

Inferring households' heterogeneous preference for home energy efficiency investment trade-offs: An example from a nationally representative Irish survey

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Abstract

To acquire grants for highly efficient heat pumps, the Irish government required the lowest building energy efficiency standard which should be met through building retrofit to various extent for different buildings. Households with heterogeneous preferences may make home energy efficiency investments for various technologies and diverse attributes. To understand the heterogeneity of households' energy efficiency investment trade-offs, a discrete choice experiment along with a nationally representative Irish survey were conducted and a mixed logit model was applied to collect and analyze data. The results showed: (1) Households with heating systems less than 10 years old prioritize building retrofits; for those with heating systems older than 20 years, the urgency of replacing aging systems is highlighted. (2) Households' willingness to pay for improved thermal comfort is lower than for bill savings, but it remains positive and substantial. (3) Households' willingness to pay for environmental sustainability is significantly negative.

Keywords: Energy efficiency investment, heat pumps, building retrofit, Irish households, choice preferences

1. Introduction

With the target of achieving net-zero greenhouse gas emissions by 2050 in the European Union (EU), an energy transition for all sectors is required. Energy consumption accounts for 25% (IEA, 2022) in the residential sector where the primary use is for space heating accounting for 63.5% (Eurostat, 2024), but renewable space heating for households only accounts for 31.4% in 2022 (Eurostat, 2024). To accomplish the energy transition in the residential sector, the share of renewable space heating should be improved. Heat pumps, powered by low-carbon electricity, and with high energy efficiency, are the mainstream method to achieve renewable space heating.

Meanwhile, heat demand peaking in winter will cause high demand for electricity and a burden on the power grid; with the increased share of heat pumps, the enhancement of building efficiency is required to relieve the pressure on the power grid (Lingard, 2020). Building retrofits could significantly improve the building efficiency evaluated and ranked through building energy rating (BER) in Ireland. The policy ambition of Ireland is to retrofit 500,000 homes to BER of B2 (SEAI, 2023) and to install 400,000 heat pumps by 2030 (SEAI, 2023), respectively. The progress of households' adoption of heat pumps and retrofitting buildings is low in many countries. In Ireland, for example, there is only 36,115 homes were retrofitted to a Building Energy Rating (BER) of B2 (7% of the ambitions) by 2023 and 10,596 heat pumps were installed for 2019-2023 (3% of the ambitions).

Governments in different countries, for example, the Irish government provide grants to households' heat pumps and building retrofit. Meanwhile, the Irish government encourages households to retrofit buildings to at least BER of B2, and then install heat pumps to operate heat pumps effectively. Previous studies have explored the heterogeneity and willingness to pay (WTP) for households' adoption of traditional heating technologies (e.g., gas boilers) and

low-carbon heating technologies (Meles, Ryan, & Mukherjee, 2022) or the WTP for retrofitting buildings (Curtis, Grilli, & Lynch, 2024). However, there is a gap between government ambitions and existing studies. Building retrofits and heat pump installations are often encouraged simultaneously, but the WTP for each is typically evaluated separately. This approach overlooks the potential trade-offs between these energy efficiency investments, particularly when considering households' budget constraints, which may result in an insufficient understanding of consumers' WTP for such investments.

This study aims to explore households' trade-offs between building retrofitting and upgrading heating systems. Specifically, it seeks to determine whether households would prioritize spending on retrofitting their homes or upgrading their heating systems. Additionally, this study examines whether households are willing to pay for the benefits associated with their choices, such as bill savings, improved thermal comfort, or environmental sustainability, and how much they are willing to pay for these attributes. Households' preferences will be analyzed through a nationally representative discrete choice experiment, with calculated marginal WTP reflecting their valuation of these benefits.

2. Literature review

2.1 Determinants for energy efficiency investment in EU states

Researchers have studied the determinants including the barriers and drivers of investing in building retrofit (Wekhof & Houde, 2023) (Maia, Harringer, & Kranzl, 2024) or home heating systems (Michelsen & Madlener, 2013) (Rilling, Kurz, & Herbes, 2024) which are helpful for understanding the influencing factors and enhancing the process of households' energy efficiency investments.

All attributes of heating systems and building retrofits in different studies could be divided into two aspects: internal cost-benefit of consumers and external cost-benefit of investment. The internal cost includes the initial investment cost and operating costs, and the internal benefit includes bill savings and thermal comfort; the external costs often are covered by the government including subsidies or tax rebates, and the external benefits are mainly environmental benefits such as a decrease of carbon emissions (Rekker et al., 2024).

In this study, the attributes are given based on the above literature, as shown in Table 1. We comprehensively consider the most common attributes: investment cost for a heating system, building retrofit levels, bill savings, thermal comfort, and environmental sustainability. The reason for not including the external cost is: first, the amount of attributes is limited to five or six considering the statistical efficiency and respondents' cognitive burden; meanwhile, this study mainly focuses on the trade-offs between heating systems and building retrofit instead of the relationship between private consumption and government expenditure. Hence, this study's five attributes are sufficient to acquire the information and balance the respondents' cognitive load.

Additionally, although the attributes such as type of home, size of the home and energy standard of the home are only considered by (Michelsen & Madlener, 2013), the consideration of existing building information inspired us that the age of the heating system and the cost of building retrofit may also influence households' preferences. Therefore, we also examine the WTPs within different groups with different ranges of heating system ages and costs on the retrofit.

Table 1. Literature of the discrete choice experiments on home energy efficiency investment topic in the EU

References	Dependent variables /Explanatory variables	Aimed consumers	Common attributes / comparable marginal WTP in the related literature
(Michelsen & Madlener, 2013)	Renewable heating system Type of home, Size of the home, Energy standard of the home, Net monthly income of the household	➤ Germany	i. Investment cost in 6 papers;
(Franceschinis et al., 2017)	Renewable heating system Investment cost, Investment duration, Operating cost, CO ₂ Emissions, Fine particle emissions, Required own work	➤ Italian	ii. Operating cost/ annual heating cost/ annual energy savings in 6 papers;
(Lang et al., 2021)	Heating technology Investment cost, Energy label, Annual heating cost	➤ Swiss	iii. Emissions/ environmental sustainability in 2 papers;
(Meles, Ryan, & Mukherjee, 2022)	Heating systems Investment cost, Bill savings, Thermal comfort, Environmental sustainability, Installation hassle	➤ Ireland	iv. Thermal comfort in 2 papers.
(Strazzer et al., 2024)	Heating systems Investment cost, Payback period, Environmental impact, Thermal comfort, Bill savings	➤ Ireland and Italy	Comparable marginal WTP in above papers:
(Curtis, Grilli, & Lynch, 2024)	Building retrofits Investment cost, Bill savings, Disruption levels	➤ Ireland	(Meles, Ryan, & Mukherjee, 2022), (Curtis, Grilli, & Lynch, 2024), (Strazzer et al., 2024)
(Fernandez-Luzuriaga et al., 2022)	building thermal insulation Investment cost, Annual energy savings, Direct public subsidy, Interest rate of available funding, Tax rebate	➤ Spain	

2.2 Households' marginal WTP for energy efficiency investment in EU

Some researchers studied the marginal WTP for different attributes of a specific energy-efficient technology in home energy systems or building renovations. (Franceschinis et al., 2017) studied Italian WTP for renewable heating technologies and marginal WTP for avoiding 1kg/year of emissions between from 1.5 to 1.99 euros in 2017. (Lang et al., 2021) studied Swiss WTP for heating technology investments and marginal WTP for energy efficiency expressed by energy labels in 2021. They found that homeowners are willing to invest on average CHF 7970 and 13,250 (2017 exchange rate CHF 1 ≈ USD 1) for efficiency class A, and A+ (relative to B), and average WTP to switch to wood pellets or heat pumps (relative to heating oil) is CHF -2630 and 4430. In those two research, the environmental benefits, also called positive externalities, such as reduction in carbon emissions and related marginal WTP are studied but the financial payback such as heating cost savings is less considered which causes the unclear of the marginal WTP for financial payback when analyzing households' WTP for energy efficiency investment.

