MODELLING THE DECARBONATION OF HOUSES FROM STOCK LEVEL TO DETAILED CASE STUDIES

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ABSTRACT

Welsh Government has set the ambitious target of a 95% reduction in carbon emissions from the Welsh housing stock. To achieve this goal, a target Energy Performance Certificate rating of 'A' has been established for all dwellings. The literature suggests this is technically possible, but widespread rollout of retrofit that meets this target poses different challenges to the deep retrofit of a single dwelling. Retrofitting the social housing landlords' stock is seen by Welsh Government as an appropriate first step to meet the 2050 target, as landlords have already improved their stock nationally as part of the Welsh Housing Quality Standard programme (2005-2020).

This paper presents research that developed a process to enable landlords to understand key actions and challenges related to stock-wide retrofit that meets this target, by moving from top-down typology stock modelling to a case-study-led approach that landlords can apply to their own stock. Case studies ('typical' homes owned by Welsh social housing landlords) were identified through the Welsh House Condition survey and a survey of all social rented dwellings. Retrofit of each case study was modelled thorough to 2030, with an emphasis on the component-led approach adopted by landlords (windows, walls, loft, heating systems, renewables, etc.). The business-as-usual approach of each social housing landlord was compared to a best practice approach to retrofit, and the differences are presented in terms of impact on emissions, fuel bills and cost.

The work is based on the UK Standard Assessment Procedure (SAP) steady state monthly model outputs and Energy Performance Certificate rating, which are used as the common language for retrofit proposals. SAP is not an appropriate measure of decarbonisation itself, but is an appropriate tool to measure the improvement in energy efficiency needed – to develop a retrofit approach which achieves decarbonisation without negatively impacting on fuel poverty). The modelling compares expected repair, maintenance and improvement with deep retrofit for decarbonisation through installation of heat pumps and renewables, to understand the conflict between fuel cost and carbon reductions. The paper also highlights how overall stock targets of EPC A were created and case studies used to communicate the outcomes of the modelling to a broad audience that included policy makers, housing management teams and project managers.

INTRODUCTION

The need to decarbonise

The UK government has committed to reduce emissions by at least 80% of 1990 levels by 2050, and contribute to limiting global temperature rise to as little as possible above 2°C. The Welsh Government has a legal duty in Part 2 of the Environment (Wales) Act 2016 to reduce carbon emissions in Wales by 80% by 2050 (NAW, 2016). Decarbonising electricity generation is a been significant clear over the last decade the levels of Carbon emissions are now around 80% of those in 1990, however, progress in the power sector masks a failure to decarbonise housing where the main source of emissions is due to the burning of natural gas to provide space heat and hot water. Housing is responsible for 29% of UK carbon emissions, however in Wales the figure is 21% (CCC, 2017), reflecting the high level of emissions from industry in Wales, and increasing the challenge of meeting carbon budgets. The targets for decarbonising the housing have therefore moved from 80% to 95% (CCC, 2019).

The make-up of the Welsh housing stock has been very stable for the last two decades, with a significant increase only in the private rented sector. Low rates of new and replacement housing (around 50% of the demand for new homes) mean that the existing housing stock will be in use for many years to come (IWA, 2019). It is likely that more than 90% of today's stock is predicted to remain in use by 2050.

The Welsh housing stock is particularly old with one third of homes were built before 1919, and just 6% were built in the last 30 years (as of 2016), increasing energy demand for heating and reducing comfort. The Welsh Government has modelled that despite energy efficiency initiatives, almost a half of households currently experience fuel poverty when defined as spending more than 10% of income on fuel (Welsh Government, 2018).

Welsh housing consists of a range of different dwelling types, ages, physical forms and construction types, many of which have been modified over time to create a diverse stock of varying quality and condition. There is no single 'solution' for a housing stock that varies so significantly. However, a taxonomy of recurring dwelling archetypes will help reveal appropriate pathways for improvement.

