IPF Research Programme 2011-2015

REPORT

Costing Energy Efficiency Improvements in Existing Commercial Buildings

This research was commissioned by the IPF Research Programme 2011–2015

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This Programme supports the IPF's wider goals of enhancing the understanding and efficiency of property as an investment. The initiative provides the UK property investment market with the ability to deliver substantial, objective and high-quality analysis on a structured basis. It encourages the whole industry to engage with other financial markets, the wider business community and government on a range of complementary issues.

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Costing Energy Efficiency Improvements in Existing Commercial Buildings

Report

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October 2012

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1.1 Background and scope

In January 2009, the Investment Property Forum (IPF) published research investigating the costs of making energy efficiency improvements to existing commercial buildings[1]. The primary aim of the research was to identify the key improvements that could be made to existing commercial buildings and the building types that presented the greatest opportunities to reduce carbon dioxide (CO_2) emissions.

Since its publication, the research has been used to support strategic decision making by the property and investment community through identifying those buildings in a portfolio that can yield the largest CO_2 savings for the least cost. The research has proven to be of particular value to investment fund managers, asset managers, property managers and letting agents.

Regulations, incentives and Government initiatives have evolved subsequently and are driving a continued interest in improving the energy performance of existing buildings. These changes include

- Revised Building Regulations in 2010 (and a proposed future change in 2013), which will result in existing buildings demonstrating a worse Energy Performance Certificate (EPC) rating when re-assessed;
- Introduction and subsequent changes made to the Feed-in Tariff incentive scheme for solar photovoltaic panels and wind turbines plus a new incentive for the production for renewable heat known as the Renewable Heat Incentive;
- Proposed simplification of the carbon reduction commitment (CRC) scheme;
- Imminent implementation of the 'Green Deal' innovative funding mechanism where owners and occupiers of buildings can take out finance to fund energy efficiency improvements with the repayment obligation being attached to the energy meter rather than the party applying for the finance; and
- Government plans to introduce a minimum energy performance standard preventing landlords letting out commercial properties with F and G EPC ratings from 2018 at the latest.

The aim and objectives of this updated research are consistent with the original research to provide the same value to users as before. However, attention to certain additional objectives is necessary to respond to the changed environmental climate affecting existing commercial buildings. Two additional areas of focus of the work are:

- Identify the cost and improvement measures required to achieve higher EPC ratings from the baseline position for selected buildings.
- Determine what EPC/CO_2 reduction targets should be set now to prevent a building being either F or G rated in 2018.

The study analyses a number of commercial building types and findings are presented from the perspective of a landlord, investor, developer or owner occupier. Therefore, only the base specification of each building was assessed and not the CO_2 emissions produced by the tenants' own equipment, nor how to reduce them.

[1] Costing Energy Efficiency Improvements in Existing Buildings, IPF London, 2009

1. EXECUTIVE SUMMARY

The update is not a complete revision of the original study because certain key changes have occurred based on previous findings. The number of office types analysed was reduced to produce more consolidated results compared with the original study. In addition, the retail and industrial/warehouse buildings were increased in size to better reflect the existing stock and, therefore, produce more useful data. A summary of building types modelled is provided in Table 1.1.

Table 1.1: Base building models

Building	Previously modelled	Services	Plan depth	Age	Glazing % / type
Office 1	Office 6	Heating only	Narrow	Pre-1940s	50%, single
Office 2	Office 3	Air-conditioned	Narrow	Pre-1995	50%, double
Office 3	Office 5	Air-conditioned	Deep	Post 2002	80%, double
Office 4	New	Air-conditioned	Deep	Post 2006	80%, double
Retail warehouse	As before	Air-conditioned	Deep	Pre-1995	10%, double
Industrial / warehouse	As before	Heating only	Deep	Pre-1995	10%, single

Office 4, built to comply with the 2006 version of the Part L Building Regulations, was introduced to demonstrate how the latest 2010 regulations would impact upon its EPC rating.

1.2 Summary results

A key objective of the update was to identify the cost of improving the EPC rating for each building. This required the modelling of each building's baseline EPC rating, an assessment of how a 'market standard' refurbishment would inherently improve the rating and then establishing the additional cost and benefit of specifying a series of enhanced energy efficiency improvements. Summary results for all buildings are presented in Table 1.2.

Table 1.2: Additional capital cost to improve EPC ratings when refurbishing existing commercial buildings

	Office 1	Office 2	Office 3	Office 4	Retail warehouse	Industrial / warehouse
			EPC rating			
Baseline	E	G	F	E	D	F
Market refurb	D	F	F	E[2]	C	B
	Additional capital cost extra over market standard refurbishment[3] (%)					
E		0.3%	1.0%			
D		1.7%	1.9%	1.0%		
C	0.8%	14.6%	12.6%	12.8%		
B	14.1%	37.3%	44.7%	45.7%	2.6%	
A	40.0%	-	-	-	-	20.7%

[2] A 'market refurbishment' would not be carried out to a building that is less than 10 years old hence no improvement in the EPC rating.

[3] All costs are cumulative.

1. EXECUTIVE SUMMARY

1.3 Headline findings are

- As expected, offices have become more energy efficient since the early 1990s, as demonstrated by better EPC ratings. Non-air-conditioned offices also perform better compared to air-conditioned offices.
- A 'market standard' refurbishment can improve the EPC rating by at least one grade for most buildings. The improvement is substantial for the industrial/warehouse building (i.e. rating improves from an F to a B).
- All offices can be improved by an extra grade for an additional cost of up to 1% of the refurbishment budget, which is potentially viable for most projects.
- Air-conditioned offices built over 10 years ago (Offices 2 and 3) represent the most cost-effective opportunity because EPC ratings can be improved by two EPC grades for a total extra spend of circa 2%.
- The EPC rating of the retail building can be improved to a B for an additional capital sum of 2.6% above the standard refurbishment cost and would therefore be attractive in terms of future-proofing the asset.
- It is unviable to achieve an A-rated EPC for all buildings (including the industrial/warehouse, which can achieve a B rating through refurbishing to a 'market standard').

It was also anticipated that the EPC rating for the office built after 2006 (Office 4) would drop to an F following the next revision to Part L based on a comparison between the 2006 and 2010 versions of the regulations. The proposed minimum energy efficiency standards for buildings let by landlords, to be introduced by 2018, will mean that even offices built to recent standards would be adversely affected by this forthcoming legislation.

1.4 Energy efficiency 'quick wins'

There are common energy efficiency 'quick wins' that can be applied to all commercial buildings, which are low cost to implement and make significant cuts in CO_2 emissions. These 'quick wins' are:

- Boilers (95% efficiency);
- Daylight controls;
- Improving air tightness;
- Variable speed heating and cooling pumps;
- Heating controls;
- Power factor correction (>0.95);
- High-efficiency chillers;
- T5 lighting;
- Heat recovery; and
- DC drive fan coil units.

These 'quick wins' can either form part of a general refurbishment during a period of vacant possession or be 'one-off' improvements when the building is wholly or partly occupied. Replacing lighting and fan coil units pose particular challenges especially for retail buildings but can still be implemented 'out of hours' over an extended period of time.

The premium to undertake these works out of hours would typically be no more than 7% because the extra cost of labour is offset by not having to pay main contractor's preliminaries, overheads and profit.

2. INTRODUCTION

Previous IPF research investigating the costs of making energy efficiency improvements identified key improvements that could be made to existing commercial buildings and the building types that presented the greatest opportunities to reduce carbon dioxide (CO_2) emissions.

The study considered the cost of reducing CO_2 in three specific sectors: office, retail and light industrial/ warehouse. The key outputs from the study were:

1. Identifying those buildings within investor portfolios that have the greatest potential for reducing CO_2 emissions.
2. Estimating the potential CO_2 reductions achievable from applying a range of energy efficiency improvements beyond current market replacement standards.
3. Calculating and comparing the additional capital expenditure required to make the improvements with the energy and CO_2 saved.
4. Packaging the improvements and estimating the likely CO_2 reductions achievable for given additional refurbishment budgets.

The energy efficiency and sustainability agenda relating to existing commercial buildings has expanded rapidly in recent years and was a key reason for commissioning the current study. At the time of the original research EPCs and the CRC energy efficiency scheme were on the horizon for the commercial property market but the full impacts of these initiatives were not known. Both EPCs and the CRC scheme have now been implemented and the market has a greater awareness of energy performance in buildings and the need to act to reduce CO_2 emissions.

Regulations, incentives and Government initiatives have evolved subsequently and are driving a continued interest in improving the energy performance of existing buildings. These changes include:

- Revised Building Regulations in 2010 (and a proposed future change in 2013), which will result in existing buildings demonstrating a worse EPC rating when re-assessed;
- Introduction and subsequent changes made to the Feed-in Tariff (FiT) incentive scheme for solar photovoltaic panels and wind turbines plus a new incentive for the production for renewable heat known as the Renewable Heat Incentive;
- Proposed simplification of the CRC scheme;
- Imminent implementation of the 'Green Deal' innovative funding mechanism whereby owners and occupiers of buildings can take out finance to fund energy efficiency improvements with the repayment obligation being attached to the energy meter rather than the party applying for the finance; and
- Government plans to introduce a minimum energy performance standard preventing landlords letting out commercial properties with F and G EPC ratings from 2018 at the latest.

2. INTRODUCTION

Updating the original research was also warranted due to improvements in energy efficiency technologies together with a convergence in cost between energy efficient and standard products. The economic landscape has also changed, with greater scrutiny being placed on energy costs and continued fuel price rises. Updating the business case for energy-efficient refurbishment was therefore required to support action to reduce CO_2 emissions and this study, like the original research, is a key way of disseminating the results to the investment community.

The aim and objectives of this update are consistent with the original research and intended to provide the same value to users as before. However, attention to certain additional objectives is necessary to respond to the changed environmental climate affecting existing commercial buildings. Two additional areas of focus of the work are:

1. Identifying the cost and improvement measures required to improve EPC ratings from the baseline position for selected buildings.
2. Determining what EPC/CO_2 reduction targets should be set now to prevent a building being either F or G rated in 2018.

The update is not a precise revision of the original study because certain key changes have occurred. For example, the total number of buildings analysed was reduced, a new office building added and the layout of results tables changed. Where changes occurred, these are indicated and a narrative provided.

The study analyses a number of commercial building types and the findings are presented from the perspective of a landlord, investor, developer or owner occupier. Only the base specification of each building was assessed, therefore, and not the CO_2 emissions produced by the tenants' own equipment, nor how to reduce them. The impacts of the occupier on building CO_2 emissions are discussed at various stages throughout the report but are not part of the modelling or data analysis.

The study focuses on the refurbishment of existing buildings (both occupied and vacant) and does **not** consider the following areas:

- new build;
- major redevelopments (i.e. stripping the building back to the frame); and
- change of use.

Timing of enhanced energy efficiency improvements is also a key points to note. This study does not advocate the strip-out and replacement of equipment in working order, only improvements when existing equipment is due for replacement. This also means that there will be no wider adverse sustainability impacts, such as on embodied carbon for example.

3. ENERGY, CO_2 AND COMMERCIAL BUILDINGS – BACKGROUND

This section provides a background to the study and subsequent results by setting out, firstly, how energy is consumed and CO_2 emitted from buildings and, secondly, why the study has focused on owner/landlord improvement opportunities in offices, warehouses and certain retail buildings.

3.1 Energy consumption and CO_2 emissions from buildings

The main energy uses within commercial buildings are:

- Lighting;
- Heating (gas fired central heating or instantaneous electric heating);
- Ventilation and air conditioning (including fans, pumps and chillers);
- Power for IT equipment, printers, photocopiers, etc.;
- Hot water for washing, showers and catering; and
- Lifts.

Energy consumption in buildings is affected by a complex interaction of the following factors:

- Geographical location (yearly temperatures and sunlight patterns)
- Orientation;
- Height, shape and form;
- Proximity of other buildings;
- Building fabric thermal performance;
- Internal temperatures;
- Occupancy density;
- IT equipment (density and efficiency);
- Hours of operation;
- Energy efficiency of the building services – heating, lighting, mechanical ventilation and cooling (if present) and hot water systems; and
- Operation of the building services (including maintenance).

The combustion of fossil fuel generates CO_2 emissions and the amount varies between fuel types. Natural gas is typically used for heating, while electricity is typically used for cooling, lighting, ventilation and small power.

Electricity from the National Grid is generated from a variety of sources (e.g. coal, gas, nuclear and wind power), each producing a different level of CO_2 emission. The average CO_2 rating, taking into account transmission losses across the Grid, is higher than that released from the local use of natural gas by almost a factor of three.

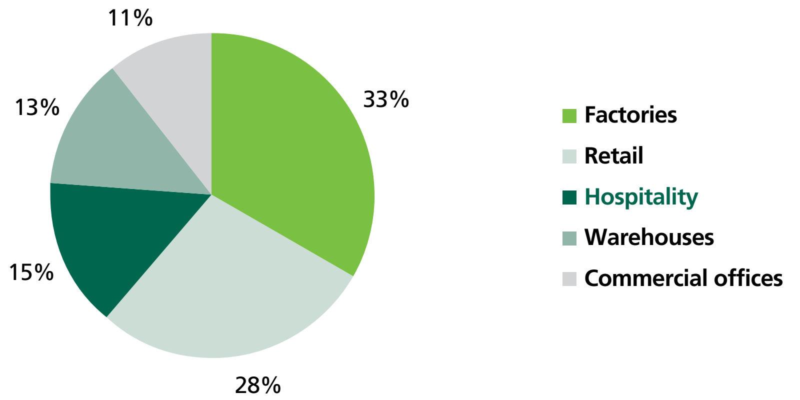
Carbon is not the same as CO_2. As an inert chemical element, carbon is not directly responsible for climate change effects. However, in the form of CO_2, it is one of the main greenhouse gases.

3. ENERGY, CO_2 AND COMMERCIAL BUILDINGS – BACKGROUND

Traditionally, carbon savings were the measure of energy efficiency; however, this has been superseded by the use of CO_2 emissions as a common measure in all UK legislation and regulation. Part L of the Building Regulations, and many planning policies, relate to CO_2 emissions and savings.

In 2003, commercial buildings were responsible for around 14% of total CO_2 emissions in the UK[4]. Remaining emissions were produced by transport (33%), domestic buildings (26%), industrial processes (22%) and public and other buildings (5%). Total emissions from commercial buildings can be further sub-divided as presented in Figure 3.1.

Figure 3.1: CO_2 emissions from commercial buildings



Source: BRE, 2006

CO_2 emissions are most significant from the stock of factory and retail buildings, accounting for over 60% of all emissions from the commercial sector. However, the majority of these emissions result from the operations carried out in the building (for example, factory processes and refrigeration equipment) rather than from the building itself.

At the individual building level, Table 3.1 indicates that large food stores are the biggest energy users compared to other commercial buildings.

Table 3.1: Energy consumption benchmarks for existing commercial buildings

	General office	General retail	Large food store	Storage facility
Annual kWh/m² of floor area	215	165	505	195

Source: CIBSE TM46 Energy Benchmarks, 2008

The energy consumption range for retail buildings is relatively wide, with supermarkets being the highest consumer. This is accounted for by the longer operating hours, typical of supermarkets, and intensive lighting levels.

[4] Source: BRE, 2006

3. ENERGY, CO_2 AND COMMERCIAL BUILDINGS – BACKGROUND

3.2 Energy performance certificates

All non-domestic and non-public buildings (with a few exceptions) require an EPC when they are constructed, sold or let. The purpose of an EPC is to rate the energy performance of the building to enable the intended purchaser or tenant to consider energy efficiency as part of their investment or business decision to buy or occupy the building.

The energy rating is based on the thermal performance of the building fabric (insulating qualities, prevention of solar gain) and the expected energy consumption of the heating, lighting and air conditioning systems. The rating is not based on actual energy consumption (as is the case for Display Energy Certificates in public buildings) but on an estimate of energy consumption assuming standard occupancy patterns. This is known as the 'Asset Rating'.

The EPC for England and Wales gives ratings from A+ to G, which are based on a CO_2 emission performance index (compared with a reference building) rather than absolute performance. The position in Scotland is different and compares buildings in terms of their absolute CO_2 emissions in $kgCO_2/m^2$.

3.3 Improvement opportunities for landlords

Both landlords and tenants have a direct influence on CO_2 emissions from buildings, derived from the energy consumed during the operation of the building. As before, the focus of the study was to identify the opportunities for landlords and building owners to make energy efficiency improvements to their existing buildings.

An owner occupier has control over all the energy consumption factors listed in Section 3.1, with the exception of location and the proximity of other buildings. The situation is more complex where there is a landlord and tenant arrangement. The landlord has sole control over the performance of the building fabric, whereas the tenant is solely responsible for using the building in terms of hours of use, density of occupants, IT equipment efficiency and setting internal temperatures. However, both landlords and tenants have some influence on the energy efficiency of the installed building services. For example, a landlord has no control over the building services in a retail unit that has been let as a 'shell only' specification. In this example, the tenant installs all services in respect of the incoming gas main and power supply. The landlord only has influence over the thermal performance of the building fabric (i.e. in terms of insulating qualities and air tightness to reduce heat transfer).

The scope of this study does not include influencing the behaviour of tenants and occupiers. The tenant's small power and equipment alone can account for up to one-third of total energy consumption, and how the tenant runs the building services can have a significant influence on total energy consumption as well. Leaving lights and equipment on overnight, opening windows whilst the air conditioning or heating is running and setting a high temperature on the thermostatic controls are typical examples of inefficient behaviour in office buildings. Addressing these wasteful actions can have a negligible cost implication but the savings can be large and, therefore, the return on investment is very attractive. The tenant or occupier will have direct influence over these behaviours; however, the landlord can have an influence through the agreement of a Green Lease or Green Memorandum of Understanding with the tenant or by setting up a Green Building Management Group to engage occupiers in a building on energy and other sustainability matters.

3. ENERGY, CO_2 AND COMMERCIAL BUILDINGS – BACKGROUND

The landlord's influence on energy consumption in different classes of commercial building is briefly discussed below.

3.3.1 Factories

The manufacturing or trade processes carried out within a factory (use class B2) account for the vast majority of energy consumed by the building. In general, in the case of industrial space that is flexible enough to accommodate a variety of industrial processes, the landlord is likely to offer non-task-specific lighting and some background space heating as part of the letting arrangement. Where the manufacturing process is more intensive and complex, factories will be built as a shell for the manufacturer to wholly fit out or be built bespoke by the manufacturer and owner-occupied or sold on a sale and leaseback arrangement. Therefore, improving the thermal performance of general light-industrial buildings, lighting efficiency and heating systems are the main opportunities for landlords. Given that factory buildings are typically single storey and have a large footprint, maximising the use of natural daylight is a key opportunity for reducing energy consumption (providing there are windows to facilitate this).

3.3.2 Warehouses

Unlike factories, warehouses and distribution centres (use class B8) are not energy intensive because a manufacturing process is absent from the building. General warehouse lighting is part of the landlord's base specification and is the main consumer of energy. In older facilities, background heating may be provided by the landlord and, therefore, presents an energy efficiency opportunity. Large modern warehouses have a particularly high level of energy consumption associated with lighting and, therefore, lighting efficiency and utilising natural light are key considerations.

3.3.3 Retail

Energy consumption in retail buildings (use class A1) is high for two reasons. Firstly, considerable energy is consumed by high levels of artificial lighting for product display purposes. This leads to high 'heat gains' from the waste heat produced by the lighting. This heat load must then be reduced by additional cooling energy, which is the second reason for high energy consumption in the retail sector.

Retail buildings are diverse in terms of their physical characteristics (including the type of air conditioning system installed) and also the extent to which a landlord can influence energy consumption. In broad terms, the main categories of retail buildings are:

- High street retail unit;
- Department store – sales space over three or more levels;
- Supermarket;
- Shopping centres – open or enclosed; and
- Retail warehouses.

3. ENERGY, CO_2 AND COMMERCIAL BUILDINGS – BACKGROUND

Each type of retail building is discussed below.

High street retail – Typically characterised by having ground-level sales space, with larger units having basement and/or first floor sales space and ancillary office/storage areas. The landlord leases high street retail units as a 'shell' because the fit-out is very specific to the tenant. The tenant therefore designs and installs the building services to suit their own requirements. There is also a high 'churn' rate in retail, where refurbishments occur frequently and services are renewed accordingly. The landlord may be responsible for heating in ancillary office and storage areas but this comprises a very small element of total energy consumption.

