IPF Research Programme 2006-2009

Costing Energy Efficiency Improvements in Existing Commercial Buildings

Research Findings

January 2009

This research was commissioned by the IPF Research Programme 2006–2009

IPF Investment Property Forum

This research was funded and commissioned through the IPF Research Programme 2006–2009.

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

The programme is funded by a cross-section of 24 businesses, representing key market participants. The IPF gratefully acknowledges the continuing support of the contributing organisations.

COSTING ENERGY EFFICIENCY IMPROVEMENTS IN EXISTING COMMERCIAL BUILDINGS

Research Findings

IPF Research Programme 2006–2009

January 2009

Research team

Isabel McAllister,
Cyril Sweett

Richard Quartermaine,
Cyril Sweett

Fiona McWilliams,
Cyril Sweett

Research steering group

Gerry Blundell,
LaSalle Investment Management

Louise Ellison,
IPF

Disclaimer

This document is for information purposes only. The information herein is believed to be correct, but cannot be guaranteed, and the opinions expressed in it constitute our judgement as of this date but are subject to change. Reliance should not be placed on the information and opinions set out herein for the purposes of any particular transaction or advice. The IPF cannot accept any liability arising from any use of this document.

CONTENTS

EXECUTIVE SUMMARY

This study was commissioned by the Investment Property Forum to investigate the costs of making energy efficiency improvements to existing commercial buildings. The primary aims of the research were 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.

The outcome of the study is an understanding of the costs of improving existing commercial building energy performance (and associated CO_2 emissions) and which improvements should be prioritised to achieve the biggest savings. It is envisaged that this report will be useful for the property and investment community, in particular:

- Investment fund managers
- Asset managers
- Property managers
- Facilities managers
- Letting agents
- Valuers
- Tenants

Method

The key elements of the study included:

1. Identifying those commercial buildings within investor portfolios which have the greatest potential for reduced 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 the additional capital expenditure required to make the improvements (including payback potential and Internal Rates of Return based on energy savings) and subsequently listing the improvements based on the cost to save one unit of CO_2
4. Packaging the improvements and applying them sequentially to the selected buildings to determine the likely CO_2 reductions achievable for given budgets

Both landlords and tenants have a direct influence on CO_2 emissions derived from the energy consumed during the operation of the building. For the purposes of this study, the buildings selected for analysis were determined by the extent of the landlord's influence on energy consumption. Where a landlord has significant influence, there is considerable scope to make energy efficiency improvements.

A number of generic building types that are best-fit representations of existing commercial stock were modelled. It was important to capture the key building characteristics that influence energy consumption such as age, glazing levels, plan depth and cooling strategy. The generic base building models used in the research are listed in Table 1.1.

Table 1.1: Base building models

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 3	Air-conditioned	Narrow	1990-1995	Part
Office 4	Air-conditioned	Narrow	1990-1995	Full
Office 5	Air-conditioned	Deep	2002	Full
Office 6	Non air-conditioned	Narrow	Pre-1940s	Part
Office 7	Mechanically ventilated	Narrow	1990-1995	Part
Supermarket	Air-conditioned	Deep	1990-1995	Minimal
Industrial/warehouse	Heating only	Deep	1990-1995	Minimal

A range of offices were modelled to determine which type is more responsive in terms of CO_2 saved when each improvement is applied.

The conclusions of this work are summarised for each building type below.

Offices

With the exception of the post-2002 office, the baseline CO_2 emissions of all offices could be reduced by approximately 25% by refurbishing to current market standards (ie no additional energy efficiency improvements). This would be likely to achieve a C rating on an Energy Performance Certificate (EPC). The post-2002 office modelled was comparable with current market standards.

The results showed that all office buildings could achieve a significant reduction in CO_2 emissions following an additional spend of 5% when undertaking a major refurbishment (based on a refurbishment base cost of £1000/m^2). The biggest improvement was seen for older offices where the baseline CO_2 emissions were reduced by almost 50%, following the additional 5% spend. For the modern office, a reduction of almost 30% was possible. It is likely that this level of additional expenditure will be sufficient to achieve an EPC rating of a B.

As the additional expenditure increased beyond £50/m^2, it became relatively more expensive to achieve further reductions to the baseline CO_2 emissions.

The office building with the highest baseline emissions (Office 2 – early 1990s, air conditioned, fully glazed deep plan) was seen to achieve the highest absolute reduction in CO_2 for each level of additional expenditure. The two fully glazed early 1990s offices (Offices 2 and 4) had higher baselines compared to the same buildings with less glazing.

However, the heated 'period' office (Office 6) achieved the biggest relative improvement for each amount of additional expenditure. As there is no air conditioning present, the heating and lighting improvements have a bigger relative impact compared with the same improvements for the air conditioned offices. Improvements to these types of offices are therefore very cost effective.

Retail

Refurbishing a supermarket to current market standards generates a 12% reduction in CO_2 emissions, which is less than is the case for the offices. However, if an additional £10/m^2 is spent over a market refurbishment almost a quarter of baseline emissions can be saved.

To make further CO_2 savings, the next most cost effective improvement is a medium wind turbine (20kW). However, this is a major capital cost item and increases the additional expenditure to £100/m^2. The investment will not create a positive return or pay back within 30 years at current energy prices.

Industrial

Modernising an existing industrial/warehouse building to current market standards would present a 35% reduction in CO_2 emissions. However, this does include making improvements to the space heating system which the landlord might not wish to carry out for the purposes of letting the unit.

For an additional expenditure of £10/m^2, the reduction in baseline emissions would be in the region of 41%. Although the relative improvement in baseline emissions is significantly more than for the supermarket, the actual CO_2 saved is less – 24kgCO_2/m^2 against 28kgCO_2/m^2. The baseline emissions for the industrial/ warehouse building are half those of the supermarket which accounts for the lower absolute saving in CO_2.

A medium wind turbine is the next most cost effective improvement, however, this is a major capital cost item and will increase the additional expenditure required up to £100/m^2. The result of this improvement is a 62% reduction in baseline emissions which equates to 36kgCO_2/m^2. Like the supermarket, the wind turbine does not give a positive return or pay back within 30 years at current energy prices.

On balance, improvements to the industrial/warehouse building give a greater relative reduction in CO_2 compared to the supermarket; however the total CO_2 saved is less.

Conclusion

This study has identified a number of cost effective energy efficiency improvements that can be made to the commercial property stock, especially 1990's and pre-1940's. Based on current gas and electricity prices, these improvements produce a positive Internal Rate of Return, the majority of which exceed 9%. Many of these opportunities not only apply to buildings awaiting a major refurbishment, but also to buildings that are in occupation. Refurbishing a building to current market standards will achieve significant initial CO_2 savings and limited additional expenditure can reduce overall emissions by almost half.

1. INTRODUCTION

This study was commissioned by the Investment Property Forum to investigate the costs of making energy efficiency improvements to existing commercial buildings. The primary aim of the research was to identify the key improvements that should be made to existing commercial buildings and the building types that presented the greatest opportunities to reduce carbon dioxide (CO_2) emissions.

The main tasks of the study were to:

1. Identify those commercial buildings within investor portfolios which have the greatest potential for reduced CO_2 emissions
2. Determine typical baseline CO_2 emissions for the commercial buildings identified
3. Estimate the potential CO_2 reductions achievable from applying a range of energy efficiency improvements beyond current market replacement standards
4. Calculate and compare the additional capital expenditure required to make the improvements (including payback potential and Internal Rates of Return based on energy savings) and list the improvements based on the capital cost required to save one unit of CO_2
5. Package the improvements and apply them sequentially to the selected buildings to determine the likely CO_2 reductions achievable for given budgets

The study analyses a number of existing buildings typical of a range of sectors, and examines the implications of making energy efficiency improvements.

1.1 Background

To date the agenda for improved energy efficiency in commercial property has predominantly focused on new buildings. This is because energy efficient solutions can be integrated, with relative ease, into the designs of new buildings at an early stage of the development process, often more cost effectively compared to adapting an existing building. In addition, proposed Building Regulations and Government targets for all non-domestic buildings to be zero carbon by 2019 have put the emphasis on new buildings. However, new buildings only make up between 1 and 2% of the total building stock, meaning significant CO_2 reductions will need to come from existing commercial buildings.

The introduction of Energy Performance Certificates (EPCs) for non-domestic buildings when they are constructed, sold or let, which rate the energy performance of the building (from A+ to G), is likely to become a key driver for building owners to improve the energy efficiency of their buildings. EPCs will make building energy performance more transparent to all stakeholders in the property market and it is therefore anticipated that more energy efficient buildings may be in higher demand than less energy efficient buildings.

The outcome of the study is a clear understanding of the cost of improving existing commercial building energy performance and associated CO_2 emissions, and which improvements should be prioritised to achieve the biggest savings. It is envisaged that these outcomes will be useful for the property and investment community, in particular:

- Investment fund managers
- Asset managers
- Property managers
- Facilities managers
- Letting agents

The next section of the report details the research methodology. This includes the selection of appropriate commercial building types for further analysis and the processes followed. The results and corresponding discussion for each commercial sector studied form subsequent sections of the report followed by a summary of the main findings with recommendations.

1.2 Limitations of the study

The study analyses a number of commercial building types and the findings are presented from the perspective of a landlord, whether investor, developer or owner-occupier. Therefore, only the base specification of each building has been assessed 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 othroughout 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 therefore does not consider the following areas:

- New build
- Major redevelopments (ie stripping the building back to the frame)
- Change of use of existing buildings

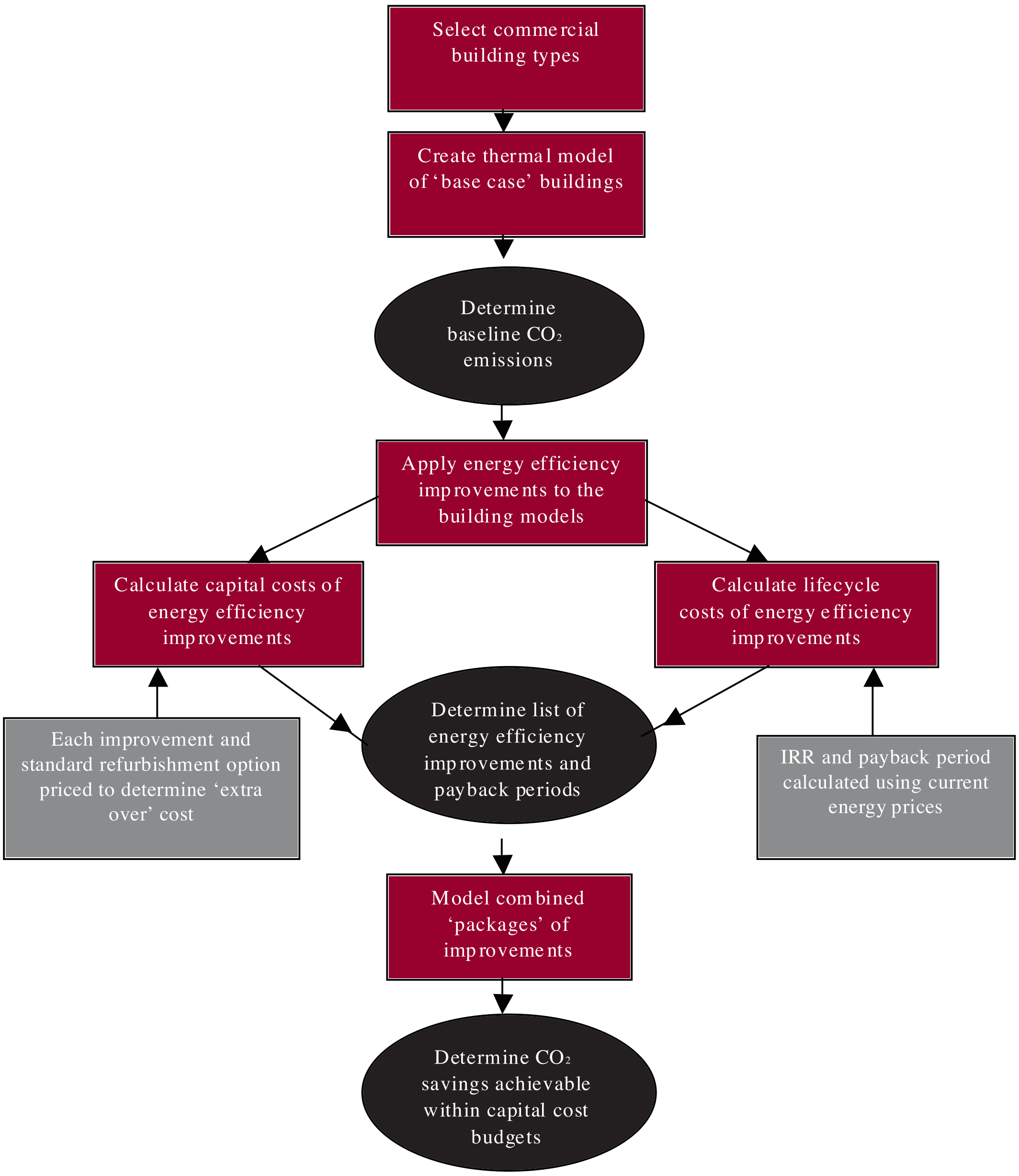
2. METHODOLOGY AND BUILDING SELECTION

2.1 Outline method

The aim of the study was to focus on the opportunities to reduce CO_2 emissions associated with energy consumption in existing commercial buildings. The research considered three types of commercial building: offices, retail and industrial.

The research method can be expressed diagrammatically in Figure 2.1 below.

Figure 2.1: Research methodology



2.2 Potential for CO_2 reductions from commercial buildings

The first task was to determine those commercial buildings in investor portfolios which have the greatest potential for CO_2 emissions reductions. This assessment was based on the available opportunities for building owners and landlords to reduce CO_2 emissions within their buildings.

Improvement opportunities for landlords are discussed in more detail in Section 2.2.3 following a brief overview of the relationship between energy consumption and CO_2 emissions from commercial buildings.

2.2.1 Energy consumption and CO_2 emissions from buildings

The main energy uses within a building 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 for example
- Hot water for washing, showers and catering
- 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
- 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, 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 more than a factor of two.

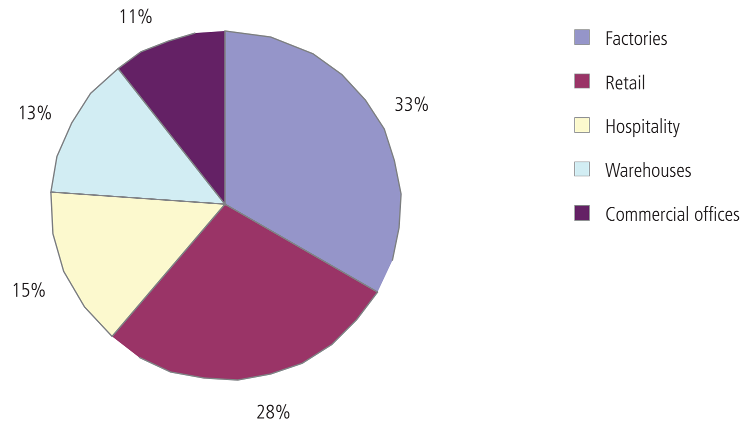
Carbon is not the same as CO_2. As an inert chemical element, carbon is not directly responsible for climate change effects. However, in the form of CO_2, it is one of the main greenhouse gases.

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

2.2.2 CO_2 emissions from the commercial stock

In 2003, commercial buildings were responsible for around 14% of total CO_2 emissions in the UK (source: BRE, 2006). The remaining emissions were produced by transport (33%), domestic buildings (26%), industrial process (22%) and public and other buildings (5%). The total emissions from commercial buildings can be further sub-divided as presented in Figure 2.2 below.

Figure 2.2: 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 2.1 below indicates that retail buildings are the biggest energy users compared to other commercial buildings.

Table 2.1: Energy consumption benchmarks for existing commercial buildings[1]

	Office Air-Conditioned	Office Non Air-Conditioned	Retail	Industrial / Warehouse
Annual kWh/m² of floor area	400	235	230-750	350-400

[1] Source: RICS and Cyril Sweett 2007

The energy consumption range for retail buildings is relatively wide, with supermarkets being the highest consumer at the top of the range followed by food stores (440 kWh/m^2), department stores (290 kWh/m^2) and non-food shops (230 kWh/m^2). This is partly accounted for by the longer operating hours typical of supermarkets.

2.2.3 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. However, 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 2.2.1 above, 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 (ie in terms of insulating qualities and air tightness to reduce heat transfer).

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

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 industrial space which 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).

Warehouses

Unlike factories, warehouses and distribution centres (use class B8) are not as energy intensive because a manufacturing process is absent from the building. General warehouse lighting (traditionally metal halide) 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 a key consideration.

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.

2. METHODOLOGY AND BUILDING SELECTION

Retail buildings are diverse in terms of their physical characteristics 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 four or more levels
- Supermarket
- Shopping centres – open or enclosed
- Retail warehouses

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' only 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 four 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. However, shopping centres are not included in the modelling stage of the research 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 which 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 therefore considered beyond the scope of this research 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 and factories.

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, 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 previous uses, without the facilities previously described. The use of gas to provide domestic hot water for the en-suite rooms 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.

Offices

Although offices only account for 11% of the CO_2 emissions from commercial buildings, there are a number 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
- 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 (often with a landlord's capital contribution), 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 CCategory 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 financial 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. As discussed, key buildings are offices, supermarkets, light industrial buildings and warehouses. The next section describes how the baseline CO_2 emissions were determined for generic versions of these buildings.

