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RESERVOIRS OF ENERGY: A JOURNEY TOWARDS ENERGY AUTONOMY FOR NINE UK EARTH-SHELTERED HOMES

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Abstract: This paper is a sequel publication to ACUUS 2023[i], 'Reservoirs of Heat: A defining characteristic of high thermal mass earth-sheltered buildings.'

Featured below is an advanced analysis of the second case study of the former paper, the nine earth-sheltered homes known as Howgate Close[ii], in the Nottinghamshire village of Eakring.

Reviewed in this paper is the hypothesis, *'to what extent can energy autonomy be achieved in one of the naturally heated Howgate earth-sheltered homes?'.* This evidence-based enquiry is essential in optimising built-in energy security for the future building performance for the balance of eight Howgate homes.

Emerging from Howgate is the advent of a new building paradigm in the UK. One where the level of energy autonomy at Howgate is delivering a net daily cash surplus for the home with a battery installed. As a consequence, there are no more energy bills, relegating the threat fuel-poverty to a distant memory. This is a continuous process of *'marginal gains'*[iii].

What difference a battery makes?

Batteries in buildings, facilitate energy storage and can be thought of as '*reservoirs of energy'*.
This paper introduces in-use building performance data from a 1bedroom earth-sheltered dwelling, pre-and-post battery installation. Also discussed, are the wider-ranging impact batteries have in reducing the burden of energy bills.

After the first three years of occupation, the selected 1bed home has exceptionally low average daily total energy costs that are less than 45pence/day (inclusive of Standing Charge). Before the battery install, the home consumed 7KWhrs/day imported energy from the grid and exported 13.5KWhrs/day to the grid.

The next stage of Howgate Close's development is the inclusion of energy storage facilities to all nine homes. However, the first phase has been to install an 11KWhr BYD battery and a Fronius hybrid inverter to one of the 1bed dwellings. At the time of submitting the full paper, sixteen weeks of in-use building performance data has been gathered. Results from 16.04.2025 to 13.08.2025 record in excess of 50% reduction in daily energy consumption from the grid compared to the same period in 2024.

This paper will add to the accumulating, independent, evidence-based research from the nine earth-sheltered homes of Howgate Close. Additional empirical data is provided in support of the premise that, *'high thermal mass buildings should be the building form of choice in reducing heating/cooling loads together with concomitant energy costs*.'

Keywords: residual heat reservoir, reservoir of energy, earth-sheltered building, energy storage facility, battery, zero heating, thermal mass, passive solar design.

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1. INTRODUCTION

This is a sequel paper to ACUUS 2023[iv], *'Reservoirs of Heat: A defining characteristic of high thermal mass earth-sheltered buildings.'*

Explored in this 2025 paper is the hypothesis:

'To what extent can energy autonomy be achieved in one of the naturally heated Howgate earth-sheltered homes, using an energy storage facility?'

An evidential enquiry will inform future design decisions in the sizing of batteries and inverters to the balance of the eight Howgate homes.

During the first three years of occupation prior to the installation of the first battery, all nine homes experienced low to no heating load requirements. The building characteristic at Howgate responsible for stabilising internal air temperatures was introduced in ACUUS 2023 by this author and is referred to as a '*residual heat reservoir'.* At Howgate, it is this phenomenon, the presence of a body of heat energy retained within the superstructure, that has been sufficient to sustain habitable internal air temperatures of 21C without resort to primary heating equipment. A good starting point for the installation of an energy storage system.

Figure 1. *2023. Harrall Dr. J.: Southeast View, Howgate Close*

2. BUILDING SPECIFICATION OF HOWGATE CLOSE (HC) *[SEE FIG1.]*

Howgate Close (HC) is a post-hydrocarbon ready residential dwelling, conceived by Dr Chris Parsons, a second generation Eakring Farmer and retired GP. Dr Parsons cited[v],

"Howgate Close was an opportunity to address some of society's most pressing issues: rural housing shortages, climate change, soil restoration, carbon sequestration, biodiversity, water management and community cohesiveness."

Howgate comprises, nine single storey earth-sheltered homes, 5no. 2beds ($63m^2$) and 4no.1beds ($41m^2$) with a gross development floor area of $479m^2$.

