A Low Carbon Retrofit Modelling and Analysis Process for Social Housing and Associated Policy Implications

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ABSTRACT

A work process has been developed for the assessment of domestic social housing heating upgrade options integrating academic-led building simulation with project implementation experience and local stakeholder considerations. The developed process allows for a fast, efficient assessment of SAP impacts combined with potential tenant savings calibrated to actual use to aid 'just-transition'-driven decision-making. Across multiple case studies the process has also highlighted limitations of the current use of the evolving SAP process as a benchmark, limitations of SAP to allow for innovative solutions and the impact of funding and resource constraints on potential solutions.

Keywords: domestic, heating, retrofit assessment

INTRODUCTION

Decarbonisation of domestic heating is a significant challenge, both from a technical and policy perspective. In a Scottish context, an independent review by Audit Scotland in 2024 (Audit Scotland, 2024) stated that meeting Scotland's climate targets will require "reducing emissions from heating homes as much as possible by 2045, which will need the majority of households to change their heating systems." and that "unless the scale and pace of activity significantly increase the Scottish Government's ambition will not be met".

The social housing sector provides an opportunity to upgrade a significant number of houses with coordinated strategies managed by a single organisation. This compares to the difficulty in targeting private householders with centralised upgrade schemes.

Scottish Social Housing Policy

The Scottish Government's 2021 'Heat in Buildings Strategy' (Scot Gov, 2021b), addressed the overall transition of building heating systems. This requires that: a large majority of buildings achieve good energy efficiency by 2030; all homes should be SAP/EPC band C by 2033; a 68% reduction in emissions from heat in buildings by 2030 from 2020 levels; and that 170,000 off-gas and 1 million (c. 50%) total homes should convert to low carbon heating by 2030 (Calvillo and Stewart, 2021).

To complement the Heat in Buildings Strategy, a review of the existing social housing decarbonisation guidelines, 'The Energy Efficiency Standard for Scottish Social Housing post 2020' (EESSH2) (Scot Gov, 2021a), is ongoing to ensure it is aligned with overall targets. Interim guidance is provided by Scot Gov (2022) but with the specific performance targets from EESSH2 on hold.

SAP/EPC

The Standard Assessment Procedure (SAP) 2012 (BRE Group, 2014) provides a formal process for assessing UK dwellings for energy performance via an Energy Performance Certificate (EPC) rating that evaluates energy use and cost against a consistent benchmark.

An updated version, SAP 10.2 (BRE Group, 2021), was introduced in 2019. The technical basis and work process are similar to SAP 2012, but with updated factoring to

account for changes in energy supply. This has been adopted in England and Wales in 2022 and in Scotland in 2023.

A new approach (SAP 11) is under development (BRE Group, 2022) which will provide a 'root-and-branch' review of how buildings are assessed for energy and carbon use. This provides another area of uncertainty regarding how existing homes will be assessed and judged compliant in the future.

The EPC benchmark rating is widely used in UK for upgrade targets. For example, in EESSH2 prior to the current review, the 2025 target was for no social housing to be let below EPC Band D and by 2032 to be Band B unless impractical to meet.

There can be flexibility to use 'equivalent' solutions where practical, but the lack of a clear definition results in this approach having significant future risk and is therefore unattractive to social housing landlords. This shows that clearly defined approaches are preferable.

'Just Transition'

As outlined, there is a strong drive in Scotland to ensure that decarbonisation funding and benefits are fairly distributed. While the SAP process provides a usual benchmark across all dwellings, it does not consider specific occupants and their energy usage. There is a need therefore to ensure any upgrade evaluation process also quantifies specific expected benefits.

Retrofit Options

Selecting potential retrofit options is dependent on the house type and location. Flats and dense multi-dwelling schemes allow for communal heating ('mini-districts') to be considered. Dwellings that currently have electric heating may have sufficient electrical incomer capacity for heat pumps but lack wet heating systems. The opposite being the case where a gas boiler is present.

A proposal paper for the Scottish Government (Smith, 2021) addressed the need for building archetype level solutions, with a focus on fabric upgrading first then energy systems, but with no clarity on the extent of fabric improvements or types of solution. There remains an open question regarding the degree of fabric upgrading that is most effective (and how that is quantified) and what types of heating system solution should be used for specific archetypes.

