Exploring key risks of energy retrofit of residential buildings in China with transaction cost considerations

Jia, Ling; Qian, Queena K.; Meijer, Frits; Visscher, Henk

DOI
10.1016/j.jclepro.2021.126099

Publication date
2021

Document Version
Final published version

Published in
Journal of Cleaner Production

Journal of Cleaner Production 293 (2021) 126099

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Exploring key risks of energy retrofit of residential buildings in China with transaction cost considerations

Ling Jia *, Queena K. Qian , Frits Meijer , Henk Visscher

Faculty of Architecture and The Built Environment, Delft University of Technology, Julianalaan 134, 2628, BL, Delft, the Netherlands

A R T I C L E I N F O

Article history:
Received 19 August 2019
Received in revised form
14 November 2020
Accepted 22 January 2021
Available online 26 January 2021

Handling editor: Yutao Wang

Keywords:
Energy retrofit
Risk management
Transaction costs
Stakeholders

A B S T R A C T

Energy retrofit of residential buildings is an approach to reduce worldwide energy consumption. Residential energy retrofitting in China mostly focuses on multi-owner residential buildings with composite ownership that dozens of private homeowners own their apartment and jointly own the common parts of a building. The implementation of residential energy retrofit faces many risks, causing the slow retrofit process in the hot summer and cold winter (HSCW) zone of China. Transaction cost theory (TCT) is conducive to enrich an in-depth understanding of risk inventories in the energy retrofitting context. This paper aims to explore the key risks in retrofit projects of residential buildings in the HSCW zone with transaction costs (TCs) considerations, in order to provide the direction for effective risk management. First, based on the theoretical risks with TCs considerations, interviews were conducted to adjust the risk list and to connect these risks with stakeholders and stages. Second, a questionnaire survey was made based on two parameters of risk probability and severity, and then ten top risks were chosen as key risks through both a risk matrix and Borda count. The results show that most of the key risks are associated with homeowners and contractors, involving retrofit awareness, cooperation performance, opportunism, professional expertise, construction management, safety management, and maintenance, of which most occur at the stage of on-site construction. Information cost is the largest source of TCs relevant to these key risks and is mainly borne by the government and homeowners. TCs can also provide a lens for the retrofitting in other countries to understand risks, and the decrease in information costs contributes to effective risk management both in China and in the international context.

1. Introduction

Building energy use has become the main driver for the growing worldwide energy consumption and CO_2 emissions. The final energy use in buildings grew from 118 EJ in 2010 to about 128 EJ in 2019, and CO_2 emissions from buildings peaked over 10 $GtCO_2$ in 2019, occupying 30% and 28% of the global total respectively (IEA, 2020). China had faster growth in CO_2 emissions related to buildings than many other countries between 2000 and 2017 (see Fig. 1). Worldwide, 70% of building energy demand and 60% of emissions are attributed to residential buildings (IEA, 2019a). Urban residential buildings also play a dominant role in building energy consumption and carbon emissions in China, sharing 38% and 41% of the national total respectively (CABEE, 2018). The total area of urban residential buildings was 24.8 billion m^2 by 2015 in China, and energy-efficient dwellings only account for about 40% (CABEE, 2017; MOHURD, 2017). Existing buildings, especially old residential buildings, have the enormous potential of energy saving in China (Ouyang et al., 2011).

The large differences in climate conditions among different regions in China result in different regional characteristics of building energy consumption. The hot summer and cold winter (HSCW) zone (0–10 °C in the coldest month and 25–30 °C in the hottest month) is of particular significance in building energy efficiency of China (Xu et al., 2013). The number of air conditioners per household in this zone is the largest in China, and the households tend to use air conditioners for longer cooling hours than most of the other regions (IEA, 2019b). Heavy use of heating facilities resulted in a considerable increase (circa 575%) in the residential heating energy consumption in the HSCW zone in the past several years (Lin et al., 2016). Existing building stock in urban locations within the HSCW region covered an area of about 9 billion m^2, of which residential

* Corresponding author.
E-mail addresses: L.Jia-2@tudelft.nl (L. Jia), k.qian@tudelft.nl (Q.K. Qian), F.M.Meijer@tudelft.nl (F. Meijer), H.J.Visscher@tudelft.nl (H. Visscher).

https://doi.org/10.1016/j.jclepro.2021.126099

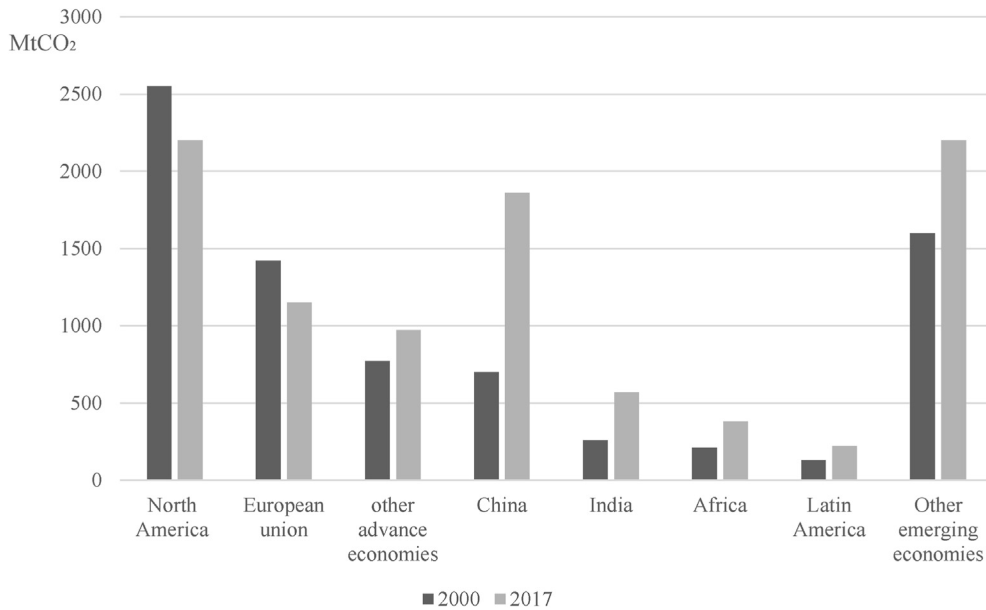

Fig. 1. Building-related CO_2 emissions by region, 2000–2017 (IEA, 2019a).

buildings comprised 66% in 2012 (Liu et al., 2017). 54% of existing urban dwellings in this region were constructed without any thermal insulation measures (Fu, 2002). Only 70.9 million m^2 of retrofit projects were completed in the HSCW zone during the 12th Five-Year Plan period (2011–2015), a much slower rate than the northern region with 990 million m^2 (MOHURD, 2017). Therefore, it is necessary to accelerate the implementation of residential energy retrofitting in China's HSCW zone.

Energy retrofits for residential buildings in China are faced with many risks in the implementation process. Risks are characterised by uncertainty and negative impacts on project objectives (Chia, 2006). Risks in this paper are concerned with uncertain events and exert a negative influence on performances of energy retrofitting projects (e.g. costs, quality, organization, and management). The multi-owner apartment building is the main form of urban residential buildings in China and is also the main object of energy retrofitting. Private homeowners own their apartment and all homeowners share ownership of the common parts of a building, but the land is owned by the state. Uncertainty lies in these retrofitting projects in terms of adequacy of investors (Bao et al., 2012; Lu et al., 2014), consistency in homeowners' opinions on retrofitting (Lv and Wu, 2009), homeowners' satisfaction and accuracy of using installed technology (Liu et al., 2015), performance in cooperation among various government departments (Lv and Wu, 2009), the perfection of technology (Lv and Wu, 2009), etc. These uncertainties pose a series of risks about the economy, homeowner attitudes and behaviours, stakeholder coordination, and technology to residential energy retrofitting in China. Such risks are also the main barriers to energy retrofitting in China, and impede the progress and the achievement of project objectives.