Department stores – Located in and around the high street, department stores are situated over three or more levels, often with restaurant facilities and electrical departments that contribute to high levels of energy consumption. Like high street retail, department stores are either let as a shell or owner-occupied.

Supermarket – Often developed by the food retailer to suit their own specification requirements, supermarkets can be sold on a sale and leaseback arrangement. The frequency of refurbishment is lower than high street retail, therefore there is greater potential for the landlord to influence the energy efficiency of the building services and fabric of the building.

Shopping centres – Landlord's building services are typically present in covered mall and ancillary areas. As before, shopping centres are not analysed in the study for two reasons:

1. Heating and cooling provision in covered mall areas is increasingly being reduced in existing and new shopping centres.
2. There is an increasing trend for open mall/circulation areas that require no servicing.

On some schemes (particularly mixed use with residential and offices) the landlord provides centralised heating and cooling, which the tenant is expected to utilise. These schemes are usually very large and complex in terms of their energy strategies. It was, considered beyond the scope of this research, therefore, to define and model a 'typical' mixed use scheme and apply a series of energy efficiency improvements to it.

Retail warehouses – These are large retail units constructed and let to a shell specification. The shell construction of these units is very similar to a modern warehouse (discussed below) but with an attractive glazed entrance. The opportunities for landlords to reduce energy consumption are similar to those for warehouses. However, it can often be the case that the landlord becomes responsible for the building services installed by a previous tenant whose tenancy has expired.

3. ENERGY, CO_2 AND COMMERCIAL BUILDINGS – BACKGROUND

3.3.4 Hospitality

The hospitality sector is very diverse in terms of building types because it includes hotel and resort properties, clubs, restaurants and casinos. Hotels (use class C1) are perhaps the main sub-sector; however, energy performance between hotels varies considerably depending on the quality of the building and its services. For example, a 5-star luxury hotel is likely to be fully air-conditioned with additional facilities such as a restaurant, conference facilities and leisure facilities (including pool), which all contribute to high levels of energy consumption. This can be compared with a smaller 2-star hotel, often converted from buildings with historically different uses, without the facilities previously described. The use of gas to provide domestic hot water for en-suite facilities makes the biggest contribution to CO_2 emissions for this grade of hotel.

Due to the diversity and complexity of hotels and other hospitality buildings, these buildings were not considered in the study.

3.3.5 Offices

Although offices only account for 11% of the CO_2 emissions from commercial buildings, there are a range of opportunities for the landlord to influence the energy consumption of their buildings. This is because office buildings are let with more building services systems compared with most other commercial buildings.

A developer's speculative office is constructed to either a Category A or shell and core standard. A Category A office specification typically comprises the following:

- Full heating, cooling and lighting systems throughout the rentable space;
- Raised floors;
- Suspended ceilings;
- Wall finishes; and
- Blinds.

The tenant then completes the fit-out to suit their own specific occupational requirements (known as a Category B fit-out). This comprises carpets, cellular offices, reception areas, meeting room facilities, furniture and IT/AV equipment.

A shell and core arrangement is where the landlord areas are fully fitted out but the office floor areas are left as a shell for the tenant to carry out the Category A fit out. However, the landlord provides central building services equipment and infrastructure. This includes the building services equipment in the plant room and on the roof, comprising boilers (for space heating and hot water), air handling units, chillers, fans and pumps. The landlord also provides capped ductwork, pipework and cabling (for power and lighting) to each office floor from which the tenant completes their own installation within the space, often with a capital contribution from the landlord.

This means that the landlord can significantly influence the energy efficiency of the heating, cooling and lighting systems installed in an office building either by directly installing the equipment themselves or by making it a condition in the agreement for lease, subject to the scale of the capital contribution provided.

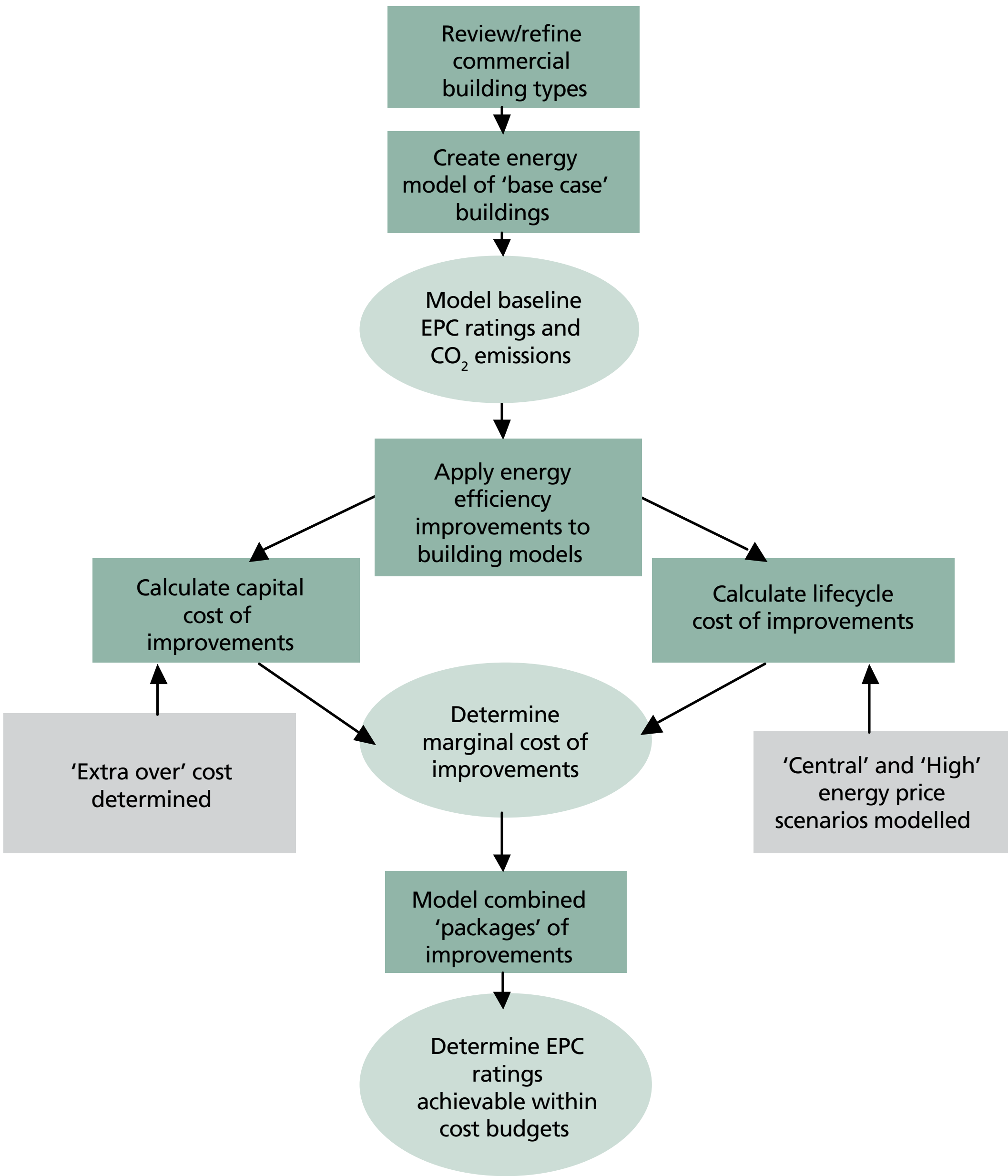
In summary, there are significant opportunities for landlords to improve the energy efficiency of the commercial buildings they let to tenants. Key buildings comprise offices, supermarkets, retail warehouses, light industrial buildings and warehouses. The next section describes how the baseline CO_2 emissions were determined for generic versions of these buildings.

4. METHODOLOGY AND BUILDING SELECTION

4.1 Outline methodology

The overall methodology adopted in the updated study was the same as before (Figure 4.1), however small changes were made that are highlighted throughout this section.

Figure 4.1: Research methodology



4. METHODOLOGY AND BUILDING SELECTION

4.2 Review of original base buildings

The first task was to review the buildings previously analysed in the original study. For consistency, the types of buildings analysed were largely maintained but with certain updates made to meet the original objective of assessing those commercial buildings in investor portfolios that would have the greatest potential for CO_2 emissions reductions.

The updated base building models are listed in Table 4.1.

Table 4.1: Base building models

Building	Previously modelled	Services	Plan depth	Age	Glazing % / type
Office 1	Office 6	Heating only	Narrow	Pre-1940s	50%, single
Office 2	Office 3	Air-conditioned	Narrow	Pre-1995	50%, double
Office 3	Office 5	Air-conditioned	Deep	Post 2002	80%, double
Office 4	New	Air-conditioned	Deep	Post 2006	80%, double
Retail	As before	Air-conditioned	Deep	Pre-1995	10%, double
Industrial / warehouse	As before	Heating only	Deep	Pre-1995	10%, single

The number of office types analysed was reduced to produce more consolidated results compared with the original study. It was found previously that the age of building and the presence of air conditioning have a high impact in terms of overall CO_2 emissions and the opportunities available to reduce baseline emissions. Offices 1 to 3 were assessed in the previous work and reflect different ages and servicing strategies.

Since the original work was published, Part L of the Building Regulations has been revised (in 2010). This revision means that new non-domestic buildings must achieve on average a 25% reduction in CO_2 emissions compared with the 2006 regulations. The change also signifies that buildings constructed prior to the introduction of the 2010 regulations will achieve a poorer EPC rating if they were to be reassessed now. This is because a building that is compliant with the latest regulations will score either a B or C rating (depending on the servicing strategy) but a change in regulations will mean that the building is comparatively less efficient, so it will be lower on the EPC scale (D- or E-rated, for example).

It was decided, therefore, to introduce an additional office building into the study that was compliant with the 2006 Part L regulations to investigate how the EPC rating could be affected and also how challenging it would translate to in terms of improvements and cost to bring it back up to a C or B rating.

The buildings included in the original study but now omitted are shown in Table 4.2. Although plan depth and extent of glazing for offices 1, 2 and 4 showed a notable impact on baseline CO_2 emissions, the range and benefit of the improvements available were largely similar. This demonstrated that building age and the efficiency of installed services had a bigger influence on baseline emissions and how a building could be improved rather than plan depth and level of glazing. It was decided, therefore, not to update the analysis for 1, 2 and 4 and also for mechanically-ventilated office 7, which showed similar results to the air-conditioned buildings.

4. METHODOLOGY AND BUILDING SELECTION

Table 4.2: Excluded base buildings

Base building model	Services	Plan depth	Age	Glazing
Office 1	Air-conditioned	Deep	1990-1995	Part
Office 2	Air-conditioned	Deep	1990-1995	Full
Office 4	Air-conditioned	Narrow	1990-1995	Full
Office 7	Mechanically-ventilated	Narrow	1990-1995	Part

It should be noted that the buildings modelled are best-fit representations of the existing stock and not case studies of actual buildings. These models represent a building that is let by a landlord to a tenant and do not consider how the tenant uses the building or the implications of IT and other equipment they may install.

Figure 4.2 gives a notional representation of the base buildings analysed in the update study.

Figure 4.2: Example buildings representing the base building models

Office 1
Reflects Mid-town and West End offices, which are predominantly period, pre-1940. Heating system only.

Office 2
Partly-glazed, air-conditioned early 1990s narrow plan office. Compliant with 1990 Part L Building Regulations.

Office 3
Fully-glazed, deep-plan, air-conditioned office. Compliant with 2002 Part L Building Regulations.

4. METHODOLOGY AND BUILDING SELECTION

Office 4
As Office 3 but compliant with 2006 Part L Building Regulations.

Retail warehouse
Single storey with lighting, heating and air conditioning. Limited windows. Office and warehouse space included. Compliant with 1990 Part L Building Regulations.

Industrial/warehouse
Single storey with lighting and heating. Limited windows or rooflights. Offices included. Compliant with 1990 Part L Building Regulations.

4.3 Modelling CO_2 emissions and energy consumption

Assessing energy consumption and CO_2 emissions was undertaken using the SBEM (Simplified Building Energy Model) software (version v4.1.c). SBEM was developed by the Department for Communities and Local Government for the purpose of demonstrating compliance with Part L of the Building Regulations and to produce EPC ratings for non-domestic buildings. Version v4.1.c was used to demonstrate compliance with Part L 2010.

An alternative would have been to use dynamic thermal modelling as used for the original study. Dynamic modelling is typically more accurate compared with static modelling tools (such as SBEM) and is commonly used as a design tool for complex buildings such as offices, schools, hospitals, airports and shopping centres. Since the original work was undertaken SBEM has become more sophisticated as an energy estimation tool and the use of dynamic modelling software was not warranted. Although office, retail and industrial warehouse buildings required modelling, the base models were simpler representations of actual buildings and, therefore, could be modelled accurately through SBEM rather than using a dynamic tool.

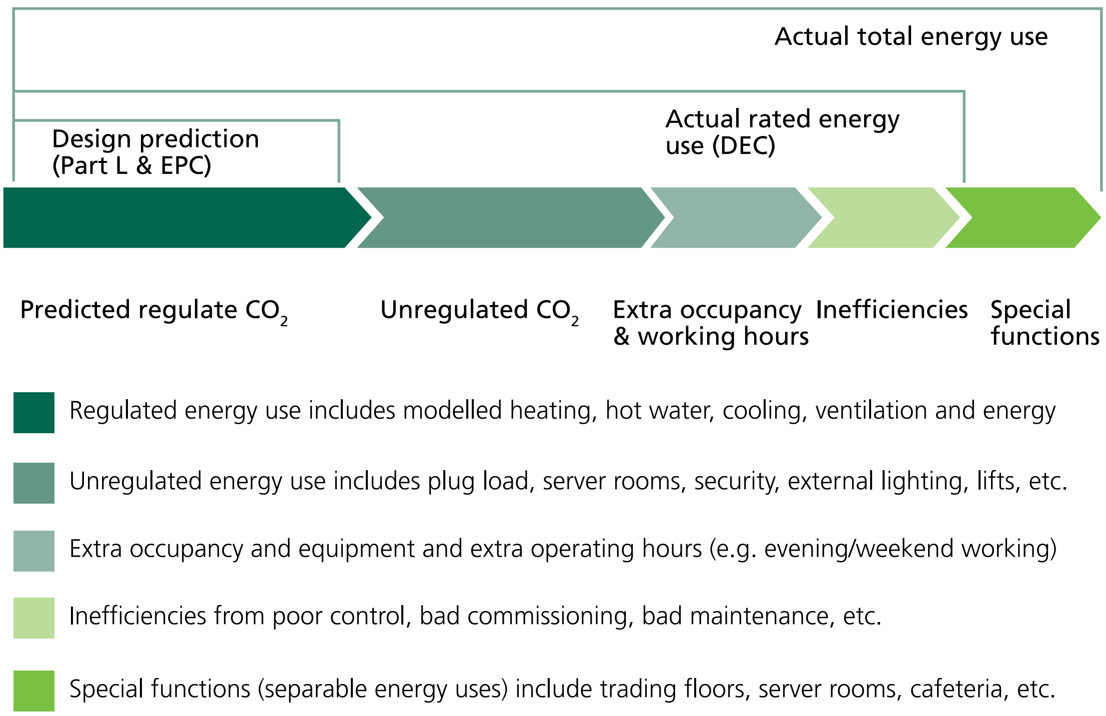
To minimise the number of assumptions made, standardised data from the National Calculation Method (NCM) database, which is used for all Part L calculations, was utilised in the analysis.

Part L and EPCs only regulate and predict a proportion of CO_2 emissions in a building as shown in Figure 4.3. Specifically, only heating, cooling, hot water, ventilation and lighting energy consumption is accounted for and standard working hours and occupancy are assumed. The modelling process did not include, therefore,

4. METHODOLOGY AND BUILDING SELECTION

any allowance for the occupants' equipment or appliances, or account for extended working hours, for example. A Display Energy Certificate (DEC), currently only mandatory for public buildings or buildings with public tenants, takes account of these additional energy uses and variables. A DEC measures virtually all elements of **actual** energy use in a building, whereas an EPC is a theoretical prediction of how a building could perform. For the purposes of this study, an EPC reflects the scale of influence a landlord has in a building to affect energy consumption and CO_2 emissions.

Figure 4.3: Building energy consumption measures by Part L, EPCs and DECs



Carbon Trust (2011), *Closing The Gap*, available from the Carbon Trust website (ref CTG047) www.carbontrust.co.uk

4.4 Key modelling parameters

The SBEM modelling software requires a range of physical building characteristics to be defined as model inputs in order to construct the base building models. Standard assumptions are made by the software in regard to building operation. The approach followed was to determine inputs that would best represent the building types under consideration. The key parameters are listed in Table 4.3.

The floor area and geometry for each office were consistent with the original study. However, the retail and industrial buildings were amended. These buildings are now over 5,000m² to reflect mid-size properties in both sectors.

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Table 4.3: Key modelling parameters

Input variable	Base building modelling parameters		
	Office	**Retail**	**Industrial/warehouse**
Building geometry			
Gross floor area	5,400m² (6 storey)	Sales area: 4,500m² Office: 600m² (2 storey) Warehouse: 500m²	Main area: 4,500m² Office: 600m² (2 storey)
Floor plate dimensions	Deep plan: 30m x 30m Narrow plan: 60m x 15m	Sales area: 75m x 60m Office: 20m x 15m Warehouse: 25m x 20m	Main area: 75m x 60m Office: 20m x 15m
Storey height	3.7m	4m	4m
Glazing %	50% 80%	Office only	Office only
Glazing specification Office 1	Double Single	Double	Single
Location	London and South East	Retail Park	Industrial Park
Building fabric and operation			
Age Office 1 Office 2 Office 3 Office 4	 Pre-1940 Pre-1995 2002 2006	Pre 1995	Pre 1995
Building services strategy			
Heating system	Gas	Gas	Gas
Natural ventilation	Office 1 only	None	Yes
Air conditioning	Offices 2 to 4 Centralised system and fan coils	Centralised system and fan coils	None
Lighting Office 1 and 2 Office 3 and 4	 T12 T8	T12	T12
Hot water	Gas	Gas	Gas
Renewable energy	None	None	None

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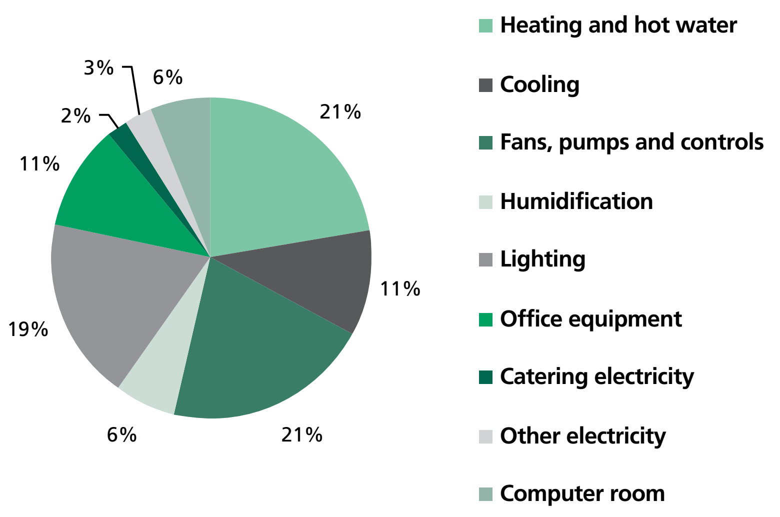
4.5 Energy efficiency improvements

The scope for reducing CO_2 emissions within an existing building depends on how energy is consumed within it.

Figure 4.4: Typical CO_2 emissions from an air-conditioned office



Action Energy (1990) Energy Consumption Guide 19: Energy use in offices, available from website www.carbontrust.co.uk

Figure 4.4, for example, shows that the majority of CO_2 (78%) produced within an existing air-conditioned office is from the following energy uses:

- Heating and hot water;
- Fans, pumps and controls associated primarily with the air conditioning system;
- Lighting; and
- Cooling (and humidification).

It is important to note that this study focuses on the energy efficiency improvements that can be made by a landlord and are assessed in relation to each of the main energy uses above. Many of the previous improvements are reassessed in this study, including renewable energy, but this study also includes a consideration of emerging technologies, such as LED lighting. However, certain technologies, for example voltage optimisation,[4] cannot be modelled adequately using SBEM and the benefits will be specific to each building. These technologies have been excluded from the analysis therefore.

