ARUP

Milton Keynes City Council

Energy efficiency standards study

TER-compatible Targets for new buildings

Job number: 305037-00

16 December 2024 | Issue 3

Arup
8 Fitzroy St, London W1T 4BJ
arup.com

ARUP

Contents

Glossary & Definitions

ASHP	Air Source Heat Pump	A device that transfers heat from outside air to heat or cool a building. It uses a refrigeration cycle to absorb heat from the air and release it indoors, providing efficient heating and cooling.
BER	Building Emissions Rate	The annual CO2 emissions from a building, measured in kilograms per square meter of floor area. It reflects the building's energy use and efficiency.
BPER	Building Primary Energy Rate	The total primary energy consumption of a building, expressed in kWh per square meter per year. It includes energy for heating, cooling, lighting, and other services.
BR	Building Regulations	Rules and standards governing the design, construction, and performance of buildings to ensure safety, health, and energy efficiency.
CPI	Carbon Performance Indicator	A metric used to assess a company's carbon emissions and efficiency. It includes measures like carbon intensity, dependency, exposure, and risk.
DEC	Display Energy Certificate	A document showing the energy performance of a public building based on actual energy consumption. It rates the building from A to G, with A being the most efficient.
DER	Dwelling Emissions Rate	The annual CO2 emissions from a new dwelling, measured in kilograms per square meter of floor area. It is used to assess compliance with energy efficiency standards.
DFEE	Dwelling Fabric Energy Efficiency	The energy required for space heating and cooling per square meter of a dwelling's floor area. It focuses on the building's insulation, air permeability, and thermal performance.
DHW	Domestic Hot Water	Hot water used for household purposes such as bathing, cooking, and cleaning. It is typically heated by a water heater or boiler.
DPER	Dwelling Primary Energy Rate	The total primary energy consumption of a dwelling, including energy for heating, cooling, lighting, and other services, expressed in kWh per square meter per year.
DSM	Dynamic Simulation Modelling	A computer-based process to model and predict the environmental performance of buildings on a time-varying basis.
EPC	Energy Performance Certificate	A certificate that rates the energy efficiency of a building on a scale from A to G. It provides recommendations for improving energy efficiency.

Glossary & Definitions

EUI	Energy Use Intensity	The amount of energy consumed per unit area of a building, typically measured in kWh per square meter per year. It indicates the building's energy efficiency.
GIA	Gross Internal Area	The total floor area within the external walls of a building, including all internal spaces but excluding external walls, balconies, and terraces.
HVAC	Heating, Ventilation and Air Conditioning	Systems used to provide heating, cooling, and ventilation in buildings. They maintain indoor air quality and comfort.
LETI	London Energy Transformation Initiative	A collaborative effort to accelerate the transition to a zero-carbon London by promoting sustainable energy practices and policies.
MKCC	Milton Keynes City Council	The local authority responsible for governing the city of Milton Keynes, providing services such as planning, housing, and environmental management.
MVHR	Mechanical Ventilation with Heat Recovery	A system that provides fresh air and improves indoor air quality by recovering heat from exhaust air and transferring it to incoming fresh air.
NLA	Net Lettable Area	The usable area within a building that can be rented to tenants, excluding common areas, service spaces, and structural elements.
NZCBS	Net Zero Carbon Building Standard	A standard for buildings that achieve net zero carbon emissions through energy efficiency, renewable energy, and carbon offsetting.
PHPP	Passive House Planning Package	A design tool used to plan and optimize buildings to meet the Passive House standard, focusing on energy efficiency, thermal comfort, and indoor air quality.
PV	Photovoltaic	Technology that converts sunlight directly into electricity using solar cells. It is used in solar panels to generate renewable energy.
RdSAP	Reduced Data SAP	A simplified version of the Standard Assessment Procedure used to assess the energy performance of existing dwellings based on limited data.
SAP	Standard Assessment Procedure	The UK government's method for assessing the energy performance of dwellings. It calculates energy use, CO2 emissions, and energy efficiency ratings.

Glossary & Definitions

TER	Target Emissions Rate	The maximum allowable CO_2 emissions for a new dwelling, set by building regulations. It is used to ensure compliance with energy efficiency standards.
TFEE	Target Fabric Energy Efficiency	The maximum allowable energy demand for space heating and cooling in a new dwelling, set by Building Regulations. It ensures high levels of insulation and thermal performance.
TPER	Target Primary Energy Rate	The maximum allowable primary energy consumption for a new dwelling, set by building regulations. It includes energy for heating, cooling, lighting, and other services.

Executive Summary

Introduction

This commission provides further technical evidence on energy efficiency standards for the Milton Keynes City Plan 2050, following Arup's original Carbon & Climate Study (2023-24) (Arup, 2024). It is intended to address the change in national policy, namely the Written Minister Statement (WMS) on Local Energy Efficiency Standards published on 13 December 2023 (Penn, 2023).

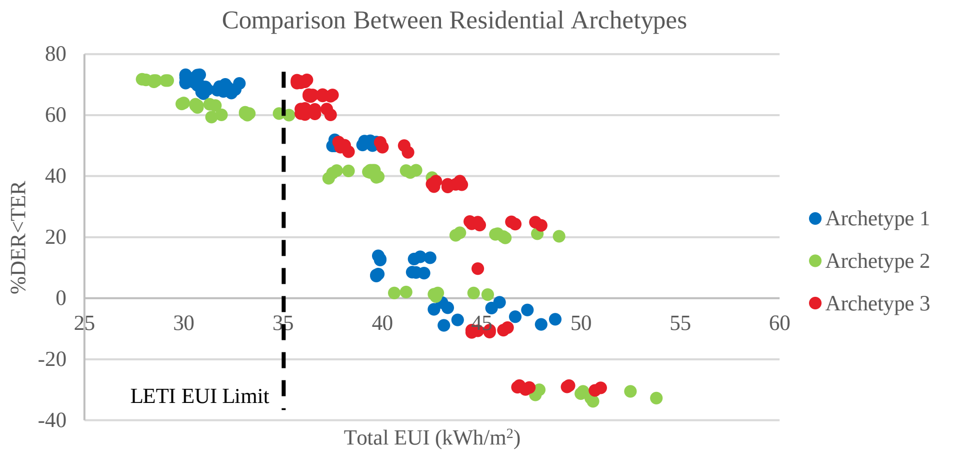
Approach

The project was split into six phases of development, as outlined below:

- Phase 1 – Project Inception, to define project objectives and outline plan of work;
- Phase 2 – Literature Review, to understand the extent of existing work completed in this field;
- Phase 3 – Parametric Modelling, to estimate EUI results for a wide range of building types and design options;
- Phase 4 – Compliance (SAP / Part L) modelling, to assess percentage improvement over TER achieved by the tested design options;
- Phase 5 – Analysis of results, to compare EUI figures and percentage improvement over Part L for tested buildings;
- Phase 6 – Target Definition, to define suitable Part L aligned targets based on the outcome of the research.

Key results & observations

The comparison between building EUI and percentage improvement over building regulations was assessed in this report. For all building archetypes, a correlation was identified between these metrics. The graph on the right shows this relationship for the residential buildings modelled in this work.



Key recommendations

- Adopt an EUI approach which is widely recognised to deliver higher energy performance in use and account for both regulated and unregulated energy;
- Align the EUI limits to the recommendations in the Carbon & Climate Study which were derived from the LETI targets, proposing applicants and developers to use CIBSE TM54 framework (CIBSE, 2022) to calculate the predicted energy usage of their building;
- In the case of the need for fallback onto the Building Emission Rate energy efficiency standard, set the following target percentage improvements over Part L:
  - Residential buildings (Flats and Homes) – 60% improvement over TER;
  - Office buildings – 20% improvement over TER;
  - Warehouse / Industrial buildings - >0% improvement over TER.

1. Introduction

1. Introduction

Project background

Arup have been appointed by Milton Keynes City Council (MKCC) to provide further evidence in support of an energy efficiency standard for the Milton Keynes City Plan 2050.

This commission follows completion of Arup's original Climate & Carbon Study (2023-24) for Milton Keynes (Arup, 2024). In the study, as part of the 'On Site energy efficiency and carbon reduction' policy recommendation, Arup recommended EUI standards for energy efficiency across different building archetypes.

In December 2023, a Written Ministerial Statement (WMS) was published (Penn, 2023), stating:

"Any planning policies that propose local energy efficiency standards for buildings that go beyond current or planned buildings regulation should be rejected at examination if they do not have a well-reasoned and robustly costed rationale that ensures:

- *That development remains viable, and the impact on housing supply and affordability is considered in accordance with the National Planning Policy Framework;*
- *The additional requirement is expressed as a percentage uplift of a dwelling's Target Emissions Rate (TER) calculated using a specified version of the Standard Assessment Procedure (SAP)."*

After MKCC sought legal advice on the WMS, Arup and MKCC have worked closely to develop a fallback position for the energy efficiency policy recommendation. This has taken the form of a modelling exercise that could define, for different building types, target improvement over TER figures that could be comparable to the initial EUI limits proposed.

The final scope of the project was agreed during the project kick off meeting held on the 30 July 2024.

The current report covers the approach followed, the results from the study and the key recommendations for City Plan policy on energy efficiency standards for new buildings in Milton Keynes.

Project aims

This work aims to:

- Provide further support for Arup's recommended EUI standard, with further technical evidence, in preparation for Examination of the City Plan;
- Provide technical evidence for a fallback Building Emission Rate energy efficiency standard, to be used in the event the EUI standard is not accepted at Examination;
- Ensure this fallback standard meets the requirements of the Written Ministerial Statement dated 13 December 2023.

2. Literature Review

2. Literature Review
Comparison between BER and EUI

Metrics for energy performance in operation: the fallacy of single indicators

Dubbed the ‘miles per gallon’ of the building industry, energy use intensity (EUI) is a key metric in figuring out a building’s energy consumption and identifying ways to reduce it. Energy use intensity is a metric used to measure the energy efficiency of a building. EUI is measured by the amount of energy a building uses per m^2 (either GIA or NLA) per year. This information is seen as a key indicator of a building’s energy performance. Additionally, EUI can be used to express an existing buildings metered energy consumption, compare the energy performance between buildings of a similar type and to communicate how much energy a building is projected to use in the future. EUI is an internationally recognised metric for assessing and benchmarking energy consumption of a building and is rapidly gaining significance over other, previously widely reported metrics such as Building Emissions Rate (BER).

The Building Regulations set out requirements for specific aspects of building design and construction. Regulation 26 of the Building Regulations 2021, Approved Document L (BR Part L), states that ‘where a building is erected, it shall not exceed the target CO_{2e} emission rate for the building’. The target CO_{2e} emission rate (TER) sets a minimum allowable standard for the energy performance of a building and is defined by the annual CO_{2e} emissions of a notional building of the same type, size and shape to the proposed building. TER is expressed in annual $kgCO_{2e}$ per m^2.

The CO_{2e} emissions rate of the proposed building is calculated based on its actual specification and is expressed as:

- Dwelling emissions rate (DER) for self-contained dwellings and individual flats (excluding common areas); this is the annual CO_{2e} emissions of the proposed dwelling expressed in kg/m^2 per year;

- Building emission rate (BER) for buildings other than dwellings. Again, this is the annual CO_{2e} emissions of the proposed building expressed in kg/m^2 per year.

The DER or BER for the proposed building must not exceed the TER in order to pass Building Regulations requirements.

The current requirements for all buildings within the UK is to pass compliance by bettering the notional on the TER, target fabric energy efficiency (TFEE) and target primary energy (TPER). The TFEE is affected by the fabric used, mainly by U-values, air tightness and thermal bridging. In contrast, TPER is influenced by both fabric and fuel used. However, these metrics have long been criticized for their poor reflection on actual energy in use. This is where the EUI metric has been gaining momentum, in an attempt to address this performance gap.

Whilst this research and work was being undertaken, the pilot version of the UK Net Zero Carbon Building Standard was released. Market research conducted in 2021 demonstrated that the term ‘net zero carbon’ was not being applied consistently by those in the UK construction industry. The standard responds to the markets desire for harmonisation on the term net zero and the need for consistent rules. The UK Net Zero Carbon Building Standard (NZCBS) has been collaboratively developed by a wide range of stakeholders in the UK built environment industry. It sets out a unified definition for ‘Net Zero Carbon Aligned buildings’ in the UK, underpinned by an evidence-based reporting methodology. The standard requires operational energy use by the building to be assessed.

The existing Climate & Carbon study refers to the EUI limits set out in the LETI climate emergency guide. The London Energy Transformation Initiative (LETI) was established in 2017 to provide guidance on the transition towards net zero carbon buildings. The metrics for assessment, reporting, and for comparison for operational energy use will be energy use intensity (EUI) per m^2 GIA per year (kWh/m^2GIA/yr). The EUI limits set out within both LETI and the NZCBS are described further in Section 3.

2. Literature Review
Comparison between BER and EUI

Summary of key resources

Further research into both domestic and non-domestic buildings and the impact on their compliance rating has been evaluated by many different authors. There is very limited research on creating a comparison between the compliance metrics of TER/BER/DER and the end use EUI. Many of the articles, journals and blogs researched highlight the issue with using a single metric to determine building performance, with even more scepticism around the specific use of the TER/BER/DER as this single metric.

The research outlined in the follow pages present an overview of key analysis in relation to this project.

'Paris-proof' targets: Energy Usage Intensity explained (Hoare Lea, 2021)

The article discusses the concept of energy usage intensity (EUI) in the context of achieving Paris Agreement targets. Here are the key findings:

1. Energy Usage Intensity (EUI): EUI measures energy consumption relative to the building's size, making it a crucial metric for assessing energy efficiency in buildings.
2. Paris-Proof Targets: The article emphasizes the importance of setting ambitious energy targets to align with the Paris Agreement goals, which aim to limit global warming.
3. Benchmarking: The article highlights the need for benchmarks to evaluate a building's performance against industry standards, helping to identify areas for improvement.
4. Decarbonization Strategies: Implementing strategies to reduce energy usage is essential for decarbonizing buildings, which includes improving insulation, using renewable energy, and enhancing operational efficiency.
5. Regulatory Framework: The article discusses the role of government regulations in promoting energy efficiency and the necessity for policies that incentivize sustainable practices in the construction and operation of buildings.
6. Long-term Vision: Achieving significant reductions in EUI requires a long-term commitment from stakeholders, including architects, developers, and policymakers, to prioritize sustainability in building design and operation.

Overall, the article advocates for the adoption of EUI as a critical metric in the journey toward more sustainable and energy-efficient buildings.

2. Literature Review
Comparison between BER and EUI

Summary of key resources

Household fuel expenditure and residential building energy efficiency ratings in Ireland (Curtis and Pentecost, 2015)

1. Statically compares the BER results with energy data in residential buildings
2. Developing a function to translate the BER result to a typical EUI result - a comparable approach to the aim on Arup's project
3. The regression was worse at predicting the BER correlation at either the high or low performance end of EUIs
4. Identifies that the age or type of occupant can also be a factor alongside the number of occupants
5. Type of home has a significant impact on energy usage - number of rooms being the best metric to compare against
6. Only considers regulated energy to make a fair comparison to the BER calculation method (approx. 70% of energy use considered within BER)

Overall conclusions show that the actual in use energy is largely down to how occupants use the home dictating the unregulated energy that is difficult to estimate. However, it does find that statistical support for the assertion that improvements in energy efficiency, as calculated by BER ratings, is associated with reductions in household expenditure.

The Overprediction of Energy Use by EPC's (Few et al., 2023)

1. Analysis of how EPCs overpredict energy use compared to EUI results from metered buildings
2. Residential focus around the study (from 2022 to 2023)
3. Based on primary energy use intensity (regulated EUI) from EPCs and from metered data
4. Key shortcomings addressed in existing literature:
    a) Homes using unmetered energy were excluded
    b) Compared quantities where the modelled/ EPC and metered energy use were expected to be comprised of the same underlying elements
    c) Compared same quantities, the SAP primary energy factors were used to convert metered energy use to EUI
5. Identifies the shortfalls of the SAP input options and methodology
6. Key conclusions:
    a) EPC modelled EUI is significantly larger than metered EUI
    b) Discrepancy is statistically insignificant in A and B ratings, but it increases with decreasing EPC ratings
    c) The discrepancy remained even in homes where the occupancy and heating behaviours were matched as closely as possible to the SAP assumptions

2. Literature Review
Comparison between BER and EUI

Summary of key resources

Metrics for energy performance in operation: the fallacy of single indicators | Buildings & Cities (Bordass, 2020)

1. An evaluation of the current metrics used within the UK and where compliance metrics such as EPCs fall short.

2. Conclusions:

   a) Policies should become less focused on single performance indicators, and should try to include supplementary indicators

   b) Avoid using only statistical benchmarking

   c) A move from 'design for compliance' to using 'in-use performance' e.g. by using DECs

   d) The focus in the UK is on carbon saving in theory, rather than in-practice carbon saving and operational ratings

3. States consequences of using various metrics for building energy use:

   a) Annual delivered energy - caused switch from fuel to much more expensive and high-carbon electricity

   b) Energy cost - energy price negotiations could result in lower costs, so investment and management were neglected

   c) Primary energy, units of CO_2 equivalent - resulted in a 'design for compliance' culture/ only regulated loads were considered/ DECs were not imposed strictly/ too fast of a shift to electricity which is expensive

4. Strengths and weaknesses of other factors used in calculation of EUIs and CPIs, such as floor area/ volume/ occupants/ volume of production or sales

5. Unintended consequences that arise from the new UK carbon emission factors for fuels which reflect the lower carbon emissions associated with electricity. This results in a rapid switch to electricity, without improvements in other factors affecting building performance such as fabric efficiency – resulting in little incentive to reduce energy demand. However, UK electricity is still expensive, and a rapid switch may result in bottlenecks in distribution.

