TARGET ZERO®

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

REPORT **V1.0 AUGUST 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.

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ProLogis is a leading provider of industrial and distribution buildings in the UK. Working with retailers, manufacturers and third party logistics operators the company owns and manages 20 million square feet of industrial space in prime locations across the country.

The company's UK market position is underpinned by ProLogis' standing as a global provider of distribution facilities with more than 475 million square feet of industrial space in markets across North America, Europe and Asia.

ProLogis is committed to the principles of sustainability as a business approach, recognising its economic, environmental and social responsibilities to its customers, its employees and the communities within which it operates.

Not only do the company's sustainable buildings provide substantial cost savings to occupiers, but ProLogis also offers its customers flexible lease terms that perfectly fit their business requirements.

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CONTENTS

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 medium-to-high rise office and a mixed-use building.

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

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

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

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

The images in this guide showcase recent examples of steel-framed distribution warehouse 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 road map 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.

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

3.0 SUSTAINABLE DISTRIBUTION WAREHOUSE BUILDINGS

PROLOGIS, DUNSTABLE

SUSTAINABLE DISTRIBUTION WAREHOUSE BUILDINGS

Changes in retail and distribution business models over recent years have led to the construction of many, large single-storey distribution warehouses throughout the UK. Virtually all of these buildings are steel framed[1] and are clad in steel-based envelope systems. The so-called 'shed' sector is now one of the most efficient and successful in UK construction with an estimated annual value of approximately £1 billion for frames and £1.5 billion for associated envelope systems.

This form of construction has grown very successfully from its beginnings in industrial buildings into a construction form that enhances many aspects of modern life including retail, leisure, transport, distribution and manufacturing.

The operational energy requirements of warehouse buildings vary greatly depending on their use. Warehouses which provide chilled storage are likely to require more energy than storage facilities which can tolerate significant temperature variations. Similarly warehouses which accommodate manufacturing processes or retail units such as hardware shops will require more energy than storage buildings. Manufacturing processes use energy, but also give off heat which will reduce the energy required for space heating, although the overall energy consumption and carbon dioxide emissions are likely to be higher than for storage warehouses. Retail units will have more lighting and often have tighter temperature controls than storage and distribution facilities.

In the UK however, the majority of new warehouse buildings are used for storage of goods prior to distribution; these buildings are generally naturally ventilated and heated using radiant systems. Cooling and mechanical ventilation are rarely required.

Recently there have been significant moves to design and construct more sustainable warehouse buildings. Initiatives have mainly focussed on improving operational energy efficiency and achieving high BREEAM ratings, although embodied carbon foot printing, coupled with carbon offsetting, to achieve 'zero embodied carbon' warehouses has also received attention. Significant interest is also being shown in the integration of low and zero carbon technologies into warehouse buildings, particularly technologies that exploit their large envelope areas, such as photovoltaics and transpired solar collector technologies (TSCs).

SolarWall is a proven TSC technology that is ideally suited for integration into large metal-clad industrial buildings. An independent UK study by BSRIA [3] into the performance of SolarWall at a production facility in northern England identified a 51% annual reduction in CO_2 emissions. At the time of writing, it was not possible to model SolarWall under the 2006 National Calculation Methodology (NCM) and therefore TSCs have not been modelled within Target Zero. However, it will be possible to model them under the 2010 version of Part L - see Appendix A for further information.

Initiatives such as feed-in tariffs (see Section 7.7.5) and the Renewable Heat Incentive are likely to drive further innovation and take-up of low and zero carbon (LZC) technologies.

Clearly regulation has an important role to play in improving the sustainability of warehouse buildings, however, developers and owner occupiers of warehouse buildings increasingly understand the commercial benefits that sustainability can bring. These include lower running costs, future proofing against more onerous regulations and increased energy prices, and the ability to attract good tenants.

1 The 2009 survey of market share conducted by Construction Markets shows that steel-framed construction has a 97.6% market share in the single-storey industrial and non-industrial buildings sector.

4.0 THE STOKE-ON-TRENT DISTRIBUTION WAREHOUSE

THE STOKE-ON-TRENT DISTRIBUTION WAREHOUSE

The building on which the warehouse research was based, is the **DC3 distribution warehouse** on ProLogis Park, Stoke-on-Trent. The distribution warehouse was completed in December 2007 and is currently leased to a large UK retailer. The net internal floor area of the warehouse is 34,000m². Attached to the warehouse is a two-storey office wing providing 1,400m² of floor space.

The warehouse structure is a four span, steel portal frame. Each span is 35m with a duo pitch, lightweight roof supported on cold rolled steel purlins. The façade columns are at 8m centres and internal columns at 16m. The primary steel beams support the intermediate rafters. The office structure is a braced steel frame with columns on a 7.3m x 6.4m grid. The first floor comprises pre-cast concrete units.

The warehouse and office buildings are clad in steel built-up systems and the warehouse roof has 15% rooflights. The building is supported on concrete pad foundations. Other features of the warehouse include:

- **24 dock levellers**
- **2 level access doors**
- **339 car parking spaces**
- **39 lorry parking spaces**
- **12m haunch height**
- **secure service yard**
- **rainwater harvesting.**

The warehouse is heated with direct gas fired radiant heaters whilst the office is heated with radiators supplied by a gas boiler. The warehouse is naturally ventilated. The offices are mechanically ventilated with local supply and extract provided to WC's. Hot water is provided by a separate gas-fired water heater.

The warehouse building has excellent sustainability credentials including:

- **an 'as designed' energy performance certificate (EPC) Asset and Rating[1] of A (22)[2]**
- **a building emissions rate (BER) of 7.7 kgCO_2/m²yr (a 55% improvement over the minimum 2006 Part L requirement)**
- **a design stage BREEAM Industrial 2006[3] rating of 'Excellent'**
- **a measured air tightness of 1.14 m³/hr per m² @ 50 Pa (a value of 2 m³/hr per m² @ 50 Pa was used for the Part L compliance assessment)**
- **Confidex Sustain®[4] was employed to offset the embodied CO_2 emissions associated with the manufacture of the steel cladding used on the building.**

DC3 WAREHOUSE PRO-LOGIS PARK, STOKE-ON-TRENT

1 EPCs were introduced under the European Energy Performance of Buildings Directive (EPBD) in 2006 in the UK. They are required for all buildings over 50m² when they are constructed, let or sold. The EPC asset rating compares a building's carbon dioxide emissions rate (BER) against the Standard Emissions Rate (SER) on a scale of 1 to 100. A building just compliant with Part L (2006) would have a rating of 50.

2 Calculated assuming frost protection heating only and providing 250 lux at floor level using a lighting efficiency of 6W/m² in the fitted-out warehouse ie taking account of high-bay racking.

3 The BREEAM methodology is updated on a regular basis. The case study ProLogis warehouse was assessed using BREEAM 2006 but the basecase warehouse has been assessed in Target Zero using BREEAM 2008. BREEAM 2008 is significantly more demanding than BREEAM 2006.

4 Confidex Sustain® is a combined guarantee that covers the durability of Colorcoat® pre-finished steel products and offsets the embodied CO_2 emissions from the manufacture of Tata Steel pre-finished steel cladding systems to provide the world's first carbon neutral building envelope.

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' is defined (see Section 5.1) that just meets the 2006 Part L requirements for operational carbon emissions and this basecase building is used as a benchmark for the assessment. It is important to note that the basecase building differs from the actual building as described in Section 5.1 and that all operational carbon reductions are reported relative to 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**
- **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 carbon buildings and buildings with 'Very Good', 'Excellent' and 'Outstanding' BREEAM ratings. See Appendix F.

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.

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 B summarises some of the limitations of the NCM with respect to distribution warehouse buildings.

However, 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.**

PROLOGIS, HEATHROW

1 Costing of the basecase distribution warehouse building was based on UK mean values current at 3Q 2009.

5.1 BASECASE WAREHOUSE BUILDING

For the purposes of the Target Zero warehouse study, a basecase building was defined based in the ProLogis Stoke-on-Trent warehouse described in Section 4, ie. based on the same dimensions, specification, etc. Changes were then made to the fabric and services of the actual building to provide a basecase warehouse 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 $7m^3$/hr per m^2 @ 50Pa.**

The basecase building model was then fine-tuned to pass Part L2A to within 1% by altering the energy efficiency of the lighting system to 4.20 W/m^2 per 100lux. See Sections 7.3 and 7.4 for further information.

It is important to note that these changes, particularly those relating to the air tightness of the building and the lighting efficiencies assumed, cause the predicted building performance to be significanly worse than the actual warehouse, ie. causing the predicted BER to change from 7.7kgCO_2/m^2 yr to 23.9kgCO_2/m^2 yr.

More detail on the specification of the basecase warehouse is given in Appendix C.

DC3 WAREHOUSE PROLOGIS PARK, STOKE-ON-TRENT OFFICE WING

6.0 KEY FINDINGS

KEY FINDINGS

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

The likely 2010 Part L compliance target of reducing operational carbon emissions by 25% is achievable by using a more efficient lighting system alone. This is predicted to yield a 37% reduction in regulated carbon emissions and save £308,700 in capital cost relative to the Part L 2006 compliant basecase warehouse. See Section 7.3.

A package of compatible, cost effective energy efficiency measures were predicted to yield a 54% reduction in regulated emissions relative to the basecase warehouse. The measures yield a capital cost saving of £190,139 and a 25 year net present value[1] (NPV) of -£2,470,354. See Section 7.3.

Two, more advanced, packages of energy efficiency measures were selected that were predicted to reduce regulated emissions by 61% and 69%. Both packages are predicted to be cost effective over a 25 year period, i.e. yield a negative NPV, however the more advanced package is less attractive both in terms of capital and NPV costs. See Section 7.3.

Lighting was found to be the most significant energy demand in the warehouse building studied, accounting for around three quarters 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 rooflight design, lighting systems, daylight dimming and racking in warehouse buildings requires detailed dynamic thermal simulations in conjunction with good lighting design to develop an optimum lighting solution. See Sections 7.4 and 7.5.

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

Many of the low and zero carbon (LZC) technologies that provide heat were predicted to increase, rather than reduce, regulated operational carbon emissions from the warehouse building using the NCM. This is mainly due to the requirement to change the heat delivery system to one which is compatible with the selected LZC technology. Changing the heat delivery system from the radiant system assumed in the basecase to an air or water-based system was predicted to incur a far greater auxiliary energy demand (mainly pumping energy in this case) and if an LZC technology is going to achieve an overall reduction in operational carbon emissions, it first has to overcome the increased emissions associated with the auxiliary energy requirement. This effect is increased as the warehouse is made more thermally efficient. See Section 7.7.1.

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 D. A negative NPV represents a saving over the 25 year period.

6.0 KEY FINDINGS

Two, single on-site LZC technologies were predicted to achieve true 'zero carbon' for the basecase warehouse building, i.e. a 117%[1] reduction in regulated carbon emissions, in conjunction with a package of appropriate energy efficiency measures. These were:

- **a large 2.5MW wind turbine**
- **a large (17,200 m²) array of roof-integrated photovoltaic panels.**

Both of these technologies are predicted to incur a high capital cost. The 2.5MW turbine is far more attractive in terms of NPV, however, it is recognised that it will not be possible to install such a large turbine on most UK sites. Therefore further analysis was undertaken to combine different compatible LZC technologies. See Sections 7.7 and 7.8.

Seven combinations of energy efficiency measures and on-site LZC technologies were identified that are predicted to yield 'zero carbon'. The most cost effective of these packages comprised a package of energy efficiency measures; a 330kW wind turbine and a 5,700m² array of amorphous thin-film photovoltaics. These measures are predicted to incur an increased capital cost of 19% but are predicted to save money over a 25 year period. See Section 7.8.

Based on the assessment of this warehouse building, the most cost-effective routes to the 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 distribution warehouse was (see Section 8.1):

- **0.04% to achieve BREEAM 'Very Good'**
- **0.4% to achieve BREEAM 'Excellent'**
- **4.8% to achieve BREEAM 'Outstanding'.**

The basecase building capital construction cost was £19.4m (£549/m²). See Section 9.

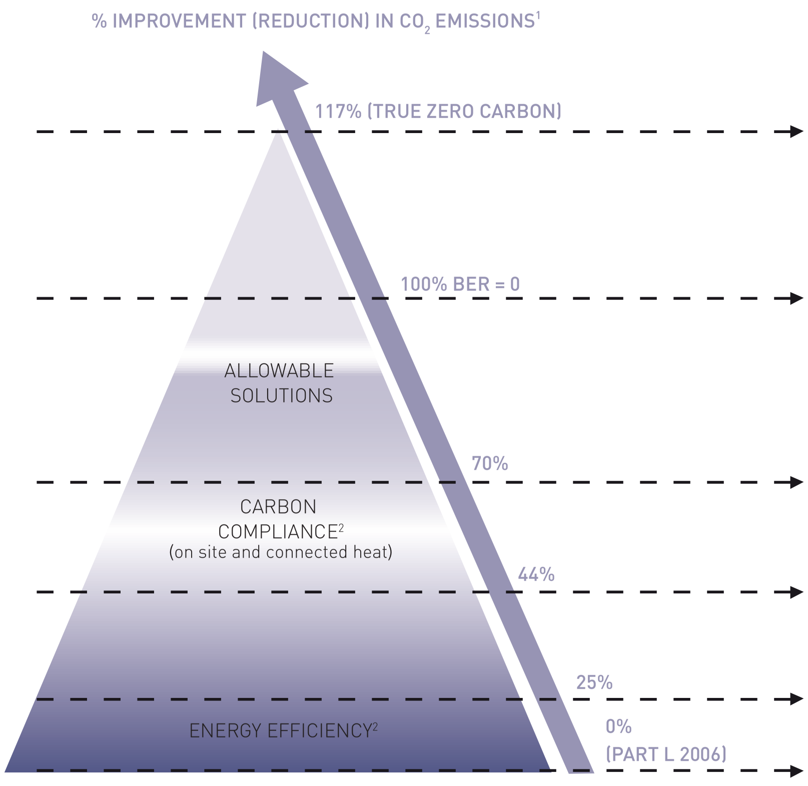
The impact of the structure on the operational carbon emissions of the basecase distribution warehouse was found to be small, the Building Emissions Rate (BER) varying by less than 1% between a steel portal-framed (basecase) and a pre-cast concrete and glulam structure (Option 1). A steel-framed solution with northlights (Option 2), was predicted to have a 3% higher BER than the basecase. See Section 9.1.

Relative to the basecase building, a pre-cast concrete and glulam structure warehouse had a higher (14%) embodied carbon impact and the steel portal-framed structure with northlights also had a higher (7%) impact. See Section 10.

1 117% is the reduction required to achieve true zero carbon for the case study warehouse building since small power demands contribute 17% of the operational carbon emissions when expressed as a percentage of the regulated emissions. This is because the unregulated percentage of the total emissions is 14% (See Figure 7) and 14% is 17% of 86%.

6.0 KEY FINDINGS

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



ENERGY EFFICIENCY MEASURES	LZC TECHNOLOGIES	ADDITIONAL CAPITAL COSTS[3] (£)	25 YEAR NET PRESENT VALUE[3] (£)
PACKAGE C (see below)	330kW on-site wind turbine 5,700m² roof intergrated photovoltaics (amorphous thin-film)	3,672,932 [18.8%]	-949,141
PACKAGE C: Glazing (rooflight) performance 0.90W/m²K Advanced thermal bridging (0.014W/m²K Occupancy sensing lighting controls Very efficient office Advanced high efficiency lamps and luminaires 1.42W/m² per 100 lux 20% rooflights with daylight dimming Ultra high air tightness 1m³/h per m² @ 50Pa Advanced wall insulation 0.15W/m²K Advanced roof insulation 0.10W/m²K High absorbtance paint	330kW on-site wind turbine	1,274,478 [6.5%]	-2,706,961
PACKAGE A (see below)	330kW on-site wind turbine	492,361 [2.5%]	-2,712,404
PACKAGE A: High efficiency lamps and luminaires 1.79W/m² per 100lux Glazing (rooflight) performance 1.50W/m²K Improved high air tightness 5m³/hr per m² @ 50Pa 10% rooflights with daylight dimming Advanced thermal bridging (0.014W/m²K)		-190,139 [-0.98%]	-2,470,354
High efficiency lamps and luminaires 1.79W/m² per 100lux		-308,700 [-1.58%]	-2,937,984
Basecase building			

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

2 The energy efficiency and carbon compliance standards for non-domestic buildings are subject to further consultation

3 Relative to the basecase building

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 road map 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 C.

Operational carbon is the term used to describe the emissions of greenhouse gases during the operational phase of a building. Emissions arise from energy consuming activities including heating, cooling, ventilation and lighting of the building, so called 'regulated' emissions under the 2006 Building Regulations, and other, currently 'unregulated' emissions, including appliance use and small power plug loads such as IT. These appliances are not currently regulated because building designers generally have no control over their specification and use and they are likely to be changed every few years.

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.

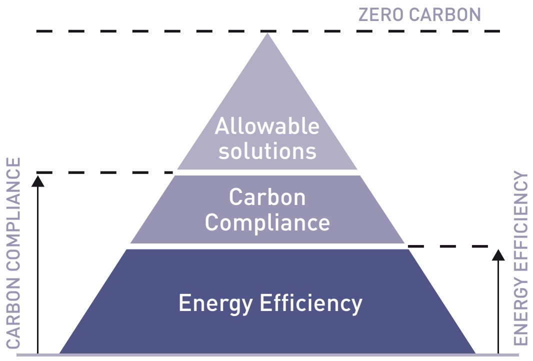
The Government supports a hierarchical approach to meeting a zero carbon standard for buildings, as shown in Figure 2. The approach prioritises, in turn:

- **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 [4], 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/m²yr). The level for this standard has currently not been set for non-domestic buildings.**
- **Carbon Compliance, on or near site. This is the minimum level of carbon abatement required using energy efficiency measures, plus on-site LZC measures or directly connected heat or coolth. Possible carbon compliance targets for non-domestic buildings have been modelled as part of the Government's consultation [4] using on-site and off-site (technology) rich scenarios and an 'aggregate' approach under which different carbon compliance targets are set for different building types. The results for 11 building types [4] show a range of possible Carbon Compliance reduction targets of between 13% (supermarkets), through to a 100% improvement (warehouses) on 2006 Part L standards**
- **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 [4] 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 [4] that the zero-carbon destination for non-domestic buildings will cover 100% of regulated emissions, i.e. a Building Emissions Rate (BER) of zero.

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



1 The standards set for dwellings are likely to be fully implemented in 2016 with an interim step introduced in 2013 [5].

7.2 BUILDING REGULATIONS PART L

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

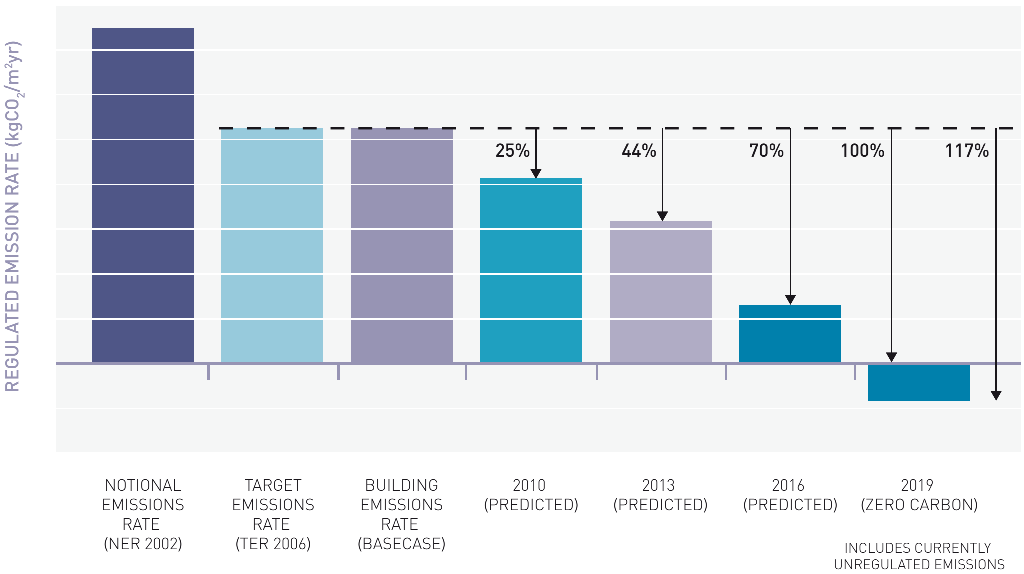
The 2006 revisions to Part L required a 23.5% saving over the 2002 standards for fully naturally ventilated spaces and 28% savings for mechanically ventilated and cooled spaces. Revisions to Part L in 2010 suggest that a further 25% (average) reduction in regulated carbon emissions over the 2006 requirements 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, the consultation for 2010 Part L [6] suggests adopting an 'aggregate' approach for non-domestic buildings. Under this approach, it is expected that distribution warehouses will be required to contribute greater operational carbon emissions reductions than the average 25%; results of recent modelling [6] suggest a possible target reduction of 36%.

