# Study on Modelled and Actual Energy Use in Social Housing and Impact on Fuel Poverty

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# 1. Introduction and Project Scope

The project aims to develop the knowledge necessary to better assess the prevalence of fuel poverty in social housing and predict more accurately the impact of energy retrofit programmes on fuel poverty and energy usage. The project was undertaken by RetroKit in collaboration with Cork City Council (CCC) and the Central Statistical Office (CSO), with funding from the Gas Innovation Fund.

The specific objectives of the study are to:

1. Develop a set of correction factors that can be applied to the BER data available for a given housing stock to derive 'realistic' energy usage values as well as electricity usage for lighting, pumps and fans before and after energy retrofit.
2. Develop a methodology to forecast the impact of the National Climate Action Plan target of a B2 BER rating on fuel usage among tenants.

This report is accompanied by set of slides giving an overview of the methodology and results. The results are also summarised in Section 8: Conclusions and further work.

# 2. Project data sources

The study focuses on the Cork City Council's housing stock (for which BER data for 7688 dwellings was sourced from SEAI with consent from the Council) where natural gas is the predominant heating fuel used by tenants.

The study leverages the following datasets:

- CSO's databases on networked gas consumption and electricity consumption at the individual dwelling meter level.
- Cork City Council's housing stock energy performance certificates (BER)'s data files at individual house level.
- SEAI's statistical data on energy use in the residential sector.
- Pobal and other sources of socio-economic data providing indicators of household income, deprivation, health and well-being.

Section 3 gives an overview of the size of the cohorts in the main datasets analysed.

# 3. Overview of housing stock and baseline energy performance

The CCC's BER dataset includes data for 7688 dwellings in Cork City. The data originated with inputs to calculations to the Energy Performance Certificate incl. building dimensions, fabric performance and systems information; and is used to derive modelled energy consumption data and associated $CO_2$ emissions. The energy performance calculations are carried out in accordance with the DEAP (Dwelling Energy Assessment Procedure) methodology, a static building physics model that assumes standard conditions of occupancy, climate, hot water use, etc.

The following graphs give an overview of the key characteristics of the sample of dwellings analysed, with a breakdown by relevant archetypes. Some of these graphs are screenshots from the RetroKit's software user interface (UI) whilst others are derived from a statistical analysis of the dataset carried out with the Python programming language and MS Excel.

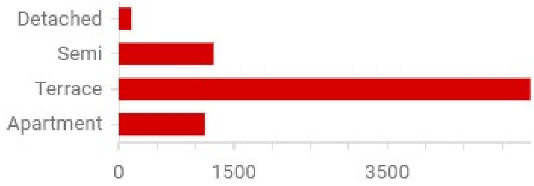


Figure 1: Breakdown of sample by type.

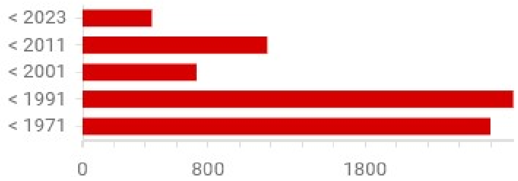


Figure 2: Breakdown of sample by age of construction.

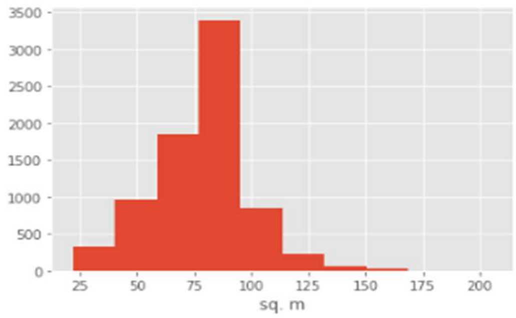


Figure 3: Breakdown of sample by treated floor area.

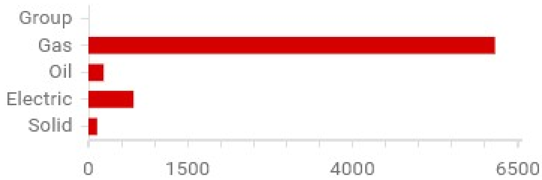


Figure 4: Breakdown of sample by main heating fuel.


Figure 5: Breakdown of sample by BER rating.

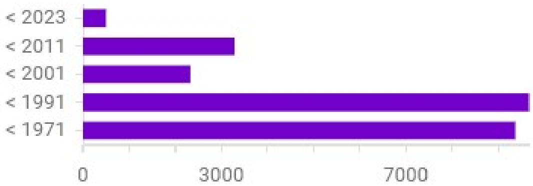


Figure 6: Breakdown of total $CO_2$ (tonnes/yr) emissions by age of construction.

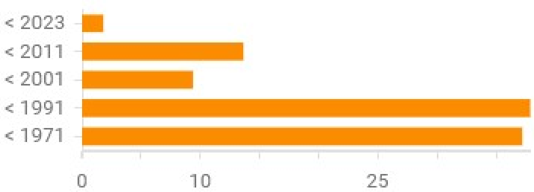


Figure 7: Breakdown of total energy usage (GWh/yr) emissions by age of construction.

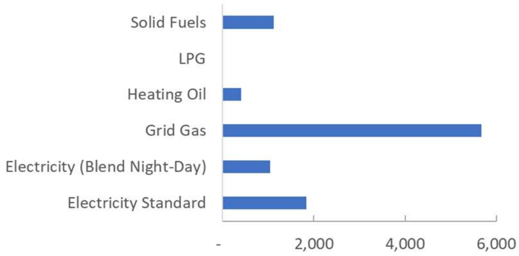


Figure 8: Breakdown of total energy costs (€,000/yr) emissions by fuel type

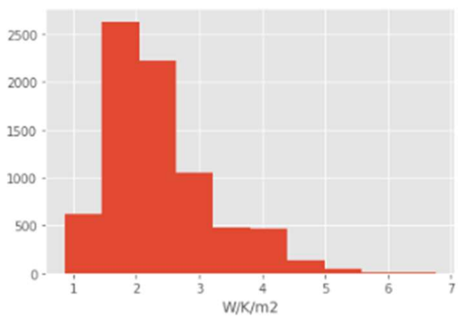


Figure 9: Breakdown of sample by HLI.

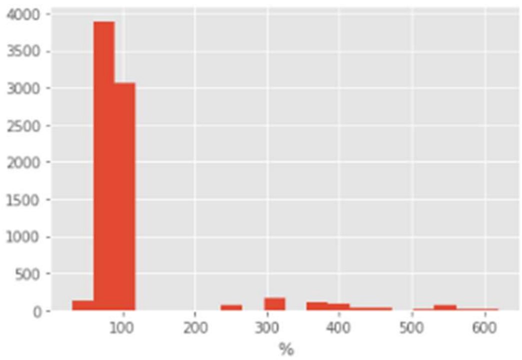


Figure 10: Breakdown of sample by heating efficiency

Overall, the dwellings analysed are relatively old (70% were built before 1991) urban social housing stock. The majority of dwellings are terraced homes, with the balance being distributed between semi-detached homes and apartments, and very few detached homes. The median floor area is just under 80 $m^2$ . Cork city is widely serviced with natural gas and c.85% of the dwellings analysed are using it as the main heating fuel. Another 9% are electrically heated. A lower number of dwellings are still on solid fuel (c.2%) and oil heating (c.3%).

The total energy usage as calculated by RetroKit (following the DEAP methodology[1]) is 100 GWh/yr, this is 13 MWh/yr per dwelling. This includes energy used for heating, lighting, fans and pumps, and excludes energy used by appliances and cooking. The associated $CO_2$ emissions are 25,147 tonne/yr or 3.27 tonne/dwelling/yr on average. The contribution of renewable energy to the overall modelled energy usage is 2.6%. The modelled annual energy cost is €10 million across the stock, and €1,313 for an average dwelling (based on Q2 2022 fuel costs published by SEAI). A large proportion of the stock was subject to a shallow retrofit and, while the average BER of the stock is a C3, 77% of dwellings have a C rating or worse.

The Heat Loss Indicator (HLI) is a useful KPI to understand how well the dwellings' fabric is performing in terms of transmission, infiltration (air leakage) and ventilation losses. According to SEAI's National Home Energy Retrofit programme's rules, a dwelling is considered heat pump ready if its HLI is below 2 W/m2.K or below 2.3 W/m2.K in some cases. Currently, the mean HLI among CCC's dwellings is 2.37 and 41% of all dwellings have a HLI above 2.3. The average heating system efficiency in dwellings on gas, oil or solid fuels is 82%, with about 50% of the entire stock having a main heating system efficiency below 85%.

The next section of the study looks at the energy upgrade options to consider as part of renovation scenarios to be modelled with RetroKit.

# 4. Modelling of Energy Retrofit Scenarios

## Introduction

RetroKit's software was used to model four energy upgrade scenarios across the 7688 dwellings in its database. Each scenario is a package of energy efficiency and renewable energy measures applied to improve the performance of the dwellings' fabric and building services (heating, hot water, ventilation, etc.). During the modelling, each measure in a given scenario is tested for its applicability (e.g. cavity wall insulation won't be applied to a solid wall), the resulting performance improvement is applied to the relevant building element (e.g. insulated cavity walls have a U-value of 0.31 when filled ), the quantity of the measure applied is recorded in RetroKit (e.g. 50 m2 of cavity wall insulation) and the associated cost calculated based on unit costs (e.g. €18.7/m2 of cavity wall insulation). All the calculation inputs and outputs are held in RetroKit's databases and exported to MS Excel for further analysis and aggregation of results.

The scenarios are summarised as follows, and explained further below:

- Medium fabric upgrade with new boiler install
- Deep fabric upgrade with new boiler install
- Electrification of heat (heat pump plus fabric upgrade)
- Efficient gas (a mix of gas fired heat pumps / fuel cells plus fabric upgrade)

The overall target to be achieved with these scenarios is a B2 Building Energy Rating or better. The scenarios applied, and the associated fabric and building services measures they include, are outlined below.

A "fabric-first" approach is applied to all scenarios to reduce heat loss. This reduced heat demand is then met with an efficient heating system. Fabric measures such as cavity and/or external wall insulation, attic insulation, replacement of windows and doors, draft proofing and so on are applied. Further information on

[1] This will be referred to hereafter as 'modelled' energy usage.

building services in the scenarios is provided below. Table 1 summarises the measures as applied across the four scenarios:

| | |
|---|---|
| Medium fabric + boiler | **Fabric insulation**: roofs and walls |
| | **Ventilation**: minor improvements |
| | **Main heating**: new boilers |
| | **Other services**: new controls, DHW tank, LEDs, stoves |
| Deep fabric + boiler | **Fabric insulation**: roofs, walls, doors and triple glazing |
| | **Ventilation**: good airtightness and demand controlled ventilation |
| | **Main heating**: new boilers |
| | **Other services**: new controls, DHW tank, LEDs, stoves |
| Electrified heat | **Fabric**: roofs, walls, doors and double glazing |
| | **Ventilation**: good airtightness and demand controlled ventilation |
| | **Main heating**: A/W heat pump |
| | **Other services**: new controls, rads, DHW tank, LEDs, stoves |
| Efficient gas | **Fabric**: roofs, walls, doors and double glazing |
| | **Ventilation**: good airtightness and demand controlled ventilation |
| | **Main heating**: fuel cells + boiler in some dwellings and gas heat pump in others |
| | **Other services**: new controls, rads, DHW tank, LEDs, stoves |

Table 1: Measures per scenario

Costings in RetroKit's database of measures were derived in 2019 based on a study carried out by quantity surveyors. These costs were re-evaluated in Q2 2022 and an uplift of 23% applies on average to the measures implemented in the above scenarios. As VAT is applied to fuel usage in RetroKit, it is also applied to the measures at a rate of 13.5%. The total "uplift" from the 2019 CAPEX (which excluded VAT) is 1.23*1.135 = 39.6% uplift including VAT.

## Further detail on Building Services Upgrades

The study focused on energy renovation scenarios contributing to the reduction of $CO_2$ emissions from dwellings on the natural gas network or with potential access to it, with a view to measure the potential impact of both heating system efficiency gains and reduction in the $CO_2$ content of the fuel itself. Gas-based solutions are then benchmarked with solutions including the electrification of heat.

In this context, the following heating system upgrade solutions were applied in the scenario modelling.

### Efficient Boilers

Some of the RetroKit scenarios include a like for like boiler replacement of existing boilers. Costs range from €1770 to €2554 ex. VAT depending on the boiler type. New gas boilers are assumed to be 91% efficient.

### Gas Fired (Absorption) Heat Pumps

Gas fired heat pumps, similar to their electrically-driven counterparts, allow efficiencies over 100% to be achieved by harvesting energy from the external air using a compression cycle.

A BEIS[2] commissioned report reviewed the state of the art of gas fired heat pumps in 2016 and identified Robur[3] as one of the principal manufacturers of gas driven heat pumps[4]. A 18kW output unit achieves a seasonal coefficient of performance (SCOP[5]) of 1.57 at 50°C flow and is supplied by Origen at approx. €10,300.

