spring design

Monmouthshire County Council

Net Zero Carbon Homes
Feasibility Study and Cost Assessment

Work Stage 2.1 Technical Feasibility

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Architecture
Low Energy Consultancy
Civil Engineering
Structural Engineering
Urban Design

Contents

Section 1: Introduction

1.1 Introduction

Spring Design Consultancy Limited is appointed to assist Monmouthshire County Council in developing suitably evidenced Net Zero policy to guide, assess and determine applications for new-build residential development within the emerging Replacement Local Development Plan 2018-2033.

This process has been divided into distinct work stages:

Work Stage 1.1 Policy Review
2 Policy Approach
3 Evidence Base

Work Stage 2.1 Methodologies
2 Technical Feasibility

Work Stage 3.1 Cost Analysis

Work Stage 4.1 Evidence
2 Cost Implications
3 Scrutiny Skillset

Work Stage 5 Examination

This report summarises the assumptions informing and the results of whole life carbon assessment of Work Stage 2.2 Technical Feasibility.

1.2 Operational Targets

Operational energy relates to the amount of energy required to operate a building. For this exercise, two measures of operational energy were quantified: Space Heating Demand and Energy Use Intensity (EUI) which both use the metric of kWh/m²/yr.

Space heating demand refers to the amount of energy required to maintain a constant internal temperature of 20°C annually based on Treated Floor Area (TFA). This does not factor in the in-/ efficiencies of the heating system but quantifies the necessary input of heat. Space heating demand was the only critical threshold applied for compliance purposes.

Energy use intensity (EUI) relates to the sum of all energy use by a building on an annual basis based on Gross Internal Area (GIA). This can be delivered via the grid or by on-site renewables and accounts for space heating, hot water, lighting and all unregulated usage in occupation (e.g. all appliance usage) - factoring in system in/ efficiencies - but excludes EV charging. EUI enables the calculation of total electricity bills and, by analysis of its constituent parts, regulated energy use.

Four operational scenarios were agreed with MCC using identical fabric specifications derived from Approved Document L (Wales) 2022 Appendix E.

Operational emission scenarios	
Reference	Space heating demand
AD: L (Wales) 2025	N/A
AECB CarbonLite	40 kWh/m²/yr
MCC	25 kWh/m²/yr
LETI	15 kWh/m²/yr

The space heating demands follow the thresholds for which they are named including the newly introduced "MCC" (Monmouthshire County Council) reflecting the proposed policy position.

1.3 Glossary

1.3.1 Carbon Definitions

Clarity and consistency in the basic terminology used to discuss carbon and Net Zero is key to ensuring meaningful outcomes.

Carbon Definitions for the Built Environment, Buildings and Infrastructure: Improving Consistency in Whole Life Carbon Assessment and Reporting (2023) is a collaboration between professions throughout the construction industry including the Chartered Institute of Building Service Engineers (CIBSE), Institution of Civil Engineers (ICE), Institution of Structural Engineers (IStructE), Low Energy Transformation Initiative (LETI), Royal Institute of British Architects (RIBA), Royal Institute of Chartered Surveyors (RICS), UK Green Building Council and the Whole Life Carbon Network (WLCN) and applies the following.

Greenhouse Gases (GHG)
often 'carbon emissions' in general usage
'Greenhouse Gases' are constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds.

Whole Life Carbon
'Whole Life Carbon' emissions are the sum total of all asset related GHG emissions and removals, both operational and embodied over the life cycle of an asset including its disposal (Modules: A0-A5; B1-B7; B8 optional; C1-C4, all including biogenic carbon, with A0 assumed to be zero for buildings). Overall Whole Life Carbon asset performance includes separately reporting the potential benefits or loads from future energy or material recovery, reuse, and recycling and from exported utilities (Modules D1, D2).

Embodied Carbon *or* **Life Cycle Embodied Carbon**
'Embodied Carbon' emissions of an asset are the total GHG emissions and removals associated with materials and construction processes throughout the whole life cycle of an asset (Modules A0-A5, B1-B5, C1-C4, with A0 assumed to be zero for buildings).

Upfront Carbon - Buildings
'Upfront Carbon' emissions are the GHG emissions associated with materials and construction processes up to practical completion (Modules A0-A5). Upfront carbon excludes the biogenic carbon sequestered in the installed products at practical completion.

Operational Carbon - Energy, Buildings
'Operational Carbon - Energy' (Module B6) are the GHG emissions arising from all energy consumed by an asset in-use, over its life cycle.

Carbon Sequestration
'Carbon Sequestration' is the process by which carbon dioxide is removed from the atmosphere and stored within a material - e.g. stored as 'Biogenic Carbon' in 'Biomass' by plants/ trees through photosynthesis and other processes.

Biogenic Carbon
'Biogenic Carbon' refers to the carbon removals associated with carbon sequestration into biomass as well as any emissions associated with this sequestered carbon. Biogenic carbon must be reported separately if reporting only upfront carbon but should be included in the total if reporting embodied carbon or whole life carbon.

These definitions only address the GHGs with Global Warming Potential assigned by the Intergovernmental Panel on Climate Change (IPCC). A0 is generally assumed to be zero for buildings.

1.3.2 Net Zero Definitions

Net Zero (whole life) Carbon
A 'Net Zero (whole life) Carbon' Asset is one where the sum total of all asset related GHG emissions, both operational and embodied, over an asset's life cycle (Modules A0-A5, B1--B8, C1-C4) are minimized, which meets local carbon, energy and water targets or limits, and with residual 'offsets', equals zero.

To meet the requirements of 'Net Zero (whole life) Carbon' the definitions for 'Net Zero Upfront Carbon', Net Zero Embodied Carbon', 'Net Zero Capital Carbon', Net Zero operational Carbon - Energy', 'Net Zero Operational Carbon - Infrastructure', 'Net Zero In-Use Carbon Asset' and 'Net Zero Operational Carbon - Water' must also be individually met as applicable.

Net Zero Carbon Embodied Carbon *or*
Net Zero Life Cycle Embodied Carbon
A 'Net Zero Embodied Carbon' asset is one where the sum total of GHG emissions and removals over an asset's life cycle (Modules A0-A5, B1-B5 and C1-C4) are minimized, which meets local carbon targets or limits (e.g. $kgCO_2e/m^2$), and with additional 'offsets', equals zero.

Net Zero Upfront Carbon
A 'Net Zero Upfront Carbon' asset is where the sum of GHG emissions, excluding 'biogenic carbon', from Modules A0-A5 is minimized, which meets local carbon targets or limits (e.g. $kgCO_2e/m^2$), and with additional 'offsets', equals zero.

Net Zero Operational Carbon - Energy
A 'Net Zero Operational Carbon - Energy' asset is one where no fossil fuels are used, all energy use Module B6) has been minimized, meets the local energy use target or limit (e.g. kWh/m²/a) and all energy use is generated on- or off- site using renewables that demonstrate additionality. Direct emissions from renewables and any upstream emissions are 'offset'. *Direct emissions must include CH_4 and N_2O emissions from the combustion of biomass and biodiesel fuels. Upstream emissions include: direct and indirect emissions from energy generation and distribution, WTT emissions for energy consumed in the building and from energy generation and distribution.*

Net Zero Operational Carbon - Water
A 'Net Zero Operational Carbon - Water' asset is one where water use (Module B7) is minimized, meets local water targets or limits (e.g. litres/person/year) and where those GHG emissions arising from water supply and wastewater treatment are 'offset'.

Net Zero In-Use Asset
A 'Net Zero In-Use Carbon Asset' is one where on an annual basis the sum total of all asset related GHG emissions, both operational and embodied, (Modules B1-B8) are minimized, which meets local carbon, energy and water targets or limits, and with residual 'offsets', equals zero.

Additionality
Procurement of renewable energy for the asset's use which results in new installed renewable energy capacity that otherwise would not have occurred had the intervention not taken place.

Carbon Neutral
All carbon emissions are balanced with offsets based on carbon removals or avoided emissions.

Absolute Zero Carbon
Eliminating all carbon emissions without the use of credits.

1.3.3 Reference Terms

ASHP
Air source heat pump: heating and hot water from electrical source. Efficiency described by COP/ SCOP.

COP/ SCOP
(Seasonal) coefficient of performance: rate of conversion of electricity to useful heat energy.

MEV
Mechanical extract ventilation: constant mechanical extraction from 'wet' rooms (bathroom, kitchen, utility, WC, etc.) with fresh air from trickle vents circulated through the building by depressurisation.

MVHR
Mechanical ventilation with heat recovery: ventilation systems that ensure a constant throughput of fresh, filtered air. 'Waste' heat is transferred from outgoing exhaust air to incoming fresh air to pre-warm it and reduce heating demand.

CO_2e Emissions
Equivalent carbon dioxide emissions calculated using the global warming potential (GWP) of exhaust gases.

Form Factor
Expresses the relationship between the treated floor area and area of the thermal envelope. A better form factor signifies a more efficiently designed building.

Thermal Envelope
The insulated components (floors, walls, ceilings) that separate internal and external volumes. Note this often excludes features such as porches and balconies.

Treated Floor Area (TFA)
The floor area of the rooms within the building that are heated. It excludes the areas of internal partitions, doors, stairs and unusable spaces.

1.3.4 Archetypes

HT 211 - GIA c. 47 m² per dwelling
Three storey block of 9x one bedroom, two person flats accessed via communal core designed to WDQR 2021 and Lifetime Homes 2010.

Form factor: 1.97

HT 212 - GIA c. 54m² per dwelling
Two storey block of 4x one bedroom, two person walk-up flats with individual accesses designed to WDQR 2021 and Lifetime Homes 2010.

Form factor: 2.99

HT 421 - GIA 83m² per dwelling
Semi-detached two bedroom, four person houses designed to WDQR 2021 and Lifetime Homes 2010.

Form factor: 3.08

HT 900 - GIA 84 m² (900 ft²) per dwelling
Semi-detached three bedroom, five person houses for open market sale.

Form factor: 3.01

HT 1800 - GIA 168 m² (1800 ft²)
Detached four bedroom, eight person house for open market sale.

Form factor: 2.89

HT 2200 - GIA 211 m² (2200 ft²)
Detached four bedroom, eight person house for open market sale.

Form factor: 2.62

Section 2: Summary

2.1 Executive Summary

Lowering emissions in the built environment is critical to limiting anthropogenic climate change to 1.5°C and meeting established international, national and regional climate commitments.

As evidenced within this study, substantial operational energy savings (and therefore operational emission reductions) are achievable with only minor changes to building specifications.

This report assesses the relative operational energy requirements of three social housing and three open market housing new-build typologies to establish the technical feasibility of reducing energy demand:

- **HT 211** - 3 storey block of nine flats;
- **HT 212** - 2 storey block of four walk-up flats;
- **HT 421** - two semi-detached dwellings;
- **HT 900** - two semi-detached dwellings (900ft²);
- **HT 900** - detached single family dwelling (1800ft²);
- **HT 2200** - detached single family dwelling (2200ft²).

Four operational scenarios were modelled in PHPP applying identical external envelope u-values to achieve increasing levels of building performance:

- **AD: L (Wales) 2025** - future Building Regulations;
- **AECB CarbonLite** - 40 kWh/m²/yr threshold;
- **MCC** - 25 kWh/m²/yr threshold;
- **LETI** - 15 kWh/m²/yr threshold.

In all scenarios air source heat pumps were applied to supply hot water and space heating. If substituted for any alternative heating and/ or hot water systems the associated energy use (and operational emissions by extension) would increase substantially.

Heating demand reductions above 80% were achieved for the assessed typologies while using identical fabric u-values. This illustrates the benefit of well-considered airtightness and thermal bridge detailing with MVHR as the ventilation strategy and how this efficiently delivers high performance, low carbon buildings.

Headlines for operational analysis

- Heating demand reductions > 80% achievable between identical buildings by improving airtightness & thermal bridging complemented by MVHR
- EUI & CO_2e reductions of 30-60% available applying these improvements
- Reduced EUI requires 40-50% fewer PV panels to balance regulated energy
- Heat pumps reduce energy required for heating & hot water demand to < 25% of the direct electric equivalent

Unregulated energy loads remain constant for each building throughout each operational scenario as no changes were made to appliances or occupancy rates. This is to allow direct comparison of the impact of the interventions on the energy use intensity (EUI) and potential CO_2e emissions: these reduce by 30-60% progressing through the operational scenarios.

Regulated energy demand - comprising space heating, hot water, lighting and ventilation - is a critical output that reduces as energy performance improves. Only space heating would vary significantly between these modelled scenarios and therefore reductions can be understood as direct savings in space heating. Other technologies could be integrated to improve hot water demand but this did not form part of this exercise.

As building performance improves, and applying the MCC policy position, reduced regulated energy demand requires fewer photovoltaics to be installed.

Headlines for MCC policy position

- Space heating demand reduced 70% upgrading **AD: L (Wales) 2025** to **MCC**
- EUI & annual energy consumption reduced > 30% by adopting **MCC**
- Regulated energy & PV provisions reduced > 50% by adopting **MCC**
- Standard specifications developed to demonstrate technical feasibility of space heating demand targets despite challenging altitude & orientation of modelled scenarios

Beyond fewer photovoltaic panels, reductions in space heating demand would also translate into smaller heat pumps and heating infrastructure. This provides further opportunities for achieving savings on the capital cost of development and associated embodied carbon.

While the fabric specifications were developed to ensure compliance by the typologies with the worst form factor, **HT 211** illustrates how application of the same fabric standards is not the most materially efficient way of achieving high performance buildings. Terracing dwellings or consolidating units into larger apartment buildings is therefore a cost-effective way of reducing operational energy demand.

This approach must be balanced against placemaking and urban design aspirations but the same principle of terracing dwellings or building apartments to reduce operational carbon applies to reducing embodied carbon versus building detached, low-rise buildings.

While embodied carbon is not considered for the policy position it must be appreciated that material and specification choices significantly impact embodied carbon. Replacing masonry build with timber frame construction can reduce embodied emissions and facilitate increased CO_2e sequestration which can be enhanced by substituting conventional petrochemical and mineral insulants with short-rotation biogenic or recycled insulations such as hemp and cellulose.

In addition to the operational cost and carbon savings available by reducing heating demand, capital cost and embodied carbon savings can also be realised. While there are costs associated with installing MVHR units these are quickly offset by the savings available from installing smaller heating systems and requiring fewer photovoltaics to achieve the Net Zero energy demand.

Material efficiency goes beyond reducing embodied carbon: it also contributes to alleviating the complex issues of social justice and ethics. Particularly in the context of extracting and refining rare earth minerals, there are well-publicised transgressions of human rights and environmental protections. Technologies reliant upon these materials, chiefly renewables such as batteries and photovoltaics, must therefore be used as efficiently as possible in the pursuit of Net Zero and only sourced from those manufacturers who can offer visibility of their supply chains.

It is acknowledged that decarbonisation of existing buildings is critical to combatting climate change. New buildings must not contribute to this retrofit workload and so must be climate resilient, achieving the lowest embodied and operational carbon practicable. Due to the range of typologies, construction methodologies and heritage constraints present in Monmouthshire it was considered impractical to accommodate analysis of the stock within the current scope and timeframes.

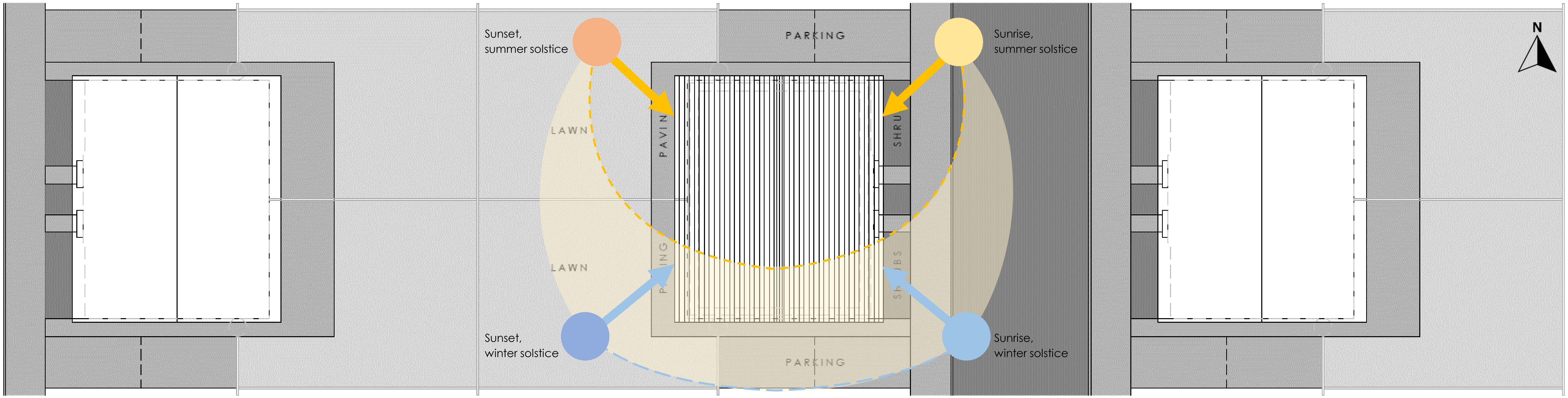

Fig. 01: Excerpt **2774-421(02)100 - Notional Site Layout**
Not to scale.

All typologies were modelled facing East-West as the least favourable orientation for solar gains. In winter this orientation excludes the majority of sunlight, limiting heat gains that could offset space heating demand; in summer it is exposed to low angle sun that can exacerbate issues with overheating.

Residential typologies were modelled to account for units of the same scale 15.0m from the front elevation and 21.0m from the rear. Non-residential typologies have slightly greater rear offsets to reflect the scale of potential parking courts.

Distances between buildings are derived from the principles established by Manual for streets (2007). Similar units are positioned to the East and West to establish horizon shading objects and ensure the assessment remains conservative: unshaded building models would overestimate the potential of solar gains to offset space heating demand.

Operational fabric specification

- Identical ground floor, external wall and roof u-values for all scenarios (N.B. **HT 211** could use degraded fabric u-values due to scale of building)
- Improved: airtightness, thermal bridging, door & window specification
- Ventilation strategy improved from MEV to increasingly efficient MVHR
- ASHP used for hot water & heating: systems other than heat pumps would substantially increase energy demand

Operational	AD: L (Wales) 2025	AECB CarbonLite	MCC	LETI
Building Fabric				
Ground floor	0.110 W/m²K	0.110 W/m²K	0.110 W/m²K	0.110 W/m²K
External wall	0.130 W/m²K	0.130 W/m²K	0.130 W/m²K	0.130 W/m²K
Roof	0.110 W/m²K	0.110 W/m²K	0.110 W/m²K	0.110 W/m²K
Air permeability	5.00 m³/m²/hr	1.50 m³/m²/hr	1.00 m³/m²/hr	0.60 m³/m²/hr
Thermal bridges	0.200 W/mK	0.100 W/mK	0.050 W/mK	-0.050 W/mK
Doors & Windows				
Frames U_f	1.400 W/m²K	0.850 W/m²K	0.810 W/m²K	0.810 W/m²K
Installation TB	0.040 W/mK	0.040 W/mK	0.040 W/mK	0.023 W/mK
Glazing U_g	1.120 W/m²K DG	1.190 W/m²K DG	0.550 W/m²K TG	0.550 W/m²K TG
Glazing g-value	0.64	0.64	0.63	0.63
Glazing edge	0.040 W/mK	0.025 W/mK	0.025 W/mK	0.025 W/mK
Ventilation Strategy				
Ventilation rate	30m³ per person/ hr	30m³ per person/ hr	30m³ per person/ hr	30m³ per person/ hr
Ventilation unit	MEV	MVHR energiSava 300	Zehnder ComfoAir 225	Zehnder ComfoAir 225
HR efficiency	N/A (extract only)	84%	92%	92%
Heating				
ASHP	Vaillant aroTHERM	Vaillant aroTHERM	Vaillant aroTHERM	Vaillant aroTHERM

Above is a summary of the fabric standards applied to the operational scenarios. These are expanded upon in 4: Specifications.

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2.2 Archetype Results

Modelling of the typologies clearly illustrates that application of standardised fabric specifications is not the most efficient way of delivering buildings that meet space heating demand targets. The specification, derived to ensure the compliance of heating demand for **HT 421** and **HT 900**, results in apartments **HT 211** overperforming by a significant margin. This offers a potential avenue for developers to realise cost savings on optimised designs with improved form factor.

In the context of the proposed MCC policy position, photovoltaics must be provided to balance the annual regulated energy consumed by a dwelling. In reality, until the complete decarbonisation of the grid, emissions would still be produced by regulated demand. This is a product of the electricity generated on-site being imported and exported to and from the grid as not all on-site generation can be immediately utilised or stored for long enough to be utilised.

Operational results are broken down into five separate metrics, tabulated individually for each typology. These were selected to evidence the correlation between thermal performance, operational emissions and the number of photovoltaics required to balance demand.