6. The study discusses standard energy weightings for various fuels – which can be used to compare the energy use in premises across the world

   a) A single metric is likely to cause people to try and get the best result with the least effort - this can be avoided with the use of multiple metrics

   b) A single metric does not show the multiplier effect of the various individual components that make up the metric - means that advantage cannot be taken of this multiplier effect

   c) Argues that multiple metrics are better than using single metrics

   Encourages supplemental info to be included with the main metric, such as 'Total annual imports/ exports of energy by type', 'Total onsite active renewable generation by energy type', 'Units used in performance indicator denominators'.

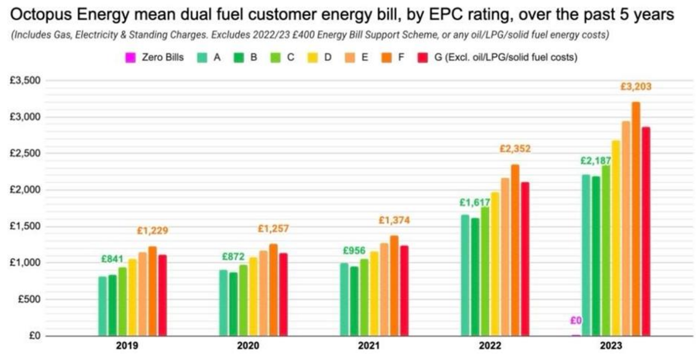
7. Mentions several approaches to benchmarking, including the top-down approach from CIBSE TM22 (CIBSE, 2006) and the top-down approach from CIBSE TM54 (CIBSE 2022), and the biggest discrepancy between predicted and actual values was found to be the control and management factor.

8. The study describes the asset rating/ EPC process, and the consequences associated, such as ignoring unregulated loads, an emphasis on CO_2 resulting in inefficient building design, and the model giving more credit to making active systems more efficient than to the careful execution of passive measures.

2. Literature Review
Comparison between BER and EUI

Key findings

Overall, there have been numerous pieces of research into the pitfalls of using compliance targets to assess energy efficiency and using those as a single metric to determine energy performance of a building. There has been no direct research into a comparison of BER and EUI results for numerous buildings which would highlight how a double metric could be used to remove the single metric indicator. Most of the current research is around EPC ratings and their connection to building performance as well as a lot of studies on the running cost comparison to EPC ratings, as shown in the graph to the right conducted by Octopus Energy (2024).



In their study, Curtis and Pentecost (2015) conducted in Ireland compared the BER results to EUI taken from the EPC certificate, so including regulated energy only. This study did find a correlation between the metrics, but only that when the BER reduced the household energy expenditure reduced, owing to a reduction in EUI. This one is difficult to make any direct comparison as the metrics for calculating BER in Ireland vary from those in England & Wales.

Another key conclusion form the research shows that there is agreement that excluding unregulated loads is not an appropriate measure of energy efficiency as it can be up to 40% of total energy consumption in a domestic property.

Another general consensus from the research puts agreement on the fallacy of using a single metric to determine the energy performance of a building, particularly BER/DER, which is a carbon-based metric and is so closely tied to the grid carbon factor for electricity. This metric alone does not encourage energy demand reduction but could result in switching to lower carbon fuels over time instead.

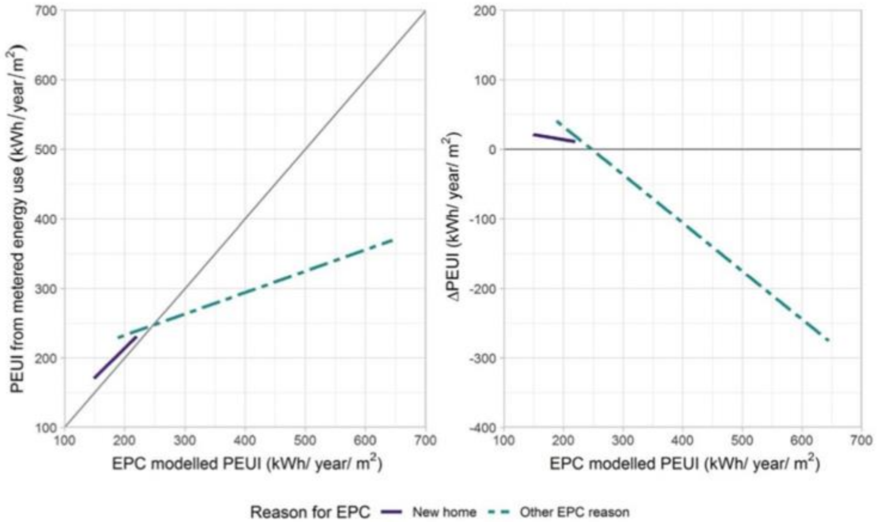
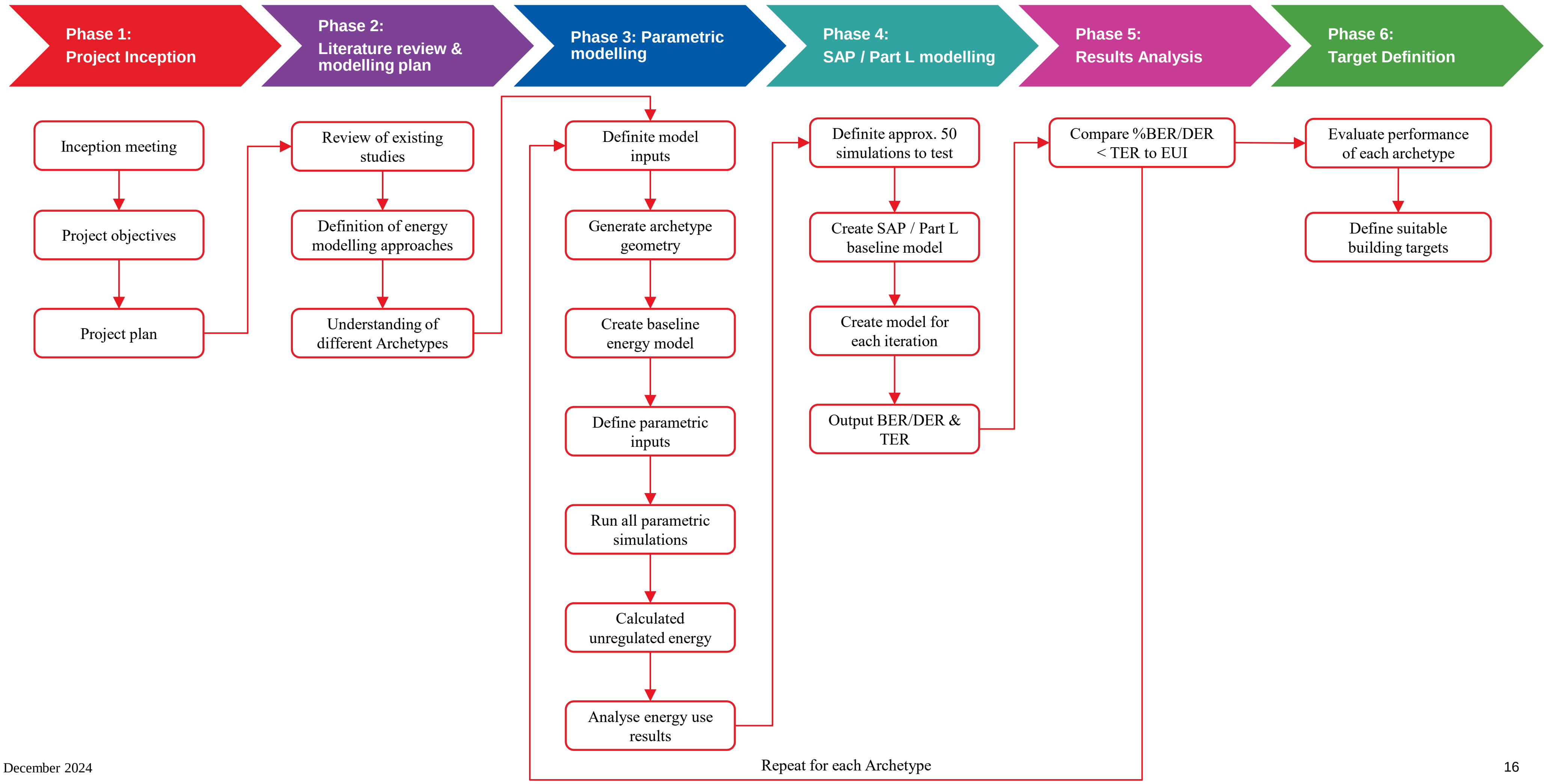


Fig. 10. Linear best fit of metered to EPC modelled PEUI for new homes (EPC generated via a full SAP process) and all other homes (EPC likely generated via an RdSAP process). The y = x line shown in black for comparison. Right panel: linear best fit of the difference in PEUI against modelled PEUI for new homes and all other homes.

3. Methodology

3. Methodology
General approach

Project workflow



3. Methodology
General approach

Overview

The workflow on the previous page summarises the methodology applied to develop this work, which was undertaken in six phases, as described below.

Phase 1: Project Inception

During the Project Inception phase, a kick off meeting was held in which the project's key objectives and drivers were set, and the programme was finalised.

The decision was made with the client to model the building archetypes to represent the work completed in the Carbon & Climate study. The following archetypes would form the basis of the modelling work:

- Archetype 1 – 2 Bed Market Flat
- Archetype 2 – 3 Bed Semi-Detached House
- Archetype 3 – 2 Bed Affordable Flat
- Archetype 4 – Office
- Archetype 5 – Warehouse

More detail on these archetypes is presented in Section 4 of this report.

It was agreed that the initial focus of this work would be to conduct a literature review of any existing research within this scope and begin initial modelling for the first archetype only. This would then be reviewed with the client to verify the approach before proceeding with the remaining work.

Phase 2: Literature Review and Model Plan

During the second phase, we analysed the existing research undertaken to compare EUI and BER/DER for both non-domestic and domestic buildings. Section 3 summarises the key findings and how these have influenced the decisions made to complete this study.

Phase 3: Parametric Modelling

In the third phase of the study, the energy model was developed for each archetype using DesignBuilder. A typical building geometry was modelled, and the design parameters were outlined. Several hundred possible design iterations were modelled to provide a breadth of results. For each iteration, the regulated and unregulated energy was calculated to provide a total building EUI.

Phase 4: SAP / BR Part L DSM

The aim of this phase was to select approximately 50 options from the several hundred design iterations tested in Phase 3. These would then be modelled in SAP (domestic) or BR Part L DSM (non-domestic) to evaluate the building's compliance performance. The key result output from this phase was the percentage improvement over the notional building (% BER < TER) for each design option.

Phase 5: Results Analysis

In this phase, the results from Phases 3 and 4 were collated together to understand the correlation between building EUI and percentage improvement over compliance. The results were plotted graphically and evaluated for each archetype.

Phase 6: Target Definition

The final phase was to evaluate the results shown in Phase 5 and use these to draw suitable conclusions on sensible BER/DER targets that would correspond to the original EUI targets. The key outputs from this being performance target recommendations for Milton Keynes to use in their 2050 City Plan.

3. Methodology
General approach

Limitations and assumptions

The research in this study required some assumptions to limit the number of simulations being executed, whilst maintaining a large spread of results.

The key limitations of this study include:

- The geometry remained fixed for each archetype. This is a parameter that has infinite potential iterations which, in turn, generate different results. Fixed geometry was chosen to represent a typical building archetype in order to yield useful results from the modelling exercise. If numerous different geometry options were assessed the parametric results would be in the tens of thousands, which would not be feasible to assess under compliance. Hence, the geometry for each archetype was selected based on the previous Carbon & Climate study that Arup carried out for Milton Keynes City Council, whereby each model represents the expected building stock to be developed in Milton Keynes over the coming years.
- The London TRY 2016 weather file was maintained throughout the simulations. With an adapting climate, testing future weather files would be beneficial to identify the performance of buildings in the future. For this study, it was deemed appropriate to use a test reference year as this is the compliance weather file used to calculate the TER/BER.
- Fabric and system efficiency options modelled were limited for each archetype due to simulation and time constraints. In reality, a building design can comprise of numerous combination of elements resulting in thousands different combinations of fabric and system efficiencies that can in turn generate thousands of EUI outputs. The fabric and system performance inputs used are compliant with Building Regulations Approved Document Part L 2021, Volumes 1 and 2 (Greater London Authority, 2021). These also represent the typical values used across previous Arup projects. However, it is to be noted that the fabric and system performance in reality may be different to those modelled in this study.
- The results from the study and recommendations in this report are based on the limited sample of simulations undertaken. This study covers a reasonable range of options based on the archetypes used in the Carbon & Climate Study, however, the results from real designs could vary from those included in this report.

3. Methodology
UK Net Zero Carbon Buildings Standard Impact

Implications of the new Standard

In September 2024, a pilot issue of the UK Net Zero Carbon Buildings Standard (NZCBS) was released defining limits for the performance of buildings in the United Kingdom that aim to be aligned with a net zero carbon built environment for the UK (BBP et al., 2024). This includes embodied carbon and, more importantly for this study, operational energy use intensity (EUI) limits for new buildings constructed between 2025 and 2050 which were defined based on extensive modelling and engagement with the construction sector.

The intention for the research in this report was to base the EUI limits on the previous work from the Carbon & Climate Study, which was based on net zero targets defined by the LETI guidance, as this was the most recent published reference available at the time of the study (LETI, 2020).

The LETI EUI limits provide an aspirational target for new developments, which are broadly aligned with the 2040 limits set in the new NZCBS, which drew upon the work from LETI and other organisations such as the UKGBC and the Carbon Trust.

Due to the aspiration of the MKCC to plan for a net zero carbon future while setting targets that are ambitious, the LETI requirements were considered when looking to define TER improvement targets for new buildings in Milton Keynes.

A comparison between the targets from the Carbon & Climate Study (LETI) and the NZCBS is shown in the table on this page. The NZCBS 2040 limits were plotted against the results shown in this report to provide context to the performance of each archetype. Reference is made to both the NZCBS and the previous work in the Carbon & Climate Study throughout this report.

Building Type	LETI EUI Limit kWh/(m^2.yr)	NZCBS EUI Limit 2025 kWh/(m^{2}GIA.yr)	NZCBS EUI Limit 2030 kWh/(m^{2}GIA.yr)	NZCBS EUI Limit 2040 kWh/(m^{2}GIA.yr)
Flats	35	40	39	35
Homes	35	45	42	35
Offices	55	85	72	45
Storage (Conditioned)	55	80	67	40

4. Building Archetypes

4. Building Archetypes
General approach

Overview

To conduct the analysis on the energy consumption within the Milton Keynes portfolio, a set of archetypes were determined. For each archetype, the building EUI and building compliance performance would be analysed over a range of different building variables.

The basis of the archetypes to be considered were formed from the Carbon & Climate Study. The following 5 archetypes formed the basis of the modelling work:

- Archetype 1 – 2 Bed Market Flat
- Archetype 2 – 3 Bed Semi-Detached House
- Archetype 3 – 2 Bed Affordable Flat
- Archetype 4 – Office
- Archetype 5 – Warehouse

These options enabled both domestic and non-domestic properties to be considered within the analysis.

The building areas were defined within the Carbon & Climate study to use for each archetype. The geometry was then developed to represent a typical layout for each archetype using DesignBuilder, an approved DSM software piece for BR Part L calculations (DesignBuilder Software Ltd, 2023). The geometry therefore remained fixed for each archetype throughout the remaining analysis. Further details of each archetype are outlined in the following pages of this section.

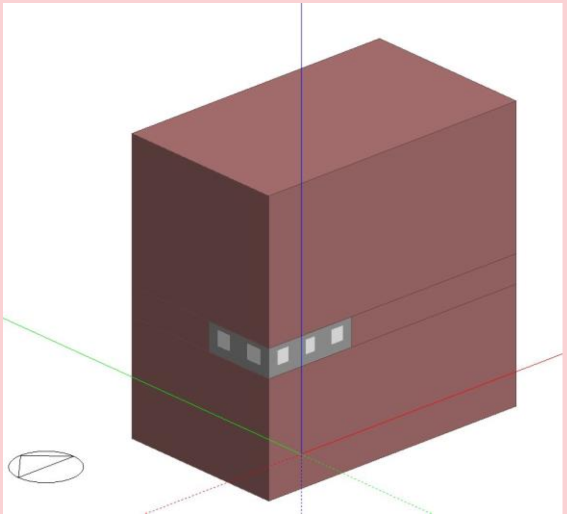
Using the initial archetype geometries, a baseline model was built. From this baseline model, parameters could then be varied to analyse a range of options. These are outlined further in Section 5.

The HVAC systems used within each archetype were determined based on previous project experience within each building sector.

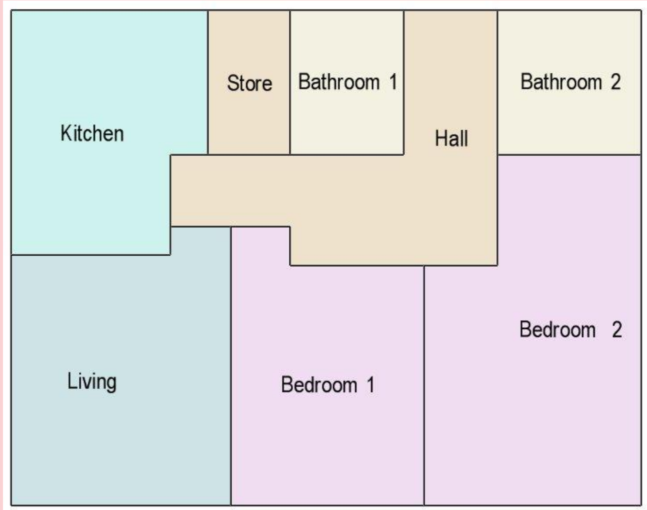
The assumptions for internal gains and system efficiencies were collated from either Part L Buildings Regulations, CIBSE guides or past project experience. The aim of these being to provide an accurate representation of how a typical building would perform under new construction.

