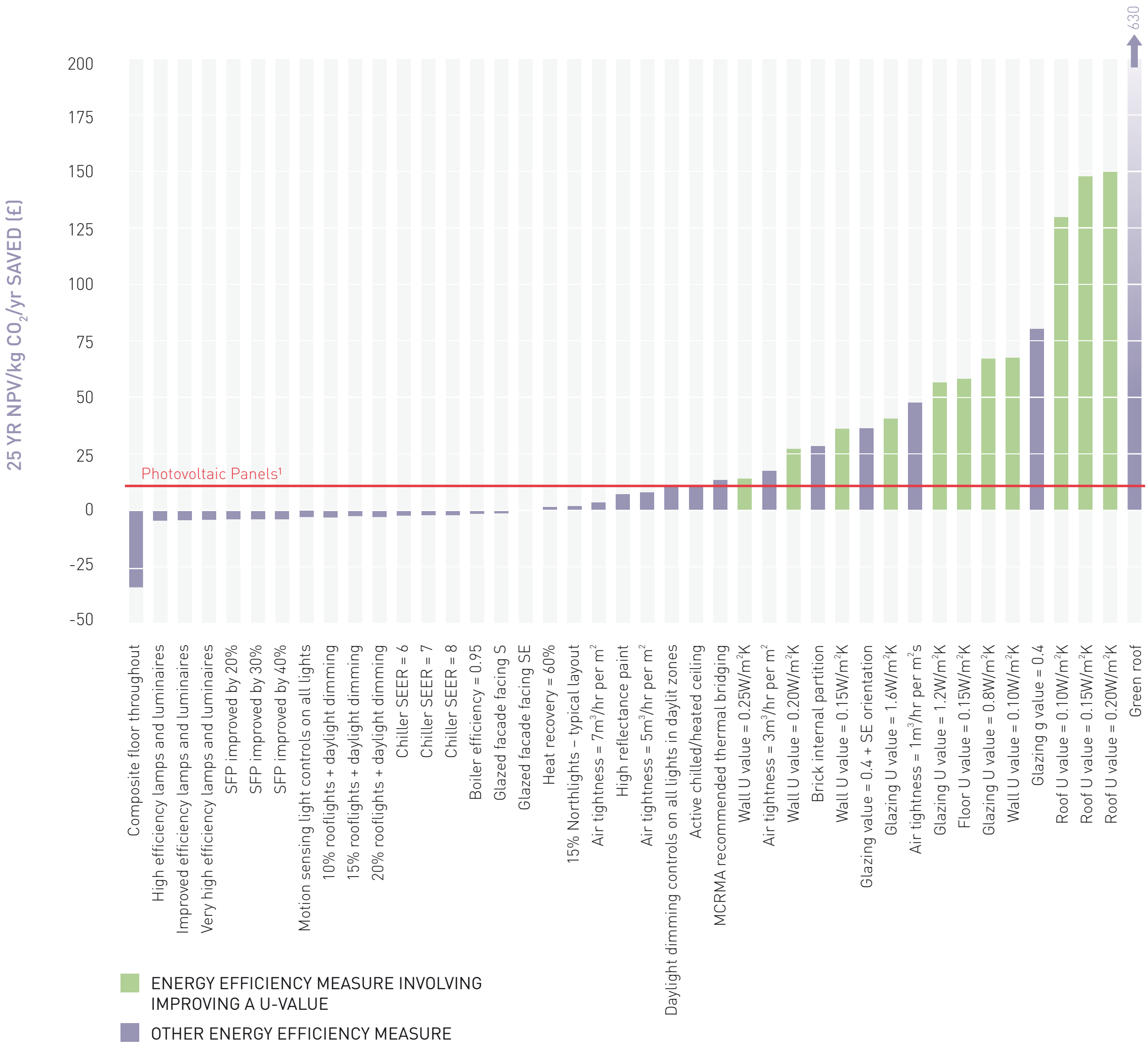
The leakage of refrigerant greenhouse gases from chiller and freezer cabinets in retail buildings is also a potentially significant contributor to the overall carbon emissions. This issue is not included in the NCM although it is addressed under BREEAM.

The results shown in Figure 4 take no account of cost and therefore the energy efficiency measures 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 basecase building performance - see Appendix E.

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. As with air tightness, the net carbon saving from such measures is relatively small and their cost-effectiveness is therefore relatively low.

FIGURE 7

COMPARISON OF NPV COST-EFFECTIVENESS OF MODELLED ENERGY EFFICIENCY MEASURES



1 This line represents the cost-effectiveness of photovoltaic panels excluding the effect of the feed-in tariff.

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

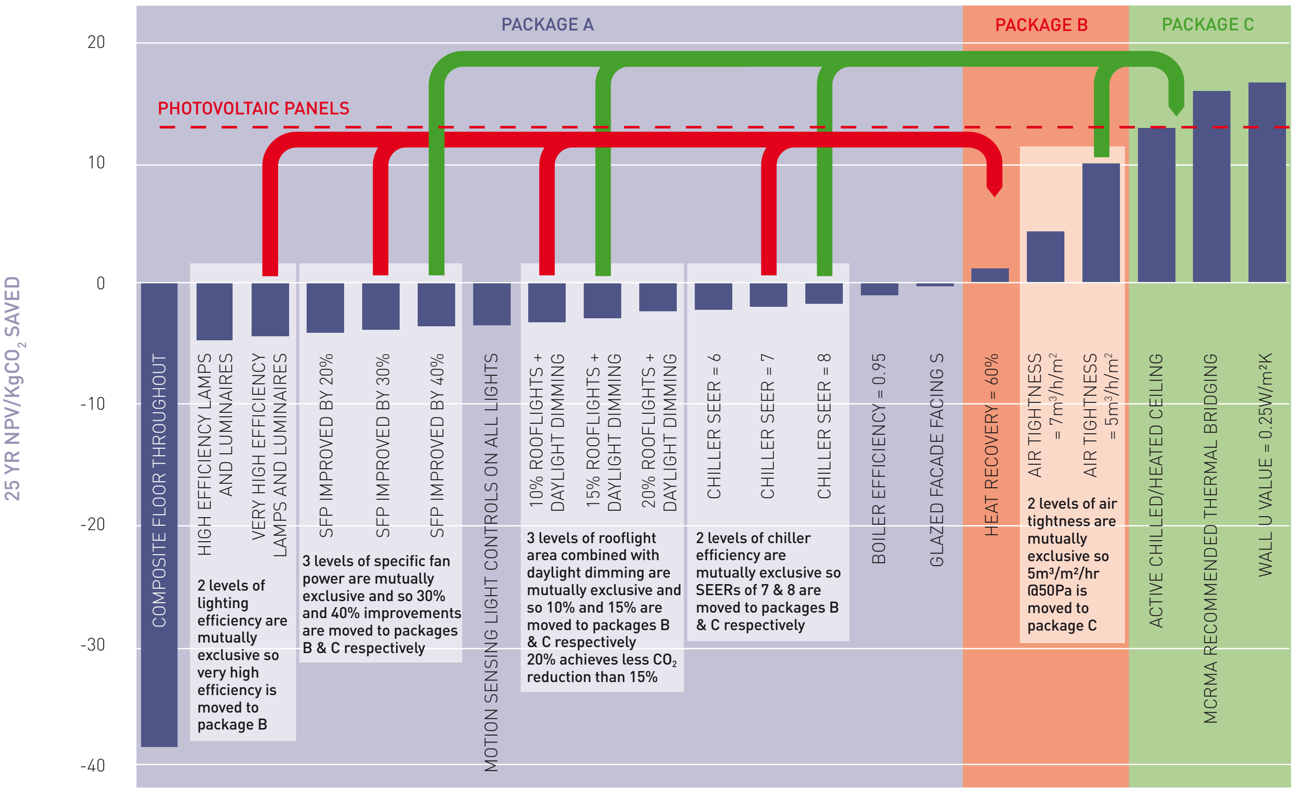
The measures shown in Figure 7 were then grouped into three energy efficiency packages, each one representing a different level of additional capital investment; low, medium and high (see Appendix C).

Packages were carefully checked to ensure that all of the energy efficiency measures were compatible with each other; however some measures were 'stepped-up' between packages. For example Package A includes an improved chiller efficiency (SEER = 6), whereas this measure is 'stepped up' in Package B to an SEER of 7. A similar approach was adopted for the lamps and luminaires, plant specific fan power, rooflights and air tightness.

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

Figure 8 shows the individual measures included within the three energy efficiency packages applied to the basecase supermarket building.

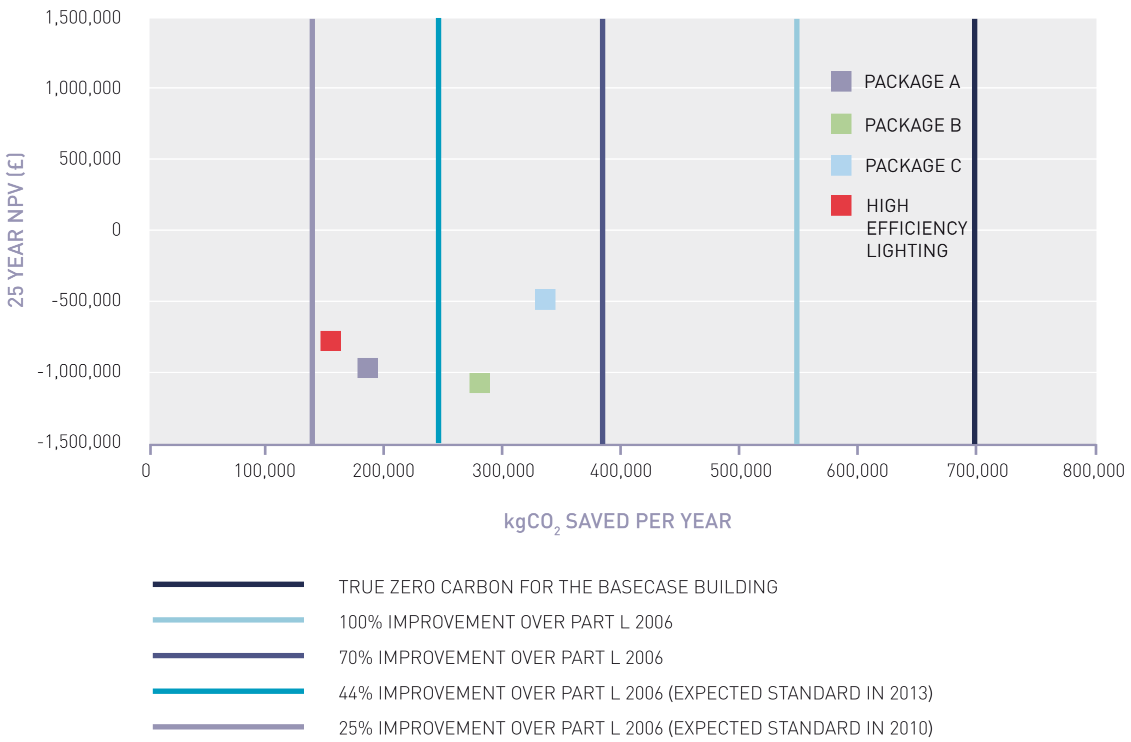
FIGURE 8
ENERGY EFFICIENCY MEASURE PACKAGES A, B AND C



7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

Figure 9 shows energy efficiency packages A, B and C plotted on axis representing carbon emissions saved per year (relative to the basecase) against 25-year NPV saving (relative to the basecase) 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 expected to be required to comply with the 2010 regulations, can easily be achieved through the use of Package A energy efficiency measures alone. In fact the 25% reduction target can be achieved by applying just the high efficiency lighting measure. This measure alone achieves a 27% reduction in regulated emissions at a capital cost of £42,900 and yields a 25-year NPV saving of £758k relative to the basecase. See also Section 7.10 which discusses the impact of Part L 2010 on operational carbon emissions reduction targets.

The current expectation is that in 2013, the Part L target will be reduced by 44% beyond the 2006 requirement; energy efficiency Packages B and C both achieve this target. However, this target can be achieved more cost-effectively using LZC technologies combined with Package A – see Section 7.6. It should also be noted that improved energy efficiency measures are likely to be applicable on all sites whereas the effectiveness of LZCs can be highly site specific.

The three energy efficiency packages are fully defined in Table 1 along with the modelled operational carbon emissions savings (relative to the basecase) achieved by their introduction into the basecase supermarket. The table also gives the capital cost and 25-year NPV of the three packages of measures relative to the basecase.

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

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 BASECASE TOTAL EMMISSIONS] [CHANGE FROM BASECASE REGULATED EMISSIONS]	CHANGE IN CAPITAL COST FROM BASECASE BUILDING (£) [%]	CHANGE IN 25 YEAR NPV FROM BASECASE BUILDING (£)
Basecase building	-	699,289	-	-
Package A	Composite internal floor[1] High efficiency lamps and luminaires[2] Specific fan powers reduced by 20% Motion sensing controls throughout Improved chiller efficiency SEER = 6 Improved boiler efficiency to 95% Building oriented so that glazed façade faces South	508,196 [-27%] [-35%]	-56,345 [-0.36%]	-973,545
Package B	Package A plus (or superseded by): Very high efficiency lamps and luminaires[2] Specific fan powers reduced by 30% Rooflights 10% with daylight dimming Improved chiller efficiency SEER = 7 Ventilation heat recovery (60% efficient) Improved air tightness 7m³/hr per m² @ 50Pa	419,895 [-40%] [-51%]	141,821 [0.90%]	-1,053,332
Package C	Package B plus (or superseded by): Specific fan powers reduced by 40% Rooflights 15% with daylight dimming Improved chiller efficiency SEER = 8 Highly improved air tightness 5m³/hr per m² @ 50Pa Active chilled beam / radiant ceiling Advanced thermal bridging (0.013W/m²K) Improved wall U-value to 0.25W/m²K	379,548 [-46%] [-58%]	805,773 [5.1%]	-495,153

1 Replacing the lightweight mezzanine retail floor with composite metal decking and in-situ concrete

2 Defined in Table C1 in Appendix C

The reduction in carbon dioxide emissions resulting from the energy efficiency packages ranges from 35% of regulated emissions (27% of total emissions) with a reduced capital cost of 0.36% up to 58% of regulated emissions (46% of total emissions) with an additional capital cost of 5.1%. All three packages are predicted to save money over a 25-year period compared to the basecase building, i.e. they have a negative NPV.

It is noted that energy efficiency Package B has a lower (and therefore more attractive) NPV than Package A. This implies that, in the long-term, Package B is a more economical way of reducing carbon dioxide emissions, although when combined with LZC technologies this is not always the case, see Section 7.6.

Despite the greater reduction in operational carbon emissions afforded by Package C, its economic performance is less attractive, i.e. it incurs a greater capital cost and yields a less attractive NPV than Package B. Therefore to reduce operational carbon emissions, beyond those achieved using energy efficiency Package B, LZC technologies can be more cost-effective than implementing Package C measures – see Section 7.6.

ASDA – BOOTLE

RECOMMENDATION

The targets for operational carbon reduction in supermarkets required from 2010 as a result of changes to Part L can be achieved by using energy efficiency measures only, i.e. without LZC technologies. The package of measures predicted to have the best NPV return was:

- composite internal floor (replacing the lightweight retail mezzanine floor)
- high efficiency lamps and luminaires
- specific fan powers reduced by 20%
- motion sensing controls throughout
- improved chiller efficiency SEER = 6
- improved boiler efficiency to 95%
- building oriented so that glazed façade faces South.

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 measures that are low maintenance.

7.4 LIGHTING AND SHELVING/RACKING

Efficient lighting of large, low rise, open buildings such as supermarkets and warehouses is highly dependent on the presence and configuration of the shelving and racking systems used. Where obstructions such as high bay racking are installed, the building is effectively split into a number of narrow, corridor-type spaces which require many more fittings, and hence more energy, to achieve the same level and uniformity of lighting.

As shown in the photograph, the height of the food display units in the case study supermarket (and therefore in the bascase supermarket) is low relative to the ceiling height, however, in the warehouse area at the rear of the store, the effect of the high bay racking on the lighting efficiency can be significant. For further information on lighting and racking in warehouse buildings see the Target Zero warehouse report [6].

RECOMMENDATION

Although not currently included within the NCM, the effect of high-bay racking in warehouse areas of buildings on the lighting design is significant and should be considered by the designer [6].

FOOD DISPLAY UNITS – ASDA FOOD STORE, STOCKTON-ON-TEES

7.5 ROOFLIGHTS

The effect of rooflight design on the operational carbon emissions of a building is complex. Rooflights impact both the heating and lighting requirements in different ways and at different times of the day and year, they also affect overheating. The basecase supermarket building does not have rooflights which is typical of most supermarket buildings however some retailers have introduced rooflights into some of their newer stores in an effort to reduce operational carbon emissions.

The key advantage to increasing the rooflight area is that it can substantially reduce the amount of energy used for lighting. However for each building there will be a point where this improvement will be cancelled out by the increased requirement for space heating as rooflights let out more heat than opaque cladding elements. The optimal solution will vary depending on the final use and layout of the building among many other variables.

The arrangement of rooflights should aim to give an even distribution of light. In some circumstances additional or reduced areas of rooflight could be considered for areas of different activity within the building. However, this approach could be counter productive if there is a future change of use of the building so, in general, rooflights are distributed uniformly over the roof area.

The distribution of both natural daylight and artificial light within a building will be highly dependent on the presence and nature of internal equipment or furniture. A building such as a sports hall with a wide open space and evenly spaced mid-slope rooflights will have a fairly uniform light intensity. However, the installation of tall internal equipment, for example high bay racking in a warehouse, will create areas of full and partial shadow causing much lower light intensities. In this case, the available natural daylight will not be fully realised and high levels of additional artificial lighting will be necessary. However, most new supermarkets in the UK have high ceilings and food display units and other furniture are generally not tall enough to cause a significant obstruction to the diffusion of light.

As the rooflight area increases, the overall light intensity within the building will increase, however this will also increase the shadow effects in areas which are not directly lit. There may also be some areas, which are in direct sunlight and may be subject to glare.

ROOFLIGHTS – ASDA FOODSTORE, STOCKTON-ON-TEES

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

The hours of operation of the supermarket will also have a significant impact on the effectiveness of rooflights. At night, rooflights serve only to release heat; releasing more heat through conduction than the opaque roof panels around them. Therefore the more hours of darkness during which the supermarket operates, the lower the optimal rooflight area will be. The National Calculation Methodology (NCM) defines that supermarkets should be assessed with occupancy from 8am to 7pm Monday to Friday, 9am to 7pm on Saturdays and from 9am to 5pm on Sundays and Bank holidays. Therefore although many large supermarkets will operate 24 hours a day, this usage profile is not currently assessed under Part L.