### Fuel Cells

Domestic scale fuel cells take hydrogen/natural gas as an input and produce heat and electricity. They are generally combined with a peaking boiler and are configured to either be heat-led (production of heat prioritised) or electricity led.

Taking one of the heat-led examples from a document produced by the PACE (Pathway to a Competitive European Fuel Cell micro-Cogeneration Market ) project[6] (Sunfire-Home 750) we assume that for each 1kWh of gas/hydrogen the unit supplies 0.38kWh of electricity and 0.4kWh of heat. Heat beyond the 1.25kW peak output is provided by a boiler at 91% efficiency. The fuel cell is assumed to account for 40% of the heat demand. Electricity generated is assumed to offset import by the dwelling. Gandiglio et al[7] estimate €9,400 for a 1kW unit, and indicate that unit costs have been falling.

### Electrification of Heat

RetroKit models the electrification of heat through the installation of electric heat pumps. The average cost is assumed to be €8927 ex VAT. Heat pumps are assumed to perform at a space heating SCOP of 3.5. This assumes the dwellings' heat loss level was reduced with fabric upgrades and that the heat pump can operate at a low flow temperature. The heat pump measure is assumed to include new DHW (domestic hot water) storage and controls in RetroKit.

Where a home does not have a wet central heating system the cost of installing radiators and piping is accounted for. Total cost for both depends on the dwelling size but is typically €10,000 excluding VAT.

## Results of the energy retrofit scenario modelling

For the retrofit scenarios, RetroKit operates on a dwelling by dwelling basis applying the package of fabric and heating system upgrades before calculating the dwelling energy performance post-upgrade. The results are then aggregated across the housing stock to compare the impact of the scenarios modelled, across different aspects of the dwellings' energy performance.

The following table summarises the results with further detail in the subsequent graphs. The figures shown in this table shown are averages across entire stock for each scenario. Electrified heat and efficient gas have comparable impact on BER grades and CAPEX. However, Electrified heat would garner more grant aid than efficient gas.

Medium retrofit with a boiler is "cheapest" scenario but doesn't achieve the B2 target (on average) as set in the Climate Action Plan. Addition of a 1kWpeak photovoltaic system at a cost of approximately €3,300 will bring "medium retrofit" to a B2 BER grade average.

All scenarios achieve "heat pump readiness" (HLI <= 2 W/m2,K)

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[2] BEIS (2016) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/787321/Gas_Drive_heat_pumps.pdf
[3] ROBUR https://www.robur.com/heat_pumps/gas_absorption_heat_pump_for_homes_k18
[4] Origen (2016) price list https://www.origen.ie/v4/0940aa0c-5421-4a9b-840d-c9a2ae5d95bb/uploads/Origen_Price_Book.pdf
[5] Seasonal Coefficient of Performance is the ratio between heat delivered and electricity used by the heat pump for space heating and hot water over a one-year period.
[6] PACE (2021) https://pace-energy.eu/wp-content/uploads/2021/05/PACE-D1.7-2021-update-FV.pdf
[7] Gandiglio et al (2020) https://www.comsos.eu/com18/com18-cont/uploads/2020/03/Fuel-cell-cogeneration-for-building-sector_-European-status-1.pdf

| Dwelling Performance | Baseline | Deep Retrofit | Medium Retrofit | Electrified Heat | Efficient Gas |
|---|---|---|---|---|---|
| *Mean HLI* | 2.37 | 1.59 | 1.86 | 1.63 | 1.63 |
| *Mean Primary Energy Value (2021)* | 212 | 116 | 131 | 88 | 92 |
| *Mean BER Grade* | C3 | B2 | B3 | B1 | B1 |
| *Mean Fixed Capex (€)* | | 14,017 | 6,636 | 22,928 | 23,494 |
| *Mean Variable Capex (€)* | | 8,186 | 3,185 | 7,605 | 7,605 |
| *Mean Total Capex (€)* | | **22,203** | **9,821** | **30,533** | **31,099** |

Table 2: Scenario Thermal Performance, BER Scores and average CAPEX

Figure 11 shows how the scenarios impact on the BER grade distribution of the stock in more detail. B2 grade or better is achieved across the stock as follows:

- Baseline: 11% of dwellings are B2 or better
- Medium retrofit with gas boiler: 48% are B2 or better
- Deep retrofit with gas boiler: 72% are B2 or better
- Electrified heat: 95% are B2 or better
- Efficient gas: 70% are B2 or better

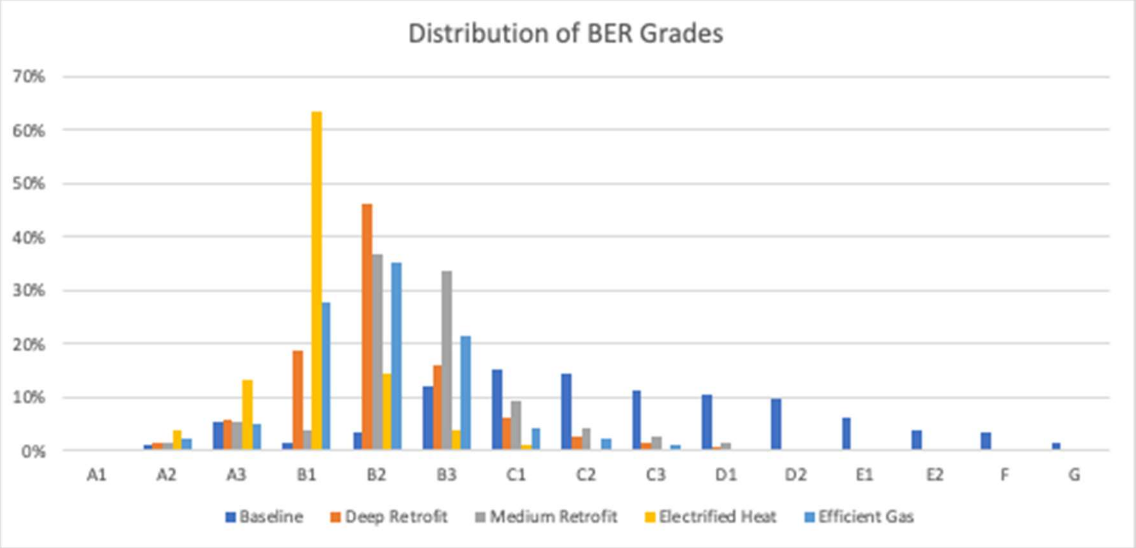



Figure 11: Impact of retrofit scenarios on distribution of BER Grades

Figure 12 shows the impact of the scenarios on some of the key dwelling heat loss characteristics. Lower U-values result in lower heat losses.

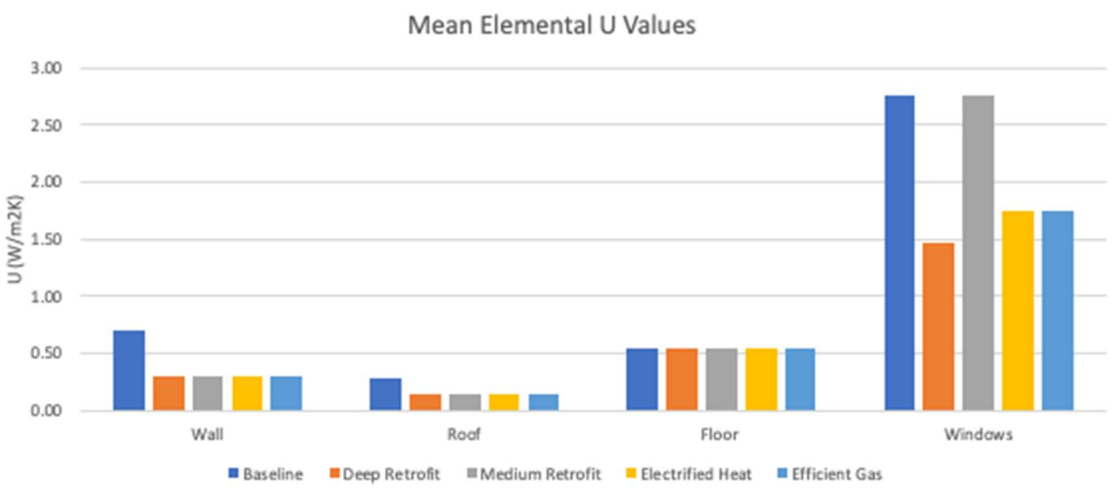



Figure 12: Elemental U-Values

Figure 13 shows total demand for space heating and domestic hot water in each scenario, illustrating the scope for reduction of space heating demand in particular.

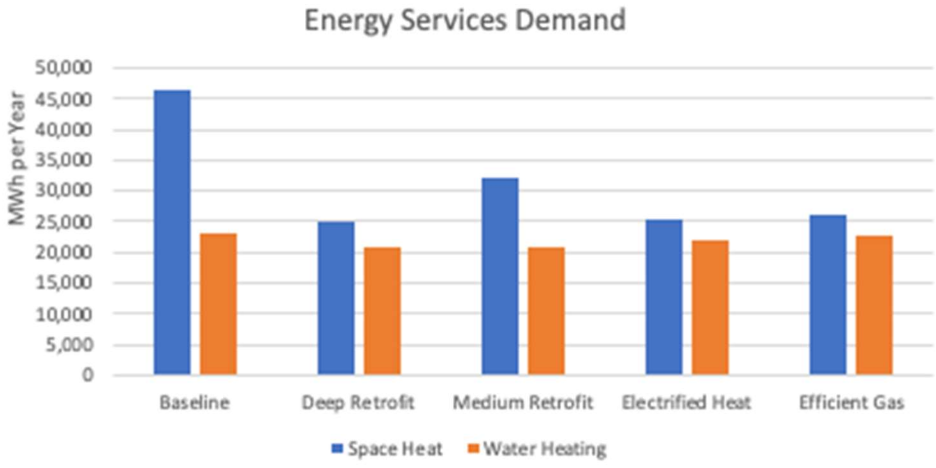



Figure 13: Scenarios: Energy Services Demand

RetroKit outputs for delivered energy, fuel costs and carbon emissions were corrected to better reflect real-world consumption, these are presented later in the document while the next section describes the process of deriving and applying these correction factors.

# 5. Comparison between actual and modelled energy usage

## Introduction & Background

The energy consumption predictions of domestic energy performance models such as the Dwelling Energy Assessment Procedure (DEAP) are based on assumptions on the performance of building fabric, building systems and the use of energy services by the occupants.

However, those assumptions do not fully describe the reality of a given building. In order to address this and more accurately represent the baseline energy consumption of a dwelling and forecast the impact of energy efficiency improvements, this study uses metered gas and electricity consumption data to derive correction factors to apply to DEAP data.

Discrepancies between predicted and real-world energy consumption and predicted and real-world energy savings from efficiency measure are a well-documented phenomenon. For example, Scheer, Clancy and Hogain (2013)[8] in their evaluation of Ireland's Home Energy Savings Scheme found a variation of 36% ±8 between the technical, calculated potential saving and the actual energy consumption impacts.

A range of factors influence the performance gap. Mohareb et al (2017)[9] describes a number of possibilities summarised into 4 principal areas:

- The use of a modelled baseline that does not reflect real world energy consumption[10] either because the model inputs are inaccurate, assumed performance does not reflect reality, occupant behaviour is not captured or the model itself does not accurately reflect the real world.
- Underperformance of equipment/materials in the real-world environment vs under test conditions.

[8] Scheer, J., Clancy, M. & Hógáin, S.N. Quantification of energy savings from Ireland's Home Energy Saving scheme: an ex post billing analysis. *Energy Efficiency* **6**, 35–48 (2013). https://doi.org/10.1007/s12053-012-9164-8

[9] See: http://centaur.reading.ac.uk/72052/1/2017%20Mohareb%20-%20Retrofit%20planning%20for%20the%20performance%20gap.pdf

10 D. Johnston, D. Farmer, M. Brooke-Peat & D. Miles-Shenton (2016) Bridging the domestic building fabric performance gap, Building Research & Information, 44:2, 147-159, DOI: 10.1080/09613218.2014.979093

- Poor workmanship in the installation of energy efficiency measures meaning they do not perform as modelled
- Changes in occupant behaviour such as comfort taking after energy upgrades are carried out.

With the widespread deployment of smart meters, 'open-sourcing' of building datasets and the advent of big-data, researchers have been applying techniques from the field of epidemiology to buildings in an attempt to better understand real world performance.

For example, Hamilton et al (2017)[11] used the UK National Energy Efficiency Database (NEED) data set, containing annualised electricity and gas demand from all UK dwellings to analyse the impact of tightening dwelling efficiency regulations. They found the real-world consumption differences between older and newer dwellings were much smaller than modelling would suggest. Similar research was delivered by Laurent et al (2013)[12] finding similar issues across a number of EU countries and a potential relationship between under/over estimation and EPC band.

