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Article

Barriers for Homeowners in Decisions to Undertake Government-Led Energy Efficiency Renovation Projects in Northern China

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Abstract: The Chinese government has taken actions to promote energy efficiency through the renovation of residential buildings in the Northern Heating Region. Homeowners have been encouraged to undertake government-led energy efficiency renovation; however, their decisions to undertake the renovation are affected by several barriers. The lack of participation from homeowners has brought difficulties in execution and financing. This study empirically investigated the barriers facing homeowners when undertaking the renovation, including barriers generated from the homeowner's cognitive biases. The results show that barriers associated with capital cost, unbalanced financial plan, unclear process, comfort, and increased energy prices are the most widely considered when homeowners make decisions about undertaking renovation projects. An adverse decision is most likely to be generated when: (1) when homeowners perceive the financial plan as unfair, (2) when they have already done renovation at their own expense, or (3) when they have the feeling of losing initiative. Among all the individual factors, the homeowners' gender, age, education level, and building type are significant in predicting their decisions. By drawing on insights from behavioral economics, we analyzed the mechanisms behind these barriers. The findings can help policymakers to design more cost-effective policy instruments to mitigate the barriers.

Keywords: energy efficiency renovation; barriers; behavioral economics; cognitive bias; existing residential buildings



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1. Introduction

The energy performance of the large existing housing stock in China is much more unsatisfactory than that in new buildings [1]. The annual energy consumption in the operation phase of existing urban and rural residential buildings is 238 million tce or 7 million tera joule, accounting for 5.2% of total national energy consumption [2]. The total floor area of domestic urban residential buildings in China is estimated to be 26 billion m², of which 12.9 billion m² are located in the Northern Heating Region [3]. This climate region consists of 15 provinces and municipalities in the country's severe-cold zone and the cold zone [4]. Approximately half of these buildings have a district heating system, and the average energy consumption for district heating is 18.55 kgce/m² (≈151 kWh/m²) [3]. Thus, energy efficiency renovation of residential buildings in the Northern Heating Region has become a crucial part of the domestic building energy issue [5].

The main target of the renovation is multi-floor private-property apartments built before the 2000s in the urban area [6]. Technical measures suitable for the Northern Heating Region include insulating building envelope; upgrading heating supply system; maintaining or replacing heating pipes to increase the energy efficiency; adopting heat metering system and indoor heating control system; and adopting renewable energy

sources [6]. These measures aim at reducing energy consumption and improving indoor comfort levels during the heating seasons from November to March in most provinces.

Because of the physical features and property rights of apartment buildings, renovation in this region has been implemented through a “top-down” model. Central and local governments take charge of renovation projects and make the majority of the investment [7], while homeowners can contribute by cooperating with the governments, including agreeing with the renovation plan and making a minor investment [6]. Technical measures of energy efficiency renovation mainly aim at reducing energy consumption by increasing energy efficiency and reducing heat loss during the heating seasons, which runs from November to March in most provinces. According to the calculation of the Ministry of Housing Construction, given the average cost of building energy efficiency renovation of CNY 200–300/m² (CNY 1 ≈ EUR 0.13), the cost will reach several thousand billion yuan for the entire region, creating a tremendous financial burden to the government.

Globally, it is well-documented that an energy-efficiency gap exists between the technical and economic potential of the housing stock and the adoption rate of energy efficiency renovation by homeowners [8]. Despite the fact that homeowners can benefit from the improvement of their homes’ energy performance in many aspects, such as potential energy cost savings in the future, improved thermal comfort, increased property value, etc., the adoption rates of these major efficiency improvements are lower than expected [9,10]. The same is true for China. Although undertaking a government-led renovation does not require a lot of effort and expense from residents, their level of participation is still not satisfactory [11]. Homeowners would perceive a decision to embark on energy efficiency renovation as a complex activity due to multiple barriers associated with the renovation.

Previous studies on homeowners’ barriers are mainly based on the premise that they behave in a rational way. Nevertheless, an individual’s decision-making in real life is subject to several cognitive biases [12], which can directly or indirectly influence their renovation decisions. Besides, many studies were carried out in countries or regions where homeowners own the exclusive property rights of their homes and the surrounding areas, which allows them to make decisions about home renovation independently. In contrast to the previous studies, this study takes homeowners’ cognitive biases into consideration to complement the traditional approach and give explanation to homeowners’ decision-making in the Chinese context. We examine the influence of barriers perceived by homeowners, including barriers associated with finance, governance, impact on the dwelling, and inconvenience. Insights from behavioral economics theory are induced to identify barriers generated from an individual’s cognitive biases. We also explore the influence of homeowners’ socio-demographic characteristics, building features, and behavioral factors. The findings of the study will provide references to design targeted policies to overcome homeowners’ barriers without significantly increasing the governments’ expenditure.

The content of the paper is organized as follows. Section 2 introduces the background of energy efficiency renovation in China, synthesizes barriers identified by existing literature, and hypothetically presents barriers related to an individual’s cognitive biases. Section 3 describes the methodology, while Section 4 presents the empirical data. Section 5 discusses the findings from four aspects: homeowners’ willingness to undertake renovation, the barriers that can be identified, the impact of cognitive biases, and the suggestions on government-led renovation. Section 6 gives conclusions and policy applications.

2. Literature Review

2.1. Barriers in Homeowners’ Decisions to Undertake Energy Efficiency Renovation

Barriers for homeowners to improve the energy performance of their homes have been the subject of a number of previous studies and have been categorized in different ways. Tuominen et al. [13] found that in EU member states, improvements in energy efficiency are hindered by a lack of effect on property prices. Stieß and Dunkelberg [14] found the main barriers to adoption of low and zero carbon technologies to be a lack of personal involvement in the issue and economic reasons. Balcombe et al. [15] reviewed

barriers associated with microgeneration adoption and categorized them as financial, environmental, security of supply, uncertainty and trust, inconvenience, and impact on residence. Wilson [8] reviewed the applied behavioral research on energy efficiency and summarized the barriers related to finances, information, and decision-making, respectively. Michelsen and Madlener [16] found commonly identified barriers including risk, high upfront costs for technologies, split incentives, imperfect information, hidden costs, and bounded rationality. Abdullah et al. [17] found that despite the high interest, the usage of solar home systems has not been widely accepted by Pakistani families because of high cost, lack of information and trust on providers. Azizi et al. [18] found the difficulty of finding a low-interest loan and reliable information sources would impede the intention to implement energy efficiency renovation. Alsabbagh [19] concluded several challenges in both buying and installing solar panels, including capital cost, lack of information, and maintenance requirements.

