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RESEARCH

Costing Energy Efficiency Improvements in Existing Commercial Property

FULL REPORT

COMMISSIONED BY THE IPF RESEARCH PROGRAMME

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

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Costing Energy Efficiency Improvements in Existing Commercial Property

Report

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EXECUTIVE SUMMARY

The energy efficiency of commercial buildings remains an important topic in the decarbonisation of the UK buildings. Regulations are driving energy performance requirements higher and ESG reporting, and disclosure is shining a spotlight on asset performance. The Climate Change Committee has clearly set out that improvements to existing buildings are part of the UK net zero carbon pathway.

This study updates the Investment Property Forum's previous work on the costs and savings from energy efficiency measures in existing buildings. It addresses the strengthening Minimum Energy Efficiency Standards (MEES) regulations and longer-term decarbonisation pathways as set in the Carbon Risk Real Estate Monitor (CRREM) tool. Seven building typologies have been studied covering retail, industrial, offices and residential sectors. A range of discrete and combined packages of improvement measures were assessed for their impact on Energy Performance Certificate (EPC) ratings, energy use, carbon emissions and cost.

The analysis shows that to achieve an EPC B (MEES requirement), asset owners may need to invest between around £200/m² to £800/m² on packages of improvements and a key strategy is decarbonisation of heat through removal of gas from the building. These costs would be lower when the interventions are part of a planned programme of asset improvements.

There are a range of variables that influence the investment required depending on building type, situation, and planned investment in an asset. A financial dataset across seven building typologies has been produced to help asset owners explore the potential improvement options available and the associated benchmark costs (accessed here).

The analysis explores the effect that these improvement measures would have on the building's performance against the CRREM pathways for energy and carbon intensity of buildings. It shows that to meet the CRREM pathways, existing buildings must decarbonise heat, and need to combine technological solutions (i.e. improvement measures) with tenant engagement and active energy management.

This supporting report provides the technical context including the importance of energy efficiency for commercial landlords, how to improve energy efficiency in existing commercial assets and recommended actions for asset owners.

EXECUTIVE SUMMARY

Key findings include:

- The change in EPC modelling method that took place in June 2022 will result in a change in EPC rating for most buildings. Owners of gas heated buildings could find that on remodelling the EPC the rating falls into a non-compliance level. Owners of electrically heated buildings might find that on remodelling they improve to a level that meets current and potentially future minimum standards without further intervention.
- The seven-year payback test, as defined in the MEES guidance was applied to all packages across all typologies. The results show that the only improvements that payback within seven years are those that are part of a planned refurbishment scenario and this is limited to lighting and ventilation improvements.
- Changing the heating type to direct electric or heat pumps can significantly improve the EPC rating of any building, assuming it is replacing gas. This is due to the decarbonisation of UK grid and therefore lower carbon factors for electricity.
- As the carbon emissions factor for electricity will continue to fall, the impact on EPC rating will continue to favour heat electrification and by 2030 some buildings may find that it is impossible to achieve an EPC B without electrifying heat.
- For most buildings, a combination package of three improvement measures - lighting, ventilation and heat pumps will meet the requirement of an EPC B. In the Retail unit, Logistics warehouse and Student accommodation typologies, the heat pump or direct electric heating package alone will also meet EPC B. This is dependent on the age and condition of the existing building.
- The LED lighting and controls package alone do not always improve the EPC, and in some cases make it worse. This is in scenarios where the increased heating demand arising from more energy efficient lighting is met by gas-fired heating.
- Previously, changing the lighting would be a relatively cheap option and could in many scenarios help a building reach an EPC C. However, under the new method, lighting upgrades may make the EPC rating worse. The improvements needed are more significant and the costs to reach the desired EPC have gone up, therefore increasing the compliance costs.
- The CRREM 1.5 energy pathway sets a trajectory for reducing energy intensity (kWh/m²/yr) of a building. Of the typologies modelled, only the improvements modelled for Office 1 would meet the EUI targets and remain better than the EUI target for more than five years without further intervention. None of the packages modelled for the retail and logistic warehouses will meet the CRREM energy intensity targets.
- CRREM 1.5 carbon intensity pathway sets a trajectory for reducing the operational carbon intensity of a building (kgCO_2/m²/yr). For most of the typologies modelled, there is a solution that would follow or better the CRREM 1.5 carbon intensity pathway. The exception to this is the Logistics warehouse where the solutions result in a carbon intensity a little higher than the pathway. The improvements that switch from gas to electricity for heating most often deliver the carbon intensity reduction required to meet the targets. The results demonstrate that individual measures alone, except for the air source heat pump (ASHP) and Direct Electric improvements, will not meet the carbon intensity reductions required.

1. INTRODUCTION

The Investment Property Forum (IPF) last published research into improving energy efficiency of existing commercial buildings in 2017. Since then, there have been substantial technological and regulatory changes. Alongside this, the property industry has seen greater adoption and awareness of decarbonisation targets.

The minimum energy efficiency standards (MEES) for leased property came into force in April 2018 and strengthened considerably with the expectation that all rental properties achieve an EPC of C in the period 2025-27 and EPC B by 2030. In addition, changes to the EPC modelling method resulting from the adoption of a new Part L of Building Regulations in June 2022 means that electrification of heat is strongly incentivised.

This update of the IPF research responds to the above changes and introduces alignment to the Carbon Risk Real Estate Monitor (CRREM) 1.5-degree decarbonisation pathway for the UK. A broader set of commercial asset typologies have been included in the study which covers office, retail, logistics, industrial, build-to-rent and student residential accommodation typologies.

The aim of the research is to help investors and asset managers to take steps to manage risk, reduce running costs and improve the long-term carbon performance of their buildings.

This study considers the scale of the investment and associated operational energy savings from implementing energy efficiency measures in existing buildings.[1] It assesses the most cost and carbon effective responses to addressing MEES for different building types and recognises the sector priority to achieve net zero carbon performance. For each typology, improvement packages and combinations of measures were assessed to achieve compliance with MEES and CRREM pathways.

The results provide benchmark costs for undertaking different carbon and energy reduction measures in commercial buildings and includes analysis of:

- the potential level of obligated expenditure for MEES compliance
- those measures that could assist in improving EPC ratings but for which a valid exemption could be claimed on the basis of payback period or other criterion
- additional measures that would enable CRREM energy and carbon pathways to be met

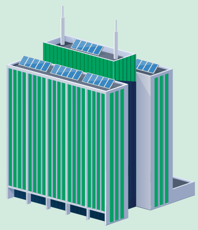
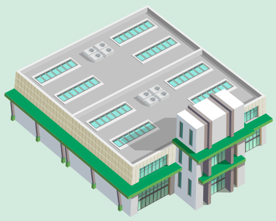
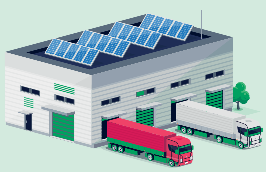
This report is accompanied by an Excel-based model that contains the key reference data tables underpinning the analysis. This model can be used to analyse the results for a specific building typology and improvement package option. Further guidance on how to use this model can be found in section 6 of this report.

Typologies have been used to provide benchmark results and therefore care should be taken when applying the analysis to a specific building. The characteristics of the building typologies assessed in this research are described in Table 1.1, together with an indicative (but not actual) image/model.[2]

1. This study does not consider new construction, major redevelopment (i.e. where the building is stripped back to its frame) or changes of use.
2. These building models are different to the previous iteration of this research.

1. INTRODUCTION

Table 1.1 Building typologies

Typology		Description	EPC rating & band
Office 1 (air conditioned)		• 12-storey (+ basement) office building, deep plan. • Approximately 20,500m² • Services including lighting, heating, ventilation, and air conditioning • Built in early 2000s, compliant with Part L 2002 • 44% glazing ratio	91 - **D**
Office 2 (older air conditioned system)		• 5-storey office building, narrow plan. • Approximately 2,000m² • Services including lighting, heating, ventilation (extract only in toilets) and air conditioning • Built in the 1970s, not compliant with any Part L version. • Lighting replacement within the last 20 years • 20% glazing ratio	257 - **G**
Retail unit in shopping centre		• 1-storey unit in a retail shopping centre • Approximately 300m² • Services including lighting, heating, ventilation and air conditioning • Built in the early 1990s • Fit out works only, no fabric interventions • Current fit out 10-15 years-old compliant with fabric limiting values under Part L 2006 • 35% glazing ratio	96 – **D**
Retail warehouse		• 1-storey, double height with mezzanine retail warehouse. • Approximately 1,500m² • Services including lighting, heating, ventilation (extract only) • Built in 1995 • Compliant with Part L 1995. Lighting and other services are not original • 18% glazing ratio	134 – **F**
Logistics		• 1-storey, double height logistics building, deep plan • Approximately 20,500m² • Services including lighting, heating, ventilation (extract only) and air conditioning to office space • Built in 2005, compliant with Part L 2002. • 20% glazing ratio	72 – **C**

Illustrations are not exact representations of the building types

1. INTRODUCTION

Table 1.1 Building typologies

Typology		Description	EPC rating & band
Build-to-rent residential		• 15-storey residential block, 175 flats (1-bed, 2-bed, 3-bed), amenity areas on the ground floor with an overall area of • Approximately 10,000m² • Natural ventilation, with extract fans in kitchens and bathrooms. Heating provided by communal gas boiler • Built 5-6 years ago, compliant with Part L 2013 • 25% glazing • Top floor unit used in modelling	61 – **D**
Student accommodation		• 7-storey student accommodation block, 150 units (ensuite bedrooms and studios). • Approximately 4,500m² • Natural ventilation, with extract fans in kitchens and bathrooms. Heating provided by communal gas boiler • Built 20 years ago, compliant with Part L 2002 • 20% glazing ratio	98 – **D**

Illustrations are not exact representations of the building types

It is important to remember that the modelled buildings are representations of the stock that might be owned by property investors and are not case studies of actual buildings.

Subsequent sections of this report address:

- **The importance of energy efficiency for commercial landlords** – summarising the key regulatory, financial and market drivers for energy efficiency;
- **Energy, carbon and commercial buildings** – current data on the energy performance of commercial buildings and factors influencing the energy performance rating;
- **Improving energy efficiency** – summary of the opportunities for landlords and their occupiers to reduce energy consumption;
- **Findings** – including information on impact of different asset upgrades for each typology on the capital costs, MEES and CRREM analysis; and
- **Taking action** – some key conclusions and recommendations arising from the analysis.

Core data underpinning this research and the user-friendly model to explore the typologies and improvements may be downloaded from the resource library on the IPF website (www.ipf.org.uk).

The research has been carried out by Currie & Brown. The energy modelling was undertaken by Introba Consulting.

2. THE IMPORTANCE OF ENERGY EFFICIENCY FOR COMMERCIAL LANDLORDS

The UK government is committed to reach net zero carbon by 2050. The Climate Change Committee reports that buildings remain the UK's second highest-emitting sector, accounting for 17% of total emissions.[3] Improving the energy efficiency of buildings is part of the UK net zero carbon pathway and buildings emissions need to fall by around 43% by 2035 (relative to 2022) to be on track. Seventy percent of the UK's non-residential building stock was constructed before the year 2000, therefore, to achieve UK net zero carbon targets, significant retrofit of the majority of the sector will be required before 2050.[4] Each year, many buildings will undergo refurbishment works as part of asset management investment and this presents an opportunity to achieve energy and carbon savings.

For commercial landlords, the implementation of regulations imposing MEES for privately leased buildings is a powerful stimulus to act on improving energy efficiency. However, it is not the only one and there are many regulatory and market factors that make energy efficiency an important issue for commercial property. Landlords should take all suitable opportunities, therefore, to improve the energy efficiency of their estates while working with their occupiers to achieve energy savings wherever possible.

A significant number of real estate investors have publicly committed to improve energy efficiency or, more significantly, achieve net zero carbon before 2050 for their portfolios. The drivers and enablers for this include mandatory disclosure of climate performance, increased availability and use of tools for benchmarking and industry frameworks for net zero.

Definitions for 'net zero' vary within the industry and a full assessment of the initiatives and frameworks across the globe can be found in the IPF study 'Pathways to Net zero Carbon Emissions in International Real Estate Investment' published in 2022.[5]

This section explores the MEES regulations and the CRREM energy and carbon intensity pathways alongside other key drivers for energy efficiency for commercial landlords.

2.1 Minimum energy efficiency standards

MEES regulations place obligations on landlords to take reasonable and cost-effective steps to improve the energy efficiency of buildings with sub-standard energy ratings.

Since 1 April 2018, landlords of non-domestic rented properties have been permitted to grant a new tenancy, or to extend or renew an existing tenancy, only if their property has at least an Energy Performance Certificate (EPC) E rating – unless they have registered a valid exemption.

As of 1 April 2023, the requirement for non-domestic landlords to obtain at least an EPC E rating, unless they have registered a valid exemption, applies to all privately rented non-domestic properties (even where there has been no change in tenancy).[6]

3. https://www.theccc.org.uk/wp-content/uploads/2023/06/Progress-in-reducing-UK-emissions-2023-Report-to-Parliament-1.pdf
4. UKGBC Delivering Net Zero: Key Considerations for Commercial Retrofits https://ukgbc.org/resources/delivering-net-zero-key-considerations-for-commercial-retrofits/
5. https://www.ipf.org.uk/resourceLibrary/pathways-to-net-zero-carbon-emissions-in-international-real-estate-investment--january-2022--full-report.html
6. https://www.gov.uk/guidance/non-domestic-private-rented-property-minimum-energy-efficiency-standard-landlord-guidance

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Since the previous IPF publication, in 2017, the expectations for MEES performance have changed considerably with the expectation that all rental properties achieve an EPC of C in the period 2025-27 and EPC of B by 2030.[7] In addition, there have also been changes to the EPC modelling method resulting from the adoption of a new Part L of Building Regulations in June 2022. This change means that electrification of heat is strongly incentivised and compliance strategies historically used by the industry, such as high efficiency lighting systems, are relatively cheap to install but are now less effective in improving EPC ratings than they were previously, and can make the rating worse. Lighting upgrades should always be considered in a package of improvement measures and the impact of this change for commercial assets is explored further in section 3.2.

Landlords are required to make improvements to all sub-standard properties unless they meet the required criteria for exemption. These criteria include:

- inability to secure necessary consents from a key stakeholder (e.g. a planning authority, superior landlord or the occupier);
- demonstrable impact on the quality of the property or a loss in value of more than 5% (e.g. where insulation could affect the integrity of the building structure or result in a significant loss in lettable floor area); and
- evidence, including quotes from installers, that show the measure is not cost effective (see below).

Improvements are deemed cost effective if the value of the energy saved over seven years is greater than the cost of the works (plus interest at the Bank of England's base rate). The cost effectiveness test has no link to the affordability of these investments for the landlord or whether occupiers are willing to make any contribution to the costs. The obligation falls entirely on the landlord who must seek consent, rather than financial contributions, from the occupier to make sufficient cost-effective improvements to achieve the minimum rating or until there are no further cost effective works.

7. The latest information from the government is that these timescales are being reviewed and may be extended.

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Suitable improvement measures are those listed in Table 6 of Building Regulations Part L2b (see Table 2.1). These measures have been used as a reference point for the improvement options considered in this report.

Table 2.1 Improvement options for complying with MEES

No.	Improvement measure
1	Upgrading heating systems more than 15 years old by the provision of new plant or improved controls
2	Upgrading cooling systems more than 15 years old by the provision of new plant or improved controls
3	Upgrading air-handling systems more than 15 years old by the provision of new plant or improved controls
4	Upgrading general lighting systems that have an average lamp efficacy of less than 60 lamp-lumens per circuit watt and that serve areas greater than $100m^2$ by the provision of new luminaires and/or improved controls
5	Installing energy metering following the guidance given in CIBSE's TM39
6	Upgrading thermal elements which have U-values worse than those set out in Approved Document Part L2b
7	Replacing existing windows, roof windows or rooflights (but excluding display windows) or doors (but excluding high-usage entrance doors) which have a U-value worse than 3.3 W/m^2K for windows, roof windows and doors; and 3.8 W/m^2K for rooflights
8	Increasing the on-site low and zero (LZC) energy-generating systems if the existing on-site systems provide less than 10% of on-site energy demand, provided the increase would achieve a simple payback of seven years or less
9	Measures specified in the Recommendations Report produced in parallel with a valid Energy Performance Certificate.

Further information on the application of MEES is available in the government guidance. It should be noted that at the time of writing, the government had recently announced a potential delay in the timeline for requiring EPC C and EPC B ratings "to allow sufficient lead in time for landlords and the supply chain".

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2.2 The Carbon Risk Real Estate Monitor pathways

Property values are increasingly exposed to climate risk and therefore climate risk is investment risk. To help investors and property owners to assess and manage these climate change related risks, the Carbon Risk Real Estate Monitor (CRREM) initiative has been developed. CRREM provides Paris-aligned decarbonisation and energy reduction pathways per country and per building type that are used to derive indicators for risk management, reporting and disclosure.

> *'Stranded assets are properties that will be exposed to the risk of early economic obsolescence due to climate change because they will not meet future regulatory efficiency standards or market expectations.' (CRREM, 2019)*

Changing market expectations result in a faster economic obsolescence of real estate assets that no longer meet new energy and technical requirements. The CRREM initiative enables investors, asset managers, banks and other market participants to leverage resources to decarbonise their real estate portfolios.

The transition to a low-carbon economy will result in a devaluation of infrastructure, knowledge and assets whose value is to some degree based on burning fossil fuels and emitting greenhouse gases. The aim of CRREM is to drive investments in energy efficiency as many assets will otherwise become 'stranded' properties[8] that will not meet future decarbonisation standards and whose energy upgrade will not be financially viable. The CRREM Tool allows investors to benchmark carbon and energy performance of buildings and portfolios against the pathways and peers.

This study has incorporated the CRREM 1.5-degree decarbonisation pathways for the UK, assessing packages of improvements for each typology for how they perform against the targets set. The CRREM pathways are widely used and have been incorporated into the GRESB framework. They are science-based, downscaled carbon targets and work has been done to map the CRREM pathways to the Science Based Targets Initiative (SBTI). The CRREM pathways V2 released in 2023 have been used.[9] Figure 2.1 illustrates the GHG intensity and energy intensity for UK offices as an example of the trajectory to 2050. There are two metrics that are used in the CRREM pathways - energy intensity and carbon intensity.

8. Stranding risk as defined by CRREM is explained here: https://www.crrem.eu/wp-content/uploads/2022/12/CRREM-initiative-definition-on-stranding-risk-and-stranded-assets-in-the-build-environment.pdf

9. https://www.crrem.eu/tool/

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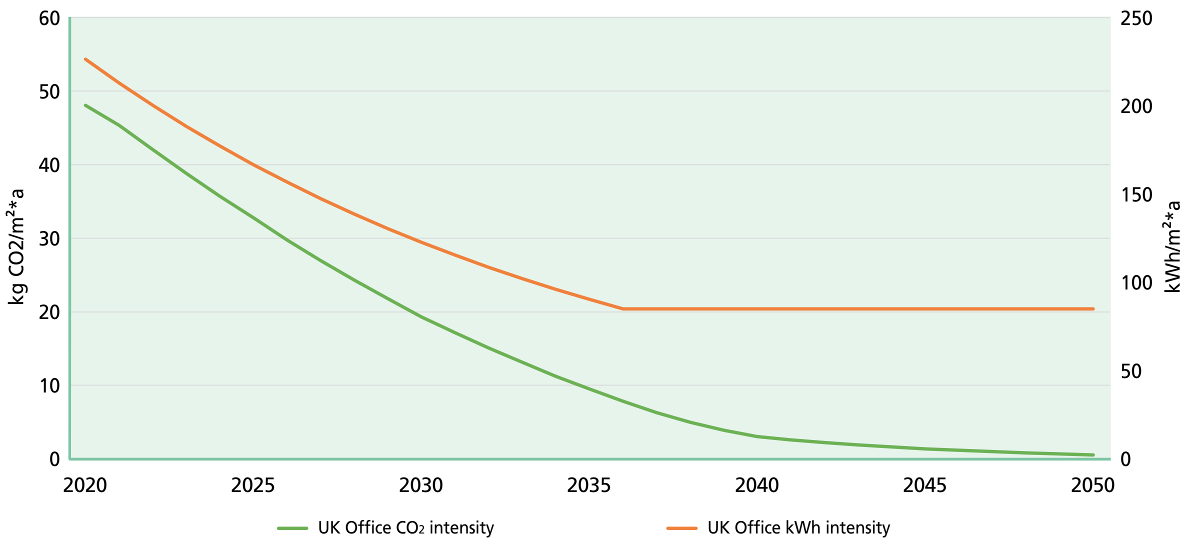
Figure 2.1 CRREM 1.5 degree pathways for UK Offices



2.3 Disclosure of climate performance

There are a range of sustainability disclosure mechanisms that are either mandatory or are gaining momentum as voluntary commitments.

Sustainability information disclosure makes it important for listed landlords to reduce their energy consumption and for major occupiers to be more selective about the energy performance of the spaces they occupy.

Larger landlords and occupiers (i.e. those listed on the FTSE) are obliged to report on the carbon emissions associated with their activities, this would include direct and indirect (i.e. electrical) emissions from their buildings. Whilst not mandating any specific action, this is one of several forms of information disclosure that make it more important for listed landlords to reduce their energy consumption and for major occupiers to be more selective about the energy performance of the spaces they occupy.

The Taskforce on Climate related Financial Disclosures (TCFD) initiated by the Financial Stability Board (FSB), created a series of eleven disclosure recommendations to support companies in providing better information on climate related risks. In 2022, it became mandatory for larger organisations and financial institutions in the UK to disclose their climate related risks against the TCFD areas of governance, strategy, risk management, and metrics and targets. If successful, this requirement is likely to expand to include smaller organisations by 2025.

In the European Union, the Corporate Sustainability Reporting Directive (CSRD) will require companies to report on how sustainability issues, such as climate change, impact their business and how their operations in turn affect people and planet – a unique principle called 'double materiality'. For in-scope companies, there is a requirement to produce disclosures in accordance with the European Sustainability Reporting Standard (ESRS) for financial years beginning on or after 1 January 2024. Real estate companies and occupiers that fall under the scope of CSRD will need to report on a range of ESG factors including energy efficiency, carbon emissions, social responsibility, diversity, and inclusion. This will no doubt increase the transparency and comparability of sustainability information.

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2.4 Benchmarking

Increasing numbers of investors and property companies are adopting tools and initiatives to benchmark asset performance. The most widely known performance benchmark, GRESB (the Global Real Estate Sustainability Benchmark), has gained significant traction. Presently, portfolios of more than 1,500 real estate companies, REITs, funds and developers, and more than 700 infrastructure funds and asset operators, participate in GRESB Assessments. This coverage provides investors with ESG data and benchmarks for more than $6.4 trillion worth of assets under management.[10]

GRESB asks for details on sustainability performance, including energy use, carbon emissions and average EPC rating. Accordingly, investors and asset managers, wanting to score highly on these metrics, will need to be able to demonstrate ongoing improvements in their portfolio's performance.

The Better Buildings Partnership's (BBP) Real Estate Environmental Benchmark (REEB) is a publicly available operational benchmark of environmental performance for commercial property in the UK. It is based on the performance of buildings 'in-use' and is increasingly becoming the industry standard used by investors, fund managers and property owners to compare the performance of their assets with other similar assets from portfolios across the UK.[11]

There are also rating systems outside of the real estate industry such as the MSCI ESG rating, a rating system designed to measure a company's resilience to long-term, industry material environmental, social and governance (ESG) risks.[12]

2.5 Market factors

For institutional investors, there are several market factors increasing the importance of both the actual energy use and asset rating of commercial buildings.

MEES side effects

The impact of MEES is likely to extend beyond basic regulatory compliance. Increased industry awareness and due diligence may make it more difficult to market a building with a 'sub-standard' EPC. Even if an asset is technically compliant with the regulations because improvement measures do not pass a cost effectiveness test, the landlord and their agent will be exposed to questions about the quality of the product offered. These concerns may be reduced if the building is already deemed a 'lower value' property but could be considerable if the building is otherwise of a reasonably high standard. Where there are other better rated, but otherwise comparable, properties in the local area, landlords may feel obliged to improve the building's rating to reduce the risk of a reduction in market value.

10. https://www.gresb.com/nl-en/welcome/for-investors/
11. https://www.betterbuildingspartnership.co.uk/our-priorities/measuring-reporting/real-estate-environmental-benchmark
12. https://www.msci.com/our-solutions/esg-investing/esg-ratings

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The changes to MEES as at 1 April 2023, have significantly increased the pressure for landlords to make the necessary efficiency improvements to their buildings, otherwise they risk having an asset that is unlettable or deemed not sufficient in the market. MEES supports the industry awareness and demand for better performing buildings. The Government's Energy White Paper published in 2020 confirmed that the future trajectory for the non-domestic minimum energy efficiency standards (MEES) will be EPC B by 2030.[13] This strengthens the case for longer term thinking about asset performance, compliance and market value. The latest information from the government is that these timescales are being reviewed and may be extended. Although the timelines may change, the direction of travel is towards significantly increasing energy efficiency.

Occupier expectations

More occupiers are reporting on the environmental impacts of their businesses, either as a result of compulsory reporting requirements or to demonstrate effective management of their wider business impacts and responsibilities. The importance of staff wellbeing and their working environment has risen on the agenda for many occupiers. Health and wellbeing indicators such as daylighting or ventilation heavily influence the quality of the internal environment.

Whilst most occupiers may not be willing to pay more rent for energy efficient buildings, they are likely to prefer this space and are now increasingly able to identify its characteristics. When the market is buoyant and/or if there is limited local competition then this may not impact on rental or asset values but during inevitable periods of softer market conditions, and particularly in areas where there are a lot of otherwise comparable properties, there is the risk that poorly performing buildings will see their desirability and, therefore, value diminish.

13. https://www.gov.uk/government/consultations/non-domestic-private-rented-sector-minimum-energy-efficiency-standards-epc-b-implementation

3. ENERGY CONSUMPTION AND COMMERCIAL BUILDINGS

The main energy uses within commercial buildings are:

- Lighting;
- Heating;
- Ventilation and air conditioning (including fans, pumps and chillers);
- Power for IT and other equipment;
- Hot water for washing, showers and catering;
- Chilled storage (some retail and industrial buildings; and
- Other uses such as lifts.

The importance of the above uses varies significantly between and within building types. Generally, heating and lighting are prime sources of energy consumption, with cooling, ventilation and ICT also being important in offices, and cold storage facilities a significant contributor to overall warehouse and retail energy use.

3.1 Predicting energy consumption

Energy consumption is affected by a complex interaction of factors, including:

- 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)

A building's energy use can be estimated using theoretical models or, if it is available, from analysis of actual consumption data. Theoretical models, such as those used to produce an EPC, typically provide an assessment of the asset's performance under a standardised use scenario and are helpful for assessing the potential energy efficiency of the building.[14] However, they do not provide a complete indication of the actual energy use in the building because they only assess regulated emissions (e.g. heating, lighting, cooling, and ventilation), and they make no allowance for variations in occupation, hours of use or the effectiveness of the building's management regime. See Figure 3.1 for an illustration of this. The CRREM energy and carbon pathways apply to total operational energy, rather than just regulated energy use.