The application of low and zero carbon (LZC) energy sources on commercial buildings should be considered carefully in order to maximise output and produce a reasonable return on investment. LZCs are not suitable to all building types and the brief summary below identifies where they will be applicable.

[4] Voltage optimisation reduces losses in electrical equipment in turn reducing energy consumption and CO_2 emissions. Quoted savings can be up to 15% of electricity consumption but will depend on the equipment used in the building and voltage delivered.

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Photovoltaics (PV)

Photovoltaic systems use cells to convert sunlight into electricity. The PV cell consists of one or two layers of a semi-conducting material, usually silicon. When light shines on the cell it creates an electric field across the layers causing electricity to flow. The greater the intensity of the light, the greater the flow of electricity.

This is a tried and tested form of renewable energy generation with a mature supply chain, long design life (typically 25 years) and virtually no maintenance is required. A south-facing orientation (or close to south) is necessary to maximise the amount of solar energy received. PV panels can be applied to all buildings provided there is sufficient unshaded space to install them.

Solar thermal

Solar thermal panels produce hot water from solar energy and reduce the need for conventional water heating (i.e. gas). Typically around 40% to 60% of annual hot water demand can be provided through the use of solar thermal panels.

This is an inexpensive, effective and straightforward technology in terms of operation and maintenance (little being required). A south-facing orientation (or close to south) is necessary to maximise the amount of solar energy received. Systems can be applied to all buildings provided there is sufficient unshaded space to install them and there is an adequate demand for domestic hot water.

Wind turbines

Wind turbines use the wind's lift forces to rotate aerodynamic blades that turn a rotor to generate electricity.

Wind turbines offer zero-emission electricity production. For optimum performance the wind speed at the site needs to be >6.5 m/s. Siting a wind turbine requires planning permission and they cannot be positioned too close to buildings. Not suitable for urban environments.

Biomass

Burning wood or wood products as a fuel is considered to be a 'carbon neutral' process because the CO_2 released during combustion is equal to that absorbed during growth of the fuel. Biomass fuels are combusted in a boiler and then heat in the form of hot water is transferred within the building to provide space heating and domestic hot water.

Sufficient space for storage of fuel onsite and an adequate supply of fuel from local sources are prerequisites. The installation of biomass boilers can lead to wider planning issues such as air quality and, accordingly, this technology is not considered within this study.

Ground source heat pumps

Ground source heat pump (GSHP) systems utilise constant temperatures from below ground, extracting heat that can be used for space heating/cooling. Heat may be extracted either by means of a 'horizontal' system, where pipe coils are laid in trenches, or by a 'vertical' system, using boreholes.

A GSHP system does not require any external solid fuel as it uses electricity to operate the circulation pumps. The heat pumps themselves therefore may only be considered a 'low', not 'zero', carbon form of renewable energy generation. GSHPs can be difficult and expensive to retrofit so were excluded from the analysis.

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Air source heat pumps

Air source heat pumps (ASHPs) work in a similar way to ground source systems. Instead of heat being extracted from the ground it is extracted from the air by an externally sited unit.

The system operates using electricity, thus not requiring any external fuel, and can be designed to heat and cool a whole building. The technology is less expensive than GSHP and does not require ground loops. The installation of the units is straightforward. Electricity is required to pump the heat and often the coefficient of performance (CoP) will be lower than that achieved with a GSHP (hence the carbon savings are much lower). As the units are mounted externally there can be visual and noise impacts.

Combined heat and power

Combined heat and power (CHP) systems generate both electricity and thermal energy from a single fuel source, which is typically natural gas. This is an efficient technology, and can generate considerable CO_2 savings in the right conditions.

CHP systems are an efficient technology as the waste heat resultant from the generation of electricity is captured and reused. Considerable CO_2 savings can be achieved in the right conditions. The technology is most efficient when operational for as many hours as possible per annum at as high an output as possible. This means that the system would ideally still be running at full capacity over the summer months, i.e. producing thermal energy during the hottest parts of the year, when thermal demand will be minimal. The incorporation of an absorption chiller can use this thermal output to provide cooling during summer; however; it is typically suited to large buildings with a high cooling demand to make the technology economically viable.

4.6 Commercial building refurbishments

The original study analysed the cost and benefits of undertaking a range of energy efficiency improvements either as part of a general refurbishment project, when a building has vacant possession, or on a 'one-off' basis, when the building is wholly or partly occupied. Some improvements can be implemented under both scenarios but there will be an increased cost if undertaken in the latter circumstance. In addition, there are some improvements that will not be practical under the 'one-off' scenario due to occupant disruption. Both scenarios are considered as part of this study.

It may be noted that the refurbishment of an existing building to meet a 'market standard' specification should naturally reduce operational CO_2 emissions. The definition of 'market standard' is the minimum energy efficiency standard a building can be refurbished to, given available technology, and to meet regulations. It does not include any plant, systems or equipment that are more energy efficient and which, in most cases, would be at an increased cost. For example, replacing a 20 year old boiler with a 'market standard' boiler will produce a reduction in gas consumption because the new version will be typically 90% efficient compared to 65% for the old model. However, a 95% efficient boiler could be specified as part of the refurbishment, which would be more expensive but would save more energy. This study examines the reduction in CO_2 emissions resulting from a 'market standard' refurbishment and the additional reduction that can be achieved if enhanced energy efficiency improvements are specified.

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By way of example, the following measures are deemed to be included as part of a 'market standard' refurbishment for an air-conditioned office:

- Boiler with 90% efficiency;
- Chiller with CoP of 3.3;
- T8 lighting;
- Specific fan power of 2.9W/l/s; and
- Power factor correction of 0.90.

For Office 4, which represented a building approximately five years old, it was assumed that a 'market standard' refurbishment would not take place because the building already includes many of the features that would be part of a 'market standard' refurbishment. For example, an office built in 2006 would typically include T8 lighting as standard. In practice, a refurbishment of the scale being considered in this study would typically take place after a minimum of 10 years. The improvements proposed in this study can be planned for a refurbishment taking place in future years, therefore.

4.7 Costing process and assumptions

4.7.1 Capital costs

The basis of the research was to assess the costs associated with making certain energy efficiency improvements, which are typically beyond the scope of a 'market standard' refurbishment. To demonstrate which of these improvements are most cost effective, it was necessary to quantify the extra capital cost of the upgrade compared with the respective like-for-like replacement under a 'market standard' refurbishment.

The 'extra over' cost was derived from the difference between the capital cost of the upgrade and the capital cost of the standard refurbishment item. These costs were estimated individually for each building type modelled and represent the total cost to a client of construction work (i.e. cost to the landlord). This included materials, labour, connected builder's work, preliminaries, overheads, contingencies and profit. Design fees were not included, based on the assumption that any increase in design fees associated with the upgrade will be marginal. Other excluded costs comprised value added tax, building control fees, survey fees, legal fees and finance costs. All costs were current at second quarter 2012 price levels.

It was assumed that all improvements modelled could be carried out within the existing buildings without structural alterations or reworking floor layouts and positions of ducts, etc, and the capital costs reported reflect this.

The 'extra over' capital cost was also calculated for those improvements that could be carried out whilst a tenant was (or multiple tenants were) in occupation of the building. Most improvements could be carried out during evenings and weekends, although there would be an extra cost for undertaking work at these times. For simplicity, phased refurbishments were not considered (where one or more floors are unoccupied and there could be an associated cost of decanting and moving tenants).

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4.7.2 Lifecycle costs and energy savings

For each energy efficiency improvement, the operational costs and energy savings were also calculated. Previously, the internal rate of return (IRR) and discounted payback period were calculated in order to indicate investment potential. The current study shows all costs and savings on an undiscounted basis and provides enough data to allow the user to calculate the financial metrics to suit their own particular requirements (Section 4.8).

The lifecycle costs of each energy efficiency improvement were determined based on expected servicing requirements, maintenance implications (major and minor overhauling) and replacement over the lifetime of the improvement (ranging from 10 to 30 years) where differing from the standard refurbishment item of work. For example, a high-efficiency boiler would not need any more maintenance than a standard boiler, whereas solar hot water heating panels require the replacement of certain components every 10 to 15 years. The lifecycle costs were estimated to reflect an average assessment of maintenance, servicing and replacement. However, in practice, significant variation could arise.

Current and projected future gas and electricity prices as published by the Department for Energy and Climate Change (DECC) were used to estimate the likely financial benefit from the energy saved. The impact of DECC's 'central' and 'high' energy price projections were considered in relation to energy savings for each energy efficiency improvement.

4.8 Calculating financial metrics: an example

The detailed results set out in the tables contained within this study provide sufficient information to enable readers to financially evaluate the individual improvements for each of the property types. The additional capital cost, estimated life of the installation and savings of gas, electricity, CO_2 (in terms of reduced CRC payments) and available incentives (where applicable) allow an IRR to be estimated. The impact of varying the price of energy and CO_2 savings may also be estimated.

To illustrate what may be achieved an example might be: the provision of T5 lighting instead of T8 lighting installed under the market standard refurbishment in Office 1 (Table 5.9). T5 lighting costs an extra £7.11/sq m and may be expected to last 20 years. On central DECC estimates of gas and electricity prices, T5 lighting would save some £1.24/sq m per annum. To this could be added a saving in CO_2 of £0.04/sq m, pricing CO_2 at £12/tonne. In simple terms, this produces an incremental yield of 18% per annum.

However, this does not allow for the need to write down the additional capital expenditure after 20 years. Assuming straight line depreciation, no tax relief and no sinking fund, this totals a cost of £0.36 per annum, which should be deducted from the T5 savings. This still produces a net yield of 12.9%, as shown below:

$$\frac{(1.24 + 0.04 - 0.36)}{7.11}$$

Over 20 years these savings would generate an IRR on the initial outlay of between 13% and 14%. Even if the remaining life of the building was only 10 years the IRR would still be over 6% per annum.

However, while these figures appear quite attractive compared with current return expectations for property, it must be remembered that much of the direct financial benefit will accrue to the tenant. It is a moot point as to how much of the benefit will be enjoyed by the landlord in the form of higher rents or shorter void periods. There is growing evidence in the USA that buildings with high energy efficiency ratings are beginning to attract rental premia, but evidence in the UK is inconclusive currently.

5. OFFICE RESULTS

5.1 Introduction

The results of the energy modelling and costing process for all office buildings are outlined in this section. The results are presented and discussed as follows:

- Baseline CO_2 emissions and EPC ratings;
- Strategies to improve EPC ratings; and
- Key energy efficiency improvements.

5.2 Baseline EPC ratings and CO_2 emissions

The baseline annual CO_2 emissions and EPC ratings for the four office buildings are set out in Table 5.1. The baseline emissions equate to the building emissions rate (BER) as calculated by the SBEM software.

Table 5.1: Baseline emissions for the office buildings

Building	Plan depth	Age	Glazing	Annual CO_2 emissions ($kgCO_2/m^2$)	EPC rating	EPC CO_2 index
Non air-conditioned						
Office 1	Narrow	Pre-1940s	Single	62.2	E	120
Air-conditioned						
Office 2	Narrow	Pre-1995	Double	84.9	G	164
Office 3	Deep	Post-2002	Double	74.5	F	143
Office 4	Deep	Post-2006	Double	59.0	E	113

The BER excludes small power consumption: IT equipment, photocopiers, task lighting, phone chargers, tea points, etc. Small power is excluded from Part L compliance as it is not a function of the building, being influenced, instead, by the tenant's own occupation and choice of equipment.

It is evident from Table 5.1 that offices have become more energy efficient since the early 1990s. CO_2 emissions are less per square metre of floor area and EPC ratings are better for more modern offices. Revisions to Part L of the Building Regulations have improved the thermal performance of the building fabric (through improved insulation and glazing) and the efficiency of building services plant.

The results also show that offices without air conditioning perform better in terms of their EPC rating and CO_2 emissions than air-conditioned offices. Air conditioning is a significant consumer of electricity (chilling plant, fans and pumps) compared with offices that are naturally ventilated and provided with heating only.

As a consequence of a revision to Part L of the Building Regulations, buildings constructed prior to the introduction of the revised regulations will achieve a poorer EPC rating if they were to be reassessed now because a building that is compliant with the stricter assessment criteria of the latest regulations will score either a B or C benchmark rating (depending on the servicing strategy) but the change in regulations will mean that the building is comparatively less efficient, so will be lower on the EPC scale (i.e. D- or E-rated f or example).

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To investigate this further, Office 4 was assessed against both the 2006 and 2010 Part L regulations using appropriate versions of the SBEM software. Table 5.2 shows the comparison.

Table 5.2: Office 4 EPC comparison under 2006 and 2010 Part L regulations

Part L regulations	EPC rating	EPC CO_2 index
2006	C	59
2010	E	113
2013*	F	>125

Office 4, which was specified to meet the standards required by 2006 Part L, would drop two EPC grades if it were to be reassessed against 2010 Part L. Future revisions to Part L (the next change is proposed for 2013/2014) are anticipated to have similar impacts on the EPC ratings for existing office buildings, resulting in more F or G ratings within the existing stock. Using Office 4 as an example, it is estimated that it would achieve a F rating if assessed against the next version of Part L. Similarly, the proposed minimum energy efficiency standards for buildings let by landlords, to be introduced by 2018, are highly likely to affect offices built to 2006 standards.

5.3 Refurbishment strategies to improve EPC ratings

5.3.1 'Market standard' refurbishment

Refurbishing an existing building to a current 'market standard' will inherently reduce CO_2 emissions and, in turn, improve its EPC rating. Table 5.3 summarises the improvement potential of a 'market standard' refurbishment for all offices. For Office 4, a 'market standard' refurbishment is not applicable as this building would already include many features typically included in a 'market standard' refurbishment. In addition, these offices would not typically be subject to a comprehensive refurbishment for at least another five years, by which time a 'market standard' refurbishment would be more energy efficient compared to current standards.

Table 5.3: Improvement potential of a 'market standard' refurbishment

	EPC rating and score / CO_2 saving against baseline (%)							
	Office 1		Office 2		Office 3		Office 4	
	EPC	CO_2	EPC	CO_2	EPC	CO_2	EPC	CO_2
Baseline	E / 120	-	G / 164	-	F / 143	-	E / 113	-
Market refurbishment	D / 91	24%	F / 138	16%	F / 132	8%	E / 113	0%

A 'market standard' refurbishment could improve the EPC rating of Office 1 and 2 by one grade and make a noticeable cut in CO_2 emissions. The cut in CO_2 emissions for Office 1 is projected to be more significant than for Office 2, representing almost a quarter of baseline emissions.

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A 'market standard' refurbishment of Office 3, which would consist of more efficient lighting and a new boiler, would not see the EPC rating improved above an F although an 8% cut in CO_2 emissions could be achieved. Additional expenditure on improving energy efficiency would therefore need to be considered to bring the office to an E rating or better.

5.3.2 Enhanced energy efficiency improvements

Tables 5.5 to 5.8 identify the additional cost of specifying enhanced energy efficiency improvements compared to the cost of a 'market standard' refurbishment to improve EPC ratings for each office. The associated cut in CO_2 emissions was identified together with the improvements that needed to be implemented to achieve the savings. All costs and savings shown are cumulative.

All additional costs are expressed as a percentage of the 'market standard' refurbishment cost for each building. Different refurbishment costs were assumed between offices because the scope of works would be different. This is a reflection of building age and services strategy. The cost and scope of refurbishment works for each office are outlined in Table 5.4. All costs were based on second quarter 2012 prices and excluded professional fees.

Table 5.4: Office refurbishment costs and scope of works

Office	Refurbishment cost	Scope of refurbishment works
1	£900/m²	Complete strip-out of the existing building; new cores and office CAT A fit-out, including reception areas, toilets, office floor fit-out, completely new central plant and services (no air conditioning)
2	£1100/m²	Complete strip-out of the existing building; new cores and office CAT A fit-out, including reception areas, toilets, office floor fit-out, completely new central plant and services (air conditioning)
3 & 4	£750/m²	Office refurbishment to CAT A; including new ceilings, lighting, carpet, blinds and painted walls to office areas, new air conditioning including replacement boilers, chillers and fan coil units

Two improvement strategies were presented for each building. Strategy A ('marginal cost' strategy) implemented each improvement based on lowest marginal cost (i.e. cost of saving one $kgCO_2/m^2$ floor area), as set out in Tables 5.9 to 5.12. The aim of this strategy was to keep additional capital outlay as low as possible, although improvement potential was thereby compromised. This strategy favoured technologies that were low cost but whose CO_2 savings were also relatively low. Strategy B ('alternative technology' strategy) included alternative technologies which were more expensive but had a larger CO_2 saving and therefore could achieve better EPC ratings.

To illustrate this, the marginal cost strategy for Office 2 shows that a C-rated EPC could be achieved by spending an additional 14.6% when undertaking a refurbishment. This strategy would feature a range of improvements including an upgrade to T5 lighting (instead of T8) and DC drive fan coil units (instead of standard versions) – see Table 5.6. However, if the target was to achieve a B-rated EPC, then a revised strategy would need to be implemented. A more efficient (and therefore more expensive) LED lighting system

5. OFFICE RESULTS

and passive chilled beams (if appropriate) would need to be specified in lieu of T5 lighting and DC drive fan coil units. This alternative specification would require an additional investment of 24.5% to achieve a C rating but would also make a B rating feasible for a total extra investment of 37.3%.

Comparing both strategies for each office demonstrates that there might be cheaper ways of meeting particular EPC ratings rather than implementing improvements based on marginal cost only. Using Office 1 as an example, achieving a B rating was cheaper under Strategy B (14.1% additional cost) than under Strategy A (23.4%). Another example is Office 3, for which the alternative technology scenario was cheaper when targeting D and C ratings compared to the marginal cost strategy.

Two notable reasons for this are:

- The net effect of combining several improvements together produced an aggregated CO_2 savings that would be less than the sum of the individual savings.
- EPC thresholds are absolute, therefore the introduction of an expensive technology might be required to exceed the threshold compared to an alternative strategy. For example, the expensive double glazing improvement for Office 1 was required to get a B rating under Strategy A.

It is of paramount importance, therefore, for a full options appraisal with financial cost–benefit analysis to be undertaken prior to any refurbishment works in order to determine the most cost-effective way of cutting CO_2 emissions and securing improved EPC ratings.

Table 5.5: Office 1 EPC improvement strategies

	Additional capital cost (%) / CO_2 saving against baseline (%)					
EPC rating	**Strategy A**		**Improvements**	**Strategy B**		**Improvements**
	Cost	**CO_2**		**Cost**	**CO_2**	
C	0.8%	38%	Boiler 95% Daylight controls Air tightness VS pumps	1.1%	38%	Daylight controls Air tightness VS pumps Heating controls Power factor
B	23.4%	65%	Heating controls Power factor T5 lighting PV 75m^2 PIR controls Double glazing	14.1%	64%	Air source heat pumps PV 375m^2
A	-	-	-	40%	83%	LED lighting PIR controls Double glazing

Key: PV = photovoltaic panels; PIR = passive infra-red; VS = variable speed; LED = light-emitting diode

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Table 5.6: Office 2 EPC improvement strategies

Additional capital cost (%) / CO_2 saving against baseline (%)

EPC rating	Strategy A		Improvements	Strategy B		Improvements
	Cost	CO_2		Cost	CO_2	
E	0.3%	24%	Daylight controls VS pumps	0.3%	24%	Daylight controls VS pumps
D	2.4%	42%	Power factor Chiller T5 lighting Air tightness Boiler 95% Heat recovery	1.7%	41%	Power factor Chiller Air tightness Boiler 95% Heat recovery
C	14.6%	57%	DC drive fan coils Heating controls Specific fan power PIR controls PV 10m^2 External shading	24.5%	64%	Heating controls Specific fan power PIR controls LED lighting Passive chilled beams
B	-	-	-	37.3%	70%	PV 375m^2 External shading
A	-	-	-	-	-	-

Table 5.7: Office 3 EPC improvement strategies

Additional capital cost (%) / CO_2 saving against baseline (%)

EPC rating	Strategy A		Improvements	Strategy B		Improvements
	Cost	CO_2		Cost	CO_2	
E	1.0%	21%	Power factor VS pumps Chiller	1.0%	21%	Power factor VS pumps Chiller
D	3.7%	34%	T5 lighting DC drive fan coils Specific fan power	1.9%	33%	Specific fan power Daylight controls
C	14.7%	56%	Daylight controls Boiler 95% External shading	12.6%	48%	Boiler 95% External shading
B	-	-	-	44.7%	62%	LED Lighting Heating controls Passive chilled beams
A	-	-	-	-	-	-

5. OFFICE RESULTS

Table 5.8: Office 4 EPC improvement strategies

Additional capital cost (%) / CO_2 saving against baseline (%)

EPC rating	Strategy A		Improvements	Strategy B		Improvements
	Cost	CO_2		Cost	CO_2	
D	1.2%	11%	VS pumps DC drive fan coils	1.0%	15%	VS pumps Chiller Daylight controls
C	14.9%	38%	T5 lighting Chiller Daylight controls Boiler 95% Specific fan power External shading	12.8%	36%	Boiler 95% Specific fan power External shading
B	-	-	-	45.7%	64%	Heat recovery LED lighting Passive chilled beams
A	-	-	-	-	-	-

The foregoing results indicate that EPC ratings for all offices could be improved by an extra grade for an additional cost of up to 1% of the refurbishment budget. This is a relatively minor amount to spend when undertaking a refurbishment project to secure a better EPC rating. For an extra 1% spend, CO_2 savings varied depending on the age of the base case building, ranging from 10% to 15% for modern offices (Offices 3 and 4), to 24% for pre-1995 air-conditioned offices and to 38% for older naturally ventilated offices.

