TARGET ZERO®

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

REPORT **V1.0 FEBRUARY 2010**

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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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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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Balfour Beatty employs more than 50,000 people around the world.

The base case school for the Target Zero project was the Christ the King Centre for Learning, Knowsley, which was part of Balfour Beatty's £163 million Knowsley Metropolitan Borough Council PPP concession to construct seven state-of-the-art new learning centres under the Building Schools for the Future (BSF) programme. Balfour Beatty worked closely with the project team to ensure the successful delivery of the design guidance.

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1.0 INTRODUCTION

INTRODUCTION

Target Zero is a programme of work, funded by Tata Steel and the British Constructional Steelwork Association (BCSA)(1) , to provide guidance on the design and construction of sustainable, low and zero carbon buildings in the UK. Five non-domestic building types have been analysed: a school, a distribution warehouse, an out-of-town supermarket, a 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[1] 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 guide, the first in a series of five, provides information and guidance for construction clients and their professional advisers on how to design and construct sustainable school buildings. More information and guidance from Target Zero is available at www.targetzero.info

The images in this guide showcase recent examples of steel-framed school buildings.

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

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 schools to be zero carbon by 2016 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. Via Part L of the Building Regulations, a roadmap of likely targets is in place to provide guidance to the construction industry to enable it to develop solutions to meet future low and zero carbon targets (see section 7.2).

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

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.

MERCHANTS' ACADEMY, BRISTOL

SUSTAINABLE SCHOOLS

Education is a cornerstone of the Government's social policy and is central to its sustainable development strategy. Better education is inextricably linked to the future economic prosperity and improved social fabric of the country.

Government would like every school to be sustainable by 2020 and a National Framework[3] has been established to guide schools towards this aim. A sustainable school has been defined as one which prepares its pupils for a lifetime of sustainable living through its teaching, fabric and day-to-day practices.

The primary requirement of schools remains to educate our children and it is important therefore that measures to improve the sustainability of school buildings do not conflict with this.

Since 2005 it has been a Department for Children, Families and Schools (DCFS) requirement that all major new school buildings and refurbishment projects are BREEAM assessed and achieve at least a 'Very Good' BREEAM rating. DCFS has also established a Zero Carbon Task Force which has now issued its recommendations has published a report that outlines a roadmap to zero carbon schools. The Target Zero findings contributes to the recommendations of this report[4].

Building Schools for the Future (BSF) is the largest single capital investment programme in schools in England for more than 50 years. Started in 2005, BSF will see virtually all of England's 3,500 secondary schools rebuilt or substantially refurbished in 15 waves of investment. The programme is part of a wider capital strategy within DCFS that will see total capital investment in schools in England increase from £6.4 billion in 2007/08 to £8.2 billion in 2010/11.

BSF is committed to reducing operational carbon emissions for new BSF schools by 60% from 2002 levels by 2011.

4.0 TARGET ZERO METHODOLOGY

MARY MAGDALENE ACADEMY, LIVERPOOL

TARGET ZERO METHODOLOGY

The Target Zero methodology is based on recently constructed buildings that are typical of current UK practice. For each building, a 'base case' is defined that just meets the 2006 Part L requirements and this base case building is used as a benchmark for the assessment.

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

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

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

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 energy use may be more accurately assessed and reduced using good thermal design software that is not constrained by the NCM.

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

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 D.

Alternative structural designs for each building were also developed to:

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

1 Costing of the base case school building was based on UK mean values current at 2Q 2009.

5.0 THE KNOWSLEY SCHOOL

CHRIST THE KING CENTRE FOR LEARNING, KNOWSLEY, MERSEYSIDE

THE KNOWSLEY SCHOOL

The building on which the schools research was based, is the Christ the King Centre for Learning secondary school in Knowsley, Merseyside. This BSF building was completed in December 2008 and is occupied by 900 pupils and 50 staff. The gross internal floor area of the school is 9,637m².

The building is based on a 9m x 9m structural grid with many classrooms 9m deep. This was a requirement of the Local Education Authority who specifically requested 81m² classrooms. This decision, based on efficient school operation and teaching requirements, precluded the use of natural ventilation strategies for this building. The school was heavily compartmented and so only single sided ventilation is available in most rooms. At 9m the floor is too deep to allow natural ventilation to work effectively in this case.

The main architectural features of the building are:

- **a standardised 9m x 9m structural grid**
- **a 591m² sports hall**
- **a winter garden covered by an ETFE roof**
- **a three-storey high atrium**
- **some external terraces at upper floors.**

The school has a structural steel frame supporting precast concrete floor slabs and is clad in a combination of timber cladding, aluminium curtain walling and terracotta rainscreen.

The building is mechanically ventilated with a centralised air handling plant on the roof and a separate energy centre, housing hot water boilers and ground source heat pumps providing all space heating and cooling.

For the Target Zero analyses, changes were made to the form, fabric and services to provide a base case school building more representative of current practice. These included:

- **the ground source heat pump was removed and replaced with conventional gas fired heating and electrically driven cooling**
- **the levels of insulation were reduced until these were no better than required by criterion 2 of Part L**
- **the winter garden was removed leaving an open courtyard space**
- **system efficiencies were altered to industry standards**
- **the facade was simplified to one construction type: timber cladding.**

The base case building model was then fine-tuned to pass Part L2A to within 1% by altering the energy efficiency of the lighting system. See Appendix A.

6.0 KEY FINDINGS

KEY FINDINGS

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

The likely 2010 Part L compliance target of reducing operational carbon emissions by 25% is achievable by using only energy efficiency measures (i.e. without LZC technologies) at an increased capital cost of just 0.14%. The measures to achieve this target result in cost savings (i.e. a negative 25-year net present value (NPV)) and therefore it is recommended that they should be adopted in all new school buildings. (See Section 7.3).

No combination of energy efficiency measures plus a single on site LZC technology can achieve true zero carbon, which would require a 124%(1) reduction in regulated emissions. The greatest on site reduction, using just one technology, is 86% of regulated emissions (69% of total carbon emissions) achieved by using fuel cell CCHP(2) when combined with a package of very high energy efficiency measures. (See Section 7.4).

Operational carbon emission reductions over 100% of regulated emissions can be achieved most cost effectively using a package of energy efficiency measures plus a 50kW wind turbine, 1,300 m^2 array of photovoltaics, a biomass boiler and 216m^2 of solar thermal panels. These measures incur an increased capital cost of 12%. (See Section 7.4).

Several of the offsite LZC technologies considered are capable of achieving zero carbon with a negative 25-year NPV. The most cost-effective option is to purchase a share in a large on shore wind farm. If offsite wind technologies are not available or allowed, i.e. not permitted as an 'allowable solution', district CHP plant is the next most cost-effective option. (See Sections 7.1 and 7.6).

The most cost-effective routes to likely future low and zero operational carbon targets are as shown in Figure 1.

BREEAM[1] (Building Research Establishment Environmental Assessment Methodology) is the leading and most widely used environmental assessment method for buildings. The estimated capital cost uplift of the case study school building was (see Section 8.1):

- **0.2% to achieve BREEAM Very Good**
- **0.7% to achieve BREEAM Excellent**
- **5.8% to achieve BREEAM Outstanding.**

The base case building capital construction cost was £22.5m (£2,335/m^2). See Section 9.

The impact of the structure on the operational carbon emissions of the base case building was found to be small, the Building Emissions Rate (BER) varying by less than 1% between lightweight (steel) and heavyweight (concrete) structural options. (See Section 9.1). No discernible difference could be found in terms of fabric energy storage could be found between the three structural options.

A significant proportion of the building's embodied carbon is in the substructure. Of three foundation solutions investigated, the best results were obtained using steel piles, which also have the sustainable advantage of being easily removable for re-use or recycling at end of life, leaving a relatively clean site. (See Section 9.3).

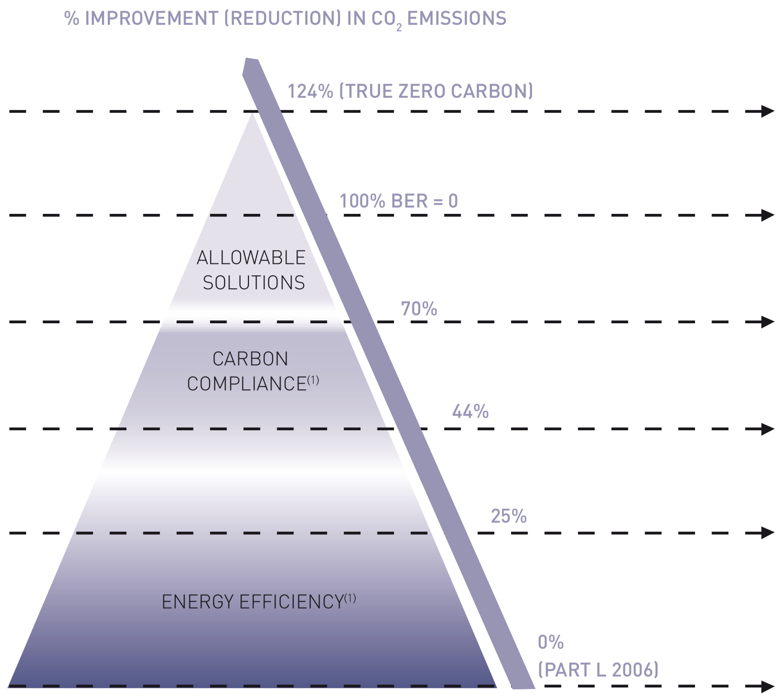
Relative to the base case, an in-situ reinforced concrete structure building had a higher (11%) embodied carbon impact whereas a steel composite structure had a marginally lower (3%) impact. (See Section 10).

1 124% is the reduction required to achieve true zero carbon for the base case study school building since unregulated energy use contribute 24% 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 19% (See Figure 19) and 19% is 24% of 81%. (For definition of regulated and unregulated energy see Section 7).

2 CCHP means combined cooling heat and power, also known as tri-generation. The technology combines a CHP unit with an absorption chiller to provide both heating and cooling.

6.0 KEY FINDINGS

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



ENERGY EFFICIENCY MEASURES	LZC TECHNOLOGIES	ADDITIONAL CAPITAL COSTS (£)	25 YEAR NET PRESENT VALUE (£)
CANNOT BE ACHIEVED BY ON SITE LZC TECHNOLOGIES ALONE			
PACKAGE A plus: Occupancy sensing lighting controls throughout; Ultra low fan power 1.5W/l.s; Improved roof insulation 0.2W/m²K; Very high chiller efficiency SEER = 700; Advanced thermal bridging; Improved wall insulation 0.25W/m²K	Biomass boiler 50kW wind turbine 216m² of solar thermal panels 1,300m² array of photovoltaics	2,591,400 [12%]	1,525,921
PACKAGE A	Air source heat pump 1,300m² array of photovoltaics	1,144,900 [5%]	140,692
PACKAGE A	Air source heat pump	57,750 [0.26%]	-433,864
PACKAGE A: Radiant ceiling; Ideal orientation; Window size optimisation; 95% efficient boiler; Efficient lighting 1.75W/m² per 100lux; Daylight dimming; Advanced air tightness 3m³/hr per m² @50Pa		31,900 [0.14%]	-580,950
BASE CASE BUILDING			

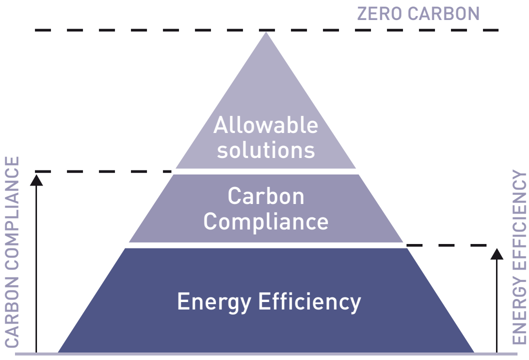
[1] The energy efficiency and carbon compliance standards are subject to further consultation

7.0 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' schools and the projected milestones on the roadmap to zero carbon, i.e. the proposed Part L compliance targets for 2010 and 2013. The approach taken to the assessment of low and zero operational carbon solutions is described in Appendix A.

Operational carbon is the term used to describe the emissions of greenhouse gases during the operational phase of a building. Emissions arise from energy consuming activities including heating, cooling, ventilation and lighting of the building, so called 'regulated' emissions under the Building Regulations, and other, currently 'unregulated' emissions, including appliance use and small power plug loads such as IT. These appliances are not currently regulated because they are not an integral part of the building fit-out and are likely to be changed every few years.

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



7.1 WHAT IS ZERO CARBON?

The Government has announced its aspiration for new schools to be zero carbon by 2016 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[5], following the precedent set for domestic buildings, is to set a standard for energy efficiency based on the delivered energy required to provide space heating and cooling. The level for this standard has currently not been set for non-domestic buildings
- Carbon Compliance on or near-site - this is the minimum reduction in carbon dioxide emissions required compared to the 2006 Part L requirements. The levels of contribution from energy efficiency measures and on site energy generation (or directly connected heat) have been modelled as part of the Government's consultation on policy options for zero carbon non-domestic buildings. The levels of carbon compliance for non-domestic buildings have not been set but the results for 11 building types[5] show a range between 13% (Supermarkets), through 86% (hotels) and on to 100% improvements (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 proposes[5] that the zero carbon target for non-domestic buildings will include both regulated and unregulated energy use. There is also 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.

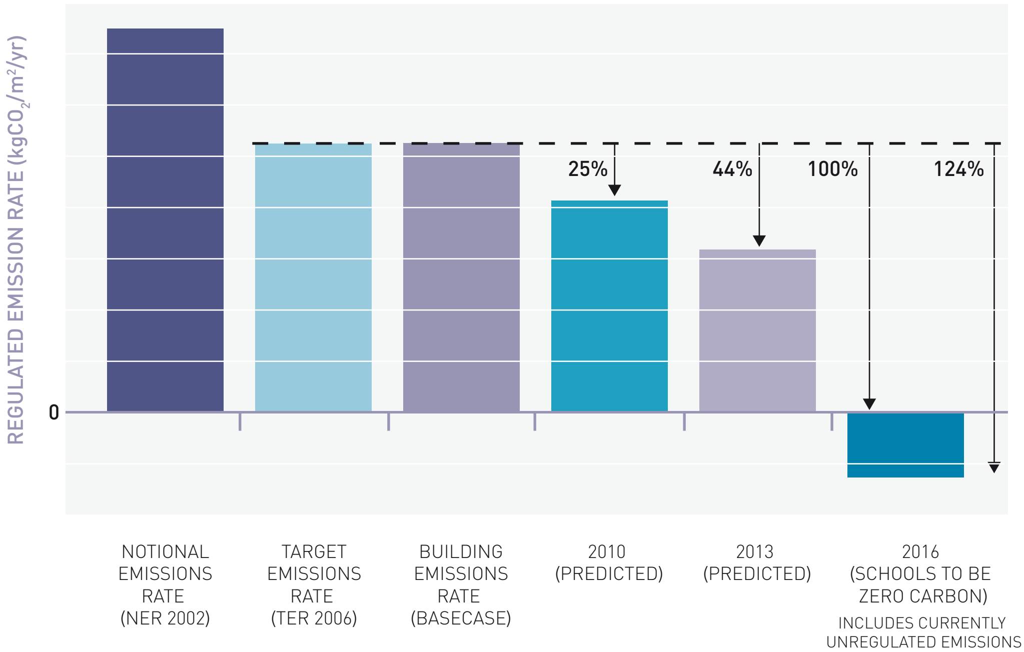
7.2 BUILDING REGULATIONS PART L

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. Proposed revisions to Part L in 2010 suggest that a further 25% reduction in regulated carbon emissions over the 2006 requirements will be required for non-domestic buildings. 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. This is expected to be a 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 school buildings.

FIGURE 3
INDICATIVE GRAPH OF PAST AND POSSIBLE FUTURE PART L CHANGES



Within Target Zero, the operational carbon emissions results for the school building are presented with the 25%, 44%, 70%, 100% (BER =0) and 124% (true zero carbon for the base case building) likely reduction requirements in mind.

These reduction targets predate the Government's consultation on policy options for new non-domestic buildings[5] published in November 2009. The 70% reduction target was based on the domestic building target.

A reduction in regulated carbon emissions of 124% is required to achieve true zero carbon for the case study school building 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. The assessed total operational carbon emissions for the base case building were 355 tonnes CO_2 per year using the NCM.

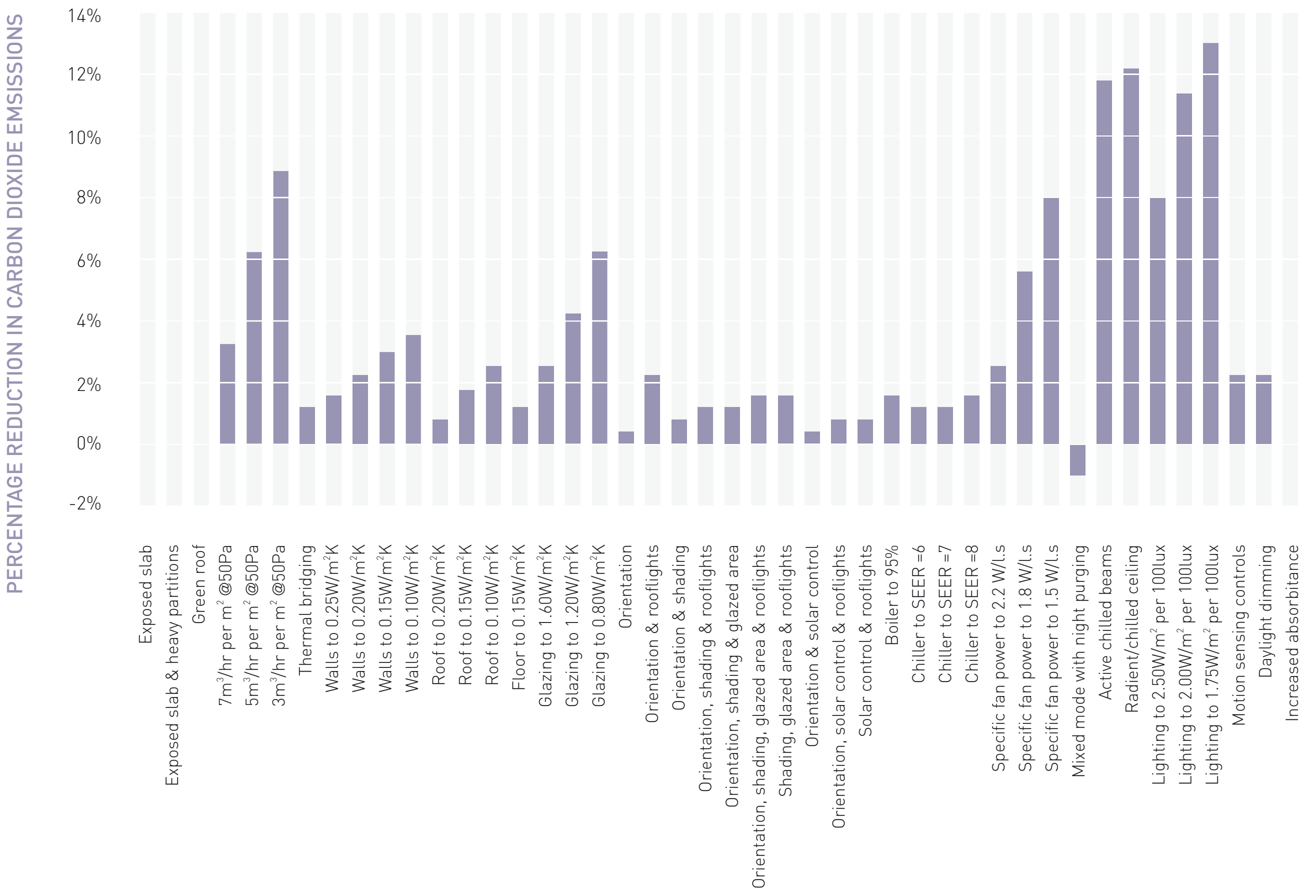
The NCM was devised primarily as an assessment tool to measure comparative emissions between a proposed building and the requirements of the Part L regulation rather than as a design tool. It is widely agreed that several assumptions in the NCM can give rise to discrepancies between the simulated prediction of energy uses and those which are likely to occur in reality.

