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Stakeholders' Risk Perception: A Perspective for Proactive Risk Management in Residential Building Energy Retrofits in China

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Abstract: The implementation of energy retrofit of residential buildings faces many risks around the world, especially in China, leading to low retrofit progress. Stakeholders' proactive risk management is the key to the smooth implementation of retrofit projects but is normally affected by risk perception. Perceived risks instead of real risks are the motivators of their proactive behaviours. This paper aims to understand and address the present risk perception of stakeholders in order to drive effective proactive risk mitigation practices. Based on a risk list identified through a literature review and interviews, a questionnaire survey was then made to analyse and compare different stakeholders' perceptions of each risk by measuring the levels of their concern about risks. It is validated that all the stakeholder groups tend to mitigate risks perceived highly proactively. Proactive risk management of risk-source-related stakeholders deserves more attention and responsibility-sharing with transaction costs (TCs) considerations contribute to the enhancement of risk perception. More responsibilities of construction quality and maintenance is taken by the government and contractors should be clarified, and the government should also be responsible for assisting design work. Effective information is beneficial to the decrease in homeowners' risk perception that can motivate their initiative of cooperation.

Keywords: energy retrofits; risk perception; proactive risk management; stakeholder behaviours; transaction costs

1. Introduction

Building energy use has become the main driver for the growing worldwide energy consumption and CO_2 emissions. Worldwide, 28% of CO_2 emissions and 30% of final energy consumption were attributed to the building sector in 2018 [1]. In particular, the final energy consumption of residential buildings accounts for over 70% of the global total [1]. The continuous global growth in building end uses mainly driven by heating, lighting, and household cooking [2]. The most striking increase in energy intensity per unit of floor area is related to space cooling with a growth of nearly 10% from 2014 to 2018 [3,4]. In China, building energy consumption was 899 million tonnes coal equivalent (tce), and CO_2 emissions were 1.96 billion tons in 2016, accounting for 20.6% and 19.4% of the national total quantity, respectively, in which energy consumption and carbon emissions of urban residential buildings share 38% and 41%, respectively [5]. Meanwhile, China has also experienced rapid growth of energy demand for space cooling over the past two decades, increasing at 13% per year since 2000 and even reaching 50% of peak electricity demand in recent summers, which leads to a large increase in CO_2 emissions [6]. Sustainable buildings are the key factors to mitigate such environmental impacts, and this goal can be achieved by replacing inefficient building elements with more efficient ones [7].

Existing building retrofitting has been identified by the GlobalABC Global Roadmap as one of the key priorities for reducing the impacts of buildings on energy and climate [8]. Canada highlighted the use of new retrofit codes in building retrofitting in the updated nationally determined contribution (NDC) in 2017 [2]. In 2018, the revised Energy Performance of Buildings Directive (EPBD) required all EU member states to implement long-term retrofitting strategies in order to achieve a highly efficient and fully decarbonised building stock by 2050 [2]. Likewise, China viewed residential building retrofitting in both the northern region and the hot summer and cold winter (HSCW) zone as one of the main tasks for energy conservation and emission reduction in the latest plan in 2017 [9].

Efforts have been made to improve the energy efficiency of residential buildings in China. The total area of urban residential buildings by 2015 in China was 24.8 billion m^2, in which energy-efficient buildings accounted for more than 40% [9,10]. These achievements are mainly attributed to China's mandatory standards for building energy efficiency, and almost all new buildings were constructed in accordance with such standards during the period of the 12th Five-Year Plan (2011-2015) [9]. By contrast, the development of energy retrofitting of residential buildings is relatively slow. Since 2006, residential buildings have been highlighted as a key potential area for energy savings through energy efficiency improvement [11,12]. The total area of urban residential energy retrofitting was about 1.2 billion m^2 by 2015 and was less than 1.6 billion m^2 by 2018 nationally. In particular, the northern region is the main undertaker of these retrofitting projects, and there is unbalanced development of energy retrofits in different regions in China. During the 12th Five-Year Plan period, 990 million m^2 of retrofit projects were completed in the northern region, but only 70.9 million m^2 in the hot summer and cold winter (HSCW) zone [9]. In fact, the urban existing residential building stock in the HSCW zone covered an area of almost 6 billion m^2 in 2012 [13]. Moreover, building energy efficiency in this region started late and developed slowly compared to cities in the northern region. In the past several years, heavy use of heating facilities resulted in a 575-fold increase in the residential heating energy consumption in the HSCW zone, which also is a major factor driving a rapid growth of residential energy consumption in China [14]. It is therefore necessary to accelerate the implementation of energy retrofitting of residential buildings in the HSCW zone of China.

The implementation process of energy retrofits is faced with many risks, especially in China, due to the interactions of the various involved stakeholders. The risks in this paper are defined as future and uncertain factors/events exerting a negative influence on project performances (e.g., costs, quality, organization, and management). Central and local governments, heating enterprises, property rights units, residents, energy-saving service firms, planning and design units, property management units, material and equipment suppliers, and construction and supervision units are viewed as the stakeholders of residential retrofit projects in China [15,16]. In China, housing is generally privatized, and the property owners of a single building are dispersed among tens or even hundreds of households, which leads to the great probability of disagreement among these homeowners on retrofitting [17]. Moreover, different personal circumstances among homeowners in terms of occupations, education levels, lifestyles, and income levels may also give rise to the differences in the satisfaction and acceptance in retrofit technology, further resulting in the possibility of homeowners' dissatisfaction as well as misuse and disruption of installed technology [18]. In addition to hundreds of homeowners, the government at all levels, and different departments are also involved in the retrofit projects [17]. As a result of more stakeholder interactions in energy retrofit projects, the whole process of such projects is more complicated than that of conventional projects [19–21]. In particular, the lack of a joint system for government departments at high levels in China is likely to lead to poor coordination [17].

Stakeholders' proactive risk management is an approach to make a response plan in advance of the occurrence of a risk event, and also contributes to a smoother project process. The stakeholder is one of the primary sources of risks in projects [22,23]. Stakeholders, through their work and behaviours, pose risks but are the most primary resources for risk mitigation [23]. Stakeholders have capabilities to proactively mitigate risks associated with them from the angles of risk probability or impact, which is key to risk management [24]. Proactive risk management was viewed by Arrow [25] as a more practical way towards project objectives. Smith and Merritt [26] also believed that proactive risk management could effectively control uncertainty. Uncertainty is one of the primary transaction characteristics and also increases transaction costs (TCs) in the transaction process [27]. TCs appear throughout the whole process of energy retrofit projects and originate from due diligence, negotiations, and monitoring [28]. When TCs are too large, the exchange, production, and economic growth would be inhibited [29]. Proactive risk management, an effective manner of controlling uncertainty, can lower TCs and thereby eliminate the barriers to energy retrofit implementation for a smooth retrofit process. However, stakeholders' proactive behaviours have not been considered by studies on energy retrofits of residential buildings as risk mitigation measures. The previous studies tended to analyse risks from the perspectives of the energy efficiency gap and investment benefits [15,30–34] and viewed risks as the basis for the selection of retrofit solutions [35,36]. Risk mitigation focuses on the development of energy-savings insurance to transfer risks of investors [37,38]. These measures aim to safeguard investors' interests rather than to eliminate the barriers to the smooth implementation of the whole energy retrofit process.