Air-conditioned offices built over 10 years ago (Offices 2 and 3) represented the most cost-effective opportunity to further enhance EPC ratings and cut CO_2 emissions. For a total extra spend of circa 2%, the EPC could be improved by two ratings above a 'market standard' refurbishment (i.e. F to D for both Offices 2 and 3). Additional CO_2 savings would be over 30% for Office 3 and around 40% for Office 2. Improving the EPC to a C rating became significantly more expensive and required additional expenditure of 12% or more.

For Offices 1 and 4, improving EPC ratings by two grades was less cost effective compared to the other offices, as an additional total investment of around 12% to 15% was required.

It was possible to improve the EPC ratings to either a C or B for air-conditioned offices but it was expensive to achieve. An A-rated EPC was not practically achievable based on the improvements considered although it could be possible if a more detailed analysis was undertaken and further options explored. The naturally ventilated office could achieve an A rating but the cost would be prohibitive as refurbishment costs would need to increase by a substantial 40%.

Both the marginal cost (Strategy A) and alternative technology (Strategy B) strategies for each office are shown in Figures 5.1 and 5.2. The vertical lines represent different EPC rating thresholds that are based on the EPC's CO_2 index score. Below 25 is an A rating and above 150 is a G, with bands in between at intervals of 25.

5. OFFICE RESULTS

Figure 5.1: Additional cost to improve office EPC ratings – Strategy A (all offices)

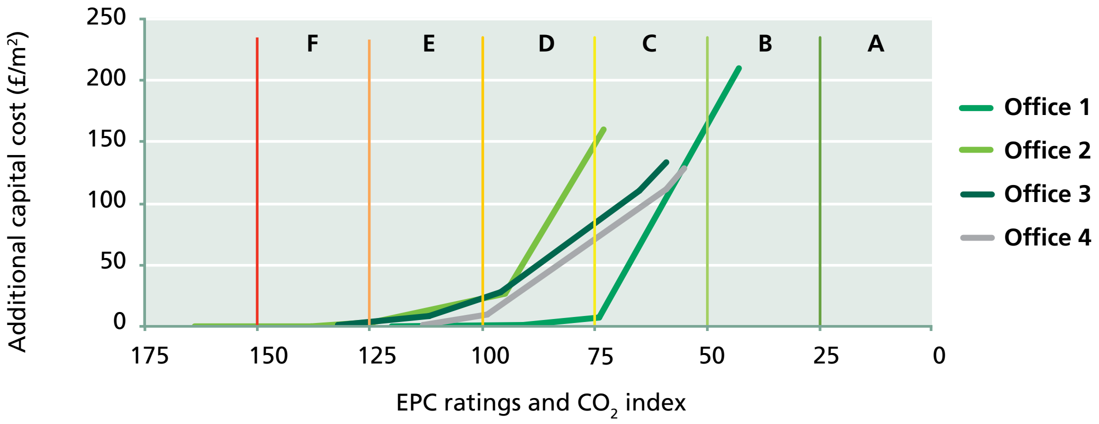
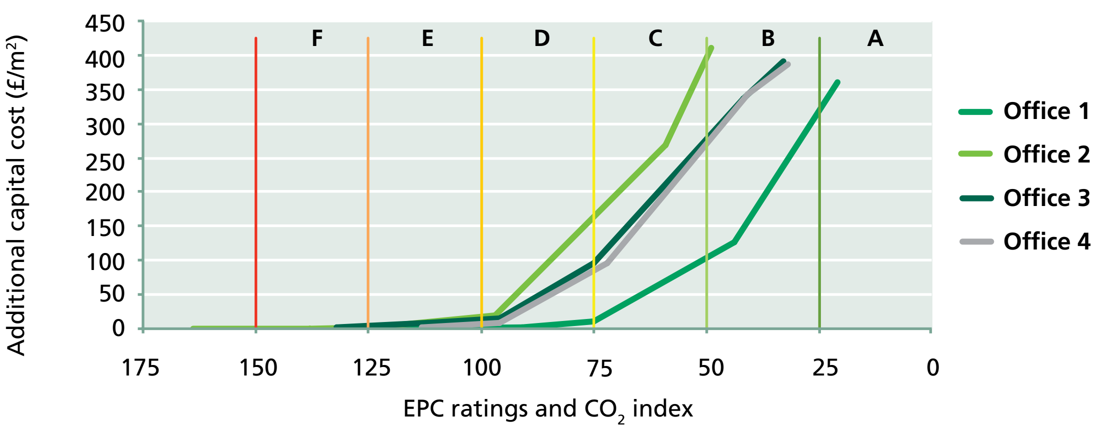


Figure 5.2: Additional cost to improve office EPC ratings – Strategy B (all offices)



It is evident from Figures 5.1 and 5.2 that all air-conditioned offices could achieve a D rating relatively cheaply whilst achieving a C rating (equivalent to new air-conditioned offices) would incur a significant premium.

The cost to improve the non-air-conditioned office was more favourable, with an extra spend required in the region of 1% to secure a C rating, but a significant 14% extra capital required to hit a B rating (which would be on a par with new non-air-conditioned offices).

5. OFFICE RESULTS

5.4 Individual improvements to offices

A range of energy efficiency improvements were analysed for each office building. The tables provided in this section (Tables 5.9 to 5.16) set out the cost–benefit of implementing each improvement on an individual basis (rather than cumulatively as in Section 5.3) in terms of EPC rating, carbon and energy savings, capital cost, lifecycle costs, CRC savings and available incentives. This data could be used to run investment appraisals, for example, payback periods, net present values, internal rate of returns and yields, as described in Section 4.7.2.

The coloured rows in Tables 5.9 to 5.12 correspond with the EPC improvements under the 'marginal cost' improvement strategy (Strategy A) for each office in Tables 5.5 to 5.8. The following tables show the baseline EPC rating, the improvement that could be achieved through undertaking a 'market standard' refurbishment and subsequent improvements required to achieve improved EPC ratings. The non-coloured rows represent those technologies that were analysed in terms of individual cost, CO_2 saving and EPC impact but were not included under Strategy A because their marginal cost was higher than alternative improvement options.

Full result tables, stating gas and electricity savings per improvement and tariffs, are included in the Appendix.

Two improvement scenarios were considered and separate tables are provided for each office under each scenario:

- full refurbishment during a period of vacant possession; and
- 'one-off' improvements when the building is wholly or partly occupied.

Previous consideration was given to making energy efficiency improvements during a vacant possession refurbishment. There is also potential to make the majority of these improvements whilst the building is fully occupied. This would be important where a planned refurbishment is some years away and one or more leases are due to expire. The introduction of EPCs have made tenants acutely aware of how buildings perform in terms of their energy performance and will be prevalent during lease negotiations. If the landlord carries out a few 'quick wins' to improve the rating of the building, these could assist in lease renewal negotiations, reduce void periods and potentially affect the rental level achieved.

All capital costs stated in the tables for the enhanced energy efficiency improvements were in addition to the cost of replacing with a standard version of the fitting or item of plant. Under the refurbishment scenario, the cost of the standard improvement would be part of the refurbishment budget. For the 'one-off' improvements, it was assumed that the replacement cost would be part of the maintenance and replacement budget for the building.

The cost of carrying out works out of hours during evenings and weekends would be greater if implemented as part of a refurbishment. However, as Tables 5.13 to 5.16 show, the extra cost was typically between 3% and 7% because the extra cost of labour was offset by not incurring main contractor's preliminaries, overheads and profit.

Most improvements considered for the refurbishment scenario were potentially feasible as 'one-off' improvements when the office was occupied. The work would generally be done out of hours. However, significant items of work in an occupied office would take considerably more time to carry out. These included lighting and fan coils units. It might be favourable to refarin from undertaking these types of improvements until the next planned refurbishment if it is in the short to medium term. Chilled beams and fabric enhancement measures (with the exception of external shading) would not be undertaken when a building is occupied due to the level of disruption likely to be caused.

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Table 5.9: Office 1 energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$/ m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)	Limitations / discussion / assumptions
-	BASELINE	120 / E	-	-	-	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	91 / D	15.20	-	-	-	-	-	-	-	-
Heating	95% efficiency boilers	87 / D	1.70	1.12	0.66	0.34	0.42	0.02	-	20	Boiler with 90% efficiency part of a market refurbishment.
Lighting	Daylight sensing	83 / D	3.90	3.38	0.87	1.14	1.19	0.05	-	10	Controls lighting when sufficient daylight enters a space.
Fabric	Air tightness	86 / D	2.30	2.43	1.05	0.46	0.57	0.028		30	Reduces heat loss in winter and heat infiltration in summer.
Heating	Variable speed pumps	90 / D	0.20	0.26	1.32	0.05	0.06	0.002		20	More efficient than fixed speed pumps.
Heating	Heating controls	88 / D	1.60	3.09	1.93	0.32	0.39	0.02	-	20	Local temperature and time controls.
Power	0.95 power factor correction	90 / D	0.20	0.40	1.98	0.06	0.07	0.002	-	20	Reduces transmission losses from electrical circuits.
Lighting	T5 lighting	84 / D	3.50	7.11	2.03	1.24	1.32	0.04	-	20	Wide variance in quality and cost of T5 light fittings. Assumed like-for-like replacement in terms of light quality.
LZC	Photovoltaics - 10kWp (75m²)	89 / D	0.80	8.95	11.19	0.42	0.43	-	0.21	25	Produces electricity. Uncertainty surrounding future FiT.
Lighting	Movement sensing (PIR)	90 / D	0.50	6.04	12.09	0.17	0.18	0.01	-	10	Turns off lighting when there are no occupants are in a space.
Fabric	Replace single glazed windows with double glazed	64 / C	13.80	177.41	12.86	2.74	3.40	0.17	-	30	Reduces heat loss in winter and heat gain in summer.

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Table 5.9 Cont'd. : Office 1 energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)	Limitations / discussion / assumptions
LZC	Air source heat pump	76 / D	7.70	74.56	9.68	-0.50	0.07	-	-	20	Provides heating and cooling.
LZC	Photovoltaics - 100kWp (750m²)	75 / D	8.30	81.65	9.84	3.76	3.91	-	1.60	25	Produces electricity. Uncertainty surrounding future FiT.
LZC	Photovoltaics - 50kWp (375m²)	83 / D	4.20	42.80	10.19	2.01	2.09	-	0.94	25	Produces electricity. Uncertainty surrounding future FiT.
Lighting	LED lighting	82 / D	4.60	49.78	10.82	1.64	1.68	0.06	-	15	Developing technology that will become more competitive over time.
LZC	Wind turbine 20kW	89 / D	1.00	16.88	16.88	0.73	0.67	-	0.41	20	Very site specific. Typically suits out of town locations.
LZC	Solar thermal 50m²	90 / D	0.30	8.56	28.53	0.19	0.21	-	0.16	25	Produces hot water.

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Table 5.10: Office 2 energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$/ m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)	Limitations / discussion / assumptions
-	BASELINE	164 / G	-	-	-	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	138 / F	13.6	-	-	-	-	-	-	-	-
Lighting	Daylight sensing	125 / E	6.8	2.25	0.33	1.95	2.05	0.08	-	10	Controls lighting when sufficient daylight enters a space.
Heating/ cooling	Heating and cooling - variable speed pumps	135 / F	1.6	0.71	0.44	0.49	0.58	0.02	-	20	More efficient than fixed speed pumps.
Power	0.95 power factor correction	136 / F	0.8	0.40	0.49	0.25	0.30	0.01	-	20	Reduces transmission losses from electrical circuits.
Cooling	Chiller CoP 5.4	125 / E	6.7	4.74	0.71	2.06	2.43	0.08	-	20	High Coefficient of Performance so less electricity consumed.
Lighting	T5 lighting	127 / F	5.4	7.11	1.32	1.74	2.03	0.06	-	20	Wide variance in quality and cost of T5 light fittings. Assumed like-for-like replacement in terms of light quality.
Fabric	Upgrades to air tightness	134 / F	1.7	2.50	1.47	0.36	0.47	0.02	-	20	Reduces heat loss in winter and heat infiltration in summer.
Heating	95% efficiency boilers	137 / F	0.5	0.90	1.79	0.10	0.13	0.01	-	20	Boiler with 90% efficiency part of a market refurbishment.
Heating	Heat recovery	130 / F	3.7	7.30	1.97	0.88	1.12	0.04	-	20	Reuses waste heat.
Cooling	DC drive fan coils	129 / F	4.7	10.03	2.16	1.42	1.68	0.06	-	20	Direct current drives allow fan speed to be varied to conserve energy.
Heating	Heating controls	137 / F	0.5	1.32	2.71	0.09	0.13	0.01	-	20	Local temperature and time controls.
Cooling	SFP 2.0W/l/s	135 / F	1.5	9.69	6.46	0.48	0.56	0.02	-	20	SFP measures energy consumed to move one litre of air per second.

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Table 5.10 Cont'd. : Office 2 energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)	Limitations / discussion / assumptions
Lighting	Movement sensing (PIR)	136 / F	0.9	6.04	6.72	0.26	0.27	0.01	-	10	Turns off lighting when there are no occupants in a space.
LZC	Photovoltaics - 10kWp (75m²)	136 / F	0.8	8.95	11.19	0.42	0.43	-	0.21	25	Produces electricity. Uncertainty surrounding future FiT.
Fabric	External shading	127 / F	5.4	98.15	18.18	2.07	2.11	0.06	-	30	Reduces heat gain in summer.
Lighting	LED lighting	124 / E	6.9	49.78	7.21	2.03	2.35	0.08	-	15	Developing technology that will become more competitive over time.
Cooling	Chilled beams - passive	100 / D	19.7	183.55	9.32	6.55	7.66	0.24	-	20	Requires less electricity to provide cooling.
LZC	Photovoltaics - 100kWp (750m²)	122 / E	8.3	81.65	9.84	3.76	3.91	-	1.60	25	Produces electricity. Uncertainty surrounding future FiT.
LZC	Photovoltaics - 50kWp (375m²)	130 / F	4.2	42.80	10.19	2.01	2.09	-	0.94	25	Produces electricity. Uncertainty surrounding future FiT.
LZC	Air source heat pump	130 / F	4.3	59.67	13.88	-0.33	0.08	-	-	20	Provides heating and cooling.
Cooling	Chilled beams - active	116 / E	11.0	160.79	14.62	3.75	4.36	0.13	-	20	Requires less electricity to provide cooling.
LZC	Wind turbine 20kW	136 / F	1.0	16.88	16.88	0.73	0.67	-	0.41	20	Very site specific. Typically suits out of town locations.
LZC	Solar thermal 50m²	137 / F	0.3	8.56	28.53	0.16	0.17	-	0.13	25	Produces hot water.

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Table 5.11: Office 3 energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$/ m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)	Limitations / discussion / assumptions
-	BASELINE	143 / F	-	-	-	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	132 / F	-	-	-	-	-	-	-	-	-
Power	0.95 power factor correction	130 / F	1.0	0.40	0.40	0.29	0.31	0.01	-	20	Reduces transmission losses from electrical circuits.
Heating/ cooling	Heating and cooling - variable speed pumps	129 / F	1.7	0.71	0.42	0.48	0.51	0.02	-	20	More efficient than fixed speed pumps.
Cooling	Chiller CoP 5.4	117 / E	7.8	6.32	0.81	2.37	2.52	0.09	-	20	High Coefficient of Performance so less electricity consumed.
Lighting	T5 Lighting - new luminaires	119 / E	6.5	7.11	1.09	1.99	2.11	0.08	-	20	Wide variance in quality and cost of T5 light fittings. Assumed like-for-like replacement in terms of light quality.
Cooling	DC drive fan coils	122 / E	5.4	8.36	1.54	1.66	1.76	0.07	-	20	Direct current drives allow fan speed to be varied to conserve energy.
Cooling	SFP 2.0W/l/s	126 / F	3.0	4.64	1.55	2.51	2.66	0.04	-	20	SFP measures energy consumed to move one litre of air per second.
Lighting	Daylight sensing	129 / F	1.3	2.25	1.73	0.36	0.38	0.02	-	10	Controls lighting when sufficient daylight enters a space.
Heating	95% efficiency boilers	131 / F	0.4	0.78	1.94	0.06	0.07	0.005	-	20	Boiler with 90% efficiency part of a market refurbishment.
Fabric	External shading	103 / E	15.0	79.44	5.30	5.06	5.32	0.18	-	30	Reduces heat gain in summer.
Heating	Heating controls	131 / F	0.2	1.32	6.85	0.03	0.04	0.002	-	20	Local temperature and time controls.
Heating	Heat recovery	131 / F	0.7	7.30	10.43	0.88	0.22	0.01	-	20	Reuses waste heat.

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Table 5.11 Cont'd. : Office 3 energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)	Limitations / discussion / assumptions
LZC	Photovoltaics - 10kWp (75m²)	130 / F	0.8	8.95	11.19	0.42	0.43	-	0.21	25	Produces electricity. Uncertainty surrounding future FiT.
Lighting	Movement sensing (PIR)	131 / F	0.3	6.04	20.15	0.08	0.09	0.004	-	10	Turns off lighting when there are no occupants in a space.
Lighting	T5 lighting - conversion packs	119 / E	6.5	14.22	2.19	1.99	2.11	0.08	-	20	Conversion packs allow existing fittings to be retained.
Lighting	LED lighting	116 / E	8.5	49.78	5.86	2.25	2.73	0.10	-	15	Developing technology that will become more competitive over time.
Cooling	Chilled beams - passive	86 / D	24.1	189.94	7.88	7.89	8.34	0.29	-	20	Requires less electricity to provide cooling.
LZC	Wind turbine 20kW	128 / F	2.0	16.88	8.44	0.73	0.66	-	0.41	20	Very site specific. Typically suits out of town locations.
LZC	Photovoltaics - 100kWp (750m²)	116 / E	8.3	81.65	9.84	3.76	3.91	-	1.60	25	Produces electricity. Uncertainty surrounding future FiT.
LZC	Photovoltaics - 50kWp (375m²)	124 / E	4.2	42.80	10.19	2.01	2.09	-	0.94	25	Produces electricity. Uncertainty surrounding future FiT.
Cooling	Chilled beams - active	108 / E	12.3	167.18	13.59	4.10	4.32	0.15	-	20	Requires less electricity to provide cooling.
LZC	Solar thermal 50m²	131 / F	0.3	8.56	28.53	0.16	0.17	-	0.13	25	Produces hot water.
LZC	Air source heat pump	129 / F	1.2	51.49	42.91	-0.24	-0.11	-	-	20	Provides heating and cooling.