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.

FIGURE 3

INDICATIVE GRAPH OF PAST AND POSSIBLE FUTURE PART L CHANGES



7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

Within Target Zero, the operational carbon emissions results for the distribution warehouse analysed are presented with 25%, 44%, 70%, 100% (BER=0) and 117% (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 [4] published in November 2009. The 70% reduction target was based on the domestic building target. A reduction in regulated carbon emissions of 117% is required to achieve true zero carbon for the case study distribution warehouse i.e. one in which the annual net carbon emissions from both regulated and unregulated energy consumption are zero or less.

The 2006 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 B. The assessed total operational carbon emissions for the basecase building were 1,059 tonnes CO_2 per year using the NCM.

PROLOGIS – TEVA, GLASSHOUGHTON

7.3 ENERGY EFFICIENCY

The range of energy efficiency measures that can be applied to warehouse buildings is more limited than the other non-domestic building types investigated under Target Zero. This is because the building does not have any cooling or significant ventilation systems or conventional glazing. Therefore energy efficiency measures relating to cooling and ventilation efficiencies or building orientation will not generally be effective for this building type.

Figure 4 shows the modelled reductions in operational carbon dioxide emissions achieved by introducing the individual energy efficiency measures defined in Appendix D into the basecase warehouse building. The results show that the measures with the greatest predicted impact are those related to the greatest energy demand in the warehouse, i.e. lighting.

Reflecting the fact that the office wing accounts for only 4% of the total floor area of the building and 18% of total operational carbon emissions, energy efficiency measures relating to the office were 'lumped together' as packages of measures rather than modelled as individual measures. These packages are defined in Appendix D.

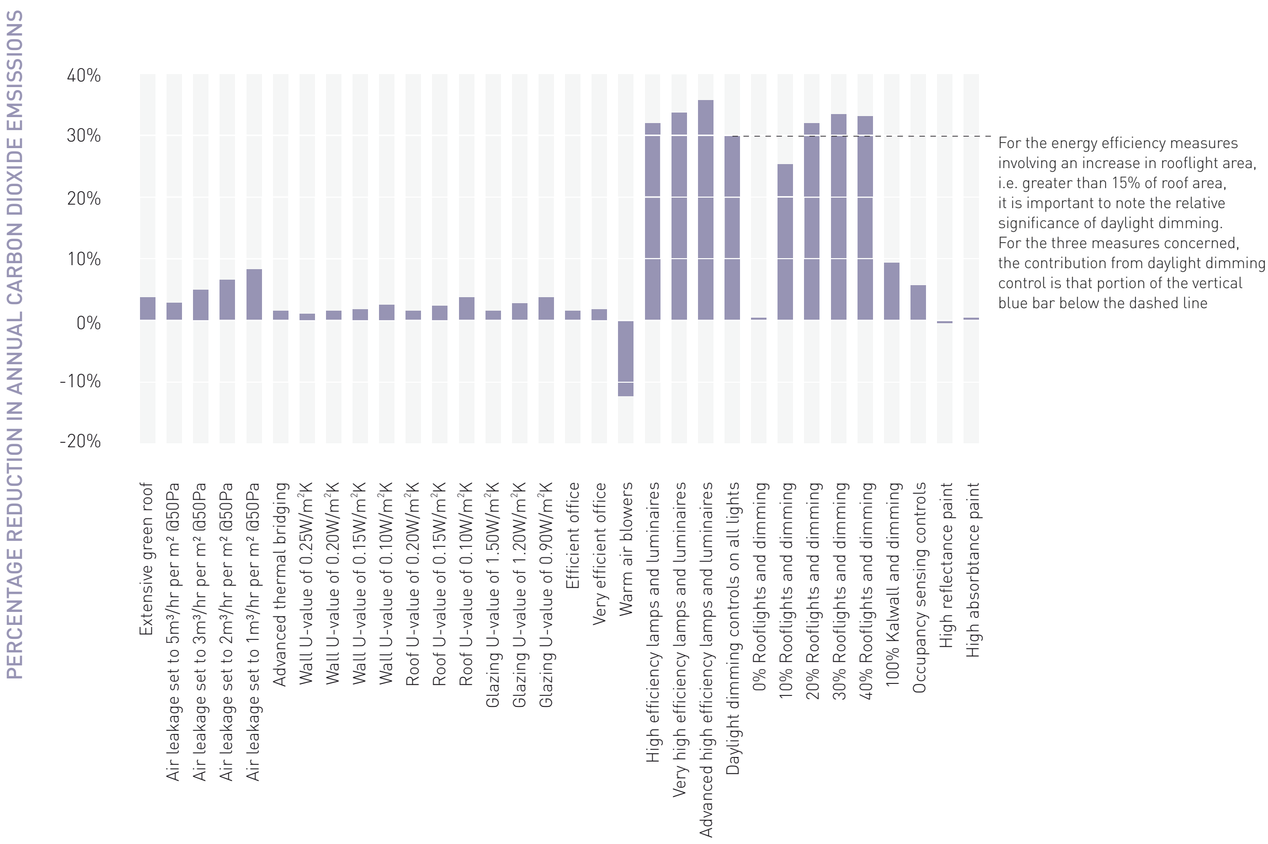
An unexpected result shown in Figure 4 is that the use of warm air blowers was predicted to increase the building's carbon dioxide emissions. This is because the fan power required for a warm air blower is greater than the power required for the radiant heating system modelled in the basecase building. See Section 7.7.1.

The results shown in Figure 4 take no account of cost and therefore the energy efficiency measures modelled have been ranked (see Figure 5a) in terms of their cost-effectiveness, i.e. 25-year NPV per kg of CO_2 saved (see Appendix F). The measures have then been grouped into three energy efficiency packages:

- **Package A Highly cost effective measures predicted to save money over a 25 year period, i.e. a negative 25 year NPV**
- **Package B Cost effective measures with an NPV better than photovoltaics**[1]
- **Package C Remaining technically viable measures.**

FIGURE 4

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

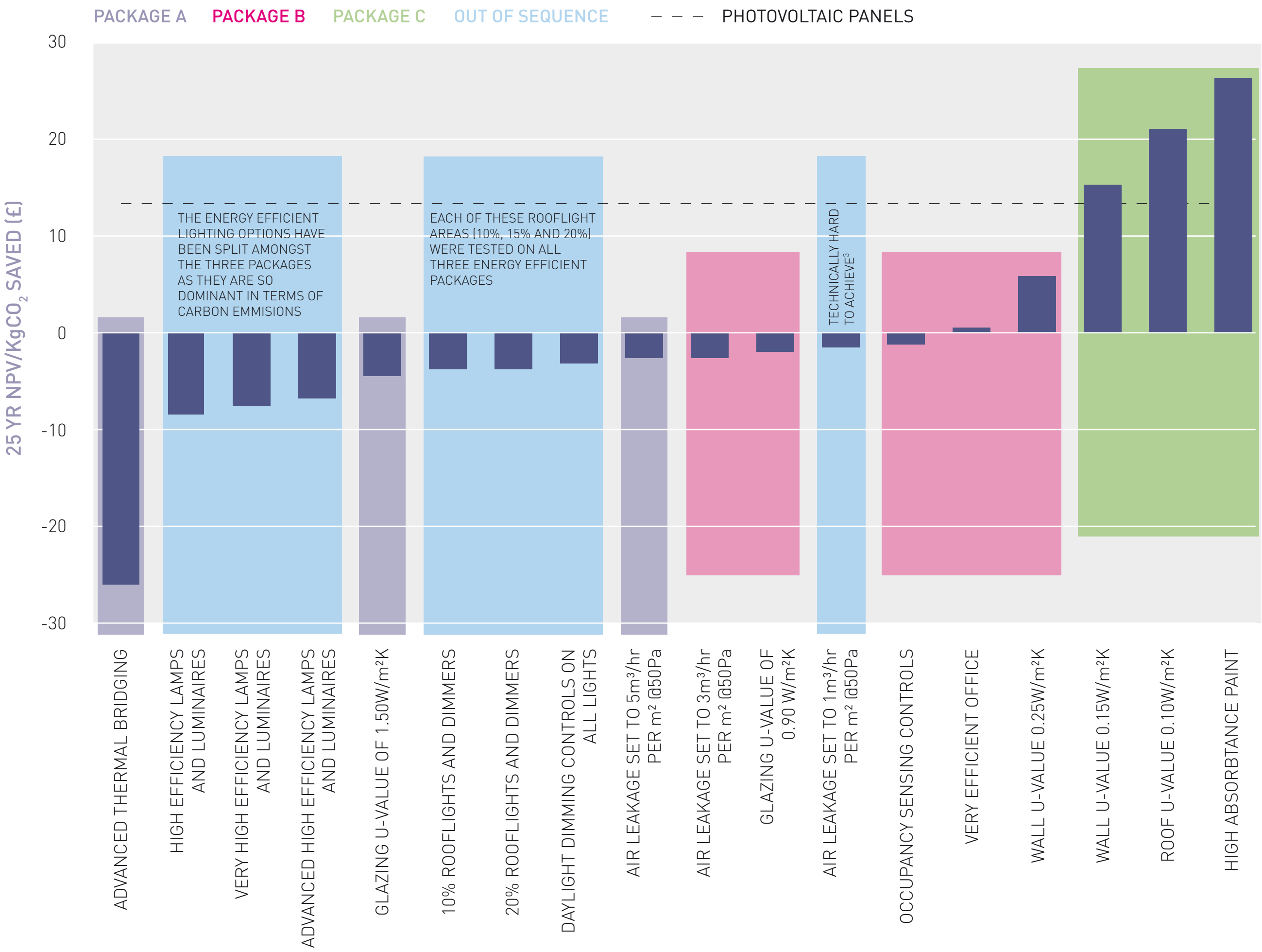


1 Photovoltaics was taken as the threshold between Packages B and C since the technology is generally considered to be one of the more capital intensive low or zero carbon technologies which can be easily installed on almost any building.

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

FIGURE 5A

ENERGY EFFICIENCY MEASURE PACKAGES A, B AND C



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.

The majority of carbon dioxide emissions from the basecase warehouse are as a result of the energy used for lighting (see Figure 7). Therefore energy efficiency measures which affect lighting energy requirements (i.e. lighting efficiency, rooflight specification and area) have been considered separately from the other energy efficiency measures. The following lighting efficiencies[1] have been modelled as part of each of the three energy efficiency packages:

- **Package A - high efficiency lighting with a power density of 1.79 W/m² per 100lux**
- **Package B - very high efficiency lighting with a power density of 1.64 W/m² per 100lux**
- **Package C - advanced high efficiency lighting with a power density of 1.42 W/m² per 100lux.**

Throughout the process of establishing the energy efficiency packages, the interaction between the individual energy efficiency measures was considered. The most significant of these interactions relates to the specification and area of rooflights. The optimum area of rooflights is affected by the U-value of the rooflight, the efficiency of the lighting system and the daylight dimming protocol, among other variables. Therefore, although the optimum area of rooflight has been established for the basecase building, having changed these variables within each of the three energy efficiency packages the optimum area of rooflights is also likely to change. Hence, each energy efficiency package was separately modelled with three rooflight areas namely 10%, 15% and 20% of the roof area[2]. See Section 7.5 for further information on rooflights.

It was also decided that, given the technical difficulty of achieving an air leakage rate of 1m³ per m² @ 50Pa, this measure was only included in energy efficiency Package C despite its ranking in Figure 5a[3].

1 It is important to note that these lighting efficiencies exclude the effect of racking within the warehouse. See Section 7.4 for futher information.

2 This range of rooflight areas (10% to 20% of roof area) was found to be the most effective based on the assessment of the basecase warehouse.

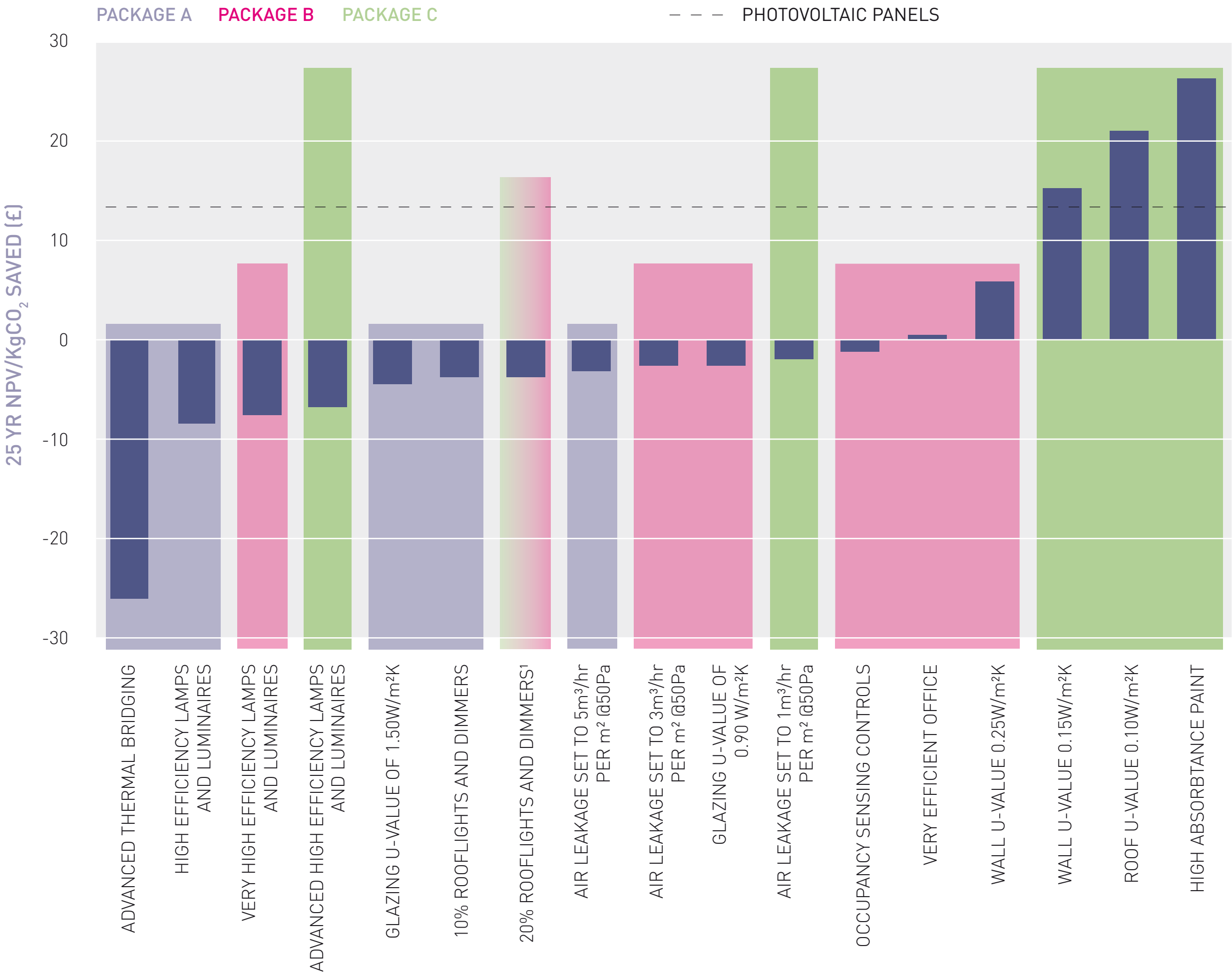
3 It is noted that an air tightness of 1.14m³/m²/per hr @ 50Pa was achieved on the case study building. With good workmanship it is possibly easy to achieve such a low value on very large warehouse buildings, however, air leakage is highly dependent on building geometry and it therefore becomes increasingly difficult to achieve good air tightness as the size of the building reduces.

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

Figure 5b shows the individual measures included within the three energy efficiency packages applied to the basecase warehouse building.

FIGURE 5B

ENERGY EFFICIENCY MEASURE PACKAGES A, B AND C



[1] The 20% rooflights with daylight dimming measure is included in both Packages B and C.

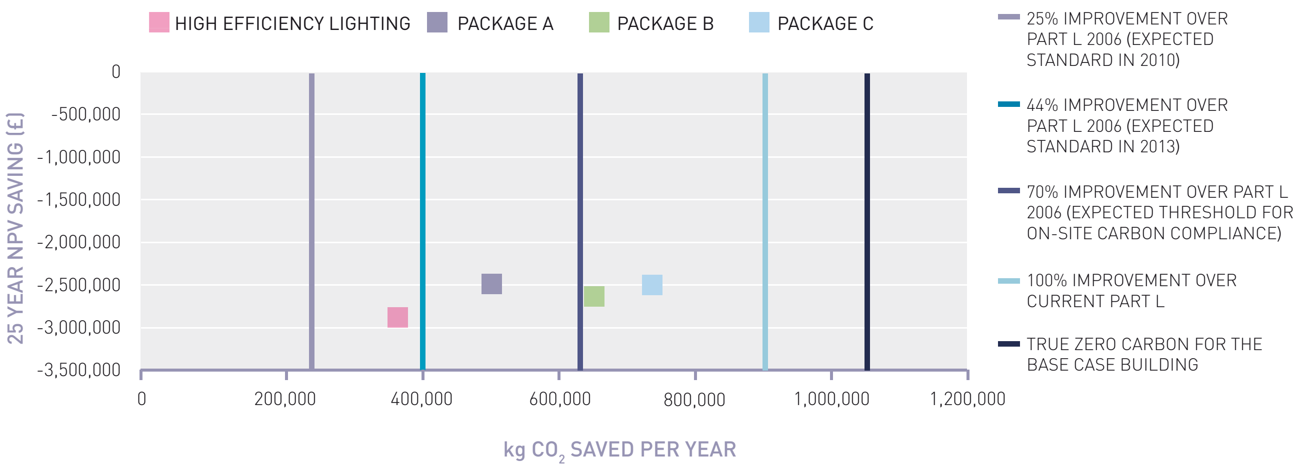
Figure 6 shows energy efficiency packages A, B and C plotted on axis representing carbon emissions saved (relative to the basecase) against 25 year NPV and with reference to future likely Part L compliance targets.

This 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 (1.79 W/m² per 100lux). This measure alone achieves a 37% reduction in regulated emissions and saves £308,700 of capital cost relative to the basecase. It is important to note that this is a theoretical cost saving relative to the 2006 compliant but inefficient and expensive lighting system assumed for the basecase warehouse – see Section 7.4 for further information.

The current expectation is that in 2013, the Part L target will be reduced by 44% beyond the current (2006) requirement; all three energy efficiency packages achieve this target. Looking further into the future it is expected that by 2019 new non-domestic buildings will be required to be 'zero carbon'. This research has found that an on-site reduction of 70% beyond current (2006) regulations can be achieved through the use of energy efficiency measures alone. Both packages B and C exceed this 70% threshold.

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

FIGURE 6
RESULTS FOR ENERGY EFFICIENCY PACKAGES A, B AND C



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

The reduction in carbon dioxide emissions resulting from the energy efficiency packages ranges from 54% of regulated emissions (47% of total emissions) with a reduced capital cost of 0.98% up to 81% of regulated emissions (69% of total emissions) with an additional capital cost of 3.0%. All three packages save money over a 25 year period, 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 Sections 7.7 and 7.8.

Despite the significant reduction in emissions using Package C, the economic performance of this package is unattractive, i.e. it incurs a greater capital cost and 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 Sections 7.7 and 7.8.