Stakeholders' proactive behaviours for risk mitigation are generally aimed at their perceived risk. The connections between risk management and project success are dependent on three elements: stakeholders, their behaviours, and their risk perception [39,40]. Indeed, the contributions of risk management to success mostly result from the impacts of risk perception on stakeholders' behaviours, namely that stakeholders adjust their behaviours according to their perception of risks [41,42]. Risk perception is a kind of subjective evaluation of risks by stakeholders and is based on the type of risk, personal experience, beliefs, attitudes, and culture [43,44]. Stakeholders' perception of risk is based on the simplified decision-making process rather than real situations, and different culture also leads to their differences in subjective rationality and further in risk perception [45]. Differences and contradictions in risk perception among different project stakeholders result in the misunderstanding and conflicts of risk mitigation practices [46]. Uncertainty avoidance is the core principle of stakeholders' behaviours [47]. If a potential risk is perceived by stakeholders to be high, they will take measures to mitigate it [48]. However, these stakeholders' actions aiming to mitigate risks produce TCs. TCs, in turn, affect stakeholders' behavioural selection. Transaction cost is an essential factor when transaction parties make trading decisions [49]. Stakeholders themselves have motivations to economize on TCs to maximize their own benefits. High TCs can be the barriers to stakeholders' proactive behaviours for risk mitigation. As with individuals' behaviours, TCs incurred by these behaviours are also subjective [50]. In effect, stakeholders who voluntarily bear high TCs tend to expect higher benefits [51]. Such behavioural conflicts among different stakeholders resulting from different risk perceptions and TCs may render those bearing high TCs unable to obtain the benefits as expected, which would lead to the dissatisfaction of some stakeholders and further influence the smooth implementation of retrofit projects.

Risk perception can motivate stakeholders' proactive risk management, which is the key to the smooth implementation of energy retrofit projects. The differences in risk perception among different stakeholders lead to the contradictions of risk mitigation practices, and TCs play an important role in stakeholders' behavioural conflicts arising from contradictions of risk perception. This paper aims to analyse and address different stakeholders' perceptions of risks in order to motivate stakeholders' initiative of effective risk management. This paper first establishes a risk list through both a literature review and interviews to connect the risks in the whole process of energy retrofit in China with the main stakeholders. Interviews are also made to explore stakeholders' proactive behaviours for risk mitigation in practice. A questionnaire survey is then conducted to examine and compare different stakeholders' perceptions of each risk by measuring the levels of their concern about risks. A validation is conducted to link high levels of risk concern with proactive risk management. Finally, some suggestions with TCs considerations are given under different risk perceptions of stakeholders to drive the effectiveness and feasibility of proactive risk mitigation practices.

2. Literature Review

2.1. Risk Perception

There is no agreement about the measurement of individuals' risk perception, and risk perception is regarded as a complex construct [52]. It is significant for studies on risk perception to choose the proper risk dimensions according to the study purpose [53]. Different items have been used by previous studies to help shape risk perception, including cognitive, emotional, societal, and subconscious factors [54–57]. In particular, cognition and emotion are the most common and are generally viewed as the main dimensions of risk perception. The cognitive dimension means the perceived likelihood and severity of risks, while the emotional dimension refers to the feelings of worry and anxiety [58]. Sjöberg [53] stated that risks cannot give rise to emotional perception but cognitive. It was also highlighted that risk perception required a more rational judgment, and people seldom determined their judgment of risks based on emotions. However, Hartono, et al. [59] argued that decision-makers tend to make decisions based on their intuition and feelings rather than the normative theory (e.g., the probability and consequences of risks). Indeed, some studies on cognition also emphasized that individuals' cognitive ability is limited due to their bounded rationality [60,61]. It is believed that emotions (e.g., worry and fear) can motivate people to self-protect [15,30–34]. In short, both cognitive and emotional factors should be considered in the judgment process of risk perception [62].

The concern is a concept involving both cognitive and affective dimensions and can be used to measure stakeholders' perceptions of risks. Dunwoody and Neuwirth [58] viewed concern as an affective judgment of risk perception, but the concern was regarded by Rundmo and Iversen [63] and Brown, et al. [64] as a more cognitive notion in risk perception. Likewise, Rundmo [65] thought that concern is one aspect of effect but is associated with cognitive risk perception. Worry is generally viewed as an active emotional state and is close to adaptive behaviours for risk mitigation [66,67]. Concern can be seen as those worried and upset topics and is closely related to actionable worry [68]. Concern itself can be used to affect people's behaviours, and certain levels of concern can motivate people to take action to handle risks [69,70]. In fact, the concept of concern has been adopted by some studies to measure risk perception. Wildavsky and Dake [71] evaluated the perception of technical, environmental, social, and economic risks based on a series of people's concerns. Similarly, how much people have concerns about risks is also used to refer to the levels of their risk perception [72–74]. Based on the Gallup environment surveys in which respondents were asked the degree of their concern about economic and social problems, Xiao and McCright [75] formed the measurement framework of risk perception. Mou and Lin [76] also used the level of risk concern to measure the public's perceived level of risks related to food supply and handling. As a result, this paper also applied stakeholders' concerns about risks to the measurement of risk perception.

2.2. Behaviours Related to Risk Perception

The role of perception in precautionary and protective behaviours has been highlighted in many studies. There is an assumption in the protection motivation theory [77] that individuals' perception of the severity of a threat and the effectiveness of mitigation measures is the basis of their protective behaviours. The protective action decision model [78,79] also points out the roles of perception in protective behaviours and postulates that risk perception has impacts on decision making on mitigation measures. In addition, the prospect theory [80] also aims to predict the individuals' behavioural responses to different risk perceptions. This theory argues that there is a negative connection between risk perception and risk-taking behaviours (e.g., risk-averse and risk-seeking) [81]. Rogers [82] stated that an individual's perception of risks facilitated their engagement in protective behaviours. Risk perception contributes to individual perception of their responsibility on environment protection [83]. The individuals with a high perception of environmental risks have stronger intentions to take environmentally friendly actions [84,85]. It has been found in the studies on disasters and hazards that risk perception can predict warning responses of reducing the losses from disaster risks [86]. People with high-risk perception are more likely to take preventive actions than their counterparts with low-risk perception [87,88]. Adams [89] described the relationships between safety perception and risk status and pointed out that the increase in safety perception could motivate individuals to have compensation behaviours to lower risk levels. Loosemore, et al. [90] applied this logic to the construction field in order to drive people to adjust their behaviours for risk mitigation. The differences in risk perception among different groups lead to the diversity of their practices in risk mitigation [91]. In short, risk perception is an important motivator of stakeholders' proactive risk management.

2.3. Transaction Costs (TCs) Considerations

TCs are different from production costs and are the economic equivalent of friction in physical systems [92]. TCs are influenced by three main transaction dimensions, including asset specificity, uncertainty, and frequency [93]. Asset specificity is usually defined as "durable investments that are undertaken in support of a particular transaction" [92]. Uncertainty is classified as environmental and behavioural uncertainty. Environmental uncertainty means that transaction circumstances cannot be specified beforehand, leading to an increase in time and processes for monitoring and controlling against ecological diversity [94]. Behavioural uncertainty refers to transaction partners concealing and distorting information [92].

Stakeholders need to bear high TCs when involved in the interactions for risk mitigation [22], such as the costs of learning knowledge, collecting information, supervising construction work, and exploring new technical schemes. Preventive behaviours originating from high-risk perception were based on low costs of behavioural change [95]. People who have positive attitudes towards proactive behaviours may not be able to put such behaviours into practice due to the lack of resources [96]. In fact, risk perception is associated with people's ability to understand and respond to risks and objective risk attributes [97,98]. Probability and impact are the main attributes of risks, which have the features of uncertainty. From a TCs perspective, asset specificity in risk management service transactions can be considered as the capability of different transaction parties for risk management [99]. In addition, the degree of people's concern about risks and their experience in risk management have essential impacts on their ability of information acquisition and processing, which also further affects their risk preparedness behaviours [100]. That also means that proactive risk management practices related to risk perception are restricted by uncertain information and specified assets concerning stakeholders' experience.