In summary, the impact of rooflight area, layout and specification affects a number of variables including space heating and cooling requirements and the energy requirement of lighting systems. Given the complex interaction of these variables, rooflights were considered separately to all the other energy efficiency measures. Each energy efficiency package was modelled with three rooflight areas (10%, 15% and 20% of available roof area)[1] and the most effective area selected for each package.

FIGURE 10
MODELLED EFFECTS OF CHANGING ROOFLIGHT AREAS

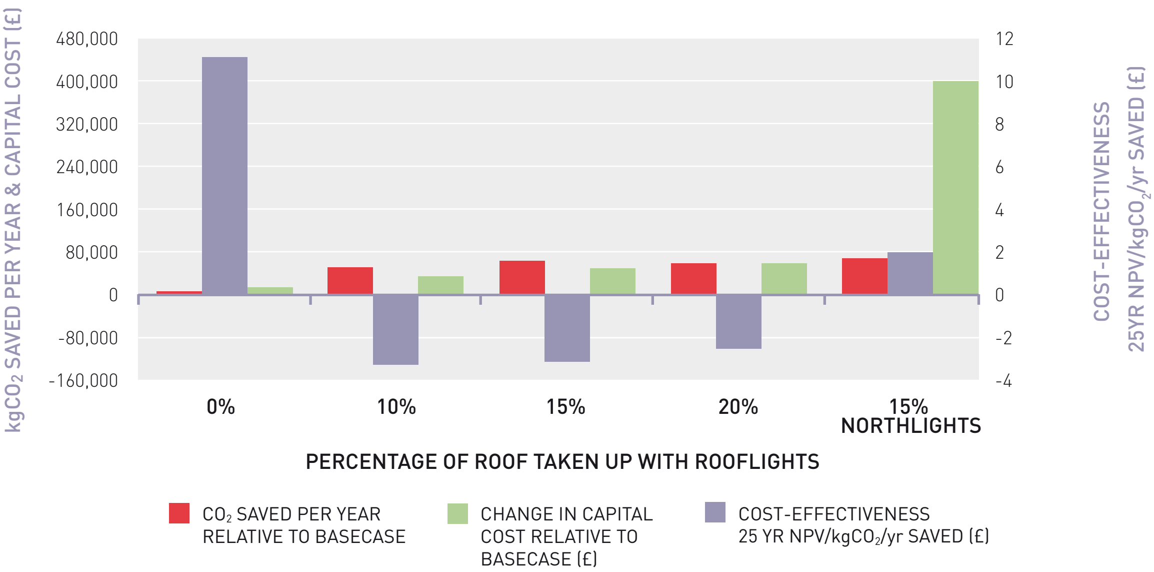


Figure 10 shows the modelled impact of changing the supermarket rooflight area on total predicted operational carbon dioxide emissions for the building. It shows the carbon emissions saved per year, relative to the basecase building, (in red) together with the capital cost of the measure (green) and its long-term cost-effectiveness, i.e. 25-year NPV per kg of CO_2 saved per year (purple). All data in Figure 10 reflect the combined cost and effect of changing the rooflight area and the inclusion of daylight dimming lighting controls. The basecase model does not have daylight dimming.

This analysis was based on the following key assumptions:

- **rooflight U-value: 2.20 W/m²K**
- **rooflight G-value: 0.5**
- **roof U-value: 0.25 W/m²K**
- **supermarket operating hours: 8am to 7pm six days a week reduced to 9am to 5pm on Sundays and Bank holidays**
- **lighting efficiency: 3.9 W/m² per 100lux**
- **illumination level: 300lux**
- **daylight dimming lighting controls.**

1 These rooflight areas were based on industry advice and detailed modelling under Target Zero [6].

Figure 10 shows that there is little variation in cost-effectiveness of flat rooflight area between 10% and 15% of roof area. Although the northlight solution yields similar carbon dioxide emissions savings, its greater capital cost means that it is far less cost-effective than the flat rooflights of an equivalent area.

Prismatic skylights are a relatively new form of rooflight for which excellent light transmittance and diffusion performance is claimed. In addition to providing good natural daylighting, studies from the US suggest that prismatic skylights can improve sales when used in retail buildings. In the UK however, there is no test data on the performance of prismatic skylights and it not currently possible to model this variant of rooflight under the NCM or using accredited dynamic thermal simulation models such as IES

RECOMMENDATION

In general it is not practical to design the rooflight positions based on the internal layout of the building. It must also be considered that the internal use or layout of the building may change during the service life of the building invalidating any rooflight optimisation.

RECOMMENDATION

The design team should consider and balance all heating, cooling and lighting factors associated with rooflights, along with the aspirations of the client, on a project-specific basis.

ROOFLIGHTS – ASDA FOODSTORE, STOCKTON-ON-TEES

7.6 ONSITE LZC TECHNOLOGIES

Thirty seven onsite LZC technologies were individually modelled on each of the three energy efficiency packages defined in Section 7.3 – see Table D1 in Appendix D. Some technologies were modelled as both large and small-scale installations, for example CHP systems were modelled as large-scale to supply space heating and hot water to the whole building and as small-scale, sized to supply hot water only. The methodology used to assess and compare LZC technologies and different combinations of technologies, is described in Appendices B and D.

The research found that no single, onsite LZC technology (in conjunction with appropriate energy efficiency measures) is predicted to achieve true zero carbon, i.e. a 127% reduction in regulated emissions. The greatest onsite reduction, using just one onsite technology, is 94% of regulated emissions (74% of total carbon emissions) achieved by using large[1] biogas-fired CCHP combined with energy efficiency Package C. 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 compliance targets. Selected packages of measures which meet these targets are illustrated in Figure D1 in Appendix D and fully defined in Table 2.

Table 2 demonstrates that significant reductions in operational carbon dioxide emissions can be achieved using combinations of energy efficiency measures and onsite LZC technologies, however the additional costs of doing this begins to become restrictive. For example, to achieve a 100% reduction in regulated emissions relative to the 2006 Part L requirements incurs a minimum capital cost increase of 14.7%. This does not account for the currently unregulated emissions associated with the energy used by small appliances such as IT equipment and white goods and, particularly in supermarkets, freezers and chiller cabinets.

TABLE 2

MOST COST-EFFECTIVE ONSITE 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 BASECASE BUILDING) (£)	25-YEAR NPV COST (RELATIVE TO THE BASECASE BUILDING) (£)
Basecase building	-	55.5	-	-
2010 revision to Part L requiring a (flat) 25% improvement over Part L 2006 See Section 7.10	High efficiency lighting See Table C1 in Appendix C	40.4	42,900 [0.27%]	-758,082
Likely 2013 revision to Part L requiring a 44% improvement over Part L 2006	Energy efficiency package B (see Table 1)	27.6	141,821 [0.898%]	-1,053,332
Possible onsite Carbon Compliance threshold: 70% improvement over Part L 2006[2]	Solution A1 comprising: Energy efficiency package A Reverse cycle air source heat pump 330kW wind turbine	12.65	652,141 [4.1%]	-2,496,463
100% improvement over 2006 Part L (excludes unregulated emissions)	Solution B1 comprising: Energy efficiency package B Reverse cycle air source heat pump 330kW wind turbine Refrigeration heat recovery 3,500m² array of photovoltaics	-5.41	2,336,493 [14.7%]	-2,367,946
True zero carbon (expected standard for non-domestic buildings in 2019) i.e. 127% improvement on Part L 2006 for this building	Solution B2 comprising: Energy efficiency package B 330kW wind turbine Biogas-fired CCHP 3,500m² array of photovoltaics	-21.28	4,179,318 [26.5%]	-517,963

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.

There are a number of technologies that are not compatible with each other; these are all LZC technologies which supply heat. If surplus electricity is generated onsite then this can be sold to the national grid for use in other buildings. However the infrastructure for doing this with heat is more complex and expensive and relies on having a close neighbour(s) with an appropriate heat requirement. Therefore 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 the technologies.

When combining LZC technologies to create a package of compatible onsite measures, care must be taken to avoid the selection of technologies which are less cost-effective than viable energy efficiency measures, as well as avoiding the combination of incompatible technologies. Applying these principles, the analyses identified 36 viable onsite solutions (combinations of compatible energy efficiency and LZC technologies).

Two of these are predicted to achieve true zero carbon, i.e. both regulated and unregulated emissions are predicted to reduce to zero, however the minimum capital cost increase required for this is 26.5% (relative to the basecase building cost). Also these solutions will not be practical on most sites as they include a 330kW wind turbine and biogas-fuelled CCHP. Not all sites will be able to accommodate such a large turbine (see Section 7.7) and biogas CCHP fed by anaerobic digestion will not be viable or practical on many sites (see Section 7.8). Both solutions are however predicted to save money over a 25-year period, relative to the basecase building.

Combinations of onsite LZC technologies were modelled without a 330kW wind turbine however the best performing solutions were not predicted to achieve true zero carbon. The greatest carbon dioxide reduction without wind power were achieved by using solutions comprising biogas CCHP as the primary heating and cooling source coupled with extensive arrays of photovoltaics. These solutions achieve a 100% and 109% reduction beyond the requirements of Part L 2006, in conjunction with energy efficiency Packages B and C respectively. Table 3 shows the most cost-effective onsite solutions to achieving a 70% and 100% improvement over Part L (2006) requirements onsite where large wind turbines are not viable.

ASDA FOOD STORE, STOCKTON-ON-TEES - MEZZANINE LEVEL

TABLE 3
MOST COST-EFFECTIVE ONSITE SOLUTIONS (WHERE WIND TURBINES ARE NOT VIABLE) TO MEET FUTURE LIKELY PART L COMPLIANCE TARGETS

TARGET	MOST COST-EFFECTIVE ROUTE	BER ($kgCO_2/yr$)	ADDITIONAL CAPITAL COST (RELATIVE TO THE BASECASE BUILDING) (£)	25-YEAR NPV COST (RELATIVE TO THE BASECASE BUILDING) (£)
Possible onsite Carbon Compliance threshold: 70% improvement over Part L 2006	Solution B5 comprising: Energy efficiency package B Reverse cycle air source heat pump Refrigeration heat recovery 3,500m² array of photovoltaics	14.6	1,666,993 [10.6%]	-927,339
100% improvement over 2006 Part L (excludes unregulated emissions)	Solution B6 comprising: Energy efficiency package B Biogas-fired CCHP 3,500m² array of photovoltaics	-1.10	3,509,818 [22.2%]	-994,044

7.7 WIND TURBINES

A range of sizes of onsite wind turbines was modelled. For offsite solutions, the purchase of a share of a large on-shore turbine was assumed. The most cost-effective solution was found to be a 2.5MW wind turbine which was predicted, in conjunction with energy efficiency Package B, to achieve a 463% reduction in regulated emissions beyond the requirements of the current (2006) Part L. A turbine of this size would achieve zero carbon for the supermarket whilst also providing a substantial income to its owner for example via the feed-in tariff. However, the size and capital cost of such a large turbine means that it is unlikely to be viable on the vast majority of sites.

A 2.5MW wind turbine should be sufficient to enable three buildings the size of the case study supermarket building to achieve zero carbon. In future, retail park developers may wish to install large wind turbines in order to make their sites more attractive to developers needing to comply with revisions to Part L.

The largest onsite wind turbine modelled was a 330kW turbine. A detailed review of the case study site in Stockton-on-Tees and the potential to erect an onsite wind turbine, found that it is not possible to erect a 330kW turbine due to site constraints. Wind turbines should not be positioned within the 'topple distance' of any occupied building or within 300m of residential buildings [7]. Therefore planning and other constraints will make the installation of such a large turbine impossible or impractical on many sites. Many supermarkets are however located in large open areas away from residential buildings and therefore it was considered appropriate to model a 330kW onsite turbine.

It should be noted that offsite wind turbines have been modelled as if they were erected on the same site as the supermarket (as required in the NCM). However, in reality, their output would probably be higher than the results show. See Appendix A.

Local obstructions are important factors in determining the wind resource at the precise location that the wind turbine is to be installed; turbulence and wind-shadows develop down-wind of obstructions, both reducing the performance of the turbine.

RECOMMENDATION

Wind monitoring should be undertaken to establish a site's wind resources to enable the output of wind turbines to be accurately predicted.

ONSITE WIND TURBINE

7.8 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 onsite generation. This can be provided by LZC technologies such as district CHP heating networks or heat networks from Energy from Waste (EfW) plants. The following technologies were modelled[1]:

- **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.**

None of these systems is predicted to achieve true zero carbon. The greatest modelled reduction in carbon dioxide emissions is 84% using biogas-fired CHP combined with energy efficiency Package C.

The most cost-effective directly connected heat route to achieving a 70% reduction below the requirements of Part L 2006 is predicted to be a biomass-fired district CHP system in conjunction with energy efficiency Package B. However most supermarkets will not be in an area where district heating schemes such as these are viable.

District heating schemes are most viable in dense urban areas where the heat demand is concentrated. By definition, large, out-of-town supermarkets are located away from town centres and therefore the thermal load is unlikely to be sufficiently large to justify establishing a local heat network.

The suitability of a retail business park to the use of a district heating network is likely to depend on the nature of the buildings within it. There are a number of adjacent building types which would increase the viability of different types of district heating system, Table 4 describes these. As most new-build supermarkets are located on retail parks where neighbouring buildings are most likely to be other retail buildings, it is unlikely that district heating will be a cost-effective option on most sites.

TABLE 4
ADJACENT BUILDING TYPES WHICH AFFECT THE VIABILITY OF DIFFERENT TYPES OF DISTRICT HEATING SYSTEM

CHARACTERISTICS OF ADJACENT BUILDINGS	SUITABLE DISTRICT HEATING NETWORK TYPE
Manufacturing process which produces a large amount of waste heat	Waste heat system
Manufacturing process which produces a significant amount of organic waste	Anaerobic digestion (AD) or Energy from waste (EfW)
Buildings with large constant heat demand	Combined heat and power (CHP)
Buildings with large seasonal heat demand	District heating supplying heat only

1 CCHP has not been modelled as a potential 'directly connected heat' technology. This is because although district cooling systems are proven technologies in some climates, they are not well suited to the UK climate. Furthermore district cooling is only likely to be potentially viable in city centres and therefore has not been considered as suitable for an out-of-town supermarket.

Almost all existing Anaerobic Digestion (AD) schemes have, to date, been located in either rural areas supplied with agricultural waste or in industrial areas. The reasons for this are mainly down to poor public image; the perception is that anaerobic digestion will cause unpleasant odours and health risks. It should be noted that these are merely the perception; a well designed and managed AD scheme should not raise health risks or excessive odour. An alternative use of waste material is incineration (energy from waste - EfW); however the predicted carbon savings from this technology were found to be less than for all other forms of district heating system modelled. Waste incineration also faces public resistance due to the perceived health risks.

Another potential barrier to the implementation of district AD CHP systems is the availability of suitable feedstuffs. Common inputs to AD schemes include food waste, animal slurry and sewage. As large producers of food waste, AD schemes based on food waste may be viable for supermarkets particularly where waste from several supermarkets can be consolidated to feed a suitably located AD CHP scheme. 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.**

The cost-effectiveness of a district heating system supplying a supermarket will be improved if the supermarket operates 24 hours a day as the annual space heating load will increase.

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

TABLE 5
DIRECTLY CONNECTED HEAT RESULTS (BASED ON ENERGY EFFICIENCY PACKAGE B)

OFFSITE TECHNOLOGY	OPERATIONAL CO_2 EMISSIONS (kgCO_2/yr) [CHANGE FROM BASECASE]	CHANGE IN CAPITAL COST FROM BASECASE[1] (£) [%]	CHANGE IN 25 YEAR NPV[1] (RELATIVE TO THE BASECASE BUILDING) (£)
Biomass-fired CHP	302,864 [-57%]	139,520 [0.9%]	-1,241,263
Fuel cell-fired CHP	342,780 [-51%]	139,520 [0.9%]	-1,409,278
Natural gas-fired CHP	352,737 [-50%]	139,520 [0.9%]	-1,340,494
Energy from waste	388,157 [-44%]	139,520 [0.9%]	-1,102,181
Waste process heat	363,577 [-48%]	139,520 [0.9%]	-1,102,181
Biogas-fired anaerobic digestion CHP	254,912 [-64%]	139,520 [0.9%]	-1,102,181

1 These are connection costs only and exclude the capital cost and NPV of Energy Efficiency Package B measures.

7.9 ALLOWABLE SOLUTIONS

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

- **further carbon reductions onsite 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 onsite LZCs. The choice may be limited, however, by the need to meet some of the carbon reduction target by onsite LZCs as Carbon Compliance measures. In addition, the NPV for the offsite wind (and other offsite LZCs) is dictated by the values assumed for current and future energy imported/exported across the site boundary, and these energy import/export values for use in evaluating Allowable Solutions may be established by regulation.

Assessment of this Asda food store has demonstrated that the use of onsite LZCs can achieve true zero carbon; however the capital cost of achieving this becomes substantially greater as the carbon reduction targets become more challenging. The analysis has demonstrated that it may often be necessary to make use of Allowable Solutions for supermarket buildings to achieve net zero carbon emissions.

This study found that there are a wide range of solutions to reducing the carbon dioxide emissions by up to 44% using onsite LZCs. The research could only identify 57 onsite routes to a 70% improvement over the current (2006) Part L, 18 solutions which achieve a 100% improvement and only two onsite solutions which achieve true zero carbon, i.e. 127% improvement over the current (2006) Part L.

Almost all of these onsite routes to the lower targets, i.e. 25%, 44% and 70% 'flat' regulated emissions reductions (see Section 7.2), are expected to be suitable for all supermarket sites. Carbon emissions reductions above 70% are only likely to be economically viable in areas where either large wind turbines can be erected, or where the local area/ community is suitable for a district heating scheme. This will not be the case for the majority of supermarket sites.

RECOMMENDATION

To achieve regulated carbon emission reduction targets greater than 70% (relative to Part L 2006) for new supermarkets where onsite wind turbines are not viable, designers should consider Allowable Solutions. This approach is likely to provide the most cost-effective routes to zero regulated and true zero carbon supermarkets.

7.10 THE IMPACT OF PART L 2010

Part L 2010 has an overarching objective of reducing total 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 ten 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 in new industrial buildings than in new hotels.

Under this 'aggregate' approach, the new 2010 notional buildings and the Target Emission Rates (TERs) are defined in terms of revised:

- **plant efficiencies**
- **U-values**
- **lighting**
- **glazed areas**
- **carbon dioxide emission factors.**

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 supermarket building have been manually implemented in the IES model used for the operational carbon assessments. Whereas these results should be considered as approximate, they do provide generic guidelines. The impact of these changes on the supermarket operational carbon emissions results, focussing particularly on the three packages of energy efficiency measures (see Section 7.3), is illustrated in Figure 11.