Some studies extended the research of barriers to include more non-monetary factors. Klöckner and Nayum [20] found the most significant barriers of energy investments in privately owned houses to be strict building protection regulations, perceived lack of contractors' competences, doubt in the trustworthiness of information, and the feeling that the right point in time had not come yet. Ebrahimigharehbaghi et al. [21] identified the lack of reliable experts and information, time and effort to find information, and complexities in work/process as critical influencing factors in renovation decision.

Some other studies explicitly evaluated the influence of a particular one or category of barriers. For example, Sunikka-Blank and Galvin [22] found potential conflicts between energy and heritage values could affect homeowners' thermal retrofit decisions in Cambridge. De Wilde [23] found homeowners did not adopt domestic low-carbon retrofit measures because they reflected upon the industry as poorly regulated and lacking transparency. De Vries et al. [24] focused on hassle as a barrier to a green home.

Policies and policy packages, including instruments such as information, price mechanisms, financing, and regulatory policies have been published in many countries to overcome the barriers homeowners are confronted with [25]. Different instruments intend to overcome different types of barriers. For example, information instruments can help overcome information barriers and some behavioral barriers; regulatory instruments address inattention to operating costs and energy-saving performance of certain products; economic and financial instruments can address rational inattention, bounded rationality, and present bias [26].

In China, energy efficiency policies are mainly implemented by a command-and-control approach [27]. These policies include design standards, national plans, and energy laws. Other policy instruments, such as economic, fiscal, and market-based instruments, mainly aim at encouraging local governments to provide local financial support for energy efficiency renovation [28]. Information and voluntary action policies are rather scarce, and their implementation faces obstacles such as insufficient testing mechanisms, weak experience, and lack of awareness [29]. Policy instruments based on understanding their demands and the situations they face are lacking. Thus, in the following section, we will hypothetically analyze barriers that Chinese homeowners are confronted with.

Barriers appear, disappear, and are transformed during the renovation process [30]. They will overlap and interact, so it is normal that a phenomenon can be explained by multiple barriers, and a barrier can fall under different categories. Thus, there is no fixed categorization of barriers in the existing literature.

2.2. Barriers for Homeowners to Undertake Government-Led Energy Efficiency Renovation in China's Northern Heating Region

Based on the review of recent studies and the understanding of China's context, we categorize the barriers that may influence the decisions to undertake government-led energy efficiency renovation into finance, governance, impact on the dwellings, and inconvenience.

We do not include barriers that are obviously not applicable to China, such as inability to get a loan or to find skillful workers.

2.2.1. Finance

In China, homeowners only need to bear part of the cost, about 10% to 15% at most [31], which should be affordable for most homeowners. However, even with this small proportion, homeowners are still unwilling to pay for the renovation [32]. In the housing sector, energy prices are so low that the extra cost for energy efficiency cannot be retrieved, so such investments are financially unattractive [33].

Furthermore, the government has subsidized district heating in the housing sector. Its cost has been charged by the floor area of units rather than by actual consumption, and some homeowners are not even aware of the subsidy. After getting used to this seemingly unreasonably cheap yet straightforward situation, many homeowners worry that their energy costs would increase if heat metering were adopted [34], because once the new calculation method is applied, the previous subsidy mechanism will be changed, and homeowners may no longer receive subsidies. Therefore, their perception of this change is that energy prices increase after renovation.

In the past decade, to ensure the promotion of renovation, most projects have proceeded without homeowners' investment. The direct beneficiaries of the central government's incentives are mainly local governments and developers [35]. In the future, when the financing of renovation increasingly relies on homeowners' input, the lack of available incentive mechanism for them will become a serious problem that may reduce their eagerness towards the renovation.

2.2.2. Governance

In apartment buildings, the property of each unit belongs to different homeowners. Chapter 3: Communicate with residents, MOHURD Guideline [6] suggests that a project can be executed if 75% of homeowners agree on the program and sign the agreement. Nevertheless, the suggestion is not mandatory, and is often not executed in renovation projects [11]. Thus, homeowners would perceive the process to be unclear.

Unifying the opinions of homeowners from the same apartment building highly relies on door-to-door visits by a working group under the local governments' commission [6]. Working group members tend to be as efficient as possible to get the consent of the homeowners, which makes the homeowners feel pressured for time.

Moreover, there are not yet mandatory regulations on homeowners' rights and obligations in the government's official documents. Responsible agencies may delay or fail to publish the progress and relevant information to the homeowners quickly and adequately. Consequently, homeowners are unsure about the outcomes of the renovation and will distrust the relevant agencies.

2.2.3. Impact on the Dwellings

Homes' living spaces and functions can be affected after renovation. For example, the usable floor area can become smaller because of added energy efficient facilities and insulation materials; balconies can no longer be used to preserve food in winters once being insulated [34].

The convenience of the dwelling may also be affected after renovation. The adoption of heat metering and the new calculation method of heating costs will force homeowners to change their daily routines and habits. To reach a balance between ideal temperature and saving money, homeowners may need to switch on and switch off the heater more frequently and regularly adjust the valve/thermostat.

Many homeowners are resistant to sacrifice comfort for saving energy [34]. They also have a solid intention to maintain the lifestyle they have been accustomed to, such as opening windows for fresh air, even in winter. If the cost of heating is charged by actual consumption, the waste would be reflected immediately in increased energy bills.

Some homeowners have decorated their heaters for a better appearance, for example, replacing cast-iron free-standing radiator systems with ceramic systems, which take up less room and heat up more quickly; or installing a decorative radiator cover. The adoption of heat metering and the replacement of heating pipes, in which indoor construction is necessary, is likely to influence the aesthetics, with all the mess and dirt of construction work.

2.2.4. Inconvenience

Some barriers would cause inconvenience either before or during the renovation process, including hassle, information cost, preference, and salient events.