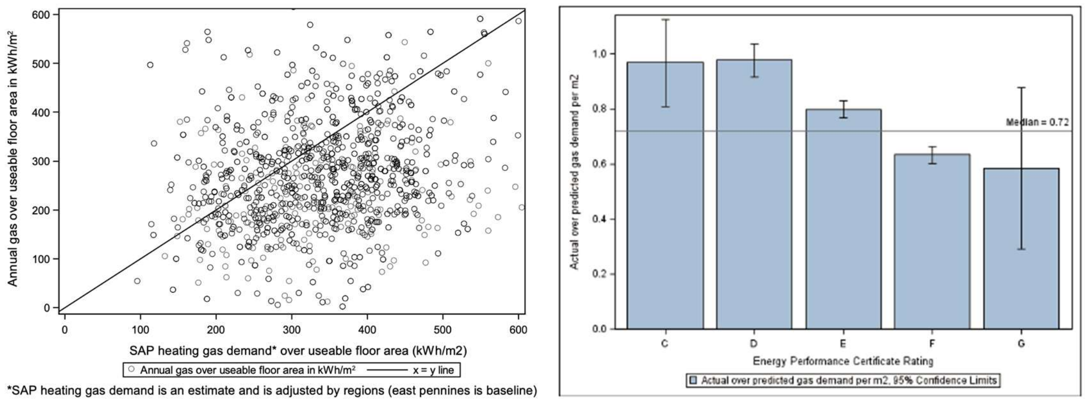



Figure 14: Real World vs Modelled Consumption (Source: Laurent et al)

The application of these epidemiological methods is powerful and allows real world impacts to be estimated empirically. The drawback of taking this type of top-down approach, is the insufficient level of detail to determine the factors having the largest impact on the gap between modelled and actual energy consumption.

## Clustering Approach

The dwelling sample for this analysis is drawn from Cork City council's housing stock as described previously in this document. Metered gas and electricity data was provided by the CSO. This work was performed on a subset of 6471 homes with a valid Eircode available alongside the BER data.

A further key restriction to accessing the CSO data is that, to ensure the anonymity of individual occupants, it is only provided in an aggregated form for a minimum cohort size of 100 dwellings. Therefore, an approach to clustering dwellings while retaining the ability to understand the drivers of any variation in energy demand was developed.

Our analysis has highlighted:

- The data mainly describes terraced houses, apartments and semi-detached dwellings but few detached homes.
- While most dwellings are heated by natural gas, the sample includes a significant number of electrically heated dwellings.

[11] Ian Hamilton, Alex Summerfield, Tadj Oreszczyn, Paul Ruyssevelt, using epidemiological methods in energy and buildings research to achieve carbon emission targets, Energy and Buildings,2017, Pages 188-197, https://doi.org/10.1016/j.enbuild.2017.08.079.

[12] See: https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2013/7-monitoring-and-evaluation/back-to-reality-how-domestic-energy-efficiency-policies-in-four-european-countries-can-be-improved-by-using-empirical-data-instead-of-normative-calculation/

- The DEAP data is relatively old. However, BER assessments are typically undertaken following dwelling upgrades as required by retrofit funding schemes. This DEAP data should therefore reflect current dwelling insulation levels etc.
- A wide range of BER ratings is covered.
- A wide range of dwelling ages is covered.

In designing a clustering approach, the aim was to minimise the variation of modelled energy consumption within the clusters. As modelled demand is driven by fabric and system performance, clusters based on these tend to have similar performance attributes as well as DEAP modelled energy demand.

The clustering algorithm iterates over the dwellings 7 times, removing layers at each run in order to keep cohort size as close as possible to the minimum size (100 dwellings) to maximise granularity. The banding is nested so that all clusters as far as iteration 6 could be grouped by BER band.

- Main Heating Fuel
  - BER Rating (A, B, C, D etc)
    - Dwelling Form (Detached house, Semi, Terraced, Apartment)
      - Dwelling Age
        - Main Wall Type
          - Main Heating System Efficiency *[0, 75, 85, 95, 105, 1000%]*
            - Heat Loss Parameter *(0, 3, 7 W/k)*

The outcome is 45 cohorts, each containing at least 100 dwellings. These were provided to the CSO to source aggregated average gas and electricity usage per cohort.

## Metered Data

The CSO provided aggregated gas and electricity consumption data for the cohorts in the form of mean consumption per quarter. Gas data is available for 44 cohorts and covers 2016 to 2020 and electricity data for all 45 cohorts is available from 2017 to 2021. Figure 15 shows the mean quarterly consumption across the cohorts illustrating the seasonal variation. Some seasonal variation of both fuels is apparent: this is useful in the case of gas in order to estimate the 'baseload' and split of consumption for heating and hot water.

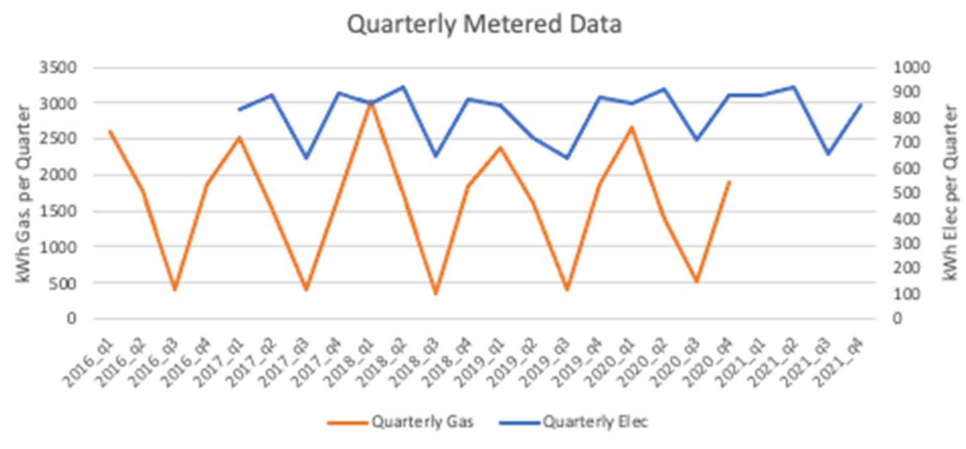



Figure 15: Metered Data from CSO, Mean Quarterly Consumption

## Weather Correction

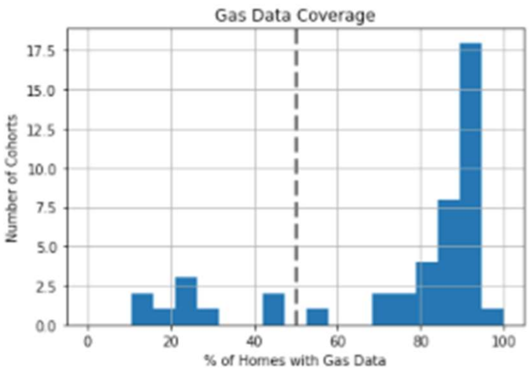
As RetroKit is aligned to DEAP calculations, its "climate" is based on Dublin long term averages. Therefore, in order make a reliable comparison it was necessary to adjust the gas data for the differences in temperatures in Cork over the periods of metered data and the DEAP assumption.

The Eurostat service provides Heating Degree Day data covering the Ireland Southwestern "NUTS 3" region and Dublin over a lengthy period. This data shows that total degree days during the heating season in Dublin were about 9% higher during the period and region for the metered data. The RetroKit modelled data is adjusted accordingly. All figures shown in the following sections include this correction.

# Calculation of Modelled / Metered Factors

The basic approach when making comparisons between the modelled and metered data was to take an average across the 5 years of available metered data and divide this by the modelled demand from RetroKit. A factor of 0.5 therefore would mean that the modelled demand was double the metered demand for example.

### *Gas*




Gas data is available for 44 of the 45 cohorts. This data did contain some anomalies. For example, one of the 'gas heated' cohorts had no data available and some other cohorts which were non-gas heated according to the DEAP data, had gas data available. None of the cohorts had metered data available for 100% of their dwellings as illustrated in Figure 16. However, the figures provided were average consumption per metered dwelling (i.e., the average doesn't include dwellings without a meter reading).

Figure 16: Metered Gas Coverage

Cohorts where coverage was low did present as outliers. These are illustrated in the first graph below (for space heating), where the majority of the factors calculated lie between 0 and 1.5 but there are a number of outliers within the orange box. Without the ability to identify whether the dwellings included in the aggregated CSO data are representative of the cohort as a whole, the decision was taken to remove any cohorts with less than 50% data coverage from the analysis.

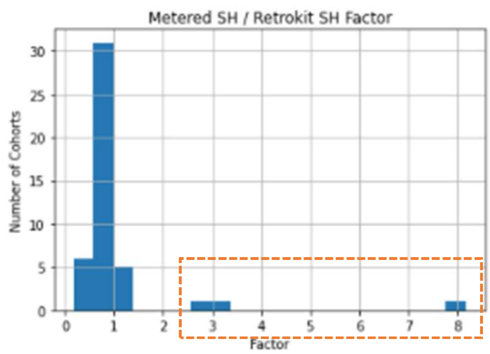



Figure 17: Metered SH / RetroKit SH Factor incl. Outliers

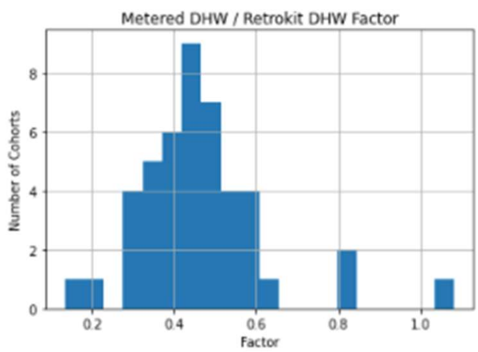



Figure 18: Metered DHW / RetroKit DHW Factor

The metered data was divided between baseload/DHW (domestic hot water) demand and space heating demand. Space heating is assumed to be required only in Q1, Q2, Q4 of each year. This is reasonably close to DEAP's heating season of Oct-May inclusive given that months close to summer will have minimal heat demand anyway. Therefore, baseload for hot water is assumed to be Q3 usage * 4. Total annual usage minus baseload is gas & electricity for space heating only. These are compared to RetroKit modelled gas demand for Space Heating and DHW (Domestic Hot Water). The resulting factors are shown in the graphs above. Space heat supplied by solid fuels or other sources is not addressed as data for usage of those fuels in these dwellings is not available from CSO.

### *Electricity*

Other than heating, RetroKit and DEAP only address energy demand for lighting and pumps + fans. Therefore, to make a comparison with the metered data, an allowance for appliances and cooking energy usage is added to the modelled demand. This is based on an estimate from national averages (derived from SEAI's residential data) of 23.7kWh per $m^2$. Figure 19 shows the resulting factors. For most cohorts, metered electricity is 0.7 – 1.4 times electricity calculated by RetroKit (plus assumed appliances and cooking electricity).

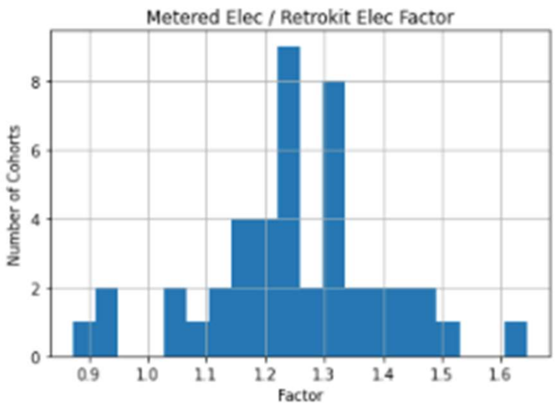



Figure 19: Metered Elec /. RetroKit Elec + Appliances

## Regression Model

This study included extensive analysis on the data to understand the relationships between metered demand and key dwelling parameters. This section highlights the main findings before focusing on the final modelling results.

Firstly, Figure 20, focuses on the main characteristics of the cohorts as derived from the DEAP data. The key learning in this graph is that the BER rating and dwelling heat loss improve (their value decreases) for more recent construction dates. It also indicates that the newer cohorts are larger which is important to note when analysing the metered data.