Location
Howgate Close is located at latitude 53^0 North, centrally located in the British Isles which straddles between the mid-latitudes of 49^0 and 61^0. The climatic conditions of these Isles are largely related to the influence of the Atlantic Ocean, as such, experiences a temperate maritime climate. Encyclopaedia Britannica[vi] report, nowhere in the UK is located more than 70miles from the coast.

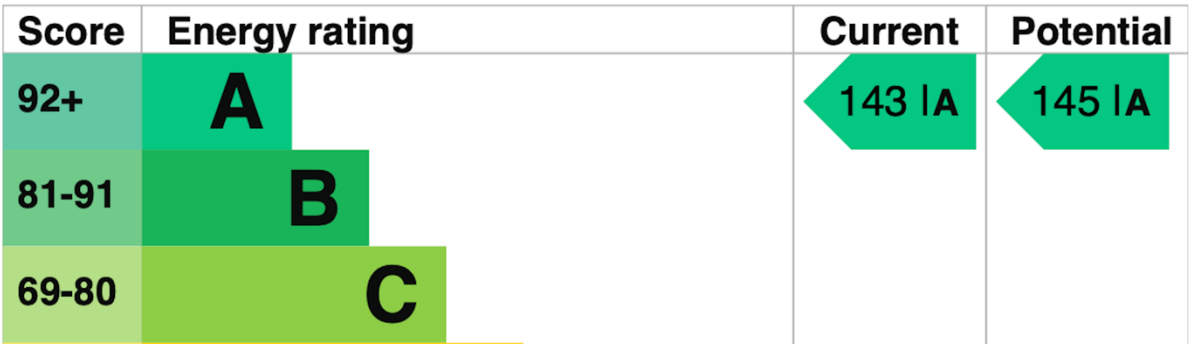

Figure 2. *2023. Extract of Howgate Close Energy Performance Certificate (EPC)*

'One-In-A-Million'
The selected building's As-Built SAP (Standards Assessment Procedure) Rating is 143A[vii]. Of the 15million registered EPC's (Energy Performance Certificate) *[See Fig2.]* in the UK, Howgate's' SAP Ratings are ranked in the top 0.01% of the country's most energy efficient dwellings, better than one in a million.

Design Principles
The original project design was undertaken by the Hockerton Housing Project (HHP)[viii] using the design principles applied at HHP by its Architects, Professors Brenda and Robert Vale (The Vale's).
These design principles were first published in The Vale's, 1975 book, 'The Autonomous House', and implemented at their former Southwell home, featured in their book 'The New Autonomous House'. In 1991, this was the first UK dwelling to export photovoltaic-generated renewable energy to the National Grid.

Dr Chris Parsons advanced the original construction specification engaging Dr J. Harrall elevating the 87A Design SAP Rating to an As-Built 143A.

Intrinsic to Howgate's performance is the utilisation of Passive Solar Design (PSD) principles; *southerly orientation, high thermal mass superstructure and a super-insulated building envelope,* allied and enhanced with triple glazing and roof mounted photovoltaics. Other differentiating construction specifications include; solid external walls (no cavities) floating slab (no foundations) contiguous external insulated envelope (no cold bridging) externally located window and door jambs (exceptional Psi values).

Post-Hydrocarbon Ready
The authors interpretation of a post-hydrocarbon era, is a time when societies primary fuel for heat and power is not derived from oil, gas or coal. The authors concur with the opinion that, *"The post-hydrocarbon era will not appear suddenly. Gradual change and individual decisions will aggregate into wide structures beyond the scope of the individual decisions."*[ix]

Howgate Close demonstrates the traits of what a post-hydrocarbon neighbourhood could look like: *energy independence, autonomy over essential resources, on-site waste management, transitioning towards fossil-fuel-free lifestyles and a strong community spirit.* These homes are fossil-fuel-free in operation, generating a surplus of energy, managing their own waste water on site with most homes experiencing low to no heating bills.

Building Performance Specification *[See Fig 3]*
At Howgate, stable internal air temperatures of 21^0C (+/- 2^0C) have been recorded over the first 30months of occupation with little to no active heating.

Howgate's building element specification, significantly out performs the UK Building Regulations 'Notional Building' (See Table 1) Improvements in fabric heat transmittance (U-Values) are 28% for its walls (0.13W/m^2K) 38% for its floors (0.08W/m^2K) and 36% for the roofs (0.07W/m^2K) The most significant improvement against the Compliance Standards is Howgate's Air Pressure Tests (APT) (0.67m^3@50Pascals) 87% reduced fabric air infiltration.