In the following pages, the key information for each archetype is outlined.

4. Building Archetypes
Archetype 1 – 2 Bed Market Flat



(a) Design Builder Model



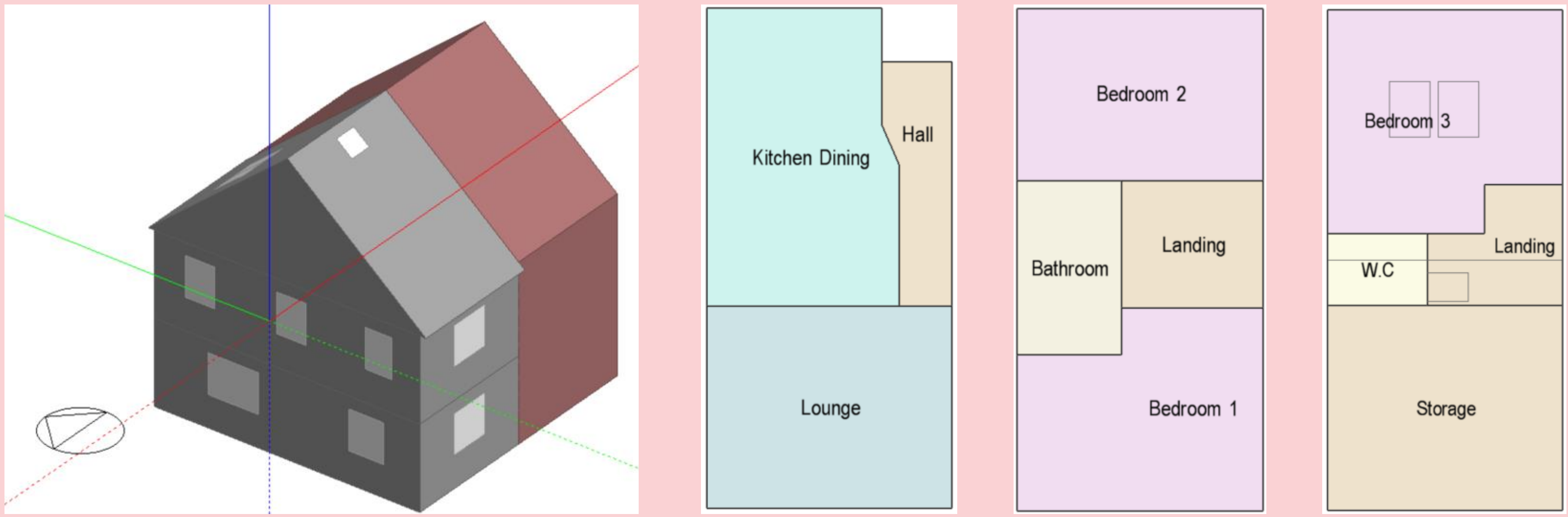
(b) Layout

Metric	Limit
LETI EUI Limit	35 kWh/(m^2.yr)
NZCBS EUI Limit	35 kWh/(m^2.yr)
Space Heating Demand Limit	15 kWh/(m^2.yr)
Hot Water Demand Limit	10 kWh/(m^2.yr)

Features	Inputs
GIA	79 m^2
No. Bedrooms	2
No. Bathrooms	2
No. Floors	5
Flats per Floor	6

HVAC System	Inputs
Heating System	Radiators (Gas Boiler or ASHP)
Domestic Hot Water System	Gas Boiler, ASHP, Direct Electric
Cooling System	None
Ventilation	MVHR

4. Building Archetypes
Archetype 2 – 3 Bed Semi-Detached House



(a) Design Builder Model

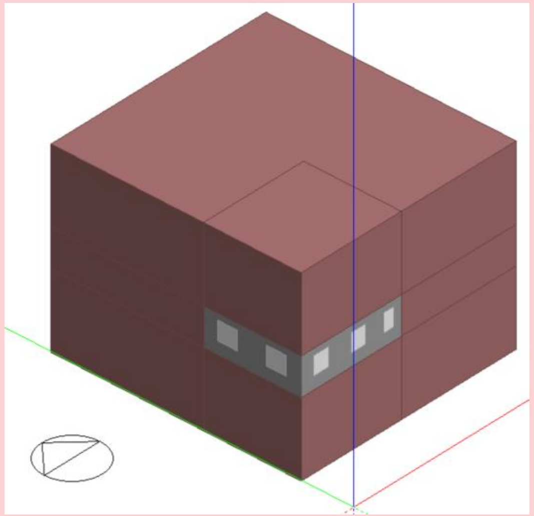
(b) Layouts: Ground, First and Second Level, respectively

Metric	Limit
LETI EUI Limit	35 kWh/(m^2.yr)
NZCBS EUI Limit	35 kWh/(m^2.yr)
Space Heating Demand Limit	15 kWh/(m^2.yr)
Hot Water Demand Limit	10 kWh/(m^2.yr)

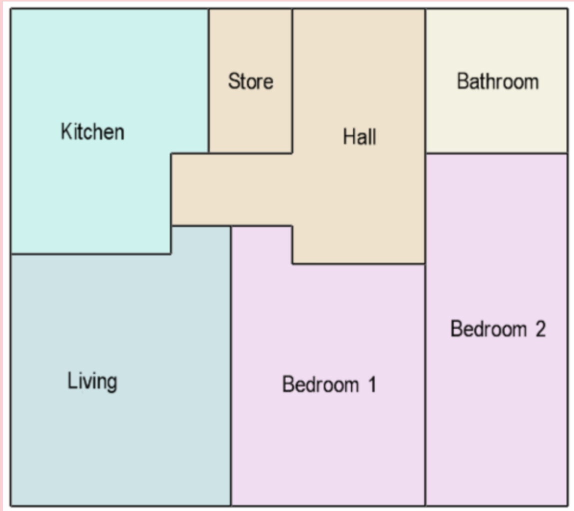
Features	Inputs
GIA	107 m^2
No. Bedrooms	3
No. Bathrooms	2
No. Floors	3

HVAC System	Inputs
Heating System	Radiators (Gas Boiler or ASHP)
Domestic Hot Water System	Gas Boiler, ASHP, Direct Electric
Cooling System	None
Ventilation	MVHR

4. Building Archetypes
Archetype 3 – 2 Bed Affordable Flat



(a) Design Builder Model



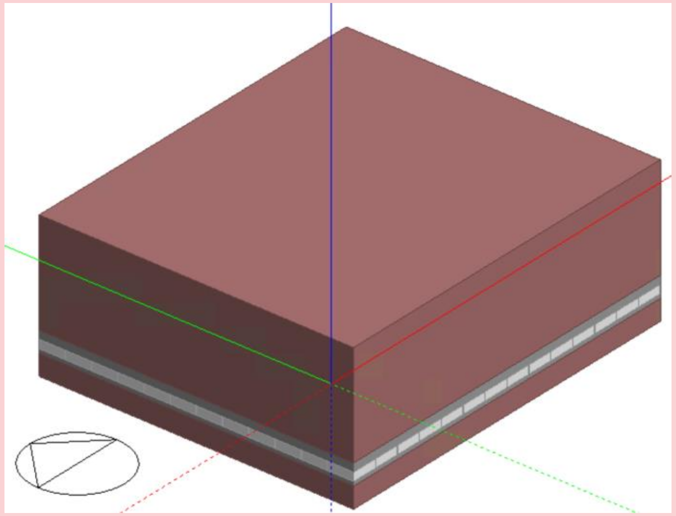
(b) Layout

Metric	Limit
LETI EUI Limit	35 kWh/(m^2.yr)
NZCBS EUI Limit	35 kWh/(m^2.yr)
Space Heating Demand Limit	15 kWh/(m^2.yr)
Hot Water Demand Limit	10 kWh/(m^2.yr)

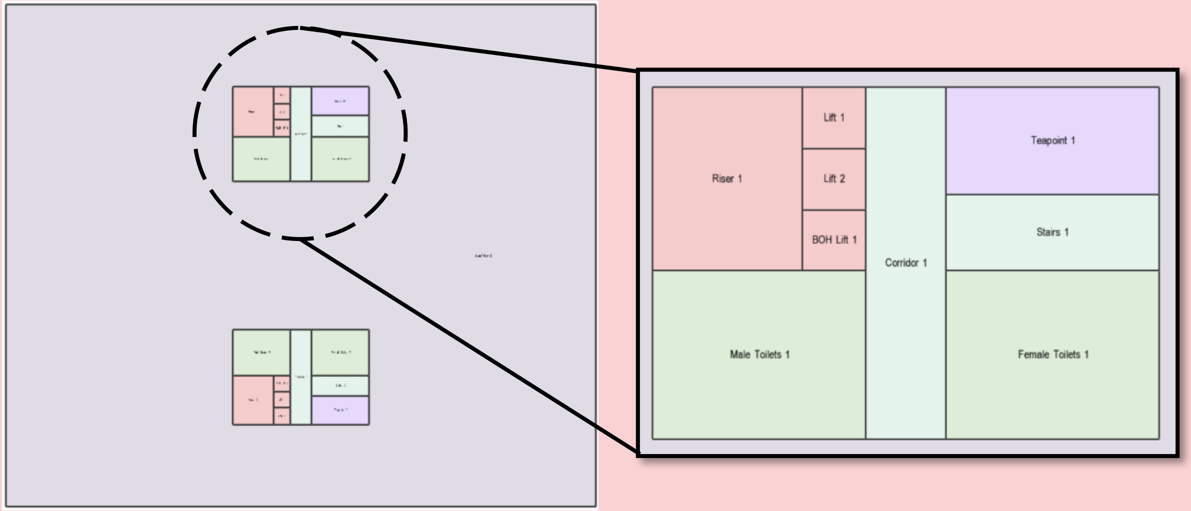
Features	Inputs
GIA	70 m^2
No. Bedrooms	2
No. Bathrooms	1
No. Floors	5
Flats per Floor	6

HVAC System	Inputs
Heating System	Radiators (Gas Boiler or ASHP)
Domestic Hot Water System	Gas Boiler, ASHP, Direct Electric
Cooling System	None
Ventilation	Natural Ventilation

4. Building Archetypes
Archetype 4 - Office



(a) Design Builder Model



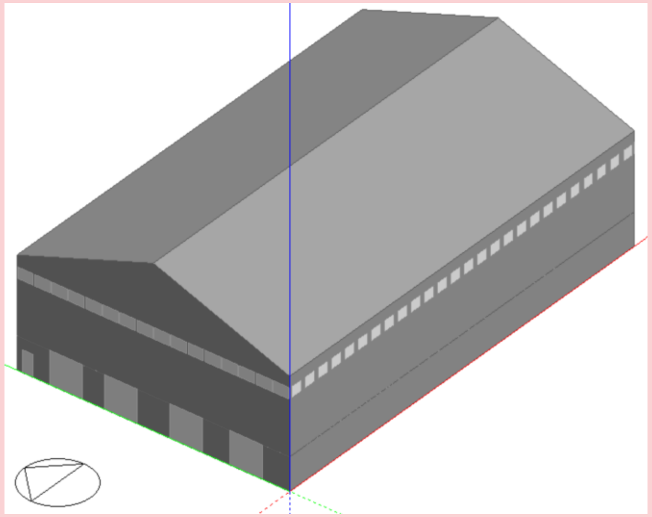
(b) Layout and Zoom-in of Core Area

Metric	Limit
LETI EUI Limit	55 kWh/(m^2.yr)
NZCBS EUI Limit	45 kWh/(m^2.yr)
Space Heating Demand Limit	15 kWh/(m^2.yr)

Features	Inputs
GIA	30616 m^2
No. Floors	7

HVAC System	Inputs
Heating System	Radiators (Gas Boiler, ASHP)
Domestic Hot Water System	Gas Boiler, ASHP, Direct Electric
Cooling System	Fan Coil Units (Chillers, ASHP)
Ventilation	AHU with Heat Recovery

4. Building Archetypes
Archetype 5 - Warehouse



(a) Design Builder Model

(b) Layout

Metric	Limit
LETI EUI Limit	55 kWh/(m^2.yr)
NZCBS EUI Limit	40 kWh/(m^2.yr)
Space Heating Demand Limit	15 kWh/(m^2.yr)

Features	Inputs
GIA	1000 m^2

HVAC System	Inputs
Heating System	Radiant Panels (Gas Boiler, Direct Electric or ASHP)
Domestic Hot Water System	Gas Boiler, ASHP, Direct Electric
Cooling System	DX Unit
Ventilation	Extract Only

5. Building Variables

5. Building Variables
Fixed and Variable Metrics for Domestic & Non-Domestic

Fixed parameters

To develop the analysis for each building archetype, the key modelling parameters were identified. These were split into parameters to remain fixed across all simulations and variables which would be varied as part of the parametric study.

The following parameters would remain constant for each archetype:

- Building location (e.g. weather data)
- Occupancy density (from NCM) (BRE, 2023)
- Heating, Cooling, Occupancy schedules (from NCM)
- Small power loads (from NCM)

Modelling variables

The following were to be varied as part of the parametric design:

- Fabric (e.g. window, wall, roof u-values)
- Building airtightness
- Lighting power loads
- Heating/Cooling set points
- Heating/Cooling system (e.g. fuel, efficiency)
- Mechanical ventilation rate
- Window to wall ratio
- Window opening %
- Building orientation

5. Building Variables
Fixed and Variable Metrics for Domestic & Non-Domestic

Fabric Performance Options

Across all of the modelling simulations, fabric performance was kept consistent to two options, with slight differences across the non-domestic and domestic archetypes.

Domestic

Level 1
- Walls- 0.26 W/m^{2}K
- Windows- 1.6 W/m^{2}K
- Roof- 0.16 W/m^{2}K
- Floor- 0.18 W/m^{2}K

Level 2
- Walls- 0.13 W/m^{2}K
- Windows- 0.9 W/m^{2}K
- Roof- 0.11 W/m^{2}K
- Floor- 0.08 W/m^{2}K

Fabric performance for the domestic archetypes was adapted from the original Carbon & Climate study undertaken by Arup. It became apparent that on domestic buildings the level 2 fabric would not result in any compliant passes in SAP (BRE, n.d.), so this was modified to result in some useful compliance results.

These levels are only representative of a set of fabric performance values. In reality, new buildings will come with a variety of different metrics owing to building constraints or materiality. These levels are intended to be representative for this study.

Window g-value was fixed at 0.4 and air tightness was set to 8m^3/(h/m^2) for all buildings under level 1.

Window g-value was fixed at 0.3 and air tightness was set to 3m^3/(h/m^2) for all buildings under level 2. Where natural ventilation was used, the air tightness was set to 5m^3/(h/m^2)

Non-Domestic

Level 1
- Walls- 0.26 W/m^{2}K
- Windows- 1.6 W/m^{2}K
- Roof- 0.16 W/m^{2}K
- Floor- 0.18 W/m^{2}K

Level 2
- Walls- 0.12 W/m^{2}K
- Windows- 1.0 W/m^{2}K
- Roof- 0.10 W/m^{2}K
- Floor- 0.10 W/m^{2}K

5. Building Variables
Archetype Parametric Inputs

For each archetype, a set of parametric inputs were defined to provide a sufficient range of results for building EUIs. The number of simulations executed each archetype were as shown below:

Archetype 1 – 2 Bed Market Flat

4 Building Orientations X 2 Fabric Levels X 2 Glazing Levels X 3 Window to Wall Ratios X 4 HVAC Systems X 2 Infiltration Rates X 2 Lighting power densities = 768 Simulations

Archetype 2 – 3 Bed Sem-Detached House

8 Building Orientations X 3 Fabric Levels X 3 Glazing Levels X 3 Window to Wall Ratios X 3 HVAC Systems = 648 Simulations

5. Building Variables
Archetype Parametric Inputs

Archetype 3 – 2 Bed Affordable Flat

8 Building Orientations X 3 Fabric Levels X 3 Glazing Levels X 2 Window to Wall Ratios X 4 HVAC Systems X 3 Infiltration Rates = 1728 Simulations

Archetype 4 – Office

8 Building Orientations X 2 Fabric Levels X 2 Glazing Levels X 3 Window to Wall Ratios X 3 HVAC Systems X 2 Cooling Setpoints X 3 Small Power Gains = 1728 Simulations

Archetype 5 – Warehouse

4 Building Orientations X 2 Fabric Levels X 2 Glazing Levels X 3 Window to Wall Ratios X 3 HVAC Systems X 2 Heated Areas X 2 Door Openings = 576 Simulations

6. Parametric Analysis

6. Parametric Analysis
General approach

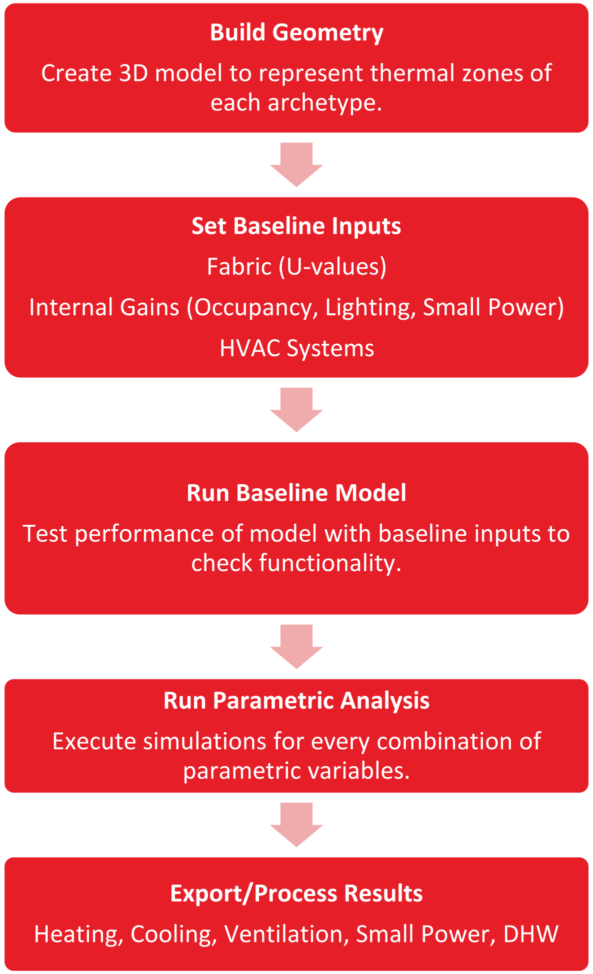
Overview

Based on the building archetypes set out in Section 4, and the variables outlined in Section 5, DesignBuilder was used to conduct a parametric analysis of each building archetype.