TABLE 1
OPERATIONAL CARBON EMISSIONS AND COST (CAPITAL AND NPV) FOR ENERGY EFFICIENCY PACKAGES A, B AND C

OPTION	ENERGY EFFICIENCY MEASURES	OPERATIONAL CO_2 EMISSIONS ($kgCO_2$ / YR) [CHANGE FROM BASECASE] [CHANGE IN REGULATED EMISSIONS]	CHANGE IN CAPITAL COST FROM BASECASE (£) [%]	CHANGE IN 25 YEAR NPV FROM BASECASE (£)
Basecase	-	1,058,860	-	-
Package A	High efficiency lamps and luminaires 1.79W/m² per 100lux Glazing (rooflight) performance 1.50W/m²K Improved air tightness 5 m³/h/m² @50Pa; 10% rooflights with daylight dimming Advanced thermal bridging (0.014W/m²K)	565,952 [-47%] [-54%]	-190,139 [0.98%]	-2,470,354
Package B	Very high efficiency lamps and luminaires 1.64W/m² per 100lux 20% rooflights with daylight dimming Advanced air tightness 3 m³/h/m² @50Pa Glazing (rooflight) performance 0.90W/m²K Occupancy sensing lighting controls Very efficient office Improved wall insulation 0.25W/m²K Advanced thermal bridging (0.014W/m²K)	415,276 [-61%] [-71%]	241,189 [1.24%]	-2,595,499
Package C	Advanced high efficiency lamps and luminaires 1.42W/m² per 100lux 20% rooflights with daylight dimming Ultra high air tightness 1 m³/h/m² @50Pa Advanced wall insulation 0.15W/m²K Advanced roof insulation 0.10W/m²K High absorbtance paint Glazing (rooflight) performance 0.90W/m²K Occupancy sensing lighting controls Very efficient office Advanced thermal bridging (0.014W/m²K)	327,620 [-69%] [-81%]	591,978 [3.04%]	-2,464,911

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

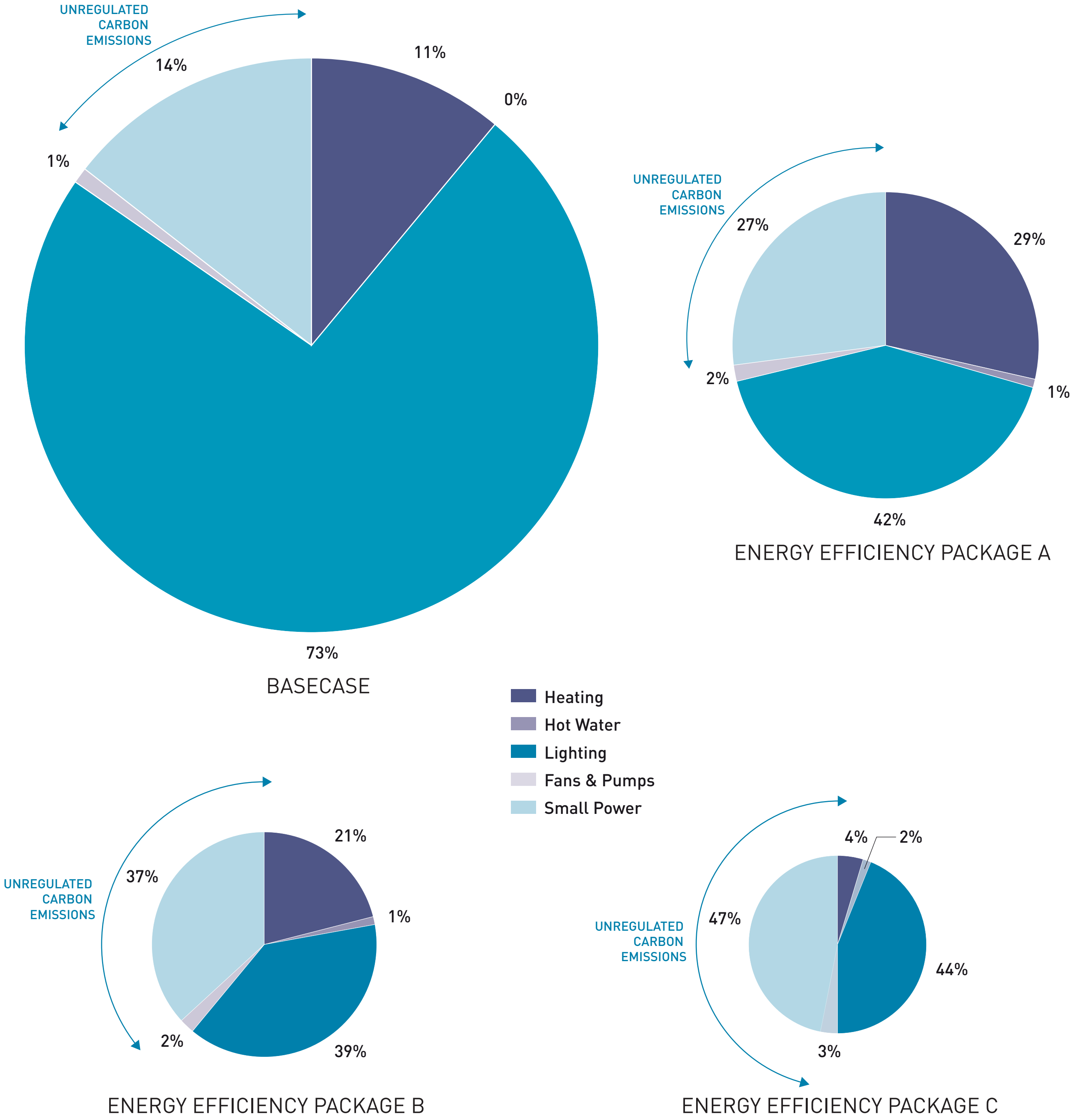
Figure 7 shows the modelled breakdown of operational carbon emissions, by energy use, when each of the three energy efficiency packages defined in Table 1 are applied to the basecase warehouse. The areas of the four pie charts are scaled in proportion to the total carbon dioxide emissions resulting from the introduction of the three packages of measures into the basecase building.

The figure shows that, as the improved energy efficiency measures reduce the total emissions, the relative magnitude of the unregulated emissions increases from 14% in the basecase building to 47% for Package C. This is because the predicted unregulated carbon emissions are fixed under the NCM and are therefore constant across all of the warehouse building thermal models.

RECOMMENDATION

The likely target for operational carbon reductions in warehouse buildings required from 2010 as a result of changes to Part L can be achieved relatively easily by using high efficiency lamps and luminaires.

FIGURE 7
BREAKDOWN OF CARBON DIOXIDE EMISSIONS FOR THE BASECASE BUILDING AND ENERGY EFFICIENCY PACKAGES A, B AND C



BSH, KETTERING

7.4 LIGHTING AND RACKING

One factor which has a major impact on the efficiency of lighting in warehouses, both natural and artificial, is the use of high bay shelving or racking. Once 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.

The National Calculation Methodology (NCM) requires that Part L assessments are based on the assumption that the illumination levels in any building being assessed for compliance should be fairly compared with the illumination levels in the notional building. The notional building is assumed to have no high bay racking and therefore the building being assessed should also be modelled without racking for the purposes of Part L compliance. This results in the predicted lighting energy consumption used for the Part L assessment being much less than that which is likely to occur in reality, i.e. after racking has been installed.

The current (2006) notional building assumes that all office, storage and industrial spaces have a lighting power density of 3.75 W/m² per 100lux. For large warehouses it is hard to design lighting systems which are this inefficient unless the effect of racking is taken into account. The basecase building has a lighting power density of 4.20 W/m² per 100lux, but this assumes a superseded lamp-type and poor quality fitting. The basecase lighting was adjusted to this level in order to pass Part L (2006) by a margin of less than 1% - see Section 5.1. This highlights how easily large modern warehouse buildings can comply with the current (2006) Part L requirements.

One of the proposed changes to Part L in 2010 [6] addresses the fact that it is easier to light large open-plan rooms more efficiently than narrower rooms; the current (2006) method ignores this. The 2010 proposal is to determine the lighting power density of each individual room in the notional building on the basis of the ratio of its wall to floor area.

Using this method the lighting power density in the basecase warehouse will be around 1.80 W/m² per 100lux; this is a 52% reduction over that of the notional building under the current (2006) method. As lighting is the largest single energy use in many warehouses, this single change to Part L will make it much harder for warehouses to comply with the proposed 2010 revision to the regulation.

PROLOGIS – TEVA, GLASSHOUGHTON. HIGH BAY RACKING AS COMMONLY USED IN WAREHOUSES

Table 2 compares the lighting requirement of the notional building under both the current 2006 Part L method and the proposed revised method for Part L 2010 [6] with the lighting systems modelled in the basecase building and in the three proposed energy efficiency packages, both with and without high bay racking. The reduction in capital cost resulting from the introduction of energy efficiency Package A, relative to the basecase (see Table 1), is largely due to the significant reduction in light fittings shown in Table 2.

RECOMMENDATION

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

TABLE 2

COMPARISON OF LIGHTING POWER DENSITIES MODELLED FOR THE WAREHOUSE

MODEL	LIGHTING DESCRIPTION			NUMBER REQUIRED		POWER DENSITY (W/M²/100LUX)	
	FITTING	LAMP	CONTROL	WITHOUT SHELVING	WITH SHELVING	WITHOUT SHELVING	WITH SHELVING
2006 NOTIONAL BUILDING	N/A	N/A	N/A	N/A	N/A	3.75	N/A
2010 PREDICTED NOTIONAL BUILDING	N/A	N/A	N/A	N/A	N/A	1.80	N/A
BASECASE	White reflectors LOR 40-50%	2x58W Linear T8	Magnetic Ballast	2,240	8,800	4.20	16.50
HIGH EFFICIENCY LIGHTING[1]	Hi-Bay LOR 70-80%	400W HSE or HIT	Electronic or magnetic ballast	448	1,760	1.79	7.04
VERY HIGH EFFICIENCY LIGHTING[2]	Hi-Bay LOR 80-90%	400W HIT	High frequency electronic ballast	448	1,760	1.64	6.46
ADVANCED HIGH EFFICIENCY LIGHTHING[3]	Hi-Bay LOR 90%+	400W HIT	High frequency electronic ballast	448	1,760	1.42	5.58

1 Forms part of Energy efficiency package A
2 Forms part of energy efficiency package B
3 Forms part of energy efficiency package C

LOR = Light output ratio
HSE = High pressure sodium lamp
HIT = Metal halide lamp

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 building has rooflights which cover 15% of the total roof area; this is towards the upper end of what is typical for new warehouse buildings in the UK, i.e. 10% to 15% of roof area.

The optimal rooflight design for a warehouse building will vary depending on the final use and internal layout of the warehouse. Most new warehouse buildings are built speculatively meaning that the design team does not know the final use of the building or the internal configuration of racking, equipment, etc.

The main advantage of increasing the rooflight area is to reduce the energy used for lighting. However for any building, there will be a point where this improvement will be negated by the increased requirement for space heating, since rooflights allow more heat to escape than opaque roof cladding elements.

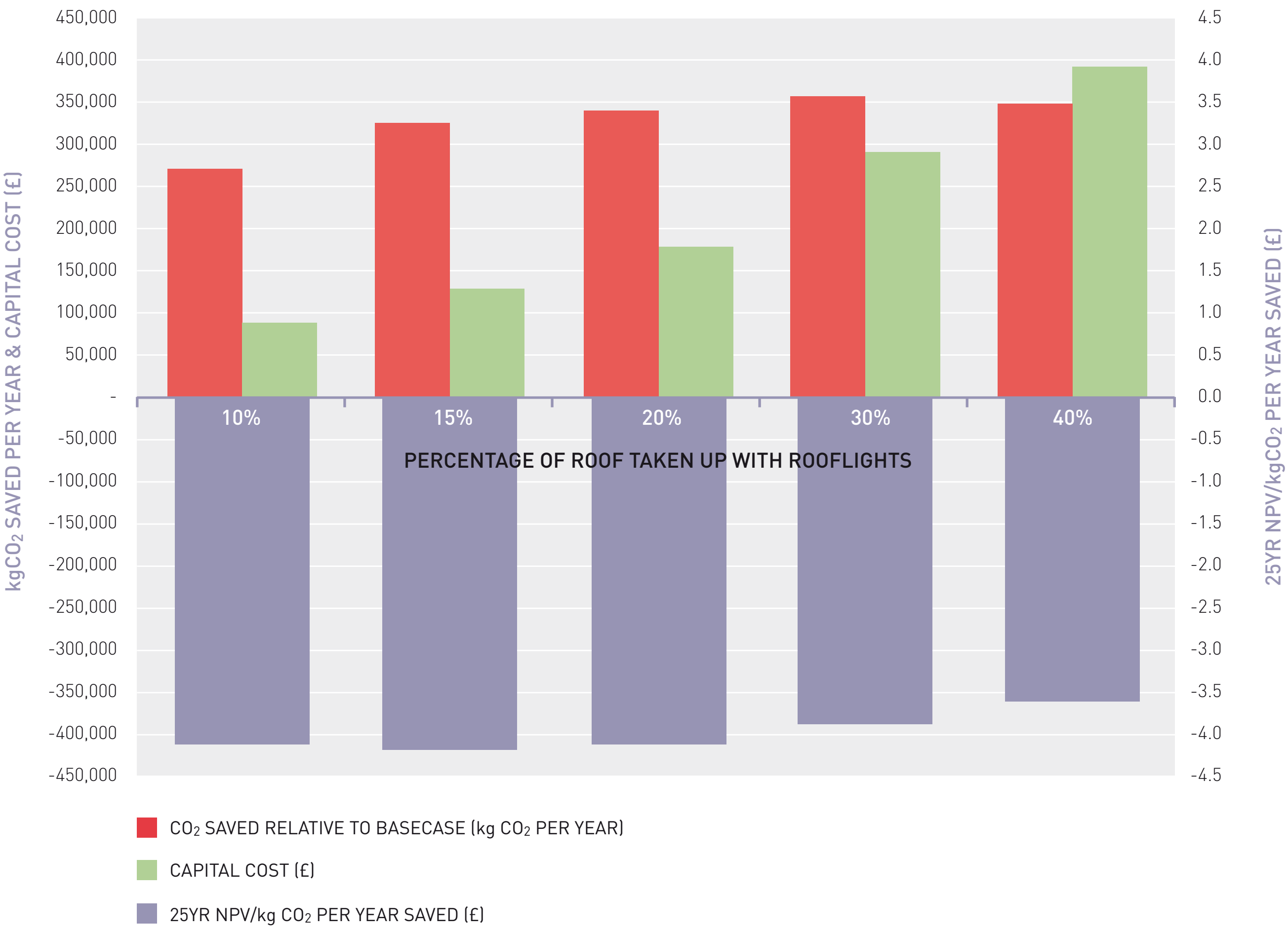
Figure 8 shows the modelled results of the impact of changing the warehouse rooflight area on total predicted operational carbon dioxide emissions for the building. It shows the carbon emissions saved per year, relative to the basecase building, (in red) together with the capital cost of the measure (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 8 reflect the combined cost and effect of changing the rooflight area and the inclusion of daylight dimming lighting controls[1]. The basecase model does not have daylight dimming. This analysis was based on the following key assumptions:

- **Rooflight U-value: 1.80 W/m²K**
- **Rooflight G-value: 0.5**
- **Roof U-value: 0.25 W/m²K**
- **Warehouse operating hours: 7am to 7pm six days a week reduced to 9am to 5pm on Sundays**
- **Lighting efficiency: 4.2 W/m² per 100lux**
- **Illumination level: 300lux.**

The figure shows that the optimum rooflight area is in the range of 10% to 20%. In this case, 15% rooflight area is marginally optimal in terms of cost effectiveness, i.e. 25 year NPV per $kgCO_2$ saved.

FIGURE 8
MODELLED EFFECTS OF CHANGING ROOFLIGHT AREAS



1 Measures to reduce the risk of overheating have not been included. See Section 7.6.

The hours of operation of warehouses have a significant impact on the usefulness of rooflights. At night, rooflights release more heat through conduction than opaque roof elements and therefore the more hours of darkness during which the warehouse is in operation, the lower the optimal rooflight area will be.

The NCM defines that storage warehouses should be assessed with occupancy from 7am to 7pm Monday to Saturday and from 9am to 5pm on Sundays and Bank Holidays. Therefore, although many large warehouses will operate 24 hours a day, this activity 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 18°C). In practice the night time temperature of the warehouse rarely falls to 12°C and so the effect of night time heat losses is delayed until the following morning when the warehouse is brought back up to 18°C.

It is important to note that the total area of rooflights is a key variable which has a complex interaction with many aspects of the building's operational energy efficiency. Energy efficiency Packages B and C both have rooflights comprising 20% of the roof area, this is significantly higher than is found in typical warehouse buildings. The primary reason that this large glazed area is effective is because the rooflights are high performance units with a very low U-value. The U-value of the rooflights modelled in Packages B and C (0.9 W/m²K) is around half the current industry standard. The occupancy constraint of the NCM (see above) is also likely to lead to an overestimation of the optimal area of rooflights in large warehouses that are operated during the night.

RECOMMENDATION

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

More detailed information about optimising rooflight areas in large industrial buildings, based on dynamic thermal simulations not constrained by the NCM, is available in [7].

7.6 OVERHEATING

The risk of overheating in the basecase warehouse was analysed using the IES dynamic thermal modelling package using 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. Anecdotal evidence suggests that modern, highly-insulated warehouse buildings are more prone to overheating than those built when building regulations were less onerous in terms of thermal performance.

Four ventilation strategies were modelled to identify the most effective way to reduce the risk of overheating in the warehouse; these are summarised in Table 3 together with the simulation results. Strategy A represents the assumed typical operation of the basecase building.

Table 3 shows that the use of high-level openings can significantly reduce the amount of overheating particularly when used in conjunction with perforated security shutters on all docking doors (Strategy D). The use of high and low level openings creates stack effect ventilation to promote air flow through the building with hot air escaping through the rooflights and cooler fresh air being drawn in through the docking doors.

The effect of changing the warehouse structure[1] on the risk of overheating was also modelled using Strategy C (as defined in Table 3)[2]. Table 4 shows the results. The risk of overheating in the basecase warehouse and (structural) Option 1[1] are very similar. The slightly higher modelled risk using Option 1 is a function of the smaller internal roof volume due to the pitch and depth of the glulam rafters. Structural Option 2[1] is a fundamentally different design to the basecase and Option 1. The effectiveness of northlights in reducing the risk from overheating is clearly shown in the table.

It is important to note that the cost of measures to mitigate the risk of overheating in the basecase building were not included in the rooflight area optimisation.

TABLE 3
MODELLED SCENARIOS TO REDUCE THE RISK OF OVERHEATING

VENTILATION STRATEGY	DOCKING DOORS OPENING	HIGH LEVEL OPENINGS	PEAK TEMPERATURE AT BOTTOM/TOP OF WAREHOUSE (°C)	PROPORTION OF OCCUPIED HOURS ABOVE 28°C[A] (%)
STRATEGY A	Fully open during occupied hours[B]	None	35.5/39.9	20.0
STRATEGY B	Fully open 24 hours a day, 7 days a week	None	33.6/38.3	8.7
STRATEGY C	Fully open during occupied hours[B]	Roof openings equivalent to 9% of rooflights or 1.35%[C] of floor area	33.5/34.5	8.2
STRATEGY D	Open with security meshes 24 hours a day, 7 days a week	Roof openings equivalent to 9% of rooflights or 1.35%[C] of floor area	31.0/32.0	1.2

A In the absence of specific overheating criteria for warehouse buildings, the CIBSE [8] benchmark summer peak temperature of 28°C has been used.

B Occupied hours - 7am to 7pm Monday to Saturday and from 9am to 5pm on Sundays and Bank Holidays

C The area of roof openings was calculated by AECOM to maintain acceptable internal conditions.

1 The different structural options modelled are described in Section 9.

2 Strategy C was considered to be a more practical and cost effective solution than Strategy D.

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

TABLE 4
INFLUENCE OF STRUCTURAL DESIGN ON THE RISK OF OVERHEATING

STRUCTURAL OPTION	PEAK TEMPERATURE AT BOTTOM OF WAREHOUSE (°C) (AT TOP OF WAREHOUSE)	PERCENTAGE OF OCCUPIED HOURS[1] ABOVE 28°C (%)	AVERAGE WAREHOUSE HEIGHT (m)
BASECASE: STEEL PORTAL FRAME	33.5 (34.5)	8.2	13.3
STRUCTURAL OPTION 1: GLUE-LAMINATED TIMBER RAFTERS ON PRECISE CONCRETE COLUMNS	33.6 (35.1)	8.6	13.0
STRUCTURAL OPTION 2: STEEL PORTAL FRAME WITH NORTHLIGHTS	30.1 (30.9)	1.5	13.7

1 7am to 7pm Monday to Saturday and from 9am to 5pm on Sundays and Bank Holidays

RECOMMENDATION

The risk of overheating in warehouse buildings should be considered by the design team. Relatively simple and cost effective ventilation measures are effective at reducing the overheating risk.

PROLOGIS, PINEHAM

7.7 ON-SITE LZC TECHNOLOGIES

Twenty LZC technologies were individually modelled on each of the three energy efficiency packages defined in Section 7.3. Some technologies were modelled as both large and small-scale installations, for example ground source heat pumps were modelled as large-scale to supply space heating to the whole building and as small-scale sized to supply space heating to the office wing only. The methodology used to assess and compare LZC technologies is described in Appendices C and E.

7.7.1 HEAT DELIVERY AND LZC TECHNOLOGIES

The space heating system modelled in the basecase warehouse building was radiant heating pipes. This technology works by burning gas in a horizontal metal pipe suspended from the ceiling. As the pipe heats up it radiates heat directly to the floor of the building. Radiant pipe systems are quick to respond to changes in load, require no fans or pumps and are cheap and easy to install. This technology is therefore very suitable for most large warehouses.

LZC technologies which provide heat, normally deliver it using water as a working fluid. These technologies are not compatible with the conventional radiant heating system used in the basecase warehouse and therefore it was necessary to change the heating system delivery type to be compatible with the chosen LZC technology before it could be integrated into the warehouse dynamic thermal model. Changing the heating system type changes the energy required for fans and pumps - known as auxiliary energy.