[14]. These might include the Simplified Building Energy Model (SBEM) or a Dynamic Simulation Model, both of which would be set up with National Calculation Method assumptions about occupancy patterns and densities.

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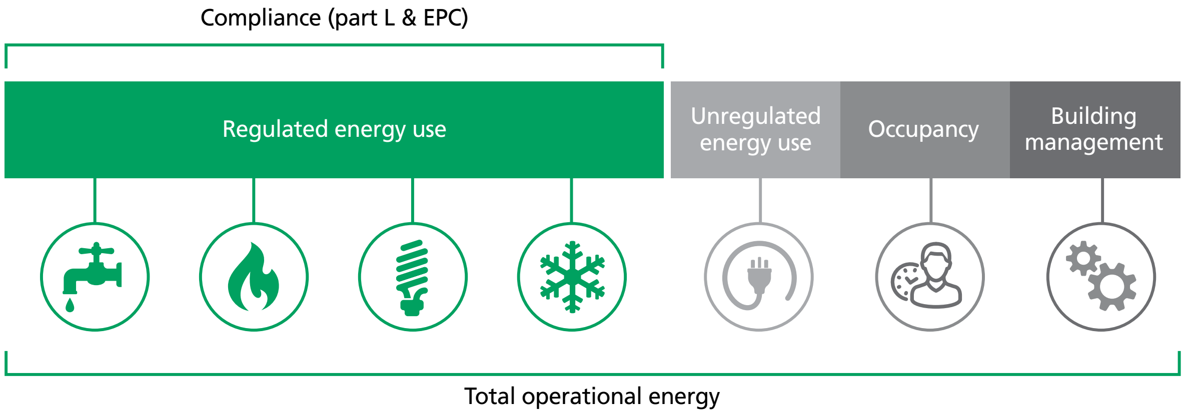
Figure 3.1 Illustration of the total operational energy for a building



Research carried out by the Better Buildings Partnership (BBP) of market insights from 2022, mapped energy intensities from Offices, with the EPC ratings for those properties. The results demonstrated a very weak relationship between these two factors and it can be seen that properties within a high-performance band can have intensities higher than a lower performance band. There is also significant variation in the range of energy intensity within each EPC band. This further indicates that EPCs are not a true representative of operational energy use and an increase in expectation of design ratings only will not be a sufficient process and policy tool to achieve the UK Government's energy reduction targets.[15]

Energy models can be used to assess the scale of the reduction in regulated energy that might arise in a building where the use pattern is unchanged. Calibration of the theoretical model, to include variations in hours of occupancy and varying levels of commissioning and management, can be used to assess the spread of potential energy impacts associated with any given measure.

To minimise the performance gap of buildings, it is essential that training and aftercare responsibilities are prioritised, ensuring building users know how to fully optimise the heating and cooling of the building and that systems are working as intended.

EPC certificates and MEES regulations are a driver to encourage action on reducing the regulated energy consumption of a building. The way an asset is used and managed impacts the unregulated energy consumption, for example tenant small power, and the total energy consumption. Asset owners need to work together with tenants to identify and act on opportunities to drive down the energy use intensity.

All other things being equal, improving the EPC rating will reduce the energy and carbon impacts. This will deliver a directionally correct result, albeit not by the exact emissions predicted by the EPC model.

15. Real Estate Environmental Benchmark: 2022 Insights Report, August 2023, Better Buildings Partnership
https://www.betterbuildingspartnership.co.uk/sites/default/files/media/attachment/REEB%202022%20Insight_v8%20Final.pdf

3. ENERGY CONSUMPTION AND COMMERCIAL BUILDINGS

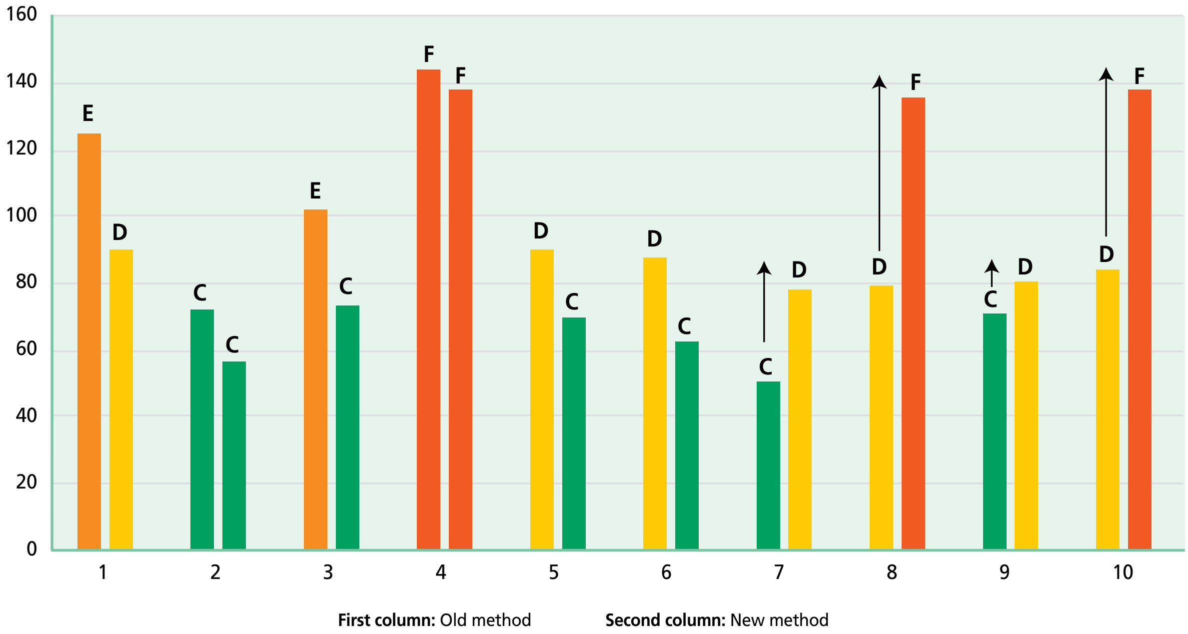
3.2 EPC methodology changes and impact on ratings

In June 2022, the method for calculating the EPC score and rating changed as part of the change to Building Regulations Part L. Among several changes, the most significant alteration was in the carbon emission factor applied to electricity. The new factor for electricity is around a third of that used previously and is now lower than that for an equivalent amount of gas.

Figure 3.2 shows the impact of these changes on the rating of a selection of office, light industrial and retail spaces grouped according to the level of gas consumption in the building.

The analysis shows that the majority of 'All electric' buildings and those with 'Low gas use', see a significant reduction in the EPC score. In several cases, this is sufficient to move the building to a lower rating. For some medium and all high gas use buildings, the EPC rating deteriorates when the new modelling method is applied. In two of three cases, the change is significant enough to move the building from a D rating to an F rating.

Figure 3.2 EPC score for properties under old and new modelling methods



Source: Currie & Brown (confidential client)

3. ENERGY CONSUMPTION AND COMMERCIAL BUILDINGS

The following initial conclusions can be drawn from the small sample illustrated:

- The change in EPC modelling method will result in a change in EPC score.
- In most cases, the change will be significant and sufficient to change the EPC score by at least one rating.
- The implications appear to be closely, albeit not exclusively, linked to the presence or level of gas use in the building.
- Owners of gas heated buildings currently rated well above the minimum EPC rating when modelled using the old assessment method could find that on remodelling the rating falls into a non-compliant band. Buildings at most immediate risk will be those with EPCs that are 8-9 years old and where heating energy use is a significant portion of overall energy use (e.g., naturally ventilated buildings).
- Conversely, in some cases, owners of electrically heated buildings that are currently rated poorly might find that on remodelling they improve to a level that meets current and potentially future minimum standards without further intervention. This is more likely to be the case for buildings with variable refrigerant flow (VRF) or other heat pump-based systems. It is also likely that the EPC ratings of directly electrically heated buildings will improve.

Looking to the mid-term, building regulation Part L is due to change again in 2025, and potentially again in 2028-2030, bringing further changes to the modelling method. It is highly likely that the emission factor for electricity will reduce further, and therefore strengthen the incentive to electrify heating and remove gas from buildings. The benchmark costs for these interventions are provided in the dataset and presented in section 5 of this report.

3.3 Progress and trajectory for carbon in commercial buildings

Over the last 20 years, CO_2 emissions from commercial buildings have incrementally fallen, although this is almost exclusively as a result of reduced carbon emissions associated with supplied grid electricity through a changing mix of fuels being used for electricity generation, such as switching from coal to natural gas and the growth in the use of renewable energy technologies. Appendix A includes more information on the UK carbon budgets and trajectories and why decarbonisation of buildings is important for these to be met.

If the UK office sector is to meet the carbon trajectory set out in the UKGBC's Whole Life Carbon Roadmap, an overall 59% reduction in energy consumption is required. The BBP's Real Estate Environmental Benchmark (REEB) 2020 research highlights the challenge for the sector, showing that 97% fall short of the UKGBC 2035-2050 target energy use intensities and 65% fall short of the 2020-2025 targets.[16]

In order for the sector to meet these targets, significant retrofit is needed across the market. A key requirement for commercial buildings is to reduce their direct emissions from on-site fossil fuel combustion systems for heating, whilst also improving energy efficiency to minimise the additional load on grid electricity in the transition towards the electrification of heat. Energy efficiency improvements must be built into the next refurbishment cycle for existing buildings, or undertaken as energy efficiency improvement works, particularly for those buildings that will not meet the MEES requirements, or will face increased stranding risk in terms of the CRREM pathways.

[16] Better Buildings Partnership (2021), Real Estate Environmental Benchmark: 2020 Energy Snapshot: https://www.betterbuildingspartnership.co.uk/real-estate-environmental-benchmark-2020-energy-snapshot

3. ENERGY CONSUMPTION AND COMMERCIAL BUILDINGS

3.4 Further considerations

It is important to note that this study has focussed on energy efficiency improvements and therefore operational carbon emissions only. The embodied carbon impact of the improvements has not been modelled. For any refurbishment works, it is recommended that limits for embodied carbon impacts are adopted in line with best practice industry guidance and that embodied carbon is measured and reported. There may be instances where to meet a desired operational saving, there could be significant embodied carbon incurred and this must be considered in line with whole life carbon commitments.

Where possible, it is advised that building performance, both operational energy and embodied carbon, are tracked before and after the retrofit process. Whole life carbon modelling and operational data can help ensure the expected performance is achieved. Defining quantitative and qualitative performance targets such as kWh/m² reductions for operational energy and $kgCO_2$ e/m² for embodied carbon can facilitate this.

4. IMPROVING ENERGY EFFICIENCY

The priorities for reducing energy use in an existing building depend on how the building consumes energy. In most buildings, the landlord-influenced energy consumption is linked to:

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

It is recognised that although a significant proportion of a building's energy consumption is for the provision of heat, the characteristics of the building in terms of its size, layout, principal construction method and use mean its energy intensity can vary considerably.

Typically, the most rapid and cost-effective means to reduce energy use and associated carbon emissions is through the implementation of an active energy management regime with close control of the settings, run time and condition of key services. Installation of effective metering systems to enable the performance and consumption of key areas and plant to be monitored is an important first step to understand the baseline performance in respect to energy use, this will enable services within buildings to be more effectively managed.

4.1 Roles of landlords and occupiers

An owner occupier has control over all the factors influencing energy consumption except for location and proximity of other buildings. The situation is more complex where there is a landlord and occupier arrangement. The landlord has sole control over the quality of the building fabric and design, whereas the occupier is responsible for hours, density of occupation, efficiency of IT and other equipment, and setting internal temperatures.

Landlords and occupiers have varying levels of influence on the energy efficiency of the installed building services. For example, a retail landlord has limited control over the building services in a retail unit that has been let as a 'shell only' specification. In this example, the occupier installs all services except for incoming gas mains and electrical power supply. Therefore, the landlord only has influence over the thermal performance of the building fabric (i.e. in terms of insulating qualities and airtightness to reduce heat transfer). By contrast, in an office building fitted to Cat A, the landlord has installed the central plant together with lighting and terminal (e.g. fan coil) units throughout. Landlords can, and should, set fit out standards that deliver energy efficiency.

An occupier's small power and equipment alone can account for up to one third of total energy consumption. However, how the occupier runs the building services also has a significant influence on total energy consumption. Leaving lights and equipment on overnight, opening windows whilst the air conditioning or heating is running and setting a high temperature on the thermostatic controls are typical examples of inefficient behaviour in office buildings. The occupier will have direct influence over these behaviours; however, the landlord can have an influence through the agreement of a Green Lease or Green Memorandum of Understanding with the occupier or by setting up a Green Building Management Group to engage occupiers in a building on energy and other sustainability matters.

The distribution of responsibilities and influence will vary within and across building uses. In this study, investment for clearly delineated landlord and occupier control over interventions have been modelled. The associated energy and carbon savings have been presented as whole building savings, rather than apportioning these to landlords and occupiers because, in practice, responsibilities will vary.

4. IMPROVING ENERGY EFFICIENCY

It should be remembered that under MEES regulations, the responsibility for compliance sits entirely with the landlord and, should it prove cost effective, they may be obliged to invest in improving the energy efficiency of the occupier's space even if they receive none of the resulting savings. The ability for the landlord to recover costs will depend on the specific building, the relationship with the occupier and the market position.

4.2 Energy efficiency improvements modelled

Table 4.1 provides a list of the improvement measures, packages and a description of the specifications modelled for each. Table 4.2 lists the package names by typology and details the items included in combination packages.

Table 4.1 List of improvement packages and descriptions

Improvement measure	Description
Lighting package	Replacement of existing lighting and controls with new LED luminaires delivering over 120 luminaire lumens per circuit Watt together with presence detection sensors and daylight compensation sensors to relevant spaces.
Ventilation packages	Ventilation upgrades including installation of air handling units with heat recovery efficiency at 80%. Balanced ventilation system with 85% heat recovery efficiency for Build-to-Rent. Demand control ventilation through CO_2 sensors and speed control in Retail warehouse, Office 1 and Office 2.
ASHP package	Replacement of existing gas boiler with air source heat pump (ASHP) and associated works including replacement of radiators, new controls and new metering. For air conditioned buildings the ASHP also provides cooling in place of the existing chiller.
Direct electric heating package	Replacement of gas boiler with direct electric heating system with radiant panels and direct electric hot water in retail warehouse and logistics warehouse only.
PV package	Installation of PV panels on roof, 20-50% of area typology dependent.
Wastewater Heat recovery	Installation of wastewater heat recovery (WWHR) system in Build-to-Rent only. A vertical WWHR system in shower has been modelled.
Fabric package	Retail warehouse and Office 2 insulation to external walls and roof to meet U-value of 0.15 W/m²K. Retail warehouse double glazing windows to meet U-value of 1.6 W/m²K and external doors to meet U-value of 1.6 W/m²K. Office 2 double glazing windows to meet U-value of 1.3 W/m²K and external doors to meet U-value of 1.3 W/m²K. BTR roof U-value 0.10; good practice thermal bridging.
Combination(s)	Combination packages for each typology have been modelled and these vary based on what is appropriate for the typology to meet EPC B and /or CRREM pathways.

4. IMPROVING ENERGY EFFICIENCY

Table 4.2 Reference list of package names

Typology	Package
Office 1	Baseline
	Lighting
	AHU (Air Handling Unit) with HR (Heat Recovery), FCU (Fan Coil Unit) and DCV (Demand Controlled Ventilation)
	AHU with HR
	FCU & DCV
	ASHP (Air Source Heat Pump)
	PV (Photovoltaic)
	Package 1 - Lighting, Ventilation & ASHP
	Package 2 - Lighting, Ventilation, ASHP and PV
	Package 3 (central plant) - ASHP, AHU & HR
	Package 4 (floor plate) - Lighting & FCU
Office 2	Baseline
	Lighting
	AHU with HR, FCU and DCV
	AHU with HR
	FCU & DCV
	ASHP
	PV
	Fabric
	Package 1 - Lighting, Ventilation & ASHP
	Package 2 (central plant) - ASHP, AHU & HR
	Package 3 (floor plate) - Lighting & FCUs
Retail unit in shopping centre	Baseline
	Lighting
	AHU with HR, FCU and DCV
	AHU with HR
	FCU & DCV
	ASHP
	Package 1 - Lighting, Ventilation & ASHP
	Package 2 (plant) - ASHP, AHU & HR
	Package 3 (floor plate) - Lighting & FCUs

4. IMPROVING ENERGY EFFICIENCY

Typology	Package
Retail warehouse	Baseline
	Lighting
	AHU with HR
	Electric heating
	Fabric
	Package 1 - Lighting, Ventilation and Electric heating
Logistics warehouse	Baseline
	Lighting
	AHU with HR
	Electric heating
	PV
	Package 1 - Lighting, Ventilation and Electric heating
Student accommodation	Baseline
	Lighting
	MVHR (Mechanical Ventilation with Heat Recovery) (shared)
	ASHP
	PV
	Package 1 - Lighting, Ventilation & ASHP
Build-to-Rent	Baseline
	ASHP
	Lighting
	WWHR (Waste Water Heat Recovery)
	Fabric
	MVHR
	Package 1 - Lighting, ASHP & Fabric

4.3 The importance of energy management and tenant engagement

This research has looked specifically at the improvement measures listed in Tables 4.1 and 4.2 and the impact these have for MEES compliance. As discussed in section 3 predicting energy consumption for MEES compliance uses the building EPC. An EPC is an asset rating and is not directly linked to actual consumption or metered data. The CRREM pathways are whole-building, total operational energy targets that do incorporate unregulated loads (see Figure 3.1).

4. IMPROVING ENERGY EFFICIENCY

To predict the total energy and carbon intensities, an estimation of the total building energy use has been made through the application of a 50% uplift to the EPC analysis results. No analysis has been undertaken on improvements in unregulated load efficiencies and management opportunities such as occupancy hours and active energy management. Energy savings can be achieved, but there are many variables that influence this which are building and occupier specific and therefore have not been assumed in this analysis.

Table 4.3 provides an indication of the costs of installation of sub-metering and BMS systems to enable active energy management by building typology. The installation of metering does not deliver the savings; it is the active energy management that is possible with the information the metering provides.

Energy savings from active energy management could be considerable depending on level of current energy management and building complexity (more complex means more can go wrong). Energy savings of a third could be achieved in buildings that are currently poorly managed. Asset owners should look at the pattern of energy use and if significant out of hours usage (e.g. overnight or at weekends) is identified that cannot be explained then it implies that significant savings might be possible.

Working with the tenant on these aspects of energy demand will provide opportunities to improve the building energy efficiency and reduce carbon intensity further (i.e. helping to further align to the CRREM pathways).

Table 4.3 Indicative benchmark costs for metering and BMS installation by typology

Building typology	Cost per m²
Offices	£8
Retail unit	£45
Retail warehouse	£27
Logistics warehouse	£6
Student accommodation	£16
Build-to-Rent Residential	£45

4.4 Further considerations

Heat pumps have been proposed as the heating package solution in most typologies as an improvement to switch from gas to electric heating and consequentially meet the EPC B performance. The applicability and feasibility of installation at a specific building will depend on several factors, including availability of space for external units. It has been assumed in this study that the space is available for the units.

4. IMPROVING ENERGY EFFICIENCY

The ASHP packages have been modelled assuming there are no thermal performance improvements to the fabric. A successful, efficient ASHP installation must carefully account for the thermal performance of the fabric and should be designed to deliver heat at a temperature which provides the necessary heat to the building. Different options exist including:

- increasing the run time of the heating system to provide more time for the building to reach the target temperature;
- increasing the capacity of the heating distribution system to provide more heat output at a lower temperature; and
- running the heat pump at a higher temperature and losing some efficiency in the heat supplied.

The preferred option will depend on the detail of the building and its operating regime. Other options for electrification of heating would include alternate heat pump solutions (e.g. ground or water source), combined heating and cooling systems (such as polyvalent chillers), and connection to local heat networks where available.

Electrification of heat, even when via a highly efficient heat pump, will place additional demands on electricity supply infrastructure and capacity to install additional building loads should always be checked in advance. Adjustments to operating regimes including set points and run hours can help to minimise peak power demand associated with heat pumps and so effective controls and management systems are an important component to any transition to heat pump based heating.

Hydrogen conversion of natural gas networks is considered by some as a potential part of a low carbon economy. Indicators shown in various Climate Change Committee reports suggest that hydrogen has a role to play but should be focused on selective sectors and regions. However, when considered holistically, it seems unlikely that zero carbon hydrogen supplied via a re-purposed gas mains network will be available for most buildings in the foreseeable future.[17]

In addition, it is unlikely that hydrogen will be a viable solution in the timeframe of the next replacement / refurbishment cycle for buildings so it is recommended that property owners focus on reducing heating demand and switching away from gas boiler systems. Installing heat pumps now will respond to the immediate need to decarbonise existing buildings, and will not impede the future use of hydrogen should that become a viable solution.

[17] https://www.leti.uk/hydrogen

5. FINDINGS

This section presents the findings from the EPC improvement and CRREM 1.5 degree pathway analysis for each of the building typologies. For each typology the following is provided:

- Description of building and key baseline characteristics, including starting EPC;
- Capital cost of improving EPC rating for MEES analysis;
- Energy use intensity for CRREM analysis;
- Carbon intensity for CRREM analysis; and
- Energy, carbon and return on investment data points in tabular format.

The capital cost scenarios modelled are as follows:

Energy upgrade scenario	Where a building owner upgrades but without a set forward investment plan. The absolute replacement costs have been modelled, without any reference to age, condition or performance of the existing assembly.
Refurbishment scenario	Where a building owner will be making these interventions as part of a planned programme of asset improvements / replacement. The cost assessment is the marginal extra over cost uplift of each energy efficiency improvement against the business-as-usual alternative that can be assumed to have formed part of a PPM plan (i.e. a like for like or 'minimum compliance' solution).

Where there is a clear delineation between landlord spaces and occupier space, improvement packages have been modelled separately.

The method for calculating each form of analysis is included in Appendix A. For the energy use intensity, carbon intensity and return on investment analysis, the EPC performance (modelled using SBEM and SAP) was adjusted using a 'performance gap' factor of 50% for all building typologies and packages. This is to help provide an indication of the impacts of the energy efficiency measures on actual energy consumption. In reality, the performance gap would depend on aspects such as the relative use of lifts and escalators, process loads and IT loads and will vary greatly between individual buildings and across building types. See section 3.2 for an explanation on the limitations of EPC ratings to predict operation energy use, and why a factor has been applied.

5.1 Overarching findings

The detail and commentary for each building is presented in the following sections. Overarching findings have been drawn out below.

Findings from the payback test

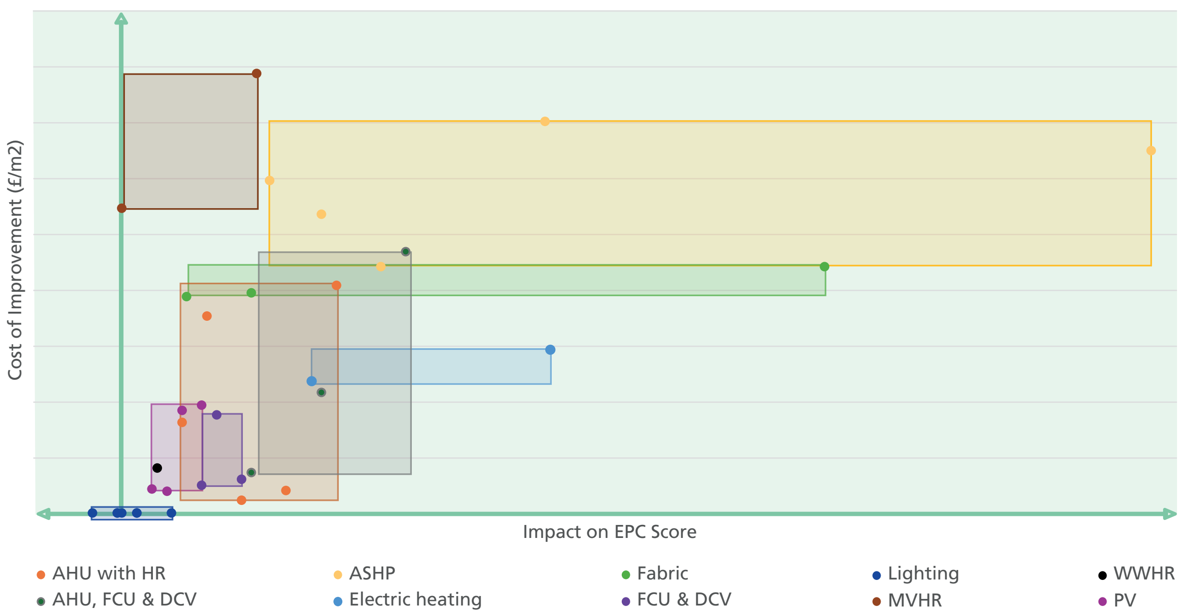
The seven-year payback test, as defined in the MEES guidance was applied to all packages across all typologies. The results show that the only improvements that pass the payback test are those that are part of a planned refurbishment scenario, and this is limited to lighting and ventilation improvements. This information can be explored in the dataset dashboard and therefore has not been presented in this summary report. Improvements are deemed cost effective if the value of the energy saved over seven years is greater than the cost of the works (plus interest at the Bank of England's base rate). The cost effectiveness test has no link to the affordability of these investments for the landlord or whether occupiers are willing to make any contribution to the costs. There will be market drivers for action to improve energy efficiency, even when there may be a valid MEES exemption for cost effectiveness.

5. FINDINGS

Impact of improvement options across the typologies

The improvement options explored showed a range of impacts on the EPC score across the typologies modelled. Figure 5.1 illustrates the range of impacts against the cost of the discrete improvement measures (not including the packages). The cost impacts are for the refurbishment scenario i.e. the marginal extra over cost uplift of each energy efficiency improvement against the business-as-usual alternative. In a refurbishment scenario, the lighting improvements present no cost uplift, as energy efficient replacements would be assumed part of a standard refurbishment. ASHPs generally deliver the most significant change in EPC score and are typically the most expensive improvement measure. Ventilation improvement options (AHU with HR; AHU, FCU and DCV) deliver a moderate positive impact on the EPC score and can range from relatively low to medium cost across the typologies.

Figure 5.1 Cost improvement options and impact on EPC score



Central plant and floor plate measures

For Office 1 and Office 2, packages were explored that isolated the central plant and floor plate measures (i.e. the landlord and tenant areas respectively). In general, the central plant improvement measures provide better EPC results compared with the floor plate measures. This is largely due to the central plant measures including a change in the heating fuel from gas to electric.

Heating fuel

Changing the heating fuel to direct electric or heat pumps can significantly improve the EPC rating of any building, assuming it is replacing gas. This is due to the de-carbonising of UK grid and lower carbon factors for electricity.

Lighting

The LED lighting and controls packages alone do not always improve the EPC, and in some cases the Lighting package makes the EPC worse. This is due to an increase in the heating demand, which remains fuelled by gas for the building.

5. FINDINGS

Fabric

Fabric measures (wall/roof insulation, new windows and/or doors) were only explored for the Office 2, the Retail warehouse and the Build-to-Rent typologies where the starting EPC was poor. The fabric measures alone will not be enough to achieve an EPC B rating. Other improvement measures will have to be combined with fabric measures.

