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Energy Performance Certificates, Household Experience and Sustainable Retrofit in London

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Abstract

Residential retrofit is expected to reduce energy demand, lower household expenditure and improve thermal comfort, yet these outcomes are not necessarily captured by energy performance certificates (EPCs) or household bills. This study examines the evidence available for evaluating residential improvement through EPC and energy-bill records for 25 London dwellings and nine separately analysed questionnaire submissions. Questionnaire responses were analysed descriptively, while the dwelling records underwent cross-file checks and two sensitivity analyses. All nine questionnaire submissions indicated awareness of their EPC rating, but only three reported using its recommendations in improvement decisions. All seven answering the relevant question reported restricting heating because of cost, while four of five respondents reported no reduction in bills following improvement. The dwelling analysis identified four conflicting bill-derived entries; substituting the alternative values reduced the mean recorded annual figure by 11.2%. Moreover, differences in energy coverage and annualisation prevented a valid comparison between EPC estimates and household consumption. This study demonstrates how inconsistencies in source records and incompatible energy measures constrain retrofit evaluation. It identifies reconciled energy records, documented interventions and linked household outcomes as necessary evidence for assessing energy savings, affordability and comfort.

Keywords: energy performance certificates; heating affordability; household energy use; resident experience; sustainable housing; sustainable retrofit; London

1. Introduction

Residential retrofit is expected to reduce emissions, improve living conditions and make heating more affordable. The benefits depend on the work undertaken and how residents use their homes, as efficiency gains may reduce energy consumption, allow more adequate heating, or both [1,2]. Heating decarbonisation introduces further decisions about the relationship between fabric and system improvements [3]. Evaluation must therefore examine completed work alongside subsequent energy use, expenditure and warmth [1–3].

Energy performance certificates (EPCs) provide a common basis for assessing residential energy efficiency and identifying improvement opportunities [4,5]. They compare dwellings under standard assumptions rather than measuring household consumption or comfort. EPC ratings and recommendations can inform investment decisions, but do not establish the savings or benefits experienced by occupants [4,5]. The purpose of the certificate and the purpose of the evaluation must therefore be distinguished. Comparisons between EPC estimates and metered consumption identify systematic disagreement, whose magnitude and direction depend on the housing stock and the quantities compared [6–8].

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Interpreting these differences requires equivalent fuel and service coverage and defined observation periods. This becomes particularly important when certificate information and household bills are used to judge improvement outcomes.

Energy demand varies with dwelling characteristics, occupancy, equipment and household practises [9–11]. Longitudinal monitoring also shows changes in demand over time [12]. EPCs and bills may therefore describe different building conditions, occupants or periods, even when they refer to the same address. Heating affordability affects those conditions directly. During the cost-of-living crisis, households reported changes in heating practise while metered evidence identified lower demand alongside continuing expenditure pressure [13,14]. Reduced consumption can therefore accompany restricted access to warmth. Research on energy insecurity and underconsumption similarly shows why assessed efficiency and the ability to obtain adequate heating require separate consideration [15,16]. Low energy use may reflect an efficient dwelling, limited heating requirements or financial restraint. These starting conditions influence the savings obtainable from improvement and the way residents experience its benefits [17]. Consumption alone cannot establish whether an intervention has improved living conditions.

An EPC rating is not evidence that its recommendations influenced subsequent retrofit work. Awareness of a rating, understanding of its meaning and use of recommendations are different forms of engagement [18,19]. Technical advice has to be considered alongside household priorities, finance and the practical arrangements for work [20,21]. National survey evidence distinguishes general awareness, knowledge of an exact rating and changes attributed to recommendations [22]. Awareness, reported influence on a decision and completed work must therefore be distinguished [18–22].

Responsibility for that decision is especially important in rented housing. Residents may manage heating expenditure while lacking authority to change the building fabric or replace equipment. London policy research identifies limitations in using EPC information to identify fuel-poor households [23], while housing-stock research documents unequal assessed performance across the city [24]. Economic appraisal adds the distribution of costs and benefits between the parties involved [25]. The interpretation of recommendation use must therefore consider who can authorise, finance and arrange an intervention. These circumstances cannot be inferred from a resident's awareness of the rating, and their influence requires evidence from the decision itself.

Interpreting outcomes also depends on knowing which improvements were made. Insulation changes heat transfer, heating replacement changes system performance and an extension can increase the accommodation and space requiring heating. These works create different expectations of subsequent demand. Their results also depend on specification, installation, commissioning and resident guidance [26–28]. A questionnaire response confirming that work occurred does not identify the measures installed or the benefits expected. Those details are needed before subsequent bills or satisfaction can be interpreted [25–28]. Otherwise, similar answers may describe materially different experiences.

Research on certificate accuracy, household demand and retrofit delivery draws on different kinds of evidence [6–12,18–28]. Consumption studies describe patterns across dwellings, while surveys document residents' knowledge and experience [13–22]. When EPC extracts, bills and questionnaires are assembled for a project, they may cover different properties, services or periods. Without verified links and records of completed work, they cannot establish energy savings or explain household outcomes.

This London study examines EPC and energy-bill records for 25 dwellings alongside nine separate questionnaire submissions. It reports residents' EPC engagement, heating-cost restraint and experiences of home improvement, while testing how conflicting entries alter the energy summaries. The questionnaire and dwelling records are analysed separately

because individual responses cannot be linked to properties. This study demonstrates how conflicting energy records, non-equivalent measurements and unlinked household responses constrain the assessment of EPC accuracy, retrofit savings and household outcomes. This study addresses two research questions:

(1) What do residents report about EPC awareness and recommendation use, heating affordability and their experiences following home improvements?