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Table 5.12: Office 4 energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$/ m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)	Limitations / discussion / assumptions
-	BASELINE	113 / E	-	-	-	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	113 / E	-	-	-	-	-	-	-	-	-
Heating/ cooling	Heating and cooling - variable speed pumps	110 / E	1.6	0.71	0.44	0.48	0.51	0.02	-	20	More efficient than fixed speed pumps.
Cooling	DC drive fan coils	101 / E	6.2	8.36	1.35	1.90	2.01	0.07	-	20	Direct current drives allow fan speed to be varied to conserve energy.
Lighting	T5 lighting - new luminaires	103 / E	5.2	7.11	1.37	1.59	1.69	0.06	-	20	Wide variance in quality and cost of T5 light fittings. Assumed like-for-like replacement in terms of light quality.
Cooling	Chiller CoP 5.4	108 / E	2.3	4.42	1.92	0.71	0.76	0.03	-	20	High Coefficient of Performance so less electricity consumed.
Lighting	Daylight sensing	111 / E	1.0	2.25	2.25	0.29	0.31	0.01	-	10	Controls lighting when sufficient daylight enters a space.
Heating	95% efficiency boilers	112 / E	0.2	0.76	3.79	0.04	0.05	0.002	-	20	Boiler with 90% efficiency part of a market refurbishment.
Cooling	SFP 2.0W/l/s	110 / E	1.4	8.43	6.02	0.45	0.47	0.02	-	20	SFP measures energy consumed to move one litre of air per second.
Fabric	External shading	89 / D	12.3	79.44	6.46	4.19	4.13	0.15	-	30	Reduces heat gain in summer.
Heating	Heat recovery	111 / E	1.0	7.30	7.30	0.28	0.31	0.01	-	20	Reuses waste heat.
Heating	Heating controls	112 / E	0.2	1.32	8.70	0.03	0.03	0.002	-	20	Local temperature and time controls.

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Table 5.12 Cont'd. : Office 4 energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)	Limitations / discussion / assumptions
LZC	Photovoltaics - 10kWp (75m²)	111 / E	0.8	8.95	11.19	0.42	0.43	-	0.21	25	Produces electricity. Uncertainty surrounding future FiT.
Lighting	T5 Lighting - conversion packs	103 / E	5.2	14.22	2.74	1.60	1.69	0.06	-	20	Conversion packs allow existing fittings to be retained.
Lighting	LED lighting	100 / D	6.7	49.78	7.43	1.96	2.25	0.08	-	15	Developing technology that will become more competitive over time.
Cooling	Chilled beams - passive	70 / C	22.2	189.94	8.56	7.33	7.75	0.27	-	20	Requires less electricity to provide cooling.
LZC	Photovoltaics - 100kWp (750m²)	97 / D	8.3	81.65	9.84	3.76	3.91	-	1.60	25	Produces electricity. Uncertainty surrounding future FiT.
LZC	Photovoltaics - 50kWp (375m²)	105 / E	4.1	41.68	10.17	2.02	2.10	-	0.94	25	Produces electricity. Uncertainty surrounding future FiT.
Cooling	Chilled beams - active	89 / D	12.5	167.18	13.37	4.17	4.40	0.15	-	20	Requires less electricity to provide cooling.
LZC	Wind turbine 20kW	111 / E	1.0	16.88	16.88	0.73	0.66	-	0.41	20	Very site specific. Typically suits out of town locations.
LZC	Air source heat pump	110 / E	1.2	50.77	42.31	-0.16	-0.04	-	-	20	Provides heating and cooling.
LZC	Solar thermal 50m²	112 / E	0.2	8.56	42.80	0.16	0.17	-	0.13	25	Produces hot water.
Lighting	Movement sensing (PIR)	113 / E	0.1	6.04	60.45	0.03	0.03	0.001	-	10	Turns off lighting when there are no occupants in a space.

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Table 5.13: Office 1 energy efficiency improvements – occupied building scenario

Energy efficiency improvement	One-off extra capital cost (£/m²)	% increase on refurb scenario	Marginal cost (£ per $kgCO_2$ / m² pa)	Limitation / discussion / assumptions
95% efficiency boilers	1.17	4.4%	0.69	Replace during summer. Assumes domestic hot water provision can be maintained.
Daylight sensing	3.63	6.9%	0.93	Out of hours.
Variable speed pumps	0.28	5.6%	1.38	Replace during summer. Assumes domestic hot water provision can be maintained.
Heating controls	3.24	4.6%	2.02	Out of hours. Retrofit during summer.
0.95 power factor correction	0.41	3.2%	2.07	Out of hours.
T5 lighting – new luminaires	7.11	4.4%	2.13	Out of hours. Replacement over a number of weeks.
Air source heat pump	74.95	0.5%	9.73	Out of hours.
Photovoltaics - 100kWp (750m²)	85.41	4.4%	10.29	Install during normal working hours. Connection out of hours.
Photovoltaics - 50kWp (375m²)	44.77	4.4%	10.66	Install during normal working hours. Connection out of hours.
LED lighting	52.07	4.4%	11.32	Out of hours. Replacement over a number of weeks.
Photovoltaics - 10kWp (75m²)	9.37	4.5%	11.71	Install during normal working hours. Connection out of hours.
Movement sensing (PIR)	6.42	5.9%	12.84	Out of hours.
Wind turbine 20kW	17.46	3.3%	17.46	Install during normal working hours. Connection out of hours.
Solar thermal 50m²	8.95	4.4%	29.85	Install during normal working hours. Connection out of hours.

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Table 5.14: Office 2 energy efficiency improvements – occupied building scenario

Energy efficiency improvement	One-off extra capital cost (£/m²)	% increase on refurb scenario	Marginal cost (£ per $kgCO_2$ / m² pa)	Limitation / discussion / assumptions
Daylight sensing	2.45	8.2%	0.36	Out of hours.
Heating and cooling - variable speed pumps	0.74	4.4%	0.46	Replace during summer/winter accordingly. Assumes domestic hot water provision can be maintained.
0.95 power factor correction	0.41	4.4%	0.52	Out of hours.
Chiller CoP 5.4	4.96	4.4%	0.74	Weekend work as services shut down required and likely road closure for delivery.
T5 lighting – new luminaires	7.44	4.4%	1.38	Out of hours. Replacement over a number of weeks.
95% efficiency boilers	0.94	4.4%	1.87	Replace during summer. Assumes domestic hot water provision can be maintained.
Heat recovery	7.65	4.6%	2.07	Out of hours.
DC drive fan coils	10.39	3.5%	2.23	Out of hours. Replacement over a number of weeks.
Heating controls	1.38	4.4%	2.83	Out of hours. Retrofit during summer.
SFP 2.0W/l/s	10.14	4.4%	6.76	Out of hours.
Movement sensing (PIR)	6.42	5.9%	7.13	Out of hours.
LED lighting	52.07	4.4%	7.55	Out of hours. Replacement over a number of weeks.
Photovoltaics - 100kWp (750m²)	85.41	4.4%	10.29	Install during normal working hours. Connection out of hours.
Photovoltaics - 50kWp (375m²)	44.77	4.4%	10.66	Install during normal working hours. Connection out of hours.
Photovoltaics - 10kWp (75m²)	9.37	4.4%	11.71	Install during normal working hours. Connection out of hours.
Air source heat pump	60.03	0.6%	13.96	Out of hours.
Wind turbine 20kW	17.46	3.3%	17.46	Install during normal working hours. Connection out of hours.
External shading	98.15	0.0%	18.18	Normal hours working.
Solar thermal 50m²	8.95	4.4%	29.85	Install during normal working hours. Connection out of hours.

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Table 5.15: Office 3 energy efficiency improvements – occupied building scenario

Energy efficiency improvement	One-off extra capital cost (£/m²)	% increase on refurb scenario	Marginal cost (£ per kgCO_2 / m² pa)	Limitation / discussion / assumptions
0.95 power factor correction	0.41	4.4%	0.41	Out of hours.
Heating and cooling - variable speed pumps	0.74	4.4%	0.44	Replace during summer/winter accordingly. Assumes domestic hot water provision can be maintained.
Chiller CoP 5.4	6.61	4.4%	0.85	Weekend work as services shut down required and likely road closure for delivery.
T5 lighting - new luminaires	7.44	4.4%	1.14	Out of hours. Replacement over a number of weeks.
DC drive fan coils	8.66	3.5%	1.60	Out of hours. Replacement over a number of weeks.
SFP 2.0W/l/s	4.85	4.4%	1.62	Out of hours.
Daylight sensing	2.45	8.2%	1.89	Out of hours.
95% efficiency boilers	0.81	4.4%	2.03	Replace during summer. Assumes domestic hot water provision can be maintained.
T5 lighting - conversion packs	14.88	4.4%	2.29	Out of hours. Converts existing T12 or T8 fittings to T5 fittings.
External shading	79.44	0.0%	5.30	Normal hours working.
LED lighting	52.07	4.4%	6.13	Out of hours. Replacement over a number of weeks.
Heating controls	1.38	4.4%	7.17	Out of hours. Retrofit during summer.
Wind turbine 20kW	17.46	3.3%	8.73	Install during normal working hours. Connection out of hours.
Photovoltaics - 100kWp (750m²)	85.41	4.4%	10.17	Install during normal working hours. Connection out of hours.
Photovoltaics - 10kWp (75m²)	9.37	4.4%	10.41	Install during normal working hours. Connection out of hours.
Photovoltaics - 50kWp (375m²)	44.77	4.4%	10.66	Install during normal working hours. Connection out of hours.
Heat recovery	7.65	4.6%	10.93	Out of hours.
Movement sensing (PIR)	6.42	5.9%	21.40	Out of hours.
Solar thermal 50m²	8.95	4.4%	29.85	Install during normal working hours. Connection out of hours.
Air source heat pump	51.96	0.9%	43.30	Out of hours.

5. OFFICE RESULTS

Table 5.16: Office 4 energy efficiency improvements – occupied building scenario

Energy efficiency improvement	One-off extra capital cost (£/m²)	% increase on refurb scenario	Marginal cost (£ per $kgCO_2$ / m² pa)	Limitation / discussion / assumptions
Heating and cooling - variable speed pumps	0.74	4.4%	0.46	Replace during summer/winter accordingly. Assumes domestic hot water provision can be maintained.
DC drive fan coils	8.66	3.5%	1.40	Out of hours. Replacement over a number of weeks.
T5 lighting - new luminaires	7.44	4.4%	1.43	Out of hours. Replacement over a number of weeks.
Chiller CoP	4.63	4.4%	2.01	Weekend work as services shut down required and likely road closure for delivery.
Daylight sensing	2.45	8.2%	2.45	Out of hours.
T5 lighting - conversion packs	14.88	4.4%	2.86	Out of hours. Converts existing T12 or T8 fittings to T5 fittings.
95% efficiency boilers	0.79	4.4%	3.96	Replace during summer. Assumes domestic hot water provision can be maintained.
SFP 2.0W/l/s	8.82	4.4%	6.30	Out of hours.
External shading	79.44	0.0%	6.46	Normal working hours.
Heat recovery	7.65	4.6%	7.65	Out of hours.
LED lighting	52.07	4.4%	7.77	Out of hours. Replacement over a number of weeks.
Heating controls	1.38	4.4%	9.11	Out of hours. Retrofit during summer.
Photovoltaics - 100kWp (750m²)	85.41	4.4%	10.29	Install during normal working hours. Connection out of hours.
Photovoltaics - 50kWp (375m²)	44.77	6.9%	10.92	Install during normal working hours. Connection out of hours.
Photovoltaics - 10kWp (75m²)	9.37	4.4%	11.71	Install during normal working hours. Connection out of hours.
Wind turbine 20kW	17.46	3.3%	17.46	Install during normal working hours. Connection out of hours.
Air source heat pump	51.23	0.9%	42.69	Out of hours.
Solar thermal 50m²	8.95	4.4%	44.77	Install during normal working hours. Connection out of hours.
Movement sensing (PIR)	6.42	5.9%	64.21	Out of hours.

6. RETAIL RESULTS

6.1 Introduction

The results of the energy modelling and costing process for the retail building are outlined in this section. The results are presented and discussed as follows:

- Baseline CO_2 emissions and EPC ratings;
- Strategies to improve EPC ratings; and
- Key energy efficiency improvements.

6.2 Baseline EPC rating and CO_2 emissions

The baseline annual CO_2 emissions and EPC rating for the retail building are set out in Table 6.1. The baseline emissions equate to the Building Emissions Rate (BER) as calculated by the SBEM software.

Table 6.1: Baseline emissions for the retail building

Building	Plan depth	Age	Glazing	Annual CO_2 emissions ($kgCO_2/m^2$)	EPC rating	EPC CO_2 index
Air-conditioned						
Retail	Deep	Pre-1995	10%, double	149.0	D	93

The BER excludes small power consumption: IT equipment, photocopiers, task lighting, phone chargers, tea points, etc. Small power is excluded from Part L compliance as it is not a function of the building, being influenced, instead, by the tenant's own occupation and choice of equipment.

Baseline performance for this type and age of retail building achieved a D EPC rating and is typical of the majority of the existing stock. Older buildings with less efficient services and fabric would perform comparatively worse. Lighting is a significant energy consumer in retail buildings and, therefore, poorly performing systems would have a significant impact on the EPC rating.

The services specification can vary between retail buildings so there is no 'developer's specification' such as is the case for office buildings. Types of light fitting and air conditioning system can vary and will subsequently have a marked impact on baseline energy consumption. For example, many retail buildings might feature a variable air volume (VAV) air conditioning system, which is less energy efficient than the fan coil units found in other retail buildings. For the purposes of this study, a retail building with fan coil units was assumed. However, the majority of improvements considered, such as new boilers, chillers and air handling fans, are equally applicable to buildings with VAV systems.

As explained in Section 5, the EPC rating for existing buildings will progressively worsen as Building Regulations are revised in the period leading up to 2018, when proposed minimum energy efficiency standards are to be introduced. Although a D rating would currently avoid being affected by these proposals, the introduction of increased energy efficiency standards under the Building Regulations will almost certainly result in the building described above being rated as F or G and thus affected by the minimum standards. An EPC is valid for 10 years, therefore a currently certified building might be temporarily shielded from the impact of the 2018 standard but any refurbishment work or request from a prospective buyer or tenant for an updated EPC is likely to expose the landlord to the new rules.

6. RETAIL RESULTS

6.3 Refurbishment strategies to improve EPC ratings

6.3.1 'Market standard' refurbishment

As outlined in Section 4.6, refurbishing an existing building to a current 'market standard' will inherently reduce CO_2 emissions and, in turn, improve its EPC rating. Table 6.2 summarises the improvement potential of a 'market standard' refurbishment for the retail building.

Table 6.2: Improvement potential of a 'market standard' retail building refurbishment

	EPC rating & score / CO_2 saving (%)	
	EPC	CO_2
Baseline	D / 93	-
Market refurbishment	C / 71	23%

A 'market standard' refurbishment could improve the EPC rating of the retail building to a C rating and also make a significant cut in CO_2 emissions of almost a quarter.

6.3.2 Enhanced energy efficiency improvements

Table 6.3 identifies the additional cost of specifying enhanced energy efficiency improvements compared to the cost of a market standard refurbishment in order to achieve better EPC ratings for the retail building. The associated cut in CO_2 emissions was also identified and the improvements that needed to be implemented to achieve the savings. All costs and savings shown are cumulative.

All additional costs were expressed as a percentage of the 'market standard' refurbishment cost of the retail building. The refurbishment cost was assumed to be £1,000/sq m (based on second quarter 2012 prices excluding professional fees) and reflected the following scope of works: complete strip-out of the existing building; completely new central plant and services (air conditioning) throughout sales space; new office CAT A fit-out, including toilets; and new lighting in warehouse area.

Unlike the offices, only one improvement strategy was considered for the retail building due to the scope to introduce alternative technologies being less for the retail building. In addition, there is less potential to improve the EPC rating because the 'market standard' refurbishment would bring the building up to a C rating and, thus, achieving an A rating would be very challenging.

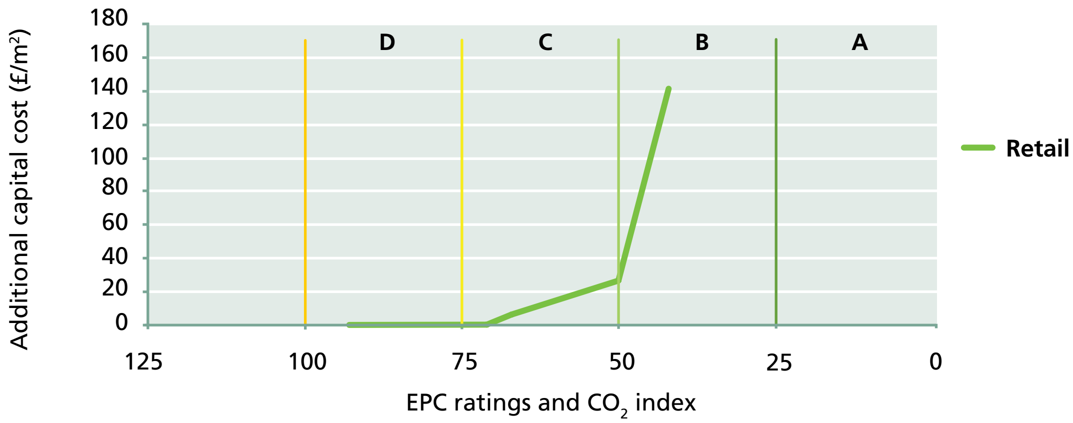
Table 6.3 and Figure 6.1 indicate that a B-rated EPC could be achieved by spending an additional 2.6% over and above the cost of a 'market standard' refurbishment project. This equated to an additional budget of £30/sq m. Further improvements became significantly more expensive and, in practice, it would be difficult to achieve an A rating based on the improvements considered, which included several LZC energy sources.

6. RETAIL RESULTS

Table 6.3: Retail EPC improvement strategy

EPC rating	Additional capital cost (%) / CO_2 saving against baseline (%)		
	Cost	CO_2	Improvements
B	2.6%	45%	Power factor correction Variable speed pumps DC drive fan coils Air tightness Heat recovery Boiler 95% Chiller
A	-	-	-

Figure 6.1: Additional cost to improve retail EPC ratings



6.4 Individual improvements to retail buildings

A range of energy efficiency improvements were analysed for the retail building. Table 6.4 sets out the cost–benefit of implementing each improvement on an individual basis (rather than cumulatively as in Section 6.3) in terms of EPC rating, carbon and energy savings, capital cost, lifecycle costs, CRC savings and available incentives. This data could be used to run investment appraisals, for example, payback periods, net present values, IRRs and yields, as described in Section 4.8.

The coloured rows in the table correspond with the EPC improvements in Table 6.3. Similarly for the offices, the table shows the baseline EPC rating, the improvement that could be achieved through undertaking a 'market standard' refurbishment and subsequent improvements required to achieve better EPC ratings. The non-coloured rows represent those technologies that were analysed in terms of individual cost, CO_2 saving and EPC impact but were not included in the overall improvement strategy. The full results table, stating gas and electricity savings per improvement and tariffs, is included in the Appendix.

6. RETAIL RESULTS

As described, two improvement scenarios were considered and separate tables are provided:

- full refurbishment during a period of vacant possession (Table 6.4); and
- 'one-off' improvements, when the building is wholly or partly occupied (Table 6.5).

Previously, consideration was given to making energy efficiency improvements during a vacant possession refurbishment. There is also potential to make the majority of these improvements whilst the building is fully occupied. This would be important where a planned refurbishment is some years away. The introduction of EPCs has made tenants acutely aware of how buildings perform in terms of their energy performance and may be prevalent during lease negotiations. If the landlord carries out a few 'quick wins' to improve the rating of the building, these could assist in lease renewal negotiations, reduce void periods and potentially affect the rental level achieved.

All capital costs stated in the tables for the enhanced energy efficiency improvements were in addition to the cost of replacing with a standard version of the fitting or item of plant. Under the refurbishment scenario (Table 6.4), the cost of the standard improvement would be part of the refurbishment budget. For the 'one-off' improvements (Table 6.5), it was assumed that the replacement cost would be part of the maintenance and replacement budget for the building.

The cost of carrying out works out of hours during evenings and weekends would be greater if implemented as part of a refurbishment. However, as shown, the premium was typically around 5%, as the extra cost of labour was offset by not incurring main contractor's preliminaries, overheads and profit.

Most improvements considered for the refurbishment scenario were potentially feasible as 'one-off' improvements when the retail building was occupied. However, due to the high hours of use of retail buildings compared to offices, improvements to lighting and fan coil units out of hours are not likely to be feasible without the high risk of disrupting trading activities. It is advisable, therefore, to refrain from undertaking these types of improvements until the next planned refurbishment.