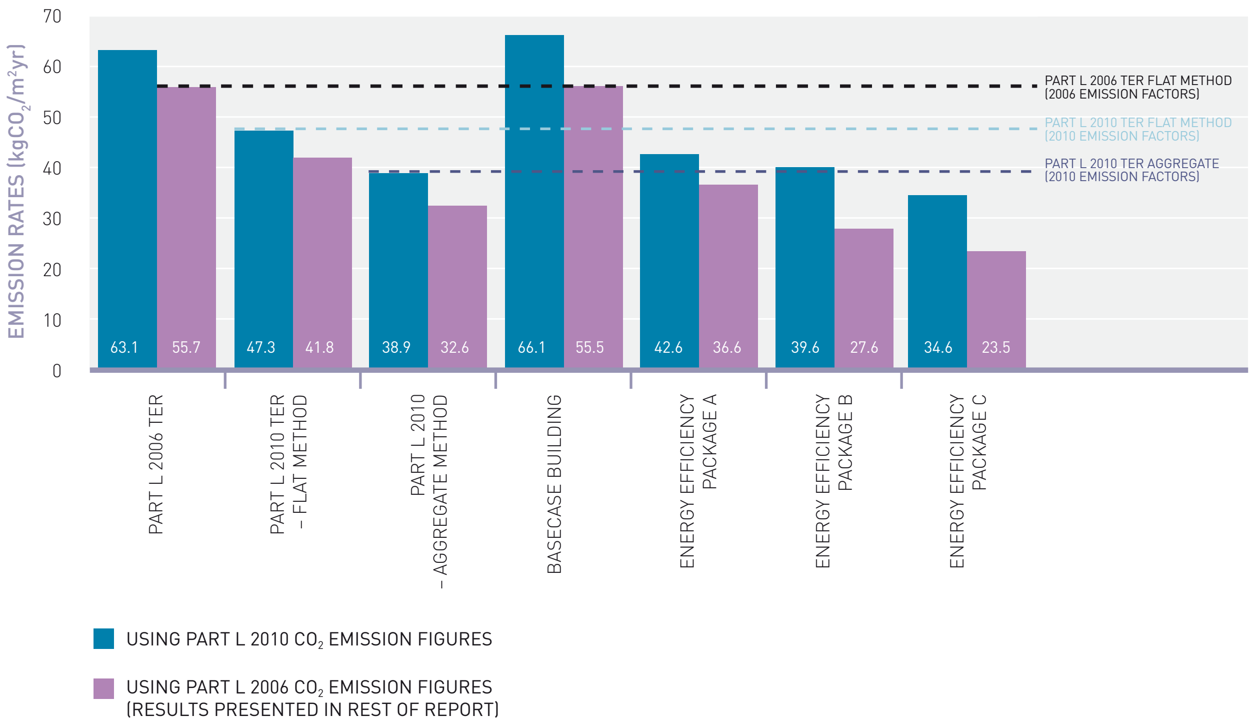
Using Part L 2006, the TER for the supermarket is 55.7kgCO_2/m²yr. The basecase building specification just meets this target, i.e. BER = 55.5kgCO_2/m²yr. Using the new Part L 2010 carbon emission factors, the 2006 TER increases to 63.1kgCO_2/m²yr and the BER of the basecase building increases to 66.1kgCO_2/m²yr.

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 41.8kgCO_2/m²yr. Using the 2010 emissions factors gives a TER of 47.3kgCO_2/m²yr. Applying the aggregate approach, the TER becomes 32.6kgCO_2/m²yr with 2006 emissions factors and 38.9kgCO_2/m²yr with 2010 emissions factors, i.e. more challenging than the flat 25% target.

Energy efficiency Package A was expected to pass Part L 2010 by 12% when assessed with the 2006 carbon emission factors. Applying the 2010 emissions factors, energy efficiency Package A passes by 10% using the flat method but fails the TER by 10% using the aggregate approach.

The assessment indicates that rather than the intended 11% reduction in operational carbon emissions for 2010 Part L compliance [3,5], the case study supermarket would need to reduce its CO_2 emissions by around 40%.

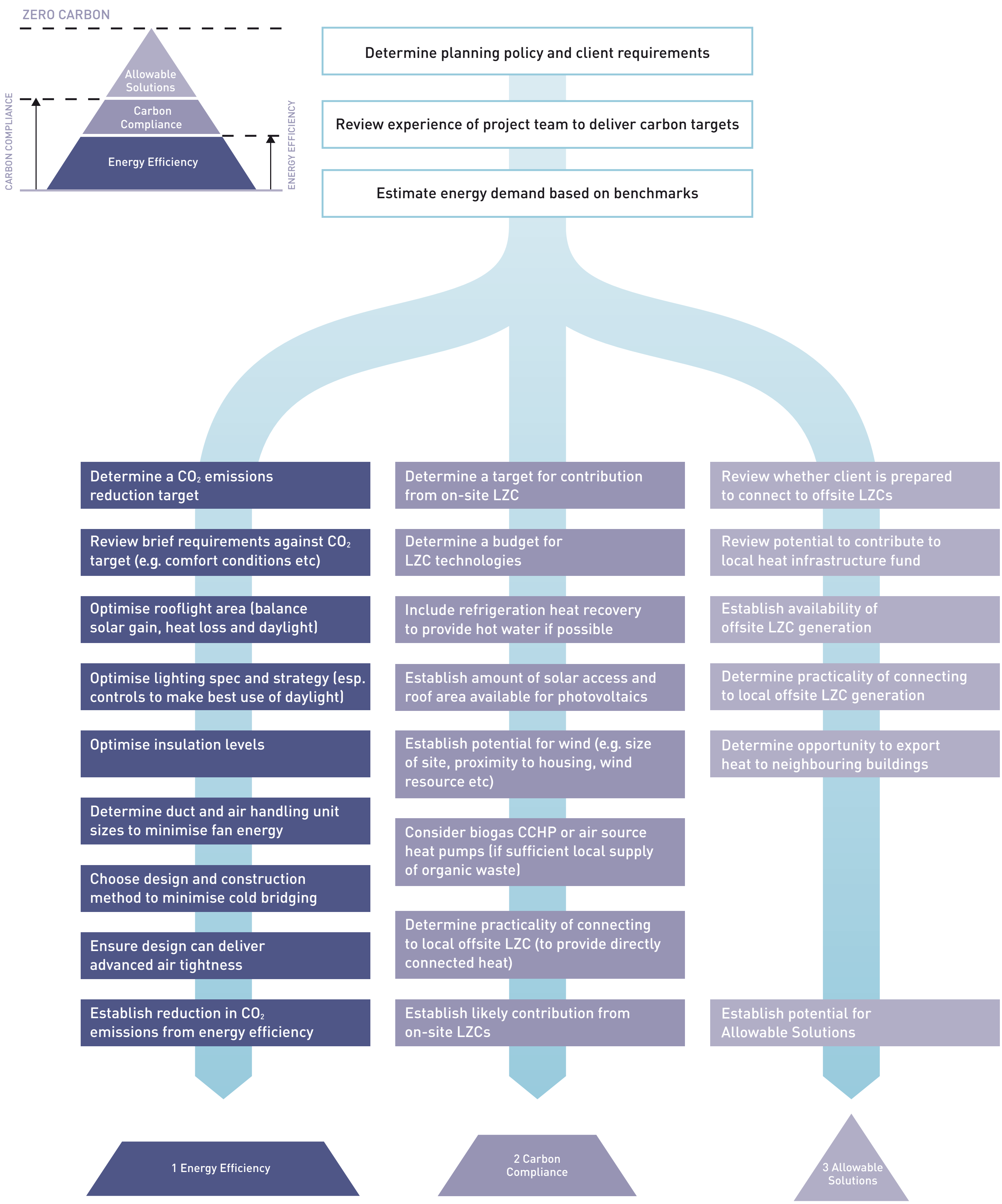
FIGURE 11
THE IMPACT OF CHANGES TO PART L 2010 ON THE SUPERMARKET BUILDING



7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

FIGURE 12

GUIDANCE FLOWCHART FOR DELIVERING LOW AND ZERO OPERATIONAL CARBON SUPERMARKET BUILDINGS



7.11 OPERATIONAL CARBON GUIDANCE

Figure 12 sets out a flowchart providing guidance on how to develop a cost-effective route to low or zero operational carbon buildings. Guidance on the steps presented in the flowchart are 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 onsite 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 a minimum proportion of a building's energy needs to be met using renewable energy.

Undertaking the relevant analyses and integration of design early enough 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 supermarket.

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

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

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.

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 basecase supermarket building, lighting is the dominant contributor and, as shown in Figure 4, improvements in lighting efficiency provide the greatest reductions in carbon dioxide emissions.

The likely occupancy pattern of the building should also be considered early on in the design process since this will affect the energy demand profile of the building. For example, a large supermarket operating 24 hours a day, will have a far higher lighting and heating demand than a supermarket with normal shop opening hours only. The National Calculation Method (NCM) applies a standard activity schedule to different building types and therefore cannot take into account different occupancy schedules. This is a limitation of the NCM.

RECOMMENDATION

The client brief for a low carbon supermarket 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

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 rooflight areas in warehouse buildings, see Section 7.5.

RECOMMENDATION

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

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 ability to introduce large wind turbines or 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 supermarkets 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

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.

Building form and fabric

Although all energy efficiency measures are important, lighting was found to be most important in delivering cost-effective carbon savings in the basecase supermarket. Lighting contributes almost half of the operational carbon dioxide emissions of the basecase building – see Figure 5. Optimising the lighting design in conjunction with the rooflight design can reduce operational energy use significantly without major capital cost implications and is predicted to yield very good payback periods for supermarkets.

This research has established that improved lighting efficiency can reduce carbon dioxide emissions by up to 27% and that careful rooflight design in combination with daylight dimming to control electrical lighting can reduce emissions by a further 10%.

The optimum rooflight solution depends on a number of variables, and therefore dynamic thermal simulation modelling should be carried out to identify the optimum area and configuration of rooflights for each individual supermarket. Where known, it is also recommended that the actual or likely hours of operation of the supermarket are taken into account when optimising the rooflight and lighting design. Although this will not affect the current Part L compliance assessment using the NCM, as discussed in Sections 7.3 and 7.5, good dynamic thermal simulation modelling should enable the natural and artificial lighting systems to be optimised and hence reduce actual operational carbon emissions. The effect of rooflight area on the overheating risk within supermarkets should also be investigated.

Although the basecase supermarket is mechanically cooled and was not designed to allow natural ventilation, the research investigated whether the supermarket could operate without mechanical cooling or ventilation. This was done using the IES dynamic thermal modelling package utilising the Macroflo module to simulate natural ventilation. Part L2A (2006) does not provide specific thresholds over which temperatures must not rise; rather it states that an assessment should be carried out and that the conditions within the building should be within limits specified by the client and the design team. The Chartered Institute of Building Service Engineers (CIBSE) recommend that a working environment should not exceed 28°C for more than 1% of occupied hours [8]. It is probable that most supermarket chains would require a more stringent threshold than this; however, in the absence of any firm definition, the CIBSE threshold has been used in this research.

FOOD DISPLAY UNITS – ASDA FOOD STORE, STOCKTON-ON-TEES

Different strategies to promote natural ventilation by increasing the area of existing openings were modelled. It was found that the risk of overheating could be significantly reduced through the use of high level openings with a free area equivalent to 1.35% of the floor area. However, the need for mechanical cooling could not be completely avoided in the case study building.

The glazing strategy of the building will have a significant impact on the risk of overheating, requirement for artificial lighting and energy for space heating. East and West facing glazing should be minimised with an emphasis on North and South facing glazing. Glazing with a sill height less than around 1m does not generally provide much useful daylight, but does increase the risk of overheating in summer and heating requirements in winter. South facing glazing should have an overhang above it to block high-angle sunlight in summer whilst allowing the useful low-angle sunlight into the building in winter. Finally, although the building layout has not been varied, consideration of reducing the plan depth to maximise daylight and the potential for natural ventilation as well as optimising the orientation should be investigated where possible. The following is a guide based on the analysis undertaken for this research:

- North facing rooms – have low solar heat gain without shading, rooms with cooling 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 (narrow plan cellular office etc.).
- 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 without 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, etc.

See also Section 7.12 on the impact of climate change

It should be noted that a number of the LZC technologies that were found to be most cost-effective will increase the plant space requirements over and above that assumed for the basecase and some will also require access for fuel delivery. Once technologies have been selected they should be integrated into the design at the earliest opportunity to reduce capital expenditure.

RECOMMENDATION

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

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

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 6 lists, in descending order of cost-effectiveness (i.e. 25-yrNPV/kgCO_2 £ saved), the ranking of energy efficiency packages and LZC technologies based on the assessment of the supermarket building. Although each supermarket 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 6

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

LZC TECHNOLOGY	ONSITE	OFFSITE	NOTES
Energy efficiency Package A			**See Table 1**
Onsite medium 330kW wind turbine	✓		**Enercon** 50m tower. 33.4m rotor diameter. May not be suitable on many sites
Fuel cell district CHP		✓	Space heating excluding radiant heating systems, hot water and electricity
Gas district CHP		✓	Space heating excluding radiant heating systems, hot water and electricity
Large 2.5MW wind turbine on-shore		✓	**Nordex** 100m tower height. 99.8m rotor diameter
Large 5.0MW wind turbine off-shore		✓	**Repower** 117m tower height. 126m rotor diameter (Largest commercially available)
Onsite medium 50kW wind turbine	✓		**Entegrity** 36.5m tower height. 15m rotor diameter. May not be suitable on all sites
Reverse cycle air source heat pump (ASHP)	✓		Providing all space heating and cooling
Biomass district CHP		✓	Space heating excluding radiant heating systems, hot water and electricity
Energy from waste district heating		✓	Space heating excluding radiant heating systems and hot water
Energy efficiency Package B			**See Table 1**
Single cycle air source heat pump (ASHP)	✓		Space heating excluding radiant heating systems
Waste process heat district heating		✓	Space heating and hot water excluding radiant heating systems
Refrigeration heat recovery large	✓		Recovering waste heat from space cooling, fridge and freezer cabinets to supply hot water
Biogas district CHP		✓	Space heating excluding radiant heating systems, hot water and electricity
Small 20kW wind turbine	✓		**Westwind** 30m tower height. 10m rotor diameter
Refrigeration heat recovery small	✓		Recovering waste heat from space cooling to supply hot water
Photovoltaics	✓		Roof-integrated amorphous PV 4,000m²
Gas CHP large	✓		Space heating excluding radiant heating systems, hot water and electricity
Energy efficiency Package C			**See Table 1**
Gas CHP small	✓		Space heating excluding radiant heating systems, hot water and electricity
Biogas CCHP large	✓		Space heating excluding radiant heating systems, hot water, cooling and electricity
Biomass CCHP large	✓		Space heating excluding radiant heating systems, hot water, cooling and electricity
Biomass boiler	✓		Space heating and hot water excluding radiant heating systems
Biomass CCHP small	✓		Space heating excluding radiant heating systems, hot water, cooling and electricity
Biomass CHP small	✓		Space heating excluding radiant heating systems, hot water and electricity
Biogas CCHP small	✓		Space heating excluding radiant heating systems, hot water, cooling and electricity
Solar water heating	✓		23.2m² sized to provide as much hot water as is practical
Biogas CHP large	✓		Space heating excluding radiant heating systems, hot water and electricity
Fuel cell CCHP small	✓		Space heating excluding radiant heating systems, hot water, cooling and electricity
Biogas CHP small	✓		Space heating excluding radiant heating systems, hot water and electricity
Small 1kW wind turbine	✓		**Futurenergy** 6.2m tower. 1.8m rotor diameter
Fuel cell CHP small	✓		Space heating excluding radiant heating systems, hot water and electricity
Single cycle open loop ground source heat pump	✓		Space heating excluding radiant heating systems
Reverse cycle open loop ground source heat pump	✓		Space heating and cooling excluding radiant heating systems
Gas CCHP small	✓		Space heating excluding radiant heating systems, hot water, cooling and electricity
Single cycle closed loop ground source heat pump	✓		Space heating excluding radiant heating systems
Reverse cycle closed loop ground source heat pump	✓		Space heating and cooling excluding radiant heating systems
Fuel cell CCHP large	✓		Space heating excluding radiant heating systems, hot water, cooling and electricity
Fuel cell CHP large	✓		Space heating excluding radiant heating systems, hot water and electricity
Ground duct small	✓		Supplying retail space
Ground duct large	✓		Supplying all air systems

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 onsite and supply, CHP systems, for example, may have a long lead in time.**

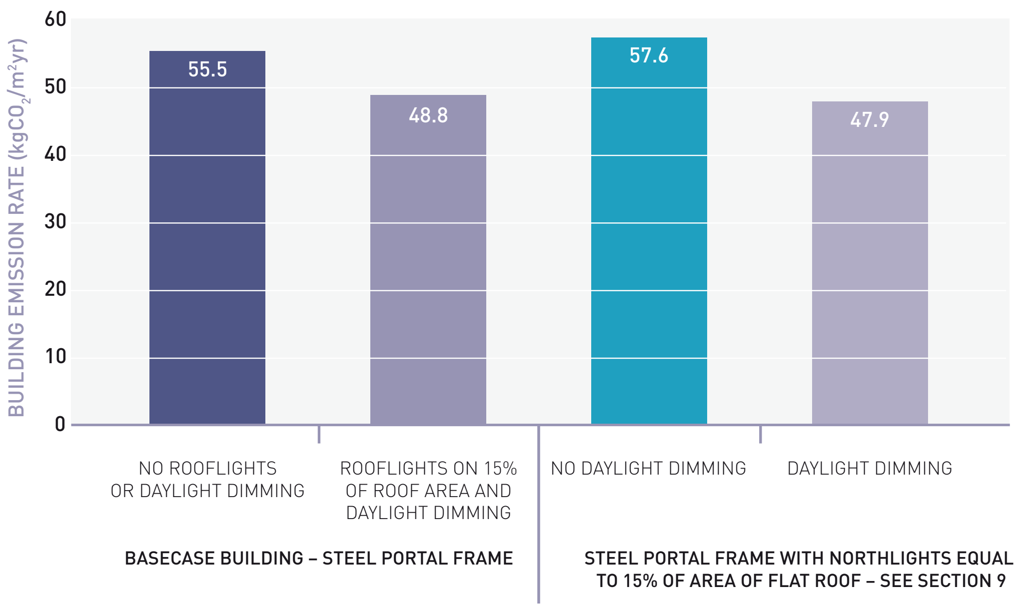
Plant room size will vary according to the LZC technologies that are to be used in the building. For example, biomass boilers will require additional storage space for wood chip fuel and for ash as well as access for fuel deliveries and waste collections. For buildings connected into district heating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

The influence of the structure on the operational carbon emissions of the supermarket building was found to be small, less than 4% - see Section 9.1.