2.3 Development of the building models

Commercial buildings are not homogenous and all have differing characteristics that influence energy consumption and in turn, CO_2 emissions. A number of generic models that are best-fit representations of the existing stock were modelled. 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 install.

The following sub-sections consider the key characteristics that affect energy consumption in existing buildings and are subsequently represented in the base building models.

2.3.1 Location

Geographical location affects external temperatures and therefore whether a building requires more heating (ie gas) in winter or cooling (ie electricity) in summer. Different daylight patterns also impact on the requirement for artificial lighting and the subsequent electricity consumed.

A South East climate was used in the modelling process because 78% of standard investment grade offices (excluding office parks) are in London and the South East compared with the remainder of the UK[2] Similarly, for standard shops and standard industrial buildings, 46% and 45% of each respective stock are situated in London and the South East.

2.3.2 Building age

The age of the building has a significant impact on the energy consumed within it for two reasons. Firstly, the materials used in the construction of external building envelopes have changed over time and this affects how well the envelope performs thermally, in other words, its ability to retain heat in winter and control solar gain during summer. In addition, since the 1990 revision of Part L of the Building Regulations (Conservation of Fuel and Power) there has been a requirement to achieve increased levels of thermal performance within building fabrics. The second reason is because the energy efficiency of building services within commercial buildings has improved over time. This has also been regulated by the Part L Building Regulation.

Building age profile data from IPD, summarised in Table 2.2, was used to determine the most appropriate age of buildings to model.

Table 2.2: Building age profiles

Offices	
City offices	39% dated 1980–1989
	21% dated pre-1940s
	18% dated 1995–2007
	22% dated 1940–1979
West End / mid town	53% pre-1940s
	16% dated 1995–2007
	14% dated 1980–1989
	17% dated 1940–1979
Retail[3]	
Retail warehouses	52% dated 1980–1994
	45% dated 1995–2007
Shopping centres	46% dated 1980–1994
	21% dated 1995–2007
Industrial	
All industrials	48% dated 1980–1989
	25% dated 1995–2007

[2] Based on data from the Investment Property Databank (IPD).

[3] The building age profile for supermarkets was not distinguishable from the data obtained.

With the exception of mid-town and West End offices, the majority of existing commercial stock was built from 1980 onwards. Given a typical economic life of 15 to 20 years for building services installations, there would be few 1980s buildings still running their original systems; they would be running systems with greater efficiencies due to subsequent replacement as part of a major refurbishment. The exception to this would be those offices that are still let on 25 year full repairing and insuring leases between the mid-eighties and early nineties after which lease lengths started to reduce. Therefore, buildings built in the early 1990s were deemed to be the best representation of the majority of the older commercial stock. A 'modern' office built post-2002 and a 'period' pre-1940s office were also modelled to reflect other notable buildings in an investment portfolio.

2.3.3 Building form

It is recognised that the depth of the floor plan (either deep or narrow) impacts on energy consumption within a building. For example, a narrow depth open plan office (less than 15m) can use natural ventilation to cool the building during the summer by opening windows in lieu of air conditioning. The depth of the building is also significant for air conditioned buildings. For example, a deep plan office (plan width exceeding 15m) has a greater floor-to-external wall ratio which means that the thermal performance of the building fabric has less influence per unit of floor area.

2.3.4 Glazing

There is now a trend in office design to have fully glazed façades (known as curtain walling) rather than 'ribbon' windows (a horizontal band) or individual casement, pivot or sash windows.

The thermal performance of glass is considerably worse than other external wall materials such as brick and therefore heat loss in winter is more apparent with a fully glazed façade compared with one which is part glazed. A further attribute of glass is it emits solar radiation into the building, known as 'solar gain', which is greater in summer. This increases the amount of cooling energy required in order to maintain a comfortable temperature within the office space.

Minimising glass could be a key design objective for commercial buildings; however increased glazing improves natural light levels and reduces the need for artificial lighting.

2.3.5 Air conditioning

Buildings with mechanical ventilation and air conditioning systems consume more electrical energy than naturally ventilated buildings – by as much as 70% when comparing a typical standard air conditioned office with a naturally ventilated office[4]. Fans, pumps and chillers consume electricity to provide cooling where internal summer temperatures exceed a set limit, typically in the range between 20°C and 24°C. Buildings which are naturally ventilated either use openable windows to reduce internal summer temperatures[5] or adopt more complex strategies such as 'stack' ventilation where the central atrium is used to create a chimney effect to remove the warm air from open floor plates.

[4] Based on Energy Consumption Guide 19 (Appendix B), comparing 'Typical' kWh/m^2 for Offices 2 and 3

[5] Where plan width is less than 15m

Based on the 2007 OSCAR[6] offices database, 71% of office buildings were air-conditioned with the remainder being non air-conditioned (ie naturally ventilated). It was therefore necessary to consider both types of office buildings in the modelling exercise. As stated earlier, supermarkets are predominantly air conditioned and industrial/warehouse buildings are non air-conditioned meaning that model variances need not be considered for these buildings.

2.3.6 Additional considerations

The base building models to which energy efficiency improvements could be applied did not reflect all possible physical and operational variations in commercial buildings. It was possible however to assess the impact of several variations on baseline emissions by making discrete adjustments. The variations considered were:

- **Location** – a city centre location as opposed to a business park/out-of-town location
- **Orientation** – the impact of building orientation on cooling requirements due to solar gain
- **Height** – low rise, high rise or mega-tall
- **Intensive office uses** – impact of extended operational hours (call centres, city banking) and IT intensive offices

The impact of these specific variations on baseline emissions is analysed in Section 3.2.4 of this report.

2.4 Base building models

The generic base building models used in the research are listed in Table 2.3 as follows:

Table 2.3: Base building models

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 3	Air-conditioned	Narrow	1990–1995	Part
Office 4	Air-conditioned	Narrow	1990–1995	Full
Office 5	Air-conditioned	Deep	2002[7]	Full
Office 6	Non air-conditioned	Narrow	Pre–1940s	Part
Office 7	Mechanically ventilated	Narrow	1990–1995	Part
Supermarket	Air-conditioned	Deep	1990–1995	Minimal
Industrial / warehouse	Heating only	Deep	1990–1995	Minimal

Analysing a number of offices will determine which type of office is more responsive in terms of CO_2 saved by the improvements applied. A range of savings for offices will then be established rather than a one-size-fits-all approach.

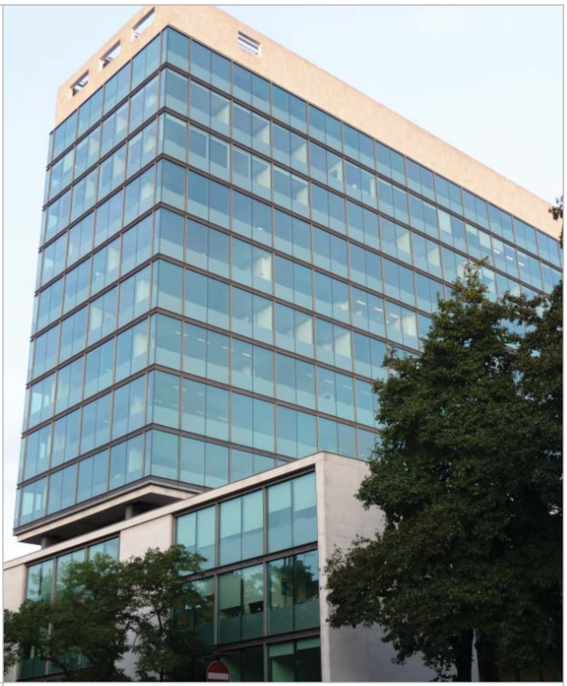
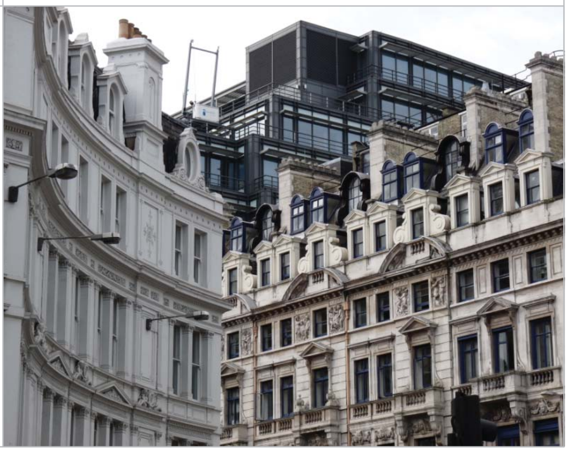
Figure 2.3 gives examples of the buildings the models represent.

[6] 'Office OSCAR 2007 – Service Charge Analysis for Offices', Jones Lang LaSalle, 2008

[7] Thermal performance requirements for new buildings were not amended by the 2006 Part L revision.

Figure 2.3: Example buildings representing the base building models

Office 1 Partly glazed air conditioned early 1990s deep plan office. Compliant with 1990 Part L Building Regulations.	
Office 2 Fully glazed air conditioned early 1990s deep plan office. Compliant with 1990 Part L Building Regulations.	
Office 3 As Office 1 but narrow plan depth.	

Office 4 As Office 2 but narrow plan depth.	
Office 5 Modern office with a fabric that meets current levels of thermal performance as required by the Building Regulations (these were set in 2002 and not amended in 2006).	
Office 6 Reflects mid-town and West End offices which are predominantly period, dating from pre-1940. Heating system only.	

Office 7 Early narrow plan partly glazed 1990s building with mechanical ventilation providing heat in winter and fresh air only in summer. Compliant with 1990 Part L Building Regulations.	This office takes the same form as Office 3.
Retail Single storey with lighting, heating and air conditioning. Limited windows. Offices not included. Compliant with 1990 Part L Building Regulations.	
Industrial/warehouse Single storey with lighting and heating. Limited windows or rooflights. Offices not included. Compliant with 1990 Part L Building Regulations.	

2.5 Dynamic thermal computer modelling

Dynamic thermal modelling is undertaken using software tools to generate a computer model of a building to simulate energy consumption over a period of time. TAS Building Designer software from EDSL was used to model the CO_2 emissions of the buildings previously identified and then quantify the effect of applying various energy efficiency improvements.

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

The information entered into each dynamic thermal model includes:

- 3D geometry and orientation
- specifications for the building fabric
- datasets to reflect the use of the building, for example, hours of occupation, number of occupants, for example
- details of the building systems, eg heating, ventilation, lighting

The thermal modelling process did not include any allowance for the occupants' equipment or appliances.

2.6 Key modelling parameters

The thermal dynamic modelling software requires a range of both physical and operational building characteristics to be defined as model inputs in order to construct the base building models. The approach followed was to determine inputs that would best represent the building types under consideration. The key parameters are listed in Table 2.4.

Table 2.4: Key modelling parameters

Input Variable	Base Building Modelling Parameters		
	Office	**Retail**	**Industrial**
Building geometry			
Gross floor area	5,400m²	1,000m²	1,000m²
Floor plate dimensions Deep plan Narrow plan	 30m x 30m 60m x 15m	40m x 25m	40m x 25m
No. of storeys	6	1	1
Storey height	3.7m	4m walls, 6m apex	4m walls, 6m apex
Glazing %	50% 80%	10%	10%
Glazing specification Office 5	Single Double	Single	Single
Location	South East Business Park	Retail Park	Industrial Park
Building Geometry			
Age Office 5 Office 6	1990 2002 Pre-1940s	1990	1990
Hours of occupation	8am to 6pm, weekdays only	8am to 8pm, inc weekends	8am to 7pm, weekdays only
Density[8]	1 person / 17.5m²	1 person / 12m²	1 person / 130m²
Building Geometry			
Internal temperatures Heating (winter) Cooling (summer)	 20°C 22°C	 20°C 22°C	 18°C n/a
Heating system	Gas	Gas	Gas
Natural ventilation	Office 6 only	n/a	Natural ventilation
Mechanical ventilation	Office 7 only	n/a	n/a
Air conditioning	Centralised system and fan coils	Centralised system and fan coils	n/a
Hot water	Electric	Electric	Electric
Renewable energy	None	None	None

[8] Over gross floor area

The building geometry (with the exception of glazing) of the commercial buildings was based on three generic building forms used in the UK-GBC report on carbon reductions in new non-domestic buildings[9]. To test two different glazing scenarios, 50% was used to represent a 'part glazed' façade and 80% for a 'fully glazed' façade. 100% glazing cannot be achieved in practice due to floor slabs and ceiling voids.

Design features, such as atria, were excluded from the modelling because it was viewed to be beyond the remit of the project to consider more complicated building forms. The impact of atria for example on CO_2 emissions depends on whether the space is heated/cooled or if it is used as part of a passive ventilation strategy.

2.7 Energy efficiency improvements

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

Figure 2.4: Typical CO_2 emissions from an air-conditioned office[10]

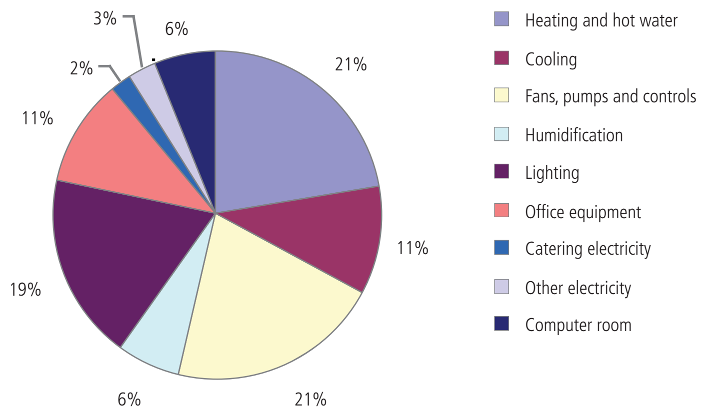


Figure 2.4, for example, shows that the majority of CO_2 (78%) produced within an existing air-conditioned office is from the following energy uses:

- Heating and hot water
- Fans, pumps and controls associated primarily with the air conditioning system
- Lighting
- 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.

[9] Communities and Local Government (2007) *Report on carbon reductions in new non-domestic buildings*, Communities and Local Government Publications, London.

[10] Action Energy (1990) *Energy Consumption Guide 19: Energy use in offices*, available from the Carbon Trust website www.carbontrust.co.uk

2.8 Commercial building refurbishments

A building refurbishment can vary based on the scope of work involved. Three grades of refurbishment are:

- Minor – update finishes and repair/replace building services as required
- Medium – carried out every 15 years; full update of the existing building services and finishes
- Major – significant structural work and remodelling to provide best grade space

For the purposes of this study, it has been assumed that the improvements proposed can be incorporated within a medium grade refurbishment and there are no physical constraints posed by the existing buildings under consideration.

The refurbishment of an existing building brings the building services and finishes up to modern market standards. This study considers the cost and CO_2 savings achievable from energy efficiency improvements which are not typically included in a market refurbishment. However, there are certain improvements that would be carried out under a market refurbishment that improve the CO_2 emissions compared to previous performance. For the purposes of this study, the following measures are included as standard in a market modernisation:

- Boiler with 85% efficiency
- Building Management System
- Chiller with Coefficient of Performance of 3.4
- Lighting output of $12W/m^2$

2.9 Costing process and assumptions

2.9.1 Capital costs

A key feature of this research was to assess the costs associated with making certain energy efficiency improvements which are typically beyond the scope of a market major refurbishment. To demonstrate which of these improvements were most cost effective, it was necessary to quantify the extra over capital cost of the upgrade compared with the respective like-for-like replacement under a market 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 (ie cost to the landlord). This includes materials, labour, builder's work in connection thereto, preliminaries, overheads, contingencies and profit. Design fees have not been included, based on the assumption that any increase in design fees associated with the upgrade will be marginal. Other excluded costs include Value Added Tax, Building Control fees, survey fees, legal fees and finance costs.

The costs are current at Q3 2008 price levels.

It has been assumed that all improvements modelled can be carried out within the existing buildings without structural alterations or reworking floor layouts and positions of ducts for example and the capital costs reflect this.

The extra over capital cost has been calculated for those improvements that could be carried out whilst a tenant is (or multiple tenants are) in occupation of the building. It assumes that the improvements can either be carried out during normal business hours or out of hours (evenings/weekends) which would typically command a 50% premium. For simplicity, phased refurbishments have not been considered where one or more floors are unoccupied and there could be an associated cost of decanting and moving tenants.

2.9.2 Internal Rate of Return and discounted payback period

For each energy efficiency improvement, the operational costs and energy savings were also calculated. This enabled the Internal Rate of Return (IRR) and discounted payback period to be established to indicate investment potential. A notional discount rate of 7% was used to calculate discounted payback periods for each improvement. These payback periods showed little sensitivity to changes in the discount rate applied.

The lifecycle costs of each energy efficiency improvement were determined based on expected servicing requirements, maintenance implications (major and minor overhauling) and replacement over a 30 year period where these were different to 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 years. The lifecycle costs were estimated to reflect an average assessment of maintenance, servicing and replacement. However, in practice, significant variance could arise.

Current gas and electricity prices were used to estimate the likely financial benefit from the energy saved. A sensitivity analysis was also carried out to reflect possible increased future energy prices and how this would improve the business case for each improvement. A 10% energy (gas and electricity) price rise per annum over five years was considered. The sensitivity of the IRR and discounted payback period to a fall in energy prices was not considered. Although prices have fluctuated in the short term, there is a general perception that prices will be higher in the medium to long term.

The IRR was calculated using undiscounted costs and energy savings over the lifecycle of the improvement, excluding subsequent replacement. This typically ranged from 10 to 20 years depending on the energy efficiency improvement applied.