Proactive risk management involves stakeholders' participation, risk management commitment, and initiating risk management processes early in the project [25]. Proactive risk management can be regarded as the activities of stakeholders' establishing and managing committee, and the success of proactive risk management efforts depends on the commitment of stakeholders' risk management. In the Chinese context of the residential energy retrofit, risk perception is concerned with environmental uncertainties about stability of retrofit policy, the ambiguity of retrofit performance, the complexity of design, the complexity of construction, and even maturity of the retrofit market in terms of technology, competence, and materials. Behavioural uncertainty is based on stakeholders' opportunism, and commitment can help prevent opportunism [101,102]. Behavioural uncertainty in risk management transaction is related to stakeholders' commitment to risk management [103]. Asset specificity and uncertainty incur more TCs in risk management service transaction and thereby prevent stakeholders from undertaking proactive risk management practices.

Based on transaction costs theory (TCT), the major characteristics of proactive risk management affected by risk perception include: (1) stakeholders' experience and ability in terms of risk management, which are the main specified assets of proactive risk management; (2) environmental uncertain factors related to proactive risk management; (3) stakeholders' commitment to risk management, which corresponds to behavioural uncertainty.

3. Research Methodology

The national documents provide a generic scope for retrofitting objects of residential buildings in China. In general, priority for energy efficiency retrofitting is given to the residential buildings with good seismic and structural safety performance and poor thermal performance of the building envelope [104]. These buildings were constructed with few energy efficiency measures, and residents need to consume a great deal of energy to improve the indoor thermal environment. At present, the comprehensive retrofitting mode for residential quarters is encouraged [9]. In this pattern, there are not only energy efficiency measures, but also those regarding environment improvement, infrastructure renovation, structure reinforcement, etc.

There are some differences in the scopes of retrofitting objects among different provinces in the HSCW zone, but old residential quarters are the common focus of energy retrofitting. These residential quarters have been generally used for at least a dozen years, and consist of several multi-story apartment buildings. This paper takes Anhui province in the HSCW zone of China as the object of empirical analysis. There are five basic criteria for the retrofitting scope in Anhui province: residential quarters were constructed and delivered before 31st December in 2000; the gross floor area is not less than 5000 m^2; these quarters are not involved in other renovation plans (e.g., urban renewal, shantytown renovation, and urban village renovation); the lands of these residential quarters are owned by the nation; and these apartment buildings are composed of complete residential packages including living rooms, bedrooms, a kitchen, a bathroom, etc.

3.1. Literature Review

This paper conducted a systematic review to identify the theoretical risks. Articles considered in the literature review were related to energy retrofitting of residential buildings and published in international scientific journals up to March 2018. Google Scholar was the main database for the literature search. Several keywords used for searching articles were classified as three categories as follows: (1) “energy retrofitting” and “energy renovation”; (2) “residential buildings” and “housing” (3) “risks”, “uncertainty”, and “barriers”. This paper selected one keyword from each category in each search and combined them to search articles, such as “energy retrofitting”, “housing”, and “risks”.

3.2. Interview

The risks were identified through literature review and face-to-face interviews in China. Based on a field survey, this paper divides the main stakeholders in retrofit projects into four groups, namely homeowners, governments, designers, and contractors. Interviewees were directly related to energy retrofitting in Anhui province in China and were mostly from energy retrofit cases in three cities, including ten government officials, four designers, four on-site construction managers, and four homeowners. In these projects, doors and windows were replaced by those with higher levels of insulation, and new thermal insulation materials were also used to strengthen the insulation of walls and roofs.

The government representatives were selected from four levels of government departments of housing and construction, including the provincial government, the municipal government, the district government, and the sub-district administrative office. Except for the provincial government, the interviewees from the other three levels of government were almost always involved in all stages of the energy retrofitting projects in practice. For this reason, government interviewees are not only familiar with all processes in retrofitting projects but also are qualified for the identification of risks existing in each stage. In particular, interviewees from sub-district administrative offices keep in close touch with contractors and homeowners, which also enables them to know something about the risks associated with these two stakeholder groups.

The industry stakeholder representatives were the chief leading members in charge of the retrofitting design and construction in practice. All of them were involved in three pilot retrofitting projects in Anhui province. As the main stakeholder groups, these interviewees from design and construction companies have a more comprehensive view of the risks occurring at the stages of design and on-site construction and can provide more detailed information about these risks.

The homeowner representatives were from three pilot projects and were also the members of either homeowners' committees or neighbourhood committees in the local residential quarters. There are 612 households in total in these three projects. The homeowners' committee acts on behalf of all the homeowners in a residential quarter. Members of homeowners committees gathered homeowners' requirements and suggestions in the course of retrofitting implementation, and reported them to other retrofitting parties. Neighbourhood committees played a similar role in the retrofitting projects. Two interviewees were both neighbourhood committee staff and homeowners. There are no homeowners' committees in some renovated residential quarters, and members of neighbourhood committee are therefore responsible for information transmission in practice. As members of homeowners committees and neighbourhood committees, these interviewees have a better understanding of the potential project risks than ordinary homeowners.

These interviewees introduced the work and responsibilities of their own stakeholder groups and elaborated on the problems they encountered and their concerns in the course of project implementation. Meanwhile, they were also asked about some proactive measures taken in practice for risk mitigation.

Interviewees' views were taken into consideration to adjust the theoretical risks to the Chinese context. The risk list is shown in Table 1, in which 21 risks exist in the whole process of residential energy retrofit projects in China.

Table 1. Risks in the whole process of energy retrofit projects in practice.

Phases	Risks	Literature Sources
Regional survey and project setup	R1: Frequent change in demolition policies	
	R2: Uncertainty on property right and occupancy	
	R3: Lack of awareness of energy efficiency retrofitting	[30,33]
	R4: Lack of government departments' coordination and support	[15]
	R5: Insufficient funds available	[15,30–34]
Project design and budget estimation	R6: Insufficient information regarding the buildings	[105]
	R7: Uncertainty on the on-site conditions	
	R8: Lack of technical staff with specific expertise	[38,106–109]
	R9: Lack of appropriate technical standards	
Construction bidding and fund appropriation	R10: Unqualified building materials	
	R11: Adverse selection	
On-site construction	R12: Lack of construction skills	[106–111]
	R13: Moral hazard	
	R14: Poor quality of old residential buildings themselves	
	R15: Poor construction management	[110]
	R16: Poor safety management	
	R17: Poor performance in cooperation	[112]
	R18: Opportunistic renegotiation	
Inspection, acceptation, and use	R19: Measurement problems	
	R20: Inadequate maintenance	[37,38,106,109,113]
	R21:Difficulties in post-retrofit repair	

3.3. Questionnaire Survey

According to the above risk list, a questionnaire survey was conducted to explore the concern of different stakeholder groups on different risks in the whole process of energy retrofit projects in China. This questionnaire comprised two sections: (1) background information of the respondents; (2) respondents' concern about different risks. In the second part of this questionnaire, a Likert scale of 1–5 was used to measure the level of stakeholders' concern about a risk from their subjective point of view (1 = not concerned, 2 = a little concerned, 3 = neutral, 4 = somewhat concerned, 5 = very concerned).

The questionnaires were distributed via personal delivery to increase the response. The questionnaires were targeted at people representing four different stakeholder groups, including governments, homeowners, contractors, and designers. A total of 450 questionnaires were delivered to the respondents. A total of 172 valid questionnaires were collected from 44 government officials, 55 homeowners, 38 construction managers, and 35 designers, respectively. This rate is 38.2 % and is acceptable and common.

These respondents have been involved in the energy retrofitting projects in five cities of Anhui province in China. Hefei, the capital of Anhui province, has been listed as the pilot city of energy retrofitting of residential buildings in the HSCW zone of China in 2012. Since 2016, the provincial government has encouraged applying energy efficiency measures to the province-wide existing residential buildings. Anhui province operated more than 300 energy retrofitting projects by 2019. The government respondents, as the decision-makers and executors, were involved in all the retrofitting projects in the city where they work. The respondents from the design and construction companies were also the participants of the completed retrofitting projects. Moreover, these design companies generally undertake the design work of most energy retrofitting projects in their own cities.