(2) How do inconsistencies in dwelling records, uncertain energy coverage and incomplete links between datasets constrain the interpretation of EPC-related energy figures and reported improvement outcomes?

This study has three corresponding objectives:

- To examine residents' reported EPC engagement, cost-related heating practises and experiences of home improvement.
- To assess the consistency and comparability of the EPC-related and bill-derived energy figures.
- To identify the evidence required to evaluate energy consumption, household expenditure and resident experience following residential improvement.

The following section develops the relevant literature. The methods then explain the record checks and descriptive calculations. The results present household findings, numerical checks and differences between versions of the dwelling data. The discussion considers their implications for evaluating residential improvement, followed by conclusions and priorities for further research.

2. Theoretical Background

2.1. EPC Assessment and Observed Energy Use

EPC calculations apply standard assumptions about occupation and energy services to specified dwelling characteristics. These assumptions allow dwellings to be compared on a common basis [4,5]. Assessment methods and default values vary between certification systems [29,30]. An EPC rating therefore supports comparison but does not describe the energy consumed or warmth obtained by an individual household [6–8,17].

The distinction between actual and predicted performance is central to research on the energy performance gap. Comparisons using British, Irish and Swiss data identify systematic differences between certificate estimates and recorded consumption, with the magnitude and direction affected by the buildings and energy quantities examined [6–8]. A British study of 1374 gas-heated homes found that overprediction of primary energy use intensity increased towards poorer EPC bands [6]. Subsequent spatial research identified variation across England and Wales [9]. These findings challenge the assumption that a certificate estimate can be transferred directly to an individual household's expected consumption or savings. They also show why evidence from one population cannot establish the direction of the difference in every dwelling [6–9].

Differences can arise from errors in assessment inputs, departures from standard occupancy assumptions or discrepancies between specified and installed system performance [17,31]. A floor-area error affects the calculation, while restricted heating changes the service obtained. Database studies identify implausible entries, while human–building research shows how operation influences demand [31–33]. A difference between annual figures cannot establish its cause without supporting evidence [17,32,33]. Government research on EPC accuracy likewise examines assessment production as well as reported outputs [34].

Energy boundaries are equally important. Useful heat, delivered energy and primary energy describe different stages of energy provision. Estimates for heating and hot water

cover fewer services than a whole-household total that includes appliances and other uses [4–6]. Certificate comparisons consequently depend on compatible fuels, services, units and periods. Research examining heat loss addresses another physical question, concerning the relationship between assessment information and the dwelling's thermal characteristics [35]. A stock-level association between better ratings and lower consumption provides evidence about relative performance, whereas agreement between predicted and measured quantities concerns estimation accuracy [6,11,35]. These questions require different observations.

Assessment dates and building changes further affect the relationship. A certificate can remain available after alterations to fabric or equipment, while consumption reflects the dwelling and household during the period measured [11]. Monitoring from 2020 to 2025 also demonstrates that energy-use patterns can change over time [12]. Linking documents by address therefore establishes a necessary connection without establishing that they describe the same building condition or operating circumstances. Consistent entries, compatible measurements and a documented sequence of changes provide the basis for interpreting a difference before attributing it to certificate error [6,11,17,32–35].

2.2. Heating Demand, Affordability and Resident Experience

Residential energy demand emerges from the interaction between building characteristics and the services households obtain. Thermal performance, floor area and equipment influence the energy required, while occupancy, schedules and appliance ownership influence its use [10,31]. Research covering 2323 British dwellings found that household and appliance information added explanatory value beyond physical characteristics, although substantial variation remained unexplained [10]. This evidence supports including household circumstances in explanations of demand. It also cautions against assigning unexplained variation to behaviour when unobserved building characteristics, measurement limitations and changing circumstances remain possible contributors [10,17,31].

Heating introduces a further distinction between energy efficiency and the adequacy of the service obtained. The prebound effect describes consumption below the level assumed by a standard assessment before improvement [36]. Where households initially heat fewer rooms or maintain lower temperatures, an intervention can support warmer conditions as well as lower energy requirements. Realised savings then depend partly on the starting level of heating and the subsequent use of the improved dwelling [17,36]. Lower energy demand and adequate warmth are distinct sustainability outcomes; low baseline consumption may reflect financial restraint rather than building efficiency [15–17,36].

Surveys during winter 2022–2023 recorded changes in heating practises, while weather-adjusted metered research identified falling demand despite higher bills [13,14]. Longitudinal monitoring recorded changes in household energy-use patterns [12]. These findings show why lower demand cannot necessarily be attributed to improved building efficiency [12–14]. Energy prices and household resources therefore need to be considered when interpreting consumption [13–16].

Energy expenditure, consumption and comfort require separate interpretation. Bills reflect both consumption and tariffs; higher prices can offset reduced demand [13,14]. Comfort depends on conditions experienced over time, rather than a thermostat setting or annual total [17,31,37]. Resident reports can distinguish affordability, thermal comfort and satisfaction with work, but improvement in one does not establish improvement in the others [15–17,31,37].