2.10 Energy Performance Certificates

From 4 January 2009 (recently extended from 1 October 2008 by the Government), all non-domestic and non-public buildings (with a few exceptions) will require an Energy Performance Certificate (EPC) when they are constructed, sold or let. The purpose of an EPC is to rate the energy performance of the building (from A+ to G) 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 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 $kgCO_2/m^2$.

Estimated EPC ratings have been provided for each building modelled based on indicative ratings for similar buildings.

3. OFFICE RESULTS

3.1 Introduction

This section of the report outlines the results of the modelling and costing processes for all office buildings. The results are presented and discussed as follows:

- Baseline CO_2 emissions of the modelled office buildings
- The key energy efficiency improvements to be included as part of a building refurbishment during vacant possession
- The potential for making these improvements outside of a refurbishment scenario whilst there are tenants occupying the building

3.2 Baseline emissions

3.2.1 Baseline results

The baseline annual CO_2 emissions for the seven office buildings modelled are set out in Table 3.1 below. The baseline emissions equate to the Building Emissions Rate (BER) as calculated by the thermal modelling software.

Table 3.1: Baseline emissions for the office models

	Plan Depth	Age	Glazing %	Annual CO_2 Emissions ($kgCO_2/m^2$)	Emissions Benchmark (ECON 19) Good	Typical
Air conditioned						
Office 1	Deep	1990s fabric & services	50	72.2	55.3	109.2
Office 2	Deep	1990s fabric & services	80	79.2	55.3	109.2
Office 3	Narrow	1990s fabric & services	50	68.3	55.3	109.2
Office 4	Narrow	1990s fabric & services	80	73.8	55.3	109.2
Office 5	Deep	2002 fabric & services	80	51.0	55.3	109.2
Non-air conditioned						
Office 6	Narrow	Pre-1940s fabric & 1990 services	50	47.8	29.0	53.7
Mechanical ventilation only (no air conditioning)						
Office 7	Narrow	1990s fabric & services	50	56.4	29.0	53.7

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

3.2.2 Energy benchmark comparison

A comparison of the results against the Energy Consumption Guide 19[13] (ECON 19), which is widely used in industry to benchmark energy consumption and CO_2 emissions in office buildings, reveals that all the office buildings modelled perform in between the 'good' and 'typical' benchmarks, with the exception of Offices 5 and 7. These benchmarks exclude CO_2 emissions relating to office equipment, humidification, catering and computer rooms for reasons of comparison.

[13] Action Energy (1990) *Energy Consumption Guide 19: Energy use in offices*, available from the Carbon Trust website www.carbontrust.co.uk

It is worth noting that the benchmarks contained in ECON 19 were based on data collected in the mid-1990s from existing office stock. The 'typical' benchmark represents the median of the data collected. It is therefore expected that Offices 1 to 4, which represent early 1990s buildings, will perform better than the 'typical' benchmark given their age of construction.

Office 7, which uses mechanical ventilation, performs marginally worse than the benchmark. This is because the benchmark is for a naturally ventilated office only and does not take into account the additional electricity consumption associated with mechanical ventilation.

Office 5, which represents an office built post-2002, is expected to perform better than the good practice benchmark for two reasons. Firstly, the thermal performance of a building built in 2002 is better than its 1990 counterpart due to successive revisions to the Building Regulations (Part L). Secondly, the efficiency of the building services plant in modern offices has also increased. The baseline emissions modelled for Office 5 were found to be comparable with the maximum required by the 2006 version of the Part L regulations.

3.2.3 Analysis

Based on the results in Table 3.1 above, the headline findings, in terms of CO_2 emissions, are:

- **Offices have become more energy efficient.** Revisions to Part L of the Building Regulations have improved the thermal performance of building fabric (through improved insulation and glazing technology) and the efficiency of building services plant.
- **Narrow plan buildings perform better than deep plan.** The 1990s deep plan office had higher CO_2 emissions due to increased heating demand during winter. This is explained by the lower surface to volume ratio which limits the amount of solar gain received during winter.
- **Part glazed offices emit less CO_2 than fully glazed offices.** Lower CO_2 emissions are emitted because less solar gain occurs during summer (ie the internal space receives less heat from direct sunlight) and lower heat occurs during winter (windows lose considerably more heat than walls which can be well insulated).
- **CO_2 emissions are highest from air conditioned offices.** Air conditioning is a significant consumer of electricity (chilling plant, fans and pumps) compared with offices which are naturally ventilated or with mechanical ventilation only (ie no chilling plant).

3.2.4 Additional considerations

Section 2.3.6 listed a range of physical and operational building variations that were discretely modelled to determine the impact on baseline CO_2 emissions. The variations tested and the results are shown in Tables 3.2 and 3.3 below.

Table 3.2: Impact of building variations on Office 5 baseline CO_2 emissions

Building Variation	Office 5 modern, deep plan ($kgCO_2/m^2$)
Baseline CO_2 emissions	51.0
Height (10 storeys)	48.1
Height (30 storeys)	47.9
Extended hours of operation	122.1
Intensive use	51.8
Terraced	45.4

Table 3.3: Impact of orientation changes on Offices 2 and 4 baseline CO_2 emissions

Building variation	Office 2 1990s, deep plan ($kgCO_2/m^2$)	Office 4 1990s, narrow plan ($kgCO_2/m^2$)
Baseline CO_2 emissions	79.2	73.8
Orientation	79.1[14]	74.1[15]

Height

Taller office buildings tend to have lower CO_2 emissions per unit of floor area. Amending the height of Office 5 from 6 to 10 storeys reduced the baseline emissions by 6%, however, the reduction was only marginally more when the height was extended up to 30 storeys. Therefore, above 10 storeys, increasing the height of a building has little impact on emissions per unit of floor area.

Hours of operation

An office which is operational for longer on weekdays (7am to 10pm as opposed to 8am to 6pm) and used at weekends (8am to 6pm) emits annually more than twice the CO_2 per m^2 than the same office occupied for fewer hours on weekdays only.

In terms of the CO_2 emitted per hour worked, the office with extended hours of operation emits approximately 133.5$kgCO_2$ per hour annually (based on 52 weeks) compared with 106.0$kgCO_2$ per hour for an office with normal hours of operation, representing an increase in CO_2 emissions of 25%. It is therefore suggested that using a building for longer is less energy efficient per hour worked. Higher internal heat gains are produced when a building is used for longer and this heat has less time to dissipate when the building is not being used. As a result, the cooling load required to remove this heat is significantly higher.

Intensive use

An office with an intensive use, such as a call centre, has marginally higher CO_2 emissions compared with a standard office. The CO_2 emissions for Office 5 increased by 0.8$kgCO_2/m^2$ when the occupant density was increased. This marginal increase is explained by a reduction in CO_2 emissions from lower gas consumption (heating) being slightly exceeded by the CO_2 emissions from higher electricity use (cooling). Although more units of gas are saved compared with electricity, the CO_2 intensity of electricity production is greater.

These results indicate that offices with a high occupation density will be more efficient in terms of CO_2 emitted per person.

Terraced

An 11% reduction in baseline CO_2 emissions is achieved when an office building is arranged in a terrace with adjacent buildings on two sides compared with a detached office. A terraced office is representative of a city centre location and a detached office reflects a business park arrangement.

Buildings built in terraces are more efficient because there are only two external wall elevations, as opposed to four, through which heat loss or gain can occur.

[14] 45° rotation

[15] 90° rotation

Orientation

The orientation of the building in relation to the sun influences the solar heat gain received during the year and impacts on heating and cooling requirements. Based on the results in Table 3.3, it appears that the orientation of the offices tested has little impact on baseline CO_2 emissions.

In practice, changing the relative orientation of a building would have a higher impact on energy consumption. The building forms modelled are relatively simple because the proportion of glazing on each façade is the same whereas in reality this will not be the case. For example, the front of an office may be highly glazed, with smaller windows to the rear. Changing the orientation in this case would have a greater impact on energy consumption because the relative amount of solar energy entering the building will be more significantly affected. Therefore, from an early stage of the design process, the building form is designed to minimise the impact of orientation.

3.2.5 Energy Performance Certificate rating

The EPC rating for each office type was not calculated using accredited software as part of this study, however, based on evidence for similar buildings[16], a guide rating is provided in Table 3.4 below.

Table 3.4: Guide EPC ratings for the office buildings

	Office description	EPC rating (Guide only)
Offices 1 to 4	1990s, air conditioned	E
Office 5	2002, air conditioned	C
Office 6	Pre-1940s, no air conditioning	D
Office 7	1990s, mechanical ventilation	D

3.3 Energy efficiency improvements in a refurbishment scenario

This section of the report sets out the energy efficiency improvements which are the most cost effective for the office buildings considered when undertaking a refurbishment during vacant possession. The results and subsequent discussion are split between air conditioned offices and non-air conditioned offices to assist the analysis. Both sub-sections consider:

- The improvements that are cheapest to implement to save 1 $kgCO_2/m^2$
- The combined CO_2 savings that are achievable following implementation of a series of improvements within certain additional capital budgets

3.3.1 Air conditioned offices

This section focuses on the most cost effective energy efficiency improvements for Offices 1 to 5, which are all air conditioned buildings. Table 3.5 below lists the seven most cost effective improvements for each office. The full results follow in Tables 3.7 to 3.11 on pages 34 to 38.

[16] Based on an article published by www.bsjonline.co.uk entitled 'The EPC experience: Swan House' dated 25 July 2008. Swan House is a seven storey air conditioned office building built in 1989 with a total floor area of 51,175ft^2 (4,754m^2) and was considered comparable with Offices 1 to 4. Swan House achieved an E rating based on a score of 104 and an emissions rate of 75.3$kgCO_2/m^2$. The ratings for the remaining offices are notional only.

Table 3.5: Key energy efficiency improvements based on initial cost (£) per $kgCO_2/m^2$ saved

Energy efficiency improvement	Office 1 (£)	Office 2 (£)	Office 3 (£)	Office 4 (£)	Office 5 (£)
Variable speed heating pumps	0.14	0.12	0.16	0.14	0.16
Energy efficient lighting	0.40	0.39	0.40	0.39	0.32
DC drive fan coil units	0.50	0.45	0.52	0.52	1.20
Heat recovery	0.75	0.75	0.75	1.34	2.51
Maximise boiler efficiency	0.88	0.72	0.94	0.82	3.67
Power factor correction	1.26	1.15	1.41	1.24	2.96
Variable speed air conditioning pumps	2.45	1.98	5.14	2.34	1.03
Internal blinds	2.75	2.97	2.70	4.74	11.81
High efficiency chiller unit	3.04	2.52	3.35	2.84	1.77

The main findings are:

Variable speed heating pumps and energy efficient lamps are key improvements for all offices. Both improvements are low cost relative to the current market alternative and save electricity, which is a bigger emitter of CO_2 compared with gas. Variable speed pumps, rather than fixed speed pumps, and T5 lamps with high frequency ballasts should be specified. However, the pump improvement only saves a very small amount of CO_2 – approximately $0.5kgCO_2/m^2$

The most cost effective improvements for all 1990s office types modelled were relatively consistent. Table 3.5 shows that the key improvements are:

- Variable speed heating pumps
- Energy efficient lighting
- DC drive fan coil units
- Heat recovery
- Maximise boiler efficiency

Heating improvements offer the biggest CO_2 savings in older offices. Three of the improvements relate specifically to improving the efficiency of the heating system (pumps, heat recovery and boiler). There is a higher heating load associated with these early 1990s buildings compared with more recent buildings. The relatively poor building fabric leads to greater heat loss so there is more demand on the heating system to maintain the internal temperature at 20°C as necessary. Significant CO_2 savings, in the range 5 – $8kgCO_2/m^2$, are generated by installing a heat recovery unit and upgrading to a 95% efficiency boiler.

Cooling improvements are also significant for older offices. There are only two air conditioning improvements in the above list because cooling requirements are less significant for these older offices compared with heating. Upgrading to DC drive fan coil units rather than standard AC drive versions (DC motors allow the fan speed to be varied to suit air flow requirements) is the third most cost effective upgrade and provides a saving in the region of $6kgCO_2/m^2$ if undertaken independently of other improvements. The CO_2 saving from upgrading the pumps is significantly less.

Positive Internal Rate of Return for most key improvements. For all offices, the following key improvements all give a minimum Internal Rate of Return of 9%:

- Variable speed heating pumps
- Energy efficient lighting
- DC drive fan coil units
- Heat recovery[17]
- Maximise boiler efficiency
- Power correction factor

No other energy efficiency improvements achieve a positive IRR.

In terms of discounted payback periods using current energy prices, the variable speed heating pumps, energy efficient lighting and DC drive fan coil units all pay back initial capital and subsequent operational costs within five years. The other key improvements listed above pay back within 15 years. The remaining improvements modelled do not provide a return within 30 years.

Using inflated energy prices to represent potential future increases, the payback periods for the key improvements listed improve considerably. However, the inflated energy prices used are not sufficient to enable the majority of the improvements modelled to pay for themselves within a 30 year period. Therefore, energy prices would need to increase substantially in order to improve the investment case for all but the key improvements listed.

Cooling is more significant than heating for the modern office. Office 5, which represents a circa 2002 building, has a significantly reduced heating demand due to the improved fabric, however the cooling load has increased. Cooling improvements are therefore more significant to reduce CO_2 cost effectively. The main upgrade is to maximise the efficiency of the chiller plant being installed – a CO_2 saving of almost $4kgCO_2/m^2$ was achieved by installing a chiller with a Coefficient of Performance of 11 (an efficiency ratio measuring cooling output to electrical input) compared with the typical market equivalent chiller of 3.4. DC drive fan coil units are the next key improvement to consider in terms of CO_2 saved.

Renewable energy technologies do not give a positive IRR. No renewable technologies produced a positive IRR or payback period of less than 30 years. The most cost effective technology was the medium wind turbine; however the application of this technology is restricted because:

- Wind speeds may not be sufficient, which is the case in urban environments. Wind speed should be assessed for all locations
- Local planning constraints due to visual impact, which can be problematic in built up areas
- Noise
- Impacts on wildlife, namely birds and bats

[17] An IRR of 5% is given by the heat recovery improvement for Office 4.

Wind turbines are best suited to business park locations and are often used to make a visual environmental statement as well as reducing CO_2 emissions.

A solar hot water system was identified as the next most cost effective renewable energy technology to install but full consideration should be given to feasibility issues such as orientation and shading from other buildings.

The least cost effective improvements are also consistent for air conditioned offices. These improvements, ranked based on their marginal cost to save 1 unit of CO_2, are shown below in Table 3.6:

Table 3.6: Least cost effective improvements for air conditioned offices based on initial cost (£) per kgCO_2/m^2 saved

Energy efficiency improvement	Office 1 (£)	Office 2 (£)	Office 3 (£)	Office 4 (£)	Office 5 (£)
Solar water heating system	8.53	8.84	8.10	10.59	9.94
Combined heat and power	9.32	8.91	9.13	8.86	11.83
Window replacement with double glazing	11.38	14.87	12.34	23.24	N/A[18]
Ground source heating and cooling	14.49	14.23	13.48	13.82	13.02
Chilled beam cooling installation	15.92	15.92	16.47	15.87	18.50
Window replacement with triple glazing	16.28	30.90	19.23	48.21	95.63
Photovoltaic panels	23.17	24.34	29.75	26.77	26.48

With the exception of photovoltaic panels, these improvements save greater amounts of CO_2 compared with the other energy efficiency improvements considered, however they are relatively more expensive for each kg of CO_2 saved. They are therefore the least preferred option from a purely marginal cost perspective.

It is worth noting that a chilled beam installation, in lieu of traditional fan coil units, and replacing windows is increasingly becoming part of the upgrade solution for new and existing buildings. This is because 10% renewable energy targets required by local planning authorities (now 20% in some London and other metropolitan local authorities) are difficult to meet in cities and other urban areas without significantly reducing the overall energy demand of the building in the first instance. Chilled beams and double glazed windows (with 'low-e' coatings to reduce solar gain) are more cost effective compared to a substantial array of photovoltaic panels. A combined heat and power system is less effective in office buildings given their typically inconsistent heating loads. Ground source heating and cooling has a limited application in refurbishments due to the physical constraints typically posed by an existing building. Chilled beams and double glazing are therefore a logical option.

[18] Double glazing is part of the base building specification.