Households' energy efficiency investment is significantly affected by financial benefits. The payback, such as energy cost savings, is as crucial to their investment as the environmental benefits. (Fernandez-Luzuriaga et al., 2022) studied Spain households' WTP for building

thermal insulation and marginal WTP for tax rebates but the tax rebate was provided in specific countries or particular circumstances such as in the initial stage of technology adoption. Cost saving is a common and primary payback benefit of households' energy efficiency investments which attracted more and more attention. They classified households as low, median and high income households and studied households' marginal WTP for bill savings. They found that the WTP of low to high income households is 172, 241, and 294 euros per 1% of savings.

Since the economic development and climate features are diverse in different countries, the marginal WTP in the same country is more comparable. (Curtis, Grilli, & Lynch, 2024) studied Irish households' WTP for building retrofit and the marginal WTP for energy cost savings as shown in Table 2. They found that households' WTPs for 30% to 70% bill savings are from 30,710 to 58760 euros through building retrofits. To achieve thermal comfort and bill saving, upgrading heating systems also plays a vital role which also could be beneficial to environmental sustainability. (Meles, Ryan, & Mukherjee, 2022) studied Irish marginal WTP for heat pumps and related attributes. They found that households' marginal WTPs for 50% to 75% bill savings are from 10,457 to 12,226 euros through upgrading heating systems, as shown in Table 2. (Strazzera et al., 2024) compared Irish and Italian marginal WTP for heating/cooling systems and classified the homeowners as early adopters, late adopters, and laggards. They found that Italian early adopters are willing to pay 25,000 euros for heat pumps which is 10,000 euros for Irish early adopters. In the two countries, laggards are not willing to pay for a new system and late adopters are willing to pay about 5700 euros which is similar in the two countries, as shown in Table 2.

Table 2. Comparison of marginal WTPs for home energy efficiency investment in Ireland

References	Objectives of investment	WTP
(Curtis, Grilli, & Lynch, 2024)	Building retrofit	Marginal WTP for 30%, 50%, 70% energy cost savings compared with 10%: 30710€, 52810€, 58760€
(Meles, Ryan, & Mukherjee, 2022)	Heating system	Marginal WTP for 50%, 75% energy cost savings compared with 0%: 10457€, 12226€
(Strazzera et al., 2024)	Heating system	Irish earlier adopters: 10000€ for changing their heating system; Laggard: not willing to pay; Late adopters: 5700 € for changing their heating system

Existing researchers established a solid foundation for future research on understanding households' WTP for heating systems or building retrofit in the EU. However, existing researchers less considered the trade-off between heating systems and retrofits. In a short period, home energy efficiency investment is a trade-off between a heating system and building renovation instead of only one investment assuming there are budget constraints for their home energy efficiency investment. Analyzing the trade-off of home energy efficiency investment is beneficial for better understanding households' energy efficiency investment and clarifying the focus of policy, such as subsidy policy. The rest of this study will be organized as follows: Section 3 introduces the materials referred to survey conduction and data collection, and also illustrates discrete choice experiment design and econometric model. Section 4 shows the results and discussions of the quantification. Finally, Section 5 summarizes the most important conclusions.

3. Materials and Methods

3.1 Survey and data

The survey of this research was conducted through an online survey in September 2024. The data collection was conducted by the University College Dublin in collaboration with the Department of the Environment, Climate and Communications. A research and market company, RedC, was appointed to carry out the survey.

The survey focused on households' uptake of renewable energy technologies and related policies including heat pumps, solar photovoltaics, electrical vehicles and tariffs. The survey questionnaire includes four parts: (i) demographic questions for general respondents, (ii) building, retrofitting, energy sources, and energy bill information, (iii) households' attitude to and status quo of heating technologies, solar photovoltaics, electric vehicles, and different tariffs, (iv) discrete choice experiment for heating systems with consideration of building retrofit, and two other discrete choice experiments on solar photovoltaics and electric vehicles.

In total, 1225 nationally representative Irish households were randomly selected for the survey. The survey participants were from a large panel of over 80,000 active respondents in Ireland. The selection of the sample was based on quotas placed on age, gender, region, social class, and educational level constructed on the Irish Central Statistics Office Census 2022 figures (CSO, 2022). Within the 1225 sample respondents, there were three discrete choice experiments separately for three subsets of data. A 95% confidence level and a margin of error of 5% for the 5,149,139 population in Ireland in the 2022 census, provide a statistically robust sample size of 385, for each of the three subsets. Table A1 in the appendix provides a summary of the overall survey data by age, gender, region, social class, and educational level relative to the Irish population.

The data on the building, retrofitting, energy sources, energy bill information, and social psychological statements regarding heating systems covers all of the 1225 respondents. The discrete choice experiment on new heating systems such as heat pumps or gas boilers was conducted with a subsample of 412 randomly selected respondents (from the 1225 samples). For the remaining 813 sample respondents, discrete choice experiments on solar photovoltaics and electric vehicles which were not covered in this paper were conducted. Based on the 95% confidence level and the 5% margin of error discussed above, the 412 sample respondents for the heating systems are significant enough to be representative.

3.2 Discrete choice experiment

We applied a discrete choice experiment to clarify trade-offs for a new home heating system and building retrofit and to elicit households' preferences for different attributes of an energy efficiency investment. The selection of the attributes and the range of each attribute were based on the previous literature.

The first attribute is the total upfront cost of heating technologies where 4000, 10500, 13500, and 19500 euros are the price of a new gas boiler, a new air-to-air heat pump, an air-to-water heat pump, and a water-to-water (geothermal source) heat pump, respectively. The upfront costs referenced existing literature from a survey conducted in 2018 (Meles, Ryan, & Mukherjee, 2022). In this study, higher upfront costs are set for heating systems to account for inflation and a broader range of house characteristics, offering a wider range of heating system prices compared to the 2018 survey.

The value of retrofit levels referred to the existing literature (Curtis, Grilli, & Lynch, 2024) and the insulation options from Sustainable Energy Authority of Ireland (SEAI) (SEAI, 2024) where 10000, 25000, 40000, and 80000 euros represent no invasive retrofitting works, minor, moderate, and major insulation.