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.

7.3 ENERGY EFFICIENCY

Figure 4 shows the modelled reductions in operational carbon dioxide emissions achieved by introducing the individual energy efficiency measures defined in Appendix B into the base case building. The results show that the measures with the largest impact are those related to the greatest energy demand in the school building i.e. lighting, see also Figure 19.

FIGURE 4
REDUCTION IN CARBON DIOXIDE EMISSIONS ACHIEVED BY INTRODUCING ENERGY EFFICIENCY MEASURES (RELATIVE TO THE BASE CASE)



The results in Figure 4 take no account of cost and therefore the energy efficiency measures have been ranked (Figure 5) in terms of cost-effectiveness and, for convenience, grouped within the three packages defined in Appendix B. Each package was checked to ensure that all of the energy efficiency measures are compatible. Package B includes all measures in Package A and Package C contains all measures in Packages A and B.

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

FIGURE 5
ENERGY EFFICIENCY MEASURE PACKAGES A, B AND C

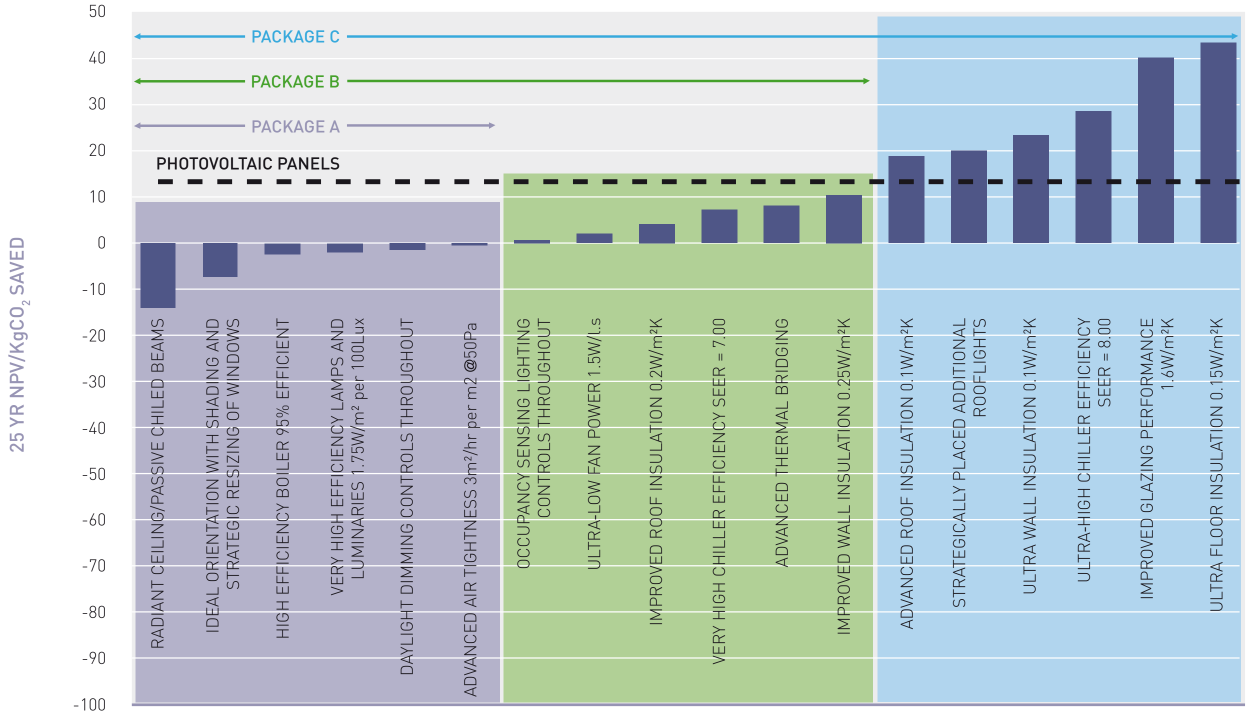
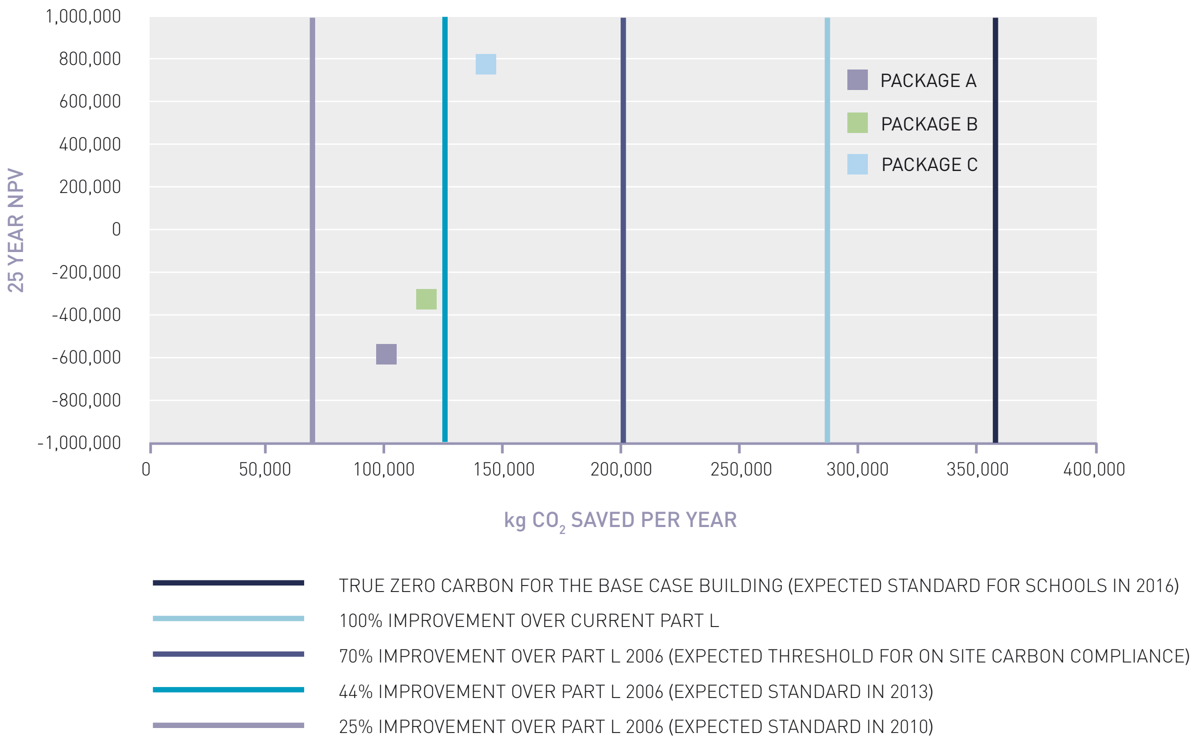


Figure 6 shows the energy efficiency packages A, B and C plotted on axis representing carbon emissions saved relative to 25-year NPV and in relation to future likely Part L compliance targets.

This shows that the 25% reduction in regulated carbon dioxide emissions, which is expected to be required to comply with the 2010 regulations, can be achieved through the use of Package A energy efficiency measures alone. Energy efficiency package C also achieves the likely compliance target for 2013 however, as shown later, this can be achieved more cost-effectively using LZC technologies combined with Package A.

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



7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

The operational carbon emissions savings from the three energy efficiency packages, together with their capital cost and 25-year NPV, are summarised in Table 1.

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 BASE CASE] [CHANGE IN REGULATED EMISSIONS]	CHANGE IN CAPITAL COST FROM BASE CASE (£) [%]	CHANGE IN 25 YEAR NPV CAPITAL COST FROM BASE CASE (£)
Base case	-	354,999	-	-
Package A	Radiant ceiling/passive chilled beams Ideal orientation with shading Window size optimisation 95% efficient boiler Efficient lighting (1.75W/m² per 100lux); Daylight dimming Advanced air tightness (3m³/hr per m² @50Pa)	252,041 [-29%] [-36%]	31,900 [0.14%]	-580,950
Package B	PACKAGE A PLUS: Occupancy sensing lighting controls throughout; Ultra-low fan power 1.5W/l.s Improved roof insulation 0.2W/m²K Very high chiller efficiency SEER = 7.00 Advanced thermal bridging 0.018W/m²K Improved wall insulation 0.25W/m²K	236,780 [-33%] [-41%]	323,400 [1.44%]	-326,309
Package C	PACKAGE B PLUS: Advanced roof insulation 0.1W/m²K Strategically placed additional rooflights Ultra wall insulation 0.1W/m²K Ultra-high Chiller efficiency SEER = 8.00 Improved glazing performance 1.6W/m²K Possible 2010 minimum floor insulation 0.15W/m²K	215,371 [-39%] [-49%]	1,478,100 [6.57%]	775,078

Despite the higher capital cost associated with all three packages, all measures in Package A save money over a 25-year period and therefore should be implemented in publically-funded school projects. Package B also has a negative NPV and so all the measures in Package B should also be considered in publically-funded school projects. They may however not be the most cost-effective means of achieving the required reductions; LZC technologies may be more cost-effective.

RECOMMENDATION

Energy efficiency measures put together to form a package with a combined negative life-cycle cost (Package B) can enable regulated carbon emission to be reduced by 41% (total emissions by 33%) with a total capital cost increase of just 1.4%. The higher level of energy efficiency achieved using Package B was found, under several of the scenarios considered, to represent the most cost-effective route to low or zero carbon emissions when LZC technologies were added. As a result, energy efficiency improvements resulting in reductions in regulated carbon emissions by up to 40% would seem to be a good benchmark for the definition of zero carbon schools.

RECOMMENDATION

The targets for operational carbon reduction in schools required from 2010 as a result of changes to Part L require attention to energy efficient measures.

Those identified with the best NPV returns were:

- Radiant ceiling/Passive chilled beams
- Ideal orientation with shading
- Window size optimisation
- 95% efficient boiler
- Efficient lighting (1.75W/m² per 100lux)
- Daylight dimming
- Advanced air tightness (3m³/hr per m² @50Pa).

7.4 ON SITE LZC TECHNOLOGIES

The methodology used to assess and compare LZC technologies is described in Appendices A and C.

The research found that no single, on site LZC technology could achieve true zero carbon in the base case building, i.e. a 124% reduction in regulated emissions. The greatest on site reduction, using just one technology, is 86% of regulated emissions (69% of total carbon emissions) achieved by using fuel cell CCHP when combined with energy efficiency Package C. Therefore, further analyses were carried out to assess the effectiveness of combining several on site LZC technologies with the energy efficiency packages (See Section 7.3) using the method described in Appendix C.

These analyses found that operational carbon emission reductions could be made up to 119% of regulated emissions, (96% of total carbon emissions) through the use of energy efficiency Package C and four LZC technologies: fuel cell CCHP; a 50kW wind turbine; a large PV array and a Biomass boiler. Therefore, the base case school cannot achieve true zero carbon through energy efficiency and on site LZC measures alone. This package of measures is very expensive, incurring an increase in capital costs of 24% and a 25-year NPV of £6,779,343.

Assessment of a range of viable combinations of LZC technologies was undertaken to identify the most cost-effective packages of compatible measures to achieve the likely future compliance targets. Selected packages of measures which meet these targets are illustrated in Figure C1 in Appendix C and fully defined in Table 2.

Table 2 demonstrates that significant reductions in operational carbon dioxide emissions can be achieved using on site technologies, however the additional cost of doing this begins to become restrictive. For example, to achieve a 100% reduction in regulated emissions relative to the 2006 Part L requirements incurs a minimum capital cost increase of 12%. This does not account for the currently unregulated emissions associated with the energy used by small appliances such as IT equipment and white goods.

RECOMMENDATION

The use of energy efficiency methods and LZC technologies can greatly reduce the carbon emissions in a modern secondary school. However, the added costs climb rapidly as the level of carbon emissions are reduced.

There is a need to set a level which can be practically, technically and economically achieved on school sites. Limitations on wind turbines due to planning, on biomass due to fuel delivery access and potentially PV and solar thermal in high rise urban sites, may also restrict what is possible.

A reduction in regulated emissions of 70% is possible with a near neutral net present value through the use of air source heat pump and photovoltaics when combined with energy Package A. For school buildings therefore, a requirement which reduces regulated carbon emissions by up to 70% compared to 2006 part L would seem to be a good benchmark for the definition of on site Carbon Compliance.

TABLE 2
MOST COST EFFECTIVE ON SITE SOLUTIONS TO MEET FUTURE LIKELY PART L COMPLIANCE TARGETS

TARGET	MOST COST EFFECTIVE ROUTE	BER ($kgCO_2$ / M^2 / Y)	ADDITIONAL CAPITAL COST (£)	25-YEAR NPV COST (£)
Likely 2010 revision to Part L requiring a 25% improvement over Part L 2006	Energy efficiency package A (see table 1)	17.6	31,900 [0.14%]	-580,950
Likely 2013 revision to Part L requiring a 44% improvement over Part L 2006	Energy efficiency package A Air source heat pump	14.1	57,750 [0.26%]	-433,864
The expected threshold for on site carbon compliance; 70% improvement over Part L 2006	Energy efficiency package A Air source heat pump 1,300m² array of photovoltaics	6.8	1,144,900 [5%]	140,692
100% improvement over current Part L (excludes unregulated emissions from energy used by small appliances such as IT equipment and white goods)	Energy efficiency package B (see table 1) Biomass boiler 50kW wind turbine 216m² of solar thermal panels 1,300m² array of photovoltaics	-1.2	2,591,400 [12%]	1,525,921
True zero carbon (expected standard for schools in 2016) i.e. 124% improvement on Part L 2006	Cannot be achieved by on site technologies alone	-	-	

7.5 DIRECTLY CONNECTED HEAT

The policy options for zero carbon non domestic buildings[5] includes the use of directly connected heat as a means of achieving carbon compliance targets. This can be provided by LZC technologies such as Fuel Cell CHP and Energy from Waste (EfW) plants.

Large offsite LZC installations tend to benefit from economies of scale and so, if these are available, they are likely to be more attractive than on site solutions. The Target Zero analyses found that many offsite LZCs are predicted to save money over the 25-year period considered and are therefore highly attractive.

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 either a gas turbine or a fuel cell was predicted to be the most cost-effective route to achieving both a 44% and 70% reduction below the current requirements of Part L 2006, although these targets will have to include a contribution from energy efficiency. The most cost-effective routes to a 100% reduction in regulated emissions and to true zero carbon, are biomass-fired CCHP and anaerobic digestion CHP respectively. These technologies are expected to save the building operator money over the life of the building as shown in Table 3. However not all schools will be in an area where district schemes such as these are viable.

District CHP schemes are most viable in dense urban areas and although some 83% of state-run secondary schools in England and Wales are in urban areas, these are generally unlikely to be in areas with a high enough heat demand density to make district CHP viable.

Table 3 summarises the main offsite technologies that could provide directly connected heat to that school building. The modelled results of savings in carbon emissions, capital costs and NPV are presented. The results are based on the technology being used in conjunction with energy efficiency Package B (See Table 1). Case 1 accounts for domestic hot water demands only whereas Case 2 accounts for both domestic hot water and space heating demands.

RECOMMENDATION

Where access is available, directly connected heat from Fuel Cell Combined Heat & Power (CHP) and Energy from Waste (EfW) plants is likely to be the most cost effective method of reducing carbon emissions.

