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Quantitative modelling of why and how homeowners decide to renovate energy efficiently

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HIGHLIGHTS

- Contextually-rich analytical framework for renovation decision-making.
- Path analysis and multivariate probit regression to model renovation decisions.
- Integrative model explaining both why and how homeowners decide to renovate.
- Results of national survey of renovation intentions of UK homeowners.
- New insights on policies and service provision for energy efficient renovations.

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ABSTRACT

Understanding homeowners' renovation decisions is essential for policy and business activity to improve the efficiency of owner-occupied housing stock. This paper develops, validates and applies a novel modelling framework for explaining renovation decisions, with an emphasis on energy-efficiency measures. The framework is tested using quantitative data from a nationally-representative survey of owner-occupied households in the UK (n = 1028).

The modelling advances formal representations of renovation decisions by including background conditions of domestic life to which renovating is an adaptive response. Path analysis confirms that three conditions of domestic life are particularly influential on renovation decisions: balancing competing commitments for how space at home is used; signalling identity through homemaking activities; and managing physical vulnerabilities of household members. These conditions of domestic life also capture the influence of property characteristics (age, type) and household characteristics (size, composition, length of tenure) on renovation decisions but with greater descriptive realism.

Multivariate probit models are used to provide rigorous, transparent and analytically tractable representations of the full renovation decision process. Model fits to the representative national sample of UK homeowners are good. The modelling shows that renovation intentions emerge initially from certain conditions of domestic life at which point energy efficiency is not a distinctive type of renovation. The modelling also shows clearly that influences on renovation decisions change through the decision process. This has important implications for policy and service providers. Efficiency measures should be bundled into broader types of home improvements, and incentives should target the underlying reasons why homeowners decide to renovate in the first place.

1. Introduction: Energy efficient renovation decisions

Improving the energy efficiency of the housing stock is integral to climate change mitigation and energy system objectives [1]. Long-term scenarios show energy use in buildings rising three to fivefold worldwide by 2100 [2]. Energy use for heating and cooling buildings is expected to grow globally by up to 40% to 2050 while "*efficiency retrofits present a tremendous opportunity to decrease energy use worldwide*" [3]. In the EU, retrofit rates have to increase from their current 0.5–1.5% to around 2.5–3% of the housing stock per year to achieve policy goals [4]. In the UK, up to 50% of energy used in homes could be saved through energy efficient renovations and other measures, contingent on policy to support household decision-making [5].

Around 67% of UK homes are owner-occupied, a proportion similar

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to the US and just below the EU average of 70% [6]. In owner-occupied homes, decisions to renovate with efficiency measures are the necessary precursor to energy-saving outcomes. Understanding why homeowners decide to renovate is therefore essential for effective policy design.

The objectives of this paper are to develop, validate and apply a descriptively-realistic model of energy efficient renovation decisions made within the context of everyday domestic life, and to demonstrate the relevance of this model for informing policy. This is consistent with Friege and Chappin [7]'s recent review of decision models which concluded: "*a deeper understanding of the decisions of homeowners is needed and we suggest that a simulation model which maps the decision-making processes of homeowners may result in … developing new mechanisms to tackle the situation*" (p196).

These objectives are consistent with the scope and concerns of *Applied Energy*. Research in this journal on energy-efficient home renovations has one of three broad aims: (1) improving analytical techniques and understanding of renovation measures, including in different housing types [e.g., 8,9]; (2) evaluating the technical and economic consequences of renovation activity in terms of future energy consumption, building performance, or performance gaps between estimated and actual energy savings [e.g., 10–12]; (3) understanding how renovation activity can be effectively stimulated through technical, policy or business-model innovations which support renovation decisions [e.g., 13–15].

By asking why and how homeowners decide to renovate energy efficiently, this paper is consistent with the third aim, although its findings are also relevant for more technical analysis. Occupant behaviour is frequently cited in *Applied Energy* articles as one of the main reasons why analytical models over-estimate [12] or under-estimate [16] expected energy savings from energy efficient renovations. More broadly, user-responsive home energy management (under the rubric of 'intelligent energy systems') is one of seven headline issues tackled in applied energy research [17]. Deviations from normative or optimised modelling assumptions emphasise the importance of research on how household *actually* make decisions to adopt and use energy-saving measures in order to understand the realistically-achievable potential for improving energy efficiency in homes [8,18,19]. This is an issue of global importance. A study of different retrofit projects in China concluded that: "*in order to improve the effectiveness of energy-saving interventions, the motives, intentions and living habits of residents need to be given more consideration when designing and implementing retrofitting*" [13].

1.1. Quantitative modelling of energy efficient renovation decisions

Choice experiments and other survey techniques for studying homeowners' decision making are important for identifying the drivers and barriers behind renovation investment decisions [20], and the reasons why homeowners may or may not participate in programmes delivering energy-saving measures [21]. Understanding why certain homeowners have higher propensities to renovate can also help service providers segment their customer base [22].

The dominant framing of energy efficient renovation decisions sees financial considerations as paramount [23]. Financial considerations include upfront costs, costs of capital, future cost savings, and payback periods [24]. Commonly cited barriers to cost-effective efficiency investments include a lack of available capital or access to capital, unreliable contractors, a perceived deficit of credible information on renovation measures and outcomes, and the hassle and inconvenience of renovating [14,20,25]. These barriers prevent otherwise positive beliefs and strong intentions towards energy efficiency from being realised [26,27].

Quantitative models of renovation decisions reinforce this basic financial framing. Discrete choice models based on stated preference data strongly emphasise financial attributes as explanatory variables. These allow the effectiveness of financial policy instruments like grants, subsidies and taxes to be evaluated [7,28–31]. Decision models based on observed market behaviour similarly focus on financial attributes [27], but can also include a wider range of decision influences. These include property characteristics including size, age, type and location, and household characteristics including size, lifecycle, and the duration and type of home tenure [32–34].

There is long-standing evidence that homeowners' decisions to carry out energy efficient renovations are not narrowly financial. Numerous cost-effective investment opportunities remain which homeowners do *not* pursue [11,35]. Even in rented properties, ample opportunities exist to recoup efficiency investments through increased rental prices or lower energy costs [10].

Some quantitative models broaden their explanatory variables to non-financial decision attributes. Models of heating system adoption decisions have included ease of use [36], and potential environmental benefits through CO_2 emission reductions [37]. Models of energy efficient renovation decisions have included installation and contractor hassle [38], thermal comfort [39], and air quality, noise reduction, and aesthetics [40]. Models of adoption decisions for specific renovation measures like energy efficient windows have identified the influence of supply-chain actors (window sellers and installers) as well as homeowners' awareness of the cost and performance of windows with lower U values [15].

1.2. The changing contexts of renovation decisions

Energy efficient renovation decisions tend to be formally represented as being discrete financially-motivated events, subject to exogenous constraints or barriers [23].