Packages to meet EPC B

For most buildings, a combination package of three improvement measures - lighting, ventilation and heat pumps will meet the requirement of an EPC B. In the Retail unit, Logistics warehouse and Student accommodation typologies, the heat pump or direct electric heating package will also meet EPC B. This is dependent on the age and condition of the existing building.

CRREM analysis

The packages to meet MEES were assessed to see what impact they would have on the building's performance against the CRREM energy and carbon pathways. The analysis suggests that focusing solely on the asset improvement measures (technological upgrades) will not be sufficient to meet the CRREM pathways. This demonstrates the need to adopt active energy management and work with the tenants towards energy saving initiatives. Asset managers need to have both a good asset and to be managing it well. Active energy management has not been modelled in this analysis; however, section 4.3 provides an indication of how significant the energy savings could be and the benchmark costs associated.

CRREM 1.5 energy intensity pathway

The CRREM energy pathway sets a trajectory for reducing energy intensity (kWh/m²/yr) of a building. In the pathway, the intensity reduces gradually to a plateau around 2035 for most building types. Of the typologies modelled, only improvements modelled for Office 1 would meet the EUI targets and remain better than the EUI target for more than five years without further intervention. No packages modelled for the retail and logistic warehouses will meet the CRREM energy intensity targets. Note that is without including energy management activities which are highly building specific and could have a significant impact on reducing energy use.

CRREM 1.5 carbon intensity pathway

For most of the typologies modelled, there is a solution that would follow or better the CRREM 1.5 carbon intensity pathway. The exception to this is the Logistics warehouse where the solutions result in a carbon intensity a little higher than the pathway. The improvements that switch from gas to electric for heating fuel most often deliver the carbon intensity reduction required to meet the targets. The results demonstrate that individual measures alone, with the exception of the ASHP and Direct Electric improvements, will not meet the carbon intensity reductions required.

Opportunities to influence EUI and carbon intensity

These results show the impact of improvement packages on both the EPC rating and the regulated energy demand. To predict the total EUI and carbon intensity, an estimation of the total building energy use has been made through the application of a 50% uplift to the EPC analysis results. No analysis has been undertaken on improvements in unregulated load efficiencies and management opportunities such as occupancy hours and active energy management. Working with the tenant on these aspects of energy demand will provide opportunities to improve the building energy efficiency and reduce carbon intensity further.

5. FINDINGS

Significance of improvement measures required for compliance post June 2022

Previously if buildings were trying to get to an EPC rating of C, changing the lighting (to T5 or LED) would be a relatively cheap option and could in many scenarios reach an EPC of C. For a B rating, a building would typically need LEDs and an ASHP.

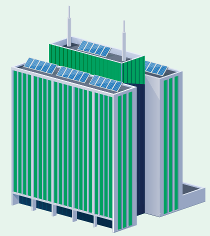
However, post June 2022 and under the new methodology, lighting upgrades are not enough to improve the EPC and may make the EPC score worse. To reach an EPC B, buildings typically need an ASHP, lighting and fan power upgrades. These improvements needed are more significant, the costs to reach the desired EPC have gone up and therefore the compliance costs to an asset manager have gone up.

5. FINDINGS

5.2 Office 1

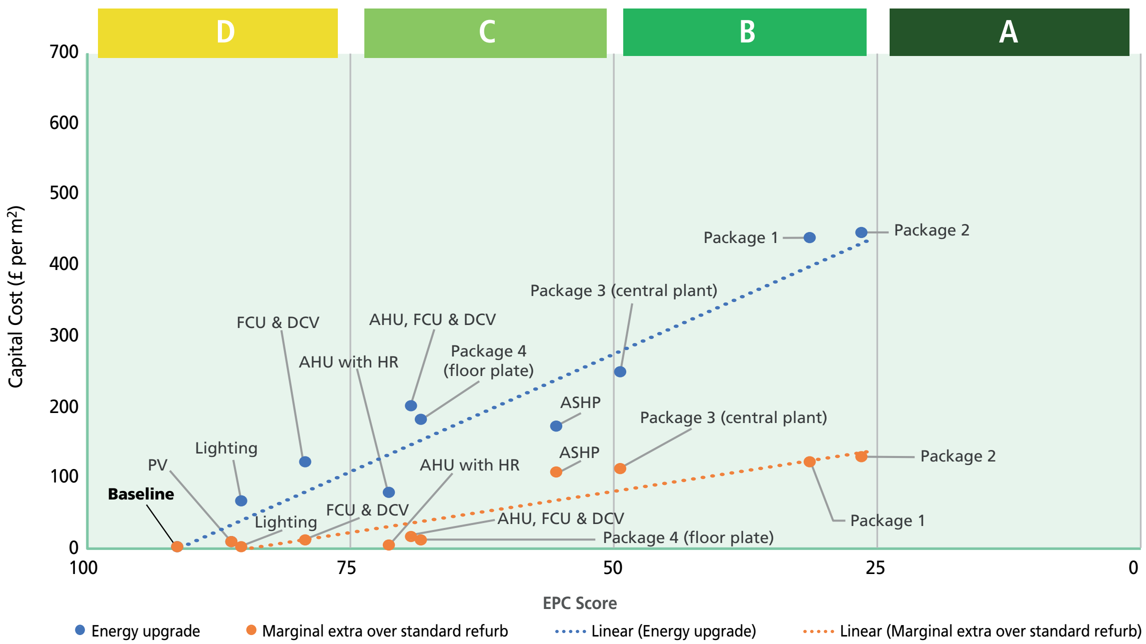
Office 1 – Deep plan, air conditioned office built in the early 2000s:

- 12-storey (+ basement) deep plan office
- 20,500m²
- Air conditioned
- Window-to-wall ratio of 45% and 44% glazing ratio (including rooflights)
- Gas boiler 80% efficient for heating and hot water (kitchens)
- Direct electric hot water for office & showers
- Lighting 45 lm/W
- **Starting EPC = 91 (D)**



Illustrations are not exact representations of the building types.

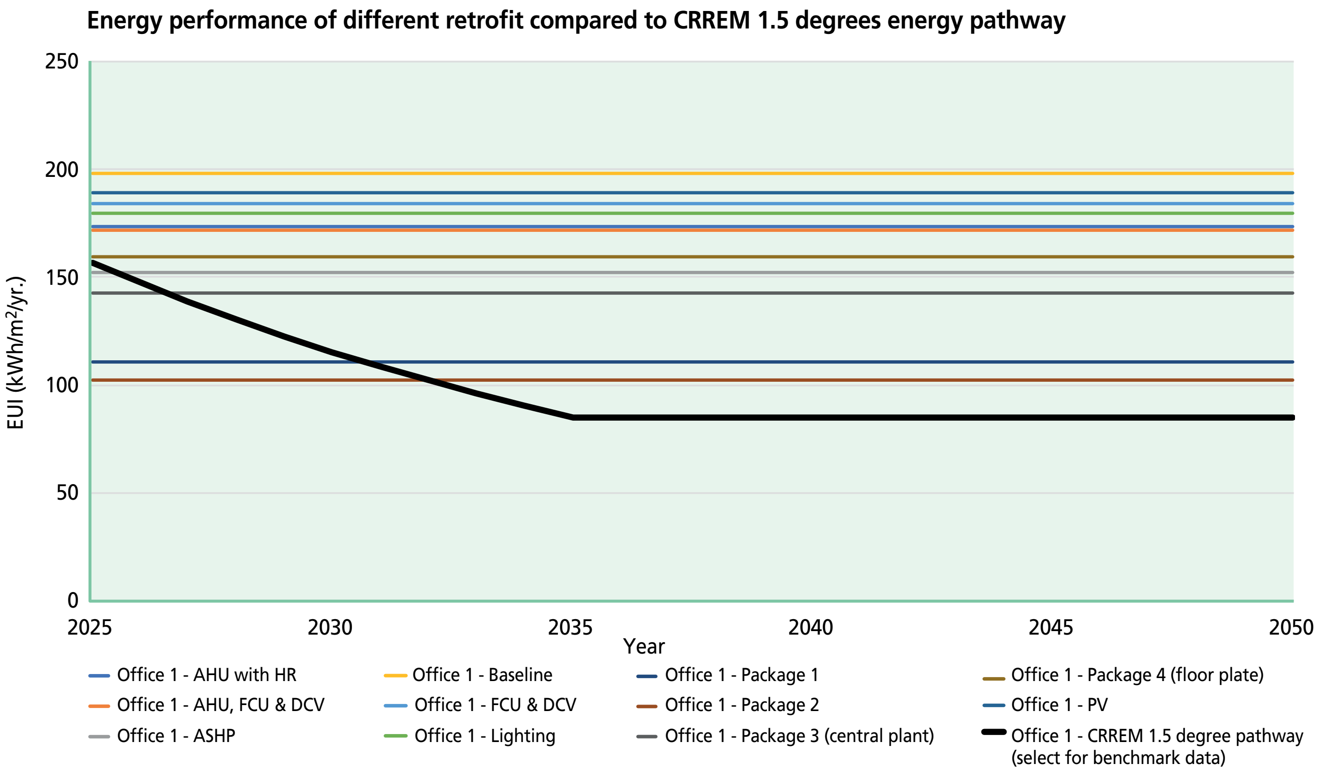
RESULT: Capital cost of improving EPC rating for MEES analysis



- The baseline building has an EPC of D, hence the landlord is not obligated to make improvements to comply with current MEES regulations.
- The building could achieve an EPC of B through investment in packages 1, 2 and the central plant package.
- Improvement to EPC B would involve installation of LED lighting and new controls, a new air handling unit and fan coils and an ASHP (Package 1). The costs would be in the region of around £437m² in an energy upgrade scenario; and £121m² in a refurbishment scenario.
- Package 2 achieves close to an EPC of A and includes the same as Package 1 with the addition of photovoltaics. The costs would be in the region of around £444m² in an energy upgrade scenario; and £129m² in a refurbishment scenario.
- Lighting improvements have the lowest capital cost at £66m² in an energy upgrade scenario.

5. FINDINGS

Energy use intensity for CRREM analysis

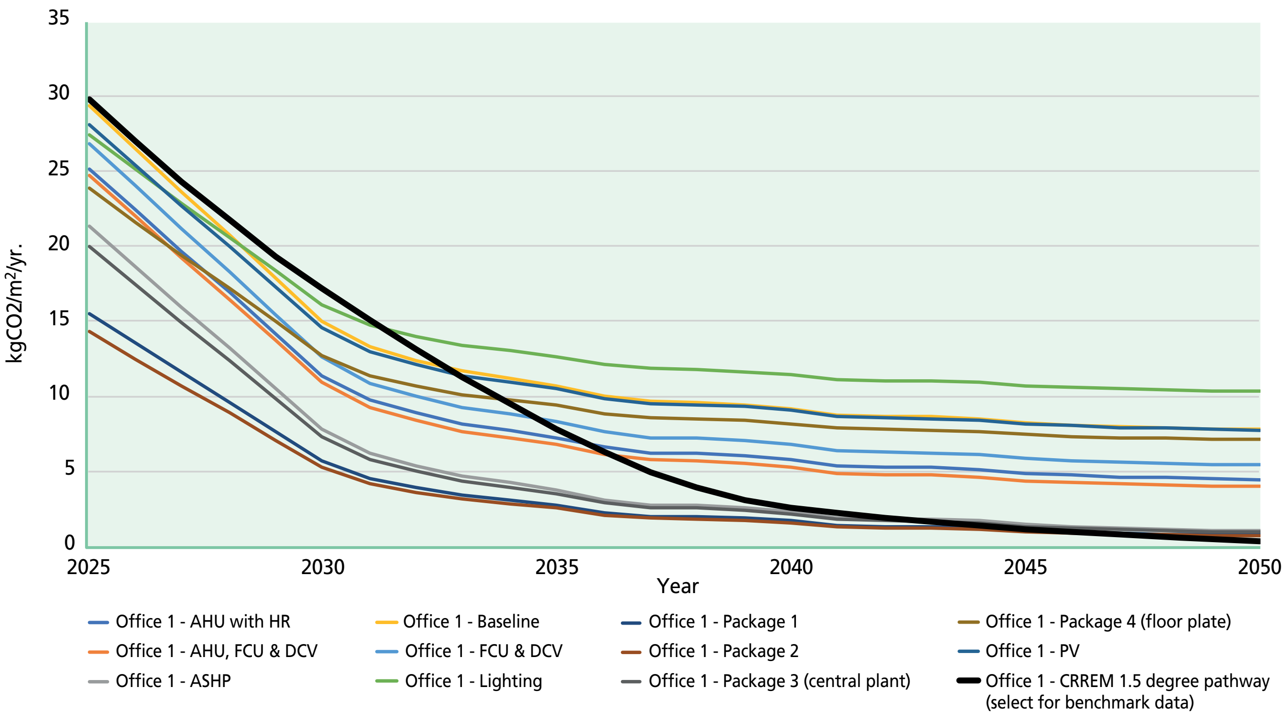


- The black line shows the CRREM 1.5 degree energy intensity targets in kWh/m²/yr. The EUI for the building with the improvement packages ranges from 150 kWh/m²/yr to 550 kWh/m²/yr.
- The baseline building EUI is significantly higher than the CRREM 1.5 degree target in 2025.
- Assuming interventions are made in 2025, only Package 1 – Lighting, Ventilation & ASHP would meet or better the CRREM 1.5 target but by 2027 the building would fall behind the pathway without further improvements.
- Package 1 – Lighting, Ventilation & ASHP and Package 2 – Lighting Ventilation, ASHP and PV would improve the EUI and bring the building below the EUI target until 2032 and 2033 respectively.

5. FINDINGS

Carbon intensity for CRREM analysis

Projected carbon emissions to 2050 in comparison to CRREM 1.5 degrees carbon pathway



- The black line shows the CRREM 1.5 degree pathway for carbon emissions in $kgCO_2/m^2$. The package lines show the trajectory for the carbon emissions assuming the intervention was installed in year 2025 and delivered operational carbon savings yearly.
- The building baseline carbon intensity is 29 $kgCO_2/m^2$ and is better than the CRREM pathway until 2034.
- Package 1 – Lighting, Ventilation & ASHP and Package 2 – Lighting Ventilation, ASHP and PV both reduce the carbon intensity to 16 $kgCO_2/m^2$ and 14 $kgCO_2/m^2$ respectively in 2025. The carbon intensity remains below or consistent with the CRREM pathway through to 2050

5. FINDINGS

Energy, carbon and return on investment table

Office 1 - Energy efficiency and carbon reduction measures						Energy upgrade scenario		Refurbishment scenario	
Improvement package	Energy Use intensity impact ($kWh/m^2/yr$)	Year 1 energy saving ($£m^2$)	Year 1 Carbon saving ($kgCO_2/m^2$)	Total Carbon saving to 2050 (25 years) ($kgCO_2/m^2$)	Year the building exceeds the CRREM Carbon pathway	Capital cost ($£/m^2$)	IRR	Capital cost ($£/m^2$)	IRR
Baseline	0	£0.00	0.00	0.00	2024	£0	0%	£0	0%
Lighting	-18	£4.14	1.94	-38.73	2023	£66	3%	£0	0%
ASHP	-46	£2.47	8.00	176.40	On pathway	£170	-7%	£107	-4%
AHU, FCU & DCV	-26	£1.46	4.59	100.35	2038	£200	-10%	£14	8%
AHU with HR	-24	£1.44	4.17	88.48	2037	£79	-5%	£4	31%
FCU & DCV	-14	£0.48	2.46	60.57	2036	£121	-13%	£10	1%
PV	-9	£1.17	1.19	7.75	2034	£8	14%	£8	14%
Package 1 – Lighting Ventilation & ASHP	-87	£8.20	13.82	214.25	On pathway	£437	-5%	£121	4%
Package 2 – Lighting, Ventilation, ASHP and PV	-96	£9.38	15.02	222.01	On pathway	£444	-5%	£129	5%
Package 3 (central plant) – ASHP, AHU & HR	-56	£3.81	9.36	185.25	On pathway	£249	-7%	£111	-1%
Package 4 (floor plate) – Lighting & FCU	-38	£5.01	5.47	44.09	2036	£181	-3%	£10	48%

5. FINDINGS

5.3 Office 2

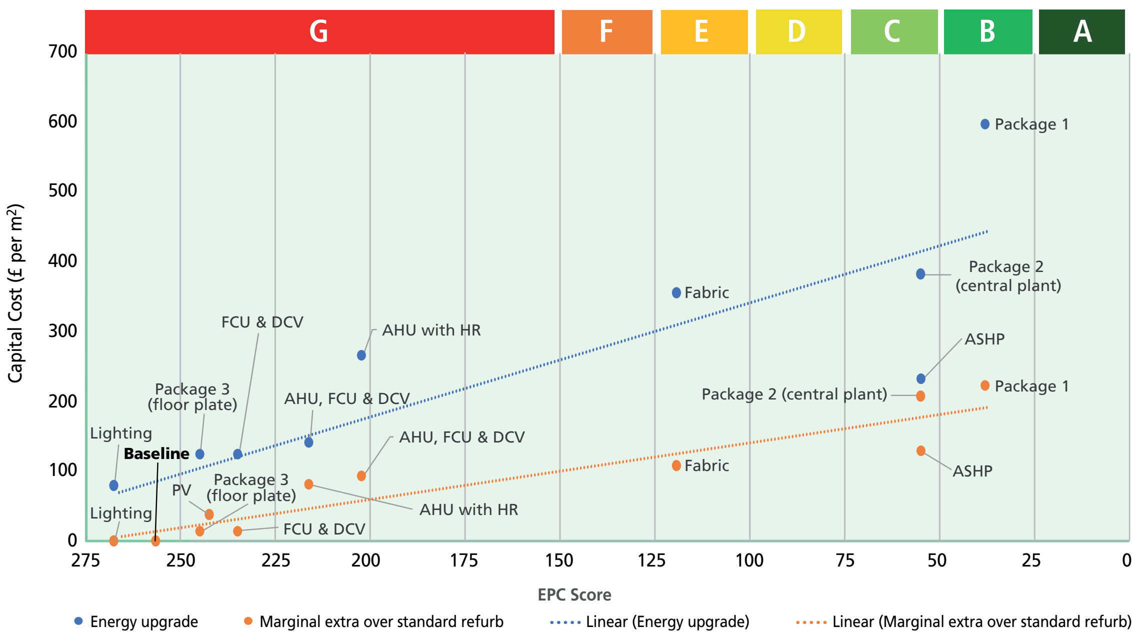
Office 2 – Narrow plan office building built in the 1970s

- 5-storey narrow plan office
- 2,000m²
- Air conditioned - older system
- Window-to-wall ratio of 20%
- Lighting replacement within last 20 years

- Gas boiler 60% efficient for heating
- Direct electric hot water
- Lighting 45 lm/W
- **Starting EPC = 257 (G)**

Illustrations are not exact representations of the building types.

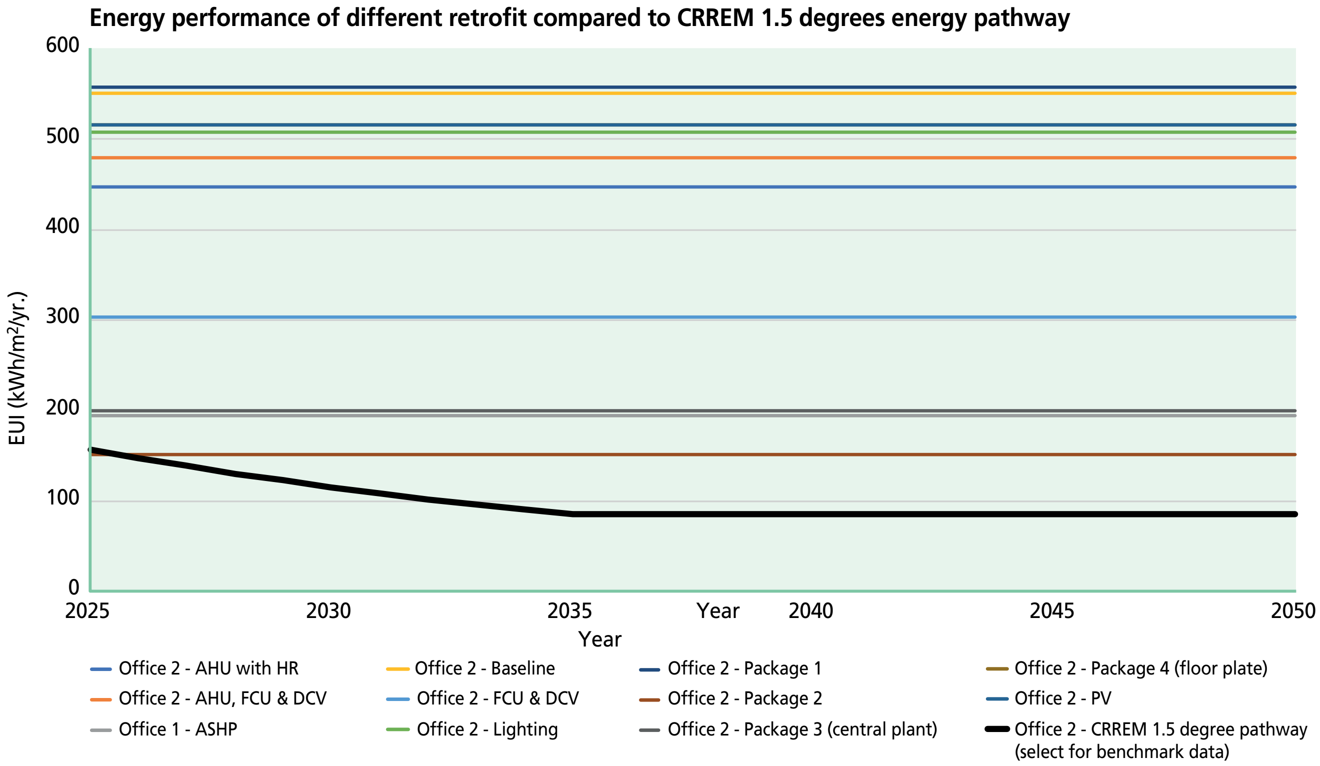
RESULTS: Capital cost of improving EPC rating for MEES analysis



- The baseline building has an EPC of G and the landlord is therefore required to try to make cost effective improvements to comply with current MEES regulations.
- The building could achieve an EPC of B through investment in package 1 only.
- Improvement to EPC B would involve installation of LED lighting and new controls, a new air handling unit and fan coils and an ASHP (Package 1). The costs would be in the region of around £596m² in an energy upgrade scenario; and £222m² in a refurbishment scenario.
- Installation of the ASHP has the greatest impact on the EPC rating, achieving an EPC of C for £232m² in an energy upgrade scenario, and £129m² in a refurbishment scenario.
- Fabric improvement package involves adding insulation to the walls and roof and installing new windows and doors would achieve an EPC of C. This has the highest capital cost at £353m² in an energy upgrade scenario.

5. FINDINGS

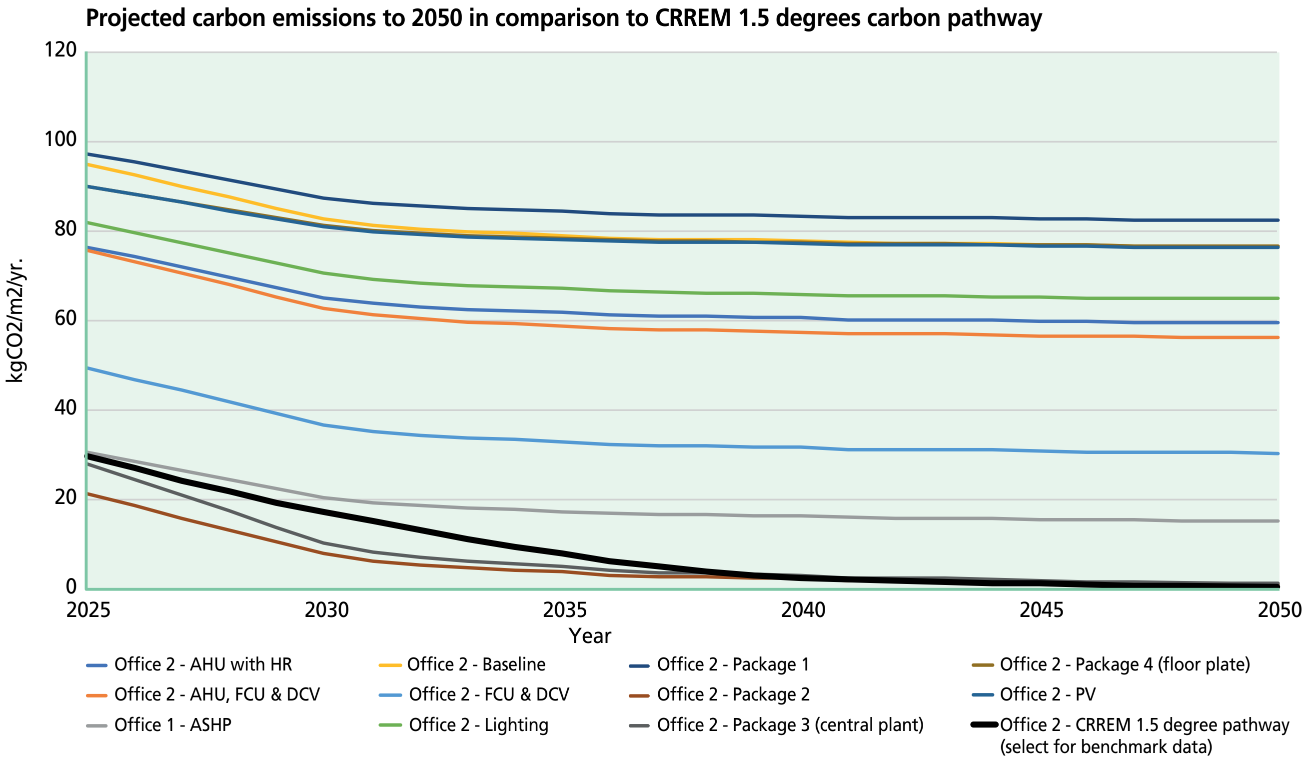
Energy use intensity for CRREM analysis



- The black line shows the CRREM 1.5 degree energy intensity targets in kWh/m²/yr. The EUI for the building with the improvement packages ranges from 150 kWh/m²/yr to 550 kWh/m²/yr.
- The baseline building EUI is significantly higher than the CRREM 1.5 degree target in 2025.
- Assuming interventions are made in 2025, only Package 1 – Lighting, Ventilation & ASHP would meet or better the CRREM 1.5 target but by 2027 the building would fall behind the pathway without further improvements.

5. FINDINGS

Carbon intensity for CRREM analysis



- The black line shows the CRREM 1.5 degree pathway for carbon emissions in kgCO²/m². The package lines show the trajectory for the carbon emissions assuming the intervention was installed in year 2025 and delivered operational carbon savings yearly.
- The building baseline is 95 $kgCO_2$/m²/yr and is worse than the CRREM pathway carbon intensity of 33 $kgCO_2$/m²/yr.
- Only the ASHP, Package 1 and Package 2 (central plant) would meet or better the CRREM carbon intensity targets, reducing to below 33 $kgCO_2$/m²/yr in 2025.
- From installation in 2025, Package 1 and Package 2 would remain below or on target with the CRREM pathway until 2050.