TABLE 3
DIRECTLY CONNECTED HEAT RESULTS

OFFSITE LZC	OPERATIONAL CO_2 EMISSIONS ($kgCO_2$ / YR) [CHANGE FROM BASE CASE]	CHANGE IN CAPITAL COST FROM BASE CASE[1] (£) [%]	CHANGE IN 25 YEAR NPV CAPITAL COST FROM BASE CASE (£)
Fuel Cell CHP (FC-CCHP) – offsite	127,091 [-64%]	14,700 [0.1%]	-437,575
Gas CHP (G-CHP) – offsite	130,469 [-63%]	14,700 [0.1%]	-437,509
Biomass CHP (B-CHP) – offsite	69,537 [-80%]	14,700 [0.1%]	-437,674
Fuel Cell CCHP[2] (FC-CCHP) – offsite	116,050 [-67%]	124,950 [0.6%]	-302,498
Gas CCHP[2] (G-CCHP) – offsite	121,340 [-66%]	124,950 [0.6%]	-302,416
Biomass CCHP[2] (B-CCHP) – offsite	53,547 [-85%]	124,950 [0.6%]	-306,091
Anaerobic Digestion CHP (AD-CHP) – offsite	-48,777 [-114%]	14,700 [0.1%]	-437,509
Energy from Waste (EfW) case 1	218,661 [-38%]	42,000 [0.2%]	-309,369
Energy from Waste (EfW) case 2	190,152 [-46%]	14,700 [0.1%]	-354,261
Waste Process Heat case 1	204,436 [-42%]	42,000 [0.2%]	-309,369
Waste Process Heat case 2	153,545 [-57%]	14,700 [0.1%]	-354,261

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

2 These technologies have been modelled as a district CHP system supplying heat to an on site absorption chiller.

7.6 ALLOWABLE SOLUTIONS

The consultation on policy options for zero carbon non-domestic buildings[5] 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.**

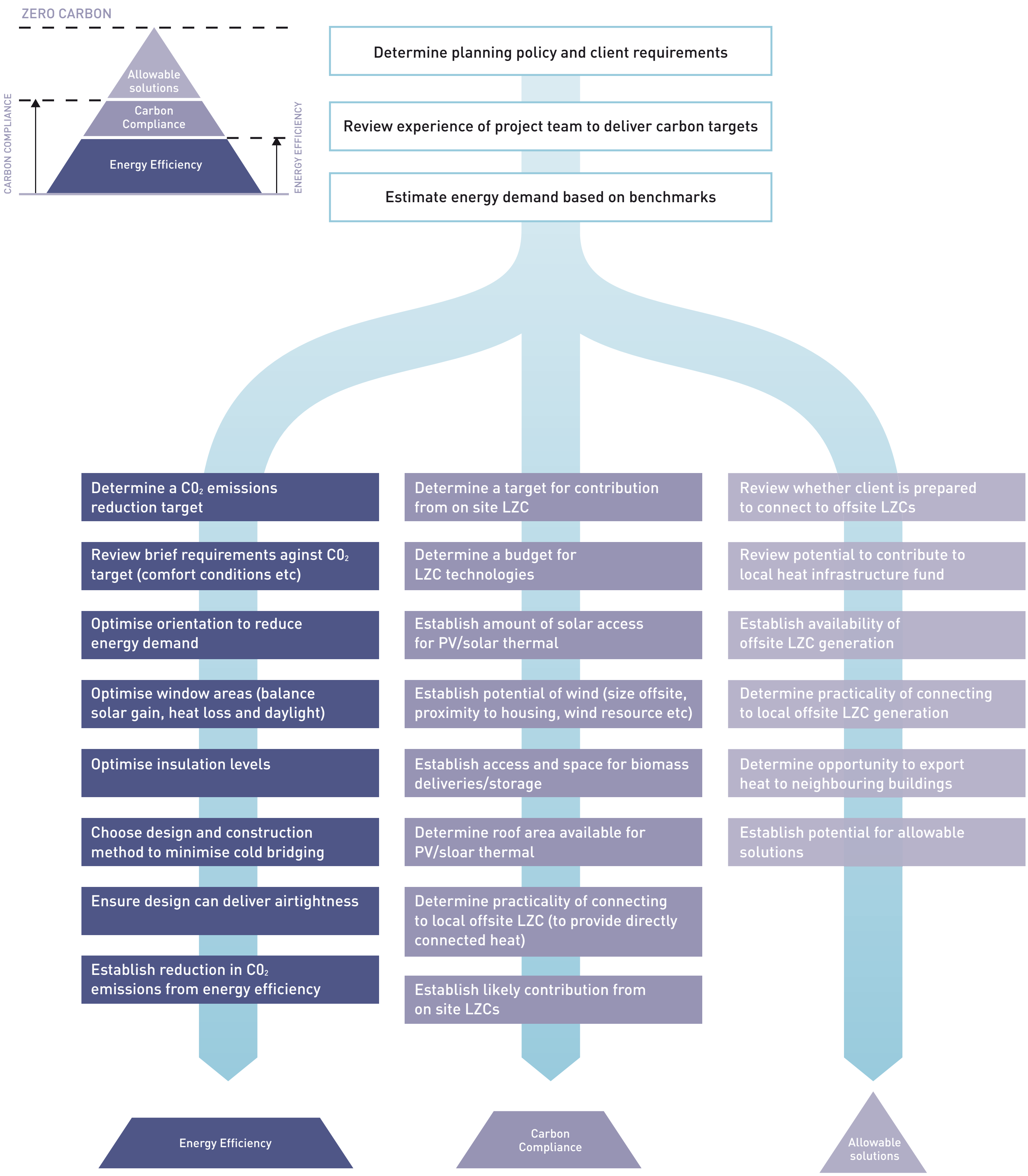
Other options also remain under consideration.

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

DENNY HIGH SCHOOL, FALKIRK

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

FIGURE 7
GUIDANCE FLOWCHART FOR DELIVERING LOW AND ZERO OPERATIONAL CARBON SCHOOL BUILDINGS



7.7 OPERATIONAL CARBON GUIDANCE

Figure 7 sets out a flowchart providing guidance on how to develop a cost-effective route to low or zero operational carbon. 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.

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

It is important to ensure that measures to improve the sustainability of school buildings do not conflict with the optimum functionality and operation of schools. For example, in the Knowsley School, the client's requirement to have large, square classrooms, meant that a shallow plan, naturally ventilated building form was not feasible.
(See section 5.0).

Ensuring the relevant analyses and integration of design is undertaken early in 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 zero carbon solution for any new-build school.

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

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

RECOMMENDATION

The client brief for a low carbon school must set out clearly the targets and the contributions to be made from energy efficiency, LZC technologies and allowable solutions. Integration of low carbon technologies must be considered from the start of the design process.

DESIGN TEAM

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

It is important to understand the breakdown of energy use within the building so that measures can be targeted where the greatest reductions are achievable. For example, in the base case school building, lighting is the dominant contributor and, as shown in Figure 4, improvements in lighting efficiency provide the greatest reductions in carbon dioxide emissions. However, cost effectiveness should also be taken into account (See Section 7.3).

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 school operating breakfast clubs and evening classes will have a higher lighting and heating demand than a school operating during normal school opening hours only. The National Calculation Method (NCM) applies a standard activity schedule to different building types and therefore cannot take into account different occupancy schedules.

SITE FACTORS

Site constraints can have a major effect on the economics and viability of low and zero carbon buildings and therefore site selection is a key issue. The ability to introduce large wind turbines or to integrate into (or initiate) a low-carbon district heating system, for example, will have a large positive impact on the cost-effectiveness of constructing zero carbon schools 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

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

RECOMMENDATION

There are limitations to the NCM and it is recommended that, where the occupancy schedule of the building is known, this is taken into account in any thermal simulation modelling rather than relying on the Part L compliance software alone to minimise actual carbon emissions.

RECOMMENDATION

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

BUILDING FORM AND FABRIC

Where school functionality and other site constraints allow, consideration should be given to altering the depth of plan to maximise daylight and the potential for adopting a natural ventilation solution.

Such an approach would involve the use of shallow plan classrooms amongst other features, however experience has shown that many new schools are not naturally ventilated as the functionality of classrooms takes priority (See Section 5).

Consideration of reducing the plan depth to maximise daylight and the potential for natural ventilation, as well as optimising orientation to minimise energy demand, should be investigated where possible. The following guidelines are based on the Target Zero research:

- **North facing rooms - have low solar heat gain without shading. Rooms requiring cooling (such as classrooms with high IT loads and server rooms) will benefit from reduced energy usage. Rooms which can be kept cool without the need for mechanical cooling would also benefit from being located on a north elevation (narrow plan cellular office, art and music rooms, etc)**
- **South facing rooms - have high useful winter solar heat gain and, when shaded, controlled solar heat gain in summer. Classrooms and offices are ideally suited with suitable fixed shading (blinds will be required to block glare from low angle sun in winter)**
- **East/West facing rooms - have high solar heat gain without solar control glazing or adjustable shading to block out low angle sun. Rooms without large levels of external glazing are ideally suited here (such as drama studios, sports halls, toilets, etc).**

Reducing demand for energy is the first step to zero carbon and building fabric performance, in particular glazing, has a major impact on three elements of a building's energy demands:

- **space heating**
- **space cooling**
- **lighting.**

When developing elevational treatments and specifications, it is important to balance these three factors together with the aesthetics and functionality of the building. Dynamic thermal modelling provides the opportunity for the energy and thermal comfort related aspects to be investigated and optimised and it is recommended that thermal modelling is commissioned on all new projects to ensure that the building orientation and glazing and solar shading strategies are optimised within the constraints imposed by the site and the functional priorities of the building.

LOW AND ZERO CARBON (LZC) TECHNOLOGIES

Once energy demands have been reduced and efficient baseline HVAC systems selected, the introduction of low and zero carbon technologies should be considered. Table 4 lists, in descending order of cost-effectiveness (i.e. £25-yrNPV/kgCO_2 saved), the LZC technologies modelled for the school building. Table 4 assumes that energy efficiency package A will be installed. This can be justified by its attractive financial return and the fact that site constraints are unlikely to prevent its implementation.

RECOMMENDATION

It is recommended that dynamic thermal modelling is commissioned on all new projects to ensure that the building orientation and glazing and solar shading strategies are optimised within the constraints imposed by the functional priorities of the building.

Where school functionality and other constraints allow, consideration should be given to altering the depth of plan to maximise daylight and building orientation to minimise energy demand.

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

TABLE 4
LZC TECHNOLOGIES MODELLED – IN ORDER OF COST EFFECTIVENESS (£25-YEAR NPV/KG CO_2 SAVED)

	TECHNOLOGY	NOTES
OFFSITE TECHNOLOGIES	LARGE 2.5MW WIND TURBINE ON SHORE	NORDEX 100M TOWER HEIGHT 99.8M ROTOR DIAMETER
	LARGE 5.0MW WIND TURBINE OFFSHORE	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
	LARGE GAS FIRED CHP OFFSITE	SPACE HEATING, HOT WATER AND ELECTRICITY
	LARGE FUEL CELL CHP OFFSITE	SPACE HEATING, HOT WATER AND ELECTRICITY
	LARGE BIOMASS FIRED CHP OFFSITE	SPACE HEATING, HOT WATER AND ELECTRICITY
	LARGE ENERGY FROM WASTE OFFSITE	SPACE HEATING AND HOT WATER
	LARGE ANAEROBIC DIGESTION CHP OFFSITE	SPACE HEATING, HOT WATER AND ELECTRICITY
	LARGE WASTE PROCESS HEAT OFFSITE	SPACE HEATING AND HOT WATER
	LARGE BIOMASS FIRED CCHP OFFSITE	SPACE HEATING, COOLING, HOT WATER AND ELECTRICITY
	LARGE FUEL CELL CCHP OFFSITE	SPACE HEATING, COOLING, HOT WATER AND ELECTRICITY
	LARGE GAS FIRED CCHP OFFSITE	SPACE HEATING, COOLING, HOT WATER AND ELECTRICITY
	SMALL WASTE PROCESS HEAT OFFSITE	HOT WATER
	SMALL ENERGY FROM WASTE OFFSITE	HOT WATER
ON SITE TECHNOLOGIES	Air Source Heat Pump Single Cycle	Space heating
	Air Source Heat Pump Reverse Cycle	Space heating and cooling
	Medium 50kW wind turbine	Entegrity 36.5m tower height 15m rotor diameter
	Small 20kW wind turbine	Westwind 30m tower height 10m rotor diameter
	Small ground duct	Supplying tempered air to the central activity area
	Large Photovoltaics	1,300m² maximum roof capacity
	Biomass Heating	Space heating and hot water
	Energy efficiency package B	See Table 1
ON SITE TECHNOLOGIES	Large Solar Water Heating	216.1m² Sized to provide as much hot water as is practical
	Open-loop Ground Source Heat Pump Single Cycle	Space heating
	Small 1kW wind turbine	Futurenergy 6.2m tower 1.8m rotor diameter
	Open-loop Ground Source Heat Pump Reverse Cycle	Space heating and cooling
	Large fuel cell CCHP	Space heating, cooling, hot water and electricity
	Large gas fired CCHP	Space heating, cooling, hot water and electricity
	Large fuel cell CHP	Space heating, hot water and electricity
	Closed-loop Ground Source Heat Pump Reverse Cycle	Space heating and cooling
	Closed-loop Ground Source Heat Pump Single Cycle	Space heating
	Large ground duct	Supplying tempered air to the whole building Small system is more cost effective than package B
	Energy efficiency package C	See Table 1
ON SITE TECHNOLOGIES	Small fuel cell CHP	Hot water and electricity
	Large gas fired CHP	Space heating, hot water and electricity
	Large biomass fired CCHP	Space heating, cooling, hot water and electricity
	Large anaerobic digestion CHP	Space heating, hot water and electricity
	Large biomass fired CHP	Space heating, hot water and electricity
	Small anaerobic digestion CHP	Hot water and electricity
	Small biomass fired CHP	Hot water and electricity
	Small gas fired CHP	Hot water and electricity

7.0 ROUTES TO LOW AND ZERO OPERATIONAL CARBON

It is noted in Table 4 that a number of the CHP options do not perform favourably due to the way the National Calculation Methodology (NCM) deals with hot water demand. It is important that LZC technologies are appraised based on accurate assessment of their performance and not purely on the theoretical energy loads in the NCM.

In the absence of large-scale and offsite technologies, it is likely that solar thermal and photovoltaic technologies will be required to enable school buildings to reach on site Carbon Compliance targets. They may also be a cost-effective solution when compared against the cost of Allowable Solutions. Therefore, allowing easy integration of these technologies from the outset can help to reduce costs. Solar panels produce optimal output when south facing, unshaded and at an elevation of 30° to 40°, therefore mounting solar panels on the roof (on the south side of a sawtooth north light, as a plant screen, etc.) or on the south façade (as shading above windows) are ideal locations. The performance of PV panels can be enhanced when located on green roofs (as green roofs help reduce the ambient temperature).

A number of the low and zero carbon technologies that were found to be most cost-effective will require plant space over and above traditional HVAC plant. Biomass technologies also require access for fuel delivery and storage.

Once LZC technologies have been selected, they should be integrated into the design at the earliest opportunity to optimise the design and reduce capital expenditure. For example the choice of heat delivery system should take account of the selected heat source.

It should be noted that improving fabric insulation performance much more than 2006 Part L levels was found to be less cost-effective than improvements to building services plant and their controls. Moderate improvements to insulation levels were found to be more cost-effective than many mainstream low and zero carbon technologies. However, ultra insulation was found to be less economic than most of the low and zero carbon technologies.

RECOMMENDATION

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

The ranking of technologies in Table 4 demonstrates that near-site and offsite solutions may well lead to the most cost effective route to zero carbon and should be investigated.

It is important therefore that the design team looks beyond the site boundary for opportunities to take advantage of LZC technologies and allowable solutions.

STRUCTURAL DESIGN CONSIDERATIONS

The influence of the structure on the operational carbon emissions of the school building analyses was found to be very small, less than 1%. See Section 9.1. The benefits of thermal mass in reducing carbon emissions and preventing overheating were found to be limited for the school building studied, particularly when future climate change was considered. See Section 7.8.

The likely impacts of climate change on the building's heating and cooling requirements should be considered during the design process. Predicted impacts are likely to increase the cooling demand in summer and reduce the heating requirements of the school in winter. This will have the effect of reducing the benefits of many LZC technologies which supply heat whilst enhancing the benefits of those which supply cooling.

It is important to consider the impacts of introducing LZC technologies and certain energy efficiency measures on other aspects of 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, variations in plant requirements may impact on space planning**
- **programming implications: for example CHP systems might have a lead in time of 30 weeks.**

Plant room size will vary according to the LZC technologies that are to be used in the building. For example, biomass boilers will require additional storage space for wood chip fuel and for ash as well as access for fuel deliveries and waste collections. Plant room sizes for offsite solutions that provide district heating could be considerably reduced if no backup plant is required for the building. 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.

ST CHRISTOPHER SCHOOL, LETCHWORTH GARDEN CITY

7.8 IMPACTS OF CLIMATE CHANGE

Modelling the effects of climate change on the school building, using CIBSE weather tapes based on UKCIP climate predictions for the UK, showed that the heat energy requirements of the school will progressively reduce, whilst cooling demands increase. Analysis of the case study school building showed that heating loads are expected to decrease by 9% between 2005 and 2020 and by 26% between 2005 and 2050. Over the same periods, cooling loads are predicted to increase by 21% and 75-79% respectively.

Although the increase in cooling loads appears large, the cooling energy demand is low in the school building studied (see Figure 19) and therefore the resultant increase in carbon emissions is more than offset by the reduction in heating demand.

The overall net effect in carbon dioxide emissions from these changes in heating and cooling demands is to reduce total building emissions by 2% by 2020 and by 5% between 2005 and 2050.

The choice of building structure makes little difference to the overall operational carbon emissions under the current and future weather scenarios considered. Changes in space heating loads reduce slightly whilst cooling loads increase slightly, depending on the nature of the framing system.

Using 2005 weather data, the operational carbon emissions of the school building were analysed; first with a concrete frame (Option 1) and then an alternative steel frame (Option 2). The concrete-framed building was predicted to emit 0.12% less CO_2 than the steel-framed building. Using 2020 weather data, the difference was calculated to be 0.09% and by 2050, just 0.01%. Details of the steel and concrete frame options are given in Section 9.

Testing of a number of different approaches to maintaining thermal comfort found that the school building studied currently requires cooling in order to maintain acceptable temperature levels and comply with the requirements in Building Bulletin 101[6]. Climate change is predicted to raise temperatures and so the need for cooling will remain and is likely to increase slightly in the future. This applies to all three structural options studied.

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 rating for the base case building.

To provide a benchmark for the BREEAM assessment, the base case building, modelled on the Knowsley School, was defined as described in Section 5.

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 suburban (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 include factors related 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 base case scenario was based on the actual location, site conditions, etc. of the Knowsley School and is used as the basis for comparison with the above six scenarios.

Credits were assigned a 'weighted value' by dividing the capital cost of achieving the credit, by its 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.

RICHARD LANDER SCHOOL, TRURO

8.0 ROUTES TO BREEAM OUTSTANDING

8.1 BREEAM RESULTS AND GUIDANCE

Figure 8 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 8
BREEAM GUIDANCE FLOWCHART

8.0 ROUTES TO BREEAM OUTSTANDING

THE TARGET RATING

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

- **the requirements in the brief**
- **any targets set as a condition of funding, e.g. DCFS, BSF, etc**
- **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 5.

TABLE 5
MINIMUM BREEAM REQUIREMENTS

BREEAM CREDIT	MINIMUM STANDARDS FOR VERY GOOD	MINIMUM STANDARDS FOR EXCELLENT	MINIMUM STANDARDS FOR OUTSTANDING
Man 1 Commissioning	1	1	2
Man 2 Considerate constructors		1	2
Man 4 Building user guide		1	1
Man 9 Publication of building information (Education only)			1
Man 10 Development of a learning resource (Education only)			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, as shown in Table 6.