Firstly, since the renovation needs to be carried out throughout the whole building, noise and dirt disturbance will continue for a relatively long period. Secondly, homeowners do not have trustworthy sources to support their decision-making, which affects their enthusiasm [35]. Thirdly, many homeowners prefer to invest in other major improvement measures, such as adding lifts to old buildings and extending underground parking. Once the energy efficiency renovation takes place, they may lose the opportunity to undertake other types of renovation. Finally, because of the rapid urban renewal process and the short lifespan of residential buildings in China [36], homeowners may find the renovation less attractive if they expect to move out in the near future.

2.3. Cognitive Biases as Barriers to Homeowners' Renovation Decision

2.3.1. Bounded Rationality and Cognitive Biases

Traditional economics assumes that individuals behave with perfect rationality, and their preferences are fixed. Thus, the essence of an individual's action is looking for a solution that can best match their expectations and bring the most benefit. However, it has been widely observed that an individual's behavior in reality often deviates from this ideal model, especially when required to make decisions under uncertain situations [12]. Because of bounded rationality and limited capability in acquiring and processing information, they make judgments based on their perception and take shortcuts to increase the efficiency of the decision-making process, also known as 'judgment heuristics' [37]. Cognitive biases can be generated as a by-product of such a process and can drive individuals to stop at a satisfying solution, rather than finding a "perfect" solution to maximize the utility of money [38,39].

Energy efficiency renovation is a complex circumstance for homeowners, especially when they need to make a decision under uncertain conditions within a limited time. Moreover, they have few chances to meet professionals and rarely obtain relevant information [40]. Thus, cognitive biases negatively affect their renovation decision when they seek to simplify the decision-making process. It should be comprehensively understood and considered when studying homeowners' barriers in their decisions.

2.3.2. Barriers for Homeowners to Undertake Renovation Generated from Cognitive Biases

In previous studies about household energy decisions, researchers have analyzed certain situations and suggested cognitive biases that are particularly relevant to it [41,42]. Similarly, we proposed some barriers generated from cognitive biases that might be relevant in energy efficiency renovation in China.

By their very nature, the hypothetical barriers do not measure actual cognitive biases. We will give some examples as the proxy of each cognitive bias to explain the process: how homeowners are affected by these cognitive biases when they make decisions and how these cognitive biases can cause barriers in renovation projects.

1. Spontaneous purchase/renovation:

Due to *sunk cost effect*, people have a high tendency to continue an endeavor once an investment in money, effort, or time has been made. Thus, if homeowners have purchased additional heating appliances or have renovated their homes at their own expenses, they

would perceive undertaking renovation as a ‘waste’ of these appliances and keep ‘investing’ in them, although to stop using these appliances would be a better choice in the long term.

2. Unbalanced financial plan:

Individuals make *social comparisons* and evaluate their performance, possessions, and wellbeing, not in absolute terms but relative to others. Gross [43] found that perceptions of fairness do influence how people perceive the legitimacy of the outcome of the wind farm. In the renovation of apartment buildings, it is common to benefit some units at the perceived expense of others. An unfair scheme will affect homeowners’ acceptance of the renovation plan.

3. Procrastination:

The phenomenon that individuals are susceptible to the over-pursuit of immediate gratification is called *present bias* [12,44], which may result in procrastination when costs are immediate. Thus, homeowners are reluctant to sacrifice short-term convenience or comfort for long-term benefits, such as expected future savings and improved indoor comfort levels.

4. Coercion:

When people feel their behavioral freedoms are reduced or threatened with reduction, they develop *reactance* [45], which can be maximized when forced to choose options that they do not like within a limited period [46]. Thus, when homeowners are asked to respond to a given option in a limited time and feel the pressure that they are highly expected to say yes, they tend to protect their freedom by doing the opposite.

5. Lose initiative:

Because of *endowment effect*, people give higher value to what they have and feel greater pain when they lose it [47]. Although undertaking a government-led renovation can yield better outcomes than each homeowner renovating his/her home separately because the latter is more difficult and less cost-effective, homeowners may overvalue the freedom to take the initiative and thus be unwilling to give it up.

6. Stick to the status quo:

People tend to prefer things to stay relatively the same as usual because of *status quo bias* [48,49]. Homeowners often fear or are unwilling to make significant changes to their status quo and tend to allow only minor and quick adjustments to their current home.

7. Uncertainty:

Risk aversion bias and *loss aversion bias* describe an individual’s worry about potential uncertainty in the future [47]. Homeowners are often unsure about the outcomes before the renovation takes place. Compared with accepting the unknowns, many homeowners would be inclined to drop the renovation decision to avoid the risk of loss.

8. Family’s opinion/peer’s opinion:

The way individuals receive and process information can influence their decisions. This process involves several cognitive biases: firstly, when homeowners need to consider undertaking a government-led renovation, under the influence of *availability bias*, the first pieces of information that come to their mind are those that are readily available [50], usually from their family members and neighbors; secondly, they process new information in a way that can intensify the existing information which is possible to be partly inaccurate because of *confirmation bias* [51]. They can be resistant towards new knowledge if it is inconsistent with their prior belief. Thus, the adverse opinion of family members and peers will become a barrier.

Through analysis of the existing literature, the theory of behavioral economics, and the Chinese situation, a list of potential barriers can be synthesized (see Table 1). Based on analysis of the above-mentioned examples, we allocate the barriers generated from cognitive biases into the category that they are most likely to belong to.

Table 1. Potential barriers for homeowners to undertake renovation in China's Northern Heating Region.

Category	Barriers	Description
Finance	Capital cost	Cost of the renovation
	Long payback period	Payback period too long or cannot payback
	Increased energy prices	Increased cost for heating after renovation
	Lack incentives	No subsidies available
	Spontaneous purchase	Previously purchased heating appliances wasted
	Spontaneous renovation	Have already done renovation at their own expense
	Unbalanced financial plan	Financial plan not fair and reasonable
Governance	Unclear process	The process not open and transparent
	Distrust	Unsure about the reliability of responsible agencies
	Time pressure	The feeling of having to make the decision in too short a time
	Procrastination	Hesitate to make decision
	Coercion	The feeling of being forced to make a decision
	Lose initiative	The feeling of being unable to make the decision on their own will
Impact on the dwelling	Function	The living space of the dwelling may be affected
	Convenience	The convenience of the dwelling may be affected
	Comfort	The comfort of the dwelling may be affected
	Aesthetics	The aesthetics of the dwelling may be affected
	Stick to the status quo	Preference to maintain the status quo
	Uncertainty	Uncertain about the outcomes of renovation
Inconvenience	Hassle	Noise and dirt during construction
	Information cost	Lacking a trustworthy information source
	Preference	Other types of renovation are preferred
	Salient events	Plan to move out in the future
	Family's opinion	Family members do not support the renovation
	Peer's opinion	Neighbors or friends do not support the renovation

3. Methodology

After carefully comparing the advantages and feasibility of different approaches, this study uses the data from homeowners' intentions indicated by their statements in a questionnaire survey (see Supplementary Materials) to measure the influence of various barriers and test the proxy of potential cognitive biases associated with homeowners' renovation decisions, because it is not easy to get permission to participate in an actual renovation project and access all the homeowners' data.