Risk identification is the premise of risk management, and the lens of transaction costs (TCs) can be considered to identify these risks. TCs are different from production costs and are the economic equivalent of friction in physical systems (Williamson, 1985). The residential energy retrofitting process can be divided into stages involving various stakeholders. TCs occur in terms of tasks or concerns amongst the stakeholders at different stages (transactions) when stakeholders rely on each other to deliver service and exchange information. Energy retrofitting of residential buildings is in its infancy in the HSCW zone of China, so that the scale of retrofitting is limited. A smaller size of projects is more likely to cause high TCs (Painuly et al., 2003). Uncertainty is a core assumption in transaction cost theory (TCT). All the transactions are conducted in an uncertain situation with imperfect information so that more effort needs to be made to collect sufficient information (Aubert et al., 2004). Uncertainty is considered to increase the probability of opportunism from specific assets, resulting in an increase in TCs of exchange (Sutcliffe and Zaheer, 1998). TCs can be searching costs for the right partners and technical information, learning costs to understand the incentives and how to apply, negotiation costs to handle conflicts and disagreements, etc. For example, uncertainty about qualified technical providers incurs TCs to search for skilled staff and employ external experts (Matschoss et al., 2013). From the new institutional economics perspective, when TCs are too large, the exchange, production, and economic growth would be inhibited (North, 1986). Those uncertain factors viewed as risks in energy retrofit projects give rise to the increase in TCs and thus hinder the retrofitting transactions. Risks need to be managed in the whole process of projects (Raj and Wadsamudrakar, 2018), and stakeholders as risk sources should also be analysed to mitigate the risk impacts (Prum and Del Percio, 2009). TCT can not only provide a more targeted identification of risks hindering the implementation of the energy retrofit, but also help have a better understanding of risks, by taking both the project stages and stakeholders into consideration.

This paper aims to identify the critical risks hindering the implementation of residential energy retrofitting projects in the HSCW zone of China, from different stages and stakeholders with TCs considerations. TCT can enrich an in-depth understanding of risk inventories in the energy retrofitting context. Two hypotheses are proposed as follows: (1) different phases of the renovation process induce various TCs, and different stakeholders also associate with TCs differently; (2) different stages and stakeholders have varying levels of importance due to the differences in the priority of their relevant risks. This paper provides a holistic understanding of the significant risks in the whole process of energy retrofit projects and, thus, contributes to developing effective measures of risk management in China. The findings also provide the local government with policy directions towards facilitating residential energy retrofitting in China. The TCT-based method can help recognize the risks in energy retrofitting projects in other countries.

The rest of the paper is organized as follows. Section 2 presents the generic risks from the previous studies and TCT-based risks. Section 3 provides the methodology used in this paper. Section 4 shows the results, including a risk list adjusted by Chinese practitioners and risk ranking according to the risk matrix and Borda count. Section 5 presents the discussion on the key risks. Section 6 draws the conclusions.

2. Literature Review

2.1. Retrofit process and stakeholders in the Chinese context

In the Chinese context, there is no fixed and uniform process for energy retrofit projects. Each provincial government has its own retrofitting measures and procedures, and the documents developed by the central government can only offer limited guidance. *Guide for Energy Saving Retrofit of Existing Residential Buildings* (MOHURD, 2012a) and *Technical Guidelines for Energy Efficiency Retrofitting of Existing Residential Building in the Hot Summer and Cold Winter Zone* (MOHURD, 2012b), published by the central government, provide some reference to advise on the retrofitting process. By summarizing these official technical guidelines, this study classifies the overall process of energy retrofit projects in the HSCW zone in China into five stages: regional survey and project setup, project design and fundraising, construction bidding and construction preparation, on-site construction, and inspection, acceptance, and use.

Menassa (2011) defined stakeholders in sustainable retrofitting projects as people who can benefit directly or indirectly from retrofitting projects. The stakeholders of retrofit projects in the northern region for the residential buildings in China, are considered to be central and local government, 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 (Bao et al., 2012; Lu et al., 2014). Given the characteristics of energy retrofit in the HSCW zone (e.g. few heating systems and few property management units in old residential quarters), this paper categorizes four main stakeholders in retrofit projects, namely occupants, government, designers, and contractors.

2.2. Risk identification from a generic perspective

Existing research on risks on energy-efficiency investments explores the potential risks leading to lower energy-saving benefits than expected, including cost increase and the decrease in energy-saving performance. Mills et al. (2006) identified several risks concerning energy-cost volatility, completeness of information on facility and environment, equipment performance, maintenance performance, and measurement accuracy. Booth and Choudhary (2013) also mentioned the inaccurate estimation of energy consumption before and after retrofitting, which was considered as the leading cause of the efficiency gap. Similarly, end-users' operation and usage mode after retrofitting was mentioned by Boutaud et al. (2011) and Olgyay and Seruto (2010). Furthermore, the incompetence of technical staff in terms of design and installation was emphasized, involving insufficient design details, lacking installation knowledge, and poor on-site quality control (Boutaud et al., 2011; Fylan et al., 2016; Mitropoulos and Howell, 2002; Olgyay and Seruto, 2010).

A few studies on the promotion of energy retrofit proposed some risks to explain the implementation difficulties in homeowner participation, fundraising, and government support. From the government's viewpoint, public awareness, feasibility of goals and plans, technical knowledge, coordination with citizens, and availability of funds, all bring obstacles to the implementation of energy retrofit projects (Caputo and Pasetti, 2015). For homeowners, low public confidence, lack of consistent and long-term policies, inability to evaluate the retrofit costs, and shortage of information on variations in future heat prices also stop them from retrofitting their homes (Biekša et al., 2011). Besides, poor coordination among different government departments was also highlighted by Bao et al. (2012) in the Chinese context. However, these studies identified risks of energy retrofit projects mainly from a single stakeholder group (e.g. investors, government, and homeowners) rather than from the overall perspective of project implementation. Most of the risks identified in previous studies are viewed as the factors influencing the selection of retrofitting solutions. Those investment risks related to the efficiency gap also only hinder the investment in retrofit, which rarely needs to be considered in the Chinese context due to the role of the local government as the investor. It is necessary to identify the risks in residential energy retrofitting projects in China from the project management perspective on promoting retrofitting processes. TCT can be applied to explore the barriers of transaction activities based on inter-organizational relationships in the transaction process, and thus can provide a reference point for risk identification to enrich the risk list.

2.3. Risk identification from a TCs perspective

TCT was introduced by Coase (1937) and developed by Williamson (1975) based on two assumptions of human behaviours (bounded rationality and opportunism) and three transaction characteristics (asset specificity, uncertainty, and frequency). Bounded rationality arises from the human mind's cognitive limitations and imperfect information (Selten, 1998; Simon, 1957). Opportunism refers to the claim that humans act out of self-interest and with guile (Williamson, 1993). In some cases, uncertain factors make it difficult for parties in a transaction to make a perfect contract, taking all circumstances into consideration, which also provides the incentive for opportunistic behaviours (Pilling et al., 1994; Walker and Weber, 1984). To be specific, influenced by uncertainty and high costs of comprehensive forecasts, bounded rational organizations and individuals have a limited capacity to find, process, and understand information. Uncertainty can generally result in risks of financial losses on the premise of asset specificity (Dorward, 2001). The characteristic of asset specificity leads to a greater probability of opportunistic expropriation due to changed bargaining power and the threat of transaction termination (Klein et al., 1978).

Uncertainty and asset specificity also result in the risk that one party in a transaction will exploit their own information advantages for misconduct (Parker and Hartley, 2003). According to transaction costs economics, many transaction problems have something to do with information asymmetry (Clemons and Hitt, 2004). With the existence of uncertainties, it is hard for contracting parties to evaluate others' contributions, leading to an increase in the potential for opportunism (Shrader, 2001). Such opportunism is in the form of selective disclosure or distortion of the data, rendering other parties unable to gain access to the actual data (Williamson, 1975). The party undertaking specific investments is more likely to be vulnerable to opportunistic expropriation, such as lower quality of the product/service and price/cost losses, due to their locked-in situation (Klein et al., 1978).

The various sources of TCs can be the basis for risk identification in the whole process of energy retrofit projects. Kiss (2016) summarized the main activities incurring TCs related to implementing energy efficiency projects, including information search and assessment, project preparation, seeking partners, persuading, negotiation, making a contract, implementation, coordination, monitoring, and maintenance. Some of these TCs are related to risks in energy retrofit and arise from (1) a lack of energy efficiency knowledge and project information, (2) uncertainty about reliable partners and willingness of homeowners, (3) uncertainty about partners' compliance with specified terms, (4) uncertainty on possible changes in energy savings, and (5) uncertainty on users' behaviours and maintenance. In fact, these risks are almost consistent with the above generic risks mentioned in previous studies but can be understood from a TCs perspective. These risks also exist in the Chinese context. Energy retrofit is a new concept for residential buildings in the HSCW zone of China. The government and industry stakeholders lack experience in management, coordination, and technical support, which means that they have to bear the corresponding TCs to develop appropriate policies, optimize technical standards, enrich technical knowledge, and improve coordination abilities. Likewise, homeowners need to search for information to advance their understanding of retrofit. Searching costs are also involved in the design stage to ensure the integrity of information relevant to old residential buildings (e.g. as-built data and the surrounding environment). In addition, the existence of opportunism (e.g. adverse selection in the phase of construction bidding as well as moral hazard and opportunistic negotiation during the on-site construction) would incur more searching costs, bargaining costs, and monitoring costs.