DesignBuilder is a state-of-the-art building performance analysis tool used for energy, carbon, lighting and comfort measurement and control. DesignBuilder combines fast three-dimensional building modelling with dynamic energy simulations with ease. It has specially developed modules in order to be used effectively at any stage of the design process. DesignBuilder uses the latest version of EnergyPlus simulation engine to calculate the energy performance of buildings.

The process to develop the model for each archetype was as shown in the diagram on the right. For each combination of inputs, the results consisted of the total energy use (EUI) of the building consisting of both the regulated and unregulated energy consumption, i.e. covering heating, cooling, ventilation, small power and domestic hot water (DHW).

Additional unregulated energy considerations such as communal lighting or vertical transported were subsequently calculated and added to the total energy consumption for each simulation.



6. Parametric Analysis
General approach

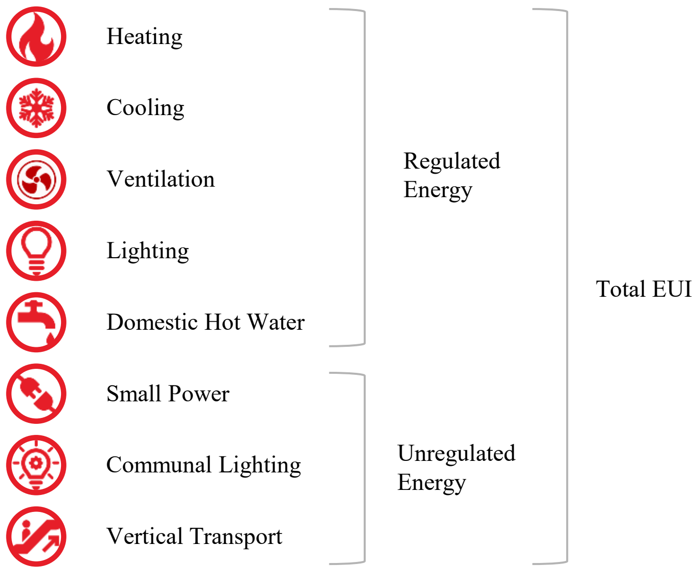
Regulated vs Unregulated Energy

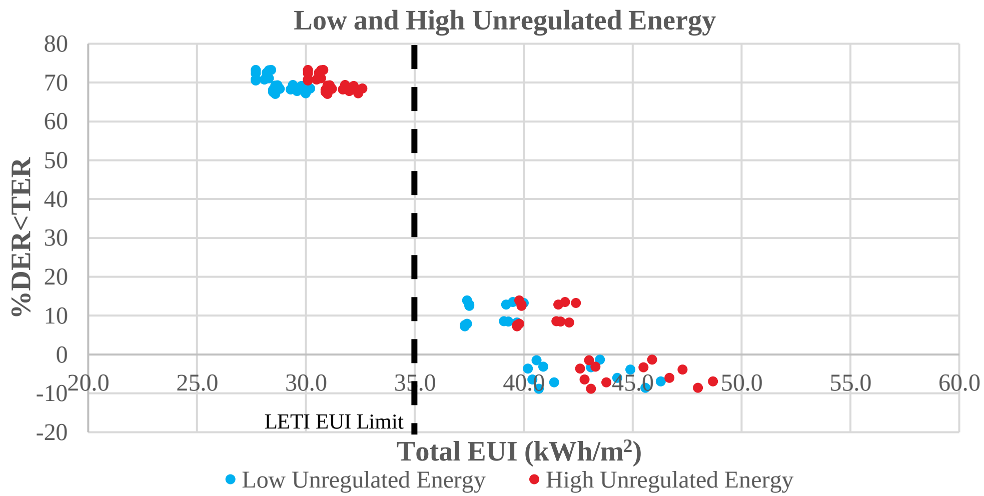
The total building EUI is a combination of both regulated and unregulated energy.

The unregulated energy is dependent on the tenants within a space and how they utilise the building, so is difficult to accurately predict. For the basis of each archetype, assumptions have been made on the unregulated energy consumption which are tabulated in Appendix A.

The graph below shows an example of how the unregulated energy of a residential archetype could impact the finals results. The difference in the usage of the building by its tenants could result in several kWh/m^2 increase in the building EUI. This variance could be the reason for a building being unable to meet its design targets. This is an important consideration when setting energy use targets as part of policy.

It is important to note that it is not the intention of MKCC to penalise developments which show a high unregulated energy usage; carbon offset payments shall only apply to any emissions from regulated energy consumption above the EUI target.





6. Parametric Analysis
Archetype 1 – 2 Bed Market Flat

EUI Results

The results from the parametric analysis outlined in Section 5 for archetype 1 are shown below. The space heating demand within each flat is plotted against the overall EUI result.

The LETI EUI target of 35kWh/m^2 is plotted to demonstrate which simulations meet the targets outlined in the Carbon & Climate report, as well as the UK NZCBS 2040 limit.

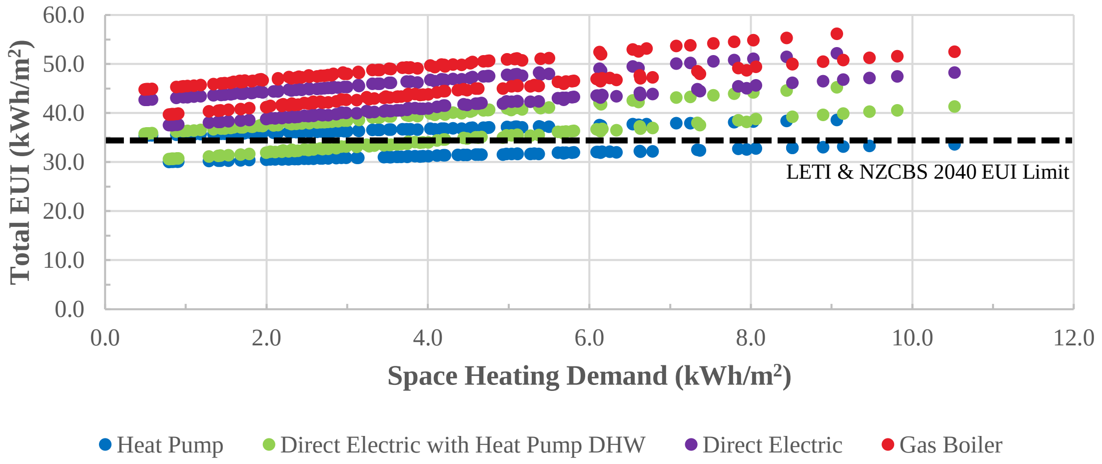
The results from the first archetype were analysed to identify the impact of different building parameters on the overall performance. This could then be considered for the simulation of the remaining buildings.

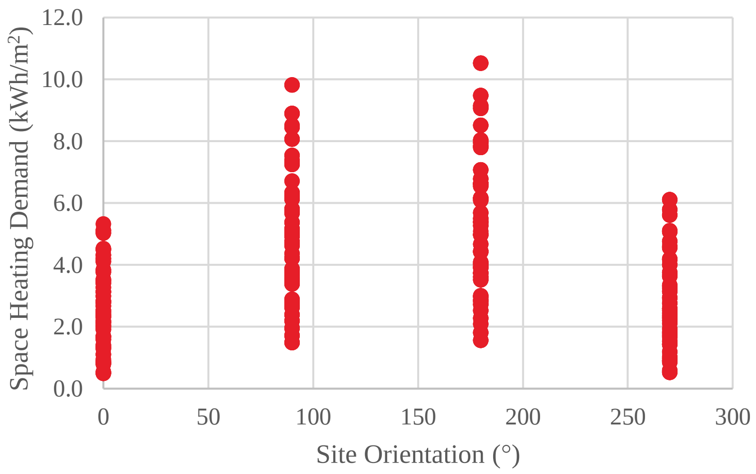
The graph on the left shows the influence of the different space heating and DHW systems on the overall building EUI. Only models with ASHP generation of DHW were able to meet the target aspirations. However, this is to be expected given the prevailing trend in performance requirements and availability of better performing components.

Building envelope parameters such as window to wall ratio and fabric level had an impact on the overall heat loss as expected, with more of an influence on the less efficient systems such as the gas boiler.

The building orientation had a significant impact on the heating demand, as shown in the graph below.

Archetype 1
Space Heating Demand against Total EUI

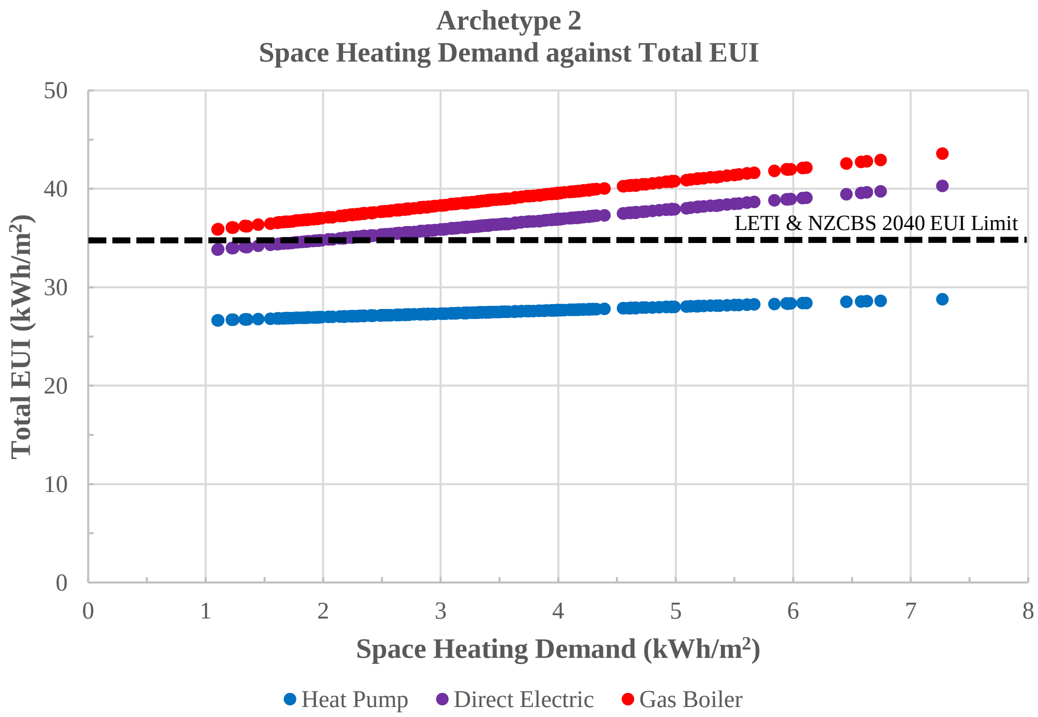




6. Parametric Analysis
Archetype 2 – 3-Bedroom Semi-Detached House

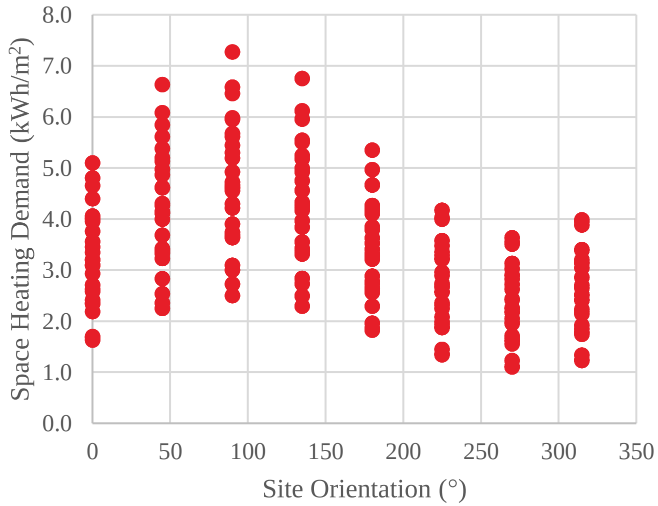
EUI Results

The results from the parametric analysis for archetype 2 are shown below. As outlined in Section 5, the selection of parameters for this archetype are different from Archetype 1 due to the outcome of results. A larger focus on the building envelope, site orientation and HVAC systems was used for this analysis with the aim of generating a spread of results.



For the semi-detached house, the fabric heat losses had more influence due to the increased façade area from the roof and ground. In most models, only the space heating via ASHP was therefore able to meet the LETI EUI target.

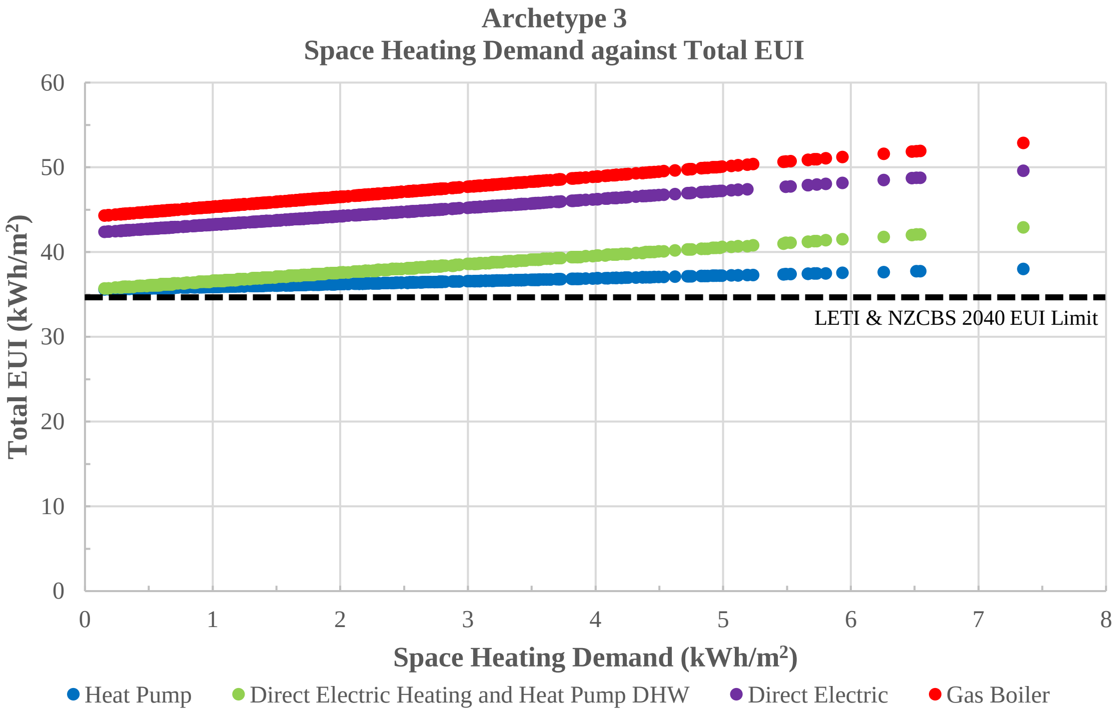
The overall building EUI for this building archetype was lower than that of the flat. This is primarily due to the reduced unregulated energy. The lack of vertical transport and communal areas resulted in small power making up the sole component of this energy use.



6. Parametric Analysis
Archetype 3 – 2-Bedroom Affordable Flat

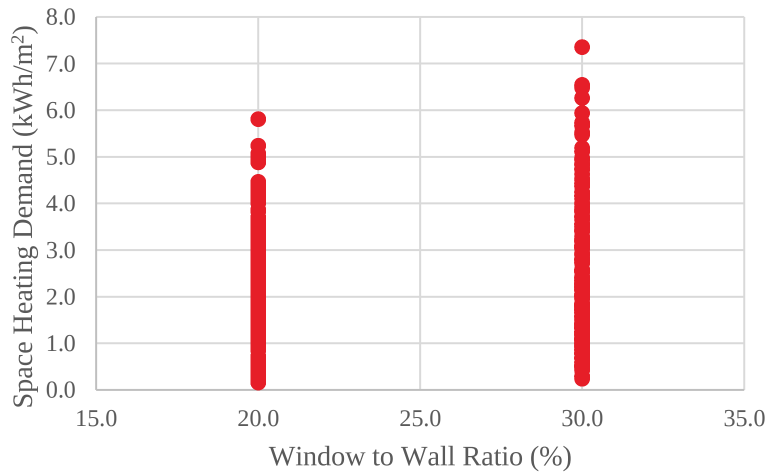
EUI Results

The results from the parametric analysis for archetype 3 are shown below. The trends observed from the first two archetypes remained consistent within these results. This provides the opportunity to draw conclusions on domestic buildings generally.



The graph on the left shows a similar trend to archetype 1, but the overall Total EUI values are higher. This is due to the higher estimated unregulated energy value across each of the 3 categories considered, i.e. small power, vertical transport and communal lighting, which is affected by both the number of storeys and apartments in a block as well as the number of people in a flat. It has been assumed that affordable flats would have higher occupancy rate (typical of lower income families) which resulted in higher energy use per floor area.