TABLE 6
COST OF ACHIEVING MINIMUM BREEAM REQUIREMENTS

BREEAM CREDIT	CAPITAL COSTS FOR VERY GOOD	CAPITAL COSTS FOR EXCELLENT	CAPITAL COSTS FOR OUTSTANDING
Man 1 Commissioning	0	0	20,000
Man 2 Considerate constructors	-	0	0
Man 4 Building user guide	-	1,500	1,500
Man 9 Publication of building information (Education only)	-	-	0
Man 10 Development of a learning resource (Education only)	-	-	10,000
Hea 4 High frequency lighting	0	0	0
Hea 12 Microbial contamination	0	0	0
Ene 1 Reduction in CO_2 emissions	-	31,900	1,013,530
Ene 2 Sub-metering of substantial energy uses	4,500	4,500	4,500
Ene 5 Low or zero carbon technologies	-	Costs included in Ene 1	Costs included in Ene 1
Wat 1 Water consumption	0	0	6,800
Wat 2 Water meter	750	750	750
Wst 3 Storage of recyclable waste	-	0	0
LE 4 Mitigating ecological impact	0	0	0

CREDITS ASSOCIATED WITH SITE FACTORS

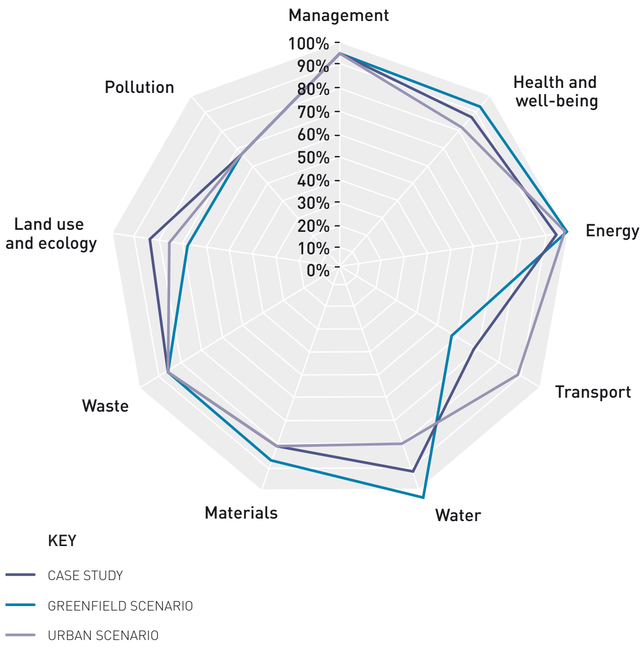
The location of the building has the most impact on:

- **Transport 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 9 shows the balance of credits required to achieve a BREEAM Outstanding rating. The radial axis represents the proportion of available credits achieved under each section of BREEAM for each site scenario using the case study building. It shows the most cost-effective routes under the urban, greenfield and case study scenarios to achieve BREEAM Outstanding.

For the greenfield scenario, Transport (Tra) and Land Use and Ecology (LE) credits are lost relative to the other scenarios, requiring credits to be obtained in other BREEAM sections. In this case, the most cost-effective credits are in the Water, Materials and the Health and Well-being sections.

FIGURE 9
COMPARISON OF URBAN AND GREENFIELD SITE SCENARIOS TO ACHIEVE A BREEAM OUTSTANDING RATING



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

- **LE1 - Re-use of land**
- **LE3 - Ecological value of site and protection of ecological features**
- **LE4 - Mitigating ecological impact**
- **LE5 - Enhancing site ecology**
- **Tra1 - Provision of public transport**
- **Tra2 - Proximity to amenities.**

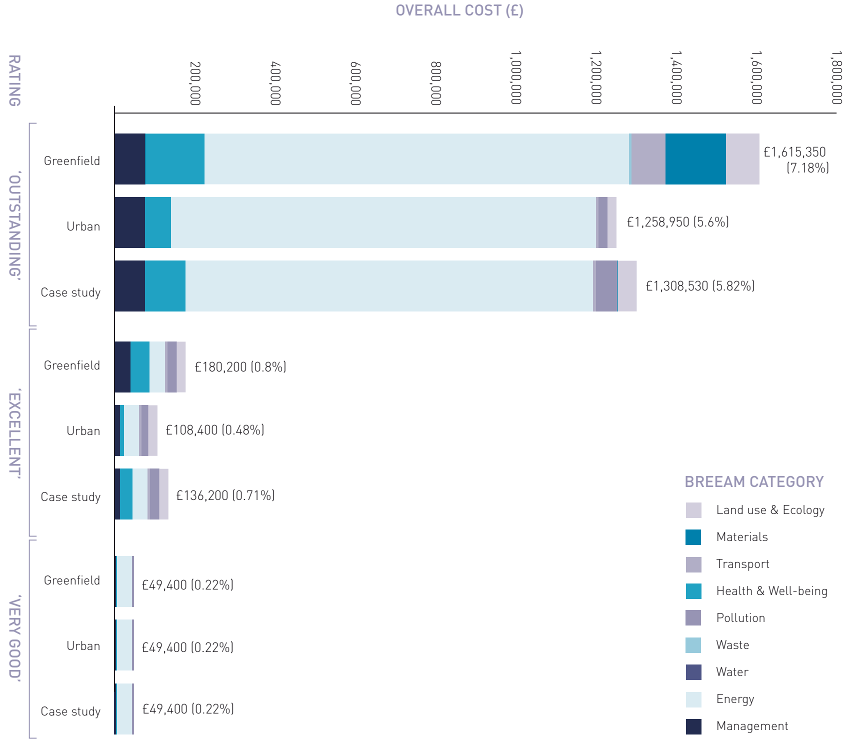
All of these credits are zero cost due to the location, except for LE5. Enhancing site ecology, which entails providing ecological features such as bird and bat boxes, green roofs, wildflower plantings, or wildlife ponds.

The total capital cost uplift for the two location scenarios considered and the case study building is shown in Figure 10.

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.

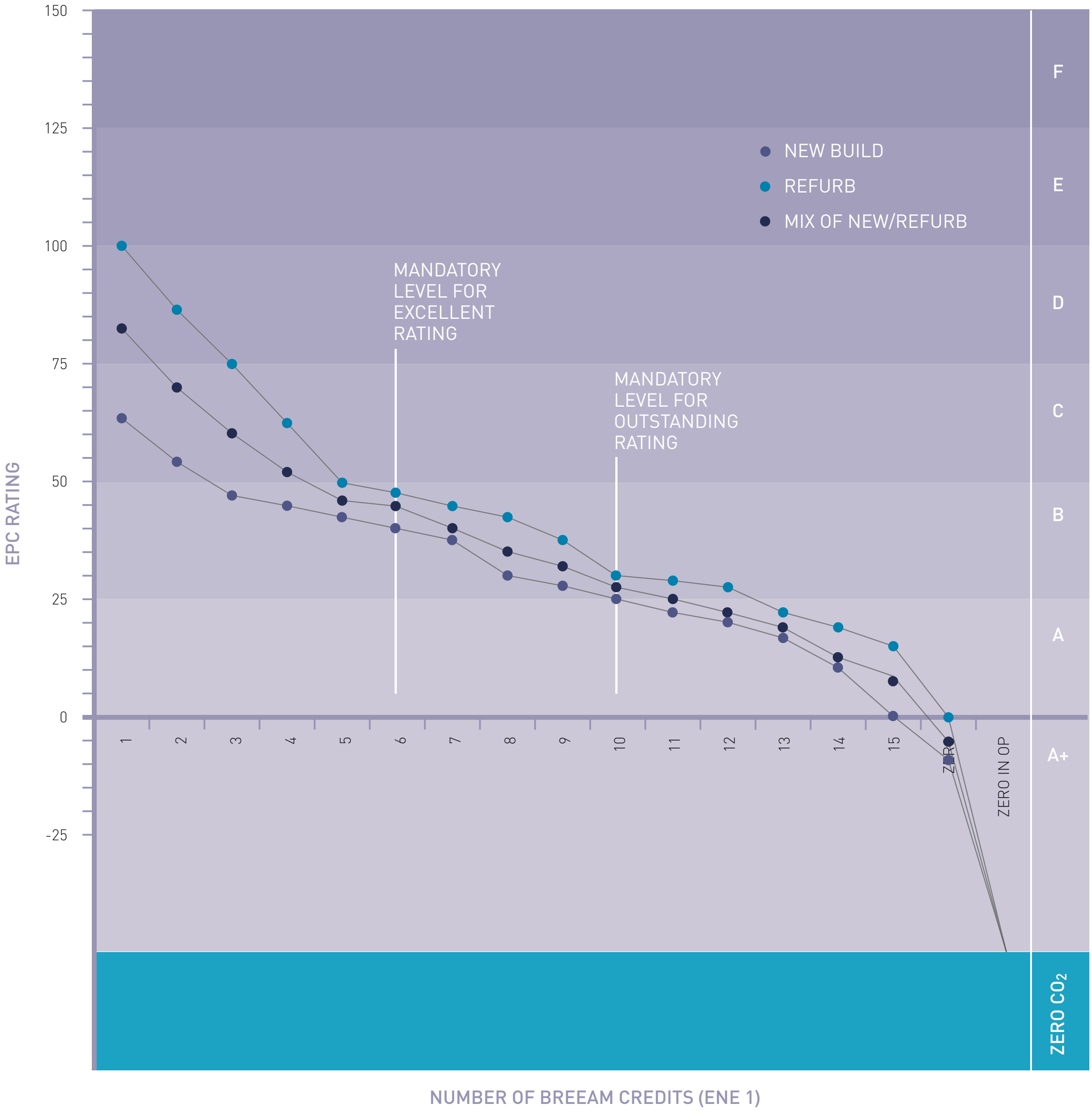
FIGURE 10
COMPARISON OF COST UPLIFT FOR URBAN AND GREENFIELD SITE SCENARIOS



CREDITS ASSOCIATED WITH ENERGY REDUCTION

Figure 11 shows the relationship between the Energy Performance Certificate (EPC) score and operational energy credit Ene1: Reduction in CO_2 emissions credits.

FIGURE 11
EPC RATING COMPARED TO BREEAM SCORE SHOWING MINIMUM STANDARDS REQUIRED FOR EXCELLENT AND OUTSTANDING RATINGS



8.0 ROUTES TO BREEAM OUTSTANDING

There may be a 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 12 shows the capital and NPV cost of two potential routes to approaching the 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 whilst acknowledging practical and economic constraints, for example, where photovoltaics are included the total area of the array is limited by the roof space available.

The bottom bar in Figure 12 represents the capital cost of the scenario where wind technologies are viable on site (a 50 kW turbine is included in the proposed package modelled). The next bar up reflects a scenario is which on site wind technologies are not viable either as a result low wind availability or other issues such as spatial or planning constraints.

The top two bars show the same two scenarios, except that they include the NPV benefit of the energy measures selected, i.e. accounting for the operational and maintenance costs of the LZC technologies and the utility cost savings over a 25-year period.

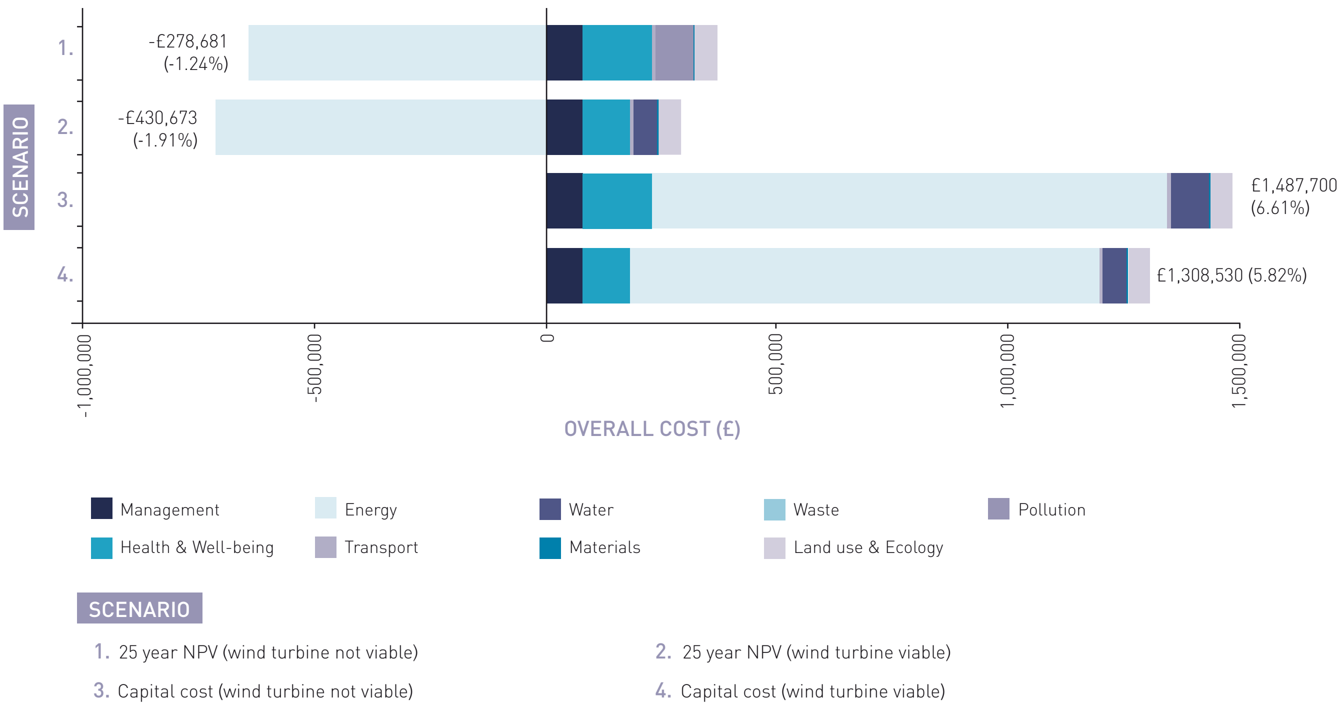
These graphs focus only on the Outstanding rating as it is perceived that if a zero carbon target was set for a school, then it would be logical to also pursue an Outstanding rating since, by far, the most significant costs associated with attaining an Outstanding BREEAM rating relate to the operational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

The energy aspects of achieving Very Good and Excellent BREEAM ratings are less arduous as it is possible to achieve these through energy efficiency measures alone, i.e. without LZC technologies.

RECOMMENDATION

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

FIGURE 12
CAPITAL COST UPLIFT AND 25 YEAR NPV OF ACHIEVING BREEAM OUTSTANDING AND TARGETING ZERO CARBON



CREDITS ASSOCIATED WITH EXPERIENCE OF 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 previous cost data relating to achieving BREEAM credits.

Contractors who have delivered BREEAM Post-Construction Reviews will have set up the required systems and processes to do this efficiently. This will help to achieve the Construction Site Impact credits (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 7. It was assumed that an 'exemplar' contractor would be able to achieve all of these credits, which are all relatively low cost.

RECOMMENDATION

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

TABLE 7
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

CREDITS ASSOCIATED WITH STRATEGIC DESIGN

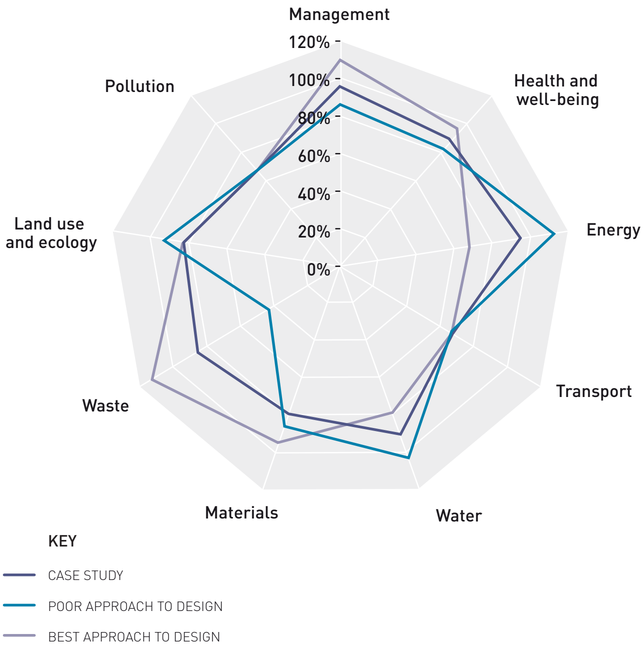
Early design decisions about the fabric and form of the building will have an impact on the following BREEAM credits:

- **Hea 2: View out, in terms of depth of floor plate**
- **Hea 7: Potential for natural ventilation, in terms of the depth of floor plate and whether the building has been designed for natural ventilation**
- **Hea 8: Indoor air quality, in terms of avoiding air pollutants entering the building**
- **Hea 13: Acoustic performance, which includes building acoustic enhancements to the music rooms as part of the design**
- **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 13 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 school building.

It shows that a 'poor approach to design' implies that less credits are achievable in the Management, Health and Well-being and Waste sections and consequently that more credits have to be achieved in other sections, notably the Energy, Water, Land Use and Ecology sections. Credits in these sections are more costly to achieve.

FIGURE 13
COMPARISON OF 'APPROACH TO DESIGN' SCENARIOS TO ACHIEVE A BREEAM OUTSTANDING RATING



8.0 ROUTES TO BREEAM OUTSTANDING

For the case study building analysed, the results show that to achieve an Excellent BREEAM rating there is a cost uplift of 1.1% for a 'poor approach to design' compared to 0.3% for a building that applies a 'best approach to design'. Similarly, to achieve an Outstanding rating, there is a cost uplift of 10.6% for poor design, compared to 2.9% for a building that applies a best approach to design. In terms of capital cost, this is a saving of £170,200 to achieve an Excellent rating and £1,750,000 to achieve an Outstanding rating for applying a best approach to design.

The total capital cost uplift of the two 'design approach' scenarios considered are shown in Figure 14.