Strategic approaches

Previous research (Green, et al., 2019) has highlighted a need for a defined strategic approach to decarbonisation, to be successful, landlord's retrofit strategies should support simple, low-cost options to reduce emissions, and should end the chopping and changing of policy, where policy is evidence-based. The withdrawal of incentives has reduced the installation of insulation to 5% of 2012 levels (CCC 2018).

The strategies must be informed by clear priorities for the decarbonisation programme. The UK Fuel Poverty Monitor and Scottish Decarbonisation Route Map both advocate fuel poverty as a key reason for retrofit. Strategies should commit to effective regulation and strict enforcement through tougher standards that can further reduce emissions while driving consumer demand, innovation, and cost reduction. Providing long line of sight to new regulations also reduces the overall economic costs of compliance.

How to retrofit

Much is already known about the implementation of individual retrofit actions, including both fabric and technologies, but there is less clarity over the most effective combinations of actions (Green, et al., 2019). There is also conflicting evidence around the effectiveness of actions, which appears to be heavily influenced by occupant engagement, and a lack of confidence generally in the associated costs (Green, et al., 2019). To understand the current landscape a review was undertaken of case studies and the grey literature. This revealed the following:

When looking at case studies they are generally one-off / bespoke, but there is scope to reduce costs by understanding key actions better and benefitting from economies of scale. Importantly, wider benefits (e.g. affordable warmth, health) increase the value of decarbonisation, and potentially offset costs when the retrofit is considered holistically (Poortinga et al. 2017, Rodgers S. et al., 2018).

Different sectors of the housing stock require different levers to make retrofit happen, factors that need considering are the Tenure which is likely to have a particularly big influence. The hardest type of homes to retrofit are the smaller, lower value owner-occupied dwellings and the off-grid owner occupied dwellings. The review (Green, et al., 2019) made clear that housing stock is complex and varied, and there is no single 'solution'. The concept of a retrofit pathways that deliver on quality as well as emissions reduction are likely to address both building fabric and energy/systems.

The review highlighted the need for a stock level modelling exercise to give an indication of the types of retrofit pathways that should be considered, and the subsequent holistic case studies to focus on.

MODELLING METHODS

The literature reveals two types of stock level modelling that can be undertaken (Swan and Ugursal, 2009), a Top Down – statistical analysis based on one typical home. (Gouldson., et al. 2012) or a Bottom up that uses limited data on all buildings usually aggregated to make results useful at a neighbourhood or stock level (Jones, Lannon and Patterson).

This work required both aspects a detailed approach with a national outcome, it was therefore decided to use a middle ground approach where the stock model is based on a series of archetypes based on the recent Welsh House Condition Survey (WHCS) (WG 2019) to propose overall stock level targets. This is followed by a series of case studies based on real buildings with their opportunities (existing retrofits already in place) and hurdles (poor tenant engagement) to explore the implementation of proposed decarbonisation standards.

The model outputs required a simple output, the SAP/EPC model was chosen as this is already used for numerous housing policies including Fuel Poverty measure, Renewable Heat Incentive and other energy efficiency policies and retrofit initiatives? such as ECO (EPC D to G only) and Minimum Energy efficiency standard for private rented EPC E. In Wales the Welsh Housing Quality standard has a requirement for all social rented homes to be SAP 65. An EPC of D. SAP/EPC is a common language for all stakeholders, who are uninterested in the mechanics of it, it is integrated into stock management systems and software freely available. The industry is also aware of the limitations of EPC. for example, EPCs are based on poor assumptions, but they value the clear messages it provides.

Archetypes

25 archetypes were used to disaggregate the Welsh housing stock, separated into n five building types and five categories for date of construction. The Valuation of Office and EPC database established that 14 of this covers 84% of the housing stock in Wales. (Figure 1) Using data from the WHCS representative values for the overall dimensions: width, depth, ceiling height, floor area, and front and back glazing ratios. This data was combined with the information about heating type and fuel to give a simple representation of the dwellings for the SAP model.