5. FINDINGS

Energy, carbon and return on investment table

Office 2 - Energy efficiency and carbon reduction measures						Energy upgrade scenario		Refurbishment scenario	
Improvement package	Energy Use intensity impact ($kWh/m^2/yr$)	Year 1 energy saving ($£m^2$)	Year 1 Carbon saving ($kgCO_2/m^2$)	Total Carbon saving to 2050 (25 years) ($kgCO_2/m^2$)	Year the building exceeds the CRREM Carbon pathway	Capital cost ($£/m^2$)	IRR	Capital cost ($£/m^2$)	IRR
Baseline	0	£0.00	0.00	0.00	Exceeds	£0	0%	£0	0%
Lighting	7	£2.46	-2.39	-126.33	Exceeds	£100	-4%	£0	0%
ASHP	-356	£14.10	64.27	1549.45	2030	£232	3%	£129	10%
AHU, FCU & DCV	-71	£0.99	13.58	373.17	Exceeds	£140	-10%	£93	1%
AHU with HR	-103	£4.52	18.48	434.94	Exceeds	£264	-6%	£81	-7%
FCU & DCV	-42	£2.10	7.38	167.02	Exceeds	£124	-6%	£12	16%
Fabric	-247	£7.60	45.46	1150.81	Exceeds	£353	-4%	£88	7%
PV	-35	£4.82	4.90	31.84	Exceeds	£39	11%	£39	11%
Package 1 -Lighting, Ventilation & ASHP	-399	£11.71	73.66	1878.29	On pathway	£596	-5%	£222	2%
Package 2 (central plant) - ASHP, AHU & HR	-350	£5.00	66.84	1833.97	2045	£372	-6%	£210	-3%
Package 3 (floor plate)- Lighting & FCUs	-35	£4.98	4.83	26.24	Exceeds	£124	0%	£12	40%

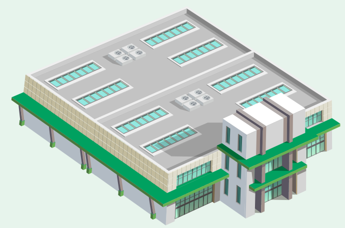
5. FINDINGS

5.4 Retail unit in shopping centre

Retail unit in shopping centre – built in the early 1990s

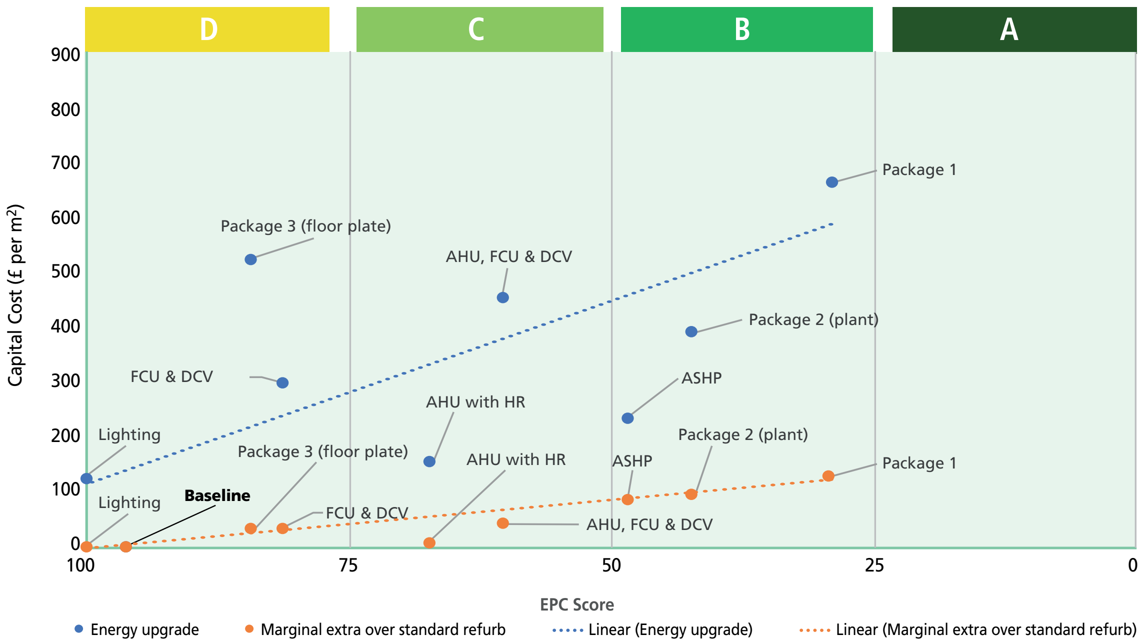
- 1-storey unit
- 300m²
- Air conditioned
- Window-to-wall ratio of 35%
- Current fit out assumed to be 10-15 years old

- Gas boiler 60% seasonal efficiency and 70% delivery efficiency
- Direct electric hot water
- Lighting 45 lm/W
- **Starting EPC = 96 (D)**



Illustrations are not exact representations of the building types.

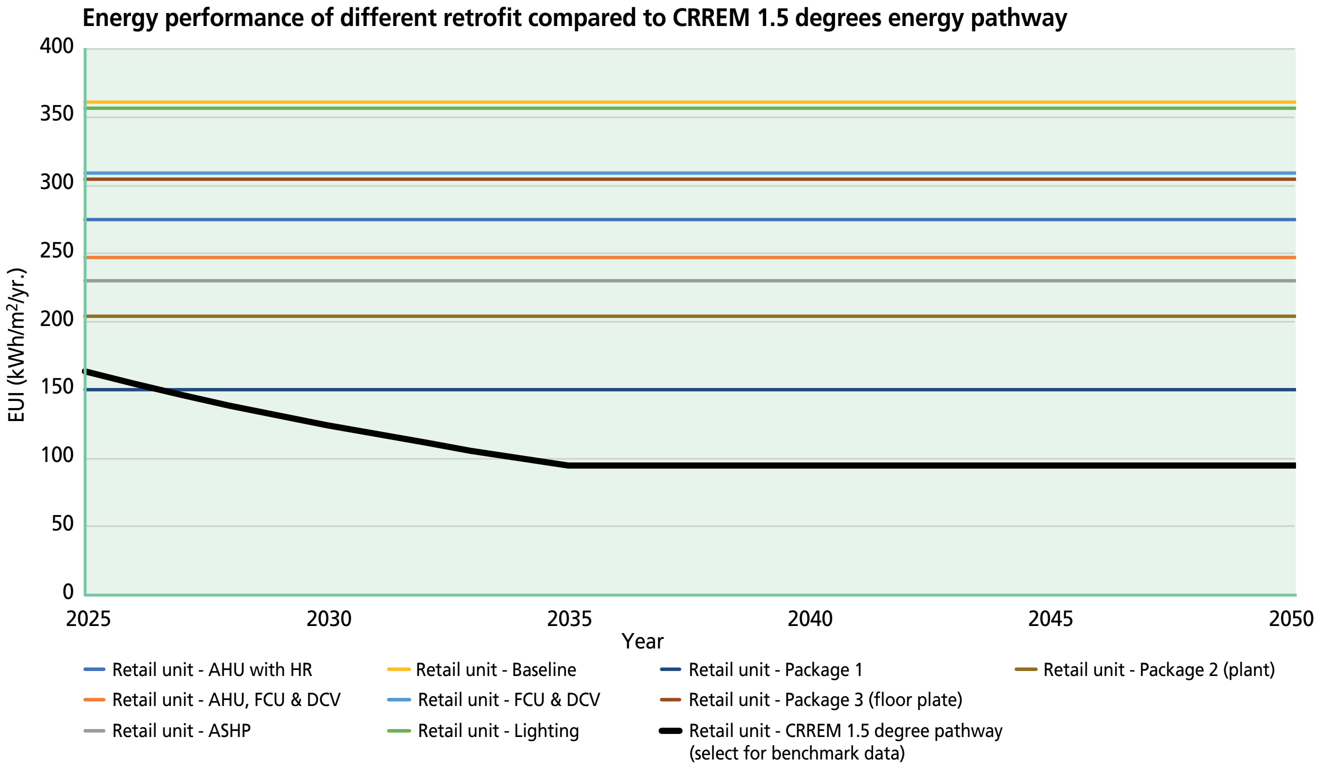
RESULT: **Capital cost of improving EPC rating for MEES analysis**



- The baseline building has an EPC of D, hence the landlord is not obligated to make improvements to comply with current MEES regulations.
- The building could achieve an EPC of B through investment in Package 1, Package 2 (plant) and the ASHP package.
- Improvement to EPC B would involve installation of LED lighting and new controls, a new air handling unit and fan coils and an ASHP (Package 1). The costs would be in the region of around £820m² in an energy upgrade scenario, and £131m² in a refurbishment scenario.
- Installation of the ASHP would achieve an EPC of B for £237m² in an energy upgrade scenario, and £88m² in a refurbishment scenario.
- The ASHP will need roof space and for this typology in particular there is a need to work closely with the landlord and it may involve a change in the model of services provision.

5. FINDINGS

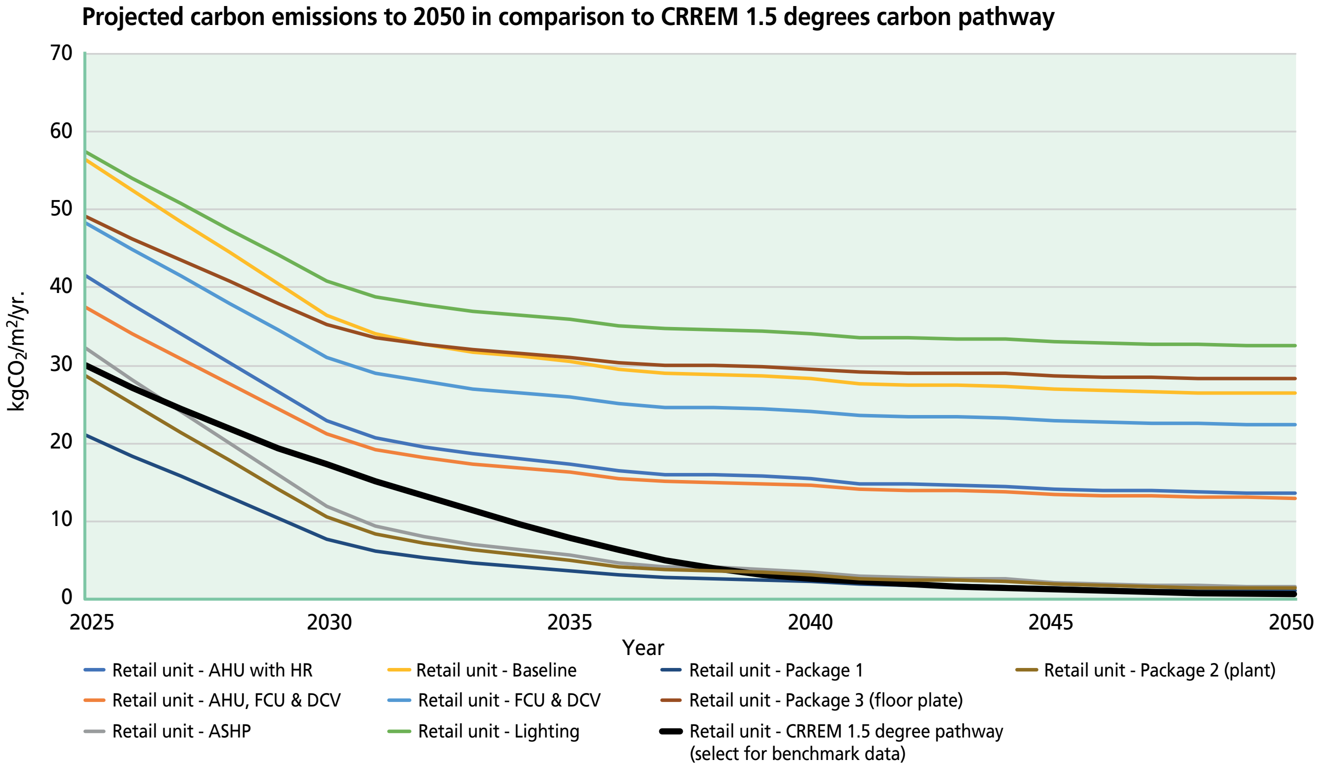
Energy use intensity for CRREM analysis



- The black line shows the CRREM 1.5 degree energy intensity targets in kWh/m²/yr. The EUI for the building with the improvement packages ranges from 150 kWh/m²/yr to 360 kWh/m²/yr.
- The baseline building EUI is significantly higher than the CRREM 1.5 degree target in 2025.
- Assuming interventions are made in 2025, only package 1 would meet or better the CRREM 1.5 target but from 2028 the building would fall behind the pathway without further improvements.

5. FINDINGS

Carbon intensity for CRREM analysis



- The black line shows the CRREM 1.5 degree pathway for carbon emissions in $kgCO_2/m^2$. The package lines show the trajectory for the carbon emissions assuming the intervention was installed in year 2025 and delivered operational carbon savings yearly.
- The building baseline is 56 $kgCO_2/m^2/yr$ and is worse than the CRREM pathway carbon intensity of 33 $kgCO_2/m^2/yr$.
- Only the ASHP, Package 1 and plant packages would enable the building to meet or better the CRREM carbon intensity targets, reducing to below 33 $kgCO_2/m^2/yr$ in 2025. The building would remain on a similar trajectory as the CRREM pathway through to 2050.

5. FINDINGS

Energy, carbon and return on investment table

Retail unit - Energy efficiency and carbon reduction measures						Energy upgrade scenario		Refurbishment scenario	
Improvement package	Energy Use intensity impact ($kWh/m^2/yr$)	Year 1 energy saving ($£m^2$)	Year 1 Carbon saving ($kgCO_2/m^2$)	Total Carbon saving to 2050 (25 years) ($kgCO_2/m^2$)	Year the building exceeds the CRREM Carbon pathway	Capital cost ($£/m^2$)	IRR	Capital cost ($£/m^2$)	IRR
Baseline	0	£0.00	0.00	0.00	Exceeds	£0	0%	£0	0%
Lighting	-5	£4.31	-0.88	-124.70	Exceeds	£125	-2%	£0	0%
ASHP	-131	£3.89	24.23	617.00	2042	£237	-6%	£88	1%
AHU, FCU & DCV	-114	£8.29	19.08	365.77	Exceeds	£457	-6%	£43	18%
AHU with HR	-86	£4.66	15.03	330.89	Exceeds	£158	-2%	£8	56%
FCU & DCV	-52	£5.00	8.15	122.44	Exceeds	£300	-6%	£35	13%
Package 1 -Lighting, Ventilation & ASHP	-211	£14.88	35.39	689.58	On pathway	£820	-6%	£131	10%
Package 2 (plant) - ASHP, AHU & HR	-157	£7.38	27.78	640.08	2045	£395	-5%	£96	6%
Package 3 (floor plate) - Lighting & FCUs	-57	£9.15	7.38	4.71	Exceeds	£525	-6%	£35	25%

5. FINDINGS

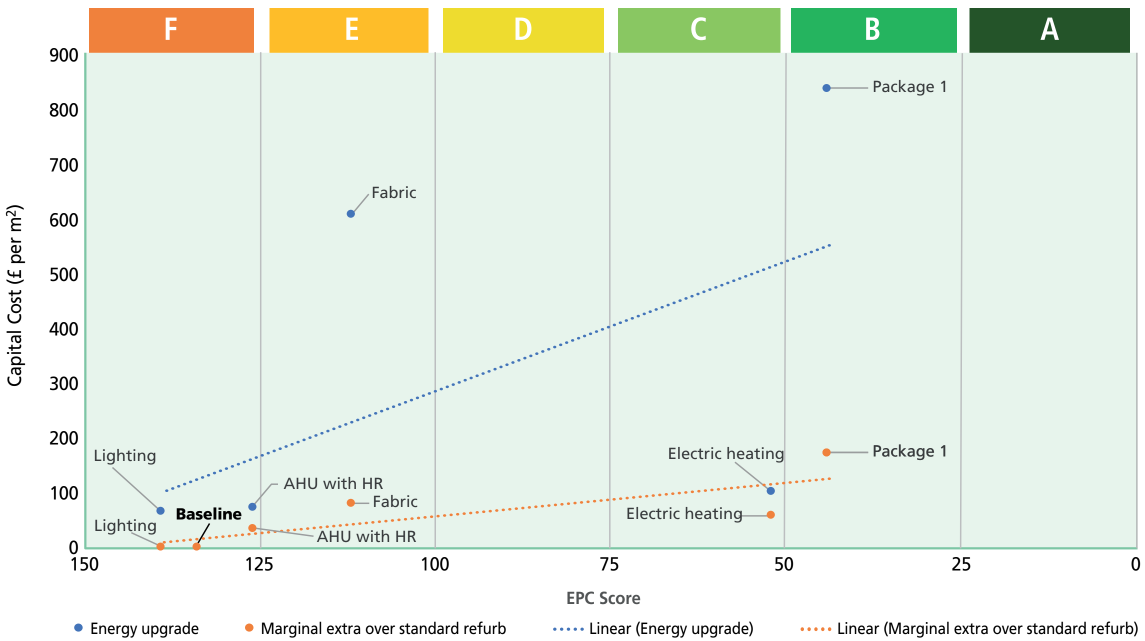
5.5 Retail warehouse

Retail warehouse single storey deep plan compliant with Part L 1995

- 1-storey unit, double height with mezzanine
- 1,500m²
- Extract only ventilation to offices and WCs, Natural ventilation to warehouse space
- Window-to-wall ratio of 18%
- Lighting and services assumed not original
- Gas radiant panels for heating with 70% efficiency
- Gas boiler for hot water 70% efficiency
- Lighting 45 lm/W
- **Starting EPC = 134 (F))**

Illustrations are not exact representations of the building types.

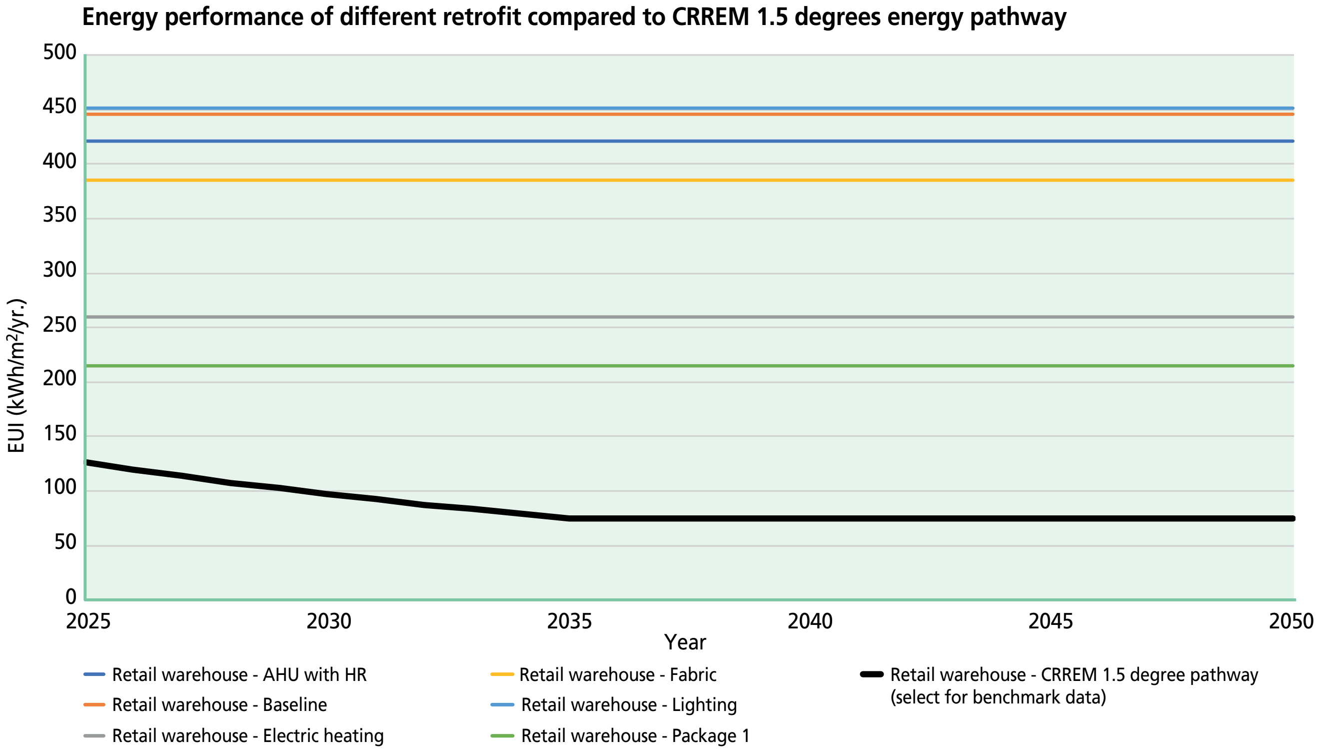
RESULT: **Capital cost of improving EPC rating for MEES analysis**



- The baseline building has an EPC of F and the landlord is required to try to make cost effective improvements for MEES compliance.
- The building could achieve an EPC of B through investment in Package 1 only.
- Improvement to EPC B would involve installation of LED lighting, a new air handling unit for Office & WCs, direct electric radiant panels for heating and direct electric for hot water, adding insulation to the walls and roof and installing new windows and doors (package 1). The costs would be in the region of around £835m² in an energy upgrade scenario, and £169m² in a refurbishment scenario.
- Changing from gas for heating and hot water to electric would achieve an EPC of C. The costs would be in the region of around £99m² in an energy upgrade scenario, and £58m² in a refurbishment scenario. This suggests that a detailed look at other measures for this building could improve the building to EPC B without incurring the significantly higher fabric costs modelled in Package 1.

5. FINDINGS

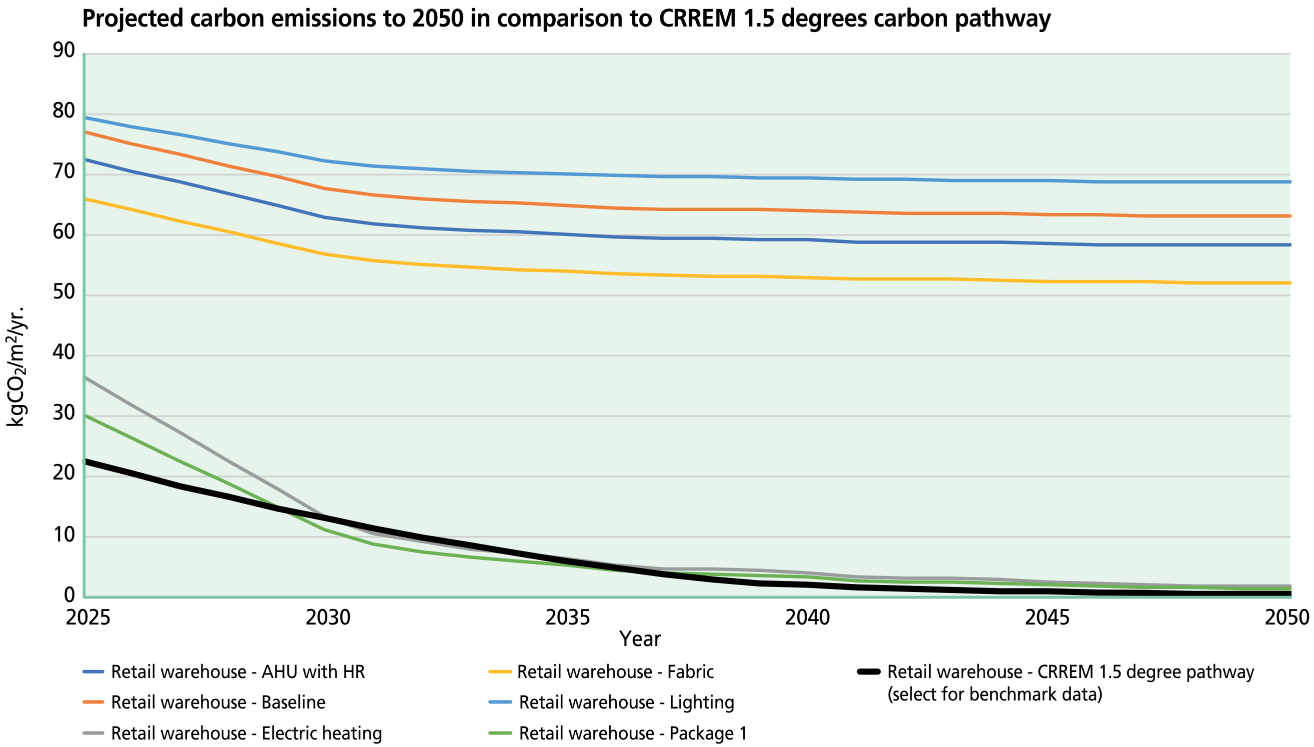
Energy use intensity for CRREM analysis



- The black line shows the CRREM 1.5 degree energy intensity targets in kWh/m²/yr. The EUI for the building with the improvement packages ranges from 210 kWh/m²/yr to 450 kWh/m²/yr.
- The baseline building EUI is significantly higher than the CRREM 1.5 degree target in 2025.
- No packages modelled would meet the CRREM 1.5 degree energy pathway in 2025.

5. FINDINGS

Carbon intensity for CRREM analysis



- The black line shows the CRREM 1.5 degree pathway for carbon emissions in $kgCO_2/m^2/yr$. The package lines show the trajectory for the carbon emissions assuming the intervention was installed in year 2025 and delivered operational carbon savings yearly.
- The building baseline is 77 $kgCO_2/m^2/yr$ and is worse than the CRREM carbon intensity of 25 $kgCO_2/m^2/yr$ in 2025.
- The electric heating package and Package 1 would enable the building to meet the CRREM intensity pathway, reducing to below 15 $kgCO_2/m^2/yr$, by 2030. The building would remain on a similar trajectory as the CRREM pathway through to 2050.