All the homeowners involved in this questionnaire survey were related to the comprehensive energy retrofitting projects that have been completed. In fact, retrofitting items (e.g., exterior windows, sunshade, roof, exterior wall, etc.) were only partially executed in the majority of energy retrofitting projects in Anhui province and even in the HSCW zone. There were only three comprehensive energy retrofitting projects in Anhui in 2017, and these respondents are some of the owners of the three retrofitting projects. These homeowners had more exposure to other participants and difficult retrofitting work due to the comprehensiveness of retrofitted building items. The complexity of comprehensive projects also enables them to have a more holistic perception of project risks. Comprehensive energy retrofitting is the major trend and is being advocated by more governments. The views of these respondents can also provide lessons for future retrofitting projects.

3.4. Data Analysis Method

The data collected from questionnaires were analysed from three aspects of the comparison of risk concern within each stakeholder group, the comparison of risk concern among all stakeholder groups, and the comparison of risk concern within different pairs of groups. First, the degree of concern on all risks in each stakeholder group was measured by mean scores, which can investigate the rankings of risks in terms of stakeholders' concern. Second, one-way ANOVA was applied to compare the mean scores of all the stakeholder groups in order to find out the main differences in stakeholders' concern about all risks from an overall perspective. Levene's test for equality of variances was applied to assess the assumption of homogeneity of variance that there was no difference in the variances among all the groups prior to one-way ANOVA. Variances among the four groups were proved to be equal if the significance value (p-value) was over 0.05, and the concern among all of the groups could be compared based on the p-value of one-way ANOVA. If not, Welch's test was used to adjust the results of one-way ANOVA, and a p-value of less than 0.05 also served as a standard to measure the significance of differences. Welch's test is considered more reliable when variances are unequal [114,115]. Third, for those risks with significant differences among all the four groups, Scheffe's test or Games-Howell test were adopted to compare risk concern within different pairs of groups according to the results of the abovementioned Levene's test, and the threshold value p was also 0.05. Scheffe's test is the most common for equal variances, and there is no need for each group to contain the same sample size. This test can also be used to make all possible comparisons among group means, not just planned pairwise comparisons. Games-Howell test is suitable when the variances are unequal and also does not assume the same sample size among all of the groups. Moreover, this test is appropriate for the results of Welch's test.

4. Survey Results and Analysis

4.1. Comparison of Risk Concern within Each Stakeholder Group

The degrees of concern on all risks of each stakeholder group are measured by mean scores, and the standard deviation (SD), the coefficient of variation (CV), and rankings are also summarized (see Table 2).

Table 2. Mean scores of concern of different stakeholder groups on risks.

	Government				Homeowners				Contractors				Designers			
	Mean	**SD**	**CV**	**Rank**	**Mean**	**SD**	**CV**	**Rank**	**Mean**	**SD**	**CV**	**Rank**	**Mean**	**SD**	**CV**	**Rank**
R1	4.07	0.73	0.18	6 *	3.69	0.69	0.19	12	2.95	1.29	0.44	20	3.43	1.34	0.39	10
R2	3.93	0.73	0.19	9	3.24	1.07	0.33	21	2.68	1.23	0.46	21	2.86	1.24	0.43	20
R3	4.25	0.75	0.18	1 *	3.67	0.9	0.25	13	3.21	1.23	0.38	12	3.29	1.25	0.38	14
R4	4.14	0.73	0.18	4 *	3.82	0.98	0.26	9	3.84	0.79	0.21	6	3.91	0.61	0.16	6
R5	4.16	0.71	0.17	3 *	3.75	1.19	0.32	10	3.87	0.74	0.19	5	3.2	1.35	0.42	15
R6	3.36	1.35	0.40	19	3.33	1.14	0.34	20	3	1.21	0.40	18	4.11	0.76	0.18	3 *
R7	3.11	1.37	0.44	20	3.35	1.19	0.36	19	3.68	0.78	0.21	9	4.09	0.7	0.17	4 *
R8	3.68	0.71	0.19	15	3.67	1.17	0.32	13	3.63	0.71	0.20	11	3.03	1.45	0.48	17
R9	3.09	1.31	0.42	21	3.58	1.15	0.32	15	2.97	1.08	0.36	19	4.14	0.49	0.12	2 *
R10	3.73	0.76	0.20	14	4.25	0.52	0.12	3 *	3.74	0.72	0.19	8	3.51	1.15	0.33	9
R11	3.86	0.73	0.19	11	3.87	0.77	0.20	8	3.03	1.05	0.35	17	2.74	1.36	0.50	21
R12	3.75	0.81	0.22	13	4.07	0.66	0.16	6 *	3.05	0.93	0.30	15	3.57	1.22	0.34	7
R13	3.93	0.76	0.19	9	4.38	0.65	0.15	1 *	3.11	1.2	0.39	14	4.2	0.63	0.15	1 *
R14	3.5	1.07	0.31	18	4.05	1.11	0.27	7 *	3.97	0.68	0.17	4	3.94	0.91	0.23	5
R15	3.59	0.84	0.23	17	3.73	0.95	0.25	11	3.05	0.99	0.32	15	3.37	1.24	0.37	11
R16	3.84	0.71	0.18	12	4.11	0.71	0.17	5 *	4.11	0.61	0.15	3 *	3.54	1.31	0.37	8
R17	4.18	0.69	0.17	2 *	3.47	0.79	0.23	18	4.18	0.61	0.15	2 *	3.31	1.26	0.38	13
R18	4.09	0.8	0.20	5 *	3.51	1.12	0.32	16	4.29	0.57	0.13	1 *	3	1.46	0.49	18
R19	3.98	0.73	0.18	8	3.51	1.14	0.32	16	3.66	0.75	0.20	10	3.11	1.35	0.43	16
R20	3.66	0.71	0.19	16	4.18	0.72	0.17	4 *	3.16	1.1	0.35	13	2.97	1.22	0.41	19
R21	4.05	0.71	0.18	7 *	4.33	0.8	0.18	2 *	3.79	0.7	0.18	7	3.34	1.26	0.38	12

Note: "*" means that the level of stakeholders' concern of this risk is high (with the mean of above 4).

SD and CV are the common measures of data dispersion. Narrow SD and CV indicate that data are stable and reliable and that respondents in the same group reach a consensus on the level of risk concern. The range of mean ± 1.64 SD is viewed as the consensus criterion for the items with a four-point Likert scale [116,117]. A wider range can be used for the consensus evaluation in this study with a five-point Likert scale. It is shown in Table 2 that all the SDs are below 1.46 and that the SDs of almost all the risks with high levels of stakeholders' concern (with the mean of above 4) in each group are below 0.80. Compared to SD, CV is a more standardized measure of statistics data dispersion and is calculated as SD divided by the mean. A CV below 0.5 is believed to indicate a reasonable and good internal agreement [118,119]. All the coefficients of variation (CVs) listed in Table 2 are below 0.5. In particular, the CVs of almost all the risks with high levels of stakeholders' concern in each group are below 0.2.

The government is concerned with all risks because none of the scores are less than 3.09. Among all risks, lack of awareness of energy-efficient retrofitting (R3), poor performance in cooperation (R17), and insufficient funds available (R5) are given the highest scores, followed by lack of government departments' coordination and support (R4), opportunistic renegotiation (R18), frequent change in demolition policies (R1) and difficulties in post-retrofit repair (R21) that also score more than 4.05. These risks are caused by homeowners' poor understanding and cooperation.

Similarly to the government, all risks are concerned by homeowners, and the scores range from 3.24 to 4.38. The scores of moral hazard (R13), difficulties in post-retrofit repair (R21), unqualified building materials (R10), inadequate maintenance (R20), poor safety management (R16), lack of construction skills (R12), and poor quality of old residential buildings themselves (R14) are more than 4 and are dominant among all risks. These risks are associated with project quality and safety.