	HOUSE End terrace	HOUSE Mid terrace	HOUSE Semi-detached	HOUSE Detached	FLAT (Purpose built)	Total
pre 1919	3% 	9% 	4% 	7% 		23%
1919- 1944			5% 			5%
1945- 1964			10% 			10%
1965 - 1990	4% 	6% 	10% 	9% 	4% 	33%
post 1990			5% 	7% 	1% 	13%
Total	7%	15%	33%	23%	6%	**84%**

Figure 1 Fourteen archetypes representing the Welsh housing stock

Data used

In addition to the physical characteristics of each archetype (which are constant over time), further information was needed to model the condition of each dwelling 'type' at three points in time – in 1990, in 2018 and in 2050. The data needed to develop these three distinct models came from three sources:

Historic data for the 1990 'baseline' condition came from the UK Housing Fact File (DECC 2014). Data for the current condition (2016) came from the EPC data for Wales (2016), which represents circa 60% of the total Welsh housing stock (collected over a 9 year period).

To develop a model for 2050, four retrofit narratives were developed. Each narrative was designed to represent a viable approach for part, or all, of the Welsh housing stock, and includes a specification detailing the level of retrofit. (Figure 2)

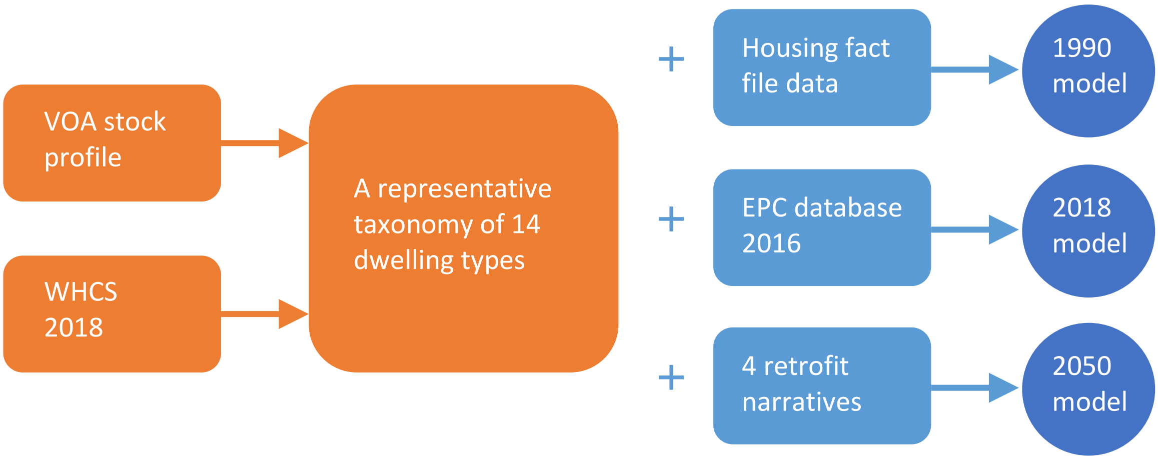


Figure 2 Modelling workflow

Modelling the changes in the carbon emissions of the energy systems is a critical part of successfully modelling the decarbonisation process. Emissions from the housing sector are estimated to have reduced by more than 40% from baseline 1990 levels, but three quarters of this improvement comes from cleaner primary energy supply (from changes to the mains gas and mains electricity grid) rather than changes to the housing stock itself.

The degree to which energy supply continues to decarbonise will significantly affect decarbonisation of the housing stock and could influence the selection and effectiveness of dwelling-specific retrofit actions. Retrofit that explicitly targets decarbonisation alone has potential to dramatically increase fuel costs for occupants. For this reason, it was deemed necessary to consider decarbonisation of energy supply within this piece of work.