The values of the “savings compared with current bill” attribute are given to 0, 1/3, and 2/3 which were given differently in existing literature. A lower bill savings range is set compared to the 2018 survey because the retrofit costs are considered. In this context, inadequate retrofit means higher heating loss and related lower bill savings. Additionally, the attributes “increase in home comfort” and “environmental sustainability” were selected based on existing literature and associated levels of the two attributes are divided into low, moderate, and high.

The choice experiment consists of 12 choice sets, divided into 2 groups. Each respondent faced 6 choice sets and each choice set included 3 alternatives: “Option A”, “Option B”, and “I would prefer my existing heating system”. The combination of the five attributes and their corresponding levels generated a total of 1296 different options (that is $4 \times 4 \times 3^4$). Practically, it is not possible to present respondents with all choices. On the other hand, it is rational to delete the logically inconsistent options. For example, it is not possible to spend 10500 euros on an air-to-air heat pump and 10000 euros on minor insulation but achieve high thermal comfort. In addition, all combinations of gas or heat pumps and four levels of retrofit costs will be included to understand the trade-off between heating systems and building retrofit. By using Bayesian optimal design in JMP statistical software and based on the above principles, 12 choice sets were selected and divided into 2 groups. The survey questions and choice sets for the discrete choice experiment are shown in Appendix Table A2 and Table A3.

3.3 Econometric model and WTP

We use a random utility model, a mixed logit model including the space preference model and WTP space model, to clarify the trade-off between heating systems and building retrofit and to elicit household preferences for a new heating system. Compared to the multinomial logit model, the mixed logit model is more flexible and realistic, as it can relax the assumption of variables being independently and identically distributed, approximate any random utility model, and handle complex substitution patterns and correlation between alternatives, making it suitable for more complex choice situations (Hensher & Greene, 2003).

According to the random utility theory, the utility of U_{ijt} of an individual $i \in \{1, \dots, N\}$ from an alternative $j \in \{1, \dots, J\}$ in a choice set $t \in \{1, \dots, T\}$ is described as a sum of an observed component $\beta_i' X_{ijt}$ and an unobserved stochastic term ε_{ijt} , as shown in Equation (1).

$$U_{ijt}^* = \alpha_i^* C_{ijt} + \beta_i^{*\prime} X_{ijt} + \varepsilon_{ijt}^*, \quad \varepsilon_{ijt}^* \sim \text{Gumbel}(0, \sigma^2 \pi^2 / 6) \quad (1)$$

Where X_{ijt} is a vector of observable variables related to the alternative j and respondent i for choice set t . α_i^* and β_i^* are the individual specific coefficients for the cost and the other non-cost attributes (J. P. Helveston, 2023). These observable variables include the five attributes of the discrete choice experiment in Appendix Table A2. The utility U_{ijt}^* is latent, we only observe the choices an individual made, which is equal to one if an alternative j is chosen in the choice set, zero otherwise. , and the unobserved error term ε_{ijt}^* is assumed to be an independently and identically distributed random variable with a Gumbel extreme value distribution (J. P. Helveston, 2023).

The model expressed by Equation (1) is not identified since there exists an infinite set of combinations of values for β_i^* , α_i^* , and σ that will produce the same choice probabilities. To specify an identifiable model, Equation 1 must be normalized. One approach is to normalize the scale of the error term by dividing Equation 1 by σ , producing the “preference space” utility specification (J. P. Helveston, 2023).

In order to derive the marginal willingness to pay for the different attributes, we specify utility, U_{ijt} , separately for the cost attribute C_{ijt} and the other non-cost attributes X_{ijt} as in Equation (2) (J. P. Helveston, 2023).

$$\frac{U_{ijt}^*}{\sigma} = \frac{\alpha_i^*}{\sigma} C_{ijt} + \left(\frac{\beta_i^*}{\sigma}\right)^T X_{ijt} + \frac{\varepsilon_{ijt}^*}{\sigma}, \quad \frac{\varepsilon_{ijt}^*}{\sigma} \sim \text{Gumbel}(0, \pi^2/6) \quad (2)$$

The typical preference space parameterization of the multinomial logit model can then be written by rewriting Equation (2) with $U_{ijt} = (U_{ijt}^*/\sigma)$, $\beta_i = (\beta_i^*/\sigma)$, $\alpha_i = (\alpha_i^*/\sigma)$, and $\varepsilon_{ijt} = (\varepsilon_{ijt}^*/\sigma)$ (J. P. Helveston, 2023).

$$U_{ijt} = \alpha_i C_{ijt} + \beta_i^T X_{ijt} + \varepsilon_{ijt}, \quad \varepsilon_{ijt} \sim \text{Gumbel}(0, \pi^2/6) \quad (3)$$

The vector β_i in Equation (3) represents the marginal utility for changes in each non-price attribute (relative to the standardized scale of the error term), and α_i represents the marginal utility obtained from changes in price (relative to the standardized scale of the error term). The coefficients β_i and α_i are only relative values rather than absolute and do not have units.

In the preference space model, estimates of the marginal WTP are computed by dividing $\hat{\beta}$ by $\hat{\alpha}$, where the “hat” symbol means a parameter estimate.

In the space preference model, the WTP is post-estimated. To calculate the WTP directly, an alternative approach to normalizing Equation (1) is to divide by $-\alpha_i^*$ instead of σ , resulting in the “WTP space” utility parameterization:

$$\frac{U_{ijt}^*}{-\alpha_i^*} = \frac{\alpha_i^*}{-\alpha_i^*} C_{ijt} + \left(\frac{\beta_i^*}{-\alpha_i^*}\right)^T X_{ijt} + \frac{\varepsilon_{ijt}^*}{-\alpha_i^*}, \quad \frac{\varepsilon_{ijt}^*}{-\alpha_i^*} \sim \text{Gumbel}\left(0, \frac{\sigma^2}{(-\alpha_i^*)^2} \frac{\pi^2}{6}\right) \quad (4)$$

Since the error term in Equation (4) is scaled by $\lambda^2 = \sigma^2/(-\alpha_i^*)^2$, it can be rewritten by multiplying both sides by $\lambda = (-\alpha_i^*/\sigma)$ and renaming $U_{ijt} = (\lambda U_{ijt}^*/-\alpha_i^*)$, $\omega_i = (\beta_i^*/-\alpha_i^*)$, and $\varepsilon_{ijt} = (\lambda \varepsilon_{ijt}^*/-\alpha_i^*)$:

$$U_{ijt} = \lambda(\omega_i^T X_{ijt} - C_{ijt}) + \varepsilon_{ijt}, \quad \varepsilon_{ijt} \sim \text{Gumbel}(0, \pi^2/6) \quad (5)$$

Where vector $\omega_i = (\beta_i^*/-\alpha_i^*)$ represents the marginal WTP for non-price attribute, with units of currency, and λ represents the scale of the deterministic portion of utility relative to the scale parameter. The model in WTP space is estimated with the user-written *logitr* package in R (J. P. Helveston, 2023).