Rooflights and northlights

Figure 13 compares the BERs of the basecase supermarket (with and without rooflights and daylight dimming lighting controls) with the equivalent BERs for the same building with a northlight roof.

FIGURE 13
IMPACT OF ROOFLIGHTS AND DAYLIGHT DIMMING ON BERS



The results show that, when the effect of daylight dimming is taken into account, the supermarket with northlights performs marginally better than the basecase. The key difference is that northlights achieve a lower cooling load, but incur a higher heating load. The net effect of this is a small overall benefit from the northlight option albeit at an increased capital cost – see Figure 10.

Some supermarket chains prefer not to use space cooling in their stores. In this case, the use of flat rooflights is likely to be more effective than northlights although the risk of overheating increases with flat rooflights.

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.

The location and hence climate of the supermarket site is also a factor in determining the relative sizes of the annual heating and cooling loads. High temperatures or clear skies are likely to favour northlights, whereas cooler temperatures or overcast skies will favour flat rooflights.

The choice of roof structure affects the surface area and volume of buildings. Buildings with a greater external envelope area will experience relatively more heat loss; this will increase the heating energy requirement in winter, but may also reduce the risk of overheating in summer.

The use of both rooflights and northlights increases heat loss from buildings and reduces the need for artificial lighting. Northlights also reduce the cooling load. In buildings where the cooling load is relatively large, northlights are likely to yield lower operational carbon dioxide emissions. See also Section 9.1.

Where the potential viability of rooflights and photovoltaics is jointly considered on a project, it should be remembered that rooflights reduce the roof area available for photovoltaics. It is therefore recommended that detailed studies, such as those performed under Target Zero, are undertaken to optimise these measures on a project specific basis.

ASDA STORE, BOOTLE

7.12 IMPACTS OF CLIMATE CHANGE

Modelling the effects of climate change on the supermarket, using CIBSE weather tapes based on UKCIP climate predictions for the UK[1], showed that the heating requirements of the supermarket will progressively reduce over time while the cooling requirements are predicted to increase. Analysis of the case study supermarket showed that heating loads are expected to decrease by 9% between 2005 and 2020 and by 26% between 2005 and 2050. Conversely cooling loads increase by between 9% and 11% between 2005 and 2020 and by between 32% and 38% from 2005 to 2050. These ranges are a function of the different supermarket structures modelled – see Section 9.

The effect on carbon dioxide emissions from these changes in heating/cooling demand is to increase total building emissions marginally (0.1% to 0.25%) by 2020 and by 0.7% to 1% between 2005 and 2050.

The choice of building structure makes little difference to the overall operational carbon emissions under the current and future weather scenarios considered. See Section 9.1.

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 supermarket could be reduced by a number of relatively simple measures including:

- **careful optimisation of the area of rooflights**
- **inclusion of high-level openings**
- **use of an efficient lighting system**
- **use of northlights rather than standard rooflights.**

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

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 Retail (2008) rating for the Asda food store in Stockton-on-Tees.

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

1. If there is a regulatory requirement for building design that is relevant, then this is used for the basecase, e.g. Building Regulations Part L provides a requirement for the operational energy performance of the building.
2. If it is typical practice for supermarkets, then this is used for the basecase, e.g. the average score under the Considerate Constructors scheme at the time of writing was 32, therefore, it was assumed that this is standard practice for contractors.
3. For design specific issues, such as materials choices, then the current specification for the supermarket is applied as the basecase.
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 for the office areas, then a cost for achieving the credit has not been included as this would require a 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 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, six 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 the approach to early design decisions: poor approach and best approach. These scenarios also include factors relating to the performance of the contractor on the project
- two scenarios related to the approach to zero operational carbon, with and without wind turbines being viable on the site.

The key inputs for these six scenarios and the basecase supermarket are set out in Table 7.

TABLE 13
KEY ASSUMPTIONS FOR THE SIX BREEAM ASSESSMENT SCENARIOS

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

*1 1= Natural ventilation opening >10m from opening; 2 = Air intake/extracts <10m apart

The basecase scenario was based on the actual location, site conditions, etc. of the Asda Stockton-on-Tees food store and is used as the basis for comparison with the above six scenarios.

Each BREEAM credit was reviewed to determine the additional work that would be required to take the building design beyond the basecase supermarket 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 basecase 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 supermarket projects. Credits were then assigned a 'weighted value' by dividing the capital cost of achieving the credit, by its credit weighting, 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.

8.1 BREEAM RESULTS AND GUIDANCE

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

FIGURE 14
BREEAM GUIDANCE FLOWCHART

THE TARGET RATING

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

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

RECOMMENDATION

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

MINIMUM STANDARDS FOR BREEAM RATINGS

The minimum standards required to achieve BREEAM 'Very Good', 'Excellent' and 'Outstanding' ratings are shown in Table 8.

TABLE 8
MINIMUM BREEAM REQUIREMENTS

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

The majority of these 'mandatory credits' are relatively simple and cost-effective to achieve, with the exception of the Ene 1 credits, which can be costly and difficult to achieve for the 'Outstanding' rating, as shown in Table 9. Most of the minimum requirements are considered to be typical practice and hence attract no additional capital cost.

TABLE 9
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	20,000
Man 2 Considerate Constructors	-	0	0
Man 4 Building user guide	-	3,750	3,750
Hea 4 High frequency lighting	0	0	0
Hea 12 Microbial contamination	0	0	0
Ene 1 Reduction in CO_2 emissions	-	118,850	980,973
Ene 2 Sub-metering of substantial energy uses	0	0	0
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	6,400
Wat 2 Water meter	0	0	0
Wst 3 Storage of recyclable waste	-	0	0
LE 4 Mitigating ecological impact	0	0	0

CREDITS ASSOCIATED WITH SITE FACTORS

The location of the building has the most impact on:

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

Figure 15 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 building. It shows the most cost-effective routes under the urban, greenfield and case study scenarios to achieve BREEAM 'Outstanding'. The case study results are coincident with the urban scenario for the Transport and Materials categories and coincident with the greenfield scenario for Land Use and Ecology.

FIGURE 15

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

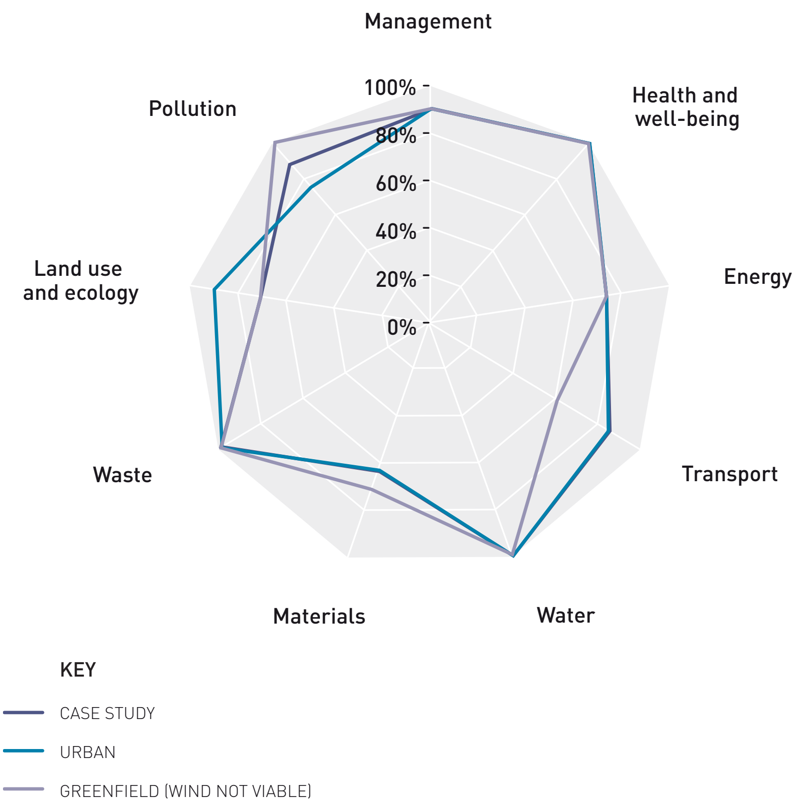


Figure 15 shows that under the greenfield scenario, Transport (Tra) and Land Use and Ecology (LE) credits are lost relative to the other scenarios, requiring credits to be obtained in other BREEAM sections. In this case, the most cost-effective credits are in the Pollution (Pol) and Materials (Mat) sections.

8.0 ROUTES TO BREEAM 'OUTSTANDING'

FIGURE 16
GREENFIELD SCENARIO, WITH AND WITHOUT WIND TURBINES BEING ACCOMODATED ON SITE

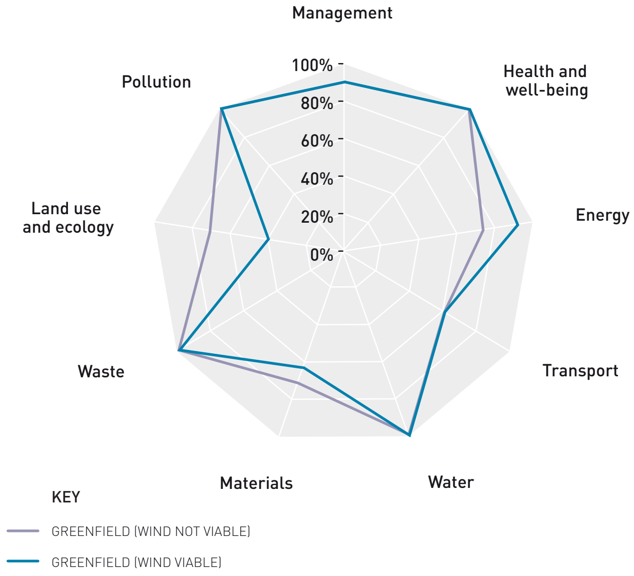


Figure 16 shows the change to the credit distribution of the greenfield scenario when wind energy is and is not viable onsite. Under the 'wind viable' scenario additional credits are achieved in the Energy section which means that some of the costly additional Materials and Land use and Ecology credits do not need to be targeted. On suitable out-of-town sites therefore developers may wish to consider the viability of a large wind turbine – see Section 7.7.

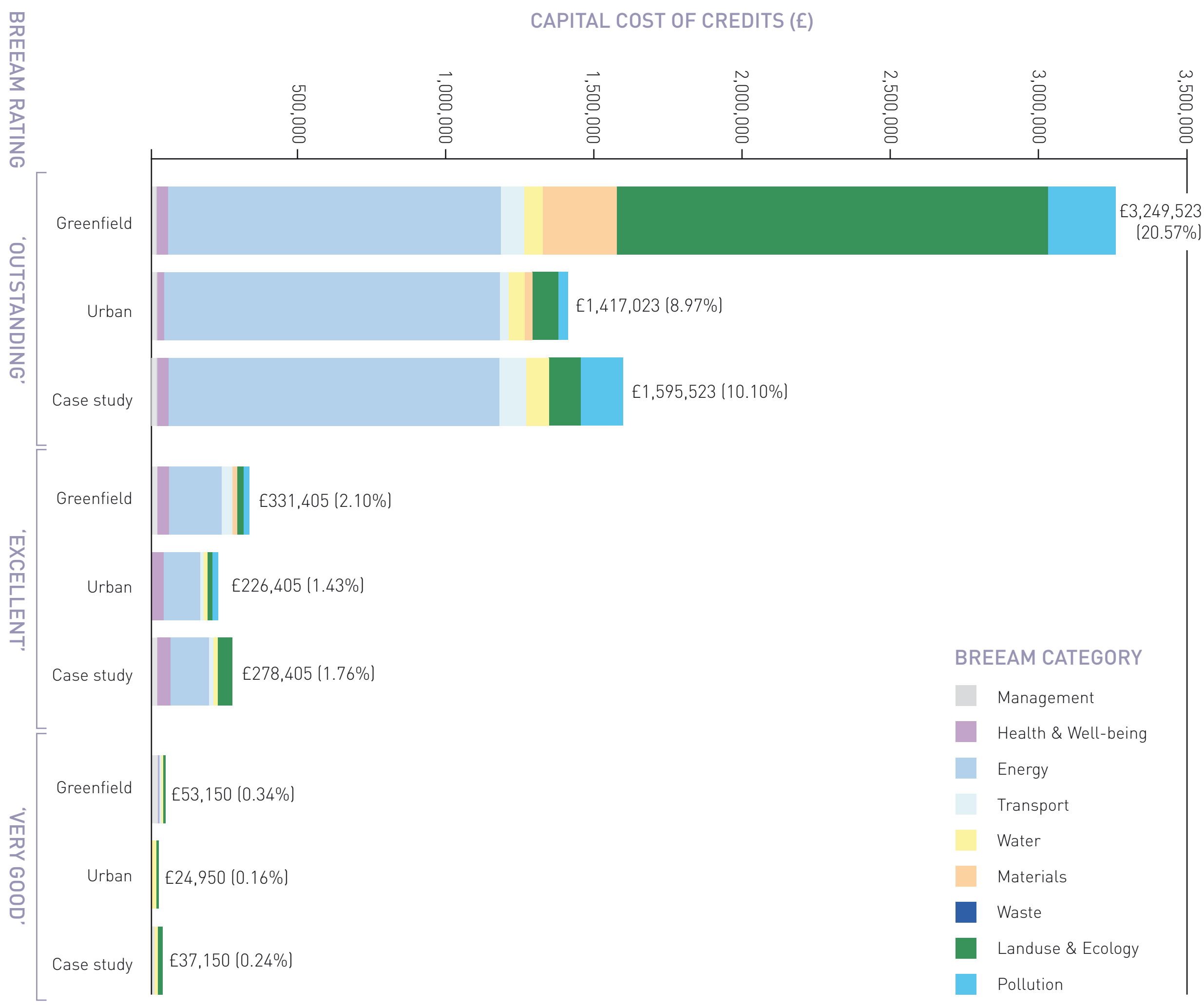
An 'urban' site is more likely to achieve the following credits:

- **LE 1 - Re-use of land**
- **LE 3 - Ecological value of site and protection of ecological features**
- **Tra 1 - Provision of public transport**
- **Tra 2 - Proximity to amenities.**

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

The total capital cost uplifts for the two location scenarios considered and the case study building are shown in Figure 17. The results for the case study building show that the capital cost uplift is 0.24% for 'Very Good', 1.76% for 'Excellent' and 10.10% for the 'Outstanding' rating.

FIGURE 17
COMPARISON OF COST UPLIFT FOR URBAN AND GREENFIELD SITE SCENARIOS



CREDITS ASSOCIATED WITH OPERATIONAL CARBON REDUCTION

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

If a 'zero carbon' target is set on a project, then there is the potential to achieve an 'Outstanding' rating relatively easily and cost-effectively. The Target Zero research explored the relationship between achieving a zero carbon target and BREEAM.

Figure 18 shows the capital and NPV cost of two potential routes to achieving a zero carbon target; one where wind technologies are viable and one where they are not. To achieve the necessary reduction in carbon dioxide emissions, packages of measures are required which are a combination of LZC technologies and energy efficiency measures.

These packages were devised on the basis that they achieve the maximum possible reduction in carbon emissions while acknowledging practical and economic constraints, for example, where photovoltaics are included, the total area of the array is limited by the available roof area.

RECOMMENDATION

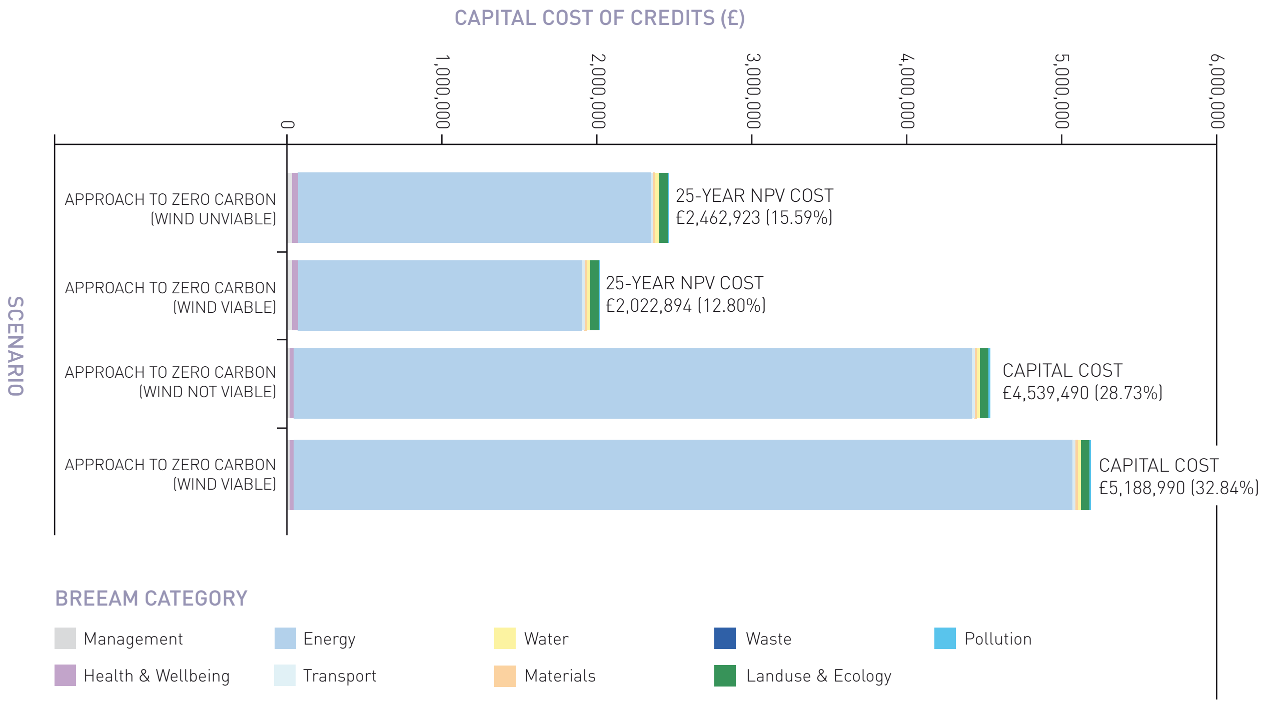
The project team should establish the number of site-related credits that can be achieved as early as possible in the design process. This will help to set the starting point for the optimum route to the targeted BREEAM rating.

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 18

CAPITAL COST UPLIFT AND NPVS OF ACHIEVING BREEAM 'OUTSTANDING' AND TARGETING ZERO CARBON



The bottom bar in Figure 18 represents the capital cost of the scenario where onsite wind technologies are viable (a 330kW turbine was assumed), the next bar up reflects a scenario in which onsite wind technologies are not viable either as a result of low wind availability or other issues such as spatial or planning constraints.

The top two bars represent the same two scenarios, but include 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 and the utility cost savings over a 25-year period.