As-Built SAP calculations produced 143A(2bed) and 129A(1Bed) At HC, exceptionally low Air Pressure Tests were achieved at HW, 0.33m^3(h.m^2) @50Pascals, lower than HW by 0.61m^3 .

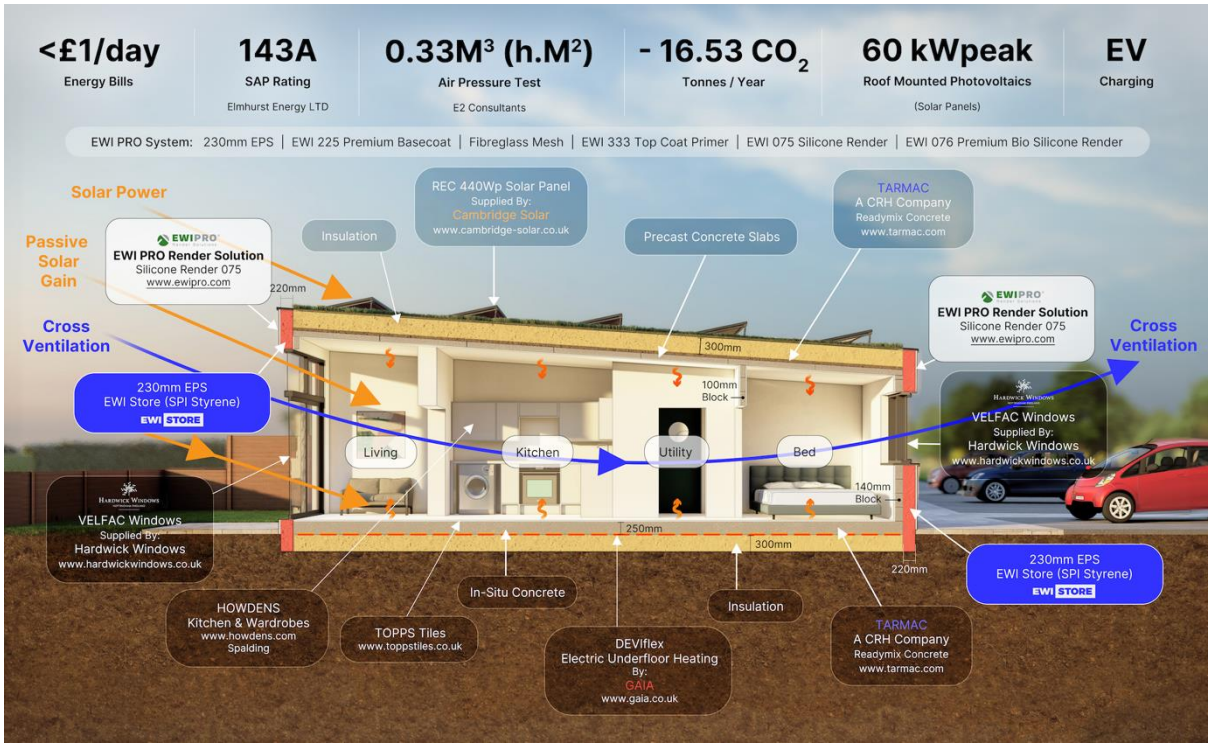

Figure 3. *2025. Howgate Close Typical Cross Section*

Residual Heat Reservoir

At Howgate, it is the combined elements of low thermal bridge junctions, contiguous insulated envelope and high thermal mass superstructure, that optimise the buildings' residual heat reservoir its retained body of heat energy within the building fabric. At Howgate, an uninterrupted layer of 220mm (XPS, walls) to 300mm (EPS, roof and floor) envelopes the building externally. Subsequently, sufficient heat is retained within the thermal mass to sustain elevated internal air temperatures of circa 21^{0}C.