The questionnaire was disseminated by both hard copies and an online survey website. To avoid the impact of unstable annual climate conditions, the eligible participants were limited to homeowners living in the same apartment in the Northern Heating Region for at least three consecutive years. A pilot questionnaire of around 30 participants was conducted to ensure that the questions' purpose can be delivered adequately. Some modifications were made afterwards to improve the clarity of the questionnaire.

A total of 500 hard copies of the questionnaire were sent to homeowners directly in person in Beijing municipality, Tianjin municipality, Hebei province, and Heilongjiang province. These municipalities and provinces were chosen because they are among the key areas for energy efficiency renovation in the Northern Heating Region. After agreeing to participate in the survey, participants were asked to bring the questionnaire home and finish it within two weeks. Altogether, 185 valid questionnaires were collected. Meanwhile, 316 respondents filled out the online questionnaire assembled through an online survey website, "wenjuanxing (Chinese: 问卷星)". The website provides an online system in which the founder can create, edit, and share the questionnaire. A total of 294 valid responses were collected from unpaid anonymous respondents in all 15 provinces and municipalities in the Northern Heating Region. Thus, the total amount of samples in this study was $N = 479$. The order of options in the body of the questionnaire was randomly displayed.

Respondents were asked to assume that they are facing an actual situation of government-led energy efficiency renovation in their apartment. The questionnaire provides a short text describing the details of the renovation explaining the process and the cost. Then, respondents needed to answer the question “*Would you like to undertake a government-led energy efficiency renovation?*” and answer another multiple-choice question: “*Which of the following barriers may cause you to disagree with undertaking a government-led energy efficiency renovation?*”. There are 25 barriers in total which were randomized and presented to the respondents.

We also collected respondents’ personal information, including their demographic profile, the building features of their homes, and their behavioral factors.

The profile of the respondents is shown in Table 2. Our sample is not representative of China’s population because it is composed primarily of homeowners under 40 years old with at least a university degree. We can have a more comprehensive view if we reach out to a larger and more balanced sample. Nevertheless, in Chinese families, the older generation often relies on their grown-up children to make decisions about their properties. The analysis of the current sample can already reflect homeowners’ perceived barriers and renovation decisions.

Table 2. Respondents’ individual factors.

	Variable	Classification	Percent (%)
Socio-demographic characteristics	Gender	Male	51.8
		Female	48.2
	Age	30 and below	45.8
		31–50	31.1
		51 and above	23.1
	Occupation status	Student	20.7
		Full-time worker	57.4
		Unemployed/retired	18.7
		Others	3.2
	Highest education level	College and below	30.2
Undergraduate		42.2	
Postgraduate and above		27.6	
Household annual income (CNY)	100,000 and below	51.7	
	100,001 to 200,000	27.6	
	200,001 and above	20.7	
Building features	Total # of floors of building	6 floors and below	48.6
		7 floors and above	51.4
	Floor area of unit	50 m ² and below	20.4
		51 m ² to 90 m ²	35.6
		91 m ² to 120 m ²	24.2
	121 m ² and above	19.8	
Behavioral factors	Satisfaction of indoor comfort	Dissatisfied	23.7
		Fair	67.7
		Very satisfied	8.6
	Awareness of environmental protection issues	Unconcerned	32.1
		Generally concerned	54.8
		Very concerned	13.1
	Knowledge of energy efficiency renovation	Not at all	15.8
		Heard about it	47.7
		Clearly understand the meaning	36.5
	Attitude towards energy efficiency renovation	Neutral or negative	6.8
		Positive	47.3
		Very positive	46.0
Experience of renovation	Renovated	19.4	
	No renovation	80.6	

Data analysis consists of several steps. In each step, the appropriate statistical test is applied. First, descriptive analysis is performed to rank the barriers to undertake renovation based on homeowners’ perceptions. Then, we group homeowners by their stated willingness to undertake the renovation, and explore in each group, what are the most perceived barriers. Chi-square test was conducted to identify what barriers are significantly different between the two groups. In the final step, binary logistic regression was applied to find out what combination of individual factors and barriers is most likely to have a negative impact on the possibility to undertake renovation.

4. Results

4.1. Homeowners' Perceived Barriers in Decision to Undertake Government-Led Energy Efficiency Renovation Projects

Barriers for homeowners to undertake government-led renovation are collected by the question: *Which of the following barriers may cause you to disagree with undertaking a government-led energy efficiency renovation?* Respondents were asked to select all that apply to them (yes = 1, or no = 0). Therefore, the variables are binary. We calculate the frequency and percentage of positive responses for each barrier (Table 3). “Cost of the renovation”, “financial plan not fair and reasonable”, “the process not open and transparent”, “the comfort of the dwelling may be affected”, and “increased cost for heating after renovation” ranked the top five reasons for homeowners not to undertake the renovation.

Table 3. The frequency of each barrier.

Barrier	Description	Frequency	Percent (%)
f-1	Capital cost	246	52.2
f-2	Unbalanced financial plan	234	49.7
g-1	Unclear process	205	43.5
d-1	Comfort	192	40.8
f-3	Increased energy prices	178	37.8
f-4	Lack incentives	175	37.2
g-2	Distrust	173	36.7
i-1	Hassle	173	36.7
d-2	Function	162	34.4
d-3	Convenience	134	28.5
f-5	Long payback period	109	23.1
i-2	Salient events	107	22.7
i-3	Preference	107	22.7
g-3	Coercion	98	20.8
f-6	Spontaneous purchase	96	20.4
i-4	Information cost	90	19.1
g-4	Time pressure	84	17.8
d-4	Uncertainty	86	18.3
d-5	Aesthetics	80	17.0
i-5	Family's opinion	64	13.6
d-6	Stick to the status quo	60	12.7
f-7	Spontaneous renovation	49	10.4
i-6	Peer's opinion	48	10.2
g-5	Lose initiative	41	8.7
g-6	Procrastination	30	6.4

f = finance, g = governance, d = impact on the dwelling, i = inconvenience. Bold: newly identified barriers generated from cognitive biases.