Three distinct energy supply scenarios were allowed to influence the models, to explore the impact of potential future changes to energy supply on decarbonisation of the existing housing stock, as follows:

- Scenario 1 – minor future improvements to the national grid
- Scenario 2 – significant future improvements to the national grid
- Scenario 3 – transformational change to the national grid.

Results of stock modelling

The results are combined to assess the impact of these different clean energy supply scenarios on decarbonisation of the housing stock (Figure 3). The x axis of Figure 3 shows the decarbonisation progress from 1990 levels of existing energy efficiency measures, the impact of the historic energy supply decarbonisation, this is followed by the potential change in energy supply decarbonisation, systems and fabric measures, with the last part being the savings through behaviour change. As can be seen, the impact of changes to energy supply on the decarbonisation of the housing stock is considerable:

Under scenario 1 (minor further improvements in clean energy supply) it is not currently tenable for the existing housing stock to achieve greater than 90% decarbonisation using established retrofit good practice.

Under scenario 2 (significant further improvements in clean energy supply) 90% decarbonisation is only achieved when the existing housing stock is retrofitted beyond current Building Regulations, with a transition to electricity as a source of heat.

Under Scenario 3 (transformational change) decarbonisation is achieved through improvements in energy supply and services alone. In this context, the significance of retrofit of the existing housing stock relates less to decarbonisation targets and more to the need to avoid increases in fuel bills for occupants, and a consequent increase in fuel poverty.

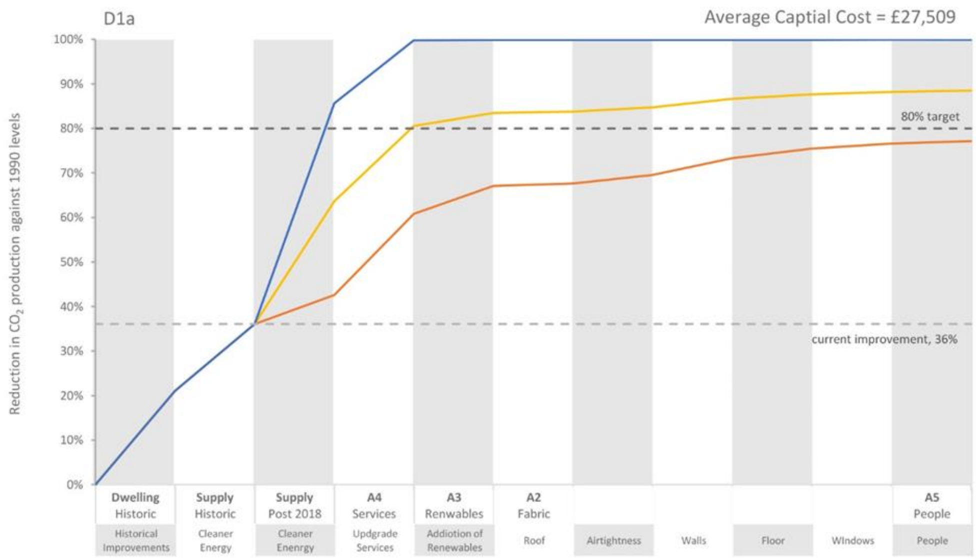


Figure 3 Stock Modelling results

The stock modelling revealed the scale of the task, the recommendations to Welsh Government were that there must be a comparable standard as a baseline MINIMUM for newbuild homes This gives a standard of SAP 92/EPC A much higher than the current SAP 65/EPC D (DHWAG, 2019). In particular there is a need to trial the process of mass retrofit, it is seen that retrofit standards are easier to enforce for social housing due to the interactions between Welsh Government and social landlords as part of the Welsh Housing Quality Standard (WHQS) (WG 2022). These trials will explore how to initiate this level of improvement for the owner-occupied sector.