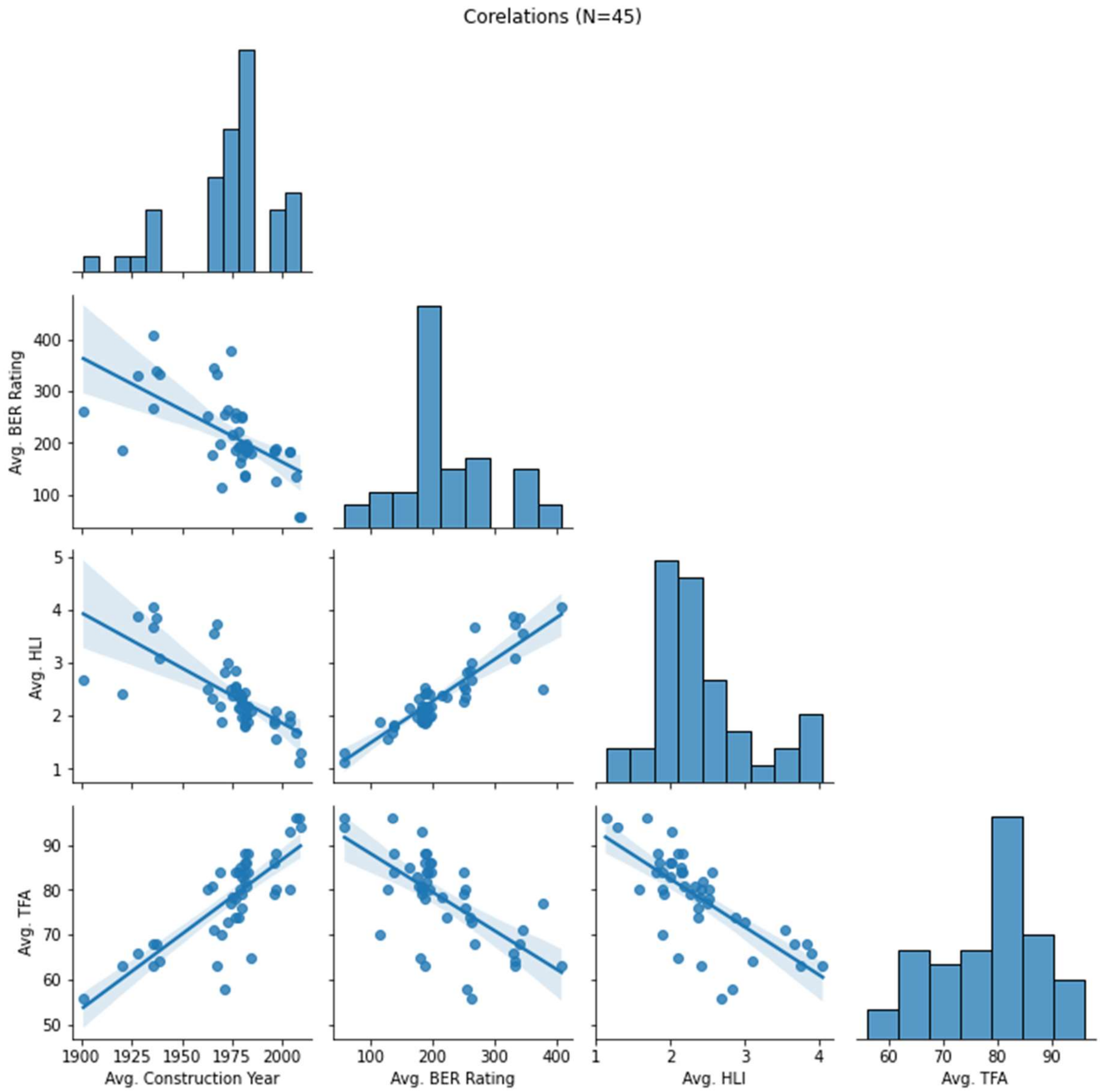



Figure 20: Main physical features and BER Score

Figure 23 focuses on the variation of metered gas demand, gas demand per m2 floor area and the ratio between metered demand and DEAP based modelled demand and a selection of the principal dwelling characteristics. This analysis focuses on 37 of the cohorts for which more than 50% of the homes have gas metered data as outlined above. There are a number of notable trends in this data.

Referring to rows and columns in Figure 23 below, for example, Row 1, Column 1 is the upper left hand graph, Row 1, Column 3 is the upper right hand graph)

- Row 1: total metered gas demand somewhat increases with construction year (column 1) but, as the newer homes in our sample tend to be larger, this trend reverses when gas usage is divided by floor area (column 2).
- Column 3: The ratio of metered to DEAP gas demand has a clear relationship to construction date, BER rating and the Heat Loss Indicator (HLI, representing total fabric plus ventilation heat losses) all of which are corelated to each other. Therefore, there are a number of possible approaches to modelling this ratio.
- Row 6 column 3: The modelled calculation increasingly overestimates demand for larger consumers. For example, a ratio of 0.5 means the modelled (DEAP) demand was 2x the metered demand. Therefore, a cohort with a modelled demand 15000kWh the metered demand was 7500kWh.

Possible hypothesis to explain large gaps between actual and modelled energy usage are:

- secondary heating (e.g., solid fuel) is being used in these homes but is not captured in the gas data, or
- homes not heated to the standard/schedule assumed in DEAP, particularly old homes that are difficult to heat. DEAP assumes heating for the 8 month heating season, with the entire home heated to minimum of 18deg C for 56 hours per week. This heating schedule / temperature is likely not achieved in homes with high heat losses.

This could be particularly relevant for occupants of social housing who tend to be on lower income. This finding aligns with the previous research from Laurent et al showing that the gap between predictions from the SAP[13] model and metered data grew with worsening dwelling performance. Figure 21 and Figure 22 compare the trend of increasing overestimation with worsening EPC rating found by Laurent and the dataset in this study.

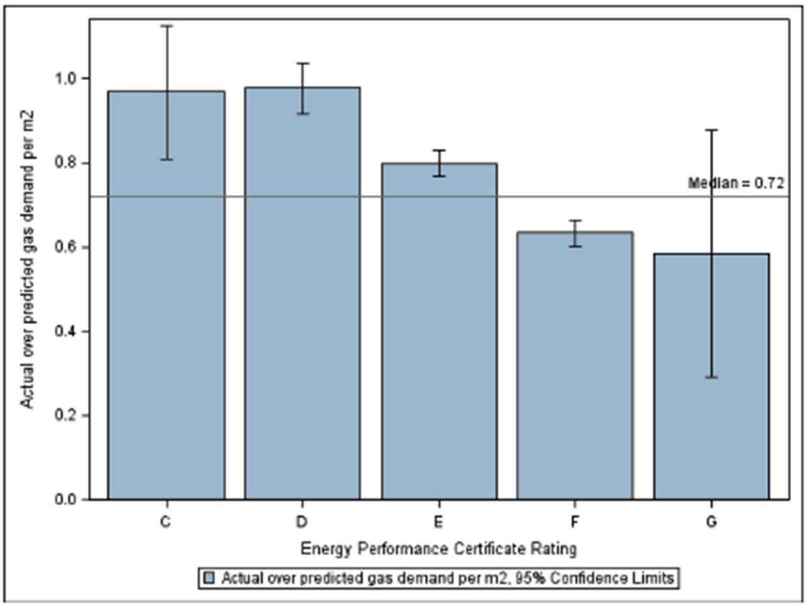



Figure 21: Findings of Laurent et al 2013.

| BER Grade | Total Heating Correction Factor | Hot Water Correction Factor | Space Heating Correction Factor |
|---|---|---|---|
| A | 0.78 | 0.52 | 1.14 |
| B | 0.80 | 0.51 | 1.03 |
| C | 0.77 | 0.50 | 0.92 |
| D | 0.68 | 0.49 | 0.79 |
| E | 0.59 | 0.48 | 0.65 |
| F | 0.53 | 0.47 | 0.56 |
| G | 0.51 | 0.45 | 0.55 |

Figure 22: Variation between metered and modelled gas use with BER rating from this dataset.

[13] SAP calculates EPCs in the UK, and is the UK equivalent of the Irish "DEAP" methodology.

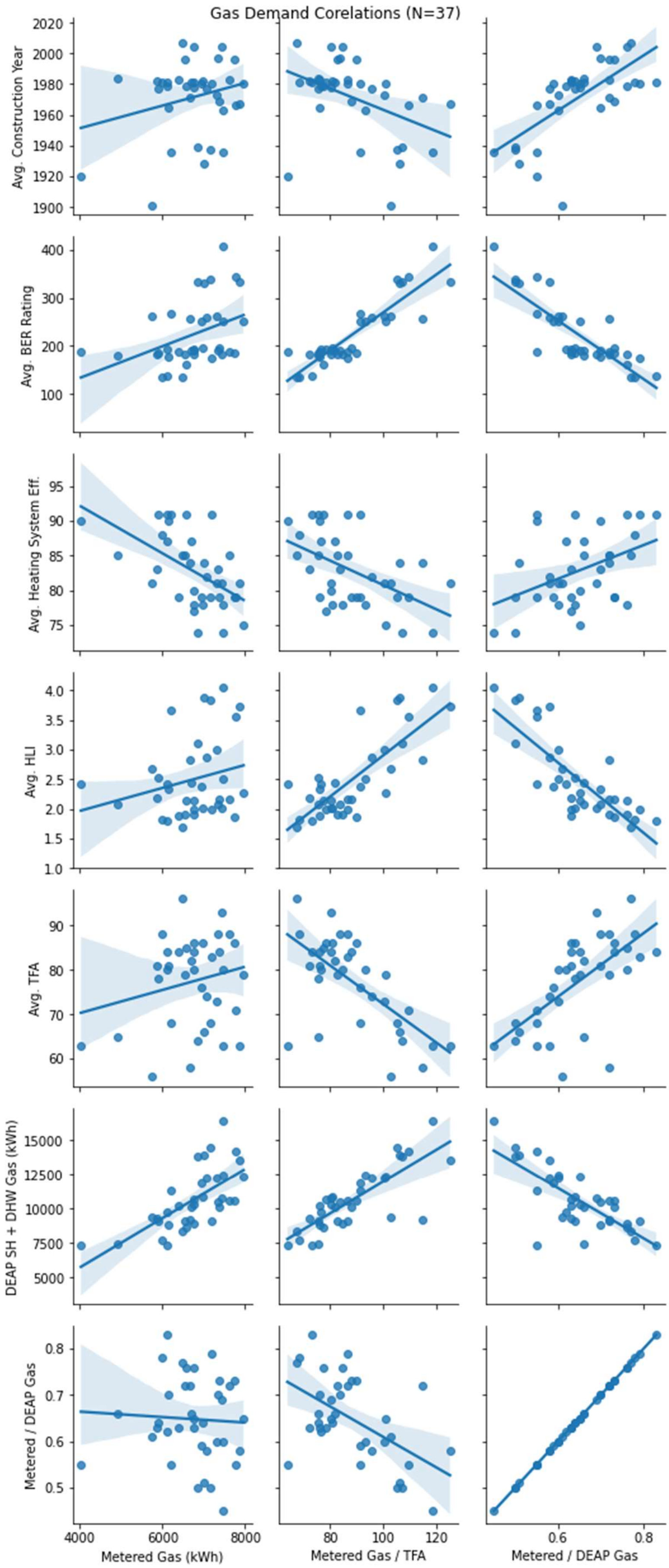



Figure 23: Metered Gas Demand vs Cohort Characteristics

Figure 25 next page repeats the analysis, this time focusing on electricity data. Note that one of the outlying cohorts with very high > 5000kWh modelled electricity consumption is excluded for clarity. In general, the relationship between metered electricity demand and the various characteristics is less well defined than the gas data with the exception of Total floor area (TFA - the fourth row below). Newer homes with lower HLI tend to be those with larger TFA's which likely explains the remaining trends on Column 1 (the most left hand column).

Two ratios are presented in Columns 3 and 4. Metered / DEAP Elec compares the total metered demand to the DEAP modelled Lighting and Pumps and Fans demand. As this excludes appliances, we observe ratios where the DEAP prediction is 3 to 5 times lower than the metered demand. The group with ratios <2 includes those with electrical heating and/or electrical DHW provision. Column 4 includes an estimate of appliance demand as described previously.

## Regression Model

While the process of developing the cohorts and averaging both the DEAP predictions and the metered data has removed much of the variation one might expect from a demand dataset of energy demand, statistical noise does remain. It is desirable to derive a simple correction factor that can be applied to the individual dwellings' DEAP results.

Our analysis has shown a range of potential drivers for the modelled/metered gap. To capture a range of these factors and account for both variations in fabric performance and heating system performance, the final model is a fit between DEAP gas and demand per $m^2$ and the ratio between measured energy demand and the DEAP based calculation. The derivation of these ratios is described in the section on Calculation of Modelled / Metered Factors above. For electricity, ratios are calculated for metered electricity per m2 vs the DEAP lighting and pumps and fans demand and vs the DEAP lighting and pumps + an estimate of appliance demand, again described in the section on Calculation of Modelled / Metered Factors.

Figure 24 shows the final set of regression model fits and equations for gas and electricity data. These are derived for the same set of cohorts as the exploratory gas analysis described above for consistency across the two sets of models. The X axis shown below is the modelled (DEAP) gas and electricity usage . The equations shown can be used to predict the energy usage for any dwelling for space heat, hot water, lighting, pumps and fans. Dwellings with lower modelled energy usage (i.e. better BER grade) are closer to reality. A ratio of "1" would indicate that modelled and actual energy use are equal.