Contractors have the most significant concern about opportunistic renegotiation (R18), poor performance in cooperation (R17), and poor safety management (R16). The three risks exist in the phase of site implementation and are associated with homeowners.

Designers express more concern about four risks of moral hazard (R13), lack of appropriate technical standards (R9), insufficient information regarding the buildings (R6), and uncertainty on the on-site conditions (R7) with scores of over 4. These risks are relevant to drawing a retrofitting plan and implementing the plan.

4.2. Comparison of Risk Concern among All Stakeholder Groups

Levene's test for equality of variances is first conducted, and the test results with a significance value (*p*-value) are shown in Table 3. According to the results, the assumption of homogeneity of variance is only valid for the risk of poor construction management (R15).

Table 3. Test of Homogeneity of Variances.

	Levene Statistic	df1	df2	Sig.		Levene Statistic	df1	df2	Sig.
R1	12.538	3	168	0.000	R12	9.997	3	168	0.000
R2	5.269	3	168	0.002	R13	5.602	3	168	0.001
R3	7.480	3	168	0.000	R14	5.255	3	168	0.002
R4	3.569	3	168	0.015	R15	2.355	3	168	0.074
R5	10.657	3	168	0.000	R16	15.567	3	168	0.000
R6	4.948	3	168	0.003	R17	13.751	3	168	0.000
R7	12.905	3	168	0.000	R18	11.888	3	168	0.000
R8	11.322	3	168	0.000	R19	10.384	3	168	0.000
R9	10.011	3	168	0.000	R20	4.364	3	168	0.005
R10	12.195	3	168	0.000	R21	10.947	3	168	0.000
R11	7.616	3	168	0.000					

The results of one-way ANOVA can be used to directly compare the concern of all the stakeholder groups on R15, while the Welch test is applied in judging the significance of differences in the other 20 risks (shown as Tables 4 and 5). Stakeholder groups hold different opinions on most of the risks, but there is no significant difference in the concern regarding three risks, namely lack of government departments' coordination and support (R4), lack of technical staff with specific expertise (R8) and poor quality of old residential buildings themselves (R14).

Table 4. ANOVA for R15.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	11.243	3	3.748	3.756	0.012
Within Groups	167.612	168	0.998		
Total	178.855	171			

As a whole, lack of government departments' coordination and support (R4) and poor quality of old residential buildings themselves (R14) are given more concern by almost all the stakeholder groups, while lack of technical staff with specific expertise (R8) is ranked in the middle and lower tiers by all stakeholders. Every stakeholder group expresses expectations to obtain the support of the relevant government departments in order to seek an extremely favourable environment to work. Likewise, quality problems attributed to buildings themselves have severe negative impacts on retrofitting quality that is focused on all of the groups. By contrast, designers' capacities are not paid too much attention.

Table 5. Robust tests of equality of means except for R15.

	Statistica	df1	df2	Sig.		Statistica	df1	df2	Sig.
R1	8.318	3	80.672	0.000	R11	12.231	3	82.962	0.000
R2	14.465	3	84.781	0.000	R12	11.520	3	82.316	0.000
R3	10.332	3	83.995	0.000	R13	12.847	3	85.769	0.000
R4	1.523	3	91.386	0.214	R14	2.551	3	90.354	0.061
R5	5.340	3	87.177	0.002	R16	2.910	3	85.437	0.039
R6	9.843	3	90.012	0.000	R17	12.882	3	86.380	0.000
R7	7.740	3	91.931	0.000	R18	12.344	3	86.729	0.000
R8	2.072	3	86.843	0.110	R19	4.805	3	87.227	0.004
R9	17.738	3	88.409	0.000	R20	14.911	3	82.535	0.000
R10	9.943	3	80.694	0.000	R21	7.363	3	85.938	0.000

4.3. Comparison of Risk Concern within Different Pairs of Groups and the Corresponding Proactive Measures

According to the results of the test of homogeneity of variances, Scheffe's test is adopted to make comparisons on R15 between any two stakeholder groups, while Games-Howell test is used to compare the other risks except R4, R8 and R14. The test results with mean difference and significance value (p-value) are shown in Table 6 (G = Government, H = Homeowners, C = Contractors, D = Designers). There is no particular stakeholder group with significant differences from all the others in terms of risk concern, but the differences between government and designers and between homeowners and contractors are the most significant among all the six pairs of comparisons.

Table 7 summarized the risks with great concern for each stakeholder group (based on Table 2) and also highlighted the stakeholder groups who have significantly less concern about each risk than the former group (based on Table 6) (G = Government, H = Homeowners, C = Contractors, D = Designers). It is also shown in Table 7 whether stakeholder groups with high levels of risk concern have taken measures for proactive risk management or not. Almost all the stakeholder groups tend to proactively mitigate risks they have more concern about. However, the majority of these proactive risk mitigation measures are considered limited and cannot mitigate these risks well. The details of proactive risk management are shown in Appendix A.

5. Discussion

5.1. Tendency of Risk Perception

According to risks with high concern shown in Table 7, it is easier for the government and industry stakeholders to perceive the risks associated with their own responsibilities due to their own professional roles. Correspondingly, these risks are also the focus of their proactive risk management. As the leader and sponsor of retrofit projects, the government is mainly responsible for the organization and decision making of projects. For this reason, the government tends to take a holistic view of these risks and pays more attention to the overall enforceability of retrofit projects instead of the details concerning design and construction. As for the matters relating to design and construction, the government is more willing to depend on those professionals who keep good cooperative relationships with the government. By contrast, designers and contractors also have more concern about the factors affecting the fulfillment of their duties, like the lack of objective information or uncooperative partners. This is in line with the views of Gambatese, et al. [120], who stated that stakeholders' perception is affected by their roles and responsibilities through the project process. There is an intragroup consistency and intergroup inconsistency of risk perception due to the differences in interests and roles of stakeholder groups [121].

Table 6. Mean differences between pairs of stakeholder groups.