6. RETAIL RESULTS

Table 6.4: Retail energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC Score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$/ m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)	Limitations / discussion / assumptions
-	BASELINE	93 / D	-	-	-	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	71 / C	-	-	-	-	-	-	-	-	-
Power	0.95 power factor correction	70 / C	1.5	0.38	0.25	0.47	0.50	0.02	-	20	Reduces transmission losses from electrical circuits.
Heating/ cooling	Heating and cooling - variable speed pumps	70 / C	1.5	1.07	0.71	0.47	0.50	0.02	-	20	More efficient than fixed speed pumps.
Cooling	DC drive fan coils	67 / C	6.2	5.71	0.92	1.90	2.01	0.07	-	20	Direct current drives allow fan speed to be varied to conserve energy.
Fabric	Air tightness	69 / C	3.7	3.80	1.03	0.59	0.80	0.04	-	30	Reduces heat loss in winter and heat infiltration in summer.
Heating	Heat recovery	68 / C	4.6	6.28	1.36	1.19	1.32	0.06	-	20	Reuses waste heat.
Heating	95% efficiency boilers	71 / C	0.7	0.96	1.37	0.14	0.16	0.01	-	20	Boiler with 90% efficiency part of a market refurbishment.
Cooling	Chiller CoP 5.4	63 / C	4.4	7.47	1.70	4.22	4.48	0.05	-	20	High Coefficient of Performance so less electricity consumed.
Cooling	SFP 2.0W/l/s	69 / C	3.0	6.60	2.20	0.98	25.75	0.04	-	20	SFP measures energy consumed to move one litre of air per second.
Heating	Heating controls	71 / C	0.4	1.59	3.97	0.08	0.09	0.005	-	20	Local temperature and time controls.
Lighting	T5 lighting - conversion packs	70 / C	1.3	5.78	4.44	0.31	0.09	0.02	-	20	Conversion packs allow existing fittings to be retained.
Lighting	T5 lighting - new luminaires	70 / C	1.3	7.11	5.47	0.31	0.09	0.02	-	20	Wide variance in quality and cost of T5 light fittings. Assumed replacement fitting maintains light quality.

6. RETAIL RESULTS

Table 6.4 Cont'd. : Retail energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC Score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)	Limitations / discussion / assumptions
LZC	Wind turbine 20kW	70 / C	1.8	16.27	9.04	0.70	0.63	-	0.38	20	Very site specific. Typically suits out of town locations.
LZC	Photovoltaics - 100kWp (750m²)	66 / C	7.9	78.73	9.97	3.62	3.73	-	1.51	25	Produces electricity. Uncertainty surrounding future FiT.
LZC	Photovoltaics - 50kWp (375m²)	69 / C	3.9	40.19	10.31	1.95	2.00	-	0.89	25	Produces electricity. Uncertainty surrounding future FiT.
LZC	Photovoltaics - 10kWp (75m²)	71 / C	0.8	8.64	10.79	0.40	0.41	-	0.20	25	Produces electricity. Uncertainty surrounding future FiT.
LZC	Air source heat pump	68 / C	2.9	33.26	11.54	-0.25	0.04	0.03	-	20	Provides heating and cooling.
Lighting	Movement sensing (PIR)	71 / C	0.3	5.47	18.24	0.10	-0.11	0.004	-	10	Turns off lighting when there are no occupants in a space.
LZC	Solar thermal 50m²	71 / C	0.4	8.25	20.64	0.17	0.19	-	0.17	25	Produces hot water.
Fabric	Fabric improvements	71 / C	0.4	15.54	38.84	0.10	-0.24	0.005	-	30	Addition of internal wall insulation.

6. RETAIL RESULTS

Table 6.5: Retail energy efficiency improvements – occupied building scenario

Energy efficiency improvement	One-off extra capital cost (£/m²)	% increase on refurb scenario	Marginal cost (£ per $kgCO_2$ / m² pa)	Limitation / discussion / assumptions
0.95 power factor correction	0.40	4.4%	0.27	Out of hours.
Heating and cooling - variable speed pumps	1.12	4.4%	0.74	Replace during summer/winter accordingly. Assumes domestic hot water provision can be maintained.
Air tightness	3.99	4.8%	1.03	Out of hours.
DC drive fan coils	5.98	4.4%	1.10	Out of hours. Replacement over a number of weeks.
95% efficiency boilers	1.00	4.4%	1.43	Replace during summer. Assumes domestic hot water provision can be maintained.
Heat recovery	6.64	5.5%	1.44	Out of hours.
Chiller CoP 5.4	7.81	4.4%	1.78	Weekend work as services shut down required and likely road closure for delivery.
SFP 2.0W/l/s	6.91	4.4%	2.30	Out of hours.
Heating - controls	1.66	4.4%	4.15	Out of hours. Retrofit during summer.
T5 lighting - conversion packs	6.04	4.4%	4.65	Out of hours. Converts existing T12 or T8 fittings to T5 fittings.
T5 lighting - new luminaires	7.44	4.4%	5.72	Out of hours. Replacement over a number of weeks.
Movement sensing (PIR)	5.82	6.1%	8.32	Out of hours.
Wind turbine 20kW	16.83	3.3%	9.35	Install during normal working hours. Connection out of hours.
Photovoltaics - 100kWp (750m²)	82.36	4.4%	10.43	Install during normal working hours. Connection out of hours.
Photovoltaics - 50kWp (375m²)	43.17	6.9%	11.07	Install during normal working hours. Connection out of hours.
Photovoltaics - 10kWp (75m²)	9.03	4.4%	11.29	Install during normal working hours. Connection out of hours.
Air source heat pump	33.42	0.5%	11.53	Out of hours.
Solar thermal 50m²	8.63	4.4%	21.59	Install during normal working hours. Connection out of hours.
Fabric improvements	16.31	4.8%	38.84	Out of hours.

7. INDUSTRIAL/WAREHOUSE RESULTS

7.1 Introduction

The results of the energy modelling and costing process for the industrial/warehouse building are outlined in this section. The results are presented and reviewed as follows:

- Baseline CO_2 emissions and EPC ratings;
- Strategies to improve EPC ratings; and
- Key energy efficiency improvements.

7.2 Baseline EPC rating and CO_2 emissions

The baseline annual CO_2 emissions and EPC rating for the industrial/warehouse building are set out in Table 7.1. The baseline emissions equate to the Building Emissions Rate (BER) as calculated by the SBEM software.

Table 7.1: Baseline emissions for the industrial/warehouse building

Building	Plan depth	Age	Glazing	Annual CO_2 emissions ($kgCO_2/m^2$)	EPC rating	EPC CO_2 index
Heating only						
Industrial / warehouse	Deep	Pre-1995	10% single	107.4	F	128

The BER excludes small power consumption: IT equipment, photocopiers, task lighting, phone chargers, tea points etc. Small power is excluded from Part L compliance as it is not a function of the building, being influenced, instead, by the tenant's own occupation and choice of equipment.

Baseline performance for this building was worse when compared to the existing stock according to SBEM and EPC benchmarks. Lighting is a significant energy consumer in industrial/warehouse buildings therefore poor performing systems would have a significant impact on the EPC rating.

As considered previously, the EPC rating for existing buildings will worsen progressively as Building Regulations are revised in the period leading up to 2018, when proposed minimum energy efficiency standards are to be introduced. The introduction of increased energy efficiency standards under the the Building Regulations will result in the industrial/warehouse building being rated as a G by 2018 and, thus, affected by the minimum standards. An EPC is valid for 10 years and, therefore, the impact of the 2018 standard could be delayed but any refurbishment work or request from a prospective buyer or tenant for an updated EPC might expose the landlord to the new rules.

7.3 Refurbishment strategies to improve EPC rating

7.3.1 'Market standard' refurbishment

Refurbishing an existing building to a current 'market standard' will inherently reduce CO_2 emissions and, in turn, improve its EPC rating. Table 7.2 summarises the improvement potential of a 'market standard' refurbishment for the industrial/warehouse building.

7. INDUSTRIAL/WAREHOUSE RESULTS

Table 7.2: Improvement potential of a 'market standard' industrial/warehouse refurbishment

	EPC rating & score / CO_2 saving (%)	
	EPC	**CO_2**
Baseline	F / 128	-
Market refurbishment	B / 44	66%

The EPC rating could be significantly improved and a two-thirds cut in CO_2 emissions achieved if a 'market standard' refurbishment was undertaken. New lighting accounts for a significant proportion of the CO_2 reduction and therefore represents a 'quick win' for any industrial or warehouse building. In this example, electricity used for lighting was cut by 75%, which contributed to the substantial reduction in CO_2 overall.

7.3.2 Enhanced energy efficiency improvements

Table 7.3 identifies the additional cost of specifying enhanced energy efficiency improvements compared to the cost of a 'market standard' refurbishment to achieve an A-rated EPC for the industrial/warehouse building. The associated cut in CO_2 emissions was also identified, together with the improvements that needed to be implemented to achieve the savings. All costs and savings shown are cumulative.

All additional costs are expressed as a percentage of the 'market standard' refurbishment cost. The refurbishment cost was assumed to be £600/sq m (based on second quarter 2012 prices excluding professional fees) and reflected the following scope of works: complete strip-out of the existing building; completely new central plant and services (lighting and heating) throughout the office and warehouse space; and new office CAT A fit-out, including toilets.

Only one improvement strategy was considered for the industrial/warehouse building in order to improve the EPC rating to an A. To achieve this target, all possible improvements needed to be considered, including LZC technologies, hence there was limited potential to achieve an A rating through an alternative strategy.

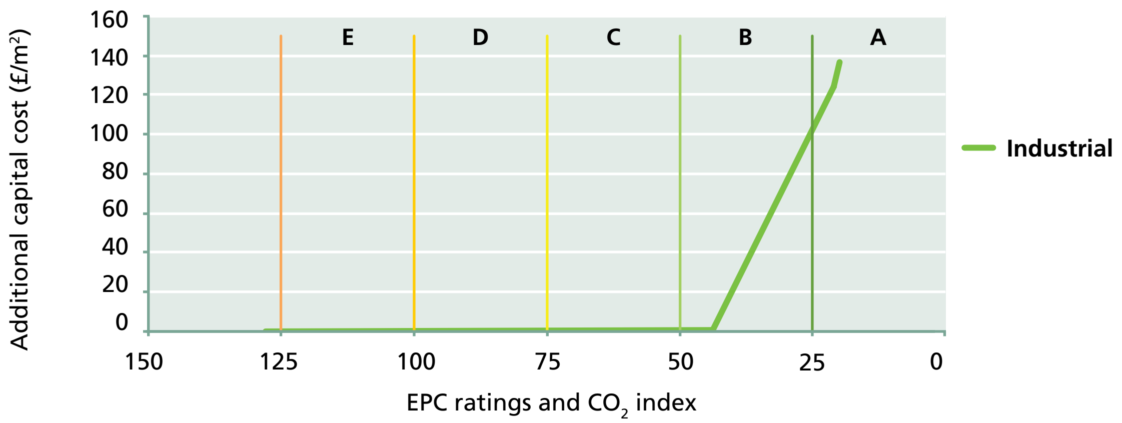
Table 7.3 and Figure 7.1 indicate that an A-rated EPC could be achieved by spending an additional 20% over and above the cost of a 'market standard' refurbishment. This equated to an additional budget of £120/sq m, which would be a significant increase to the base refurbishment cost and not feasible in most cases. A large photovoltaic array and a wind turbine would also be needed to achieve an A rating, which will not be feasible for some buildings.

7. INDUSTRIAL/WAREHOUSE RESULTS

Table 7.3: Industrial/warehouse: EPC improvement strategy

EPC rating	Additional capital cost (%) / CO_2 saving against baseline (%)		
	Cost	CO_2	Improvements
A	20.7%	84%	Power factor correction Variable speed pumps Boiler 95% External wall insulation Heat control Warm air blowers Wind turbine (20kWp) Photovoltaics (750m²)

Figure 7.1: Additional cost to improve industrial/warehouse EPC ratings



7.4 Individual improvements to industrial/warehouse buildings

A range of energy efficiency improvements was analysed for the industrial/warehouse building. Table 7.4 sets out the costs and benefits of implementing each improvement on an individual basis (rather than cumulatively as in Section 7.3) in terms of EPC rating, carbon and energy savings, capital cost, lifecycle costs, CRC savings and available incentives. This data could be used to run investment appraisal based on, for example, payback periods, net present values, IRRs and yields.

The coloured rows in the table correspond to the EPC improvements above baseline EPC rating (F), the improvement that could be achieved through undertaking a 'market standard' refurbishment (B) and subsequent improvements required to achieve an A rating. The non-coloured rows represent those technologies that were analysed in terms of individual cost, CO_2 saving and EPC impact but were not included in the overall improvement strategy. The full results table, stating gas and electricity savings per improvement and tariffs, is included in the Appendix.

7. INDUSTRIAL/WAREHOUSE RESULTS

As described, two improvement scenarios were considered and separate tables are provided:

- full refurbishment during a period of vacant possession (Table 7.4); and
- 'one-off' improvements when the building is wholly or partly occupied (Table 7.5).

Previously, consideration was given to making energy efficiency improvements during a vacant possession refurbishment. There is also potential to make the majority of these improvements whilst the building is fully occupied. This would be important where a planned refurbishment is some years away. The introduction of EPCs has made tenants acutely aware of how buildings perform in terms of their energy performance and may be prevalent during lease negotiations. If the landlord carries out a few 'quick wins' to improve the rating of the building it could assist in lease renewal negotiations, reduce void periods and potentially affect the rental level achieved.

All capital costs stated in the tables for the enhanced energy efficiency improvements were in addition to the cost of replacing with a standard version of the fitting or item of plant. Under the refurbishment scenario (Table 7.4), the cost of the standard improvement will be part of the refurbishment budget. For the 'one-off' improvements (Table 7.5), it was assumed that the replacement cost would be part of the maintenance and replacement budget for the building.

The cost of carrying out works out of hours during evenings and weekends would be greater if implemented as part of a refurbishment. However, as shown, the premium was typically around 5% because the extra cost of labour was offset by not incurring main contractor's preliminaries, overheads and profit.

Most improvements considered for the refurbishment scenario are potentially feasible as 'one-offs' when the industrial/warehouse building is occupied. However, replacing the full lighting system would take more time to complete if carried out at weekends.

7. INDUSTRIAL/WAREHOUSE RESULTS

Table 7.4: Industrial/warehouse energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC Score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)	Limitations / discussion / assumptions
-	BASELINE	128 / F	-	-	-	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	44 / B	-	-	-	-	-	-	-	-	-
Power	0.95 power factor correction	43 / B	0.4	0.42	1.05	0.12	0.12	0.005	-	20	Reduces transmission losses from electrical circuits.
Heating	Heating - variable speed pumps	43 / B	0.1	0.11	1.12	0.01	0.02	0.001	-	20	More efficient than fixed speed pumps.
Heating	95% efficiency boilers	43 / B	0.4	0.79	1.99	0.08	0.10	0.005	-	20	Boiler with 90% efficiency part of a market refurbishment.
Fabric	Fabric improvements	36 / B	6.5	18.04	2.78	1.31	1.63	0.08	-	30	External wall insulation.
Heating	Heating controls	43 / B	0.3	1.12	3.72	0.04	0.07	0.004	-	20	Local temperature and time controls.
Heating	Warm air blowers	43 / B	0.9	6.27	6.97	0.17	0.21	0.011	-	20	High efficiency warm air blowers
LZC	Wind turbine 20kW	41 / B	2.0	17.87	8.93	0.77	0.69	-	0.42	20	Very site specific. Typically suits out of town locations.
LZC	Photovoltaics - 100kWp (750m²)	33 / B	8.8	86.45	9.82	3.98	4.14	-	1.69	25	Produces electricity. Uncertainty surrounding future FiT.
Lighting	T5 lighting - conversion packs	43 / B	0.7	5.44	7.77	0.22	0.23	0.01	-	20	Conversion packs allow existing fittings to be retained.
LZC	Photovoltaics - 50kWp (375m²)	38 / B	4.4	44.13	10.03	2.14	2.22	-	1.00	25	Produces electricity. Uncertainty surrounding future FiT.
Lighting	T5 lighting - new luminaires	43 / B	0.7	7.11	10.16	0.22	0.23	0.01	-	20	Wide variance in quality and cost of T5 light fittings. Assumed replacement fitting maintains light quality.

7. INDUSTRIAL/WAREHOUSE RESULTS

Table 7.4 Cont'd. : Industrial/warehouse energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC Score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)	Limitations / discussion / assumptions
LZC	Photovoltaics - 10kWp (75m²)	42 / B	0.9	9.48	10.54	0.44	0.46	-	0.22	25	Produces electricity. Uncertainty surrounding future FiT.
Fabric	Air tightness	43 / B	0.2	2.37	11.86	0.05	0.06	0.002	-	30	Reduces heat loss in winter and heat infiltration in summer.
Lighting	Movement sensing (PIR)	43 / B	0.2	3.22	16.10	0.07	0.07	0.002	-	10	Turns off lighting when there are no occupants in a space.

7. INDUSTRIAL/WAREHOUSE RESULTS

Table 7.5: Industrial/warehouse energy efficiency improvements – occupied building scenario

Energy efficiency improvement	One-off extra capital cost (£/m²)	% increase on refurb scenario	Marginal cost (£ per $kgCO_2$ / m² pa)	Limitation / discussion / assumptions
0.95 power factor correction	0.44	4.4%	1.09	Out of hours.
Heating - variable speed pumps	0.12	4.4%	1.17	Out of hours. Retrofit during summer.
95% efficiency boilers	0.83	4.4%	2.08	Replace during summer. Assumes domestic hot water provision can be maintained.
Fabric improvements	18.94	4.8%	2.78	Out of hours.
Heating - controls	1.17	4.4%	3.89	Out of hours.
Warm air blowers	6.56	4.4%	7.29	Out of hours. Replace during summer.
T5 lighting - conversion packs	5.44	0.0%	7.77	Out of hours. Converts existing T12 or T8 fittings to T5 fittings.
Wind turbine 20kW	18.48	3.3%	9.24	Install during normal working hours. Connection out of hours.
Photovoltaics - 100kWp (750m²)	90.44	4.4%	10.28	Install during normal working hours. Connection out of hours.
T5 lighting - new luminaires	7.44	4.4%	10.63	Out of hours. Replacement over a number of weeks.
Photovoltaics - 50kWp (375m²)	47.41	6.9%	10.77	Install during normal working hours. Connection out of hours.
Photovoltaics - 10kWp (75m²)	9.92	4.4%	11.02	Install during normal working hours. Connection out of hours.
Air tightness	2.49	4.8%	11.86	Out of hours.
Movement sensing (PIR)	3.42	5.8%	17.10	Out of hours.