Table 3.7: Energy efficiency improvements for Office 1 in a refurbishment

Upgrade Category	Description of upgrade	Capital cost £/m² (extra over)	$kgCO_2$/m² saved	Marginal Cost £ per $kgCO_2$/m²	Internal Rate of Return	Payback - current energy costs (Year)	Payback - future energy costs (Year)	Limitations / discussion / assumptions
Heating	Upgrade heating pumps to variable speed pumps	0.06	0.45	0.14	124%	1	1	Variable speed more efficient than fixed speed pumps
Lighting	Upgrade lamps within office luminaires to 10W/m²	0.81	2.04	0.40	48%	3	2	12W/m² lamps part of a market standard refurbishment and luminaires not replaced
Cooling	DC drive fan coil units	3.13	6.29	0.50	40%	3	2	Direct current motors allow the fan speed to be varied to suit air flow requirements and conserve energy
Heating	Heat recovery through a thermal wheel	5.14	6.85	0.75	16%	8	5	Waste heat in the exhaust air to be returned into the incoming air supply
Heating	Upgrade boiler to achieve efficiency of 95%	5.37	6.11	0.88	12%	10	5	Boiler with an efficiency of 85% part of a market standard refurbishment
Power	Upgrade power correction factor to 0.95	2.28	1.81	1.26	11%	12	7	Improving the power factor of an electrical circuit reduces transmission losses
Cooling	Upgrade air conditioning pumps to variable speed pumps	0.51	0.21	2.45	-	No return	No return	Variable speed more efficient than fixed speed pumps
Shading	Internal blinds	14.26	5.18	2.75	-	No return	No return	No blinds present before refurbishment.
Cooling	Upgrade chiller plant to achieve a CoP of 11	6.51	2.14	3.04	-	No return	No return	High Coefficient of Performance (an efficiency ratio measuring cooling output to electrical input) compared with alternative chiller types
Renewable energy	Wind turbine 20kW	16.06	4.76	3.37	-	No return	No return	Suitable for business park locations
Cooling	Upgrade specific fan power to 1.5W/l/s	3.61	0.61	5.92	-	No return	No return	SFP is an efficiency measure of the amount of energy consumed to move each litre-per-second of air
Renewable energy	Solar water heating system 50m²	9.64	1.13	8.53	-	No return	No return	Provides domestic hot water
Heating and power	Combined heat and power system	80.31	8.62	9.32	-	No return	No return	CHP system meets 25% of the annual heating demand
Glazing	Reglazing single glazed window panes with double glazed panes	101.85	8.95	11.38	-	No return	No return	Reduces heat loss in winter and 'low-e' glazing reduces solar gain in summer
Renewable energy	Ground source heating and cooling	144.57	9.98	14.49	-	No return	No return	Suitable for business park locations
Cooling	Replace fan coil units with passive chilled beam installation	178.35	11.20	15.92	-	No return	No return	Cool air circulated by convection and not fan driven
Glazing	Replacing complete single glazed window units with triple glazed units	201.85	12.40	16.28	-	No return	No return	Reduces heat loss in winter and 'low-e' glazing reduces solar gain in summer
Renewable energy	Photovoltaics 100m²	24.09	1.04	23.17	-	No return	No return	Provides electricity

Note: 'No return' means that the initial cost of the improvement, maintenance costs and replacement costs are not paid back over a 30 year period by the energy saved. The IRR in these circumstances is negative.

Table 3.8: Energy efficiency improvements for Office 2 in a refurbishment

Upgrade Category	Description of upgrade	Capital cost £/m²	$kgCO_2$/ m² saved	Marginal Cost £ per $kgCO_2$ /m²	Internal Rate of Return	Payback - current energy costs (Year)	Payback - future energy costs (Year)	Limitations / discussion / assumptions
Heating	Upgrade heating pumps to variable speed pumps	0.06	0.52	0.12	144%	1	1	Variable speed more efficient than fixed speed pumps
Lighting	Upgrade lamps within office luminaires to 10W/m²	0.81	2.07	0.39	49%	3	2	12W/m² lamps part of a market standard refurbishment and luminaires not replaced
Cooling	DC drive fan coil units	3.13	6.99	0.45	44%	3	2	Direct current motors allow the fan speed to be varied to suit air flow requirements and conserve energy
Heating	Upgrade boiler to achieve efficiency of 95%	5.37	7.47	0.72	16%	7	4	Boiler with an efficiency of 85% part of a market standard refurbishment
Heating	Heat recovery through a thermal wheel	5.14	6.87	0.75	16%	8	5	Waste heat in the exhaust air to be returned into the incoming air supply
Power	Upgrade power correction factor to 0.95	2.28	1.98	1.15	12%	11	6	Improving the power factor of an electrical circuit reduces transmission losses
Cooling	Upgrade air conditioning pumps to variable speed pumps	0.51	0.26	1.98	-	No return	No return	Variable speed more efficient than fixed speed pumps
Cooling	Upgrade chiller plant to achieve a CoP of 11	6.51	2.58	2.52	-	No return	No return	High Coefficient of Performance (an efficiency ratio measuring cooling output to electrical input) compared with alternative chiller types
Shading	Internal blinds	23.15	7.79	2.97	-	No return	No return	No blinds present before refurbishment.
Renewable energy	Wind turbine 20kW	16.06	4.74	3.39	-	No return	No return	Suitable for business park locations
Cooling	Upgrade specific fan power to 1.5W/l/s	3.61	0.61	5.92	-	No return	No return	SFP is an efficiency measure of the amount of energy consumed to move each litre-per-second of air
Renewable energy	Solar water heating system 50m²	9.64	1.09	8.84	-	No return	No return	Provides domestic hot water
Heating and power	Combined heat and power system	90.75	10.19	8.91	-	No return	No return	CHP system meets 25% of the annual heating demand
Renewable energy	Ground source heating and cooling	168.66	11.85	14.23	-	No return	No return	Suitable for business park locations
Glazing	Reglazing single glazed window panes with double glazed panes	192.59	12.95	14.87	-	No return	No return	Reduces heat loss in winter and 'low-e' glazing reduces solar gain in summer
Cooling	Replace fan coil units with chilled beam installation	178.35	11.20	15.92	-	No return	No return	Cool air circulated by convection and not fan driven
Renewable energy	Photovoltaics 100m²	24.09	0.99	24.34	-	No return	No return	Provides electricity
Glazing	Replacing complete single glazed window units with triple glazed units	551.85	17.86	30.90	-	No return	No return	Reduces heat loss in winter and 'low-e' glazing reduces solar gain in summer

Table 3.9: Energy efficiency improvements for Office 3 in a refurbishment

Upgrade Category	Description of upgrade	Capital cost £/m²	$kgCO_2$/m² saved	Marginal Cost £ per $kgCO_2$/m²	Internal Rate of Return	Payback - current energy costs (Year)	Payback - future energy costs (Year)	Limitations / discussion
Heating	Upgrade heating pumps to variable speed pumps	0.06	0.40	0.16	110%	1	1	Variable speed more efficient than fixed speed pumps
Lighting	Upgrade lamps within office luminaires to 10W/m²	0.81	2.03	0.40	48%	3	2	12W/m² lamps part of a market standard refurbishment and luminaires not replaced
Cooling	DC drive fan coil units	3.13	5.98	0.52	38%	3	2	Direct current motors allow the fan speed to be varied to suit air flow requirements and conserve energy
Heating	Heat recovery through a thermal wheel	5.14	6.84	0.75	16%	8	5	Waste heat in the exhaust air to be returned into the incoming air supply
Heating	Upgrade boiler to achieve efficiency of 95%	5.37	5.68	0.94	11%	11	6	Boiler with an efficiency of 85% part of a market standard refurbishment
Power	Upgrade power correction factor to 0.95	2.28	1.62	1.41	9%	15	8	Improving the power factor of an electrical circuit reduces transmission losses
Shading	Internal blinds	17.59	6.52	2.70	-	No return	No return	No blinds present before refurbishment.
Renewable energy	Wind turbine 20kW	16.06	4.82	3.33	-	No return	No return	Suitable for business park locations
Cooling	Upgrade chiller plant to achieve a CoP of 11	6.51	1.94	3.35	-	No return	No return	High Coefficient of Performance (an efficiency ratio measuring cooling output to electrical input) compared with alternative chiller types
Cooling	Upgrade air conditioning pumps to variable speed pumps	0.51	0.10	5.14	-	No return	No return	Variable speed more efficient than fixed speed pumps
Cooling	Upgrade specific fan power to 1.5W/l/s	3.61	0.53	6.82	-	No return	No return	SFP is an efficiency measure of the amount of energy consumed to move each litre-per-second of air
Renewable energy	Solar water heating system 50m²	9.64	1.19	8.10	-	No return	No return	Provides domestic hot water
Heating and power	Combined heat and power system	69.87	7.65	9.13	-	No return	No return	CHP system meets 25% of the annual heating demand
Glazing	Reglazing single glazed window panes with double glazed panes	126.85	10.28	12.34	-	No return	No return	Reduces heat loss in winter and 'low-e' glazing reduces solar gain in summer
Renewable energy	Ground source heating and cooling	120.47	8.94	13.48	-	No return	No return	Suitable for business park locations
Cooling	Replace fan coil units with chilled beam installation	178.35	10.83	16.47	-	No return	No return	Cool air circulated by convection and not fan driven
Glazing	Replacing complete single glazed window units with triple glazed units	251.85	13.10	19.23	-	No return	No return	Reduces heat loss in winter and 'low-e' glazing reduces solar gain in summer
Renewable energy	Photovoltaics 100m²	24.09	0.81	29.75	-	No return	No return	Provides electricity

Table 3.10: Energy efficiency improvements for Office 4 in a refurbishment

Upgrade Category	Description of upgrade	Capital cost £/m²	$kgCO_2$/m² saved	Marginal Cost £ per $kgCO_2$/m²	Internal Rate of Return	Payback - current energy costs (Year)	Payback - future energy costs (Year)	Limitations / discussion
Heating	Upgrade heating pumps to variable speed pumps	0.06	0.46	0.14	127%	1	1	Variable speed more efficient than fixed speed pumps
Lighting	Upgrade lamps within office luminaires to 10W/m²	0.81	2.07	0.39	49%	3	2	12W/m² lamps part of a market standard refurbishment and luminaires not replaced
Cooling	DC drive fan coil units	3.13	6.05	0.52	38%	3	2	Direct current motors allow the fan speed to be varied to suit air flow requirements and conserve energy
Heating	Upgrade boiler to achieve efficiency of 95%	5.37	6.57	0.82	14%	9	5	Boiler with an efficiency of 85% part of a market standard refurbishment
Power	Upgrade power correction factor to 0.95	2.28	1.84	1.24	11%	12	7	Improving the power factor of an electrical circuit reduces transmission losses
Heating	Heat recovery through a thermal wheel	5.14	3.85	1.34	5%	No return	9	Waste heat in the exhaust air to be returned into the incoming air supply
Cooling	Upgrade air conditioning pumps to variable speed pumps	0.51	0.22	2.34	-	No return	No return	Variable speed more efficient than fixed speed pumps
Cooling	Upgrade chiller plant to achieve a CoP of 11	6.51	2.29	2.84	-	No return	No return	High Coefficient of Performance (an efficiency ratio measuring cooling output to electrical input) compared with alternative chiller types
Renewable energy	Wind turbine 20kW	16.06	4.71	3.41	-	No return	No return	Suitable for business park locations
Shading	Internal blinds	28.70	6.05	4.74	-	No return	No return	No blinds present before refurbishment.
Cooling	Upgrade specific fan power to 1.5W/l/s	3.61	0.60	6.02	-	No return	No return	SFP is an efficiency measure of the amount of energy consumed to move each litre-per-second of air
Heating and power	Combined heat and power system	80.31	9.06	8.86	-	No return	No return	CHP system meets 25% of the annual heating demand
Renewable energy	Solar water heating system 50m²	9.64	0.91	10.59	-	No return	No return	Provides domestic hot water
Renewable energy	Ground source heating and cooling	144.57	10.46	13.82	-	No return	No return	Suitable for business park locations
Cooling	Replace fan coil units with chilled beam installation	178.35	11.24	15.87	-	No return	No return	Cool air circulated by convection and not fan driven
Glazing	Reglazing single glazed window panes with double glazed panes	240.74	10.36	23.24	-	No return	No return	Reduces heat loss in winter and 'low-e' glazing reduces solar gain in summer
Renewable energy	Photovoltaics 100m²	24.09	0.90	26.77	-	No return	No return	Provides electricity
Glazing	Replacing complete single glazed window units with triple glazed units	688.89	14.29	48.21	-	No return	No return	Reduces heat loss in winter and 'low-e' glazing reduces solar gain in summer

Table 3.11: Energy efficiency improvements for Office 5 in a refurbishment

Upgrade Category	Description of upgrade	Capital cost £/m²	$kgCO_2$/ m² saved	Marginal Cost £ per $kgCO_2$ /m²	Internal Rate of Return	Payback - current energy costs (Year)	Payback - future energy costs (Year)	Limitations / discussion
Heating	Upgrade heating pumps to variable speed pumps	0.06	0.40	0.16	124%	1	1	Variable speed more efficient than fixed speed pumps
Lighting	Upgrade lamps within office luminaires to 10W/m²	0.81	2.57	0.32	48%	3	2	12W/m² lamps part of a market standard refurbishment and luminaires not replaced
Cooling	Upgrade air conditioning pumps to variable speed pumps	0.51	0.50	1.03	-	No return	No return	Variable speed more efficient than fixed speed pumps
Cooling	DC drive fan coil units	3.13	2.61	1.20	40%	3	2	Direct current motors allow the fan speed to be varied to suit air flow requirements and conserve energy
Cooling	Upgrade chiller plant to achieve a CoP of 11	6.51	3.67	1.77	-	No return	No return	High Coefficient of Performance (an efficiency ratio measuring cooling output to electrical input) compared with alternative chiller types
Heating	Heat recovery through a thermal wheel	5.14	2.05	2.51	15%	8	5	Waste heat in the exhaust air to be returned into the incoming air supply
Power	Upgrade power correction factor to 0.95	2.28	0.77	2.96	11%	12	7	Improving the power factor of an electrical circuit reduces transmission losses
Renewable energy	Wind turbine 20kW	16.06	4.82	3.33	-	No return	No return	Suitable for business park locations
Heating	Upgrade boiler to achieve efficiency of 95%	5.37	1.46	3.67	12%	10	5	Boiler with an efficiency of 85% part of a market standard refurbishment
Cooling	Upgrade specific fan power to 1.5W/l/s	3.61	0.43	8.41	-	No return	No return	SFP is an efficiency measure of the amount of energy consumed to move each litre-per-second of air
Renewable energy	Solar water heating system 50m²	9.64	0.97	9.94	-	No return	No return	Provides domestic hot water
Shading	Internal blinds	23.15	1.96	11.81	-	No return	No return	No blinds present before refurbishment.
Heating and power	Combined heat and power system	48.98	4.14	11.83	-	No return	No return	CHP system meets 25% of the annual heating demand
Renewable energy	Ground source heating and cooling	72.28	5.55	13.02	-	No return	No return	Suitable for business park locations
Cooling	Replace fan coil units with chilled beam installation	178.35	9.64	18.50	-	No return	No return	Cool air circulated by convection and not fan driven
Renewable energy	Photovoltaics 100m²	24.09	0.91	26.48	-	No return	No return	Provides electricity
Glazing	Replacing complete double glazed window units with triple glazed units	554.63	5.80	95.63	-	No return	No return	Reduces heat loss in winter and 'low-e' glazing reduces solar gain in summer

3.3.2 Non air conditioned offices

This section focuses on the most cost effective improvements for Offices 6 and 7, which are non air conditioned. A summary of the key improvements are shown in Table 3.12 with the full results in Tables 3.13 and 3.14.

Table 3.12: Key energy efficiency improvements for Office buildings 6 and 7

Office 6 key improvements	Office 7 key improvements
Variable speed heating pumps	Variable speed heating pumps
Energy efficient lighting	DC drive fan coil units
Maximise boiler efficiency	Energy efficient lighting
Power correction factor	Heat recovery
Medium wind turbine	Specific fan power
Internal blinds	Power correction factor
Retrofit wall insulation	Maximise boiler efficiency

Positive Internal Rate of Return for all Office 7 key improvements. All the key improvements listed in Table 3.12 provide a positive IRR. Maximising the boiler efficiency gives an IRR of 5% whilst all other key improvements range from 9% up to 154%. In terms of discounted payback periods, all key improvements for Office 7 (except the boiler improvement) pay back within 15 years. If inflated energy prices are used, all key improvements pay back within 10 years.

For Office 6, only the top four key improvements generate a positive IRR, ranging from 5% for the power factor improvement up to 151% for the variable speed heating pumps. These improvements pay back within 11 years based on current energy prices or six years if prices increase.