3. Research methodology

3.1. Three case studies

This study views Anhui province in the HSCW zone of China as the object of empirical analysis. 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. Three energy retrofit projects are chosen from three cities in Anhui province as cases. These three projects were funded jointly by the provincial, municipal and district governments. Government is the only investor in most residential retrofitting projects in China. The basic information on these cases is shown in Table 1.

These three cases adopted the most common retrofitting measures in the HSCW zone of China, and can reflect the daily practices in this region. The main retrofitting items involved in these projects include exterior windows, roofs, and exterior walls. In these projects, doors and windows were replaced by those with higher levels of insulation, and new thermal insulation materials were also used to improve the insulation effectiveness of walls and roofs. There are differences in building materials (e.g. windows and thermal insulation plates) used among these cases, but these projects were implemented based on the same design standard for energy efficiency of residential buildings issued by Anhui provincial government. This standard was also developed based on the standard for the HSCW zone established by the Chinese central government.

It is shown, based on the case study data, that the majority of apartments in these buildings are owner-occupied. Moreover, only homeowners have the right to determine whether these residential buildings can be renovated and how to renovate them. As a result, homeowners replace occupants as one of the four main stakeholder groups in this paper.

3.2. Interviews with key stakeholders in cases

Interviews are necessary to adjust the theoretical risks to the Chinese context. Semi-structured interviews were conducted with 22 interviewees from the provincial government, the municipal and district governments in the provincial capital city, and the above three cases, including 10 government officials, 4 designers, 4 on-site construction managers, and 4 homeowners. Appendix A presents the profiles of all interviewees.

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. Given the differences in the departments in charge of residential energy retrofitting between different cities, the government interviewees for different cases were selected from various government levels and departments. The first three officials, from the provincial government and the government of provincial capital, were first interviewed to discuss the general situations of energy retrofit and the common risks affecting the implementation. All the rest were directly involved in three cases and were almost involved in all stages of the energy retrofitting projects. Compared to other stakeholder groups, government interviewees are more familiar with all processes in retrofitting projects, and more qualified to identify risks existing in each stage.

The industry stakeholder representatives from design and construction companies were the primary designers and construction managers in the above cases. In particular, three construction representatives were the chief managers in charge of on-site construction for three projects. These interviewees have a 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 cases. Two of them are the members of homeowners' committees that act on behalf of all the homeowners in a residential quarter. The other two are both homeowners and neighbourhood committee staff. There are no homeowners' committees in some renovated residential quarters, and members of neighbourhood committees are therefore responsible for information transmission in practice. As members

Table 1
Case information.

Case No.		1	2	3
Year of completion		1987	1990s	1998
Year of retrofit		2017	2017	2017
Number of residential buildings		Three five-story buildings	Four five-story buildings, one four-story building, and six two-story buildings	Six six-story buildings
Gross floor area/m^2		4160	25,000	23,600
Number of households		180	247	185
Bid price/CNY		1,284,371	3,700,000	6,310,000
Energy retrofit contents	Windows	✓	✓	✓
	Doors	✓		
	External walls	✓	✓	✓
	Roof	✓	✓	✓

of homeowners committees and neighbourhood committees, these interviewees have a better understanding of the potential project risks than ordinary homeowners.

The interview questions mainly focus on three aspects: the work and tasks in the entire renovation process, responsibilities and roles of the stakeholders, and verification of the theoretical risks. Based on interviews, this paper can empirically test the existence of the theoretical risks identified from the literature review and TCT, and adjust the theoretical retrofitting process to the practice. Interviews also provide information about the distribution of risks in different project stages and the stakeholders associated with each risk.

3.3. Questionnaire survey of professional practitioners

A questionnaire survey was conducted to help collect experts' views to explore the significance of different risks. The questionnaire was designed based on the risk list adjusted by interviewees. The final risk list is presented in Table 2, and detailed descriptions for each risk are shown in Appendix B. These risks are composed of three origins, including reviewing previous studies on retrofit risks, identifying risks in the retrofit context of China based on TCT as a supplement to the above risks collected from the literature review, and adding risks depending on interviewees' feedbacks. This questionnaire comprises two sections: (1) information about the respondents' profile; (2) respondents' evaluation on risk ranking. Risk probability and risk severity are the most common parameters for assessing risks (Lyons and Skitmore, 2004; Taroun, 2014). These two parameters should be considered to assess risks in a project (El-Sayegh, 2008). In the second part of this questionnaire, a Likert scale of 1–5 is used to evaluate the likelihood of risk occurrence (1 = very unlikely, and, 2 = unlikely, 3 = possible, 4 = likely, 5 = very likely) and severity of risk impacts (1 = negligible, 2 = minor, 3 = moderate, 4 = serious, 5 = critical) (El-Sayegh, 2008).

The questionnaires were delivered to the professionals who have been involved in the local retrofitting projects. The respondents are mostly from the three cities where three cases are selected; the rest are from the government departments in the provincial capital city. The participants have experience in three case projects, if not in other retrofitting projects. The respondents from the municipal governments and the design companies were involved in almost all the retrofitting projects in the city where they are located with good knowledge and experience. Despite some differences between different projects, a broader range of survey data can validate the universality of risks identified from interviews and cases and also reduce the potential prejudices from the minority. This questionnaire survey was used to quantify the significance of these risks, and interviewers' opinions can help understand the results or rankings of quantification.

These responses were collected via personal delivery or e-mails. The response rates of face-to-face questionnaires were higher than those via e-mails, which is possibly due to closer social relations with face-to-face respondents. A total of 150 questionnaires were delivered, and 67 were completed and used in this paper. The respondents' profiles are summarized in Table 3.

3.4. Data analysis method

Tests for normality of data of each variable of each risk were first made by SPSS. Q-Q plot and values for skewness and kurtosis were used for checking normality. Q-Q plot is a visual inspection of the distribution. The normal Q-Q plot of each variable presents an

Table 3
Respondents' profile.

	Category	Number
Role	Government Official	18
	Contractor	25
	Designer	24
Years of working experience	<5 years	10
	5–10 years	23
	10–15 years	18
	>15 years	16

Table 2
Risks in residential energy retrofitting projects in China.

No.	Risks	Sources
R1	Frequent change in demolition policies	Interview
R2	Uncertainty on property right and occupancy	TCT
R3	Lack of awareness of energy efficiency retrofitting	(Biekša et al., 2011; Caputo and Pasetti, 2015)
R4	Lack of government departments' coordination and support	Bao et al. (2012)
R5	Insufficient funds available	(Bao et al., 2012; Biekša et al., 2011; Caputo and Pasetti, 2015; Dahlhausen et al., 2015; Li, 2009; Lo, 2015)
R6	Insufficient information regarding the buildings	Mitropoulos and Howell (2002)
R7	Uncertainty on the on-site conditions	TCT
R8	Lack of technical staff with specific expertise	(Boutaud et al., 2011; Ferreira and Almeida, 2015; Hallikas et al., 2004; Mills et al., 2006; Olgyay and Seruto, 2010)
R9	Lack of appropriate technical standards	TCT
R10	Unqualified building materials	Interview
R11	Adverse selection	TCT
R12	Lack of construction skills	(Boutaud et al., 2011; Ferreira and Almeida, 2015; Fylan et al., 2016; Goldman, 1985; Hallikas et al., 2004; Olgyay and Seruto, 2010; Sunikka-Blank and Galvin, 2012)
R13	Moral hazard	TCT
R14	Poor quality of old residential buildings themselves	Interview
R15	Poor construction management	(Fylan et al., 2016; Goldman, 1985)
R16	Poor safety management	Interview
R17	Poor performance in cooperation	Rovers (2014)
R18	Opportunistic renegotiation	TCT
R19	Measurement problems	TCT
R20	Inadequate maintenance	(Boutaud et al., 2011; Mills, 2003; Mills et al., 2006; Olgyay and Seruto, 2010; Walker et al., 2014)
R21	Difficulties in post-retrofit repair	Interview

approximately straight diagonal line, meaning normally distributed data. Skewness and kurtosis were also measured to judge whether data distributions of this study deviate from normal. A z-score was obtained by dividing the values of skewness or kurtosis by their standard errors. In small samples ($20 < n < 80$), the critical value of z-score for the normal distribution is ±1.96 (Wright and Herrington, 2011). All the z-scores in this study are within this range, and more results are shown in Appendix C. Based on the test results, data of each risk variable are considered to be distributed normally.

The mean values of the probability and impact of each risk were calculated. A risk matrix is considered as a good way to integrate possibility with impact (El-Sayegh, 2008). The risk matrix was proposed by the U.S. Air Force Electronic Systems Centre (ESC) in 1995 (Fu et al., 2011) and is also used in various international standards such as ISO and IEC (Duijm, 2015). According to the study of El-Sayegh (2008), the risk matrix divides the risk significance into three levels, including high, moderate and low (shown in Fig. 2).