It is only possible to achieve zero carbon under the scenario where onsite wind technology is viable. The predicted reduction in carbon emissions where wind is viable is 144% whereas the maximum possible reduction achievable where wind technologies are not viable on the site is 109%. The zero carbon target for this development is a 127% reduction in total carbon emissions. It is noted that the capital cost of the 'zero carbon' scenario where wind is not viable is less than where wind is viable however in terms of NPV, the package of measures including the onsite turbine provides the better return.

This graph focuses only on the 'Outstanding' rating as it is reasoned that if a zero carbon target was set for a supermarket 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 a 'zero carbon' (or very low carbon) target is set for a project, it should be relatively easy and cost-effective to also achieve a BREEAM 'Outstanding' rating.

CREDITS ASSOCIATED WITH THE EXPERIENCE OF THE DESIGN AND CONSTRUCTION TEAM

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

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

Contractors who have delivered BREEAM Post-Construction Reviews will have set up the required systems and processes to do this efficiently. This will help to achieve the Construction site Impact credits (monitoring energy, water and waste onsite) and the Responsible Sourcing credits, 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 10. It was assumed that an 'exemplar' contractor would be able to achieve all of these credits, which are all relatively low cost.

TABLE 10
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	2,000
	Second credit	5,000
	Third credit	9,000
	Fourth credit	0
Wst 1 Construction site Waste Management	First credit	0
	Second credit	0
	Third credit	0
	Fourth credit	0

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.

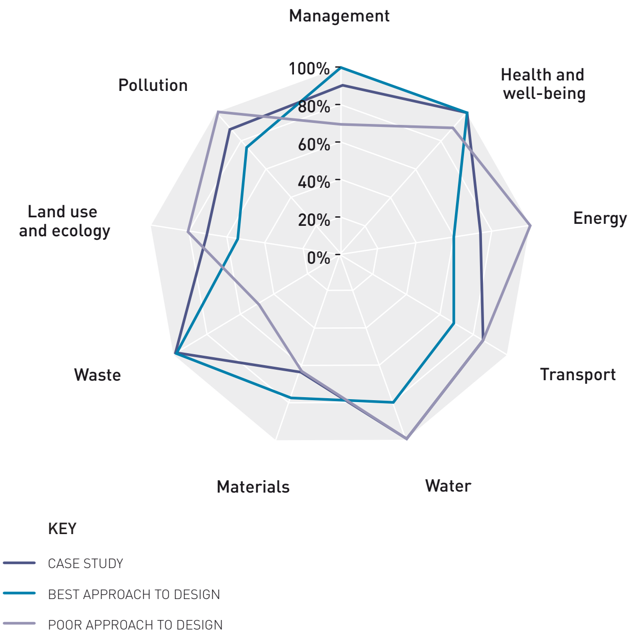
CREDITS ASSOCIATED WITH STRATEGIC DESIGN

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

- **Hea 14 Office Space: View out, in terms of depth of floor plate of the office areas**
- **Hea 14 Office Space: 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. Typically this is the office areas of the building**
- **Hea 8 Indoor air quality, in terms of avoiding air pollutants entering the building**
- **Hea 14 Office Space: 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 the balance of credits required to achieve a BREEAM 'Outstanding' rating most cost-effectively under the typical 'best' and 'poor' approaches to design assumed for the supermarket building.

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



It shows that a 'poor approach to design' implies that less credits are achievable in the Management, Health and Well-being, Materials and Waste sections and consequently that more credits have to be achieved in other sections: the Energy, 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.

For the case study building, the results show that to achieve an 'Excellent' rating there is a cost uplift of 4.58% if a 'poor' design approach is followed compared to 1.13% where 'best practice' approach is adopted. In terms of capital cost, this is a £546,400 saving. To achieve an 'Outstanding' rating there is a capital cost uplift of 36.13% if a 'poor' approach is adopted compared to 7.59% for a building on which a 'best practice' approach is followed. In terms of capital cost, this represents a substantial difference of £4,509,467.

8.0 ROUTES TO BREEAM 'OUTSTANDING'

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

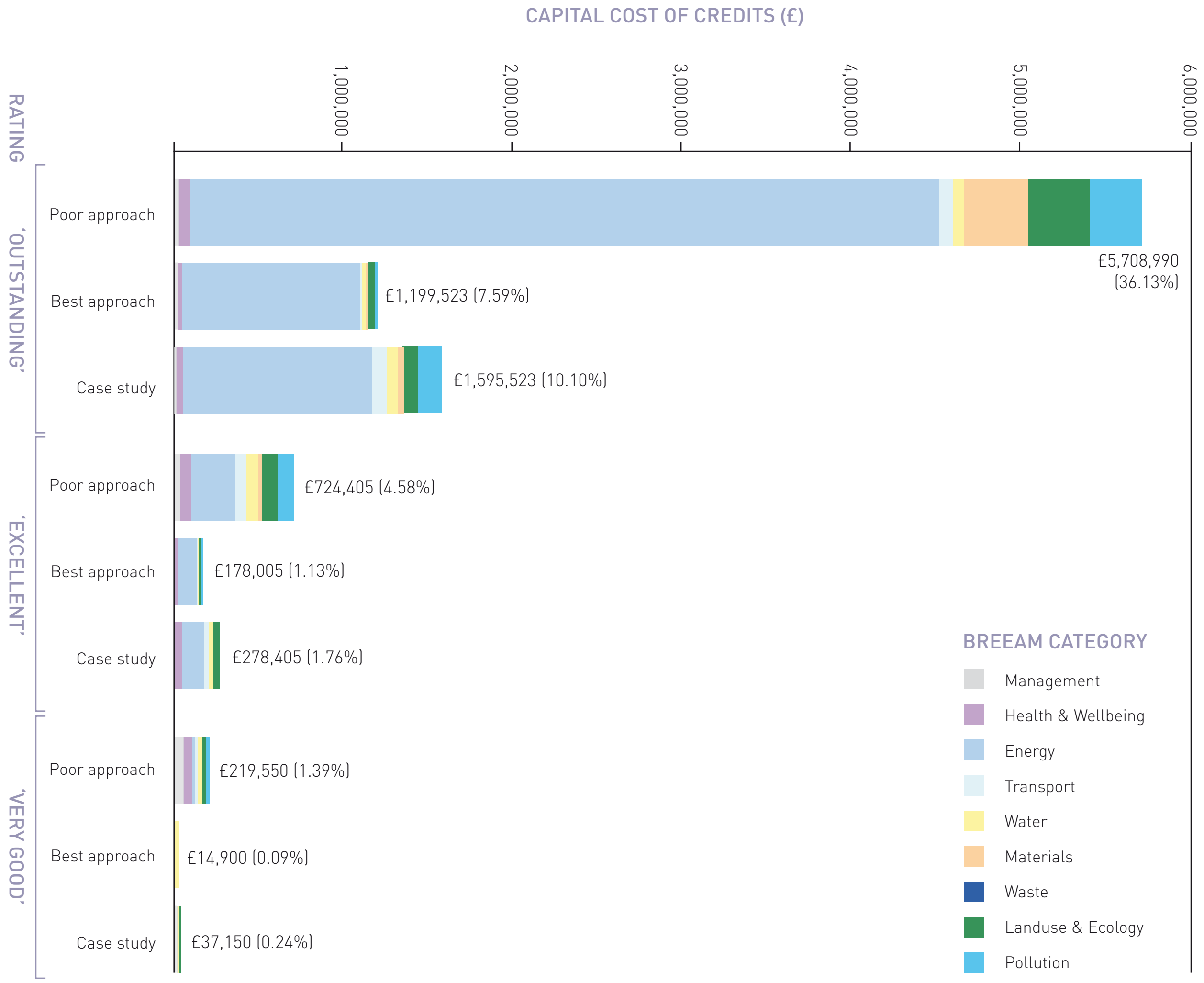


Table 11 shows the credits that relate to the form and fabric of the building. These should be considered at an early stage in the project so that they can be cost-effectively integrated into the design.

TABLE 11
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 plan retail areas, this needs to be considered when deciding the depth and orientation of the sales and common spaces to ensure at least 35% of the floor area meets the criteria.	3,000 (to undertake day lighting study)
Hea 14 Office Space - 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.	Costs included in Hea 1 above.
Hea 14 Office Space – 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 and orientation of the office wing.	0
Hea 14 Office Space – 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.	10,500
Ene 1 Reduction of CO_2 emissions	Fabric performance in terms of: air tightness (5 m³/h/m² at 50Pa); glazing performance (1.79W/m²/100 lux); area and position of rooflights.	Cost varies depending on energy package: £118,850 for Excellent and £980,973 for Outstanding for case study scenario.

To achieve the Hea credits in Table 11, a narrow floor plate in the office areas would have to be used to allow desks to be less than 7m from a window and to allow cross-flow ventilation. The approach to ventilation and cooling would have to be integrated with the structural and building services design.

The location and design of the office area of the building will have an impact on the above credits. Offices could be incorporated into the main building on the ground floor or as a mezzanine which could reduce the potential to achieve Hea 14 Office space: Daylighting, Hea 14 Office space: View out and Hea 14 Office space: Potential for natural ventilation.

The design of the rooflights is a key parameter in the energy and carbon performance for the supermarket. The impact of rooflight specification, area and configuration affects a number of variables including space heating requirements, space cooling requirements in summer and the energy requirement of lighting systems. In the case study building, lighting is the largest single source of regulated carbon dioxide emissions.

As the rooflight area is increased, the overall light intensity within the building will increase, however this will also increase the shadow effects in areas which are not directly lit. There may also be some areas, which are in direct sunlight and may be subject to glare. In general it is not always practical to design the rooflight positions around the internal layout. It must also be considered that the internal material use or layout of the building may change during the service life of the building.

Table 12 gives the credits that relate specifically to the space and layout of the building and its site.

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.

TABLE 12
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 4 Compactor baler	Space will need to be allocated for either an industrial waste compactor or baler to be installed for compacting/baling waste materials generated onsite and a water outlet is provided for cleaning.	0
Wst 5 Composting	Space will need to be allocated for a vessel onsite 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 full time equivalent staff and the equivalent of 1 rack per 20 car parking spaces for customers. There also needs to be showers, changing facilities and lockers along with drying space for staff use.	33,500 for the first credit. 7,500 for the second credit
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.	35,000
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.	0 (for both credits if land of low ecological value or for the first credit if land is of medium / high ecological value) 50,000 (for the second credit if land is of medium / high ecological value)
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.	60,000 (for the first two LE5 credits if land of low ecological value). 230,000 (for the first two LE5 credits if land of medium / high ecological value) For the third credit it would cost an additional 275,000 if land of low ecological value and 1,150,000 if land is of medium / high ecological value

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. Plant room sizes for offsite solutions that provide district heating could be considerably less if no backup plant is required for the building. Similarly, the use of onsite technologies such as ground source heat pumps can result in smaller plant rooms, if no backup or supplementary heating or cooling plant is required.

POTENTIAL COSTS OF BREEAM CREDITS

Figures 21 to 23 show the most cost-effective routes to achieve a BREEAM 'Very Good', 'Excellent' and 'Outstanding' respectively for the case study supermarket 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 site location. Credits are ranked in terms of their weighted cost (capital cost of the credit divided by the credit weighting).

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

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

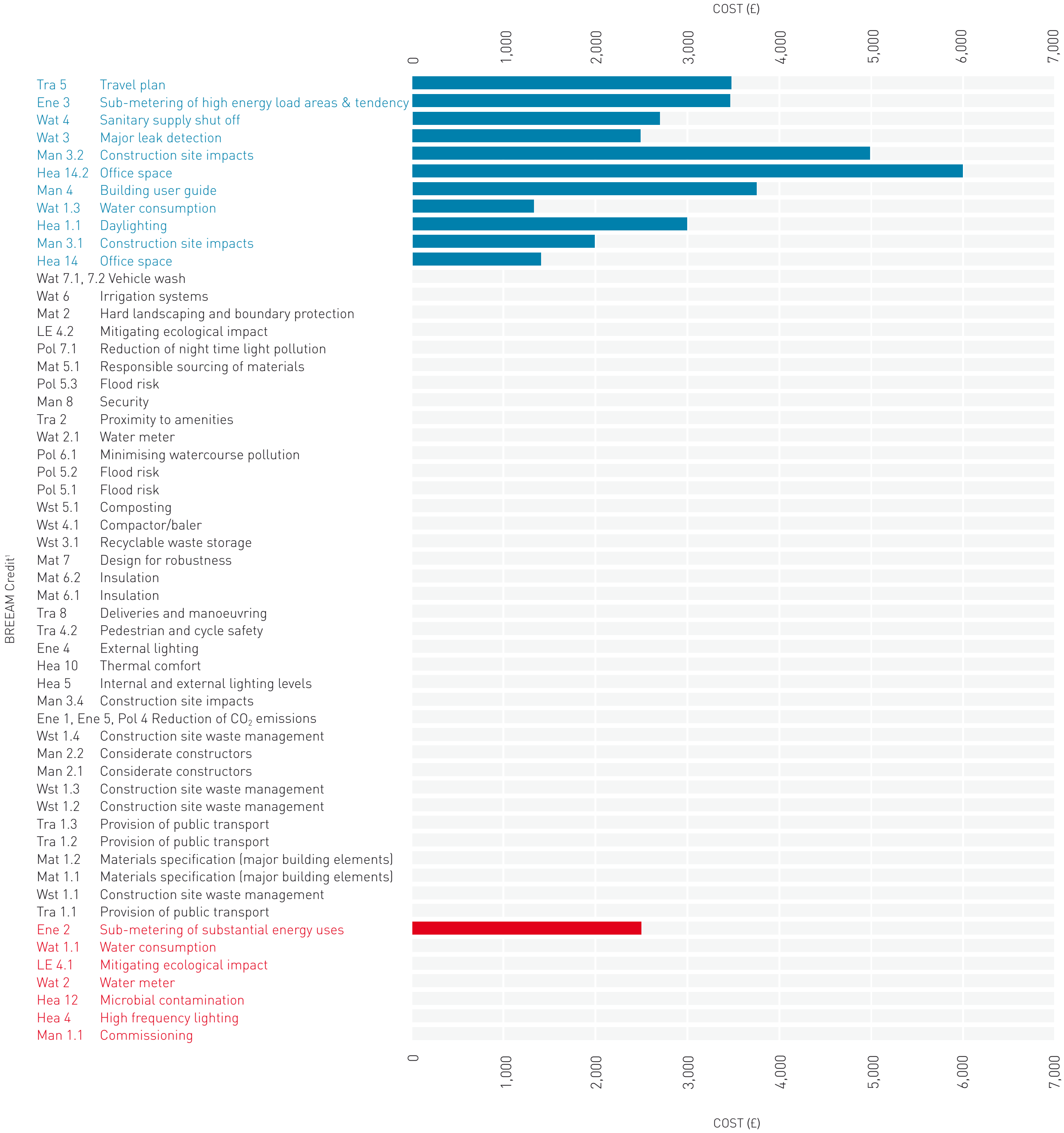
The graphs show that there are a number of credits that are considered zero cost for the case study supermarket building. These credits will be low or zero cost on similar supermarket buildings and can therefore be used as a guide to selecting the lowest cost credits on other projects. The graphs also 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.

FIGURE 21

LOWEST COST ROUTE TO BREEAM 'VERY GOOD' RATING

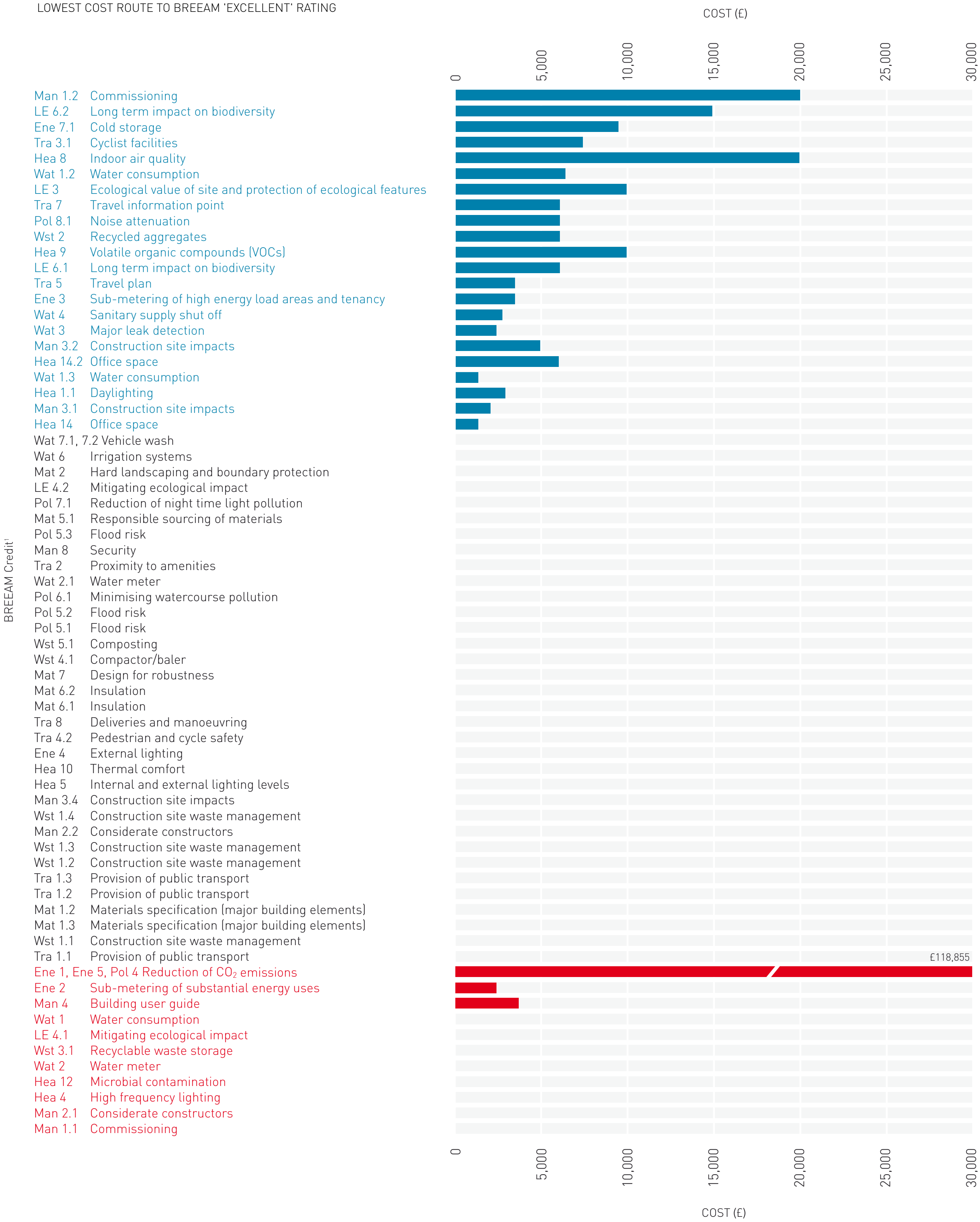


1 Ranking of credits is based on their weighted cost (capital cost of the credit divided by the credit weighting), whereas the values shown in the figures are the actual (non-weighted) cost of achieving the credit.