Table 3.13: Energy efficiency improvements for Office 6 in a refurbishment

Upgrade Category	Description of upgrade	Capital cost £/m²	$kgCO_2$/ m² saved	Marginal Cost £ per $kgCO_2$ /m²	Internal Rate of Return	Payback - current energy costs (Year)	Payback - future energy costs (Year)	Limitations / discussion
Heating	Upgrade heating pumps to variable speed pumps	0.06	0.54	0.12	151%	1	1	Variable speed more efficient than fixed speed pumps
Lighting	Upgrade lamps within office luminaires to 10W/m²	0.81	4.58	0.18	42%	3	2	12W/m² lamps part of a market standard refurbishment and luminaires not replaced
Heating	Upgrade boiler to achieve efficiency of 95%	5.37	5.33	1.01	10%	11	6	Boiler with an efficiency of 85% part of a market standard refurbishment
Power	Upgrade power correction factor to 0.95	2.28	1.19	1.92	5%	No return	12	Improving the power factor of an electrical circuit reduces transmission losses
Renewable energy	Wind turbine 20kW	16.06	3.84	4.18	-	No return	No return	Suitable for business park locations
Shading	Internal blinds	17.59	3.58	4.91	-	No return	No return	No blinds present before refurbishment.
Building fabric	Improve external wall insulation by adding high performance insulation to internal surface	25.93	3.97	6.53	-	No return	No return	Approximately 10cm internal floor area lost around the building perimeter
Heating and power	Combined heat and power system	69.87	9.06	7.71	-	No return	No return	CHP system meets 25% of the annual heating demand
Renewable energy	Solar water heating system 50m²	9.64	1.03	9.36	-	No return	No return	Provides domestic hot water
Renewable energy	Ground source heating and cooling	120.47	7.35	16.39	-	No return	No return	Suitable for business park locations
Glazing	Reglazing single glazed window panes with double glazed panes	126.85	5.23	24.25	-	No return	No return	Reduces heat loss in winter and 'low-e' glazing reduces solar gain in summer
Renewable energy	Photovoltaics 100m²	24.09	0.82	29.38	-	No return	No return	Provides electricity
Glazing	Replacing complete single glazed window units with triple glazed units	251.85	8.36	30.13	-	No return	No return	Reduces heat loss in winter and 'low-e' glazing reduces solar gain in summer

Table 3.14: Energy efficiency improvements for Office 7 in a refurbishment

Upgrade Category	Description of upgrade	Capital cost £/m² (extra over)	$kgCO_2$/ m² saved	Marginal Cost £ per $kgCO_2$ /m²	Internal Rate of Return	Payback - current energy costs (Year)	Payback - future energy costs (Year)	Limitations / discussion
Heating	Upgrade heating pumps to variable speed pumps	0.06	1.09	0.06	154%	1	1	Variable speed more efficient than fixed speed pumps
Ventilation	DC drive fan coil units	3.13	13.83	0.23	67%	2	1	Direct current motors allow the fan speed to be varied to suit air flow requirements and conserve energy
Lighting	Upgrade lamps within office luminaires to 10W/m²	0.81	2.16	0.37	49%	3	2	12W/m² lamps part of a market standard refurbishment and luminaires not replaced
Heating	Heat recovery through a thermal wheel	5.14	13.32	0.39	39%	3	2	Waste heat in the exhaust air to be returned into the incoming air supply
Ventilation	Upgrade specific fan power to 1.5W/l/s	3.61	6.62	0.55	30%	4	3	SFP is an efficiency measure of the amount of energy consumed to move each litre-per-second of air
Power	Upgrade power correction factor to 0.95	2.28	2.12	1.08	9%	14	8	Improving the power factor of an electrical circuit reduces transmission losses
Heating	Upgrade boiler to achieve efficiency of 95%	5.37	4.09	1.31	5%	No return	9	Boiler with an efficiency of 85% part of a market standard refurbishment
Renewable energy	Wind turbine 20kW	16.06	5.77	2.78	-	No return	No return	Suitable for business park locations
Shading	Internal blinds	17.59	5.36	3.28	-	No return	No return	No blinds present before refurbishment.
Renewable energy	Solar water heating system 20m²	3.86	1.09	3.54	-	No return	No return	Provides domestic hot water
Heating and power	Combined heat and power system	69.87	6.27	11.14	-	No return	No return	CHP system meets 25% of the annual heating demand
Renewable energy	Ground source heating and cooling	96.38	6.30	15.30	-	No return	No return	Suitable for business park locations
Renewable energy	Photovoltaics 100m²	24.09	1.56	15.45	-	No return	No return	Provides electricity
Glazing	Reglazing single glazed window panes with double glazed panes	126.85	6.78	18.71	-	No return	No return	Reduces heat loss in winter and 'low-e' glazing reduces solar gain in summer
Building fabric	Improve external wall insulation by adding high performance insulation to internal surface	25.93	0.82	31.62	-	No return	No return	Approximately 10cm internal floor area lost around the building perimeter
Glazing	Replacing complete single glazed window units with triple glazed units	251.85	7.74	32.54	-	No return	No return	Reduces heat loss in winter and 'low-e' glazing reduces solar gain in summer

Heating, lighting and power improvements are consistent with those for air conditioned offices. There is consistency between air conditioned and non-air conditioned offices with regards to upgrading the heating pumps, lighting, boiler and power factor correction. The remaining key improvements for Office 7 also resemble those for the air conditioned offices, with the exception of specific fan power.

Wind turbines, internal blinds and retrofit wall insulation are further considerations for naturally ventilated offices. However, the marginal cost of the medium wind turbine, internal blinds and extra wall insulation are at least double the cost of the first four measures listed. In addition, the wind turbine may not be feasible given site issues, blinds may have been present in the existing building and improving the wall insulation means retrofitting it to the inside surface thus reducing lettable floor area.

The least cost effective improvements are similar to air conditioned offices. These improvements are shown in Table 3.15.

Table 3.15: Least cost effective improvements for Offices 6 and 7

Office 6	Office 7
Combined heat and power	Combined heat and power
Solar water heating system	Ground source heating and cooling
Ground source heating and cooling	Photovoltaic panels
Window replacement with double glazing	Window replacement with double glazing
Photovoltaic panels	Retrofit wall insulation
Window replacement with triple glazing	Window replacement with triple glazing

In summary, there is broad consistency between all offices studied in terms of the cost effective energy efficiency improvements to include in a major refurbishment.

3.3.3 Combining improvements

In a refurbishment scenario, it is likely that several energy efficiency improvements would be implemented. With the exception of renewable energy, the combined reduction in CO_2 savings from applying several improvements will be lower compared to the sum of the individual savings shown in the results tables. This is because the absolute CO_2 saving from each improvement will be proportionately reduced when applied to a diminishing level of baseline emissions.

Tables 3.16 and 3.17 below summarise the CO_2 savings that are achievable from implementing improvements in packages.

Table 3.16: Cumulative CO_2 savings for additional capital expenditure

Cumulative CO_2 saving ($kgCO_2/m^2$)							
	Office 1	Office 2	Office 3	Office 4	Office 5	Office 6	Office 7
Market improvement	18.3	20.7	17.0	18.6	0	14.1	13.6
£25/m^2 budget	26.8	30.8	23.6	25.9	7.12	2.22	1.8
£50/m^2 budget	34.0	36.8	31.6	30.9	14.12	4.22	8.5
£75/m^2 budget	35.2	41.0	33.1	34.0	15.0	26.3	28.7
£150/m^2 budget	39.1	45.6	36.6	40.2	18.2	30.1	30.5

Table 3.17: Percentage reduction in CO_2 emissions against base case emissions

Cumulative % saving							
	Office 1	Office 2	Office 3	Office 4	Office 5	Office 6	Office 7
Market improvement	25%	26%	25%	25%	0%	30%	24%
£25/m^2 budget	37%	39%	35%	35%	14%	47%	39%
£50/m^2 budget	47%	46%	46%	42%	28%	51%	50%
£75/m^2 budget	49%	52%	48%	46%	29%	55%	51%
£150/m^2 budget	54%	58%	54%	54%	36%	63%	54%

The capital budget thresholds shown equate to approximately 2.5%, 5%, 7.5% and 15% extra over the cost of a major refurbishment (excluding design fees). The costs of major refurbishment projects usually occur within a broad range (Q3 2008: £700 to £1 000/m^2 excluding professional fees) because the scope of works can vary considerably. For the purposes of this study, a notional refurbishment cost of £1 000/m^2 has been adopted (assuming a Category A fit out) and the budget thresholds reflect this.

Each budget allowance comprises a number of improvements which have been applied to the base case as a series of packages. The budget allowances in Tables 3.16 (shown graphically in Figure 3.1 on page 45 below) and 3.17 correspond to the coloured improvements in the respective results tables (Tables 3.6 to 3.10, 3.13 and 3.14 in Sections 3.3.1 and 3.3.2). The different packages have been applied sequentially. For example, the £50/m^2 budget for Office 1 includes the darker blue improvements (heating pumps, lamps, DC fan coil units, heat recovery, high efficiency boiler, power factor correction, air conditioning pumps) and the lighter blue improvements (internal blinds, chiller plant upgrade, medium wind turbine).

The main findings are:

Modernising older offices to current market standards (£1000/m^2) reduces baseline CO_2 emissions by approximately 25%. Refurbishing all older offices up to modern standards (ie with no extra expenditure over a standard market refurbishment) will reduce baseline emissions by approximately one quarter and will probably be sufficient to achieve an Energy Performance Certificate rating of a C. The saving is greatest for the non-air conditioned 'period' office (Office 6) which achieves a 30% reduction. There is no improvement for Office 5 because it reflects the performance of a modern office. These CO_2 savings are shown on the x-axis of Figure 3.1 where the cumulative additional capital cost is zero (y=0).

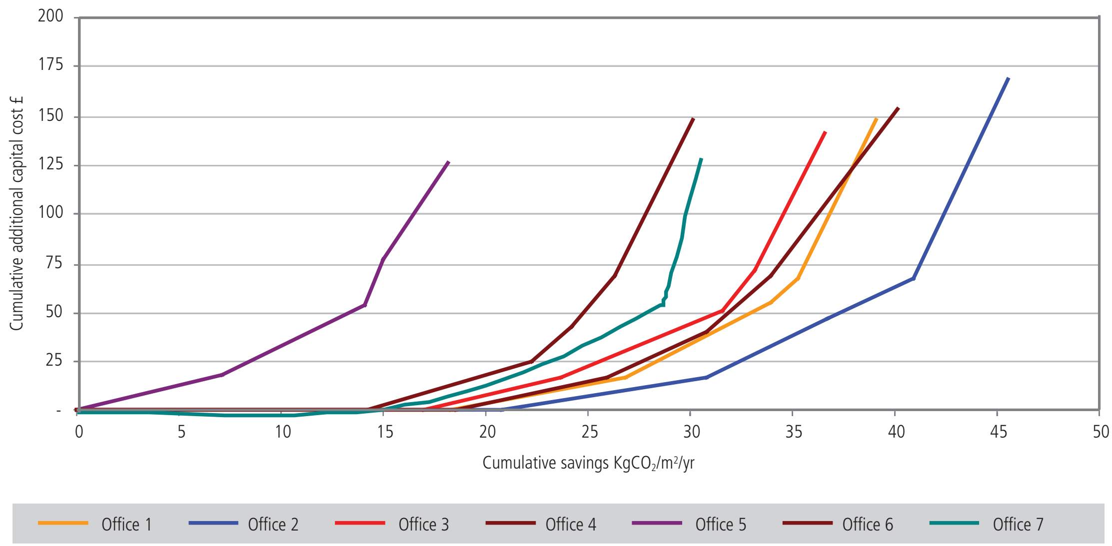
Additional expenditure of 2.5% reduces total baseline emissions by between 35% and 47% for older offices. By spending an additional £25/m^2 when undertaking a major refurbishment of 1990s offices, the total CO_2 saved from baseline emissions will be in the range between 35% and 39%. The saving for Office 6 is more significant at 47% and this is also the case for all levels of additional expenditure. Similarly, the saving is less pronounced for the modern office at all levels of additional expenditure because the improvements are being applied to a lower starting baseline.

Additional expenditure of £50/m^2, equating to an extra spend of 5% based on a £1 000/m^2 refurbishment cost, will achieve a baseline reduction in the range of 42% to 51% for all older offices. It is envisaged that this additional capital cost would be sufficient to achieve an EPC rating of a B.

Absolute CO_2 reductions are highest for Office 2. The deep plan, fully glazed 1990's office achieves the largest reduction in CO_2 in kg/m^2 for each additional budget allowance, as represented by the blue line in Figure 3.1.

Further reductions in CO_2 emissions become increasingly more expensive. The increased gradient of the line graphs in Figure 3.1 below show that beyond £50/m^2 the cumulative cost of saving additional units of CO_2 becomes significantly less cost effective.

Figure 3.1: Cumulative cost of reducing CO_2 emissions for all offices



3.4 Energy efficiency improvements in an occupied building

The previous discussion related 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 will be important where a planned refurbishment is some years away and one or more leases are due to expire. The introduction of EPCs will make 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 it could assist the lease renewal, reduce void periods and potentially affect the rental level achieved.

The full list of the improvements that can be undertaken in an occupied office are included in Tables 3.19 to 3.23, 3.25 and 3.26 in Sections 3.4.1 to 3.4.3 below.

3.4.1 Air conditioned 1990s offices

The improvements that can be implemented when the building is occupied by one or more tenants are discussed below for the older air conditioned offices.

The main findings are:

The most cost effective improvements are the same compared with a refurbishment scenario. For Offices 1 to 4, the key improvements that can be carried out in a fully occupied office are:

Table 3.18: Energy efficiency improvements based on initial cost (£) per $kgCO_2/m^2$ saved

Energy efficiency improvement	Office 1 (£)	Office 2 (£)	Office 3 (£)	Office 4 (£)
Variable speed heating pumps	0.14	0.12	0.16	0.14
Energy efficient lighting	0.60	0.59	0.60	0.59
Maximise boiler efficiency	0.88	0.72	0.94	0.82
Heat recovery	1.13	1.12	1.13	2.00
Power factor correction	1.89	1.73	2.11	1.86
Variable speed air conditioning pumps	2.45	1.98	[19]	2.34

The full results for Offices 1 to 4 are shown in Tables 3.19 to 3.22 below.

Table 3.19: Office 1 energy efficiency improvements without vacant possession

Upgrade Category	Description of upgrade	Capital cost £/m² (extra over)	$kgCO_2/m^2$ saved	Marginal Cost £ per $kgCO_2/m^2$	Internal Rate of Return	Payback - current energy costs (Year)	Normal working or out of hours working	Limitations / discussion / assumptions
Heating	Upgrade heating pumps to variable speed pumps	0.06	0.45	0.14	124%	1	Normal	Assumes that there are stand-by pumps (good practice design) to provide heating and domestic hot water. Undertake replacement during summer.
Lighting	Upgrade lamps within office luminaires to 10W/m²	1.21	2.04	0.60	31%	4	Out of hours	
Heating	Upgrade boiler to achieve efficiency of 95%	5.37	6.11	0.88	12%	10	Normal	Assumes that there are stand-by boilers (good practice design) to provide heating and domestic hot water. Undertake replacement during summer.
Heating	Heat recovery through a thermal wheel	7.71	6.85	1.13	8%	13	Out of hours	
Power	Upgrade power correction factor to 0.95	3.42	1.81	1.89	5%	No return	Out of hours	
Cooling	Upgrade air conditioning pumps to variable speed pumps	0.51	0.21	2.45	-	No return	Normal	Assumes that there are stand-by pumps to provide cooling
Renewable energy	Wind turbine 20kW	16.06	4.76	3.37	-	No return	Normal	Suitable for business park locations
Shading	Internal blinds	19.07	5.18	3.68	-	No return	Out of hours	
Cooling	Upgrade chiller plant to achieve a CoP of 11	9.76	2.14	4.56	-	No return	Out of hours	Likely to be weekend work because a road closure will be required in an urban environment. Integration with existing building services means that a weekend shut down will be required.
Renewable energy	Solar water heating system 50m²	9.64	1.13	8.53	-	No return	Normal	
Cooling	Upgrade specific fan power to 1.5W/l/s	5.42	0.61	8.89	-	No return	Out of hours	
Renewable energy	Photovoltaics 100m²	24.09	1.04	23.17	-	No return	Normal	

[19] The variable speed air conditioning pumps have a higher marginal cost (£5.14) compared to the wind turbine (£3.33), internal blinds (£3.69) and high efficiency chiller unit (£5.03).

Table 3.20: Office 2 energy efficiency improvements without vacant possession

Upgrade Category	Description of upgrade	Capital cost £/m² (extra over)	$kgCO_2$/m² saved	Marginal Cost £ per $kgCO_2$/m²	Internal Rate of Return	Payback - current energy costs (Year)	Normal working or out of hours working	Limitations / discussion / assumptions
Heating	Upgrade heating pumps to variable speed pumps	0.06	0.52	0.12	144%	1	Normal	Assumes that there are stand-by pumps (good practice design) to provide heating and domestic hot water. Undertake replacement during summer.
Lighting	Upgrade lamps within office luminaires to 10W/m²	1.21	2.07	0.59	32%	4	Out of hours	
Heating	Upgrade boiler to achieve efficiency of 95%	5.37	7.47	0.72	16%	7	Normal	Assumes that there are stand-by boilers (good practice design) to provide heating and domestic hot water. Undertake replacement during summer.
Heating	Heat recovery through a thermal wheel	7.71	6.87	1.12	8%	13	Out of hours	
Power	Upgrade power correction factor to 0.95	3.42	1.98	1.73	-	No return	Out of hours	
Cooling	Upgrade air conditioning pumps to variable speed pumps	0.51	0.26	1.98	-	No return	Normal	Assumes that there are stand-by pumps to provide cooling
Renewable energy	Wind turbine 20kW	16.06	4.74	3.39	-	No return	Normal	Suitable for business park locations
Cooling	Upgrade chiller plant to achieve a CoP of 11	9.76	2.58	3.78	-	No return	Out of hours	Likely to be weekend work because a road closure will be required in an urban environment. Integration with existing building services means that a weekend shut down will be required.
Shading	Internal blinds	30.56	7.79	3.92	-	No return	Out of hours	
Renewable energy	Solar water heating system 50m²	9.64	1.09	8.84	-	No return	Normal	
Cooling	Upgrade specific fan power to 1.5W/l/s	5.42	0.61	8.89	-	No return	Out of hours	
Renewable energy	Photovoltaics 100m²	24.09	0.99	24.34	-	No return	Normal	