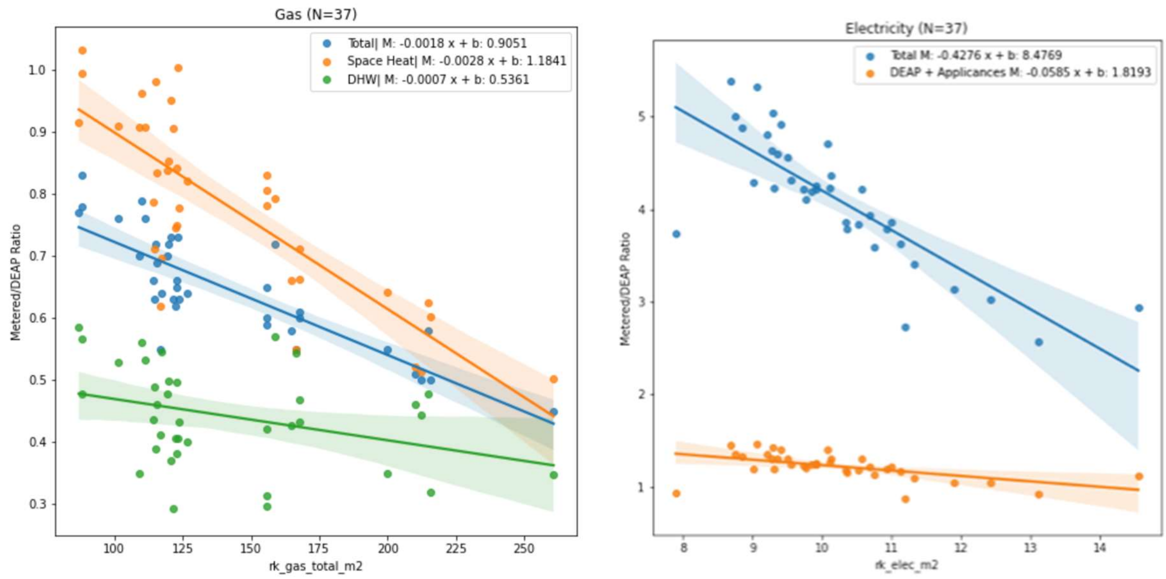



Figure 24: Final Regression Models

The equations shown on the graphs in Figure 24 were implemented in a spreadsheet for each of the scenarios. This is described in the next section.

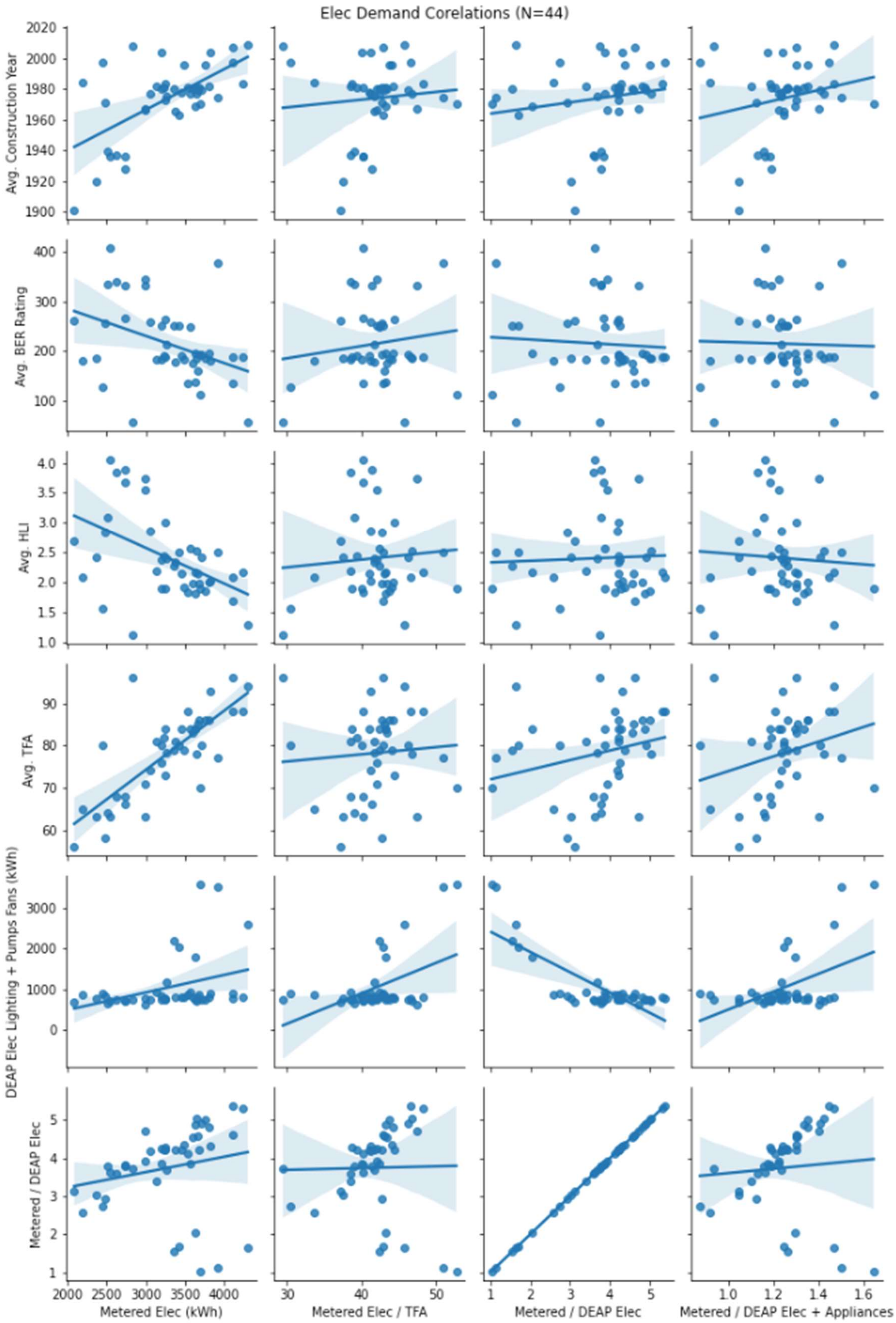



Figure 25: Metered Elec demand vs Cohort Characteristics

## Application to RetroKit Outputs

The regression models were implemented in a spreadsheet aggregating all RetroKit baseline and scenario output results in order to derive correction factors for space heating, domestic hot water (DHW) and lighting + pumps and fans for the full set of over 7,000 dwellings modelled as described in Section 3.

The coefficients shown in Figure 26 below are used to generate correction factors (y) from the equation

$y = mx + b$.

x is either the annual space heating demand from DEAP / the $m^2$ floor area, the annual DHW demand from DEAP /the $m^2$ floor area or the annual lights + pumps and fans demand from DEAP / the $m^2$ floor area. Table 3 gives an example for a dwelling with TFA = 80m2 and total DEAP demand of 7000 (space heating) + 2000 (water heating) + 800 (lights, pumps and fans). In the example, the corrected space heating demand is 6622 kWh (compared to 7,000kWh for this dwelling as modelled in DEAP).

| **Correction Factors** | |
|---|---|
| ***m x (spaceheat demand kwh/m2) + b*** | |
| SH m | -0.0028 |
| SH b | 1.1841 |
| ***m x (dhw demand kwh/m2) + b*** | |
| DHW m | -0.0007 |
| DHW b | 0.5361 |
| ***m x (lights + pump and fans kwh/m2) + b*** | |
| Total Elec m | -0.0585 |
| Total Elec b | 1.8193 |

Figure 26: Spreadsheet Regression Parameters

| | DEAP Demand kWh | TFA | m | x | b | Correction Factor (y) | Corrected Demand kWh |
|---|---|---|---|---|---|---|---|
| Space Heat | 7000 | | -0.0028 | 87.5 | 1.1841 | 0.9461 | 6622 |
| DHW | 2000 | 80 | -0.0007 | 25 | 0.5361 | 0.5168 | 1034 |
| Lights + Fans | 800 | | -0.0585 | 10 | 1.8193 | 1.2343 | 987 |

Table 3: Example: Calculating and Applying Correction Factors

The resulting correction factors vary from:

- 0.5 to 1.2 with a mean of 0.9 for space heating,
- from 0.2 to 0.9 for hot water with a mean of 0.5 and
- from 0.5 to 1.6 for electricity demand with a mean of 1.2.

Note in all cases the bottom of the range was imposed as a minimum value to avoid outlying data generating very small correction factors.

### Overall Impact

Figure 27 and Figure 28 below illustrate the impact of applying the correction factors on modelled fuel demand in the Baseline and Deep Retrofit (plus boiler) scenarios. Demand for grid gas, the dominant fuel in both scenarios, is reduced by ~30% in the baseline and ~22% in the deep retrofit scenario when the correction factors are applied.

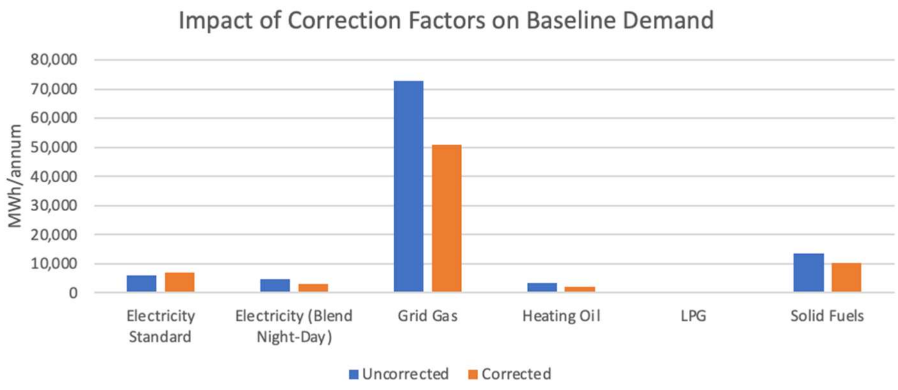



Figure 27: Impact of applying correction factors to modelled baseline demand

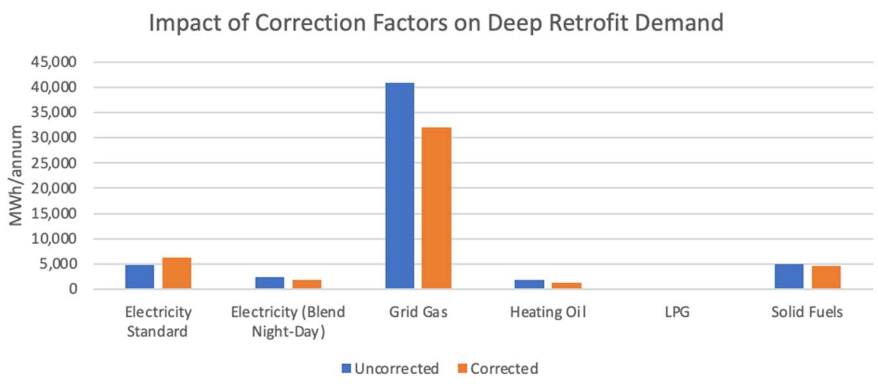



Figure 28: Impact of applying correction factors to modelled deep retrofit with boiler upgrade demand

Figure 29, Figure 30 and Figure 31 are distributions of modelled demand for Space Heat, Domestic Hot Water and Lighting plus Pumps & Fans from the baseline scenario with and without correction factors applied. For example, for Space Heating, the correction factors shift the distribution slightly to the left and reduce the number of outliers on the upper end of the distribution significantly. In other words, predicted energy usage for space heating tends to be lower than modelled, and there are far less dwellings with exceptionally high space heat demand in the predicted data.