Complementary Technologies

In addition to the upgrading of building fabric and heating systems, there is also the potential to include a number of different complementary technologies to enhance the level or practicality of the basic decarbonisation options. The most common technology for inclusion would be roof top solar panels, but fabric-integrated solar, batteries and complex optimisation controls can also be considered.

At present, significant EV charging demand is not considered due to low current ownership among social housing occupants, plus this is not currently considered for performance certification of individual housing units, but this is likely to require integration with the work process in the future.

AIM

The aim of the work process developed between Power Circle and ESRU was to develop an effective method for evaluating the optimum retrofit requirements for social housing. The method necessarily reflects the iterative nature, where frequent stakeholder discussion and reassessment is required at all stages, with a focus on speed and adaptability in addition to accuracy.

The objective of this paper is (1) to outline the building simulation work process, integrating SAP and occupant specific benefit evaluations, and (2) to provide a discussion of the gap between the ambition and reality of bulk Scottish housing upgrading, and how building simulation can be used to assess this gap.

METHOD DEVELOPMENT

Building Review

Prior to considering potential upgrade options, a detailed review of the current building state and performance is undertaken to provide a benchmark. At the level of detail required a desk-based analysis combining landlord interviews, existing EPC reviews, drawings, energy use data and online mapping tools is sufficient. However, site visits are typically a worthwhile exercise in general, and

are useful to confirm, or to infill gaps in, source information, but may be impractical for remote projects.

Option Appraisal for Modelling

During the course of three case studies, three broad categories of potential upgrades to building fabric and heating systems became apparent. (1) A minimal approach with no or limited fabric improvement and householder disruption (this is a key consideration not always addressed in strategies). Typically focused on heating system upgrading only. (2) An intermediate solution, with a practical level of standard fabric upgrading that could be achieved with the tenants in-situ plus heating upgrades. (3) A 'deep' retrofit at or approaching Enerphit standard. These options provide both a realistic level of upgrading plus a wide range of impact from which cost-benefit can be gauged.

EPC/SAP Appraisal

As outlined, the main high-level performance target for social housing is achieving a required EPC rating. The full SAP/EPC calculation process has been ported by ESRU to Excel, allowing an assessment of each upgrade option based on a set of standard building performance inputs and the dwelling's basic dimensions. This has been done for both SAP 2012 and 10.2 including both individual and communal heating system options.

Detailed Energy System Modelling

Decarbonisation policies typically combine energy performance benchmark requirements with a focus on a 'just transition', i.e. using decarbonisation to alleviate fuel poverty. Building modelling, used in parallel with the EPC benchmarking process, allows a more detailed assessment of the actual cost benefit (both to landlord and tenant) to be made.

The basis for the building energy model is the integrated appliance, heating, and transport model detailed in Flett and Tuohy (2022). A detailed stochastic occupancy, hot water and EV charging model is coupled with a simple single-zone space heating model as shown in Figure 1.

Development of more detailed building simulation models, using platforms such as ESPr, was found to be impractical for retrofit appraisals at scale. For retrofit projects there is generally existing energy demand data, even if only monthly bill data, plus EPC data, by which a simpler energy model can be calibrated. The assumed fabric parameters (U-values, air changes, thermal bridges) can be adjusted slightly from assumed values