This representation of deliberative, instrumental, and isolable decisions has been criticised for failing to account for the context in which decisions to renovate are made. As Guy and Shove [41] conclude with respect to narrowly-framed research on energy efficiency: "*greater attention should be paid to the changing contexts of energy-related decision-making*" (p135). For energy efficient renovations, these "*changing contexts*" mean life at home, or as Maller and Horne [42] put it, "*the conventions and practices of households*" (p61). In other words, renovation decisions are situated within and emergent from everyday life at home and need to be analysed as such.

There are three important descriptively-realistic features of renovation decision making made in the context of everyday life at home.

First, decisions to renovate and subsequent renovation activities are part of a process by which households continually adapt their homes to the demands of domestic life. As Karvonen [43] argues: "*Domestic retrofit is not an activity of changing a house … from poor energy performance to exceptional energy performance, but an intervention into the rhythms of domestic habitation*" (p569).

Second, from a decision-making perspective, efficiency measures are not a distinct type of renovation. Judson and Maller [44] found that efficiency measures in one part of the home often went hand-in-hand with expansions or intensifications of other parts of the home (e.g., additional bathrooms). Noonan et al. [45] found that US neighbourhoods with homes undergoing larger remodelling projects had greater adoption rates for energy-efficient heating and cooling systems.

Third, models of renovation and other home-related decisions invariably represent the decision statically as a discrete point in time with a characteristic set of influences [46]. Yet renovation decisions are long-drawn out processes or 'journeys', not singular events [47].

These three features of renovation decision-making are omitted from quantitative analysis and modelling of energy efficient renovation decisions which narrowly emphasise:

i. renovation decision events, but not the processes preceding them nor the origins of the decision process;
ii. property and household characteristics, but not the conditions of domestic life from which renovation decisions emerge;

iii. energy-efficiency measures, but not other types of amenity renovation and improvements to the home.

By excluding variables characterising domestic life, and by failing to recognise the changing influences on renovation decisions as they progress, renovation decision models are limited in their ability to explain *why* households may be considering energy efficient renovations in the first place.

2. Conceptual framework

2.1. Renovation decisions made in the context of everyday domestic life

The decision model developed and applied in this paper is descriptively realistic, contextualised, and tractable for quantitative modelling. Its underlying conceptual framework was developed primarily to explain energy efficient renovation decisions, although many of its elements are generic to all renovation types. This allows the distinctiveness of energy efficient renovation decisions to be tested rather than assumed.

The decision process is approximated by a series of decision stages, adapted from the model used by Rogers [48] to explain the adoption of innovations. This is shown in the upper part of Fig. 1 with identifiable decision stages moving from initial awareness through positive attitude formation to an eventual decision and change in behaviour.

The innovation-decision model has been tested in many different contexts relevant to energy efficient renovations including the adoption of heating systems [49–51] and solar photovoltaic systems [52–54]. As shown in Fig. 1, the decision process originates in conditions that create problems or needs to which current practices are maladapted [15]. Social norms can also initiate decisions, particularly in the majority segments of potential adopters who are more receptive or susceptible to social influence [48,55].

The lower part of Fig. 1 represents the renovation decision process. It has three key features:

i. renovation decisions are a process represented by a series of four cross-sectional stages;
ii. renovation decisions emerge initially in response to certain conditions of domestic life, or in some situations can be triggered by extraordinary events;
iii. the distinctiveness of energy efficient renovation decisions becomes clear only during the later stages of the decision process as intentions to renovate strengthen.

The stages of the renovation decision process move from ‘thinking about’ (stage 1), ‘planning’ (stage 2), and ‘finalising’ renovations (stage 3). A final ‘experiencing’ stage describes how households experience and adapt domestic life to the structural changes made to their home [56]. This paper is concerned with why and how homeowners decide to renovate, so the ‘experiencing’ stage is not considered further here.

A null non-decision stage (stage 0) is included as a control condition characterising homeowners ‘not thinking about’ renovations in any way. Inclusion of a control allows differences between renovators and non-renovators to be identified. Relatively few other studies have systematically explored the differences between renovating and non-renovating households through the use of control groups or samples of non-adopters [21]. One Swedish study found that if homeowners were satisfied with the physical condition, thermal performance, and aesthetic of their existing home, they were unlikely to renovate [57]. This article takes the converse approach in line with [48]: unresolved tensions or problems in domestic life make it more likely homeowners will renovate.

The conceptual framework shown in Fig. 1 defines both outcome variables - renovation intentions culminating in a decision to renovate - and four blocks of explanatory variable:

- The ‘Conditions of Domestic Life’ (CDLs) describe issues, tensions or imbalances within homes and domestic life to which renovating is an adaptive response; an example is *Prioritising* which is the balancing of competing commitments for how space at home is used (see Section 2.2);
- ‘Property & Household Characteristics’ describe physical features of the property (e.g., age, type) and socio-demographic features of the household (e.g., size, composition) which may be associated with renovation decisions (see Section 2.3);
- ‘Intentional Decision Making’ describes attitudes and perceived social norms towards renovating; these are the explanatory variables in the innovation-decision process in Rogers [48] (see Section 2.4);
- ‘Triggers’ describe one-off events that can either precipitate renovation decisions or short-circuit potentially lengthy decision processes; an example is a boiler breaking down (see Section 2.5).

As shown in Fig. 1, the relevance of these explanatory variables changes over the decision process. The conceptual framework thus distinguishes proximate influences from ultimate influences on renovation decisions [23].

2.2. Ultimate influences: Why are renovation decisions made?

Ultimate influences explain *why* homeowners decide to renovate in the first place (*Stage0to1* in Fig. 1; note that the shorthand *Stage XtoY* is used throughout this paper to denote movement between stages in the decision model). Ultimate influences act through certain conditions of domestic life associated with renovating which are qualitatively characterised in sociological research on homes and domestic life. This paper represents a first attempt to include them in a quantitative decision model.

Table 1 identifies five Conditions of Domestic Life (CDLs) characteristic of renovating households identified in the literature. These CDLs were confirmed in a prior interview study with owner-occupied households in the UK [58], and are explained further in Appendix A1 (All Appendices are provided in online Supplementary Information).

The CDLs characterise why homeowners may decide to renovate their home as an adaptive response to tensions or imbalances in the use, function, design or arrangement of the home. The CDLs are broadly analogous to the prior conditions for the adoption of innovations identified by Rogers [48] (see also Fig. 1).

The CDLs have a high degree of generality and do not distinguish efficiency from amenity measures in the conceptual framework of renovation decisions (grey arrow[1] in Fig. 1). Moreover, the CDLs shown in Table 1 are neither exclusive, static, nor characteristic of all households. They should be interpreted as lenses through which to view certain salient characteristics of domestic life associated with a propensity to renovate.