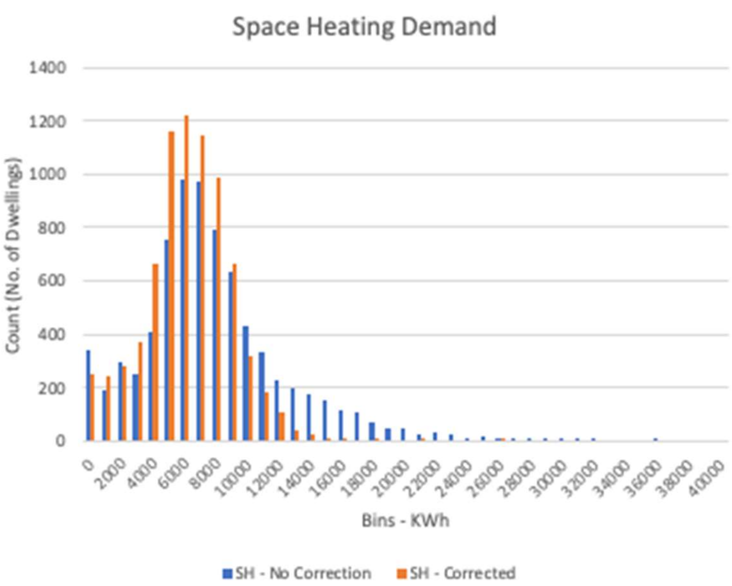



Figure 29: Impact of applying correction factors to distribution of Baseline SH Demand

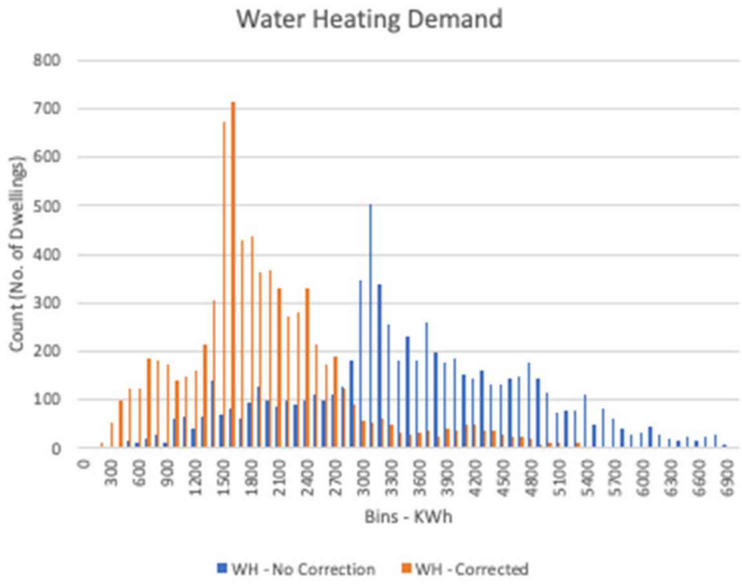



Figure 30: Impact of applying correction factors to distribution of Baseline WH Demand

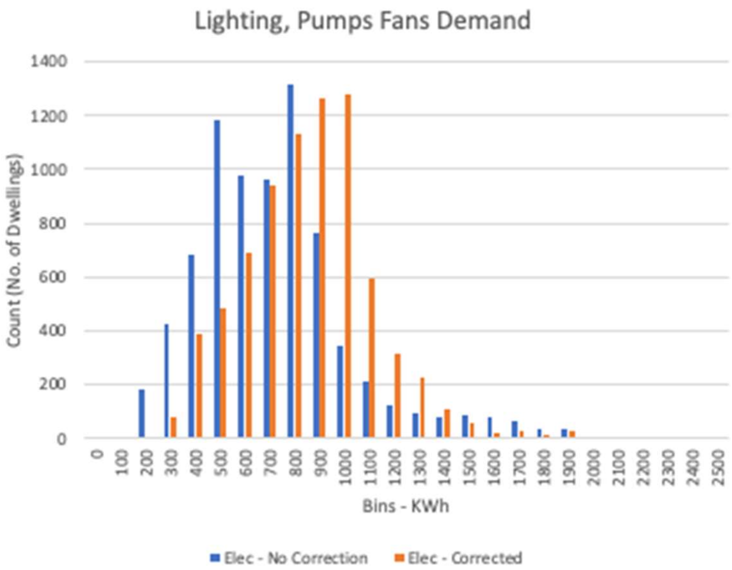



Figure 31: Impact of applying correction factors to distribution of Baseline Elec. Demand

Figure 32 shows that for the baseline, modelled energy usage is 37% higher than the predicted usage, compared to 11% in the electrified heat scenario. This indicates that, as well as the upgraded dwelling being likely to maintain closer to modelled heating schedules and temperatures, that the predicted energy savings will be lower than modelled energy savings. This type of analysis can enable better forecasting of the impact of proposed energy retrofit projects in terms of energy usage and $CO_2$ emission reduction when using DEAP (and RetroKit) as a modelling tool.

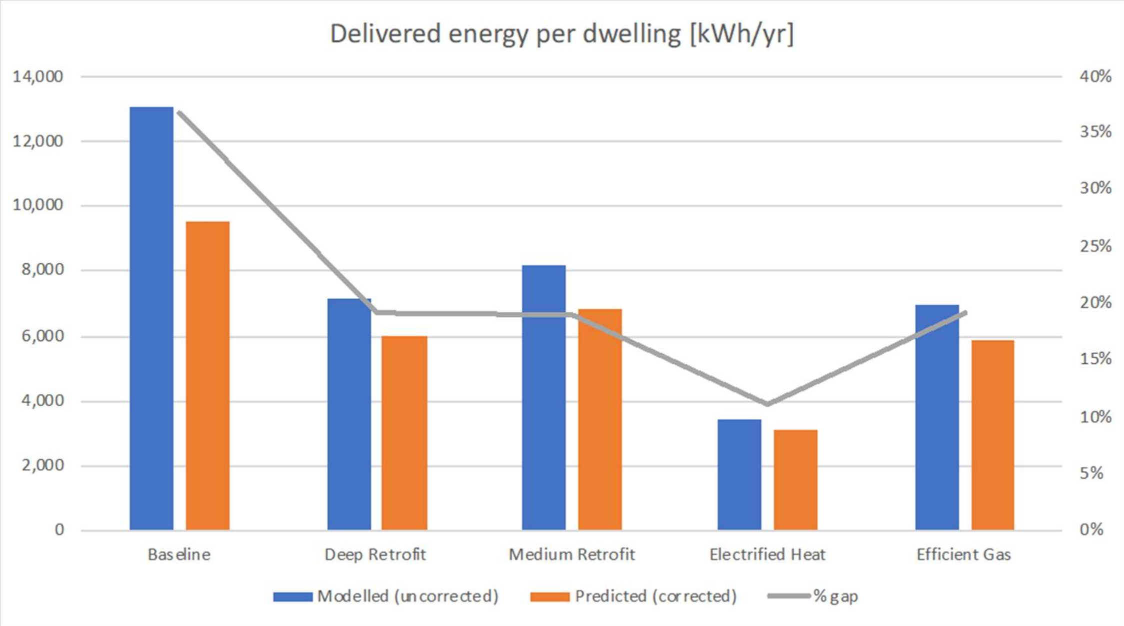



Figure 32: Predicted vs modelled energy usage: all scenarios

# 6. Forecasted results: 2030 and 2050

## Forecasted energy costs

Estimates of unit fuel costs for 2030 and 2050 were applied to the results in this study with and without the correction factors. Please note that energy spent calculations do not include energy costs for appliances or cooking.

| Costs (€/kWh) | 2022 | 2030 | 2050 |
|---|---|---|---|
| Electricity | 0.31 | 0.175 | 0.180 |
| Electricity (Night/Day) | 0.21 | 0.175 | 0.180 |
| Natural Gas (call it gas on network) | 0.08 | 0.089 | 0.160 |
| Heating Oil | 0.12 | 0.145 | 0.145 |
| LPG | 0.14 | 0.152 | 0.131 |
| Solid Fuels | 0.08 | 0.094 | 0.114 |

Table 4: Fuel & electricity costs.

2022 fuel costs were based on SEAI's Domestic Fuel Cost Comparison (1st July 2022). 2030 and 2050 fuel costs were based on SEAI's National Heat Study "Net Zero by 2050" published in 2022. All fuel costs used in this section include carbon taxes. SEAI forecast a significant increase in the price of grid gas as it becomes decarbonised by 2050 with the replacement of natural gas by a mix of biomethane (forecasted at €0.08/kWh) and renewable hydrogen (forecasted at €0.16/kWh). The price of electricity is projected to decrease to €0.18/kWh by 2030 and remain at that level by 2050.

Prior to applying the correction factor (i.e. assuming modelled energy usage), the energy expenditure drops by 40 – 60% in 2022 and 2030 once upgrade scenarios are applied. In 2022, the energy spend is at its lowest in the "efficient gas" scenario. By 2050, all gas based scenarios have higher energy costs than 2030, whereas electrified heat scenario achieves the lowest energy costs in 2050.

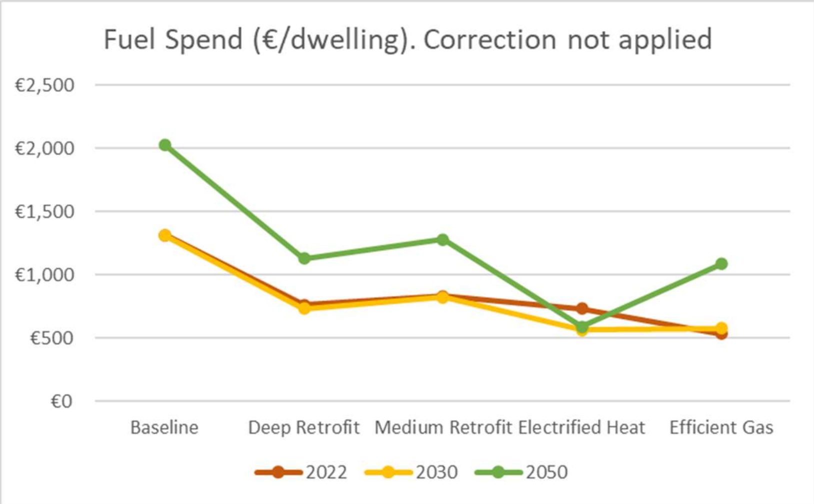



Figure 33: Fuel spend per dwelling per scenario. 2022, 2030, 2050. No correction factor applied

After applying the correction factor to account for predicted rather than modelled energy usage, the predicted baseline energy spend is €350 lower (25%) than modelled energy spend. The medium scenario is a more cost effective means of reducing energy costs than the other (deeper) energy retrofit scenarios. Again, the 2022 and 2030 costs remain similar across the different scenarios.

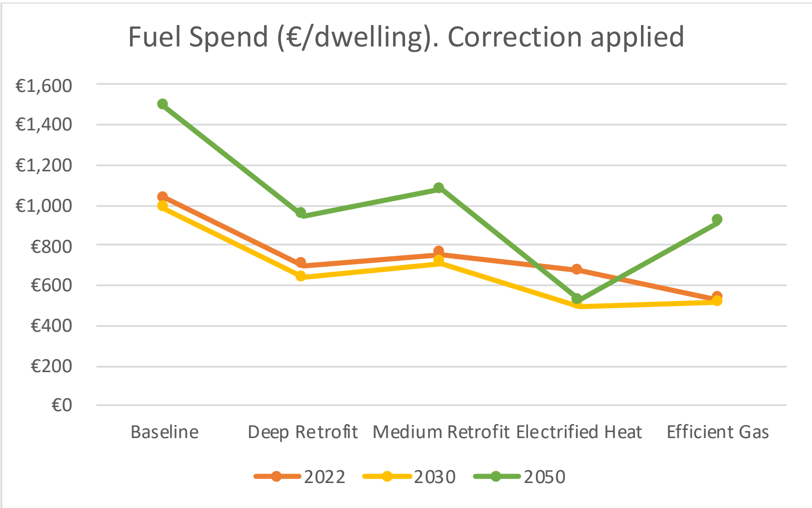



Figure 34: Fuel spend per dwelling per scenario. 2022, 2030, 2050. Correction factor applied

## Forecasted $CO_2$ emissions

Estimates of $CO_2$ emissions per kWh fuel for 2030 and 2050 were applied to forecast future emissions in the different scenarios. The $CO_2$ content of fuels applied for 2022 are based on SEAI's Energy in Ireland report (2021). The values for 2030 and 2050 are based on SEAI's National Heat Study (2022). $CO_2$ emissions in this section do not include $CO_2$ from appliances or cooking energy usage.

SEAI forecast modest gains in penetration of renewable gas in 2030 (13% biomethane) resulting in a 10.5% reduction in $CO_2$. While SEAI forecast a phasing out of natural gas with hydrogen and biomethane by 2050[14], it also forecasts the decommissioning of the gas network for the residential sector.

| $CO_2$ content ($kgCO_2/kWh$) | 2022 | 2030 | 2050 |
|---|---|---|---|
| Electricity | 0.257 | 0.090 | -0.047 |
| Natural Gas (call it gas on network) | 0.202 | 0.181 | 0.000 |
| Heating Oil | 0.272 | 0.272 | 0.272 |
| LPG | 0.232 | 0.208 | 0.000 |
| Solid Fuels | 0.197 | 0.197 | 0.197 |

Table 5: $CO_2$ content of fuels & electricity.

Generally, electrified heat is most effective at decarbonising heat relative to other scenarios. SEAI Heat Study's "Balanced Scenario" forecasts significant reduction in $CO_2$ intensity of electricity by 2030, down to negative emissions in 2050.