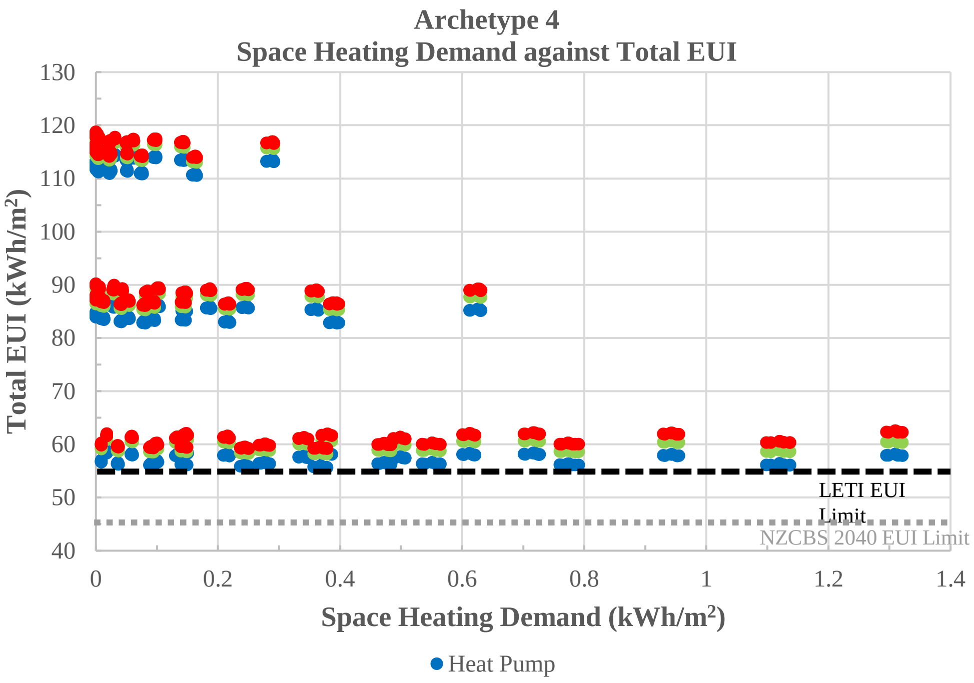
As observed in the previous archetypes, the models that used heat pumps for DHW and/ or space heating were closer to meeting the LETI EUI target, whereas those using only direct-electric or gas boiler systems were difficult to pass.



6. Parametric Analysis
Archetype 4 – Office

EUI Results

The results from the parametric analysis, outlined in Section 5, for archetype 4 are shown below. The space heating demand is plotted against the overall EUI results, with the LETI EUI target for commercial developments plotted at 55kWh/m². As outlined in Section 5, the parameters used in the modelling were the building envelope, site orientation, HVAC systems, along with the cooling setpoints and small power gains selected to be investigated due to the nature of the building.



For the office, the EUI target of 55kWh/m² is very challenging due to high regulated and unregulated energy use figures which result from the inherent nature of the development, which is characterised by high density of occupants and energy use throughout the day. This falls in line with what has been observed in previous Arup projects for office developments.

Some simulations have (almost) zero space heating which is expected in cooling dominant buildings. Typically, in modern offices the internal gains from small power loads, occupants and high performing fabric mitigate any need for extensive heating.

It was observed that models with higher cooling setpoints compared to the 24degC set by the notional building specifications were closer to meeting the LETI EUI target. Allowing for adaptive thermal comfort in cooling scenarios, whereby the internal conditions more closely reflect the outdoor climate. When higher setpoints are allowed for, this results in lower cooling demand and lower overall energy consumption.

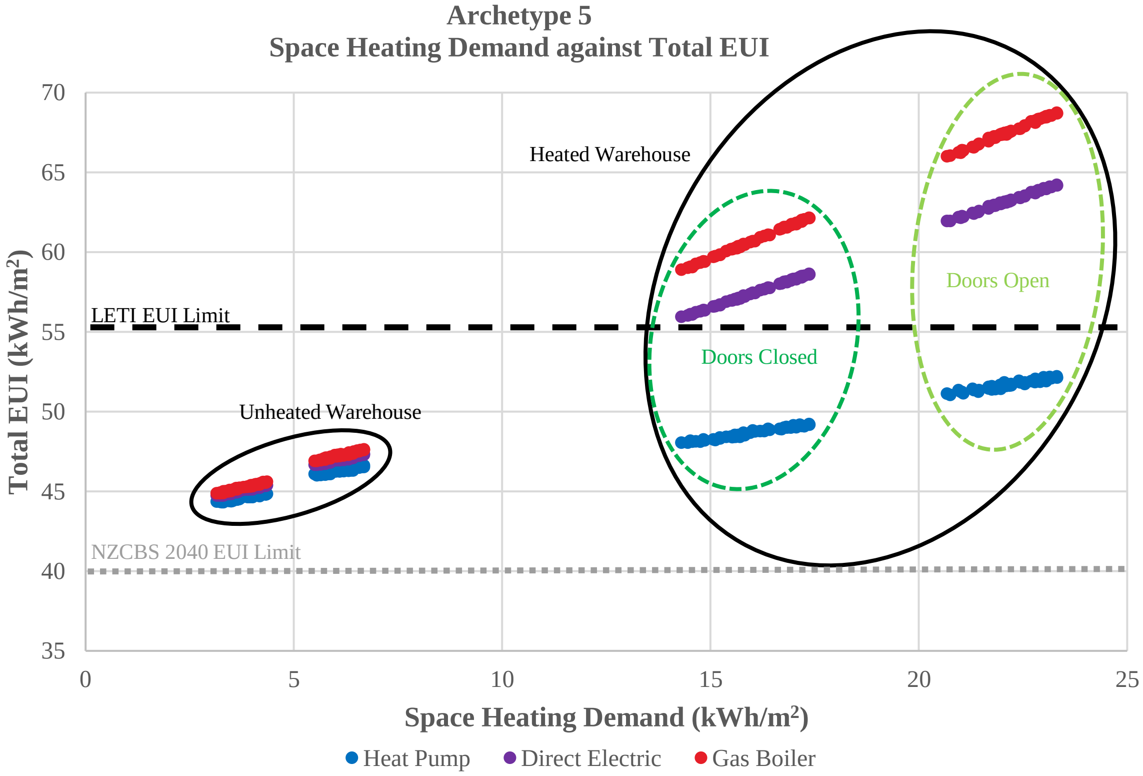
Whilst robust databases of building EUI's is not readily available, we can lean on recent internal project experience to determine if the LETI EUI targets are feasible. Looking at building certification standard NABERS (NABERS UK, 2024) it sets its highest performance target at six stars, which is roughly an EUI of 35*kWh/m². Currently there are no six-star NABERS projects in the UK, however a five–star target of 70*kWh/m² is far more readily targeted and achieved.

*Figures are kWh/m²NLA/year

6. Parametric Analysis
Archetype 5 – Warehouse

EUI Results

The results from the parametric analysis, outlined in Section 5, for archetype 5 are shown below. The input parameters were selected so that they reflected the use of the building. As previously, the building envelope, site orientation and HVAC systems were varied, along with which areas of the warehouse were heated/ unheated and door openings that corresponded to varying levels of natural ventilation.



As observed previously, the results of the warehouse further emphasise that how the space is used will have a significant impact on the results.

The graph on the left shows that the two key parameters responsible for the significant spread in results are the decision to heat or not heat the warehouse, and whether the doors are modelled to be open, allowing large volumes of unheated fresh air into the space.

These different design decisions have a huge impact on the results for this building typology.

Additionally, the size of the office area within the warehouse will also impact the results where it is the only conditioned area of the building.

Regarding the choice of HVAC systems, as observed in the previous archetypes, the Air Source Heat Pumps result in the lowest EUI values and thus may be the best option to meet the LETI EUI target in the case of the specific modelled warehouse.

With warehouses having a wide range of potential uses and configurations finding a harmonious typology to represent all potential warehouses is particularly challenging. But it does also reflect the reality of such buildings being assessed under the current Building Regulations. To ensure a compliant proposal, careful consideration should be given to such elements such as HVAC systems, building fabric and use of space.

7. Compliance Modelling

7. Compliance Modelling
General approach

Overview

Following from the parametric analysis of each archetype, shown in Section 6, the results were modelled using compliance software.

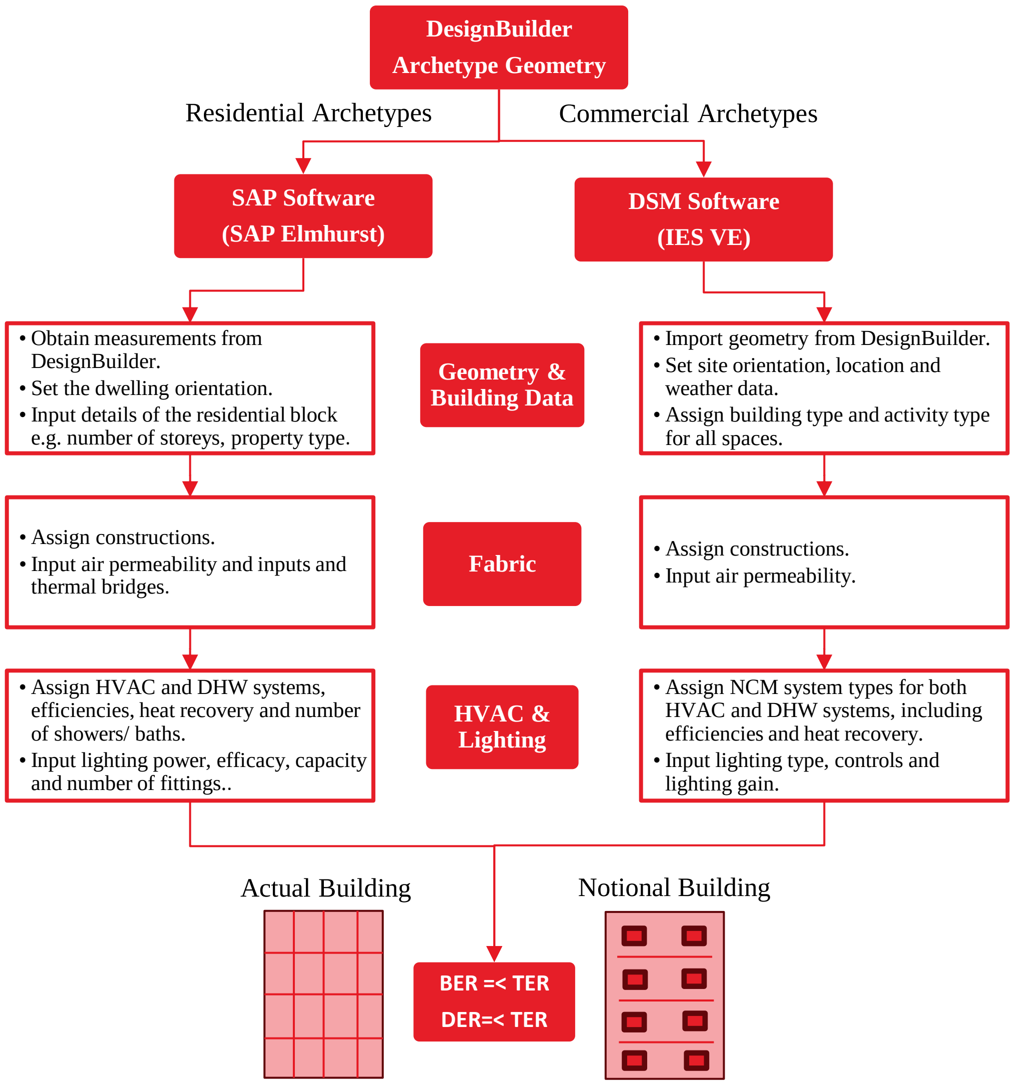
From the several hundred simulations for each archetype, approximately 50 models were selected to test against building regulations. The number of simulations were required to be limited to this because currently building regulation software such as SAP, DesignBuilder or IESVE (Integrated Environmental Solutions Limited, 2023) are not capable of performing parametric compliance simulations. Therefore, the time to complete the modelling is significantly increased.

The 50 models were selected to focus on variables which had a large influence on compliance results. Compliance modelling only considers the regulated energy output so any variance in unregulated energy would not be captured, although it would impact the total EUI of the building.

The buildings regulations process also contains many fixed inputs as part of the National Calculation Methodology (NCM) (BRE, 2023). The following inputs are fixed within the compliance models:

- Occupancy density,
- Heating/Cooling/DHW usage patterns
- Heating / Cooling set points,
- Small power gain,
- Ventilation rate,

The calculation process between domestic and non-domestic properties differs slightly, although both must comply to Part L Buildings Regulations standards.



7. Compliance Modelling
General approach

Domestic

For all domestic building archetypes, the building compliance was calculated using the SAP methodology.

The key output metrics produced from this software are:

- DPER (Dwelling Primary Energy Rate) & TPER (Target Primary Energy Rate)
- DFEE (Dwelling Fabric Energy Efficiency) & TFEE (Target Fabric Energy Efficiency)
- DER (Dwelling Emission Rate) & TER (Target Emission Rate)

For each of these output metrics, the modelled dwelling is compared to the target (notional) building. To comply with Part L Building's Regulations, the dwelling must outperform the target in each metric. This places more stringent requirements on specifically the fabric performance of the building.

In addition to the general limitations of compliance identified previously, another limitation of SAP is that the weather data is set by default as the UK average and cannot be specified by the modeller. Furthermore, the SAP methodology is primarily designed to be used for new residential developments, so the results obtained would most likely apply to new builds – for retrofit and refurbishment of existing buildings, RdSAP may be more appropriate to use.

Non-Domestic

For non-domestic building archetypes, Part L building compliance was calculated using IES Virtual Environment, an approved piece of software for BR Part L energy modelling. Unlike the SAP calculation, this is a dynamic energy model calculation.

The key output metric for non-domestic buildings is the Building Emissions Rate (BER) which is compared against the target emissions rate (TER). To comply with building's regulations, the BER must be lower than the TER.

Due to the NCM methodology, a few limitations were identified when modelling the non-domestic archetypes including:

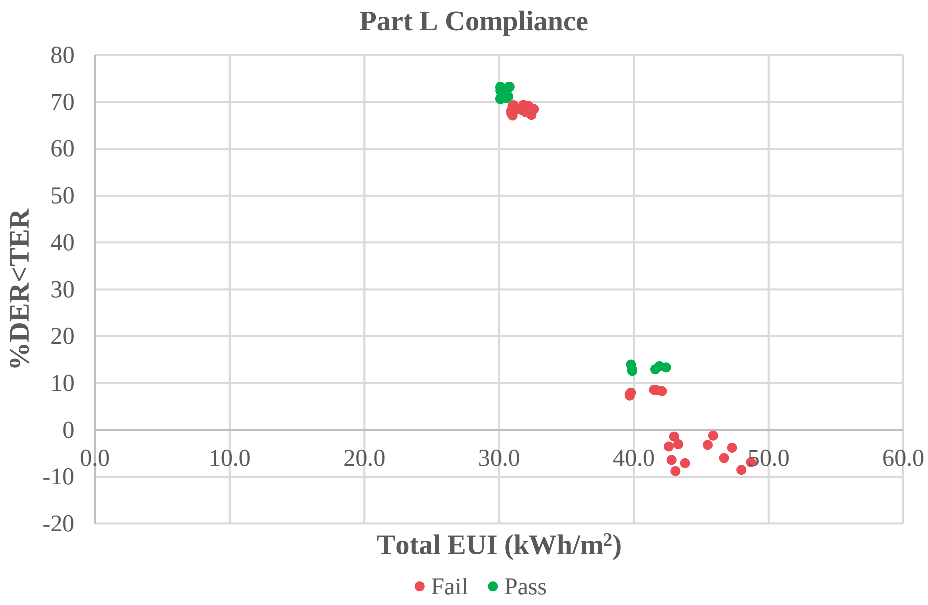
- When a building uses a space heating source that is not an ASHP (e.g. Direct Electric or Gas Boiler) the notional building will add PV area proportional to the building's foundation area. For single storey buildings this becomes a very large kWh/m^2 reduction in electricity for the notional building. In these instances, with a large heated area, building compliance becomes impossible to meet.
- Compliance modelling cannot account for natural ventilation. When selecting models to consider for the warehouse, only models with the doors assumed closed were used.

7. Compliance Modelling
Results

Domestic

Initial analysis of the SAP results from modelling of archetype 1 identified a large disparity between the performance of some of the models. System types were resulting in a large gap between the percentage improvement over the notional building. This is highlighted on the graph below, which was an initial results dataset for gas boiler and heat pump models.

Another key point is related the requirement of all metrics to pass for dwelling compliance. Models with high performance systems such as a heat pump were still failing due to the DFEE metric. In the graph, some models with almost a 70% improvement against the notional emissions rate were still failing the overall compliance. The aim of this study is to primarily focus on the buildings emission rates so this will not have an impact on the targets set.



Non-Domestic

For building compliance of non-domestic buildings, the only metric required to pass is the overall buildings emissions rate versus the target set by the notional building.