For Part L compliance, the auxiliary energy requirement is calculated by a method prescribed in the NCM. Under the NCM, the auxiliary energy requirement is a function of the occupancy of the building, i.e. its daily period of operation, rather than with the actual use of the system.

This means that the energy used by fans and pumps in an NCM-modelled heating system does not reduce as levels of fabric thermal insulation increase. A well-insulated building will need less heating and so less energy will be required by fans and pumps which deliver this heat as they will be on for less time. The NCM neglects this saving. In the context of this project, this means that, under the NCM, the auxiliary energy requirement does not change between energy efficiency packages A, B and C; in reality the differing levels of thermal insulation would result in lower auxiliary energy requirements as the level of thermal insulation is increased.

For most of the LZC technologies modelled that provide heat, it was required to switch the heat delivery system to under floor heating. The NCM auxiliary energy requirement for under floor heating (0.951 W/m^2) is around 10 times that of radiant pipes. Therefore changing the basecase warehouse heat delivery system to under floor heating was predicted (using NCM) to increase carbon emissions by 51,000 $kgCO_2$/year; for energy efficiency Package C; this equates to an increase of 15%. Therefore, if the LZC technology is to provide an overall reduction in carbon dioxide emissions, it first has to overcome this increase in auxiliary energy.

Overcoming this increase in auxiliary energy demand becomes more difficult as the heating load of the building is reduced. This is because LZC technologies which provide heat rely on the building they supply having a demand for it; if this heat demand is reduced then the technology is used less and so its benefits are reduced.

RECOMMENDATION

Designers should consider the compatibility of LZC technologies with appropriate heat delivery systems and assess the impact of any additional auxiliary energy requirements on overall operation carbon emissions.

Furthermore, designers need to consider the compatibility of the LZC heat delivery system with the intended function of the warehouse building. For example although under floor heating is compatible with several viable LZC technologies for many warehouses under floor heating will not be appropriate

Each energy efficiency package defined in Section 7.3 has different levels of thermal insulation. As shown in Figure 7, space heating contributes just 4% of the carbon dioxide emissions under the scenario based on energy efficiency Package C. Therefore LZC technologies supplying heat in conjunction with advanced energy efficiency standards will struggle to offset the increased carbon dioxide emissions resulting from the increased auxiliary energy requirement. As the level of thermal insulation increases, the number of LZC technologies which are predicted to yield a net increase in carbon dioxide emissions grows, Table 5 shows these technologies.

As described in Appendix B, the NCM exaggerates the impact of increases in fan and pump energy requirements and so the number of technologies which fall foul of this problem is likely to be lower in practice.

The only LZC technology considered which does not increase the requirements for auxiliary energy whilst providing heat to the whole building is biogas radiant heating. This is a system which takes biogas from an on-site anaerobic digester and burns it in a conventional radiant pipe heating system. This system has the same low auxiliary energy requirements as the radiant pipe system used in the basecase building and therefore is not hampered by the need to overcome an increase in auxiliary energy.

TABLE 5
LZC TECHNOLOGIES PREDICTED TO CAUSE A NET INCREASE IN CARBON DIOXIDE EMISSIONS DUE TO THE REQUIREMENTS FOR CHANGING THE HEATING SYSTEM AND DELIVERY TYPE

COUPLED WITH ENERGY EFFICIENCY PACKAGE A	COUPLED WITH ENERGY EFFICIENCY PACKAGE B	COUPLED WITH ENERGY EFFICIENCY PACKAGE C
Ground duct	Ground duct	Ground duct
Small gas-fired CHP on-site	Small gas-fired CHP on-site	Small gas-fired CHP on-site
	Large gas-fired CHP on-site	Large gas-fired CHP on-site
	Open-loop Ground Source Heat Pump	Open-loop Ground Source Heat Pump
	Closed-loop Ground Source Heat Pump	Closed-loop Ground Source Heat Pump
	Energy from waste	Energy from waste
	Air Source Heat Pump	Air Source Heat Pump
	Small anaerobic digestion CHP on-site	Small anaerobic digestion CHP on-site
		Large anaerobic digestion CHP on-site
		Fuel cell CHP on-site
		Anaerobic digestion CHP off-site
		Gas CHP off-site
		Fuel cell CHP off-site
		Biomass CHP on-site
		Biomass CHP off-site
		Biomass heating
		Waste process heat

PROLOGIS, HEATHROW

7.7.2 SINGLE ON-SITE LZC TECHNOLOGIES

Only two on-site LZC technologies, in conjunction with appropriate energy efficiency measures, were predicted to achieve true 'zero carbon' i.e. a 117% reduction in regulated emissions. These were a 2.5MW wind turbine and roof-integrated photovoltaics. Table 6 shows the modelled results for these two on-site technologies in conjunction with energy efficiency Package C.

TABLE 6
MODELLED RESULTS OF ON-SITE LZC TECHNOLOGIES ACHIEVING ZERO CARBON (IN CONJUNCTION WITH PACKAGE C)

ON-SITE LZC TECHNOLOGY	REDUCTION IN TOTAL CO_2 EMISSIONS ($kgCO_2$/yr) (% REDUCTION IN REGULATED EMISSIONS)	CAPITAL COST (£) FOR PACKAGE C + LZC	25 YEAR NPV[1] SAVING (£) FOR PACKAGE C + LZC
2.5MW wind turbine (26% share)	1,058,860 (-117%)	1,501,978	-3,483,645
2.5MW wind turbine	2,913,135 (-322%)	4,555,728	-6,668,934
17,200m² array of roof integrated PV	1,147,995 (-127%)	7,626,793	2,496,337

[1] Excluding any income from feed-in tariffs – see Section 7.7.5.

7.7.3 ON-SITE WIND TURBINES

A range of sizes of on-site wind turbines was modelled. The largest and most cost effective was found to be a 2.5MW wind turbine which was predicted, in conjunction with energy efficiency Package C, to achieve a 322% reduction in regulated emissions beyond the requirements of the current (2006) Part L. A turbine of this size would achieve zero carbon for the warehouse whilst also providing a substantial income to its owner – see Section 7.7.5.

The research found that a 2.5MW wind turbine can provide sufficient energy to enable two warehouse buildings, each the size of the case study building, to be zero carbon. In future, business park developers may wish masterplan their sites so that large wind turbines can be erected to future-proof their buildings against ever tightening operational energy/carbon reduction requirements.

A 2.5MW wind turbine is a large structure with typical tower height of around 100m. Many warehouse buildings are located in large open areas away from residential buildings and therefore it was considered appropriate to model such a large turbine on-site. However, in reality, planning and other constraints will make the installation of such a large turbine impossible or impractical on many sites. Wind turbines should not be positioned within the 'topple distance' of any occupied building or within 300m of residential buildings [9].

A detailed review of the case study site in Stoke-on-Trent and the potential to erect a wind turbine, identified that it is possible to erect a 330kW turbine on the site but not the larger 2.5 MW turbine. Therefore when modelling combinations of LZC technologies on the basecase warehouse (see Section 7.8), a 330kW turbine was selected as the largest viable option for the case study site.

Local obstructions are important factors in determining the wind resource at the precise location where the wind turbine is to be installed; turbulence and wind-shadows develop down-wind of obstructions, both reducing the performance of the turbine. Therefore wind monitoring should be undertaken to establish a site's wind resources accurately.

7.7.4 ROOF-INTERGRATED PHOTOVOLTAICS

Photovoltaic (PV) panels covering approximately 50% of the total roof area (17,200m²), combined with either energy efficiency Package B or C, were predicted to provide an alternative route to zero carbon, although they incur a high capital cost and are not expected to pay back over the 25 year period considered. See Table 6 and also Section 7.7.5 on feed-in tariffs.

Progress in the development of photovoltaic technology over recent years has been rapid; this, combined with dramatic expansion in PV manufacturing capacity, has helped to reduce the capital costs of the technology. The PV variant modelled on the warehouse is a recent technology which intergrates thin amorphous photovoltaic panels into insulated roof panels. This technology has increased the cost effectiveness of PV and is suitable for most warehouse buldings.

Photovoltaic technology is silent and has no moving parts; the only situation when it would not be technically suitable is where the roof is shaded for much of the year. However the low-rise form of warehouses coupled with their usual out of town location, means the PV will be suitable technology for virtually all new warehouse buildings in the UK.

7.7.5 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 on-site or exported to the local electricity network.
2. An **export tariff** which is either metered and paid as a guaranteed amount that generators are eligible for, or is, in the case of very small generation, assumed to be a proportion of the generation in any period without the requirement of additional metering.

The scheme currently supports new anaerobic digestion, hydro, solar photovoltaic (PV) and wind projects up to a 5MW limit, with differing generation tariffs for different scales of each of those technologies. The current feed-in tariffs for low and zero carbon electricity are shown in Table 7.

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.

The Target Zero analysis on the warehouse building was undertaken before the Government published details of the feed-in tariff. Clearly FITs will have a major impact on the cost effectiveness of eligible LZC technologies and therefore will be included in other buildings considered under Target Zero, i.e. the out-of-town supermarket, the office and the mixed-use building.

TABLE 7
FEED-IN TARIFFS FOR LOW AND ZERO CARBON ELECTRICITY (DECC)

TECHNOLOGY	SCALE	TARIFF LEVEL FOR NEW INSTALLATIONS IN PERIOD (P/KWH)			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	10.0	10.0	10.0	10
PV	≤4kW (new build)	36.1	36.1	33.0	25
PV	≤4kW (retrofit)	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	25
Wind	>1.5-15kW	26.7	26.7	25.5	25
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	20.0
Wind	>1.5MW-5MW	4.5	4.5	4.5	20.0
Existing microgenerators transferred from the RO		9.0	9.0	9.0	to 2027

7.8 COMBINED ON-SITE LZC TECHNOLOGIES

Other than wind turbines and large-scale PV, the other on-site LZC technologies modelled were predicted to be unable to get the basecase warehouse to zero carbon; therefore further analyses were carried out to assess the effectiveness of combining several on-site LZC technologies using the method described in Appendix E.

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 on-site then this can be sold to the national grid for use in other buildings, however the infrastructure for doing this with heat is 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.

Therefore when combining LZCs technologies to create a package of compatible on-site 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 seven packages of on-site measures (energy efficiency and LZC technologies) that can achieve zero carbon; see Table 8. Where wind turbines have been modelled, their size has been limited to a 330kW turbine – see Section 7.7.3.

The table below shows that the most cost effective route (lowest NPV) to zero carbon is the combination of energy efficiency Package C with a 330kW wind turbine and a 5,700 m² array of photovoltaic panels. This combination of measures is the only one with a negative NPV.

Assessment of a range of viable combinations of energy efficiency measures and LZC technologies was also undertaken to identify the most cost-effective packages of compatible measures to achieve the likely future regulatory compliance targets. The most cost effective packages of measures which meet these targets are illustrated in Figure E1 in Appendix E and are fully defined in Table 9.

TABLE 8

PACKAGES OF COMPATIBLE MEASURES PREDICTED TO ACHIEVE ZERO CARBON

SOLUTION DESCRIPTION	BER (kgCO_2/M²/YR)	CAPITAL COST INCREASE (£) [%]	CHANGE IN 25 YEAR NPV (£)	LIMITATIONS
ENERGY EFFICIENCY PACKAGE A 23,360m² Photovoltaics	-4.80	9,320,299 [47.7%]	4,240,371	■ High capital costs of Photovoltaics
ENERGY EFFICIENCY PACKAGE A 330kW wind turbine 15,519m² Photovoltaics	-4.80	7,016,312 [36.0%]	1,989,576	■ Planning for wind turbine ■ High capital costs of Photovoltaics
ENERGY EFFICIENCY PACKAGE A Biogas-fired radiant heating 330kW wind turbine 9,518m² Photovoltaics	-4.80	6,036,079 [31.0%]	1,265,186	■ Space and infrastructure required for anaerobic digestion ■ Planning for wind turbine ■ High capital costs of Photovoltaics
ENERGY EFFICIENCY PACKAGE B 17,200m² Photovoltaics	-4.68	7,276,004 [37.3%]	2,362,078	■ High capital costs of Photovoltaics
ENERGY EFFICIENCY PACKAGE B 330kW wind turbine 9,301m² Photovoltaics	-4.64	4,782,127 [24.5%]	304,391	■ Planning for wind turbine ■ High capital costs of Photovoltaics
ENERGY EFFICIENCY PACKAGE C 13,522m² Photovoltaics	-4.61	6,147,766 [31.5%]	1,472,501	■ High capital costs of Photovoltaics
ENERGY EFFICIENCY PACKAGE C 330kW wind turbine 5,683m² Photovoltaics	-4.61	3,672,932 [18.8%]	-949,141	■ Planning for wind turbine ■ High capital costs of Photovoltaics

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

TABLE 9

SUMMARY OF MOST COST EFFECTIVE ROUTES TO ACHIEVING THE EXPECTED REQUIREMENTS OF FUTURE REVISIONS TO PART L (ASSUMING NO CONTRIBUTION FROM ALLOWABLE SOLUTIONS)

TARGET	MOST COST EFFECTIVE ROUTE	BER (kgCO_2/m²yr)	ADDITIONAL CAPITAL COST (£) [%]	25 YEAR NPV SAVING (£)
Likely 2010 revision to Part L requiring a 25% improvement over Part L 2006	High efficiency lamps and luminaires 1.79W/m² per 100 lux	15.2	-308,700 [-1.59%]	-2,937,984
Likely 2013 revision to Part L requiring a 44% improvement over Part L 2006	Energy efficiency package A (see Table 1)	11.1	-190,100 [-0.98%]	-2,470,354
The expected threshold for domestic on-site carbon compliance; 70% improvement over Part L 2006	Energy efficiency package A (see Table 1) On-site 330kW wind turbine	5.8	492,361 [2.52%]	-2,712,404
100% improvement over 2006 Part L (excludes unregulated emissions from energy used by small appliances such as IT equipment and white goods)	Energy efficiency package C (see Table 1) 330kW wind turbine	0.75	1,274,478 [6.54%]	-2,706,961
True zero carbon (expected standard for nondomestic buildings in 2019) i.e. 117% improvement on Part L 2006 for this warehouse	Energy efficiency package C (see table 1) 330kW wind turbine 5,700 m² of roof-integrated photovoltaics (Amorphous thin film)	-4.61	3,672,932 [18.84%]	-949,141

Table 9 demonstrates that significant reductions in operational carbon dioxide emissions can be achieved using a combination of energy efficiency measures and on-site LZC technologies, however the additional costs of doing this begins to become restrictive. For example it is predicted that to achieve a 70% improvement over the current (2006) Part L requirement incurs a capital cost increase of 2.5%, however to improve this to a 100% improvement requires a 6.5% increase in capital cost. This does not include the off-setting of the currently unregulated emissions, which increases the threshold to 117% and equates to true zero carbon.

7.9 DIRECTLY CONNECTED HEAT

The Carbon Compliance target discussed in the consultation on policy options for zero carbon non-domestic buildings [4] allows for 'directly-connected heat' as well as on-site generation. This can be provided by LZC technologies such as district CHP heating networks or heat networks from Energy from Waste (EfW) plants.

The Target Zero research found that the most cost-effective route to providing directly-connected heat is a district CHP plant. A number of CHP variants were modelled and a district CHP system powered by burning biogas from an anaerobic digester, in conjunction with energy efficiency Package A was predicted to be a cost effective route to achieving a 70% reduction below the current requirements of Part L 2006, although the use of Package B on its own is more cost effective than this. No district heating systems were predicted to achieve zero carbon; the greatest reduction in carbon dioxide emissions achieved by a district heating system was 86% using anaerobic digestion CHP combined with either energy efficiency Package A or B. However not all storage warehouses will be in an area where district schemes such as these are viable.

District heating schemes are most viable in dense urban areas where the heat demand is concentrated. A recent report [10] identifies that, although warehouse buildings account for over 20% of the heat demand from non-domestic buildings in the UK, there are two key issues that affect their suitability to the application of district heating networks:

- **warehouse buildings are often low density single storey buildings and the business parks that they are built on are often spread out with large spaces between buildings**
- **warehouse buildings are often located on out-of-town sites or relatively isolated areas for example next to motorways.**

However the report [10] goes on to say that if a sufficient thermal load does exist then a local district network within a business park may be as effective as connection to a larger network supplying a larger urban area.

The suitability of a 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 building types which would increase the viability of different types of district heating systems, Table 10 describes these.

TABLE 10
BUILDING TYPES WHICH AFFECT THE VIABILITY OF DIFFERENT TYPES OF DISTRICT HEATING SYSTEMS

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

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 (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 struggles with public resistance due to fear of 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. 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.**

As most new-build warehouses are located on business parks where there may be industrial processes taking place, there is a possibility that one or more of the adjacent buildings may be able to form the basis of a viable district heating network. CHP may be one of the most viable solutions technically; however its cost effectiveness is highly dependent on the proximity of the building to appropriate neighbouring properties and businesses.

Table 11 summarises the main off-site technologies that could provide directly-connected heat to the warehouse building. The modelled results of savings in carbon emissions, capital costs and NPV figures are presented. The results are based on energy efficiency Package B (see Table 1). Compared to the on-site LZC technologies, the directly connected heat technologies are relatively expensive with less good NPVs. This is principally due to the requirement to change the heating system from gas-fired radiant to under floor heating.

TABLE 11
DIRECTLY CONNECTED HEAT RESULTS

OFF-SITE TECHNOLOGY	OPERATIONAL CO2 EMISSIONS ($kgCO_2/yr$) [CHANGE FROM BASECASE]	CHANGE IN CAPITAL COST FROM BASECASE[1] (£) [%]	CHANGE IN 25 YEAR NPV[1] (£)
Biomass CHP off-site	334,846 [-68%]	683,044 [3.5%]	596,958
Fuel Cell CHP off-site	380,664 [-64%]	690,578 [3.6%]	604,493
Nat Gas CHP off-site	392,814 [-63%]	702,633 [3.6%]	616,548
Energy from waste	419,959 [-60%]	690,578 [3.6%]	839,185
Waste process heat	382,269 [-64%]	690,578 [3.6%]	839,185
Anaerobic digestion CHP off-site	280,887 [-73%]	690,578 [3.6%]	604,493

1 These costs exclude the capital cost and NPV of Energy Efficiency Package B measures

7.10 ALLOWABLE SOLUTIONS

The consultation on policy options for zero carbon non-domestic buildings [4] proposes the following Allowable Solutions:

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

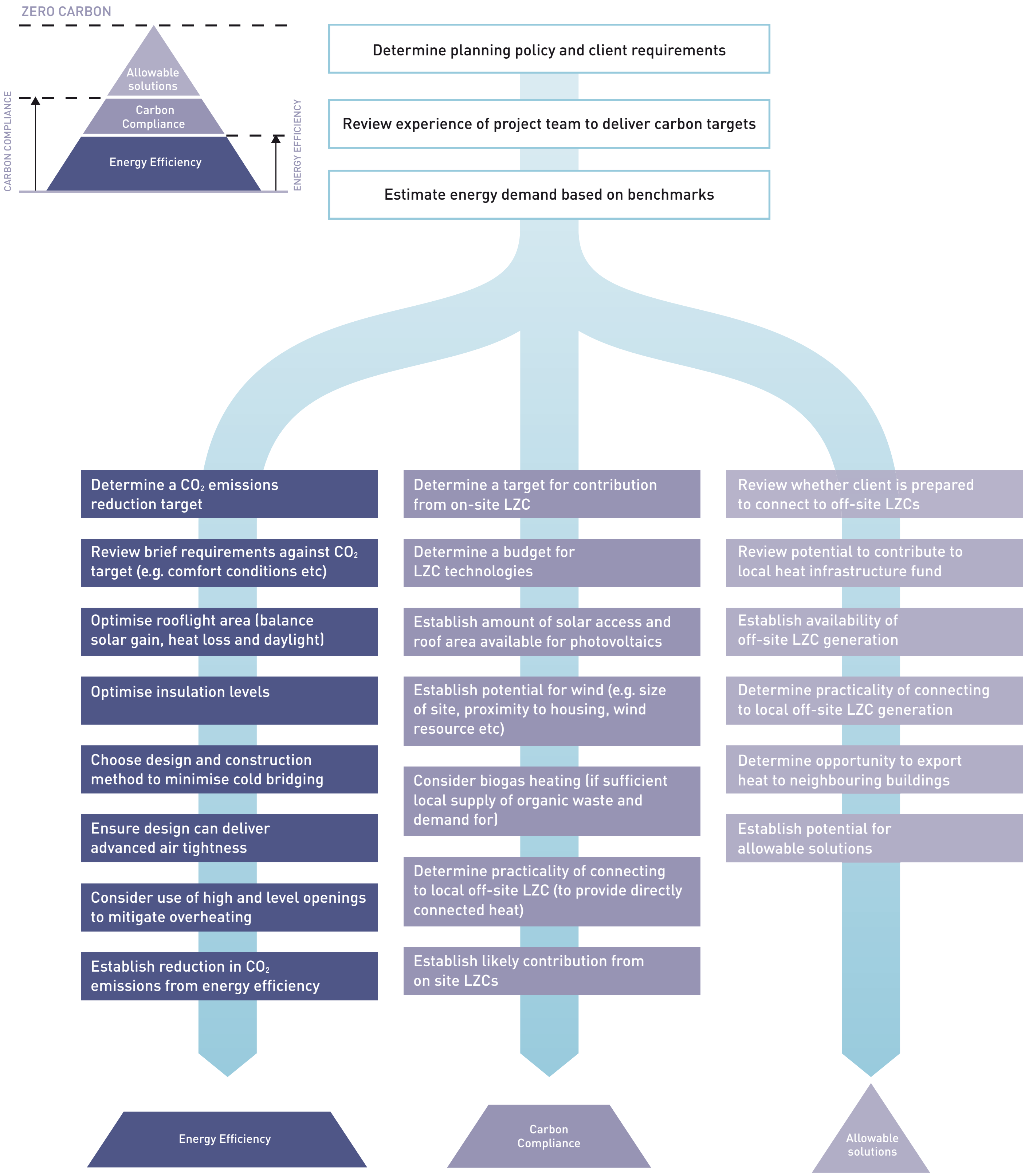
Other options also remain under consideration.