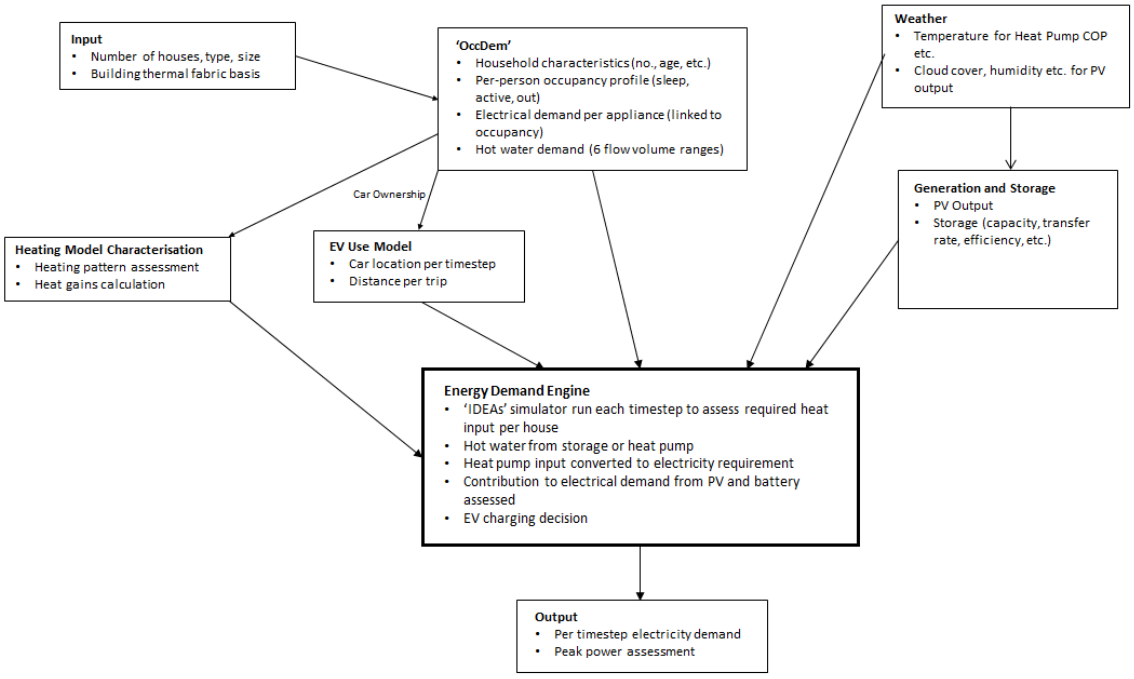

Figure 1: Demand model structure

related to building age and design to match actual energy demand and EPC rating. This ensures that the modelled upgrade potential for the building is valid for the actual building as currently occupied. In general, good correlation for both actual demand and EPC rating assessment has been achieved with a single demand profile, but two distinct profiles may be necessary in some cases where there is clear evidence of lower or higher demand than average (i.e. where demand levels cannot be replicated with realistic building fabric or assumed occupancy adjustments).

The benefit of the dynamic modelling approach used (i.e. incorporating realistic (typically half-hourly) timestep-based variation of various key inputs, such as occupancy, appliance demand and weather, and per timestep reassessment of heating demand), is that the natural day-to-day variation and extremes are captured, whereas if only averaged conditions are assumed (e.g. if only SAP analysis is carried out) this can lead to underestimation. This is increasingly important for modelling with time-specific inputs, such as renewable generation, time-of-use tariffs, time-based grid flexibility payment schemes etc.

The dynamic energy model is run to provide demand data for a techno-economic model that assessed the energy inputs, costs and carbon contributions to meet the demand requirements under different types of heating system. This also provides multi-year NPV cashflow assessments to allow the different options to be directly compared.

Detailed Implementation Financial Analysis

The output from the ESRU demand and SAP modelling was then used as an input by Power Circle (PCP) for detailed project-level financial analysis in an iterative process with the landlord. The following is a summary:

Overall analysis method:

1. Initial sift of wider options, resulting in a shortlist of potential heating systems and onsite generation options.
2. Creation of a scenario matrix from shortlist.
3. 1st round analysis (20-year NPV basis, plus RdSAP 2012 and 10.2) including creation of high-resolution (half-hourly) profiles for heat and non-heat demand => *ESRU model output*
4. 2nd round detailed analysis (30-year Discounted Cashflow (DCF)), utilising cost estimates generated by PCP and ESRU. PCP model with solar PV output profiles from commercial software (PVSol).
5. 3rd round detailed analysis (30-year DCF), utilising budget estimates from suppliers. PCP model
6. Selection of recommended and backup options based on both SAP rating and energy cost benefits.

Detailed (2nd and 3rd round) analysis method

- 30-year DCF utilising versatile financial model developed internally by PCP with costs based on consultant and then supplier estimates.
- Includes sensitivity analyses for variation in future energy prices, cost of capital, impact of metering solar PV.
- Constructed based on half-hourly demand profiles with heat and non-heat demand profiles from ESRU model.
- For some scenarios using time of use tariffs where appropriate.
- Assumes electrical batteries (BMS) are capable of demand shifting where a time of use tariff is in place and limited participation in grid services.
- Takes into account replacement cycle and maintenance costs.
- Different funding and financing models assessed.
- Disaggregates tenant and landlord, allowing us to show differential impact of different options.