When sorted by category, it can be concluded that, in general, barriers about finance are the most severe (see Figure 1). It is not surprising that the considerations about cost and financial plan are prioritized by homeowners, followed by the fairness of the financial plan. Furthermore, homeowners would be concerned about the project's practical details, such as the impact on the dwelling and their daily life both during and after the renovation.

4.2. Main Barriers Related to the Decision Not to Undertake Renovation Projects

Table 4 presents whether homeowners would agree to undertake a government-led energy efficiency renovation project. A total of 84.1% of respondents chose “yes” after reading the description about a typical government-led renovation project, indicating a relatively high approval rate.

Table 4. Homeowner's decision on whether to undertake a government-led energy efficiency renovation project.

Classification	N	Percent (%)
I would undertake government-led renovation	366	84.1
I would not undertake government-led renovation	69	15.9
Total	435	100%

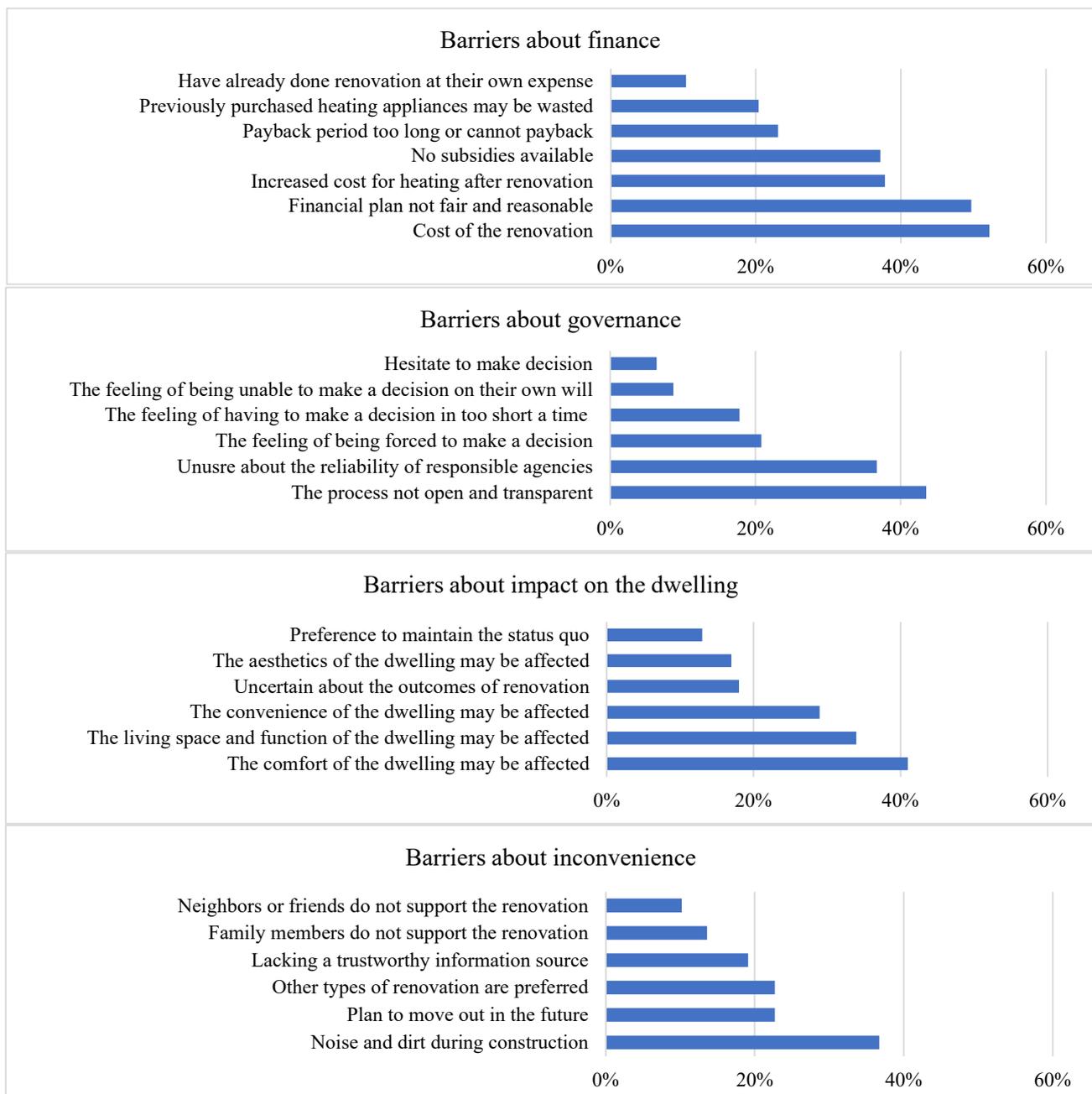


Figure 1. Homeowners' perceived barriers in four categories.

As shown in Table 5, for homeowners who are willing to undertake renovation, the top five barriers are: "cost of the renovation", "financial plan not fair and reasonable", "the process not open and transparent", "the comfort of the dwelling may be affected", and "no subsidies available". These barriers are the same as the top five barriers for the entire sample. For those who are unwilling to renovate, *the process not open and transparent, noise and dirt during construction, unsure about the reliability of responsible agencies, cost of the renovation, financial plan not fair and reasonable* were selected the most.

Table 5. Barriers perceived by homeowners who are willing to undertake the renovation and those who are not and the significance of group difference.