FIGURE 14
COMPARISON OF COST UPLIFT FOR DIFFERENT APPROACHES TO DESIGN SCENARIOS

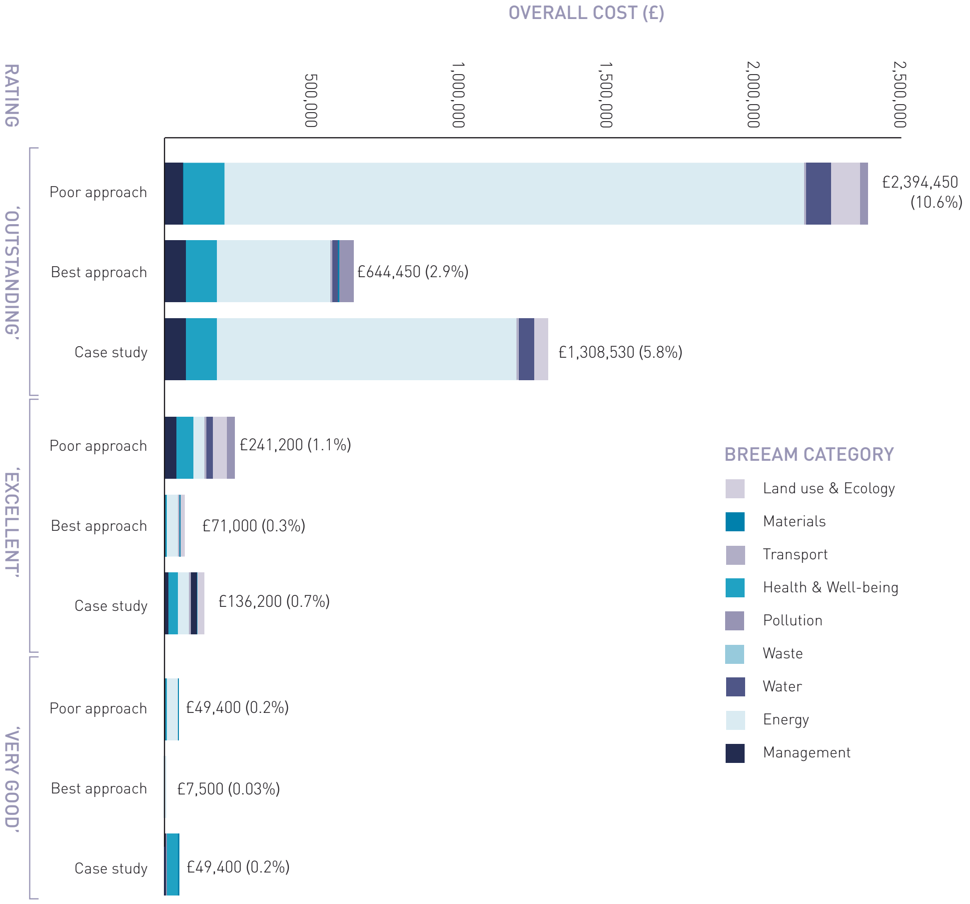


Table 8 shows the credits that relate to the form and fabric of the building. These should be considered at an early stage in the project so that they can be cost-effectively integrated into the design.

TABLE 8
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	Daylight calculations – 2% daylight factor, uniformity ratios and room depth criterion.	3,000 (to undertake daylighting study)
Hea 2 View Out	Desks 7m from a window and window is >20% of the inside wall area.	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.	17,000
Ene 1 Reduction in CO_2 emissions	A natural ventilation strategy would considerably reduce energy demand.	-

To achieve these credits, a narrow floor plate 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 case study building is based on a 9m x 9m grid with many classrooms that are 9m deep. This means that most of the credits in Table 8 are not achievable in the case study building. The 9m x 9m grid was chosen because the Local Education Authority specifically requested 81m^2 classroom sizes and several of the other spaces worked very efficiently on a 9m x 9m structural grid. It was recognised that the deeper classrooms would reduce daylight penetration and view out and preclude the use of natural ventilation strategies and therefore, a mechanical ventilation strategy was proposed in this case. (See Section 5.0)

It is common for schools to have 64m^2 classrooms based on an 8m x 8m structural grid. This grid size would be more conducive to natural ventilation or seasonal mixed mode solutions and would allow desks to be positioned to within 7m of a window and to achieve the 2% daylight factor.

More guidance and details on natural ventilation can be found in CIBSE AM10 Natural ventilation in non-domestic buildings[7].

Table 9 gives the credits that relate specifically to the space allocation, adjacencies and to the layout of the building and associated landscape.

RECOMMENDATION

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

If contemplating a naturally ventilated strategy for a school building, consideration should be given to the following rules-of-thumb:

- For single-sided ventilation with a single opening, the limiting depth for effective ventilation is approximately twice the floor-to-ceiling height;
- For single-sided ventilation with a double opening the limiting depth for effective ventilation is approximately 2.5 times the floor-to-ceiling height;
- For cross-flow ventilation the maximum distance between the two facades is five times the floor-to-ceiling height.

TABLE 9
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 10m^2 (for buildings over 5000m^2) and there would need to be an additional 10m^2 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.	6,600 (for both credits)
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 is of low ecological value or for the first credit if the land is of medium/high ecological value. 35,000 for the second credit if the 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.	32,500 for the first two credits and 50,000 for the third credit. This cost is dependant on site area and therefore could vary greatly.

POTENTIAL COSTS OF BREEAM CREDITS

Figures 15 to 17 show the most cost-effective routes to achieve a BREEAM 'Very Good', 'Excellent' and 'Outstanding' respectively for the case study school building. They show the cumulative credits, and costs, required to achieve the target rating and taking into account mandatory and scenario-related credits, e.g. relating to site location.

The graphs show the 'weighted value' for each of the credits required to achieve the 'Very Good', 'Excellent' and 'Outstanding' BREEAM rating. The 'weighted value' is the capital cost of the credit divided by the credit weighting.

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

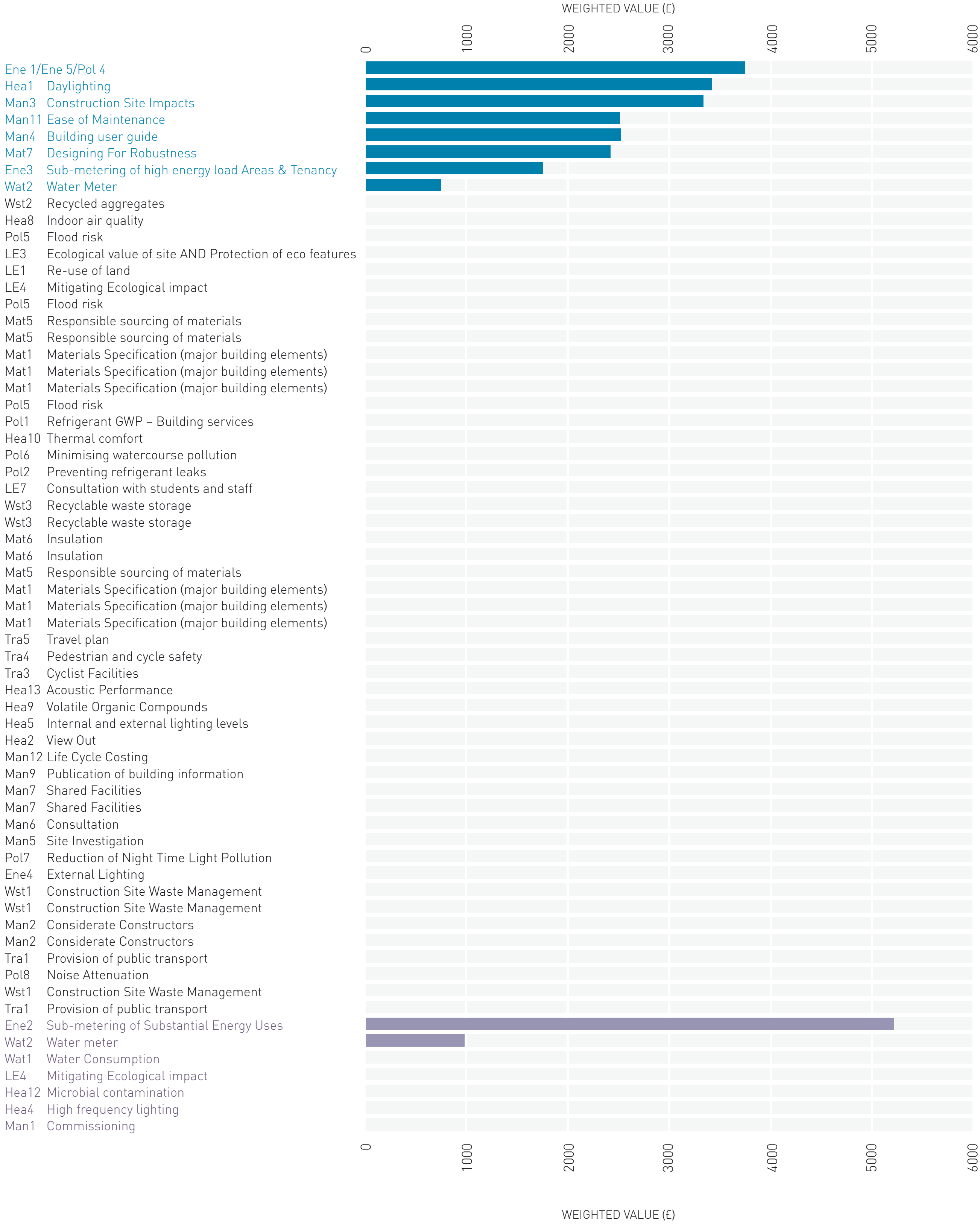
Working from the bottom up, the graphs identify (in purple) the mandatory credit requirements. Above these the zero cost optional credits are listed (in black). These are not ranked in any particular order. Above these (in blue) are the non-zero cost optional credits. Collectively, these credits identify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

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

It is recommended that the low and high cost credits are 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.

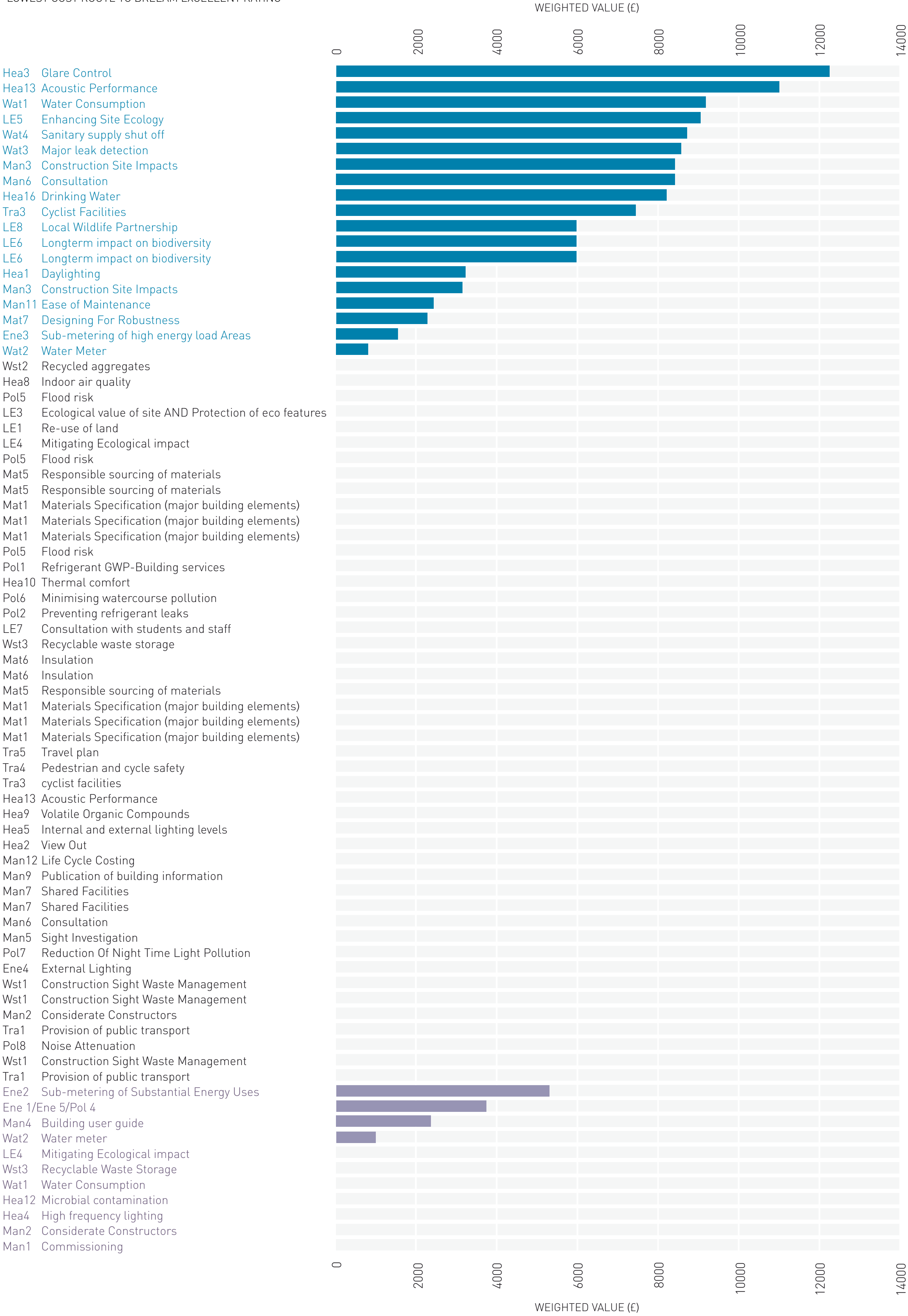
8.0 ROUTES TO BREEAM OUTSTANDING

FIGURE 15
LOWEST COST ROUTE TO BREEAM VERY GOOD RATING



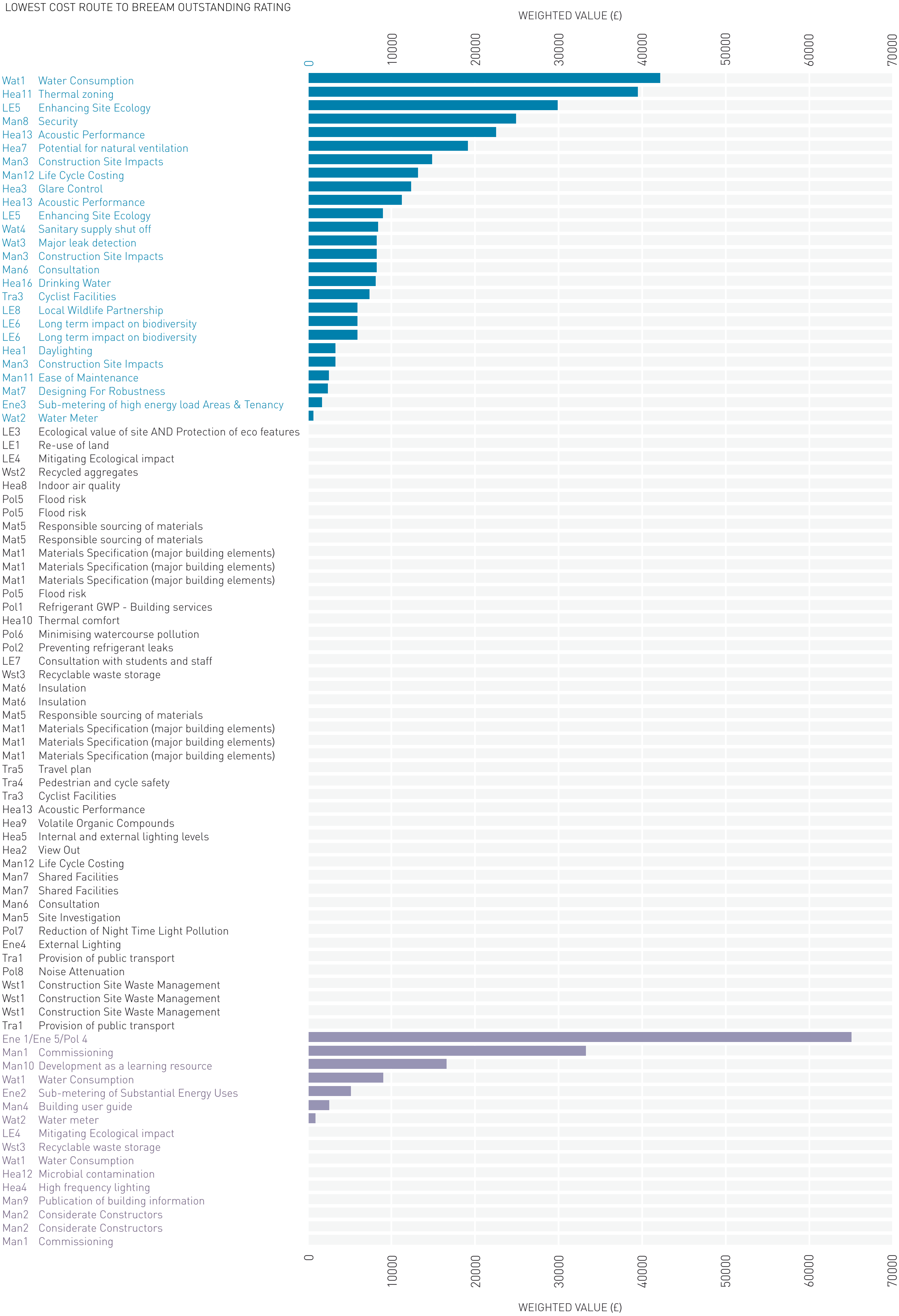
8.0 ROUTES TO BREEAM OUTSTANDING

FIGURE 16
LOWEST COST ROUTE TO BREEAM EXCELLENT RATING



8.0 ROUTES TO BREEAM OUTSTANDING

FIGURE 17
LOWEST COST ROUTE TO BREEAM OUTSTANDING RATING



GUIDANCE ON MATERIALS SELECTION

The research showed that there is an inherent weighting within the tool used to calculate the score under credit Mat 1 in the materials section of BREEAM. This inherent weighting is used in addition to weighting each element by area. The inherent weightings are shown in Table 10.

TABLE 10
ELEMENT WEIGHTINGS WITHIN THE BREEAM MATERIALS ASSESSMENT TOOL

ELEMENT:	EXTERNAL WALLS	WINDOWS	ROOF	UPPER FLOOR	INTERNAL WALLS	FLOOR FINISHES
WEIGHTING:	1.0	0.30	0.74	0.25	0.33	0.64

Table 10 shows that external walls, roofs and floor finishes are the most highly weighted. For the case study building, the full six credits were achieved by selecting Green Guide to Specification[8], A+ rated materials for the external walls, roofs and floor finishes. The relative areas of these elements change for different building configurations, which will change the number of points achieved. For example, a five-storey building will have less roof relative to floor area than the base case school.