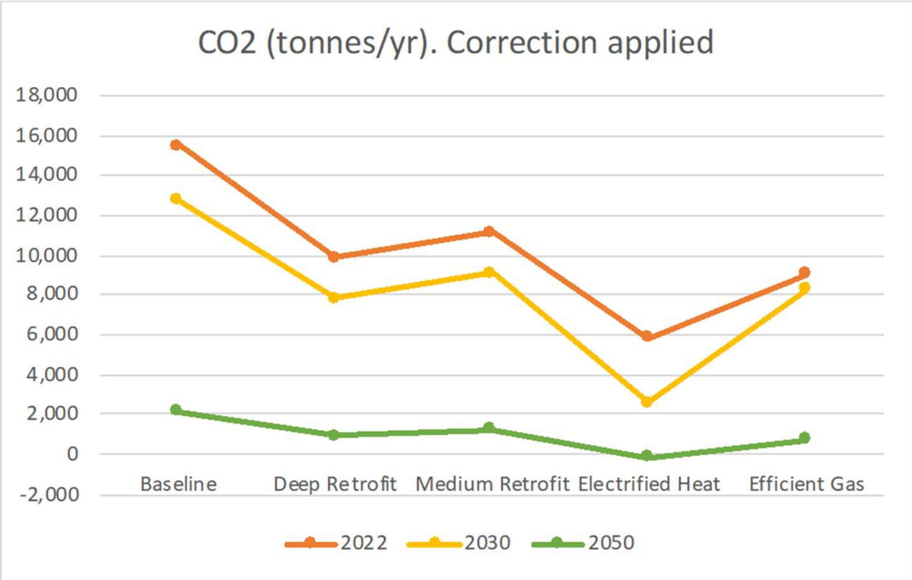



Figure 35: $CO_2$ (tonnes per year) per scenario. 2022, 2030, 2050. Correction factor applied

[14] Please note that the $CO_2$ emission factor for renewable gas forecasted in the SEAI National Heat Study for 2050 is not down to zero as upstream emissions are included in the calculation of this factor (e.g. emissions associated with the production of grass silage used for the generation of biomethane are considered).

# 7. Fuel Poverty

## Fuel Poverty Thresholds

The Oireachtas Library and Research Service[15] recently published a review on energy poverty, citing an ESRI study from 2020 that estimated 17.5% of households in Ireland were in energy poverty. It is reasonable to expect that this number has grown with the recent increases in energy prices. The review provides the following definition of energy/fuel poverty.

| Methodologies | Explanation |
|---|---|
| **Expenditure method** | Calculates the proportion of household income (net of housing costs) that is devoted to meeting energy (e.g., heating / lighting) needs. If a household spends more than 10% of their income on energy, they are considered to be in energy poverty, with the severity of energy poverty increasing as the proportion of income spent on energy increases to 15% (classified as severe poverty) and 20% (extreme poverty). The expenditure method was adopted in 2011 on a preliminary basis.[15] |

Table 6: Oireachtas Library and Research Service Fuel Poverty Definition

Income data for the occupants of the study sample is not available., Instead, we explore energy poverty risk across a range of income deciles. The Survey on Income and Living Conditions, 2019[16] gives estimates of Net Disposable Income deciles as shown below in Figure 36.

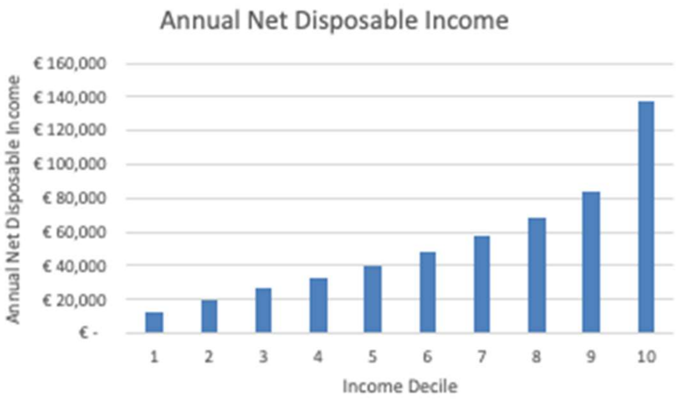



Figure 36: Annual Net Disposable Income by Decile (Source: SILC, 2019)

The fuel poverty as defined above is calculated after housing costs. These were calculated following the policy on rents in Cork City (https://www.corkcity.ie/en/council-services/services/housing/renting-a-council-house/renting-a-council-house1.html) which is approximately 15% of income with a minimum of €24.30 per week. Table 7 below sets out the calculation for income deciles 1 to 5 and the resulting threshold for fuel poverty per decile.

[15] Lawlor and Visser (2022) Energy Poverty in Ireland https://data.oireachtas.ie/ie/oireachtas/libraryResearch/2022/2022-03-04_l-rs-note-energy-poverty-in-ireland_en.pdf

[16] https://www.cso.ie/en/releasesandpublications/ep/p-silc/surveyonincomeandlivingconditionssilc2019/

| Income Decile | | 1 | | 2 | | 3 | | 4 | | 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| Annual Net Income | € | 12,778 | € | 19,220 | € | 27,118 | € | 33,069 | € | 40,333 |
| Rent @ 15% (or minimum) | € | 1,264 | € | 2,883 | € | 4,068 | € | 4,960 | € | 6,050 |
| After Rent | € | 11,514 | € | 16,337 | € | 23,050 | € | 28,109 | € | 34,283 |
| Decile Fuel Poverty Threshold (10%) | € | 1,151.44 | € | 1,633.72 | € | 2,305.03 | € | 2,810.90 | € | 3,428.28 |

Table 7: Approximate Annual Fuel Cost per Income Decile for Household to Cross Fuel Poverty Threshold

## Retrofit Impact on Fuel Poverty

Figure 37 compares the fuel poverty thresholds established in this study against the estimated average fuel costs (corrected as described earlier in this document). The figures presented here account for the full fuel spend for lighting, pumps fans as per DEAP and an additional allowance for appliances as described previously under Calculation of Modelled / Metered Factors above. The total spend also includes electricity and gas standing charges. It is apparent that the 1st decile remains in fuel poverty through all of the scenarios, while the 3rd decile is not in fuel poverty in any of the scenarios. The energy efficiency measures applied in the Efficient Gas and Electrified Heat scenarios are sufficient to remove the second decile from fuel poverty.

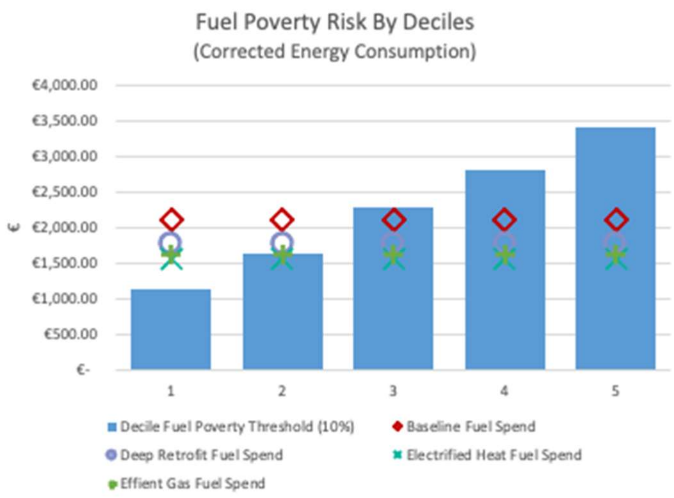



Figure 37: Scenario Energy Costs vs Fuel Poverty Thresholds

Previous analysis has highlighted the variation in energy use across the various cohorts in the sample. Therefore, it is possible that certain sections of the 3rd and 4th decile may still be at risk of fuel poverty in some homes. Figure 38 shows mean metered energy spend for each cohort in comparison to the fuel poverty threshold for each of the income deciles. This shows that, there are a number of homes at risk of fuel poverty for the 3rd and 4th deciles, these are primarily larger cohorts with direct electric heating. Where the bars cross the threshold, it indicates that income decile living in that dwelling cohort may be in fuel poverty. We can see, even though decile 3 (purple line) is not in fuel poverty on average, there are 4 dwelling cohorts where this occurs (generally a mix of older homes heated by direct electricity).

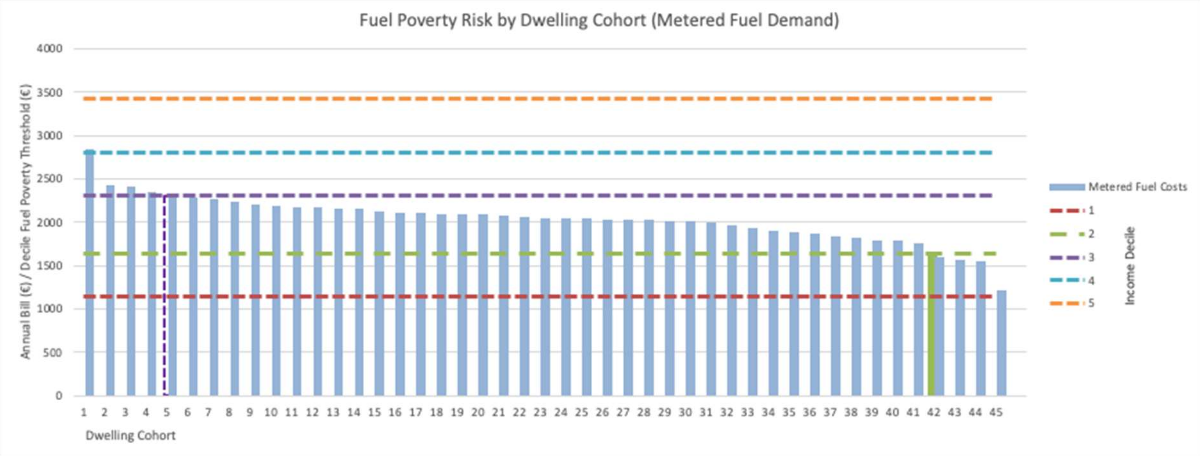



Figure 38: Metered Energy Costs vs Fuel Poverty Thresholds

It is also possible to look at the impact the retrofit scenarios across the cohorts. Figure 42 presents the results of the Deep Retrofit (with gas boiler) scenario which has a significant impact on the fuel poverty risk for the 2nd income decile with energy bills for almost all cohorts reducing to below or near the threshold.

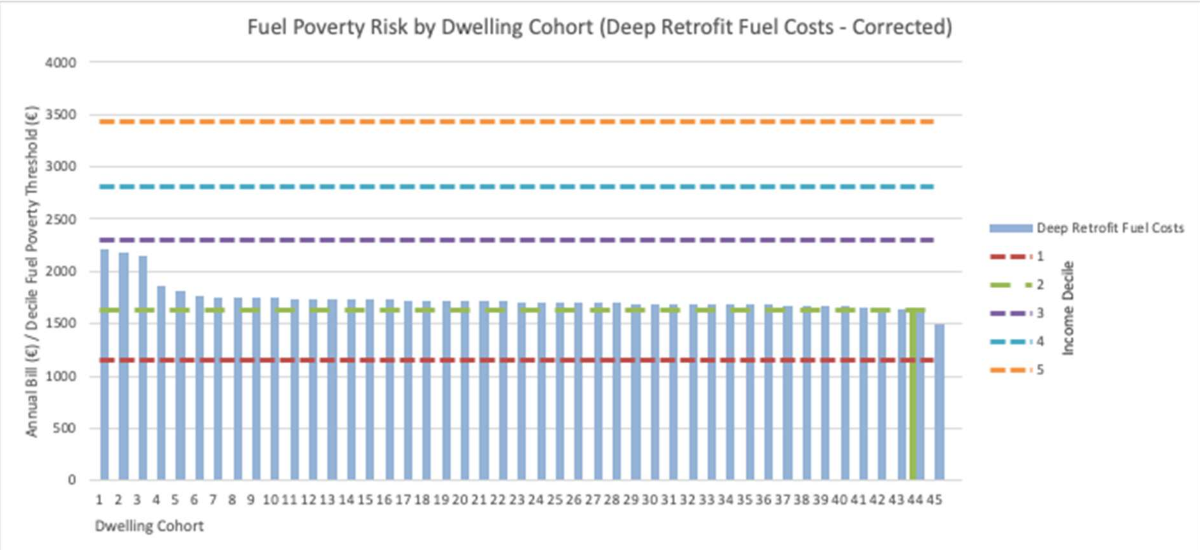



Figure 39: Deep Retrofit Scenario Energy Costs vs Fuel Poverty Thresholds

It is notable that the cohorts with direct electric heating (1,2,3) remain as outliers in this scenario, which does not include fuel switches. This is addressed both in the Electrified Heat (Figure 41) and Efficient Gas (Figure 41: Efficient Gas Energy Costs vs Fuel Poverty Thresholds) scenarios which substantially reduce the risk of fuel poverty for the second decile.

