CABE Research Forum – Building Engineers Embedding Sustainability and Resilience in the Built Environment
Celtic Manor, Newport, Wales, UK | 13 October 2022

Whole House Energy System Retrofit of Six Off-Gas Bungalows in South Wales

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Abstract

UK housing stock is carbon intensive and residents face growing energy bills, with the risk of fuel poverty high. To overcome this, the LCBE team worked with Swansea Council to design and implement an affordable and replicable installation of a whole house energy system as part of a deep energy retrofit strategy for six off-gas Bungalows in South Wales. This aims to reduce energy use, energy bills and carbon emissions. The challenge was not only to select the right individual technologies for the bungalows but to encourage all stakeholders to work together to ensure technologies work as a system. Compared to pre-retrofit calibrated modelling, the amount of energy imported from the grid each year was reduced from 16,117 kWh to just 2,476 kWh post-retrofit (85%). The bungalows are 52% self-sufficient and no longer rely on either oil and LPG for heating. Based on current market prices [7] and conversion factors [8], energy bills fall by 69% and net operational carbon reduces by 3,115.8 kgCO_2eqv annually (94%). Benefits are not limited to energy: indoor air quality improved and indoor air temperature increased in winter, achieving the desired set point.

Background

Homes in the UK account for 16% of greenhouse gas emissions [1]. To achieve Net Zero by 2050, we must decarbonise our housing stock, including retrofitting 29 million existing homes in the United Kingdom [2]. Combined with continued increases in market energy prices, high energy consumption leaves residents facing high energy bills and at risk of fuel poverty [3], with 45% of households in Wales estimated to currently live in fuel poverty [4]. Homes must be comfortable and high quality, particularly for vulnerable or older residents [5]. To demonstrate the benefits of a whole house energy system to address these issues, the LCBE team collaborated with Swansea Council to install a whole house energy system as part of a deep energy retrofit for six off-gas bungalows in south Wales. Each 1970s 64 m^2 bungalow has two bedrooms, all are terraced in an L shape and were heated by LPG oil. Benchmarking showed bungalows consumed significantly more energy than others with their typology, making them expensive to run. Fabric performance was poor, with filled cavity walls (measured performance: 1.11 $Wm^{-2}K^{-1}$) and poor airtightness (13.5 ACH).

Methodology and results

A system based approach was taken to designing retrofit measures for the bungalows. The measures were informed by a thermal and energy model in HTB2, which was calibrated using pre-retrofit monitoring data and used to compare combinations of options. The following measures were selected:

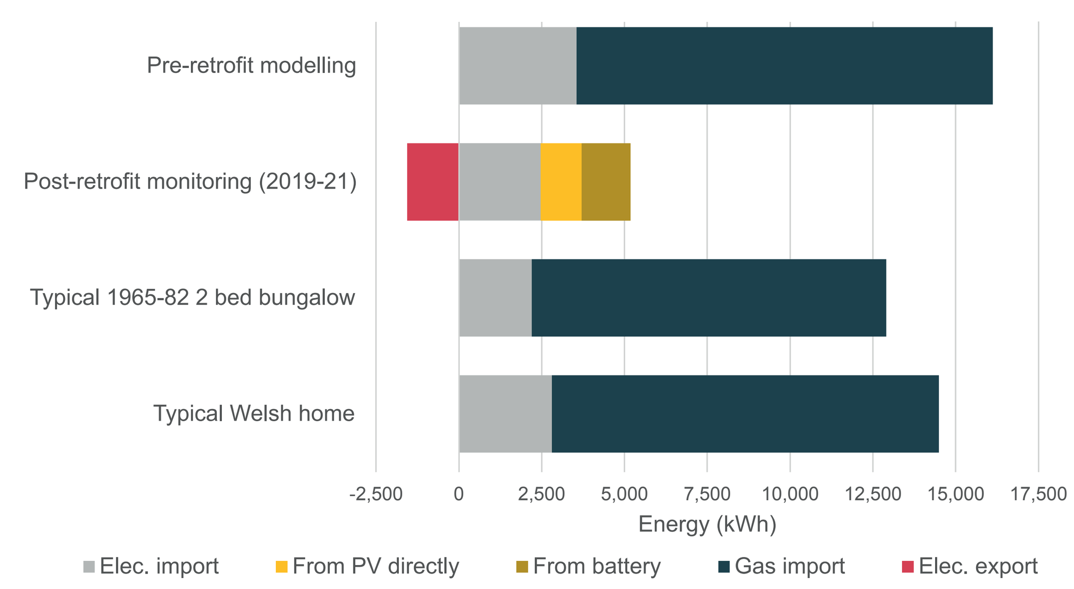
- Reduce energy demand: passive measures including external wall insulation, loft insulation and window replacement and active measures such as LED lighting and mechanical ventilation with heat recovery (MVHR) system.
- Supply renewable energy: building integrated photovoltaic (BIPV) solar panels were installed on two roof orientations at every bungalow, with a total capacity for each home of 5.8 kW_p. A ground source heat pump (GSHP) was installed to supply domestic hot water and space heating.
- Store renewable energy: a 13.5 kWh Tesla Powerwall 2 lithium-ion battery.