4. Results

4.1 Descriptive statistics

We provide the summary statistics of 1225 sample respondents (full sample) and the 412 subsample respondents in Table 3. In the full sample, a smaller portion of respondents prefer not to say part of the information. The portion of females and males is half to half, the main ages are higher than 34 years old accounting for 82%, and over half of respondents have an

educational level of lower than secondary school. As for household annual income level, 34% of them have a lower than 36,000 euros, 32% of them have a higher than 36,000 euros but lower than 69,000 euros annual income, and 24% of them have a higher than 69,000 euros annual income. Most properties (43%) were built between 1976 and 2004, 27% property were built before 1976, and 26% property were built after 2004. 71% of those buildings are detached or semi-detached houses, and 16% and 12% of those buildings are terrace houses and flats or departments, respectively. Overall, the distribution of the characteristics of the 412 subsample respondents is similar to that of the full sample respondents.

Table 3. Summary statistics of the demographic information of sample respondents

Variables / Sample size	Full sample (1225)	Full percentage (100%)	Subsamples (412)	Full percentage (100%)
	Total number	Percentage	Total number	Percentage
Gender	1225	100%	412	100%
Female	622	51%	193	47%
Male	603	49%	218	53%
Age	1225	100%	412	100%
18-24	42	4%	18	4%
25-34	182	15%	67	16%
35-44	279	23%	94	23%
45-54	239	21%	81	20%
55+	483	37%	157	38%
Educational level	1224	99.91%	411	99.76%
Lower than secondary school	621	51%	214	52%
Third Level Degree	467	38%	162	39%
Third Level Postgraduate Degree	136	11%	35	8%
Household annual income	1105	90.20%	377	91.50%
< 36,000	418	34%	132	32%
≥ 36,000 and < 69,000	392	32%	140	34%
≥ 69,000	295	24%	105	25%
Regions in Ireland	1225	100%	410	99.51%
Dublin	342	28%	120	29%
Outside Dublin	883	72%	290	70%
Built year	1170	95.51%	391	94.90%
Pre 1976	329	27%	107	26%
1976-2004	522	43%	175	42%
After 2004	319	26%	109	26%
Property types	1208	98.61%	407	98.79%
Flat or apartment	141	12%	45	11%
Terraced house	201	16%	58	14%
Semi-detached house	448	37%	161	39%
Detached house	418	34%	143	35%

To better understand the households' current home energy situation, the summary of heating information is shown in Table 4. In terms of primary heating sources, most households rely on gas and oil, accounting for 35% and 34% of homes, respectively. Only 18% of households use electricity for heating, while 12% use solid fuels, such as wood, coal, or peat. Among respondents who reported the age of their heating system, approximately 28% indicated their system was less than 5 years old, 18% stated it was between 5 and 10 years old, 23% reported it was between 10 and 20 years old, and 31% reported it was over 20 years old or were unsure of the age of the heating system. Regarding annual heating costs, 29% of respondents' annual heating bills are higher than 1,000 euros but less than 2,000 euros, and 23% of respondents' annual heating bills are lower than 1,000 euros or higher than 2,000 euros. Approximately 23% of respondents thought their heating cost is higher than average but 19% of respondents plan to upgrade their heating systems within 5 years. Almost half of respondents don't plan to

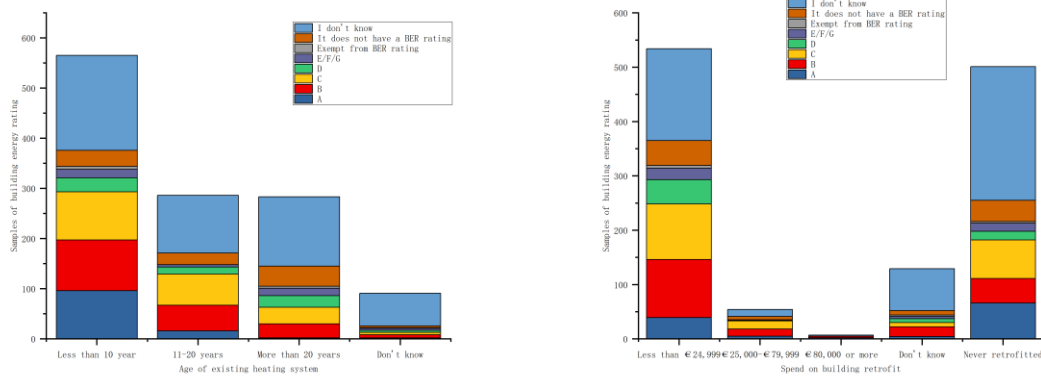
upgrade their heating systems and 12% of them plan to upgrade their heating systems in more than 6 years.

Table 4. Summary statistics of the heating information of sample respondents

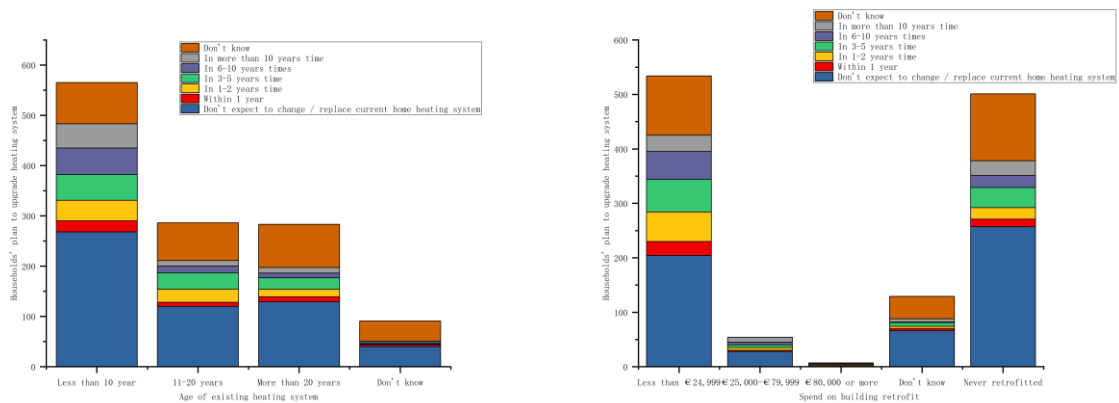
Variables / Sample size	Sample size	Proportion	Sample size	Proportion
Primary source of heating in home	1213	99.02%	407	98.79%
Oil	418	34%	142	34%
Gas	429	35%	143	35%
Electricity/ heat pumps/solar	218	18%	75	18%
Solid fuels	148	12%	47	11%
Age of main heating system	1225	100%	411	99.76%
Within 5 years	342	28%	122	30%
6-10 years	223	18%	72	17%
11-20 years	286	23%	99	24%
More than 20 years/ Don't know	374	31%	117	28%
Annual heating bills	920	75.10%	316	76.70%
< €1,000	283	23%	99	24%
≥ €1,000 and < € 2000	358	29%	128	31%
≥ €2000	279	23%	89	22%
Perception of one's heating cost	1175	95.92%	399	96.84%
Higher than most	287	23%	101	25%
Average	660	54%	225	55%
Lower than most	228	19%	73	18%

To further describe the proportion of building information, heating information, and households' plans to upgrade their heating systems, the descriptive information of building energy rating (BER), age of heating systems, amount spent insulating property lived in, and the time they plan to replace the heating systems are presented in Figure 1. As shown in Figure 1a, excluding the "I don't know" options, for most buildings with a BER above level C, the ages of heating systems are primarily less than 10 or 20 years. In cases where the heating system is over 20 years old, more than half of these buildings have a BER rating below level C. In the full samples, most respondents spent less than 24,999 euros on the building retrofit, or never retrofitted their house. For households that have never retrofitted their homes, a large proportion have an A-level BER, indicating they may have purchased the property in recent years. For households that have retrofitted their buildings, most have achieved a BER above level C, but there are a small proportion of their buildings are still under the C-level BER or don't have a BER.