The results of the Target Zero analysis show:

- **roof credits are generally easier to achieve with a steel frame (A+ to A Green Guide ratings) rather than concrete (generally B to D);**
- **upper floor credits are generally easier to achieve with steel frame using precast concrete planks or profiled metal decking (A+ to A) rather than concrete (generally B to D);**
- **pre-finished steel wall and roof cladding systems all have Green Guide ratings of A or A+;**
- **external walls, internal walls, windows and floor finishes are all largely independent of structure.**

The inherent weighting of the roof (0.74) in the BREEAM tool makes this an important element and, in this case, the analysis shows that steel construction achieves the required credits more easily than a concrete frame.

RECOMMENDATION

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.

STRUCTURAL DESIGN

Three alternative structural options for the school building were assessed as shown in Figure 18.

FIGURE 18
ALTERNATIVE STRUCTURAL OPTIONS

BASE CASE: STEEL FRAME WITH PRECAST HOLLOW CORE FLOOR SLABS	OPTION 1: IN SITU CONCRETE FLAT SLAB AND COLUMNS, LIGHTWEIGHT STEEL ROOF	OPTION 2: STEEL FRAME AND DECKING WITH IN SITU CONCRETE, STEEL PILES AND GLULAM SPORTS HALL FRAME

The structure and total build costs for these three options are given in Table 11. The rates and prices used were UK mean values, current at 2Q 2009.

TABLE 11
COMPARATIVE COSTS OF ALTERNATIVE STRUCTURAL DESIGNS

STRUCTURAL OPTION	DESCRIPTION	STRUCTURE COST[1] £/m^2 of GIFA	TOTAL COST PLAN (£)	TOTAL BUILDING RATE £/m^2 of GIFA	DIFFERENCE RELATIVE TO BASE CASE %
BASE CASE	Steel frame; 250mm hollow core precast units; 75mm screed	203	22,500,000	2,335	-
OPTION 1	In-situ 350mm concrete flat slab; 400 x 400mm columns	182	22,300,000	2,314	-0.88
OPTION 2	Steel frame; 130mm concrete slab on metal deck	190	22,100,000	2,294	-1.78

The capital cost of the base case building was compared with a number of other BSF funded schools, ranging from 6,100m² to 12,600m² floor area. The build rate for each of these projects was adjusted for direct comparison with the base case, i.e. ensuring a consistent base date for pricing, level of scope, etc. This generated a range of build costs of £2,145 to £2,605 per square metre. The base case cost fell at approximately the midpoint of this range.

9.1 IMPACT OF STRUCTURE ON OPERATIONAL CARBON EMISSIONS

Dynamic thermal modelling of the school building showed very little variation in operational carbon emissions; the Building Emissions Rate (BER) varying by less than 1%, between the three structural options. The predicted annual CO_2 emissions for each of the three buildings are shown in Table 12.

TABLE 12
BUILDING EMISSIONS RATE (BER) FOR THE BASE CASE BUILDING AND OPTIONS 1 AND 2

BUILDING	DESCRIPTION	BER (kgCO_2/m^{2}yr)
BASE CASE	Steel frame with hollow core precast concrete units	27.3
OPTION 1	In-situ concrete flat slab with a lightweight steel roof	27.1
OPTION 2	Steel beams with a concrete slab on steel deck, steel piles and glulam sports-hall frame	27.2

1 Frame and upper floors.

9.2 THERMAL MASS

Buildings with high thermal mass are constructed from materials which have a large capacity to absorb and store heat. Careful utilisation of this 'inertia' effect can help to stabilise internal temperatures and reduce summer cooling loads. Thermal mass is only really effective when it is directly exposed, most commonly by leaving the soffit of the floor above the occupants exposed. Frequently this does not occur in modern buildings which often have false ceilings that isolate the thermal mass.

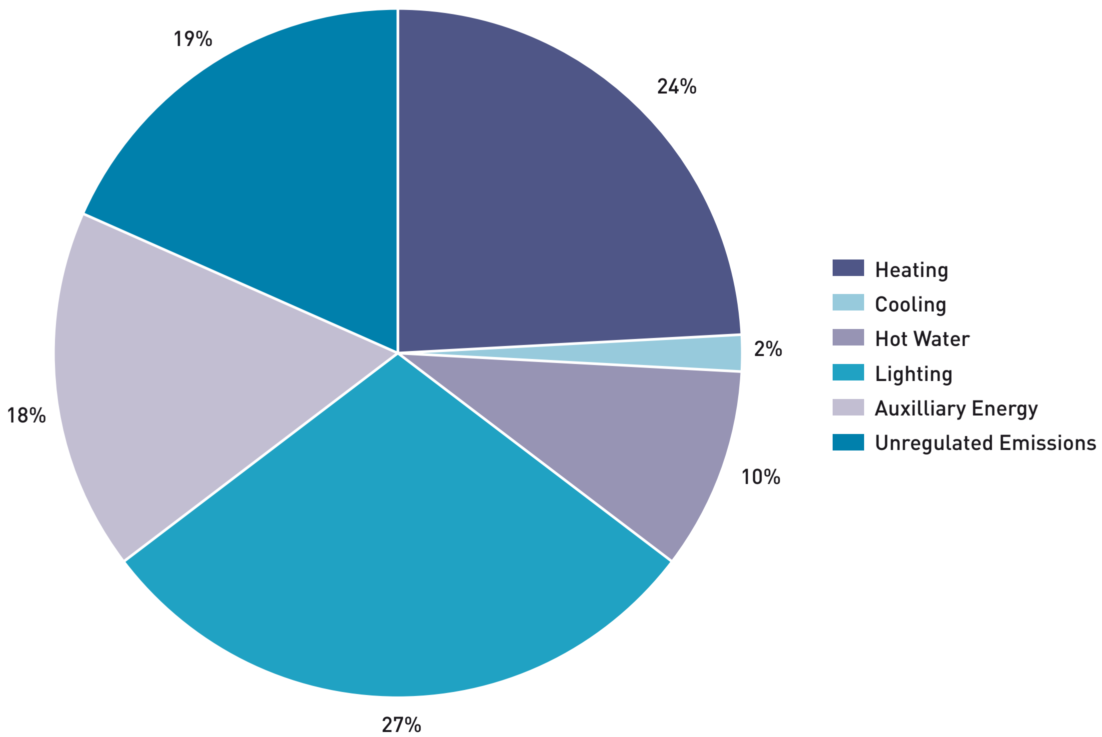
Thermal mass is only effective at providing a stable internal temperature if the heat stored in the fabric during the day is dissipated at night. Modern buildings are required to be well insulated and so this dissipation of heat cannot happen unless external air is allowed to circulate inside the building; so called night cooling or purging. If night cooling does not take place then each morning the building will still be warm from the previous day and so a steady build up in temperature can occur during prolonged periods of hot weather.

Night cooling can be provided either mechanically or naturally. Natural night cooling can be as simple as leaving windows open to allow cool night air to circulate inside the building. However this approach is often difficult to achieve due to the associated security risk. An alternative is to provide mechanical ventilation which runs through the night although this can consume considerable electrical energy and hence be counter productive.

Unless the energy consumed in cooling the building is a significant proportion of its total energy demand then the benefits of thermal mass are generally small and may even increase the building's carbon dioxide emissions unless the ventilation is carefully controlled to maximise night cooling. This is illustrated by Figure 19 which gives the breakdown of carbon emissions in the base case school building by energy demand. Cooling accounts for only 2% of the total operational carbon emissions based on 2005 weather data; this proportion is predicted to increase to 3% by 2050 as a consequence of climate change.

There are situations where it may be appropriate to consider a naturally ventilated, thermal mass solution to reduce operational carbon emissions. However, as this case study school building has demonstrated, there are often other important factors that can mitigate against this (see section 5.0). Furthermore, any presumption of improved operational energy performance of a heavyweight building should be tested using dynamic thermal modelling (see section 7.8). Where it is decided to utilise thermal mass in a building, studies have shown that, at most, it is possible to mobilise about 75-100mm of the structural depth of the exposed soffit. This is available in most common multi-storey framing systems, including all three described in the previous page.

FIGURE 19
BREAKDOWN OF CARBON EMISSIONS BY ENERGY DEMAND FOR THE CASE STUDY SCHOOL BUILDING



9.3 FOUNDATION DESIGN

To explore the influence of the substructure on the cost and embodied carbon of the base case building, the foundations for the alternative building options were redesigned. The base case school building has precast concrete piled foundations. Building Option 1 (reinforced concrete) was redesigned also with pre-cast concrete piles, but a greater number of larger piles were required because of the heavier superstructure. Option 2 (composite metal deck) was redesigned using steel H-piles. Table 13 defines the different foundation solutions assessed.

TABLE 13
FOUNDATIONS ASSESSED IN EACH BUILDING OPTION

BUILDING	FOUNDATION TYPE AND NUMBER
BASE CASE	Pre-cast concrete piles (390 Nr 7m x 235 x 235 mm)
OPTION 1	Pre-cast concrete piles (450 Nr 7m x 270 x 270 mm)
OPTION 2	Steel H-piles (248 Nr of various sizes)[1]

The comparative costs for these different foundation options are shown in Table 14 and represent an estimate of the cost for a piling subcontractor to carry out the works, including materials supply and installation, sub-contractor's preliminaries, overheads, testing and profit. The bulk excavation and ground bearing slabs are the same for each option considered. Notional allowances have been made for the piling mat, contamination, site obstructions etc.

TABLE 14
BREAKDOWN BY COST FOR THE DIFFERENT FOUNDATION OPTIONS

BUILDING	BASE CASE (£)	£/m² OF GROUND SLAB	OPTION 1 (£)	£/m² OF GROUND SLAB	OPTION 2 (£)	£/m² OF GROUND SLAB
BULK EXCAVATION; INCLUDING PILING MAT	210,500	48.95	210,500	48.95	210,500	48.95
PILING	205,500	47.80	264,400	61.49	102,800	23.90
PILECAPS AND GROUND BEAMS	177,400	41.25	188,800	43.90	141,700	32.95
GROUND BEARING SLAB	325,600	75.72	325,600	75.72	325,600	75.72
TOTAL	**919,000**	**213.72**	**989,300**	**230.06**	**780,600**	**181.52**

Overall the substructure cost for Option 2 is estimated to be up to 15% less than the base case and 21% less than Option 1. In terms of the piling costs alone, the H-pile solution (Option 2) offers a saving of up to 50% relative to the base case pre-cast concrete pile solution and 61% relative to Option 1. This is primarily as a result of the reduction in pile numbers for Option 2 relative to the other options, together with the potential to rationalise the design of pile caps, ground beams etc. and the consequential impact on the cost of preliminaries.

1 Care was taken in the design of the foundations to avoid the error of comparing the steel and concrete pile options by assuming the same configuration. The design load capacity for steel piles, based on careful analysis of the ground conditions, is significantly greater than that used to develop the concrete pile configuration resulting in fewer piles and a different optimum configuration.

The embodied carbon of the different substructure options were assessed using the CLEAR model (see Section 10 and Appendix E). Table 15 summarises the amounts of materials used for the piles, pile caps and ground beams and the total embodied carbon for each option. These results have been included in the whole building embodied carbon assessments described in Section 10.

TABLE 15
EMBODIED CARBON RESULTS AND BREAKDOWN OF MASS OF MATERIALS FOR EACH FOUNDATION OPTION

BUILDING	NUMBER AND TYPE OF PILES	NUMBER OF PILECAPS	CONCRETE GROUND BEAMS (m)	MASS OF MATERIALS (t)	EMBODIED CARBON (tCO_2e)
BASE CASE	390 precast concrete piles	124	686	1,101	215
OPTION 1	450 precast concrete piles	129	490	1,414	265
OPTION 2	248 steel H-piles	101	517	593	194

The embodied carbon of the piles, pile caps and ground beams represents between 7% and 8% of the total embodied carbon footprint of the school building. Building Option 1 has the heaviest substructure and the highest embodied carbon footprint. Relative to the best performing H-pile solution, the Option 1 substructure is 139% heavier and has a 37% larger carbon footprint.

Steel piles also have the major advantage that they can be easily extracted, recycled and reused leaving the site uncontaminated for redevelopment.

HARRIS ACADEMY, SOUTH NORWOOD, CROYDON

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, the objective of this aspect of Target Zero was to understand and quantify the embodied carbon emissions of school buildings focussing particularly on different structural forms.

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

- **manufacture and transport of the construction materials**
- **construction process**
- **demolition and 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. If end of life issues are not considered, then the analysis considers as equal demolition scenarios where the materials are recycled or reused and demolition scenarios where they are sent to landfill. This is a common failing of many embodied carbon datasets and analyses that only assess 'cradle-to-gate' carbon emissions i.e. finishing 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.

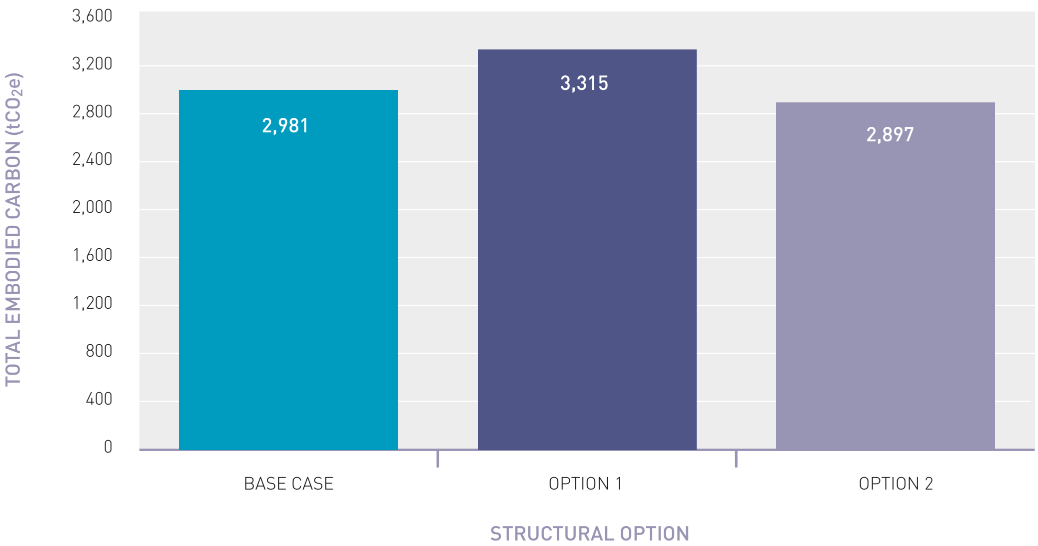
The embodied carbon impact of the three structural options considered (see Section 9) was measured using the life-cycle assessment (LCA) model CLEAR - See Appendix E.

Each building was assumed to have the same facade, windows and drainage and therefore the embodied carbon of these elements was identical. Maintenance issues were excluded from the analysis as there is sparse data on this and any impacts are likely to be similar between the different building options assessed.

Figure 20 shows the total embodied carbon impact of the base case school building and the two alternative structural options studied. Relative to the base case, the in-situ reinforced concrete structure (Option 1) has a higher (11%) embodied carbon impact whereas the steel composite structure (Option 2) has a marginally (3%) lower impact.

Normalising the data to the total floor area of the building, gives the following embodied carbon emissions of 309, 344 and 301 $kgCO_2e/m^2$ for the base case and structural Options 1 and 2 respectively.

FIGURE 20
TOTAL EMBODIED CARBON EMISSIONS OF THE BASE CASE BUILDING AND STRUCTURAL OPTIONS 1 AND 2



10.0 EMBODIED CARBON

Figures 21 and 22 show the mass of materials used to construct each of the three buildings broken down by element and material respectively. The total mass of materials used to construct the school was estimated to vary between 18.5kt (Option 2) and 23.3kt (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 upper floors and drainage also take significant quantities of materials, mainly concrete. A relatively small proportion (3 to 4%) of the total building materials is used in the bearing structure.

FIGURE 21
MASS OF MATERIALS - BREAKDOWN BY ELEMENT

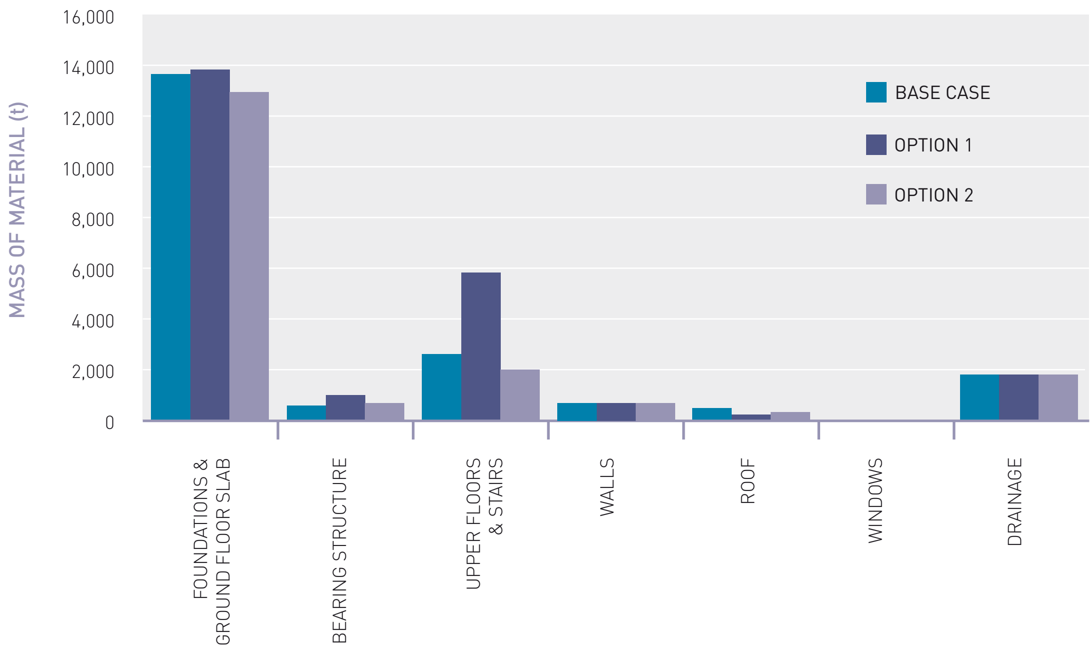
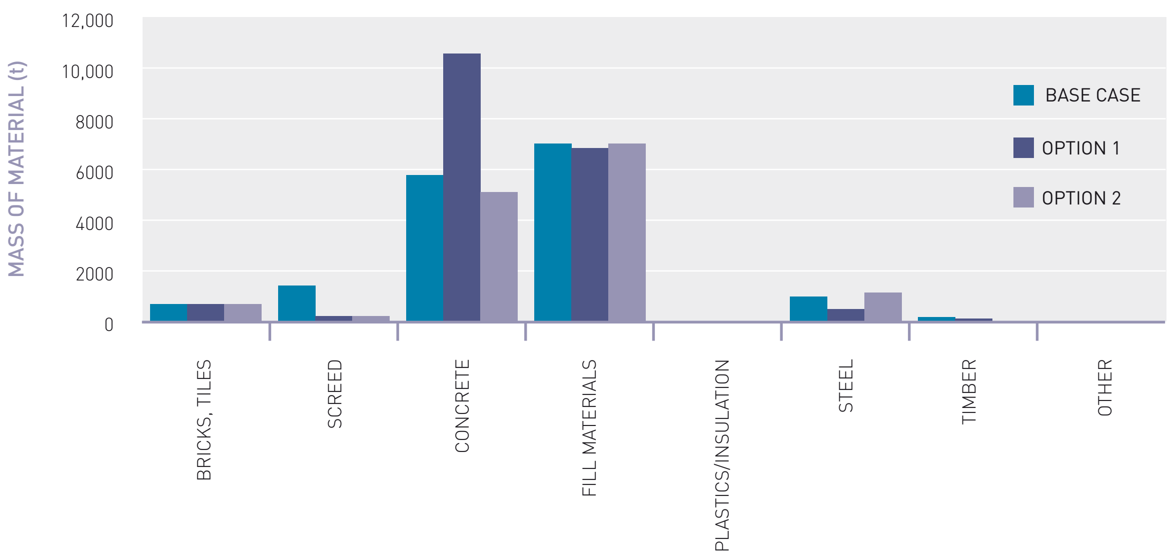