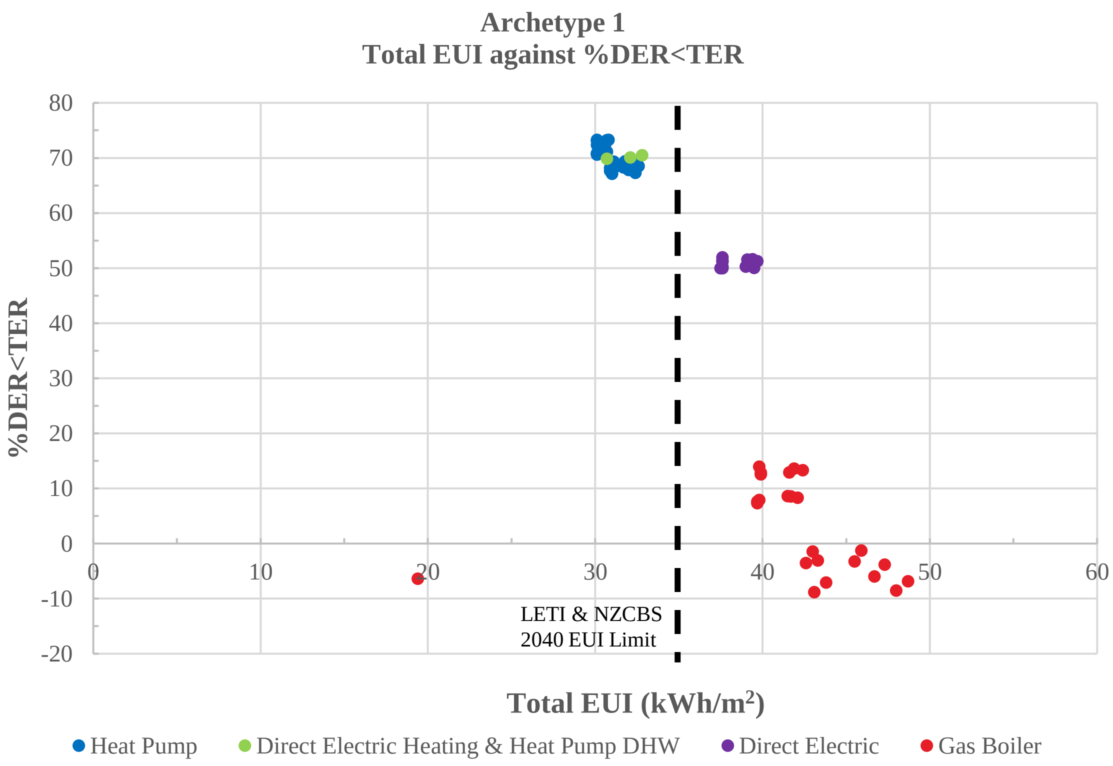
Relative to the improvements achieved from the domestic properties, the percentage improvements were much lower. The following results were observed:

- The new Part L requirements are proving challenging for office buildings which typically struggle to achieve more than 10-15% improvement on offices; this is due to the Notional Building having very low window ratio compared to typical office buildings and high level of renewable energy generation which is often not viable due to space requirement for plants on the roof;
- Existing targets, such as a 35% recommendation by the GLA (Greater London Authority, 2022) will be very difficult to meet for typical non-domestic buildings;
- For industrial spaces, such as warehouses, it proved difficult to achieve much improvement over the Notional Building, due to the fact that these spaces present high volumes to be heated and limited internal gains.

8. EUI vs DER & BER Results

8. EUI vs DER Results
Archetype 1 – 2 Bed Market Flat

The parametric results and compliance results outlined in the previous sections have been plotted against each other for the 5 archetypes. These results for total EUI vs % improvement against the notional building are outlined in this section.



The results from Archetype 1 are shown on the left. As expected, the buildings with a lower total EUI achieve an improved performance against the building regulations.

The large difference in performance against building regulations stem from the HVAC systems utilised within the space to provide space heating and domestic hot water.

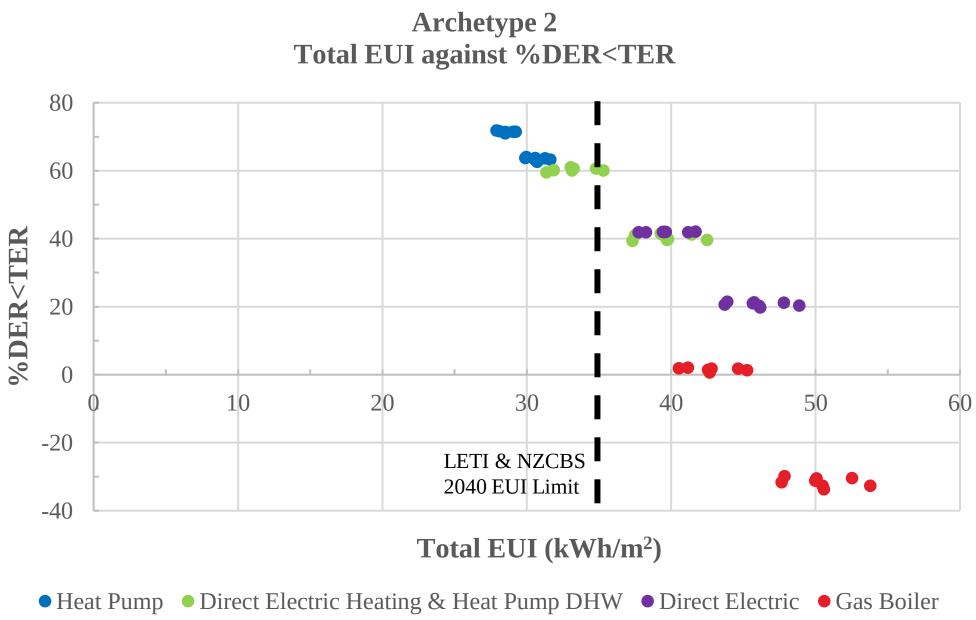
To achieve the 35kWh/m^2 LETI EUI target, all dwellings which achieve at least a 60% reduction of Part L building regulations will also meet this criteria. This has been calculated by interpolating between the results from this study.

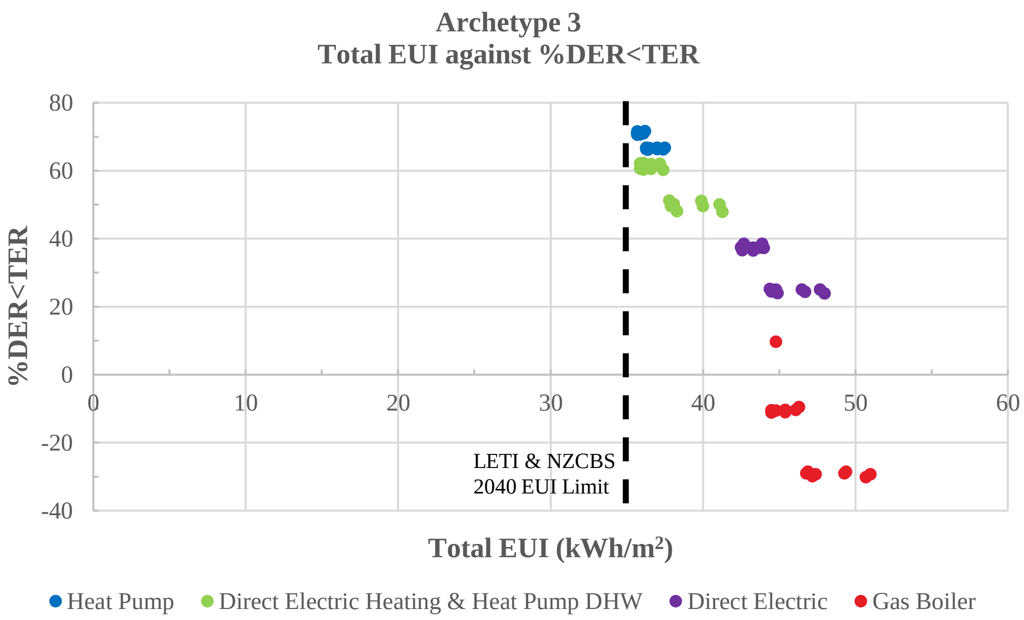
8. EUI vs DER Results
Archetypes 2 & 3

The results for the other residential archetypes (2 & 3) followed a similar trend to the results from the first archetype.

The archetype 2 dwellings supplied by an ASHP for both space heating and DHW met the LETI EUI target and achieved a reduction of at least 60% over building's regulations in most instances.

For archetype 3, none of the buildings meet the LETI EUI target. In this model, there is not any mechanical ventilation or heat recovery so this may be a requirement to specify in the policy agreement for all new dwellings. This will provide a sufficient energy saving to meet these targets for dwellings using ASHPs and retain a consistent approach between both market and affordable properties.



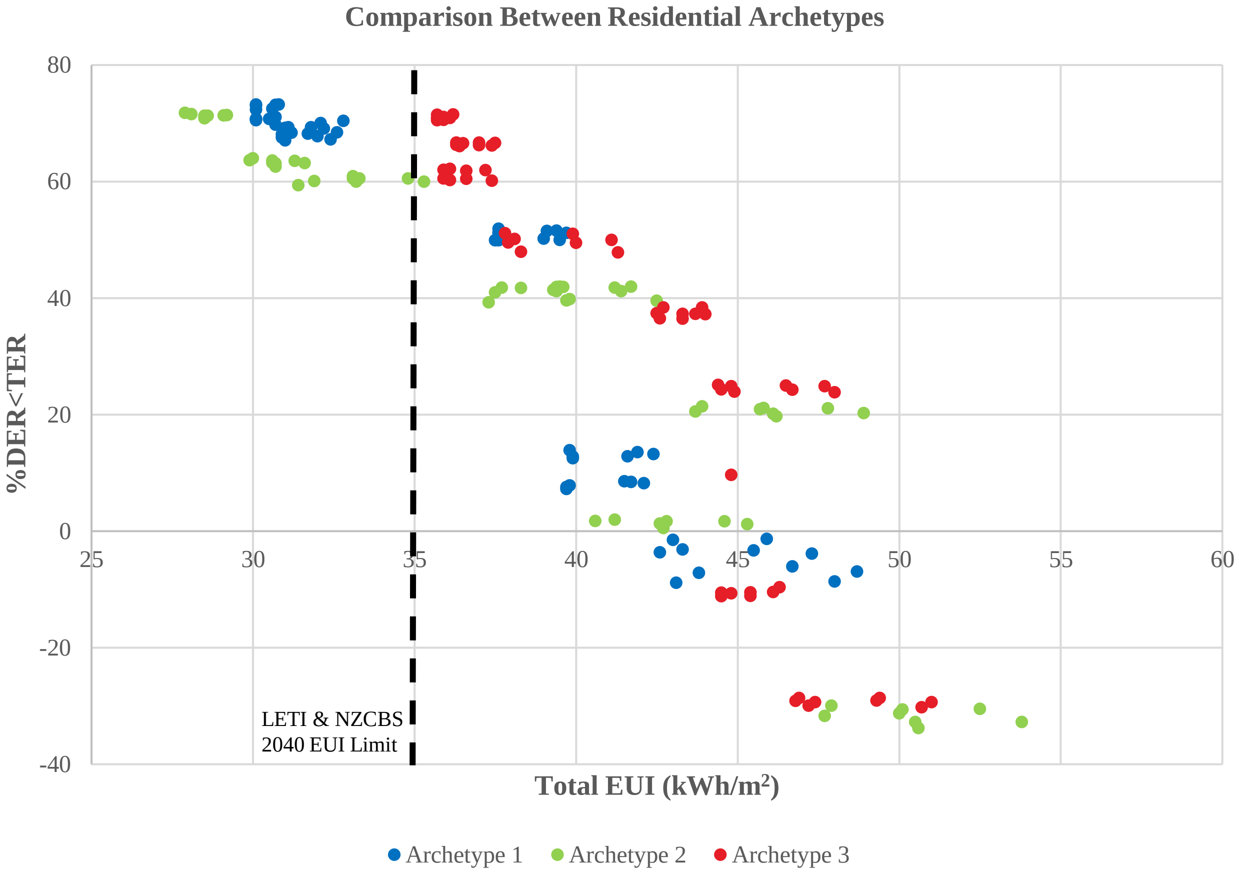


8. EUI vs DER Results
Archetypes 1, 2 & 3

The results for each of the residential archetypes were plotted together to compare the trend in results, as shown in the graph.

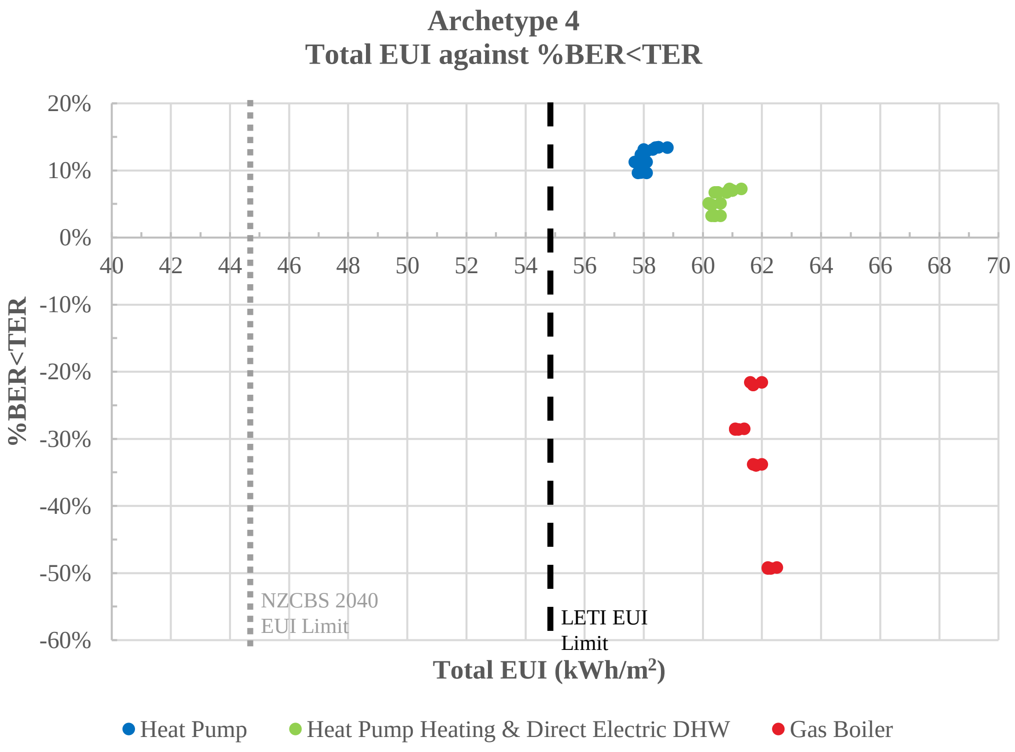
Each archetype produced comparable results, suggesting that generalised conclusions can be made about all dwellings.

The dwellings with higher EUIs, and therefore a worse building compliance performance, produced a large variety in results. This suggests that the validity of building compliance as a metric of building performance is more suitable for higher performing dwellings. The compliance method is not as refined to capture these performance differences.



8. EUI vs BER Results
Archetype 4 – Office

Comparison between EUI and % Improvement of Emissions Rate over Part L



The results for the total EUI and percentage improvement over Part L for the office are shown on the left. The results show a similar trend to the residential archetypes with regards to the system types. Offices with heat pumps providing space heating and/ or DHW were significantly better in terms of both having a lower EUI and higher percentage improvement over Part L, when compared against models using gas boilers. This was attributed to the higher heating/ cooling efficiency of the heat pumps as well as due to being all-electric and a renewable technology, which all resulted in lower carbon emissions being emitted relative to the gas boiler system.

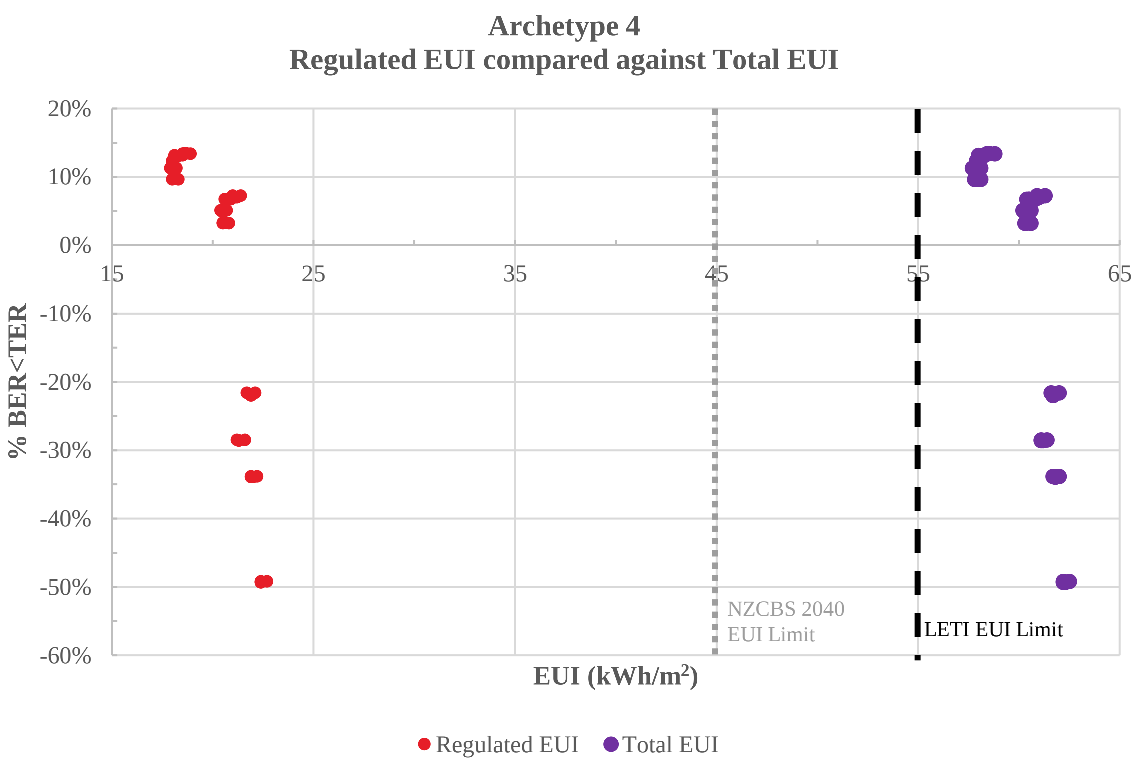
A key difference in the office results when compared with the residential archetypes is that regardless of the system type or fabric properties modelled, none of the models pass the LETI EUI limit. Offices with heat pumps are the closest to meeting the limit, but based on these results designs should aim to achieve higher efficiency levels than those modelled, which are currently available on the high end of market.