Table 3.21: Office 3 energy efficiency improvements without vacant possession

Upgrade Category	Description of upgrade	Capital cost £/m² (extra over)	$kgCO_2$/ m² saved	Marginal Cost £ per $kgCO_2$ /m²	Internal Rate of Return	Payback - current energy costs (Year)	Normal working or out of hours working	Limitations / discussion / assumptions
Heating	Upgrade heating pumps to variable speed pumps	0.06	0.40	0.16	110%	1	Normal	Assumes that there are stand-by pumps (good practice design) to provide heating and domestic hot water. Undertake replacement during summer.
Lighting	Upgrade lamps within office luminaires to 10W/m²	1.21	2.03	0.60	31%	4	Out of hours	
Heating	Upgrade boiler to achieve efficiency of 95%	5.37	5.68	0.94	11%	11	Normal	Assumes that there are stand-by boilers (good practice design) to provide heating and domestic hot water. Undertake replacement during summer.
Heating	Heat recovery through a thermal wheel	7.71	6.84	1.13	8%	13	Out of hours	
Power	Upgrade power correction factor to 0.95	3.42	1.62	2.11	4%	No return	Out of hours	
Renewable energy	Wind turbine 20kW	16.06	4.82	3.33	-	No return	Normal	Suitable for business park locations
Shading	Internal blinds	24.07	6.52	3.69	-	No return	Out of hours	
Cooling	Upgrade chiller plant to achieve a CoP of 11	9.76	1.94	5.03	-	No return	Out of hours	Likely to be weekend work because a road closure will be required in an urban environment. Integration with existing building services means that a weekend shut down will be required.
Cooling	Upgrade air conditioning pumps to variable speed pumps	0.51	0.10	5.14	-	No return	Normal	Assumes that there are stand-by pumps to provide cooling
Renewable energy	Solar water heating system 50m²	9.64	1.19	8.10	-	No return	Normal	
Cooling	Upgrade specific fan power to 1.5W/l/s	5.42	0.53	10.23	-	No return	Out of hours	
Renewable energy	Photovoltaics 100m²	24.09	0.81	29.75	-	No return	Normal	

Table 3.22: Office 4 energy efficiency improvements without vacant possession

Upgrade Category	Description of upgrade	Capital cost £/m² (extra over)	kgCO2/ m² saved	Marginal Cost £ per kgCO2 /m²	Internal Rate of Return	Payback - current energy costs (Year)	Normal working or out of hours working	Limitations / discussion / assumptions
Heating	Upgrade heating pumps to variable speed pumps	0.06	0.46	0.14	127%	1	Normal	Assumes that there are stand-by pumps (good practice design) to provide heating and domestic hot water. Undertake replacement during summer.
Lighting	Upgrade lamps within office luminaires to 10W/m²	1.21	2.07	0.59	32%	3	Out of hours	
Heating	Upgrade boiler to achieve efficiency of 95%	5.37	6.57	0.82	14%	9	Normal	Assumes that there are stand-by boilers (good practice design) to provide heating and domestic hot water. Undertake replacement during summer.
Power	Upgrade power correction factor to 0.95	3.42	1.84	1.86	5%	11	Out of hours	
Heating	Heat recovery through a thermal wheel	7.71	3.85	2.00	-	25	Out of hours	
Cooling	Upgrade air conditioning pumps to variable speed pumps	0.51	0.22	2.34	-	No return	Normal	Assumes that there are stand-by pumps to provide cooling
Renewable energy	Wind turbine 20kW	16.06	4.71	3.41	-	No return	Normal	Suitable for business park locations
Cooling	Upgrade chiller plant to achieve a CoP of 11	9.76	2.29	4.26	-	No return	Out of hours	Likely to be weekend work because a road closure will be required in an urban environment. Integration with existing building services means that a weekend shut down will be required.
Shading	Internal blinds	37.96	6.05	6.27	-	No return	Out of hours	
Cooling	Upgrade specific fan power to 1.5W/l/s	5.42	0.60	9.04	-	No return	Out of hours	
Renewable energy	Solar water heating system 50m²	9.64	0.91	10.59	-	No return	Normal	
Renewable energy	Photovoltaics 100m²	24.09	0.90	26.77	-	No return	Normal	

The one exception is the high efficiency (DC drive) fan coil units which can only be installed during a period of vacant possession. This work requires full access to the ceiling void in order to install the fan coil units and amend the pipework, ductwork and electrical connections accordingly. The work would be typically carried out to a whole floor at any one time and will be part of a major refurbishment which would also renew the lighting and suspended ceiling.

Undertaking the improvements listed above should coincide with the maintenance and replacement regime of the building. Some improvements, such as the replacement of lamp fittings, can be integrated with the ongoing planned preventative maintenance programme in order to minimise both capital cost outlay and waste. Replacement of other items, such as the heating and air conditioning pumps, can coincide with a major overhaul of this equipment.

The only improvements that give a positive Internal Rate of Return are:

- Variable speed heating pumps
- Energy efficient lighting
- Maximise boiler efficiency
- Heat recovery
- Power correction factor

These key improvements all provide an IRR exceeding 8%, with the exception of the power correction factor improvement.

3.4.2 Air conditioned 2002 office

Table 3.23 shows the possible improvements that can be undertaken in an occupied modern office (Office 5).

Table 3.23: Office 5 energy efficiency improvements without vacant possession

Upgrade Category	Description of upgrade	Capital cost £/m² (extra over)	$kgCO_2$/m² saved	Marginal Cost £ per $kgCO_2$/m²	Internal Rate of Return	Payback - current energy costs (Year)	Normal working or out of hours working	Limitations / discussion / assumptions
Heating	Upgrade heating pumps to variable speed pumps	0.06	0.40	0.16	124%	1	Normal	Assumes that there are stand-by pumps (good practice design) to provide heating and domestic hot water. Undertake replacement during summer.
Lighting	Upgrade lamps within office luminaires to 10W/m²	1.21	2.57	0.47	31%	4	Out of hours	
Cooling	Upgrade air conditioning pumps to variable speed pumps	0.51	0.50	1.03	-	No return	Normal	Assumes that there are stand-by pumps to provide cooling
Cooling	Upgrade chiller plant to achieve a CoP of 11	9.76	3.67	2.66	-	No return	Out of hours	Likely to be weekend work because a road closure will be required in an urban environment. Integration with existing building services means that a weekend shut down will be required.
Renewable energy	Wind turbine 20kW	16.06	4.82	3.33	-	No return	Normal	Suitable for business park locations
Heating	Upgrade boiler to achieve efficiency of 95%	5.37	1.46	3.67	12%	10	Normal	Assumes that there are stand-by boilers (good practice design) to provide heating and domestic hot water. Undertake replacement during summer.
Heating	Heat recovery through a thermal wheel	7.71	2.05	3.76	8%	13	Out of hours	
Power	Upgrade power correction factor to 0.95	3.42	0.77	4.44	5%	No return	Out of hours	
Renewable energy	Solar water heating system 50m²	9.64	0.97	9.94	-	No return	Normal	
Cooling	Upgrade specific fan power to 1.5W/l/s	5.42	0.43	12.61	-	No return	Out of hours	
Shading	Internal blinds	30.56	1.96	15.59	-	No return	Out of hours	
Renewable energy	Photovoltaics 100m²	24.09	0.91	26.48	-	No return	Normal	

The first three key improvements are the same as the refurbishment scenario: variable speed heating and air conditioning pumps and energy efficient lighting. However, the efficient chiller plant and wind turbine improvements were the next cost effective improvements to undertake because the heat recovery and power factor correction improvements incur the out of hours premium.

The increased cost of carrying out certain improvements in the evenings and at weekends means that only the variable speed pumps and the lamp improvement provide a reasonable pay back on initial capital and associated operational costs for Office 5.

3.4.3 Non air conditioned offices

This section focuses on the most cost effective energy efficiency improvements for Offices 6 and 7 whilst the buildings are in occupation. A summary of the key improvements are shown in Table 3.24 and the full results in Tables 3.25 and 3.26.

Table 3.24: Office buildings 6 and 7 key energy efficiency improvements

Office 6 key improvements	Office 7 key improvements
Variable speed heating pumps	Variable speed heating pumps
Energy efficient lighting	Energy efficient lighting
Maximise boiler efficiency	Heat recovery
Power correction factor	Specific fan power
Medium wind turbine	Maximise boiler efficiency

Table 3.25: Office 6 energy efficiency improvements without vacant possession

Upgrade Category	Description of upgrade	Capital cost £/m² (extra over)	$kgCO_2$/ m² saved	Marginal Cost £ per $kgCO_2$ /m²	Internal Rate of Return	Payback - current energy costs (Year)	Normal working or out of hours working	Limitations / discussion / assumptions
Heating	Upgrade heating pumps to variable speed pumps	0.06	0.54	0.12	151%	1	Normal	Assumes that there are stand-by pumps (good practice design) to provide heating and domestic hot water. Undertake replacement during summer.
Lighting	Upgrade lamps within office luminaires to 10W/m²	1.21	4.58	0.27	27%	4	Out of hours	
Heating	Upgrade boiler to achieve efficiency of 95%	5.37	5.33	1.01	10%	11	Normal	Assumes that there are stand-by boilers (good practice design) to provide heating and domestic hot water. Undertake replacement during summer.
Power	Upgrade power correction factor to 0.95	3.42	1.19	2.88	-	No return	Out of hours	
Renewable energy	Wind turbine 20kW	16.06	3.84	4.18	-	No return	Normal	Suitable for business park locations
Shading	Internal blinds	24.07	3.58	6.72	-	No return	Out of hours	
Renewable energy	Solar water heating system 50m²	9.64	1.03	9.36	-	No return	Normal	
Renewable energy	Photovoltaics 100m²	24.09	0.82	29.38	-	No return	Normal	

Table 3.26: Office 7 energy efficiency improvements without vacant possession

Upgrade Category	Description of upgrade	Capital cost £/m² (extra over)	$kgCO_2$/ m² saved	Marginal Cost £ per $kgCO_2$ /m²	Internal Rate of Return	Payback - current energy costs (Year)	Normal working or out of hours working	Limitations / discussion / assumptions
Heating	Upgrade heating pumps to variable speed pumps	0.06	1.09	0.06	154%	1	Normal	Assumes that there are stand-by pumps (good practice design) to provide heating and domestic hot water. Undertake replacement during summer.
Lighting	Upgrade lamps within office luminaires to 10W/m²	1.21	2.16	0.56	31%	4	Out of hours	
Heating	Heat recovery through a thermal wheel	7.71	13.32	0.58	25%	5	Out of hours	
Cooling	Upgrade specific fan power to 1.5W/l/s	5.42	6.62	0.82	17%	6	Out of hours	
Heating	Upgrade boiler to achieve efficiency of 95%	5.37	4.09	1.31	5%	No return	Normal	Assumes that there are stand-by boilers (good practice design) to provide heating and domestic hot water. Undertake replacement during summer.
Power	Upgrade power correction factor to 0.95	3.42	2.12	1.61	4%	No return	Out of hours	
Renewable energy	Wind turbine 20kW	16.06	5.77	2.78	-	No return	Normal	Suitable for business park locations
Renewable energy	Solar water heating system 20m²	3.86	1.09	3.54	-	8	Normal	
Shading	Internal blinds	24.07	5.36	4.49	-	13	Out of hours	
Renewable energy	Photovoltaics 100m²	24.09	1.56	15.45	-	No return	Normal	

Improvements to the occupied non-air conditioned offices are similar to those under a refurbishment. For Office 6, the key improvements are the same for a refurbishment scenario and whilst the building is occupied. The one exception to this is the retrofit wall insulation which can only realistically be done during a major refurbishment because it would need empty floor space and would require a replacement ceiling and carpet and reconfiguration of the heating system.

Installing the efficient fan coil units is the only unfeasible improvement in the occupied building scenario for the mechanically ventilated office (Office 7).

Positive Internal Rate of Return for all Office 7 key improvements. All the key improvements listed in Table 3.24 for Office 7 provide a positive IRR, as was the case under the refurbishment scenario. Maximising the boiler efficiency gives an IRR of 5% whilst all other key improvements are 17% and above.

For Office 6, the top three key improvements generate a positive IRR of 10% or above. The remaining improvements modelled give negative IRRs.

In summary, the majority of key improvements that could be undertaken during a full vacant possession refurbishment could also be carried out as stand alone improvements whilst the building is fully occupied, with the exception of installing DC drive fan coil units.

The consistency between the office buildings and the different upgrade scenarios, in terms of the key improvements to implement, will make it easier for asset managers to adopt a common improvement strategy for their office portfolio.

3.5 Improvements not modelled

It was not possible to accurately model all energy efficiency improvements using the thermal dynamic software. Table 3.27 identifies further relatively low cost improvements that can be carried out to existing office buildings although it has not been possible to determine how much CO_2 can be saved from each improvement. Based on the results of the improvements modelled, all the improvements listed (with the exception of improving floor insulation) are considered to be cost effective and are recommended for implementation.

Table 3.27: Energy efficiency improvements not modelled

Improvement	Implication	Relative capital cost[20]
Building services improvements		
Lighting controls – movement sensors	Controls lighting for occupant presence; can be disruptive if lights switch off when there is no movement from occupants; re-wiring required to install the controls; out of hours work	££
Lighting controls – daylight sensors	Perimeter lights switched off when there is sufficient daylight therefore reducing the need for artificial lighting; out of hours work	£-££
Lifts	Regenerative lifts that return energy back to the grid due to running up empty and down full	££££
Building fabric improvements		
Light coloured walls and ceilings	Improves the effectiveness of natural daylight and may reduce the need for artificial lighting; narrow plan buildings only; refurbishment only	£
Fit draught proofing strips	Improves the air tightness of the building; simple to retrofit to windows and doors; out of hours work	£
Improve floor insulation	Reduces heat loss through the floor; relevant for the ground floor only; likely to reduce clear floor to ceiling height unless incorporated within a raised floor; refurbishment only	££

It should be noted that the installation of a biomass boiler was not considered to be an improvement worth pursuing for the office buildings. This was for the following reasons:

- Air quality impacts from biomass boilers are problematic in urban locations
- A robust fuel supply chain is required and is an important building management consideration either for the landlord or tenant
- Adequate space is required for storing the biomass fuel.

20 Source: RICS and Cyril Sweett 2007

4. RETAIL RESULTS

4.1 Introduction

This section of the report outlines the results of the modelling and costing process for the retail supermarket considered by this report. As per the previous section, the results are presented and discussed as follows:

- Baseline CO_2 emissions
- The key energy efficiency improvements to be undertaken as part of a major store refurbishment programme
- The potential for improvements without disruption to store trading where practical

4.2 Baseline emissions

4.2.1 Baseline results

The baseline annual CO_2 emissions for the supermarket are 122.8kgCO_2/m^2. This excludes the power consumed by the retailer's own equipment such as the refrigeration units, bakery ovens, display units and small power in ancillary office areas for example.

CO_2 emissions for the supermarket are substantially higher compared to the office buildings due primarily to the considerable electricity consumption associated with the high lighting levels in the sales area.

4.2.2 Energy benchmark comparison

As mentioned previously, supermarkets are the biggest energy users when compared to other types of retail building. The total energy consumed, both gas and electricity, for the modelled supermarket is 328 kWh/m^2. It must be noted that the energy demands of the retailer's own equipment accounts for over 50% of the annual energy consumed in a supermarket and therefore there is considerable scope for the retailer to implement their own energy efficiency measures to reduce their process loads.

4.3 Energy efficiency improvements

4.3.1 Refurbishment scenario

The list of energy efficient improvements in Table 4.1 below are typically beyond the scope of a market standard supermarket refurbishment and the capital cost shown is extra over what would normally be done.

Table 4.1: Supermarket refurbishment scenario energy efficiency improvements

Upgrade Category	Description of upgrade	Capital cost £/m² (extra over)	$kgCO_2$/m² saved	Marginal Cost £ per $kgCO_2$/m²	Internal Rate of Return	Payback - current energy costs (Year)	Payback - future energy costs (Year)	Limitations / discussion
Lighting	Upgrade lamps within retail space to achieve 35W/m²	0.00	16.62	0.00	-	0	0	No cost premium for lower output lamps compared to the 42W/m² market standard lamps
Heating	Upgrade heating pumps to variable speed pumps	0.35	0.34	1.02	10%	8	5	Variable speed more efficient than fixed speed pumps
Cooling	Upgrade air conditioning pumps to variable speed pumps	1.04	0.91	1.14	7%	9	5	Variable speed more efficient than fixed speed pumps
Heating	Upgrade boiler to achieve efficiency of 95%	4.68	2.73	1.72	1%	No return	13	Boiler with an efficiency of 85% part of a market standard refurbishment
Renewable energy	Wind turbine 20kW	86.74	26.30	3.30	-	No return	No return	Suitable for business park locations
Cooling	Upgrade chiller to type with a 'Turbocor' compressor with CoP of 11	26.75	8.01	3.34	-	No return	27	High Coefficient of Performance (an efficiency ratio measuring cooling output to electrical input) compared with alternative chiller types
Power	Upgrade power correction factor to 0.95	12.32	3.07	4.01	-	No return	No return	Improving the power factor of an electrical circuit reduces transmission losses
Heating	Heat recovery through a thermal wheel	27.76	6.83	4.06	-	No return	23	Waste heat in the exhaust air to be returned into the incoming air supply
Renewable energy	Solar water heating system 20m²	20.82	1.99	10.46	-	No return	No return	Provides domestic hot water
Cooling	Upgrade specific fan power to 1.5W/l/s	10.41	0.78	13.34	-	No return	No return	SFP is an efficiency measure of the amount of energy consumed to move each litre-per-second of air
Renewable energy	Photovoltaics 500m²	585.50	21.91	26.72	-	No return	No return	Provides electricity
Heating and power	Combined heat and power system	114.05	3.73	30.58	-	No return	No return	CHP system meets 25% of the annual heating demand
Renewable energy	Ground source heating and cooling	1301.10	8.06	161.43	-	No return	No return	Space constraints for a 'horizontal' system and more expensive for a 'vertical' system. Suitable for an out of town retail store.

The results show that the most cost effective improvements to consider in the first instance when a supermarket is due to be refurbished are:

- Lighting
- Pumps
- Boilers

Increasing the energy efficiency of the lighting installation is clearly advantageous as there is no associated increase in cost from the lower output lamps. However, an important consideration is that the lighting level achieved in the sales space may be lower compared to the less energy efficient lamps, which will not suit the aesthetic requirements of the retailer whose preference is to achieve the best level of lighting for the products on sale.