Table 1. *Howgate Close Fabric Performance Comparison With Notional Building*

HOWGATE CLOSE VS UK BUILDING REGULATIONS NOTIONAL BUILDING					
Minimum Standards for Fabric Performance			**Notional Building**	**HOWGATE CLOSE**	**% Difference**
	Part L 2013	**Part L 2021**	**Part L 2021**		
External walls	0.3 w/m²k	0.26 w/m²k	0.18 w/m²k	**0.13 w/m²k**	**+28**
Floors	0.25 w/m²k	0.18 w/m²k	0.13 w/m²k	**0.08 w/m²k**	**+38**
Roofs	0.2 w/m²k	0.16 w/m²k	0.11 w/m²k	**0.07 w/m²k**	**+36**
Windows	2 w/m²k	2.2 w/m²k	1.2 w/m²k	**0.78 w/m²k**	**+35**
Doors	2 w/m²k	1.6 w/m²k	1.0 w/m²k	**0.9 w/m²k**	**+10**
Air Permeability	10 m³/m²/hr @ 50Pa	8.0 m³/m²/hr @ 50Pa	5.0 m³/m²/hr @ 50Pa	**0.67m³/m²/hr @50Pa**	**+87**

Thermal Bridges *[See Fig 4]*

Thermal bridges (aka cold bridges) are thermally weak junctions with significantly higher heat transfer than surrounding materials. These junctions form a bridge between inner and outer surfaces e.g. window jamb, where paths of least resistance for heat transference, can result in up to 30% of total building heat loss As a consequence, thermal bridges are at risk of internal surface condensation formation, potentially leading to mould growth, presenting a health risk.

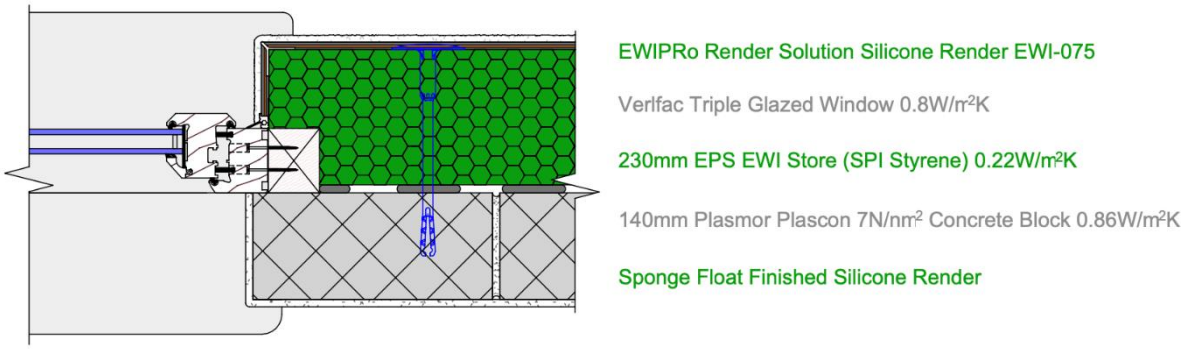

Figure 4. *Window Jamb Detail At Howgate Close*

Four principal categories of thermal bridge;

1) **Repeating thermal bridges** –regular interruptions in the building fabric e.g. brick mortar joints, wall ties and studs;- *U-Values*
2) **Linear (non-repeating) thermal bridges** –gaps in the insulation layer e.g. windows and doors – *Psi-Values*
3) **Geometrical thermal bridges** –meeting junctions different building elements e.g. external corners, where the heat loss area is greater than the internal surface – *Psi-Values*
4) **Point thermal bridges** –single penetrations in the thermal envelope flues, fastenings, brackets, stanchions – *Chi-Values*

Linear Thermal Transmittance

For the purposes of this paper, only linear and geometrical thermal bridges are calculated. The heat loss associated with these thermal bridges is expressed as Linear Thermal Transmittance (Ψ-value) – referred to as *psi-value*. At Howgate Close, there are no repeating thermal bridges and negligible point thermal bridges. A lower Psi-value indicates lower heat loss through a junction.

Calculated Psi-Values[x] for Howgate Close are compared to the UK Building Regulation 'Notional Building' (see Table 1)[xi]. The 'notional building specification' is a recipe approach that will ensure minimum compliance if all standards are met.

Calculated perimeter heat loss from Howgate window and door frames, their average Linear Heat Transference (Psi-Value) is 0.024W/m.K.[xii] Heat transfer through Howgate's bespoke window/door junction is half that of the Notional Building compliance standard. Conversely, a building built to minimum Building Regulation standards, loses twice as much heat from its window/door junctions compared to Howgate Close.