The potential for cost-effective Allowable Solutions needs to be considered alongside the Energy Efficiency and Carbon Compliance solutions. For instance, it would be expected that large-scale off-site Allowable Solutions would be more efficient than smaller-scale on-site LZCs. The choice may be limited, however, by the need to meet some of the carbon reduction target by on-site LZCs as Carbon Compliance measures. In addition, the NPV for the off-site wind (and other off-site 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.

PROLOGIS, PINEHAM

FIGURE 9

GUIDANCE FLOWCHART FOR DELIVERING LOW AND ZERO OPERATIONAL CARBON WAREHOUSE BUILDINGS



7.11 OPERATIONAL CARBON GUIDANCE

Figure 9 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 is given below.

Client and brief

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

The brief, and any operational carbon targets, should specify the contribution to be made from on-site LZC technologies and whether the client is prepared to connect to off-site 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 distribution warehouse.

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 Section 7.7.5) 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 warehouse building, lighting is the dominant contributor and, as shown in Figure 7, 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 of the building. For example, a large distribution warehouse operating 24 hours a day, seven days a week will have a far higher lighting and heating demand than a warehouse in operation during normal working 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 warehouse must set out clearly the targets and the contributions to be made from energy efficiency, LZC technologies (on- and off-site) 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.

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. However, the orientation of warehouse buildings is generally not a key factor in reducing operational carbon emissions. This is because, other than any office areas, warehouses generally have no conventional, vertical glazing.

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 zero carbon warehouses 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 off-site 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 for the basecase warehouse. Lighting contributes almost three quarters of the operational carbon dioxide emissions of the basecase building – see Figure 7. Optimising the lighting design in conjunction with the rooflight layout can reduce energy use significantly without major capital cost implications and is predicted to yield very good payback periods for warehouses.

This research has established that the design of rooflights for warehouse buildings is a key parameter in their operational energy and carbon performance. Careful rooflight design in combination with daylight dimming to control electrical lighting can reduce the carbon dioxide emissions of the basecase warehouse by over 30%. The use of an energy efficient lighting system can yield a similar carbon emissions reduction – see Figure 4.

Figure 8 shows the financial and carbon impacts of changing the area of rooflights. This reveals that the cost effectiveness (in terms of 25 year NPV) of altering rooflight area is almost constant between 10% and 20% with the optimum being at around 15% in this case.

The optimum solution depends on a number of variables, and therefore dynamic thermal modelling should be carried out to identify the optimum area of rooflights for each individual warehouse building. Where known, it is also recommended that the actual or likely hours of operation of the warehouse are taken into account when optimising the rooflight and lighting design. Although this will not affect the Part L compliance assessment using the NCM, as discussed in Sections 7.4 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 warehouses should also be investigated.

Where night time operation is assumed and/or very low U-value rooflights are used, the optimal rooflight area is likely to be in the range of 10% to 15% of total roof area [7].

This research established that the risk of overheating in summer can be significantly reduced through the use of high level openings with a free area equivalent to 1.35% of the floor area together with perforated security shutters on all docking doors to allow cool air to enter the building at night without compromising security. See Section 7.6.

RECOMMENDATION

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

- **area of rooflights for warehouse**
- **glazing strategy for office**
- **solar shading for office windows**
- **opening areas required for effective 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 12 lists, in descending order of cost-effectiveness (i.e. 25yr NPV/kgCO_2 saved), the ranking of energy efficiency packages and LZC technologies based on the assessment of the warehouse building. Although each 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.

The research found that a number of LZC technologies modelled actually caused an increase in carbon dioxide emissions and hence the number of viable LZC technologies in the table is limited. This is because of the relative efficiency of the radiant pipe system modelled in the basecase and the additional auxiliary energy requirement if alternative heat delivery systems, that are compatible with the selected LZC technology, are used (see Section 7.7.1). As discussed in Appendix B, the NCM exaggerates this impact and therefore using software not constrained by the NCM may provide a more accurate assessment of the benefits of LZC technologies that provide heat.

The only heat-producing LZC technology which does not increase the requirements for auxiliary energy whilst providing heat to the whole building is biogas radiant heating. This is a system which takes biogas from an on-site anaerobic digester and burns it in a conventional radiant pipe heating system. This system has the same low fan and pump energy requirements as the radiant pipe system used in the basecase building and so is not hampered by the need to overcome an increase in auxiliary energy.

TABLE 12
LZC TECHNOLOGIES MODELLED – IN DESCENDING ORDER OF COST-EFFECTIVENESS (25 YEAR NPV/kgCO_2 SAVED)

TECHNOLOGY	NOTES
Energy Efficiency package A	■ Advanced thermal bridging ■ High efficiency lamps and luminaires 1.79W/m² per 100lux ■ Glazing (rooflight) performance 1.50W/m²K ■ Improved air tightness 5m³/hr per m² @50Pa ■ 10% rooflights with daylight dimming
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)
Medium 330kW wind turbine	■ Enercon ■ 50m tower height ■ 33.4m rotor diameter ■ Could be on-site in some cases
Energy efficiency package B	■ Advanced thermal bridging ■ Very high efficiency lamps and luminaires 1.64W/m² per 100lux ■ 20% rooflights with daylight dimming ■ Glazing (rooflight) performance 0.90W/m²K ■ Advanced air tightness 3m³/hr per m² @50Pa ■ Occupancy sensing lighting controls ■ Very efficient office ■ Improved wall insulation 0.25W/m²/K
Energy efficiency package C	■ Advanced thermal bridging ■ Advanced high efficiency lamps and luminaires 1.42W/m² per 100lux ■ 20% rooflights with daylight dimming ■ Glazing (rooflight) performance 0.90W/m²K ■ Occupancy sensing lighting controls ■ Ultra high air tightness 1m³/hr per m² @50Pa ■ Very efficient office ■ Advanced wall insulation 0.15W/m²K ■ Advanced roof insulation 0.10W/m²K ■ High absorbtance paint
Medium 50kW wind turbine	■ Entegrity ■ 36.5m tower height ■ 15m rotor diameter
Small 20kW wind turbine	■ Westwind ■ 30m tower height ■ 10m rotor diameter
Photovoltaics	■ Roof-integrated amorphous PV ■ 17,200m²
Small1kW wind turbine	■ Futurenergy ■ 6.2m tower ■ 1.8m rotor diameter
Biomass heating for whole building on-site	■ Space heating and hot water
Solar Water Heating	■ 8.64m² sized to provide as much hot water as is practical (i.e. around 45%)
Waste process heat	■ Space heating and hot water
Biogas heating on-site	■ On-site anaerobic digestion supplying biogas to conventional gas fired heating and hot water systems
Open loop ground source heat pump for office only on-site	■ Space heating
Closed loop ground source heat pump for office only on-site	■ Space heating

Structural design considerations

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

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

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

The influence of the structure on the operational carbon emissions of the warehouse building was found to be small, less than 3.5% - see Section 9.1.

RECOMMENDATION

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

7.12 IMPACTS OF CLIMATE CHANGE

Modelling the effects of climate change on the warehouse building, using CIBSE weather tapes based on UKCIP climate predictions for the UK[1], showed that the heating requirements of the warehouse will progressively reduce over time. Analysis of the case study warehouse building showed that heating loads are expected to decrease by 10% between 2005 and 2020 and by 24% to 33% between 2005 and 2050. This range is a function of the warehouse structure – see Section 9.

The effect on carbon dioxide emissions from these changes in heating demand is to reduce total building emissions by 1% by 2020 and by 4% between 2005 and 2050. The carbon emissions of the three building structures modelled (see Section 9) converge as climate change progresses.

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

Climate change is predicted to raise temperatures and so the risk of overheating is also likely to rise in future. Anecdotal evidence already suggests that modern, highly insulated warehouses frequently experience high internal temperatures. Testing of a number of different approaches found that the risk of overheating in the warehouse could be significantly reduced by a number of relatively simple measures including:

- careful optimisation of the area of rooflights
- inclusion of high-level openings combined with perforated security shutters on docking doors to allow the secure natural ventilation of the warehouse on summer nights
- 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 warehouse 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.

8.0 ROUTES TO BREEAM 'OUTSTANDING'

ROUTES TO BREEAM 'OUTSTANDING'

The objective of this aspect of the study was to determine the most cost-effective routes to achieving a 'Very Good', 'Excellent' and 'Outstanding' BREEAM industrial (2008) rating for the basecase distribution warehouse building. It is important to note that the BREEAM assessment was undertaken on the basecase building (see below). The actual case study building achieved a BREEAM (2006) 'Excellent' rating with a score of 76.08%[1].

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 warehouses, 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 warehouse 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 fundamental redesign of the building. Instead, the credits that are based on fundamental design decisions are identified in the guidance.
5. For site related issues, e.g. re-use 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 followed:

- 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 are set out in Table 13.

1 The current version of BREEAM Industrial is BREEAM 2008 which is more demanding then BREEAM 2006.

TABLE 13

KEY ASSUMPTIONS FOR THE SIX BREEAM ASSESSMENT SCENARIOS

ASSUMPTION	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)
Biomasss feasible	Yes	No	Yes	Yes	Yes	Yes	Yes
Public transport links	Average	Good	Poor	Average	Average	Average	Average
Within 500m of shop, post box and cash machine?	No	Yes	No	No	No	No	No
Has ≥ 75% of the site been developed in the last 50 years?	Yes	Yes	No	Yes	Yes	Yes	Yes
Ecological value	Low	Low	High	Low	Low	Low	Low
Zero carbon pursued?	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	4	1	1
On-site wind viable?	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= Nat vent openings >10m from opening; 2 = <10m from opening; 3 = intakes/extracts >10m apart; 4 = intakes/extracts <10m apart

The basecase scenario was based on the actual location, site conditions, etc. of the Stoke-on-Trent distribution warehouse 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 to achieve the target 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 warehouse 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 10 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 10
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 14.

TABLE 14
MINIMUM BREEAM REQUIREMENTS

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

The majority of these 'mandatory credits' are relatively simple and cost-effective to achieve, with the exception of the Ene1 credits, which can be costly and difficult to achieve for the 'Outstanding' rating, as shown in Table 15.

TABLE 15
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	-	1,500	1,500
Hea 4 High frequency lighting	0	0	0
Hea 12 Microbial contamination	0	0	0
Ene 1 Reduction in CO_2 emissions	-	5,000	586,264
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	2,200	2,200	44,000
Wat 2 Water meter	0	0	0
Wst 3 Storage of recyclable waste	-	0	0
LE 4 Mitigating ecological impact	0	0	0

8.0 ROUTES TO BREEAM 'OUTSTANDING'

CREDITS ASSOCIATED WITH SITE FACTORS

The location of the building has the most impact on:

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

Figure 11 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. It shows the most cost-effective routes under the urban, greenfield and case study scenarios to achieve a BREEAM 'Outstanding' rating.

FIGURE 11

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

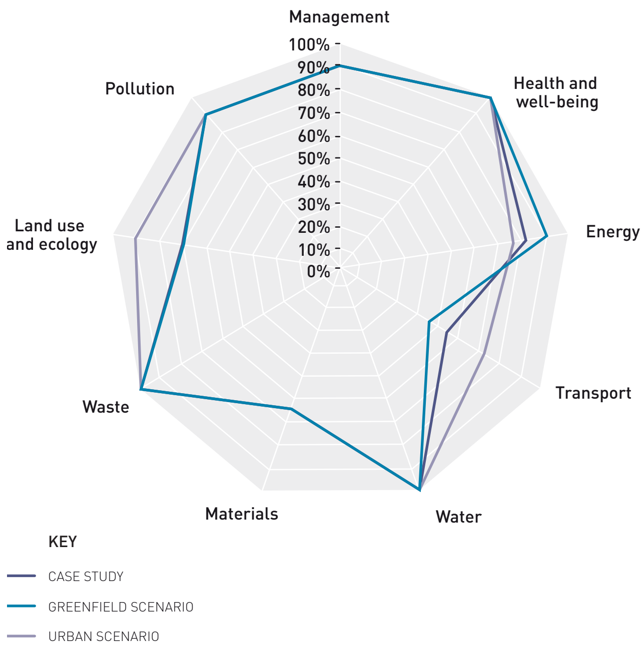


Figure 11 shows that under the greenfield scenario, Transport (Tra) and Land Use and Ecology (LE) credits are lost relative to the other scenarios, requiring credits to be obtained in other BREEAM sections. In this case, the most cost-effective credits were achieved in the Energy section.

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 uplift for the two location scenarios considered and the case study building is shown in Figure 12. The results for the case study building show that the capital cost uplift is 0.04% for 'Very Good', 0.43% for 'Excellent' and 4.82% for the 'Outstanding' rating.

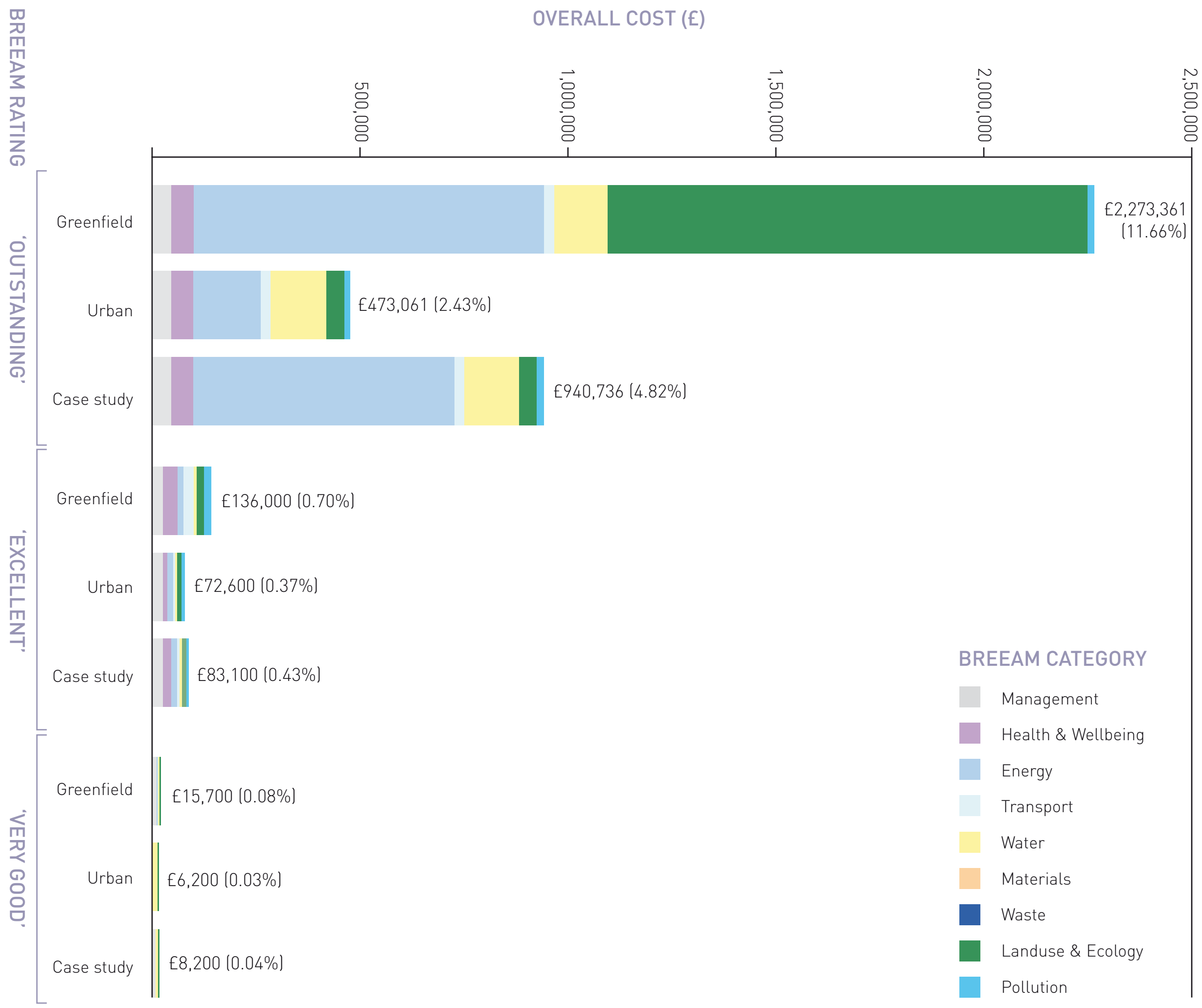
The Greenfield scenario is more expensive than the urban and case study scenarios. This is due to factors such as the high ecological value of the site and poor transport access limiting the overall number of credits available. To achieve an 'Outstanding' rating, all of the available ecology credits need to be achieved. This is particularly expensive on a site that already has a high ecological value as additional features have to be incorporated on the site to achieve the credits. For the case study building, it was assumed that an extensive green roof would be installed over approximately 25% of the roof and a strip of wildlife planting and a small pond would be provided to achieve the necessary credits.

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.

FIGURE 12

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 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 13 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.

The bottom bar in Figure 13 represents the capital cost of the scenario where on-site wind technologies are viable (a 330kW turbine was assumed), the next bar up reflects a scenario is which on-site 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 show 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 and the utility cost savings over a 25 year period.

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

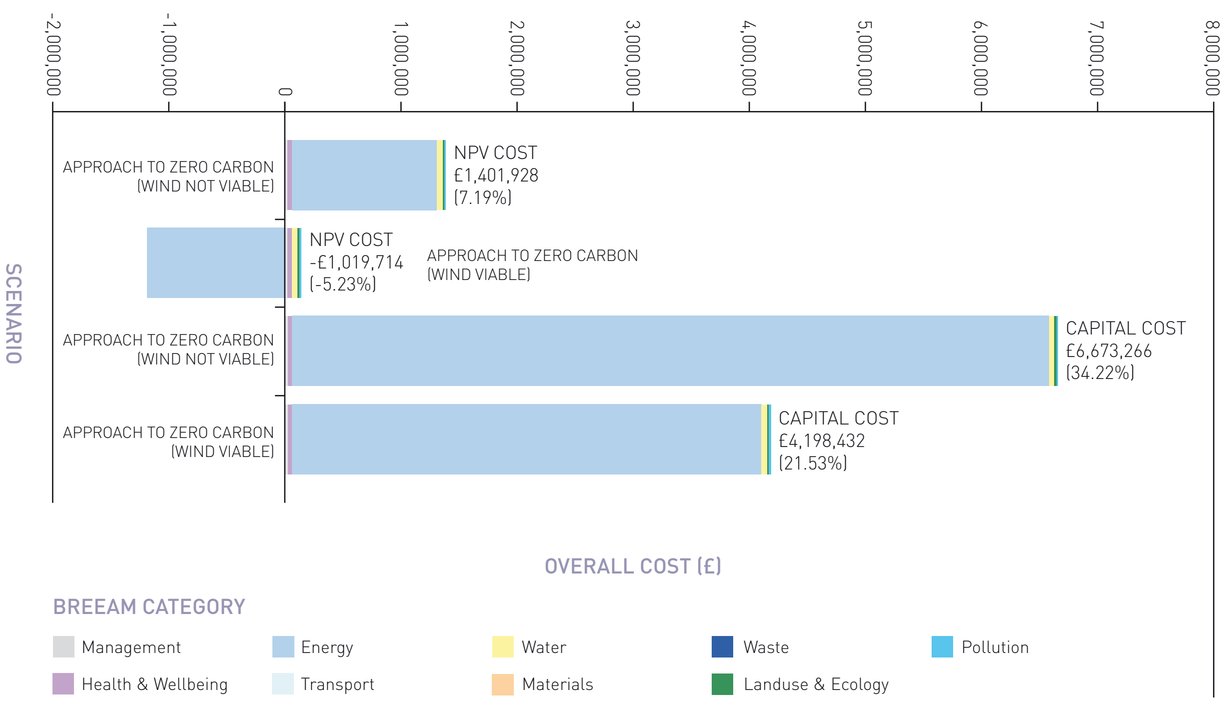
RECOMMENDATION

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

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.