The high EUI values are attributed to the significant unregulated energy use, this was calculated to be approximately 40 kWh/m^2, meaning that most of the proportion of the Total EUI for the office is made up of the unregulated energy uses. This was as expected due to the nature of the development since in particular the small power load would be significantly high.

Initial results suggested that the LETI EUI targets are very challenging for typical office buildings, and it may be advisable to revise these targets at a future date. However, in line with the brief for this study, the modelling has aimed to identify a parallel between the LETI Targets set in the previous Carbon & Climate Study and percentage improvement over Part L.

8. EUI vs BER Results
Archetype 4 – Office

Comparison between Regulated EUI and Total EUI



The graph on the left shows the sensitivity of the total EUI value to the estimated unregulated energy use. All models that only consider the regulated energy use component as part of the EUI pass the LETI EUI limit by a large margin. However, the same models when combined with the unregulated energy use fail to meet the limit. This highlights the importance of the unregulated energy uses in energy modelling.

Although none of the models simulated in this study have achieved the LETI EUI target, the inputs tested were limited by the bounds of what can be varied within compliance. This EUI target is still viable for policy, with more focus on occupant engagement.

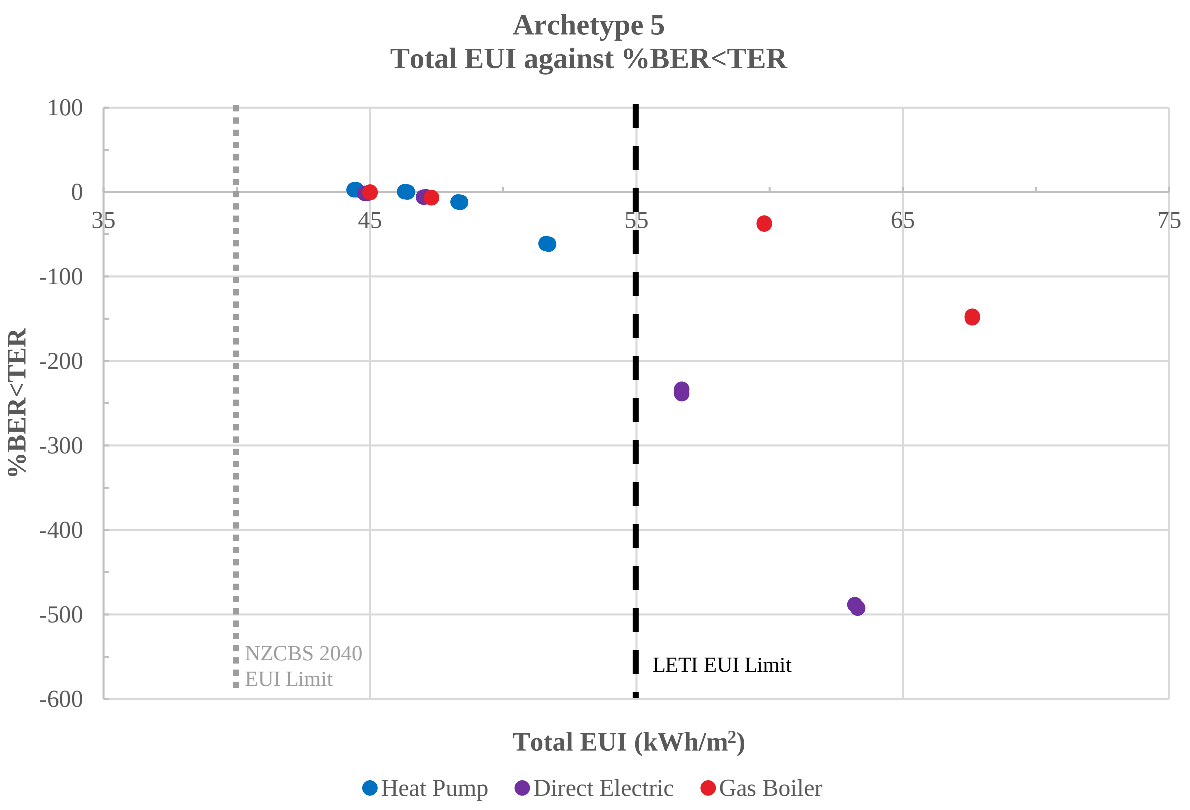
Accuracy is key in ensuring that the unregulated energy use estimated is as close to the actual energy use so that the results can accurately reflect reality – although a performance gap is still likely to exist as the required data might not exist or may be challenging to obtain from existing data.

Additionally, as seen previously, the unregulated energy use can vary significantly based on the type of development under consideration. The graph on the left shows that the estimated unregulated energy for an office is very significant (primarily due to the small power load).

It is recommended that 20% improvement over TER is required to align with the set LETI targets for office buildings.

8. EUI vs BER Results
Archetype 5 – Warehouse

Comparison between EUI and % Improvement of Emissions Rate over Part L



The results for Archetype 5 presented more complicated scenarios than the other 4 archetypes in this study.

As mentioned previously, natural ventilation was excluded from the compliance models leaving only results for a closed envelope. Of these, scenarios with both heated and unheated storage space were tested.

The graph on the right demonstrates a large range of performance relative to the notional building. Most simulations struggle to meet the necessary requirement to comply with the non-domestic building regulations. There are a few factors which contribute to this, which will be outlined in the following pages.

An initial conclusion that can be drawn from the results being that any industrial building able to comply with Part L will be suitable from an operational energy use perspective.

8. EUI vs BER Results
Archetype 5 – Warehouse

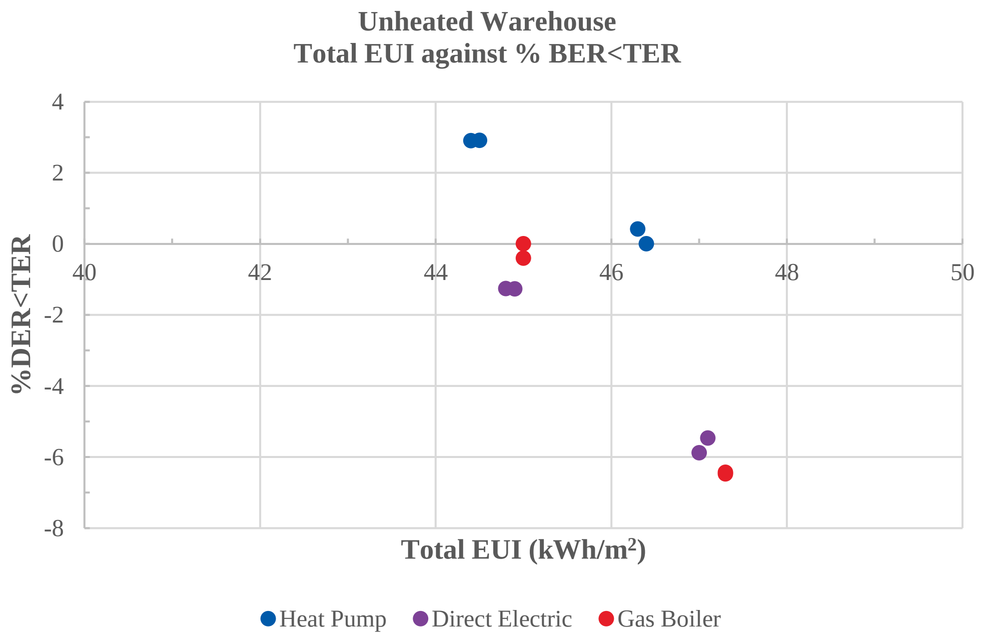
Unheated vs Heated Warehouse

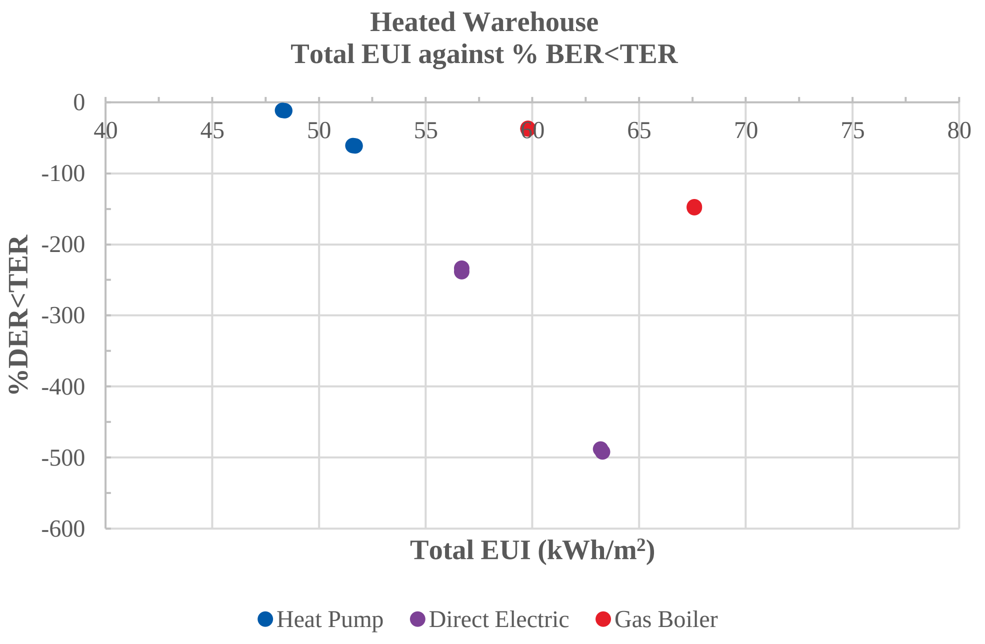
The simulations where the main warehouse area is unconditioned, are shown in the graph below. All simulations meet the EUI limit due to the reduced heating from the unconditioned warehouse area.

Any simulation which uses an ASHP for heating the remaining areas of the building will comply with building's regulations. With aspirations of both building compliance and a low energy building, ASHPs could become a necessary design implementation for industrial buildings.

When the warehouse area is required to be heated, the extra heating demand causes drastic results versus the notional building. Percentage differences of up to -500% occur. In the instance where a heating method other than an ASHP is utilised, the notional building is also applying a large PV area to account for the inefficient heating systems. This penalises the building even further resulting in these unrealistic results.

Any industrial building able to comply with Part L will be suitable from an operational energy use perspective.





9. Conclusions

9. Conclusions
Key conclusions

Overall approach & findings

This study has analysed the performance of 5 different building archetypes (in line with the previous Carbon & Climate Study) both in relation to energy use intensity and percentage improvement over building regulations. Throughout the research, it has been proven that there is a correlation between these two metrics for building performance, although this correlation is based on the specific case studies and scenarios assessed in this study. A gap within existing studies was identified with regards to these metrics and this research has been able to provide some insights into how targets can be set.

The results in this study, although comprehensive, are a small sample size of the real building stock which will have to comply with the new local plan. The 5 archetypes modelled are reflective of typical buildings in development within Milton Keynes and aligned with those assessed in the previous Carbon and Climate Study, but any further variation in design and geometry could yield substantial variations in results.

There are a few important factors which should be considered when setting targets for performance. In large scale residential and commercial developments, the unregulated energy component is difficult to predict and will have a large impact on total energy use. This is something not captured by compliance modelling so setting targets related to compliance may not be viable for all use cases. In most instances, the work has shown that complying with Part L buildings regulations is not sufficient to achieve a high-performance building in operation, as per the latest best practice guidance around net zero carbon.

Despite the limitations mentioned, the results from this research have enabled a statistical correlation to be drawn between the EUI metric and compliance result, highlighting that buildings designed in alignment with the latest best practice (i.e. high fabric performance and high-efficiency AHSPs) typically results in good performance both under a EUI and a BR Part L approach. If required, the percentage improvement against Building Regulations can provide suitable targets for policy.

9. Conclusions
Key conclusions

Recommendations

Based on the current study, covering a thorough literature review of the research in this field, this study recommends the following approach when setting targets for the new Local Plan:

- Adopt an EUI approach which is widely recognised to deliver higher energy performance in use and account for both regulated and unregulated energy;
- Align the EUI limits to the recommendations in the Carbon & Climate Study which were derived from the LETI targets;
- Maintain awareness of the newly published UK NZCBS which are based on extensive modelling and engagement with the construction industry and is likely to become the key best practice reference for net zero carbon aligned buildings in the UK.

To address the WMS 2023, this study provides fallback policy wording and advice for the ‘On-site energy efficiency and carbon reduction’ policy recommendation in Arup’s original Recommendations report (pp. 11-12):

- It is recommended that the fallback policy uses a Building Emission Rate energy efficiency standard with target percentage improvements over Part L:
  - Residential buildings (Flats and Homes) – 60% improvement over TER;
  - Office buildings – 20% improvement over TER;
  - Warehouse / Industrial buildings - >0% improvement over TER.
- The fallback policy wording is provided on page 53 overleaf.

For the original and fallback policy positions, provision of an Energy Statement and post-construction EUI monitoring are recommended, the latter to be secured through planning condition. As per Arup’s original report, developer guidance is recommended via a Supplementary Planning Document (SPD).

For planning application stage design, the SPD should include a defined methodology for developers covering:

- Applicant and developer use of the CIBSE TM54 framework to calculate the predicted energy usage of their building at planning stage in EUI terms;
- An appropriate planning stage form to enable applicants to submit their energy estimates with the responsibility of the developer clearly set out in the agreement;
- Encourage use of the more detailed energy modelling during design stages, such as NABERs IDR framework (CIBSE Certification Ltd, n.d.) and advanced energy modelling as per CIBSE TM54 requirements to ensure more confidence in results.

The GLA’s Energy Assessment Guidance (2022) (sections 7.13-7.15) are signposted as a starting point.

For post-construction stage design, the SPD should:

- Set out a strategy, similar to the GLA’s ‘Be Seen’ Energy Monitoring Guidance (Greater London Authority, 2021) and current in-use monitoring regime guidance in MKCC existing Sustainable Construction SPD (at section 7.6), to ensure developments align with MKCC’s net zero-carbon ambitions (Milton Keynes City Council, 2021);
- Require submission of carbon savings against the notional building and EUI targets as evidence and the applicant’s commitment to reducing energy demand;
- Include requirements for appropriate documentation of these results to enable the applicant to clearly outline their as-built compliance with the policy.

9. Conclusions
Key conclusions

Recommendation for fallback policy

As part of the transition to net zero carbon buildings, it is recommended that all developments are designed in line with the Energy Hierarchy and so take a ‘fabric first’ approach.

Major developments must meet the following on-site targets:

- Major residential development:
    - 60% improvement in operational energy (excluding renewable generation) over the latest Target Emissions Rate (TER) in Part L of the Building Regulations 2021.
    - < 625 $kgCO_2e/m^2$ as whole lifecycle carbon requirement
    - 4-star HQM score for new build development.
- Major non-residential development:
    - For office-led development, 20% improvement in operational energy (excluding renewable generation) over the latest Target Emissions Rate (TER) in Part L of the Building Regulations 2021.
    - For warehouse or industrial building-led development, >0% improvement in operational energy (excluding renewable generation) over the latest Target Emissions Rate (TER) in Part L of the Building Regulations 2021.
    - For all major non-residential development, < 750 $kgCO_2e/m^2$ as whole lifecycle carbon requirement.
    - For all major non-residential development, BREEAM Outstanding score for new build development.

After fully appraising fabric improvement options, applicants shall accommodate 25% of electricity demand by on-site renewable generation where sufficient roof space is available. This generation must be supported by high efficiency electric heating systems, such as low carbon district heating.

It is recommended that applicants evidence the design approach in a detailed Energy Statement, including the results of appraising and modelling different interventions to reduce regulated and unregulated emissions. These interventions should consider the latest net zero technology, such as for energy generation and smart demand control measures.

For developments of more than 100 dwellings or 100 sqm (GIA) non-residential floorspace, applicants must also detail their approach to reducing whole life-cycle carbon emissions, such as by applying circular economy principles.

In setting planning conditions, we recommend that the Council stipulates EUI monitoring by building archetype for the first five years of occupation of a development to gauge any disparity with the policy EUI target and actual carbon emissions arising from new developments brought forward by the MKCC City Plan 2050.