Table 2: *Comparison Table of Linear Heat Transference*

COMPARISON TABLE OF LINEAR HEAT TRANSFERENCE 2D PSI CALCULATION **Howgate Close & Notional Building** (UK Building Regulations 2023)			
	Notional Building * (Psi-Value W/m.K	**Howgate Close** (Psi-Value) W/m.K	**Condensation Risk**** (f-value) 1 = Zero Risk
Window Jamb	0.05	0.023	0.935
Window Lintel	0.05	0.027	0.956
Window Cill	0.05	0.023	0.927
Roof/Wall	0.08	0.067	0.965
**f-Value: risk of condensation forming on internal surface when external temperature is 0^{0}C and internal room temperature is 20^{0}C			
*Psi-Value: minimum building specification to ensure compliance with UK Building Regulation Standards			
Calculation undertaken by MES www.mesbuildingsolutions.co.uk and commissioned by EWIPro www.ewipro.com			

Surface Temperature, Mould growth and Health

Calculated as part of the Psi-Value calculation is the *f-value*. The *f-value* estimates the risk of surface mould formation in a building. As the f-value approaches '1', the calculated incident of internal surface condensation formation at junctions reduces and with it, the risk of mould growth. For comparison, the Notional Building *f-value* compliance threshold is 0.75. At Howgate, its window/door junction average *f-value* is 0.94. The risk of internal surface condensation occurring on window/door junction detail at Howgate is reduced by 19% compared to the compliance standards for Building Regulations.

Interstitial Condensation

Interstitial condensation can occur between building construction interface layers of roofs, walls and floors. Persistent interstitial condensation within the building fabric can lead to degradation of materials, increased risk of mould formation and a reduction in air quality.

At Howgate, its modified solid externally insulated wall, designs out the cavity wall and locates the insulation on the external face of the solid block wall. A Condensation Risk Analysis[xiii] has evaluated the likelihood of interstitial condensation in Howgate's wall construction. These calculations demonstrate compliance with 'UK Building Regulation Part C'.

The analysis concluded that Howgate's external wall detail, avoided critical surface moisture, with no danger of mould growth. On the incidence of interstitial condensation, it concluded there was no risk of condensation forming at any interface in any month.

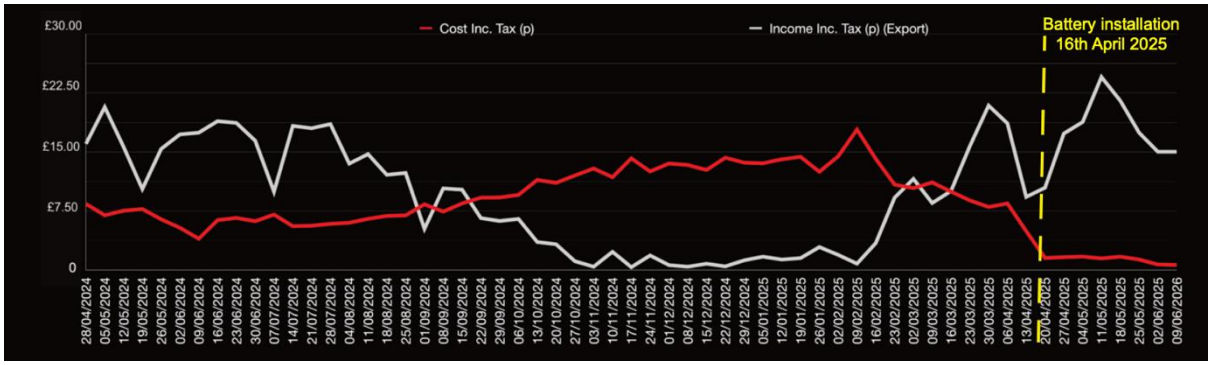

Figure 5. *2025. 14months of Octopus Bills at Howgate Close 1bed with a battery installed*

3. WHAT A DIFFERENCE A BATTERY MAKES *[SEE FIG 5]*

Over the first three years of occupation, the selected 1bed home has recorded exceptionally low average daily total energy costs that are less than 45pence/day (inclusive of Standing Charge)[xiv]. Before the battery install, the home's average daily consumption was 7KWhrs/day imported energy from the grid while exporting 13.5KWhrs/day to the grid.