FIGURE 13

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



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 on site) 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 16. It was assumed that an 'exemplar' contractor would be able to achieve all of these credits, which are all relatively low cost.

TABLE 16
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

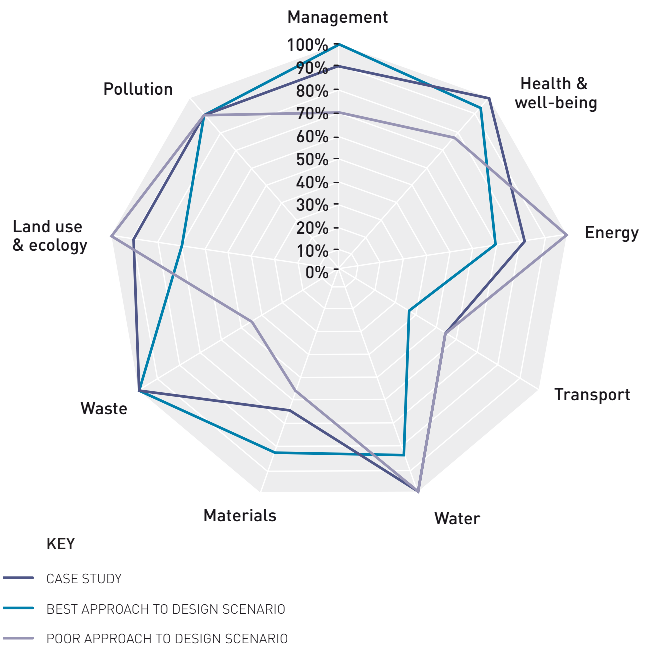
Early design decisions about the fabric and form of the building will have an impact on the following BREEAM credits:

- **Hea 2: View out, in terms of depth of floor plate of the office areas**
- **Hea 7: Potential for natural ventilation, in terms of the depth of floor plate and whether the occupied areas have been designed to be naturally ventilated. An occupied area is defined as a room or space in the building that is likely to be occupied for 30 minutes or more by a building user. Typically this is the office area of the building**
- **Hea 8: Indoor air quality, in terms of avoiding air pollutants entering the building**
- **Hea 13: Acoustic performance, which includes the performance of the façade**
- **Pol 5: Flood risk, assuming that the building has been designed to comply with Planning Policy Statement 25 and Sustainable Urban Drainage Systems have been included in the design.**

Figure 14 shows a comparison between the credits required under typical 'best practice' and 'poor' approaches to design. It illustrates the balance of credits required to achieve a BREEAM 'Outstanding' rating under the typical 'best' and 'poor' approaches assumed for the industrial building.

FIGURE 14

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 Wellbeing, Materials and Waste sections and consequently that more credits have to be achieved in other sections, notably the Energy, Water and Land Use and Ecology sections. Credits in these sections are more costly to achieve.

For the case study building, the results show that to achieve an 'Excellent' rating there is a cost uplift of 2.17% if a 'poor' design approach is followed compared to 0.17% where 'best practice' approach is adopted. In terms of capital cost, this is a £390,683 saving. To achieve an 'Outstanding' rating, a best practice design approach has to be followed and incurs a marginal capital cost of £295,736. An 'Outstanding' rating cannot be achieved using a 'poor' design approach; the maximum achievable score of 82% being lower than the threshold required to achieve an 'Outstanding' rating.

The total capital cost uplift of the two 'design approach' scenarios considered is shown in Figure 15.

FIGURE 15
COMPARISON OF COST UPLIFT FOR DIFFERENT APPROACHES TO DESIGN SCENARIOS

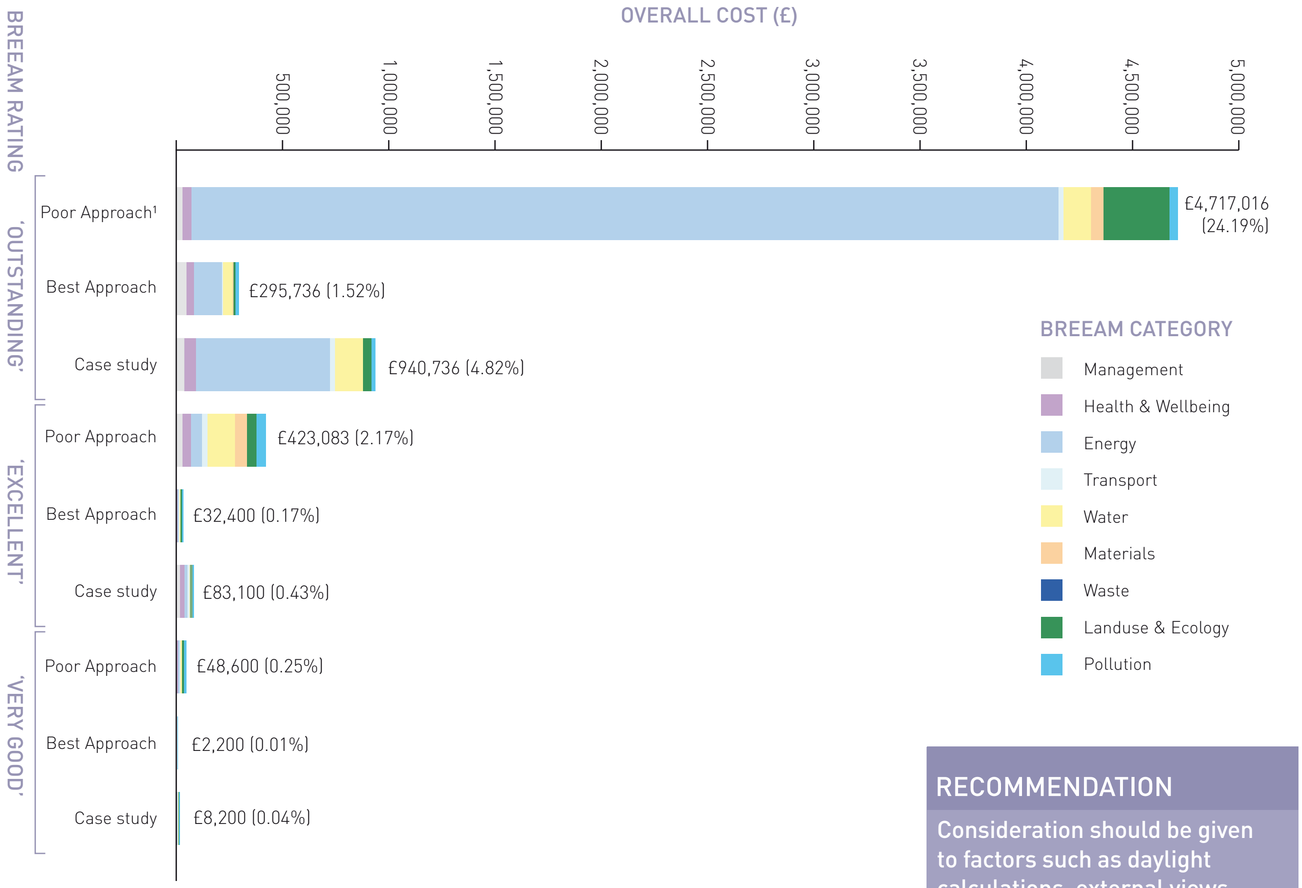


Table 17 shows the credits that relate to the form and fabric of the building. These should be considered at an early stage in the project so that they can be cost-effectively integrated into the design. It is noted that most of these credits relate to the office areas of the warehouse[2].

RECOMMENDATION

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

TABLE 17
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 office areas, this needs to be considered when deciding the depth and orientation of the office wing.	3,000 (to undertake day lighting study)
Hea 2 View Out	This credit needs desks in the office areas to be within 7m of a window which needs to be considered when deciding the depth and orientation of the office wing.	0
Hea 7 Potential for Natural Ventilation	Openable windows equivalent to at least 5% of the floor 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 (5m³/hr per m² @50Pa); glazing performance (1.79W/m² per 100lux); area and position of rooflights.	Cost varies depending on energy package: £5,000 for 'Excellent' and £584,264 for 'Outstanding' for case study scenario

1 The Poor Approach to design scenario does not achieve an 'Oustanding' rating (achieving only 82%).

2 Under BREEAM Industrial, the approach to the assessment (and hence the relative importance) of office areas within industrial buildings differs depending on the size of office space provided. The relevant threshold for the office floor area is 500 m2. An industrial building with an office floor area greater than 3,000 m2 has to be assessed by the BRE. For more information refer to the BREEAM Industrial Assessor Manual [1].

To achieve the Hea credits in Table 17, 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.

The case study building has an office as an additional wing of the warehouse. Offices could be incorporated into the main building on the ground floor or as a mezzanine however this could reduce the potential to achieve Hea1 Daylighting, Hea 2 View Out and Hea 7 Potential for natural ventilation.

The design of the rooflights is a key parameter in the operational energy performance of warehouses. Dynamic thermal simulation of the case study warehouse (see Section 7.3) showed that careful rooflight design in combination with the use of daylight dimming to control electrical lighting can have a significant effect on operational carbon emissions.

The results show that the cost effectiveness of altering the rooflight area is almost constant between 10% and 20% with the optimum being at 15% based on NCM assumptions. See Section 7.5 for more detailed information on rooflights.

Table 18 gives the credits that relate specifically to the space allocation, adjacencies and to the layout of the building and associated landscape:

TABLE 18
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	Facilities need to be within accessible distance of the building (20m) with good vehicular access. Typically, the storage space would need to be 10m² (for buildings over 5,000m²) and there would need to be an additional 10m² where catering is provided.	0
Tra 3 Cyclists facilities	Secure, covered cycle racks have to be provided for between 5 and 10% of building users, depending on the number of occupants and the location. There also needs to be showers, changing facilities and lockers along with drying space.	10,500 for the first credit. 10,000 for the second credit.
Tra 4 Access for pedestrians and cyclists	Site layout has to be designed to ensure safe and adequate cycle access away from delivery routes and suitable lighting has to be provided.	0
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). 20,000 (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.	32,000 (for the first two LE5 credits if land of low ecological value). 421,000 (for the first two LE5 credits if land of medium / high ecological value). For the third credit it would cost an additional 265,000 if land of low ecological value and 1,105,000 if land is of medium / high ecological value.

POTENTIAL COSTS OF BREEAM CREDITS

Figures 16 to 18 show the most cost-effective routes to achieve a BREEAM 'Very Good', 'Excellent' and 'Outstanding' respectively for the case study warehouse building. They show the cumulative credits, and costs, required to achieve the target BREEAM 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 warehouse 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 achieve high BREEAM ratings in buildings of a similar type and size, 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 industrial building.

The graphs show that there are a number of credits that are considered zero cost for the case study warehouse building. These credits will be low or zero cost on similar 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.

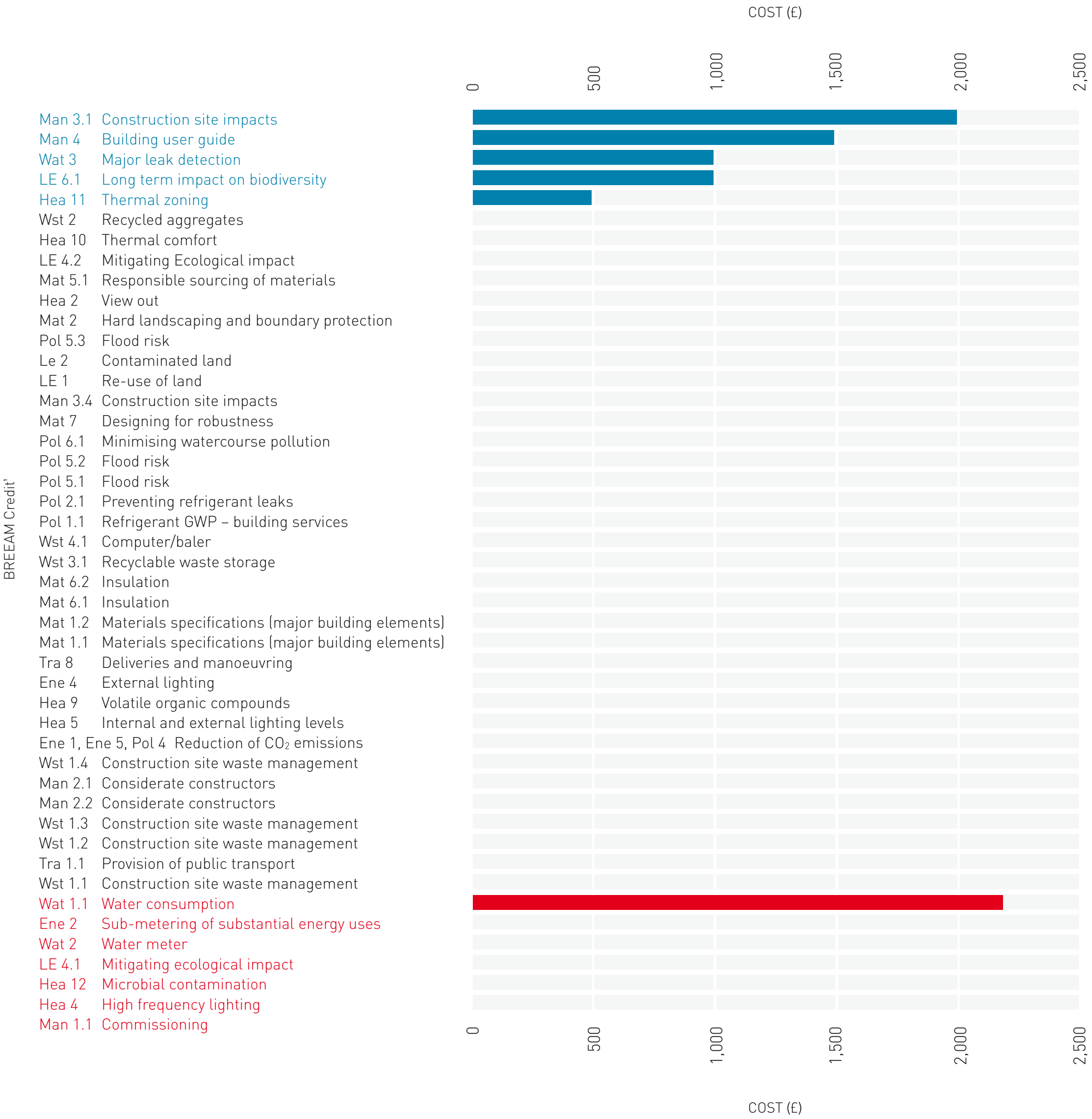
RECOMMENDATION

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.

8.0 ROUTES TO BREEAM 'OUTSTANDING'

FIGURE 16
LOWEST COST ROUTE TO BREEAM VERY GOOD RATING

ROUTE TO VERY GOOD - CASE STUDY SCENARIO

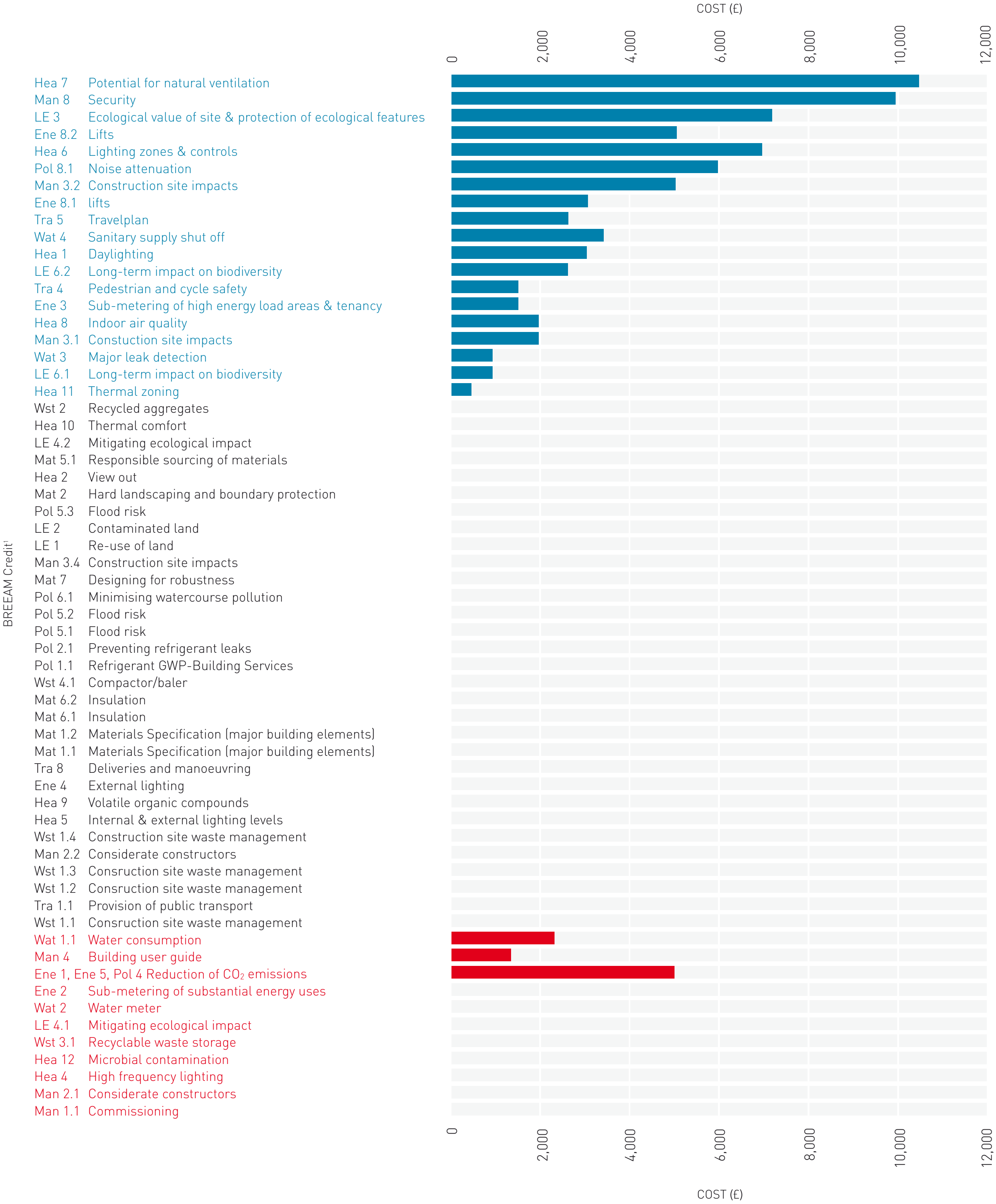


1 Ranking of credits is based on their weighted cost (capital cost of the credit divided by the credit weighting), whereas the values shown in the figure are the actual (non-weighted) cost of achieving the credit.