There are still some limitations to the original risk matrix in terms of risk rating. In general, the original risk matrix makes a ranking with many ties, which may lead to the sharing of the same level among some risks (Ni et al., 2010). The Borda count method was developed by ESC researchers to solve this problem. The Borda method can be introduced to the risk matrix in order to reduce the number of risk ties (Garvey and Lansdowne, 1998) significantly. It was also pointed out that the Borda method could be used to make a cross-check on the ratings of the risk matrix as well as to show what changes in possibility or severity were needed to mitigate a critical risk. Therefore, the Borda voting method needs to be applied to the risk matrix to rank risks more appropriately.

The Borda count for the risk j is calculated by Equation (1):

$$b_j = \sum_{k=1}^{2} (N - r_{jk}) \quad (1)$$

Where.

N is the total number of risks.

r_{jk} is the number of risks with higher scores than the risk j under the criterion k; $j = 1, 2, \ldots, N$; $k = 1$ and 2.

The Borda rank for risk is the number of risks with a higher Borda count than this risk. The higher the Borda rank, the more critical this risk is. The results of both the original risk matrix and Borda voting are considered in the overall risk rankings.

4. Results and analysis

Through the interviews, the process and stages of energy retrofit projects were adjusted to China's practical context (as shown in Fig. 3). Fig. 3 also summarizes the distribution of risks in each project stage and the stakeholders associated with each risk based on interviewees' descriptions. Most of the risks can be explained by TCT to some extent and are related to specific TCs (e.g. searching costs, monitoring costs, negotiation costs, etc.).

Table 4 presents the statistical analysis for risks, including mean scores, the standard deviation (SD), the coefficient of variation (CV), and rankings of each risk based on means. SD and CV are the standard measures of data dispersion. Narrow SD and CV indicate stable and reliable data as well as the consistency of respondents' views on risk significance. The range of mean ± 1.64 SD is viewed as the consensus criterion for the items with a four-point Likert scale (Rogers and Lopez, 2002; West and Cannon, 1988). A wider range can be used for the consensus evaluation in this study with a five-point Likert scale. It is shown in Table 4 that all the SDs are below 1.27. 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 fair internal agreement (English and Kernan, 1976; Zinn et al., 2001). All the CVs listed in Table 4 are below 0.5.

Table 5 shows the level of each risk by considering the mean values of probability and impact. 12 risks have a high level of significance and the rating of 7 risks is medium. Only 2 risks are considered as low. Risk rankings based on the Borda method are also presented in Table 5. Borda voting is an extension of the risk matrix method and enables risks at the same or similar risk matrix

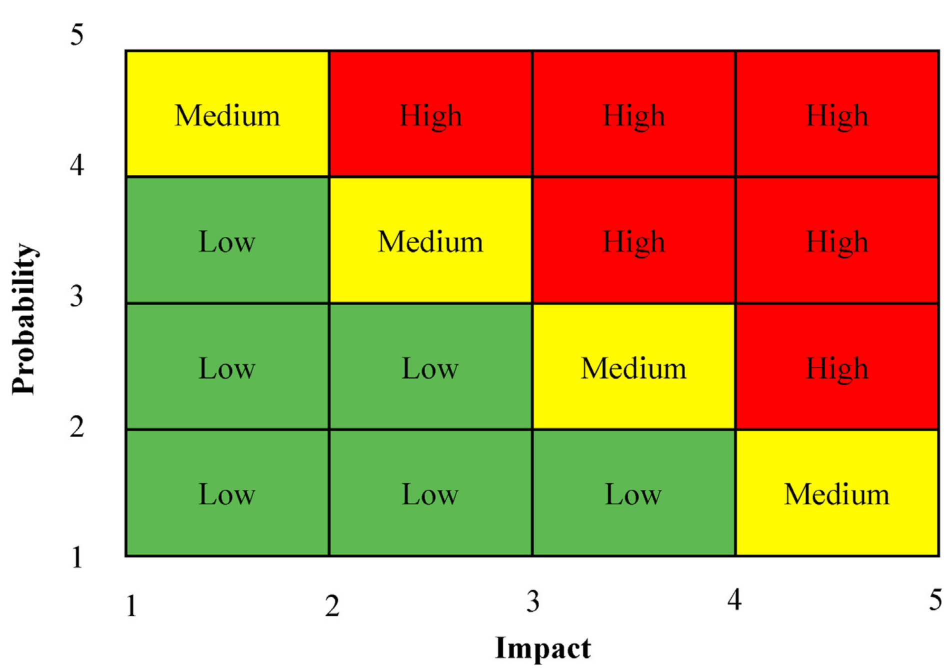

Fig. 2. Probability-Impact matrix.

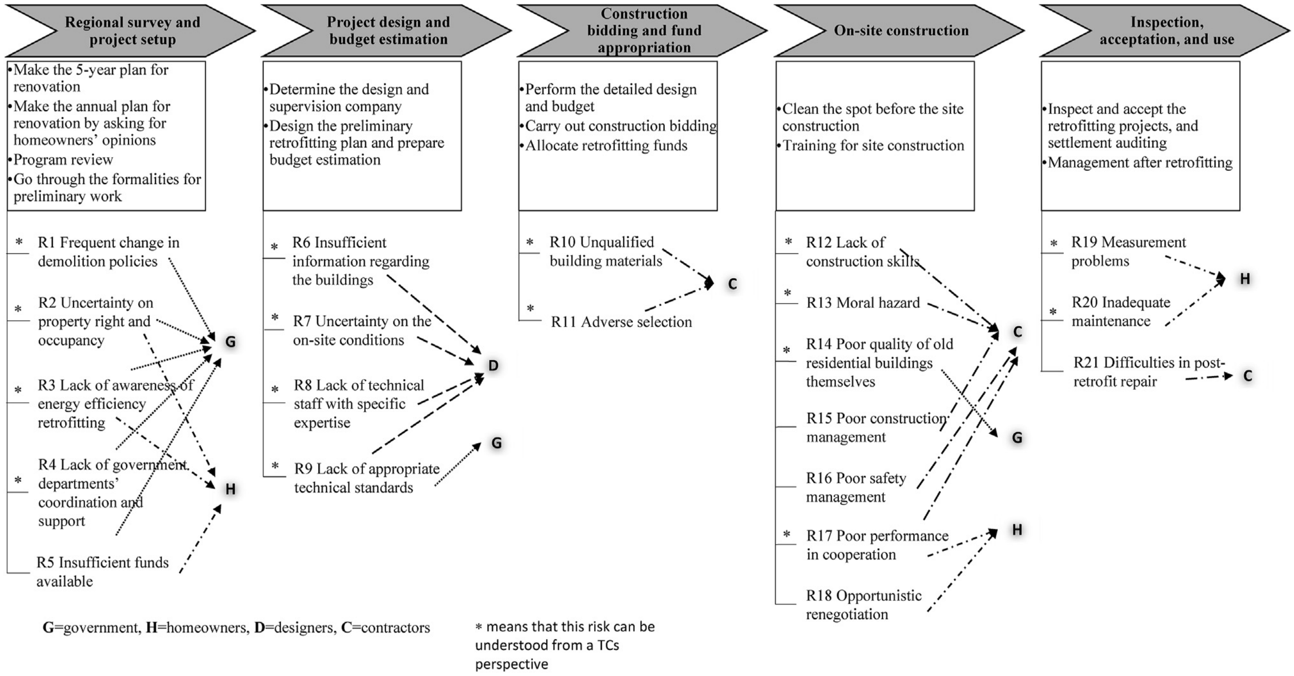

Fig. 3. Risks in the whole process of energy retrofit projects in practice (by the authors).

Table 4
Statistical analysis for risks.

	Probability				Impact			
	Mean	SD	CV	Rank	Mean	SD	CV	Rank
R1	2,91	1,22	0,42	15	3,01	1,33	0,44	18
R2	2,82	0,83	0,30	17	2,37	0,85	0,36	21
R3	3,94	0,87	0,22	1	3,66	0,51	0,14	6
R4	2,94	1,13	0,38	13	3,49	0,77	0,22	11
R5	3,09	1,18	0,38	11	3,30	1,13	0,34	13
R6	3,40	0,85	0,25	4	2,94	0,69	0,24	19
R7	3,16	0,91	0,29	10	3,12	0,98	0,31	16
R8	2,69	1,20	0,44	21	4,01	0,83	0,21	1
R9	3,18	0,87	0,27	9	3,70	0,97	0,26	4
R10	2,81	1,16	0,41	18	3,61	0,98	0,27	8
R11	3,09	0,87	0,28	11	3,30	0,85	0,26	13
R12	2,84	1,19	0,42	16	3,82	0,82	0,21	2
R13	2,81	1,25	0,44	18	3,07	1,27	0,41	17
R14	3,70	0,89	0,24	2	3,69	0,84	0,23	5
R15	3,31	0,86	0,26	7	3,66	0,62	0,17	6
R16	3,37	1,00	0,30	5	3,52	0,94	0,27	10
R17	3,36	1,01	0,30	6	3,75	0,84	0,22	3
R18	3,42	0,99	0,29	3	3,55	0,80	0,23	9
R19	2,75	1,11	0,40	20	2,64	1,06	0,40	20
R20	3,19	1,03	0,32	8	3,18	0,94	0,29	15
R21	2,93	1,22	0,42	14	3,37	1,04	0,31	12

levels to have different priorities.