The literature and interview data on which the CDLs are based provided certain expectations about how the CDLs interrelate. In particular, the conditions of *Prioritising*, *Embodying* and *Demonstrating* are considered antecedent to the *Adapting* condition. Tensions or imbalances can be created by competing commitments of household members, by the physicality of life at home, and by the absorption of social norms and other external influences. Each of these conditions of domestic life increases a household's propensity to make changes to the home. *Adapting* can therefore be regarded as an outcome condition within the set of five CDLs.

2.3. Property and household characteristics

Ultimate influences on renovation decisions that explain why

[1] For interpretation of color in Fig. 1, the reader is referred to the web version of this article.

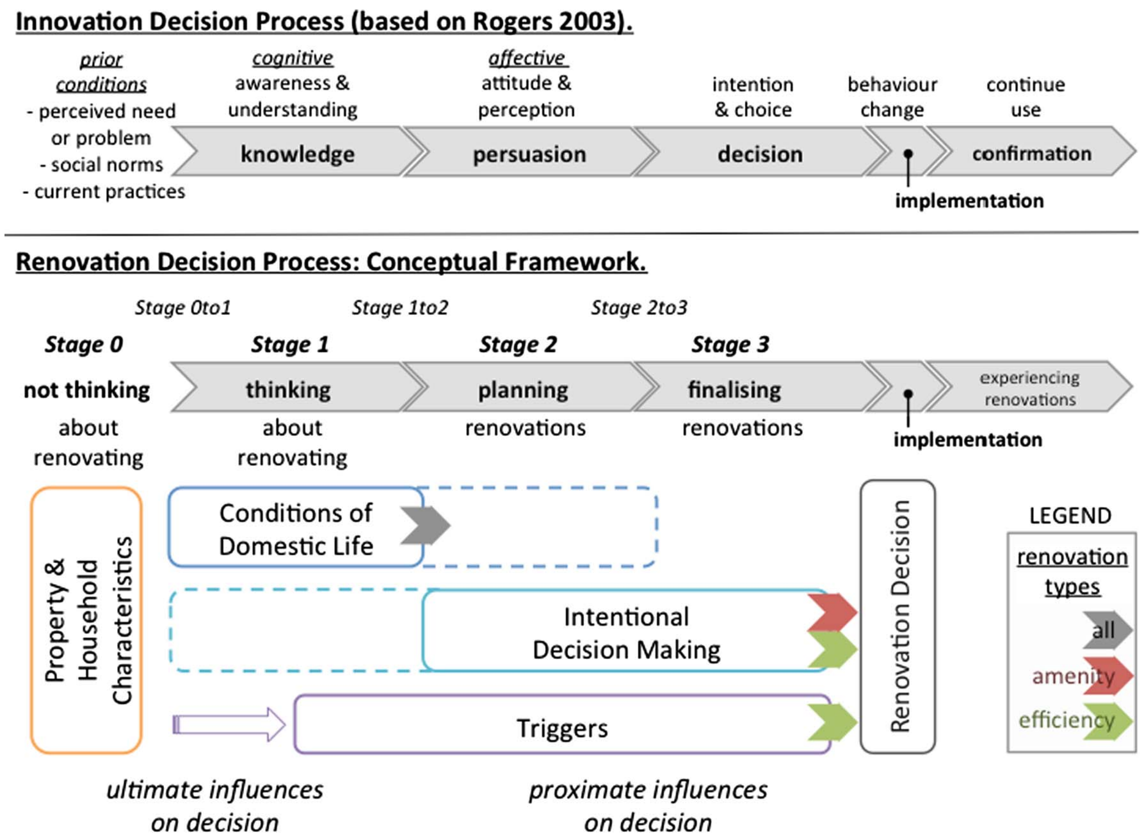

Fig. 1. Conceptual framework for renovation decisions made in the context of everyday domestic life.

Table 1
Conditions of Domestic Life (CDLs) associated with why homeowners decide to renovate.

Conditions of Domestic Life (CDLs)	Brief description	Renovating as a potential response to an imbalance or tension *between* …
Prioritising	The balancing of competing and at times conflicting commitments in domestic life [59,60]	… *between* the design or function of the home *and* the multiple, changing demands placed on it
Embodying	The impact of the body and its abilities on how space at home is used and arranged [61,62]; includes old age and caring [44]	… *between* the actual or anticipated physical abilities of household members *and* the configuration of the home
Demonstrating	The generation of thoughts and ideas for changing the home, including the absorption of social norms, media representations, and other external influences [63,64]	… *between* the current design and feel of the home *and* information signalled about how others have their homes
Home as Project	The meaning of home as a 'project' to be continually updated to express a household's identity [65,66]	… *between* the identity signalled by the home *and* household members' own sense of identity
Adapting	The tacit acknowledgement or explicit awareness of a need to change the physical characteristics of the home to solve perceived problems with objects or the use of space [67,68]	… *between* the home as it is *and* the home as it is could be adapted better to perceived needs

homeowners start thinking about renovating are not typically included in decision models [20,69]. Instead, property and household characteristics are used as observable proxies for personal and contextual influences on renovation activity. As these characterise all households, regardless of their renovation intentions, they are shown on the left side of Fig. 1 spanning the other blocks of explanatory variable.

The CDLs are designed to capture the same basic influences as property and household characteristics on renovation decisions but with greater descriptive realism. As an example, a household with elderly members in an old, un-insulated home might be more likely to renovate to improve energy efficiency. This expectation could be tested using property and household characteristics as explanatory variables for renovation propensity. But household composition and property age do not directly explain renovation decisions; the underlying causal mechanisms are omitted. In contrast, the conceptual framework shown in Fig. 1 captures how elderly household members may experience physical discomfort in their home (*Embodying*) and how older properties may pose greater challenges for how space is designed and heated (*Prioritising*) (Table 1).

The CDLs therefore mediate the effect of property and household characteristics on renovation decisions. Expectations for these causal relationships include:

- *smaller properties, older properties* and *larger household sizes* are associated with *Prioritising* (balancing competing commitments);
- *household compositions with vulnerable members* (including young children and elderly people) are associated with *Embodying* (physical experience of thermal comfort);
- *short length of tenure* (households who have recently moved in) is associated with *Adapting* (changing things around).

2.4. Proximate influences: What renovation decisions are made?

Proximate influences reinforce renovation intentions once formed

(*Stage1to2* and *Stage2to3* in Fig. 1). Positive attitudes towards renovation outcomes and perceived social norms on renovating are the main forms of personal influence in the innovation-decision model [48]. Attitudes towards energy efficient technology adoption are commonly found to be positive predictors of behavioural outcomes [50,70]. Perceived social norms have been shown to be influential on home energy use [71,72] and home renovation activity [45].

Proximate influences in the innovation-decision model explain how decisions become increasingly focused and object-specific as intentions strengthen. In the case of renovation decision-making, specific attributes such as the energy efficiency of renovation measures become clear later on in the decision process [51]. Proximate influences on renovation decisions are therefore distinguished for efficiency and amenity renovations (red and green arrows in Fig. 1).