8.0 ROUTES TO BREEAM 'OUTSTANDING'

FIGURE 17
LOWEST COST ROUTE TO BREEAM EXCELLENT RATING

ROUTE TO EXCELLENT - CASE STUDY SCENARIO



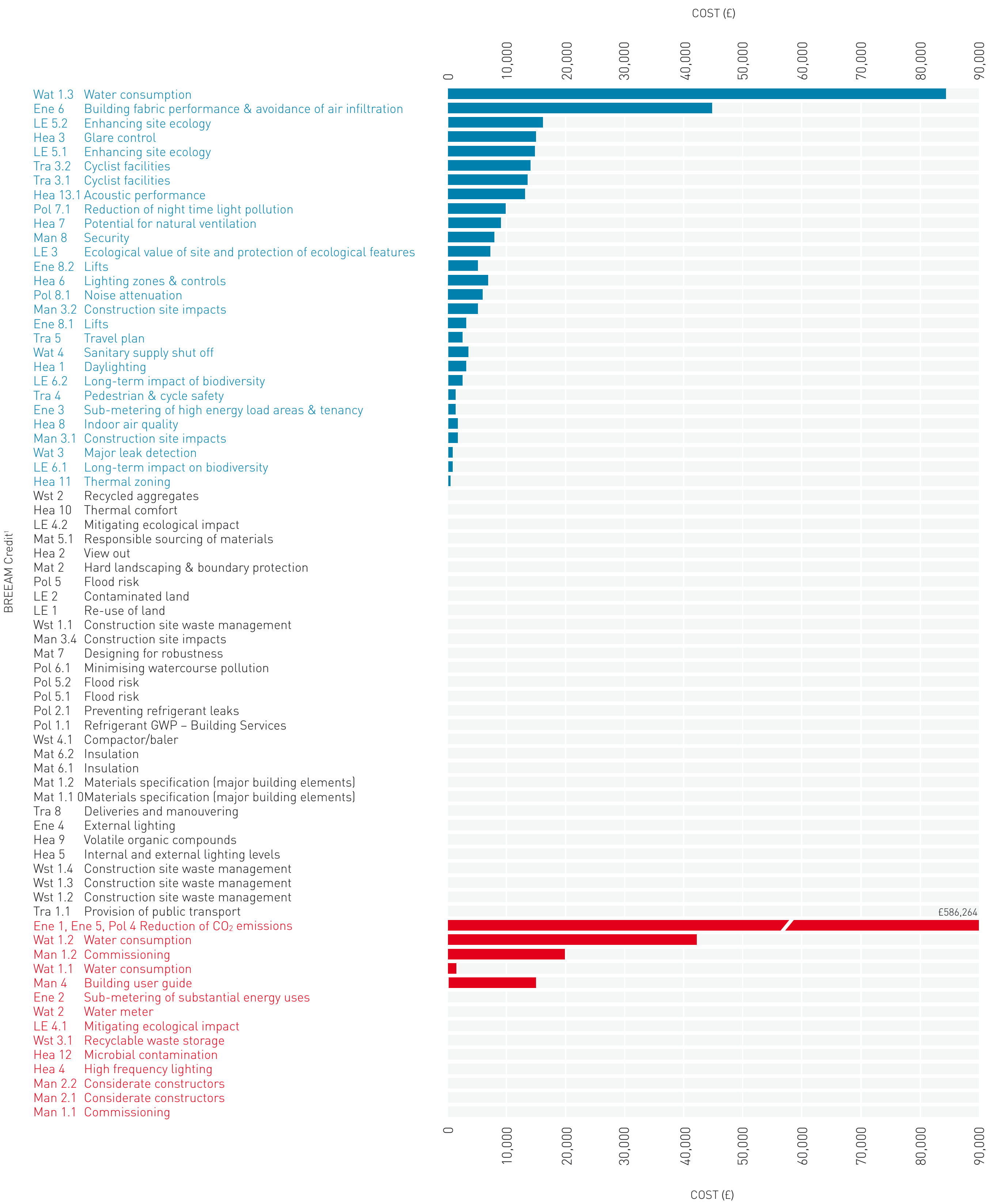
1 Ranking of credits is based on their weighted cost (capital cost of the credit divided by the credit weighting), whereas the values shown in the figure are the actual (non-weighted) cost of achieving the credit.

8.0 ROUTES TO BREEAM 'OUTSTANDING'

FIGURE 18

LOWEST COST ROUTE TO BREEAM OUTSTANDING RATING

ROUTE TO OUTSTANDING - CASE STUDY SCENARIO



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 figure are the actual (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 daylight factors from 2% to 3%**
- **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 £9,100, 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 £84,400.

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 for BREEAM Industrial are shown in Table 19. Reflecting the relative simplicity of industrial buildings, only two elements are assessed.

TABLE 19
ELEMENT WEIGHTINGS WITHIN THE BREEAM MATERIALS ASSESSMENT TOOL

ELEMENT	EXTERNAL WALLS	ROOF
Weighting	1	0.73

Table 19 shows that external walls have a higher weighting than the roof. For the case study building, the full two (Mat 1) credits were achieved by selecting Green Guide to Specification [11], A+ rated materials for the external walls and roof. The research showed that it is easier to achieve the materials credits under the BREEAM Industrial scheme (compared to other BREEAM schemes) as pre-finished steel wall and roof cladding systems all have Green Guide ratings of A or A+.

The inherent weighting of the external wall (1) in the BREEAM tool makes this a more important element, but as there are only two elements, the potential score is heavily reliant on the area ratios of the roof and walls.

9.0 STRUCTURAL DESIGN

STRUCTURAL DESIGN

Three alternative structural options for the warehouse building were assessed as shown in Figure 19.

FIGURE 19
ALTERNATIVE STRUCTURAL OPTIONS

BASECASE: STEEL PORTAL FRAME

OPTION 1: GLUE-LAMINATED TIMBER RAFTERS ON PRECAST CONCRETE COLUMNS

OPTION 2: STEEL PORTAL FRAME WITH NORTHLIGHTS

The office structure in the basecase building and Option 2 comprised a braced steel frame supporting pre-cast concrete planks. For Option 1, the office structure comprised pre-cast concrete columns and beams supporting pre-cast concrete planks.

Full building cost plans for each structural option were produced using mean values, current at 3Q 2009. These costs are summarised in Table 20.

TABLE 20

COMPARATIVE COSTS OF ALTERNATIVE STRUCTURAL DESIGNS

STRUCTURAL OPTION	DESCRIPTION	WAREHOUSE COST		OFFICE COST		TOTAL COST PLAN[1]	TOTAL BUILDING RATE	DIFFERENCE RELATIVE TO BASECASE
		(£k)	(£/m² GIFA)	(£k)	(£/m² GIFA)	(£k)	(£/m² GIFA)	(%)
Basecase	Steel portal frame	14,700	432	1,641	1,180	19,441	549	-
Option 1	Glulam beams and purlins supported on concrete columns	17,000	500	1,649	1,185	21,749	615	+12
Option 2	Steel portal frame with northlights	16,300	479	1,641	1,180	21,041	595	+8

1 Includes site works cost of £3,100,000.

With reference to external published cost analyses, such as the RICS Building Cost Information Service (BCIS), the typical benchmark cost range for steel-framed warehouses in excess of 2,000m² gross internal floor area (GIFA) is in the order of £370/m² to £560/m². These figures exclude site works. The rate for the basecase warehouse, £432/m², falls in the lower half of the typical cost range.

The cost of site works, car parking, landscaping, services, lighting etc., is clearly project specific. As a broad rule of thumb for large warehouses, however, a budget allowance in the order of 12% to 15% of the total construction cost is not uncommon, and the cost plan reflects this, with the estimate of £3.1m equating to 15% of the total cost.

Table 21 gives a breakdown of the structural frame cost for each building option. The 'frame' includes all primary and secondary structural members, bracing and fire protection. In addition to the higher structure cost for the pre-cast concrete and glulam building (Option 1), the extra weight of this structure required larger and hence more costly foundations. Relative to the basecase, the foundation cost for Option 1 showed a 36% increase.

TABLE 21

COST BREAKDOWN FOR THE STRUCTURAL FRAME

STRUCTURAL OPTION	DESCRIPTION	WAREHOUSE FRAME COST		OFFICE FRAME COST		TOTAL FRAME COST		DIFFERENCE RELATIVE TO BASECASE
		(£k)	(£/m² GIFA)	(£k)	(£/m² GIFA)	(£k)	(£/m² GIFA)	(%)
Basecase	Steel portal frame	2,158	63	126	91	2,284	65	-
Option 1	Glulam beams and purlins supported on concrete columns	4,042	119	135	97	4,177	118	+83
Option 2	Steel portal frame with northlights	2,868	84	126	91	2,994	85	+31

9.1 IMPACT OF STRUCTURE ON OPERATIONAL CARBON EMISSIONS

Dynamic thermal modelling of the warehouse showed little variation in operational carbon emissions; the Building Emissions Rate (BER) varying by only 0.8kgCO_2/m²yr, or 3%, between the three structural options considered. The predicted annual CO_2 emissions for each of the three buildings are shown in Table 25. The small difference modelled between the basecase and Option 1 was a function of the warehouse volume. Although both buildings were designed with a clear height to haunch of 12m, the depth and pitch of the glulam rafters in Option 1 reduced the height of the building slightly reducing the space heating requirement marginally.

Option 2 is a fundamentally different design from the basecase. The inclusion of northlights allows diffuse light to enter the middle of the warehouse 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 warehouse 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 0.8kgCO_2/m²yr i.e. 3.3% relative to the basecase.

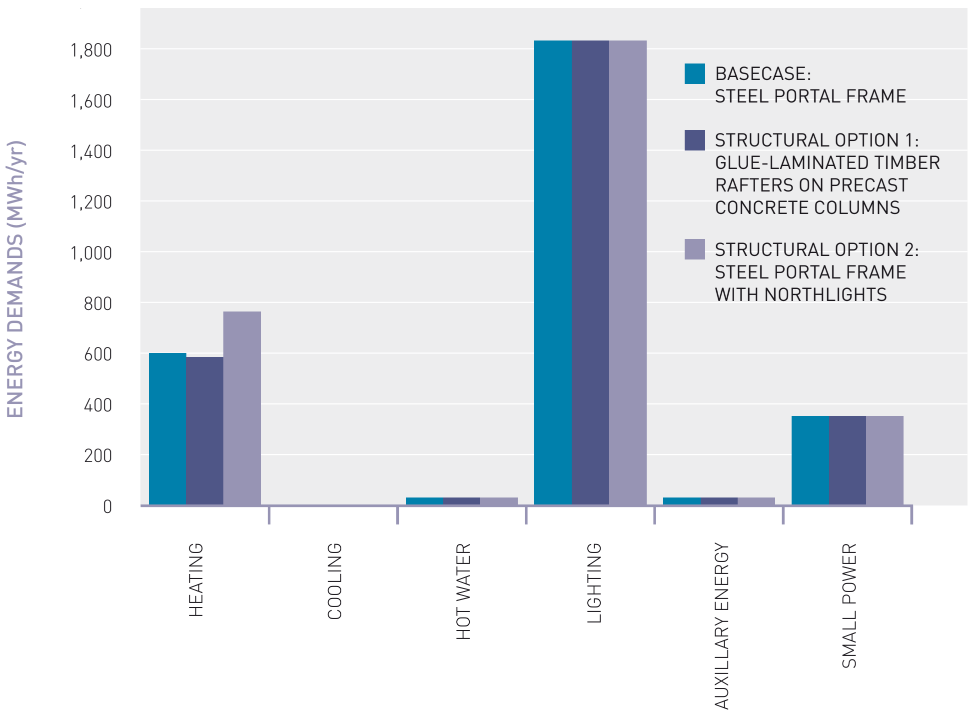
Figure 20 (below)) shows the variation in energy demand between the basecase warehouse and the alternative structural options. Note that the energy required for lighting in Option 2 is the same as for Option 1 and the basecase since daylight dimming was not included in these models. Had daylight dimming lighting controls been included, the northlight solution may have yielded a lower BER than the basecase building.

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 facades to place photovoltaic panels. 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.

TABLE 22
BUILDING EMISSIONS RATE (BER) FOR THE BASECASE BUILDING AND OPTIONS 1 AND 2

BUILDING	DESCRIPTION	BER (kgCO_2/m² yr)
Basecase	Steel portal frame	23.9
Option 1	Glulam beams and purlins supported on concrete columns	23.8
Option 2	Steel portal frame with northlights	24.7

FIGURE 20
VARIATION IN OPERATIONAL ENERGY DEMAND



EMBODIED CARBON

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

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

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

It is important that all 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.

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 G.

The building elements included in the embodied carbon assessment were:

- **foundations and ground floor slab, including associated fill materials**
- **superstructure (including all structural columns and beams, cladding rails and fire protection)**
- **office upper floors and stairs**
- **walls (internal partition and external)**
- **roof**
- **windows and rooflights**
- **drainage**
- **external works (parking and paving).**

Each building was assumed to have the same facade, glazing and drainage and therefore the embodied carbon of these elements of the building was identical.

The Target Zero model should not be considered as a full assessment of embodied carbon for a completed development. Certain items were excluded from the analysis principally because they did not vary between the three structural forms considered and there was insufficient data on precise material quantities or embodied carbon emissions associated with these items. Items excluded from the scope of the study included internal doors, internal fit-out, lifts, dock doors and levellers, wall, floor and ceiling finishes and building services.

ProLogis has commissioned indepedent carbon footprint analyses of other UK distribution warehouse buildings which are more comprehensive in scope than the Target Zero study, ie. they include all elements of the development – see www.prologis.co.uk.

Figure 21 shows the total embodied carbon impact of the basecase warehouse building and the two alternative structural options studied. Relative to the basecase, the concrete/glulam structure (Option 1) has a higher (14%) embodied carbon impact and the steel portal frame with northlights (Option 2) has a 7% greater impact.

Normalising the data to the total floor area of the building, gives the following embodied carbon emissions of 234, 266 and 251kgCO_2e/m² for the basecase and structural Options 1 and 2 respectively.

FIGURE 21
TOTAL EMBODIED CARBON EMISSIONS OF THE BASECASE BUILDING AND STRUCTURAL OPTIONS 1 AND 2

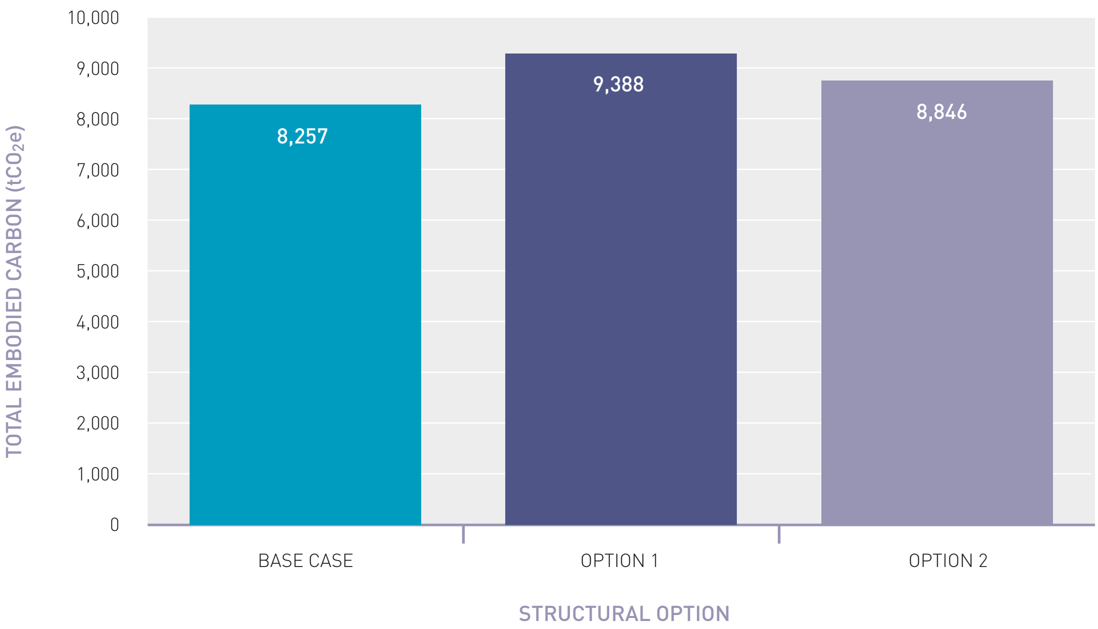
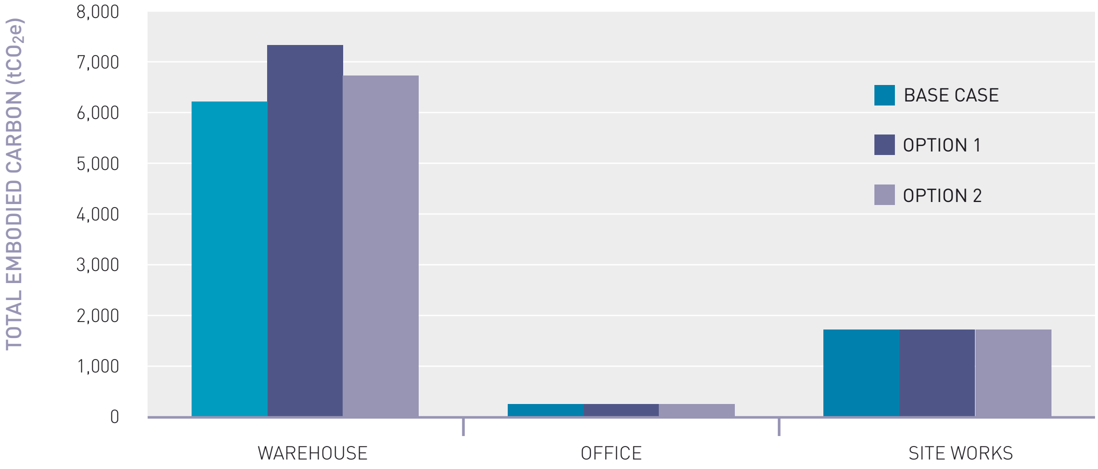


Figure 22 shows the breakdown of embodied carbon between the warehouse, office wing and site works. Site works include hard-standings, landscaping, etc. The embodied carbon in the warehouse represents between 75% and 78% of the total impact of the building. Site works, which are the same for each warehouse assessed, represent between 18% and 21% of the total embodied carbon impact.

Comprising just 4% of the total floor area of the building, the embodied carbon of the office is relatively low representing between 3% and 4% of the total impact of the building. Normalising the data to floor area however the embodied carbon of the office wing ranges from 230 to 23kgCO_2e/m² whereas the embodied carbon of the warehouse is between 183 and 21kgCO_2e/m².

FIGURE 22

BREAKDOWN OF EMBODIED CARBON BETWEEN WAREHOUSE, OFFICE AND SITE WORKS



Figures 23 and 24 show the mass of materials used to construct each of the three warehouse buildings, broken down by element and material respectively. The total mass of materials used to construct the warehouse was estimated to vary between 73.4kt (Basecase) and 76.2kt (Option 1).

The figures show that most of the materials (60% to 70%) are used in the foundations and floor slab, comprising mainly concrete and fill materials. The site works and drainage also take significant quantities of materials, also dominated by concrete and fill. A relatively small proportion (3 to 4%) of the total building materials is used in the bearing structure.

FIGURE 23

MASS OF MATERIALS - BREAKDOWN BY ELEMENT

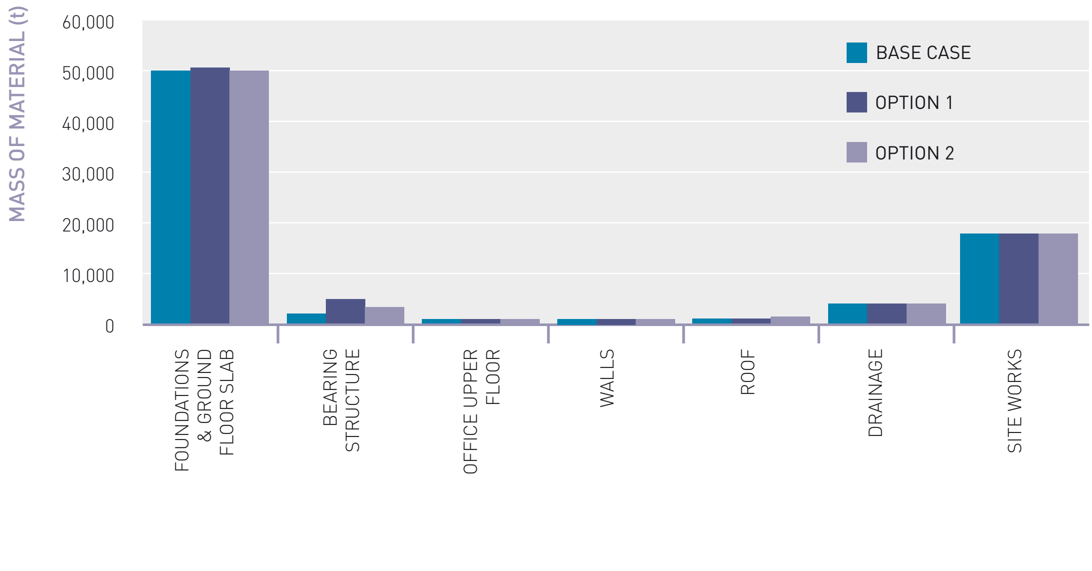
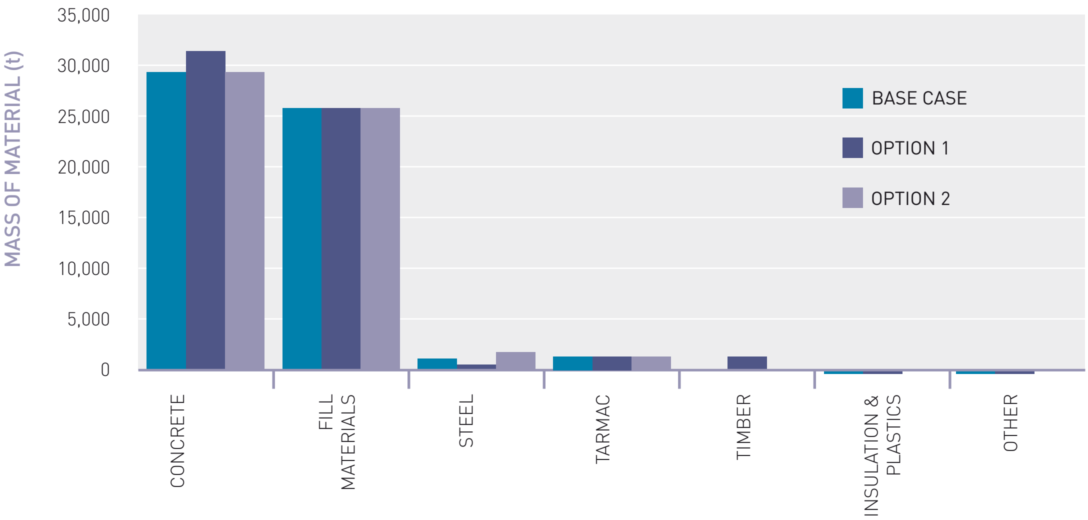


FIGURE 24

MASS OF MATERIALS - BREAKDOWN BY MATERIAL



Option 1 is marginally the heaviest of the three options due to the use of concrete columns and glulam beams. 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. The structural solution with a typical pitched roof used in the basecase was 37% lighter at 1,048 t compared to the Option 2 which required additional structural steel to create the northlight roof design.
The concrete and glulam superstructure in Option 1 was around three times as heavy as the basecase with a total mass of 2,915t.