5. FINDINGS

Energy, carbon and return on investment table

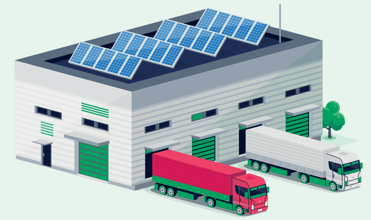
Office 1 - Energy efficiency and carbon reduction measures						Energy upgrade scenario		Refurbishment scenario	
Improvement package	Energy Use intensity impact ($kWh/m^2/yr$)	Year 1 energy saving (£m^2)	Year 1 Carbon saving ($kgCO_2/m^2$)	Total Carbon saving to 2050 (25 years) ($kgCO_2/m^2$)	Year the building exceeds the CRREM Carbon pathway	Capital cost (£/m^2)	IRR	Capital cost (£/m^2)	IRR
Baseline	0	£0.00	0.00	0.00	Exceeds	£0	0%	£0	0%
Lighting	7	£2.41	-2.28	-121.96	Exceeds	£64	-1%	£0	0%
AHU with HR	-24	£0.58	4.55	119.44	Exceeds	£71	-9%	£32	30%
Electric heating	-186	-£10.11	40.66	1418.25	2038	£99	0%	£58	0%
Fabric	-60	£1.99	11.00	274.96	Exceeds	£601	-14%	£79	13%
Package 1 -Lighting, Ventilation and Electric heating	-230	-£4.00	46.86	1458.61	2039	£835	0%	£169	-2%

5. FINDINGS

5.6 Logistics

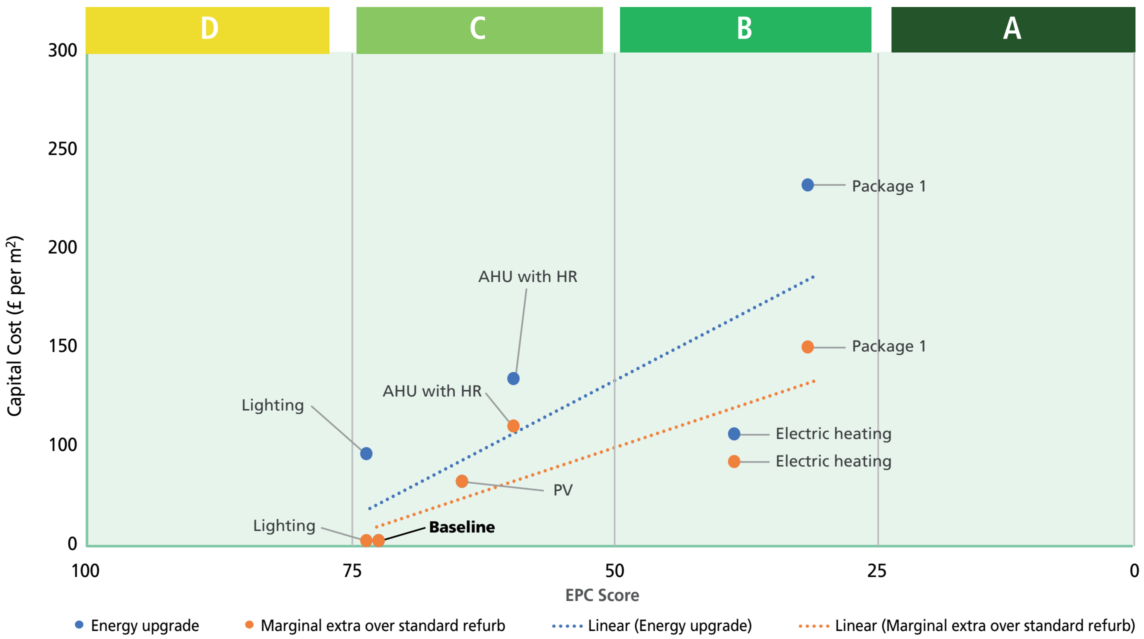
Logistics warehouse built in 2005

- 1-storey unit, double height, deep plan
- 20,500m²
- Extract only ventilation
- Air conditioning to office space
- Window-to-wall ratio of 20%
- Gas boiler for heating and hot water at 80% efficiency
- Radiant panels for main areas; VRF system for office areas
- Lighting 45 lm/W
- **Starting EPC = 72 (C)**



Illustrations are not exact representations of the building types.

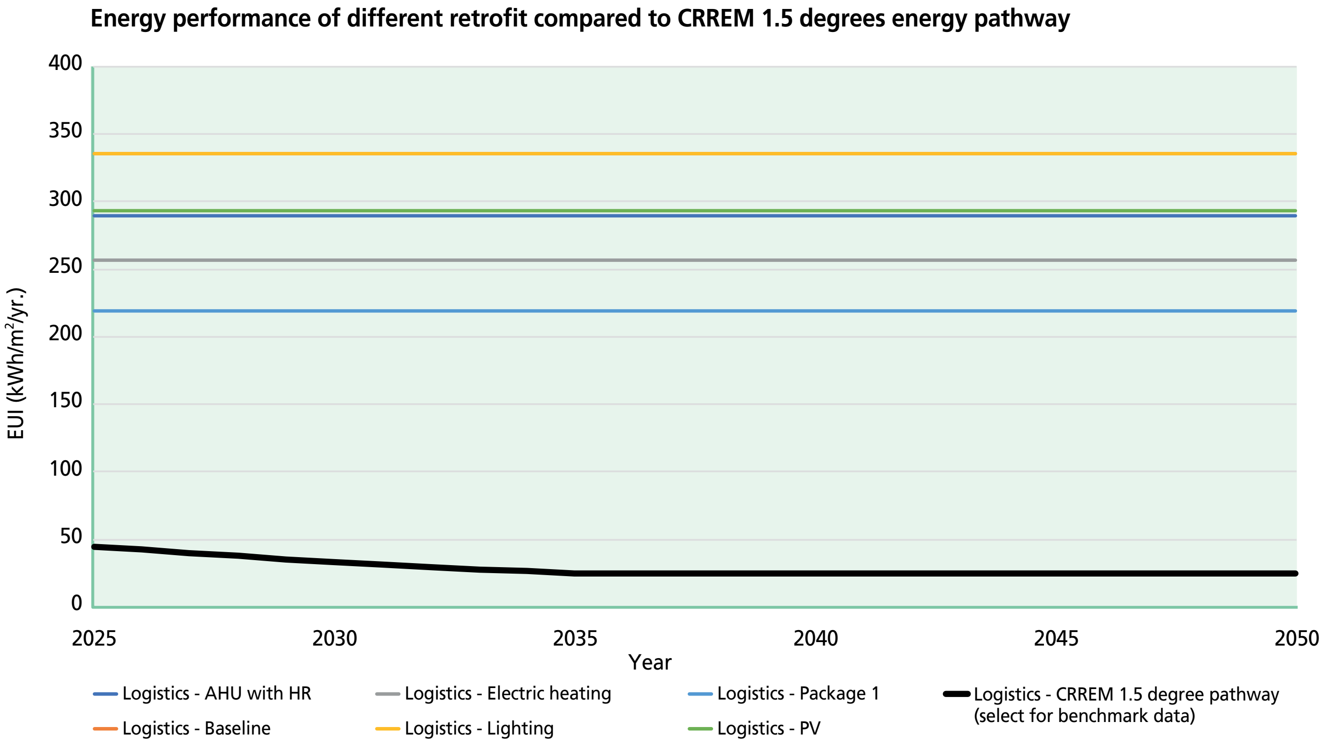
RESULT: Capital cost of improving EPC rating for MEES analysis



- The baseline building has an EPC of C, hence the landlord is not obligated to make improvements to comply with current MEES regulations.
- The building could achieve an EPC of B through investment in Package 1 or Electric heating.
- Package 1 would improve the EPC to B. It would involve installation of LED lighting, a new air handling unit with heat recovery, direct electric radiant panels for heating and direct electric for hot water. The costs would be in the region of around £215m² in an energy upgrade scenario, and £117m² in a refurbishment scenario.
- The building would also achieve an EPC B by changing from gas to electric heating and hot water to electric. The costs would be in the region of around £64m² in an energy upgrade scenario, and £47m² in a refurbishment scenario.

5. FINDINGS

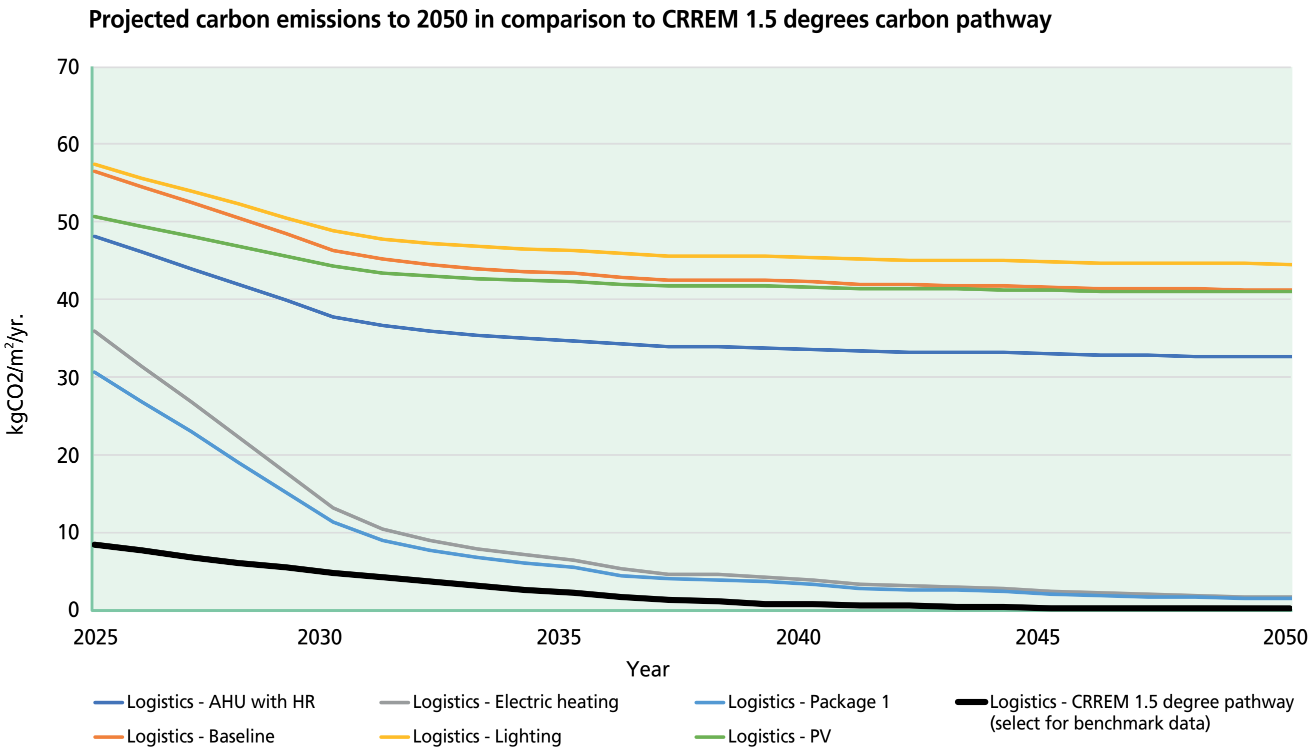
Energy use intensity for CRREM analysis



- The black line shows the CRREM 1.5 degree energy intensity targets in kWh/m2/yr. The EUI for the building with the improvement packages ranges from 215 kWh/m²/yr to 340 kWh/m²/yr.
- The baseline building EUI is significantly higher than the CRREM 1.5 degree target in 2025.The base line and lighting package EUI are the same.
- No packages modelled would meet the CRREM 1.5 degree energy pathway in 2025.

5. FINDINGS

Carbon intensity for CRREM analysis



- The black line shows the CRREM 1.5 degree pathway for carbon emissions in $kgCO_2/m^2$. The package lines show the trajectory for the carbon emissions assuming the intervention was installed in year 2025 and delivered operational carbon savings yearly.
- The building baseline is 57 $kgCO_2/m^2/yr$ and is significantly worse than the CRREM pathway for 2025 of 9 $kgCO_2/m^2/yr$.
- The electric heating package and Package 1 would reduce the carbon intensity significantly to below 10 $kgCO^2/m^2/yr$ by 2031 but would ultimately not quite meet the CRREM intensity pathway, through to 2050.

5. FINDINGS

Energy, carbon and return on investment table

Logistics - Energy efficiency and carbon reduction measures						Energy upgrade scenario		Refurbishment scenario	
Improvement package	Energy Use intensity impact ($kWh/m^2/yr$)	Year 1 energy saving ($£m^2$)	Year 1 Carbon saving ($kgCO_2/m^2$)	Total Carbon saving to 2050 (25 years) ($kgCO_2/m^2$)	Year the building exceeds the CRREM Carbon pathway	Capital cost ($£/m^2$)	IRR	Capital cost ($£/m^2$)	IRR
Baseline	0	£0.00	0.00	0.00	Exceeds	£0	0%	£0	0%
Lighting	0	£1.92	-0.85	-69.04	Exceeds	£53	-1%	£0	0%
AHU with HR	-46	£1.36	8.42	214.15	Exceeds	£98	-7%	£70	-2%
Electric heating	-79	-£12.27	20.60	883.17	Exceeds	£64	0%	£47	24%
PV	-42	£5.79	5.88	38.22	Exceeds	£37	14%	£37	3%
Package 1 - Lighting, Ventilation and Electric heating	-116	-£7.16	25.79	916.90	Exceeds	£215	0%	£117	8%

5. FINDINGS

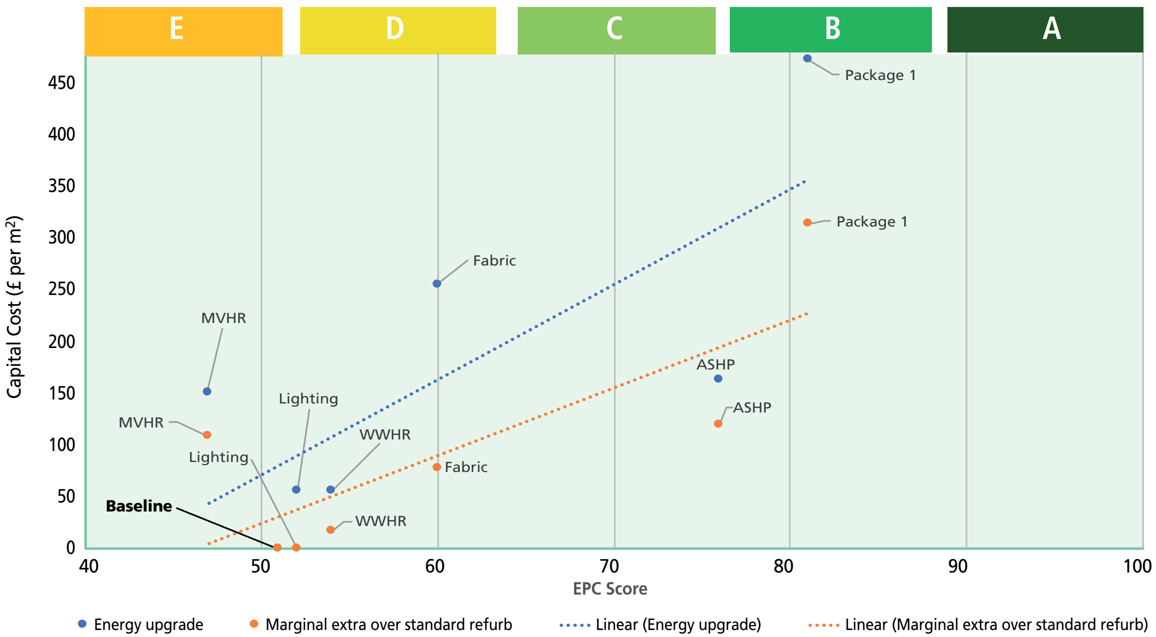
5.7 Build-to-rent residential

Build-to-Rent residential block compliant with Part L 2013

- 15-storey medium rise square plan
- 10,000m² overall
- 175 units
- Window-to-wall ratio of 35%
- Natural ventilation with extract fans in kitchens and bathrooms
- Communal gas boiler for heating and hot water at 70% efficiency
- Radiators
- Lighting 45 lm/W
- Top floor flat modelled, 103 m²
- **Starting EPC = 51 (E)**

Illustrations are not exact representations of the building types.

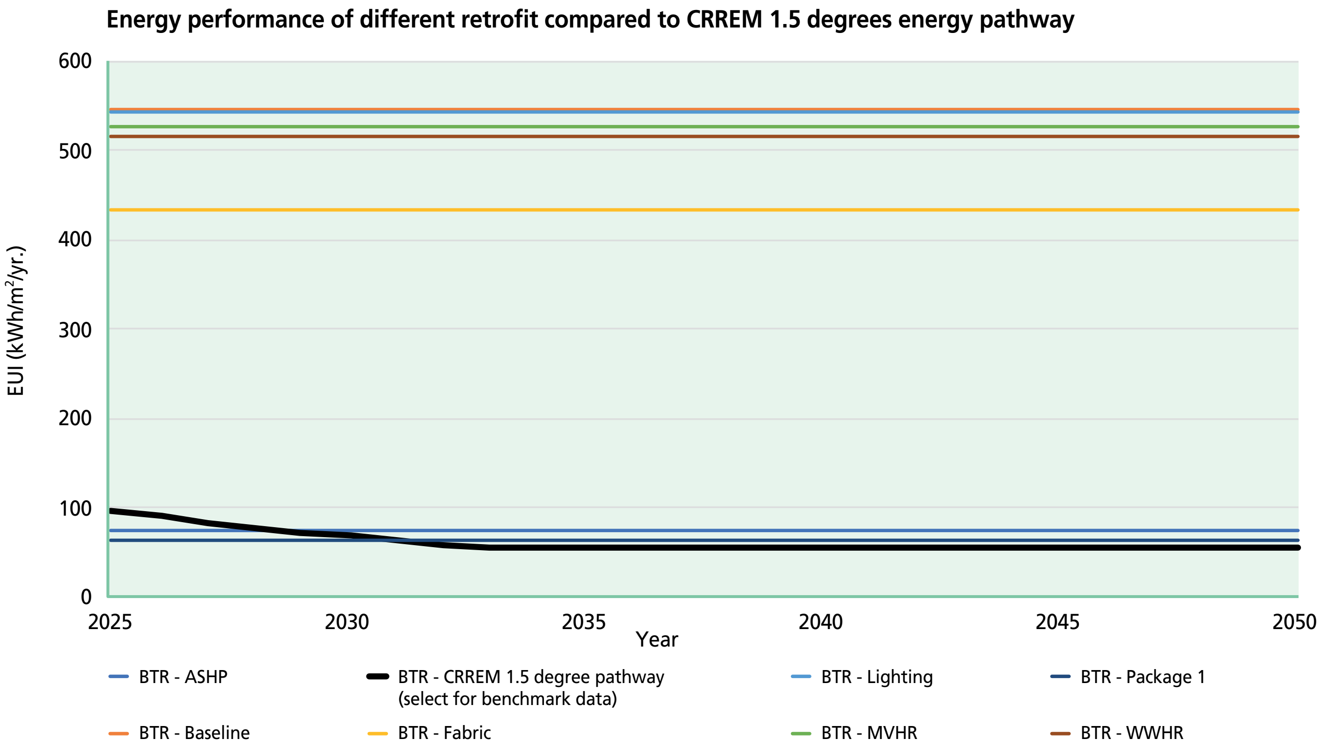
RESULT: **Capital cost of improving EPC rating for MEES analysis**



- The baseline building has an EPC of E and the landlord is therefore required to try to make cost effective improvements to comply with MEES regulations.
- The building could achieve an EPC of B through investment in Package 1 only.
- Package 1 would involve installation of LED lighting, a community ASHP, heating controls, insulation to LTHW pipework, new windows and doors and good practice thermal bridging. The costs would be in the region of around £473m² in an energy upgrade scenario, and £313m² in a refurbishment scenario.
- By changing from gas to heating and hot water to an ASHP, the building would achieve an EPC of C. The costs would be in the region of around £163m² in an energy upgrade scenario, and £119m² in a refurbishment scenario.

5. FINDINGS

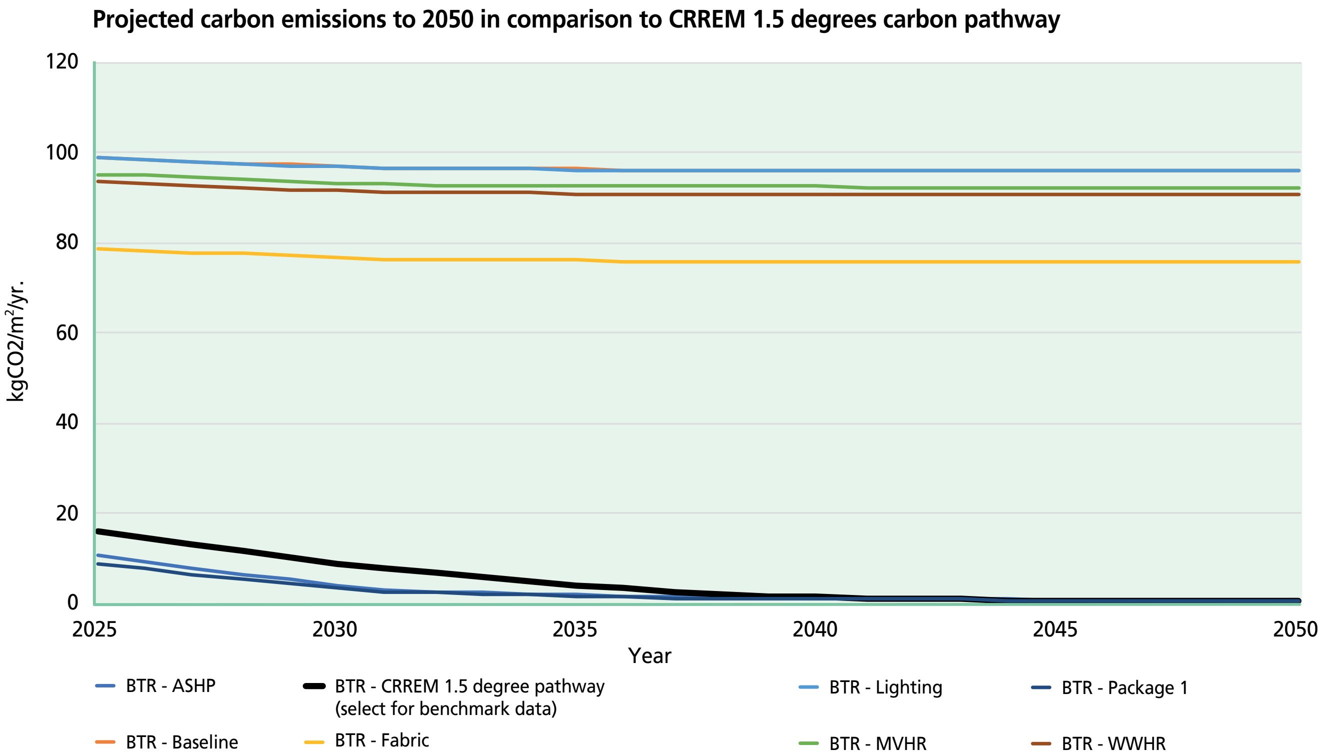
Energy use intensity for CRREM analysis



- The black line shows the CRREM 1.5 degree energy intensity targets in kWh/m²/yr. The EUI for the building with the improvement packages ranges from around 70 kWh/m²/yr to 545 kWh/m²/yr.
- The baseline building EUI is significantly higher than the CRREM 1.5 degree target in 2025. The lighting package EUI is very similar.
- Assuming interventions are made in 2025, Package 1 and the MVHR would both meet or better the CRREM 1.5 target but from 2031 the building would fall behind the pathway without further improvements.

5. FINDINGS

Carbon intensity for CRREM analysis



- The black line shows the CRREM 1.5 degree pathway for carbon emissions in $kgCO_2/m^2/yr$. The package lines show the trajectory for the carbon emissions assuming the intervention was installed in year 2025 and delivered operational carbon savings yearly.
- The building baseline is 99 $kgCO_2/m^2/yr$ and is significantly worse than the CRREM carbon intensity for 2025 of 18 $kgCO_2/m^2/yr$.
- The ASHP and Package 1 would reduce the carbon intensity significantly to around 10 $kgCO_2/m^2/yr$ in 2025 and would meet the CRREM carbon intensity target. The building would continue to be on track with the CRREM pathway through to 2050.

5. FINDINGS

Energy, carbon and return on investment table

Build to Rent - Energy efficiency and carbon reduction measures						Energy upgrade scenario		Refurbishment scenario	
Improvement package	Energy Use intensity impact ($kWh/m^2/yr$)	Year 1 energy saving (£m^2)	Year 1 Carbon saving ($kgCO_2/m^2$)	Total Carbon saving to 2050 (25 years) ($kgCO_2/m^2$)	Year the building exceeds the CRREM Carbon pathway	Capital cost (£/m^2)	IRR	Capital cost (£/m^2)	IRR
Baseline	0	£0.39	-32.51	-957.14	Exceeds	£0	3%	£0	3%
Lighting	-2	£0.63	-32.28	-955.61	Exceeds	£55	-18%	£0	0%
ASHP	-470	£10.53	55.87	1386.78	On pathway	£163	4%	£119	7%
MVHR	-20	£1.05	-28.88	-866.34	Exceeds	£151	-14%	£109	-12%
WWHR	-29	£1.37	-27.13	-822.71	Exceeds	£55	-6%	£16	3%
Fabric	-111	£4.05	-12.27	-451.15	Exceeds	£254	-7%	£77	1%
Package 1 - Lighting, ASHP & Fabric	-483	£12.26	57.62	1398.18	On pathway	£473	-3%	£313	0%

5. FINDINGS

5.8 Student accommodation

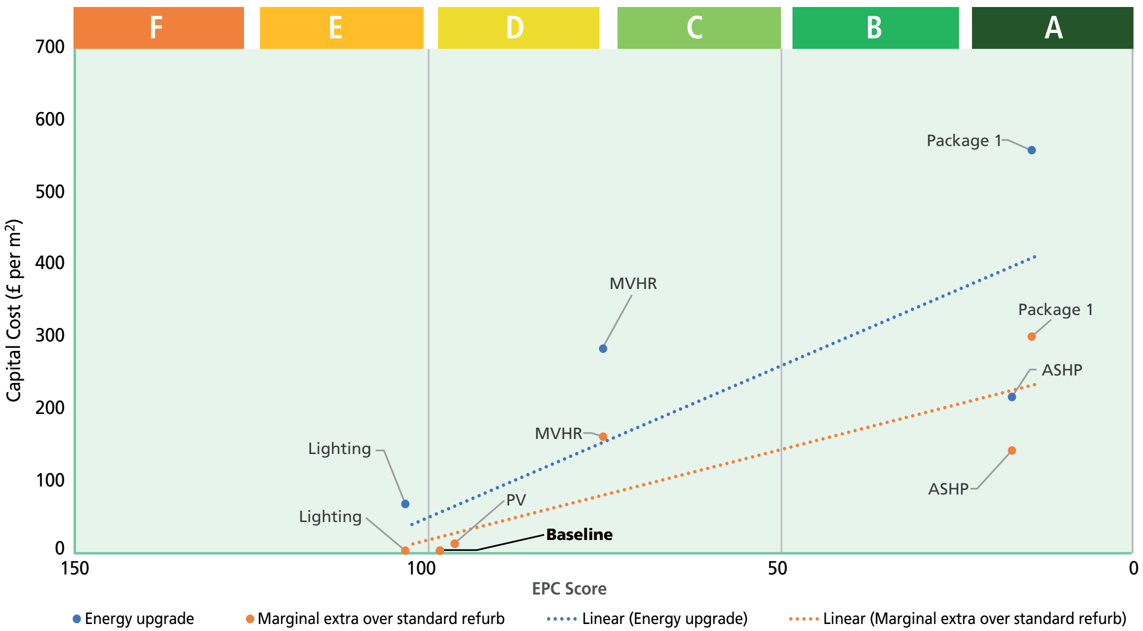
Student accommodation block, low rise built in the early 2000s

- 7-storey low rise shallow plan block
- 4,500m² overall
- 150 units
- Window-to-wall ratio of 20%
- Natural ventilation with extract fans in kitchens and bathrooms

- Communal gas boiler for heating and hot water at 80% seasonal efficiency & 50% delivery efficiency
- Radiators
- Lighting 45 lm/W
- **Starting EPC = 98 (D)**

Illustrations are not exact representations of the building types.