	G and H			G and C			G and D			H and C			H and D			C and D		
	MD	**SE**	**Sig.**	**MD**	**SE**	**Sig.**	**MD**	**SE**	**Sig.**	**MD**	**SE**	**Sig.**	**MD**	**SE**	**Sig.**	**MD**	**SE**	**Sig.**
R1	0.377	0.144	0.050	1.121 *	0.237	0.000	0.640	0.251	0.065	0.744 *	0.230	0.011	0.262	0.244	0.706	−0.481	0.308	0.407
R2	0.695 *	0.181	0.001	1.248 *	0.228	0.000	1.075 *	0.237	0.000	0.552	0.247	0.123	0.379	0.255	0.449	−0.173	0.290	0.933
R3	0.577 *	0.166	0.004	1.039 *	0.230	0.000	0.964 *	0.240	0.001	0.462	0.234	0.209	0.387	0.244	0.394	−0.075	0.291	0.994
R5	0.414	0.193	0.148	0.291	0.161	0.281	0.959 *	0.252	0.002	−0.123	0.201	0.928	0.545	0.278	0.214	0.668	0.257	0.057
R6	0.036	0.255	0.999	0.364	0.282	0.573	−0.751 *	0.240	0.014	0.327	0.249	0.557	−0.787 *	0.200	0.001	−1.114 *	0.234	0.000
R7	−0.232	0.261	0.811	−0.571	0.241	0.094	−0.972 *	0.238	0.001	−0.339	0.204	0.35	−0.740 *	0.200	0.002	−0.402	0.173	0.102
R9	−0.491	0.251	0.213	0.117	0.264	0.97	−1.052 *	0.214	0.000	0.608	0.234	0.052	−0.561 *	0.176	0.011	−1.169 *	0.194	0.000
R10	−0.527 *	0.134	0.001	−0.010	0.164	1.000	0.213	0.225	0.780	0.518 *	0.137	0.002	0.740 *	0.206	0.004	0.223	0.227	0.760
R11	−0.009	0.152	1.000	0.837 *	0.203	0.001	1.121 *	0.255	0.000	0.846 *	0.200	0.000	1.130 *	0.252	0.000	0.283	0.286	0.755
R12	−0.323	0.151	0.152	0.697 *	0.194	0.003	0.179	0.240	0.878	1.020 *	0.175	0.000	0.501	0.225	0.130	−0.519	0.255	0.187
R13	−0.450 *	0.144	0.013	0.827 *	0.226	0.003	−0.268	0.157	0.324	1.277 *	0.214	0.000	0.182	0.138	0.557	−1.095 *	0.223	0.000
R15	−0.136	0.202	0.928	0.538	0.221	0.120	0.219	0.226	0.815	0.675 *	0.211	0.019	0.356	0.216	0.440	−0.319	0.234	0.604
R16	−0.268	0.144	0.252	−0.264	0.146	0.274	0.298	0.247	0.625	0.004	0.137	1.000	0.566	0.242	0.103	0.562	0.243	0.109
R17	0.709 *	0.149	0.000	−0.002	0.144	1.000	0.868 *	0.236	0.003	−0.711 *	0.145	0.000	0.158	0.237	0.909	0.870 *	0.234	0.003
R18	0.582 *	0.193	0.017	−0.199	0.152	0.560	1.091 *	0.274	0.001	−0.780 *	0.177	0.000	0.509	0.289	0.301	1.289 *	0.263	0.000
R19	0.468	0.189	0.070	0.319	0.164	0.215	0.863 *	0.253	0.007	−0.149	0.195	0.871	0.395	0.274	0.480	0.544	0.258	0.163
R20	−0.523 *	0.145	0.003	0.501	0.209	0.088	0.688 *	0.233	0.024	1.024 *	0.204	0.000	1.210 *	0.229	0.000	0.186	0.274	0.904
R21	−0.282	0.152	0.254	0.256	0.157	0.367	0.703 *	0.238	0.024	0.538 *	0.157	0.005	0.984 *	0.238	0.001	0.447	0.241	0.262

Note: "*" means that the difference in the concern about this risk between two stakeholder groups is significant.

Table 7. Comparisons of risk perception within different pairs of stakeholder groups.

	Risks with High Concern	G	H	C	D	Taking Proactive Measures for Risk Mitigation
G	R1: Frequent change in demolition policies			1.121 *		Yes
	R3: Lack of awareness of energy efficiency retrofitting		0.577 *	1.039 *	0.964 *	Yes
	R4: Lack of government departments' coordination and support					Yes but limited
	R5: Insufficient funds available				0.959 *	Yes but limited
	R17: Poor performance in cooperation		0.709 *		0.868 *	Yes
	R18: Opportunistic renegotiation		0.582 *		1.091 *	Yes but limited
	R21: Difficulties in post-retrofit repair				0.703 *	No
H	R10: Unqualified building materials	0.527 *		0.518 *	0.740 *	Yes but limited
	R12: Lack of construction skills			1.020 *		No
	R13: Moral hazard	0.450 *		1.277 *		Yes but limited
	R14: Poor quality of old residential buildings themselves					Yes but limited
	R16: Poor safety management					Yes
	R20: Inadequate maintenance	0.523 *		1.024 *	1.210 *	Yes but limited
	R21: Difficulties in post-retrofit repair			0.538 *	0.984 *	No
C	R16: Poor safety management					Yes
	R17: Poor performance in cooperation		0.711 *		0.870 *	Yes but limited
	R18: Opportunistic renegotiation		0.780 *		1.289 *	Yes but limited
D	R6: Insufficient information regarding the buildings	0.751 *	0.787 *	1.114 *		Yes
	R7: Uncertainty on the on-site conditions	0.972 *	0.740 *			Yes but limited
	R9: Lack of appropriate technical standards	1.052 *	0.561 *	1.169 *		Yes but limited
	R13: Moral hazard			1.095 *		Yes but limited

Note: "*" means that the difference in the concern about this risk between two stakeholder groups is significant.

Unlike the above three stakeholder groups, homeowners, as the owners and end-users of projects, attach more importance to the retrofit effects, which is considered the key to safeguard their own interests (see Table 7). They focus on the improvement of building quality and appearance and thus have more concern about the risks associated with on-site construction, including whether materials and contractors are qualified, whether contractors can conduct themselves lawfully, and whether their safety can be ensured. This is different from the traditional interests of homeowners. Homeowners in the international context generally have more concern about the cost-benefit analysis to make sure that their costs can be offset by retrofit benefits (including economic benefits and non-economic benefits) due to their roles as investors [122–124]. By contrast, cost-recovering is not the focus of homeowners in China since they do not need to bear the costs of retrofitting. In their opinion, the decrease in costs cannot contribute to the increase in their interests, and they attach more importance to the improvement of living quality.

5.2. Barriers to rRisk Perception

It can be reflected in Table 2 that industry stakeholders tend to have confidence in their own professional ability, which makes it possible for the relevant risks to be ignored subjectively by these stakeholders. As the professional provider of the construction service, designers and contractors rarely question their abilities to deliver services. They, however, worry about some external risks like the lack of objective information or uncooperative partners, which concerned their familiarity with design and construction work. The current energy efficiency technologies applied to the residential energy retrofit in China are relatively traditional, and there is no significant difference in the design and construction of energy-efficient measures between new-build projects and retrofit projects. This also convinces them that their professional expertise is enough to cope with the tasks in energy retrofit projects. Indeed, familiarity with a task can result in a decrease in risk perception [125]. People's understanding of their actions lead to their optimistic views of the relevant risks, and these risks are thus considered to be under control [126]. Such low perception can, in turn, weaken the incentives for the continuous improvement of their professional abilities.

In the comparisons between governments and both homeowners and designers in Table 7, governments are generally optimistic about designers' competence of making up for the shortage of technical standards (R9) and homeowners' ability of post-retrofit maintenance (R20), but such optimism is not recognized by designers and homeowners. The only technical specification for energy retrofit of residential buildings in the HSCW zone was issued in 2012 but is very difficult to be enforced in practice. The local government is more inclined to assign and complete retrofit tasks as soon as possible rather than spending much time improving the technical specification. In the opinions of the local government, retrofit schemes can be entirely dependent on designers' professional knowledge, even if there is a lack of technical guidance for the retrofit design. This was viewed by Wildavsky and Dake [71] as the individualist bias in culture theory, and it is believed that the severity of technical risks can be controlled and compensated for by technical institutions. However, designers actually complain that they do not know how to design the retrofitting schemes for old residential buildings due to the lack of specifications, so that they can only apply some necessary energy-efficient measures of new-built projects to retrofit projects, including the installation of insulation layers on roofs and exterior walls as well as the installation of windows with double glazing. It is also these limited and relatively simple retrofit measures that lead to the optimism of the local government about homeowners' performance in operation and maintenance after retrofitting. Instead, homeowners themselves are not convinced due to the lack of guidance and assistance.

5.3. Conflicts of Risk Perception

Based on the comparisons between homeowners and contractors in Table 7, it seems hard for them to perceive the risks posed by their own actions, especially related to opportunism. Both homeowners and contractors have opportunities during the on-site construction to adopt opportunistic behaviours. In homeowners' opinions, contractors' breaching of contracts by cutting corners has a direct negative impact on living comfort after retrofitting, but homeowners' poor cooperation and opportunistic requirements, causing project delay and cost increase, are regarded by themselves as a reasonable approach to perfecting the retrofit and building a better living environment. Xenidis and Angelides [127] and Loosemore, Raftery, Reilly and Higgon [90] viewed this as a bias resulting from contradictory interests. Similarly, for contractors, the execution of construction work requires cooperation from the homeowners, including the removal of obstacles in the pubic area, the placement of building materials, the negotiation of home-entry construction, etc. Meanwhile, faced with homeowners' unexpected demands like opportunistic compensation and unplanned retrofit requirements, contractors need to spend more time and costs on the negotiation with homeowners and the adjustment of construction schemes. However, contractors believe that they take the government projects more seriously and perform the contract strictly, and thus tend to neglect the risk arising from their opportunistic behaviours. Indeed, few people can acknowledge the relationships between their actions and the potential risks [128].