Variables	Unwilling Group N (%)	Willing Group N (%)	Chi-Square Test of Independence	
			χ^2	p-Value
Barriers to finance				
Cost of the renovation	23 (33.3)	199 (54.5)	10.425	0.001 ***
Financial plan not fair and reasonable	22 (31.9)	192 (52.6)	9.966	0.002 **
No subsidies available	18 (26.1)	146 (40.0)	4.778	0.029 *
Increased cost for heating after renovation	20 (29.0)	139 (38.1)	2.069	0.150
Payback period too long or cannot payback	12 (17.4)	87 (23.8)	1.369	0.242
Previously purchased heating appliances may be wasted	18 (26.1)	68 (18.6)	2.031	0.154
Have already done renovation at their own expense	12 (17.4)	34 (9.3)	3.994	0.046 *
Barriers to governance				
The process not reasonable and transparent	29 (42.0)	157 (43.0)	0.023	0.880
Unsure about the reliability of responsible agencies	26 (37.7)	129 (35.3)	0.138	0.710
The feeling of being forced to make decision	16 (23.2)	78 (21.4)	0.113	0.737
The feeling of having to make the decision in too short a time	17 (24.6)	61 (16.7)	2.472	0.116
The feeling of not being able to make the decision on their own will	15 (21.7)	24 (6.6)	16.315	0.000 ***
Hesitate to make decision	2 (2.9)	24 (6.6)	1.393	0.403
Barriers to the impact on the dwelling				
The comfort of the dwelling may be affected	19 (27.5)	152 (41.6)	4.837	0.028 *
The living space and function of the dwelling may be affected	20 (29.0)	120 (32.9)	0.402	0.526
The convenience of the dwelling may be affected	20 (29.0)	100 (27.4)	0.073	0.787
Uncertain about the outcomes of renovation	15 (21.7)	65 (17.8)	0.596	0.440
The aesthetics of the dwelling may be affected	10 (14.5)	63 (17.3)	0.318	0.573
Preference to maintain the status quo	10 (14.5)	43 (11.8)	0.398	0.528
Barriers to inconvenience				
Noise and dirt during construction	27 (39.1)	135 (37.0)	0.114	0.736
Plan to move out in the future	12 (17.4)	89 (24.4)	1.589	0.207
Other types of renovation are preferred	15 (21.7)	82 (22.5)	0.018	0.894
Lacking a trustworthy information source	14 (20.3)	66 (18.0)	0.197	0.657
Family members do not support the renovation	11 (15.9)	50 (13.7)	0.242	0.623
Neighbors or friends do not support the renovation	8 (11.6)	36 (9.9)	0.191	0.662

* p-value \leq 0.05; ** p-value \leq 0.01; *** p-value \leq 0.001.

Then we used chi-square test to explore the group differences. We found that the “willing” group have a significantly higher perception of the following barriers: *cost of the renovation, financial plan not fair and reasonable, no subsidies available, and the comfort of the dwelling may be affected*. Meanwhile, the “unwilling” group perceive much more of the *feeling of not being able to make the decision on their own will*.

4.3. Significant Factors Regarding the Willingness to Undertake Renovation in the Binary Logistic Regression Analysis

In this step, we use logistic regression to investigate the impact of socio-demographic characteristics, building features, and barriers to the willingness to undertake renovation. The dependent variable is whether the respondent would like to undertake a government-led energy efficiency renovation, after them being presented the descriptive text of the renovation.

Statistical Package for the Social Sciences (SPSS) (version 25.0) was used in the analysis. The dependent variable is binary (yes = 1, no = 0). Before performing the analysis, the multicollinearity of socio-demographic characteristics and building features is tested using the variance inflation factor (VIF). VIF values of more than 10 are often considered as showing multicollinearity. The results show that the VIF of the planned regression is between 1.111 and 2.345, which indicates that the multicollinearity is acceptable, and the data is reliable.

Based on the above-mentioned main barriers, a wide range of variables were tested for inclusion in the model to identify factors that can best predict homeowners’ decisions. The variables that provided the optimum predictive capability were included in the model and are presented in Table 6 below. The results of omnibus tests of model coefficients are significant, indicating the model shows better results with explanatory variables than without. The Hosmer–Lemeshow test indicates that the information in the data has been fully extracted, and the model has better goodness of fit (Table 6).

Table 6. Assessing the regression regarding the goodness of fit.

Omnibus Tests of Model Coefficients			Hosmer–Lemeshow Test		
Chi-Square	df	Sig.	Chi-Square	df	Sig.
51.820	7	0.000	2.346	8	0.969

Table 7 indicates what factors are most significantly associated with adverse decisions. Based on the results, homeowners' age, gender, highest education level, and building type are statistically significant.

Table 7. Logistic regression analysis.

Category	Variable	B	S.E.	Wald	Sig.	Exp(B)
Socio-demographic characteristics	Age	0.744	0.256	8.451	0.004 **	2.104
	Gender (1)	−0.717	0.316	5.148	0.023 *	0.488
	Highest education level	−0.466	0.230	4.115	0.042 *	0.627
Building feature	Building type (1)	−0.638	0.307	4.324	0.038 *	0.528
	Unbalanced financial plan	0.874	0.315	7.720	0.005 **	2.397
Barriers	Spontaneous renovation	−0.904	0.425	4.518	0.034 *	0.405
	Lose initiative	−1.482	0.415	12.735	0.000 ***	0.227

* p -value ≤ 0.05 ; ** p -value ≤ 0.01 ; *** p -value ≤ 0.001 .

Homeowners' age positively affects the likelihood of undertaking a government-led renovation: elder homeowners are more prone to it. Meanwhile, homeowners that are female and have a relatively lower education level indicate a higher tendency to renovate.

We collected data on two aspects of the building features: building type and floor area. Renovation in the Northern Heating Region has specified requirements on the construction age, building status, and energy performance of the target buildings, so in this study, these conditions are not considered. Results suggest that homeowners who live in high-rise residential building (more than six floors) are more inclined to renovate, while the floor area of the unit indicates no significant influence. Income, occupation status, and all the behavioral factors are not significant in explaining the willingness.

Among the barriers, it can be found that if homeowners have done renovation at their own expense, or have the feeling of losing the initiative, they will be less willing to undertake the government-led renovation. By contrast, if homeowners perceive the financial plan to be unbalanced, there is more chance that they would undertake the renovation.