2.5. Triggers of renovation decisions

Other important influences on renovation intentions include one-off, 'extraordinary' or high salience events which act as 'triggers' for renovation decisions. Triggers are included as a separate block of explanatory variable in the renovation decision model (Fig. 1). Equipment breakdown is the principal type of trigger. Tweed [56] notes how energy efficiency is "*barely differentiated from other aspects of experience within the home environment unless a problem occurs … [domestic life] is a form of absorbed coping, which is only disrupted by 'breakdowns' that bring other concerns to the fore*." Other examples of triggers include a major change in household composition or circumstance (e.g., having a baby, moving job), or a step change in the adoption environment for energy-efficiency measures (e.g., short-term availability of very generous financial incentives, high levels of neighbourhood activity) [23,27,73,74]. Depending on their immediacy and urgency, triggers can either bypass a cumulatively reinforcing decision process or precipitate it. Triggers are therefore shown in Fig. 1 as beginning either in stage 1 (as an ultimate influence on why households start thinking about renovations) or in stage 2 (as a proximate influence on households' renovation plans).

2.6. Testing the conceptual framework

The conceptual framework shown in Fig. 1 can be formalised as a series of hypotheses on energy efficient renovation decision-making:

H1. Influences on renovation decisions change over the decision process.

H2. The conditions of domestic life (CDLs) explain why homeowners start thinking about renovations.

H3. Energy efficient renovation decisions are not distinctive at the early stages of the decision process.

H4. The conditions of domestic life (CDLs) capture the influence of property and household characteristics on renovations.

These four hypotheses are all derived from descriptively-realistic studies of renovation decision-making noted above. H1 is based on observations that renovation decisions tend to be long-drawn out processes, lasting on average over a year [47]. H2 is based on sociological studies of domestic habitation and activities from which renovation decisions emerge [44]. H3 is based on market data including household expenditure surveys which show energy-efficiency measures tend to be installed alongside amenity measures [75,76]. H4 is based on the conceptualization of CDLs as direct measures of the ultimate influences on renovation decisions [58].

To test these hypotheses, and so the validity of the conceptual framework for quantitative modelling of renovation decisions, each block of explanatory variable shown in Fig. 1 was developed into sets of measurement items for inclusion in a nationally-representative survey of UK owner-occupied households. A comparative summary of each block of explanatory variable is provided in Appendix A1.

3. Materials and methods

3.1. UK homeowner survey

An online survey was administered by Ipsos Mori in September 2012 to a representative sample of owner-occupied households in the UK. Individual respondents in each household were screened to ensure they were solely or jointly responsible for financial decisions regarding their home and were over the age of 18. The survey response rate was 15.9% with a median survey completion time of 26 min. Surveys completed in an unrealistically short time (3 times faster than the median) were excluded. The full survey instrument and dataset are publicly available via the UK Data Service (http://dx.doi.org/10.5255/UKDA-SN-7773-1).

The survey used a quota sampling design to ensure even representation across the four decision stages. Screened respondents were asked to self-identify with one of four statements that best described their household's current renovation plans. Renovations were defined as major changes to the physical properties of the home which would usually require contractors or builders to do the work; do-it-yourself (DIY) projects, redecorating, and changing appliances were specifically excluded (see Box 1). Based on their responses, households were assigned to one of the three renovation decision stages (1 − 3) or the null non-decision stage (0):

- We are not currently thinking about renovations as a possibility (*assigned to stage 0*).
- We are currently thinking about renovations as a possibility (*stage 1*).
- We are currently planning renovations to be done at some point in the near future (*stage 2*).
- We are finalising plans for renovating or are currently in the middle of renovating (*stage 3*).

The quota sampling continued until at least 250 complete responses were received for each decision stage. A final sample of n = 1028

Box 1
Definitions and Terms.

Throughout this paper, we use the term 'renovations' to mean structural improvement work to a home or substantive physical changes to a property [77]. 'Retrofits' and 'renovations' are generally used interchangeably. Renovations tend to have high time, cost, and/or skill requirements, and are typically carried out by professional contractors with appropriate technical expertise [42].
We use the term 'energy efficient measures' to describe changes or upgrades to the building envelope, windows, doors, cavity or loft insulation, or heating and hot water systems [19]. In contrast, we use the term 'amenity measures' to describe changes to kitchens, living areas, bathrooms, lofts, and so on. These are not primarily energy-related although may include some efficiency measures.
We also note that renovations can include DIY (do-it-yourself) projects carried out by homeowners; but DIY projects do not have to form part of renovations. 'Home improvements', and in the US, 'remodelling', are general umbrella terms for all these activities [75].

Table 2
Sample characteristics of households per renovation decision stage.

Sample characteristics	Stage 0 Not thinking about renovating	Stage 1 Thinking about renovating	Stage 2 Planning renovations	Stage 3 Finalising renovations	All stages
Sample size	n = 259	n = 254	n = 253	n = 262	n = 1028
Measures (efficiency only)	–	14%	9%	10%	11%
Measures (amenity only)	–	35%	38%	32%	35%
Measures (mixed efficiency + amenity)	–	51%	53%	58%	54%
Triggers (fix or replace)[a]	–	21%	25%	27%	25%
Triggers (other)[a]	–	9%	11%	15%	11%

[a] Triggers (fix or replace) = something has broken and needs fixing or replacing; Triggers (other) = unusually strong recommendations by someone who lives locally or by an expert or contractor, or extraordinarily attractive financial incentives.

respondents completed the survey. The characteristics of each quota of n ≈ 250 per decision stage were similar, and representative of the home-owning population in the UK. Full sample characteristics are provided in Appendix A2.

Respondents who self-identified as being in the renovation decision process (stages 1–3) were asked which measures they were considering, and whether any one-off events had 'triggered' their decision process. Measures were coded as efficiency (windows, doors, insulation, heating or hot water system) or amenity (kitchen, bathrooms, conversions, living spaces, other). Amenity measures dominated respondents' renovation plans, and around one third of respondents reported some trigger (Table 2).

It is important to note that the sample was cross-sectional which does not allow for longitudinal analysis of *within-subject* progression through the decision process. Consequently the hypotheses were tested through *between-subject* comparisons across the decision stages.

3.2. Measurement items and data

All variables used in the analysis based on measurement items from the survey are shown in Appendix A3. The names of variables are italicised throughout this paper (e.g., *Prioritising*).

All measurement items were short statements with a 7 point Likert scale response (1 = strongly disagree | 7 = strongly agree). Multiple items were included for each of the CDLs and intentional decision variables, and were reduced into single factors if clear and interpretable factor structures were found (*Demonstrating*, *Attitudes*, *Social Norms*). For CDLs lacking a clear factor structure, single items were selected as most representative of the general meaning of the CDL (*Adapting*, *Prioritising*, *Embodying*, *Home as Project*).