In terms of households' plans for upgrading their heating system (as shown in Figure 1c and Figure 1d), there is a large proportion of samples that don't expect to replace their home heating system. For those who are planning to replace their home heating system, most of them are planning to replace it in 10 years. The "more than 10 years" option is chosen by respondents whose heating system age are less than 10 years. Excluding the options of "Don't know", households who have spent less than 24,999 euros on building retrofit, over half of them have plans to upgrade their heating systems, but for others, less than half of them have plans to upgrade their heating systems.



a. BER and age of heating system b. BER and building retrofit



c. Households' plan and age of heating system d. Households' plan and building retrofit

Figure 1. Households' building energy rating (BER) and plan to upgrade their heating system based on the age of heating systems, and the cost of building retrofit: a. BER and age of heating system, b. BER and building retrofit, c. households' plan and age of heating system, d. households' plan and building retrofit

4.2 Trade-offs between building retrofit and heating system

Approximately 68% (1678) of the total 2,472 choices made from the six choice sets by the 412 respondents preferred to keep their existing heating systems. The reasons that they prefer their current heating system include “I do not trust such options exist in the market”(117), “The choice task is difficult to understand”(97), “My existing heating system is superior to the options presented”(281), “It is not my priority to change to a new heating system” (602). About 32% of the choices made were to upgrade their heating systems. Immediately after completing their selections for the six choice sets, respondents were asked to rate their confidence in their decisions on a scale from 1 to 5, where 1 indicated ‘very all confident’, and 5 indicated ‘not at all confident’. About 82% of respondents rated their confidence as 3 or lower while 8% of respondents selected 5.

Table 5 presents the results of the discrete choice experiment. The model estimates the correlation between each variable and heating systems through the value of the mean coefficient of each parameter, and the z-value of each parameter.

Table 5. Coefficients in the mixed logit model

Variables	Value of variables	Coefficients Estimate (St. Err.)	Pr(> z)
Upfront cost	Scale par	-0.00006 (0.00002)	0.00286**
Retrofit levels	Major work	-0.58996 (0.59841)	0.32419
Ref: No invasive internal work	Moderate work	0.31556 (0.41193)	0.44365
	Minor work	1.71480 (0.62507)	0.00608***
Savings compared with current bill Ref: 0	30%	1.26820 (0.23001)	0.00000***
	70%	3.70160 (0.78527)	0.00000***
Increase in home comfort Ref: low	Moderate	0.47979 (0.25395)	0.05885*
	High	1.80670 (0.87722)	0.03944**
Environmental sustainability Ref: low	Moderate	-1.77380 (0.72651)	0.01462**
	High	-1.87780 (0.76023)	0.01351**
ASC (Alternative-specific constant)		0.859505 (0.029228)	0.00000***
Number of Observations:		793	
Number of respondents:		412	
Log-Likelihood:		-451.92484	
Pseudo-R ²		0.17782	
AIC:		923.84968	
BIC:		970.60790	

In terms of the attribute distributions, this study explored various attribute distributions (normal, log-normal, fixed) and ultimately selected the fixed distribution because there is no theoretical basis for assuming that β_i , marginal utilities and marginal WTPs should follow standard distributions (e.g., normal or log-normal) (J. P. Helveston, 2023).

The ‘total upfront cost’ is specified as a continuous price variable and other variables are automatically coded as dummy variables (J. Helveston, 2023) to convert the categorical variables to numeric form. Meanwhile, the reference levels of attribute variables are specified to compare the effects of different categories on the outcome. We also included an alternative as a dummy-coded variable identifying which alternative was chosen (1 means the option is chosen, 0 means another option is not chosen). For each choice observation, only one option can be selected, meaning that only one alternative should be marked with a 1 per observation.

As shown in the Column of ‘Pr(>|z|)’ in Table 5, most of the variables have statistically significant effects on the dependent variable. The coefficient for the attributes ‘Retrofit levels of moderate work and major work’ is not statistically significant, which is consistent with the descriptive statistics for the whole samples shown in Figure 1b showing that only a small percentage of households have spent over €25,000 on retrofitting buildings. All standard errors

of the estimated coefficients are significantly different from zero (as shown in the parentheses in Table 4) which means the model estimated coefficients appropriately.

In terms of the coefficients, the more positive and higher the coefficients, the more important the attribute for respondents. According to the coefficients in Table 5, the attributes of bill savings (coefficient of 70% bill saving = 3.70, and coefficient of 30% bill saving = 1.26), thermal comfort (coefficient of high thermal comfort = 1.8, and coefficient of moderate thermal comfort = 0.48), and the attribute of building retrofit (coefficient of minor work = 1.71) are vital, respectively, for households' choice of heating systems. The coefficient of environmental sustainability is negative, indicating that this attribute is less important in respondents' decision-making of choosing heating systems.

The coefficients are consistent with the 2018 survey results (Meles, Ryan, & Mukherjee, 2022) where the bill saving (coefficient of 75% bill saving = 2.941, and coefficient of 50% bill saving = 2.918) is most significant for households' choice of heating systems, and the coefficient of thermal comfort (coefficient of moderate thermal comfort = 0.318) is also significant. The difference between the two surveys' results is that the coefficient of high thermal comfort was negative in the 2018 survey and positive in the 2024 survey. Conversely, the coefficient of environmental sustainability is negative in the 2024 survey but positive for the high environmental sustainability attribute in the 2018 survey. According to the comparison of the two surveys, facing different heating system options, households are more concerned about bill saving; meanwhile, the correlation of thermal comfort has increased but the correlation of environmental sustainability has decreased which may come from the consideration of building retrofit in the options in the 2024 survey. In other words, for Irish households, the building retrofit coupled with the heating system brings thermal comfort which they are willing to pay for but they are unwilling to pay for the environmental sustainability or they expect the costs of environmental benefit to be socialized (Ponce Oliva et al., 2024; van Klingeren & De Moor, 2024).

The mixed logit models include both a preference space model and a WTP space model. While preference space models provide estimates along an abstract utility-scale, WTP space models directly estimate WTP without the need for post-estimation calculations. The estimates of the WTP model are expressed in currency units, making them more interpretable and providing concrete meaning for attribute effects (J. P. Helveston, 2023). This study estimated WTP using the WTP space model as shown in Table 6.

Table 6. Willingness to pay (WTP) for attributes in the mixed logit model

Variables	Value of variables	WTP (unit: euro)
Retrofit levels	Major work	-9358.55
Ref: No invasive internal work	Moderate work	5010.68
	Minor work	27216.73***
Savings compared with current bill	30%	20125.38***
	70%	58742.18***
Ref: 0	Moderate	7613.92**
	High	28673.15***
Increase in home comfort	Moderate	-28151.55***
	High	-29800.96***
Ref: low		
Environmental sustainability	Moderate	-28151.55***
Ref: low	High	-29800.96***
Log-likelihood		-451.92

Based on the WTP estimation, Irish households' energy efficiency investment is 27,216.73 euros to upgrade their heating systems and include a minor building retrofit. However, their WTPs to include a moderate or major building retrofit are not significant. The negative WTP for a major building retrofit may stem from an aversion to disruption caused by a large building job. This result is in line with existing research (Curtis, Grilli, & Lynch, 2024), which highlights a trade-off between the retrofitting works and house disruption levels.