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Appendix Table 1: Office 1 energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$ / m² pa)	Gas saving pa (kWh/m²)	Electricity saving pa (kWh/m²)	DECC 'central' av. gas price (£/kWh)
-	BASELINE	120 / E	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	91 / D	15.20	-	-	-	-	-
Lighting	T5 lighting	84 / D	3.50	7.11	2.03	-8.38	10.04	0.039
Lighting	LED lighting	82 / D	4.60	49.78	10.82	-10.98	13.08	0.038
Lighting	Daylight sensing	83 / D	3.90	3.38	0.87	-3.39	8.81	0.038
Lighting	Movement sensing (PIR)	90 / D	0.50	6.04	12.09	-1.58	1.65	0.038
Heating	95% efficiency boilers	87 / D	1.70	1.12	0.66	8.80	0.00	0.039
Heating	Heating controls	88 / D	1.60	3.09	1.93	8.31	0.00	0.039
Power	0.95 power factor correction	90 / D	0.20	0.40	1.98	0.00	0.41	0.039
Heating	Variable speed pumps	90 / D	0.20	0.26	1.32	0.00	0.35	0.039
Fabric	Air tightness	86 / D	2.30	2.43	1.05	11.61	0.00	0.040
Fabric	Replace single glazed windows with double glazed	64 / C	13.80	177.41	12.86	69.93	0.00	0.040
LZC	Photovoltaics - 10kWp (75m²)	89 / D	0.80	8.95	11.19	0.00	1.58	0.039
LZC	Photovoltaics - 50kWp (375m²)	83 / D	4.20	42.80	10.19	0.00	7.90	0.039
LZC	Photovoltaics - 100kWp (750m²)	75 / D	8.30	81.65	9.84	0.00	15.80	0.039
LZC	Wind turbine 20kW	89 / D	1.00	16.88	16.88	0.00	1.93	0.039
LZC	Solar thermal 50m²	90 / D	0.30	8.56	28.53	1.86	0.00	0.039
LZC	Air source heat pump	76 / D	7.70	74.56	9.68	126.90	-33.66	0.039

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DECC 'central' av. electricity price (£/kWh)	DECC 'high' av. gas price (£/kWh)	DECC 'high' av. electricity price (£/kWh)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.158	0.047	0.173	1.24	1.32	0.04	-	20
0.152	0.046	0.161	1.64	1.68	0.06	-	15
0.144	0.044	0.152	1.14	1.19	0.05	-	10
0.144	0.044	0.152	0.17	0.18	0.01	-	10
0.158	0.047	0.173	0.34	0.42	0.02	-	20
0.158	0.047	0.173	0.32	0.39	0.02	-	20
0.158	0.047	0.173	0.06	0.07	0.002	-	20
0.158	0.047	0.173	0.05	0.06	0.002		20
0.169	0.049	0.179	0.46	0.57	0.028		30
0.169	0.049	0.179	2.74	3.40	0.17	-	30
0.164	0.048	0.173	0.42	0.43	-	0.21	25
0.164	0.048	0.173	2.01	2.09	-	0.94	25
0.164	0.048	0.173	3.76	3.91	-	1.60	25
0.158	0.047	0.173	0.73	0.67	-	0.41	20
0.164	0.048	0.173	0.19	0.21	-	0.16	25
0.158	0.047	0.173	-0.50	0.07	-	-	20

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Appendix Table 2: Office 2 energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$ / m² pa)	Gas saving pa (kWh/m²)	Electricity saving pa (kWh/m²)	DECC 'central' av. gas price (£/kWh)
-	BASELINE	164 / G	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	138 / F	13.6	-	-	-	-	-
Lighting	T5 lighting	127 / F	5.4	7.11	1.32	-5.15	12.38	0.039
Lighting	LED lighting	124 / E	6.9	49.78	7.21	-6.81	16.05	0.038
Lighting	Daylight sensing	125 / E	6.8	2.25	0.33	-2.97	14.34	0.038
Lighting	Movement sensing (PIR)	136 / F	0.9	6.04	6.72	-0.86	2.04	0.038
Heating	95% efficiency boilers	137 / F	0.5	0.90	1.79	2.51	0.00	0.039
Heating	Heating controls	137 / F	0.5	1.32	2.71	2.50	0.00	0.039
Heating/ cooling	Heating and cooling - variable speed pumps	135 / F	1.6	0.71	0.44	0.00	3.16	0.039
Heating	Heat recovery	130 / F	3.7	7.30	1.97	12.12	2.6	0.039
Power	0.95 power factor correction	136 / F	0.8	0.40	0.49	0.00	1.61	0.039
Cooling	Chiller CoP 5.4	125 / E	6.7	4.74	0.71	0.00	13.01	0.039
Cooling	DC drive fan coils	129 / F	4.7	10.03	2.16	0.00	9	0.039
Cooling	Chilled beams - active	116 / E	11.0	160.79	14.62	-2.61	22.33	0.039
Cooling	Chilled beams - passive	100 / D	19.7	183.55	9.32	-1.5	38.64	0.039
Cooling	SFP 2.0W/l/s	135 / F	1.5	9.69	6.46	-1.45	3.46	0.039
Fabric	Upgrades to air tightness	134 / F	1.7	2.50	1.47	7.19	0.52	0.039
Fabric	External shading	127 / F	5.4	98.15	18.18	-12.71	15.27	0.040
LZC	Photovoltaics - 10kWp (75m²)	136 / F	0.8	8.95	11.19	0.00	1.58	0.039
LZC	Photovoltaics - 50kWp (375m²)	130 / F	4.2	42.80	10.19	0.00	7.9	0.039
LZC	Photovoltaics - 100kWp (750m²)	122 / E	8.3	81.65	9.84	0.00	15.8	0.039
LZC	Wind turbine 20kW	136 / F	1.0	16.88	16.88	0.00	1.93	0.039
LZC	Solar thermal 50m²	137 / F	0.3	8.56	28.53	1.55	0.00	0.039
LZC	Air source heat pump	130 / F	4.3	59.67	13.88	71.91	-19.1	0.039

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DECC 'central' av. electricity price (£/kWh)	DECC 'high' av. gas price (£/kWh)	DECC 'high' av. electricity price (£/kWh)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.158	0.052	0.187	1.74	2.03	0.06	-	20
0.152	0.046	0.161	2.03	2.35	0.08	-	15
0.144	0.044	0.152	1.95	2.05	0.08	-	10
0.144	0.044	0.152	0.26	0.27	0.01	-	10
0.158	0.052	0.187	0.10	0.13	0.01	-	20
0.158	0.052	0.187	0.09	0.13	0.01	-	20
0.158	0.052	0.187	0.49	0.58	0.02	-	20
0.158	0.052	0.187	0.88	1.12	0.04	-	20
0.158	0.052	0.187	0.25	0.30	0.01	-	20
0.158	0.052	0.187	2.06	2.43	0.08	-	20
0.158	0.052	0.187	1.42	1.68	0.06	-	20
0.158	0.052	0.187	3.75	4.36	0.13	-	20
0.158	0.052	0.187	6.55	7.66	0.24	-	20
0.158	0.052	0.187	0.48	0.56	0.02	-	20
0.158	0.052	0.187	0.36	0.47	0.02	-	20
0.169	0.049	0.179	2.07	2.11	0.06	-	30
0.164	0.048	0.173	0.42	0.43	-	0.21	25
0.164	0.048	0.173	2.01	2.09	-	0.94	25
0.164	0.048	0.173	3.76	3.91	-	1.60	25
0.158	0.048	0.173	0.73	0.67	-	0.41	20
0.164	0.048	0.173	0.16	0.17	-	0.13	25
0.158	0.048	0.173	-0.33	0.08	-	-	20

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Appendix Table 3: Office 3 energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$ / m² pa)	Gas saving pa (kWh/m²)	Electricity saving pa (kWh/m²)	DECC 'central' av. gas price (£/kWh)
-	BASELINE	143 / F	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	132 / F	-	-	-	-	-	-
Lighting	T5 lighting - new luminaires	119 / E	6.5	7.11	1.09	-1.36	13.06	0.039
Lighting	T5 lighting - conversion packs	119 / E	6.5	14.22	2.19	-1.36	13.06	0.039
Lighting	LED lighting	116 / E	8.5	49.78	5.86	-1.75	16.99	0.038
Lighting	Daylight sensing	129 / F	1.3	2.25	1.73	-0.18	2.58	0.038
Lighting	Movement sensing (PIR)	131 / F	0.3	6.04	20.15	-0.07	0.63	0.038
Heating	95% efficiency boilers	131 / F	0.4	0.78	1.94	1.47	0.00	0.039
Heating	Heating controls	131 / F	0.2	1.32	6.85	0.99	0.00	0.039
Heating/ cooling	Heating and cooling - variable speed pumps	129 / F	1.7	0.71	0.42	0.00	3.15	0.039
Heating	Heat recovery	131 / F	0.7	7.30	10.43	0.00	1.33	0.039
Power	0.95 power factor correction	130 / F	1.0	0.40	0.40	0.00	1.82	0.039
Cooling	Chiller CoP 5.4	117 / E	7.8	6.32	0.81	0.00	15.02	0.039
Cooling	DC drive fan coils	122 / E	5.4	8.36	1.54	0.00	10.5	0.039
Cooling	Chilled beams - active	108 / E	12.3	167.18	13.59	-2.01	24.4	0.039
Cooling	Chilled beams - passive	86 / D	24.1	189.94	7.88	-1.36	47.08	0.039
Cooling	SFP 2.0W/l/s	126 / F	3.0	4.64	1.55	-1.5	16.33	0.039
Fabric	External shading	103 / E	15.0	79.44	5.30	-6.63	31.57	0.040
LZC	Photovoltaics - 10kWp (75m²)	130 / F	0.8	8.95	11.19	0.00	1.58	0.039
LZC	Photovoltaics - 50kWp (375m²)	124 / E	4.2	42.80	10.19	0.00	7.9	0.039
LZC	Photovoltaics - 100kWp (750m²)	116 / E	8.3	81.65	9.84	0.00	15.8	0.039
LZC	Wind turbine 20kW	128 / F	2.0	16.88	8.44	0.00	1.93	0.039
LZC	Solar thermal 50m²	131 / F	0.3	8.56	28.53	1.53	0.00	0.039
LZC	Air source heat pump	129 / F	1.2	51.49	42.91	23.38	-6.65	0.039

APPENDIX

DECC 'central' av. electricity price (£/kWh)	DECC 'high' av. gas price (£/kWh)	DECC 'high' av. electricity price (£/kWh)	DECC 'central' av. Net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO$_2$ (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.158	0.047	0.168	1.99	2.11	0.08	-	20
0.158	0.047	0.168	1.99	2.11	0.08	-	20
0.152	0.046	0.161	2.25	2.73	0.10	-	15
0.144	0.044	0.152	0.36	0.38	0.02	-	10
0.144	0.044	0.152	0.08	0.09	0.004	-	10
0.158	0.047	0.168	0.06	0.07	0.005	-	20
0.158	0.047	0.168	0.03	0.04	0.002	-	20
0.158	0.047	0.168	0.48	0.51	0.02	-	20
0.158	0.047	0.168	0.88	0.22	0.01	-	20
0.158	0.047	0.168	0.29	0.31	0.01	-	20
0.158	0.047	0.168	2.37	2.52	0.09	-	20
0.158	0.047	0.168	1.66	1.76	0.07	-	20
0.158	0.047	0.168	4.10	4.32	0.15	-	20
0.158	0.047	0.168	7.89	8.34	0.29	-	20
0.158	0.047	0.168	2.51	2.66	0.04	-	20
0.169	0.049	0.179	5.06	5.32	0.18	-	30
0.164	0.048	0.173	0.42	0.43	-	0.21	25
0.164	0.048	0.173	2.01	2.09	-	0.94	25
0.164	0.048	0.173	3.76	3.91	-	1.60	25
0.158	0.047	0.168	0.73	0.66	-	0.41	20
0.164	0.048	0.173	0.16	0.17	-	0.13	25
0.158	0.047	0.168	-0.24	-0.11	-	-	20

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Appendix Table 4: Office 4 energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$ / m² pa)	Gas saving pa (kWh/m²)	Electricity saving pa (kWh/m²)	DECC 'central' av. gas price (£/kWh)
-	BASELINE	113 / E	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	113 / E	-	-	-	-	-	-
Lighting	T5 lighting - new luminaires	103 / E	5.2	7.11	1.37	-0.95	10.43	0.039
Lighting	T5 lighting - conversion packs	103 / E	5.2	14.22	2.74	-0.95	10.43	0.039
Lighting	LED lighting	100 / D	6.7	49.78	7.43	-1.27	13.88	0.038
Lighting	Daylight sensing	111 / E	1.0	2.25	2.25	-0.11	2.11	0.038
Lighting	Movement sensing (PIR)	113 / E	0.1	6.04	60.45	-0.02	0.27	0.038
Heating	95% efficiency boilers	112 / E	0.2	0.76	3.79	1.10	0.00	0.039
Heating	Heating controls	112 / E	0.2	1.32	8.70	0.78	0.00	0.039
Heating/ cooling	Heating and cooling - variable speed pumps	110 / E	1.6	0.71	0.44	0.00	3.10	0.039
Heating	Heat recovery	111 / E	1.0	7.30	7.30	2.00	1.26	0.039
Cooling	Chiller CoP 5.4	108 / E	2.3	4.42	1.92	0.00	4.50	0.039
Cooling	DC drive fan coils	101 / E	6.2	8.36	1.35	0.00	12.00	0.039
Cooling	Chilled beams - active	89 / D	12.5	167.18	13.37	-1.20	24.68	0.039
Cooling	Chilled beams - passive	70 / C	22.2	189.94	8.56	-0.71	43.37	0.039
Cooling	SFP 2.0W/l/s	110 / E	1.4	8.43	6.02	-0.63	3.07	0.039
Fabric	External shading	89 / D	12.3	79.44	6.46	-6.44	26.37	0.040
LZC	Photovoltaics - 10kWp (75m²)	111 / E	0.8	8.95	11.19	0.00	1.58	0.039
LZC	Photovoltaics - 50kWp (375m²)	105 / E	4.1	41.68	10.17	0.00	7.90	0.039
LZC	Photovoltaics - 100kWp (750m²)	97 / D	8.3	81.65	9.84	0.00	15.80	0.039
LZC	Wind turbine 20kW	111 / E	1.0	16.88	16.88	0.00	1.93	0.039
LZC	Solar thermal 50m²	112 / E	0.2	8.56	42.80	1.53	0.00	0.039
LZC	Air source heat pump	110 / E	1.2	50.77	42.31	19.84	-5.26	0.039

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DECC 'central' av. electricity price (£/kWh)	DECC 'high' av. gas price (£/kWh)	DECC 'high' av. electricity price (£/kWh)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.158	0.047	0.168	1.59	1.69	0.06	-	20
0.158	0.047	0.168	1.60	1.69	0.06	-	20
0.152	0.046	0.161	1.96	2.25	0.08	-	15
0.144	0.044	0.152	0.29	0.31	0.01	-	10
0.144	0.044	0.152	0.03	0.03	0.001	-	10
0.158	0.047	0.168	0.04	0.05	0.002	-	20
0.158	0.047	0.168	0.03	0.03	0.002	-	20
0.158	0.047	0.168	0.48	0.51	0.02	-	20
0.158	0.047	0.168	0.28	0.31	0.01	-	20
0.158	0.047	0.168	0.71	0.76	0.03	-	20
0.158	0.047	0.168	1.90	2.01	0.07	-	20
0.158	0.047	0.168	4.17	4.40	0.15	-	20
0.158	0.047	0.168	7.33	7.75	0.27	-	20
0.158	0.047	0.168	0.45	0.47	0.02	-	20
0.169	0.049	0.169	4.19	4.13	0.15	-	30
0.164	0.048	0.173	0.42	0.43	-	0.21	25
0.164	0.048	0.173	2.02	2.10	-	0.94	25
0.164	0.048	0.173	3.76	3.91	-	1.60	25
0.158	0.047	0.168	0.73	0.66	-	0.41	20
0.164	0.048	0.173	0.16	0.17	-	0.13	25
0.158	0.047	0.168	-0.16	-0.04	-	-	20

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Appendix Table 5: Retail energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$ / m² pa)	Gas saving pa (kWh/m²)	Electricity saving pa (kWh/m²)	DECC 'central' av. gas price (£/kWh)
-	BASELINE	93 / D	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	71 / C	-	-	-	-	-	-
Lighting	T5 lighting - new luminaires	70 / C	1.3	7.11	5.47	0.62	0.43	0.039
Lighting	T5 lighting - conversion packs	70 / C	1.3	5.78	4.44	0.62	0.43	0.039
Lighting	Movement sensing (PIR)	71 / C	0.3	5.47	18.24	0.69	-0.91	0.038
Heating	95% efficiency boilers	71 / C	0.7	0.96	1.37	3.49	0.00	0.039
Heating/ cooling	Heating and cooling - variable speed pumps	70 / C	1.5	1.07	0.71	0.00	3.03	0.039
Heating	Heat recovery	68 / C	4.6	6.28	1.36	9.94	5.09	0.039
Heating	Heating controls	71 / C	0.4	1.59	3.97	2.06	0.00	0.039
Power	0.95 power factor correction	70 / C	1.5	0.38	0.25	0.00	2.95	0.039
Cooling	Chiller CoP 5.4	63 / C	4.4	7.47	1.70	0.00	26.72	0.039
Cooling	DC drive fan coils	67 / C	6.2	5.71	0.92	0.00	12.00	0.039
Cooling	SFP 2.0W/l/s	69 / C	3.0	6.60	2.20	0.42	153.42	0.039
Fabric	Air tightness	69 / C	3.7	3.80	1.03	24.77	-2.33	0.040
Fabric	Fabric improvements	71 / C	0.4	15.54	38.84	1.19	-1.69	0.040
LZC	Photovoltaics - 10kWp (75m²)	71 / C	0.8	8.64	10.79	0.00	1.50	0.039
LZC	Photovoltaics - 50kWp (375m²)	69 / C	3.9	40.19	10.31	0.00	7.48	0.039
LZC	Photovoltaics - 100kWp (750m²)	66 / C	7.9	78.73	9.97	0.00	14.97	0.039
LZC	Wind turbine 20kW	70 / C	1.8	16.27	9.04	0.00	1.83	0.039
LZC	Solar thermal 50m²	71 / C	0.4	8.25	20.64	2.02	0.00	0.039
LZC	Air source heat pump	68 / C	2.9	33.26	11.54	49.86	-13.23	0.039

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DECC 'central' av. electricity price (£/kWh)	DECC 'high' av. gas price (£/kWh)	DECC 'high' av. electricity price (£/kWh)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO$_2$ (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.158	0.047	0.168	0.31	0.09	0.02	-	20
0.158	0.047	0.168	0.31	0.09	0.02	-	20
0.144	0.044	0.152	0.10	-0.11	0.004	-	10
0.158	0.047	0.168	0.14	0.16	0.01	-	20
0.158	0.047	0.168	0.47	0.50	0.02	-	20
0.158	0.047	0.168	1.19	1.32	0.06	-	20
0.158	0.047	0.168	0.08	0.09	0.005	-	20
0.158	0.047	0.168	0.47	0.50	0.02	-	20
0.158	0.047	0.168	4.22	4.48	0.05	-	20
0.158	0.047	0.168	1.90	2.01	0.07	-	20
0.158	0.047	0.168	0.98	25.75	0.04	-	20
0.169	0.049	0.179	0.59	0.80	0.04	-	30
0.169	0.049	0.179	0.10	-0.24	0.005	-	30
0.164	0.048	0.173	0.40	0.41	-	0.20	25
0.164	0.048	0.173	1.95	2.00	-	0.89	25
0.164	0.048	0.173	3.62	3.73	-	1.51	25
0.158	0.047	0.168	0.70	0.63	-	0.38	20
0.164	0.048	0.173	0.17	0.19	-	0.17	25
0.158	0.047	0.168	-0.25	0.04	0.03	-	20

APPENDIX

Appendix Table 6: Industrial/warehouse energy efficiency improvements - refurbishment scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Extra capital cost (£/m²)	Marginal cost (£ per $kgCO_2$ / m² pa)	Gas saving pa (kWh/m²)	Electricity saving pa (kWh/m²)	DECC 'central' av. gas price (£/kWh)
-	BASELINE	128 / F	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	44 / B	-	-	-	-	-	-
Lighting	T5 lighting - new luminaires	43 / B	0.7	7.11	10.16	-0.21	1.48	0.039
Lighting	T5 lighting - conversion packs	43 / B	0.7	5.44	7.77	-0.21	1.48	0.039
Lighting	Movement sensing (PIR)	43 / B	0.2	3.22	16.10	-0.07	0.52	0.038
Heating	95% efficiency boilers	43 / B	0.4	0.79	1.99	2.10	0.00	0.039
Heating	Warm air blowers	43 / B	0.9	6.27	6.97	4.50	0.00	0.039
Heating	Heating - variable speed pumps	43 / B	0.1	0.11	1.12	0.00	0.12	0.039
Heating	Heating controls	43 / B	0.3	1.12	3.72	1.61	0.00	0.039
Power	0.95 power factor correction	43 / B	0.4	0.42	1.05	0.00	0.73	0.039
Fabric	Air tightness	43 / B	0.2	2.37	11.86	1.24	0.00	0.040
Fabric	Fabric improvements	36 / B	6.5	18.04	2.78	33.09	0.00	0.040
LZC	Photovoltaics - 10kWp (75m²)	42 / B	0.9	9.48	10.54	0.00	1.67	0.039
LZC	Photovoltaics - 50kWp (375m²)	38 / B	4.4	44.13	10.03	0.00	8.37	0.039
LZC	Photovoltaics - 100kWp (750m²)	33 / B	8.8	86.45	9.82	0.00	16.73	0.039
LZC	Wind turbine 20kW	41 / B	2.0	17.87	8.93	0.00	2.00	0.039