CASE STUDIES

The targets set by the stock level modelling may be applied to social landlord stock before 2030, this limited timescale allows for more certain grid scenarios than the ones used in the stock modelling. To explore the potential for retrofit a series of detailed case studies in which the Anticipated Repair Maintenance and improvement (RMI) describes 'business as usual' for the landlords – repair, maintenance and improvement has been compared to the decarbonisation retrofit that describes a current best practice that targets 95% decarbonisation.

The scope of anticipated RMI varies depending on dwelling condition and, typically, age, providing a new mains gas combi boiler is the most common measure and usually does not include renewables. The decarbonisation retrofit includes improving fabric such that switching the existing heating and hot water system with heat from electricity heat, does not impact significantly on fuel costs. In addition, the installation of photovoltaic panels as a renewable, to benefit to the tenant by reducing overall fuel bills.

This research is the result of a collaboration with Social Housing Landlords during the discussions with the landlords one theme that emerged that has a direct impact on the holistic retrofitting process is the focus on a component approach to works.

All of the SHLs involved in the study currently consider their stock from this component-based perspective, and most of the retrofit currently taking place is component-driven. This component-based approach to stock may well be a result of the reporting requirements of recent (2002 – 2020) WHQS work. There is a conflict between a component-based perspective and the need for an holistic approach to successfully decarbonise stock, which needs to be explored further. Any wider work on retrofit strategies or the development of supporting guidance / tools / grant aid should bear this in mind.

CASE STUDY RESULTS

The case studies are not intended to be adopted as the 'correct' solution for any particular archetype, in terms of dwelling type, age or other factor. The case studies are worked examples and are as useful for the lessons they offer about how not to retrofit, as much as they offer examples about how to retrofit. It is also important to acknowledge that 'best practice' retrofit will continue to evolve and

develop as more work is undertaken, innovations become mainstream, and lessons continue to be learnt.
Case studies explore the complexities of working with ‘real’ homes, and in particular to appreciate the tension between retrofit for decarbonisation, capital cost of retrofit, and impact on tenant fuel bills.
Each case study provides an overview of the case study (Figure 4), in terms of the type of home, the existing condition, the nature of the proposed work, and the ‘headline’ results. The proposed RMI works and the decarbonisation retrofit, are given as two different specifications and are based on the particular setup of the building including any structural work need or need to respond to a tenants requirements. The specifications and costs of the case studies (Tables 1 and 2) can all be found in the full report (Green and Lannon 2020).

Figure 4 Example case study overview

The results of each case study, with the impact of the assumed RMI retrofit described in the top half of the figure, and the impact of the decarbonisation retrofit described in the bottom half (Figure 5). Tabulated numerical results describe the impact of each retrofit on SAP rating (for energy efficiency), decarbonisation (% reduction in emissions versus 1990 baseline), and fuel costs for the tenant. In addition to the numerical results, pie charts describe the relative impact of each retrofit measure in terms of emissions (left hand side pie chart) and capital costs (right hand side pie chart). The size of each pie chart reflects the total emissions reduction (left hand side) or total capital cost (right hand side). To ensure that tenant fuel costs remain a central part of the discussion, comments between the pie charts relate impact on fuel bills to changes in both emissions and cost.

component:	**why:**	**how: (specification)**	**likely cost**
walls	Wall insulation programme	External Wall insulation 100mm	£3,263
roof	Whole stock review	Assumed to be sufficient 300mm	
floor	Nothing planned	No upgrade	
window, door	RMI cycle	Standard high performance upvc	£4,670
heating and hot water	RMI cycle	Mains gas combi boiler	£3,580
airtightness , ventilation	As part of works	Normal practice	
renewables	Nothing planned	No upgrade	
Total cost			**£11,512**

Table 1 Example of anticipated retrofit

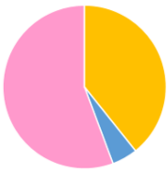
component:	specification:	likely cost
walls	External Wall insulation 100mm	£3,263
roof	Assumed to be sufficient at 300mm	
floor	50mm over-floor insulation.	£2,113
window, door	Triple Glazing composite (timber)	£9,340
heating and hot water	Air Source Heat Pump	£8,180
airtightness, ventilation	Best practice without MVHR	£816
renewables	PV 4kWp	£7,000
Total cost		**£30,710**