Additional survey questions were included to identify property and household characteristics relevant to energy efficient renovations.

Various approaches were used to ensure individual responses characterised household-level renovation decision variables: (1) only sampling adult household members with financial decision responsibilities; (2) dynamically scripting question phrasing to be in the 'we/our' form for two or more person households, and in the 'I/my' form for single person households; (3) having question prompts such as "*How much do you agree with the following statements about your household?*"; (4) having further survey prompts reminding respondents to take the household perspective such as "*Now we are going to ask you about your household. We define household as one person or a group of people who live together in their only or main home, and share important financial decisions to do with this home*".

3.3. Analytical methods

3.3.1. Mean differences between decision stages

Responses per decision stage for all the CDL variables and intentional decision variables were tested for differences using a Scheffe multiple comparison test of means. The Scheffe test is a post hoc significance test which allows comparison between mean statistics for multiple groups. This served as an initial evaluation of whether influences changed over the decision process as well as the strength of particular variables in each decision stage (testing H1).

3.3.2. Path analysis of interrelationships between the Conditions of Domestic Life (CDLs)

Each CDL characterises a distinctive and specific condition of everyday life at home linked to renovation propensity. Hypothesised linkages between CDLs were formalised into a network of 'paths' or relationships. Empirical support for these relationships could then be tested using path analysis. Path analysis is an extension of multiple regression, providing estimates of the magnitude and significance of hypothesised causal connections between sets of variables. For the renovation decision model, path analysis was used to test the direction and strength of bivariate relationships between CDLs using pairwise partial correlations (controlling for other relationships). This resulted in a series of 'decision maps' of the relationships between CDLs (testing H2 and H4).

3.3.3. Multivariate probit models of full renovation decision model

The full decision model including all four blocks of explanatory variable was tested using multivariate probit regressions on dichotomous decision stage variables (Fig. 1). The main outcome variable was *Stage0to1* which compared households not thinking about renovating (stage 0) and households thinking about renovating in general terms (stage 1). The multivariate probit model is a further extension of path analysis, used to estimate several correlated outcome variables simultaneously. Multivariate probit was preferred as it enables clear comparison between renovation decision stages as well as providing goodness of fit statistics for the models (see Appendix A6 for further details).

4. Results

4.1. Mean differences between decision stages

Table 3 reports mean responses for all CDL and intentional decision variables for households grouped by renovation decision stage. Scheffe tests confirm that four of the five CDLs are significantly stronger in renovating households (stages 1–3) compared to non-renovating households (stage 0). In other words CDLs help explain the initial formation of renovation intentions (consistent with H2). Table 3 shows the results for stage 0 compared to stage 1 and stage 2; full results are included in Appendix A4.

Attitudes and norms are also significantly stronger in households planning renovations compared to those not thinking about renovations (consistent with H1). However, a reverse causal interpretation cannot be ruled out. Positive attitudes towards renovating may strengthen intentions and move households forwards through the decision process; or households may decide to renovate for other reasons which makes attitudes more positive to ensure self-consistency and avoid dissonance.

Table 3
Mean response on CDL and intentional decision variables for each decision stage.

Decision variable	Total n (all stages)	Mean response (with s.d.) per decision stage				Scheffe test[a]	
		Stage 0	Stage 1	Stage 2	Stage 3	Stage *0 to 1*	Stage *0 to 2*
Conditions of Domestic Life (CDLs)							
Prioritising	995	2.8 (1.7)	3.5 (1.9)	4.2 (1.8)	4.0 (1.9)	+*	+*
Embodying	867	2.7 (2.0)	2.7 (2.0)	2.9 (2.1)	3.2 (2.2)		+ns
Demonstrating	1010	3.0 (1.3)	3.6 (1.3)	3.8 (1.4)	3.7 (1.4)	+*	+*
Home as Project	1018	3.3 (1.7)	4.0 (1.8)	4.6 (1.7)	4.7 (1.8)	+*	+*
Adapting	1008	2.6 (1.5)	3.0 (1.5)	3.4 (1.7)	3.6 (1.8)	+*	+ns
Intentional Decision Making							
Attitudes-Amenity	1006	3.9 (1.1)	4.3 (0.9)	4.7 (0.8)	4.8 (0.8)	+*	+*
Attitudes-Efficiency	1011	4.2 (1.2)	4.5 (1.1)	4.7 (1.1)	4.8 (1.1)	+*	+*
Social Norms-Amenity	997	4.2 (1.05)	4.4 (0.9)	4.5 (1.1)	4.5 (0.9)	+*	+*
Social Norms-Efficiency	998	4.2 (1.1)	4.5 (0.9)	4.4 (0.9)	4.5 (1.0)	+*	+*

[a] + = mean response is higher.
* Significant at p ≤ 0.05.
[ns] Not significant.

4.2. Interrelationships between CDLs

Path analysis was used to test for strong and significant interrelationships between the CDLs, and between the CDLs and property and household characteristics. *Social Norms-Amenity* was also included as normative influence is one of the main sources of external influence internalised by households in the *Demonstrating* condition, and 89% of households in the sample were considering amenity measures (see Table 2).

The base path model for all households in stages 1–3 of the renovation decision process is summarised in Fig. 2; full results are included in Appendix A5. In general, expected relationships between CDLs were all confirmed. The base model was further tested on subsamples of households in discrete decision stages, households considering only amenity measures, and households considering efficiency measures either alone, or mixed with amenity measures. Each model had a similar structure of interrelationships between CDLs as shown in Fig. 2 for the base model (consistent with H3 and H4). Good overall model fits were found in all cases ($R^2 > 0.25$, CFI = 0.93–0.97, and RMSEA < = |0.05|; see Appendix A5 for full explanation of fit statistics).

Adapting describes changing things around at home in response to perceived needs, and so serves as the outcome condition for the endogenous structure of the CDLs. The pathways to *Adapting* are clearly interpretable and explain why households need to make changes to their homes (consistent with H2).