Risk rankings based on Borda method are largely consistent with risk ratings in the original risk matrix. The top seven risks in Borda method are labelled as the high level in risk matrix, and the last four risks are viewed as moderate and low levels. The differences mainly focus on the risks ranked in the middle. *Uncertainty on the on-site conditions* (R7) is at a high level based on the original risk matrix but has a low risk ranking through the Borda voting due to a relatively low ranking for its impact (16th). On the contrary, *Lack of construction skills* (R12) with a high ranking of risk impact (2nd) and a low score of risk probability ($P < 3$) is at the moderate level in the risk matrix but is ranked ahead of some risks with a high level. Furthermore, although *Lack of government departments' coordination and* support (R4), *Insufficient* funds *available* (R5), and *Adverse selection* (R11) have the same ranking based on Borda voting, their risk levels are noticeably different: R5 and R11 are at a high level, but R4 is at a moderate level due to a relatively low score of its probability ($P < 3$). Similarly, both *Insufficient information regarding the buildings* (R6) and *Inadequate maintenance* (R20) are ranked the 10th, but R6 is at the moderate level in the risk matrix and R20 is high due to a low score of R6's impact ($I < 3$).

Table 5 combines the results of two methods to show the final risk rankings with the least risk knots. Following other studies (Wang and Qin, 2017; Zhang et al., 2018), the final rankings are mostly based on the results of the Borda method. Risk ratings in the original risk matrix are used to re-rank the risks that are given the same priority by the Borda method. For example, R20 is viewed to be more important than R6 due to R20's higher level in the risk matrix than R6.

A higher priority is given to the top-ranked risks in order to ensure more effective risk management with the least inputs. The top ten risks are chosen to represent the key risks, which is also in line with other similar studies (Tam et al., 2004; Zou et al., 2007). The ten risks are ranked in the top half of 21 risks and mostly at a high-risk level. Fig. 4 presents the ten risks and the relevant work with TCs considerations. Two hypotheses are verified based on the analysis of project stages, stakeholders, and TCs, related to key risks. These key risks are scattered throughout the whole process of energy retrofit projects, especially at the design and on-site construction stages. Most of the key risks occur at the on-site construction stage and are related to homeowners and contractors. The key risks associated with homeowners are mainly caused by their negative attitudes towards retrofits in the early stage, cooperation in the execution phase, and maintenance after retrofitting. These risks lead the government, contractors, and even homeowners to bear more TCs. As the providers of construction service, contractors are the main actors in the process of on-site construction. Their technical competence and management performance greatly influence project objectives (e.g. quality and safety). Similarly, designers are also the important technical staff in energy retrofit

Table 5
Overall risk significance based on risk matrix and Borda voting.

Rank based on two methods	Risk	Probability rank	Impact rank	Risk rank based on Borda voting	Risk matrix
1	R3	1	6	1	High
1	R14	2	5	1	High
3	R17	6	3	3	High
4	R18	3	9	4	High
5	R9	9	4	5	High
6	R15	7	6	5	High
7	R16	5	10	7	High
8	R12	16	2	8	Moderate
9	R8	21	1	9	High
10	R20	8	15	10	High
11	R6	4	19	10	Moderate
12	R5	11	13	12	High
12	R11	11	13	12	High
14	R4	13	11	12	Moderate
15	R7	10	16	15	High
16	R10	18	8	15	Moderate
16	R21	14	12	15	Moderate
18	R1	15	18	18	Moderate
19	R13	18	17	19	Moderate
20	R2	17	21	20	Low
21	R19	20	20	21	Low

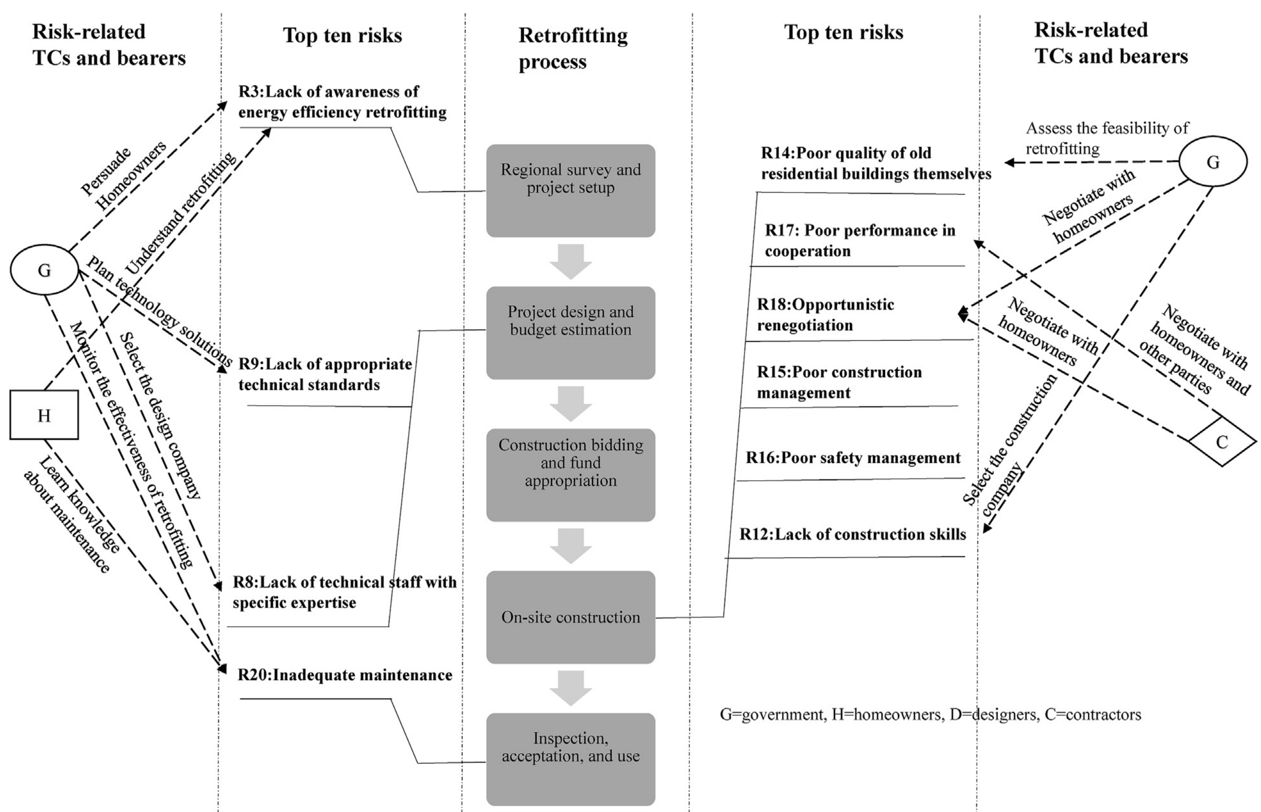

Fig. 4. Connections of key risks, project stages, TCs, and stakeholders (by the authors).

projects so that the risk with respect to professional abilities also has something to do with them. Correspondingly, these risks about contractors' and designers' competency cause an increase in the government's TCs. The key risks associated with government arise from their inadequate preparation for project selection and technical requirements, and involve their own TCs.

5. Discussion

5.1. Focus of risk management from a stakeholder perspective: homeowners' participation and cooperation

Three of the four most critical risks hindering the implementation of energy retrofit projects in China are associated with homeowners. The implementation of energy retrofitting projects requires most homeowners' approval (more than 2/3) in an apartment building in China. It is common for homeowners that there is a lack of retrofit knowledge and information in China. The local government, therefore, needs to provide professional knowledge to raise their awareness. However, homeowners' attitudes towards retrofitting and their coordination during the on-site construction are also affected by the damages that retrofitting entails. For instance, homeowners are asked to demolish the illegal construction around the buildings and on the roof before on-site construction. That is similar to the international context in which homeowners need to understand the merits of energy retrofitting and should bear the costs and the destruction involved in retrofitting (Ürge-Vorsatz et al., 2012). In China, the local government needs to spend time negotiating with homeowners to demolish the illegal construction and even have to provide compensations in the form of money for homeowners. The Chinese government is the main investor of housing energy retrofitting projects, but in the Northern European countries, the lacking of funding for homeowners is seen as one of the main barriers to energy retrofit implementation (Itard and Meijer, 2008). Such a difference also leads to homeowners showing little concern about costs in China. It is more likely to result in homeowners' changeable opinions on what to be included in the retrofit package, or to raise additional demands that are not included in the original retrofit plans during the on-site construction process, thus disrupting its efficiency.