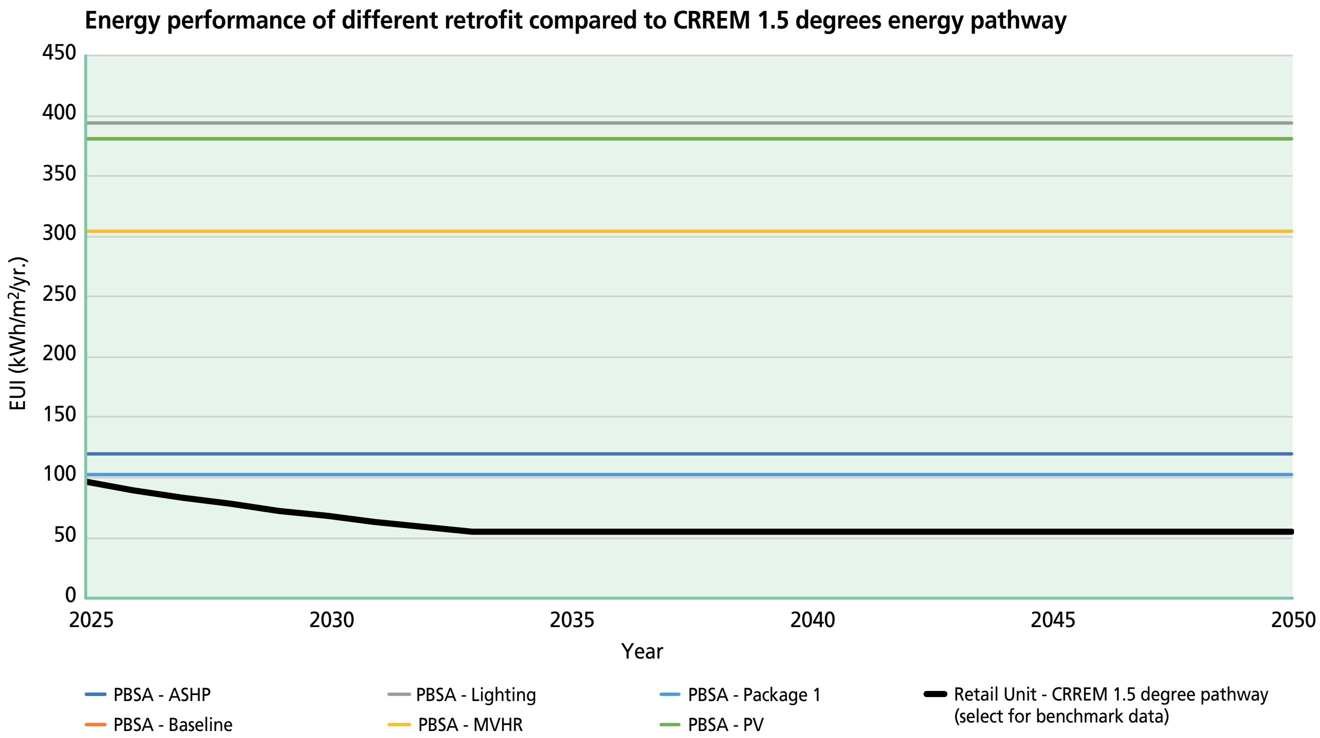
RESULT: Capital cost of improving EPC rating for MEES analysis



- The baseline building has an EPC of D, hence the landlord is not obligated to make improvements to comply with current MEES regulations.
- The building could achieve an EPC of A through investment in Package 1 and the ASHP package.
- Package 1 would involve installation of LED lighting and controls, communal ASHPs, new mechanical ventilation with heat recovery to service bedrooms, heating controls, insulation to LTHW pipework and metering. The costs would be in the region of around £556m² in an energy upgrade scenario, and £296m² in a refurbishment scenario.
- The ASHP package would achieve an EPC of A. The costs would be in the region of around £212m² in an energy upgrade scenario, and £140m² in a refurbishment scenario.
- Upgrading only the lighting drops the EPC to an E. This is because the heating load increases, and the energy source remains gas fired.

5. FINDINGS

Energy use intensity for CRREM analysis

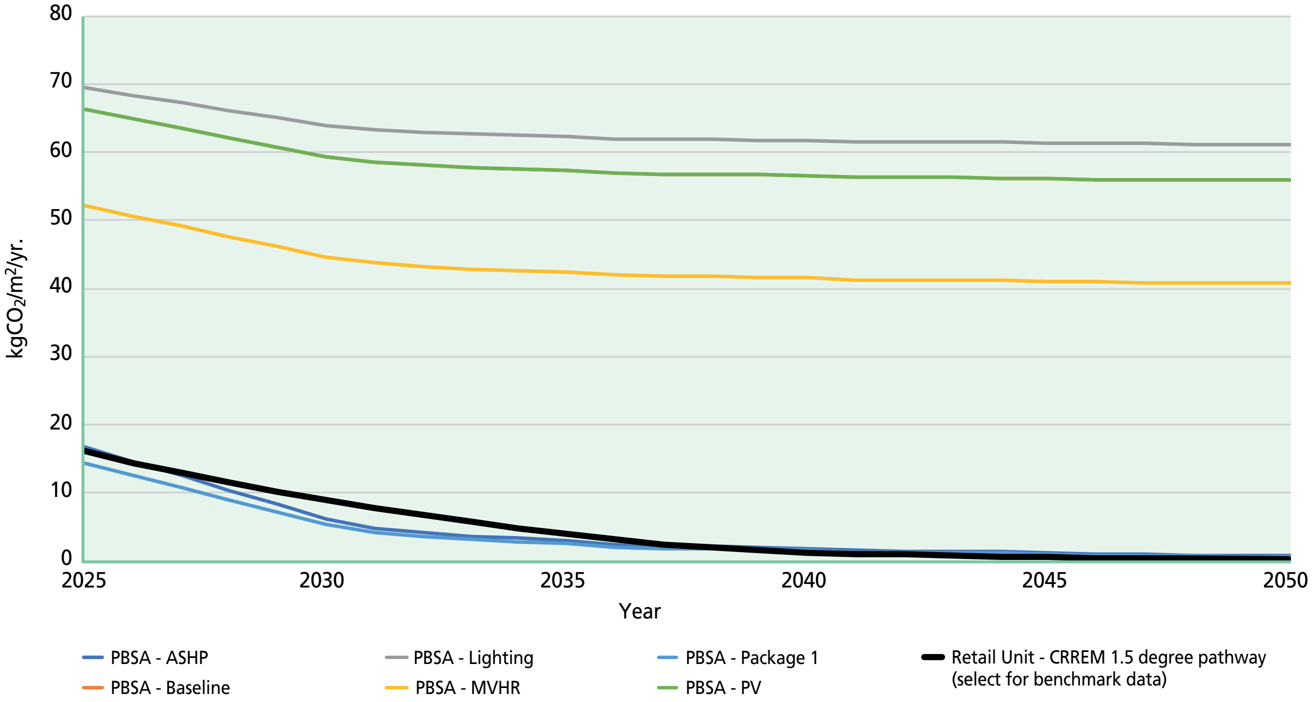


- The black line shows the CRREM 1.5 degree energy intensity targets in kWh/m²/yr. The EUI for the building with the improvement packages ranges from around 100 kWh/m²/yr to 400 kWh/m²/yr.
- The baseline building EUI is significantly higher than the CRREM 1.5 degree target in 2025.
- Assuming interventions are made in 2025, Package 1 would meet the CRREM 1.5 target but from then onwards the building would fall behind the pathway without further improvements.

5. FINDINGS

Carbon intensity for CRREM analysis

Projected carbon emissions to 2050 in comparison to CRREM 1.5 degrees carbon pathway



- The black line shows the CRREM 1.5 degree pathway for carbon emissions in $kgCO_2/m^2/yr$ The package lines show the trajectory for the carbon emissions assuming the intervention was installed in year 2025 and delivered operational carbon savings yearly.
- The building baseline is 66 $kgCO_2/m^2/yr$ and is significantly worse than the CRREM carbon intensity target for 2025 of 18 $kgCO_2/m^2/yr$.
- The ASHP and Package 1 would reduce the carbon intensity significantly to 17 $kgCO_2/m^2/yr$ and 14 $kgCO_2/m^2/yr$ respectively in 2025. These would meet the CRREM carbon intensity target and the building would continue to be on track with the CRREM pathway through to 2050.

5. FINDINGS

Energy, carbon and return on investment table

Student accommodation - Energy efficiency and carbon reduction measures						Energy upgrade scenario		Refurbishment scenario	
Improvement package	Energy Use intensity impact ($kWh/m^2/yr$)	Year 1 energy saving (£m^2)	Year 1 Carbon saving ($kgCO_2/m^2$)	Total Carbon saving to 2050 (25 years) ($kgCO_2/m^2$)	Year the building exceeds the CRREM Carbon pathway	Capital cost (£/m^2)	IRR	Capital cost (£/m^2)	IRR
Baseline	0	£0.00	0.00	0.00	Exceeds	£0	0%	£0	0%
Lighting	13	£1.31	-3.08	-119.95	Exceeds	£64	-5%	£0	0%
ASHP	-261	£4.34	49.58	1345.88	2048	£212	-4%	£140	-1%
PV	0	£0.00	0.00	0.00	Exceeds	£8	0%	£157	-8%
MVHR	-76	£1.84	14.19	371.59	Exceeds	£280	-11%	£8	0%
Package 1 - Lighting, Ventilation & ASHP	-278	£6.64	51.92	1361.07	2048	£556	-7%	£296	-4%

6. TAKING ACTION

This section includes guidance on how to use the supporting dataset dashboard to explore the results and the core recommendations arising from the analysis.

It is important to remember that typologies have been used to run this analysis and they are representative of core commercial sector assets, rather than case studies. Care should be taken when applying the analysis to a specific building.

6.1 Dataset dashboard

The results dataset has been developed into a user-friendly dashboard which will enable readers to filter for relevant results. It includes the reference data tables to enable users to identify preferred solutions and benchmark costs for meeting MEES and CRREM goals. The dashboard allows users to filter by asset typology and improvement package to see the resulting cost and carbon analysis. It is an excel file and is available from the IPF resources library (accessed here).

The full dataset can be found on the 'input sheet' tab in the excel dashboard.

6.2 Recommendations

The seven typologies explored in this research demonstrate that cost effective energy efficiency measures exist for a range of building types of different age and condition. When considering energy efficiency upgrades, investors and asset managers should adopt the following recommendations:

- **Long term thinking -** take a long-term approach to decision making for energy efficiency improvements to buildings and portfolios.
- **Align with future building works -** When planning future building works/refurbishment, it is recommended that full consideration is given to current requirements and the direction of travel for policy and that all opportunities to improve the energy performance of the asset are explored. Energy efficiency must be in building refurbishment plans.
- **For MEES compliance, prioritise updating EPCs -** It is important to be aware of the risk of inaccurate EPCs and to prioritise getting updated EPCs for properties that could be at risk and, in relation to new or renewal of tenancies, assess current and future risk.
- **Work with tenants on meeting CRREM pathways –** to drive down both regulated and unregulated energy consumption in the building. For most existing assets, meeting the CRREM pathways (energy and carbon intensity) will require active energy management alongside improvement measures alongside property management interventions.

The following steps are recommended to help landlords take the right steps to improve building performance.

1. Determine standards and reporting requirements

- Determine the reporting requirements, both mandatory and voluntary corporate objectives relating to energy and carbon.

2. Identify priority buildings

Identify priority buildings which may have the following characteristics:

- Poor EPC ratings
- No EPC
- Large size / asset value
- Competitive local market (otherwise comparable buildings with better ratings nearby)
- Are due for refurbishment / planned lifecycle investment / vacant possession
- High maintenance costs (indicating that plant may be at the end of its economic life)

3. Review performance of priority buildings

- Review existing EPC rating and, if considered inadequate (e.g. frequent use of default assumptions for key plant items), commission a new assessment.
- Review available data on actual energy consumption (even if only for communal areas), to identify opportunities for quick savings by controlling out of hours consumption (e.g. overnight and weekends) and through adjustment of run times and loading of key plant.
- Use energy modelling, ideally including, actual energy data to identify opportunities to further improve energy and carbon efficiency through investment.
- Review the costs and impacts of different improvement options. Costs provided in this report could be used as a guide during initial scoping with a surveyor's assessment of possible measures to develop project specific costs and delivery plans.

4. Develop a costed improvement strategy

Develop a costed improvement strategy for each priority building to include:

- Timescale for implementation considering external factors (e.g. MEES regulations), planned lifecycle investment, likely timing of vacant possession, etc.
- Target performance and rationale (risk of occupier loss, protection of asset value, need for essential lifecycle expenditure, compliance with corporate policy, etc)
- Improvement measures to include both management and asset investments
- Key tasks and responsibilities for managing delivery.

5. Get started and deliver the strategy

- Ensure delivery of the improvements through robust commissioning, handover and quality assurance post intervention,
- Work collaboratively with occupiers to optimise building performance in use.
- Review asset performance against chosen metrics regularly

APPENDIX A: BACKGROUND TO ENERGY, CARBON AND COMMERCIAL BUILDINGS

Energy use in commercial buildings

According to Non-Domestic National Energy Efficiency Data (ND-NEED), non-domestic buildings in England and Wales used 127 TWh of electricity and 147 TWh of gas in 2020 (the most recent year for which data are available).[18]

Non-domestic building energy consumption and energy intensity varies by building use. For electricity, the ND-NEED reports that the three highest consuming building uses, excluding Other buildings, are Factories at 33%, Offices at 15% and Warehouses at 12%. Data from ND-NEED shows that offices consumed 19 TWh of electricity in 2020; Shops 15 TWh; Warehouses 15TWh. For gas, the three highest consuming building uses, also excluding Other buildings, are Factories at 38%, Education at 9% and Offices at 8%.

EPC rating statistics

All rental properties will need to achieve an EPC rating of C in the period 2025-27 and EPC B by 2030. The Department for Levelling Up, Housing & Communities publishes quarterly statistics on EPCs issued. The information can be explored by region, local authority and over time. It is accessed at this link: DLUC – Energy Performance Certificates .

This could be used by property investors to explore and understand the current market EPC ratings for a particular region of interest and how this is trending over time. The dataset is a register of EPCs – 'lodgements' and is not equivalent to total building stock as some buildings will not have registered an EPC and some will have registered more than one over time.

Some relevant extracts of this information have been included below.[19]

Table A.1 Total number of non-domestic EPC lodgements and EPC rating as of Q3 2023 (England and Wales)

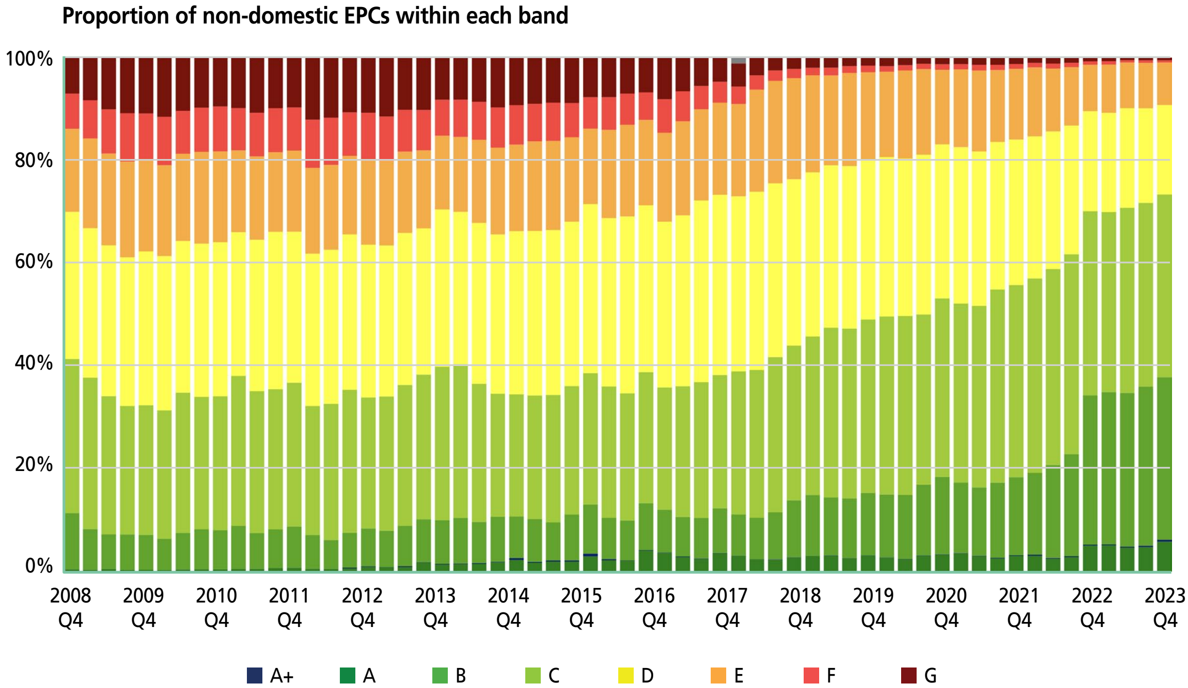
Rating	Number of EPCs registered as of Q3 2023	% of all certificates
Rating A+	1,385	0.11%
Rating A	29,520	2.26%
Rating B	162,778	12.45%
Rating C	394,528	30.17%
Rating D	379,773	29.04%
Rating E	203,214	15.54%
Rating F	62,294	4.76%
Rating G	75,205	5.75%
Not recorded	302	0.02%
TOTAL	**1,307,614**	**100.00%**

[18] The Non-Domestic National Energy Efficiency Data-Framework 2022 (England and Wales), June 2022
https://assets.publishing.service.gov.uk

[19] Department for Levelling Up, Housing & Communities, Energy Performance Certificates
https://app.powerbi.com

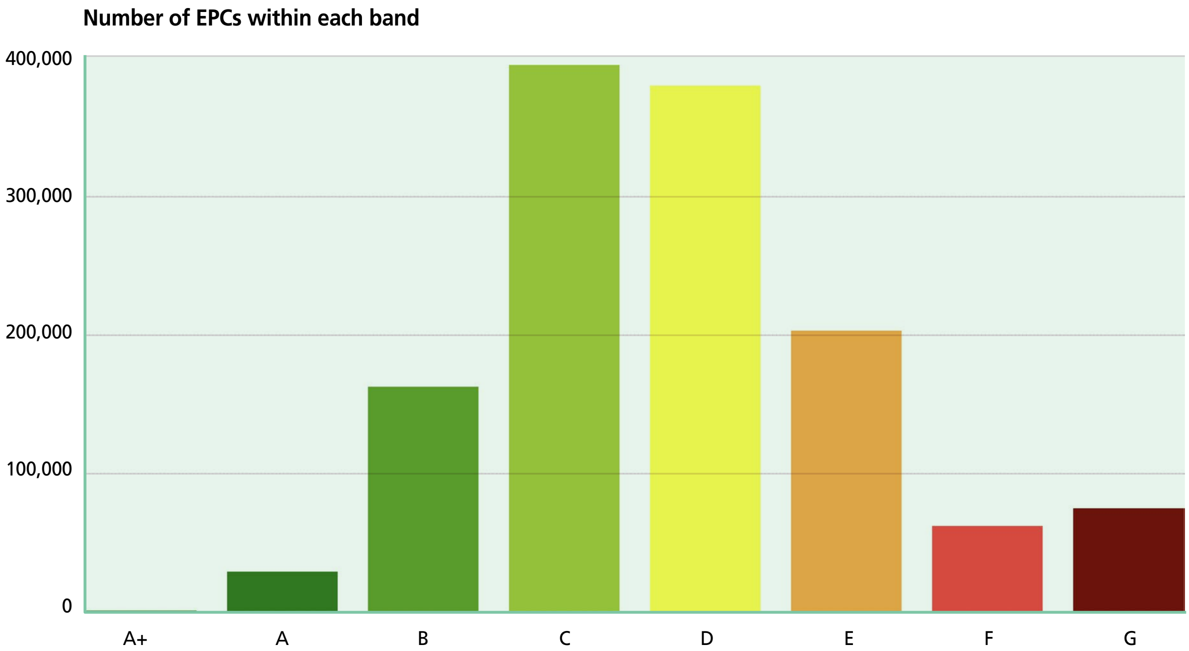
APPENDIX A: BACKGROUND TO ENERGY, CARBON AND COMMERCIAL BUILDINGS

Figure A.1 Proportion of non-domestic EPC lodged within each band per quarter (England & Wales)



Source: [Energy Performance of Buildings Certificates: Data dashboard - GOV.UK (www.gov.uk)]

Figure A.2 Energy Performance Certificates for non-domestic properties (England & Wales)



Source: [Energy Performance of Buildings Certificates: Data dashboard - GOV.UK (www.gov.uk)]

APPENDIX A: BACKGROUND TO ENERGY, CARBON AND COMMERCIAL BUILDINGS

Carbon & grid decarbonisation

UK targets

Emissions from non-domestic buildings currently account for around 22% of emissions from buildings, and 4% of all UK GHG emissions.[20] Under Carbon Budget 6, these emissions will be expected to broadly halve by 2035 and fall to zero by 2050.

The carbon intensity of electricity consumption has reduced in recent years, predominantly through the transition away from coal to natural gas and significant uptake in renewable technologies. Carbon dioxide (CO_2) emissions in the UK are provisionally estimated to have decreased by 2.4% in 2022 from 2021, to 331.5 million tonnes (Mt), and total greenhouse gas emissions by 2.2% to 417.1 million tonnes carbon dioxide equivalent ($MtCO_2e$).

In 2022, low carbon energy sources such as nuclear and renewables accounted for 54% of fuel used for electricity generation, increasing from 22.2% in 1990.[21] Achievement of the UK's emissions targets rests heavily on the key goal of decarbonisation of electricity by 2035.

Carbon budgets

In 2019, the United Kingdom led the world's major economies in setting a target of net zero emissions by 2050. The Climate Change Act passed in 2008 established a system of legally binding interim emissions reduction targets, referred to as carbon budgets, covering successive five-year periods as part of a long-term objective of achieving net-zero by 2050.

Carbon budgets have been established and are considered to be consistent with the UK's commitment under the Paris Agreement (COP21). The fourth carbon budget, covering the period between 2023–2027, aims to reduce carbon emissions by 52% compared to 1990 levels and, although it is recognised, there is a gap in supporting policies which presents a significant risk to achieving net zero by the mandated 2050 deadline.[22]

Table A.2 Carbon budgets by date

Budget period	GHG's ($MtCO_2e$)	Reduction on 1990 emissions levels (%)
1st Carbon Budget (2008 to 2012)	3,018	26%
2nd Carbon Budget (2013 to 2017)	2,782	32%
3rd Carbon Budget (2018 to 2022)	2,544	38%
4th Carbon Budget (2023 to 2027)	1,950	52%
5th Carbon Budget (2028 to 2032)	1,725	57%
6th Carbon Budget (2033 to 2037)	965	77%

20 Evidence update of low carbon heating and cooling in non-domestic buildings, November 2022 https://assets.publishing.service.gov.uk

21 Department for Energy Security & Net Zero 2022 UK greenhouse gas emissions, provisional figures https://assets.publishing.service.gov.uk

22 CCC Advice on reducing the UK's emissions https://www.theccc.org.uk/about/our-expertise/advice-on-reducing-the-uks-emissions/

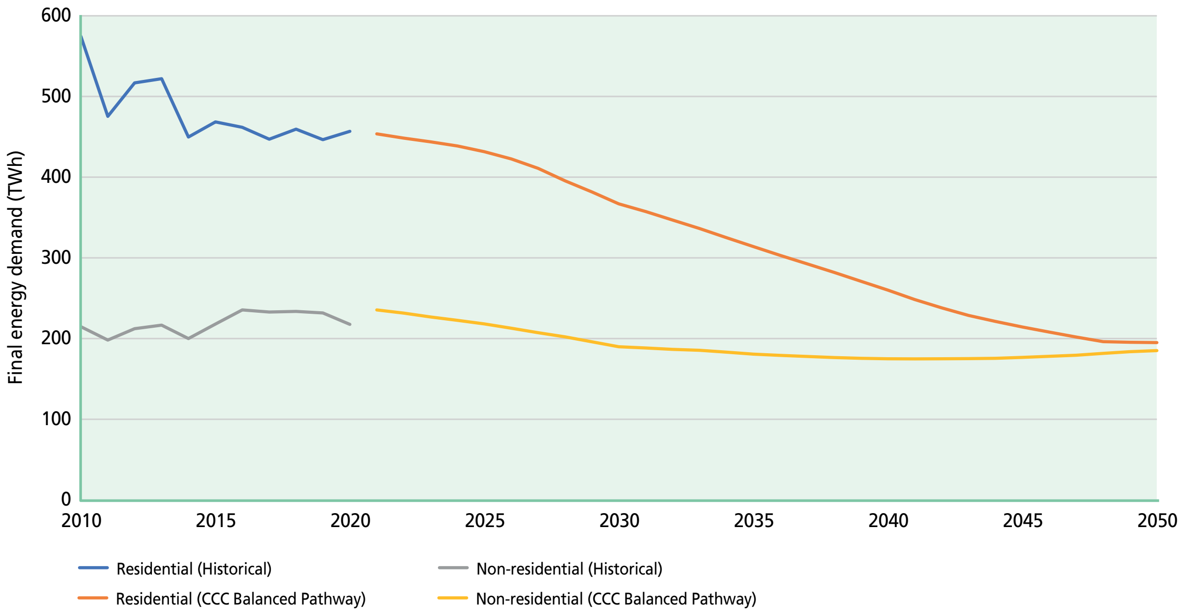
APPENDIX A: BACKGROUND TO ENERGY, CARBON AND COMMERCIAL BUILDINGS

The sixth carbon budget has become the first to be set under the UK's new net zero target by 2050 and was legislated for in June 2021. The Glasgow Climate Pact, agreed at COP26 in November 2021, recognised the need for accelerated action to limit global warming to 1.5°C above pre-industrial temperatures. The UK revisited its 2030 Nationally Determined Contribution (NDC) to ensure it remained a fair and ambitious contribution to global action on climate change. The target is to reduce all gas emissions by at least 68% by 2030 compared to 1990 levels.[23]

Progress and trajectory for carbon in commercial buildings

Over the last 20 years, CO_2e emissions from commercial buildings have incrementally fallen, although this is almost exclusively as a result of reduced carbon emissions associated with supplied grid electricity through a changing mix of fuels being used for electricity generation, such as switching from coal to natural gas and the growth in the use of renewable energy technologies. Figure A.3 shows how energy demand in non-residential buildings has begun to fall over the last few years.