The next stage of Howgate Close's development is the inclusion of energy storage facilities to all nine homes. However, the first phase has been to install an 11KWhr BYD battery and a Fronius hybrid inverter to one of the 1bed dwellings. At the time of submitting this paper, eight weeks of in-use building performance data has been gathered. Results from 16.04.2025 to 15.06.2025 record in excess of 50% reduction in daily energy consumption from the grid compared to the same period in 2024.

For the period from 12th July to 13th August 2025, 18KWhrs electricity were imported from the grid[*See Fig6]* (2.5kWhrs/day) and 298kWhrs (42kWhrs/day) were exported to the grid in the same period of time[*See Fig7]*. Comparing the data from the same period in 2024, 117kWhrs were imported from the grid and 480kWhrs exported to the grid.

99kWhrs less imported, an 85% reduction in energy consumed from the grid and 190kwhrs less exported, a 38% reduction in exported energy.

Despite the presence of the 11kWhr battery, the 1bed still imports energy from the grid on a daily basis. Peak demand for energy occurs regular pattern from 7am for approximately an hour and again around 6pm for another hour. These spikes in energy demand are understood to derive from the combined uses of the following electrical appliances, a 9kW shower, 5kW oven, 3kW kettle and 2kW air fryer in addition to other devices e.g. computers, TV, Smart Metre, router.

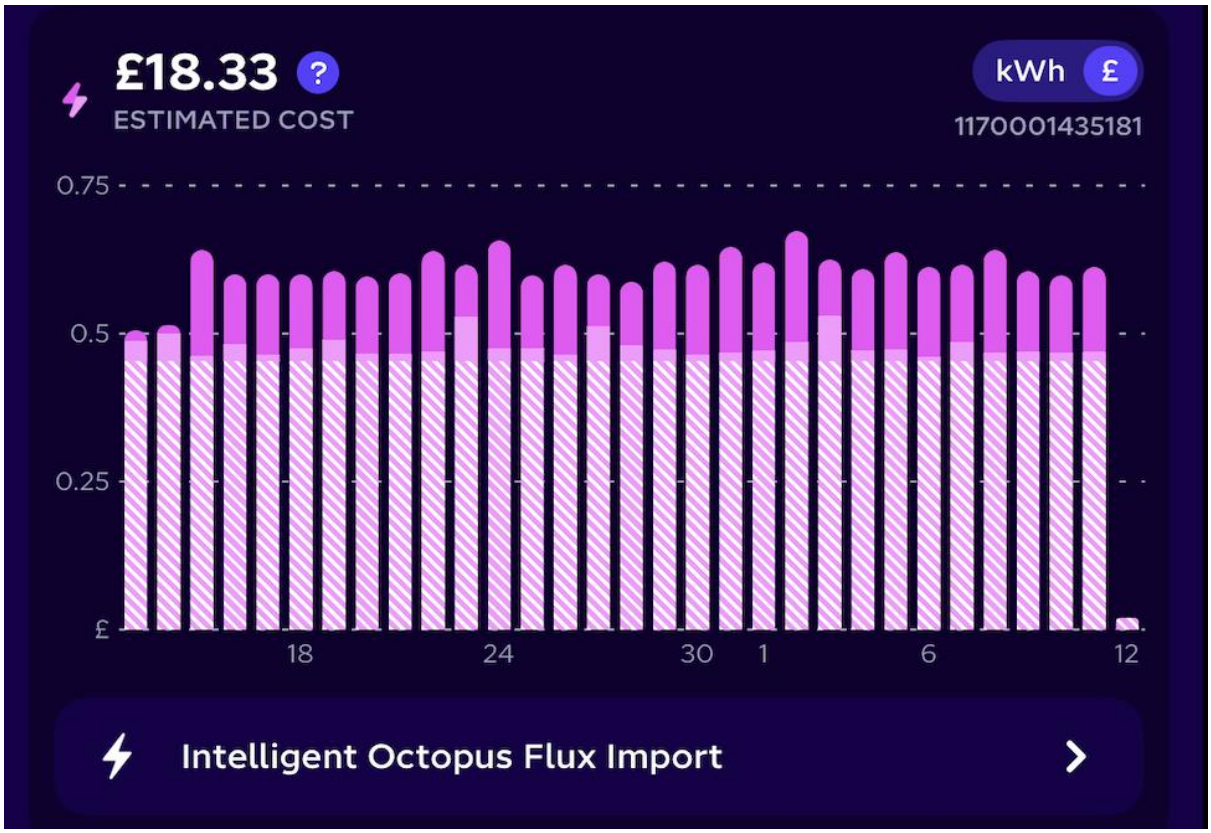

Figure 6. *12th July to 13th August 2025 Octopus Bill at Howgate Close 1bed with a battery installed*