The applied metrics are:

- space heating demand;
- energy use intensity (EUI);
- annual energy use per dwelling;
- regulated energy demand;
- kWp of photovoltaics to balance regulated demand.

As demonstrated within the results tabulated opposite, minor improvements to build quality - not fabric specification – can significantly reduce operational emissions. Upgrading from the assumed build quality of **AD: L (Wales) 2025** to **LETI** lowers energy use and associated emissions by 35-50% across the assessed social and open market housing typologies. Full details of the interventions applied to improve performance are captured in 4: Specifications.

Headlines for residential typologies

- Performance of identical buildings is significantly impacted by airtightness, thermal bridging & ventilation > 80% reduction of heating demand possible
- EUI reductions > 30% in upgrading **AD: L (Wales) 2025** to **MCC**
- Lower demand requires 50% less PV to balance regulated energy
- Fewer PV panels reduces embodied carbon & realises cost savings
- Better form factor/ higher density significantly reduces heating demand

Diminishing energy demand also requires less on-site generation to balance regulated energy, reducing the size of photovoltaic arrays. Reducing numbers of photovoltaic panels lowers both the embodied energy and capital cost of the works. Such cost implications will be explored in Work Stage 3 - Cost Viability.

The graphs in 5: Building Assessment demonstrate how EUI is split between regulated and unregulated uses. As building performance improves, heating reduces from c. 35% of total consumption to < 10%.

EUI and regulated energy must be contextualised with the use of highly efficient ASHPs. The units specified deliver heating and hot water at a rate of 4.1 kWh of heat for every 1 kWh input of electricity: if heating and hot water were delivered by any other system, energy use and resulting emissions would increase c. 400%.

Operational scenarios	Space heating demand	Energy use intensity (EUI)	Annual energy use per dwelling	Regulated energy demand	PV to balance regulated
Operational outputs - HT 211					
AD: L (Wales) 2025	63.7 kWh/m$^2_{TFA}$/yr	75.3 kWh/m$^2_{GIA}$/yr	3,586 kWh/yr	61.1 kWh/m$^2_{GIA}$/yr	3.4 kWp
AECB CarbonLite	20.9 kWh/m$^2_{TFA}$/yr	38.2 kWh/m$^2_{GIA}$/yr	1,819 kWh/yr	23.9 kWh/m$^2_{GIA}$/yr	1.3 kWp
MCC	11.9 kWh/m$^2_{TFA}$/yr	32.6 kWh/m$^2_{GIA}$/yr	1,550 kWh/yr	18.3 kWh/m$^2_{GIA}$/yr	1.0 kWp
LETI	3.4 kWh/m$^2_{TFA}$/yr	28.2 kWh/m$^2_{GIA}$/yr	1,342 kWh/yr	13.9 kWh/m$^2_{GIA}$/yr	0.8 kWp
Operational outputs - HT 212					
AD: L (Wales) 2025	85.4 kWh/m$^2_{TFA}$/yr	66.9 kWh/m$^2_{GIA}$/yr	3,630 kWh/yr	51.1 kWh/m$^2_{GIA}$/yr	3.8 kWp
AECB CarbonLite	36.5 kWh/m$^2_{TFA}$/yr	39.2 kWh/m$^2_{GIA}$/yr	2,126 kWh/yr	23.4 kWh/m$^2_{GIA}$/yr	1.8 kWp
MCC	24.9 kWh/m$^2_{TFA}$/yr	36.7 kWh/m$^2_{GIA}$/yr	1,992 kWh/yr	21.0 kWh/m$^2_{GIA}$/yr	1.6 kWp
LETI	12.8 kWh/m$^2_{TFA}$/yr	34.0 kWh/m$^2_{GIA}$/yr	1,847 kWh/yr	18.3 kWh/m$^2_{GIA}$/yr	1.4 kWp
Operational outputs - HT 421					
AD: L (Wales) 2025	90.2 kWh/m$^2_{TFA}$/yr	64.4 kWh/m$^2_{GIA}$/yr	5,358 kWh/yr	45.8 kWh/m$^2_{GIA}$/yr	5.2 kWp
AECB CarbonLite	38.7 kWh/m$^2_{TFA}$/yr	44.5 kWh/m$^2_{GIA}$/yr	3,700 kWh/yr	25.9 kWh/m$^2_{GIA}$/yr	3.0 kWp
MCC	25.9 kWh/m$^2_{TFA}$/yr	42.7 kWh/m$^2_{GIA}$/yr	3,555 kWh/yr	24.2 kWh/m$^2_{GIA}$/yr	2.8 kWp
LETI	15.2 kWh/m$^2_{TFA}$/yr	40.5 kWh/m$^2_{GIA}$/yr	3,368 kWh/yr	21.9 kWh/m$^2_{GIA}$/yr	2.4 kWp
Operational outputs - HT 900					
AD: L (Wales) 2025	99.1 kWh/m$^2_{TFA}$/yr	72.6 kWh/m$^2_{GIA}$/yr	6,116 kWh/yr	50.2 kWh/m$^2_{GIA}$/yr	5.8 kWp
AECB CarbonLite	39.4 kWh/m$^2_{TFA}$/yr	50.7 kWh/m$^2_{GIA}$/yr	4,272 kWh/yr	28.3 kWh/m$^2_{GIA}$/yr	3.4 kWp
MCC	25.9 kWh/m$^2_{TFA}$/yr	49.0 kWh/m$^2_{GIA}$/yr	4,130 kWh/yr	26.6 kWh/m$^2_{GIA}$/yr	3.0 kWp
LETI	15.1 kWh/m$^2_{TFA}$/yr	46.8 kWh/m$^2_{GIA}$/yr	3,939 kWh/yr	24.3 kWh/m$^2_{GIA}$/yr	2.8 kWp
Operational outputs - HT 1800					
AD: L (Wales) 2025	72.8 kWh/m$^2_{TFA}$/yr	56.9 kWh/m$^2_{GIA}$/yr	9,549 kWh/yr	39.5 kWh/m$^2_{GIA}$/yr	9.6 kWp
AECB CarbonLite	33.7 kWh/m$^2_{TFA}$/yr	40.0 kWh/m$^2_{GIA}$/yr	6,724 kWh/yr	22.6 kWh/m$^2_{GIA}$/yr	5.6 kWp
MCC	22.0 kWh/m$^2_{TFA}$/yr	38.1 kWh/m$^2_{GIA}$/yr	6,401 kWh/yr	20.7 kWh/m$^2_{GIA}$/yr	5.0 kWp
LETI	12.3 kWh/m$^2_{TFA}$/yr	36.1 kWh/m$^2_{GIA}$/yr	6,059 kWh/yr	18.7 kWh/m$^2_{GIA}$/yr	4.6 kWp
Operational outputs - HT 2200					
AD: L (Wales) 2025	60.6 kWh/m$^2_{TFA}$/yr	49.9 kWh/m$^2_{GIA}$/yr	10,518 kWh/yr	36.1 kWh/m$^2_{GIA}$/yr	10.4 kWp
AECB CarbonLite	28.0 kWh/m$^2_{TFA}$/yr	32.8 kWh/m$^2_{GIA}$/yr	6,919 kWh/yr	19.0 kWh/m$^2_{GIA}$/yr	5.6 kWp
MCC	18.5 kWh/m$^2_{TFA}$/yr	31.4 kWh/m$^2_{GIA}$/yr	6,616 kWh/yr	17.5 kWh/m$^2_{GIA}$/yr	5.0 kWp
LETI	11.5 kWh/m$^2_{TFA}$/yr	29.8 kWh/m$^2_{GIA}$/yr	6,275 kWh/yr	15.9 kWh/m$^2_{GIA}$/yr	4.6 kWp

Section 3: Context

3.1 Replacement LDP

The Deposit Replacement Local Development Plan 2018-2033 (2024) (RLDP) proposes where and how new development will take place over the period to 2033. It outlines potential site allocations for different land uses such as housing and employment and policies to help tackle the declared climate and nature emergencies, safeguard the environment and secure high-quality design. When adopted the RLDP will be used as a basis for determining planning applications.

The Deposit RLDP allocates land for approximately 1,320-2,130 dwellings including 660-1,065 new affordable homes. A conservative estimate of the resulting GIA that will be built translate to 175,000 m²+ of residential development.

In May 2019 MCC declared a Climate Emergency with a commitment to strive to reduce its own carbon emissions to Net Zero in line with the 2030 target set by Welsh Government. This also established policy to encourage and support both residents and businesses to reduce carbon emissions and work with partners across the country to help develop and implement best practice methods to limit global warming to 1.5°C.

Following this declaration an action plan was published in October 2019, revised first in 2021 to address the attendant nature emergency and again in 2024 to reflect Monmouthshire's Community and Corporate Plan 2022-2028 with the ambition to create "a zero carbon county, supporting well-being, health and dignity for everyone at every stage of life".

Net Zero Carbon Homes Feasibility Study and Cost Assessment represents the culmination of these action plans to inform an evidence base for the policy proposed within the RLDP (pending this feasibility and the following viability assessment). In what Welsh Government have identified as the Decade of Action, and with hundreds of thousands of square metres of development anticipated, policy aimed at delivering low carbon housing is poised to make a significant impact in reducing carbon emissions.

3.2 Strategic Sites

The Deposit RLDP identifies Strategic Growth Areas and, within this, four key affordable housing-led sites. Approximately 89% of new dwelling allocations are anticipated within primary settlements with 600 in Abergavenny, 146 in Chepstow, 330 in Monmouth and 810 in Caldicot including Severnside.

Identification of these Strategic Sites is critical to the analysis of the Net Zero Carbon Homes as it informs the climatic assumptions, including altitude, used for PHPP modelling. Due to the variable topography of Monmouthshire, sites share few general characteristics and so modelling will adopt the worst-case scenario: this will provide conservative guidance on the required specification for buildings to comply with the proposed policy.

Within the BRE defined climate region (Severn) this establishes the most appropriate climate data set. It also confirms an altitude of 140m (Abergavenny East) as worst-case for development on the strategic sites: the majority of allocations within the RLDP are for lower altitude sites which will be subject to milder winter conditions, lowering the resultant space heating demand. Applying the maximum altitude in modelling should therefore stress test the agreed specification to ensure feasibility throughout Monmouthshire.

All new residential developments will be required to contribute towards the provision of an appropriate mix of market and affordable housing. Policy will require 50% affordable housing across new site allocations.

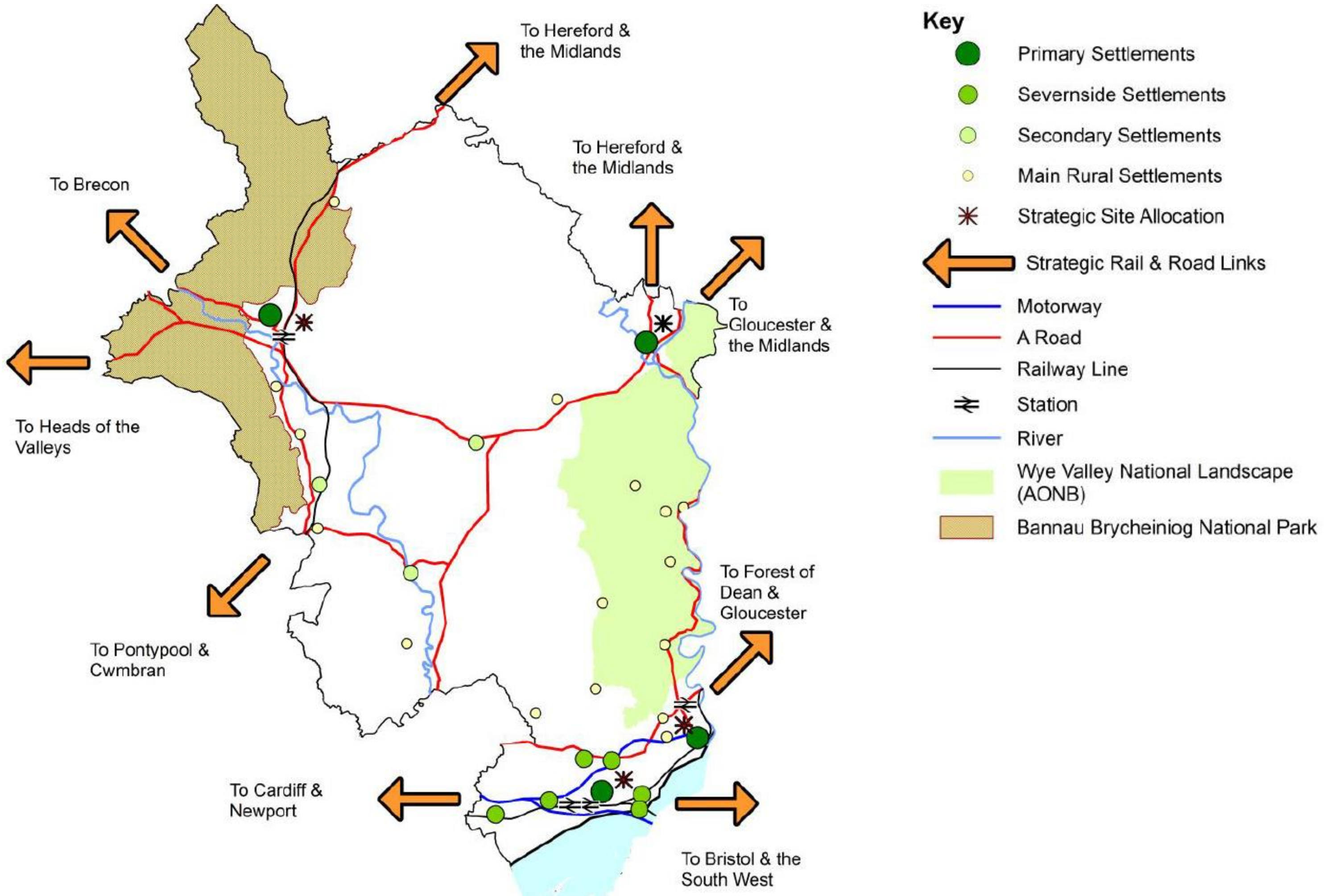


Fig. 02: MCC diagram illustrating how development and growth is anticipated to be delivered in Monmouthshire through the Deposit RLDP.

3.3 Principles

To reflect the anticipated growth within the RLDP a representative selection of housing typologies were identified for modelling. This comprises three social housing - HT 211, HT 212 and HT 421 - and three open market typologies - HT 900, HT 1800 and HT 2200.

General principles applied to the modelling are to emulate the worst-case scenario and therefore provide conservative guidance on what would be required to achieve the agreed operational standards.

As such, typologies were modelled facing East-West with units of the same scale 15.0m from the front elevation and 21.0m from the rear. For illustrative building drawings and their modelled context refer to 7: Appendices.

East-West orientation is the least favourable for solar gains as in winter it excludes the majority of sunlight, limiting the free heat gains that could otherwise offset space heating demand; in summer it exposes buildings to low angle solar gain that is difficult to control and can exacerbate issues with overheating.

East-West facing roofs have lower generation potential than an equivalent South facing roof. This provides a conservative kWp array sizing. However, East-West oriented photovoltaics can help reduce grid stress as output peaks are different to South-facing arrays.

Distances between buildings are derived from the principles established by Manual for streets (2007). Similar units are positioned to both the East and West to establish horizon shading objects and ensure the assessment remains conservative: unshaded building models would overestimate the potential of solar gains to offset space heating demand.

Section 4: Specifications

Scenario 1: AD: L (Wales) 2025

Building Fabric	
Ground floor	0.110 W/m²K
External wall	0.130 W/m²K
Roof	0.110 W/m²K
Air permeability	5.00 m³/m²/hr
Thermal bridges	0.200 W/mK
Doors & Windows	
Frames U_f	1.400 W/m²K uPVC
Installation TB	0.040 W/mK
Glazing U_g	1.120 W/m²K double low-e glazing 16mm Ar
Glazing g-value	0.64
Glazing edge	0.040 W/mK
Ventilation Strategy	
Ventilation rate	30m³ per person per hour via MEV
Ventilation unit	MEV
HR efficiency	N/A (extract only)
Ducting	
Duct insulation	
Heating	
ASHP	Vaillant aroTHERM plus
F-gas	R290
GWP	3
Controls	On/off

AD: L (Wales) 2022 Appendix E currently establishes the minimum performance specification for grant-funded social housing built in Wales. As adoption of the RLDP is anticipated for 2025-2026, it is appropriate to apply projected future scenarios to the modelling process to reflect an improving regulatory baseline.

In lieu of published details of proposed 2025 revisions, Appendix E has been applied as the baseline building fabric for AD: L (Wales) 2025. This reflects the Welsh Government aspiration to align market and social housing performance requirements.

Mirroring The Future Homes and Buildings Standard: 2023 consultation published in England the ventilation strategy applies mechanical extract ventilation (MEV).

Scenario 2: AECB CarbonLite

Building Fabric	
Ground floor	0.110 W/m²K
External wall	0.130 W/m²K
Roof	0.110 W/m²K
Air permeability	1.50 m³/m²/hr
Thermal bridges	0.100 W/mK
Doors & Windows	
Frames U_f	0.810-0.850 W/m²K Rehau Artevo
Installation TB	0.040 W/mK
Glazing U_g	1.190 W/m²K double glazing (4w-16Ar-KS4)
Glazing g-value	0.64
Glazing edge	0.025 W/mK
Ventilation Strategy	
Ventilation rate	30m³ per person per hour MVHR
Ventilation unit	EnviroVent energiSava 300
HR efficiency	84%
Ducting	Semi-rigid radial
Duct insulation	50mm closed cell Armaflex
Heating	
ASHP	Vaillant aroTHERM plus
F-gas	R290
GWP	3
Controls	On/off

AECB CarbonLite Building Standard was developed by the Association for Environment Conscious Building (AECB) to apply a less onerous demand-based performance standard than Passivhaus for the UK context. Excepting airtightness and ventilation rate, the values above are not prescribed by the AECB but were developed through the modelling process to ensure the least favourable typology (**HT 421** & **HT 900**) could come close to achieving the targeted space heating demand of 40 kWh/m²/yr.

Scenario 3: MCC

Building Fabric	
Ground floor	0.110 W/m²K
External wall	0.130 W/m²K
Roof	0.110 W/m²K
Air permeability	1.00 m³/m²/hr
Thermal bridges	0.050 W/mK
Doors & Windows	
Frames U_f	0.810-0.850 W/m²K Rehau Artevo
Installation TB	0.040 W/mK
Glazing U_g	0.550 W/m²K double glazing (4-18Ar-4-18Ar4)
Glazing g-value	0.63
Glazing edge	0.025 W/mK
Ventilation Strategy	
Ventilation rate	30m³ per person per hour MVHR
Ventilation unit	Zehnder ComfoAir 225
HR efficiency	92%
Ducting	Semi-rigid radial
Duct insulation	50mm closed cell Armaflex
Heating	
ASHP	Vaillant aroTHERM plus
F-gas	R290
GWP	3
Controls	Acc. to ambient temperature

MCC heating demand targets reflect the policy aspirations of Monmouthshire County Council. The values above are not prescribed by MCC but were developed through the modelling process to ensure the least favourable typology (**HT 421** & **HT 900**) could come close to achieving the targeted space heating demand of 25 kWh/m²/yr.

Scenario 4: LETI

Building Fabric	
Ground floor	0.110 W/m²K
External wall	0.130 W/m²K
Roof	0.110 W/m²K
Air permeability	0.60 m³/m²/hr
Thermal bridges	-0.050 W/mK
Doors & Windows	
Frames U_f	0.810-0.850 W/m²K Rehau Artevo
Installation TB	0.009-0.023 W/mK
Glazing U_g	0.550 W/m²K double glazing (4-18Ar-4-18Ar4)
Glazing g-value	0.63
Glazing edge	0.025 W/mK
Ventilation Strategy	
Ventilation rate	30m³ per person per hour MVHR
Ventilation unit	Zehnder ComfoAir 225
HR efficiency	92%
Ducting	Semi-rigid radial
Duct insulation	50mm closed cell Armaflex
Heating	
ASHP	Vaillant aroTHERM plus
F-gas	R290
GWP	3
Controls	Acc. to ambient temperature

LETI performance standards were developed by the Low Energy Transformation Initiative (LETI), formerly the London Energy Transformation Initiative, as net zero building standards that apply demand-based performance targets. Excepting ventilation rate, the values above are not prescribed by LETI but were developed through the modelling process to ensure the least favourable typology (**HT 421** & **HT 900**) could come close to achieving the targeted space heating demand of 15 kWh/m²/yr.

Section 5: Building Assessment

5.1 Methodology

Whole life carbon assessment for the built environment 2nd edition (2023) requires operational energy use predictions to be completed by a suitably qualified professional using the guidance outlined either in CIBSE's TM54, NABERS, ASHRAE Standard 90.1 or the Passivhaus Planning Package (PHPP). Approved Document L 2021/ 2022 calculations using the SAP methodology are explicitly forbidden: these are not considered to be either an appropriate or accurate prediction of energy consumption.