5. Discussion

5.1. Homeowners' Willingness to Undertake Renovation

In an existing study in 2007, it was found that homeowners' enthusiasm for energy efficiency renovation was relatively low in China [52]. However, in our study, a total of 84.1% of respondents indicated their willingness to undertake a government-led renovation. Notice that the approval rate based on questionnaire results might be higher than that in reality, for respondents may tend to behave more positively in the survey than in their real lives. Nevertheless, we can still conclude that Chinese homeowners' attitudes towards energy efficiency has improved over the years. It is consistent with the findings of a more recent study in 2019 that the Chinese public's attention toward green buildings has enhanced significantly in the past decade [53].

Despite the improvement of homeowners' willingness and the rapid spreading of energy efficiency renovation, homeowners' involvement in the renovation projects is still lacking, and the energy efficiency potential of the housing stock is not fully exploited. By the end of 2018, the renovation of existing residential buildings in urban and rural areas has covered a total floor area of 1.4 billion m², only accounting for 5% of the entire building stock. Homeowners' favorable impression cannot naturally translate into the decision

to undertake the renovation, even when it is ensured that a government-led renovation can bring excellent results and is financially appealing. We found some evidence that homeowners can react unexpectedly to the setup of the government-led renovation which was intended to mitigate the difficulties for them to get involved. It suggests that barriers can not only stop homeowners from constituting the willingness to renovate but can also interfere with the implementation of the willingness.

Homeowners' unwillingness will also hinder the depth of renovation. The current heat supply system and energy costs calculation method has led to considerable heat waste. Thus, the adoption of heat metering and consumption-based pricing systems (also known as "the heat reform") is an important part of energy efficiency renovation. However, its penetration rate in most provinces is very low [28], partly because of homeowners' reluctance. Barriers associated with the heat reform must be eliminated to accelerate the current depth of renovation.

5.2. Barriers for Homeowners to Undertake Renovation

5.2.1. Main Barriers Perceived by Homeowners

The main barriers are those related to financial issues and comfort considerations, which is consistent with a large body of existing literature. Moreover, compared to the situation in other countries and regions where homeowners can be motivated to renovate their home by the potential savings on energy bills, Chinese homeowners draw back because the cost for district heating may increase after the renovation. They can also refuse the renovation to avoid hassle and distrust of responsible agencies. Apart from these barriers, *unclear process* is also a determinative barrier. Compared to the homeowners who are willing to undertake the renovation, those unwilling to renovate are more sensitive to the feeling of losing initiative.

Based on these results, we conclude that homeowners tend to avoid uncertain and complex situations, which is specifically relevant to the nature of the government-led model. Although there is much uncertainty even if homeowners take on the renovation independently, this is particularly salient in government-led projects. Homeowners feel out of control when they must accept arrangements from the outside passively, and the details are not explained clearly, because people are more sensitive to the feeling of losing something.

The findings can also support the idea that some barriers are specifically relevant in different stages of the decision [21]. When homeowners are considering or planning the renovation, the feeling that the renovation is difficult and troublesome will result in decisions against it. In this stage, the barriers mainly arise from uncertainty and lack of knowledge. After overcoming the barriers in the early stage, homeowners will continue the decision-making process and have some practical conditions well-considered, such as cost-effectiveness, potential outcomes, and how the construction work will be carried out.

5.2.2. The Impact of Individual Factors

Through the regression analysis, we better understand how the perceived barriers of different groups affect their decisions to undertake the renovation.

Among socio-demographic characteristics, the homeowners' age positively affects the likelihood of undertaking a government-led renovation project, which is contrary to several studies suggesting younger homeowners are more environmentally conscious and have more reasons to renovate [54]. One possible explanation is that older people spend more time at home and thus have the motivation to improve the indoor thermal conditions and the possibility to adjust their lifestyle to implement the process. Another reason is that government-led renovation projects in China take fewer efforts from homeowners: the responsible agencies will make most of the arrangements, making it easier for elderly homeowners to get involved.

Some previous studies found high-educated homeowners can gather reliable information and get a low-interest bank loan more easily [18], and thus are more likely to renovate. This study found the opposite. Like the influence of age, we can also infer that

the government-led renovation may help relatively low-educated homeowners to overcome some knowledge and financial barriers; meanwhile, highly educated homeowners might be more reluctant to commit to renovations arranged by others.

We found that female homeowners are more likely to renovate, while the influence of homeowners' gender is usually not significant in the previous studies [32,55]. Klöckner and Nayum's finding that female homeowners tend to trust information and contractors more can possibly explain the conclusion [20]. The gender difference may also root in the differences in risk perception or individual judgment patterns [56].

It is worth mentioning that the composition of the sample may affect the results. A limitation of the study is that homeowners who are younger and have a high education level are over-represented. It remains unsure whether age and education level can directly influence homeowner's decision-making and its barriers. However, an indirect influence is possible because age and education may affect an individual's knowledge and attitude. Longitudinal studies across the population are needed to better understand the barriers for different types of homeowners to make energy efficiency renovation decisions.

5.3. The Impact of Cognitive Biases

Insights from behavioral science provide knowledge by revealing the mechanism of an individual's cognitive thinking, making it possible to explain why spontaneous renovation, lose initiative, and unbalanced financial plan can significantly affect homeowners' decisions.

Firstly, the sunk cost effect discourages homeowners who have already done renovations at their own expense because people tend to recover the losses once they have invested in something. For homeowners in Northern China, undertaking a government-led renovation is a better choice to improve their homes' energy performance because the cost will be lower (because it is often subsidized), and professional workers will carry out the construction. However, homeowners would still stick to their own renovation plan, especially when their plan is not a one-off project but will take continuous investment in cost and time.

Secondly, homeowners are affected by the endowment effect and do not like the feeling of losing initiative. Loss-framed messages often have a more significant behavioral impact than gain-framed messages, mainly when a self-referencing frame (i.e., emphasizing losses to oneself) is used, or losses for the current generation are emphasized [57]. In some cases, homeowners hate to lose initiative because they distrust or dislike the government's decision and plan or because they have their own ideas on how to renovate their own homes. Nevertheless, in some other cases, homeowners are merely affected when the feeling of loss is salient, even when the loss is not substantial.