Commentary

- Iterative nature with 1st round based on market knowledge estimates allows identification of practical solutions quickly and then to focus and refine analysis.
- Balances resource constraints (by allowing a focus on more promising options in later rounds of modelling) against the need for robust analysis projecting the financial implications of different options.
- Allows client to see results early, giving time for discussion and/or changes to analysis or areas of focus, in keeping with Agile project management methodology.

Table 1: Assumed costs for case study modelling

Option (all £'000s)	Fabric Option	Fabric Upgrade	Heat Source	Hot Water Store	Bore-holes	Network Piping	Heat Interface Unit	Wet Heating System	TOTAL
Communal ASHP (40kW)	Minimal	-	25	18	-	20	25	36	124
Communal ASHP (35kW)	Interm.	200	25	18	-	20	25	36	324
Communal ASHP (20kW)	Enerphit	540	20	18	-	15	25	27	645
Communal GSHP (40kW)	Minimal	-	20	18	70	20	25	36	169
Communal GSHP (35kW)	Interm.	200	20	18	60	20	25	36	359
Communal GSHP (20kW)	Enerphit	540	15	18	40	15	25	27	660
High Ret. Storage	Min./Int.	-/200	45	18	-	-	-	-	63/263
High Ret. Storage	Enerphit	540	32	18	-	-	-	-	590
Ind. GSHP (6kW)	Min./Int.	-/200	54	18	70/60	15	-	36	173/373
Ind. GSHP (3kW)	Enerphit	540	45	18	40	12	-	27	662

CASE STUDY

The work process has been applied to cases ranging from individual dwellings to tower blocks. The following case study is a 3-storey, 9-flat block located in a rural Scottish town; an example of a multi-dwelling scenario with a number of potential heating upgrade options. (Note: For privacy reasons the exact location and building details are not provided)

The 32-year old housing has electric storage heating. Metered total energy demand is c.6000kWh/yr. per property, with an assumed split of 1000 for appliances, 1000 for hot water and 4000 for space heating. Day/night tariffs are assumed, with a 31p/kWh day rate and 13.7p night rate used for modelling based on tenant rates at the time of modelling (2022).

Table 2: Building properties for fabric options

	Minimal	Intermediate	Enerphit
Wall U-Value	0.35	0.2	0.15
Floor U-Value	0.7	0.7	0.12
Roof U-Value	0.17	0.17	0.12
Windows U-Value	3.1	1.2	1.0
Thermal Bridge Factor	0.15	0.08	0.06
Air Changes/h	0.8	0.8	0.15*

* Effective ventilation for heat loss with MVHR recovery

Initial analysis identified potential upgrade options:

Heating: Replacement of the existing standard electric storage heaters with:

(1) Communal air source heat pump (ASHP)
(2) Communal ground source heat pump (GSHP)
(3) Individual GSHP (e.g. Kensa Shoebox)
(4) High retention electric storage heaters

External wall insulation (EWI): EWI to reduce wall U-value from 0.35 to 0.2 and thermal bridging from 0.15 to 0.05-0.08. Internal insulation was not considered due to the loss of space and resident disruption.

Windows: Upgrade from current old double glazing (3.1 U-value assumed) to triple glazing (1.2 U-value).

Enerphit: A full Passivhaus conversion with higher levels of wall insulation and roof and floor insulation upgrading, plus extensive sealing, MVHR addition and high performance triple glazing.

Table 1 shows the estimated capital costs. Table 2 shows how these were translated to the building simulation input properties for the 'minimal', 'intermediate' and 'Enerphit' options outlined above.

RESULTS

The following section describes the results for the case study analysis of the different heating system types and building upgrades.

Table 3 shows the SAP scores for each of the upgrade options for the mid-floor flats. The results show a number of issues in relation to the EESSH2 requirements:

- There is no direct consistency between SAP 2012 and 10.2 results. Achieving a 'B' rating in 2012 does not guarantee a similar rating in 10.2.
- High retention storage heaters are potentially acceptable under 2012 but c. 2 grades lower in 10.2.
- Achieving 'B' without a deep retrofit is not possible.