Figure 7. *12th July to 13th August 2025. Octopus Export Income at Howgate Close for a 1bed with a battery installed*

Energy Storage Installation *[See Fig 5]*
On 16th April 2025, at a 1bed Howgate home, the existing Fronius Primo 4.6kW inverter was replaced with Gen24 Primo 4.5kW inverter and BYD HVM 11kWh battery.

From 16th April to 13th August 2025, the property has been 93% self-sufficient with 434kWh additional benefit from battery storage and 72kWhrs drawn from the grid due to short periods of high loads.

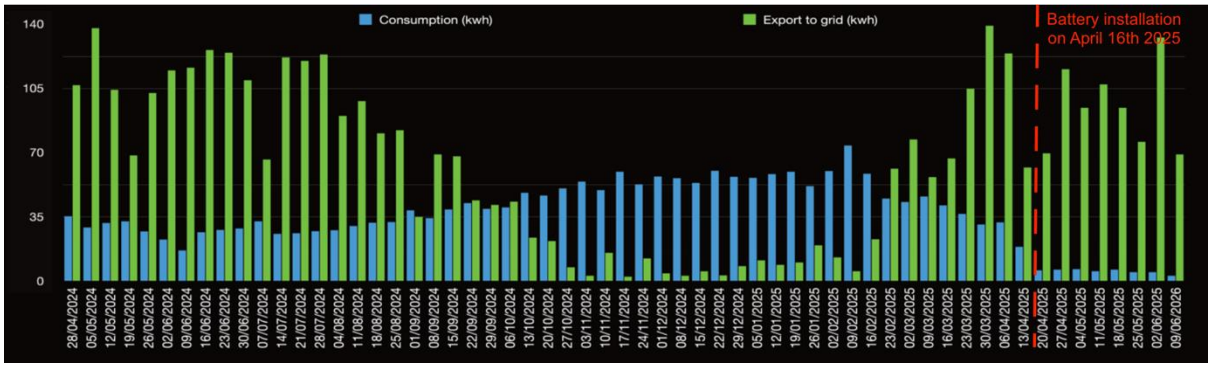

Figure 8. *2025. 14months of Octopus Energy imported and exported at Howgate Close 1bed with a battery installed*

Over the first 120days of installation, over 1.58MWhrs of renewable energy generated from the roof mounted pv's was exported. 59% of the renewable energy generated was still exported despite the presence of the battery.

Data from July 2024 and 2025 shows higher generation in 2025, probably due to better insolation.

Some Observations And Feedback

While the Howgate home is demonstrating an encouraging level of self-sufficiency over the first four months since the battery installation, it is recognised the time line is 8weeks either side of the Summer Solstice, perhaps the months of lowest heating load demand.

Peak energy demand, 'spiking', occurs from a few seconds to a couple of minutes. Recommendations to the tenants are to consider higher efficiency appliances to reduce peak loading.

A full year of data in the current working mode would allow for an optimisation of PV, inverter and battery sizing. This would be applicable to any country with similar insolation levels.

4. SUMMARY

What difference has the 11kWh battery installed at a 1bed earth-sheltered home at Howgate Close?

In the first four months of the battery installation there has been an 85% reduction in energy consumed from the grid compared to the same period in 2024. Despite a 38% reduction in exporting energy, the revenue from Exported Energy has increased due to the new Tariff in the presence of a battery.

This paper articulates how Howgate Close's exceptional energy efficiency standards have delivered a low energy demand that compares favourably to the UK Building Regulations 'Notional Building'. In part due to the consequential low daily energy demand, the installation of a 11kWhr battery has been transformational in reducing reliance on the National Grid.

A further 8months of in-use building performance data will enable accurate sizing of inverters and batteries for the balance of eight buildings at Howgate Close.

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