FIGURE 22
MASS OF MATERIALS - BREAKDOWN BY MATERIAL



Figures 23 and 24 show the breakdown of embodied carbon in the three buildings by material and building element respectively. The following points are noted:

- **the extra 4,577 tonnes of concrete used in Option 1 contribute an additional 900 tCO_2e compared to the base case. 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**
- **although the amounts of timber used in the buildings were relatively small, the impact of the timber shuttering on the in-situ concrete structure (Option 1) is apparent**
- **the results for the base case and Option 2 are quite similar. The base case having heavier screeded, concrete floors than Option 2 which, in comparison, has more steel both in the upper floor decking and the H-piles**
- **the walls, windows and drainage impacts are identical for each option**
- **by combining the bearing structure with the upper floors, the advantage of the structural steel solutions become apparent showing around a 30% smaller embodied carbon impact than the in-situ concrete flat slab option**
- **there is little variation in the transport impact between the three options. The impact being around 7% of the total**
- **although based on less robust data, the estimate of embodied carbon from on site construction activity is relatively significant at 10% of the total impact.**

FIGURE 23
BREAKDOWN OF EMBODIED CARBON BY MATERIAL

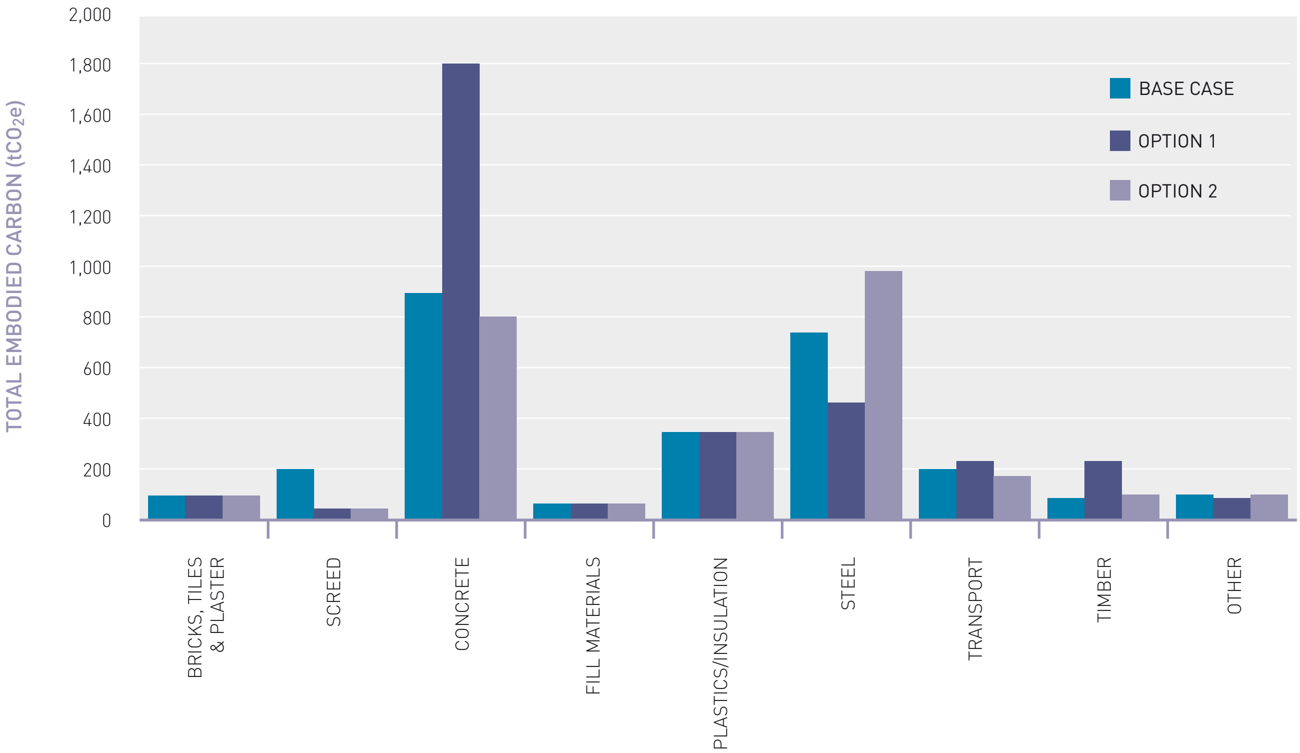
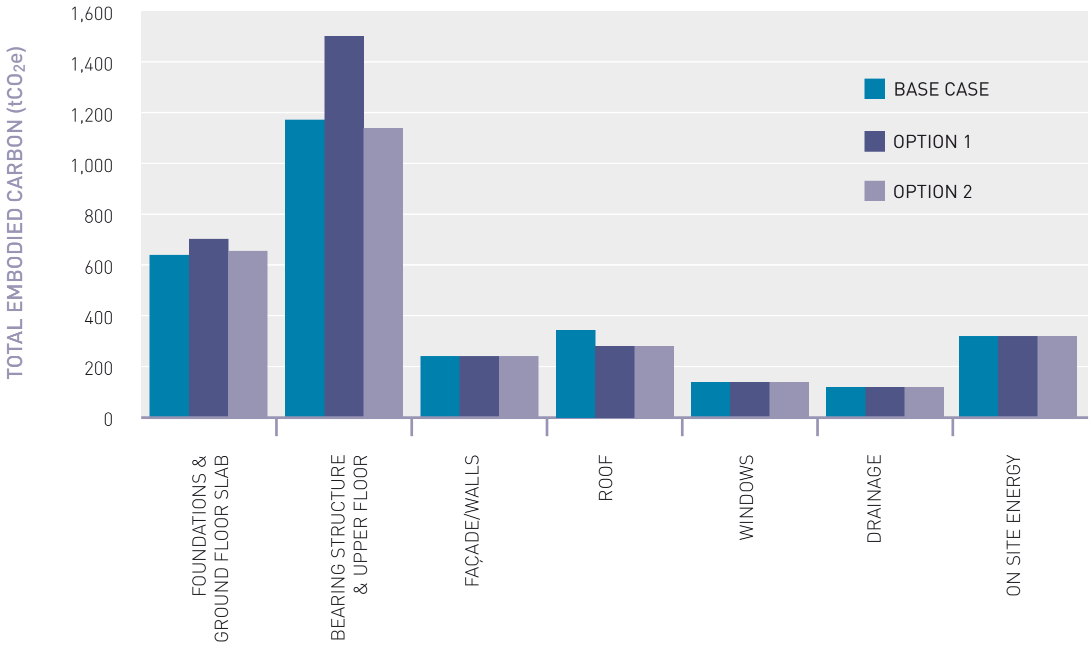


FIGURE 24
BREAKDOWN OF TOTAL EMBODIED CARBON BY ELEMENT



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.

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.**

Embodied carbon assessments can be very sensitive to the assumptions made and methods used for data sourcing and analysis.

When undertaking embodied carbon assessments therefore transparency is crucial so that all assumptions are clearly set out alongside the results.

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

APPENDIX A

METHODOLOGY USED TO ASSESS LOW AND ZERO OPERATIONAL CARBON SOLUTIONS

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

1. In order to produce a building which is more typical of current practice, the Knowsley School building was amended as follows:

- **the ground source heat pump was removed and replaced with conventional gas-fired heating and electrically-driven cooling**
- **the levels of insulation were reduced until these were no better than that required by criterion 2 of Part L (2006)**
- **the winter garden was removed leaving an open courtyard space**
- **HVAC system efficiencies were altered to industry standards**
- **the facade was simplified to one construction type.**

2. A dynamic thermal model of the building was then developed using the IES software suite. This Part L approved software is capable modelling the annual operational energy/carbon performance of the building.

3. The model was then fine-tuned to just pass Part L2A (2006) by altering the energy efficiency of the lighting system. This was done to ensure that the base case was no better than the current minimum regulatory requirements, i.e. within 1% of the Target Emission Rate (TER). The base case building was defined in terms of elemental U-values, air-tightness, etc. shown in Table A1.

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

5. Forty four different energy efficiency measures were then introduced individually into the base case model. The results of the operational carbon analysis, combined with the cost data, were then used to derive three energy efficiency packages that utilise different combinations of energy efficiency measures which were found to be cost-effective (see Appendix B).

6. Thirty four low and zero carbon technologies were then individually incorporated into each of the three energy efficiency packages (see Appendix C). The results of these models, together with the associated cost data, were then used to derive a number of low and zero carbon school solutions. This approach has been devised to reflect the carbon hierarchy shown in Figure 2 and the likely future regulatory targets (see Figure 1).

TABLE A1
BASE CASE BUILDING FABRIC PERFORMANCE PARAMETERS

ELEMENT	U-VALUE (W/m²K)
EXTERNAL WALL	0.35
GROUND FLOOR	0.25
OVERHANG FLOOR	0.25
INTERNAL CEILING/FLOOR	1.00
INTERNAL PARTITION	1.67
ROOF (FLAT ROOF)	0.25
ROOF (TERRACE)	0.25
OPAQUE DOORS	2.20
EXTERNAL WINDOWS	2.20
INTERNAL WINDOWS	3.69
BUILDING AIR TIGHTNESS	$10m^3$/hr per m^2 @50Pa
THERMAL BRIDGING	0.035 W/m^2K

APPENDIX B

ENERGY EFFICIENCY ASSESSMENT METHODOLOGY

For the purposes of this research, energy efficiency measures are defined as changes to the building which will reduce the demand for operational energy and, in so doing, reduce carbon emissions. The 44 energy efficiency measures modelled on the base case building are shown in Table B1.

Where it was suspected that one of these measures might cause the building to overheat, thus causing it to fail criterion 3 of Part L (2006), an additional overheating assessment was carried out. Although some measures did cause internal temperatures to rise, the thermal performance of occupied spaces remained within the acceptable limits as defined in Building Bulletin 101 Ventilation of School Buildings[5].

Dynamic thermal modelling, using IES software, was used to predict the operational energy requirements of the 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. 25 years was chosen because this is the period of school contracts and because most significant plant has a design life of approximately this period.

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

The cost data and the energy modelling results were then combined to provide each energy efficiency measure with a cost-effectiveness measure in terms of £25-yrNPV/kgCO_2 saved relative to the base case. The 44 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.

In the context of this document, once the three packages were defined, Package B was then considered to include all measures also in Package A and Package C was considered to include all measures in Packages A & B. (See Figure 6).

The results obtained for this assessment are shown in Figure 4.

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

TABLE B1
ENERGY EFFICIENCY MEASURES CONSIDERED

ENERGY EFFICIENCY AREA	DESCRIPTION OF MEASURE
Thermal mass	Removed ceiling tiles to expose thermal mass of ceiling
	Heavyweight internal partitions and removed ceiling tiles to expose thermal mass of ceiling
	Green roof (extensive type applied to all roofs excluding terraces)
Air permeability	Improved to 7 m^3/hr per m^2 @50Pa
	Improved to 5 m^3/hr per m^2 @50Pa
	Improved to 3 m^3/hr per m^2 @50Pa
Thermal bridging	Reduced from 0.035 W/m²K to 0.018 W/m²K
External wall insulation	Improved to 0.25 W/m²K
	Improved to 0.20 W/m²K
	Improved to 0.15 W/m²K
	Improved to 0.10 W/m²K
Roof insulation	Improved to 0.20 W/m²K
	Improved to 0.15 W/m²K
	Improved to 0.10 W/m²K
Ground floor insulation	Improved to 0.15 W/m²K
Improved external glazing	Improved to 1.60 W/m²K (kalwall rooflight also improved)
	Improved to 1.20 W/m²K (kalwall rooflight also improved)
	Improved to 0.80 W/m²K (kalwall rooflight also improved)
Building orientation & solar shading and solar control glazing	Re-orientate to minimise heating load
	Ideal orientation with strategically placed additional rooflights
	Ideal orientation with shading on existing windows
	Ideal orientation with shading on existing windows and additional rooflights
	Ideal orientation with shading and optimised glazed area
	Ideal orientation with shading and optimised glazed area and additional rooflights
	Original orientation with shading and optimised glazed area and additional rooflights
	Ideal orientation with strategically placed solar control glazing
	Ideal orientation with strategically placed solar control glazing and additional rooflights
	Original orientation with strategically placed solar control glazing and additional rooflights
Heating, cooling and ventilation	Improved boiler efficiency to 95%
	Improve cooling plant efficiency to SEER = 6
	Improve cooling plant efficiency to SEER = 7
	Improve cooling plant efficiency to SEER = 8
	Improve specific fan power to 2.2 W/l.s
	Improve specific fan power to 1.8 W/l.s
	Improve specific fan power to 1.5 W/l.s
	Mixed mode system with night purging
	Active chilled beams
	Passive chilled beams / radiant ceilings / watercooled / heated slabs
Lighting	Improved lighting efficiency to 2.50 W/m^2 per 100lux
	Improved lighting efficiency to 2.00 W/m^2 per 100lux
	Improved lighting efficiency to 1.75 W/m^2 per 100lux
	Occupancy sensing controls to all light fittings
	Daylight dimming controls on all lights, wired up to control near windows light fittings and away from window light fittings separately
Miscellaneous	High absorbance paint finish to reduce heating loads applied to external surfaces

APPENDIX C

LOW AND ZERO CARBON (LZC) TECHNOLOGY ASSESSMENT

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

34 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 B) individually and was modelled as both a large and a small-scale installation, for example the CHP units were modelled at a large-scale, sized to supply all the space and water heating, and at a small-scale, sized to supply the hot water alone, this smaller option being the more common approach on projects and normally more cost-effective.

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 showed that no single on site technology was able to achieve zero carbon and therefore it was necessary to combine a number of on site technologies. This was done using graphs such as Figure C1.

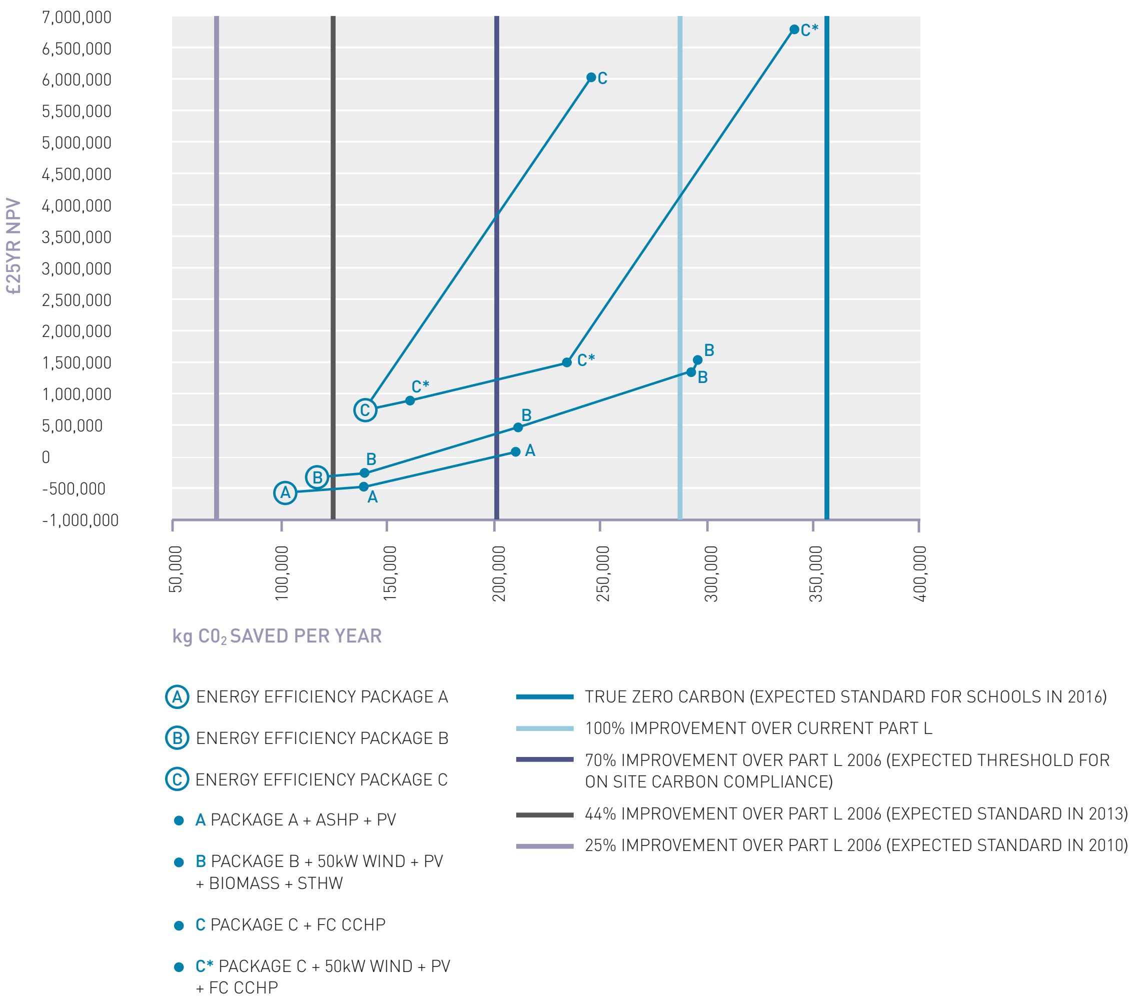
Figure C1 shows the relationship between carbon dioxide emissions saved per year (relative to the base case) on the horizontal axis, against the change in 25-year NPV (relative to the base case) on the vertical axis. The figure shows just a subset of the many combinations of energy efficiency measures and LZC technologies assessed. Figure C1 shows the on site LZC solutions defined and discussed in Section 7.4.