8.0 ROUTES TO BREEAM 'OUTSTANDING'

FIGURE 22

LOWEST COST ROUTE TO BREEAM 'EXCELLENT' RATING

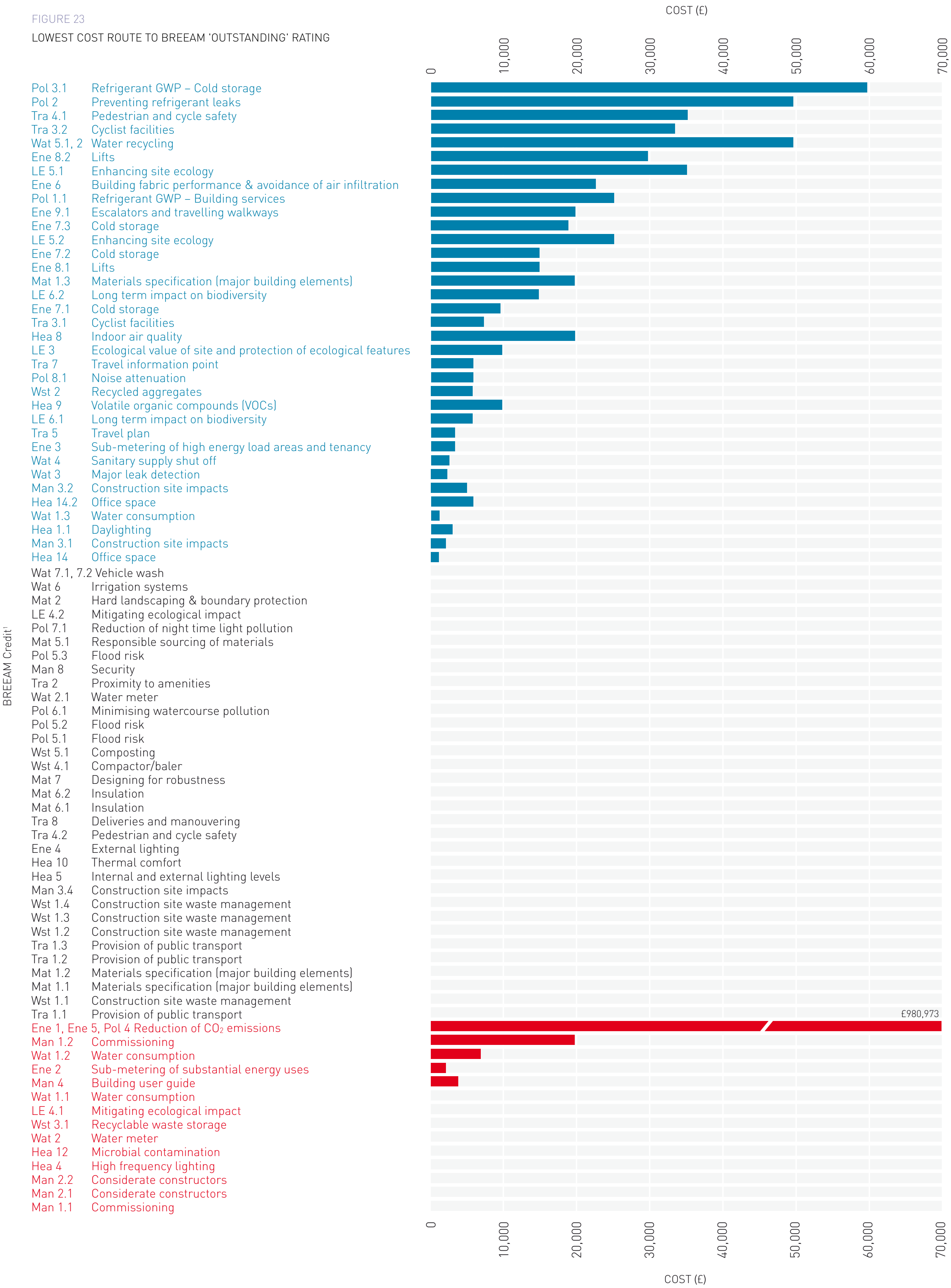


1 Ranking of credits is based on their weighted cost (capital cost of the credit divided by the credit weighting), whereas the values shown in the figures are the actual (non-weighted) cost of achieving the credit.

8.0 ROUTES TO BREEAM 'OUTSTANDING'

FIGURE 23

LOWEST COST ROUTE TO BREEAM 'OUTSTANDING' RATING



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

EXEMPLAR PERFORMANCE AND INNOVATION CREDITS

There are two types of innovation credits within BREEAM:

- **those that represent 'exemplary performance', such as increasing the area achieving a daylight factor of 2% from 35% to 50% of the retail area**
- **credits that provide additional recognition for a building that innovates in the field of sustainable performance, above and beyond the level that is currently recognised and rewarded by standard BREEAM credits.**

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 weighted value (the capital cost divided by the credit weighting) of the credit next to the 'Excellent' threshold is £16,666, so an innovation measure that is cheaper than this would achieve the 'Excellent' rating at a lower cost. Similarly, for the 'Outstanding' rating, the weighted value of the credit next to the threshold is £78,000.

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

The research showed that there is an inherent weighting within the tool used to calculate the score under credit Mat 1 in the materials section of BREEAM. This inherent weighting is used in addition to weighting each element by area. The inherent weightings are shown in Table 13.

TABLE 13
ELEMENT WEIGHTINGS WITHIN THE BREEAM MATERIALS ASSESSMENT TOOL

ELEMENT	EXTERNAL WALLS	WINDOWS	ROOF	UPPER FLOORS
Weighting	1.00	0.30	0.85	0.28

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

- **the external walls achieve an A rating in the Green Guide to Specification [9] using steel composite profiled panels, with an opportunity to achieve an A+ rating by using cedar boarding**
- **the aluminium curtain walling only achieves a Green Guide D rating and requires a different glazing solution to achieve higher ratings, e.g. uPVC windows or timber, which is likely to be considered impractical on this type of building**
- **the aluminium standing seam roof construction achieves an A rating. This could be raised to an A+ rating by substituting the outer skin of the roof build-up with coated steel sheet**
- **the upper floor slab achieves an A (back-of-house) or A+ (mezzanine retail floor) rating for the case study building.**

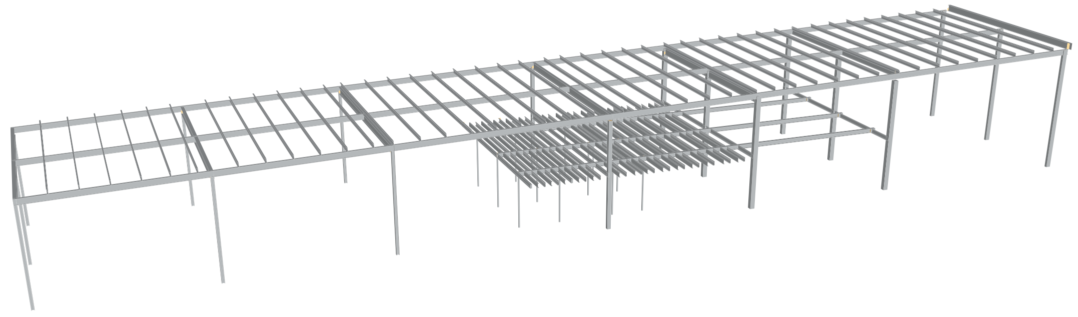
For the case study building, the first two (of four) Mat 1 credits were achieved by using the basecase building specification. To achieve the third credit the windows would need to be upgraded for example, using timber to achieve an A+ rating. This is estimated to incur an increased capital cost of £20,000. The fourth Mat 1 credit can be easily achieved by substituting the aluminium standing seam roof with a steel-based construction.

For the case study building, the full four Mat 1 credits can be achieved by selecting A+ materials for the external walls and the roof with all the other elements achieving only an E rating.

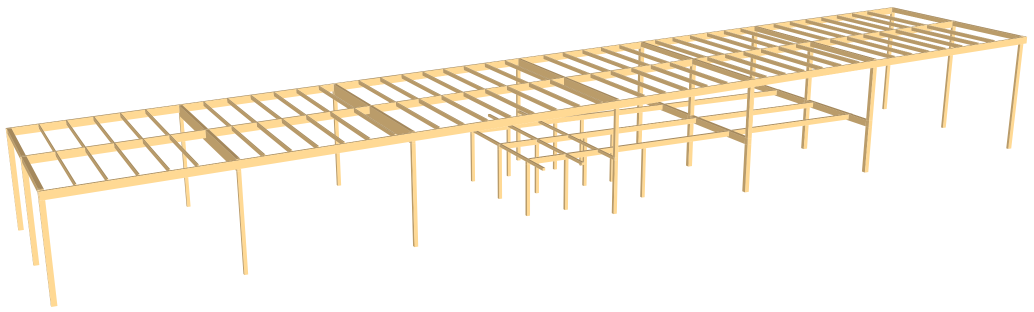
STRUCTURAL DESIGN

Three alternatives for the supermarket building were assessed as shown in Figure 24. The figure shows typical structural sections through the building.

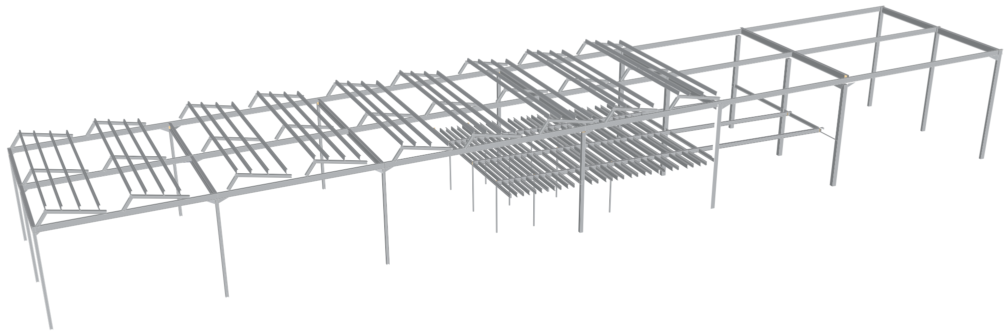
FIGURE 24
ALTERNATIVE STRUCTURAL OPTIONS



BASECASE: STEEL PORTAL FRAME



OPTION 1: GLUE-LAMINATED TIMBER RAFTERS AND COLUMNS



OPTION 2: STEEL PORTAL FRAME WITH NORTHLIGHTS

Full building cost plans for each structural option were produced using mean values, current at 4Q 2009. These costs are summarised in Table 14.

TABLE 14
COMPARATIVE COSTS OF ALTERNATIVE STRUCTURAL DESIGNS

STRUCTURAL OPTION	DESCRIPTION	STRUCTURE UNIT COST[1] (£/m² of GIFA)	TOTAL BUILDING COST (£)	TOTAL BUILDING UNIT COST (£/m² of GIFA)	DIFFERENCE RELATIVE TO BASECASE BUILDING (%)
Basecase building	Braced steel frame Suspended concrete floor slab CFA piles Upper floor concrete slab on metal deck Mezzanine: light gauge steel supporting timber decking	107	16,400,000	1,746	-
Option 1	Glulam frame Suspended concrete floor slab CFA piles Upper floor concrete slab on metal deck Mezzanine: Glulam beams supporting timber decking	141	16,800,000	1,789	+2.4
Option 2	Braced steel frame Suspended concrete floor slab Steel H- piles Upper floor concrete slab on metal deck Mezzanine: light gauge steel supporting timber decking Northlight roof profile in retail area	117	16,300,000	1,735	-3.0

[1] Frame and upper floors

With reference to external published cost analyses, such as the RICS Building Cost Information Service (BCIS), the typical benchmark cost range for steel-framed supermarkets within the range of 7,000m² to 15,000m² gross internal floor area (GIFA) is of the order of £400/m² to £700/m² for the shell building, with a further cost of £800/m² to £1,200/m² for fitting out; giving a notional cost range for the complete building of between £1,200/m² to £1,900/m². The basecase building cost model is positioned in the upper half of this range.

The cost of site works, car parking, landscaping, services, lighting etc., is clearly project specific. As a broad rule of thumb for large retail supermarkets, however, a budget allowance in the order of 15% to 20% of the total construction cost is typical, and the cost plan reflects this, with the estimate of £3.0m equating to 18% of the total cost.

CAFETERIA - ASDA STORE, BOOTLE

9.1 IMPACT OF STRUCTURE ON OPERATIONAL CARBON EMISSIONS

Dynamic thermal modelling of the supermarket building showed little variation in operational carbon emissions; the Building Emission Rate (BER) varying by only 2.1kgCO_2/m²yr, or 3.8%, between the three structural alternatives considered. The predicted annual CO_2 emissions for each of the three buildings are shown in Table 15. The small predicted difference between the basecase building and Option 1 is a function of the supermarket volume. Although both buildings were designed with the same internal clear height, the depth and pitch of the glulam rafters in Option 1 increased the height of the building slightly increasing the space heating requirement marginally.

Option 2 is a fundamentally different design from the basecase building. The inclusion of northlights allows diffused light to enter the middle of the supermarket while reducing the amount of direct solar radiation; this improves the consistency and uniformity of the light and reduces the risk of overheating. A secondary effect is to increase the surface-to-volume ratio of the supermarket which also reduces the risk of overheating but requires more space heating. The net effect of this approach is to increase the Building Emission Rate (BER) by 2.1kgCO_2/m²yr i.e. 3.8% relative to the basecase.

TABLE 15
BUILDING EMISSION RATE (BER) FOR THE BASECASE BUILDING AND OPTIONS 1 AND 2

BUILDING	DESCRIPTION	BER (kgCO_2/m² yr)
Basecase	Steel portal frame	55.5
Option 1	Glulam rafters and columns	55.7
Option 2	Braced steel portal frame with northlights	57.6

9.0 STRUCTURAL DESIGN

Figure 25 shows the variation in energy demand between the basecase supermarket and the alternative structural options. Note that the energy required for lighting in Option 2 is the same as for Option 1 and the basecase since daylight dimming lighting controls were not included in these models. Had daylight dimming lighting controls been included, the northlight solution may have yielded a lower BER than the basecase building. See Figures 13 and 26.

Another benefit of northlights is that they are orientated to avoid high solar gains and therefore they are ideal for buildings where temperatures must be kept low and/or mechanical cooling is included. Furthermore the south-facing side of northlights provides an ideal series of façades on which photovoltaic panels can be installed. In the UK, the optimum orientation for solar panels is south-facing with an elevation of around 30°- 35° above the horizontal. This elevation can increase the annual output of solar panels by around 10% compared to horizontally-mounted panels.

FIGURE 25

VARIATION IN OPERATIONAL ENERGY DEMAND

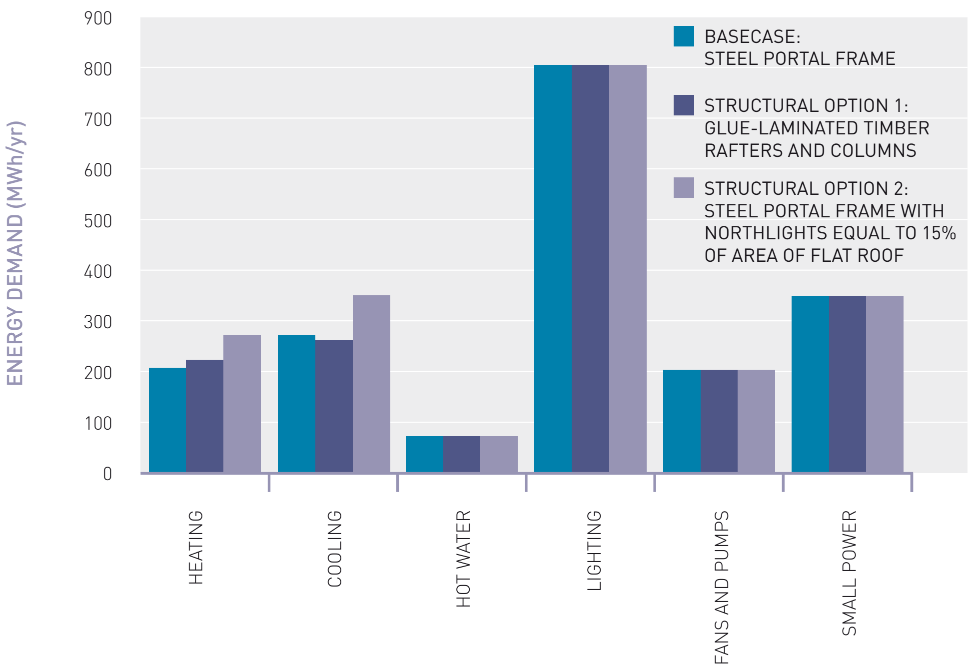
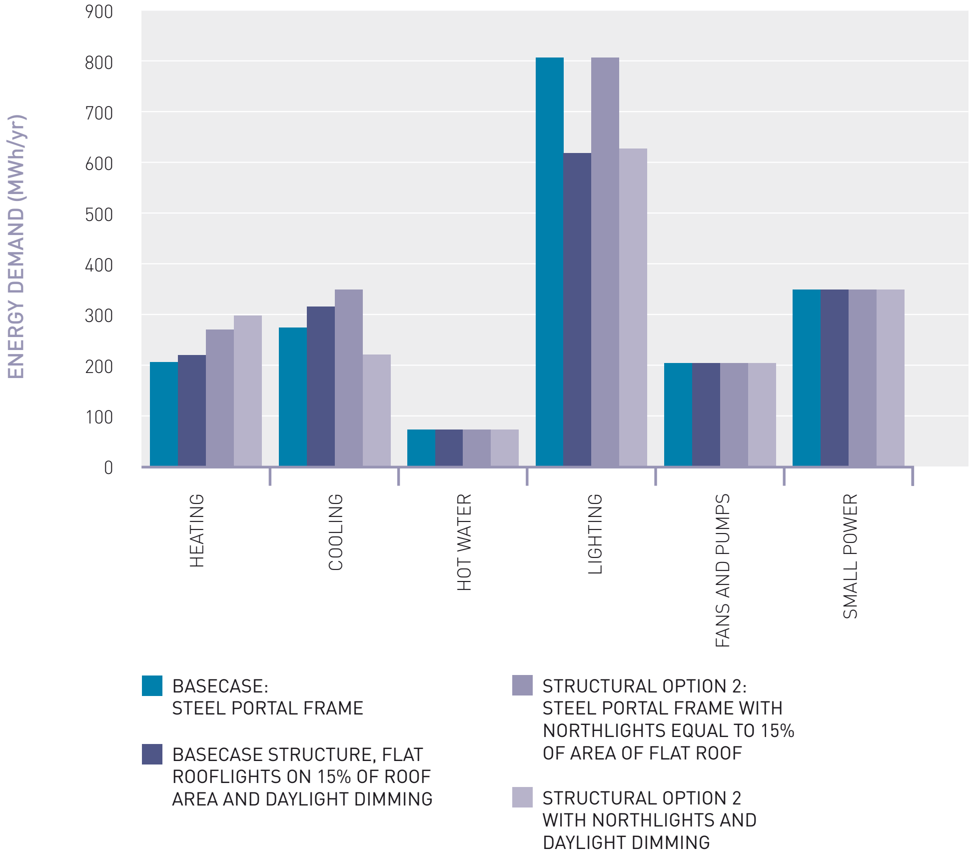


Figure 26 illustrates the effects of introducing rooflights and daylight dimming into the basecase and Option 2 building models. It shows that the use of northlights rather than flat rooflights (both combined with daylight dimming) increases the demand for lighting by 1% and heating by 35%. However the supermarket with northlights avoids peak solar gains in summer and as a consequence, the cooling load is predicted to reduce by 29%. This explains the marginal operational carbon benefit of the northlight solution as shown in Figure 13.