In terms of bill savings, households are willing to pay €58,742.18 to achieve a 70% bill savings. Although the focus of this study is on households' willingness to pay for heating systems, the combined effect of upgrading both the heating system and retrofitting the building contributed to this 70% bill savings. This indicates that households are willing to pay €58,742.18 for the combined benefits of upgrading their heating systems and retrofitting their buildings. For a 30% bill savings, households are willing to pay €20,127.04, compared to €30,710 when only considering building retrofits (Curtis, Grilli, & Lynch, 2024).

Households' willingness to pay for thermal comfort, while lower than for bill savings, is still positive and significant. Compared to paying nothing for low thermal comfort, households are willing to pay €28,673.15 for high thermal comfort and €7,613.92 for moderate thermal comfort. These results indicate that households are willing to invest more to achieve higher thermal comfort.

This study finds a negative WTP for environmental sustainability which may stem from the inclusion of building retrofits. When considering building retrofits, the environmental sustainability attributes may evoke thoughts of green buildings and the use of sustainable and circular building materials, which are significantly more expensive than standard materials. Alternatively, the negative WTPs also indicate that households expect the costs of environmental benefits to be socialized rather than to fall on households (Ponce Oliva et al., 2024; van Klingereren & De Moor, 2024). For example, subsidies for environmentally sustainable consumption may help meet these expectations (You et al., 2024).

4.3 Trade-offs between past investment and choices

Households' willingness to pay (WTP) for upgrading heating systems or retrofitting buildings is also influenced by the age of their heating systems and the amount they have already spent on building retrofits. Homeowners with heating systems that are less than 10 or 20 years tend to have higher-than-average WTP for energy efficiency investment. In contrast, those with systems older than 20 years, where over 68.31% of the primary heating source is oil or solid fuel, have significantly lower WTP.

For households with heating systems less than 10 years old, they are willing to invest €41550.15 in a minor building retrofit when upgrading heating systems, compared with no invasive internal works (as shown in Table 7). Households with systems between 10 and 20 years are willing to pay €28,753 and €7930.41 to acquire a minor or moderate building retrofit when upgrading heating systems. Since the average lifetime of a heating system is around 15-20 years or longer (Marinelli et al., 2019; Vignali, 2017), households with systems less than 10 or 20 years are likely to prioritize building retrofits and defer heating system upgrades but the results showing less significance of WTP for a moderate building retrofit may be caused by their unwillingness to the disruption (Curtis, Grilli, & Lynch, 2024).

Whereas those with older systems prioritize heating upgrades, notably, for households with systems older than 20 years, their willingness to energy efficiency investment to include a

minor or moderate building retrofit (€5204.88 and €4147.33) is lower than that in other groups, highlighting the urgency for these households to upgrade their heating systems instead of including a minor or moderate building retrofit. Households who don't know their heating system age are willing to pay €31282.64 to include a minor building retrofit and most of them also don't know their BER (as shown in Figure 1a) and don't have a plan to upgrade heating systems (as shown in Figure 1c), which indicates the urgency for them to invest on the building retrofit.

Table 7. WTPs for attributes based on different ages of the main heating system

Variables	Value of variables	WTPs (unit: euro)			
		Within 10 years (N=72, 17%)	11-20 years (N=98, 24%)	More than 20 years (N=116, 28%)	Don't know (N=126, 31%)
Retrofit levels	Major work	8118.645	-14178.6*	-13582.6	-15683.2
Ref: No invasive internal work	Moderate work	18877.38	7930.41***	4147.33**	-4206.8
Savings compared with current bill	Minor work	41550.15*	28753.39**	5204.88*	31282.64*
Ref: 0	30%	14543.08**	17151.68	20585.27	25793.88***
Increase in home comfort	70%	64225.35**	53982.66	52363.76	68767.21***
Ref: low	Moderate	5735.163	3222.96	8569	12182.62
Environmental sustainability	High	41106.42	27120.34	12081.45	37854.75
Ref: low	Moderate	-37225	-31851.5	-10037.8	-34683.4*
	High	-52543.3	-24437.6	-15670.4	-36084.5*

For households with heating systems less than 10 years old, their willingness to pay (WTP) for bill savings and thermal comfort through heating system upgrades and building retrofits is significant, as shown in Table 7. These households are willing to pay more than the average to reduce energy bills and improve thermal comfort. However, they show no significant WTP for environmental sustainability. In other groups with older heating systems, WTP for bill savings, thermal comfort, and environmental sustainability is not significant. Households who don't know their heating system age are also willing to pay more than the average for reducing bills but not for thermal comfort. And their WTPs for environmental sustainability are significantly negative.

Homeowners who have spent less than €9,999, or don't know how much they spent on building retrofits are willing to invest about €29135, and those who have spent more than €10,000 on building retrofit are willing to invest about €29378 in a minor building retrofit and upgrading their heating system, as shown in Table 8. Households that have spent more than €10,000 on building retrofits show a lower WTP for saving 30% on energy bills but a higher WTP for saving 70% compared to those who have spent less than €9,999. This aligns with the expectation that households who invest more in retrofits are willing to pay more for significant bill savings. Similarly, these households who have spent more than €10,000 on building retrofits also show a higher WTP for enhanced thermal comfort, which corresponds to their investment in their past retrofit works. Households generally do not believe that energy efficiency investments contribute significantly to environmental sustainability. This may be due to a perception that achieving environmental sustainability through building retrofits requires the use of green and recyclable materials (Jagarajan et al., 2017) or because they expect the costs of environmental benefits to be socialized.

Table 8. WTPs for attributes based on the amount spent insulating property lived in

Variables	Value of variables	WTPs (unit: euro)		
		Less than €9999 (N=145, 37%)	More than 10,000 (N=107, 27%)	Don't know (N=145, 37%)
Retrofit levels Ref: No invasive internal work	Major work	7564.53	-3868.9	7564.68
	Moderate work	13079.34	7766.846	13082.25
	Minor work	29134.70*	29378.13**	29135.24*
Savings compared with current bill Ref: 0	30%	16006.77***	10926.08***	16005.87***
	70%	39770.21**	46341.28***	39764.68**
Increase in home comfort Ref: low	Moderate	4721.24	9565.21*	4721.59
	High	12081.39	39911.69**	12080.60
Environmental sustainability Ref: low	Moderate	-26237.66	-30298.2**	-262360
	High	-17923.07	-41055.4**	-17919.70

5. Discussions

5.1 Comparison of willingness to pay between different surveys

As illustrated in Figure 2a, when considering only building retrofits without upgrading the heating system, the marginal willingness to pay for a 70% bill savings on building retrofits is €52,810 (Curtis, Grilli, & Lynch, 2024), while the willingness to pay for upgrading the heating system alone was €12,226 in 2018 (Meles, Ryan, & Mukherjee, 2022). For a 30% bill savings, households are willing to pay €20,127.04, compared to €30,710 when considering building retrofits alone (Curtis, Grilli, & Lynch, 2024). The lower willingness to pay in this study could be attributed to the varying composition of attributes in each survey, a phenomenon also observed in previous studies (Meles, Ryan, & Mukherjee, 2022; Strazzer et al., 2024).

