Housing stock energy modelling: Towards a model for Wales

The combination of increasing global demand for energy and strict carbon emissions targets have made the decision-making process around acquiring and using energy complex. In the context of the net zero by 2050 commitment, the UK and devolved governments are interested in understanding the emissions implications of policy decisions and the interrelationships between decisions in different sectors.

Carbon modelling provides a structured way of assessing carbon emissions produced under various policy decisions. It enables scenarios to be tested, to inform the policy-making process, and will be particularly useful in informing and understanding the implementation of policies and proposals in the Net Zero Wales Plan (Welsh Government, 2021).

WCPP was asked to support the Welsh Government to develop an approach to capture the carbon impact of policy decisions in the housing sector, including an assessment of how examples of good practice can be built upon.

Housing and energy in Wales

The Welsh Government's decarbonisation strategy calls for a reduction in carbon demand from Welsh homes by 80% from 1990 levels by 2050. In the UK the energy efficiency of homes is measured using Energy Performance Certificate (EPC) ratings from A to G. The Welsh Housing Condition Survey (WHCS) conducted in 2017/18 showed that 73% of dwellings in Wales were rated D or lower.

The Decarbonisation of Homes Advisory Group has recommended that the Welsh Government set a target to retrofit the housing stock to achieve an EPC A rating. Understanding how this transformation can be achieved requires energy modelling of the Welsh housing stock to enable calculated predictions to be made about the impact of different policy decisions, taking into account:

- Housing stock: represented in a disaggregated manner, discriminating by age and thus mode of construction as well as by archetype (e.g. detached, semi, terraced or flat);
- Mode of tenure: within the housing stock and, preferably, accounting for the policy measures that target these different tenures (e.g. social, private or owner-occupied);
- Likely outcomes from policy and regulatory measures that target different property types and tenures; and
- Anticipated and actual changes in the composition of the Welsh housing stock by 2050, as houses are demolished, renovated and (re-) constructed.

Housing stock energy modelling

Housing stock energy models (HSEMs) calculate the energy performance and associated carbon emissions of national and sub-national housing stocks. HSEMs can broadly be divided into two types: traditional and dynamic.

Traditional HSEMs

Traditional housing stock energy models (T-HSEMs) focus on modelling annual energy use and associated carbon emissions. They consist of two interrelated components: i) energy use modelling calculations; and ii) the processing of data representing the housing units to be modelled.

The approach to energy use calculations varies. Top-down T-HSEMs rely on aggregate information describing historical energy use for the housing sector as a whole. This does not permit disaggregation of energy use by types of dwelling or of the end use of energy. Bottom-up approaches do disaggregate energy use by dwelling type, and potentially also of their end uses. They use either statistical or engineering techniques. Engineering techniques support more refined modelling of the impacts of upgrades to a house's envelope or its energy systems.

Since it is impractical to model every individual house in a (sub-)national stock, modelling techniques cluster housing units into archetypes. Bottom-up T-HSEMs employ different strategies for sampling housing stock, with different levels of granularity, often depending on the availability of data.

Many of the most commonly used models in the UK are derivatives of one particular bottom-up engineering model: the Building Research Establishment Domestic Energy Model (BREDEM). BREDEM and related models use simplified monthly or yearly energy balance models to evaluate the energy demands of housing archetypes. However, more recent T-HSEMs (e.g. EnHub and ResStock) employ dynamic energy simulation techniques.

Dynamic energy simulation is useful because it allows for hourly energy use and factors like room temperature to be calculated. It also explicitly simulates how the envelope, energy systems and occupants' behaviours dynamically interact. As such, their simulations can reveal how housing energy use and indoor conditions respond to changes in energy systems (e.g. replacing gas boilers with heat pumps) or to people's behaviours (e.g. choosing warmer temperatures as a house becomes better insulated). Such an approach can also increase the understanding of fuel poverty by balancing the cost of energy use with indoor conditions.

Bottom-up *dynamic* engineering models are therefore the most powerful type of T-HSEMs as they explicitly calculate energy use and how this is split by end uses as well as indoor temperatures. They can simulate the impacts of a broad range of potential interventions.

T-HSEMs have a long history of supporting assessments of energy use in housing in England and of indirectly contributing to the formulation of energy-related housing policy. However, a weakness of these models is that the structure of the housing stock remains unchanged in the scenarios, whereas in practice the housing stock changes all the time. They also only test the impacts of assumed uptake of the modelled scenarios (e.g. what will happen if 60% of remaining houses with solid walls become insulated?). Therefore, while useful these models are limited in the extent to which they can accurately forecast how the housing stock and resulting carbon emissions are likely to evolve in response to future policies.