5.2. Key stage for risk management: on-site construction involving contractors and homeowners

Since most of the key risks are concentrated in the stage of on-site construction, more attention should be given to the contractor-associated risks in this phase in China's energy retrofit. This is consistent with the views of Fylan et al. (2016) that the most common risks during the on-site construction are usually associated with contractors. However, survey results show that the great importance of the risk related to contractors' competence is mostly due to its severe impacts and the probability of its occurrence is smaller than that of most risks. That is triggered by the technical limitation in the survey area. Suppose homeowners do not bear the expenses of retrofitting. In that case, a limited fiscal budget leads to only basic technology options, including external wall and roof insulation, energy-efficient windows, and indoor public space LED-lighting. Even in the northern area where energy retrofitting is developed better, energy-saving technologies in the local government-led projects are only limited to external thermal insulation and energy-efficient windows (Liu et al., 2015). These basic energy-saving technologies are mastered by many contractors fulfilling the qualification requirements, but the recognition of contractors' ability does not mean that their work performance can be recognized. The risks about construction management and safety management are still emphasized by survey respondents, which is also partly in line with by Fylan et al. (2016) attributing contractor-associated risks to their poor performance in installing retrofitting equipment and quality control.

Cooperation between stakeholders is also viewed as an essential risk factor in the Chinese context. Still, the difference from the international context is that the relevant risks are associated with both contractors and homeowners. During the process of on-site construction, cooperation risks are generally considered to occur, arising from disruptions between construction parties on-site, leading to a chaotic construction process (Rovers, 2014). Such chaos brings more burdens to homeowners because the buildings are still inhabited during the construction. The troubles (e.g. dirt and stress) are the leading causes of homeowners' negative attitudes towards energy-saving measures (Zundel and Stieβ, 2011), further leading them to be more reluctant to cooperate. In fact, poor cooperation is more likely to be caused by homeowners since multi-family building typology is dominant in China. Multi-family building residents are more inclined to only consider their apartment unit as their home rather than the whole building, as shown by Miezis et al. (2016). Some residents worry about whether certain construction activities undermine their own interests, causing them to raise objections and question or challenge some construction works.

5.3. Main sources of TCs associated with key risks: information, negotiation and monitoring

Information costs are related to most of the key risks in energy retrofit projects in China. Given their unprofessional background, homeowners in China need to bear these costs in order to know more about the advantages and disadvantages of retrofits, the reliability of skilled service providers, and even how to undertake the maintenance of retrofit works. Indeed, building owners are generally considered the bearer of information costs in the international context (Kiss, 2016; Matschoss et al., 2013). Hein and Blok (1995) also attributed these higher information costs to homeowners' insufficient access to knowledge of energy efficiency technologies. However, as the investor and leader of energy retrofits, the government is the main bearer of information costs at an early stage in China. The local government undertakes more work involving information searching and assessment to set up technical guidance for retrofit solutions and then judge whether design and construction companies are competent for retrofit projects when selecting partners. Beyond that, the Chinese government is also responsible for project selection, and is thus involved in searching for the building information on structure type and stability to make sure that the existing building condition can withstand the stresses from retrofitting.

Negotiation and monitoring costs are also associated with key risks in energy retrofit projects. The local government in China needs to pay more in terms of negotiation costs in the early phase to introduce the concept of energy retrofit to homeowners, in order to persuade and encourage more homeowners to be involved in retrofit projects. Besides, negotiation costs in China's implementation phase arise from the need to undertake cooperation and renegotiation with homeowners due to their lack of understanding of construction activities and the unplanned retrofit requirements. By contrast, it is more general in the international context to connect negotiation costs with the coordination among construction parties (Bleyl-Androschin et al., 2009; Mundaca, 2007). The uncertainty on post-retrofit maintenance incurs more TCs for monitoring the usage and maintenance of energy-efficient technologies. In fact, monitoring costs are also widely considered to be related to measurement and verification (Mundaca, 2007; Mundaca T et al., 2013). To achieve good performance of energy-saving measures, buildings maintenance and even homeowners' usage and occupancy behaviours in public space are monitored after retrofitting to keep these technologies in good condition.

6. Conclusion

Energy retrofit of residential buildings has been recognized as an important measure to promote energy conservation and emission reduction as well as to improve the quality of people's lives. For effective risk management, it is necessary to understand the key risks in the whole process of retrofit projects and its stakeholders. This paper has identified 21 risks with TCs considerations in the entire process of retrofitting projects in the HSCW zone of China and ranked them based on Borda voting and risk ratings in the original risk matrix. Two hypotheses are supported by the results. It is confirmed that homeowners and contractors are the key stakeholders associated with seven of ten key risks and on-site construction is the key stage at which most of the key risks are concentrated. TCs are induced by different stakeholders in different stages and can help understand most risks.

Homeowners are related to the most critical risks at the stage of on-site construction and even in the whole process. Their low awareness, poor cooperation, and opportunistic behaviours have negative impacts on project initiation and execution. The contractor is the other key group during the on-site construction due to the risks of their professional expertise, construction management, and safety management. Most key risks are relevant to TCs, including information, negotiation, and monitoring costs. Information costs scattered throughout the whole process are the most prominent. Such costs are affected not only by the selection of government on technical standards, retrofit projects, and technical staff, but also by homeowners' lack of understanding of retrofit merits, the reliability of construction partners, and what, when, and how to do maintenance. Even in the original risk matrix, information costs are still dominant and are associated with most of risks rated at a high level.

TCs, especially information costs, exist widely in energy retrofitting projects in China and other countries, and can also enrich the understanding of risks in the international context. In China, information costs are involved in government's work at the early stage of retrofitting projects and also induced by homeowners' insufficient knowledge. Homeowners bear more information costs in some other countries where retrofits of private dwellings are decided and funded by owners themselves. Given the universality of information costs in retrofitting risks, it is suggested to enhance information disclosure and provision in retrofitting projects in China and worldwide. First, information provision on energy retrofit technologies and schemes at the early stage of projects reduces the change of plans and minimizes homeowners' dissatisfaction in the subsequent phases in China. Second, homeowners' trust in on-site construction can be enhanced by increasing access to more information on technical staff, further improving their performance in cooperation. Third, knowledge of maintenance is conducive to homeowners' involvement in maintaining good performance of retrofitting measures. Fourth, information disclosure on designers and constructors' technologies and ability can facilitate the rational decision-making of the government in China and homeowners in the international context.

The empirical cases and data were conducted on retrofitting projects in four cities in Anhui province to showcase the common retrofitting measures and practices. Only the standard and basic energy-saving technologies were considered in these selected case projects. For future research, more case projects can be collected to exemplify the retrofitting projects with a better pool of representation for the HSCW zone in China to withdraw more broad conclusions on the retrofitting processes and stakeholders' experiences in risk content.

CRediT authorship contribution statement

Ling Jia: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Queena K. Qian:** Conceptualization, Writing - review & editing. **Frits Meijer:** Conceptualization, Writing - review & editing. **Henk Visscher:** Conceptualization, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work is supported by the China Scholarship Council and Department of Management in the Built Environment, Delft University of Technology. The second author is grateful for the Delft Technology Fellowship (2014–2020) for its generous funding support. The authors would also like to acknowledge the editing by Dr. Paul W. Fox of an earlier draft of this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2021.126099.