FIGURE 26

IMPACT OF ROOFLIGHTS AND DAYLIGHT DIMMING ON OPERATIONAL ENERGY DEMAND



9.2 FOUNDATION DESIGN

To explore the influence of the substructure on the cost and embodied carbon of the Asda Stockton-on-Tees food store, the foundations for the alternative building options were redesigned. The basecase supermarket has CFA concrete piled foundations. The weight of the superstructure in building Option 1 was 14% greater than the basecase supermarket however this extra load did not require additional foundations and therefore the same foundation design was used for Option 1. 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
Basecase	CFA concrete piles (1,144 Nr 13m x 380mm nominal diameter)
Option 1	CFA concrete piles (1,144 Nr 13m x 380mm nominal diameter)
Option 2	Steel H-piles (641 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. The foundation costs include the pile caps and ground beams. Notional allowances have been made for the piling mat, contamination, site obstructions etc.

TABLE 17
BREAKDOWN BY COST OF THE DIFFERENT FOUNDATION SOLUTIONS

	BASECASE AND OPTION 1 CFA PILES		OPTION 2 H-PILES	
	COST (£)	COST (£/m² GROUND SLAB)	COST (£)	COST (£/m² GROUND SLAB)
Bulk excavation, disposal and backfill; including piling mat	341,120	51	378,300	57
Piling	685,460	103	366,890	55
Pile caps and ground beams	204,740	31	168,430	25
Ground floor slab	461,830	70	537,820	81
Total	**1,693,150**	**255**	**1,451,440**	**218**

The reduced number of piles and pile caps in the H-pile solution leads to a significant cost saving of 40% for the piling, pile caps and ground beams compared to the CFA option. This saving is partially offset by the thicker slab and associated excavation works required in the H-pile solution. Overall the total sub-structure cost of the H-pile solution is estimated to be 14% less than for the basecase (and Option 1) CFA solution.

The embodied carbon of the different substructure options were assessed using the CLEAR model (see Section 10 and Appendix E). Table 18 summarises the amounts of materials used for the piles, pile caps, ground 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	NUMBER OF PILE CAPS	CONCRETE GROUND/EDGE BEAMS (m)	GROUND FLOOR SLAB VOLUME (m^3)	MASS OF MATERIALS (tonnes)	EMBODIED CARBON (tCO_2e)
Basecase and Option 1	1,144 CFA concrete piles	193	800	1,417	16,795	1,750
Option 2	641 steel H-piles	128	800	2,059	14,554	1,869

The embodied carbon of the piles, pile caps, ground beams and ground floor slab represents between 48% and 50% of the total embodied carbon footprint of the supermarket (3,528 to 3,706 tCO_2e). The basecase and Option 1 buildings have the heavier substructure and the lowest embodied carbon footprint. Relative to the H-pile solution (Option 2), the basecase and Option 1 substructure is 15% heavier and has a 6% smaller 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.

MEZZANINE LEVEL – ASDA FOOD STORE, STOCKTON-ON-TEES

10.0 EMBODIED CARBON

EMBODIED CARBON

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

The term 'embodied carbon' refers to the life-cycle 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 recovery or disposal of the building materials at the end-of-life.**

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

The embodied and operational carbon emissions from the building together make up the complete life-cycle 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 F.

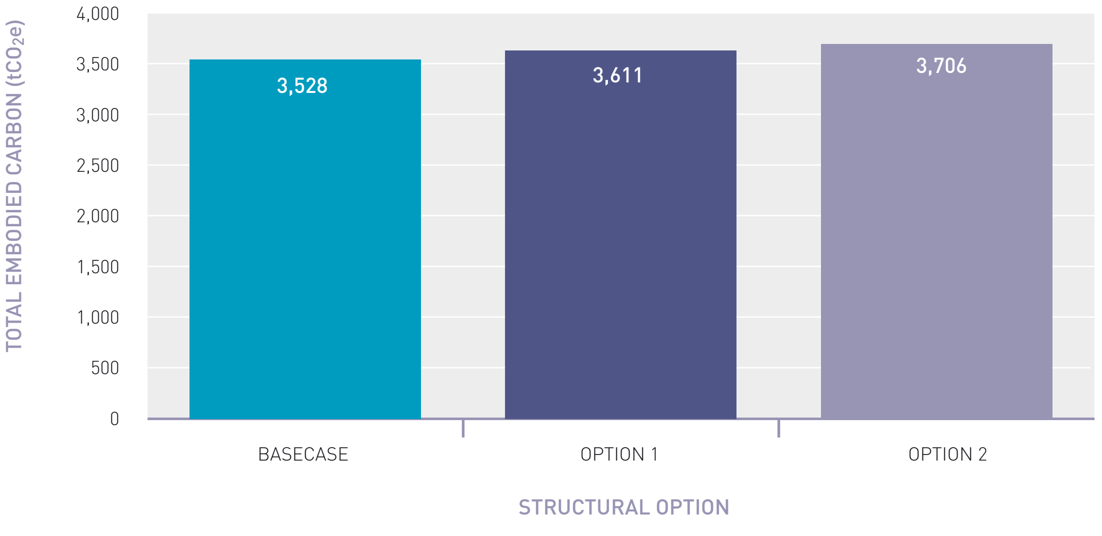
The CLEAR model has successfully undergone a third party critical review to the relevant ISO standards on Life Cycle Assessment by Ove Arup & Partners Ltd. This review concluded that the CLEAR methodology and its representation in the GaBi software has been undertaken in accordance with the requirements of ISO 14040 (2006) and ISO 14044 (2006). Furthermore Ove Arup are also confident that the data quality rules used to select the material life-cycle 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 façade, glazing and drainage and therefore the embodied carbon of these elements was identical. 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 27 shows the total embodied carbon impact of the basecase supermarket building and the two alternative structural options studied. Relative to the basecase, the glulam structure (Option 1) has a 2.4% higher embodied carbon impact and the steel frame with northlights (Option 2) has a 5% higher impact.

Normalising the data to the total floor area of the building, gives the following embodied carbon emissions of 376, 384 and 395 $kgCO_2e/m^2$ for the basecase and structural Options 1 and 2 respectively.

FIGURE 27
TOTAL EMBODIED CARBON EMISSIONS OF THE BASECASE BUILDING AND STRUCTURAL OPTIONS 1 AND 2



10.0 EMBODIED CARBON

Figures 28 and 29 show the mass of materials used to construct each of the three supermarket buildings, broken down by element and material respectively. The total mass of materials used to construct the supermarket was estimated to vary between 24.4kt (Option 2) and 26.6kt (Option 1).

The figures show that most of the materials (60% to 63%) are used in the foundations and floor slab, comprising mainly concrete and fill materials. The external site works and drainage also take significant quantities of materials, dominated by concrete, fill and tarmac. A relatively small proportion (1.5%) of the total building materials is used in the bearing structure.

FIGURE 28

MASS OF MATERIALS - BREAKDOWN BY ELEMENT

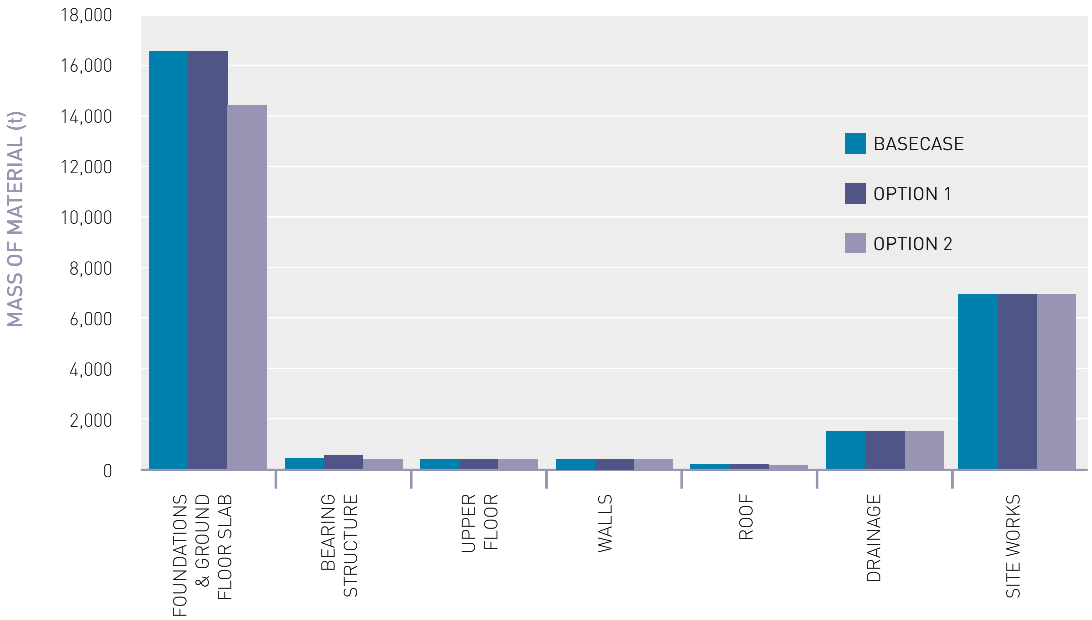
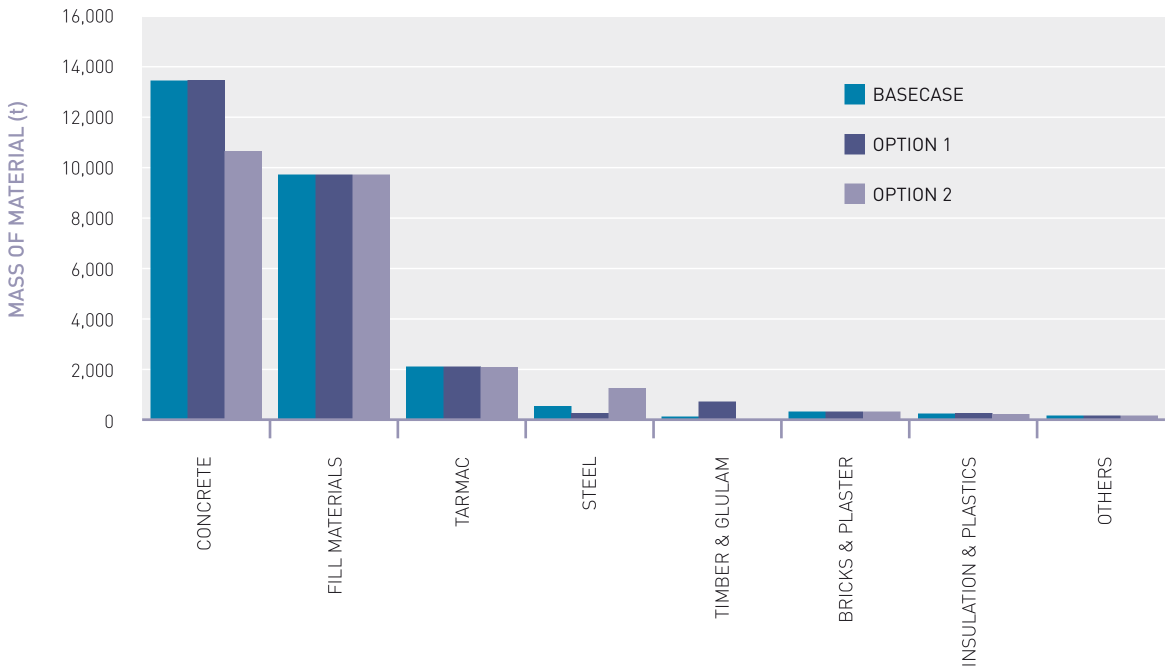


FIGURE 29

MASS OF MATERIALS - BREAKDOWN BY MATERIAL



10.0 EMBODIED CARBON

Option 1 is the heaviest of the three building options due to the use of a glulam structure. The basecase and Option 2 have lighter superstructures due to the use of structural steel frames however the increase in the height of the eaves for the use of northlights in Option 2 results in an increase of the use of steel for this structural option compared to the basecase. Option 2 also has steel H-piles instead of concrete CFA piles.

Figures 30 and 31 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 foundations and floor slab. Even though on a per tonne basis concrete is relatively low in embodied carbon, the amount of concrete used in the building makes its contribution significant**
- **the impact of substituting the steel frame in the basecase with glulam (Option 1) is evident in both figures. This is mainly due to the release of methane emissions resulting from the current common practice of landfilling timber demolition waste**
- **the reduced concrete embodied impact in Option 2 is due to the substitution of the CFA piles with fewer steel H-piles**
- **despite its large volume, the embodied carbon contribution from fill materials is small**
- **the results for the basecase and Option 2 are quite similar although Option 2 has more structural steelwork and more cladding because of its northlight roof construction**
- **the walls, drainage and external site works impacts are identical for each alternative**
- **there is little variation in the transport impact between the three alternatives. The impact being around 9% of the total**
- **although based on less robust data, the estimate of embodied carbon from onsite construction activity is relatively small at around 0.7% of the total impact.**

FIGURE 30

BREAKDOWN OF EMBODIED CARBON BY MATERIAL

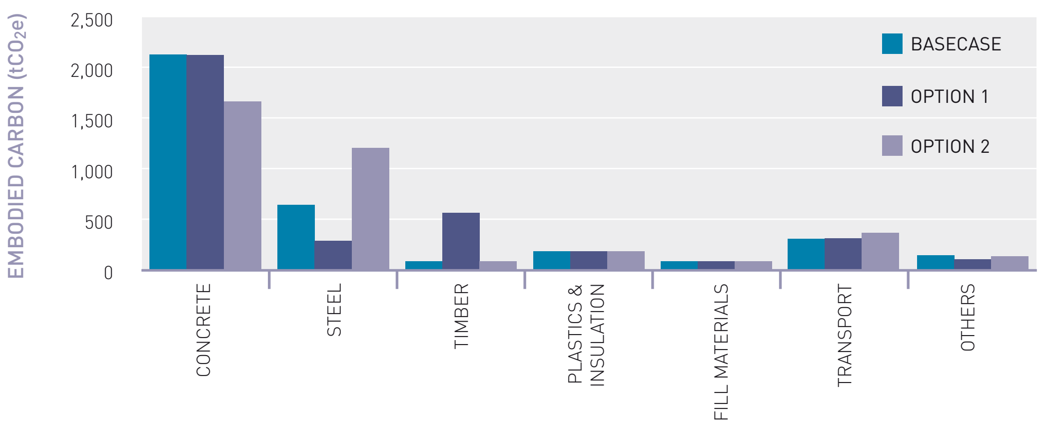
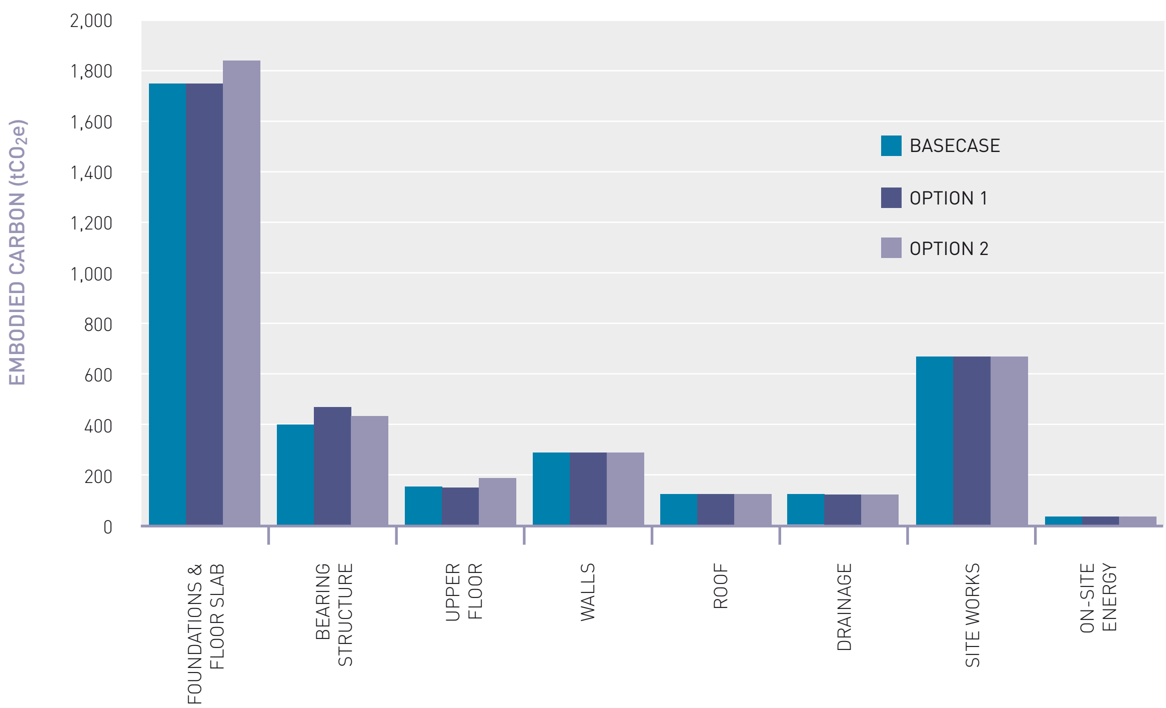


FIGURE 31

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 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 life-cycle 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 life-cycle impacts[1]. 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 supermarket assessment are given in Appendix F.