All modelling has been undertaken in the Passivhaus Planning Package (PHPP), an Excel-based design tool introduced in 1998 and subjected to continual refinement since. PHPP is produced by the Passivhaus Institute and aimed for use by architects, engineers and other building designers to determine compliance with the spectrum of low energy building standards.

The reliability of these calculations has been established over the last twenty-five years and tens of thousands of built projects. Extensive post-occupancy evaluation and scientific analysis of completed projects in various climates has compared operational heating demand with the calculated outputs and demonstrated high levels of correlation between PHPP calculations and the in-use performance of buildings. This proves that an appropriate understanding of building physics in building design, accompanied by quality control on site, can eliminate the performance gap.

PHPP considers a wide range of variables which affect heat loss, energy use and internal comfort, allowing for a superior fit between predicted energy use and real-world performance. Detailed modelling results in outputs that can be used to assess and optimise the latent efficiency of building proposals.

As presented elsewhere the reportable metrics calculated through PHPP are: space heating demand; energy use intensity (EUI); annual energy use per dwelling; regulated energy demand and photovoltaics per dwelling to balance regulated energy consumption.

All scenarios employ air source heat pumps (ASHPs) for hot water and heating. Heat strategy for Wales (2024) reviews the policy context for affordable warmth and decarbonisation of heating across the built environment and recognises heat pumps as the most suitable pathway for decarbonising heat and commits to review permitted development rights to facilitate adoption. Efficiency is expressed as the seasonal coefficient of performance (SCOP).

The SCOP describes the average rate of conversion for each 1 kWh of electricity delivered into the unit into multiple kWh of useful heat (whether for space heating or hot water). If heating and hot water were delivered by any other system, associated energy use and resulting CO_2e emissions would increase by at least that factor. Regulated energy and EUI must be recognised as significantly lower than would be possible with the use of any other heat source.

Individual ASHPs are modelled for all typologies but it is recognised this is unlikely to be the most cost-effective way of heating flats where air or ground heat pumps could feed communal heating and hot water circuits. However, this approach provides a replicable specification across typologies. Flats of a suitably high level of performance could utilise exhaust air heat pumps (EAHP) as an all-in-one solution.

Wales Net Zero 2035 Challenge Group's How could Wales meet energy needs whilst phasing out fossil fuels by 2035? (2024) identifies wind and solar as the dominant forms of renewable energy generation available in Wales. Photovoltaics are recognised as the most widely applicable building-mounted technology.

Batteries and other emerging forms of energy storage are not considered within this assessment because while they can also be used to load-shift and save money via accessing favourable tariffs, they do not address the need of the building to consume energy or achieve any overall reduction in energy consumption.

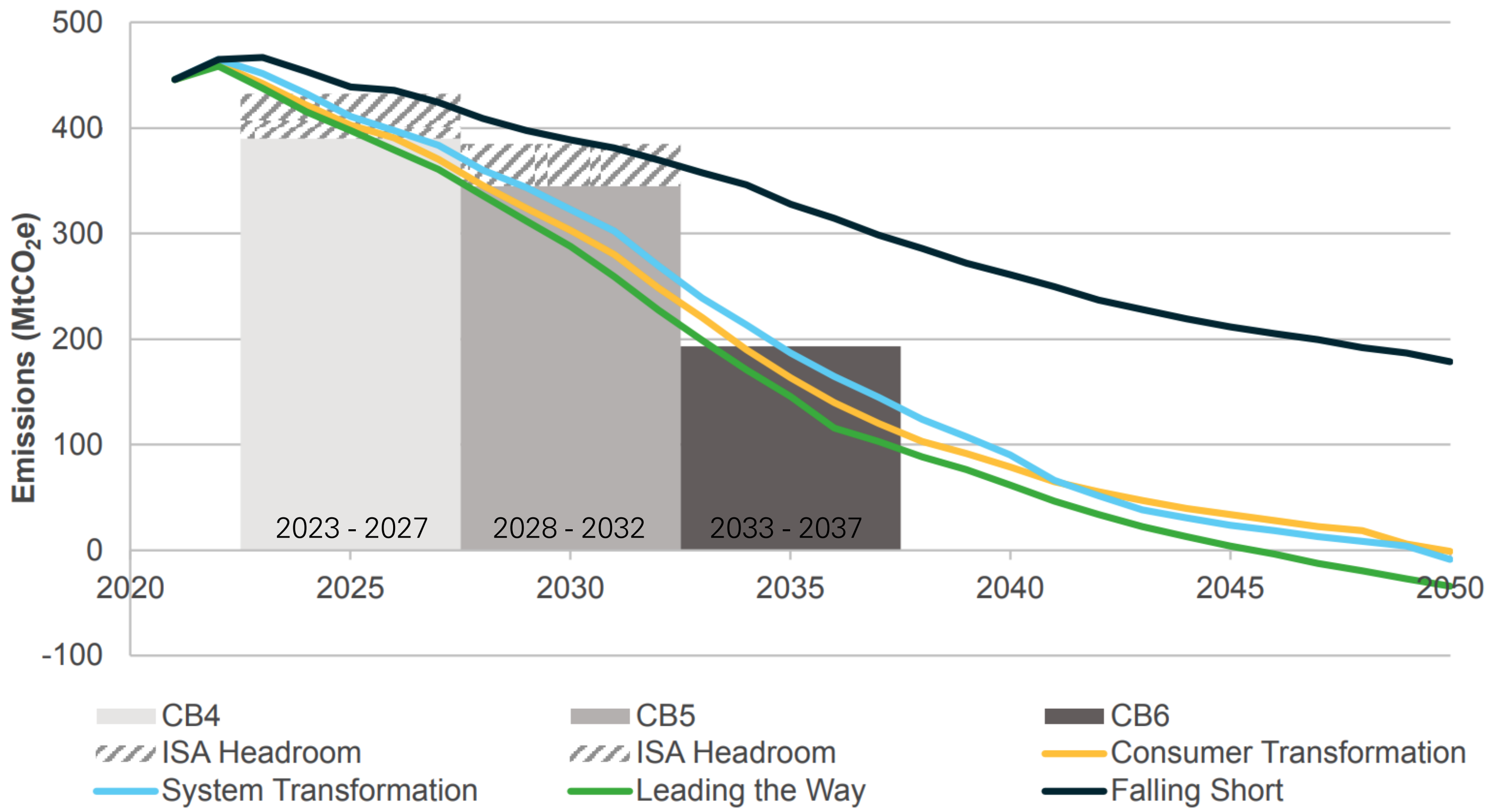


Fig. 03: Net greenhouse gas emissions including carbon budgets, National Grid Future Energy Scenarios (2023)

While not converted into CO_2e, operational emissions must be contextualised with an understanding of the operational carbon of electricity. WLCA primarily uses National Grid's Falling Short energy scenario (slowest electricity grid decarbonisation) with reducing emissions over time to avoid underestimating the extent of operational carbon. If the rate of grid decarbonisation increases then calculated operational carbon emissions would reduce accordingly.

The graph above illustrates four decarbonisation scenarios for the UK grid with **CB***X* = Carbon Budgets and **ISA** (sic) = International Aviation and Shipping.

Leading the Way reaches net zero by 2046 and achieves annual net emissions of -34 $MtCO_2e$ by 2050 which amounts to removal of Greenhouse Gas (GHG) emissions from the atmosphere.

Consumer Transformation and System Transformation reach net zero by 2050. Falling Short - the scenario applied by RICS WLCA 2nd edition methodology - does not achieve net zero by 2050 and results in 179 Mt of residual CO_2e emissions.

Net zero power sector emissions are reached in 2034 for both scenarios Leading the Way and Consumer Transformation: one year earlier than the target of 2035. System Transformation reaches net zero power sector emissions by 2035 and Falling Short in 2046.

How the grid ultimately decarbonises is not a matter MCC can control. However, policy should reduce grid demand and contribute to renewable generation.

Section 5: Building Assessment

5.2 Archetypes

5.2.1 HT 211

This section contains the quantitative assessment of **HT 211**. For full details of the modelled assumptions for each operational scenario refer to 4: Specifications; for illustrative drawings of the building and its modelled context, please refer to 7: Appendices.

Operational outputs demonstrate the benefits of form factor and the efficiencies of density achieved by flats, delivering significantly reduced space heating demand versus the applicable thresholds. AECB CarbonLite and MCC achieve approximately 50% reductions on the targeted space heating demand while LETI reduces to less than 25% of the requirement.

This typology illustrates that applying a standard specification is not the most efficient or economical way of achieving low energy building standards. Apartments and other buildings with good form factor can implement a lower fabric specification and still achieve the highest levels of performance. Reducing the fabric specification - in its simplest form, reducing the thickness of insulation - could lower build costs and achieve savings for developers.

AD: L (Wales) 2025 establishes the baseline for comparisons. Space heating demand is calculated at 63.7 kWh/m^2/yr with an EUI of 75.3 kWh/m^2/yr of which regulated energy comprises 61.1 kWh/m^2/yr.

AECB CarbonLite reduces space heating demand more than 65% from AD: L (Wales) 2025 and accomplishes a 50% reduction in EUI. Regulated energy demand falls 60% and therefore 40% of the photovoltaics are required to meet energy demand.

Applying the standardised specification for MCC's chosen policy position reduces space heating demand 80% from AD: L (Wales) 2025 and results in an almost 60% reduction in EUI and 70% reduction in regulated energy use, requiring a third of the photovoltaics.

Operational outputs					
Operational scenarios	Space heating demand	Energy use intensity (EUI)	Annual energy use per dwelling	Regulated energy demand	PV per dwelling to meet regulated
1 AD: L (Wales) 2025	63.7 kWh/m$^2_{TFA}$/yr	75.3 kWh/m$^2_{GIA}$/yr	3,586 kWh/yr	61.1 kWh/m$^2_{GIA}$/yr	3.4 kWp
2 AECB CarbonLite	20.9 kWh/m$^2_{TFA}$/yr	38.2 kWh/m$^2_{GIA}$/yr	1,819 kWh/yr	23.9 kWh/m$^2_{GIA}$/yr	1.3 kWp
3 MCC	11.9 kWh/m$^2_{TFA}$/yr	32.6 kWh/m$^2_{GIA}$/yr	1,550 kWh/yr	18.3 kWh/m$^2_{GIA}$/yr	1.0 kWp
4 LETI	3.4 kWh/m$^2_{TFA}$/yr	28.2 kWh/m$^2_{GIA}$/yr	1,342 kWh/yr	13.9 kWh/m$^2_{GIA}$/yr	0.8 kWp

Headlines for HT 211

- Space heating demand reduced 80% upgrading **AD: L (Wales) 2025** to **MCC**
- EUI & annual energy consumption reduced 60% by adopting **MCC**
- Regulated energy & PV provisions reduced 70% by adopting **MCC**
- Fabric specification could lower and still achieve the highest operational standards, realising CAPEX savings for developers & housing providers

Space heating demand reduces more than 90% from AD: L (Wales) 2025 to LETI. This achieves more than 60% reduction in EUI and almost 80% reduction in regulated energy, requiring less than a quarter of the photovoltaics to balance regulated use.

Installing photovoltaics on every roof slope in every orientation, approximately 99 panels could be accommodated on the building. Assuming 400W panels this translates into a potential 39.6 kWp array: 30.6 kWp is the minimum to meet the regulated energy use of AD: L (Wales) 2025 with just over 8 photovoltaic panels per dwelling.

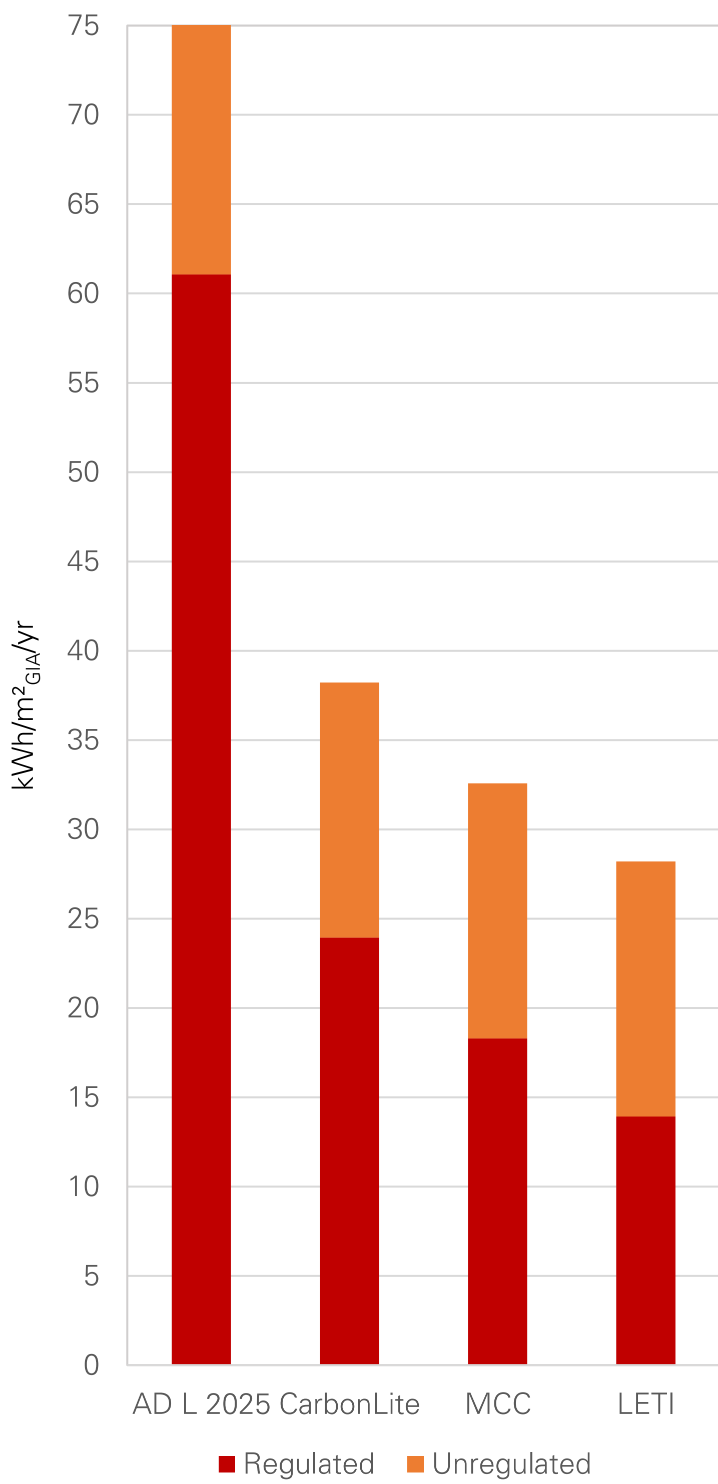
Being close to capacity limits the articulation of the building by constraining the design of the roofscape. The roof form could not change from pitched to flat (without a separately framed photovoltaic system) or the gables hipped without reducing potential panel numbers; similarly, dormers and rooflights cannot be introduced without impacting the size of the array.

The above commentary applies to the current three storey proposals. Attempting to densify with additional storeys could generate operational and embodied efficiencies: however, it would increase the number of photovoltaics required to be installed on the roof. This demonstrates that attempting to balance consumption without addressing energy demand constrains design opportunities and actively inhibits densification.

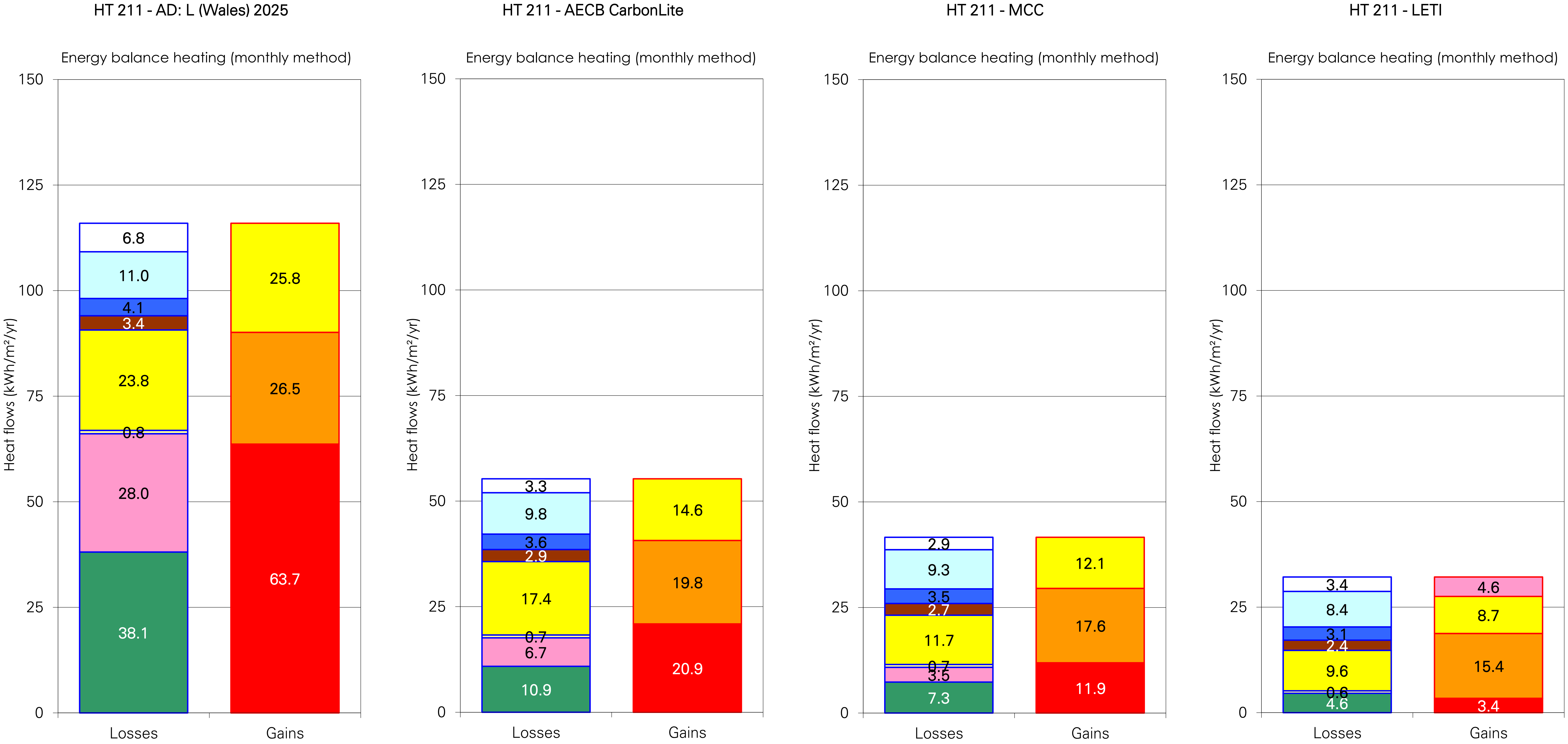
Energy consumption graphed opposite shows how use is split between regulated (heating, domestic hot water, ventilation and lighting) and the unregulated household uses. Regulated energy is represented in red with the already discussed reductions clearly illustrated between the operational scenarios.

As the occupancy and appliances were identical between all modelled scenarios, unregulated energy use - captured in orange - is the same in each instance.

Energy consumption - HT 211



Operational Scenarios



This page contains the energy balance from PHPP for the four energy scenarios. These graphical outputs illustrate where both heat losses and gains - which must be balanced to maintain a stable, comfortable internal temperature - occur: this information can be used to interrogate the performance of the building fabric and optimise specifications.

Annual energy bills calculated by multiplying EUI by Ofgem Q4 2024 electricity unit rate of £0.245 per kWh

Projected Annual Electricity Bills

- AD:L (Wales) 2025 £878.53
- AECB CarbonLite £445.64
- MCC £379.82
- LETI £328.85

excludes standing charge & PV offsets

spring design

5.2.2 HT 212

This section contains the quantitative assessment of **HT 212**. For full details of the modelled assumptions for each operational scenario refer to 4: Specifications; for illustrative drawings of the building and its modelled context, please refer to 7: Appendices.

Operational outputs					
Operational scenarios	Space heating demand	Energy use intensity (EUI)	Annual energy use per dwelling	Regulated energy demand	PV per dwelling to meet regulated
1 AD: L (Wales) 2025	85.4 kWh/m$^2_{TFA}$/yr	66.9 kWh/m$^2_{GIA}$/yr	3,630 kWh/yr	51.1 kWh/m$^2_{GIA}$/yr	3.8 kWp
2 AECB CarbonLite	36.5 kWh/m$^2_{TFA}$/yr	39.2 kWh/m$^2_{GIA}$/yr	2,126 kWh/yr	23.4 kWh/m$^2_{GIA}$/yr	1.8 kWp
3 MCC	24.9 kWh/m$^2_{TFA}$/yr	36.7 kWh/m$^2_{GIA}$/yr	1,992 kWh/yr	21.0 kWh/m$^2_{GIA}$/yr	1.6 kWp
4 LETI	12.8 kWh/m$^2_{TFA}$/yr	34.0 kWh/m$^2_{GIA}$/yr	1,847 kWh/yr	18.3 kWh/m$^2_{GIA}$/yr	1.4 kWp

Operational outputs demonstrate that despite generally improved form factor within flats there are certain inefficiencies for traditional walk-ups. However, the typology achieves the defined space heating demand of each operational scenario.