In terms of households' WTP for thermal comfort, in the 2018 survey (as shown in Figure 2b), households were willing to pay €1,635 for moderate thermal comfort, but the willingness to pay for high thermal comfort was not significant. Furthermore, the comparison of results indicates that households are more willing to pay for building retrofits than for upgrading heating systems when it comes to improving thermal comfort.

In contrast to the 2018 survey, where households were willing to pay €2,626 for high environmental sustainability, this study finds a negative willingness to pay for environmental sustainability (as shown in Figure 2c). The discrepancy between the two surveys may stem from the inclusion of building retrofits in this study. When considering building retrofits, the environmental sustainability attributes may evoke thoughts of green buildings and the use of sustainable and circular building materials, which are significantly more expensive than standard materials. The findings also suggest that if sustainable building materials are to be used to achieve environmental sustainability, government subsidies will be necessary to make them affordable for consumers.

To verify the results of households' WTP for environmental sustainability, this study compares the results on the questions "I am concerned about the environment" and "I think heat pumps are good for the environment" (as shown in Figure 2d). The results showed that respondents' concerns about the environment in our survey are higher compared to the 2018 survey but the proportion of respondents who chose "heat pumps are good for the environment" is smaller

than the portion in the 2018 survey. The reason for a remarkable decline in the households' WTP for environmental sustainability may be the addition of building retrofit. The results also present the attitude-behaviour gaps in the energy efficiency investment.

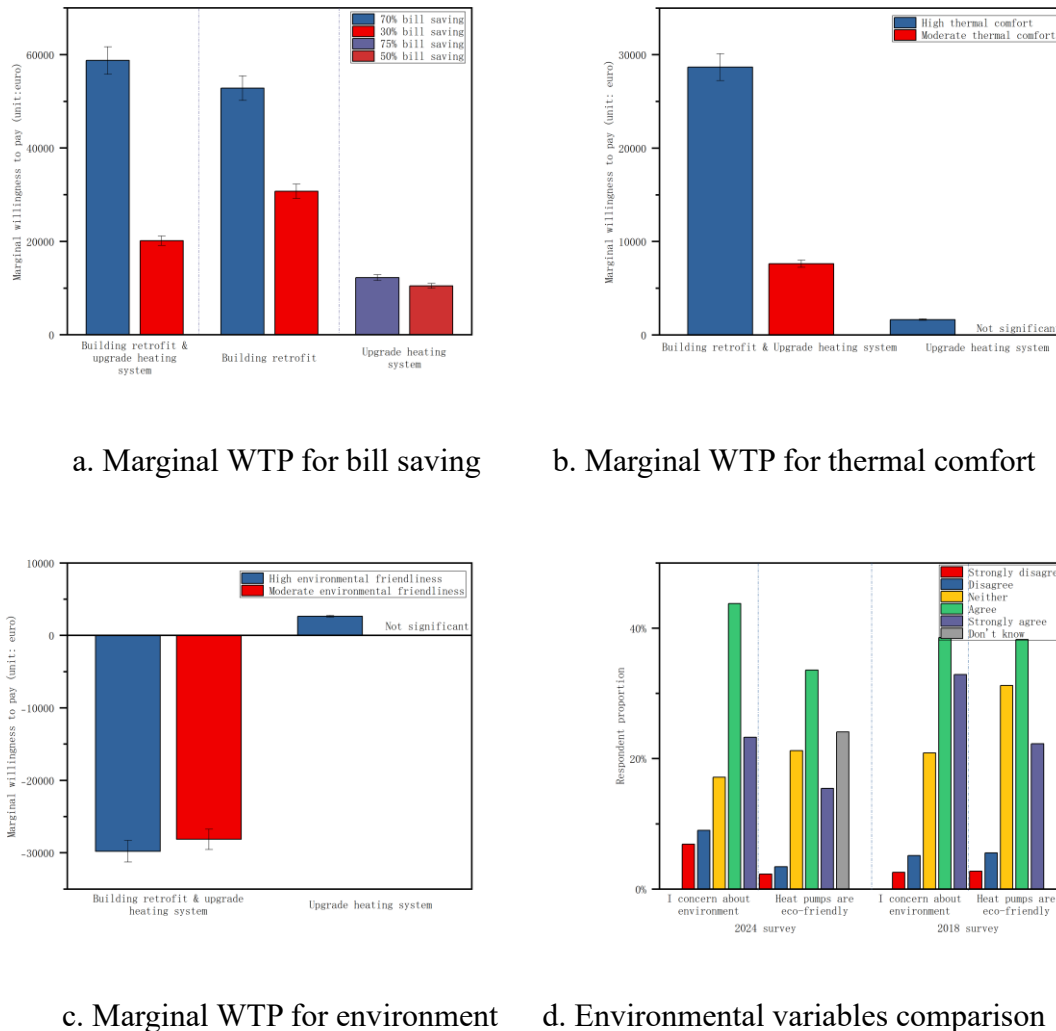


Figure 2. Marginal WTP comparison between different papers: a. Marginal WTP for bill saving, b. Marginal WTP for thermal comfort, c. Marginal WTP for environment, d. Environmental variables comparison

5.2 Expected heating cost inflation

Researchers found the mean and median implicit discount rates were higher than the general market discount rate when analyzing consumers' energy efficiency investment (Haq & Weiss, 2018; Park et al., 2023). Consumers apply individual discount rates of $19 \pm 17\%$ when purchasing efficient energy technology (Haq & Weiss, 2018). A more precise estimation by (Park et al., 2023) indicates an average individual discount rate of approximately 23.81%, with median values of roughly 6.59% under a gain frame and 10.15% under a loss frame. These frames were presented as, "If you make an energy efficiency investment, you could reduce energy costs" and "If you don't make an energy efficiency investment, you may lose the reduction of energy cost", respectively.

Based on the households' mean annual heating cost of 1,459 euros per year (as shown in Table A5), and their willingness to pay for 70% and 30% bill savings, the real discount rate could be calculated if assuming that the lifespan of the new heating system is 15 years. Based on the results of the discrete choice experiment, households are willing to pay €58,742.18 to achieve a 70% reduction in energy bills, and reversely calculate households' heating cost inflation based on the average annual heating cost, the real discount rate equals 17.3%. Based on the results of the discrete choice experiment, households are willing to pay €20125.38 to achieve a 30% reduction in energy bills, the real discount rate equals 14.6%. The results are consistent with other findings in energy efficiency investment research (Haq & Weiss, 2018; Park et al., 2023).

5.3 Robustness test

To test the robustness of the results in this paper, the potential differences in households' WTPs across subgroups of control variables including living area, region, and gender were tested because there is a limitation of logitr package and it is impossible to directly include control variables in the model. The living area was categorized as "rural" or "urban", the region was divided into "Dublin" or "out of Dublin", and the gender was grouped as "male" or "female".