Table 3: SAP Results for retrofit options

Option	Fabric	SAP 2012	SAP 10.2
Current	Current	71(C)	28(E)
Communal A/GSHP	Minimal	71(C)	68(D)
Communal A/GSHP	Interm.	76(C)	75(C)
Communal A/GSHP	Enerphit	81(B)	81(B)
High Ret. Storage	Minimal	73(C)	33(E)
High Ret. Storage	Interm.	79(C)	48(E)
High Ret. Storage	Enerphit	82(B)	63(D)
Individual GSHP	Minimal	75(C)	68(D)
Individual GSHP	Interm.	81(C)	75(C)
Individual GSHP	Enerphit	84(B)	79(C)

Table 4 shows the basic costs for the retrofit options. The results show a significant reduction in heat-related costs with both fabric and heating system conversions.

Table 4: Basic energy results for retrofit options

Option	Fabric	Capital Cost (£'000s)	Annual Energy Cost (£/yr.)	Annual Heat Cost (£/yr.)
Current	Curr.	0	10,363	7,645
Communal ASHP	Min.	124	7,396	4,678
Communal ASHP	Int.	324	6,116	3,398
Communal ASHP	Ener.	645	4,626	1,908
Communal GSHP	Min.	189	5,907	3,189
Communal GSHP	Int.	379	5,045	2,328
Communal GSHP	Ener.	660	4,093	1,375
High Ret. Storage	Min.	63	9,830	7,112
High Ret. Storage	Int.	263	8,143	5,425
High Ret. Storage	Ener.	590	5,923	3,205
Individual GSHP	Min.	193	6,914	4,197
Individual GSHP	Int.	383	5,773	3,055
Individual GSHP	Ener.	662	4,302	1,584

The NPV analysis in Table 5 allows a direct comparison of each option in terms of lifetime costs. The 20-year option provides a comparison based on typical heat source lifetimes and the 60-year option allows for a longer-term assessment of the fabric option benefit. The annual CO_2 for heat energy is also shown, and is based on per-timestep analysis using 2022 UK grid data.

Comparison of the results between Table 4 and 5 indicates the following:

- Tenant energy costs are significantly reduced with higher levels of fabric improvement (see Figure 2)
- However, overall lifetime costs are minimised with a simple heating system changeover

Table 5: NPV Expenditure analysis for retrofit options

Option	Fabric	20-yr NPV Total Expenditure (£'000s)*	20-yr NPV Δ vs. Current (£'000s)*	60-yr NPV Total Expenditure (£'000s)*
Current	Curr.	314.6	-	653.2
Comm. ASHP	Min.	286.5	-28.1	571.8
Comm. ASHP	Int.	347.6	+33.0	599.0
Comm. ASHP	Ener.	462.9	+158.3	664.6
Comm. GSHP	Min.	273.8	-40.8	514.5
Comm. GSHP	Int.	342.7	+28.1	560.5
Comm. GSHP	Ener.	454.3	+139.7	636.7
High Ret. St.	Min.	361.4	+46.8	685.9
High Ret. St.	Int.	510.2	+195.8	790.0
High Ret. St.	Ener.	769.8	+455.2	977.5
Ind. GSHP	Min.	306.4	+9.3	577.9
Ind. GSHP	Int.	366.7	+52.1	608.0
Ind. GSHP	Ener.	461.6	+147.0	651.6

Table 6 shows that the most cost effective decarbonisation option is to replace the heating system with a heat pump and that the intermediate solution is more cost effective where a degree of fabric improvement (and tenant cost reduction) is preferred.