AD: L (Wales) 2025 establishes the baseline for comparisons. Space heating demand is calculated at 85.4 kWh/m²/yr with an EUI of 66.9 kWh/m²/yr of which regulated energy comprises 51.1 kWh/m²/yr.

AECB CarbonLite reduces space heating demand almost 60% from AD: L (Wales) 2025 and accomplishes a 40% reduction in EUI. Regulated energy demand falls 55% and therefore 45% of the photovoltaics are required to meet energy demand.

Applying the standardised specification for MCC's chosen policy position reduces space heating demand 70% from AD: L (Wales) 2025 and results in an almost 45% reduction in EUI and almost 60% reduction in regulated energy, requiring 40% of the photovoltaics.

Space heating demand reduces more than 85% from AD: L (Wales) 2025 to LETI. This achieves more than 50% reduction in EUI and almost 65% reduction in regulated energy, requiring 35% of the photovoltaics to balance regulated use.

Installing photovoltaics on the roofscape in both orientations could accommodate approximately 64 panels (not accounting for potential pop-ups from soil vent pipes, ventilation ducting or other penetrations in the roof). Assuming 400W panels this translates into a potential 25.6 kWp array: 15.2 kWp was assessed as the minimum quantity to meet the regulated energy demand of AD: L (Wales) 2025 with 9.5 photovoltaic panels required per dwelling.

While headroom does exist for additional photovoltaics beyond meeting regulated energy demand, this does nonetheless constrain the design of the roofscape. The roof form could not change from pitched to flat (without a separately framed photovoltaic system) and the gables cannot be hipped without reducing potential panel numbers; similarly the introduction of dormers and rooflights would have to be carefully managed to avoid significantly reducing the potential array size.

The above commentary applies to the current two storey proposals. Attempting to densify with a third storey could generate operational and embodied efficiencies: however, it would increase the number of photovoltaics required on the roof. This demonstrates that attempting to balance consumption without first addressing energy demand constrains design opportunities and can actively inhibit densification.

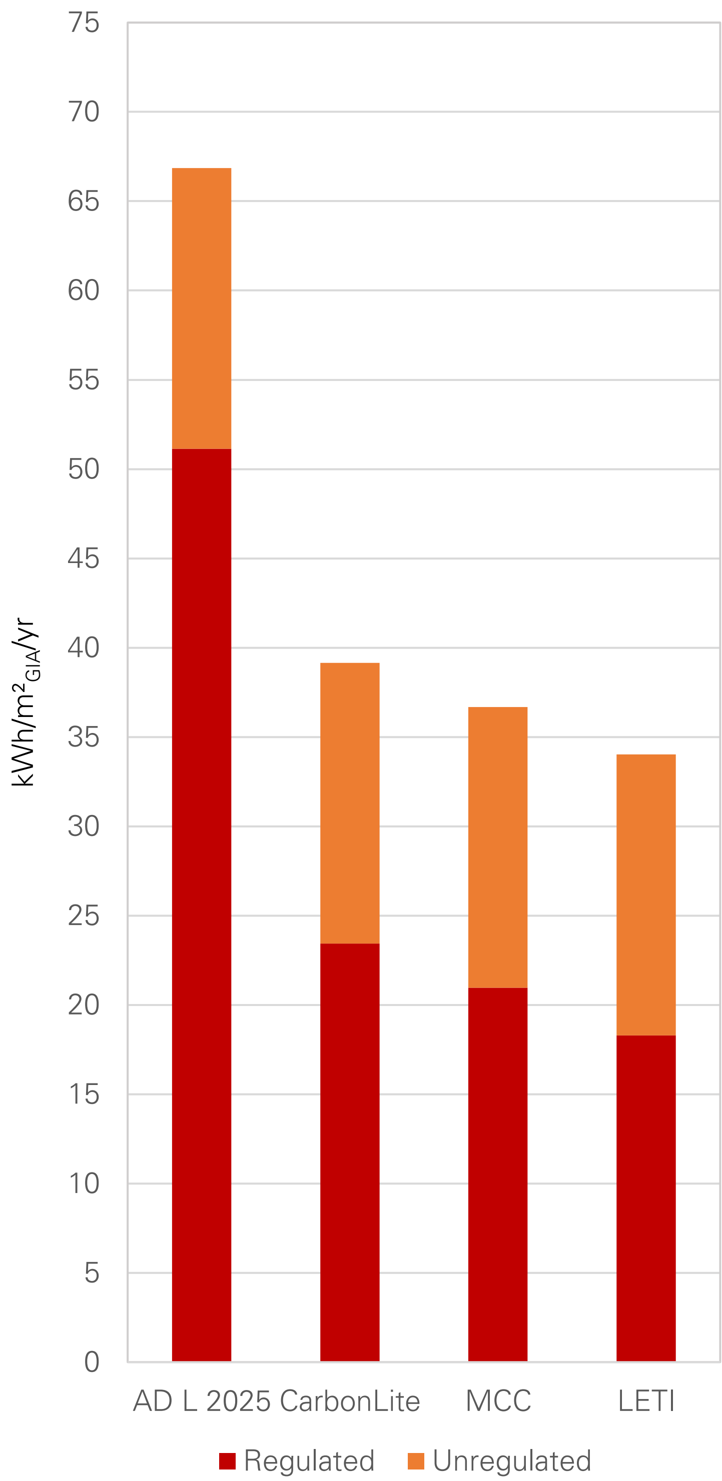
Energy consumption graphed opposite shows how use is split between regulated (heating, domestic hot water, ventilation and lighting) and the unregulated household uses. Regulated energy is represented in red with the already discussed reductions clearly illustrated between the operational scenarios.

As the occupancy and appliances were identical between all modelled scenarios, unregulated energy use - captured in orange - is the same in each instance.

Headlines for HT 212

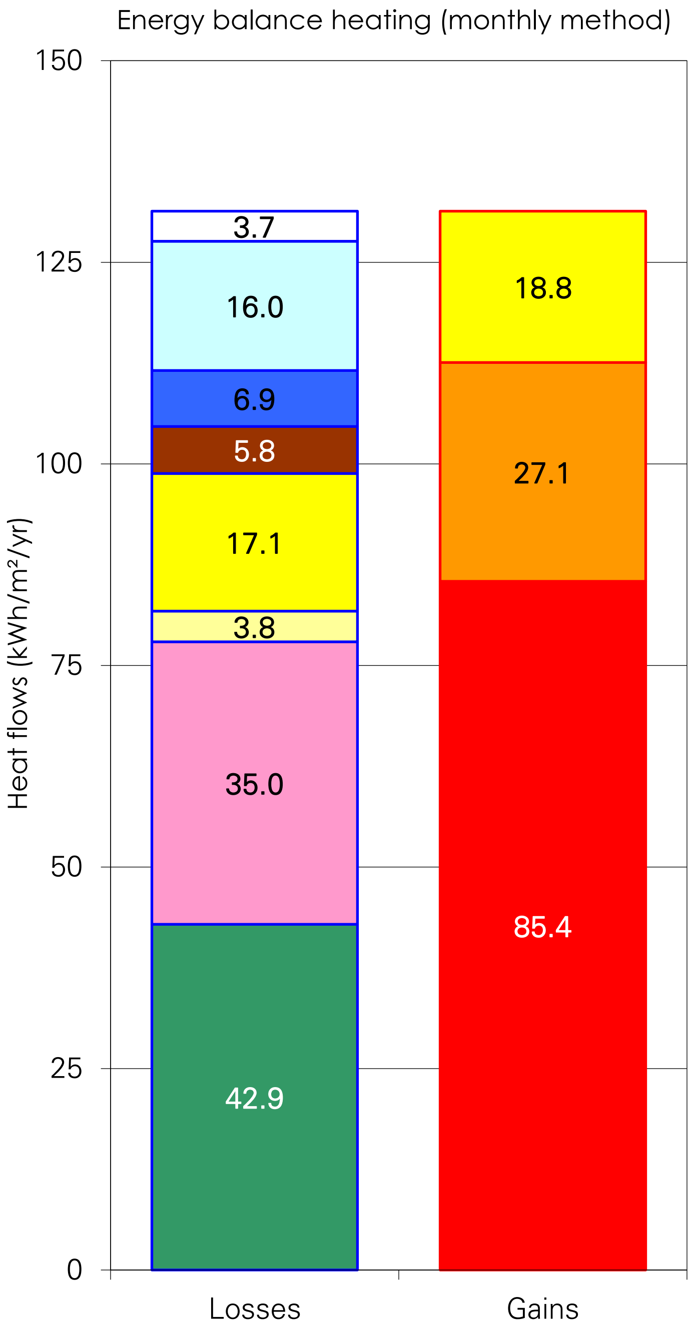
- Space heating demand reduced 70% upgrading **AD: L (Wales) 2025** to **MCC**
- EUI & annual energy consumption reduced 45% by adopting **MCC**
- Regulated energy & PV provisions reduced 60% by adopting **MCC**
- Standard specifications deliver all space heating demand targets across the modelled scenarios: optimised orientation could reduce specification

Energy consumption - HT 212

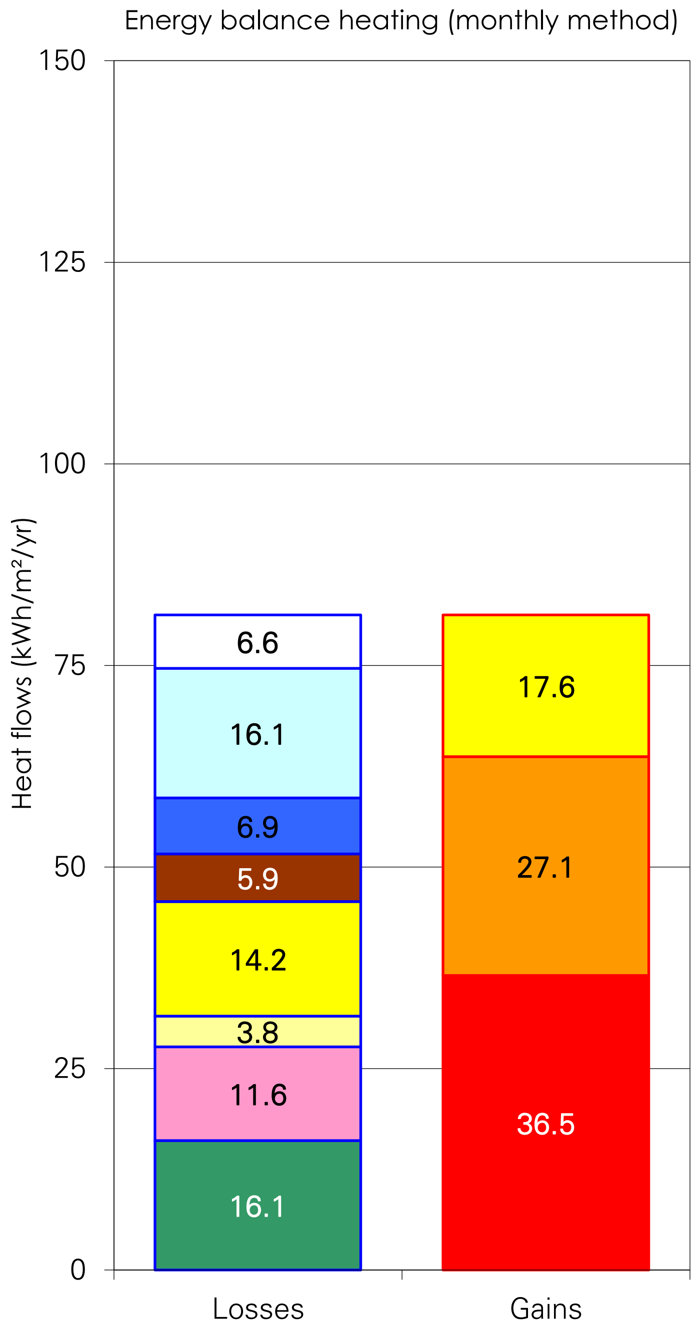


Operational Scenarios

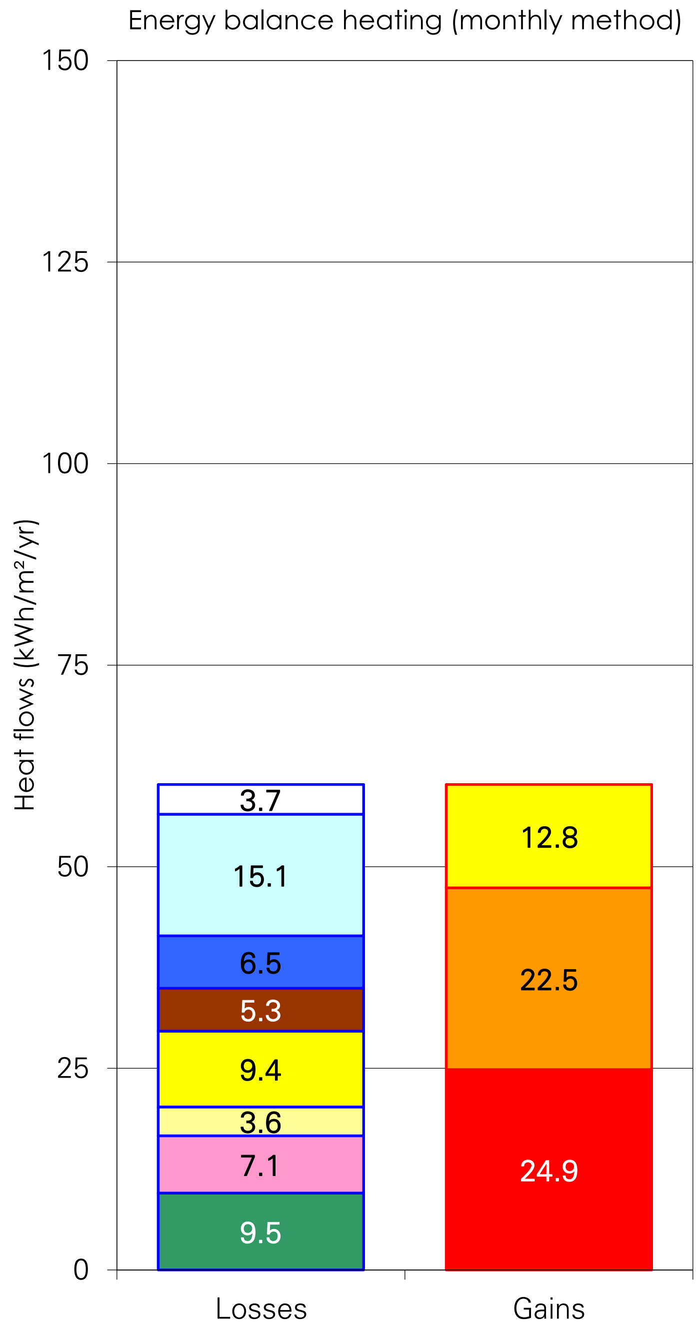
HT 212 - AD: L (Wales) 2025



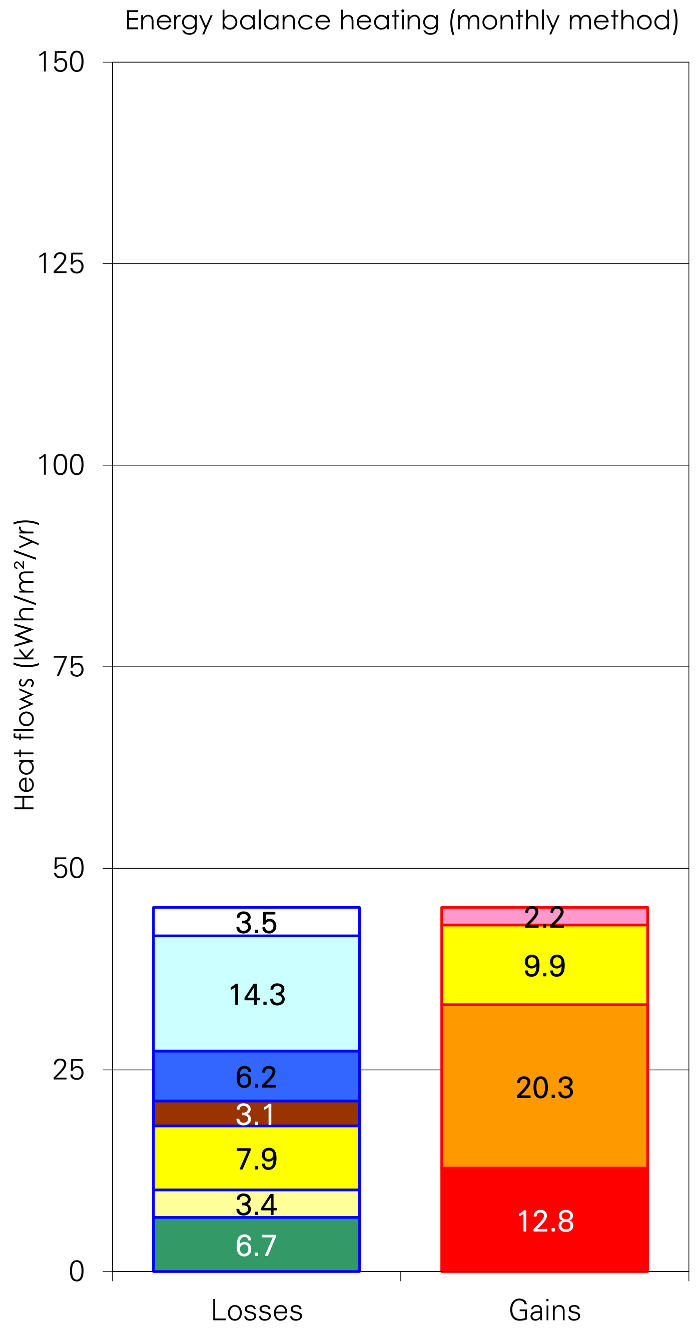
HT 212 - AECB CarbonLite



HT 212 - MCC



HT 212 - LETI



- Non-useful gains
- External walls
- Roof/ ceiling
- Floor slab
- Windows
- External door
- Thermal bridges
- Ventilation
- Thermal bridges
- Solar gains
- Internal gains
- Heating demand

This page contains the energy balance from PHPP for the four energy scenarios. These graphical outputs illustrate where both heat losses and gains - which must be balanced to maintain a stable, comfortable internal temperature - occur: this information can be used to interrogate the performance of the building fabric and optimise specifications.

Annual energy bills calculated by multiplying EUI by Ofgem Q4 2024 electricity unit rate of £0.245 per kWh

Projected Annual Electricity Bills

- AD:L (Wales) 2025 £889.43
- AECB CarbonLite £520.94
- MCC £488.06
- LETI £452.56

excludes standing charge & PV offsets

5.2.3 HT 421

This section contains the quantitative assessment of **HT 421**. For full details of the modelled assumptions for each operational scenario refer to 4: Specifications; for illustrative drawings of the building and its modelled context, please refer to 7: Appendices.

Operational outputs demonstrate the inefficiencies associated with smaller semi-detached dwellings due to poor form factor. While achieving the defined space heating demand for both AECB CarbonLite and LETI this typology falls just short of the MCC target.

As the modelled scenarios apply the maximum altitude of strategic development sites and the least favourable building orientation, failing to achieve the threshold by less than 5% is considered acceptable and would not present the same issue on lower altitude sites. At or above the modelled 140m altitude the issue could be overcome by simply optimising orientation with no additional capital expenditure; alternatively, properties could be organised in terraces to significantly reduce space heating demand.

AD: L (Wales) 2025 establishes the baseline for comparisons. Space heating demand is calculated at 90.2 kWh/m²/yr with an EUI of 64.4 kWh/m²/yr of which regulated energy comprises 45.8 kWh/m²/yr.

AECB CarbonLite reduces space heating demand almost 60% from AD: L (Wales) 2025 and accomplishes a 30% reduction in EUI. Regulated energy demand falls 45% and therefore 55% of the photovoltaics are required to meet energy demand.

Applying the standardised specification for MCC's chosen policy position reduces space heating demand 70% from AD: L (Wales) 2025 and results in an almost 35% reduction in EUI and almost 50% reduction in regulated energy, requiring 50% of the photovoltaics.