References

Aubert, B.A., Rivard, S., Patry, M., 2004. A transaction cost model of IT outsourcing. Inf. Manag. 41 (7), 921–932. https://doi.org/10.1016/j.im.2003.09.001.
Bao, L., Zhao, J., Zhu, N., 2012. Analysis and proposal of implementation effects of heat metering and energy efficiency retrofit of existing residential buildings in northern heating areas of China in "the 11th Five-Year Plan" period. Energy Pol. 45, 521–528. https://doi.org/10.1016/j.enpol.2012.02.065.
Biekša, D., Šiupšinskas, G., Martinaitis, V., Jaraminienė, E., 2011. Energy efficiency challenges in multi-apartment building renovation in Lithuania. J. Civ. Eng. Manag. 17 (4), 467–475. https://doi.org/10.3846/13923730.2011.622408.
Bleyl-Androschin, J.W., Seefeldt, F., Eikmeier, B., 2009. Energy Contracting: How Much Can it Contribute to Energy Efficiency in the Residential Sector, ECEEE 2009 Summer Study Proceedings: : Act! Innovate! Deliver! Reducing Energy Demand Sustainably, pp. 985–996.
Booth, A., Choudhary, R., 2013. Decision making under uncertainty in the retrofit analysis of the UK housing stock: implications for the Green Deal. Energy Build. 64, 292–308. https://doi.org/10.1016/j.enbuild.2013.05.014.
Boutaud, B., Koch, A., Girault, P., 2011. The Franklin District of Mulhouse: First French Experience of Low Energy Building Renovation in a Historic Area of the City Centre, World Renewable Energy Congress-Sweden; 8-13 May; 2011. Linköping University Electronic Press, Linköping; Sweden, pp. 3308–3315.
CABEE, 2017. Research Report on Building Energy Consumption in China in 2017. China Association of Building Energy Efficiency, Shanghai, China.
CABEE, 2018. Research Report on Building Energy Consumption in China in 2018. China Association of Building Energy Efficiency, Shanghai, China.
Caputo, P., Pasetti, G., 2015. Overcoming the inertia of building energy retrofit at municipal level: the Italian challenge. Sustainable Cities and Society 15, 120–134. https://doi.org/10.1016/j.scs.2015.01.001.
Chia, E.S., 2006. Risk Assessment Framework for Project Management, 2006 IEEE International Engineering Management Conference. IEEE, Bahia, Brazil, pp. 376–379. https://doi.org/10.1109/IEMC.2006.4279889.
Clemons, E.K., Hitt, L.M., 2004. Poaching and the misappropriation of information: transaction risks of information exchange. J. Manag. Inf. Syst. 21 (2), 87–107. https://doi.org/10.1080/07421222.2004.11045802.
Coase, R.H., 1937. The nature of the firm. Economica 4 (16), 386–405.
Dahlhausen, M., Heidarinejad, M., Srebric, J., 2015. Building energy retrofits under capital constraints and greenhouse gas pricing scenarios. Energy Build. 107, 407–416. https://doi.org/10.1016/j.enbuild.2015.08.046.
Dorward, A., 2001. The effects of transaction costs, power and risk on contractual arrangements: a conceptual framework for quantitative analysis. J. Agric. Econ. 52 (2), 59–73. https://doi.org/10.1111/j.1477-9552.2001.tb00925.x.
Duijm, N.J., 2015. Recommendations on the use and design of risk matrices. Saf. Sci. 76, 21–31.
El-Sayegh, S.M., 2008. Risk assessment and allocation in the UAE construction industry. Int. J. Proj. Manag. 26 (4), 431–438. https://doi.org/10.1016/j.ijproman.2007.07.004.
English, J.M., Kernan, G.L., 1976. The prediction of air travel and aircraft technology to the year 2000 using the delphi method. Transport. Res. 10 (1), 1–8. https://doi.org/10.1016/0041-1647(76)90094-0.
Ferreira, M., Almeida, M., 2015. Benefits from energy related building renovation beyond costs, energy and emissions. Energy Procedia 78, 2397–2402. https://doi.org/10.1016/j.egypro.2015.11.199.
Fu, S., Zhou, H., Xiao, Y., 2011. The Application of a Risk Matrix Method on Campus Network System Risk Assessment, 2011 IEEE 3rd International Conference on Communication Software and Networks. IEEE, pp. 474–478.
Fu, X., 2002. Building Energy Saving Technology in Hot Summer and Cold Winter Region. China Architecture and Building Press, Beijing, China.
Fylan, F., Glew, D., Smith, M., Johnston, D., Brooke-Peat, M., Miles-Shenton, D., Fletcher, M., Aloise-Young, P., Gorse, C., 2016. Reflections on retrofits: overcoming barriers to energy efficiency among the fuel poor in the United Kingdom. Energy. Res. amp; Social Sci. 21, 190–198. https://doi.org/10.1016/j.erss.2016.08.002.
Garvey, P.R., Lansdowne, Z.F., 1998. Risk matrix: an approach for identifying, assessing, and ranking program risks. Air Force J. Logist. 22 (1), 18–21.
Goldman, C.A., 1985. Measured energy savings from residential retrofits: updated