Identifying households requiring support also requires evidence of their financial circumstances and access to adequate heating [23]. Assessed efficiency describes the property, but cannot establish the resources and circumstances of its occupants. Research on

energy insecurity and administrative estimates of underconsumption similarly demonstrates the limitations of using efficiency classifications alone to characterise household need [15,16]. City-level evidence of unequal housing performance adds a spatial dimension to these differences [24]. Effective evaluation therefore connects the condition of the dwelling with the household's access to energy services, rather than treating either as a complete measure of residential performance [15,16,23,24].

2.3. Certificate Information and Improvement Decisions

The use of EPCs in investment decisions depends on the relationship between information, judgement and the capacity to act. Awareness establishes that a household recognises the certificate; understanding concerns interpretation; and use concerns its contribution to a decision [18,19]. These are related but distinct forms of engagement. Research on trust and involvement indicates that the reception of energy labels depends on more than the availability of information [18]. Studies on end-user expectations similarly identify demand for advice that is understandable, relevant and useful [19,20]. Recognition of a rating therefore provides limited evidence about the influence of its recommendations on subsequent work.

National survey evidence illustrates the difference between visibility and use. The Winter 2025 Public Attitudes Tracker reported that 83% of adults had heard of EPCs, while 16% knew their property's exact rating. Changes attributed to recommendations represented 9% of all respondents [22]. Differences in sampling and question wording also require care when using national estimates to contextualise findings from a small household study. Research on recommendation lists identifies barriers involving prioritisation, technical detail and practical relevance [20]. Improving communication can address some of these barriers, but its effectiveness depends on whether recipients can relate advice to an achievable investment [18–22].

Evidence on decision-making questions whether financial information alone leads to action. A Slovenian home-choice experiment associated preferences with trust and energy-related financial literacy; presenting information in monetary terms did not significantly alter choices [38]. This experiment concerned hypothetical choices, while post-audit interviews identified barriers between receiving advice and completing work [21]. These studies place EPC advice within decisions shaped by appraisal, finance and implementation [18,20,21,38].

Household circumstances influence each stage. The person receiving a certificate may have limited authority over the building, while those financing an intervention may receive different benefits from those occupying it. Economic appraisal therefore depends on whose costs, savings and wider benefits are included [25]. Household archetype modelling also shows that patterns of use can alter the estimated suitability and benefits of measures [39]. Recommendations become actionable through their relationship to ownership, resources, existing plans and expected services [20,21,25,39]. This explains why limited implementation cannot automatically be attributed to poor understanding, and why reported use in a decision should be distinguished from the specification and completion of work.

EPC advice may influence the choice or sequencing of work without initiating an investment already shaped by maintenance needs or planned alterations [20,21,25]. Reading recommendations, consulting an installer and commissioning work are distinct forms of engagement. Separating these stages helps identify where advice informs decisions and where financial or delivery barriers remain [19–21].

2.4. Retrofit Delivery and Outcome Evaluation

International studies identify fragmented retrofit supply chains, business risks and uneven customer engagement and aftercare [28]. Research on retrofit delivery highlights

organisational capacity, continuity and effective implementation of standards [26,27]. Evaluating outcomes therefore requires attention to specification, installation, commissioning and resident support, not just the measure selected [26–28].

The interaction between measures also affects their interpretation. Fabric, heating, controls and ventilation alter different aspects of the dwelling, and their sequencing influences cost, disruption and achievable benefits [1–3,40]. Recent debate on retrofit priorities supports assessing these relationships against the condition of the home and the objectives of the intervention [1,3]. Household economic appraisal further distinguishes energy savings from comfort, maintenance and other benefits that may accrue to different parties [25]. A broad category of home improvement can therefore contain works with substantially different purposes. Evaluation gains explanatory value when the intervention and its intended outcome are specified [25–28,40].

Time is another component of outcome evaluation. Linked administrative studies can examine changes in consumption following installed measures through defined observation periods and comparison groups [11,41]. Interpretation nevertheless depends on distinguishing total savings from changes in the additional effect estimated in a particular year [42]. Programme research on energy coaching and minor physical measures also examines how advice and interventions interact, subject to the strengths and limits of its comparison design [43]. These approaches provide evidence about outcomes through an explicit relationship between the work, its timing and subsequent observations. They cannot be replaced by an undated report of improvement combined with a general judgement about bills [11,41–43].

Before-and-after observations can document change without isolating a retrofit effect, since weather, prices, occupancy and other alterations also influence outcomes [11–14,17]. Repeated measurements and suitable comparison groups can strengthen causal interpretation [11,41–43]. Resident responses identify perceived benefits and difficulties, but experience following work should not be treated as an effect caused by it [17,21,44].

Retrofit also affects indoor environmental quality, including ventilation and air quality, alongside thermal performance [44]. Evaluating the sustainability of retrofit therefore requires distinguishing energy demand, heating affordability and household comfort, rather than treating an EPC rating or energy bill as a measure of all three [17,25–28,44].

3. Materials and Methods

3.1. Research Design

An exploratory case study design [45] was adopted to investigate residential energy performance using EPC records and household-supplied energy bills as documentary sources [46] for 25 occupied London dwellings, alongside nine questionnaire responses collected for this research in March 2026. This study aimed to examine the correspondence between EPC-related energy estimates and household energy records, while documenting residents' heating practises, affordability and experiences of residential improvement. Numerical entries were checked and summary statistics recalculated during the preparation of this manuscript.