Thirdly, the barrier 'financial plan not fair and reasonable' is associated with the perception of fairness, which will complicate the unification of homeowners' opinions. Since most of the renovation projects currently do not require homeowners to pay, respondents may not yet have a clear picture of the payment calculation method. We found that homeowners who are more willing to renovate can perceive more of this barrier, indicating that the consideration of fairness may only start to dominate when a homeowner already decided to go for a government-led renovation. Another possible reason is that homeowners will only undertake the renovation when they believe they can benefit from the financial plan.

As mentioned before, to promote the renovation further, it is crucial that homeowners should bear part of the cost. Our finding suggests that if a renovation project involves investments from the homeowners, the working group should focus its efforts on designing a fair and proper financial plan. The renovation cost should be allocated to the homeowners in proportion to the relevant variables they control, which could be the floor, the size, the orientation, or the current energy performance of the unit. The working group must take the extra complexity to the payment calculation and the effort to persuade homeowners into consideration.

5.4. Suggestions on Government-Led Energy Efficiency Renovation

Since homeowners' ability to collect and process information is limited, undertaking an energy efficiency renovation can be perceived as a complex activity involving extensive knowledge and information. The top-down model in China's Northern Heating Region has been proved to be effective in practice. Results and analysis in this study also suggest that government-led renovation can help to overcome several barriers, especially those related to finance and information gathering.

However, we must acknowledge that the central and local governments achieved gratifying progress under the premise of massive financial expenditure, and the participation of homeowners has been bypassed in many projects. Exploring an alternative governance model would involve tremendous efforts. Thus, optimizing the existing model remains the most effective approach to ensure the smooth implementation of energy efficiency renovation projects in the current stage without significantly increasing the governments' investment.

Firstly, the role of energy costs must be taken into consideration. In many countries where natural gas and oil are not cheap energy sources, homeowners will be motivated to upgrade their heating system to be less dependent on fossil fuels and prevent the threat of a future rise in energy prices. However, in China, energy prices are so low that if homeowners take it as a "reference point", then the investment for energy efficiency is less cost-effective for them. It is essential to help homeowners find another reference point to overcome the barrier related to the capital cost. For example, during the door-to-door visit, working group members can compare the future savings after renovation to some goods that homeowners are familiar with, such as the price of necessities or food. The comparison can give them a more intuitive impression of the benefit of the renovation.

Secondly, energy efficiency measures can be bundled into a broad suite of renovation plans. Empirical studies show that energy efficiency is of potential appeal to all households considering major renovations to their homes regardless of the type of renovation work they are initially considering [58]. In our study, a large proportion of respondents indicated their considerations about the comfort, function, convenience, and aesthetics of the dwelling. If the renovation plan can integrate these aspects and bring a comprehensive improvement to the building and its outdoor environment, it will attract homeowners who prefer other renovation types. The working group should emphasize this information when presenting the plan to homeowners.

Furthermore, information instruments can help to overcome some barriers. As Galvin and Sunikka-Blank [59] pointed out, "*a balance needs to be struck between deep, immediate retrofitting and long-term piecemeal upgrading*", the renovation bundle does not have to be completed in one go. Thus, when informing homeowners about the renovation plan, the working group can propose several combinations of renovation measures, energy performance outcomes, and costs. If homeowners do not like one-off deep energy efficiency renovation, they could opt for a simple and inexpensive combination, do the rest step-by-step, or choose a combined plan of energy efficiency renovation and other renovation types. The process can also mitigate homeowners' feelings of being forced or losing initiative. Nevertheless, the number of alternatives should be controlled. Too many options will challenge an individual's capacity and be proved counterproductive.

It is also important to target homeowners who have already done renovation at their own expense and thus feel it unfair if they must pay equally with other homeowners in government-led projects. Their spontaneous action indicates their positive attitude towards energy efficiency renovation, and if treated properly, their enthusiasm can be extended. If the monetary incentive is not on the table, some intangible compensation can be made, such as prioritizing their demands during the renovation process or giving more weight value to their views during the opinion unifying phase. The role model can also influence other homeowners in the same residential community.

6. Conclusions

While several previous studies have emphasized the energy-saving potential and economical attraction of residential energy efficiency renovation in China, the purely technical or economic perspective is inadequate to address the constantly updated challenges of reducing energy consumption in the building sector. To further promote energy efficiency in existing residential buildings, homeowners' cooperation and investment are required to ensure the smooth implementation of renovation projects.

This study uncovered the barriers in homeowners' decisions about energy-efficient renovation and provided knowledge to better understand the reasons that prevent them from undertaking the renovation. Apart from commonly identified barriers, we enriched the list by analyzing homeowners' cognitive biases associated with energy efficiency improvements. Considering that the research is based on the empirical data in a specific region, the results cannot be generalized to all contexts. However, it provides an overview of cognitive biases in homeowners' decision-making processes concerning undertaking an energy efficiency renovation.

We also evaluated several individual factors' influence to identify predictors of homeowners' decisions on whether to undertake government-led renovation. Differences in gender, age, education level, and building type can predict homeowners' renovation decisions. Female, elder homeowners with less education living in high-rise residential buildings were more likely to renovate. Other socio-demographic characteristics and building features are less related to renovation decisions. Thus, while consolidating the willingness of these homeowners, targeting policy instruments at homeowners who do not have the characteristics mentioned above may be particularly effective for the unification of all homeowners in the whole apartment building.

Three main barriers have been identified as the main reasons homeowners opt-out: unreasonable financial plan, self-financed renovation in the past, and the feeling of losing the initiative. All these three barriers are directly related to the features of government-led renovation. The responsible agencies should spend more effort optimizing the current renovation process and ensuring the homeowners can easily understand it. We suggest that energy efficiency renovation can be combined with other types of renovation, and suitable reference points should be provided when persuading homeowners. If some homeowners have already spontaneously renovated their homes, they should be treated appropriately, depending on the circumstances. Finally, it is worth further investigating how to design a fair and reasonable renovation plan that balances the energy efficiency requirement and the acceptance of homeowners.

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Nomenclature

Kgce	kilogram of coal equivalent (energy intensity)
Tce	ton of coal equivalent (energy intensity)
CNY	Chinese Yuan Renminbi (currency unit), CNY 1 \approx EUR 0.13
N	number of cases
χ^2	chi-square test
df	degree of freedom
Sig.	<i>p</i> -value (significance level)
B	unstandardized coefficients
S.E.	standard error
Exp(B)	exponentiation of the B coefficients, the odd ratio

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