Table 2 Example of decarbonisation retrofit

Results 1: **Anticipated retrofit**

Predicted incremental impact of retrofit:

	1990	now	+wall	+roof	+floor	+glazing	+heat.	+vent.	+renew
SAP	40	42	54			56	67		
fuel bills (£)*	£1,327	£1,277	£1,018			£983	£726		
Decarbon**	0%	33%	49%			51%	67%		



Upgrading the external walls is cost effective. Upgrading glazing is more expensive, with a limited impact on emissions.

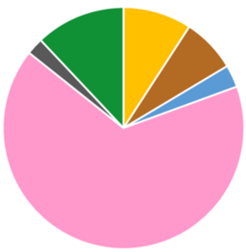
Installation of traditional mains gas wet central heating system limits potential to decarbonise (67% overall), and annual fuel costs for tenants remain expensive.

Comparison of decarbonising impact against capital costs for each component

Results 2: **Decarbonising retrofit**

Predicted incremental impact of retrofit:

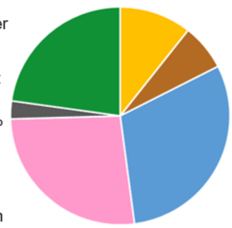
	1990	now	+wall	+roof	+floor	+glazing	+heat.	+vent.	+renew
SAP	40	42	54		64	67	67	68	93
fuel bills (£)*	£1,327	£1,277	£1,018		£794	£739	£729	£701	£148
Decarbon**	0%	33%	49%		62%	66%	92%	92%	96%



Fabric first helps protect tenants from fuel poverty, reducing fuel bills by £300 per year.

The transition to electric heat is key to meeting decarbonisation targets (97% overall, with two thirds of the impact from heating).

Renewables make retrofit desirable for tenants, through a dramatic reduction in fuel bills of £550 per year.



Comparison of decarbonising impact against capital costs for each component

* energy costs are based on current cost per unit
** emissions relative to 1990, based on energy supply predictions for 2023 (source: NationalgridESO, 2019)

Figure 5 Case study results

CONCLUSION

Stock modelling shows that SAP ratings can be used to predict energy efficiency and fuel costs but cannot be used as the sole basis to judge whether retrofit will meet decarbonisation targets. A low carbon heat source must also form part of the decarbonisation strategy. If the dwelling fabric is improved to an enhanced standard, retrofit of low carbon heating systems can be cost effective for tenants (meaning that, at current fuel costs, annual fuel bills remain approximately the same), and the transition to low carbon heat sources could take the place of existing boiler replacement. To ensure that the decarbonisation target will not increase fuel poverty, the target for all Welsh social homes by 2030 has been set at EPC A. The SAP method has limitations around innovative low carbon solutions such as battery storage and PV generation that will be addressed in the SAP 11 development, this will bring a clearer view on the balance between fabric and systems retrofit options (Etude 2021).

The stock modelling produced a difficult target for social landlords to achieve using established RMI and retrofit practice. The next step in the research was to communicate the difference between business-as-usual component-based retrofit, and the ambitious decarbonisation retrofits required of landlords. Learning was delivered through case studies based on their own existing properties with their own specifications and tenants. These case studies have highlighted both opportunities and barriers inherent in retrofit for decarbonisation and have enabled landlords to start planning their stock programmes for the next decade.

The case studies have provided learning for the landlords and Welsh Government, supporting good decision making, when situations are too complex for simple 'rules' or a one-size-fits-all approach. They have highlighted that it is possible to achieve the EPC A target and have given the Welsh Government evidence to set ambitious targets to be achieved by 2030 for both energy efficiency and carbon in the latest Welsh Housing Quality Standard.

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