Operational outputs					
Operational scenarios	Space heating demand	Energy use intensity (EUI)	Annual energy use per dwelling	Regulated energy demand	PV per dwelling to meet regulated
1 AD: L (Wales) 2025	90.2 $kWh/m^2_{TFA}/yr$	64.4 $kWh/m^2_{GIA}/yr$	5,358 kWh/yr	45.8 $kWh/m^2_{GIA}/yr$	5.2 kWp
2 AECB CarbonLite	38.7 $kWh/m^2_{TFA}/yr$	44.5 $kWh/m^2_{GIA}/yr$	3,700 kWh/yr	25.9 $kWh/m^2_{GIA}/yr$	3.0 kWp
3 MCC	25.9 $kWh/m^2_{TFA}/yr$	42.7 $kWh/m^2_{GIA}/yr$	3,555 kWh/yr	24.2 $kWh/m^2_{GIA}/yr$	2.8 kWp
4 LETI	15.2 $kWh/m^2_{TFA}/yr$	40.5 $kWh/m^2_{GIA}/yr$	3,368 kWh/yr	21.9 $kWh/m^2_{GIA}/yr$	2.4 kWp

Headlines for HT 421

- Space heating demand reduced 70% upgrading **AD: L (Wales) 2025** to **MCC**
- EUI & annual energy consumption reduced 35% by adopting **MCC**
- Regulated energy & PV provisions reduced 50% by adopting **MCC**
- Applying standard specification falls just short of **MCC** threshold: lower altitude development would comply, as would optimised orientation

Space heating demand reduces by almost 85% from AD: L (Wales) 2025 to LETI. This achieves more than 35% reduction in EUI and more than 50% reduction in regulated energy, requiring 50% of the photovoltaics to balance regulated use.

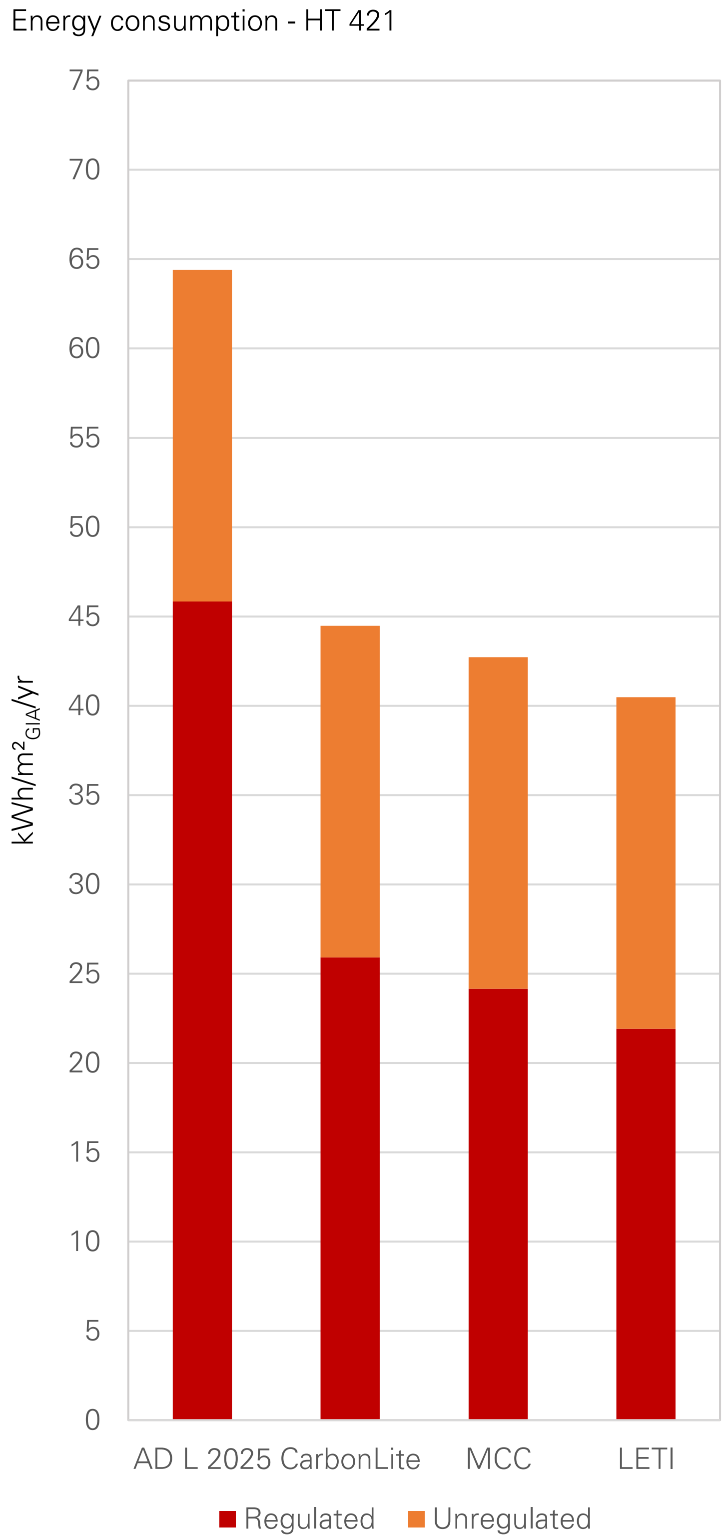
Installing panels on both roof slopes accommodates a maximum 30 panels per dwelling. Assuming 400W panels this translates into maximum 12 kWp array for each with a requirement for 5.2 kWp (13 panels) to balance the calculated regulated energy demand of AD: L (Wales) 2025.

While this demonstrates significant headroom, any features added to the roofscape could either displace panels or create shading that would reduce the output of the photovoltaics. As such the introduction of any features into the roofscape - including rooflights and dormers if taken to 2.5 storeys to increase density - must be carefully managed to avoid reducing the potential array size. Similarly the roof form could not change from pitched to flat (without a separately framed photovoltaic system) and the gables cannot be hipped without reducing potential panel numbers.

As referenced above, this commentary applies to two storey proposals. Creating rooms in the roof or adding a third storey could generate operational and embodied efficiencies but would also increase the number of photovoltaics required on the roof.

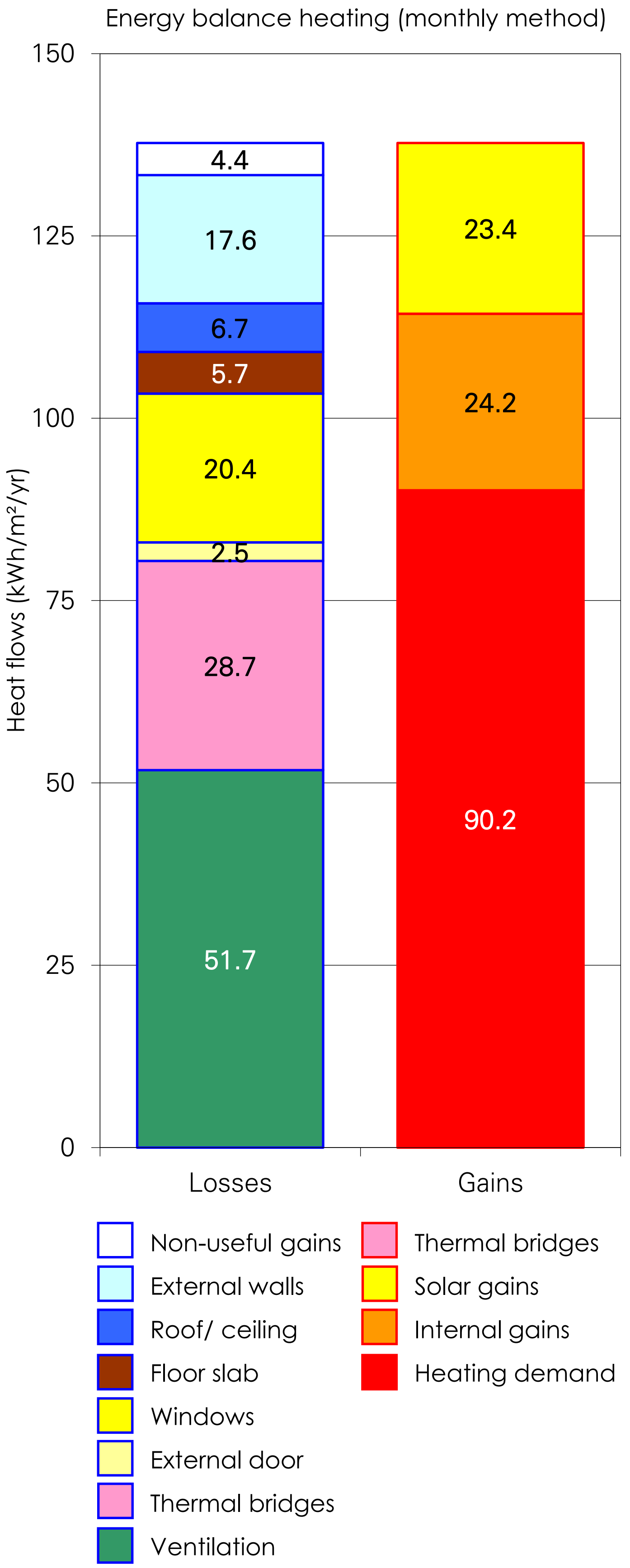
Energy consumption graphed opposite shows how use is split between regulated (heating, domestic hot water, ventilation and lighting) and the unregulated household uses. Regulated energy is represented in red with the already discussed reductions clearly illustrated between the operational scenarios.

As the occupancy and appliances were identical between all modelled scenarios, unregulated energy use - captured in orange - is the same in each instance.

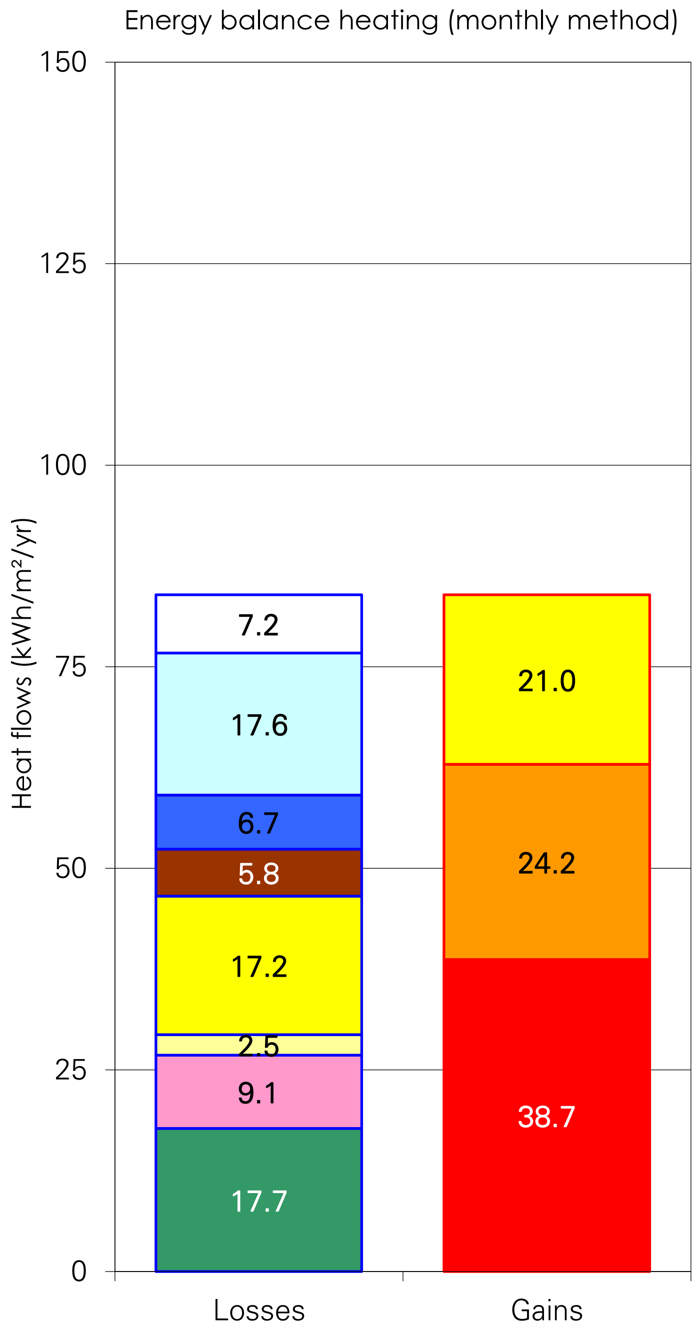


Operational Scenarios

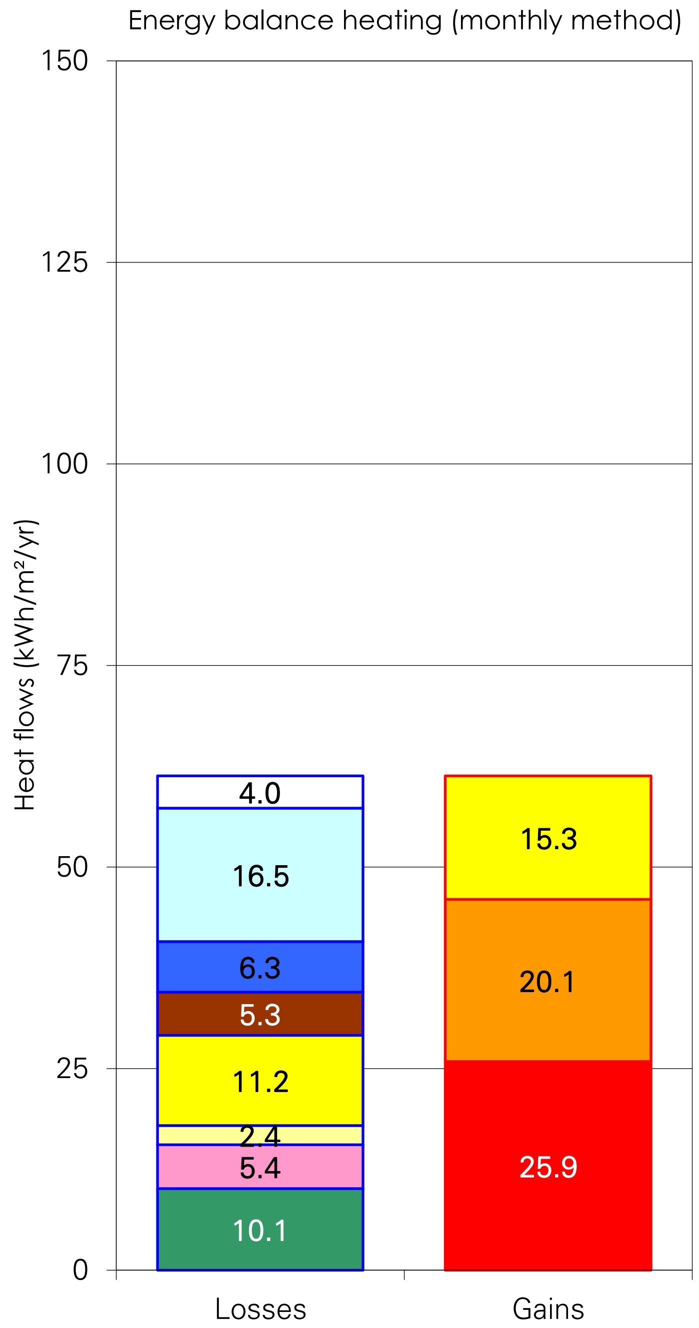
HT 421 - AD: L (Wales) 2025



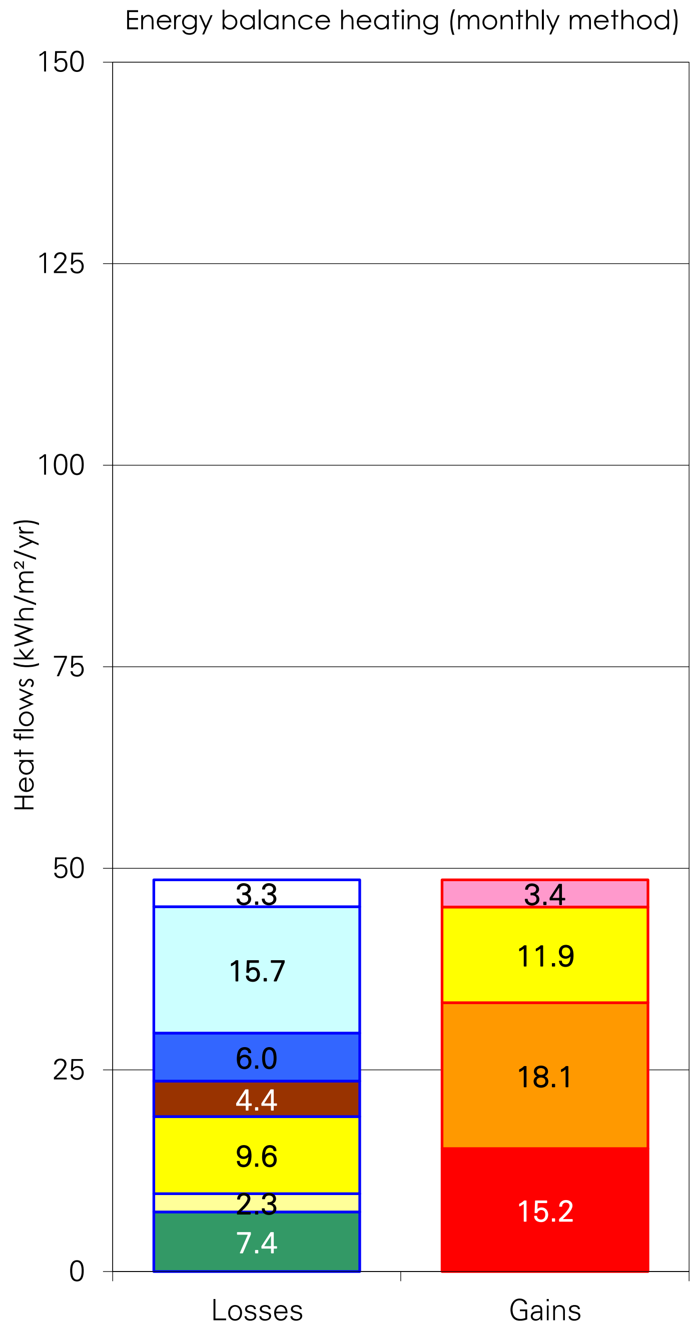
HT 421 - AECB CarbonLite



HT 421 - MCC



HT 421 - LETI



This page contains the energy balance from PHPP for the four energy scenarios. These graphical outputs illustrate where both heat losses and gains - which must be balanced to maintain a stable, comfortable internal temperature - occur: this information can be used to interrogate the performance of the building fabric and optimise specifications.

Annual energy bills calculated by multiplying EUI by Ofgem Q4 2024 electricity unit rate of £0.245 per kWh

Projected Annual Electricity Bills

• AD:L (Wales) 2025	£1,312.66
• AECB CarbonLite	£906.51
• MCC	£870.86
• LETI	£825.10

excludes standing charge & PV offsets

5.2.4 HT 900

This section contains the quantitative assessment of **HT 900**. For full details of the modelled assumptions for each operational scenario refer to 4: Specifications; for illustrative drawings of the building and its modelled context, please refer to 7: Appendices.

Operational outputs demonstrates how these semi-detached open market typology performs. Despite similarities with **HT 421** it has increased occupancy courtesy of an additional bedroom and an en suite to Bed 1. While these changes do little to impact space heating demand - it also achieves targets for AECB CarbonLite and LETI, failing MCC - EUI and regulated energy demand are significantly increased.

As the modelled scenarios apply the maximum altitude of strategic development sites and the least favourable building orientation, failing to achieve the threshold by less than 5% is considered acceptable and would not present the same issue on lower altitude sites. At or above the modelled 140m altitude the issue could be overcome by simply optimising orientation with no additional capital expenditure; alternatively, properties could be organised in terraces to significantly reduce space heating demand.

AD: L (Wales) 2025 establishes the baseline for comparisons. Space heating demand is calculated at 99.1 kWh/m²/yr with an EUI of 72.6 kWh/m²/yr of which regulated energy comprises 50.2 kWh/m²/yr.

AECB CarbonLite reduces space heating demand 60% from AD: L (Wales) 2025 and accomplishes a 30% reduction in EUI. Regulated demand reduces almost 45% and therefore 55% of the photovoltaics are required to balance this demand.

Applying the standardised specification for MCC's chosen policy position reduces space heating demand almost 75% from AD: L (Wales) 2025 and results in 30% reduction in EUI and almost 50% reduction in regulated energy, requiring 50% of the photovoltaics.

Space heating demand reduces 85% from AD: L (Wales) 2025 to LETI. This achieves more than 35% reduction in EUI and 50% regulated energy demand, requiring fewer than 50% of the photovoltaics.

As **HT 421** a maximum 30 panels could be installed per dwelling across the roof. This potential 12 kWp array meets the required 5.8 kWp (14.5 panels) to balance the regulated energy of AD: L (Wales) 2025.