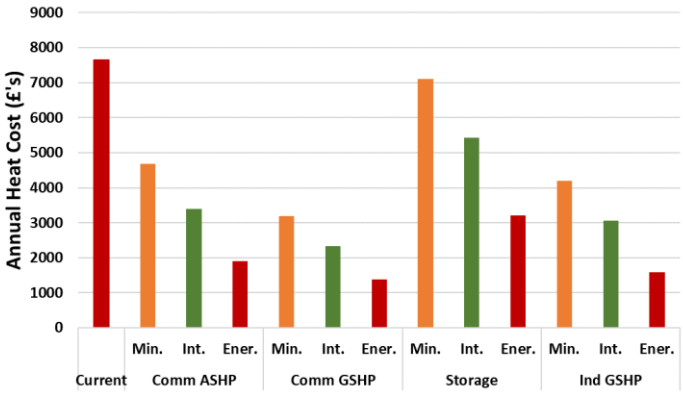

Figure 2: Annual heat costs for the retrofit options

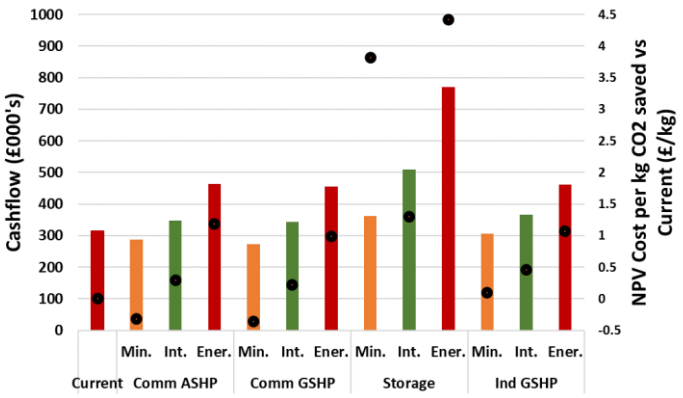

Figure 3: 20-year NPV Cashflow vs. cost per kg CO_2 saved

Overall the results highlight the difficulty in finding a solution that provides a 'just', cost-effective, and opportunity maximising solution for all stakeholders. Figure 3 demonstrates a lack of consistency between NPV costs and decarbonisation cost-benefit.

The main benefit of the developed work process is that it provides quick and effective input data to allow the various cost and benefits to be assessed.

Table 6: CO_2 analysis for retrofit options

Option	Fabric	Annual CO_2 for Heat (kg/yr.)	20-yr. NPV Cost per kg saved vs. Current (£)
Current	Current	8,099	-
Comm. ASHP	Minimal	3,690	-0.32
Comm. ASHP	Interm.	2,676	0.30
Comm. ASHP	Enerphit	1,470	1.19
Comm. GSHP	Minimal	2,507	-0.36
Comm. GSHP	Interm.	1,826	0.22
Comm. GSHP	Enerphit	1,056	0.99
High Ret. St.	Minimal	7,487	3.82
High Ret. St.	Interm.	5,561	1.30
High Ret. St.	Enerphit	2,955	4.42
Ind. GSHP	Minimal	3,312	0.10
Ind. GSHP	Interm.	2,406	0.46
Ind. GSHP	Enerphit	1,218	1.07

DISCUSSION

Ultimately the retrofit problem becomes a question of breadth or depth. More houses faster and cheaper versus fewer houses but with maximised improvements and tenant benefits. The mooted 2032 target of a 'B' rating suggests a depth focus but this is not matched by funding availability or well defined implementation processes to achieving this.

The outlined method provides a practical basis for assessment and discussion, which is more targeted than generic stock modelling.

Benchmarking Uncertainty

One of the key outcomes from the work is the finding that the current state of development of EPC and SAP processes cause considerable confusion to the option appraisal process. Results for SAP 2012 and 10.2, particularly for heat pump conversions, are not consistent and it is not clear what should be used as the benchmark or whether any changes to the process in the future will be applied retroactively. In addition, a new SAP basis 'SAP 11' is currently in development and will have a fundamentally different approach, adding to planning uncertainty.

Benchmarking Requirements Limit Innovation

The results from the case study emphasise that the requirements to meet defined EPC targets limits heating options in most situations to heat pumps. In addition, there is limited or no benefit from innovative solutions that would allow nominally higher carbon solutions to utilise surplus renewables generation in an efficient way.

As an example, the current requirements make any investment in storage heating either impossible or with significant future risk of obsolescence. There is, however, an argument that a moderate level of high performance storage heating with smart charging could provide a useful storage option for overall grid management at a lower combined lifetime cost for landlords and consumers (Connected Response, 2024).

Another example of inflexibility is SAP is unable to take account of affordable and/or renewable energy provision via private wire or peer-to-peer transfer. Which acts as a disincentive for social landlords in particular to explore such solutions which have the potential as cost-effective means of reducing fuel poverty and carbon emissions either in combination with or in place of actual physical retrofit.

A further bottleneck for innovative solutions include a lengthy process for new technologies to get SAP approval via Appendix Q inclusion.