Figure C1 shows three open circles with identities which represent the three energy efficiency packages described in Appendix B. Straight lines emanating from these circles represent a possible progression of non-conflicting LZC technology or technologies with the identity being indicated on the line. The gradient of each line represents the cost effectiveness of each measure. Having decided the carbon reduction target, as represented by the 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 28 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 D.

FIGURE C1
MOST COST-EFFECTIVE ON SITE SOLUTIONS TO MEET FUTURE LIKELY PART L COMPLIANCE TARGETS



APPENDIX D

ENERGY EFFICIENCY AND LZC TECHNOLOGY COSTING

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

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

CAPITAL COSTS

The base case school building cost plan was developed by Cyril Sweett using their cost database. UK mean values current at 2Q 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 base case cost plan. The methodology and basis of the pricing is as used for the construction costing. Where possible, costs have been based on quotations received from contractors and suppliers.

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

THROUGH-LIFE COSTS

The through-life costs were assessed using a simple net present value (NPV) calculation. The 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 E

CLEAR LIFE-CYCLE ASSESSMENT MODEL

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

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

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

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

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

LCA DATA SOURCES

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

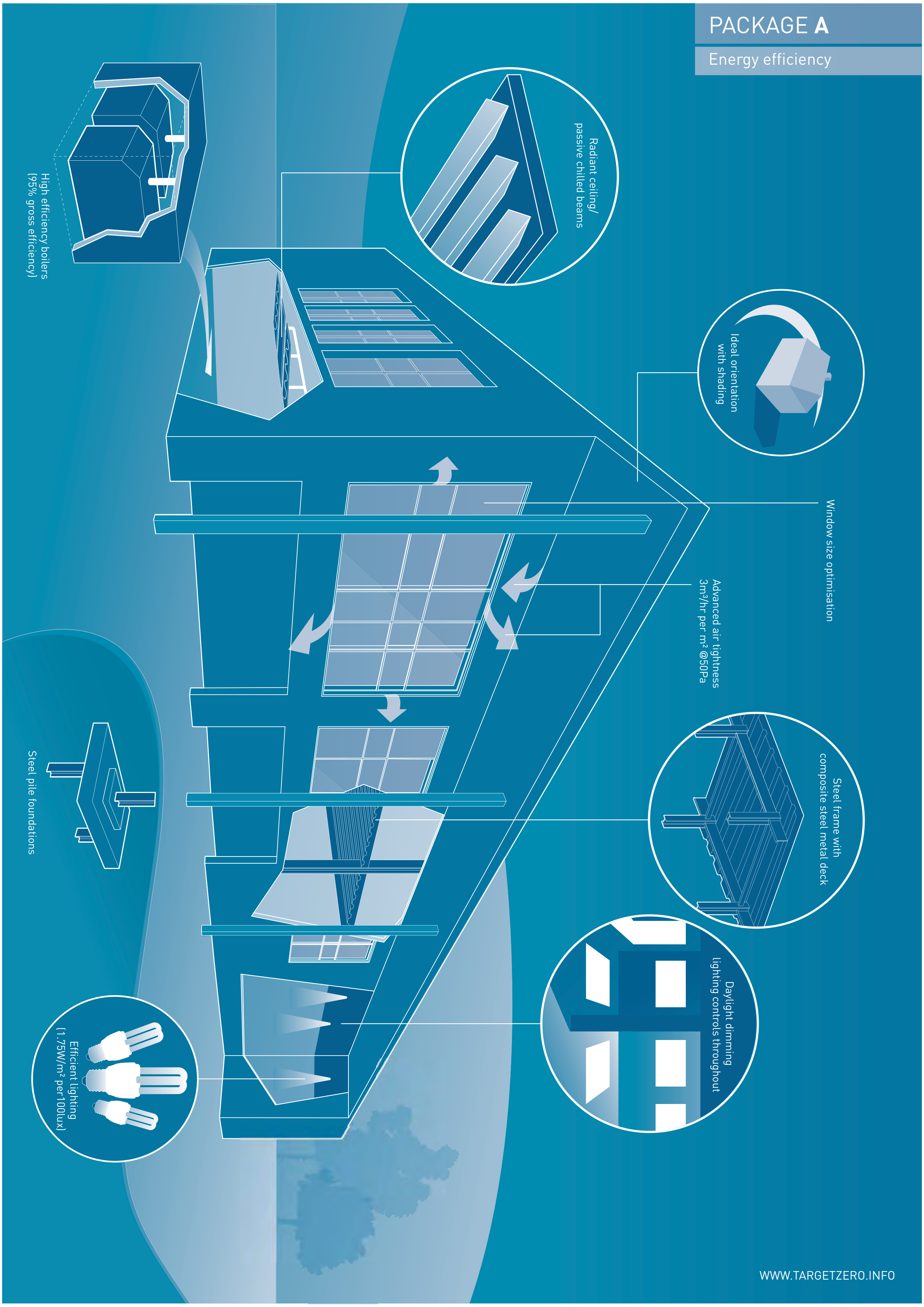
The most appropriate steel data was provided by the World Steel Association (worldsteel) and is based on 2000 average production data. The worldsteel LCA study is one of the largest and most comprehensive LCA studies undertaken and has been independently reviewed to ISO standards 14040 and 14044.

TABLE E1
THE EMBODIED CARBON COEFFICIENTS FOR THE PRINCIPLE MATERIALS USED IN THE SCHOOL ASSESSMENTS

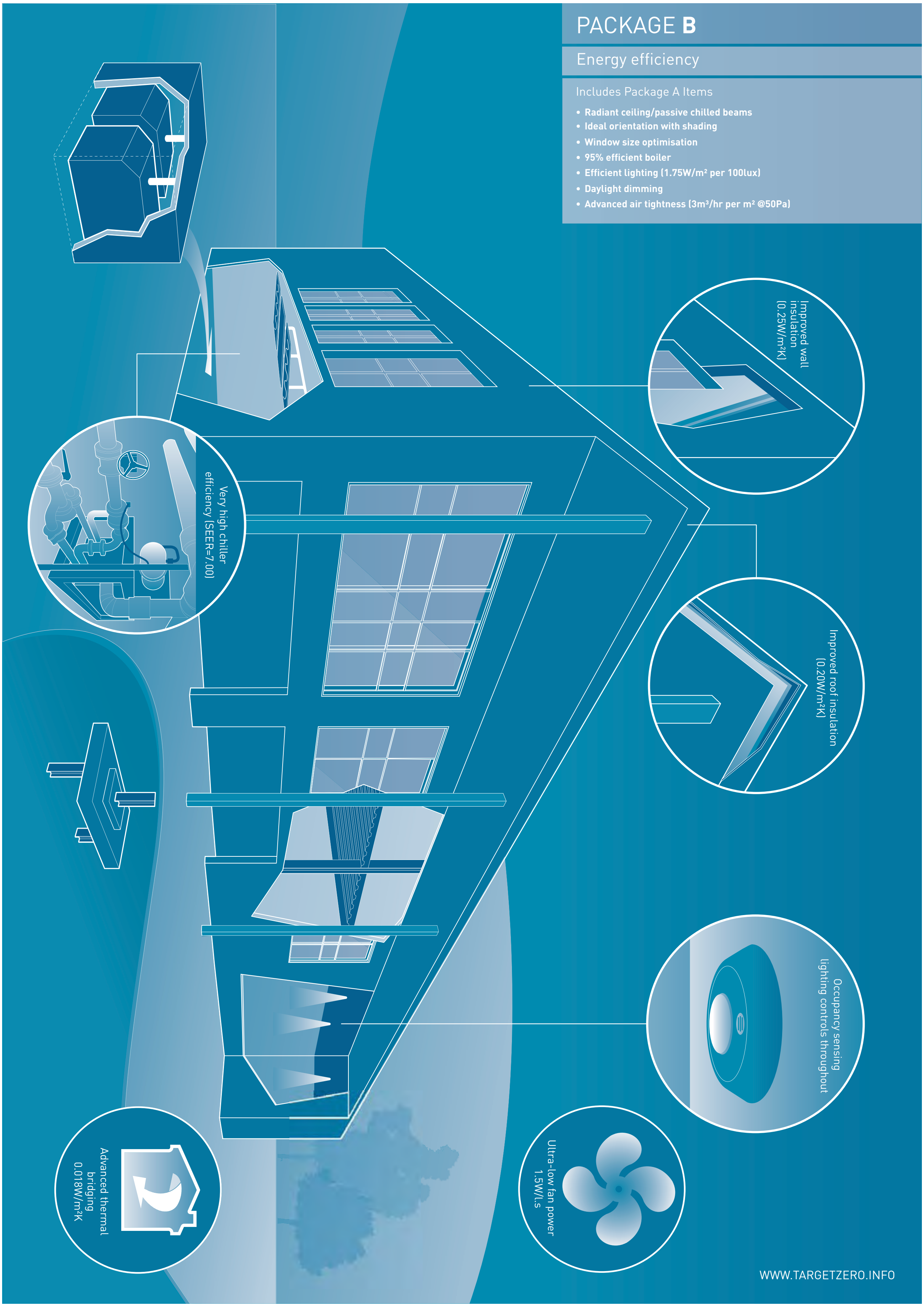
MATERIAL	CO_2 EMISSIONS DATA (tCO_2e/t)			
	Data source	End-of-life assumption	Source	Total lifecycle
Steel sections, inc. fabrication	worldsteel (2002)	99% closed loop recycling, 1% landfill	MFA of the UK steel construction sector[1]	1.009
Purlins and other light gauge steel products, inc. fabrication.	worldsteel (2002)	99% closed loop recycling, 1% landfill	MFA of the UK steel construction sector[1]	1.317
Organic Coated Steel, inc. rolling, slitting and other forming proceses	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 (C30/37)	GaBi LCI database 2006 – PE International	80% open loop recycling, 20% landfill	Department for Communities and Local Government2	0.139
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
Plasterboard	GaBi LCI database 2006 - PE International	20% recycling, 80% landfill	WRAP[4]	0.145

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, http://www.communities.gov.uk/publications/planningandbuilding/surveyconstruction2005
[a] Adjusted for material left in ground at end-of-life.
3. TRADA Technology wood information sheet 2/3 Sheet 59 ' Recovering and minimising wood waste', revised June 2008
4. WRAP Net Waste Tool Reference Guide v 1.0, 2008 (good practice rates)

ENERGY EFFICIENCY PACKAGES



ENERGY EFFICIENCY PACKAGES



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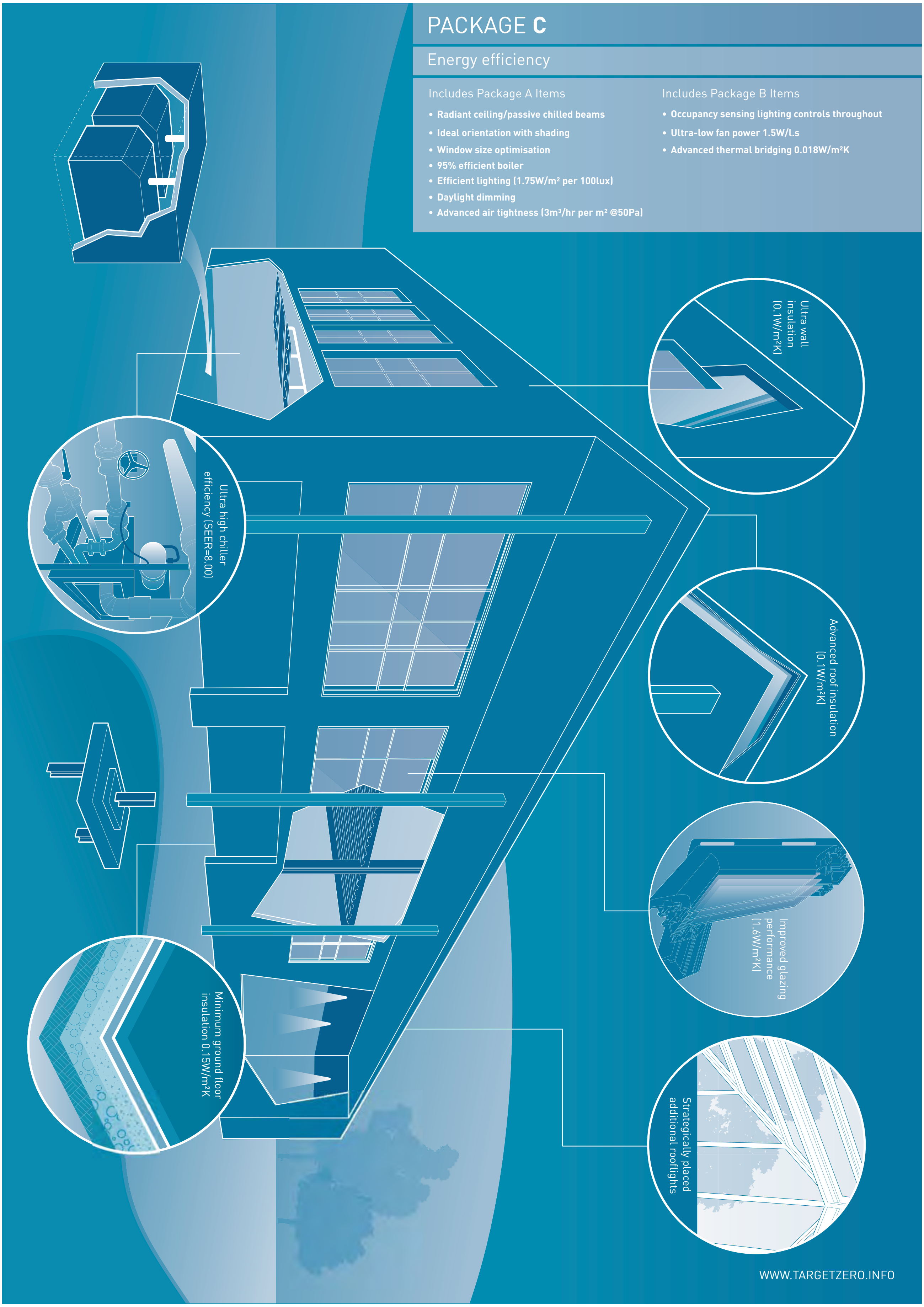
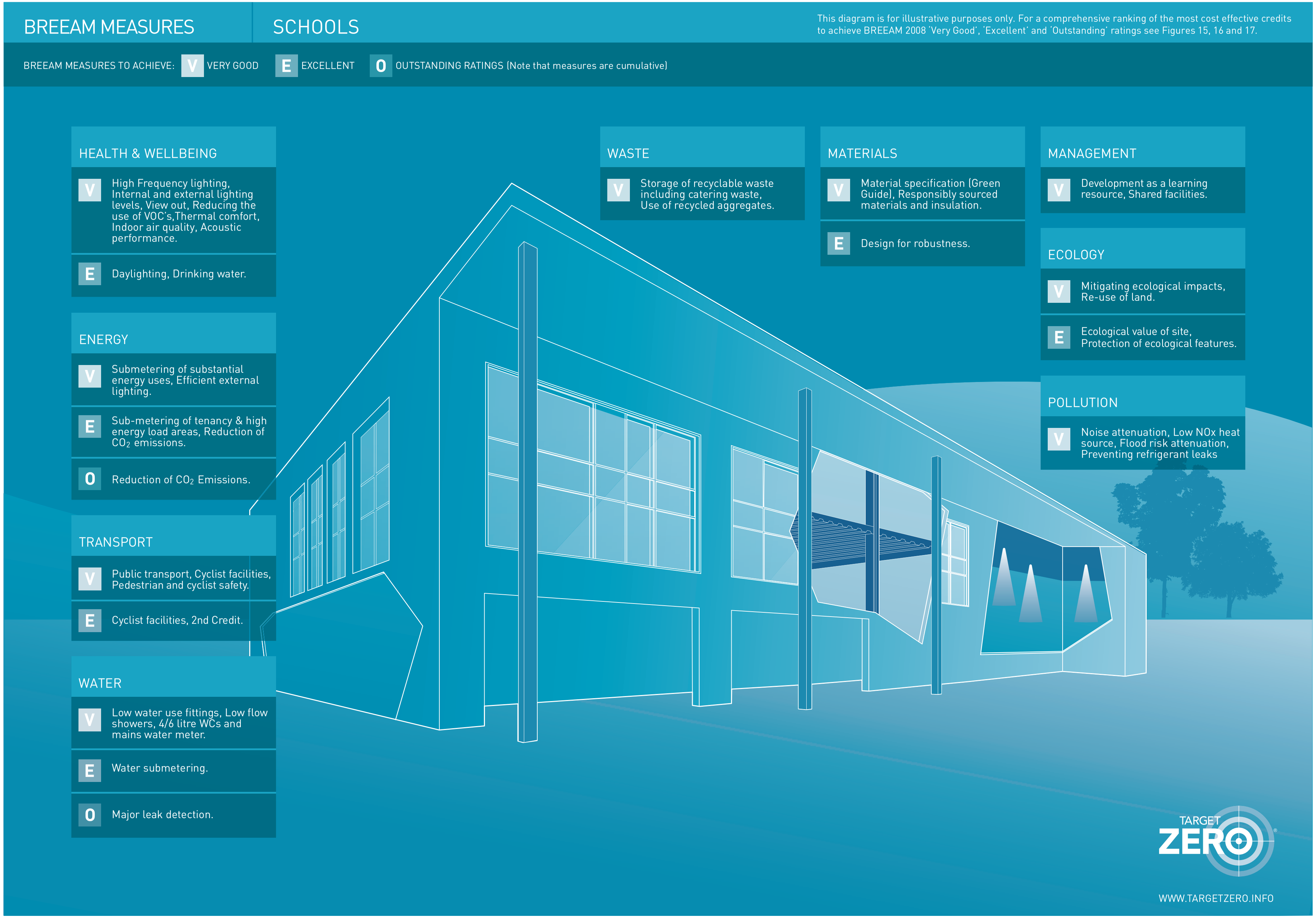


BREEAM MEASURES



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8 www.bre.co.uk/greenguide.

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