In terms of risks given high levels of concern by homeowners, it can be seen from the comparisons between homeowners and others in Table 7 that there are significant differences in the perception of some construction-related risks between homeowners and practitioners. Homeowners cast doubt on contractors' abilities and material quality as well as even the legalization of their actions. Excessive concern leads to their suspicion of whether these residential buildings can be renovated as they expected or not, which, in turn, affects their cooperation with contractors to some extent. As with the views of Ward and Chapman [22], stakeholders' approaches to risk mitigation arising from their perception of risks are likely to only focus on their benefits and thus to be detrimental to others. Influenced by risk perception, homeowners are more inclined to strengthen self-protection by making more requests for retrofitting. By contrast, the government does not view these risks as concerns, as believed by homeowners. In general, contractors are selected by the government through bidding, and such selection is also built on trust. Indeed, the differences in risk perception are related to the lack of confidence in people producing risks [129]. Moreover, project staff who feel untrusted are more likely to have moral hazard behaviours [130], which also means that contractors' opportunism originates from homeowners' mistrust to some extent.

5.4. Insights from Risk Perception and TCs Considerations

The decrease in homeowners' risk perception plays an important role in promoting homeowners' participation and cooperation, which also contributes to the mitigation of homeowner-associated risks. Information is essential to the adjustment of risk perception. Consumers' risk perception is dependent on product-related information collected from various sources [131], and risk perception is, in turn, also a direct predictor of information seeking [132]. Information search is one of the primary sources of TCs that are viewed to affect make–buy decisions [133]. From a TCs perspective, insufficient effective information leads homeowners to bear higher costs of information search, which is not only detrimental to the shaping of low levels of risk perception but also to their rational decision making on their involvement in energy retrofitting projects. In the Chinese context, the development of residential energy retrofit relies mostly on the government's propaganda and sponsorship. The local government is the main decision maker about the selection of projects, designers, and contractors as well as the scope of retrofit items, although homeowners' approval is still the premise of project initiation and the execution of design schemes. Few homeowners have access to sufficient project information in practice. In particular, the relationships between homeowners and other project parties are new and more temporary, which leads homeowners to have no prior knowledge of others' experience and reliability. To lower homeowners' concern about project risks, other parties should provide initiatively more positive and understandable information about material quality, the expertise of construction staff, safety guarantee, and post-retrofit maintenance. Moreover, the government and contractors should create a more transparent environment for the follow-up information on retrofit construction in order to enable homeowners to realize that their home is being improved with the help of other project parties.

It is essential for other stakeholder groups to enhance their risk perception and to improve the feasibility and effectiveness of proactive risk management measures. In consideration of the tendency of stakeholders' risk perception towards their own responsibilities, there is a need for all of the stakeholder groups to share the risks posed by them in order to trigger their awareness of proactively mitigating these risks. For example, industry stakeholders are required to enhance the technical knowledge to ensure the quality of their service; the government should assist in the development of technical guidance of energy retrofit and the establishment of systematic post-retrofit maintenance. Indeed, risk allocation is viewed as an approach to responsibility-sharing and has high impacts on stakeholders' behavioural motivations [22]. However, risk allocation requires the investment of resources, which is also likely to limit stakeholders' actions for risk mitigation. Economic condition is considered as one of the leading causes of the weak relationships between risk perception and stakeholders' actions [134]. Both uncertainties in the environment of proactive risk management and asset specificity concerning stakeholders' own abilities and resources give rise to higher TCs in the risk management transaction, which further restricts their behaviours in proactive risk management. There is no need for each stakeholder group to be involved in proactive management of all risks that are relevant to them. For instance, although homeowners and contractors need to be jointly responsible for on-site construction safety, it seems that contractors, owning experience and professional knowledge, can undertake more extra work with lower searching costs and monitoring costs to prevent safety issues. TCs incurred by proactive risk mitigation (e.g., searching costs, learning costs, negotiation costs, monitoring costs, etc.) should be considered in the risk allocation of energy retrofit projects in order to make sure that risk mitigation behaviours of risk-takers can be carried out successfully and effectively.

6. Conclusions

Energy retrofits of residential buildings in China are exposed to many risks due to the involvement of various stakeholders. Proactive risk management is a more functional approach to project success and can help economize on TCs by controlling uncertainty to smoothen the whole process of energy retrofit projects. Stakeholders' proactive actions for risk mitigation are based on their perception of these risks. Perceived risks are different from real risks, and contradictions of risk perception among different stakeholder groups can also result in the conflicts of risk mitigation practices. In order to motivate stakeholders' proactive management for real risks, it is essential to have a good understanding of stakeholders' present risk perception. This paper analysed and compared the perception of four main stakeholder groups of 21 risks (identified from a literature review and interviews) in residential energy retrofit projects in the form of risk concern. The proactive measures of different stakeholder groups for risk mitigation were also explored through interviews to validate the relationships between high levels of risk perception and proactive risk management.

Responsibilities and interests are the focus of stakeholders' risk perception, and high levels of risk perception can drive people to take proactive measures for risk management. The risk perception of government and industry stakeholders generally originate from their sense of duty as the project organizer and service providers, while homeowners tend to view their interests as a base of risk perception. Correspondingly, all the stakeholder groups are active in proactive mitigation for these risks. However, influenced by individuals' knowledge and external environment factors, the effectiveness of some proactive measures is not enough. Homeowners cannot do much about the risks relevant to professional knowledge (e.g., skills and work normativity of construction staff, quality of materials and buildings, and building maintenance). Designers have limited roles in the operational normativity of construction staff and the making up of the deficiency of some external information. By contrast, in terms of the risks concerning the coordination and support from other groups, proactive measures of the government are limited. Likewise, the contractors do not have sufficiently effective measures to proactively mitigate the risks arising from homeowners' cooperation.

It is essential for proactive risk management to enhance the risk perception of risk-source-related stakeholder groups in consideration of their more effective proactive measures compared to the affected groups. Stakeholders related to risk sources should share the risk, and their increased responsibilities can motivate them to enhance their awareness of proactive risk management. The government and contractors need to take more responsibilities for construction quality and maintenance. The government should set more explicit standards for the selection of retrofitting projects, construction materials, and contractors. Meanwhile, it is necessary to clarify contractors' responsibilities with respect to the procurement of materials, personnel abilities, service normativity, and post-retrofitting quality warranty. Furthermore, the government also needs to shoulder some responsibilities for design work, including not only developing more specific design standards but also assisting designers to probe deeper into buildings and the surroundings. TCs have an important role in both the enhancement of risk perception and responsibility-sharing. Risk allocation with TCs considerations can make responsibility-sharing more reasonable and effective and further drive the achievement of stakeholders' proactive risk management.

Homeowners' proactive measures also need to be encouraged, which can be achieved through changes (including both enhancement and reduction) in their risk perception. The key to managing the homeowner-associated risks lies with the enhancement of their self-awareness of active cooperation. Responsibility sharing (e.g., encouraging homeowners to bear some of retrofitting costs) contributes to reducing the barriers from homeowners during the construction period. Meanwhile, the decrease in homeowners' perception of risks caused by other stakeholder groups is also necessary to motivate homeowners' cooperative awareness. Sufficient and effective information should be provided to reduce homeowners' risk perception, which is also an approach to lowering TCs borne by homeowners and to further improve their initiative of participation and cooperation.