Appendices

ARUP

Appendix A

Assumptions

Archetype 1 Assumptions

Parameter	Description	Unit	Type	Source
Archetype	2 Bed Market Flat	-	Fixed	
Weather File	London TRY 2016	-	Fixed	
Orientation(s)	0°, 90°, 180°, 270°	-	Variable	
External Roof U-Value(s)	0.16, 0.11	W/(m2.K)	Variable	Part L / LETI
Heat Loss Floor U-Value(s)	0.18, 0.08	W/(m2.K)	Variable	Part L / LETI
External Wall U value(s)	0.26, 0.13	W/(m2.K)	Variable	Part L / LETI
Window to wall ratio(s)	20%, 30%, 40%	%	Variable	
Window U value(s)	1.60, 1.00	W/(m2.K)	Variable	Part L / LETI
Window g value(s)	0.40	-	Fixed	Part L
Y-value	0.08	-	Fixed	
Occupancy	2 (1.61)	-	Fixed	NCM
Small power load kitchen	30.3	W/m2	Fixed	NCM
Small power load living room	3.9	W/m2	Fixed	NCM
Small power load bedroom	3.6	W/m2	Fixed	NCM
Small power load bathroom	1.7	W/m2	Fixed	NCM
Small power load circulation	1.6	W/m2	Fixed	NCM
Lighting load(s)	2, 4	W/m2	Variable	
Ventilation system	MVHR	-	Fixed	
Ventilation rate(s)	0.25, 0.50	ACH/hr	Variable	NCM
Heat recovery Efficiency	87%	-	Fixed	SAP
Fan SFP	0.8	W/(l/s)	Fixed	
Infiltration rate	3	m3/(h.m2fac) @50Pa	Fixed	LETI
Heating Generation System – 1	Gas boiler - condensing	-	Variable	
Heating Generation Efficiency – 1	84% (83.6% - summer) (80.7% - winter)	-	Fixed	SAP
Heating Generation Controls – 1	2107 (Programmer, TRVs and Bypass)	-	Fixed	SAP
Heating Generation System – 2	Direct electric	-	Variable	
Heating Generation Efficiency – 2	100%	-	Fixed	
Heating Generation System – 3	Air source heat pump	-	Variable	
Heating Generation Efficiency – 3	300%	-	Fixed	
Heating Generation Controls – 3	2309 (Charging system linked to use of community heating, programmer and room thermostat)	-	Fixed	SAP
Hot Water Generation System(s)	Same as space heating	-	-	
Hot Water Generation Efficiency	Same as space heating	-	-	
DHW demand	41.9	l/day	Fixed	NCM
DHW flow temp	60	°C	Fixed	
Communal Lighting Energy Consumption Calculation Inputs:				
Number of storeys in block	10	-	Fixed	
Number of hours lights are switched on per day	10	hr	Fixed	
Number of apartments per floor	8	-	Fixed	
Communal lighting gain	2	W/m2	Fixed	
Vertical Transport Energy Consumption Calculation Inputs:				
Number of lifts in block	2	-	Fixed	
Lift starts per day	300	-	Fixed	
Days of operation for lifts	365	-	Fixed	
Motor power	15 kW	kW	Fixed	
Floor height	3m	m	Fixed	
Lift speed	2 m/s	m/s	Fixed	
Standby power	1.32kW	kW	Fixed	
Ratio of travel distance	49%	-	Fixed	

Archetype 2 Assumptions

Parameter	Description	Unit	Type	Source
Archetype	3 Bed Semi-Detached House	-	Fixed	
Weather File	London TRY 2016	-	Fixed	
Orientation(s)	0°, 45°, 90°, 135°, 180°, 225°, 270°	-	Variable	
External Roof U-Value(s)	0.16, 0.14, 0.11	W/(m2.K)	Variable	Part L / LETI
Heat Loss Floor U-Value(s)	0.18, 0.13, 0.08	W/(m2.K)	Variable	Part L / LETI
External Wall U value(s)	0.26, 0.20, 0.13	W/(m2.K)	Variable	Part L / LETI
Window to wall ratio(s)	15%, 25%, 35%	%	Variable	
Window U value(s)	1.60, 1.30, 1.00	W/(m2.K)	Variable	Part L / LETI
Window g value(s)	0.40	-	Fixed	Part L
Y-value	0.08	-	Fixed	
Occupancy	3 (2.17)	-	Fixed	NCM
Small power load kitchen	30.3	W/m2	Fixed	NCM
Small power load living room	3.9	W/m2	Fixed	NCM
Small power load bedroom	3.6	W/m2	Fixed	NCM
Small power load bathroom	1.7	W/m2	Fixed	NCM
Small power load circulation	1.6	W/m2	Fixed	NCM
Lighting load	2	W/m2	Fixed	
Ventilation system	MVHR	-	Fixed	
Ventilation rate(s)	0.31	ACH/hr	Fixed	NCM
Heat recovery Efficiency	87%	-	Fixed	SAP
Fan SFP	0.8	W/(l/s)	Fixed	
Infiltration rate	3	m3/(h.m2fac) @50Pa	Fixed	LETI
Heating Generation System – 1	Gas boiler - condensing	-	Variable	
Heating Generation Efficiency – 1	84% (83.6% - summer) (80.7% - winter)	-	Fixed	SAP
Heating Generation Controls – 1	2107 (Programmer, TRVs and Bypass)	-	Fixed	SAP
Heating Generation System – 2	Direct electric	-	Variable	
Heating Generation Efficiency – 2	100%	-	Fixed	
Heating Generation System – 3	Air source heat pump	-	Variable	
Heating Generation Efficiency – 3	300%	-	Fixed	
Heating Generation Controls – 3	2309 (Charging system linked to use of community heating, programmer and room thermostat)	-	Fixed	SAP
Hot Water Generation System(s)	Same as space heating	-	-	
Hot Water Generation Efficiency	Same as space heating	-	-	
DHW demand	56.6	l/day	Fixed	NCM
DHW flow temp	60	°C	Fixed	

Archetype 3 Assumptions

Parameter	Description	Unit	Type	Source
Archetype	2 Bed Affordable Flat	-	Fixed	
Weather File	London TRY 2016	-	Fixed	
Orientation(s)	0°, 45°, 90°, 135°, 180°, 225°, 270°	-	Variable	
External Roof U-Value(s)	0.16, 0.14, 0.11	W/(m2.K)	Variable	Part L / LETI
Heat Loss Floor U-Value(s)	0.18, 0.13, 0.08	W/(m2.K)	Variable	Part L / LETI
External Wall U value(s)	0.26, 0.20, 0.13	W/(m2.K)	Variable	Part L / LETI
Window to wall ratio(s)	20%, 30%	%	Variable	
Window U value(s)	1.60, 1.30, 1.00	W/(m2.K)	Variable	Part L / LETI
Window g value(s)	0.40	-	Fixed	Part L
Y-value	0.08	-	Fixed	
Occupancy	2 (1.61)	-	Fixed	NCM
Small power load kitchen	30.3	W/m2	Fixed	NCM
Small power load living room	3.9	W/m2	Fixed	NCM
Small power load bedroom	3.6	W/m2	Fixed	NCM
Small power load bathroom	1.7	W/m2	Fixed	NCM
Small power load circulation	1.6	W/m2	Fixed	NCM
Lighting load(s)	2	W/m2	Fixed	
Ventilation system	Natural Ventilation	-	Fixed	
Ventilation rate(s)	N/A	ACH/hr	-	
Heat recovery Efficiency	N/A	-	-	
Fan SFP	N/A	W/(l/s)	-	
Infiltration rate	6, 8, 10	m3/(h.m2fac) @50Pa	Variable	
Heating Generation System – 1	Gas boiler - condensing	-	Variable	
Heating Generation Efficiency – 1	84% (83.6% - summer) (80.7% - winter)	-	Fixed	SAP
Heating Generation Controls – 1	2107 (Programmer, TRVs and Bypass)	-	Fixed	SAP
Heating Generation System – 2	Direct electric	-	Variable	
Heating Generation Efficiency – 2	100%	-	Fixed	
Heating Generation System – 3	Air source heat pump	-	Variable	
Heating Generation Efficiency – 3	300%	-	Fixed	
Heating Generation Controls – 3	2309 (Charging system linked to use of community heating, programmer and room thermostat)	-	Fixed	
Hot Water Generation System(s)	Same as space heating	-	-	
Hot Water Generation Efficiency	Same as space heating	-	-	
DHW demand	41.9	l/day	Fixed	NCM
DHW flow temp	60	°C	Fixed	
Communal Lighting Energy Consumption Calculation Inputs:				
Number of storeys in block	5	-	Fixed	
Number of hours lights are switched on per day	10	hr	Fixed	
Number of apartments per floor	6	-	Fixed	
Vertical Transport Energy Consumption Calculation Inputs:				
Number of lifts in block	2	-	Fixed	
Lift starts per day	300	-	Fixed	
Days of operation for lifts	365	-	Fixed	
Motor power	15	kW	Fixed	
Floor height	3	m	Fixed	
Lift speed	1	m/s	Fixed	
Standby power	1.32	kW	Fixed	
Ratio of travel distance	49%	-	Fixed	

Archetype 4 Assumptions

Parameter	Description	Unit	Type	Source	Comments
Archetype	Office	-	Fixed		
Weather File	London TRY 2016	-	Fixed		
Orientation(s)	0°, 45°, 90°, 135°, 180°, 225°, 270°	-	Variable		
External Roof U-Value(s)	0.16, 0.10	W/(m2.K)	Variable	Part L / LETI	
Heat Loss Floor U-Value(s)	0.18, 0.10	W/(m2.K)	Variable	Part L / LETI	
External Wall U value(s)	0.26, 0.12	W/(m2.K)	Variable	Part L / LETI	
Window to wall ratio(s)	40%, 50%, 60%	%	Variable		
Window U value(s)	1.60, 1.00	W/(m2.K)	Variable	Part L / LETI	
Window g value(s)	0.40, 0.30	-	Variable	Part L / LETI	
Occupancy Density	10	m^2/person	Fixed	NCM	
Small power load office	11.8	W/m2	Fixed	NCM	
Small power load toilets	5.48	W/m2	Fixed		
Small power load tea-points	14.72	W/m2	Fixed		
Small power load stairs/ corridors	1.85	W/m2	Fixed		
Small power load lifts/ risers	0	W/m2	Fixed		
Lighting load(s)	4.5	W/m2	Fixed		
Ventilation system	Central balanced AHU	-	Fixed		
Ventilation rate(s)	10	L/s/p	Fixed		
Heat recovery Efficiency	87%	-	Fixed		
Fan SFP	0.8	W/(l/s)	Fixed		Average SFP for AHU & FCUs
Infiltration rate	8, 3	m3/(h.m2fac) @50Pa	Variable		
Heating Generation System – 1	Gas boiler - condensing	-	Variable		
Heating Generation Efficiency – 1	84%	-	Fixed		
Heating Generation System – 2	Air source heat pump	-	Variable		
Heating Generation Efficiency – 2	300%	-	Fixed		
Cooling Generation System	Air source heat pump	-	Fixed		
Cooling Generation Efficiency	450%	-	Fixed		
Hot Water Generation System(s)	Direct electric	-	Fixed		
Hot Water Generation Efficiency	100%	-	Fixed		
DHW demand	16226	l/day	Fixed	NCM	
DHW flow temp	60	°C	Fixed		
Communal Lighting Energy Consumption Calculation Inputs:					
Number of storeys in block	7	-	Fixed		
Communal lighting gain for all spaces	4.5	W/m2	Fixed		
Vertical Transport Energy Consumption Calculation Inputs:					
Number of lifts in block	6	-	Fixed		
Lift starts per day	300	-	Fixed		
Days of operation for lifts	365	-	Fixed		
Motor power	15	kW	Fixed		
Floor height	4	m	Fixed		
Lift speed	2	m/s	Fixed		
Standby power	1.32	kW	Fixed		
Ratio of travel distance	44%	-	Fixed		

Archetype 5 Assumptions

Parameter	Description	Unit	Type	Source
Archetype	Warehouse	-	Fixed	
Weather File	London TRY 2016	-	Fixed	
Orientation(s)	0°, 45°, 90°, 135°, 180°, 225°, 270°	-	Variable	
External Roof U-Value(s)	0.16, 0.10	W/(m2.K)	Variable	Part L / LETI
Heat Loss Floor U-Value(s)	0.18, 0.10	W/(m2.K)	Variable	Part L / LETI
External Wall U value(s)	0.26, 0.12	W/(m2.K)	Variable	Part L / LETI
Window to wall ratio(s)	10%, 15%, 20%	%	Variable	
Window U value(s)	1.60, 1.00	W/(m2.K)	Variable	Part L / LETI
Window g value(s)	0.40, 0.30	-	Variable	Part L / LETI
Door U value	3.00, 1.20	W/(m2.K)	Variable	Part L / LETI
Occupancy	51	-	Fixed	NCM
Small power load office	12.0	W/m2	Fixed	NCM
Small power load toilet	4.7	W/m2	Fixed	NCM
Small power load warehouse	5.0	W/m2	Fixed	NCM
Lighting load office	5.5	W/m2	Fixed	BCO
Lighting load toilet	2.5	W/m2	Fixed	
Lighting load warehouse	1.5	W/m2	Fixed	
Ventilation system	Extract only	-	Fixed	
Ventilation rate(s)	1.0	ACH/hr	Fixed	
Heat recovery Efficiency	N/A	-	-	
Fan SFP	0.5	W/(l/s)	Fixed	
Infiltration rate	8, 3	m3/(h.m2fac) @50Pa	Variable	
Heating Generation System – 1	Gas boiler - condensing	-	Variable	
Heating Generation Efficiency – 1	80%	-	Fixed	SAP
Heating Generation System – 2	Direct electric	-	Variable	
Heating Generation Efficiency – 2	100%	-	Fixed	
Heating Generation System – 3	Air source heat pump	-	Variable	
Heating Generation Efficiency – 3	300%	-	Fixed	
Hot Water Generation System(s)	Direct electric	-	Fixed	
Hot Water Generation Efficiency	100%		Fixed	
DHW demand	100	l/day	Fixed	NCM
DHW flow temp	60	°C	Fixed	

Appendix B

References

References

Arup (2024). *Carbon & Climate Study*. [online] Available at: https://www.milton-keynes.gov.uk/sites/default/files/2024-07/Carbon%20%26%20Climate%20Study%20Recommendations.pdf [Accessed 4 Dec. 2024].

BBP, BRE, CIBSE, Carbon Trust, IStructE, LETI, RIBA, RICS and UKGBC (2024). *UK Net Zero Carbon Buildings Standard - Pilot Version Revision 1*. [online] Available at: https://www.nzcbuildings.co.uk/pilotversion [Accessed 4 Dec. 2024].

Bordass, B. (2020). Metrics for energy performance in operation: the fallacy of single indicators. *Buildings and Cities*, 1(1), pp.260–276. doi:https://doi.org/10.5334/bc.35.

BRE (n.d.). *Standard Assessment Procedure SAP 10*. [online] BRE Group. Available at: https://bregroup.com/expertise/energy/sap/sap10 [Accessed 5 Dec. 2024].

BRE (2023). *UK NCM: iSBEM for England*. [online] Available at: https://www.uk-ncm.org.uk/download.jsp?id=35 [Accessed 4 Dec. 2024].

CIBSE (2006). *TM22 Energy assessment and reporting method*. [online] Available at: https://www.cibse.org/knowledge-research/knowledge-portal/tm22-energy-assessment-and-reporting-methodology [Accessed 5 Dec. 2024].

CIBSE (2022). *TM54: Evaluating operational energy use at the design stage*. [online] CIBSE. Available at: https://www.cibse.org/knowledge-research/knowledge-portal/tm54-evaluating-operational-energy-use-at-the-design-stage-2022 [Accessed 4 Dec. 2024].

CIBSE Certification Ltd (n.d.). *Independent Design Review (IDR) Panel*. [online] Cibsecertification.co.uk. Available at: https://www.cibsecertification.co.uk/nabers-uk/products/design-for-performance/idr-panel/ [Accessed 5 Dec. 2024].

Curtis, J. and Pentecost, A. (2015). Household fuel expenditure and residential building energy efficiency ratings in Ireland. *Energy Policy*, 76, pp.57–65. doi:https://doi.org/10.1016/j.enpol.2014.10.010.

DesignBuilder Software Ltd (2023). *DesignBuilder* (Version 7.1.4.005) [software]. Available at: https://designbuilder.co.uk/download/previous-versions-of-designbuilder.

Elmhurst Energy (2022). *Design SAP 10* (Version 10.2)[software]. Available at:https://www.elmhurstenergy.co.uk/design-sap-software/.

Few, J., Manouseli, D., McKenna, E., Pullinger, M., Zapata-Webborn, E., Elam, S., Shipworth, D. and Oreszczyn, T. (2023). The over-prediction of energy use by EPCs in Great Britain: A comparison of EPC-modelled and metered primary energy use intensity. *Energy and Buildings*, [online] 288. doi:https://doi.org/10.1016/j.enbuild.2023.113024.

References

Greater London Authority (2021). *London Plan Guidance Documents - 'Be Seen' energy monitoring guidance*. [online] Available at: https://www.london.gov.uk/programmes-strategies/planning/implementing-london-plan/london-plan-guidance/be-seen-energy-monitoring-guidance [Accessed 5 Dec. 2024].

Greater London Authority (2022). *Energy Assessment Guidance*. [online] Available at: https://www.london.gov.uk/programmes-strategies/planning/planning-applications-and-decisions/pre-planning-application-meeting-service/energy-planning-guidance [Accessed 5 Dec. 2024].

HM Government (2021). *Conservation of fuel and power: Approved Document L*. [online] Available at: https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l [Accessed 4 Dec. 2024].

Hoare Lea (2021). *'Paris-proof' targets: Energy Usage Intensity explained.* [online] Hoare Lea. Available at: https://hoarelea.com/2021/06/10/paris-proof-targets-energy-usage-intensity-explained/ [Accessed 5 Dec. 2024].

Integrated Environmental Solutions Limited (2023). *IESVE* (Version7.1.4.005) [software]. Available at: Integrated Environmental Solutions Limited.

LETI (2020). *LETI Climate Emergency Design Guide*. [online] Available at: https://www.leti.uk/cedg [Accessed 4 Dec. 2024].

Milton Keynes City Council (2021). *Sustainable construction - Supplementary planning document*. [online] Available at: https://www.milton-keynes.gov.uk/planning-and-building/planning-policy/sustainable-construction-supplementary-planning-document [Accessed 5 Dec. 2024].

Milton Keynes City Council (2024). *Milton Keynes City Plan 2050 - Ambition and Objectives and Sustainability Appraisal Scoping Report*. [online] Available at: https://www.milton-keynes.gov.uk/sites/default/files/2024-07/Regulation%2018%20Consultation%20Statement.pdf [Accessed 5 Dec. 2024].

NABERS UK (2024). *The Rules - Energy for Offices*. [online] United Kingdom: CIBSE Certification Ltd. Available at: https://www.cibsecertification.co.uk/media/z0ajqvca/nabers-uk-energy-for-offices-rules-v21.pdf [Accessed 5 Dec. 2024].

Octopus Energy (2024). *Zero Bills and House Price Premiums*. [online] Available at: https://irp.cdn-website.com/037925b4/files/uploaded/Zero_Bills_and_Higher_Values_Octopus_Report_Mar24_Final.pdf [Accessed 5 Dec. 2024].

Penn, B. (2023). *Planning - Local Energy Efficiency Standards Update*. [online] Available at: https://questions-statements.parliament.uk/written-statements/detail/2023-12-13/hlws120 [Accessed 4 Dec. 2024].

ARUP