London was selected because of its varied housing stock and access to certificate and household bill information. Research in London identifies inequalities in housing energy performance and the need for socioeconomic information when assessing households' requirements for retrofit support [23,24]. Recruitment was purposive and depended on record availability and voluntary participation. Neither the 25 dwelling records nor the nine questionnaire submissions constitute a representative sample of London's housing stock or households. The findings are therefore restricted to the participating cases and do not support population-level estimates [47].

The dwelling was the unit of observation for numerical descriptions. Questionnaire findings retained the response base for each item. A verified respondent-to-property key was unavailable, so questionnaire findings were reported separately and were not used to explain energy differences for individual dwellings.

The research included participant information and consent materials. Participation was described as voluntary. Questionnaire respondents were asked to confirm consent before responding and were informed that they could withdraw. The project documentation stated that information was collected for academic purposes, stored securely and de-identified before analysis. The results report coded dwelling records and aggregate questionnaire findings. Names, house numbers, full addresses, postcodes, contact details and identifiable bill images were excluded. Dwelling records are identified as P01–P25 throughout this study so that numerical entries and conflicting values can be traced across the text and tables.

3.1.1. Dwelling Records

The 25 dwellings were selected purposively on the basis of an available EPC, household-supplied gas and/or electricity bills, and willingness to participate [47]. EPC information was accessed through the government's Find an Energy Certificate service during March 2026. Households supplied their most recent available bills during the same month.

Recorded fields comprised a property identifier, dwelling type, floor area, EPC band, an annual EPC-related energy figure, a bill-derived annual energy figure, and current and potential carbon estimates. Property characteristics were retained as recorded. Carbon estimates represented assessed conditions under the certificate calculation method [4,5].

Bills covered different periods. March 2026 therefore identified the collection month, rather than a common consumption year. The term bill-derived annual figure describes the annual values entered in the project tables, whose derivation could not be established consistently from the supplied bill material.

The recruitment plan proposed excluding major non-domestic loads, electric vehicles and photovoltaic generation. These were documented as intended selection criteria. Complete screening records were unavailable, so their application to every dwelling could not be confirmed.

3.1.2. Resident Questionnaire

The questionnaire was administered through Google Forms (https://www.google.com/forms/about/, accessed on 17 November 2026) between 5 and 28 March 2026 and received nine submissions. It contained 40 numbered questions combining closed responses and written prompts. The questionnaire was distributed to households willing to participate, following purposive recruitment based on the availability of EPC and household energy information. As individual questionnaire responses could not be linked to the dwelling records, the survey was treated as a separate descriptive sample rather than a matched subset of the 25 properties. Participation was voluntary, with no incentives offered. As recruitment was based on voluntary participation rather than a defined invitation sample, a conventional response rate was not calculated. The complete questionnaire is reproduced in Appendix A.

The survey covered household circumstances, energy expenditure, heating practises, comfort, improvement experience and EPC engagement. These were self-reported measures, interpreted according to the wording and response options of each question [48]. Winter comfort was assessed through four descriptive categories ('very warm', 'comfortable', 'slightly cold' and 'often cold'), without accompanying definitions, examples or temperature thresholds. Collection dates established when respondents completed the survey; retrospective questions concerned the periods specified in the instrument.

EPC questions distinguished awareness of the rating, understanding, perceived correspondence with the home's performance and use of recommendations in improvement decisions. Improvement questions addressed whether work had occurred, the measures reported, subsequent bills and installation satisfaction. Written prompts invited explanations of energy costs, comfort difficulties, desired improvements and trust in energy assessments.

3.2. Data Analysis

Analysis comprised descriptive summaries of dwelling records and questionnaire responses. Frequencies described dwelling types and EPC bands. Ranges, means and medians summarised numerical fields. During manuscript preparation, energy summaries were recalculated from the dwelling entries, with rounding applied when reporting results.

Dwelling energy entries were compared across the main data sheet in Microsoft Excel workbook (https://www.microsoft.com/en-gb/microsoft-365/excel/, accessed on 17 November 2026), five complete reproductions and the chart-preparation tables. The main sheet and complete reproductions agreed for all 25 dwellings and defined the principal version used for calculation. This selection was based on consistency across the original records rather than independent verification against supplier bills. Heating plus hot water totals and bill-derived sensitivity calculations were independently recalculated. Four conflicting bill-derived entries were examined through two sensitivity checks. The first substituted the alternative entries while retaining all 25 dwellings. The second excluded the four disputed records, leaving 21. All other retained entries were unchanged. These checks assessed sensitivity to source selection without assuming that either conflicting version was correct.

EPC-related and bill-derived figures were summarised separately because their fuel coverage, energy services and observation periods could not be reconciled consistently [6,17]. Arithmetic differences between these non-equivalent quantities were excluded from the performance analysis. Sensitivity checks instead examined how conflicting source entries affected the bill-derived energy summaries.

Energy figures were reported without weather normalisation. Numerical monthly expenditure summaries were excluded because their response bases could not be reconciled. The workbook summary specified seven responses, while its property-matching table listed nine expenditure pairs without identifying which entries generated the summary. Current and potential carbon estimates were reported as modelled quantities and were not interpreted as achieved emission reductions [4–6,17].