Skill Shortage

The second conclusion that can be drawn is that the potential options, particularly in rural areas, are limited by both the lack of available contractors and significant cost adders in comparison with urban projects. Much of the discussion on the project centred on the practicalities of achieving any form of upgrade, which indicates that there is a mismatch between policy and modelling on one hand, and implementation.

PV on Communal Roofs

The addition of rooftop PV panels for individual houses significantly improves SAP ratings. However, a similar benefit is not available in multi-dwelling blocks unless

the panels are connected to individual household meters directly, or via a main distribution board, assuming there is no export capability.

This acts as a disincentive to including PV on such blocks as the additional connection and metering systems required to obtain a SAP rating benefit are in excess of the potential savings from installing the PV system. In the context of the wider energy system, there is no additional benefit from this additional equipment, therefore allowing for floor area pro-rata SAP rating benefit to any installed capacity regardless of connection type would incentivise additional capacity with the maximum cost-benefit.

New technology developments in behind-the-meter distribution are beginning to overcome this obstacle (e.g. Allume Solshare claims that SAP points can be obtained for each connected property). But promising options such as private wire microgrids are still disincentivised or require expensive solutions that achieve no additional decarbonisation.

CONCLUSIONS

The method has been successfully applied on multiple retrofit studies for housing associations and demonstrates a optimal balance of academic modelling rigour with project implementation experience. It has been found to provide useful input for iterative discussion with stakeholders, where project-specific costs and resources are integrated with high-level targets, with a practical level of resourcing. Both of these functions are important, as the retrofit process is evolving as new analysis emerges and must be sensitive to the available funding and potential future savings.

REFERENCES

Audit Scotland (2024). Decarbonising heat in Scotland. [Online]. [Accessed 8th July 2024]. Available at: https://audit.scot/uploads/docs/report/2024/nr_240201_decarbonising_heat_in_homes.pdf

BRE Group (2022). BRE announces new project with BEIS to modernise home energy rating scheme in time for Future Homes Standard. [Online]. [Accessed 5th July 2024]. Available at: https://bregroup.com/news/bre-announces-new-project-with-beis-to-modernise-home-energy-rating-scheme-in-time-for-future-homes-standard

BRE Group (2014). SAP 2012: The Government's Standard Assessment Procedure for Energy Rating of Dwellings, 2012 Edition.

BRE Group (2021). SAP 10.2: The Government's Standard Assessment Procedure for Energy Rating of Dwellings, Version 10.2.

Calvillo, C., Stewart, J. (2021). Scottish Government Heat in Buildings Strategy. [Online]. [Accessed 8th July 2024]. Available at: https://www.strath.ac.uk/humanities/centreforenergypolicy/newsblogs/2021/scottishgovernmentheatinbuildingsstrategy/

Connected Response (2024). HeatSage: Optimisation of electric storage heating and hot water. [Online]. [Accessed 17th July 2024]. Available at: https://connectedresponse.co.uk/electric-storage-heating-optimisation/

Flett, G., Tuohy, P. (2022). Towards a high-resolution, stochastic, domestic energy demand model to assess the local network impact of heat and transport electrification. In Proceedings, uSim 2022: 3rd uSim Conference of IBPSA-Scotland, Friday 25th November 2022, Glasgow, Scotland.

Scottish Government (2021a). The Energy Efficiency Standard for Social Housing post 2020 (EESSH2): Scottish Government Guidance for Social Landlords.

Scottish Government (2021b). Heat in Buildings Strategy: Achieving Net Zero Emissions in Scotland's Buildings. Summary Document, October 2021.

Scottish Government (2022). Interim Guidance for Social Landlords during the review of the Energy Efficiency Standard for Social Housing post 2020 (EESSH2). October 2022.

Scottish Government (2024). Home Energy and fuel poverty: Energy efficiency in social housing. [Online]. [Accessed 14th May 2024]. Available at: https://www.gov.scot/policies/home-energy-and-fuel-poverty/energy-efficiency-in-social-housing/

Smith, S. (2021). Developing Net Zero Technical Solutions for Scotland's Future Mass Retrofit Housing Programme. [Online]. [Accessed 8th May 2024]. Available at: https://www.gov.scot/publications/developing-net-zero-technical-solutions-for-scotlands-future-mass-retrofit-housing-programme/