The results of the robustness test showed that the living area doesn't affect the significance of households' WTP (as shown in Table A6). Meanwhile, the region affects the significance of households' WTP for thermal comfort, while the estimates for other attributes remain stable (as shown in Table A7). However, gender significantly affects households' WTP, while the results for bill saving remain stable (as shown in Table A8). The results indicated that households' preferences varied by gender. Compared with females, males have a significantly positive WTP for thermal comfort and a significantly negative WTP for environmental sustainability.

6 Conclusions

This study examined the trade-offs in home energy efficiency investments by analyzing Irish households' preferences and willingness to pay (WTP) for building retrofits and heating system upgrades. A discrete choice experiment (DCE) was conducted at a nationally representative level to collect household choice data, and a mixed logit model was used to estimate heterogeneous preferences and WTP across different attributes and within various household groups based on their heating systems and building characteristics. The main findings are as follows:

(1) Investing €25,000 in building retrofits is seen as more valuable than spending the same amount on upgrading heating systems. The attributes for retrofits costing €40,000 and €80,000 were not significant, which aligns with the survey data showing that only a small percentage of households have spent more than €25,000 on retrofits.

(2) Households are willing to pay €58,742.18 to achieve a 70% reduction in energy bills through building retrofits and heating system upgrades. Their willingness to pay for improved thermal comfort is lower than for bill savings, but it remains positive and substantial.

(3) Households with heating systems less than 10 years old prioritize building retrofits first and plan to upgrade heating systems later. For those with heating systems older than 20 years,

spending €25,000 on retrofits is considered equivalent to spending €5,204 on heating system upgrades, highlighting the urgency of replacing aging systems.

(4) Households with heating systems less than 10 years old showed significant WTP for both bill savings and improved thermal comfort from upgrading heating systems and retrofitting buildings.

(5) Homeowners who have spent less than €9,999 on building retrofits are more inclined to prioritize heating system upgrades.

Supplementary

Table A1. Summary of the survey data relative to the Irish population

Variables	Ireland (in %)	Full sample (N=1228)	Variables	Ireland (in %)	Full sample (N=1228)
Gender			Kildare	4.49%	3.76%
Female	51%	51%	Kilkenny	2.00%	1.47%
Male	49%	49%	Laois	1.69%	1.39%
Age			Leitrim	0.74%	0.49%
18-24	11%	4%	Limerick	4.15%	4.57%
25-34	16%	15%	Longford	0.88%	1.22%
35-44	20%	23%	Louth	2.69%	3.92%
45-54	18%	21%	Mayo	2.83%	3.51%
55+	35%	37%	Meath	3.95%	2.53%
Regions in Ireland			Monaghan	1.24%	0.65%
Carlow	1.21%	1.06%	Offaly	1.56%	1.96%
Cavan	1.57%	0.98%	Roscommon	1.41%	1.39%
Clare	2.53%	2.45%	Sligo	1.46%	1.55%
Cork	11.48%	13.06%	Tipperary	3.38%	3.10%
Donegal	3.35%	3.43%	Waterford	2.60%	2.29%
Dublin	28.23%	29.47%	Westmeath	1.85%	1.39%
Galway	5.37%	4.08%	Wexford	3.22%	3.92%
Kerry	3.17%	3.35%	Wicklow	2.94%	3.02%

Table A2. Survey questions

Choice set 6	Option A	Option B
Total upfront cost	€4,000	€4,000
Retrofit cost	Major work	Minor work
Disruption level	High	Moderate
Savings compared with current bill	30% cheaper	Zero

Increase in home comfort	High	Moderate
Environmental sustainability	High	Moderate
Which heating system would you prefer?		
Option A		
Option B		
I would prefer my existing heating system		

Table A3. Choice sets

Attributes	Choice values
Total upfront cost	€4,000, €10,500, €13,500, €19,500
Retrofit levels	No invasive internal work, Minor work, Moderate work, Major work
Savings compared with current bill	Zero, 30% cheaper, 70% cheaper
Increase in home comfort	Low, moderate, high
Environmental sustainability	Low, moderate, high

Table A4. WTPs for attributes through building retrofit and heat pumps in existing literature

Attributes	(Curtis, Grilli, & Lynch, 2024)	WTPs in 2023 survey	(Meles, Ryan, & Mukherjee, 2022)	WTPs in 2018 survey
Savings compared with current bill	30%	€30710	50%	€10459
	70%	€52810	75%	€12226
	Ref: 0		Ref: 0	
Increase in home comfort	/		Moderate	€1,635
	/		High	Not significant
	/		Ref: low	
Environmental sustainability	/		Moderate	Not significant
	/		High	€2,626
	/		Ref: low	

Table A5. Annual heating costs in each sample groups

Annual heating cost	Samples	Ireland (in %)	Annual heating cost	Samples	Ireland (in %)
€0-€499	79	6%	€1750-€1999	19	2%
€500-€749	115	9%	€2000-€2249	133	11%
€750-€999	89	7%	€2250-€2499	14	1%
€1000-€1249	184	15%	€2500-€2749	51	4%
€1250-€1499	36	3%	€2750-€2999	6	*
€1500-€1749	119	10%	€3000+	75	6%
Don't know	306	25%			
Mean (€'s)			1495		

Table A6. Robustness test of WTPs across different living areas

Variables	Value of variables	WTPs (unit: euro)	
		Rural (N=246, 60%)	Urban (N=166, 40%)
Retrofit levels Ref: No invasive internal work	Major work	-13380.50	-13743.00
	Moderate work	-2518.14	9780.87
	Minor work	32049.53**	37447.31**
Savings compared with current bill Ref: 0	30%	20200.71***	22890.20***
	70%	58356.29***	80386.65***
Increase in home comfort Ref: low	Moderate	10637.15*	12992.78*
	High	38733.18*	48651.91**
Environmental sustainability Ref: low	Moderate	-33494.40**	-41276.70**
	High	-30737.60*	-55324.60***

Table A7. Robustness test of WTPs across different regions

Variables	Value of variables	WTPs (unit: euro)	
		Dublin (N=126, 31%)	Out of Dublin (N=286, 69%)
Retrofit levels Ref: No invasive internal work	Major work	-21149.80	-1312.52
	Moderate work	-6867.58	13106.09
	Minor work	25305.52**	26861.16**
Savings compared with current bill Ref: 0	30%	19707.15***	19532.67***
	70%	61579.98***	52597.09***
Increase in home comfort Ref: low	Moderate	9549.93	6343.01
	High	32442.70*	25313.32
Environmental sustainability Ref: low	Moderate	-28228.80**	-27038.90*
	High	-26828.30*	-29389.50*

Table A8. Robustness test of WTPs across different genders

Variables	Value of variables	WTPs (unit: euro)	
		Male (N=221, 54%)	Female (N=191, 46%)
Retrofit levels Ref: No invasive internal work	Major work	-15613.20	-3363.66
	Moderate work	2168.54	7900.34
	Minor work	35596.56***	13556.65
Savings compared with current bill Ref: 0	30%	24166.30***	16654.43***
	70%	81155.85***	32705.51*
Increase in home comfort Ref: low	Moderate	9666.03*	4936.484
	High	40904.36**	10470.94
Environmental sustainability Ref: low	Moderate	-40408.50***	-10243.20
	High	-47497.00***	-6100.39

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