Questionnaire results were reconciled against the original labelled Google Forms charts and secondary Excel summaries. Where distributions conflicted, the original chart counts were retained. The employment question permitted multiple selections, producing 15 selections across eight submissions rather than mutually exclusive employment categories. The two questions concerning heating restraint were analysed separately according to their wording. Item denominators ranged from three to nine, and missing responses were excluded. Repeated questionnaire findings across charts and summary tables were reconciled against the original Google Forms charts and were not counted as additional observations [48].

EPC engagement questions were examined separately. Trust in official EPC assessments was considered descriptively, without adjustment for tenure, as the available summaries did not preserve individual links between trust responses and housing tenure. Reported use of recommendations concerned their contribution to decisions and did not establish implementation. Improvement descriptions, subsequent bill responses and installation satisfaction also remained separate because the aggregate summaries did not preserve respondent-level links between them. Self-reported bill changes were not independently

verified or adjusted for seasonal variations in consumption or tariff changes, as comparable pre- and post-improvement records were unavailable. Combined response categories were retained where their original distributions could not be recovered. The original survey analysis grouped open-ended responses into descriptive content categories covering heating behaviour, cost pressure, EPC understanding, improvement experience, comfort, heat loss and working from home. These summaries were used to contextualise the descriptive findings rather than support a separate formal thematic analysis [46]. Reported perceptions of heat loss were not independently validated against physical housing characteristics, as questionnaire responses could not be matched to individual dwelling records. They were therefore interpreted as self-reported experiences rather than measured indicators of building performance.

During manuscript preparation, ChatGPT (OpenAI, GPT-6) was used to assist with drafting, literature searches, language editing and arithmetic checks of reported figures. Its use was separate from the original research design, data collection and primary analysis. All outputs were reviewed by the authors.

4. Results

4.1. EPC Engagement, Heating Affordability and Retrofit Experience

4.1.1. Household Profile and EPC Engagement

Nine questionnaire submissions were recorded, with completion varying between items. Seven answered the dwelling-type question. Three reported detached houses, two purpose-built flats, one a semi-detached house and one an end-terrace house. Six of the seven tenure responses indicated private renting, and one indicated owner occupation. Among seven respondents providing an EPC band, four reported D, two C and one B.

All seven households answering the age-group question included adults aged 25–34. The employment item asking about the main earner recorded six full-time, five part-time, three self-employed and one unemployed selection across eight responses. These overlapping selections could not be interpreted as mutually exclusive employment categories. The occupancy summary described presence mainly in the mornings and evenings, while three of eight respondents reported working from home.

All nine answered yes when asked whether they were aware of their EPC rating, although only seven provided an EPC band in the separate question. Awareness was self-reported and was not independently verified. Five reported understanding what the rating meant, three selected somewhat and one answered no. Understanding was self-reported rather than tested. The aggregate project summary recorded three respondents using EPC recommendations in improvement decisions and six who had not. The remaining engagement distributions were available in labelled response charts.

Five respondents judged that their home did not perform as efficiently as the EPC suggested, compared with three who considered that it did and one who was unsure. Awareness of the rating was therefore more widespread than either reported understanding or use of recommendations. Perceived correspondence concerned residents' judgements of their home's performance.

4.1.2. Heating Costs, Operation and Comfort

Six of seven respondents reported significant bill increases over the preceding two years; one was unsure. All seven answering the heating-restraint question reported reducing heating because of cost. Five selected sometimes, one often and one always. All eight respondents answering the heating-system question selected gas boilers. Manual switching was the most common operating arrangement, reported by six. One used a timed schedule, and one reported heating being on for most of the day. Winter thermostat settings ranged

from approximately 17 to 20 °C across seven answers. The aggregate summaries recorded six of eight respondents heating all rooms and two heating only part of the home. Six of eight reported comfortable winter conditions, while two were grouped under suboptimal comfort, a combined category that did not distinguish between the original less favourable response options. Three of nine respondents reported concerns about heat loss. Winter comfort and cost-related heating restraint were reported within the group, but the summaries did not establish how these experiences overlapped within individual households.

4.1.3. Reported Improvement and Resident Judgements

Six of eight respondents reported that improvement work had occurred. The item requesting details received three responses, recording loft insulation, a new boiler and an extension. These descriptions did not provide a complete inventory of the reported work.

The subsequent-bill question received five responses. Four reported that bills had not decreased after work. The source summary did not specify the category of the fifth response. These findings concerned recalled expenditure following work, without accompanying energy readings, tariffs or follow-up dates.

Installation satisfaction was also recorded for five respondents. Two answered positively; the remaining three were reported as no or not sure. This combined category did not distinguish dissatisfaction from uncertainty. Table 1 consolidates the questionnaire findings across the three research themes, retaining the response base for each item. Only response categories recoverable from the project summaries are shown.

Table 1. Summary of household questionnaire findings.

Questionnaire Item	Recorded Response or Value	N
EPC engagement		
Awareness of EPC rating	Yes (9)	9
Understanding of rating	Yes (5); somewhat (3); no (1)	9
Home performs as efficiently as the EPC suggests	Yes (3); no (5); not sure (1)	9
Recommendations used in improvement decisions	Yes (3); no (6)	9
Heating affordability and comfort		
Significant bill increase over the previous two years	Yes (6); not sure (1)	7
Reducing heating because of cost	Sometimes (5); often (1); always (1)	7
Main heating system	Gas boiler (8)	8
Heating operation	Manual (6); timed (1); on most of the day (1)	8
Winter thermostat setting (°C)	Approximately 17–20	7
Heating all rooms	Yes (6); no (2)	8
Winter comfort	Comfortable (6); suboptimal comfort (2)	8
Heat-loss concerns	Reported (3)	9
Improvement and resident judgements		
Improvement work undertaken	Yes (6)	8
Specified work	Loft insulation (1); new boiler (1); extension (1)	3
Bills decreased after work	No (4)	5
Satisfied with installation quality	Yes (2); no or not sure (3)	5

Note: N denotes recorded questionnaire submissions answering each item, rather than a verified count of distinct respondents. Response counts are shown in parentheses.