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. A more comprehensive approach would be to undertake a more thorough life-cycle assessment (LCA) study that includes other environmental impacts such as water use, resource depletion, ecotoxicity, eutrophication, ozone depletion, acidification, etc. in addition to embodied carbon.

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.

Each assessment should be accompanied by 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

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.

1 There is significant uncertainty over calculating carbon emissions from timber, particularly at end-of-life. Carbon emissions are affected by the methodology, data and assumptions used in the assessment.

APPENDIX A

THE NATIONAL CALCULATION METHODOLOGY (NCM)

The National Calculation Methodology (NCM) must be used for Part L compliance assessment. The NCM strictly defines the way in which building use is modelled in terms of temperature set points, lighting levels and use, internal heat gains from people and equipment, etc.

The NCM was devised primarily as an assessment tool to measure comparative operational carbon emissions between a proposed building and the requirements of the Part L regulation rather than as a design tool. It is widely agreed that several assumptions in the NCM can give rise to discrepancies between the prediction of energy uses and those which are likely to occur in reality. Several of these assumptions can make a significant impact on the assessment of operational carbon performance of large supermarket buildings. The most significant of these are briefly discussed below.

It is likely that, as Part L is modified over time, the NCM itself will also be improved, however it is not possible to predict what these modifications might be and so the current NCM has been used within Target Zero on the assumption that the generic approach to Part L assessments will remain constant.

Hours of operation

The hours of operation of supermarkets have a significant impact on the usefulness of rooflights and daylight dimming lighting controls. At night, rooflights serve no useful purpose but they release more heat through conduction than the opaque roof elements around them. Therefore the more hours of darkness during which the supermarket is in operation, the lower the optimal rooflight area will be. Similarly the effectiveness of daylight dimming controls is diminished if supermarkets are open 24 hours a day.

The NCM defines that supermarkets should be assessed with occupancy from 8am to 7pm Monday to Saturday and from 9am to 5pm on Sundays and Bank holidays. Therefore although many large supermarkets will be in operation 24 hours a day, this occupancy schedule is not currently assessed under Part L (2006). During unoccupied hours, the NCM defines that the heating set point reduces to 12°C (from the occupied set point of 20°C). In practice the night time temperature of supermarkets rarely falls to 12°C and so the effect of night time heat losses is delayed until the following morning when the supermarket is brought back up to 20°C.

Offsite wind turbine output

Larger wind turbines are unlikely to be suitable for many supermarkets sites due to planning and other restrictions however they may be permitted as an allowable solution under future revisions to Part L. The output of wind turbines modelled using the NCM is currently based on the wind speeds in the weather tape selected for the simulation, i.e. the weather tape for the location of the building. Large wind turbines are generally located in exposed areas with high wind-speeds and therefore their output predicted using the NCM is likely to be much less than their actual output.

It is recommended therefore that if the use of offsite turbines through allowable solutions is permitted in future versions of Part L, calculations of their output should be carried out separately from the Part L modelling software.

Small power energy consumption & heat gains

For thermal modelling purposes, each room template contains predefined heat gains for equipment such as IT; these are defined in terms of magnitude and variation over time by the NCM and cannot be changed. When the features such as high efficiency chilled cabinets have been incorporated in the building or when retailers have specified cabinets with doors rather than open fronted units, the variation between actual and (NCM) modelled emissions from small power loads can be large. Similarly the magnitude of the heat gains from these small power loads will affect cooling and heating loads.

APPENDIX B

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 Stockton-on-Tees supermarket building was amended as follows:
   - the levels of thermal insulation were reduced until these were no better than criterion 2 of Part L2A (2006) requires;
   - HVAC system efficiencies were altered to industry standards;
   - 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.

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 basecase was no better than the current minimum regulatory requirements, i.e. within 1% of the Target Emission Rate (TER). The basecase building was defined in terms of elemental U-values, air-tightness, etc. shown in Table B1.

4. This basecase building was then modified to have two alternative structures to investigate the influence of the structural form on the operational carbon emissions

5. Around 50 energy efficiency measures were then introduced individually into the basecase 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 C).

6. Thirty seven low and zero carbon technologies were then individually incorporated into each of the three energy efficiency packages (see Appendix D). The results from these models, together with the associated cost data, were then used to derive a number of low and zero carbon supermarket solutions. This approach has been devised to reflect the carbon hierarchy shown in Figure 2 and the likely future regulatory targets (see Figure 3).

TABLE B1
BASECASE BUILDING FABRIC PERFORMANCE PARAMETERS

ELEMENT	U-VALUE (W/m²K)
External wall	0.35
Ground floor	0.25
Composite intermediate floor	3.19
Composite intermediate floor + false ceiling	0.34
Blockwork partition	0.35
Insulated partition	0.37
Standing seam roof	0.25
Membrane roof	0.25
External doors	2.20
Docking doors	1.50
Curtain walling	2.20
Rooflights	1.80
Building air tightness	10 m³/hr per m² @50Pa
Thermal bridging	0.035 W/m²/K

APPENDIX C

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 energy efficiency measures modelled on the basecase building are shown in Table C1.

Dynamic thermal modelling, using IES software, was used to predict the operational energy requirements of the supermarket 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 basecase supermarket, 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 basecase. The 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 8.

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

TABLE C1
ENERGY EFFICIENCY MEASURES CONSIDERED

ENERGY EFFICIENCY AREA	DESCRIPTION OF MEASURE
Construction materials (thermal mass)	Heavyweight internal floors, changing internal mezzanine from timber slab to composite floor throughout
	Heavyweight internal partitions, changing from lightweight plaster cavity partitions to plastered blockwork walls throughout
	Green roof extensive, sedum type
Air tightness	Improved to 7 m³/hr per m² @50Pa
	Improved to 5 m³/hr per m² @50Pa
	Improved to 3 m³/hr per m² @50Pa
	Improved to 1 m³/hr per m² @50Pa
Thermal bridging	Enhanced thermal bridging details as specified in MCRMA & Tata Steel guidance
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 to 1.60 W/m²K
Improved external glazing	Improved to 1.20 W/m²K
	Improved to 0.80 W/m²K
Building orientation & Solar shading & Solar control glazing	Transparent canopy to replace opaque canopy
	South east orientation with transparent canopy to replace opaque canopy
	Real orientation with no canopy
	Original orientation with transparent canopy & daylight dimming
	Main glazing facing South West
	Main glazing facing South
	Main glazing facing South East
	Non-solar control glass (g-value=0.7)
	Non-solar control glass & South East orientation (g-value=0.7)
	Solar control glass (g-value=0.4)
	Solar control glass & South East orientation (g-value=0.4)
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%
	Radiant ceiling heating and cooling throughout
Lighting & Rooflights	Daylight dimming and rooflights covering 10% of the roof area
	Rooflights covering 10% of the roof area
	Daylight dimming and rooflights covering 15% of the roof area
	Daylight dimming and rooflights covering 20% of the roof area
	Northlights to achieve similar natural lighting levels to 15% rooflights
	Improved lighting efficiency: ■ Single height warehouse 2.40 W/m² per 100lux ■ Double height warehouse 2.05 W/m² per 100lux ■ Single height retail: 2.50 W/m² per 100lux ■ Double height retail: 3.00 W/m² per 100lux ■ Office area: 2.50 W/m² per 100lux
	High efficiency lighting: ■ Single height warehouse 2.00 W/m² per 100lux ■ Double height warehouse 1.70 W/m² per 100lux ■ Single height retail: 2.10 W/m² per 100lux ■ Double height retail: 2.30 W/m² per 100lux ■ Office area: 2.00 W/m² per 100lux
	Very high efficiency lighting: ■ Single height warehouse 1.60 W/m² per 100lux ■ Double height warehouse 1.35 W/m² per 100lux ■ Single height retail: 1.70 W/m² per 100lux ■ Double height retail: 1.80 W/m² per 100lux ■ Office area: 1.75 W/m² per 100lux
Lighting controls	Occupancy sensing lighting controls
	Daylight dimming controls
	Heat recovery to all air handling & heat pump units (60%)
Miscellaneous	Heat recovery removed from all air handling & heat pump units (0%)
	High reflectance paint to reduce sloar gain

APPENDIX D

LOW AND ZERO CARBON (LZC) TECHNOLOGY ASSESSMENT

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

Thirty seven LZC technologies were modelled (see Table D1) on each of the three energy efficiency packages. Each of the LZCs was applied to each energy efficiency package (see Appendix C) 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 relative to the basecase building.

Initial results of the LZC modelling revealed that no single, onsite technology is predicted to achieve zero carbon and therefore further modelling was undertaken to combine a number of onsite technologies. This was done using graphs similar to that shown in Figure D1.

Figure D1 shows the relationship between carbon dioxide emissions saved per year (relative to the basecase) on the horizontal axis, against the change in 25-year NPV (relative to the basecase) on the vertical axis. The figure shows just a subset of the many combinations of energy efficiency measures and LZC technologies assessed. Figure D1 shows the onsite LZC solutions defined in Tables 2 and 3 in Section 7.6.

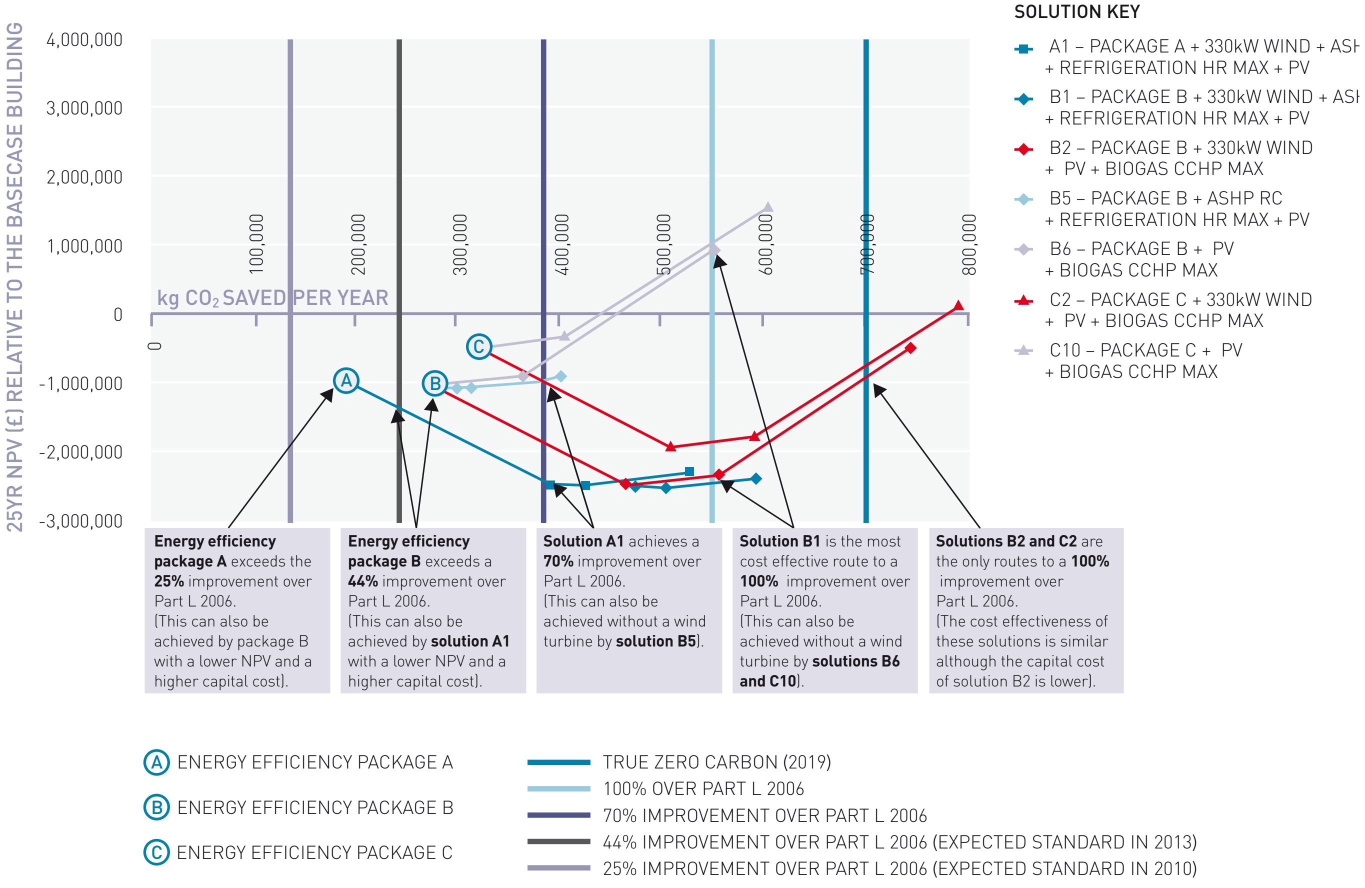
Figure D1 shows three coloured circles representing the three energy efficiency packages described in Appendix C. Straight lines emanating from these circles represent an LZC technology. The gradient of each line represents the cost-effectiveness of each measure. Having decided the carbon reduction target, 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 36 different combinations of compatible onsite technologies (based on the three energy efficiency packages).

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

FIGURE D1

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



APPENDICES

TABLE D1
LZC TECHNOLOGIES MODELLED

LZC TECHNOLOGY	ONSITE	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 1kW wind turbine	✓		**Futurenergy** 6.2m tower height. 1.8m rotor diameter
Solar			
Solar Thermal Hot Water (STHW)	✓		23.2m² sized to provide as much hot water as is practical
Photovoltaics	✓		Roof integrated amorphous, area dependent on area of rooflights:
Heat Pumps			
Open-loop Ground Source Heat Pump Single Cycle	✓		Space heating excluding radiant heating systems
Open-loop Ground Source Heat Pump Reverse Cycle	✓		Space heating and cooling excluding radiant heating systems
Closed-loop Ground Source Heat Pump Single Cycle	✓		Space heating excluding radiant heating systems
Closed-loop Ground Source Heat Pump Reverse Cycle	✓		Space heating and hot water excluding radiant heating systems
Air Source Heat Pump Single Cycle	✓		Space heating excluding radiant heating systems
Air Source Heat Pump Reverse Cycle	✓		Space heating and cooling excluding radiant heating systems
Biomass Boilers			
Biomass Heating	✓		Space heating and hot water excluding radiant heating systems
Combined Heat & Power CHP			
Small Biomass CHP	✓		Space heating excluding radiant heating systems, hot water and electricity to all areas excluding corridors and storage spaces
Large Biogas CHP	✓	✓	Space heating excluding radiant heating systems, hot water and electricity to all areas
Small fuel cell CHP	✓		Space heating excluding radiant heating systems, hot water and electricity to all areas excluding corridors and storage spaces
Large fuel cell CHP	✓	✓	Space heating excluding radiant heating systems, hot water and electricity to all areas
Small gas-fired CHP	✓		Space heating excluding radiant heating systems, hot water and electricity to all areas excluding corridors and storage spaces
Large gas-fired CHP	✓		Space heating excluding radiant heating systems, hot water and electricity to all areas
Small anaerobic digestion CHP	✓		Space heating excluding radiant heating systems, hot water and electricity to all areas excluding corridors and storage spaces
Large anaerobic digestion CHP	✓		Space heating excluding radiant heating systems, hot water and electricity to all areas
Combined Cooling Heat & Power CCHP			
Small Biomass CHP	✓		Space heating excluding radiant heating systems, hot water, cooling and electricity to all areas excluding corridors and storage spaces
Large Biogas CHP	✓	✓	Space heating excluding radiant heating systems, hot water, cooling and electricity to all areas
Small fuel cell CHP	✓		Space heating excluding radiant heating systems, hot water, cooling and electricity to all areas excluding corridors and storage spaces
Large fuel cell CHP	✓	✓	Space heating excluding radiant heating systems, hot water, cooling and electricity to all areas
Small gas-fired CHP	✓		Space heating excluding radiant heating systems, hot water, cooling and electricity to all areas excluding corridors and storage spaces
Large gas-fired CHP	✓	✓	Space heating excluding radiant heating systems, hot water, cooling and electricity to all areas
Small anaerobic digestion CHP	✓		Space heating excluding radiant heating systems, hot water, cooling and electricity to all areas excluding corridors and storage spaces
Large anaerobic digestion CHP	✓	✓	Space heating excluding radiant heating systems, hot water, cooling and electricity to all areas
Waste			
Energy from waste		✓	Space heating and hot water excluding radiant heating systems
Waste process heat		✓	Space heating and hot water excluding radiant heating systems
Miscellaneous			
Small ground duct system	✓		Supplying retail space
Large ground duct system	✓		Supplying all air systems
Small refrigeration heat recovery system	✓		Recovering heat from space cooling to supply hot water
Large refrigeration heat recovery system	✓		Recovering heat from space cooling and chilled display cabinets to supply hot water

Photovoltaics — rooflight packages:

PACKAGE	ROOFLIGHTS	PV AREA (M²)
A	0%	4,000
B	10%	3,500
C	15%	3,300

APPENDIX E

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 basecase 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 basecase cost.**

Capital costs

The basecase supermarket building cost plan was developed by Cyril Sweett using their cost database. UK mean values current at 4Q 2009 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 basecase 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 April 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 onsite 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 for low and zero carbon electricity are shown in Table E1.

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 E1

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

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

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

APPENDIX F

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 life-cycle. 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.

A third party critical review of the CLEAR model has been commissioned by Tata Steel, to confirm its alignment with the ISO 14040 standards for LCA. The initial review has found that the degree of alignment with the ISO 14040 standards is high.

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 life cycle 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 F1 gives the embodied carbon coefficients for the principle materials used in the supermarket assessment

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TABLE F1

THE EMBODIED CARBON COEFFICIENTS FOR THE PRINCIPLE MATERIALS USED IN THE SUPERMARKET 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	GaBi LCI database 2006 – PE International	16% recycling, 4% incineration, 80% landfill	TRADA[3]	1.10
Plywood[5]	GaBi LCI database 2006 – PE International	16% recycling, 4% incineration, 80% landfill	TRADA[3]	1.05
Plasterboard	GaBi LCI database 2006 – PE International	20% recycling, 80% landfill	WRAP[4]	0.145
Aggregate	GaBi LCI database 2006 – PE International	50% recycling, 50% landfill	Department for Communities and Local Government[2(a)]	0.005
Tarmac	GaBi LCI database 2006 – PE International	77% recycling, 23% landfill	Department for Communities and Local Government[2]	0.020

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

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

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

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

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

5 Data excludes CO_2 uptake or CO_2 emissions from biomass.

REFERENCES

1 www.breeam.org

2 Climate Change Act, 2008

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

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

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

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

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

8 CIBSE Guide A – Environmental design (2006)

9 www.bre.co.uk/greenguide

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

TARGET ZERO INFORMATION LINE

T +44 (0) 1709 825544
E INFO@TARGETZERO.INFO

WWW.TARGETZERO.INFO

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