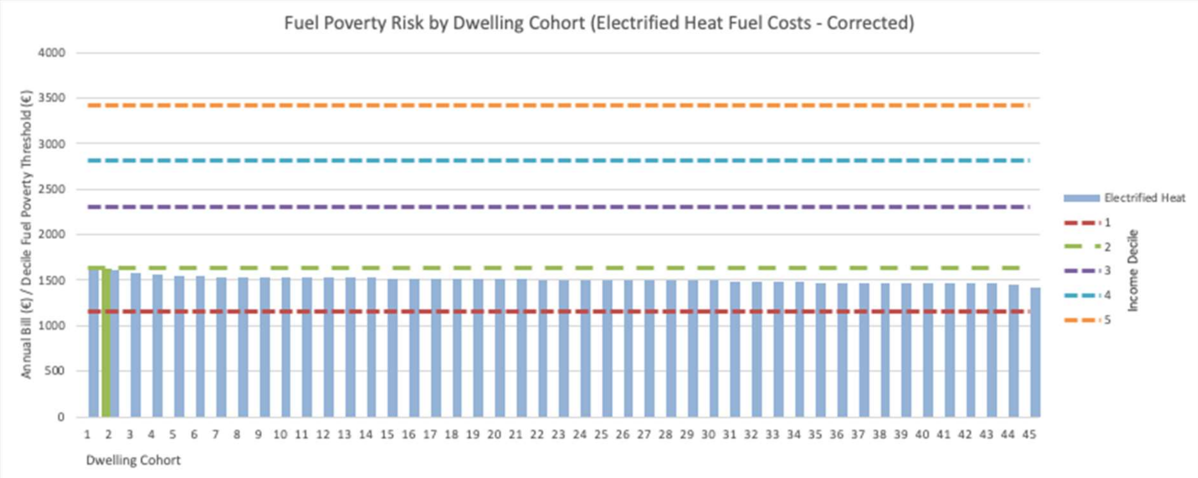



Figure 40: Electrified Heat Energy Costs vs Fuel Poverty Thresholds

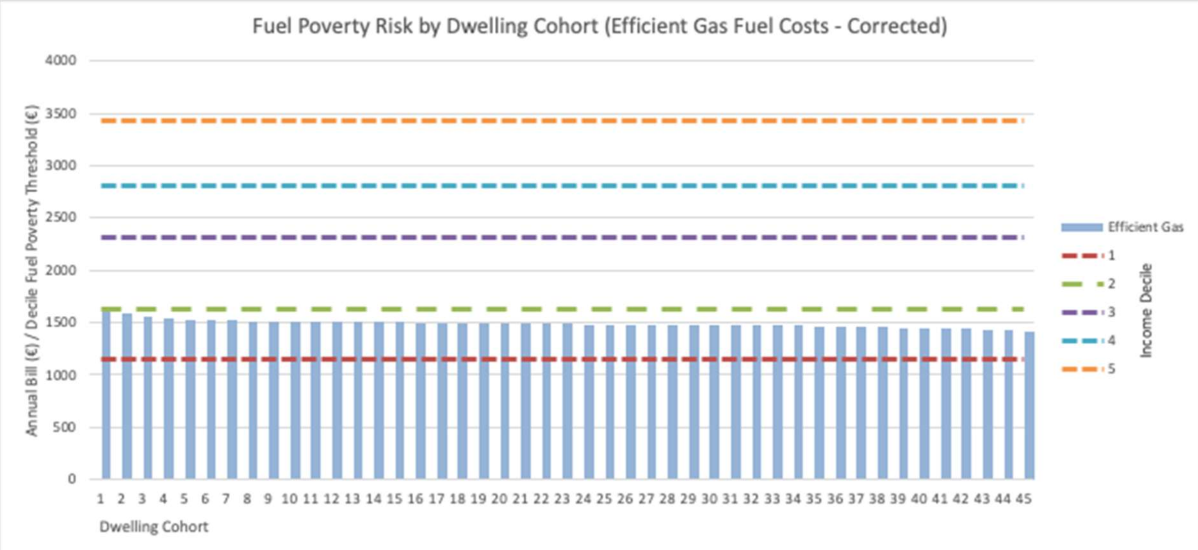



Figure 41: Efficient Gas Energy Costs vs Fuel Poverty Thresholds

When considering this analysis, it is important to note that metered and modelled energy use corrected with this metered data may not fully represent the fuel poverty risk. Households may choose to underheat their homes or utilise non metered energy sources (solid fuel) for example. This can increase the divergence between modelled and actual energy use. These households may still be in fuel poverty even though their annual bills do not cross the threshold..

The graph below illustrates this phenomenon. The correction applied to account for the gap between modelled and metered fuel costs grows as modelled fuel spend increases. For example, there is no correction applied to a predicted bill of €1500 whereas the correction factors reduce a modelled bill of €4000 by €2000. Further work on secondary heating use and comfort levels would be required to fully understand these risks.

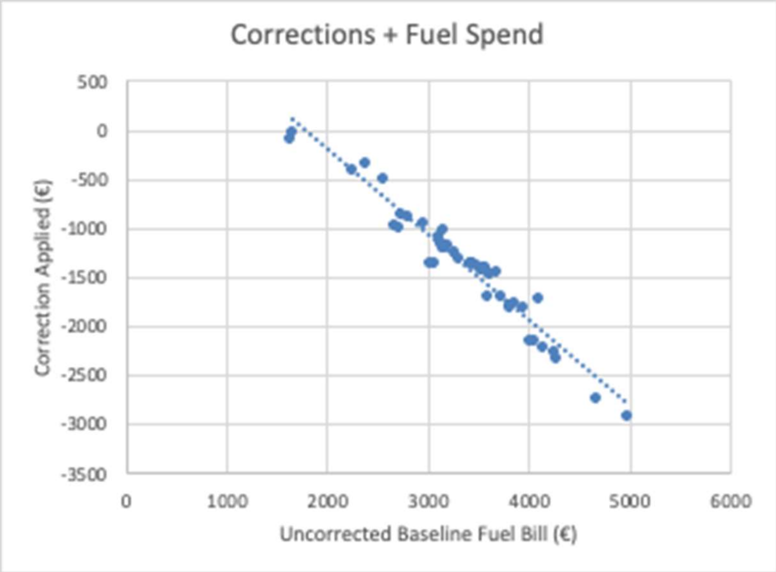



Figure 42: Baseline Model Correction vs Baseline Fuel Cost Estimate

## Conclusion

This analysis shows a considerable risk of fuel poverty in the study sample. Households with income in the 1st decile are likely to need considerable financial support to avoid fuel poverty while households up as far as the 4th income decile may be at risk of fuel poverty in certain homes.

Deep Retrofitting homes has the potential to reduce fuel poverty risk substantially but in order to address the most at-risk dwellings it will be important to switch away from direct electric heating.

# 8. Conclusions and further work

## Summary of methodology and findings

This study carries out a detailed analysis of the energy performance and usage data for a large sample of houses to gain better understanding of gap between modelled and actual energy usage, and gain insights into fuel poverty and the impact of a range of low energy upgrades thereon. The study was funded by the Gas Innovation Fund and supported with data and expertise by the Central Statistics Office (CSO).

The specific objectives of the study were to:

- Deepen understanding of gap between modelled and actual energy use in social housing.
- Develop a comparative analysis of energy retrofit scenarios, with and without natural gas.
- Gain insight into the relationship between fuel poverty and energy performance rating in an urban social housing stock, and forecasting the impact of energy retrofit scenarios on same.
- Better forecast $CO_2$ emissions and fuel costs for retrofit scenarios

The study covers over 7,600 dwellings in Cork City Council's social housing stock. These dwellings have an average BER grade of C3, and are primarily heated by gas. They are mostly terraced houses and are primarily built prior to the 1990s.

Four retrofit scenarios were modelled across the housing stock: 1) a medium and 2) deep fabric retrofit with a new gas boiler; 3) an electric heat pump scenario and 4) an efficient gas scenario (including a mixture of gas fired heat pumps and fuel cells with boiler backup). All scenarios barring the medium plus boiler scenario achieved the average B2 BER rating targeted in the government's Climate Action Plan.

The study used gas and electricity metered data provided by the CSO (anonymised and aggregated into cohorts) to compare actual vs modelled energy usage per cohort. Generally, dwellings with better BER grades (higher energy performance) have modelled energy usage closer to actual usage. This indicates that dwellings with poorer BER grades are likely to be heated to a lower standard (shorter heating schedules and lower temperatures) than dwellings with better BER grades. As a result, predicted energy savings from low energy upgrades are likely to be less than would be expected from modelling of energy upgrades. The analysis carried out in this study can help decision-makers better forecast the impact of energy retrofit programmes in terms of energy use, energy expenditure and $CO_2$ emissions.

Forecasted energy expenditure for the retrofit scenarios modelled show reductions between 25% and 50% compared to the baseline. When looking to 2030, the electrified heat and efficient gas scenarios results in close to €500/year reduction in energy expenditure against the baseline, compared to €350 and €270 for the deep retrofit and medium retrofit with gas boiler scenarios respectively. However, by 2050, the electrified heat scenario results in much deeper reductions in energy expenditure (-65%) than gas-based scenarios (-30 to -40%) as the projected cost of gas supplied by the grid will be double its current price as it is decarbonised over the next 30 years.

Finally, the expected impact of energy retrofits on fuel poverty were studied, focussing on the lowest 5 income deciles. In this section of the study, standing charges are also considered as part of the energy expenditure calculations. The analysis indicates that the lowest income decile (1) remains in fuel poverty in the baseline and each of the energy upgrade scenarios in most of the dwelling cohorts analysed. At October 2022 energy costs, deciles 3 to 5 are rarely impacted by fuel poverty. The electrified heat and efficient gas scenarios reduce the risk of fuel poverty in decile "2" across all of the 45 dwelling cohorts.

## Further work: building on this study

Range of cohorts

While this study covers a reasonably large sample of dwellings it is somewhat limited in dwelling type, age, sizes and fuel type. It would be best to expand this to include a wider range on each of these parameters. In particular, actual usage figures for fuels other than gas and electricity were not available from CSO. This, combined with the lack of detached houses in the study mean that the results of the analysis are less relevant to rural dwellings. Solid fuel and oil usage and energy usage for detached houses would enhance the applicability of this study's results to a wider range of dwelling types.

It would also be useful to conduct a similar comparative analysis with a focus on dwellings that have benefitted from an energy renovation, with a cohort of dwellings that would be representative nationally. Considering different levels of renovation would enrich this analysis considerably. One objective would be to measure the actual impact of home energy upgrades on energy consumption & $CO_2$ emissions, and have a better evidence and understanding of the rebound effect.

More detailed on type of energy usage

Separation of DHW / space heating energy usage was carried out by assuming a "baseline" load for DHW based on Q3 metered data . While this is the only option given the nature of the quarterly data from CSO, ideally monthly metered data, or, better still, actual energy for space and water heating would provide more accurate breakdown of space and water heating.

In addition, the assumption for appliance and cooking energy usage is based on a simple per $m^2$ national average, which limits the ability to accurately split electricity usage from space and water heating, lighting, pumps and fans from appliances / cooking. More accurate electricity usage (e.g. from smart metering in future) could alleviate this issue.

It would also be interesting to conduct a comparative analysis of energy usage in different locations for similar dwelling archetypes to try and understand better the impact of climate (currently the DEAP methodology takes Dublin airport climate data as the standard for energy performance rating for all dwellings across Ireland).

Further improvements and analysis:

Refinements in the DEAP calculations happen over time and will have an impact on the modelling of energy performance and energy usage. Changes to the modelled calculation mean that the factors we apply to forecasted actual energy use will need to be updated.

Impact of current fuel price increases and inflation in general on user behaviour resulting in a widening of the gap and increase in fuel poverty will require rerunning the analysis in this study in future. While the extraction of data from RetroKit into custom built spreadsheets is effective, it would be more efficient to implement the analysis in RetroKit software itself to enable regular updates to the factors. Finally, the summary results of this study should be relayed to policy-makers and regulators, to assist with more accurate impact assessment of energy upgrade programmes, and their impact on fuel poverty in particular.

## What does this mean for RetroKit

RetroKit's calculations are based on the same standardised assumptions as DEAP, particularly regarding heating schedules, climate, dwelling occupancy, lighting levels, accuracy of BER assessments and so on as outlined in Section 5. This is particularly useful in the context of energy upgrades and the landscape in which RetroKit's typical client base operate. For example, One Stop Shop funding eligibility is based on the BER grade achieved, (B2), the primary energy uplift (100kWh/$m^2$/yr) when the works are carried out, and, in the case of heat pump installations, the heat pump readiness of the dwelling. These are all based on the DEAP methodology are followed by RetroKit for it to be of use to market operators.

However, this "asset based" approach does not account for actual user behaviour or actual climate and can be adjusted as outlined in this document to give a more accurate indication of energy usage and energy costs in different renovation scenarios and therefore the fuel cost savings in those scenarios. It is not possible to predict exact savings as exact usage in a particular household cannot be predicted in any given year, even if no renovation works were to be carried out. To this end, RetroKit could account for actual energy usage (and associated costs) using the approach in the Section "Application to RetroKit Outputs" above. The resulting "actual" figures could be presented alongside the modelled costs and energy usage graphs and figures currently displayed in RetroKit. To allow for more accurate adjustment factors evolving over time, the factors would be set as configurable by RetroKit's administration staff.

BER grade, HLI and uplift etc. as used for grant eligibility checks do not change then the "actual" energy usage factors are applied as these are always based on the standard assumptions in DEAP.

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