Operational outputs						
Operational scenarios	Space heating demand	Energy use intensity (EUI)	Annual energy use per dwelling	Regulated energy demand	PV per dwelling to meet regulated
1 AD: L (Wales) 2025	99.1 $kWh/m^2_{TFA}/yr$	72.6 $kWh/m^2_{GIA}/yr$	6,116 kWh/yr	50.2 $kWh/m^2_{GIA}/yr$	5.8 kWp
2 AECB CarbonLite	39.4 $kWh/m^2_{TFA}/yr$	50.7 $kWh/m^2_{GIA}/yr$	4,272 kWh/yr	28.3 $kWh/m^2_{GIA}/yr$	3.4 kWp
3 MCC	25.9 $kWh/m^2_{TFA}/yr$	49.0 $kWh/m^2_{GIA}/yr$	4,130 kWh/yr	26.6 $kWh/m^2_{GIA}/yr$	3.0 kWp
4 LETI	15.1 $kWh/m^2_{TFA}/yr$	46.8 $kWh/m^2_{GIA}/yr$	3,939 kWh/yr	24.3 $kWh/m^2_{GIA}/yr$	2.8 kWp

Headlines for HT 900

- Space heating demand reduced 75% upgrading **AD: L (Wales) 2025** to **MCC**
- EUI & annual energy consumption reduced 30% by adopting **MCC**
- Regulated energy & PV provisions reduced 50% by adopting **MCC**
- Applying standard specification falls just short of **MCC** threshold: lower altitude development would comply, as would optimised orientation

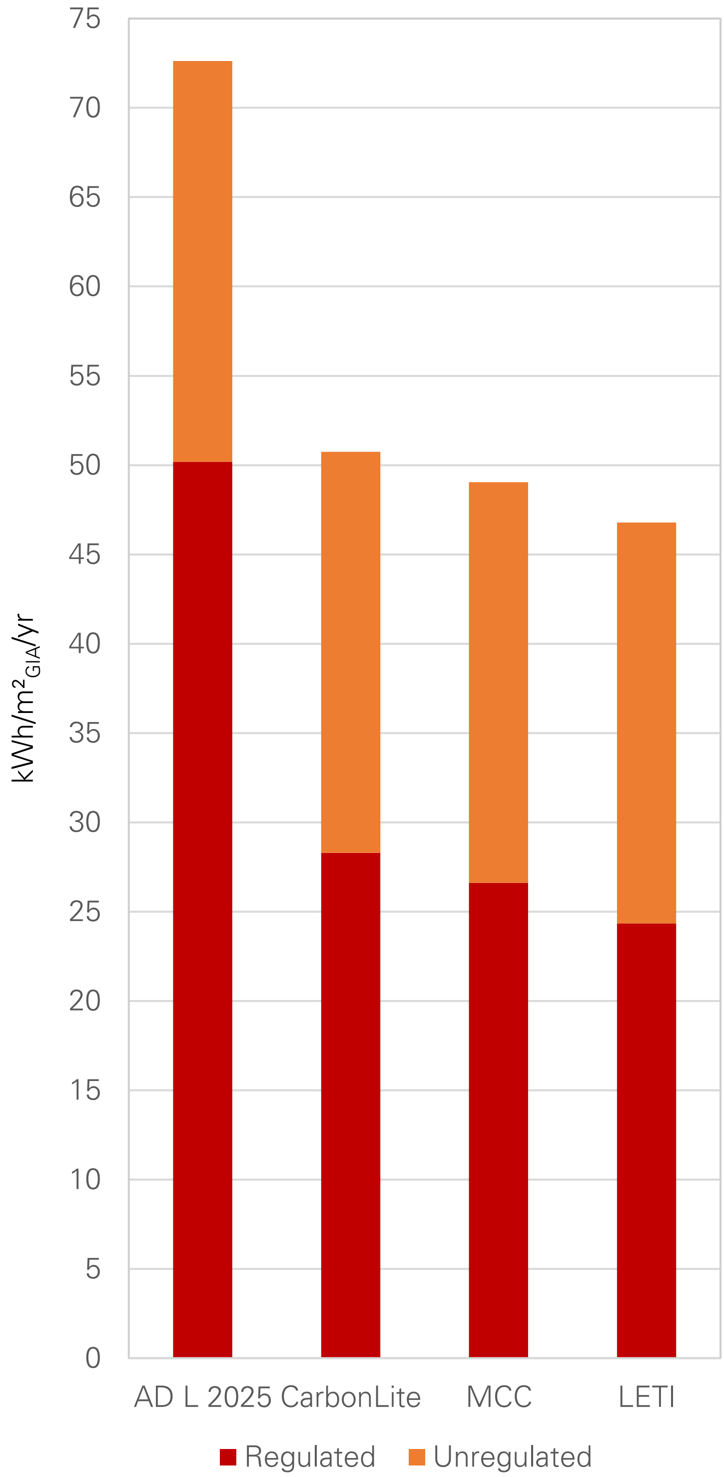
While this demonstrates significant headroom, any features added to the roofscape could either displace panels or create shading that would reduce the output of the photovoltaics. As such the introduction of any features into the roofscape - including rooflights and dormers if taken to 2.5 storeys to increase density - must be carefully managed to avoid reducing the potential array size. Similarly the roof form could not change from pitched to flat (without a separately framed photovoltaic system) and the gables cannot be hipped without reducing potential panel numbers.

As referenced above, this commentary applies to two storey proposals. Creating rooms in the roof or adding a third storey could generate operational and embodied efficiencies but would also increase the number of photovoltaics required on the roof.

Energy consumption graphed opposite shows how use is split between regulated (heating, domestic hot water, ventilation and lighting) and the unregulated household uses. Regulated energy is represented in red with the already discussed reductions clearly illustrated between the operational scenarios.

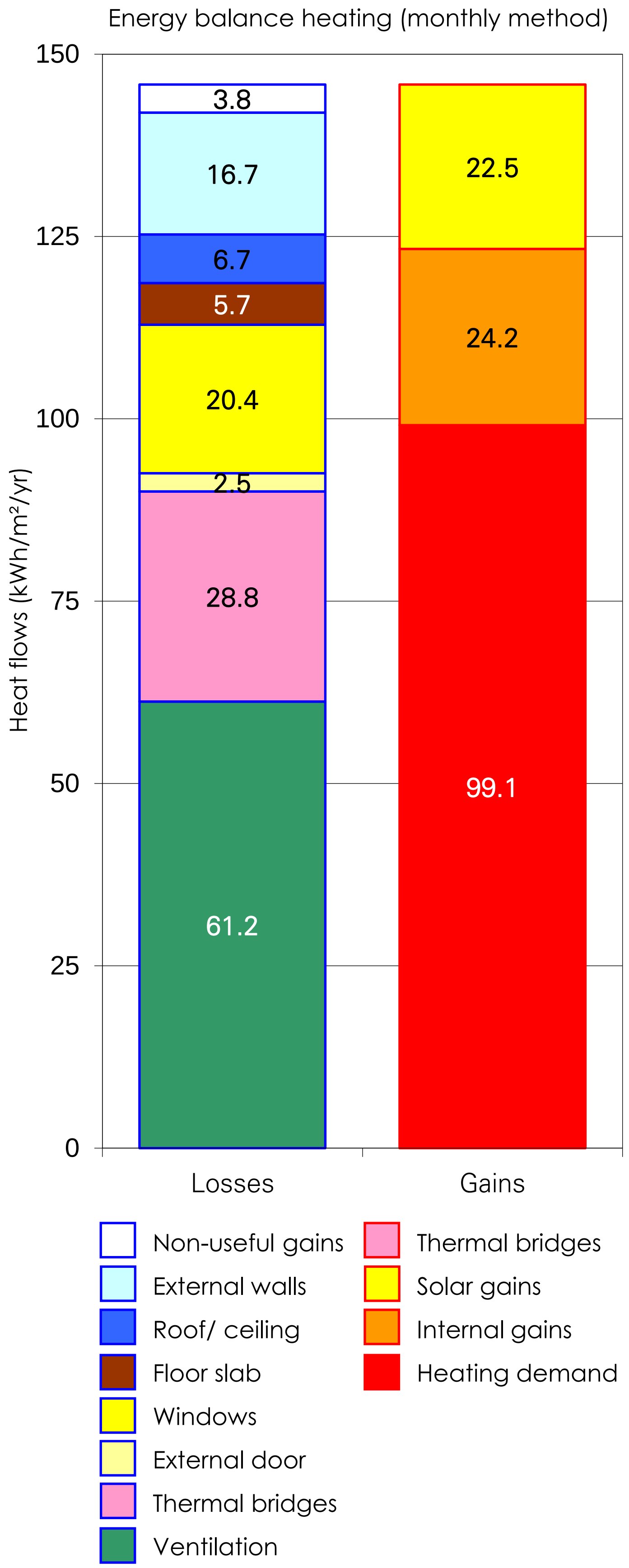
As the occupancy and appliances were identical between all modelled scenarios, unregulated energy use - captured in orange - is the same in each instance.

Energy consumption - HT 900

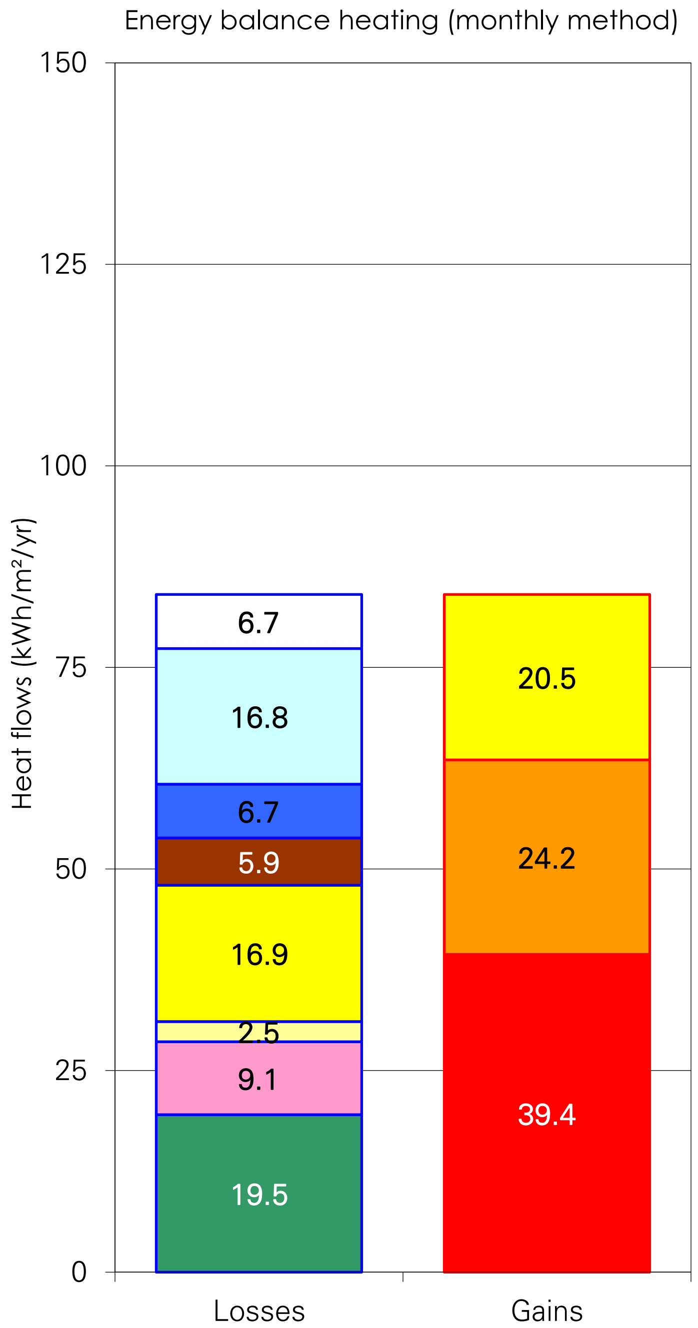


Operational Scenarios

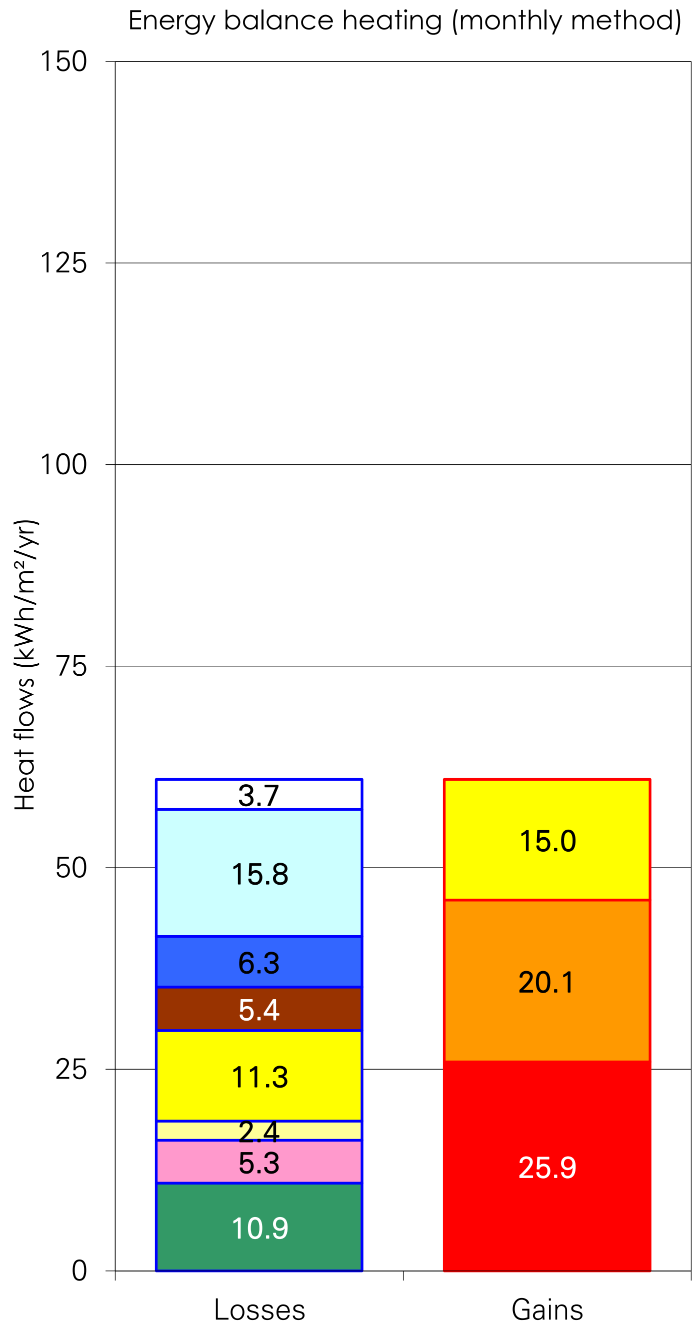
HT 900 - AD: L (Wales) 2025



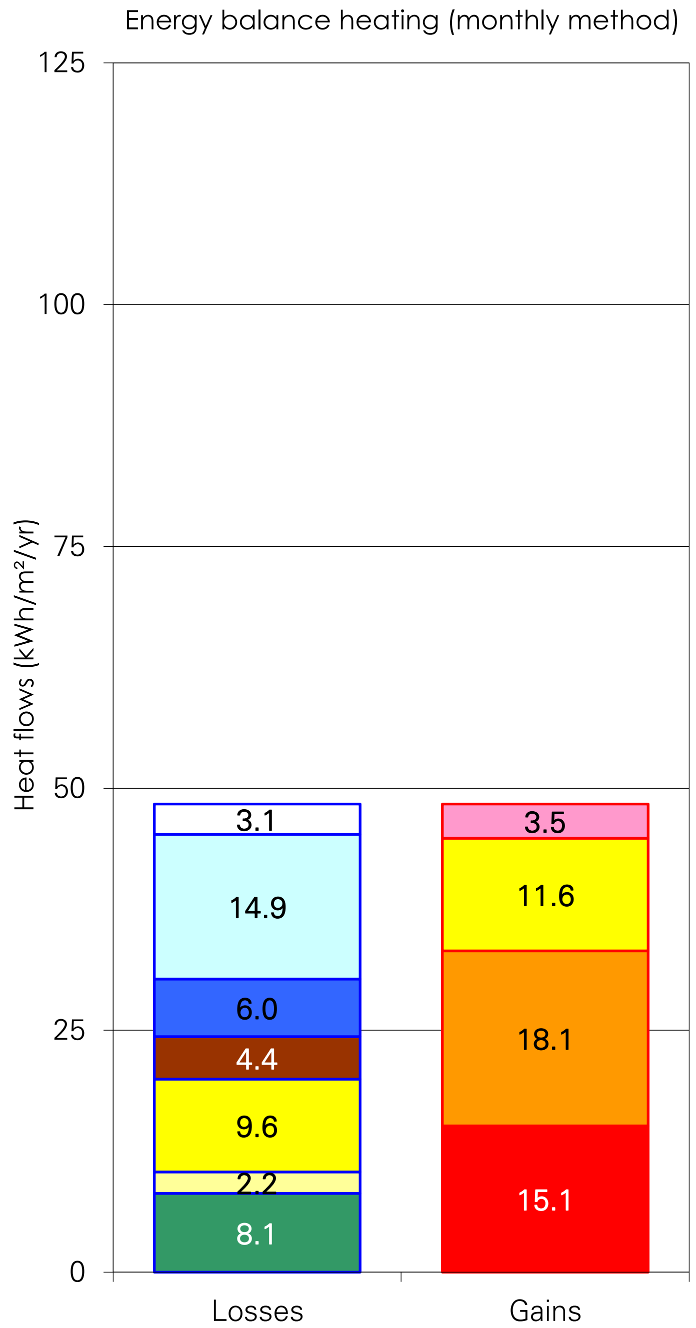
HT 900 - AECB CarbonLite



HT 900 - MCC



HT 900 - LETI



This page contains the energy balance from PHPP for the four energy scenarios. These graphical outputs illustrate where both heat losses and gains - which must be balanced to maintain a stable, comfortable internal temperature - occur: this information can be used to interrogate the performance of the building fabric and optimise specifications.

Annual energy bills calculated by multiplying EUI by Ofgem Q4 2024 electricity unit rate of £0.245 per kWh

Projected Annual Electricity Bills

• AD:L (Wales) 2025	£1,498.34
• AECB CarbonLite	£1,046.63
• MCC	£1,011.81
• LETI	£964.94

excludes standing charge & PV offsets

5.2.5 HT 1800

This section contains the quantitative assessment of **HT 1800**. For full details of the modelled assumptions for each operational scenario refer to 4: Specifications; for illustrative drawings of the building and its modelled context, please refer to 7: Appendices.

Operational outputs demonstrate the benefits and relative efficiencies gained by larger dwellings - even when detached and featuring appropriately detailed, North-facing feature bay windows - with improved form factor. Applying the standard specification, this typology successfully exceeds the defined space heating demand of each operational scenario.

AD: L (Wales) 2025 establishes the baseline for comparisons. Space heating demand is calculated at 72.8 kWh/m²/yr with an EUI of 56.9 kWh/m²/yr of which regulated energy comprises 39.5 kWh/m²/yr.

AECB CarbonLite reduces space heating demand 55% from AD: L (Wales) 2025 and accomplishes a 30% reduction in EUI. Regulated demand reduces almost 45% and therefore 55% of the photovoltaics are required to balance this demand.

Applying the standardised specification for MCC's chosen policy position reduces space heating demand 70% from AD: L (Wales) 2025 and results in almost 35% reduction in EUI and 50% reduction in regulated energy, requiring 50% of the photovoltaics.

Space heating demand reduces nearly 85% from AD: L (Wales) 2025 to LETI. This achieves more than 35% reduction in EUI and 55% regulated energy demand, requiring 45% of the photovoltaics.

The roofscape of the chosen design solution - with a feature rear gable and chimneys bookending the gables - applies some limits to the size of a potential photovoltaic array. Without these features each slope could accommodate a maximum of approximately 30 panels: as proposed the front elevation can host 28 and the rear just 22 (fewer if omitting those shaded by the gable feature) for a total of 50 of a potential 60. This provides an interesting case study into how roof features impact potential photovoltaic provisions.

Assuming 400W photovoltaics the maximum output of the array would be 20 kWp. To match regulated energy of AD: L (Wales) 2025 requires 24 panels across the roof delivering 9.6 kWp. While this still provides quite significant headroom it does demonstrate how quickly panels can be displaced by design features. Further ornamentation of the roofscape - including rooflights and dormers to achieve rooms in the roof if taken to 2.5 storeys - must be carefully managed. Similarly, if more contemporary aesthetics were pursued, the roof form could not change from pitched to flat (without a separately framed photovoltaic system) or the gables hipped without reducing potential panel numbers.

As referenced above, this commentary applies to two storey proposals. Creating rooms in the roof or adding a third storey could generate operational and embodied efficiencies but would also increase the number of photovoltaics required on the roof.

Energy consumption graphed opposite shows how use is split between regulated (heating, domestic hot water, ventilation and lighting) and the unregulated household uses. Regulated energy is represented in red with the already discussed reductions clearly illustrated between the operational scenarios.