Figure A.3 Energy demand in residential and non-residential buildings forecast to 2050

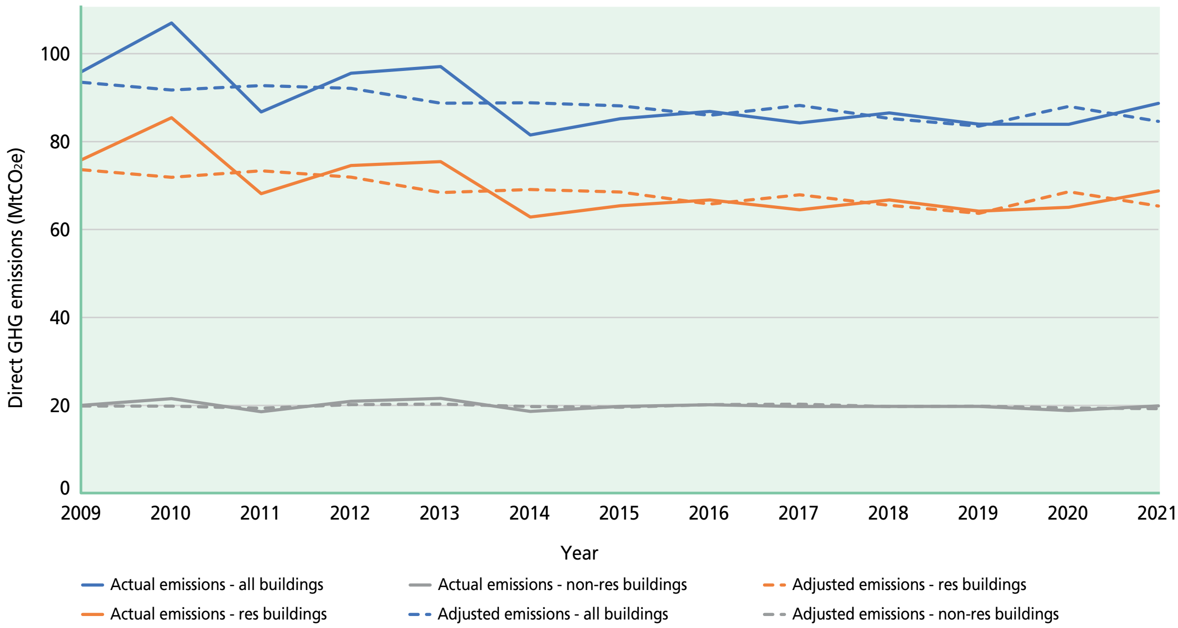


Source: BEIS (2021) Energy consumption in the UK 2021; BEIS (2021) Digest of UK Energy Statistics (DUKES) 2021; CCC (2020) Sixth Carbon Budget
Notes: CCC pathways have been adjusted to align with actual energy demand in 2018.

[23] UK's Nationally Determined Contribution, updated September 2022 https://www.gov.uk/government/publications/the-uks-nationally-determined-contribution-communication-to-the-unfccc

APPENDIX A: BACKGROUND TO ENERGY, CARBON AND COMMERCIAL BUILDINGS

Figure A.4 Direct GHG emissions ($MtCO_2e$) for residential and non-residential buildings



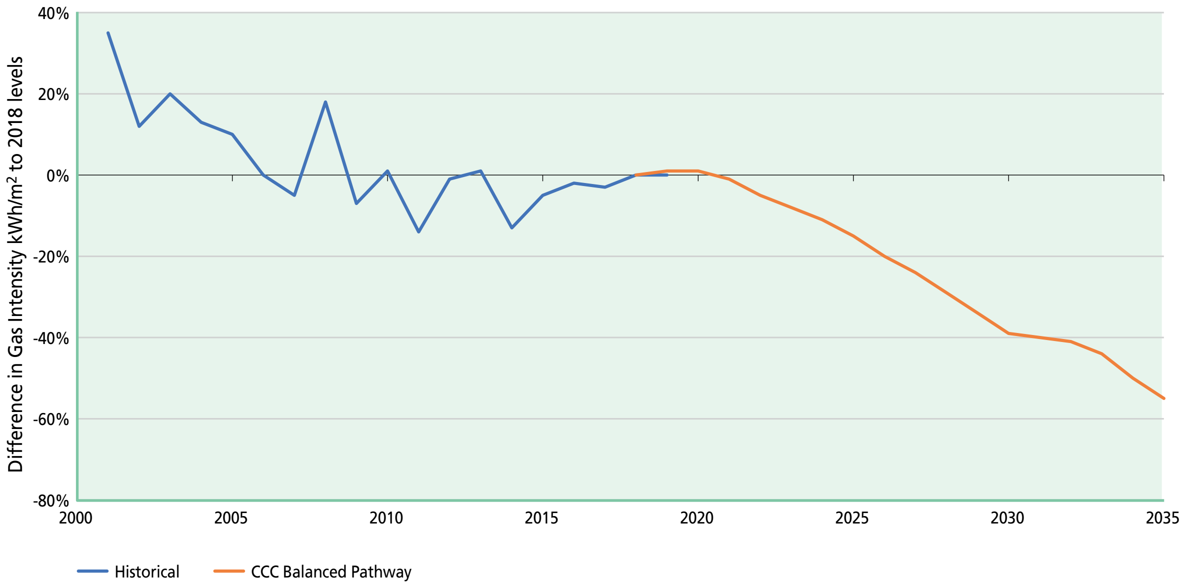
Source: BEIS (2022) Provisional UK greenhouse gas emissions national statistics 2021; BEIS (2022) Final UK greenhouse gas emissions national statistics: 1990 to 2020; BEIS (2022) Average temperatures, heating degree-days and deviations from the long-term mean (ET 7.1)', Energy Trends: UK weather; CCC analysis. Notes: Relates to direct buildings emissions only. The bottom figure corresponds to temperature-adjusted emissions and is not directly comparable to the top figure. See Box 4.1 for more on temperature adjustment and changes in the emissions data for 2018, 2019 and 2020 in the latest emissions inventory.

The COVID-19 pandemic impacted occupancy and associated carbon emissions from commercial buildings. The increase in home working during 2020 had a corresponding 5% reduction in emissions from commercial buildings[24]. It is anticipated that carbon emissions from commercial buildings will further reduce through the continued decarbonisation of the electricity grid. Figure A.5 demonstrates there has been no significant change in energy intensity in retail or office buildings since 2014. A steep decline in gas intensity is required over the next decade to meet carbon reduction targets.

[24] Committee on Climate Change, Progress in reducing emissions 2022 Report to Parliament https://www.theccc.org.uk/publication/2022-progress-report-to-parliament/

APPENDIX A: BACKGROUND TO ENERGY, CARBON AND COMMERCIAL BUILDINGS

Figure A.5 Change in gas intensity for commercial retail and office buildings



Source: Analysis by Eunomia for the CCC based on ONS, Energy Performance Certificate statistics for new and existing flats and houses and Government targets in the Heat and Buildings Strategy. Notes: The annual historical pathway does not represent a snapshot of the state of the stock at any time – rather the percentage of EPCs lodged on the register during the time period in question. The cumulative historical pathway is based on ONS data for financial years up to March 2021. The Government target and indicative pathway to the target were produced based on Eunomia's assumption that 89% of homes in the stock can reach EPC C.

APPENDIX B: METHOD

Overview

The basis of the research was to assess the costs associated with making energy efficiency improvements to a selection of existing building typologies. Measures included those that would improve the EPC rating of the building. To demonstrate which of these improvements were most cost effective, capital cost of the upgrade was set against its estimated impact on energy use and the associated costs and carbon emissions.

Typology selection

The asset classes requested by IPF and modelled in this research are listed and detailed in the Table 1.1. These typologies represent a large proportion of the existing commercial property stock and cover asset classes that are important for investors in the current UK market. The typologies are a progression from the previous buildings modelled in IPF Costing Energy Efficiency Improvements (2017) and provide a breadth to the analysis. The typologies were selected to provide realistic variation across the sector to capture differences in building age, form and baseline EPC rating.

For the Build-to-Rent scenario, the SAP[25] methodology was applied and therefore the EPC assessment was based on one top floor flat in the wider development. A sensitivity analysis was run to test the EPC performance of a top floor corner flat, where heat losses may be higher, compared to a mid-level flat. The top floor flat baseline EPC rating was E-51 and the mid-level flat was D-60. For the purpose of this study a top floor flat was selected to show the worst-case scenario.

The baseline buildings were modelled using specifications relevant to the building age and type.

Locational context

Location was not a variable in the analysis. For the EPC modelling, a specific location is used to apply a specific weather file for the region. A range of UK locations in both suburban and urban context were chosen across the typologies. The locations assumed for this study are listed in Table B.1.

Table B.1 Typology locations

Typology	Location (for weather file)
Retail unit in shopping centre	London
Retail warehouse	London
Logistics	Manchester
Office 1 (Air conditioned)	London
Office 2 (Older air conditioned system)	Birmingham
Build-to-Rent	London
Student accommodation	Manchester

[25] Note, under the SAP methodology, EPC grade is based on calculated running costs rather than carbon emissions and is shown on a scale of 0-100. Unlike a non-domestic EPC rating scores related to better EPC grades.

APPENDIX B: METHOD

Measure and package selection

For each building, a series of refurbishment measures were selected reflecting the key contributors to regulated energy and carbon emissions and including those items identified in Table 6 of Building Regulations Part L2b (see Table 2.1). Table 6 is an important reference point as, under MEES regulations, landlords will need to consider the listed measures when evaluating which might be suitable and cost effective to apply to improve the rating of their buildings.

Measures were selected based on their anticipated impact on the EPC rating, the relative ease of implementation/level of disruption and the anticipated cost impact. The measures and specifications where chosen based on what is currently available in the market, would be feasible for the building types and would have a tangible impact on the EPC rating. The measures were grouped into the following package categories:

- Lighting package;
- Ventilation packages (split by those that could be undertaken for landlord central plant and those requiring work on occupied floor plates);
- Heating package (ASHP/Direct electric systems);
- Fabric package;
- PV package; and
- Combination packages seeking to achieve EPC B and CRREM 1.5 degrees energy intensity and carbon intensity targets.

Not all packages are relevant to all typologies and the specifications explored within each package varied across the typologies. Details on the specifications can be found in Appendix C.

Capital cost estimation and assumptions

Capital costs were estimated for each building typology and represent the total cost to a client of construction work. This includes materials, labour, buildings work in connection preliminaries, overheads, contingencies, and profit. Professional fees (including design fees) have not been included, based on the assumption that any increase in professional fees associated with the improvements will be marginal. Other excluded costs include Value Added Tax, Building Control fees, survey fees, legal fees and finance costs. All costs are current at Q3 2023 price levels.

Known enabling and modification works have been allowed for, but the costs do not include any major restructuring or creation of new spaces. 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 and the capital costs reflect this.

No upgrades to utilities or major infrastructure have been included.

APPENDIX B: METHOD

The capital cost scenarios modelled are as follows:

Energy upgrade scenario: where a building owner upgrades but without a set forward investment plan. The absolute replacement costs have been modelled, without any reference to age, condition or performance of the exiting assembly.

Refurbishment scenario: where a building owner will be making these interventions as part of a planned programme of asset improvements / replacement. The cost assessment is the marginal extra over cost uplift of each energy efficiency improvement against the business-as-usual alternative that can be assumed to have formed part of a PPM plan (i.e., a like for like or 'minimum compliance' solution).

Where there is a clear delineation between landlord spaces and occupier space, improvement packages have been modelled separately.

Modelling energy consumption and CO_2 emissions

Assessing energy consumption and CO_2 emissions was undertaken using SBEM (Simplified Building Energy Model) software. SBEM was developed by the Department for Communities and Local Government for the purpose of demonstrating compliance with Part L of the Building Regulations and to produce EPC ratings for non-domestic buildings. The Build-to-rent residential typology was modelled using the SAP 10 methodology for residential units.

The software used was Design SAP 10 by Elmhurst for the BTR and IESVE version 2023.0.0 for all other buildings.

Adjusting for indication of actual consumption

Part L and EPCs only regulate and predict a proportion of CO_2 emissions in buildings. Specifically, only heating, cooling, hot water, ventilation and lighting energy consumption is accounted for. This methodology assumes standard working hours and occupancy. The EPC modelling process did not include, therefore, any allowance for occupants' equipment or appliances or account for extended working hours.

To help provide an indication of the impacts of efficiency measures on actual energy consumption, the analysis of EPC performance (using SBEM and SAP) was adjusted using a 'performance gap' factor of 50% for all building typologies and packages.

Seven-year cost effectiveness test

Compliance of different individual measures with the seven-year cost effectiveness test was determined through comparison of costs and savings over the seven-year period as follows:

- Implementation costs
  - Multiplication of capital cost by interest rate factor (current 17.3% where the Bank of England's Base Interest Rate is 5.25%) and then by seven years
- Efficiency savings
  - Change in annual gas and electricity costs multiplied by seven years

APPENDIX C: KEY MODELLING PARAMETERS

Whilst the Bank of England's interest rate is included in the analysis, no discounting of future savings is included, and it is assumed that unit charges for gas and electricity remain constant.

Projection of future energy costs and carbon emissions

In addition to the seven-year test, a series of further analyses were undertaken. These further studies used published projections for the future unit cost[26] and carbon intensity[27] of energy to estimate the future annual costs of energy and associated emissions between 2025 and 2050.

Analyses included the following assessments:

- Net present value of investment and savings over 25 years at the public sector discount rate of 3.5%;
- Internal Rate of Return over 25 years post upgrade;
- Total carbon savings over 25 years post upgrade;
- Cost of carbon savings based on the quantity of CO_2e saved over 25 years divided by the net cost (i.e. capital costs and operational savings); and
- Annual and cumulative reduction in carbon emissions relative to the baseline building in 2025, between 2025 and 2050.

The core lifecycle analysis was undertaken using results from EPC modelling adjusted to consider unregulated energy and performance gap. The savings in terms of energy and carbon have been presented as whole building figures, rather than apportioned to landlord and tenant spaces.

CRREM 1.5 degree pathways

The CRREM pathways V2 released in 2023 have been used in this study.[28]

Some building typologies, for example retail buildings with a high refrigerant load, can have a high proportion of their total global warming potential (CO_2e) coming from refrigerant losses. These emissions have not been included in this analysis at typology level but should be considered when assessing and reporting on specific building.[29] The CRREM pathways provide carbon-only targets and these have been used in this assessment.

[26] BEIS, 2022. Treasury Green Book supplementary appraisal guidance on valuing energy use and greenhouse gas (GHG) emissions. Interdepartmental Analysts Group.

[27] CRREM, 2023. CRREM Global Pathways v2.02.

[28] https://www.crrem.eu/tool/

[29] An accurate assessment of transition risk in line with TCFD recommendations would require an appropriate assessment of refrigerants. This information must be gathered for corporate sustainability reporting as well as transition risk analysis, as all GHG emissions, including CO2 equivalents, must be reported and disclosed.

APPENDIX C: KEY MODELLING PARAMETERS

The modelling software requires a range of physical building characteristics to be defined as model inputs in order to construct the base building models. Standard assumptions are made by the software with regards to building operation. The approach followed was to determine inputs that would best represent the building types under consideration. The key parameters modelled for each typology and the packages are presented in this appendix. The modelling was undertaken by Introba Consulting.

Retrofit options | Year of construction 2000s

	0. Baseline	1. Lighting package	2. Ventilation package	3. ASHP package	4. PV package	5. Combination 1	6. Combination 2	2A (Landlord - AHU + HR%) Ventilation package	2B (Tennant - FCU + Demand Control). Ventilation package	5A (Landlord - Heat Pump + AHU + HR%). Combination 1A	5B (Tennant - Lighting + PIRs + FCU + Demand Control). Combination 1B
Thermal Model	EPC_OFF01_V0	EPC_OFF01_V1	EPC_OFF01_V2	EPC_OFF01_V3	EPC_OFF01_V4	EPC_OFF01_V5	EPC_OFF01_V6	EPC_OFF01_V2A	EPC_OFF01_V2B	EPC_OFF01_V5A	EPC_OFF01_V5B
Description	AD L2 (2002) Fabric + Business as usual MEP system	Baseline + Lighting Upgrades	Baseline + Ventilation Upgrades	Baseline + ASHP	Baseline + 50% of roof area PV	Baseline + Packages 1,2,3	Baseline + Packages 1,2,3, 4	Baseline + Ventilation Upgrades	Baseline + Ventilation Upgrades	Baseline + Packages 2A,3	Baseline + Packages 1,2B
Construction Type	SFS with 40mm insulation	SFS with 40mm insulation	SFS with 40mm insulation	SFS with 40mm insulation	SFS with 40mm insulation	SFS with 40mm insulation	SFS with 40mm insulation	SFS with 40mm insulation	SFS with 40mm insulation	SFS with 40mm insulation	SFS with 40mm insulation
Floor U-Value (W/m^2K)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
External wall U-Value (W/m^2K)	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Roof U-Value (W/m^2K)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Windows/Rooflights U-value (W/m^2K)	2.0	2.00	2.00	2.00	2.00	2.00	0.00	2.00 2.00	2.00	2.00	2.00
Windows g-value	0.7	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
External doors (W/m^2K)	2.0	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Thermal bridging (W/m^2K)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)
Air Permeability ($m^2/m^2/hr$)	10	10	10	10	10	10	10	10	10	10	10
Ventilation system and design	Supply and extract	Supply and extract	**AHU with heat recovery**	Supply and extract	Supply and extract	**AHU with heat recovery**	**AHU with heat recovery**	**AHU with heat recovery**	Supply and extract	**AHU with heat recovery**	Supply and extract
AHU heat recovery efficiency	N/A	N/A	**80%**	N/A	N/A	**80%**	**80%**	**80%**	N/A	**80%**	N/A
AHU specific fan power	2.9 W/l/s 0.5 (FCU terminal)	2.9 W/l/s 0.5 (FCU terminal)	**1.8 W/l/s** **0.3 W/l/s (FCU terminal)**	2.9 W/l/s 0.5 (FCU terminal)	2.9 W/l/s 0.5 (FCU terminal)	**1.8 W/l/s** **0.3 W/l/s (FCU terminal)**	**1.8 W/l/s** **0.3 W/l/s (FCU terminal)**	**1.8 W/l/s** 0.5 W/l/s (FCU terminal)	2.9 W/l/s **0.3 W/l/s (FCU terminal)**	**1.8 W/l/s** 0.5 W/l/s (FCU terminal)	2.9 W/l/s **0.3 W/l/s (FCU terminal)**
Demand Control Ventilation	No	No	**Yes - CO_2 sensors with speed control**	No	No	**Yes - CO_2 sensors with speed control**	**Yes - CO_2 sensors with speed control**	No	**Yes - CO_2 sensors with speed control**	No	**Yes - CO_2 sensors with speed control**
Internal Lighting (lm/W)	45	**120**	45	45	45	**120**	**120**	45	45	45	**120**
Lighting Control	No	**Office: Absence Detection** **Rest: Presence Detection**	No	No	No	**Office: Absence Detection** **Rest: Presence Detection**	**Office: Absence Detection** **Rest: Presence Detection**	No	No	No	**Office: Absence Detection** **Rest: Presence Detection**
Heating System	Gas Boiler	Gas Boiler	Gas Boiler	**ASHP**	Gas Boiler	**ASHP**	**ASHP**	Gas Boiler	Gas Boiler	ASHP	Gas Boiler
Description	Gas boiler serving a heating system with flow and return temperature 70°C/50°C	Gas boiler serving a heating system with flow and return temperature 70°C/50°C	Gas boiler serving a heating system with flow and return temperature 70°C/50°C	**ASHPs serving a heating system with low flow and return temperatures 45°C/40°C fed from ambient loop** **Note: re-insulation of the pipework, and changes to heat emitters required.**	Gas boiler serving a heating system with flow and return temperature 70°C/50°C	**ASHPs serving a heating system with low flow and return temperatures 45°C/40°C fed from ambient loop** **Note: re-insulation of the pipework, and changes to heat emitters required.**	**ASHPs serving a heating system with low flow and return temperatures 45°C/40°C fed from ambient loop** **Note: re-insulation of the pipework, and changes to heat emitters required.**	Gas boiler serving a heating system with flow and return temperature 70°C/50°C	Gas boiler serving a heating system with flow and return temperature 70°C/50°C	**ASHPs serving a heating system with low flow and return temperatures 45°C/40°C fed from ambient loop** **Note: re-insulation of the pipework, and changes to heat emitters required.**	Gas boiler serving a heating system with flow and return temperature 70°C/50°C
Heating emitters	LTHW Fan Coil Unit fed by Gas Boiler	LTHW Fan Coil Unit fed by Gas Boiler	LTHW Fan Coil Unit fed by Gas Boiler	**LTHW Fan Coil Unit fed by ASHP**	LTHW Fan Coil Unit fed by Gas Boiler	**LTHW Fan Coil Unit fed by ASHP**	**LTHW Fan Coil Unit fed by ASHP**	LTHW Fan Coil Unit fed by Gas Boiler	LTHW Fan Coil Unit fed by Gas Boiler	**LTHW Fan Coil Unit fed by ASHP**	LTHW Fan Coil Unit fed by Gas Boiler
Hot water system	Direct electric hot water for offices (50L storage) and showers (300L storage) Kitchen areas fed by a gas boiler	Direct electric hot water for offices (50L storage) and showers (300L storage) Kitchen areas fed by a gas boiler	Direct electric hot water for offices (50L storage) and showers (300L storage) Kitchen areas fed by a gas boiler	**Direct electric hot water for offices (50L storage) and showers (300L storage)** **Kitchen areas fed by a ASHP**	Direct electric hot water for offices (50L storage) and showers (300L storage) Kitchen areas fed by a gas boiler	**Direct electric hot water for offices (50L storage) and showers (300L storage)** **Kitchen areas fed by a gas boiler**	**Direct electric hot water for offices (50L storage) and showers (300L storage)** **Kitchen areas fed by a ASHP**	Direct electric hot water for offices (50L storage) and showers (300L storage) Kitchen areas fed by a gas boiler	Direct electric hot water for offices (50L storage) and showers (300L storage) Kitchen areas fed by a gas boiler	**Direct electric hot water for offices (50L storage) and showers (300L storage)** **Kitchen areas fed by a ASHP**	Direct electric hot water for offices (50L storage) and showers (300L storage) Kitchen areas fed by a gas boiler
Heating and Hot Water Seasonal efficiency	80% for heating 80% for hot water (gas boiler) 100% for hot water (direct electric)	80% for heating 80% for hot water (gas boiler) 100% for hot water (direct electric)	80% for heating 80% for hot water (gas boiler) 100% for hot water (direct electric)	**400% for heating** **300% for hot water (ASHP)** **100% for hot water (direct electric)**	80% for heating 80% for hot water (gas boiler) 100% for hot water (direct electric)	**80% for heating** **80% for hot water (gas boiler)** **100% for hot water (direct electric)**	**400% for heating** **300% for hot water (ASHP)** **100% for hot water (direct electric)**	80% for heating 80% for hot water (gas boiler) 100% for hot water (direct electric)	80% for heating 80% for hot water (gas boiler) 100% for hot water (direct electric)	**400% for heating** **300% for hot water (ASHP)** **100% for hot water (direct electric)**	80% for heating 80% for hot water (gas boiler) 100% for hot water (direct electric)
Cooling Seasonal Efficiency	2.0 EER 2.5 SEER	2.0 EER 2.5 SEER	2.0 EER 2.5 SEER	**3.5 EER 5.0 SEER**	2.0 EER 2.5 SEER	**3.5 EER 5.0 SEER**	**3.5 EER 5.0 SEER**	2.0 EER 2.5 SEER	2.0 EER 2.5 SEER	**3.5 EER 5.0 SEER**	2.0 EER 2.5 SEER
PV	No	No	No	No	**Yes - 600 m^2**	No	**Yes - 600 m^2**	No	No	**No**	No
EPC Rating	**D 91**	**D 85**	**C 69**	**C 55**	**D 86**	**B 31**	**B 26**	**C 71**	**D 79**	**B 49**	**C 68**
EPC Certificate											