results from the BECA-B project. Energy Build. 8 (2), 137–155. https://doi.org/10.1016/0378-7788(85)90022-2.
Hallikas, J., Karvonen, I., Pulkkinen, U., Virolainen, V.-M., Tuominen, M., 2004. Risk management processes in supplier networks. Int. J. Prod. Econ. 90 (1), 47–58. https://doi.org/10.1016/j.ijpe.2004.02.007.
Hein, L.G., Blok, K., 1995. Transaction costs of energy efficiency improvement, Sustainability and the reinvention of government: a challenge for energy efficiency. Mandelieu.
IEA, 2019a. The Critical Role of Buildings. IEA, Paris. https://www.iea.org/reports/the-critical-role-of-buildings.
IEA, 2019b. The Future of Cooling in China. IEA, Paris. https://www.iea.org/reports/the-future-of-cooling-in-china.
IEA, 2020. Tracking Buildings 2020. IEA, Paris. https://www.iea.org/reports/tracking-buildings-2020.
Itard, L., Meijer, F., 2008. Towards a Sustainable Northern European Housing Stock: Figures, Facts, and Future. IOS Press, Amsterdam, the Netherlands.
Kiss, B., 2016. Exploring transaction costs in passive house-oriented retrofitting. J. Clean. Prod. 123, 65–76. https://doi.org/10.1016/j.jclepro.2015.09.035.
Klein, B., Crawford, R.G., Alchian, A.A., 1978. Vertical integration, appropriable rents, and the competitive contracting process. J. Law Econ. 21 (2), 297–326. https://doi.org/10.1086/466922.
Li, D., 2009. Fiscal and tax policy support for energy efficiency retrofit for existing residential buildings in China's northern heating region. Energy Pol. 37 (6), 2113–2118. https://doi.org/10.1016/j.enpol.2008.11.036.
Lin, B., Wang, Z., Liu, Y., Zhu, Y., Ouyang, Q., 2016. Investigation of winter indoor thermal environment and heating demand of urban residential buildings in China's hot summer–Cold winter climate region. Build. Environ. 101, 9–18. https://doi.org/10.1016/j.buildenv.2016.02.022.
Liu, H., Wu, Y., Li, B., Cheng, Y., Yao, R., 2017. Seasonal variation of thermal sensations in residential buildings in the Hot Summer and Cold Winter zone of China. Energy Build. 140, 9–18. https://doi.org/10.1016/j.enbuild.2017.01.066.
Liu, W., Zhang, J., Bluemling, B., Mol, A.P., Wang, C., 2015. Public participation in energy saving retrofitting of residential buildings in China. Appl. Energy 147, 287–296. https://doi.org/10.1016/j.apenergy.2015.02.090.
Lo, K., 2015. The "Warm Houses" program: insulating existing buildings through compulsory retrofits. Sustain. Energy. Technol. Ass. 9, 63–67. https://doi.org/10.1016/j.seta.2014.12.003.
Lu, S., Feng, W., Kong, X., Wu, Y., 2014. Analysis and case studies of residential heat metering and energy-efficiency retrofits in China' s northern heating region. Renew. Sustain. Energy Rev. 38, 765–774. https://doi.org/10.1016/j.rser.2014.07.015.
Lv, S., Wu, Y., 2009. Target-oriented obstacle analysis by PESTEL modeling of energy efficiency retrofit for existing residential buildings in China's northern heating region. Energy Pol. 37 (6), 2098–2101. https://doi.org/10.1016/j.enpol.2008.11.039.
Lyons, T., Skitmore, M., 2004. Project risk management in the Queensland engineering construction industry: a survey. Int. J. Proj. Manag. 22 (1), 51–61. https://doi.org/10.1016/S0263-7863(03)00005-X.
Matschoss, K., Heiskanen, E., Atanasiu, B., Kranzl, L., 2013. Energy renovations of EU multifamily buildings: do current policies target the real problems, ECEEE Summer Study 2013 Rethink. Renew, Restart 1485–1496.
Menassa, C.C., 2011. Evaluating sustainable retrofits in existing buildings under uncertainty. Energy Build. 43 (12), 3576–3583. https://doi.org/10.1016/j.enbuild.2011.09.030.
Miezis, M., Zvaigznitis, K., Stancioff, N., Soeftestad, L., 2016. Climate change and buildings energy efficiency–the key role of residents. Environ. Clim. Technol. 17 (1), 30–43. https://doi.org/10.1515/rtuect-2016-0004.
Mills, E., 2003. Risk transfer via energy-savings insurance. Energy Pol. 31 (3), 273–281. https://doi.org/10.1016/S0301-4215(02)00040-X.
Mills, E., Kromer, S., Weiss, G., Mathew, P.A., 2006. From volatility to value: analysing and managing financial and performance risk in energy savings projects. Energy Pol. 34 (2), 188–199. https://doi.org/10.1016/j.enpol.2004.08.042.
Mitropoulos, P., Howell, G.A., 2002. Renovation projects: design process problems and improvement mechanisms. J. Manag. Eng. 18 (4), 179–185. https://doi.org/10.1061/(ASCE)0742-597X(2002)18:4(179).
MOHURD, 2012a. Guide for Energy Saving Retrofit of Existing Residential Buildings. Ministry of Housing and Urban-Rural Development, Beijing, China.
MOHURD, 2012b. Technical Guidelines for Energy Efficiency Retrofitting of Existing Residential Building in Hot Summer and Cold Winter Zone. Ministry of Housing and Urban-Rural Development, Beijing, China.
Mohurd, 2017. 13th Five-Year Plan for Building Energy Conservation and Green Building Development. Ministry of Housing and Urban-Rural Development Beijing, China.
Mundaca, L., 2007. Transaction costs of tradable white certificate schemes: the energy efficiency commitment as case study. Energy Pol. 35 (8), 4340–4354. https://doi.org/10.1016/j.enpol.2007.02.029.
Mundaca T, L., Mansoz, M., Neij, L., Timilsina, G.R., 2013. Transaction costs analysis of low-carbon technologies. Clim. Pol. 13 (4), 490–513. https://doi.org/10.1080/14693062.2013.781452.
Ni, H., Chen, A., Chen, N., 2010. Some extensions on risk matrix approach. Saf. Sci. 48 (10), 1269–1278. https://doi.org/10.1016/j.ssci.2010.04.005.
North, D.C., 1986. The new institutional economics. Zeitschrift für die gesamte Staatswissenschaft 142 (1), 230–237. https://www.jstor.org/stable/40726723.
Olgyay, V., Seruto, C., 2010. Whole-building retrofits: a gateway to climate stabilization. Build. Eng. 116 (2), 1–8.
Ouyang, J., Lu, M., Li, B., Wang, C., Hokao, K., 2011. Economic analysis of upgrading aging residential buildings in China based on dynamic energy consumption and energy price in a market economy. Energy Pol. 39 (9), 4902–4910. https://doi.org/10.1016/j.enpol.2011.06.025.
Painuly, J.P., Park, H., Lee, M.-K., Noh, J., 2003. Promoting energy efficiency financing and ESCOs in developing countries: mechanisms and barriers. J. Clean. Prod. 11 (6), 659–665. https://doi.org/10.1016/S0959-6526(02)00111-7.
Parker, D., Hartley, K., 2003. Transaction costs, relational contracting and public private partnerships: a case study of UK defence. J. Purch. Supply Manag. 9 (3), 97–108. https://doi.org/10.1016/S0969-7012(02)00035-7.
Pilling, B.K., Crosby, L.A., Jackson Jr., D.W., 1994. Relational bonds in industrial exchange: an experimental test of the transaction cost economic framework. J. Bus. Res. 30 (3), 237–251. https://doi.org/10.1016/0148-2963(94)90054-X.
Prum, D., Del Percio, S., 2009. Green building claims: what theories will a plaintiff pursue, who has exposure, and a proposal for risk mitigation. R. Estate Law J. 37 (4).
Raj, M., Wadsamudrakar, N.K., 2018. Risk management in construction project. Int. J. Eng. Manage. Res 8 (3), 162–167. https://doi.org/10.31033/ijemr.8.3.22.
Rogers, M., Lopez, E., 2002. Identifying critical cross-cultural school psychology competencies. J. Sch. Psychol. 40 (2), 115–141. https://doi.org/10.1016/S0022-4405(02)00093-6.
Rovers, R., 2014. New energy retrofit concept:'renovation trains' for mass housing. Build. Res. Inf. 42 (6), 757–767. https://doi.org/10.1080/09613218.2014.926764.
Selten, R., 1998. Features of experimentally observed bounded rationality. Eur. Econ. Rev. 42 (3–5), 413–436. https://doi.org/10.1016/S0014-2921(97)00148-7.
Shrader, R.C., 2001. Collaboration and performance in foreign markets: the case of young high-technology manufacturing firms. Acad. Manag. J. 44 (1), 45–60. https://doi.org/10.5465/3069336.
Simon, H.A., 1957. Models of Man; Social and Rational. Wiley, Oxford, England.
Sunikka-Blank, M., Galvin, R., 2012. Introducing the prebound effect: the gap between performance and actual energy consumption. Build. Res. Inf. 40 (3), 260–273. https://doi.org/10.1080/09613218.2012.690952.
Sutcliffe, K.M., Zaheer, A., 1998. Uncertainty in the transaction environment: an empirical test. Strat. Manag. J. 19 (1), 1–23. https://doi.org/10.1002/(SICI)1097-0266(199801)19:1<1::AID-SMJ938>3.0.CO;2-5.
Tam, C., Zeng, S., Deng, Z., 2004. Identifying elements of poor construction safety management in China. Saf. Sci. 42 (7), 569–586. https://doi.org/10.1016/j.ssci.2003.09.001.
Taroun, A., 2014. Towards a better modelling and assessment of construction risk: insights from a literature review. Int. J. Proj. Manag. 32 (1), 101–115. https://doi.org/10.1016/j.ijproman.2013.03.004.
Ürge-Vorsatz, D., Eyre, N., Graham, P., Harvey, D., Hertwich, E., Jiang, Y., Kornevall, C., Majumdar, M., McMahon, J.E., Mirasgedis, S., Murakami, S., Novikova, A., 2012. Chapter 10 - Energy End-Use: Building, Global Energy Assessment - toward a Sustainable Future. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 649–760 and the International Institute for Applied Systems Analysis, Laxenburg, Austria.
Walker, G., Weber, D., 1984. A transaction cost approach to make-or-buy decisions. Adm. Sci. Q. 373–391. https://doi.org/10.2307/2393030.
Walker, S., Lowery, D., Theobald, K., 2014. Low-carbon retrofits in social housing: interaction with occupant behaviour. Energy. Res. amp; Social Sci. 2, 102–114. https://doi.org/10.1016/j.erss.2014.04.004.
Wang, H.-L., Qin, S., 2017. Safety Risk Assessment Model of Heavy-Haul Transport, International Conference on Green Intelligent Transportation System and Safety. Springer, pp. 125–137.
West, J.F., Cannon, G.S., 1988. Essential collaborative consultation competencies for regular and special educators. J. Learn. Disabil. 21 (1), 56. https://doi.org/10.1177/002221948802100111. Essential collaborative consultation competencies for regular and special educators. Journal of Learning Disabilities 21(1), 56-63.
Williamson, O., 1985. The Economic Institutions of Capitalism. Free Press, New York.
Williamson, O.E., 1975. Markets and Hierarchies. Free Press, New York.
Williamson, O.E., 1993. Calculativeness, trust, and economic organization. J. Law Econ. 36 (1, Part 2), 453–486. https://doi.org/10.1086/467284.
Wright, D.B., Herrington, J.A., 2011. Problematic standard errors and confidence intervals for skewness and kurtosis. Behav. Res. Methods 43 (1), 8–17. https://doi.org/10.3758/s13428-010-0044-x.
Xu, L., Liu, J., Pei, J., Han, X., 2013. Building energy saving potential in Hot Summer and Cold Winter (HSCW) Zone, China—influence of building energy efficiency standards and implications. Energy Pol. 57, 253–262. https://doi.org/10.1016/j.enpol.2013.01.048.
Zhang, N., Zhang, Z., Rui, Z., Li, J., Zhang, C., Zhang, Q., Zhao, W., Patil, S., 2018. Comprehensive risk assessment of high sulfur-containing gas well. J. Petrol. Sci. Eng. 170, 888–897. https://doi.org/10.1016/j.petrol.2018.07.016.
Zinn, J., Zalokowski, A., Hunter, L., 2001. Identifying indicators of laboratory management performance: a multiple constituency approach. Health Care Manag. Rev. 26 (1), 40–53. https://doi.org/10.1097/00004010-200101000-00004.
Zou, P.X., Zhang, G., Wang, J., 2007. Understanding the key risks in construction projects in China. Int. J. Proj. Manag. 25 (6), 601–614. https://doi.org/10.1016/j.ijproman.2007.03.001.
Zundel, S., Stieß, I., 2011. Beyond profitability of energy-saving measures—attitudes towards energy saving. J. Consum. Pol. 34 (1), 91–105. https://doi.org/10.1007/s10603-011-9156-7.