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Appendix A

Table A1. Proactive risk mitigation measures taken by stakeholders with high levels of risk concern.

	Stakeholder Groups with High Risk Concern	Taking Proactive Measures for Risk Mitigation	Details
R1:Frequent change in demolition policies	Government	Yes	"There is a criterion for the selection of renovation projects. These old residential buildings cannot be demolished in the next five years. We consult departments of urban construction and housing construction about the demolition scope. It is better to make sure that these buildings renovated can continue to be used for over ten years . . . "
R3: Lack of awareness of energy efficiency retrofitting	Government	Yes	"During the project set-up, we provided some information about energy retrofit for residents to enable them to have an understanding of retrofit. It is necessary to communicate with residents, which is the responsibility of the neighbourhood committee and the subdistrict office. During the dissemination of information, we also need to focus on those who are reluctant and indecisive . . . "
R4: Lack of government departments' coordination and support	Government	Yes but limited	"Actually, we (the Department of Housing and Urban-Rural Development) are mainly responsible for building renovation, but renovation is also related to water, electricity, and gas that should be handled under the responsibility of other departments. These departments did not actively cooperate with us. In general, if we cannot gain the cooperation of these other departments, we would ask heads of the municipal government and district for help . . . " "Before the implementation of retrofit, we had a workshop and all involved departments are required to attend. We needed to show the construction drawings to these departments to make sure that they can know about the potential impacts of retrofit on water, electricity, and gas . . . "

Table A1. *Cont.*

	Stakeholder Groups with High Risk Concern	Taking Proactive Measures for Risk Mitigation	Details
R5: Insufficient funds available	Government	Yes but limited	"We encourage homeowners to provide some money for energy efficiency retrofits, but this is simply a suggestion. In reality, homeowners are reluctant to pay for anything. Maybe the minority of homeowners are willing, while most homeowners reject it because of their own interests."
R6:Insufficient information regarding the buildings	Designers	Yes	"We acquired the aerial photos from the planning bureau. Moreover, we tried our best to do fieldwork for the measurement of building data such as contour lines of buildings and the size of windows and doors."
R7:Uncertainty on the on-site conditions	Designers	Yes but limited	"Prior notice was given on the drawings to highlight the potential obstructs (e.g., cable and gas pipelines on the external walls) during the construction. We also pointed out the possible deviations between design drawings and the on-site practical situations (e.g., hidden pipelines) so that the government could do preparations in advance . . . "
R9: Lack of appropriate technical standards	Designers	Yes but limited	"Actually, we also do not know how to design the retrofitting schemes for old residential buildings due to the lack of requirements so that we can only regard these old buildings as newly built buildings . . . " "For residential buildings, no matter newly built buildings or old buildings, we used the same energy-saving design software for modeling and calculation. We viewed the old residential buildings as newly built buildings. For example, when designing the insulation of exterior walls, we need to suppose first the original wall surface to be eradicated. Then we redesign the insulation layer and the surface . . . "
R10: Unqualified building materials	Homeowners	Yes but limited	"We could only observe the materials and touch the surface to make a judgment. We also did not know if these materials are safe and nontoxic. What we knew were dependent on what the contractors said. When having doubts about some materials, we still put forward our opinions and suggested contractors change it." "We also asked what materials were used, and they told us something about the materials. However, we generally still knew little about it so that we could not be too serious about them."
R12: Lack of construction skills	Homeowners	No	"We knew little about retrofit construction and these construction workers. We are the laypeople, so we could not think about it too much. We could not also do something about it . . . "
R13: Moral hazard	Homeowners	Yes but limited	"During the construction, we could supervise them, and many people crowded around to watch them. Sometimes I also talked with them about mortar and concrete mixing. They told us that these materials were tested. If noticing that they cut corners on retrofit construction, we could call the mayor's hotline for complaints. However, it was still hard for us to supervise them because we did not have professional knowledge."

Table A1. *Cont.*

	Stakeholder Groups with High Risk Concern	Taking Proactive Measures for Risk Mitigation	Details
	Government	Yes	"In terms of construction, there is a set of supervision systems, including supervisors, acceptance inspection, and a two-year warranty. We also arranged some people to do field supervision. In general, we went to the construction site every two days, and there was a regular supervision meeting every four days. Homeowners could also feed some problems back to the neighbourhood community, and the neighbourhood community fed these problems back to us. Moreover, the supervision company was selected in the bidding process. Municipal and district departments of quality inspection were also involved in the supervision process. If they found out some problems, they would punish the relevant construction staff, which also could lead these companies to have a bad record . . . "
	Designers	Yes but limited	"During the construction, we went to do the on-site supervision to check if the construction was conducted according to our design requirements, such as the fixation of insulation walls, external walls, and the original walls. However, it was also impossible for us to be always there for follow-up supervision . . . "
R14: Poor quality of old residential buildings themselves	Homeowners	Yes but limited	"Before the implementation of retrofit, some professionals came here for quality inspection. During this period, we also asked some questions about building quality to them. Beyond that, we could do nothing. After all, we were the laypeople and could not do something about it."
R16: Poor safety management	Homeowners	Yes	"We paid more attention to our own safety, and also remind others to be careful. For example, when the construction workers were building the scaffold, we reminded the neighbours who were passing by the scaffold to take care."
	Contractors	Yes	"We erected some barriers around the construction site to prevent residents from approaching the dangerous areas. We also kept up with garbage collection, and always reminded residents to pay attention to their safety. In terms of our own safety, we always supervise the construction workers to wear safety helmets and to fasten safety belts."
R17: Poor performance in cooperation	Government	Yes	"During the design process, we did the field survey in order to respect the will of people. If we did it very well, it would be possible to make the conflicts during the construction less and to make the alteration less." "The demolishment of illegal constructions was based on the aerials photos in both 1982 and 1996. These photos could be the evidence to enable us to require homeowners to cooperate on the removal of illegal constructions." "We had some rules and regulars for the prevention of conflicts. For example, we had a mechanism for on-site compromise, and someone was put in charge of some conflicts. There was a billboard on which homeowners could be informed of retrofit contents, parties participating in retrofit projects, the personnel in charge of quality control, and design schemes."

Table A1. *Cont.*

	Stakeholder Groups with High Risk Concern	Taking Proactive Measures for Risk Mitigation	Details
	Contractors	Yes but limited	"We usually informed homeowners of construction conditions to encourage their cooperation. We paid more attention to our own attitudes and language when communicating with homeowners in order to avoid an unnecessary quarrel. We also asked the subdistrict office and neighbourhood community for coordination."
R18: Opportunistic renegotiation	Government	Yes but limited	"In the previous projects, we experienced many unnecessary financial losses. For example, before renovating the roof, we had to remove solar water heaters on it. However, many homeowners used the damage of their heaters as an excuse to ask us for the compensation, and we also did not know whether these heaters had been broken before removing them. As a result, we did view the roof renovation as the universal retrofit items. If there was a need to renovate the roof, we first required good coordination among neighbours."
	Contractors	Yes but limited	"We tried our best to prevent unnecessary contacting with homeowners' personnel items. Moreover, before the construction, we needed to check if homeowners' solar water heaters have been broken."
R20: Inadequate maintenance	Homeowners	Yes but limited	"We generally supervise each other and cherish and protect our own home."
R21:Difficulties in post-retrofit repair	Government	No	"The government promotes building energy efficiency, so there are the insulating layers on the exterior wall of the buildings constructed in recent years. However, the insulating layers broke apart from some residential buildings only a few years after they were built. At present, the technology of the external thermal insulation wall is not mature in our country . . . "
	Homeowners	No	"We are not the professionals and know little about it. We cannot do anything, in addition, to rely on government and construction workers."

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