Prioritising, *Demonstrating*, and *Home as Project* are all antecedent to *Adapting*. Each of these CDLs represent a potential source of tension or imbalance in domestic life which making changes to the home may help resolve. *Prioritising* captures imbalances between the physical arrangement of the home and the competing commitments or needs for it. *Home as Project* engenders homemaking as a means of expression and of signalling identity, potentially creating a dynamic tension between the home as it is and the home as it should ideally be. This is related to *Demonstrating* which measures the receptiveness of households to external sources of idea and influence for changing their home. As

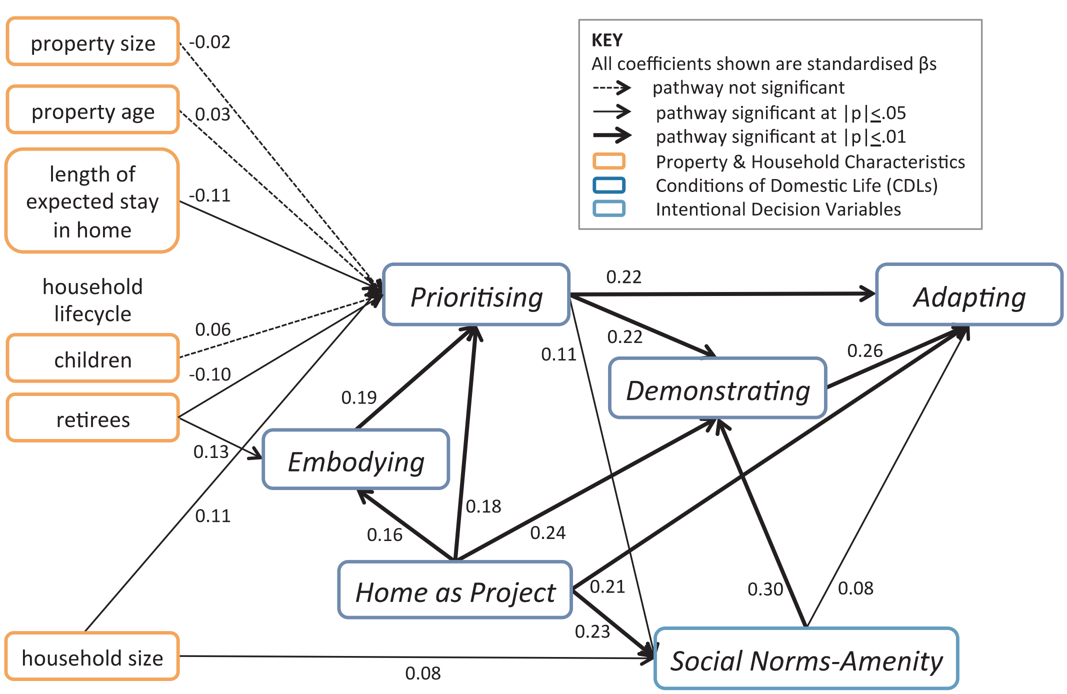

Fig. 2. Endogenous structure of CDLs for all renovating households (in stages 1–3 of the renovation decision process).

Table 4
Multivariate probit model coefficients and fit statistics: CDLs only, decision stages 0 to 1, and 0 to 1, 2, 3.

CDLs only as explanatory variables	Outcome variable: *Stage0to1*		Outcome variable: *Stage0to1,2,3*	
	Full sample	Excluding triggers	Full sample	Excluding triggers
Variable coefficients (β)				
Prioritising	0.18**	0.18*	0.23**	0.24**
Embodying	−0.07	−0.02	−0.04	0.02
Demonstrating	0.14*	0.11	0.07	0.10
Home as Project	0.17**	0.18*	0.26**	0.24**
Adapting	−0.02	0.08	0.04	0.07
Model statistics				
Pseudo R^2	0.12**	0.14**	0.20**	0.24**
AIC[a]	12,659	8659	25,029	16,153
BIC[a]	12,817	8803	25,213	16,321
N (*Stage 0*)	236	166	236	166
N (*Stage 1* or *Stage 1,2,3*)	239	159	716	451

** p < .01.
* p < .05.
[a] AIC = Akaike's Information Criterion, BIC = Bayesian Information Criterion.

expected, *Demonstrating* and *Social Norms-Amenity* are also closely related. Normative influence is an important source of ideas and inspirations for changing the home which are internalised by households.

The influences of property and household characteristics on *Adapting* are mediated by particular CDLs which capture the underlying influence with greater descriptive realism (consistent with H4). Competing commitments on the use of space at home (*Prioritising*) are more common in larger households, and less common in households with elderly members and in households not intending to stay long in their current property. Each is clearly interpretable. Larger households have a greater range of demands on domestic space. A short expected length of tenure suggests moving home rather than renovating as a response to any imbalances or tensions [78]. The needs of elderly members are picked up by *Embodying* which characterises the anticipation or facing of tensions between physical capabilities and the use of the home.

4.3. Full renovation decision model

4.3.1. Initial formation of renovation intentions: CDLs and triggers

Table 4 summarises the multivariate probit regression results for the direct effects of CDLs on the *Stage0to1* and *Stage0to,2,3* outcome variables; full results, including antecedent relationships between CDLs, are reported in Appendix A6.

The *Stage0to1* models test the initial formation of renovation intentions, distinguishing households not thinking about renovating (stage 0) from those thinking about renovating in general terms (stage 1). The *Stage0to1,2,3* models have larger sample sizes and contrast non-renovators with renovating households at any stage of the decision process (stages 1–3 combined).

Pseudo R^2 values for the full samples in the *Stage0to1* and *Stage0to1,2,3* models are 0.12 and 0.20 respectively. (Pseudo R^2s are closest in interpretation to a conventional R^2 in OLS regressions; see [79] and Appendix A6 for details). The information criteria (AIC, BIC) provide alternative measures for comparing the relative goodness of fit of different models, and include penalties for additional variables that do not significantly improve fit [80]. Lower AIC and BIC values indicate better fits.

Removing households that report triggers improves the pseudo R^2 of the *Stage0to1* model from 0.12 to 0.14, and of the *Stage0to1,2,3* model from 0.20 to 0.24. Both the AIC and BIC values also drop by around one third. This is consistent with expectations that triggers bypass emergent decision processes, and so removing households reporting triggers improves model fit.

Overall the models confirm the role of the CDLs in explaining why households move out of the null non-decision stage (consistent with H2). CDLs that significantly predict the emergence of a renovation decision process are also consistent across models, with coefficients of similar strength, significance and direction (see Appendix A6 for details).

Using the results for the *Stage0to1* model excluding triggers as an example, *Prioritising* (β = 0.18*) and *Home as Project* (β = 0.18*) are strong and significant predictors of change in decision stage, controlling for the effect of other variables. Shown in the path analysis to be precursors of the *Adapting* condition, both these CDLs also directly explain the initial formation of renovation intentions as a response to tensions or imbalances from competing commitments and mis-signalled identity respectively.

Contrary to prior expectations none of the other CDLs (*Embodying, Demonstrating, Adapting*) explained the initial formation of renovation intentions. *Embodying* is likely to be characteristic only of a subsample of households with physically vulnerable members including the elderly or young children (Fig. 2). *Adapting* is a broad construct describing households with a propensity to change things around at home in response to perceived needs. This could be anything from rearranging furniture to redecorating or DIY, but also contracting out for major renovations. This breadth of interpretation means there is no simple relationship from *Adapting* to the renovation decision process. *Demonstrating* was an influential variable on *Adapting* in the path analysis, but does not directly predict renovation intentions in the probit model. One interpretation is that the *Demonstrating* condition is more commonly linked to design and DIY alterations to homes, but not to more substantial renovations (see Box 1).