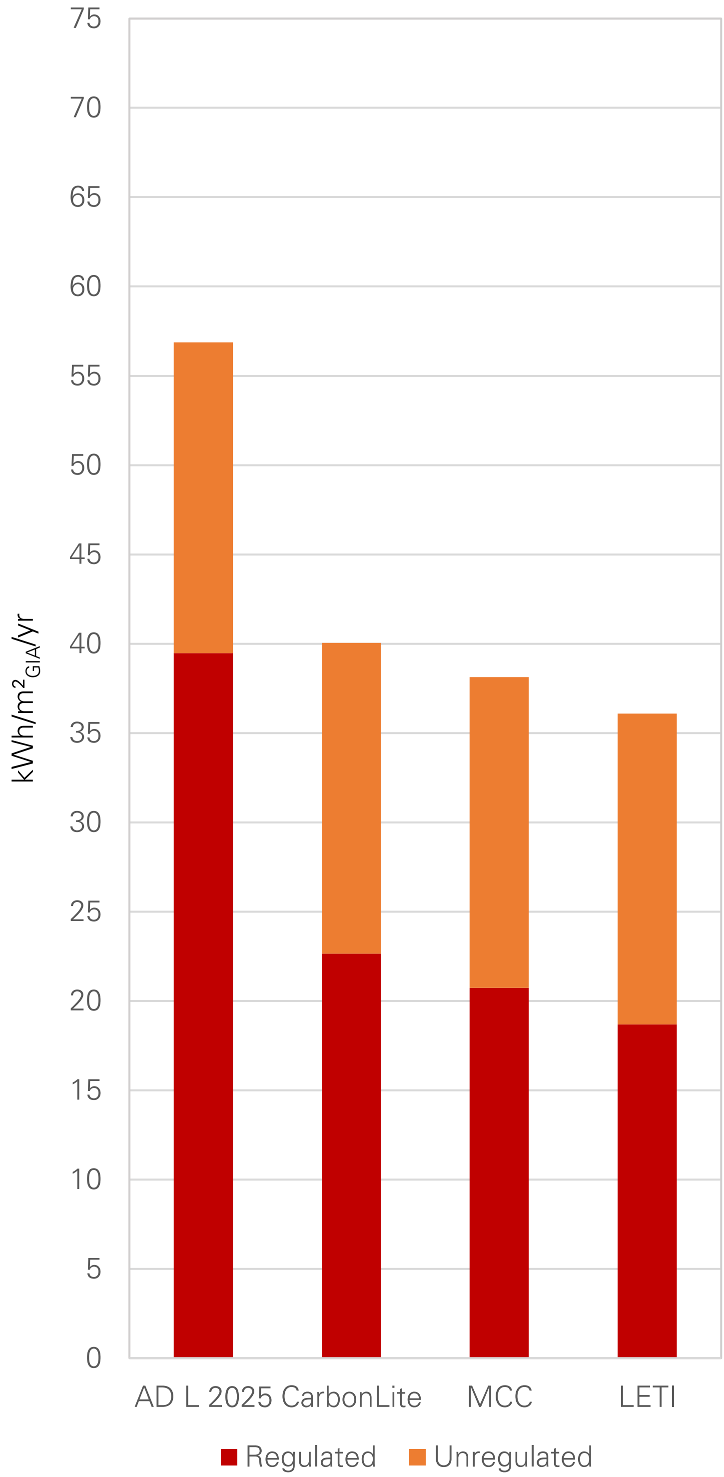
As the occupancy and appliances were identical between all modelled scenarios, unregulated energy use - captured in orange - is the same in each instance.

Operational outputs					
Operational scenarios	Space heating demand	Energy use intensity (EUI)	Annual energy use per dwelling	Regulated energy demand	PV per dwelling to meet regulated
1 AD: L (Wales) 2025	72.8 kWh/m²$_{TFA}$/yr	56.9 kWh/m²$_{GIA}$/yr	9,549 kWh/yr	39.5 kWh/m²$_{GIA}$/yr	9.6 kWp
2 AECB CarbonLite	33.7 kWh/m²$_{TFA}$/yr	40.0 kWh/m²$_{GIA}$/yr	6,724 kWh/yr	22.6 kWh/m²$_{GIA}$/yr	5.6 kWp
3 MCC	22.0 kWh/m²$_{TFA}$/yr	38.1 kWh/m²$_{GIA}$/yr	6,401 kWh/yr	20.7 kWh/m²$_{GIA}$/yr	5.0 kWp
4 LETI	12.3 kWh/m²$_{TFA}$/yr	36.1 kWh/m²$_{GIA}$/yr	6,059 kWh/yr	18.7 kWh/m²$_{GIA}$/yr	4.6 kWp

Headlines for HT 1800

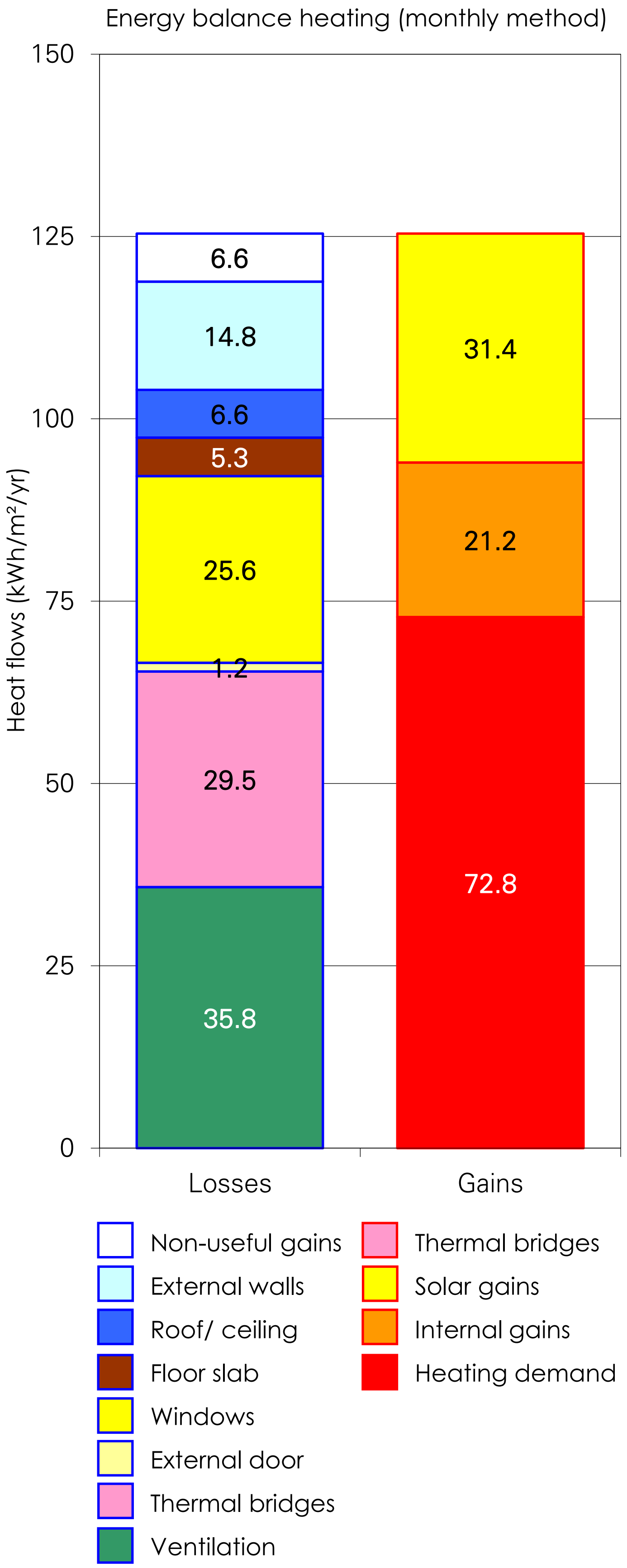
- Space heating demand reduced 70% upgrading **AD: L (Wales) 2025** to **MCC**
- EUI & annual energy consumption reduced 35% by adopting **MCC**
- Regulated energy & PV provisions reduced 50% by adopting **MCC**
- Standard specification easily delivers **MCC** targets: development at lower altitudes or with optimised orientation could apply a lower specification

Energy consumption - HT 1800

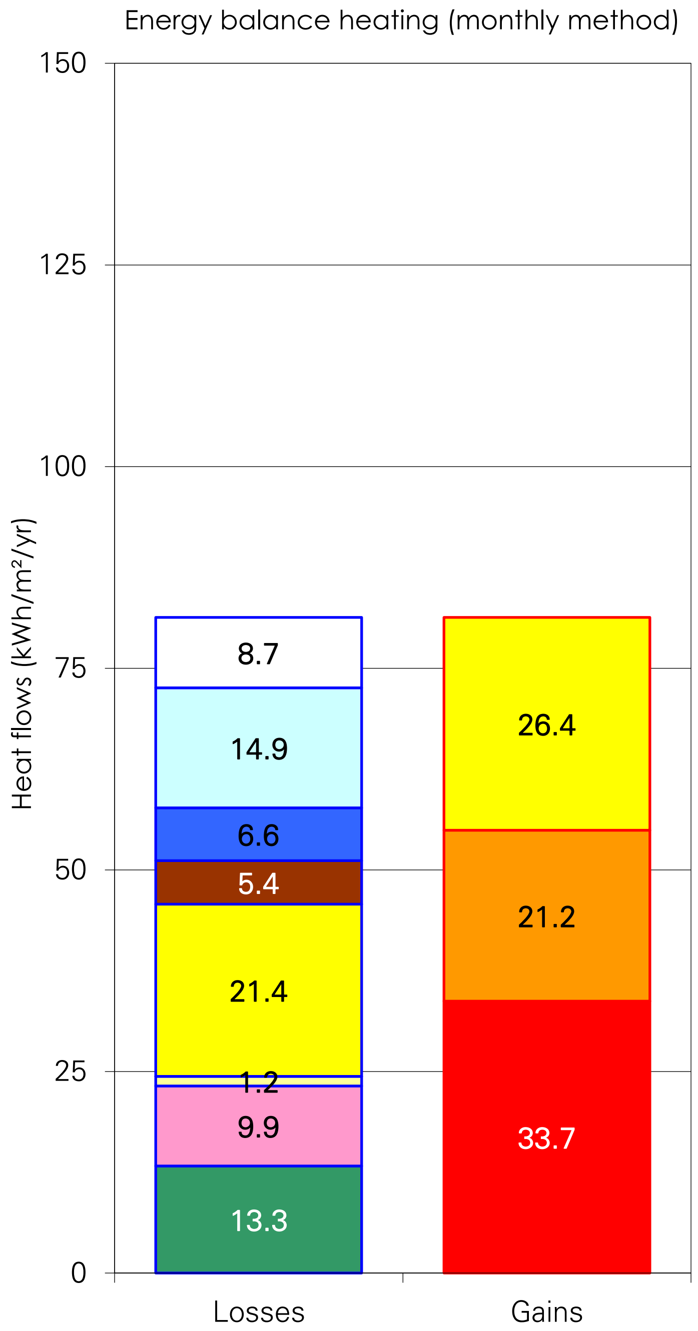


Operational Scenarios

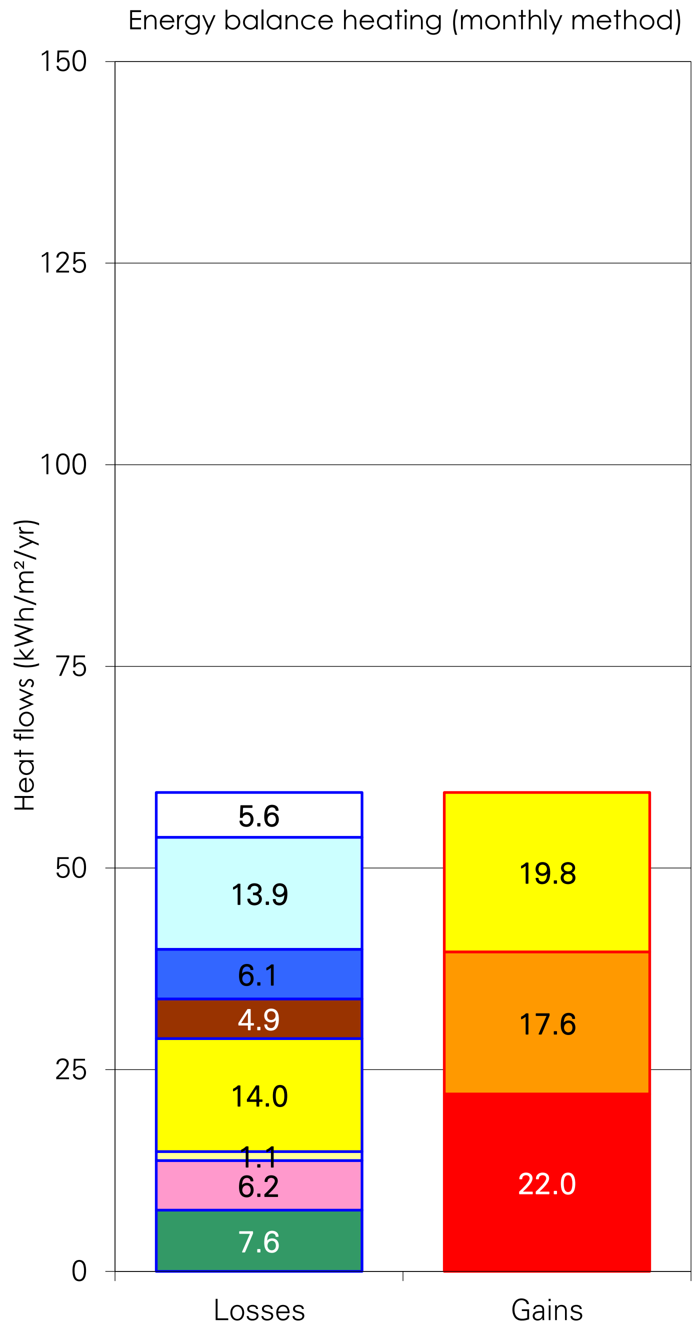
HT 1800 - AD: L (Wales) 2025



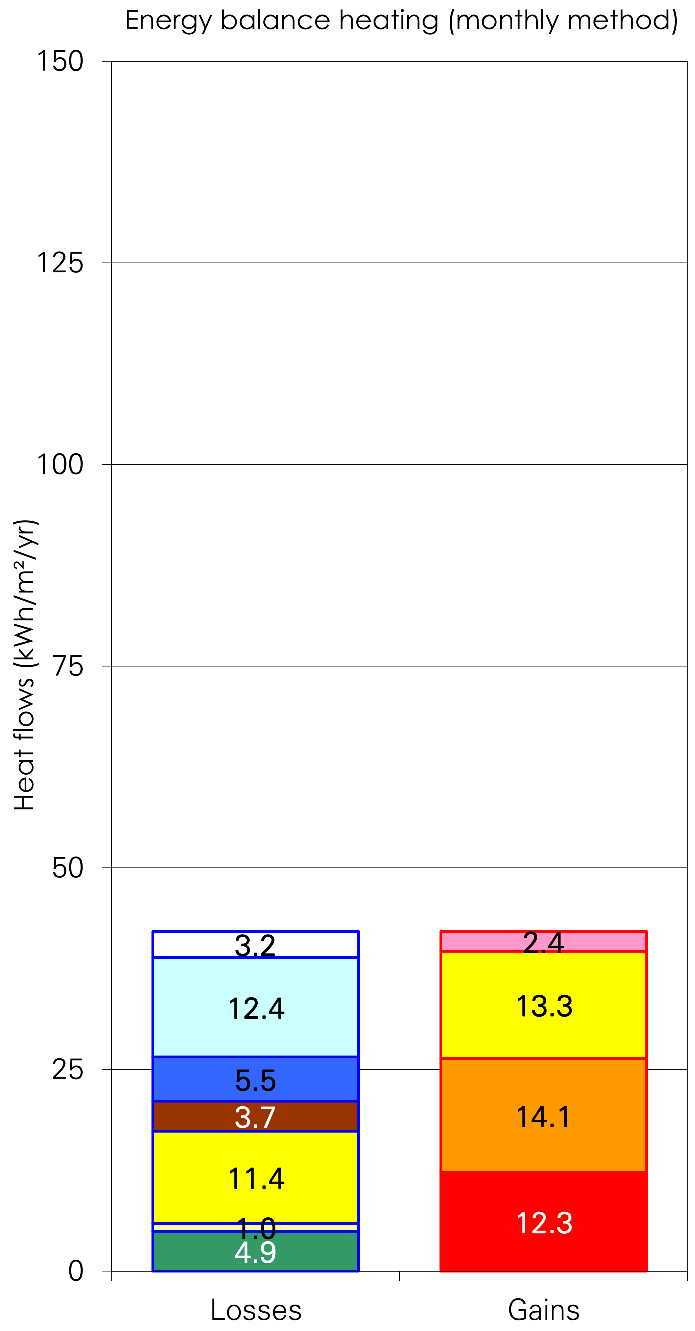
HT 1800 - AECB CarbonLite



HT 1800 - MCC



HT 1800 - LETI



This page contains the energy balance from PHPP for the four energy scenarios. These graphical outputs illustrate where both heat losses and gains - which must be balanced to maintain a stable, comfortable internal temperature - occur: this information can be used to interrogate the performance of the building fabric and optimise specifications.

Annual energy bills calculated by multiplying EUI by Ofgem Q4 2024 electricity unit rate of £0.245 per kWh

Projected Annual Electricity Bills

- AD:L (Wales) 2025 £2,339.39
- AECB CarbonLite £1,647.33
- MCC £1,568.31
- LETI £1,484.54

excludes standing charge & PV offsets

5.2.6 HT 2200

This section contains the quantitative assessment of **HT 2200**. For full details of the modelled assumptions for each operational scenario refer to 4: Specifications; for illustrative drawings of the building and its modelled context, please refer to 7: Appendices.

Operational outputs again demonstrate the efficiencies of improved form factor when applying identical fabric and plant specifications. Despite the same occupancy as **HT 1800**, this larger typology exceeds the defined space heating demand of each operational scenario by a more significant margin.

AD: L (Wales) 2025 establishes the baseline for comparisons. Space heating demand is calculated at 60.6 kWh/m²/yr with an EUI of 49.9 kWh/m²/yr of which regulated energy comprises 36.1 kWh/m²/yr.

AECB CarbonLite reduces space heating demand 55% from AD: L (Wales) 2025 and accomplishes a 35% reduction in EUI. Regulated demand reduces almost 50% and therefore 50% of the photovoltaics are required to balance this demand.

Applying the standardised specification for MCC's chosen policy position reduces space heating demand 70% from AD: L (Wales) 2025 and results in almost 30% reduction in EUI and more than 50% reduction in regulated energy, requiring 50% of the photovoltaics.

Space heating demand reduces over 80% from the AD: L (Wales) 2025 scenario to LETI. This achieves more than 40% reduction in EUI and 55% regulated energy demand, requiring 45% of the photovoltaics.

The roofscape of the chosen design solution - with a feature front gable and chimney on the South gable - limits the scale of potential photovoltaic installations. If reduced to a straightforward dual pitch the roof could accommodate a maximum of approximately 54 panels: as proposed the front elevation can host 17 and the rear 26 for a total of 43 of a potential 54. As previously discussed with **HT 1800** this illustrates the impact of roof features on potential photovoltaic provisions.

Assuming 400W photovoltaics the maximum output of the array would be 17.2 kWp. To match regulated energy of AD: L (Wales) 2025 requires 26 panels across the roof delivering 10.4 kWp. While this still provides quite significant headroom it does again show how quickly panels can be displaced by design features. Further ornamentation of the roofscape - including rooflights and dormers to achieve rooms in the roof if taken to 2.5 storeys - must be carefully managed. Similarly, gables could not be converted to hips and - if more contemporary aesthetics were pursued - the roof form would not be able to alter from pitched to flat without reducing panel numbers.

As referenced above, this commentary applies to two storey proposals. Creating rooms in the roof or adding a third storey could generate operational and embodied efficiencies but would also increase the number of photovoltaics required on the roof to balance the increased overall energy consumption.

Energy consumption graphed opposite shows how use is split between regulated (heating, domestic hot water, ventilation and lighting) and the unregulated household uses. Regulated energy is represented in red with the already discussed reductions clearly illustrated between the operational scenarios.