The improvements to the pumps and boilers are more straightforward in comparison, however, the CO_2 saving derived from these improvements will be less effective as the level of internal heat gains increase. This is caused by increasing the density of people and heat generating equipment (ie ovens, refrigeration units) per unit of floor area. Based on current energy prices, the pump and boiler improvements would produce IRRs of 10% and 7% respectively and pay back within 10 years. Pay back would fall to within five years using inflated gas and electricity prices.

4. RETAIL RESULTS

Secondary improvements to implement as part of a supermarket refurbishment include:

- Medium wind turbine
- High efficiency chiller plant
- Power factor correction
- Heat recovery

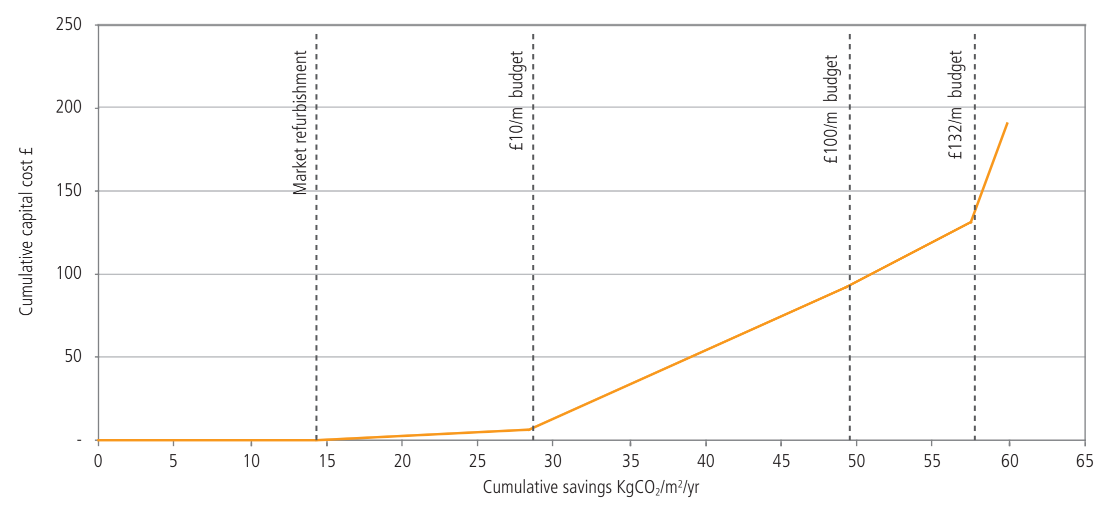
The wind turbine improvement gives the lowest marginal cost compared to the other renewable energy improvements listed. However, a turbine is only suitable for out of town and retail park type locations because wind speeds will not be sufficient in urban areas and there will be likely planning constraints. The feasibility of using wind turbines in non-urban locations should be given full consideration at the earliest possible stage of the refurbishment programme.

Table 4.2 and Figure 4.1 below show the likely cumulative CO_2 savings achieved by implementing a combination of improvements in a refurbishment. Within each combined package of improvements are the improvements listed in Table 4.1 and colour-coded accordingly.

Table 4.2: Supermarket CO_2 savings from combined energy efficiency improvements

	Building CO_2 emissions ($kgCO_2/m^2$)	CO_2 saving ($kgCO_2/m^2$)	% CO_2 saving achieved (on baseline)	Capital cost £/m² (extra over)	CO_2 saved per £/m² spent
Supermarket baseline	122.8	-	-	-	-
µMarket standard refurbishment	108.4	14.4	12%	-	-
Combined Package 1	94.3	14.0	23%	6.1	4.69
Combined Package 2	73.5	20.8	40%	86.7	0.53
Combined Package 3	65.2	8.3	47%	39.1	0.44
Combined Package 4	62.9	2.3	49%	59.0	0.31

Figure 4.1: Costs of achieving different levels of CO_2 savings in a supermarket



Refurbishing to the current market standard gives a 12% reduction in CO_2 emissions on the base building for 'free'. This is because there are certain elements of a standard refurbishment that are now more efficient than they were in the past due to revisions to the Building Regulations and general technological developments. For example, a like-for-like replacement of a 1990 boiler with an efficiency of 55% could not be undertaken today because the 2006 revision of the Part L Building Regulations requires a minimum 80% efficiency to be achieved.

The results show that a further $14kgCO_2/m^2$could be saved relatively cheaply, only costing an additional £6/m^2 in capital cost terms, by implementing Package 1 – efficient lamps, variable speed pumps and high efficiency boiler.

Although installing the wind turbine (Package 2) saves a significant $20kgCO_2/m^2$, it is a major capital cost item. A wind turbine is still more cost effective (in terms of the cost of carbon saved) than implementing the improvements under Packages 3 and 4. An additional budget of £90/m^2 may not be available to provide a wind turbine or there may be site constraints preventing its application, in which case, based on these results, the high efficiency chiller unit and heat recovery improvements under Package 3 would be the preferred option.

4.3.2 Non-refurbishment scenario

The key opportunities to make further reductions in CO_2 emissions beyond the measures included in a standard supermarket refurbishment discussed previously, can also be carried out as one-off capex improvements or as part of the buildings maintenance regime.

Table 4.3: below shows the improvements that could be undertaken whilst a retailer is occupying the building.

Table 4.3: Supermarket energy efficiency improvements not part of a major refurbishment

Upgrade Category	Description of upgrade	Capital cost £/m² (extra over)	$kgCO_2$/m² saved	Marginal Cost £ per $kgCO_2$ /m²	Internal Rate of Return	Payback - current energy costs (Year)	Normal working or out of hours working	Limitations / discussion
Lighting	Upgrade lamps within retail space to achieve 35W/m²	0.00	16.62	0.00	-	0	Out of hours	Conduct as part of a planned preventative maintenance regime
Heating	Upgrade heating pumps to variable speed pumps	0.35	0.34	1.02	10%	8	Normal	Assumes that there are stand-by pumps (good practice design) to provide heating and domestic hot water. Undertake replacement during summer.
Cooling	Upgrade air conditioning pumps to variable speed pumps	1.04	0.91	1.14	7%	9	Normal	Assumes that there are stand-by pumps to provide cooling
Heating	Upgrade boiler to achieve efficiency of 95%	4.68	2.73	1.72	1%	No return	Normal	Assumes that there are stand-by boilers (good practice design) to provide heating and domestic hot water. Undertake replacement during summer.
Renewable energy	Wind turbine 20kW	86.74	26.30	3.30	-	No return	Normal	Suitable for business park locations only. An element of out of hours working will be required to connect the turbine to the store's electrical system
Cooling	Upgrade chiller to type with a 'Turbocor' compressor with CoP of 11	40.12	8.01	5.01	-	No return	Out of hours	Likely to be weekend work because a road closure will be required if in an urban environment. Integration with existing building services means that night working will be required.
Power	Upgrade power correction factor to 0.95	18.48	3.07	6.02	-	No return	Out of hours	
Heating	Heat recovery through a thermal wheel	41.64	6.83	6.10	-	No return	Out of hours	
Renewable energy	Solar water heating system 20m²	20.82	1.99	10.46	-	No return	Normal	
Cooling	Upgrade specific fan power to 1.5W/l/s	15.61	0.78	20.02	-	No return	Out of hours	
Renewable energy	Photovoltaics 500m²	585.50	21.91	26.72	-	No return	Normal	

The results show that the order of preference for the improvements based on the marginal cost of CO_2 saved are the same as that in Table 4.1. The only noticeable change is that the combined heat and power upgrade or the ground source heating and cooling upgrade have not been listed. This is because these improvements are significant pieces of work involving the likely addition of a new plant room and integration with existing building services and are not therefore one-off improvements.

The main opportunities are therefore:

- Higher efficiency lighting
- Variable speed pumps
- 95% efficiency boilers

Undertaking the improvements listed in Table 4.3 should coincide with the maintenance and replacement regime of the building. Some improvements, such as the replacement of lamp fittings, can be integrated with the ongoing planned preventative maintenance programme in order to minimise both capital cost outlay and waste.

Out of hours working is considerably more restricted in retail buildings compared to offices or industrial buildings due to the long hours of operation seven days a week. This means night working is most viable, however, the logistics of such work will require attention and there will be an associated cost premium. As an approximate guide, a 50% increase in the cost of the improvement will be expected for out of hours working.

4.3.3 Improvements not modelled

It was not possible to accurately model several energy efficiency improvements using the thermal dynamic software. Table 4.4 identifies further improvements that can be carried out to an existing retail building although it has not been possible to determine how much CO_2 can be saved from each improvement.

Table 4.4: Energy efficiency improvements not modelled

Improvement	Implication	Relative capital cost
Building services improvements		
Solar collector cladding	A new technology, this is a cladding system that can be retrofitted to external facades that can be used to heat and ventilate indoor spaces by capturing solar energy. This is a solar air heating system and not a solar hot water system	££££
Building fabric improvements		
Control of air infiltration	Improves the air tightness of the building; out of hours work; includes (for example): • Insulated goods doors with seals • Plastic strip curtains or impact doors between the goods area and external areas • Partitioning between goods unloading areas and other storage areas	££-£££

It should be noted that the installation of a biomass boiler was not considered to be an improvement worth pursuing for the retail buildings. This was for the following reasons:

- Air quality impacts from biomass boilers are problematic in urban locations
- A robust fuel supply chain is required and is an important building management consideration either for the landlord or tenant
- Adequate space is required for storing the biomass fuel.

5. INDUSTRIAL AND WAREHOUSE RESULTS

5.1 Introduction

This section of the report outlines the results of the modelling and costing process for the light industrial/warehouse building studied. The results are presented and discussed as follows:

- Baseline CO_2 emissions
- The key energy efficiency improvements to be undertaken as part of a major building refurbishment
- The potential for improvements without disruption to the tenants' occupation of the building

5.2 Baseline emissions

5.2.1 Baseline results

The baseline annual CO_2 emissions for the industrial/warehouse building were 57.7kgCO_2/m^2. This excludes the power consumed by the tenants' own equipment, which is specific to the trade carried out in the building. The energy consumed by different occupiers will vary considerably depending on the intensity of the process (if any) being undertaken.

The use of gas in connection with meeting space heating requirements accounts for two thirds of the building's CO_2 emissions. Lighting accounts for 27% of CO_2 emissions and the remainder is produced by pumps and domestic hot water production.

5.2.2 Energy benchmark comparison

A typical annual energy consumption benchmark for existing industrial buildings is 350 to 400kWh/m^2 . The benchmark only takes into account building performance rather than the impacts of the industrial processes that take place within them. The total energy consumed, both gas and electricity, for the modelled building in this study is below the benchmark at 245Wh/m^2. The modelled industrial/warehouse building does not include a mechanical ventilation system, ancillary two storey offices or other features of some industrial buildings such as dock levellers which could all account for the lower energy consumption.

5.3 Energy efficiency improvements

5.3.1 Refurbishment scenario

Table 5.1 shows that the range of possible energy efficiency improvements is less for light industrial buildings than for office and retail buildings. Industrial buildings are inherently simpler because they have lighting and possibly heating systems rather than more complex air conditioning.

Table 5.1: Light industrial/warehouse building refurbishment scenario energy efficiency improvements

Upgrade Category	Description of upgrade	Capital cost £/m² (extra over)	$kgCO_2$/m² saved	Marginal Cost £ per $kgCO_2$/m²	Internal Rate of Return	Payback - current energy costs (Year)	Payback - future energy costs (Year)	Limitations / discussion / assumptions
Lighting	Upgrade lamps within luminaire fittings to 10W/m²	0.52	0.82	0.63	26%	4	3	11W/m² lamps part of a market standard refurbishment and luminaires not replaced
Heating	Upgrade gas fired space heaters to achieve efficiency of 95%	7.81	8.07	0.97	8%	11	6	Space heaters with an efficiency of 85% part of a market standard refurbishment
Renewable energy	Wind turbine 20kW	86.74	18.84	4.60	-	No return	No return	Suitable for industrial park locations
Building fabric	Improve roof insulation only by adding additional insulation to the underside of the roof	21.00	3.40	6.18	-	No return	No return	Reduces heat loss in winter
Power	Upgrade power correction factor to 0.95	12.32	1.44	8.55	-	No return	No return	Improving the power factor of an electrical circuit reduces transmission losses
Renewable energy	Solar water heating system 20m²	20.82	2.06	10.11	-	No return	No return	Provides domestic hot water
Heating and power	Combined heat and power system	114.05	10.64	10.72	-	No return	No return	CHP system meets 25% of the annual heating demand
Building fabric	Additional roof and wall insulation	46.00	3.84	11.98	-	No return	No return	Reduces heat loss in winter
Renewable energy	Ground source heating and cooling	208.18	10.88	19.13	-	No return	No return	Space constraints for a 'horizontal' system and more expensive for a 'vertical' system.
Renewable energy	Photovoltaics 450m²	585.50	18.84	31.08	-	No return	No return	Provides electricity
Glazing	Reglazing single glazed window panes with double glazed panes	38.00	0.95	40.00	-	No return	No return	Reduces heat loss in winter and 'low-e' glazing reduces solar gain in summer

The results show that the most cost effective improvements to investigate in the first instance when considering the refurbishment of an industrial building are:

- Lighting
- Space heating equipment

Improving the efficiency of the lighting installation is again the most cost effective improvement in terms of the CO_2 saving achieved for the initial capital outlay. If the industrial unit is used for production, the lighting conditions may be important for the process being undertaken, for example, colour rendering. Less efficient lamps may therefore not provide sufficient lighting standards for the occupant and this should be a consideration. For warehouses, fluorescent lighting (T5 and T8 lamps) is preferred to metal halide lighting because it reduces electricity usage and lasts longer.

The lighting and space heating improvements give IRRs of 26% and 8% and pay back after four and 11 years respectively. The remaining upgrades don't give positive IRRs or pay back within 30 years.

The replacement of lighting and space heating during a refurbishment by the landlord is not a compulsory requirement in order to let the building because a typical developer's outline specification for a new industrial unit constructs to a shell only standard. However, if the landlord is offering an incentive to the tenant to provide lighting and possibly heating, this would be a good opportunity to make cost effective reductions in building CO_2 emissions.

Replacing existing fixed speed pumps with variable speed pumps is not an option for this building because radiant space heating units have been assumed which do not require a distribution system unlike a central heating system.

Secondary improvements to implement as part of a refurbishment would include:

- Medium wind turbine
- Retrofitting roof insulation
- Power factor correction
- Solar water heating

The wind turbine improvement gives the lowest marginal cost compared with the other improvements listed. However, a turbine is only suitable for out of town industrial park type locations because wind speeds will not be sufficient in urban areas and there are likely to be planning constraints. The feasibility of using wind turbines in non-urban locations should be given full consideration at the earliest possible stage of the refurbishment programme because wind speeds and local planning policy may constrain its use as a viable energy solution. The results show that where these limitations do not apply other renewable energy solutions are less cost effective in comparison.

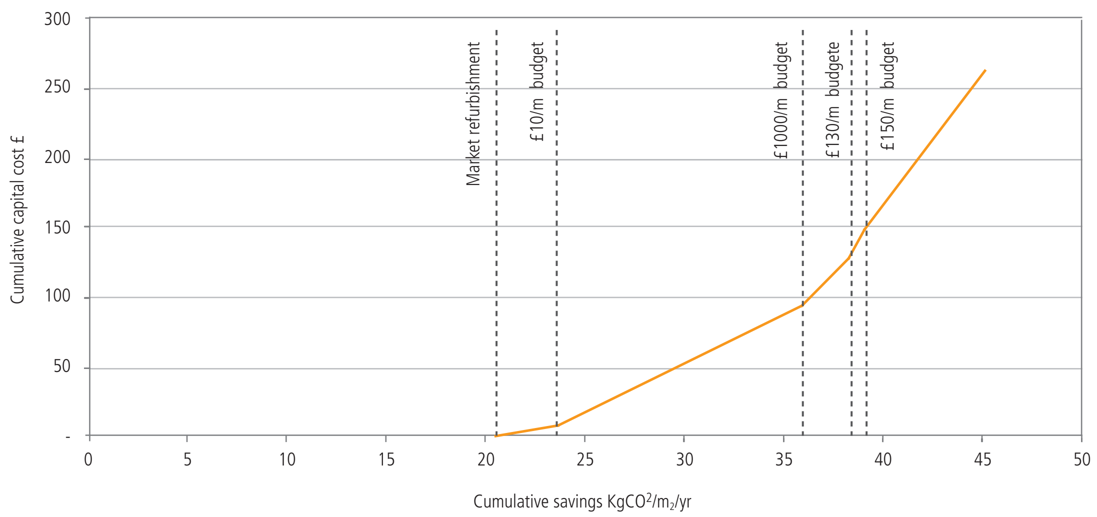
Retrofitting roof insulation will prevent significant heat loss in winter, which will benefit industrial units with and without heating systems. Installing insulation to both the roof and external walls was found to be less cost effective than just roof insulation, however, in practice, it would be appropriate to do both elements especially if lighting or heating improvements or a wind turbine are not being carried out.

Table 5.2 and Figure 5.1 below show the likely cumulative CO_2 savings achieved by implementing a combination of improvements in a refurbishment. Within each combined package of improvements are the improvements listed in Table 5.1. They are colour-coded accordingly.