The summaries did not link the named works to individual bill or satisfaction responses. These findings therefore described separate aspects of residents' experience without identifying which interventions preceded particular outcomes. The written-response summary described rising costs, manual heating operation and efforts to manage expenditure. Comfort-related material referred to cold rooms, draughts and heat escaping through windows, doors or poorly insulated areas. Improvement comments concerned insulation and upgrades, alongside uncertainty about financial benefits. Desired improvements included better insulation, replacement windows and smart thermostats. The summary identified

working from home and longer occupancy as possible influences on heating, lighting and appliance use, without quantifying their contribution to consumption. EPC-related comments concerned the value of assessments as a broad guide and their ability to represent household practises.

4.2. Comparability of EPC and Bill-Derived Energy Records

The two datasets provide complementary evidence. The dwelling analysis examines the consistency and comparability of recorded energy figures, while the questionnaire describes EPC engagement, heating affordability and improvement experiences. Although the workbook contained provisional postcode matches, these did not establish reliable respondent–dwelling links. The findings are therefore interpreted together to identify limitations in retrofit evaluation, without attributing questionnaire responses to individual properties.

4.2.1. Dwelling Characteristics and Numerical Comparison

The numerical dataset comprised 25 dwellings. Ten were mid-terrace houses, five end-terrace houses and three semi-detached houses. The remaining seven comprised four mid-floor flats, one ground-floor flat, one top-floor flat and one top-floor maisonette. Floor areas ranged from 50 to 142 m^2, with a mean of 89.28 m^2 and a median of 87 m^2. Fifteen dwellings were rated D, seven C, two E and one B. Detached houses appeared in the questionnaire profile but were absent from the numerical dataset. This difference, together with the missing respondent-to-property links, prevents the two samples from being treated as matched observations.

The principal record contained a mean EPC-related annual figure of 11,538.6 kWh and a mean bill-derived annual figure of 16,845.8 kWh. The corresponding medians were 12,330 and 15,977.9 kWh. Table 2 presents the two distributions separately because differences in energy coverage and observation periods prevent a valid like-for-like comparison.

Table 2. Descriptive statistics for EPC-related and bill-derived energy figures across 25 dwellings.

Quantity	Mean (kWh)	Median (kWh)	Range (kWh)
EPC-related figure	11,538.6	12,330.0	1936–21,286
Bill-derived figure	16,845.8	15,977.9	2500–31,153

Note: EPC-related figures cover heating and hot water, while bill-derived figures may include additional energy uses. The quantities were not verified as equivalent, and their differences should not be interpreted as EPC prediction errors.

Current certificate-related carbon estimates ranged from 0.5 to 6.1 tonnes of CO_2, compared with potential values of 0.5–2.4 tonnes. Their means were 3.36 and 1.49 tonnes respectively. Both sets of carbon values were EPC-modelled estimates for current and potential conditions. Their difference described assessed potential rather than measured emissions savings. Two dwellings had identical current and potential carbon values. P01 recorded 1.1 tonnes in both fields, and P15 recorded 0.5 tonnes. The remaining records contained lower potential values.

4.2.2. Source Consistency and Energy Coverage

Four bill-derived entries differed between the principal record and the chart-preparation material. The conflicts concerned P02, P03, P05 and P10, as shown in Table 3.

Table 3. Conflicting bill-derived entries in the project records.

Dwelling	Principal Record (kWh)	Chart-Preparation Record (kWh)
P02	24,810.70	2480.70
P03	14,818.20	10,818.20
P05	21,561.20	2156.20
P10	11,370.00	10,070.00

Substituting the alternative values reduced the mean from 16,845.8 to 14,964.4 kWh, a change of 11.2%. Excluding the four disputed records produced a mean of 16,599.3 kWh across the remaining 21 dwellings. These results demonstrate the sensitivity of the recorded figures to source selection, rather than changes in energy consumption or EPC prediction accuracy. Neither version could be independently verified against the original supplier bills.

The calculation sheet identified the EPC-related total as the sum of heating and hot-water entries. For P23, 9716 kWh for heating and 2026 kWh for hot water produced the recorded total of 11,742 kWh. Fuel codes divided the records into four marked E, three G and eighteen GE. Their definitions did not establish equivalent fuel and service coverage across the comparison. For the 18 GE-coded dwellings, the available records did not consistently separate heating and hot-water consumption from other household energy uses or provide the system-efficiency information needed for a comparable delivered-energy calculation.

One supplier bill examined in the original project records itemised consumption for February–March 2026 and separately reported estimated annual electricity and gas use of 4201.8 and 17,582 kWh, respectively. Their sum (21,783.8 kWh) matches the bill-derived entry for P16. This illustrates how an annual total was obtained from supplier estimates rather than 12 months of measured consumption. Equivalent source-level derivations could not be established consistently for the remaining dwellings.