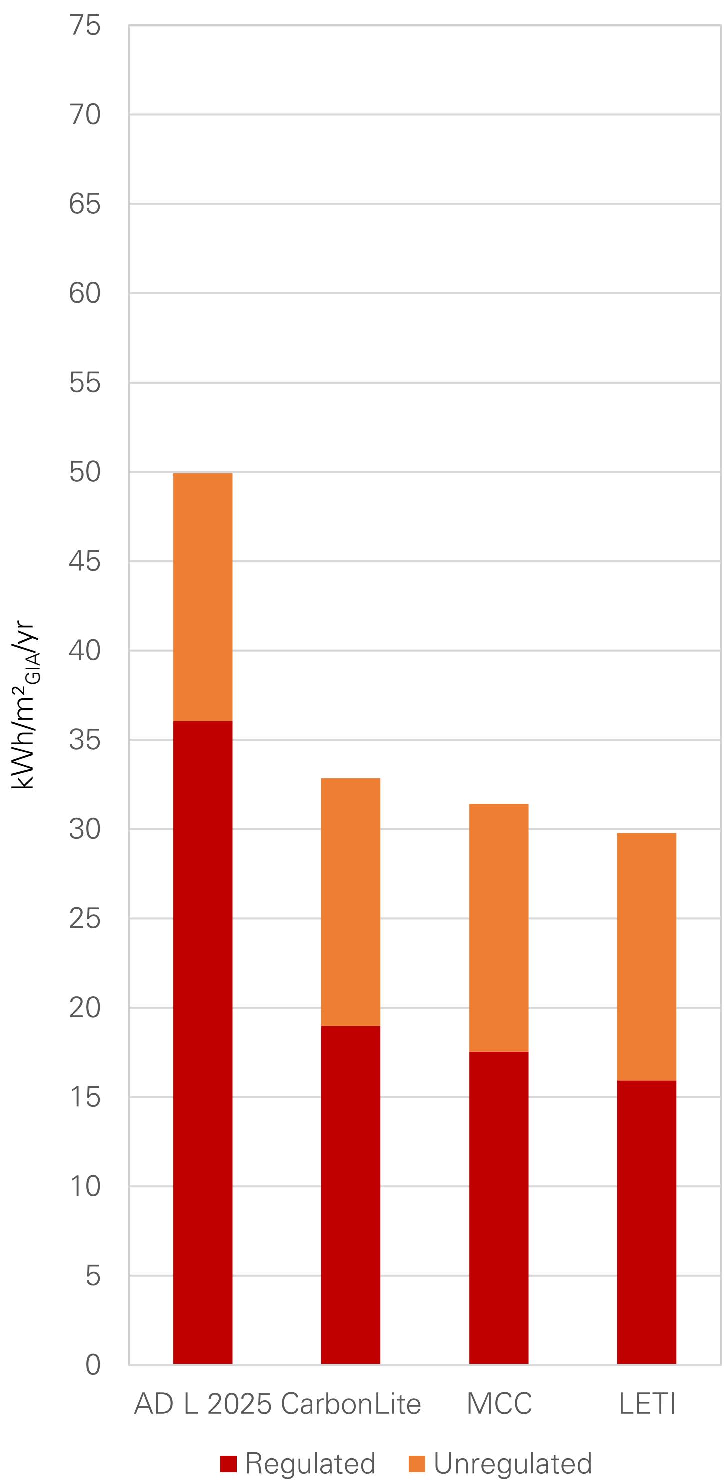
As the occupancy and appliances were identical between all modelled scenarios, unregulated energy use - captured in orange - is the same in each instance.

Operational outputs					
Operational scenarios	Space heating demand	Energy use intensity (EUI)	Annual energy use per dwelling	Regulated energy demand	PV per dwelling to meet regulated
1 AD: L (Wales) 2025	60.6 kWh/m$^2_{TFA}$/yr	49.9 kWh/m$^2_{GIA}$/yr	10,518 kWh/yr	36.1 kWh/m$^2_{GIA}$/yr	10.4 kWp
2 AECB CarbonLite	28.0 kWh/m$^2_{TFA}$/yr	32.8 kWh/m$^2_{GIA}$/yr	6,919 kWh/yr	19.0 kWh/m$^2_{GIA}$/yr	5.6 kWp
3 MCC	18.5 kWh/m$^2_{TFA}$/yr	31.4 kWh/m$^2_{GIA}$/yr	6,616 kWh/yr	17.5 kWh/m$^2_{GIA}$/yr	5.0 kWp
4 LETI	11.5 kWh/m$^2_{TFA}$/yr	29.8 kWh/m$^2_{GIA}$/yr	6,275 kWh/yr	15.9 kWh/m$^2_{GIA}$/yr	4.6 kWp

Headlines for HT 2200

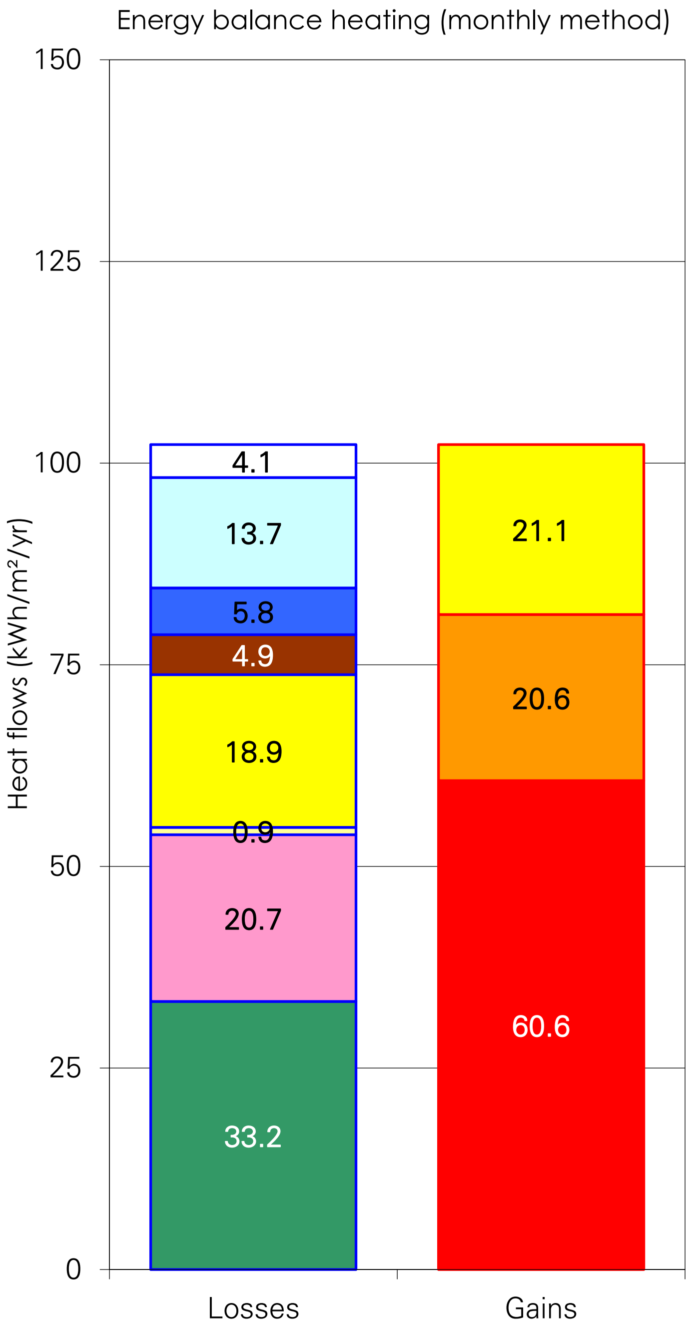
- Space heating demand reduced 70% upgrading **AD: L (Wales) 2025** to **MCC**
- EUI & annual energy consumption reduced 30% by adopting **MCC**
- Regulated energy & PV provisions reduced 55% by adopting **MCC**
- Standard specification easily delivers **MCC** targets because of the improved form factor, despite modelling the typology in a detached scenario

Energy consumption - HT 2200

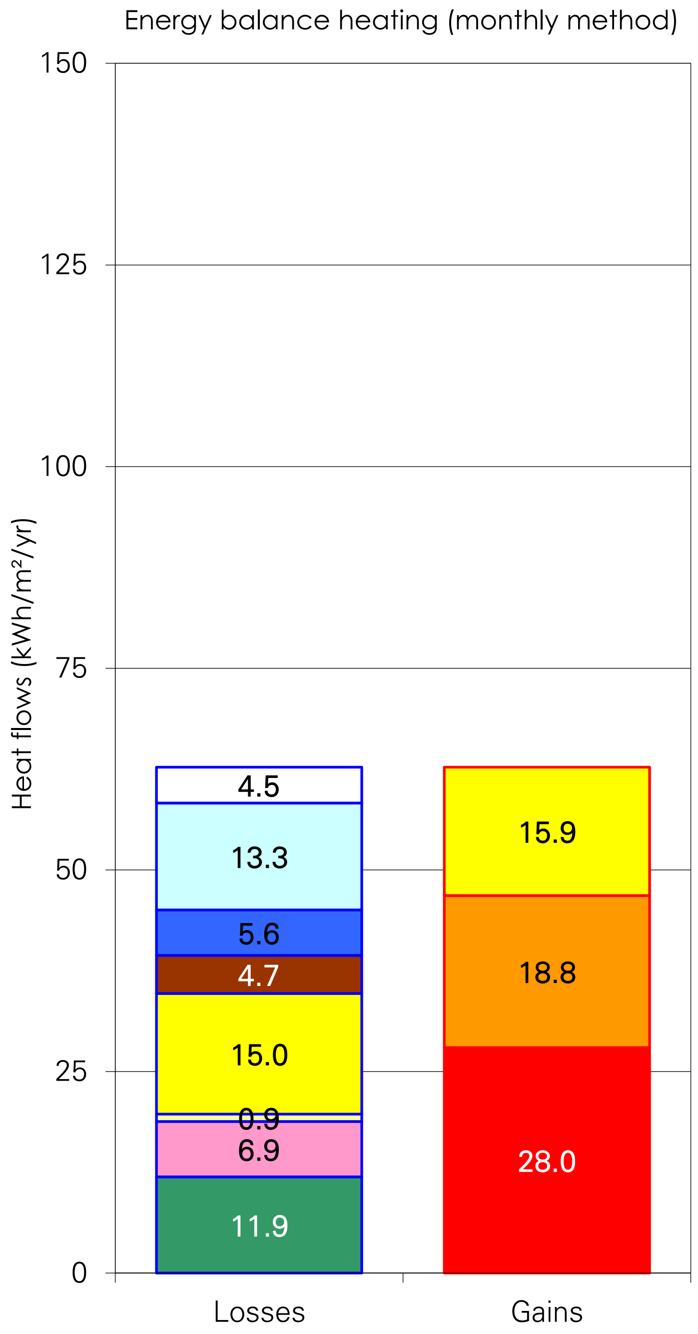


Operational Scenarios

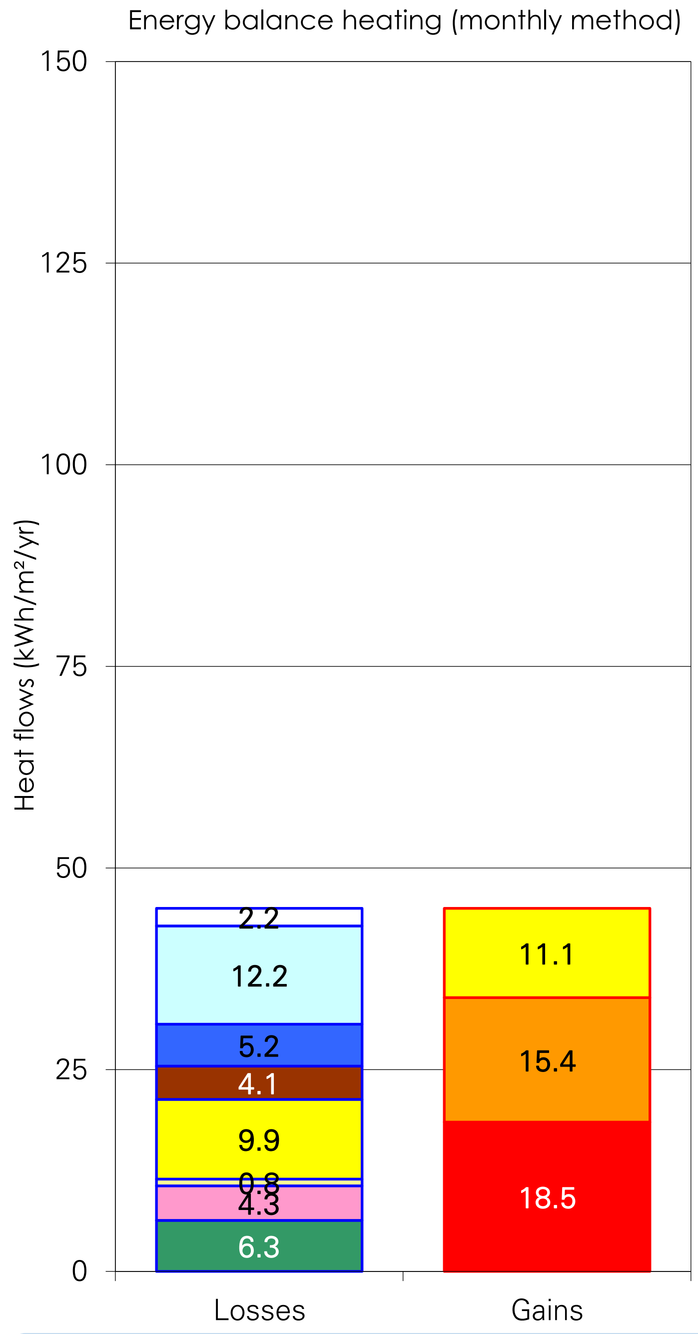
HT 2200 - AD: L (Wales) 2025



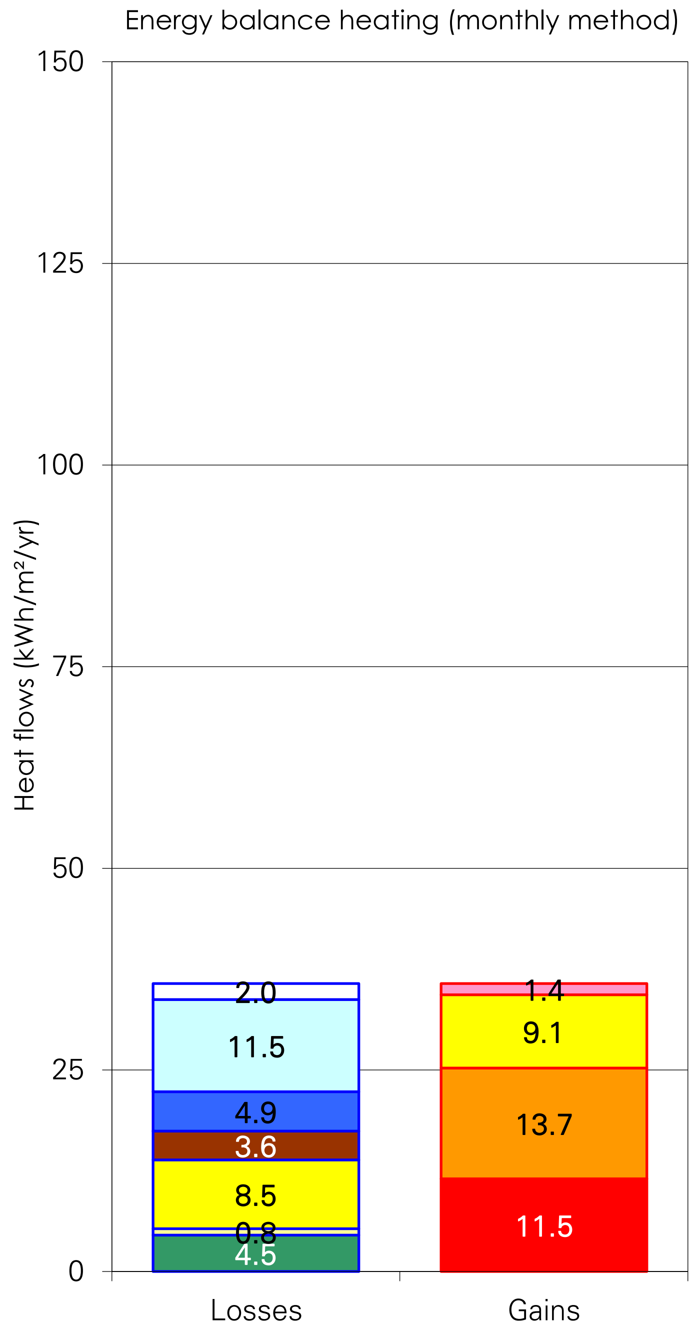
HT 2200 - AECB CarbonLite

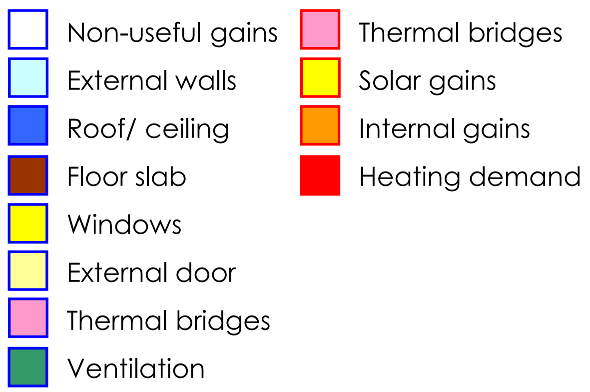


HT 2200 - MCC



HT 2200 - LETI





This page contains the energy balance from PHPP for the four energy scenarios. These graphical outputs illustrate where both heat losses and gains - which must be balanced to maintain a stable, comfortable internal temperature - occur: this information can be used to interrogate the performance of the building fabric and optimise specifications.

Annual energy bills calculated by multiplying EUI by Ofgem Q4 2024 electricity unit rate of £0.245 per kWh

Projected Annual Electricity Bills

- AD:L (Wales) 2025 £2,576.91
- AECB CarbonLite £1,695.23
- MCC £1,620.97
- LETI £1,537.31

excludes standing charge & PV offsets

spring design

Section 6: Conclusions

6.1 Conclusions

As demonstrated through this quantitative assessment operational energy demand and associated emissions can be significantly reduced by minor optimisations with no bearing on physical appearance. Without altering the layout or external appearance of the assessed residential typologies, operational energy could reduce 30-60%.

High performance buildings are achievable without significantly altering the fabric specification of the anticipated 2025 Building Regulations. Uplifts beyond basic compliance are limited to improved airtightness, mitigation of thermal bridges, improved quality of windows and provision of MVHR for ventilation.

Improved levels of building performance result in an inherently lower need for heat generation and on-site renewables. This can reduce the number of photovoltaic panels required to achieve Net Zero and the size of heat pumps and heating infrastructure.

In the case of larger buildings, or those that are otherwise optimised, targeting heating demand or EUI based performance metrics could leverage potential reductions in insulation thicknesses with the resulting material efficiencies benefitting embodied carbon.

This assessment has focused on a range of residential typologies modelled on a notional site at an altitude of 140m. Applying typical design responses in an East-West orientation to achieve the identified operational performance standards demonstrates the technical feasibility of reducing energy demand throughout the strategic housing delivery sites identified by MCC.

Further operational optimisations - including but not limited to improved form factor, orientation and fenestration design - could more efficiently achieve this ambition to deliver cost savings and reductions in embodied emissions.

Headlines for operational analysis

- Heating demand reductions > 80% achievable between identical buildings by improving airtightness & thermal bridging complemented by MVHR
- EUI & CO_2e reductions of 30-60% available applying these improvements
- Reduced EUI requires 40-50% fewer PV panels to balance regulated energy
- Heat pumps reduce energy required for heating & hot water demand to < 25% of the direct electric equivalent

Headlines for MCC policy position

- Space heating demand reduced 70% upgrading **AD: L (Wales) 2025** to **MCC**
- EUI & annual energy consumption reduced > 30% by adopting **MCC**
- Regulated energy & PV provisions reduced > 50% by adopting **MCC**
- Standard specifications developed to demonstrate technical feasibility of space heating demand targets despite challenging altitude & orientation of modelled scenarios

Section 7: Appendices

7.1 Residential Typologies

7.1.1 Social

Refer to drawings:

2774-211(02)100 - HT 211 Notional Site Layout
2774-211(02)101 - HT 211 Notional Street Elevation
2774-211(02)200 - HT 211 GF Plan
2774-211(02)201 - HT 211 1F Plan
2774-211(02)202 - HT 211 2F Plan
2774-211(02)300 - HT 211 Elevations
2774-211(02)301 - HT 211 Elevations

2774-212(02)100 - HT 212 Notional Site Layout
2774-212(02)101 - HT 212 Notional Street Elevation
2774-212(02)200 - HT 212 Floor Plans
2774-212(02)300 - HT 212 Elevations

2774-421(02)100 - HT 421 Notional Site Layout
2774-421(02)200 - HT 421 Floor Plans
2774-421(02)300 - HT 421 Elevations

7.1.2 Open Market

Refer to drawings:

2774-900(02)100 - HT 900 Notional Site Layout
2774-900(02)200 - HT 900 Floor Plans
2774-900(02)300 - HT 900 Elevations

2774-1800(02)100 - HT 1800 Notional Site Layout
2774-1800(02)200 - HT 1800 Floor Plans
2774-1800(02)300 - HT 1800 Elevations

2774-2200(02)100 - HT 2200 Notional Site Layout
2774-2200(02)200 - HT 2200 Floor Plans
2774-2200(02)300 - HT 2200 Elevations

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