Office 2

Retrofit options | Year of construction 1970s

	0. Baseline	1. Lighting package	2. Ventilation package	3. ASHP package	4. PV package	5. Combination 1	6. Combination 2	2A (Landlord - AHU + HR%) Ventilation package	2B (Tennant - FCU + Demand Control). Ventilation package	6A (Landlord - Heat Pump + AHU + HR%). Combination 1A	6B (Tennant - Lighting + PIRs + FCU + Demand Control). Combination 1B
Thermal Model	EPC_OFF02_V0	EPC_OFF02_V1	EPC_OFF02_V2	EPC_OFF02_V3	EPC_OFF02_V4	EPC_OFF02_V5	EPC_OFF02_V6	EPC_OFF01_V2A	EPC_OFF01_V2B	EPC_OFF01_V6A	EPC_OFF01_V6B
Description	Fabric + MEP systems as per 1970s	Baseline + Lighting Upgrades	Baseline + Ventilation Upgrades	Baseline + ASHP	Baseline + 50% of roof area PV	Baseline + Fabric Upgrades	Baseline + Packages 1,2,3	Baseline + Ventilation Upgrades	Baseline + Ventilation Upgrades	Baseline + Packages 2A,3	Baseline + Packages 1,2B
Construction Type	Masonry with unfilled cavity	Masonry with unfilled cavity	Masonry with unfilled cavity	Masonry with unfilled cavity	Masonry with unfilled cavity	Masonry with unfilled cavity	Masonry with unfilled cavity	Masonry with unfilled cavity	Masonry with unfilled cavity	Masonry with unfilled cavity	Masonry with unfilled cavity
Floor U-Value (W/m^2K)	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
External wall U-Value (W/m^2K)	1.60	1.60	1.60	1.60	1.60	0.15 (200mm insulation)	0.15 (200mm insulation)	0.15 (200mm insulation)	0.15 (200mm insulation)	0.15 (200mm insulation)	0.15 (200mm insulation)
Roof U-Value (W/m^2K)	1.50	1.50	1.50	1.50	1.50	0.15 (200mm insulation)	0.15 (200mm insulation)	0.15 (200mm insulation)	0.15 (200mm insulation)	0.15 (200mm insulation)	0.15 (200mm insulation)
Windows/Rooflights U-value (W/m^2K)	4.80	4.80	4.80	4.80	4.80	1.30	1.30	1.30	1.30	1.30	1.30
Windows g-value	0.70	0.70	0.70	0.70	0.70	0.40	0.40	0.40	0.40	0.40	0.40
External doors (W/m^2K)	4.80	4.80	4.80	4.80	4.80	1.30	1.30	1.30	1.30	1.30	1.30
Thermal bridging (W/m^2K)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)
Air Permeability ($m^2/m^2/hr$)	30	30	30	30	30	30	30	30	30	30	30
Ventilation system and design	Natural with extract fans (toilets)	Natural with extract fans (toilets)	**AHU with heat recovery**	Natural with extract fans (toilets)	Natural with extract fans (toilets)	**Natural with extract fans (toilets)**	**AHU with heat recovery**	**AHU with heat recovery**	Supply and extract	**AHU with heat recovery**	Supply and extract
AHU heat recovery efficiency	N/A	N/A	**80%**	N/A	N/A	**N/A**	**80%**	**80%**	N/A	**80%**	N/A
AHU specific fan power	0.6 (extract)	0.6 (extract)	**1.8 W/l/s 0.3 W/l/s (FCU terminal)**	0.6 (extract)	0.6 (extract)	**0.6 (extract)**	**1.8 W/l/s 0.3 W/l/s (FCU terminal)**	**1.8 W/l/s 0.8 W/l/s (FCU terminal)**	2.9 W/l/s 0.3 W/l/s (FCU terminal)	**1.8 W/l/s 0.8 W/l/s (FCU terminal)**	2.9 W/l/s 0.3 W/l/s (FCU terminal)
Demand Control Ventilation	N/A	N/A	**Yes - CO_2 sensors with speed control**	N/A	N/A	**N/A**	**Yes - CO_2 sensors with speed control**	No	**Yes - CO_2 sensors with speed control**	No	**Yes - CO_2 sensors with speed control**
Internal Lighting (lm/W)	45	**120**	45	45	45	**45**	**120**	45	45	45	**120**
Lighting Control	No	**Office: Absence Detection Rest: Presence Detection**	No	No	No	**No**	**Office: Absence Detection Rest: Presence Detection**	No	No	No	**Office: Absence Detection Rest: Presence Detection**
Heating System	Gas Boiler	Gas Boiler	Gas Boiler	**ASHP**	Gas Boiler	**Gas Boiler**	**ASHP**	Gas Boiler	Gas Boiler	ASHP	Gas Boiler
Description	Gas boiler serving a heating system with flow and return temperature 70°C/50°C	Gas boiler serving a heating system with flow and return temperature 70°C/50°C	Gas boiler serving a heating system with flow and return temperature 70°C/50°C	**ASHPs serving a heating system with low flow and return temperatures 45°C/40°C fed from ambient loop Note: re-insulation of the pipework, and changes to heat emitters required.**	Gas boiler serving a heating system with flow and return temperature 70°C/50°C	**Gas boiler serving a heating system with flow and return temperature 70°C/50°C**	**ASHPs serving a heating system with low flow and return temperatures 45°C/40°C fed from ambient loop Note: re-insulation of the pipework, and changes to heat emitters required.**	Gas boiler serving a heating system with flow and return temperature 70°C/50°C	Gas boiler serving a heating system with flow and return temperature 70°C/50°C	**ASHPs serving a heating system with low flow and return temperatures 45°C/40°C fed from ambient loop Note: re-insulation of the pipework, and changes to heat emitters required.**	Gas boiler serving a heating system with flow and return temperature 70°C/50°C
Heating emitters	LTHW Fan Coil Unit fed by Gas Boiler	LTHW Fan Coil Unit fed by Gas Boiler	LTHW Fan Coil Unit fed by Gas Boiler	**LTHW Fan Coil Unit fed by ASHP**	LTHW Fan Coil Unit fed by Gas Boiler	**LTHW Fan Coil Unit fed by Gas Boiler**	**LTHW Fan Coil Unit fed by ASHP**	LTHW Fan Coil Unit fed by Gas Boiler	LTHW Fan Coil Unit fed by Gas Boiler	**LTHW Fan Coil Unit fed by ASHP**	LTHW Fan Coil Unit fed by Gas Boiler
Hot water system	Direct electric hot water	Direct electric hot water	Direct electric hot water	**Direct electric hot water**	Direct electric hot water	**Direct electric hot water**	**Direct electric hot water**	Direct electric hot water	Direct electric hot water	**Direct electric hot water**	Direct electric hot water
Heating and Hot Water Seasonal efficiency	60% for heating 100% for hot water	60% for heating 100% for hot water	60% for heating 100% for hot water	**400% for heating 100% for hot water**	60% for heating 100% for hot water	**60% for heating 100% for hot water**	**400% for heating 100% for hot water**	60% for heating 100% for hot water	60% for heating 100% for hot water	**400% for heating 100% for hot water**	60% for heating 100% for hot water
Cooling Seasonal Efficiency	2.0 EER 2.5 SEER	2.0 EER 2.5 SEER	2.0 EER 2.5 SEER	**3.5 EER 5.0 SEER**	2.0 EER 2.5 SEER	**2.0 EER 2.5 SEER**	**3.5 EER 5.0 SEER**	2.0 EER 2.5 SEER	2.0 EER 2.5 SEER	**3.5 EER 5.0 SEER**	2.0 EER 2.5 SEER
PV	No	No	No	No	**Yes - 267 m^2**	No	**No**	No	No	**No**	No
EPC Rating	**G 257**	**G 267**	**G 204**	**C 55**	**G 245**	**E 120**	**B 38**	**G 218**	**G 237**	**C 55**	**G 247**
EPC Certificate											

Retail unit in shopping centre

Retrofit options | Year of construction 1990s

	0. Baseline	1. Lighting package	2. Ventilation package	3. ASHP package	4. Combination 1	2A (Landlord - AHU + HR%) Ventilation package	2B (Tennant - FCU + Demand Control) Ventilation package	4A (Landlord - Heat Pump + AHU + HR%) Combination 1A	4B (Tennant - Lighting + PIRs + FCU + Demand Control) Combination 1B
Thermal Model	EPC_RET_SC_V0	EPC_RET_SC_V1	EPC_RET_SC_V2	EPC_RET_SC_V3	EPC_RET_SC_V4	EPC_RET_SC_V2A	EPC_RET_SC_V2B	EPC_RET_SC_V4A	EPC_RET_SC_V4B
Description	ADL2B (2006) Fabric + MEP systems as per 1990s	Baseline + Lighting Upgrades	Baseline + Ventilation Upgrades	Baseline + ASHP	Baseline + Scenarios 1,2, 3	Baseline + Ventilation Upgrades	Baseline + Ventilation Upgrades	Baseline + Scenarios 2A, 3	Baseline + Scenarios 1,2B
Construction Type	Masonry with 100mm insulation	Masonry with 100mm insulation	Masonry with 100mm insulation	Masonry with 100mm insulation	Masonry with 100mm insulation	Masonry with 100mm insulation	Masonry with 100mm insulation	Masonry with 100mm insulation	Masonry with 100mm insulation
Floor U-Value (W/m^2K)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
External wall U-Value (W/m^2K)	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Roof U-Value (W/m^2K)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Windows U-value (W/m^2K)	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Windows g-value	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Thermal bridging (W/m^2K)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)
Air permeability ($m^3/m^2/hr$)	20	20	20	20	20	20	20	20	20
Ventilation system and design	Supply and extract	Supply and extract	Supply and extract	Supply and extract	Supply and extract	Supply and extract	Supply and extract	Supply and extract	Supply and extract
AHU heat recovery efficiency (%)	N/A	N/A	**80 (Plate heat exchanger)**	N/A	**80 (Plate heat exchanger)**	**80 (Plate heat exchanger)**	**N/A**	**80 (Plate heat exchanger)**	N/A
AHU specific fan power (W/l/s)	4.0 0.8 (FCU terminal)	4.0 0.8 (FCU terminal)	**1.8 0.3 (FCU terminal)**	4.0 0.8 (FCU terminal)	**1.8 0.3 (FCU terminal)**	**1.8** 0.8 (FCU terminal)	4.0 **0.3 (FCU terminal)**	**1.8** 0.8 (FCU terminal)	4.0 **0.3 (FCU terminal)**
Demand control ventilation	No	No	**Yes - CO_2 sensors with speed control**	No	**Yes - CO_2 sensors with speed control**	**No**	**Yes - CO_2 sensors with speed control**	No	**Yes - CO_2 sensors with speed control**
Internal lighting efficacy (lm/W)	45	**120**	45	45	**120**	**45**	**45**	45	**120**
Internal lighting control	No	**Presence Detection**	No	No	**Presence Detection**	**No**	No	No	**Presence Detection**
Electric power factor	< 0.9	< 0.9	< 0.9	**< 0.9**	< 0.9	**< 0.9**	**< 0.9**	< 0.9	< 0.9
Heating system	Gas boiler with 60% seasonal efficiency and 70% delivery efficiency serving a heating system with flow and return temperature 70°C/50°C	Gas boiler with 60% seasonal efficiency and 70% delivery efficiency serving a heating system with flow and return temperature 70°C/50°C	Gas boiler with 60% seasonal efficiency and 70% delivery efficiency serving a heating system with flow and return temperature 70°C/50°C	**ASHP with 400% seasonal efficiency and 90% delivery efficiency serving a heating system with flow and return temperature 45°C/40°C Note: Re-insulation of the pipework, and changes to heat emitters required"**	**ASHP with 400% seasonal efficiency and 90% delivery efficiency serving a heating system with flow and return temperature 45°C/40°C Note: Re-insulation of the pipework, and changes to heat emitters required**	**Gas boiler with 60% seasonal efficiency and 70% delivery efficiency serving a heating system with flow and return temperature 70°C/50°C**	**Gas boiler with 60% seasonal efficiency and 70% delivery efficiency serving a heating system with flow and return temperature 70°C/50°C**	**ASHP with 400% seasonal efficiency and 90% delivery efficiency serving a heating system with flow and return temperature 45°C/40°C Note: Re-insulation of the pipework, and changes to heat emitters required"**	Gas boiler with 60% seasonal efficiency and 70% delivery efficiency serving a heating system with flow and return temperature 70°C/50°C
Heating emitters	LTHW Fan Coil Unit fed by Gas Boiler	LTHW Fan Coil Unit fed by Gas Boiler	LTHW Fan Coil Unit fed by Gas Boiler	**LTHW Fan Coil Unit fed by ASHP**	**LTHW Fan Coil Unit fed by ASHP**	**LTHW Fan Coil Unit fed by Gas Boiler**	**LTHW Fan Coil Unit fed by Gas Boiler**	LTHW Fan Coil Unit fed by ASHP	LTHW Fan Coil Unit fed by Gas Boiler
Hot water system	Direct electric with 100% seasonal efficiency	Direct electric with 100% seasonal efficiency	Direct electric with 100% seasonal efficiency	**Direct electric with 100% seasonal efficiency**	Direct electric with 100% seasonal efficiency	**Direct electric with 100% seasonal efficiency**	**Direct electric with 100% seasonal efficiency**	Direct electric with 100% seasonal efficiency	Direct electric with 100% seasonal efficiency
Heating system controls	No	No	No	**Yes**	**Yes**	**No**	**No**	**Yes**	No
Cooling seasonal efficiency	2.0 EER 2.5 SEER	2.0 EER 2.5 SEER	2.0 EER 2.5 SEER	**3.5 EER 5.0 SEER**	**3.5 EER 5.0 SEER**	**2.0 EER 2.5 SEER**	**2.0 EER 2.5 SEER**	**3.5 EER 5.0 SEER**	2.0 EER 2.5 SEER
Metering provision	No	No	No	**Yes**	**Yes**	No	No	**Yes**	No
PV	No	No	No	No	No	No	No	No	No
EPC Rating	**D 96**	**D 100**	**C60**	**B48**	**B 29**	**C 67**	**D 81**	**B 42**	**D 84**
EPC Certificate									

Retail warehouse

Retrofit options | Year of construction 1995

	0. Baseline	1. Lighting package	2. Ventilation package	3.Direct Electric	4. Fabric package	5. Combination 1
Thermal Model	EPC_WAR_V0	EPC_WAR_V1	EPC_WAR_V2	EPC_WAR_V3	EPC_WAR_V4	EPC_WAR_V5
Description	AD L1 (1995) Fabric + Business as usual MEP system	Baseline + Lighting Upgrades	Baseline + Ventilation Upgrades	Baseline + Direct Electric Heating	Baseline + Fabric Upgrades	Baseline + All packages
Construction Type	SFS with 20mm insulation	SFS with 20mm insulation	SFS with 20mm insulation	SFS with 20mm insulation	SFS with 20mm insulation	SFS with 20mm insulation
Floor U-Value (W/m^2K)	0.45	0.45	0.45	0.45	0.45	0.45
External wall U-Value (W/m^2K)	0.45	0.45	0.45	0.45	**0.15 (200mm insulation)**	**0.15 (200mm insulation)**
Roof U-Value (W/m^2K)	0.25	0.25	0.25	0.25	**0.15 (200mm insulation)**	**0.15 (200mm insulation)**
Windows/Rooflights U-value (W/m^2K)	3.3	3.3	3.3	3.3	**1.60**	**1.60**
Windows g-value	0.7	0.7	0.7	0.7	**0.40**	**0.40**
External doors (W/m^2K)	3.3	3.3	3.3	3.3	**1.60**	**1.60**
Thermal bridging (W/m^2K)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)
Air Permeability ($m^3/m^2/hr$)	25	25	**25**	25	**25**	**25**
Ventilation system and design	Exhaust only (Office & WCs), Natural Ventilation (Warehouse)	Exhaust only (Office & WCs) Natural Ventilation (Warehouse)	**AHU with Heat Recovery (Office & WCs) Natural Ventilation (Warehouse)**	Exhaust only (Office & WCs) Natural Ventilation (Warehouse)	**Exhaust only (Office & WCs) Natural Ventilation (Warehouse)**	**AHU with Heat Recovery (Office & WCs) Natural Ventilation (Warehouse)**
AHU heat recovery efficiency	N/A	N/A	**80%**	N/A	**N/A**	**80%**
AHU specific fan power	0.8 W/l/s	**0.8 W/l/s**	**1.6 W/l/s**	0.8 W/l/s	**0.8 W/l/s**	**1.6 W/l/s**
Demand Control Ventilation	No	**No**	No	No	**No**	**No**
Internal Lighting (lm/W)	45	**120**	45	**45**	45	**120**
Lighting Control	No	**No**	No	**No**	**No**	**No**
Heating System	Gas Radiant Panels	Gas Radiant Panels	Gas Radiant Panels	**Direct Electric**	**Gas Boiler**	**Direct Electric**
Description	Gas Radiant Panels	Gas Radiant Panels	Gas Radiant Panels	**Direct Electric**	Gas boiler serving a heating system with flow and return temperature 70°C/50°C	**Direct Electric**
Heating emitters	Radiant panels	Radiant panels	Radiant panels	**Radiant panels**	**Radiant panels**	**Radiant panels**
Hot water system	Gas boiler	Gas Boiler	Gas Boiler	**Direct Electric**	**Gas Boiler**	**Direct Electric**
Heating and Hot Water Seasonal efficiency	70% for heating and hot water	70% for heating and hot water	70% for heating and hot water	**100% for heating 100% for hot water**	**70% for heating and hot water**	**100% for heating 100% for hot water**
Cooling Seasonal Efficiency	N/A	N/A	N/A	N/A	N/A	**N/A**
PV	**No**	No	No	No	No	**No**
EPC Rating	**F 134**	**F 139**	**F 126**	**C 52**	**E 112**	**B 44**
EPC Rating						

Retrofit options | Year of construction 2005

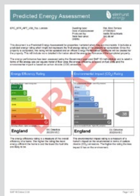
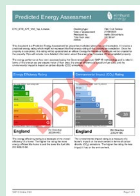
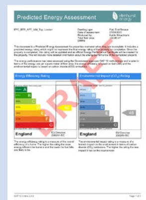
	0. Baseline	1. Lighting package	2. Ventilation package	3.Direct Electric	4. PV package	5. Combination 1
Thermal Model	EPC_LOG_V0	EPC_LOG_V1	EPC_LOG_V2	EPC_LOG_V3	EPC_LOG_V4	EPC_LOG_V5
Description	AD L2 (2002) Fabric + Business as usual MEP system	Baseline + Lighting Upgrades	Baseline + Ventilation Upgrades	Baseline + Direct Electric Heating	Baseline + 20% of roof area PV	Baseline + Packages 1,2,3
Construction Type	SFS with 40mm insulation	SFS with 40mm insulation	SFS with 40mm insulation	SFS with 40mm insulation	SFS with 40mm insulation	SFS with 40mm insulation
Floor U-Value (W/m^2K)	0.25	0.25	0.25	0.25	0.25	0.25
External wall U-Value (W/m^2K)	0.35	0.35	0.35	0.35	0.35	**0.35**
Roof U-Value (W/m^2K) Windows/Rooflights	0.25	0.25	0.25	0.25	0.25	**0.25**
U-value (W/m^2K)	2.0	2.0	2.0	2.0	2.0	**2.0**
Windows g-value	0.7	0.7	0.7	0.7	0.7	**0.7**
External doors (W/m^2K)	2.2	2.2	2.2	2.2	2.2	**2.2**
Thermal bridging (W/m^2K)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)	Default. (25% of losses)
Air Permeability ($m^3/m^2/hr$)	10	10	**10**	10	10	10
Ventilation system and design	Exhaust only	Exhaust only	**AHU with heat recovery**	Exhaust only	Exhaust only	**AHU with heat recovery**
AHU heat recovery efficiency	N/A	N/A	**80%**	N/A	N/A	**0.8**
AHU specific fan power	0.5 W/l/s	**0.5 W/l/s**	**1.6 W/l/s**	0.5 W/l/s	0.5 W/l/s	**1.6 W/l/s**
Demand Control Ventilation	No	**No**	No	No	No	**No**
Internal Lighting (lm/W)	45	**120**	45	**45**	45	**120**
Lighting Control	No	**No**	No	**No**	No	**No**
Heating System	Gas Boiler	Gas Boiler	Gas Boiler	**Direct Electric**	Gas Boiler	**Direct Electric**
Description	Gas boiler serving a heating system with flow and return temperature 70°C/50°C	Gas boiler serving a heating system with flow and return temperature 70°C/50°C	Gas boiler serving a heating system with flow and return temperature 70°C/50°C	**Direct Electric**	Gas boiler serving a heating system with flow and return temperature 70°C/50°C	**Direct Electric**
Heating emitters	Radiant panels for main areas VRF system for office areas"	Radiant panels for main areas VRF system for office areas	Radiant panels for main areas VRF system for office areas	**Radiant panels**	Radiant panels for main areas VRF system for office areas"	**Radiant panels**
Hot water system	Gas Boiler	Gas Boiler	Gas Boiler	**Direct Electric**	Gas Boiler	**Direct Electric**
Heating and Hot Water Seasonal efficiency	80% for heating and hot water	80% for heating and hot water	80% for heating and hot water	**100% for heating 100% for hot water"**	80% for heating and hot water	**100% for heating 100% for hot water"**
Cooling Seasonal Efficiency	3.0 EER 4.0 SEER	3.0 EER 4.0 SEER	3.0 EER 4.0 SEER	3.0 EER 4.0 SEER	3.0 EER 4.0 SEER	**3.0 EER 4.0 SEER**
PV	**No**	No	No	No	**Yes - 3400 m^2**	**No**
EPC Rating	**C 72**	**C 73**	**C 59**	**B 38**	**C 64**	**B 31**
EPC Rating						

Retrofit options | Year of construction 2000s

	0. Baseline	1. Lighting package	2. Ventilation package	3.ASHP package	4. PV package	5. Combination 1
Thermal Model	EPC_PBSA_V0	EPC_PBSA_V1	EPC_PBSA_V2	EPC_PBSA_V3	EPC_PBSA_V4	EPC_PBSA_V5
Description	AD L2A (2002) Fabric + AD L2A (2002) MEP system	Baseline + Lighting Upgrades	Baseline + Ventilation Upgrades	Baseline + ASHP	Baseline + 50% of roof area PV	Baseline + Packages 1,2,3
Construction Type	Precast concrete with 80mm insulation	Precast concrete with 80mm insulation	Precast concrete with 80mm insulation	Precast concrete with 80mm insulation	Precast concrete with 80mm insulation	Precast concrete with 80mm insulation
Floor U-Value (W/m^{2}K)	0.25	0.25	0.25	0.25	0.25	0.25
External wall U-Value (W/m^{2}K)	0.35	0.35	0.35	0.35	0.35	0.35
Roof U-Value (W/m^{2}K)	0.25	0.25	0.25	0.25	0.25	0.25
Windows U-value (W/m^{2}K)	2.2	2.2	2.2	2.2	2.2	2.2
Windows g-value	0.5	0.5	0.5	0.5	0.5	0.5
External doors (W/m^{2}K)	2.2	2.2	2.2	2.2	2.2	2.2
Thermal bridging (W/m^{2}K)	Default (25% of losses)	Default (25% of losses)	Default (25% of losses)	Default (25% of losses)	Default (25% of losses)	Default (25% of losses)
Air permeability (m^3/m^2/hr)	10	10	10	10	10	10
Ventilation type	Natural with extract fans (kitchens, bathrooms)	Natural with extract fans (kitchens, bathrooms)	**Natural with extract fans (kitchens, bathrooms) AHU with heat recovery (bedrooms, communal areas)**	Natural with extract fans (kitchens, bathrooms)	Natural with extract fans (kitchens, bathrooms)	**Natural with extract fans (kitchens, bathrooms) AHU with heat recovery (bedrooms, communal areas)**
AHU heat recovery efficiency (%)	N/A	N/A	**80 (Plate heat exchanger)**	N/A	N/A	**80 (Plate heat exchanger)**
AHU specific fan power (W/l/s)	0.5	0.5	**1.8 (MVHR) 0.3 (local extract)**	0.5	0.5	**1.8 (MVHR) 0.3 (local extract)**
Demand control ventilation	N/A	N/A	N/A	N/A	N/A	**N/A**
Internal lighting efficacy (lm/W)	45	**120**	45	45	45	**120**
Internal lighting control	No	**None (bedrooms, bathrooms) Auto-On-Dimmed (circulation, communal areas, kitchens)**	No	No	No	**None (bedrooms, bathrooms) Auto-On-Dimmed (circulation, communal areas, kitchens)**
Electric power factor	< 0.9	< 0.9	< 0.9	< 0.9	< 0.9	< 0.9
Heating system	Community Gas Boiler with 80% seasonal efficiency & 50% delivery efficiency (throughout) Direct electric with 100% seasonal efficiency (circulation areas)	Community Gas Boiler with 80% seasonal efficiency & 50% delivery efficiency (throughout) Direct electric with 100% seasonal efficiency (circulation areas)	Community Gas Boiler with 80% seasonal efficiency & 50% delivery efficiency (throughout) Direct electric with 100% seasonal efficiency (circulation areas)	**ASHPs serving a heating system with low flow and return temperatures 45°C/40°C fed from ambient loop Note: re-insulation of the pipework, and changes to heat emitters required.**	Community Gas Boiler with 80% seasonal efficiency & 50% delivery efficiency (throughout) Direct electric with 100% seasonal efficiency (circulation areas)	**ASHPs serving a heating system with low flow and return temperatures 45°C/40°C fed from ambient loop Note: re-insulation of the pipework, and changes to heat emitters required.**
Heating emitters	Radiators	Radiators	Radiators	**Radiators**	Radiators	Radiators
Heating system controls	No	No	No	**Yes**	No	**Yes**
Hot water system	Communal Gas Boiler with 80% seasonal efficiency & 50% delivery efficiency	Communal Gas Boiler with 80% seasonal efficiency & 50% delivery efficiency	Communal Gas Boiler with 80% seasonal efficiency & 50% delivery efficiency	**Communal ASHP with 300% seasonal efficiency & 90% delivery efficiency**	Communal Gas Boiler with 80% seasonal efficiency & 50% delivery efficiency	**Communal ASHP with 300% seasonal efficiency & 90% delivery efficiency**
Hot water storage	7,500L	7,500L	7,500L	7,500L	7,500L	7,500L
Hot water losses	0.0147kWh/(l.day)	0.0147kWh/(l.day)	0.0147kWh/(l.day)	**0.0034kWh/(l.day)**	0.0147kWh/(l.day)	**0.0034kWh/(l.day)**
Cooling system	No	No	No	No	No	**No**
Metering provision	No	No	No	**Yes**	No	**Yes**
PV	No	No	No	No	Yes - 145 m^2	No
EPC Rating	**D 98**	**E 103**	**C 75**	**A 17**	**D 96**	**A 14**
Metering provision						

BTR - Top floor flat

Retrofit options | 5-6 years old (2017-2018)

	0. Baseline	1. Baseline + ASHP	2. Baseline + Lighting Package	3.Baseline + WWHR	4. Baseline + Fabric Package	5. Baseline + Ventilation Package	6. Baseline + 1,2,4 packages
SAP Model	EPC_BTR_APT_V00_Top	EPC_BTR_APT_V01_Top	EPC_BTR_APT_V02_Top	EPC_BTR_APT_V03_Top	EPC_BTR_APT_V04_Top	EPC_BTR_APT_V05_Top	EPC_BTR_APT_V06_Top
Description	AD L2A (2013) Fabric + ADL2 (2013) MEP system	AD L2A (2013) Fabric + ADL2 (2013) MEP system	AD L2A (2013) Fabric + ADL2 (2013) MEP system	AD L2A (2013) Fabric + ADL2 (2013) MEP system	AD L2A (2013) Fabric + ADL2 (2013) MEP system	AD L2A (2013) Fabric + ADL2 (2013) MEP system	AD L2A (2013) Fabric + ADL2 (2013) MEP system
Construction Type	Masonry with 100mm insulation	Masonry with 100mm insulation	Masonry with 100mm insulation	Masonry with 100mm insulation	Masonry with 100mm insulation	Masonry with 100mm insulation	Masonry with 100mm insulation
Floor U-Value (W/m^2K)	N/A	N/A	N/A	N/A	N/A	N/A	0.25
External Wall U-Value (W/m^2K)	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Roof U-Value (W/m^2K)	0.20	0.20	0.20	0.20	**0.10**	0.20	**0.10**
Windows. U-value (W/m^2K)	2.0	2.0	2.0	2.0	**1.0**	2.0	**1.0**
Windows g-value	0.5	0.5	0.5	0.5	0.5	0.5	0.5
External Doors (W/m^2K)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Thermal Bridging (W/m^2K)	Default. y value 0.25	Default. y value 0.25	Default. y value 0.25	Default. y value 0.25	**Good practice. y value 0.1**	Default. y value 0.25	**Good practice. y value 0.1**
Air Permeability ($m^3/m^2/hr$)	10	10	10	10	10	10	10
Ventilation Type	Natural with extract fans (kitchen, bathrooms)	Natural with extract fans (kitchen, bathrooms)	Natural with extract fans (kitchen, bathrooms)	Natural with extract fans (kitchen, bathrooms)	Natural with extract fans (kitchen, bathrooms)	Balanced with heat recovery	Natural with extract fans (kitchen, bathrooms)
Heat Recovery Efficiency (%)	N/A	N/A	N/A	N/A	N/A	**85%**	N/A
SFP (W/l/s)	0.5 (extract)	0.5 (extract)	0.5 (extract)	0.5 (extract)	0.5 (extract)	**1.5**	0.5 (extract)
Internal Lighting (lm/W)	45	45	120	45	45	45	**120**
Power (W)	60	60	10	60	60	60	**10**
Heating Control	Time and temperature	Programmer, TRVs, and bypass	Time and temperature	Time and temperature	Time and temperature	Time and temperature	**Programmer, TRVs, and bypass**
Space Heating System	Community Gas Boiler 70%	Community ASHP 300%	Community Gas Boiler 70%	Community Gas Boiler 70%	Community Gas Boiler 70%	Community Gas Boiler 70%	**Community ASHP 300%**
Domestic Hot Water System	Community Gas Boiler 70%	Community ASHP 300%	Community Gas Boiler 70%	Community Gas Boiler 70%	Community Gas Boiler 70%	Community Gas Boiler 70%	**Community ASHP 300%**
Heating Emitters	Radiators	Radiators	Radiators	Radiators	Radiators	Radiators	Radiators
Hot Water Cylinder. Present (Yes/ No)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Size	180L	180L	180L	180L	180L	180L	180L
Insulation	25mm	100mm	25mm	25mm	25mm	25mm	**100mm**
WWHR	No	No	No	Yes	No	No	No
Space Cooling. Present (Yes/ No)	No	No	No	No	No	No	No
PV	No	No	No	No	No	No	No
EPC Rating	**E 51**	**C 76**	**E 52**	**E 54**	**D 60**	**E 47**	**B 81**
EPC Certificate							

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