> **Developing new HSEMs, uniting the advantages of both traditional and dynamic models, needs to be a long-term investment and commitment if policies and strategies are to be effective in achieving 2050 decarbonisation targets.**

Dynamic HSEMs

In contrast to T-HSEMs that focus on identifying what is possible within the constraints of the current housing stock, D-HSEMs aim to capture the ongoing changes that occur in the housing stock.

D-HSEMs model how the size and composition of the housing stock changes over time due to demolition, construction and renovation activity. D-HSEMs can also consider the extent to which external factors influencing housing energy use, such as climate change and the broader energy system are represented (albeit using simplified energy modelling techniques). They could, therefore, offer a more sophisticated approach to modelling the emissions consequences of policy decisions.

D-HSEMs have to date been under-used but they have the potential to enable policymakers to estimate the likely economic and carbon impacts of strategies to decarbonise the housing stock over the longer term.

Comparing T-HSEMs and D-HSEMs

Traditional and dynamic HSEMs model the housing stock from opposing but complementary viewpoints:

- T-HSEMs represent the housing stock as it stands now and test the impacts of assumed (or simplistically modelled) uptake of specific material or technology substitutions.
- T-HSEMs focus on the reduction of energy use to varying degrees of rigour.
- T-HSEMs employing dynamic energy simulation techniques represent the gold standard in this category. They calculate hourly energy use and indoor conditions and how these are affected by changes in a houses envelope, systems and occupants' behaviours.
- D-HSEMs in contrast model how the stock might evolve (demolition, renovation, (re-) construction) over long timescales and what the life cycle impacts might be.
- D-HSEMs are comparatively good at capturing energy used for house construction and renovation (energy that is embodied in the fabrication of materials), but model day-to-day energy use somewhat simplistically.

Designing better HSEMs

HSEMs have thus far been developed in a largely ad-hoc way, mainly by academic and research organisations, in an environment which is not tailored to the production of commercial-strength software. As such the models tend to be used exclusively by these experts, with little regard for usability, longevity or transparency in their underlying assumptions. As well as limiting their use, it also makes them difficult to update.

Developing new HSEMs, uniting the advantages of both traditional and dynamic models, needs to be a long-term investment and commitment if policies and strategies are to be effective in achieving 2050 decarbonisation targets. Sound software development principles will help to reap and sustain the rewards from this investment as well as offering opportunities to support the straightforward definition of decarbonisation scenarios and the automated modelling of their impacts.

This could enable the carbon impacts of specific policy interventions to be revealed, along with their location and timing. This would enhance the quality of evidence underpinning housing stock decarbonisation policy.

Conclusion and recommendations

HSEMs have considerable potential to underpin housing decarbonisation policy; to help target programmes of subsidy, education, training and estimate the corresponding impacts on future emissions and employment.

The development and application of HSEMs in the UK has been dominated by T-HSEMs. These show what is possible and help to forecast future energy supply requirements. The models help to identify where the potential for renovation measures lie and what the impacts might be, based on assumed levels of uptake amongst homeowners. In contrast, D-HSEMs aim to capture the ongoing changes that occur in the housing stock and how this is driven by homeowners' decisions.

There is no single overarching tool that can model all the factors that influence the energy and carbon performance of housing stocks, how this changes over time and what the comfort and health implications might be. Unifying the two main types of model, T-HSEMs and D-HSEMs, would support the analysis of policies that are formulated with long-term decarbonisation targets in mind.

Given the increasing urgency of developing evidence-based housing decarbonisation policies that are specific to Wales, the following research, development and application priorities are recommended.

Proposed short-term strategy

Adopt a T-HSEM that employs dynamic simulation techniques, such as EnHub, and substitute the EHS dataset for England with the WHCS dataset, to create the Welsh Housing Model (WHM). This could provide Wales with an internationally competitive T-HSEM, on a par with the US ResStock platform as it would support a dynamic simulation that captures the heterogeneity of the housing stock and would allow for a broad range of renovation scenarios. It would also capture impacts on energy use, carbon emissions and indoor comfort.

Proposed medium- and long-term strategies

In the medium term the WHM could be further developed to include additional analytical capabilities such as tri-dimensional archetyping, spatial analysis, behavioural modelling, a scenario modeller, and web interface / crowd sourcing techniques. This would support the targeting of where interventions (differentiating by location, tenure and household socio-economic circumstances) are most needed and the form that these should take.

In the longer term the WHM modelling capabilities could be enhanced to include population, relocation and housing stock deterioration, renovation investment decisions, future climate scenarios, and other aspects of scenario modelling including sensitivity and uncertainty analysis and optimisation. This would provide world leading housing stock energy modelling capability, to rigorously test the impacts of specific policy interventions,, accounting for a changing climate, energy system and local infrastructure.

Find out more

For the full report see: Robinson, D., Tilley, H., Price, J., Lloyd, A. (2023). **Housing stock energy modelling: Towards a model for Wales**. Wales Centre for Public Policy.

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