5. Discussion

The findings suggest that EPC awareness does not necessarily translate into the use of recommendations when making improvements. Heating affordability and inconsistencies in the dwelling records also point to the importance of considering household circumstances alongside energy data when evaluating retrofit outcomes. Research on energy labels and post-audit decisions identifies understanding, confidence, relevance and practical constraints as influences on action [18–22]. The present survey records whether recommendations were used, but not which were considered or why others were set aside. Recording those decisions would make it possible to evaluate the contribution of advice without equating awareness with implementation.

Responsibility for acting on recommendations is also relevant. Six of seven tenure responses indicated private renting, making the relationship between the occupant receiving information and the party authorising work relevant to interpretation. Research on recommendations and household investment identifies resources, priorities and the distribution of costs and benefits as important conditions surrounding decisions [20,21,25]. Retrofit-delivery research adds the availability of suitable services and support [26–28]. These studies indicate why advice must be considered alongside the resources and authority needed to undertake work. The predominance of private renters, alongside the absence of linked individual responses, prevents a meaningful comparison by tenure and limits the applicability of the findings to owner-occupiers. This study also did not establish who authorised the reported improvements.

Heating affordability affects how observed consumption should be interpreted. All seven respondents answering the cost-restraint question reported reducing heating because of cost, predominantly “sometimes”. Survey and metered research during the energy-price

crisis documents reductions in demand alongside continuing financial pressure [12–14]. Research on underconsumption and the prebound effect also shows why improvement can permit greater warmth as well as reduced energy requirements [15–17,36].

Comfortable winter conditions were reported within the group, but the aggregate summaries did not show whether those households also restricted heating. Thermostat settings likewise did not establish indoor temperatures or the duration and distribution of warmth. Heating practises and financial circumstances therefore need to accompany dwelling assessments when evaluating access to adequate heating [10,15,16,23,31,37].

The reported improvements could have served different purposes and should not be assigned a common expected energy outcome. Loft insulation, boiler replacement and an extension appeared within one category, although their implications for demand differ. An extension may increase the accommodation requiring heating, while insulation and heating replacement address different components of energy use. Recent retrofit research and guidance emphasise the relationship between fabric, equipment, controls and ventilation when selecting and sequencing measures [1–3,40]. Economic appraisal also distinguishes energy savings from comfort, maintenance and other benefits [25]. A report that improvement occurred therefore needs a sufficiently precise description of the work and intended benefit before subsequent performance can be judged.

Reported bill changes cannot establish energy savings because expenditure is also affected by tariffs and charges [13,14,25]. Studies estimating intervention effects use defined measures, observation periods and comparison procedures to examine changes associated with completed work [11,41–43]. The survey did not link these responses to specific interventions, preventing an assessment of attributable savings.

Installation satisfaction introduces a further outcome requiring its own interpretation. Combining no and not sure obscured whether respondents were dissatisfied or uncertain, while the absence of individual explanations prevented examination of their reasons. Research on retrofit quality identifies specification, commissioning, communication and aftercare as relevant influences on delivery [26–28]. These provide subjects for investigation rather than explanations established by this survey. Residents' reports of cold rooms, draughts and heat loss identify specific concerns for further investigation. Their contribution should be preserved alongside observations addressing physical performance, ventilation and indoor environmental quality [17,31,44].

This study contributes an empirical assessment of the limitations of combining EPC records, household bills and resident accounts to evaluate retrofit. Four conflicting entries altered the mean bill-derived figure by 11.2%, while incompatible energy boundaries and missing respondent–dwelling links prevented assessment of EPC prediction accuracy or improvement outcomes. Reliable evaluation therefore requires reconciled energy records, documented interventions and linked evidence of household expenditure and comfort [4–8,11,17,41–43].

These findings are constrained by this study's small, purposive samples, variable questionnaire completion and incomplete source documentation. Neither sample is representative, and the absence of verified links between respondents and dwellings prevents subgroup comparisons or causal interpretation. The results are therefore limited to the participating records and cannot establish population-level patterns or realised retrofit benefits.

For housing providers, EPCs should inform the identification of potential improvements rather than serve as forecasts of household energy savings. Before undertaking retrofit work, providers should check the certificate date and relevant dwelling characteristics, record which recommendations informed the decision, and document the measures installed, their completion dates and who authorised the work [20,21,25–28]. Local authorities commissioning or funding retrofit should require consistent pre- and post-improvement

records, including energy consumption for comparable fuels, services and periods; changes in tariffs and expenditure; and residents' reported heating conditions. This would allow energy savings, affordability and comfort to be evaluated separately [11,15–17,25]. In rented properties, follow-up should involve both landlords responsible for improvements and tenants experiencing their outcomes. Such records would provide a stronger basis for assessing the effectiveness of completed measures and informing future retrofit investment [26–28,40,43,44].

6. Conclusions

All nine questionnaire submissions indicated awareness of the EPC rating, while three reported using their recommendations. Heating affordability was a continuing concern in the responses. All seven households answering the relevant question reported reducing heating because of cost. Four of five answering the separate question about bills following improvements reported no decrease. These responses do not establish whether improvement work reduced energy consumption or increased household warmth. Four conflicting entries affected the recorded bill-derived energy values, with their substitution reducing the mean by 11.2%. Without comparable energy records and documented interventions, neither EPC prediction accuracy nor achieved retrofit benefits can be established.