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DECC 'central' av. electricity price (£/kWh)	DECC 'high' av. gas price (£/kWh)	DECC 'high' av. electricity price (£/kWh)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.158	0.047	0.168	0.22	0.23	0.01	-	20
0.158	0.047	0.168	0.22	0.23	0.01	-	20
0.144	0.044	0.152	0.07	0.07	0.002	-	10
0.158	0.047	0.168	0.08	0.10	0.005	-	20
0.158	0.047	0.168	0.17	0.21	0.011	-	20
0.158	0.047	0.168	0.01	0.02	0.001	-	20
0.158	0.047	0.168	0.04	0.07	0.004	-	20
0.158	0.047	0.168	0.12	0.12	0.005	-	20
0.169	0.049	0.179	0.05	0.06	0.002	-	30
0.169	0.049	0.179	1.31	1.63	0.08	-	30
0.164	0.048	0.173	0.44	0.46	-	0.22	25
0.164	0.048	0.173	2.14	2.22	-	1.00	25
0.164	0.048	0.173	3.98	4.14	-	1.69	25
0.158	0.047	0.168	0.77	0.69	-	0.42	20

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Appendix Table 7: Office 1 energy efficiency improvements - occupied building scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Base capital cost (£/m²)	Extra capital cost (£/m²)	% increase	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
-	BASELINE	120 / E	-	-	-	-	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	91 / D	-	-	-	-	-	-	-	-	-	-
Lighting	T5 lighting	84 / D	3.50	7.11	7.44	4.4%	2.13	1.24	1.32	0.04	-	20
Lighting	LED lighting	82 / D	4.60	49.78	52.07	4.4%	11.32	1.64	1.68	0.06	-	15
Lighting	Daylight sensing	83 / D	3.90	3.38	3.63	6.9%	0.93	1.14	1.19	0.05	-	10
Lighting	Movement sensing (PIR)	90 / D	0.50	6.04	6.42	5.9%	12.84	0.17	0.18	0.01	-	10
Heating	95% efficiency boilers	87 / D	1.70	1.12	1.17	4.4%	0.69	0.34	0.42	0.02	-	20
Heating	Heating controls	88 / D	1.60	3.09	3.24	4.6%	2.02	0.32	0.39	0.02	-	20
Power	0.95 power factor correction	90 / D	0.20	0.40	0.41	3.2%	2.07	0.06	0.07	0.002	-	20
Heating	Variable speed pumps	90 / D	0.20	0.26	0.28	5.6%	1.38	0.05	0.06	0.002		20
Fabric	Air tightness	86 / D	2.30	2.43	2.43	-0.2%	1.05	0.46	0.57	0.028		30
Fabric	Replace single glazed windows with double glazed	64 / C	13.80	177.41	177.41	0.0%	12.86	2.74	3.40	0.17	-	30
LZC	Photovoltaics - 10kWp (75m²)	89 / D	0.80	8.95	9.37	4.5%	11.71	0.42	0.43	-	0.21	25
LZC	Photovoltaics - 50kWp (375m²)	83 / D	4.20	42.80	44.77	4.4%	10.66	2.01	2.09	-	0.94	25
LZC	Photovoltaics - 100kWp (750m²)	75 / D	8.30	81.65	85.41	4.4%	10.29	3.75	3.90	-	1.60	25
LZC	Wind turbine 20kW	89 / D	1.00	16.88	17.46	3.3%	17.46	0.73	0.67	-	0.41	20

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Appendix Table 7 Cont'd. : Office 1 energy efficiency improvements - occupied building scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Base capital cost (£/m²)	Extra capital cost (£/m²)	% increase	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
LZC	Solar thermal 50m²	90 / D	0.30	8.56	8.95	4.4%	29.85	0.19	0.21	-	0.16	25
LZC	Air source heat pump	76 / D	7.70	74.56	74.95	0.5%	9.73	-2.14	0.07	-	-w	20

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Appendix Table 8: Office 2 energy efficiency improvements - occupied building scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Base capital cost (£/m²)	Extra capital cost (£/m²)	% increase	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
-	BASELINE	164 / G	-	-	-	-	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	138 / F	-	-	-	-	-	-	-	-	-	-
Lighting	T5 lighting	127 / F	5.4	7.11	7.44	4.4%	1.38	1.74	2.03	0.06	-	20
Lighting	LED lighting	124 / E	6.9	49.78	52.07	4.4%	7.55	2.03	2.35	0.08	-	15
Lighting	Daylight sensing	125 / E	6.8	2.25	2.45	8.2%	0.36	1.95	2.05	0.08	-	10
Lighting	Movement sensing (PIR)	136 / F	0.9	6.04	6.42	5.9%	7.13	0.26	0.27	0.01	-	10
Heating	95% efficiency boilers	137 / F	0.5	0.90	0.94	4.4%	1.87	0.10	0.13	0.01	-	20
Heating	Heating controls	137 / F	0.5	1.32	1.38	4.4%	2.83	0.09	0.13	0.01	-	20
Heating/ cooling	Heating and cooling - variable speed pumps	135 / F	1.6	0.71	0.74	4.4%	0.46	0.49	0.58	0.02	-	20
Heating	Heat recovery	130 / F	3.7	7.30	7.65	4.6%	2.07	0.88	1.12	0.04	-	20
Power	0.95 power factor correction	136 / F	0.8	0.40	0.41	4.4%	0.52	0.25	0.30	0.01	-	20
Cooling	Chiller CoP 5.4	125 / E	6.7	4.74	4.96	4.4%	0.74	2.06	2.43	0.08	-	20
Cooling	DC drive fan coils	129 / F	4.7	10.03	10.39	3.5%	2.23	1.42	1.68	0.06	-	20
Cooling	Chilled beams - active	116 / E	11.0	160.79	168.11	4.4%	15.28	3.75	4.36	0.13	-	20
Cooling	Chilled beams - passive	100 / D	19.7	183.55	191.91	4.4%	9.74	6.55	7.66	0.24	-	20
Cooling	SFP 2.0W/l/s	135 / F	1.5	9.69	10.14	4.4%	6.76	0.48	0.56	0.02	-	20

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Appendix Table 8 Cont'd. : Office 2 energy efficiency improvements - occupied building scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Base capital cost (£/m²)	Extra capital cost (£/m²)	% increase	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
Fabric	Upgrades to air tightness	134 / F	1.7	2.50	2.50	0.0%	1.47	0.36	0.47	0.02	-	20
Fabric	External shading	127 / F	5.4	98.15	98.15	0.0%	18.18	2.07	2.11	0.06	-	30
LZC	Photovoltaics - 10kWp (75m²)	136 / F	0.8	8.95	9.37	4.4%	11.71	0.42	0.43	-	0.21	25
LZC	Photovoltaics - 50kWp (375m²)	130 / F	4.2	42.80	44.77	4.4%	10.66	2.01	2.09	-	0.94	25
LZC	Photovoltaics - 100kWp (750m²)	122 / E	8.3	81.65	85.41	4.4%	10.29	3.75	3.90	-	1.60	25
LZC	Wind turbine 20kW	136 / F	1.0	16.88	17.46	3.3%	17.46	0.73	0.67	-	0.41	20
LZC	Solar thermal 50m²	137 / F	0.3	8.56	8.95	4.4%	29.85	0.16	0.17	-	0.13	25
LZC	Air source heat pump	130 / F	4.3	59.67	60.03	0.6%	13.96	-1.48	0.08	0.05	-	20

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Appendix Table 9: Office 3 energy efficiency improvements - occupied building scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Base capital cost (£/m²)	Extra capital cost (£/m²)	% increase	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-In tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
-	BASELINE	143 / G	-	-	-	-	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	132 / F	-	-	-	-	-	-	-	-	-	-
Lighting	T5 lighting - new luminaires	119 / E	6.5	7.1	7.44	4.4%	1.14	1.99	2.11	0.08	-	20
Lighting	T5 lighting - conversion packs	119 / E	6.5	14.2	14.88	4.4%	2.29	1.99	2.11	0.08	-	20
Lighting	LED lighting	116 / E	8.5	49.8	52.07	4.4%	6.13	2.25	2.73	0.10	-	15
Lighting	Daylight sensing	129 / F	1.3	2.3	2.45	8.2%	1.89	0.36	0.38	0.02	-	10
Lighting	Movement sensing (PIR)	131 / F	0.3	6.0	6.42	5.9%	21.40	0.08	0.09	0.004	-	10
Heating	95% efficiency boilers	131 / F	0.4	0.8	0.81	4.4%	2.03	0.06	0.07	0.005	-	20
Heating	Heating controls	131 / F	0.2	1.3	1.38	4.4%	7.17	0.03	0.04	0.002	-	20
Heating/ cooling	Heating and cooling - variable speed pumps	129 / F	1.7	0.7	0.74	4.4%	0.44	0.48	0.51	0.02	-	20
Heating	Heat recovery	131 / F	0.7	7.3	7.65	4.6%	10.93	0.88	0.22	0.01	-	20
Power	0.95 power factor correction	130 / F	1.0	0.4	0.41	4.4%	0.41	0.29	0.31	0.01	-	20
Cooling	Chiller CoP 5.4	117 / E	7.8	6.3	6.61	4.4%	0.85	2.37	2.52	0.09	-	20
Cooling	DC drive fan coils	122 / E	5.4	8.4	8.66	3.5%	1.60	1.66	1.76	0.07	-	20
Cooling	Chilled beams - active	108 / E	12.3	167.2	174.80	4.4%	14.21	4.10	4.32	0.15	-	20
Cooling	Chilled beams - passive	86 / D	24.1	189.9	198.61	4.4%	8.24	7.89	8.34	0.29	-	20

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Appendix Table 9 Cont'd. : Office 3 energy efficiency improvements - occupied building scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Base capital cost (£/m²)	Extra capital cost (£/m²)	% increase	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-In tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
Cooling	SFP 2.0W/l/s	126 / F	3.0	4.6	4.85	4.4%	1.62	2.51	2.66	0.04	-	20
Fabric	External shading	103 / E	15.0	79.4	79.44	0.0%	5.30	5.06	5.32	0.18	-	30
LZC	Photovoltaics - 10kWp (75m²)	130 / F	0.9	9.0	9.37	4.4%	10.41	0.42	0.43	-	0.21	25
LZC	Photovoltaics - 50kWp (375m²)	124 / E	4.2	42.8	44.77	4.4%	10.66	2.01	2.09	-	0.94	25
LZC	Photovoltaics - 100kWp (750m²)	116 / E	8.4	81.6	85.41	4.4%	10.17	3.75	3.90	-	1.60	25
LZC	Wind turbine 20kW	128 / F	2.0	16.9	17.46	3.3%	8.73	0.73	0.66	-	0.41	20
LZC	Solar thermal 50m²	131 / F	0.3	8.6	8.95	4.4%	29.85	0.16	0.17	-	0.13	25
LZC	Air source heat pump	129 / F	1.2	51.5	51.96	0.9%	43.30	-3.36	-0.11	0.01	-	20

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Appendix Table 10: Office 4 energy efficiency improvements - occupied building scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Base capital cost (£/m²)	Extra capital cost (£/m²)	% increase	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
-	BASELINE	113 / E	-	-	-	-	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	113 / E	-	-	-	-	-	-	-	-	-	-
Lighting	T5 lighting - new luminaires	103 / E	5.2	7.1	7.44	4.4%	1.43	1.59	1.69	0.06	-	20
Lighting	T5 lighting - conversion packs	103 / E	5.2	14.2	14.88	4.4%	2.86	1.60	1.69	0.06	-	20
Lighting	LED lighting	100 / D	6.7	49.8	52.07	4.4%	7.77	1.96	2.25	0.08	-	15
Lighting	Daylight sensing	111 / E	1.0	2.3	2.45	8.2%	2.45	0.29	0.31	0.01	-	10
Lighting	Movement sensing (PIR)	113 / E	0.1	6.0	6.42	5.9%	64.21	0.03	0.03	0.001	-	10
Heating	95% efficiency Bboilers	112 / E	0.2	0.8	0.79	4.4%	3.96	0.04	0.05	0.002	-	20
Heating	Heating controls	112 / E	0.2	1.3	1.38	4.4%	9.11	0.03	0.03	0.002	-	20
Heating/ cooling	Heating and cooling - variable speed pumps	110 / E	1.6	0.7	0.74	4.4%	0.46	0.48	0.51	0.02	-	20
Heating	Heat recovery	111 / E	1.0	7.3	7.65	4.6%	7.65	0.28	0.31	0.01	-	20
Cooling	Chiller CoP 5.4	108 / E	2.3	4.4	4.63	4.4%	2.01	0.71	0.76	0.03	-	20
Cooling	DC drive fan coils	101 / E	6.2	8.4	8.66	3.5%	1.40	1.90	2.01	0.07	-	20
Cooling	Chilled beams - active	89 / D	12.5	167.2	174.80	4.4%	13.98	4.17	4.40	0.15	-	20
Cooling	Chilled beams - passive	70 / C	22.2	189.9	198.61	4.4%	8.95	7.33	7.75	0.27	-	20
Cooling	SFP 2.0W/l/s	110 / E	1.4	8.4	8.82	4.4%	6.30	0.45	0.47	0.02	-	20

APPENDIX

Appendix Table 10: Office 4 energy efficiency improvements - occupied building scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Base capital cost (£/m²)	Extra capital cost (£/m²)	% increase	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
Fabric	External shading	89 / D	12.3	79.4	79.44	0.0%	6.46	4.19	4.13	0.15	-	30
LZC	Photovoltaics - 10kWp (75m²)	111 / E	0.8	9.0	9.37	4.4%	11.71	0.42	0.43	-	0.21	25
LZC	Photovoltaics - 50kWp (375m²)	105 / E	4.1	41.7	44.77	6.9%	10.92	2.01	2.09	-	0.94	25
LZC	Photovoltaics - 100kWp (750m²)	97 / D	8.3	81.6	85.41	4.4%	10.29	3.75	3.90	-	1.60	25
LZC	Wind turbine 20kW	111 / E	1.0	16.9	17.46	3.3%	17.46	0.73	0.66	-	0.41	20
LZC	Solar thermal 50m²	112 / E	0.2	8.6	8.95	4.4%	44.77	0.16	0.17	-	0.13	25
LZC	Air source heat pump	110 / E	1.2	50.8	51.23	0.9%	42.69	-0.35	-0.04	0.01	-	20

APPENDIX

Appendix Table 11: Retail energy efficiency improvements - occupied building scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Base capital cost (£/m²)	One-off extra capital cost (£/m²)	% increase	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
-	BASELINE	93 / E	-	-	-	-	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	71 / E	-	-	-	-	-	-	-	-	-	-
Lighting	T5 lighting - new luminaires	70 / C	1.3	7.11	7.44	4.4%	5.72	0.31	0.09	0.02	-	20
Lighting	T5 lighting - conversion packs	70 / C	1.3	5.78	6.04	4.4%	4.65	0.31	0.09	0.02	-	20
Lighting	Movement sensing (PIR)	71 / C	0.7	5.47	5.82	6.1%	8.32	0.10	-0.11	0.01	-	10
Heating	95% efficiency boilers	71 / C	0.7	0.96	1.00	4.4%	1.43	0.14	0.16	0.01	-	20
Heating/ cooling	Heating and cooling - variable speed pumps	70 / C	1.5	1.07	1.12	4.4%	0.74	0.47	0.50	0.02	-	20
Heating	Heat recovery	68 / C	4.6	6.28	6.64	5.5%	1.44	1.19	1.32	0.06	-	20
Heating	Heating - controls	71 / C	0.4	1.59	1.66	4.4%	4.15	0.08	0.09	0.005	-	20
Power	0.95 power factor correction	70 / C	1.5	0.38	0.40	4.4%	0.27	0.47	0.50	0.02	-	20
Cooling	Chiller CoP 5.4	63 / C	4.4	7.47	7.81	4.4%	1.78	4.22	4.48	0.05	-	20
Cooling	DC drive fan coils	67 / C	5.4	5.71	5.98	4.4%	1.10	1.90	2.01	0.07	-	20
Cooling	SFP 2.0W/l/s	69 / C	3.0	6.60	6.91	4.4%	2.30	0.98	25.75	0.04	-	20
Fabric	Air tightness	69 / C	3.7	3.80	3.99	4.8%	1.08	0.59	0.80	0.04	-	30
Fabric	Fabric improvements	71 / C	0.4	15.54	16.31	4.8%	40.78	0.10	-0.24	0.005	-	30

APPENDIX

Appendix Table 11 Cont'd. : Retail energy efficiency improvements - occupied building scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Base capital cost (£/m²)	One-off extra capital cost (£/m²)	% increase	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
LZC	Photovoltaics - 10kWp (75m²)	71 / C	0.8	8.64	9.03	4.4%	11.29	0.40	0.41	-	0.20	25
LZC	Photovoltaics - 50kWp (375m²)	69 / C	3.9	40.19	43.17	6.9%	11.07	1.94	1.99	-	0.89	25
LZC	Photovoltaics - 100kWp (750m²)	66 / C	7.9	78.73	82.36	4.4%	10.43	3.61	3.72	-	1.51	25
LZC	Wind turbine 20kW	70 / C	1.8	16.27	16.83	3.3%	9.35	0.70	0.63	-	0.38	20
LZC	Solar thermal 50m²	71 / C	0.4	8.25	8.63	4.4%	21.59	0.17	0.19	-	0.17	25
LZC	Air source heat pump	68 / C	2.9	33.26	33.42	0.5%	11.53	-0.25	0.04	0.03	-	20

APPENDIX

Appendix Table 12: Industrial/warehouse energy efficiency improvements - occupied building scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Base capital cost (£/m²)	One-off extra capital cost (£/m²)	% increase	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
-	BASELINE	128 / E	-	-	-	-	-	-	-	-	-	-
-	MARKET STANDARD REFURBISHMENT	44 / E	-	-	-	-	-	-	-	-	-	-
Lighting	T5 lighting - new luminaires	43 / B	0.7	7.1	7.44	4.4%	10.63	0.22	0.23	0.01	-	20
Lighting	T5 lighting - conversion packs	43 / B	0.7	5.4	5.44	0.0%	7.77	0.22	0.23	0.01	-	20
Lighting	Movement sensing (PIR)	43 / B	0.2	3.2	3.42	5.8%	17.10	0.07	0.07	0.002	-	10
Heating	95% efficiency boilers	43 / B	0.4	0.8	0.83	4.4%	2.08	0.08	0.10	0.005	-	20
Heating	Warm air blowers	43 / B	0.9	6.3	6.56	4.4%	7.29	0.17	0.21	0.011	-	20
Heating	Heating - variable speed pumps	43 / B	0.1	0.1	0.12	4.4%	1.17	0.01	0.02	0.001	-	20
Heating	Heating - controls	43 / B	0.3	1.1	1.17	4.4%	3.89	0.06	0.07	0.004	-	20
Power	0.95 power factor correction	43 / B	0.4	0.4	0.44	4.4%	1.09	0.12	0.12	0.005	-	20
Fabric	Air tightness	43 / B	0.2	2.4	2.49	4.8%	12.46	0.05	0.06	0.002	-	30
Fabric	Fabric improvements	36 / B	6.5	18.0	18.94	4.8%	2.91	1.31	1.63	0.08	-	30
LZC	Photovoltaics - 10kWp (75m²)	42 / B	0.9	9.5	9.92	4.4%	11.02	0.44	0.46	-	0.22	25
LZC	Photovoltaics - 50kWp (375m²)	38 / B	4.4	44.1	47.41	6.9%	10.77	2.13	2.21	-	1.00	25

APPENDIX

Appendix Table 12: Industrial/warehouse energy efficiency improvements - occupied building scenario

Upgrade category	Energy efficiency improvement	EPC score / rating	Carbon saving pa ($kgCO_2/m^2$)	Base capital cost (£/m²)	One-off extra capital cost (£/m²)	% increase	Marginal cost (£ per $kgCO_2$ / m² pa)	DECC 'central' av. net saving pa (£/m²)	DECC 'high' av. net saving pa (£/m²)	CRC EES saving pa @ £12/tCO_2 (£/m²)	Feed-in tariff / Renewable heat incentive revenue pa (£/m²)	Improvement lifetime (years)
LZC	Photovoltaics - 100kWp (750m²)	33 / B	8.8	86.5	90.44	4.4%	10.28	3.97	4.13	-	1.69	25
LZC	Wind turbine 20kW	41 / B	2.0	17.9	18.48	3.3%	9.24	0.77	0.69	-	0.42	20

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