4.3.2. Strengthening of renovation intentions through the decision process: Limited explanatory power of CDLs

Intentions once formed become more focused and object-specific [81]. Households deciding about renovations (stages 1–3) may be considering only amenity measures, only energy-efficiency measures, or a mix of both. Progression through the decision process (*Stage1to2* and *Stage2to3*) is modelled for households grouped by renovation type to test whether energy efficient renovation decisions are distinctive. Two renovation types are distinguished: amenity only, and efficiency only + mixed efficiency with amenity (combined to avoid small sample sizes).

The upper half of Table 5 reports the model fit statistics for *Stage1to2* and *Stage2to3* relative to the *Stage0to1* model using only CDLs as explanatory variables, and excluding households who reported triggers; full model results including variable coefficients are included in Appendix A6.

The expectation is that these CDL-only model fits should progressively weaken because the CDLs lose explanatory power once renovation intentions are formed. This is broadly confirmed (consistent with H2). Three of the four models have similar or lower pseudo R^2s. The AIC and BIC in both the *Stage1to2* and *Stage2to3* models are lower relative to the *Stage0to1* model but this is explained by the lower sample sizes. The *Stage1to2* model for efficiency only + mixed renovators is anomalous as the pseudo R^2 increases relative to the *Stage0to1* model. For this model, *Prioritising* increases in strength and significance as a predictor of *Stage1to2* (see Appendix A6). It is not clear why. One interpretation is that households with strengthening intentions towards energy efficient renovations express these by making certain tensions in domestic life more salient to ensure self-consistency.

Additional models were tested with property and household characteristics included. Adding these as explanatory variables along with the CDLs did not improve model fits (consistent with H4); see Appendix A6 for details.

Table 5
Multivariate probit model fit statistics: Decision stages 0 to 1, 1 to 2, and 2 to 3, excluding households who reported a trigger. Upper half of table shows models with CDLs only as explanatory variables; Lower half of table shows models with CDLs and intentional decision variables as explanatory variables.

Model fit statistics	Outcome variable: *Stage0to1*	Outcome variable: *Stage1to2*		Outcome variable: *Stage2to3*	
	All renovation types	Amenity only	Efficiency only + mixed	Amenity only	Efficiency only + mixed
CDLs only					
Pseudo R^2	0.14**	0.10	0.26*	0.15*	0.05
AIC[a]	8659	4126	3251	3893	2803
BIC[a]	8803	4242	3358	4008	2905
N (moving from *Stage X*)	166	74	63	82	62
N (moving to *Stage Y*)	159	82	62	71	45
CDLs and intentional decision variables					
Pseudo R^2	0.25**	0.15*	0.33**	0.20*	0.17
AIC[a]	4622	2401	1870	2247	1596
BIC[a]	4748	2498	1965	2343	1685
N (moving to *Stage X*)	151	71	62	80	59
N (moving from *Stage Y*)	151	80	59	67	43

** $p \leq 0.01$.
* $p \leq 0.05$.
[a] AIC = Akaike's Information Criterion, BIC = Bayesian Information Criterion.

4.3.3. Strengthening of renovation intentions through the decision process: Intentional decision variables

Object-specific intentional decision variables become relevant as renovation intentions strengthen through the decision process. Including attitudes towards renovation outcomes and perceived social norms on renovating should improve the model fits for the later stages of the decision process, and also help distinguish amenity from efficiency renovation types.

This is broadly confirmed in the lower half of Table 5 which reports the model fit statistics using both CDLs and intentional decision variables as predictors of progression through the decision process, excluding households who reported triggers (see Appendix A6 for full results). Compared to the CDL-only models reported in the upper half of Table 5, pseudo R^2s are higher and/or more strongly significant in all cases, and the AIC and BIC are around one third to a half lower in all cases. In other words, the intentional decision variables help explain strengthening renovation intentions (consistent with H1).

Comparison of the model fits and variable coefficients also shows notable differences between amenity- and efficiency-focused renovation decisions (consistent with H3). As an example, positive attitudes towards specific renovation outcomes are significant influences on amenity renovators, but not efficiency renovators (see Appendix A6 for details).

5. Discussion

5.1. Validation of conceptual framework

This paper developed a novel conceptual framework to explain household renovation decisions, with an emphasis on energy efficiency measures. The conceptual framework introduced a block of variables describing certain conditions of domestic life (CDLs) associated with renovating. The CDLs explain the initial formation of renovation intentions as an adaptive response to tensions and imbalances with the design, arrangement, and use of space at home.

Four hypotheses were identified to test this central proposition of the conceptual framework. All four hypotheses were broadly confirmed. Table 6 summarises the evidence.

5.2. Implications for policymakers & service providers

By situating renovation decisions within domestic life, the validated conceptual framework demonstrates how the tractable, empirical strengths of quantitative modelling can be retained in a contextual, descriptively-rich framing of renovation decisions as an adaptive response to certain conditions of domestic life. The resulting decision model explicitly recognises the complexities of homes as adoption environments for renovation measures, and explains not just *how* households plan energy efficient renovations, but also *why* they are considering renovations in the first place. This research provides new insights for policymakers and service providers seeking to stimulate energy efficient renovation decisions. This is a major challenge.

Across Europe, renovation rates remain stubbornly below what is needed to meet sustainable energy and climate change goals [4,82]. The UK currently has no major policies to support improvements in the housing stock, yet reducing emissions from the residential sector is absolutely vital for near-to-medium term climate change goals [83]. The Green Deal was introduced with fanfare in 2013 and largely withdrawn less than two years later. Replacing obligations on utilities with an inform-and-finance approach targeting homeowners, the Green Deal did effectively raise the salience of energy efficient renovations but failed in other important ways [84]. First, it treated energy efficient renovations as discrete rather than a 'mundane' feature of broader home improvements. Second, it was attractive to homeowners only once they had already decided to renovate rather than initiating renovation decisions. Third, it emphasised financial attributes of the decision (cost, interest rate, payback) rather than tapping into underlying tensions in domestic life which renovations could help resolve. These design flaws are characteristic of many, if not most policies aiming to stimulate energy efficient home renovations. Innovative one-stop shop type business models providing audit, finance and implementation work with quality control measures like the Green Deal have also been proposed and implemented in other countries including in Scandinavia [14]. However like the Green Deal in the UK, these rely on motivated homeowners initiating the decision process. Well-designed business models can increase conversion rates of initial contacts into renovators, but fail to address why homeowners may be deciding to renovate in the first place. Three main insights from this research can help address these flaws and so transform policymaking to boost renovation rates.

First, decisions to carry out renovations that include efficiency measures are influenced as much by factors relevant to amenity measures as by a desire to be more energy efficient. Energy-efficiency measures are much more commonly part of broader 'amenity' home improvements than a distinctive type of renovation; only one in ten UK renovators are considering only efficiency measures [76]. Energy-efficiency policy should target the bundling of efficiency measures into other types of home renovation, rather than trying to stimulate efficiency-only renovations in households not considering renovations.