Future research should link EPC assessments and recommendations to specific retrofit measures, their specifications and installation dates. Comparable energy records, ideally covering at least 12 months before and after improvement, should distinguish fuels and energy services and account for weather and occupancy changes. Energy consumption should be evaluated separately from household expenditure using recorded tariffs, while indoor temperature measurements and resident feedback would provide evidence of changes in thermal comfort. Larger samples with linked dwelling and questionnaire records, including both tenants and owner-occupiers, would support comparisons across household circumstances. These measures would strengthen the assessment of energy savings, affordability and comfort as distinct outcomes of sustainable residential retrofit.

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Abbreviations

The following abbreviations are used in this manuscript:

CO_2	Carbon dioxide
EPC	Energy performance certificate

Appendix A. Household Energy Use and EPC Questionnaire

This appendix reproduces the complete 40-question household survey, covering dwelling characteristics, energy expenditure, household practises, thermal comfort, residential improvements and EPC engagement.

Appendix A.1. Your Home

1. Post Code:
.....
2. Dwelling type: Please select one option.
□ Detached
□ Semi-detached
□ Purpose-built flat
□ Terraced
□ Converted flat
□ Other
□ End-terrace house
3. Approximate construction period: Please select one option.
□ Pre-1919
□ 1919–1944
□ 1945–1964
□ 1965–1980
□ 1981–2000
□ Post-2000
□ No idea
4. Tenure: Please select one option.
□ Owner-occupied
□ Private rented
□ Social housing
5. Approximate floor area, if known:
..... m^2
6. EPC rating, if known:
.....
7. How do you pay for energy? Please select one option.
□ Direct debit
□ Prepayment meter
□ Other

Appendix A.2. Energy Costs

8. Approximate monthly gas bill (£):
£ .....
9. Approximate monthly electric bill (£):
£ .....
10. Have your bills increased significantly in the past two years? Please select one option.

□ Yes
□ No
□ Not sure
11. Do you ever reduce heating due to cost? Please select one option.
□ Always
□ Often
□ Sometimes
□ Rarely
□ Never

Appendix A.3. Household and Occupancy

12. Number of occupants:
.....
13. Age groups present: Please tick all that apply.
□ 0 to 5
□ 5 to 12
□ 12 to 18
□ 18 to 24
□ 25 to 34
□ 35 to 46
□ 47 to 54
□ Over 55
14. Employment status of main earner: Please tick all that apply.
□ Full-time
□ Part-time
□ Self-employed
□ Retired
□ Unemployed
15. Typical weekday occupancy:
□ Home most of day
□ Home mornings and evenings
□ Variable
Please give the hour range and how many hours.
.....
16. Do you work from home?
□ Full-time
□ Part-time
□ No
If part-time, how many hours do you work from home in a typical 40-h working week?
..... hours

Appendix A.4. Heating, Comfort and Household Energy Practices

17. Main heating system: Please tick all that apply.
□ Gas boiler
□ Electric heating
□ Heat pump
□ Communal system
□ Other
18. Average winter thermostat setting (°C):
..... °C

19. Heating schedule: Please select one option.
□ Timed schedule
□ Manual switching
□ On most of the day
20. Do you heat all rooms?
□ Yes
□ No
If no, which rooms are not heated and for how long?
.....
21. How would you describe winter comfort? Please select one option.
□ Very warm
□ Comfortable
□ Slightly cold
□ Often cold
22. Have you ever avoided heating due to cost? Please select one option.
□ Yes
□ No
□ Don't know
23. Cooking type: Please select one option.
□ Gas hob
□ Electric hob
□ Induction
24. Cooking frequency: Please select one option.
□ Daily
□ 3 to 5 times per week
□ Less often
25. Use of dishwasher: Please select one option.
□ Often
□ Sometimes
□ Rarely
□ Never

Appendix A.5. Home Improvements

26. Has the property been retrofitted? Please select one option.
□ Yes
□ No
□ Not sure
27. If the property has been retrofitted, please indicate improvements. Please tick all that apply.
□ Loft insulation
□ Wall insulation
□ Double/triple glazing
□ New boiler
□ Heat pump
□ Solar panels
□ Room extension
□ Other
28. Have you installed or received funding for any of the above installations? If yes, when and how?
.....

29. Did energy bills decrease after retrofit?
□ Yes
□ No
□ Not sure
If yes, how much?
.....

30. Were you satisfied with installation quality? Please select one option.
□ Yes
□ No
□ Not sure

Appendix A.6. EPC Awareness and Use

31. Are you aware of your EPC rating? Please select one option.
□ Yes
□ No
□ Not sure

32. Do you understand what the EPC rating means? Please select one option.
□ Yes
□ No
□ Somewhat

33. Do you think your home performs as efficiently as the EPC suggests? Please select one option.
□ Yes
□ No
□ Not sure

34. Have you used EPC recommendations to make decisions to improve your house energy system? Please select one option.
□ Yes
□ No
□ Not sure

Appendix A.7. Your Experience

35. Why do you think your energy bills are at this level?
.....
.....

36. Do you feel your home loses heat quickly? Please explain.
.....
.....

37. What challenges do you face in keeping your home comfortable?
.....
.....

38. What improvements would make the biggest difference to your comfort or bills?
.....
.....

39. Do you trust official energy assessments, EPCs? Why or why not?
.....
.....

40. I would also like to ask about available funding and local authority retrofit programmes. Are you interested in participating in such schemes? Have you previously taken part, and if so, what was your experience, positive or negative?

.....
.....

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