10.0 EMBODIED CARBON

Figures 25 and 26 show the breakdown of embodied carbon in the three building alternatives by material and building element respectively. The following points are noted from the figures:

- **the largest contribution in all three 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 volume of concrete used in the building makes its contribution significant. This additional concrete is also significant if other issues such as resource depletion, waste and end-of-life are considered**
- **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 construction**
- **the walls, drainage and site-works impacts are identical for each option**
- **the impact of the heavier structural solution (Option 1) on the foundations is observable in both figures**
- **there is little variation in the transport impact between the three options. The impact being between 8% and 9% of the total**
- **although based on less robust data, the estimate of embodied carbon from on-site construction activity is relatively insignificant at around 1% of the total impact.**

FIGURE 25
BREAKDOWN OF EMBODIED CARBON BY MATERIAL

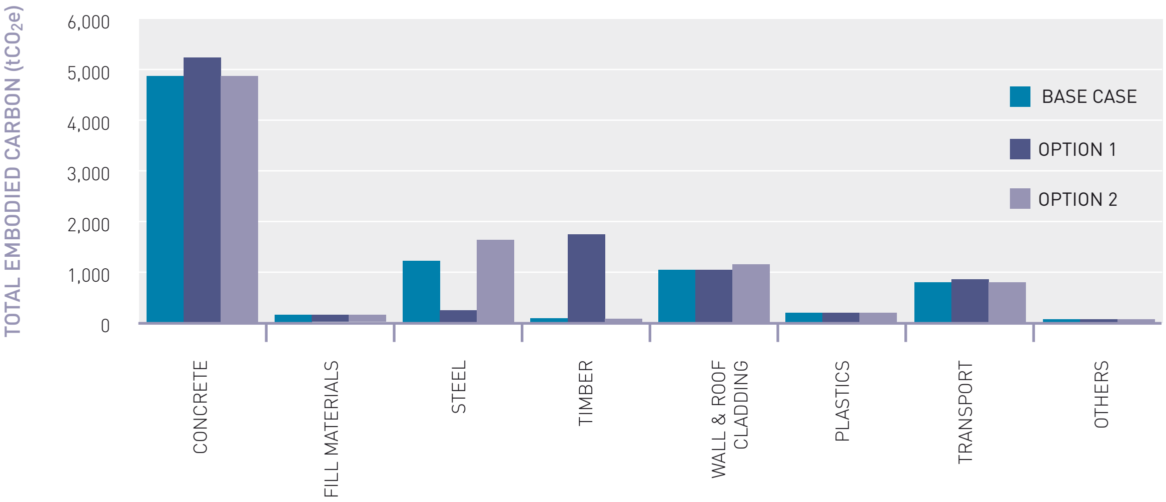
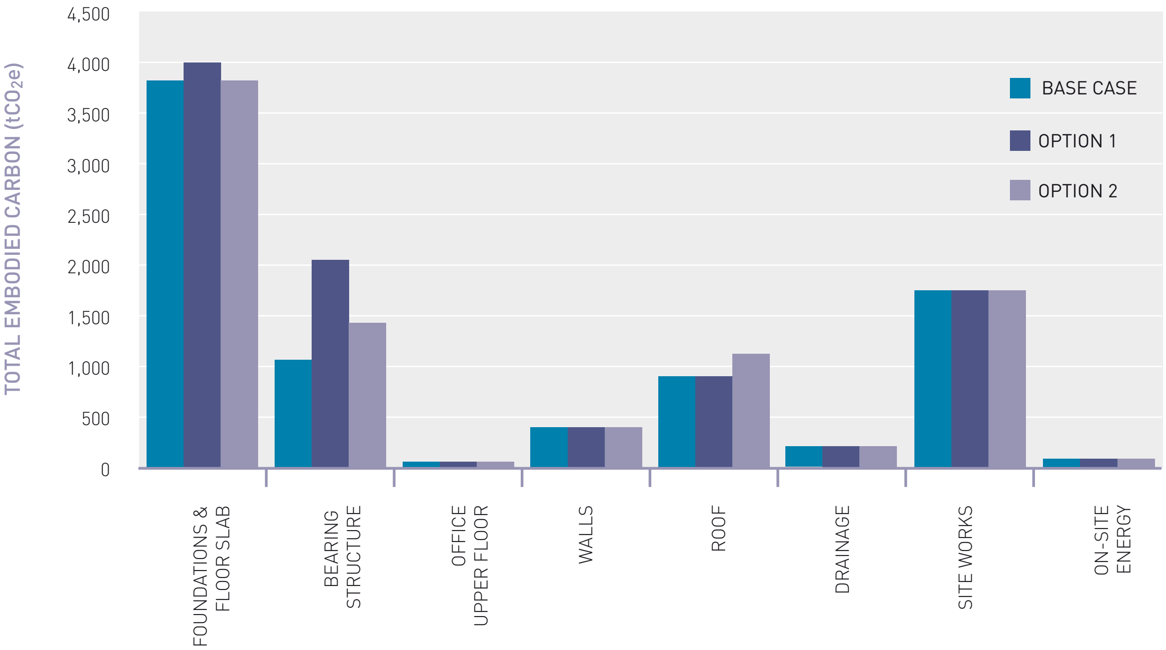


FIGURE 26
BREAKDOWN OF TOTAL EMBODIED CARBON BY ELEMENT



10.1 EMBODIED CARBON GUIDANCE

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

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

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

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

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

RECOMMENDATION

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

RECOMMENDATION

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

PROLOGIS, PINEHAM

APPENDIX A

TRANSPIRED SOLAR COLLECTORS (TSCs)

Transpired Solar Collectors, such as SolarWall®, refer to a generic solar air heating technology that utilises the sun's energy to heat fresh, outdoor air before it is drawn into a building. The technology, pioneered in North America, has been used for over 25 years and in more than 30 countries in applications ranging from space heating to agricultural ventilation and process drying.

TSCs are well suited for integration within large, single storey buildings although their integration within a range of building types including industrial, commercial, warehousing, healthcare and schools is also likely to be effective and is under trial in the UK.

The generic TSC system generally comprises pre-coated, profiled steel sheets with small uniformly spaced, perforations. The size and spacing of the perforations is typically 1mm and 100mm respectively. This 'solar collector' is mounted in front of the façade of the building. As solar radiation strikes the surface of the collector it is absorbed and the heat is conducted to the air adjacent to it. This heated boundary layer is drawn through the perforations into the engineered cavity created between the collector and the façade and then drawn into the building through the mechanical ventilation supply duct. TSC installations generally require a large area of south facing façade which is not significantly shaded from direct solar gain. On a typical clear day, each square metre of collector can generate the equivalent output of a 0.5kW heater.

The heated air can either be supplied directly into the building as heated ventilation or 'make up' air, or it can be used as a primary heater to a warm air heating system. The system can also be integrated with other types of air-based heating systems such as air source heat pumps, mechanical ventilation and heat recovery units and biomass.

Due to the unique way in which TSCs operate (forced convection rather that passive solar) the current (2006) NCM is not capable of accurately simulating the systems performance. Work is underway to resolve this and it is expected that a specific module capable of modelling TSCs for Part L compliance will be implemented in the Simplified Building Energy Model (SBEM) to be released in 2010.

At present, the RETScreen® Solar Air Heating Project model (v3.1) is the main software tool used for analysing SolarWall® installations. Developed by Natural Resources Canada (NRCan), in association with NASA, UNEP & GEF, RETScreen® v3.1 was specifically developed for evaluating the transpired plate collector and is based on empirical data obtained from dynamic testing.

An independent assessment by the Building Services Research & Information Association (BSRIA) [3], of a SolarWall installation at a 1,800m² production facility in County Durham, identified a reduced demand for gas-fired heating resulting in a 51% annual reduction in CO_2 emissions.

APPENDIX B

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 warehouse 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 warehouses have a significant impact on the usefulness of rooflights. 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 warehouse is in operation, the lower the optimal rooflight area will be.

The NCM defines that storage warehouses should be assessed with occupancy from 7am to 7pm Monday to Saturday and from 9am to 5pm on Sundays and Bank Holidays. Therefore although many large warehouses 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 18°C). In practice the night time temperature of warehouses rarely falls to 12°C and so the effect of night time heat losses is delayed until the following morning when the warehouse is brought back up to 18°C.

The NCM also assumes that the building has all windows and doors closed at all times (except when used for natural ventilation to prevent overheating) whereas, in a distribution warehouse for example, there may be several docking doors open throughout the day and night. The effect of this is to underestimate the heating demand of the building.

Off-site wind turbine output

Larger wind turbines are unlikely to be suitable for many warehouse 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-speed 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 off-site 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.

Auxiliary energy

The NCM specifies a list of heating, cooling and ventilation system types that can be used in a building. For each of these systems the methodology specifies an amount of energy which it assumes will be used by fans and pumps, collectively referred to as auxiliary energy.

Most warehouses are naturally ventilated with no mechanical cooling and therefore fans and pumps will only operate when there is a requirement for heating and the heating system is operating. However the NCM assumes that the amount of energy used by fans and pumps is a function of the occupancy of the building rather than the building heat load i.e. the auxiliary energy calculated under the NCM does not vary between summer and winter.

The effect of this simplification is that, in the case of well insulated buildings with a small heat load, the assumed auxiliary energy requirement is the same as would be the case if the building was not well insulated.

Some LZC technologies that provide heat require that the heat delivery system is changed to one with a higher auxiliary energy value, see Section 7.7.1. In this case the effect of overstating the auxiliary energy requirements can mean that the NCM model predicts that the LZC technology causes an overall increase in carbon dioxide emissions. It is possible that, in some situations, this may be the case, however this simplification does impact the modelled effectiveness of certain LZC technologies under the NCM.

Lighting, rooflights and shelving

The current method by which the NCM models the effectiveness of daylight dimming is to assume that the warehouse is empty, however most distribution warehouses will have high bay shelving almost up to the ceiling. The effect of this shelving will be to reduce the amount of light from artificial lights and from rooflights which will reach the floor of the warehouse.

The NCM requires that Part L assessments are based on the assumption that the building being assessed should be fairly compared with the illumination levels in the notional building. The notional building has no high bay racking within it, so the building being assessed should be assumed to contain no racking for the purposes of the Part L assessment. This results in the lighting energy consumption used for the assessment being much less than that which is likely to occur in reality. Therefore, the daylight dimming controls in the model also assume that there is no high bay shelving; this exaggerates their effectiveness.

APPENDIX C

METHODOLOGY USED TO ASSESS LOW AND ZERO OPERATIONAL CARBON SOLOUTIONS

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 Stoke-on-Trent warehouse building was amended as follows:
   - the levels of thermal insulation were reduced until these were no better than criterion 2 of Part L (2006) requires
   - HVAC system efficiencies were altered to industry standards
   - the air leakage value was increased to 7m³/m²/hr @ 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 – see Section 7.3 and 7.4. 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 C1.

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. Thirty two different 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 D).

6. Twenty one low and zero carbon technologies were then individually incorporated into each of the three energy efficiency packages (see Appendix E). The results of these models, together with the associated cost data, were then used to derive a number of low and zero carbon warehouse 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 C1
BASECASE BUILDING FABRIC PERFORMANCE PARAMETERS

ELEMENT	U-VALUE (W/m²K)
External wall	0.35
Ground floor (office)	0.25
Ground floor (warehouse)	0.07
Internal ceiling/floor	2.20
Heavyweight partition	2.20
Lightweight partition	0.46
Roof (flat roof)	0.25
Opaque doors	2.20
Docking doors	1.50
External windows	2.20
Rooflights	1.80
Building air tightness	7 m³/hr per m² @50Pa
Thermal bridging	0.35 W/m²/K

APPENDIX D

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 32 energy efficiency measures modelled on the basecase building are shown in Table D1. It was found that, although some of the energy efficiency measures did cause internal temperatures to rise, the thermal performance of occupied spaces remained within the acceptable limits – see Section 7.6.

Dynamic thermal modelling, using IES software, was used to predict the operational energy requirements of the warehouse 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. The 25 year period was chosen firstly because this predicted life span of modern warehouse buildings and secondly because most significant plant has a design life of approximately this period.

These NPVs were expressed as a deviation from that of the basecase warehouse, 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 25yr NPV per kgCO_2 saved relative to the basecase. The 32 measures were then ranked in terms of this cost-effectiveness measure. At this point, some energy efficiency measures were rejected on one or more of the following bases:

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

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

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

Package B contains measures which fall between these two thresholds. Package B also includes Package A measures and Package C includes 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 lighting efficiency – see Section 7.3.

The results obtained for this assessment are shown in Figure 5.

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

TABLE D1
ENERGY EFFICIENCY MEASURES CONSIDERED

ENERGY EFFICIENCY AREA (BASECASE SPEC)	DESCRIPTION OF MEASURE
Air permeability (7m³/hr per m² @50Pa	Improved to 5 m³/hr per m² @50Pa
	Improved to 3 m³/hr per m² @50Pa
	Improved to 2 m³/hr per m² @50Pa
	Improved to 1 m³/hr per m² @50Pa
Thermal bridging (0.035 W/m²K)	Reduced from 0.035 W/m²K to 0.014 W/m²K for the warehouse and to 0.018 W/m²K for the office
External wall insulation (0.35 W/m²K)	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 (0.25 W/m²K) Improved external glazing (1.80 W/m²K)	Improved to 0.20 W/m²K
	Improved to 0.15 W/m²K
	Improved to 0.10 W/m²K
	Improved to 1.50 W/m²K
	Improved to 1.20 W/m²K
	Improved to 0.90 W/m²K
Office specification: ■ Boiler: 92% ■ Lighting: 3.75W/m² per 100lux ■ Wall: 0.35W/m²K ■ Roof: 0.25W/m²K ■ Floor: 0.25W/m²K ■ Glazing: 2.20W/m²K ■ Specific fan power: 1.8W/l/s	Efficient office specification; ■ Boiler efficiency increased to 95% ■ Lighting improved to 1.75W/m² per 100lux ■ Wall insulation improved to 0.25W/m²K ■ Roof insulation improved to 0.20W/m²K
	Very efficient office specification; ■ Boiler efficiency increased to 95% ■ Lighting improved to 1.75W/m² per 100lux ■ Wall insulation improved to 0.10W/m²K ■ Roof insulation improved to 0.10W/m²K ■ Floor insulation improved to 0.15W/m²K ■ Glazing improved to 1.60W/m²K ■ Specific fan power improved to 1.5W/m²K
Heating, cooling and ventilation (Radiant heating)	Warm air blowers in warehouse
Lighting and rooflights ■ 4.2 W/m² per 100lux ■ No daylight dimming or occupancy sensing ■ 15% rooflights	Improved lighting efficiency to 1.79W/m² per 100lux
	Improved lighting efficiency to 1.64W/m² per 100lux
	Improved lighting efficiency to 1.42W/m² per 100lux
	Occupancy sensing controls to all light fittings
	0% Rooflights
	Daylight dimming controls to all lights
	Daylight dimming controls and reduce rooflights to 10% of roof area
	Daylight dimming controls and increase rooflights to 20% of roof area
	Daylight dimming controls and increase rooflights to 30% of roof area
	Daylight dimming controls and increase rooflights to 40% of roof area
	Daylight dimming controls and 100% Kalwall envelope
Miscellaneous (Standard finish, no green roof)	High absorptance paint finish to reduce heating loads applied tp external surfaces
	High reflectivity paint finish to reduce cooling loads applied to external surfaces Extensive sedum green roof

APPENDIX E

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.

Twenty LZC technologies were modelled on each of the three energy efficiency packages. Each of the LZCs was applied to each energy efficiency package (see Appendix D) 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 to the whole building and as a small case sized to supply space heating to the office only.

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

Initial results of the LZC modelling revealed just two, single on-site technology that were able to achieve zero carbon and therefore further modelling was undertaken to combine a number of on-site technologies. This was done using graphs similar to that shown in Figure E1.

Figure E1 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 E1 shows the on-site LZC solutions defined and discussed in Section 7.8.

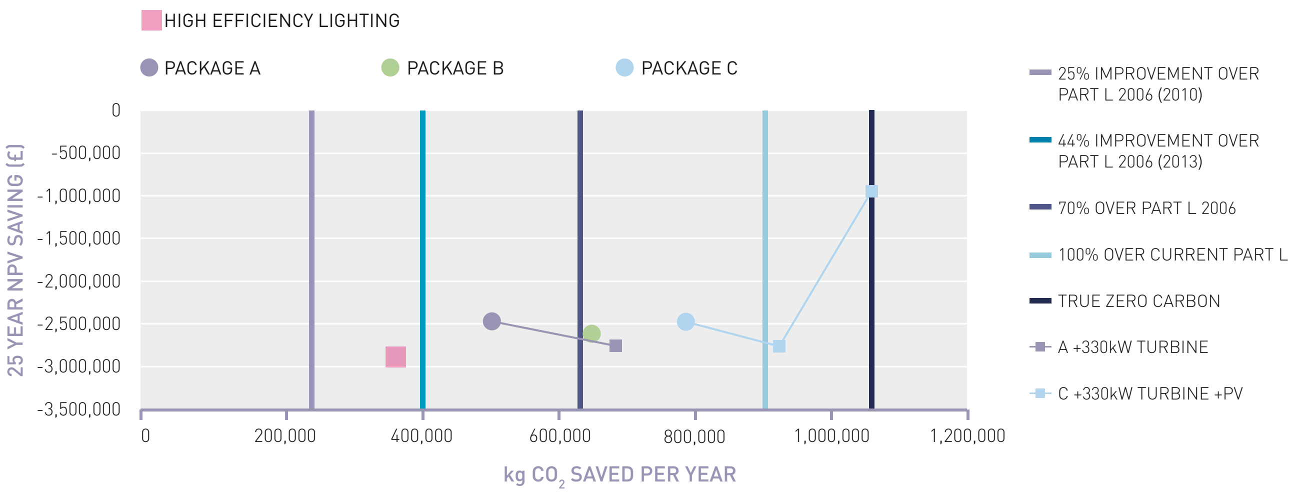
Figure E1 shows three coloured circles representing the three energy efficiency packages described in Appendix D. Straight lines emanating from these circles represent an LZC technology. The gradient of each line represents the cost effectiveness of each measure. Having decided the carbon reduction target, 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 seven different combinations of on-site technologies (based on the three energy efficiency packages).

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

FIGURE E1

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



APPENDIX F

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 warehouse building cost plan was developed by Cyril Sweett using their cost database. UK mean values current at 3Q 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 NPV has been 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) and the Climate Change Levy.

Revenue associated with any financial incentives aimed at supporting the use of specific renewable energy technologies, for example, a feed-in tariff such as the Clean Energy Cashback scheme, or the Renewable Heat Incentive, has not been factored into the analysis. The incorporation of these additional revenue streams will have an impact on the NPV and hence the cost-effectiveness of the affected technologies.

APPENDIX G

CLEAR LIFECYCLE 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, re-use, 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.**

More detail on the assumptions and data used to model these aspects are available from the Target Zero website **www.targetzero.info**

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 G1 gives the embodied carbon coefficients for the principle materials used in the warehouse assessments.

TABLE G1
THE EMBODIED CARBON COEFFICIENTS FOR THE PRINCIPLE MATERIALS USED IN THE WAREHOUSE ASSESSMENTS

MATERIAL	DATA SOURCE	END OF LIFE ASSUMPTION	END OF LIFE INFORMATION 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
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	GaBi LCI database 2006 – PE International	16% recycling, 4% incineration, 80% landfill	TRADA[3]	1.05
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/surveyconstruction200
[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

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1 www.breeam.org

2 Climate Change Act, 2008.

3 SolarWall monitoring CA roll mill, BSRIA Final report 50052/A/1

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

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

6 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

7 Colorcoat Technical Paper: Integrated lighting solutions for low energy buildings, Tata Steel Colors

8 CIBSE Guide A – Environmental design (2006)

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

10 The Potential and Costs of District Heating Networks. Department of Energy and Climate Change. April 2009

11 www.bre.co.uk/greenguide