Table 5.2: Light industrial/warehouse building CO_2 savings from combined energy efficiency improvements

	Building CO_2 emissions ($kgCO_2/m^2$)	CO_2 saving ($kgCO_2/m^2$)	% CO_2 saving achieved (on baseline)	Capital cost £/m^2 (extra over)	CO_2 saved per £/m^2 spent
Industrial baseline	57.7	-	-	-	-
Market standard refurbishment	37.3	20.5	35%	-	-
Combined Package 1	34.0	3.3	41%	8.3	2.85
Combined Package 2	21.8	12.2	62%	86.7	0.38
Combined Package 3	19.4	2.4	66%	33.3	0.30
Combined Package 4	18.7	0.8	68%	20.8	0.26
Combined Package 5	12.5	6.2	78%	114.0	0.17

Figure 5.1: Costs of achieving different levels of CO_2 savings for a light industrial/warehouse building



Refurbishing to the current market standard gives a significant 35% reduction in CO_2 emissions on the base building for 'free'. However, this should be qualified because it is based on the assumption that both the lighting and heating units would be improved to meet current standards, which may not be carried out by the landlord as previously discussed.

The results show that a further 6% of baseline emissions could be saved relatively cheaply, costing an additional £8/m^2 in capital cost terms, by implementing Package 1 – efficient lamps and the high efficiency space heating.

As before, the medium wind turbine is a major capital cost item at £87/m^2. This additional budget may not be available or there may be site constraints preventing its application, in which case, the retrofit roof insulation and power factor correction upgrade under Package 3 would be the preferred options.

5.3.2 Non-refurbishment scenario

The key opportunities to make further reductions in CO_2 emissions beyond a standard refurbishment of a light industrial/warehouse unit can also be carried out as one off capital improvements or as part of the building maintenance regime.

Table 5.3 shows the improvements that could be carried whilst a tenant is occupying the building.

Table 5.3: Industrial building energy efficiency improvements not part of a major refurbishment

Upgrade Category	Description of upgrade	Capital cost £/m² (extra over)	$kgCO_2$/ m² saved	Marginal Cost £ per $kgCO_2$ /m²	Internal Rate of Return	Payback - current energy costs (Year)	Normal working or out of hours working	Limitations / discussion / assumptions
Lighting	Upgrade lamps within luminaire fittings to 10W/m²	0.78	0.82	0.95	16%	8	Out of hours	11W/m² lamps part of a market standard refurbishment and luminaires not replaced
Heating	Upgrade gas fired space heaters to achieve efficiency of 95%	7.81	8.07	0.97	8%	11	Normal	Space heaters with an efficiency of 85% part of a market standard refurbishment
Renewable energy	Wind turbine 20kW	86.74	18.84	4.60	-	No return	Normal	Suitable for industrial park locations only. An element of out of hours working will be required to connect the turbine to the electrical system
Renewable energy	Solar water heating system 20m²	20.82	2.06	10.11	-	No return	Normal	
Power	Upgrade power correction factor to 0.95	18.48	1.44	12.83	-	No return	Out of hours	
Renewable energy	Photovoltaics 500m²	585.50	18.84	31.08	-	No return	Normal	

The results show that the order of preference for the improvements based on the marginal cost of CO_2 saved are the same as those in Table 5.1, with the exception of solar water heating which is now preferred ahead of upgrading the power correction factor. This is because the premium for undertaking this work out of hours makes it less cost effective than the solar water heating which can be installed predominantly during normal business hours.

Some improvements however are better suited to include as part of a major refurbishment as they are significant pieces of work involving disruption to the building occupant. These comprise fabric, insulation and glazing improvements, combined heat and power and the ground source heating and cooling upgrade.

The main opportunities are therefore:

- Higher efficiency lighting
- Space heating equipment

Undertaking the improvements listed in Table 5.3 should coincide with the maintenance and replacement regime of the building. Some improvements, such as the replacement of lamp fittings, can be integrated with the ongoing planned preventative maintenance programme in order to minimise both capital cost outlay and waste.

Out of hours working is less restricted in industrial buildings compared with retail sites because these buildings are not typically in operation during evenings and weekends, with the possible exception of Saturday. However, large distribution warehouses serving the retail sector (especially food) will have a 24-hour operation.

5.3.3 Improvements not modelled

It was not possible to accurately model several energy efficiency improvements using the thermal dynamic software. Table 5.4 identifies further improvements that can be carried out to an existing light industrial/warehouse building although it has not been possible to determine how much CO_2 can be saved from each improvement.

Table 5.4: Energy efficiency improvements not modelled

Improvement	Implication	Relative capital cost
Building services improvements		
Solar collector cladding	A new technology, this is a cladding system that can be retrofitted to external building fabrics that can be used to heat and ventilate indoor spaces by capturing solar energy. This is a solar air heating system and not a solar hot water system	££££
Building fabric improvements		
Control of air infiltration	Improves the air tightness of the building; out of hours work; includes (for example): • Insulated goods doors with seals • Plastic strip curtains or impact doors between the goods area and external areas • Partitioning between goods unloading areas and other storage areas	££-£££

6. FURTHER CONSIDERATIONS

The previous sections highlight the energy efficiency improvements that could be made by landlords to existing office, retail and industrial shed buildings to reduce baseline CO_2 emissions from their buildings. However, occupant behaviour is key if these potential CO_2 reductions are to be realised. Whilst this research highlights the actions landlords can take to reduce energy consumption, and therefore enable them to negotiate a share of the savings, actions are also required by the occupant to facilitate this.

This section of the report briefly sets out how the occupier can be engaged to reduce CO_2 emissions. It also describes how the landlord can make the energy efficiency improvements as cost effectively as possible through claiming Capital Allowances and if available, Enhanced Capital Allowances.

6.1 Reducing occupier CO_2 emissions

The landlord affects the energy consumption of buildings through owning the thermal performance of the building envelope, the type and efficiency of the building services – lighting, heating and air conditioning (unless this forms part of the occupant's own fit out works) – and appropriate commissioning and timely maintenance thereafter.

The occupant can affect building CO_2 emissions in two ways:

1. Power (electricity) consumed by the tenant's equipment, whether it be IT, photocopiers, refrigeration equipment, machinery and plant; and
2. Operation of the building services

Power consumption levels depend on the occupant's business, hours of operation, density of equipment and people and equipment efficiency. How the building services are operated depends on the internal heat gains from people and the occupant's equipment (affecting heating and cooling requirements) and other factors such as:

- Internal temperatures: adjusting summer and winter set temperatures has a noticeable impact on energy consumption
- Hours of operation: energy consumed in the building outside of these hours should be minimised
- Energy management policies: commitment from the occupant to monitor energy consumption/CO_2 emissions and to set targets to achieve reductions over time
- Occupant actions: lack of knowledge regarding adjusting temperatures, controlling lights, the impact of opening windows and using blinds often means that energy is wasted
- Category B fit out: floor layout considerations including positions of internal partitions, printers and photocopiers will impact on the performance of the air conditioning system

The landlord can engage with the occupier on these issues either informally, through an occupier's handbook, or formally through a 'green lease' or Memorandum of Understanding. This is discussed briefly below:

6.1.1 Occupier's Green Handbook

This takes the form of a guide covering the fit out of the floor space and subsequent occupation that meets environmental best practice. The guide should include advice on reducing energy consumption and CO_2 emissions but also water, materials, waste, transport and ecology.

The guide needs to cover two main areas:

Fit out design guidance

In terms of energy, this includes:

- The designed level of building energy consumption, akin to the EPC asset rating, which shows the intended performance of the building
- The key design criteria and performance information for use by the tenant's design team
- Technical description of the building services systems
- Guidance regarding partition layouts that are in keeping with the thermal zoning and lighting strategies of the floor space
- Information on low energy office equipment

Occupancy guidance

This section of the guide addresses the measures the occupier could take to minimise energy consumption during their occupation such as:

- Promoting energy efficient awareness including disseminating energy consumption information to building users
- Recommended frequency of cleaning light fittings
- Simple non-technical instructions for users to adjust temperatures
- Guidance for internal winter and summer temperature set points
- Managing energy consumption through energy audits, energy monitoring and setting targets

Simple actions on the part of the occupant such as improving staff awareness and promoting low carbon behaviour, checking thermostats and minimising energy consumption out of working hours are low cost and make a significant contribution to reducing CO_2 emissions. A short term payback would also be expected.

6.1.2 Green leases and Memorandum of Understanding

Much has been written about the limitations of the traditional lease structure in England and Wales in promoting or facilitating landlords and tenants working together to improve the environmental performance of the building. A so-called 'Green Lease' structure has been implemented in Australia with some success in resolving this conflict by setting out the environmental obligations of each party in relation to the building and penalties or incentives to ensure performance. However, the use of a similar system in the UK has to date been limited and research shows there is resistance to such a formal arrangement from both parties within the UK market.

A potentially viable alternative is the development of a Memorandum of Understanding (MoU) between landlord and tenant that sets out specific obligations with regards to environmental performance of the building. The key areas addressed would be the same or similar to those within a Green Lease, typically energy, water and waste including measurement and monitoring of their use and sharing of information between landlord and tenant. However such an arrangement would be personal to the parties involved and would fall away should the building be sold or the lease assigned, substantially reducing the risk of an adverse impact on value – one of the key concerns of the landlord. A MoU has the potential to ensure that the energy efficiency improvements installed by a landlord are understood and accepted by both parties and that the building is operated in such a way as to reap the full benefit of the improvements. A MoU also has the potential to establish a methodology for cost sharing where the landlord makes capital expenditure resulting in lower operating costs for the tenant.

6.2 Enhanced Capital Allowances

Enhanced Capital Allowances (ECAs) are an accelerated form of capital allowances available for energy efficient and environmentally beneficial plant and machinery. ECAs were first introduced in 2001 as an incentive to invest in these technologies.

Investing in ECA qualifying technology attracts 100% first year Capital Allowances relief against profits in the year of expenditure. For property refurbishment projects, this can help to reduce the initial investment associated with an energy efficient refurbishment. ECAs would improve the payback or IRR on each item for which they are available.

ECAs are only available for plant and machinery which is included in the energy technology list issued by DEFRA[22]. The energy efficiency improvements considered in this report that are likely to attract ECAs are shown in Table 6.1.

Table 6.1: Energy efficiency improvements likely to attract ECAs

Energy efficiency improvements
• Variable speed pumps
• Energy efficient lighting
• Heat recovery systems
• Boilers
• Chiller units
• Solar hot water
• Combined heat and power plant[23]
• Ground source heat pumps

The potential for claiming ECAs on the equipment listed in Table 6.1 is subject to the product specified and therefore, a detailed review is required of the building services specification to determine which items will attract ECAs.

Those improvements which are not eligible for ECAs are likely to qualify for standard Capital Allowances relief. This includes the plant and machinery allowance and the integrated features allowance which give relief on a 20% and 10% writing down basis respectively. Improvements eligible for relief include any items associated with the heating, air conditioning and electrical systems.

In order to claim, the investor must be a UK tax payer and hold the qualifying plant and machinery as an investment. For example, property traders, including most developers, would not be able to claim ECAs. Property investors, owner occupiers and tenant occupiers subject to UK tax can all claim ECAs.

The expenditure must be incurred on new and unused plant and machinery. For property refurbishments, this shouldn't generally pose a problem, although relocation of existing equipment would not attract the relief.

[22] Available at www.eca.gov.uk

[23] Only good quality CHP units qualify and a 'Certificate of Energy Efficiency' is required before a claim can be made.

7. CONCLUSION

The primary aim of this research was to identify the key energy efficiency improvements that could be made to existing commercial buildings typically held in investor portfolios and those that present the greatest opportunities to make reductions in CO_2 emissions. Representative office, retail, industrial and warehouse buildings were analysed.

The conclusions of this work are summarised for each building type below.

7.1 Offices

7.1.1 Key energy efficiency improvements

The key improvements were found to be broadly similar for vacant office buildings undergoing a refurbishment and for occupied buildings. For air conditioned offices dating back to the early 1990s, these were:

- Variable speed heating pumps
- Energy efficient lighting
- DC drive fan coil units (refurbishment scenario only)
- Heat recovery
- Maximise boiler efficiency
- Power factor correction

Whereas heating improvements were significant for the early 1990s offices, cooling improvements (DC drive fan coil units and high efficiency chillers) were more significant for modern air conditioned offices.

The key improvements listed were also relevant to mechanically ventilated offices (plus fan power improvements) and naturally ventilated offices where applicable.

Based on current gas and electricity prices, the key improvements produce a positive Internal Rate of Return, the majority of which exceed 9%. The discounted payback period ranges from one to 15 years for these improvements and within 10 years when inflated energy prices are used.

7.1.2 Building opportunities

With the exception of the post-2002 office, the baseline CO_2 emissions of all office buildings can be reduced by approximately 25% by refurbishing to current market standards (ie no additional energy efficiency improvements). This would be likely to achieve a C rating on an Energy Performance Certificate (EPC).

The results showed that all office buildings can achieve a significant further reduction in CO_2 emissions from an additional spend of 5% when undertaking a major refurbishment (based on a refurbishment base cost of £1000/m^2). The biggest improvement is seen in older offices where the baseline CO_2 emissions are reduced by almost 50% following the additional 5% spend. For a modern office, a reduction of almost 30% is possible. It is likely that this level of additional expenditure will be sufficient to achieve an EPC rating of B.

As additional expenditure increases beyond £50/m^2, it is relatively more expensive to make further reductions to the baseline CO_2 emissions.

The office building with the highest baseline emissions (Office 2 – early 1990s, air conditioned, fully glazed deep plan) achieves the highest absolute reduction in CO_2 for each level of additional expenditure.

However, the heated 'period' office (Office 6) achieves the biggest relative improvement for each amount of additional expenditure. Because there is no air conditioning present, the heating and lighting improvements have a bigger relative impact compared with the same improvements for the air conditioned offices. Improvements to these types of offices are therefore more cost effective.

7.2 Retail

7.2.1 Key energy efficiency improvements

CO_2 emissions for the supermarket are substantially higher compared to the office and industrial/warehouse buildings due primarily to the considerable electricity consumption associated with the high lighting levels in the sales area and longer hours of operation. The 1990s supermarket analysed would likely achieve an E rating on an EPC.

The key improvements were found to be:

- Energy efficient lighting
- Variable speed heating and air conditioning pumps
- High efficiency boilers
- Medium wind turbine
- High efficiency chiller plant
- Power factor correction
- Heat recovery

These opportunities are also relevant whilst the store is occupied, however, out of hours working is considerably more restricted in retail buildings compared to offices or industrial sites due to the long hours of operation seven days a week.

Improving the efficiency of the lighting system is an important consideration because the cost of energy efficient lamps is not that different from traditional lamps meaning the resulting CO_2 savings are gained for 'free'.

Variable speed heating and air conditioning pumps both give an IRR of 10% and 7% respectively based on current gas and electricity prices and pay back within 10 years. The payback reduces to five years if inflated energy prices are used.

7.2.2 Building opportunities

Refurbishing to the current market standard gives a 12% reduction in CO_2 emissions, which is a smaller reduction when compared to the offices. However, if an additional £10/m^2 is spent over and above a market refurbishment cost, almost a quarter of baseline emissions can be saved.

To make further CO_2 savings, the next most cost effective improvement is a medium wind turbine. However, this is a major capital cost item that increases additional expenditure required up to £100/m^2. The investment will not create a positive return or pay back within 30 years at current energy prices.

7.3 Industrial

7.3.1 Key energy efficiency improvements

The baseline annual CO_2 emissions for the industrial/warehouse buildings are on a par with the non-air conditioned offices. This excludes the emissions arising from a tenant's equipment or machinery and assumes that the base building is heated. The likely EPC rating that could be achieved for this building would be an E.

In terms of refurbishing a vacant building, the key improvements are:

- Energy efficient lighting
- Space heating equipment (if required)
- Medium wind turbine
- Additional roof insulation
- Power factor correction
- Solar water heating

These improvements are also viable whilst the building is let to a tenant with the exception of retrofitting additional roof insulation due to the disruption caused.

Only the lighting and space heating improvements give positive IRRs (26% and 8% respectively) and pay back after four and 11 years respectively. The remaining upgrades do not give positive IRRs or pay back within 30 years.

7.3.2 Building opportunities

Modernising the existing industrial/warehouse building to current market standards presents a 35% reduction in CO_2 emissions. However, this includes making improvements to the space heating system which the landlord might not wish to carry out for the purposes of letting the unit.

For additional expenditure of £10/m^2, the reduction in baseline emissions is in the region of 41%. Although the relative improvement in baseline emissions is significantly more than the supermarket, the actual CO_2 saved is less - 24kgCO_2/m^2 against 28kgCO_2/m^2.

A medium wind turbine is the next most cost effective improvement; however, this is a major capital cost item that increases the additional expenditure required up to £100/m^2. The result of this improvement is a 62% reduction in baseline emissions which equates to 36kgCO_2/m^2. Improvements to the industrial/warehouse building give a greater relative reduction in CO_2 compared to the supermarket; however, the total CO_2 saved is less.

7.4 Summary

This study has identified a number of cost effective energy efficiency improvements that can be made to the existing commercial property stock. Capturing these 'low hanging fruit' for 1990's and pre-1940's office buildings can achieve significant energy savings. Many of these opportunities not only apply for buildings awaiting a major refurbishment, but also to buildings that are in occupation. Refurbishing a building to current market standards will achieve significant initial CO_2 savings and limited additional expenditure can reduce overall emissions by almost one half.

Price: £150.00 plus VAT
(Free to IPF Members)

Investment Property Forum
New Broad Street House
35 New Broad Street
London EC2M 1NH

Telephone: 020 7194 7920
Fax: 020 7194 7921
Email: ipfoffice@ipf.org.uk
Web: www.ipf.org.uk

Printed on recycled paper