A comprehensive monitoring campaign taking place between October 2017 and May 2021 has demonstrated the benefits of the system based approach. Thermal transmittance through the walls, sub-metered electricity consumption, heat delivery, outdoor weather, indoor air temperature and relative humidity have all been used to assess both individual technologies and their performance as an entire system.

Comparing calibrated pre-retrofit modelling with post-retrofit monitoring, energy consumption fell from 16,117 kWh to 5,181 kWh (67.9%). Thermography shows a significantly improved fabric quality with previous heat loss areas, such as below the windows, reduced by new insulation. Indoor air temperature consistently matches the set point providing more comfortable living spaces. The BIPV solar panels provide 1,242 kWh directly to each bungalow with 1,463 kWh of excess generation stored in the battery. The GSHPs have a seasonal COP of between 3.0 and 3.5. The whole house energy system combining a GSHP, BIPV solar panels and battery has ensured a measured self-sufficiency of 52% and a self-consumption of 63%, reducing the total energy imported from the grid from an average of 16,117 kWh pre-retrofit to 2,467 kWh post-retrofit (82%). Export to the grid is 1,159 kWh, with residents able to use income from this to offset their energy bills.

Recommendations and future work

The bungalows are an exemplar for deep energy retrofit of off-gas homes and successfully provided a whole house energy system that significantly reduces energy import from the grid, reducing energy bills by 69% [7] and net operational carbon from 3312.7 kgCO_2eqv to 196.8 kgCO_2eqv (94%) [8]. Benchmarking (figure, right) shows that the bungalows greatly outperforming similar 1965-89 2 bed bungalows. Several lessons were learned, particularly around the coordination of retrofit work when implementing novel technologies together. To overcome this it is recommended that 1) a single supplier with sub-contractors is used to ensure accountability for the construction stage and 2) all installers should attend site and agree a comprehensive installation plan at the design stage. This will ensure efficiency with higher quality commissioning. Future work will focus on replicating whole house energy systems and continuing their evaluation in other retrofits.



References

[1] Department for Business Energy and Industrial Strategy. 2020 UK Greenhouse Gas Emissions, Final Figures. London: Department for Business Energy and Industrial Strategy; 2022.
[2] Committee on Climate Change. UK housing: Fit for the future? London: Committee on Climate Change; 2019.
[3] National Energy Action. UK Fuel Poverty Monitor 2021: Every home should be a warm and safe place. Newcastle: National Energy Action; 2021.
[4] Welsh Government. Fuel poverty modelled estimates for Wales (headline results): as at October 2021. Cardiff: Welsh Government; 2022.
[5] World Health Organization. WHO Housing and Health Guidelines. 2018. 978-92-4-155037-6.
[6] Department for Business, Energy and Industrial Strategy. National Energy Efficiency Data-Framework (NEED): consumption data tables. 2021.
[7] Ofgem. Default tariff cap level: 1 October 2022 to 31 December 2022. London: Ofgem; 2022.
[8] DBEIS. Greenhouse gas reporting: conversion factors 2022. London: Department for Business, Energy and Industrial Strategy; 2022.

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