Table 6
Evidence confirming hypotheses on renovation decision-making (including links to relevant sections in text and appendices).

	Scheffe tests	Path analysis	Probit models
H1: Influences on renovation decisions change over the decision process.	Significant mean differences between stages (4.1, A4).	Interrelationships between CDLs change in strength and significance between stages while maintaining similar structure (4.2, A5).	CDLs influential only in initial stages (4.3.2). Intentional decision variables help explain strengthening intentions (4.3.3, A6).
H2: The conditions of domestic life (CDLs) explain why homeowners start thinking about renovations.	CDLs stronger in renovating households compared to null non-decision households (4.1, A4).	Clearly interpretable interrelationships between CDLs (4.2, A5).	Good model fit for predicting households in renovation decision process (4.3.1, A6).
H3: Energy efficient renovation decisions are not distinctive at the early stages of the decision process.	–	Few differences in interrelationships between CDLs for amenity and efficiency renovators (A5).	Object-specific attitudes and perceived social norms become more influential through decision process (4.3.3, A6).
H4: The conditions of domestic life (CDLs) capture the influence of property and household characteristics on renovations.	–	CDLs mediate influence of property and household characteristics (4.2, A5).	Inclusion of household and property characteristics does not improve fit of CDL-only model (A6).

Marketing, sales channels, and existing points of contact between homeowners and the amenity supply chain (such as installers visiting homes to quote or measure up) can be used to target efficiency measures at would-be amenity renovators.

Second, homeowners start thinking about efficiency renovations just as they do amenity renovations - as ways of resolving certain conditions of domestic life that create tensions, imbalances or issues within the home. Would-be renovators may face competing commitments in using available space at home; they may face or expect to face physical issues with home life; or they may think their home does not suitably express their own identity. Service providers can link their product and services more clearly to these underlying reasons why homeowners start thinking about renovating. The modelling analysis of energy efficient renovation decisions shows that efficiency measures can help make spaces in the home more useable or thermally comfortable, reduce environmental stresses on vulnerable household members, and combine functionality with design and aesthetics. These correspond to the *Prioritising*, *Embodying*, and *Home as Project* conditions respectively, each of which have significant and similarly strong effects on households thinking about or planning energy efficient renovations (see Appendix A6).

Third, market segmentation strategies can help identify households with conditions of domestic life most strongly associated with renovating. Using proxy indicators to identify homes with unresolved tensions over the use of space can help actors in the renovation supply chain to target their service offerings more effectively [22]. The *Prioritising* condition describes households juggling competing commitments with how space at home gets used. This is more likely in larger households, those with more than one child, or more than one adult working from home, those whose members have a diverse range of activities and interests, or whose circumstances have just changed significantly (e.g., new job, new mode of transport, recently moved home). The *Embodying* condition, which describes households facing or expecting to face physical issues, is more likely in cases of poor health, old age, but also very young children. The *Demonstrating* condition describes households that see their homes as a means of expressing their own sense of identity, and that are more likely to receive ideas and inspiration from other people's homes, TV shows and stores, and to be DIY enthusiasts or serial home improvers. These proxy indicators all offer ways for service providers to target particular market segments with a higher propensity to renovate.

Market segmentation is more commonly based on readily observable property and household characteristics. The modelling confirms that these are only indirectly linked to renovation decisions. The path analysis shows that smaller properties, older properties, larger households, households with young children, and households which have recently moved in, are all more likely to be balancing competing commitments for the design and use of space at home (*Prioritising*). Households with elderly members are also more likely to physically experience thermal discomfort (*Embodying*). Both these conditions in turn predict a propensity to change things around at home (*Adapting*) including through renovating. The multivariate probit models further test these relationships on renovation propensity and confirm significant effects of larger households and households with young children.

5.3. Implications for applied energy research

There are several limitations to this research (see Appendix A7 for full discussion). In particular, the development and testing of measurement items for the conditions of domestic life (CDLs) is experimental. The applicability of the CDLs can usefully be tested further in open-ended interviews with samples of renovators and non-renovators to establish their validity in differentiated domestic contexts. In addition, using cross-sectional data to analyse movement between stages allows only correlational support for the basic representation of changing influences over the decision process. A longitudinal (panel) sample would allow causal effects to be identified, by analysing sub-samples of households who have moved forwards or backwards through the decision process.

In the introduction to this article, three broad streams of research on energy-efficient home renovations were identified as of interest to the *Applied Energy* readership: (1) technical and modelling analysis of renovation measures; (2) building performance, economic and energy consequences of renovating; (3) occupant behaviour and renovation decision-making. This article has contributed novel insights on this third stream, but these in turn inform more technical research in the first two streams. The adoption, use, and consequences of energy-saving measures in homes is clearly influenced by both technological and behavioural factors [85]. Technical research commonly points to the occupants of homes and buildings as the source of unexplained variance, model or estimation error, differences between expected and actual energy performance.

Understanding proximate influences on *how* homeowners decide to renovate is necessary for modelling the uptake and performance of specific energy renovation measures [8], for evaluating performance gaps [12], and for designing user-centred home energy management solutions [86].

Understanding ultimate influences on *why* homeowners decide to renovate is necessary for designing, implementing and evaluating the consequences of policies and business models for stimulating renovation uptake [14,20,21,87].

By answering both why and how questions in combination, this article also provides a behaviourally-realistic basis for improving housing stock or energy system models used to evaluate efficiency potentials [69,88]. System design and optimisation modelling tend to exclude the role of human agents when analysing the technical potential for renovation measures [8]. Yet the homes, systems, or buildings being designed and modelled are *for* their occupants. Discrete decision models representing occupant behaviour can be integrated directly into systems models which describe exogenous influences from energy prices to policy measures [89].

6. Conclusions

This paper advances understanding and modelling of energy efficient renovation decisions by including the underlying reasons why homeowners decide to renovate, by representing the decision as a process comprising a sequence of stages rather than as a one-off event, and by showing that the distinctiveness of efficiency-type renovations emerges through the decision process rather than being distinctive from the outset.

The key contributions of this paper are:

i. a novel conceptual framework explaining renovation decisions, drawing on theory and empirical work on domestic life;
ii. an innovative mixed methods research design with quantitative measurement items developed from qualitative constructs characterising renovation decisions;
iii. results from a nationally-representative survey measuring decision variables (with the full dataset publicly available via the UK Data Service archive);
iv. path modelling to test the decision model and validate the conceptual framework;
v. multivariate probit regression to apply the model for developing robust, replicable policy insights.

As such, this paper is an original attempt to link contextualised qualitative research into homes and domestic life with more narrowly-framed quantitative modelling of renovation decisions. This is a critical area for researchers to develop further as it draws on descriptively-realistic characterisations of renovation decision-making to build a rigorous, replicable, and generalizable evidence base to inform public policy.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.apenergy.2017.11.099.

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